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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Investigating Black Cotton Soil Blended with Basaltic Quarry Dust and Portland cement for Road Sub-grade Material (The Case of Akaki - Goro Road Segment)

By:-Tewodros Tesfu

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Road and Transport Engineering)

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Addis Ababa University
School of Graduate Studies
Addis Ababa Institute of Technology, AAiT
School of Civil and Environmental Engineering

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By

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Declaration

I, the undersigned, certify that this research work titled "Investigating Black Cotton Soil Blended with Basaltic Quarry Dust and Portland cement for Road Sub-grade Material: The Case of Akaki - Goro Road Segment" is my own work performed under the supervision of my research advisor Dr. Alemgena Alene as part of Master of Science Program in Road and Transport Engineering and has not been presented elsewhere for assessment and for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged in the text.

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Abstract

The construction industry has presented different types of ground improvement techniques to modify and/or stabilize soils that exhibits expansive nature. Different chemical stabilizers have been used for stabilization of Black Cotton soils. Portland cement is the common one used for stabilizing black cotton soil. Though Cement is the effective soil stabilizing material, stabilizing soils with Cement alone would not be economically viable as Cement is relatively expansive. Hence, in this research work, investigation has been carried out to analyze the effect of blending Basaltic Quarry Dust and Portland cement on the properties of black cotton soil.

The performance of Cement and Quarry dust was evaluated based on laboratory tests on Black Cotton soil collected from Akaki-Goro road segment, Central part of Ethiopia, which was classified as A-7-6 or CL soil using AASHTO and USCS classifications respectively. The sample soil was treated with 0-12% Cement alone, 0-20% Quarry Dust alone and, with the combination of Cement and Quarry Dust mixture by keeping the 4%, 8% and 12% cement constant and varying the Quarry dust content by 5%, 10% 15% and 20% by dry weight of the soil.

The analysis of test results showed that, the sample soil treated with Cement alone shows significant improvement in strength parameters and lower the swelling potential of the treated soil. Whereas, for the soil treated with Quarry Dust alone, no significant improvements were observed on the strength and swelling potential of the treated soil; however reduction has been observed on the Plasticity Index of the quarry dust treated soil. On the other hand, for the soil stabilized with the combination of Quarry Dust and Cement mixture, very significant improvement in strength parameters and a substantial decrease in the plasticity index and swelling potential were recorded than the soil treated with Cement alone and the mixes of the two additives acts as a '*Cement-Mortar*'.

It has been concluded that, Quarry dust only by itself is not an effective stabilizer for stabilizing expansive soil. However, the combination of Cement and Quarry Dust mixture effectively stabilized the treated soil and the mix proportion of (4%OPC + 15%QD) is found to be the optimum stabilizer content for the studied soil to utilize it as a road subgrade soil.

Key Words: ***Black Cotton Soil, Curing, Expansive Clay Soil, Portland-Cement, Quarry Dust, Soil Stabilization, Unconfined Compressive Strength.***

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Lists of Abbreviations/Glossary

AASHTO……American association of State Highway and Transportation officials

A_C………….. Activity of Clay

ASTM…….American Society for Testing of Materials

BC………Black Cotton soil

CAH……Calcium-Aluminum-Hydrate

CBR……California Bearing Ratio

CSH……Calcium-Silicate-Hydrate

ERA……..Ethiopians Roads Authority

LL………Liquid Limit

MDD……Maximum Dry Density

OMC…….Optimum Moisture Content

OPC……..Ordinary Portland cement

PCA……Portland cement Association

PI………Plasticity Index

PL………Plastic Limit

QD……… Quarry Dust

UCS………Unconfined Compressive Strength

USCS…….. Unified Soil Classification System

XRD……… X-Ray Diffraction

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Chapter 1 Introduction

1.1. General

Black cotton soil or vertisol is a soil which occurs in continuous stretches as superficial deposits and is typical of flat terrains with poor drainage areas.

Black cotton soil is a highly expansive soil that has a very low bearing capacity, high shrinkage and swelling characteristics. It usually exhibit high shrinkage and swell characteristics with surface crack opening during the dry seasons. These cracks close during the wet season and uneven soil surface is formed by irregular swelling and heaving. These properties make them unsuitable for construction of embankment, highway, building or any other load bearing engineering structure in their natural state. These soils when subjected to vehicular traffic in road pavement gets heaved and crack due to swelling and shrinkage.

Due to the above mentioned reasons, construction activities especially road construction on a black cotton soil subgrade is done mainly by excavating the black cotton soil up to a reasonable depth and replaced it with other selected materials and in doing so excessive embankment and pavement thickness is required for designing and constructing flexible pavements. However, replacing the black cotton soil with other selected soil materials is costly and requires considerable effort and machinery inputs.

To that regard, different methods of stabilization on black cotton soils have been made in different parts of the world by many researchers at different time. Among the different chemical stabilizers, Portland cement is the common one used for stabilizing black cotton soil. Though cement is the effective soil stabilizing material, stabilizing soils with cement alone would not be economically viable as cement is relatively expensive material as compared to other stabilizers.

Apart from the above, with the rise in the construction of civil works, the rate of the production of waste material has greatly increased. Now a days, it is promising that unexplored wastes are being researched to determine their suitability as road pavement material.

Among the different construction waste materials, Quarry dust is one of them. Quarry dust is a bi-product which is formed in the production of aggregates of different sizes from crushing industries and from cement factories and considered as a waste material.

It is a fact that quarry dust has exhibited a non-plastic nature so that blending of quarry dust with other construction materials like expansive soils could improve the poor engineering properties of the expansive soils and can be considered as dual advantage in improving the poor engineering property of the soil and in re-using of the waste generated.

As cement is the widely used and effective soil stabilizing material, minimum percentage of cement with relatively higher proportion of Quarry dust as an additive and/or stabilizing agent will be an efficient technique for stabilizing expansive soils because of the fact that adopting only cement as a stabilizing material would not be economically viable.

To that regard, this research thesis is aimed to investigate the treatment of black cotton soil by blending it with Basaltic Quarry dust and Portland cement so as to use it for road subgrade material taking the case of road construction projects in Ethiopian where the road bed material is emanated from black cotton soil.

1.2. Background of the Problem

Black cotton soil is the predominant soil type in most Ethiopia's flat terrain areas. Because of its peculiar characteristics with regard to volume fluctuations in dry and wet seasons, Black Cotton soil is a challenge to engineers. These properties make it unsuitable for construction of embankment, highway, building and any other load bearing engineering structure in its natural state.

So far practices of road construction activities in Ethiopia where black cotton soil occurs as a subgrade in the stretch of the roadway, excavating the black cotton soil up to a reasonable depth and replacing it with other borrow/selected materials is a dominant practice. However, replacing the black cotton soil with other selected borrow materials is costly.

Therefore, in developing countries like Ethiopia where infrastructural development is still a challenge, utilizing locally available construction materials is crucial.

On the other hand, the number of cement factories and other stone processing industries which are found in Ethiopia getting increased and consequently the amount of dust generated by those factories while processing the raw material has also increased. However, the generated dust can be converted in to an asset if proper exploration is made to utilize it on other sectors like road construction projects.

The increase in the cost of road construction projects' and equally the increase in the cost of energy and waste disposal has made soil improvement with materials considered to be waste as a prime aim of interest.

So, this research thesis is aimed to investigate the effect of blending Quarry dust and Portland cement with Black Cotton soil and to evaluate the applicability of the treated Black Cotton soil as a road Sub-grade material.

1.3. Study Area

In Ethiopia, black cotton soil occurs in the northern and central Ethiopian Plateaus, the Rift valley, inter-mountain depressions, alluvial plains, etc. Even in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC and Mekanisa, are covered by black cotton soils.

In this research Black cotton soils in the central part of Ethiopia is used for conducting the study. Among the so many roads constructed within the central part of Ethiopia, Lebu–Akaki-IT Park Outer Ring Road is selected as the study area for this research.

Generally the road traverses through a Black Cotton soil. About four- fifths of road sections pass through the sedimentary deposit of black cotton soil with thickness of 1~3 meters and even higher than that on some locations.

From as built-drawings and also from field observation it has been noted that the embankment construction of the Lebu–Akaki-Goro IT Park Outer Ring Road was done by excavating the deposit of Black Cotton soil up to a depth of 2-meters and replaced with selected backfill materials (CBR on the order of >5, and not too pervious in order not to act as a drain).

The adopted Excavation and Replacement technique on the Lebu–Akaki-Goro IT Park Outer Ring Road effectively eliminates the problems. However, backfill materials were obtained from long-distance hauled borrow pits, which resulted in higher portion/weightage of the cost of Earthwork as compared from the total project cost.

At present, there are no observed failures on the pavement structure since the road construction was completed and opened for traffic on the early 2016.

Though there is no access problem on the main roadway for vehicle transport, during rainy seasons the most parts of the study area are water logged and the soil becomes sticky and slippery making accessibility difficult for the people who live near the project area and create difficulty on the means of transport which are carried out by horse and carts.

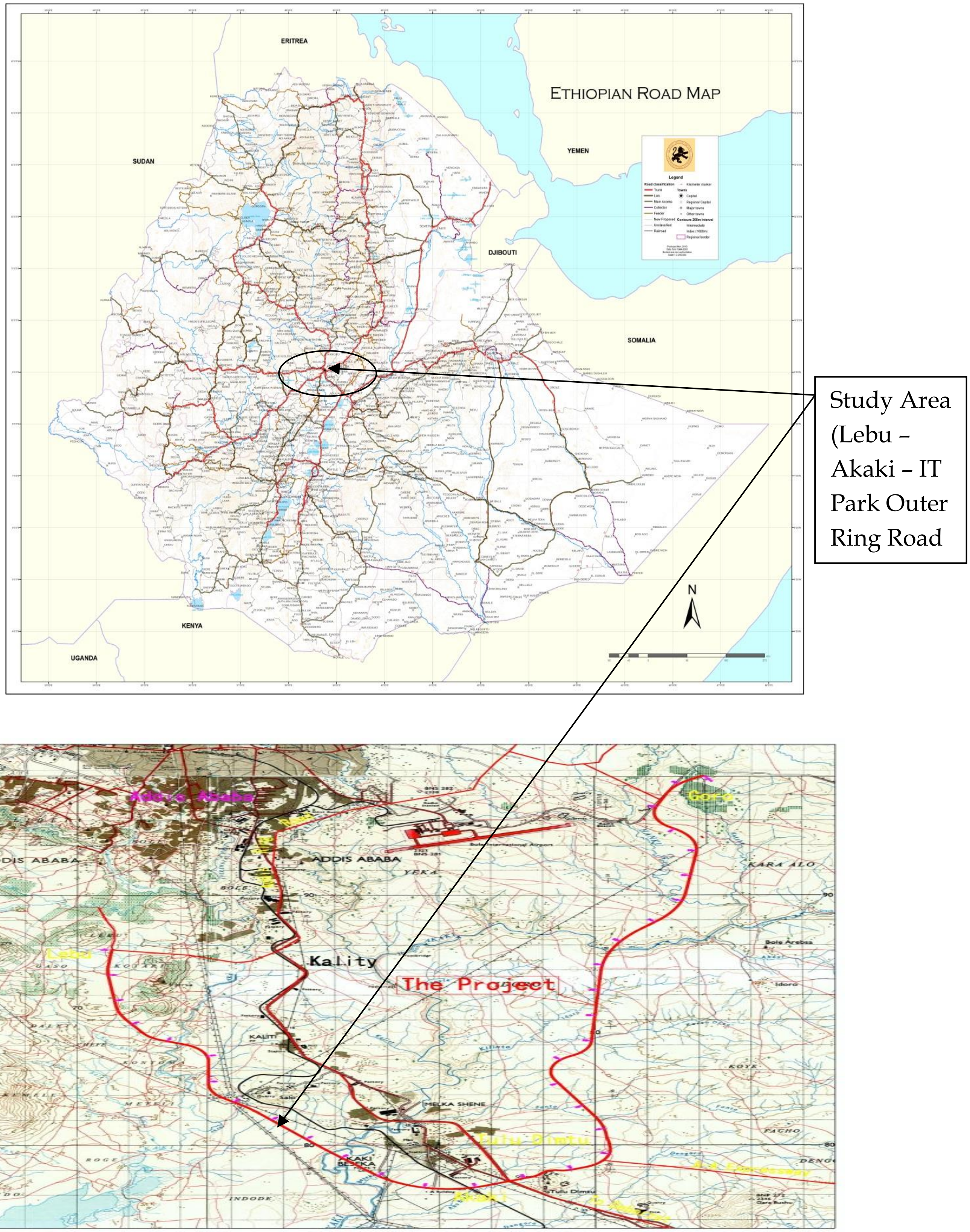


Figure 1: Location Map of Study Area (Source: ERA, 2013a)

1.4. Research Question

To what extent/how significantly the strength, volume-stability, and plasticity characteristics of the Black Cotton soil are improved when treated with Quarry Dust and Portland cement?

1.5. Objective of the Study

1.5.1. General Objective

- The general aim of this research thesis is to study and/or investigate the effect of blending Basaltic Quarry dust and Portland cement with Black Cotton soil and to evaluate the applicability of the treated Black Cotton soil as a road sub-grade material for the case of Lebu – Akaki – Goro area of a road segment.

1.5.2. Specific Objectives

- To characterize the performance parameters and/or the engineering properties of the Black Cotton soil treated with Basaltic Quarry dust and Portland cement.
- To determine the optimum blending proportion of Quarry dust and Portland cement as an admixture to improve the poor engineering properties of the black cotton soil.

1.6. Scope and Limitations

The scope of this research is to the extent of examining the strength, volume stability and plasticity characteristics of the Black Cotton soil material collected from Lebu–Akaki-IT Park Outer Ring Road treated with Quarry dust only, Portland cement only and Portland cement & Quarry dust combinations with different proportions for the Quarry dust collected from the crusher plant of Dire Dawa – Dewelle road project which is a byproduct resulted from crushing of asphalt and concrete aggregates and for the Ordinary Portland Cement (OPC).

In conducting this research, the following limitations were encountered:-

- It is important to carryout clay mineral composition tests using X-Ray Diffraction (XRD) machine so as to know the degree of the expansiveness of the Black Cotton soil. However, due to the bureaucracy and longtime waiting to get the chance to conduct the X-Ray Diffraction (XRD) soil test at Geological Survey of Ethiopia, mineral composition of the native Black Cotton soil is not carried out.
- The Quarry Dust being utilized for this research was collected from Diredawa – Dewelle road project from aggregate processing quarries that has a Basaltic Rock

nature. Due to time and capacity limitations, dust other than the ones originated from Basalt Rock type were not investigated.

Therefore, the findings of this research should have to be considered as a complete only for sample soil from Lebu–Akaki-Goro IT Park Outer Ring Road Area and for Quarry Dust generated from rock quarries with Basaltic-rock nature. However, further studies and additional tests are required before implementing these findings for other areas expansive soils and stabilizing materials from other sources, hence shall be considered as indicative only.

1.7. Organization of the thesis

The presentation of this thesis work is organized in Five (5) chapters.

- The First chapter contains a general introduction and description about Black Cotton soil, back ground of the problem, study area location, Objectives and Scope & limitations of the study.
- Chapter Two reviews related literatures on expansive soils which include properties of Black cotton soil, classification of expansive soils, Stabilization of Expansive soils, treatment of expansive soil with Portland cement and mechanisms involved in soil stabilization with OPC, related works on expansive soil treated with Quarry Dust.
- Chapter Three covers the Research Methods followed and Materials used to conduct the research. In this chapter, a brief discussion has made on the general description of the study area & the proposed material sources, description of the conducted Laboratory tests and finally characterizing the native Black Cotton soil and stabilizers were discussed.
- Chapter Four presents the test results obtained for the treated Black Cotton soil, analysis and discussion of results from the theoretical and reviewed literatures standpoint. Furthermore, discussion has been made on the economic evaluation of stabilization of black cotton soil as compared to cut-to-replace based on qualitative assessment.
- Chapter Five discusses about the conclusions and recommendations drawn from the research study.
- The detail test results of the laboratory work for the native Black Cotton soils, for treated Black Cotton soil with Quarry dust only, Portland cement only and Cement and Quarry dust combination for the respective proportions are presented in an Annexure.

Chapter 2 Literature Review

In order to provide a conceptual framework of the problems associated with expansive soils and/or black cotton soil, a literature review has been carried out. An attempt was made to understand, what methodologies were adopted by the previous researchers and what their findings were.

Based on the observations from the previous studies a systematic methodology was worked out for the present study. A summary of literature review relevant to the present study is presented in the following paragraphs.

2.1. Expansive Soils

Expansive soils are typically clayey soils that undergo large volume changes in direct response to moisture changes in the soil. Expansive soils tend to increase in volume as the moisture content of the soil increases and decrease in volume as the moisture content decreases. Although the expansion potential of a soil can be related to many factors, it is primarily controlled by the clay mineralogy and moisture (*ERA, 2002b)*.

2.1.1. Mineralogy of Expansive Soils

The three most important groups of clay minerals are Kaolinite, Illite, and Montmorillonite. Kaolinite exhibit low degree of expansiveness whereas, illite and montmorillonite has medium and very high degree of expansiveness respectively (Teferra and Leikun, 1999).

The parent materials of expansive soils may be classified into two groups. The first group comprises the basic igneous rocks such as basalt, dolerite sills and dykes, gabbros. etc., where feldspar and pyroxene minerals of the parent rocks decompose to form Montmorillonite, the predominant mineral of expansive soil and other secondary minerals. The second group comprises sedimentary rocks that contain Montmorillonite, and break down physically to form expansive soils. There are indications that confirm that the expansive soils of Ethiopia are derived from both groups.

Soil containing substantial amounts of montmorillonite will exhibit high shrinkage and swelling characteristics. Experience shows that swelling problems arise when soils contain more than 20% montmorillonite mineral. The expansive clay soils prevalent in Ethiopia are either black (black cotton soil) or dark grey (Teferra and Leikun, 1999).

2.1.2. Distribution of Expansive Soil

Expansive soils occur in continuous stretches as superficial deposits and are typical of flat terrains with poor drainage. The absence of quartz in the clay mineralogy enhances the formation of fine grained soil material, which is impermeable and waterlogged.

Expansive soil occurs in many countries such as; Australia, Canada, Ethiopia, Ghana, India, South Africa, USA, etc. African black clay soils causing the most severe problems have formed over basic volcanic rocks, which are geologically, relatively recent in their origin (Morin, 1971).

In Ethiopia, black cotton soil occurs in the northern and central Ethiopian Plateaus, the Rift valley, inter-mountain depressions, alluvial plains, etc. Even in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC and Mekanisa, are covered by black cotton soils. Ethiopian black clay soils have formed over Tertiary to recent basaltic volcanic rocks. Ethiopian black clay soils are found in areas with poor drainage and low to moderate rainfall and contain Montmorillonite as the principal clay mineral with accessory Kaolinite and Halloysite (Morin and Parry, 1971).

2.2. Classification of Expansive Soils

The parameters determined from expansive soil identification tests have been combined in a number of different classification schemes. But before using any classification system, it should be understood the database from which it was derived and establish its limitations; otherwise, poor reliability and lack of confidence in the system may result. The different classification systems are categorized into two:

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

2.2.1. General Classification

Soils are classified in the general schemes; Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials Method (AASHTO) according to index properties. Soils rated CL or CH by USCS, and A6 or A7 by AASHTO, may be considered potentially expansive soils (Nelson and Miller, 1992).

2.2.2. Classification Specific to Expansive soils

The parameters determined from expansive soil identification tests have been combined in a number of different classification schemes to give a qualitative assessment of the degree of probability expansion. Unfortunately, there has not yet evolved a standard classification procedure, and a different scheme is used in practically every different location (Nelson and Miller, 1992). The common methods of classifying expansive soils based on indirect measurements or parameters of the soils are discussed hereunder:

I. Skempton's Method

Skempton classified clays into three classes according to their activities as indicated in Table-1.

$$Activity = \frac{\text{PI}}{(\text{Percent of Clay}<0.002\text{mm})} \quad \text{……………………….. Eq. (1)}$$

Table 1: Classification of Expansive Soils based on Skempton's Method

Degree of Activity	Activity
Inactive Clay	Ac <0.75
Normal Clay	0.75 < Ac < 1.25
Active Clay	Ac > 1.25

Based on the above classification, montmorillonitic clay (Expansive Clay) is defined as active, illitic clay as normal and Kaolinitic clay as inactive (Chen, 1988).

II. U.S.B.R. Classification Method

This method was developed by Holtz and Gibbs to establish the degree of expansion based on simultaneous consideration of shrinkage limit, plasticity index, percent smaller than 0.001mm, free swell (FS) and percent swell under a pressure of 1 psi. Thus, the abovementioned four parameters are used to indicate the criteria for identification of expansive soils by U.S. bureau of reclamation (1960) and are reproduced in Table-2.

Table 2: Indicative Criteria for Classification of Expansive Soils based on U.S.B.R. Classification Method

Classification of potential swell	Colloid content % <0.001mm	Plasticity Index (PI),%	Shrinkage Limit (SL), %	Potential Swell (%)
Low	<15	<18	>15	<10
Medium	13-23	15-28	10-15	10-20
High	20-31	25-41	7-12	20-30
Very high	>28	>35	<11	>30

III. Activity Method (Seeds's Classification Method)

The activity of a soil is taken as the dimensionless ratio of plasticity index to clay contents (C), both taken in percent. Seed et al, classify clayey soil according to its swelling potential defined as the percent vertical swell under a pressure of 1 psi of laterally confined sample compacted to the maximum dry density and optimum moisture content.

According to the Seed et al, 1962 model Activity is calculated using Eq. (2),

$$A_C = \frac{PI}{C-5} \quad \text{.......................... Eq. (2)}$$

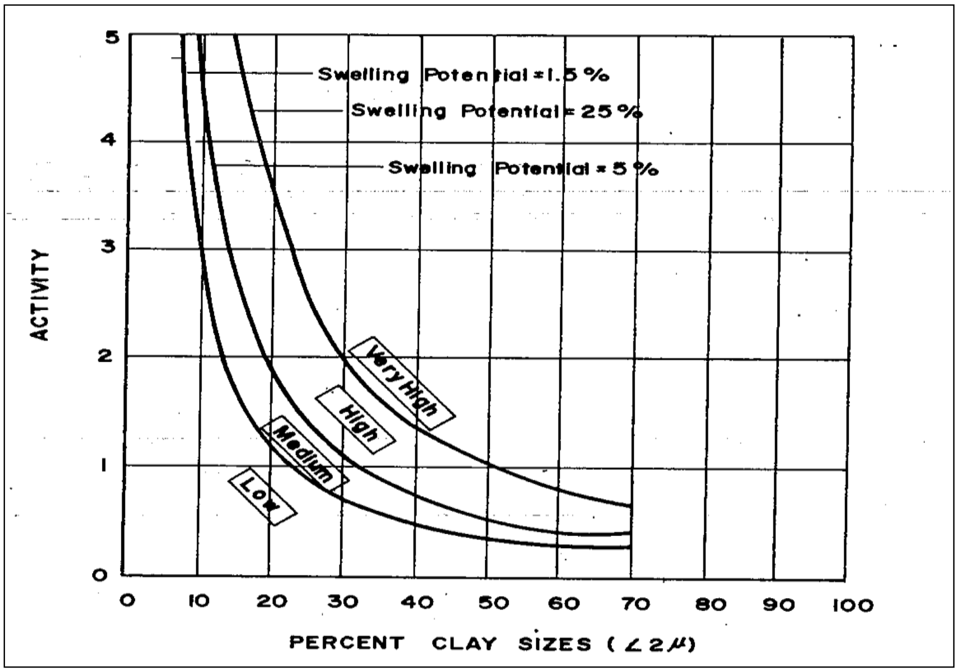


Figure 2: Classification chart for swelling potential (Seed et al, 1962)

IV. Unified Soil Classification Method

Unified classification method is based on the plot of plastic limit against liquid limit to detect the potential swell of the soils in accordance with Casagrande's plasticity chart. Most of the time, soils that plot above the A-line are clayey soils with high plasticity.

2.3. Review on Soil Stabilization

Soil stabilization or modification refers to the improvement of the soil physically or chemically by using various techniques including mechanical compaction and the use of various calcium rich chemicals. The selection of proper stabilization technique depends on the soil type and its condition.

Quite often soils in their natural state cause problems to the pavement engineer. These problems may be due to a poor workability or poor strength characteristics. In other cases soil s need to be stabilized in order to achieve dust control or moisture control (Molenaar, 2007).

Stabilization allows borderline materials to be used. By this materials are meant that are at the borderline between suitable and not suitable materials. Furthermore stabilization allows waste materials, like e.g. fly-ash, to be used. It may also be applied in order to make the layer impervious to water and other fluids. In general one can state that stabilization is applied for improve workability, improve strength & durability, and waterproofing.

2.3.1. Methods of Stabilization

Soil stabilization improves the stability or bearing capacity of a poor soil by the use of compaction; proportioning and the addition of suitable stabilizers or admixtures. Soil stabilization includes mechanical, chemical, physico-chemical methods to make the soil stabilized. This process basically involve excavation of soil, this is an ideal technique for improving of soil in shallow depths, as in pavements. Stabilization method may be categories as two mail types:

- ❖ Mechanical Stabilization (Improvement of soil properties of existing soil with-out using any type of admixture); and
- ❖ Chemical Stabilization (Improve the properties with the admixtures/additives)

a) Mechanical Stabilization

Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, a central plant, or a borrow area. The blended material is then spread and compacted to required densities by conventional means.

b) Chemical Stabilization

Chemical stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. The selection of type and determination of the percentage of additive to be used is dependent upon the soil classification and the degree of improvement in soil quality desired. Generally, smaller amounts of additives are required when it is simply desired to modify soil properties such as gradation, workability, and plasticity. When it is desired to improve the strength and durability significantly, larger quantities of additive are used. After the additive has been mixed with the soil, spreading and compaction are achieved by conventional means (US AFJMAN, 1994).

2.3.1.1. Cement Stabilization

When stabilization of soil is done by mixing of pulverized soil and measured amount of cement and water it is known as soil cement stabilization. Cement has been found to be effective in stabilizing a wide variety of soils and waste materials such as pulverized bituminous pavements and crushed concrete.

Soil cement stabilization technique has been in existence for a long time. Cement treatment causes chemical reaction similar to lime and can be used for both modification and stabilization purposes. Cement can be applied to stabilize any type of soil, except those with organic content greater than 2% or having pH lower than 5.3 (ACI, 1990).

The improvement of soils/aggregates containing clay through the addition of Portland cement involves four distinct processes discussed here in the order of their occurrence:

i. Cation exchange
ii. Flocculation and Agglomeration
iii. Cementitious hydration and Pozzolanic reaction

i. Cation Exchange

The first reaction in calcium reach stabilizers is hydration reaction which occurs between the reaction of lime and water. This reaction is an exothermic reaction which produces calcium ions and hydrogen ions. The calcium ions produced from the hydration process and other elements / compounds which are the constituents of the stabilizer are responsible for cation exchange.

$$CaO\ (lime) + H_2O \rightarrow Ca^{++} + 2(OH) \ \ldots\ldots\ldots\ldots\ldots\ldots \ Eq\ (3)$$

Generally, sodium or potassium (Na^+ or K^+) are prevalent in clay minerals along with water. However, these cations can be replaced by the higher valance cations like Al^{+3}, Ca^{+2}, Mg^{+2} etc. so called cation exchange. During this process calcium rich chemical stabilizer provides enough cations to replace the monovalent cations resulting in a reduced thickness of diffused double layer of the clay soils (Sanjay, 2012).

ii. Flocculation and Agglomeration

Flocculation and agglomeration, which is made possible through cation exchange (Herzog and Mitchell, 1966), is the process of clay particles altering their arrangement from a flat, parallel structure to a more random edge-to-face orientation. The restructuring of modified soil/aggregate particles changes the texture of the material from that of a plastic, fine-grained material to one more resembling a friable, granular soil/aggregate.

iii. Cementitious hydration and Pozzolanic reaction

Cementitious hydration is a process that is unique to cement, and produces cement hydration products referred to in cement chemistry as calcium-silicate-hydrate (CSH) and calcium-aluminum-hydrate (CAH). CSH and CAH act as the "glue" that provides structure in a cement-modified soil/aggregate by stabilizing flocculated clay particles through the formation of clay-cement bonds.

$$Ca^{++} + 2(OH)^{-} + SiO_2 \text{ (soil silica)} \longrightarrow CSH \text{ ....Eq (4)}$$

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \text{ (soil alumina)} \longrightarrow CAH \text{ .... Eq (5)}$$

Time dependent pozzolanic reactions play a major role in the stabilization of soils. Pozzolanic reaction produces calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystalizes to form an interlocking structure which increases the soil strength.

2.4. Review on Engineering Properties of Expansive soils treated with Cement and Lime

2.4.1. Plasticity of the Soil

The plasticity index (PI) of cement treated clay reduces with the increase of cement content and curing time arising from an increase in plastic limit (PL) and constant to slight decrease in liquid limit (Uddin et al., 1997)..

Sivapullaiah et al. (2000) reported that with the addition of lime or cement, the plasticity index (PI) of Black Cotton Indian soil decreases. It is found that immediately after the addition of lime, the liquid limit (LL) reduces significantly. This liquid limit was found to increase as the curing time increases to 7 days. On the other hand, the plastic limit increases with time. It was suggested that the significant reduction of liquid limit immediately after the addition of lime is due to the depression of double layer, resulting from the crowding of calcium ion (Ca++) concentration on clay surface. The increase of liquid limit with curing time is also attributed to the changes of clay fabric towards more flocculated condition (Sridharan and Jayadeva, 1982; Sivapullaiah et al., 2000).

According to the Portland Cement Association (PCA) the effect of cement modification on five clay soils has been investigated. And the index property & the shrinkage limit

(SL), indicates that the substantial reduction of PI's and increase in SL's indicates not only an improvement in the volume change characteristics but also modification of the soils into more stable and workable materials (Gregory E. et al., 2008).

Table 3: Effect of Cement Treatment on Properties of Clay Soils (PCA, Publication Cement Modification of Clay Soils, RD002.)

Soil No.	AASHTO Classification	Cement Content (percent)	Plasticity Index	Shrinkage Limit
1	A-7-6 (20)	none 3 5	30 13 12	13 24 30
2	A-6 (8)	none 3 5	17 2 1	13 26 28
4	A-6 (9)	none 3 5	20 9 5	10 21 25
7	A-7-6 (18)	none 3 5	36 21 17	13 26 32
10	A-7-6 (20)	none 3 5	43 24 16	14 24 31

The effect of cement treatment on Atterberg limits of a Soil with LL=54% and PI=11% for untreated samples were studied by Muhunthan and Sariosseiri (2008) and it has been observed that the liquid limit increased slightly (initially) and decreased with increasing cement content, while plastic limit remained relatively constant. Consequently the plasticity index increased initially followed by a decrease with increase in cement content.

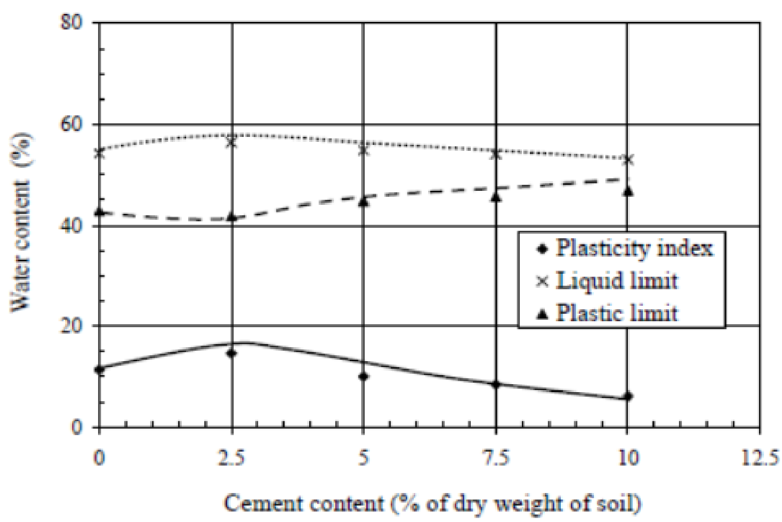


Figure 3: Variation of liquid and plastic limits for different cement content (Muhunthan and Sariosseiri, 2008)

2.4.2. Moisture Density Relation

The change in chemical composition of the soil can be noticed by decrease in the maximum dry density (MDD) and increase in the optimum moisture content (OMC) of the soil-stabilizer mixture. However; from compaction test result of cement treated soil, it was found that a slightly difference is observed from MDD and OMC due to increment of stabilizer content. In general, the changes in the MDD and OMC were considered too small due to addition of cement content is small and hydration process is not occurred within a short period of time (Amu et al. 2005, Grytan et al. 2012, and Bello, 2012).

Generally, as cement content increased, optimum water content increased whereas maximum dry unit weight decreased. It can also be seen that, changes in compaction characteristics are significant at lower percentages of cement content. However at higher percentages of cement, the changes in compaction characteristics of treated soils are minimal (Muhunthan and Sariosseiri, 2008).

In addition to the above, Grytan et al. (2012) investigated the effect of cement (0, 5, 7.5, 10 and 12.5% by weight) on compaction characteristics of cement stabilized soil with LL=46% and PI=19% and results showed that the MDD of the soil decreases gradually with an increase of cement content. On the other hand, the OMC of soil increases with an in cement content.

Horpibulsuk et al. (2010) reported that during the clay and cement mixing, and with an increase in cement content, the formation of clay–cement clusters occurring due to physicochemical interaction, leads to reduction of the small inter-aggregate pore (0.01–0.1 mm) volume, and to slight increase in the large inter-aggregate pore (0.1–10 mm) volume, which results in the decrease of the dry unit weight. However, with time, large inter-aggregate pores are filled due to the growth of cementitious products. Thus, as a result of that, the total pore volume decreases with time.

2.4.3. California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) value of high PI soils increases significantly with the increase of the stabilizer content and curing periods, and soaked CBR values are greater than un-soaked CBR values (Osinubi et al. (2012), Nur et al. (2014) and Bello (2011)). Osinubi et al. (2012) investigated effect on addition of cement on black cotton soil which belongs to A-7-6(13) in the AASHTO classification system and reported that, generally, CBR values increasing the cement content.

Nur et al. (2014) studied the effect of cement content (0, 7, 13% by weight) on Kaolin clay soil with LL=54% and PI=24.8% treated with cement and cure for 7 days and found that the CBR value increased with the increasing of percentage of cement. CBR value equal to 16, 76 and 110% for 0, 7 and 13% cement were attained respectively.

The CBR value of 2 percent for the untreated soil represents a relatively unstable material that would be difficult to work with during pavement construction operations. At a cement content of only 3 percent by dry weight of the untreated soil, the CBR value is increased to 42 percent, which would not only provide a stable working platform but would meet CBR requirements as a sub base layer in a flexible (asphalt surfaced) pavement design (Felt, E.J., 1955)

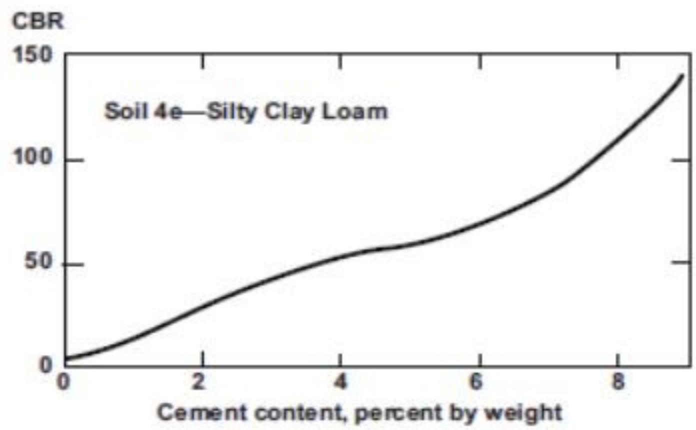


Figure 4: CBR versus cement content (Felt, E.J., Highway Research Board, Bulletin No. 108, 1955)

2.4.4. Unconfined Compressive Strength (UCS)

Unconfined compression test provides an approximate value of the strength of cohesive soils in terms of total stresses. The primary purpose of the unconfined compression test is to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state. It is not always possible to conduct the bearing capacity test in the field. Sometimes it is cheaper to take the undisturbed soil sample and test its strength in the laboratory. Also to choose the best material for the embankment, one has to conduct strength tests on the samples selected. Under these conditions it is easy to perform the unconfined compression test on undisturbed and remolded soil sample.

Unconfined compression test is used to determine the unconsolidated, un-drained strength of a cohesive soil for a cylinder of soil without lateral support which demonstrates evaluation of soils without later support like road embankment materials.

In general, it has been found that the strength of the treated clay increases with the increase of cement content. The unconfined compressive strength and cement content relationship is a function of initial water content of the untreated clay. The unconfined compressive strength of cement treated clay decreases significantly with the increase of initial water content of the untreated soil (Porbaha et al., 2000). Similar results were also observed by other researcher (Chew et al., 1997).

Muhunthan and Sariosseiri (2008) investigated the effect of cement treatment on unconfined stress-strain behavior of Soil with LL=54% and PI=11% for un-soaked and soaked samples and it has been observed that the peak axial stress increased significantly due to cement treatment, but the corresponding strain to peak axial stress decreased from approximately 4% to slightly greater than 1%. Thus, cement treated soils exhibited much more brittle behavior than non-treated soils.

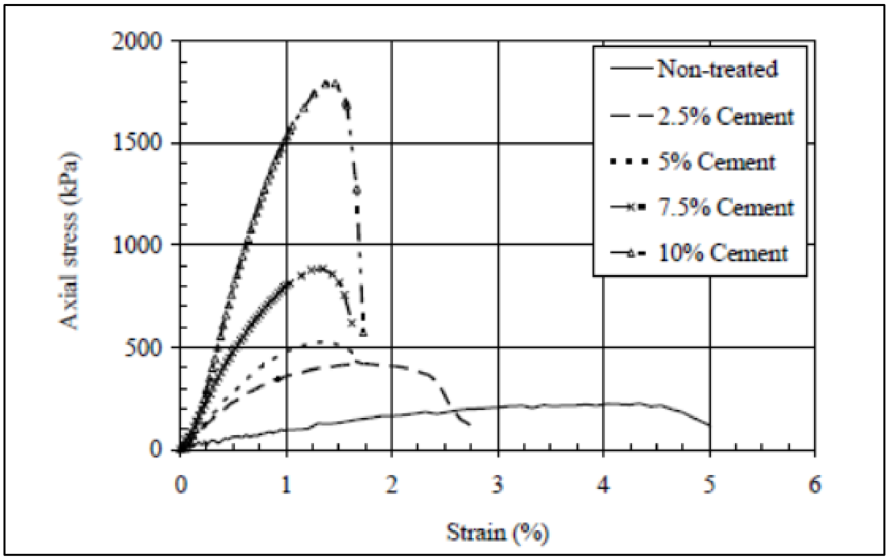


Figure 5: Effect of cement treatment on unconfined stress-strain behavior of, un-soaked soil samples (Muhunthan and Sariosseiri, 2008)

Muhunthan and Sariosseiri (2008) looked at effect of compaction delay on UCS values and reported similar results and suggested that the achievement of stronger material with immediate compaction can be attributed to the physicochemical phenomenon resulting from the hydration of Portland cement. Within a short time after mixing Portland cement with soil, the mixture becomes granular due to agglomeration, which primarily results from the hydration of the cement grains and helps form a network. If the compaction is delayed, the network is broken during compaction and never re-established, leading to a weaker mass. However, compaction prior to such granulation is more efficient and provides a stable network with superior engineering properties.

Similarly, (Bell, 1993) found that as the clay content increases, higher quantity of stabilizing agent is required to increase the strength, perhaps owing to the increase in surface area and contact between the clay particles.

2.5. Review on Quarry/Stone Dust as Soil Stabilizing Material

Eden A. (2017) has investigated the effect of Basaltic and Trachyte Quarry dust on the performance parameters of an expansive soil collected from Addis Ababa of Bole area which is characterized as A-7-5 soil according to AASHTO soil classification system. Based on laboratory tests, she has evaluated the performance of a soil treated with Quarry dust of proportion of 2%, 4%, 8%, 10%, 20% and 30% by dry weight of the soil. And accordingly, she has reported that for the soil treated with Quarry dust even at a higher proportion, there is a slight reduction in the Plasticity index and swelling potential and it could not bring significant improvement in strength characteristics of the treated soil.

Mishra et al. (2014) conducted an investigation on the effect of granite dust on the engineering characteristics of BC soil stabilized with 5% lime. A laboratory study was undertaken to evaluate the effect of granite dust as a soil stabilizer.

Soil sample containing 5% lime and 0%, 10%, 20% and 30% of granite dust were prepared and compaction characteristic and California bearing ratio test were conducted**.** The test results revealed that the compaction parameters and CBR values of the soil are improved substantially with the addition of the granite dust. It is also found that the swelling of the BC soil is almost controlled. The result showed the CBR value increased from 1.7% to 7.15%, the optimum moisture content have been reduced from 22% to 14.3% and the maximum dry density have been increased from 1.58 g/cc to 1.88 g/cc.

Table 4: Effect of Granite Dust and Lime on the Engineering Properties of treated Black Cotton Soil (Mishra et al., 2014)

S.No	Particulars	Observation and Results				
		BC + 0%Lime + 0%Granite Dust	BC + 5%Lime + 0%Granite Dust	BC + 5%Lime + 10%Granite Dust	BC + 5%Lime + 20%Granite Dust	BC + 5%Lime + 30%Granite Dust
1	Compaction Characteristics					
1.1	OMC (%)	22	16.5	15.4	15.1	14.3
1.2	MDD (g/cc)	1.58	1.64	1.72	1.81	1.88
2	CBR (%)	1.7	3.95	4.92	5.74	7.15
3	Swelling Characteristics					
3.1	Differential Free Swell	56.6	20	11.0	5.26	4.1

Akanbi and Job, (2014) done research on suitability of stabilized black cotton soils with cement and quarry dust for road sub-base and foundations by mixing with 0-6% cement and 0-20% quarry dust by weight of dry soil. The laboratory tests like California Bearing

Ratio (CBR), Unconfined Compressive Strength (UCS) and compaction and from the test results, there is an improvement in the Atterberg's limit of the soil, decrease in the plasticity index (PI), liquid limit (LL), plastic limit (PL) and an increase in maximum dry density (MDD) with increase in quarry dust content in all cement proportions used and as compared with the values obtained from the natural soil.

Ken c et al. (2012) studied on the geophysical use of quarry dust as admixture to soil stabilization and modification. The introduction of quarry dust improves the engineering behaviors of the soil. There is an improvement in the CBR value of the soil by addition of quarry dust, higher CBR values enhances their potential for use as a sub base for flexible pavement. When quarry dust is added with expansive soil it is expected that it will more porous, less durable, reduce cohesion etc. It also causes a gain in strength due to better interlocking**.**

According to the same author referred above, it was also observed that as QD increased the UCS and CBR values of the stabilized black cotton soil increased with compaction effort. The peak UCS value of 1880kN/m2 was obtained for soil stabilized with 6% cement and 20% QD contents and 186% for CBR. The economic analysis reveals that stabilized black cotton soil with 6% cement and 20% QD results in savings of approximately 20% cost compared with the only cement stabilized soil.

2.6. Curing Time and its effect on Cement-treated Expansive soils

It is well established that the strength of the cement treated clay increases with the increase of curing time (Kawasaki et al, 1981, Uddin et.al, 1997). By curing time, the time is meant during which evaporation of moisture is prevented.

Probaha et al, (2000) reported that the rate of increase of strength is generally rapid in the early stages of curing period and thereafter decreases with time. This rate of reduction also depends on the amount of cement added. Uddin et.al, 1997 has found that beyond a certain curing period (> 4 months) the rate of increase of unconfined compressive strength is almost negligible.

Also curing temperature has a paramount importance as curing time. The way of compaction is important for the clayey soils. The compaction method with the lowest kneading action will give the highest strength. Also the degree of pulverization of the soil that has to stabilize is important. A better pulverization leads to more intensive reaction between soil and cement. The higher degree of pulverization must not be prolonged mixing. This can lead to a decreased strength because during the prolonged mixing the soil may react with the cement but this process of strength building is destroyed by the mixing.

Chapter 3 Materials and Methods

3.1. Conceptual Design and Research Approach

Present concerns for sustainable development have led to a revival of construction practices using the local available and recycled resources. In developing countries like Ethiopia where infrastructural development is still a challenge, utilizing locally available construction materials is crucial.

The wide spread of Black cotton soil in various places of Ethiopia possess problems to the road construction activities due to its peculiar characteristics with regard to volume fluctuations in dry and wet seasons. The dominant practices of road construction activities in Ethiopia where black cotton soil occurs as a subgrade in the stretch of the roadway, excavating the black cotton soil up to a reasonable depth and replacing it with other borrow/selected materials is a dominant practice. However, replacing the black cotton soil with other selected borrow materials is costly and become efficient only when borrow/selected materials are available within nearest vicinity of the project area.

On the other hand, the conventional stabilizing agents commonly used on expansive soils are lime and cement, which are fairly expensive; particularly in areas where suitable replacement materials are abundant and therefore rarely used in construction of roads passing on expansive soils in such areas. Therefore, there is a need to investigate an alternative economical technique for stabilizing in-situ expansive clay soil in to acceptable construction materials.

Unexplored wastes are being researched to determine their suitability as a modifier to use it as road pavement materials. Now a day, the number of cement factories and other stone processing industries which are found in Ethiopia getting increased and consequently the amount of waste/byproduct generated by those factories while processing the raw material has also increased from time to time. However, the generated waste materials can be converted in to an asset if proper exploration is made to utilize it on other sectors like road construction projects.

Among the different construction waste materials, Quarry dust is one of them. As cement is the widely used and effective soil stabilizing material, minimum percentage of cement with relatively higher proportion of Quarry dust as an additive and/or stabilizing agent could be an efficient technique for stabilizing expansive soils

Therefore, a research shall be conducted to explore the effect of Cement and Quarry Dust combination on stabilization of expansive clay soil. So, this research thesis is aimed to investigate the effect of blending Quarry dust and Portland cement with Black

Cotton soil and to evaluate the applicability of the treated Black Cotton soil as a road Sub-grade material.

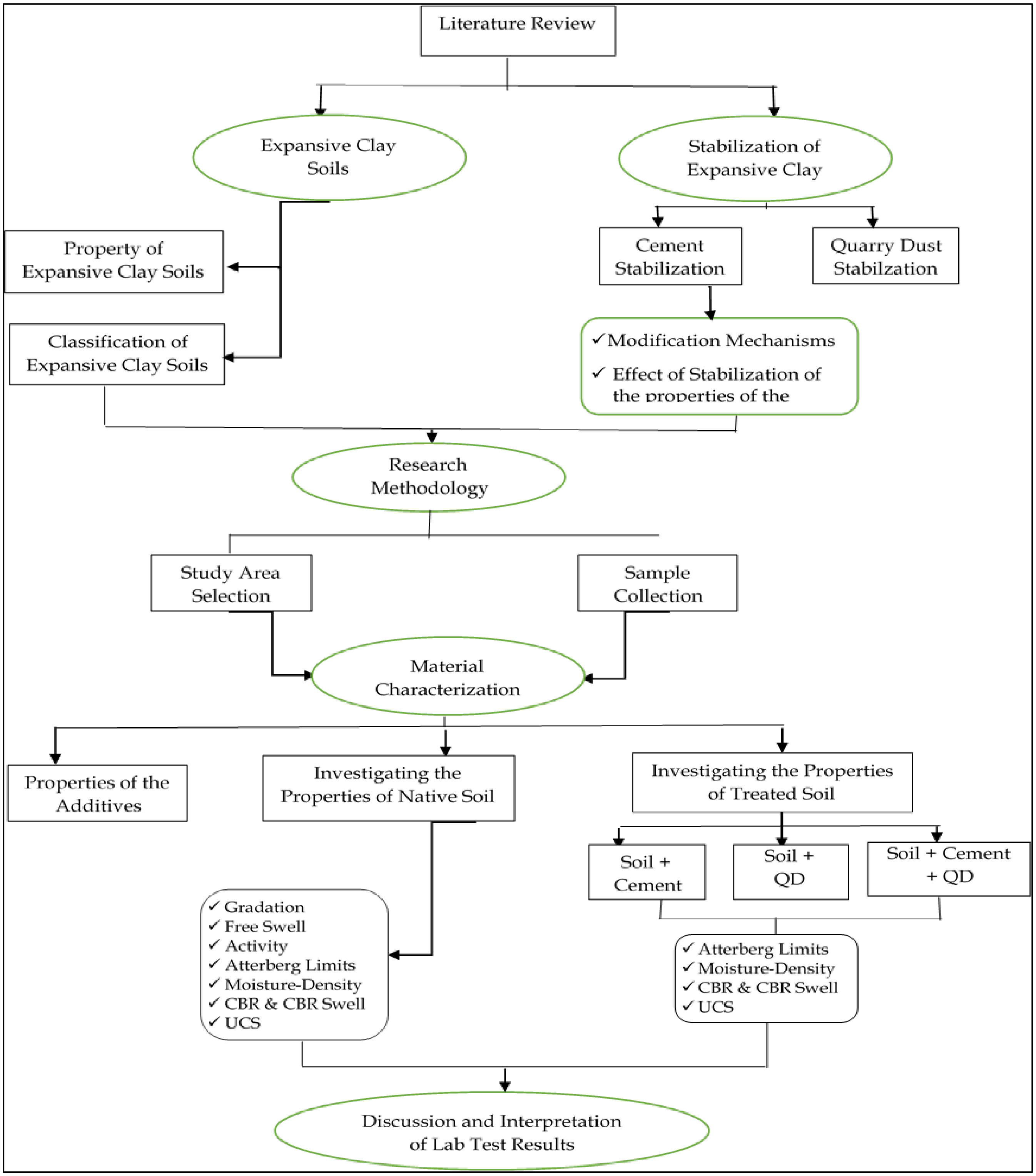


Figure 6: A general overview of the research approach

A research project design is useful to organize the desired activities within the research project because it states what has to be done and how it will be organized.
Hence, the research approach, see Figure 6, based on reviewed literatures and laboratory experiments to be used as a platform in order to explore the effect of Cement and Quarry dust combination on stabilization of black cotton soil.

3.2. Research Methods

3.2.1. Study Area Selection

In Ethiopia, black cotton soil occurs in the northern and central Ethiopian Plateaus, the Rift valley, inter-mountain depressions, alluvial plains, etc. Even in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC and Mekanisa, are covered by black cotton soils.

In this research Black cotton soils in the central part of Ethiopia is used for conducting the study. Among the so many roads constructed within the central part of Ethiopia, Lebu–Akaki-IT Park Outer Ring Road is selected as the study area for this research.

This project is located in southern suburb of Addis Ababa, the capital of Ethiopia. It starts from Lebu, passes through Akaki roundabout and Tulu Dimtu interchange, then joints IT Park at the terminal, the total length is 28.1km and this road segment is a continuation of Legetafo-Yerer Goro Principal Arterial Road and it is connected to Addis-Adama motorway at Tulu Dimtu interchange.

Generally the project road traverses with altitude ranges between 2050-2250 meters above mean sea level and the rainfall is mainly concentrated in June to September which is 70.2% of the total annual rainfall. In general the area is accessible by foot and four wheel drive vehicles, mainly during dry seasons. During rainy seasons, the most parts of the study area is water logged and the soil becomes sticky and slippery making accessibility difficult.

Having referred to the Geotechnical Design Report which has been carried out during the construction of the road project, the geological setting of the project area was assessed by referring the geological map of Akaki-Beseka area prepared by the geological survey of Ethiopia with scale of 1: 250,000. According to the geological map, the study area is covered with different geological units. The geology map of the study area is shown in figure 7.

It is shown in the geological survey that the study area is mainly covered by Tertiary volcanic rocks, Quaternary volcanic rocks and few Quaternary types of sediment. The surface coverage is mainly black clay which has substantial strongly hydrophilic mineral so that it has the feature of expansive soil which dilates after absorbent and contracts after dehydration.

The major unfavorable geology of the project is black cotton soil. About four- fifths of road sections passes through the sedimentary deposit of black cotton soil with thickness of 1~3 meters and even higher than that on some locations.

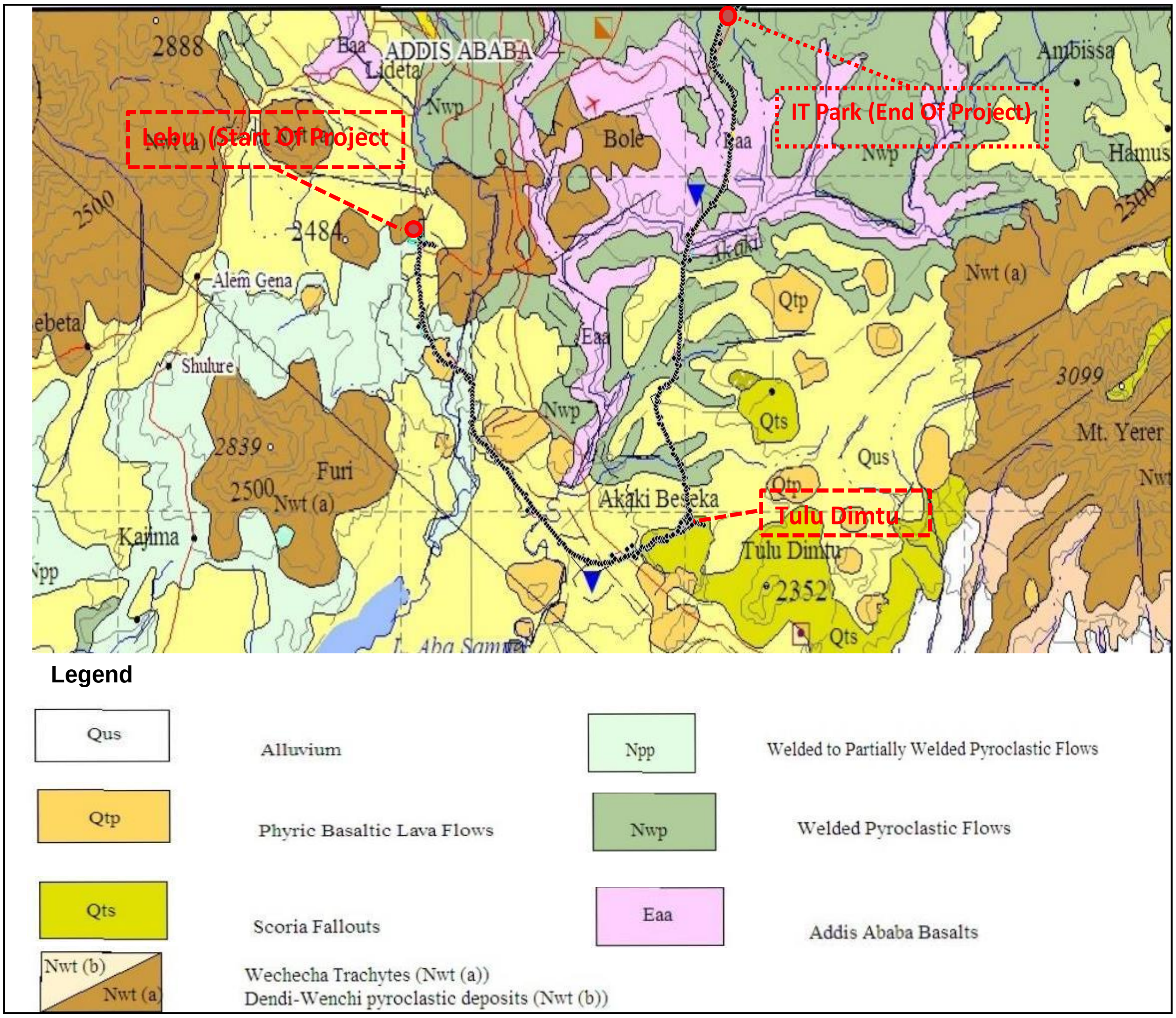


Figure 7: The Geology map of the study area (adopted from Geotechnical Investigation Report of the road project, 2014)

From the desk study and field observation, it has been noted that there are many shallow excavations with depth of 1 - 3 meters, generally located on the road section of black cotton soil and the shallow excavation are carried out with necessity of treatments owing to the fact that the road surface is located above the black cotton soil course.

3.2.2. Sample Collection

I. Soil Sample

Black cotton soil samples from three test pits from Lebu–Akaki-IT Park Outer Ring Road Project road at km 13+200 of approximately 15m offset to the Right hand side and Left hand side from the road center were collected for this research. Moreover, other soil samples were collected from the 28m median section of the road.

Black cotton soil at Km 13+200 that has been excavated and dumped to the sides of the road during the construction of the Lebu–Akaki-IT Park Outer Ring Road project were taken and the other soil samples were collected by excavating manually using pick axe and shovel to a depth 0.5m to 1.00m from the median section of the road that has been found between the two frontage roads located at Km 25 representing the natural subgrade level during the construction of the said road project.

Then after, the soil samples were transported to laboratories for conducting the necessary tests.

Figure 8: Sampling Area and Black Cotton Soil Sample Collection

II. Quarry Dust

Quarry dust sample used in this research were collected from the Dire Dawa – Dewelle Road project where aggregate crushing activities were performed from Basalt rock quarries for producing Asphalt and Concrete aggregates that has been utilized during the construction of the Dire Dawa – Dewelle road project.

Figure 9: Dire Dawa – Dewelle Road project Quarry Site and Quarry Dust Sample Collection

The Quarry dust collected for this research is a byproduct resulted from the crusher plant of capacity 300 Ton/hr crushing asphalt and concrete aggregates. In the quarries/crusher plant site, considerable volume of quarry dust which is a byproduct after the extraction and processing of aggregate of different sizes from the basaltic rock is available. The aggregate crushing activity passes through quaternary crushing processes (one Jaw and three Cone crusher plants).

First, the big rock stones drilled and blasted from the basaltic rock quarries were damped to the jaw crusher. However, since it is difficult to avoid the intrusion of weathered rock and soil materials in the production of the bigger stones, the materials entered into the primary/jaw crusher are big rock stones, weathered rock and soil materials. Therefore, the dust/waste material collected from the Jaw crusher is composed of rock and soil materials, substantial amount of dust/waste is collected from the Jaw crusher. In addition to the above, additional dust materials with a small amount are collected from the secondary/cone crusher plants.

During the aggregate crushing activity, Quarry dust is collected by using a separate conveyor belt so as to separate the different sizes aggregate from the byproduct (quarry dust) and then dumped by Loader to near side place.

Once the Quarry dust brought from the crusher plant, it was dried with the atmospheric air and become ready for the laboratory tests. Physical properties and Engineering properties of the Quarry dust such as, Natural moisture content, Specific gravity, Gradation, Plasticity Index (%) were assessed.

III. Portland cement

The cement used for this research is DANGOTE Ordinary Portland Cement (OPC) type-I cement purchased from the retailers found in Addis Ababa.

The physical and chemical properties of the OPC such as oxide composition such as Silica, Alumina, Iron Oxide, Calcium Oxide (Lime), and Magnesia, Sulphur Trioxide, free Lime (%), and Loss on ignition were obtained at DANGOTE Cement Factory Laboratory.

3.3. Proportion of Stabilizing Materials

The quantity of stabilizers that is going to be added on the native soil is computed either based on volume or based on dry weight of the native soil. In this research, the quantities of stabilizing materials were given as a percentage of the dry weight of the untreated soil.

a) Proportion of Cement

The minimum amount of cement added to the soil was determined according to AASHTO requirement for soil groups given in Table 5. Since the natural soil was classified as A-7, the quantity of cement that is required to stabilize the soil is from 10% to 16% by weight of the soil and the typical cement content percent by weight is 13%.

Table 5: The minimum amount of cement added to the soil determined according to AASHTO requirement for soil groups

AASHTO Soil Group	Usual Range in Cement Requirement in Percent by		Typical Cement Content Percent by Weight
	Volume	Weight	
A-1-a	5-7	3-5	5
A-1-b	7-9	5-8	6
A-2	7-10	5-9	7
A-3	8-12	7-11	9
A-4	8-12	7-12	10
A-5	8-13	8-13	10
A-6	10-14	9-15	12
A-7	10-14	10-16	13

Hence, from reviewed literature and economic point of view, the quantity of cement added to the black cotton soil is taken at 12% by dry weight of the soil as a maximum and additional mixes were prepared at 2%, 4% and 8% cement by dry weight of the soil so as to investigate the effect of smaller percentages of cement content on the native soil.

b) Proportion of Quarry Dust

From reviewed literature and historical data from previously conducted research, the amount of quarry dust required to improve the quality of the expansive clay soil ranges up to 20% by dry weight of the soil. Thus, in this research it has been decided that the proportion of quarry dust combined with the Black cotton soil to be 5%, 10%, 15% and 20% by dry weight of the soil.

c) Proportion of Cement - Quarry Dust Mixture

Taking into account of the results of each of the different mixes of Black cotton soil combined with cement only and also mixes of Black cotton soil combined with Quarry Dust only, and using some rationale, Cement and Quarry Dust combinations were mixed with the Black cotton soil accordingly:-

- Varying the Quarry Dust content by 5% (i.e. 5%, 10%, 15% and 20%) , while keeping 4% cement content constant for the 1st -group,
- Varying the Quarry Dust content by 5% (i.e. 5%, 10%, 15% and 20%), while keeping 8% cement content constant for the 2nd -group,
- Varying the Quarry Dust content by 5% (i.e. 5%, 10%, 15% and 20%), while keeping 12% cement content constant for the 3rd -group.

3.4. Test Frequencies

For the native Black Cotton soil, three (3) samples (Test pit-1, Test pit-2 and Test pit -3) are taken and for each Test pit, Gradation, Free Swell, Linear Shrinkage, Specific gravity, Atterberg Limits, Modified Proctor, CBR &CBR Swell and Unconfined Compressive Strength tests are carried out.

On the other hand, for the soil treated with Quarry Dust, two (2) samples are prepared, for each of the mix soil-quarry dust proportion and Atterberg Limit tests, CBR & CBR Swell tests and Unconfined Compressive Strength tests are carried out for each of the two samples prepared and the average value of the two test results were taken for the analysis.

For the Black Cotton soil treated with Cement only and for the soil treated with Cement-Quarry Dust mixture, one (1) sample is prepared for each of the different mix proportions and Atterberg Limits, Modified Proctor, CBR &CBR Swell are carried out for each of the distinct Soil-Cement and Soil-Cement-Quarry Dust mix proportions.

Table 6: Number of Tests Carried out for the native and treated Black Cotton Soil

No	Proportion	Number of Tests carried out						
		Test Description						
		Wet Sieve & Hydrometer	Free Swell	Linear Shrinkage	Atterberg Limit	Modified Proctor Test	CBR & CBR Swell	UCS
1	Black Cotton Soil	3	3	3	3	3	3	3
2	BC + 2% OPC	--	--	--	1	1	1	2
3	BC + 4% OPC				1	1	1	2
4	BC + 8% OPC				1	1	1	2
5	BC + 12% OPC				1	1	1	2
6	BC + 5% QD	--	--	--	2	1	2	2
7	BC + 10% QD				2	1	2	2
8	BC + 15% QD				2	1	2	2
9	BC + 20% QD				2	1	2	2
10	BC + 4%OPC + 5%QD	--	--	--	1	1	1	1
11	BC + 4%OPC + 10%QD				1	1	1	1
12	BC + 4%OPC + 15%QD				1	1	1	1
13	BC + 4%OPC + 20%QD				1	1	1	1
14	BC + 8%OPC + 5%QD				1	1	1	1
15	BC + 8%OPC + 10%QD				1	1	1	1
16	BC + 8%OPC + 15%QD				1	1	1	1
17	BC + 8%OPC + 20%QD				1	1	1	1
18	BC + 12%OPC + 5%QD				1	1	1	1
19	BC + 12%OPC + 10%QD				1	1	1	1
20	BC + 12%OPC + 15%QD				1	1	1	1
21	BC + 12%OPC + 20%QD				1	1	1	1

With regard to the Unconfined Compressive Strength (UCS) test, for the soil treated with Portland cement, two (2) samples are prepared for the each of the distinct Soil-Cement mix proportions. From the two samples prepared, one of the specimen were subjected to compression test immediately after compaction and for the other specimen the sample is cured for 7 days before carrying out the compression test so as to demonstrate the effect of curing on the Un-drained strength (UCS) value of the treated Black Cotton soil.

- For the 1st sample, the remolded specimen is prepared and subjected to UCS test immediately after compaction (there is no curing applied).
- For the 2nd sample, the remolded specimen is cured for 7-Days by sealing with a plastic bag and after the end of the 7 days of curing; the sample is subjected to UCS test. (7 Days curing).

For the black cotton soil treated with Cement and Quarry dust mixture, one (1) sample specimen were prepared for each of the mix proportion and then each of the samples were cured for 7 Days prior to conducting the UCS test.

3.5. Curing Time

It is well established that the strength of cement treated clay increases with the increase of curing time. In this research the samples were sealed in plastic bags and stored at room temperature to prevent the effect of carbonation and loss of moisture during the curing period. And the curing time for the respective of the black cotton soil with the different proportions of stabilizers are shown in the following Table 7.

Table 7: Curing Time for each of the different mix proportions for the treated soil

It.No	Proportion	Curing Time (Cure at Room Temperature)			
		Test Description			
		Atterberg Limit	Modified Proctor Test	CBR and CBR Swell	UCS
1	Black Cotton Soil	No Curing	No Curing	4 Days Soaked	No Curing
2	BC + 2% OPC	7 Days	15 Minutes	7 Days Cure + 4 Days Soaked	7 Days
3	BC + 4% OPC				
4	BC + 8% OPC				
5	BC + 12% OPC				
6	BC + 5% QD	15 Minutes	15 Minutes	4 Days Soaked	15 Minutes
7	BC + 10% QD				
8	BC + 15% QD				
9	BC + 20% QD				
10	BC + 4%OPC + 5%QD	7 Days	15 Minutes	7 Days Cure + 4 Days Soaked	7 Days
11	BC + 4%OPC + 10%QD				
12	BC + 4%OPC + 15%QD				
13	BC + 4%OPC + 20%QD				
14	BC + 8%OPC + 5%QD				
15	BC + 8%OPC + 10%QD				
16	BC + 8%OPC + 15%QD				
17	BC + 8%OPC + 20%QD				
18	BC + 12%OPC + 5%QD				
19	BC + 12%OPC + 10%QD				
20	BC + 12%OPC + 15%QD				
21	BC + 12%OPC + 20%QD				

(a) Curing of Sample Specimen for Atterberg Limits Test

(b) Curing of Sample Specimen for CBR Test

(c) Trimming of sample from the extruded Shelby tube sampler, Measuring the Mass of the specimen and Curing of Sample Specimen for UCS Test

Figure 10: Preparation and Curing of Sample Specimen for Atterber Limit, CBR and UCS Tests

3.6. Material Characterization

3.6.1. Properties of Black Cotton Soil

After the Black cotton soil samples are collected as discussed above, the engineering property of the black cotton soil are studied. In so doing, the following tests were conducted for the soil samples collected for the three (3) test pits: natural moisture content, grain size analysis, free swell, Atterberg limits, Shrinkage limits, Specific gravity, Modified Proctor, California Bearing Ratio (CBR) strength, CBR Swell, and Unconfined Compressive Strength (UCS).

a) Grain Size Distribution

Wet sieve and Hydrometer analysis tests were conducted to determine the percentage of different grain sizes contained within a soil. Wet sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles.

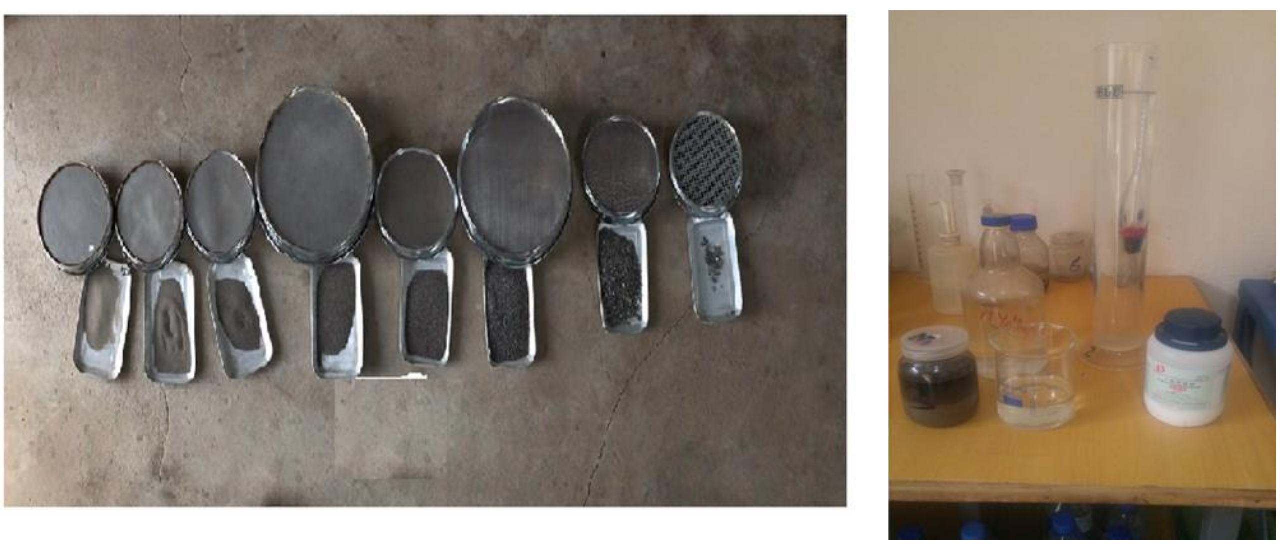


Figure 11: Wet Sieve and Hydrometer tests for the Native Black Cotton Soil

The sieve and hydrometer analysis test results showed that on average the native black cotton soil contained 4% sand, 40% silt and 56% clay by weight. The grain size distribution of the soil samples is presented in Table 8 and Figure 12.

Table 8: Grain Size Distribution for the three (3) test pits of the native Black Cotton Soil

Sample -1		Sample 2		Sample -3	
Sieve Size	% Passing	Sieve Size	% Passing	Sieve Size	% Passing
4.75	100	4.75	100	4.75	100
2.00	97.3	2.00	98.0	2.00	98.6
0.425	96.5	0.425	97.8	0.425	97.6
0.075	96.1	0.075	95.3	0.075	96.9
0.029	96.0	0.028	94.7	0.029	95.7
0.018	93.0	0.018	90.5	0.018	92.1
0.011	88.2	0.011	84.1	0.011	86.2
0.008	81.3	0.008	77.6	0.008	80.2
0.005	74.0	0.005	71.2	0.005	73.8
0.003	63.0	0.003	59.8	0.003	61.3
0.001	50.7	0.001	50.0	0.001	51.8

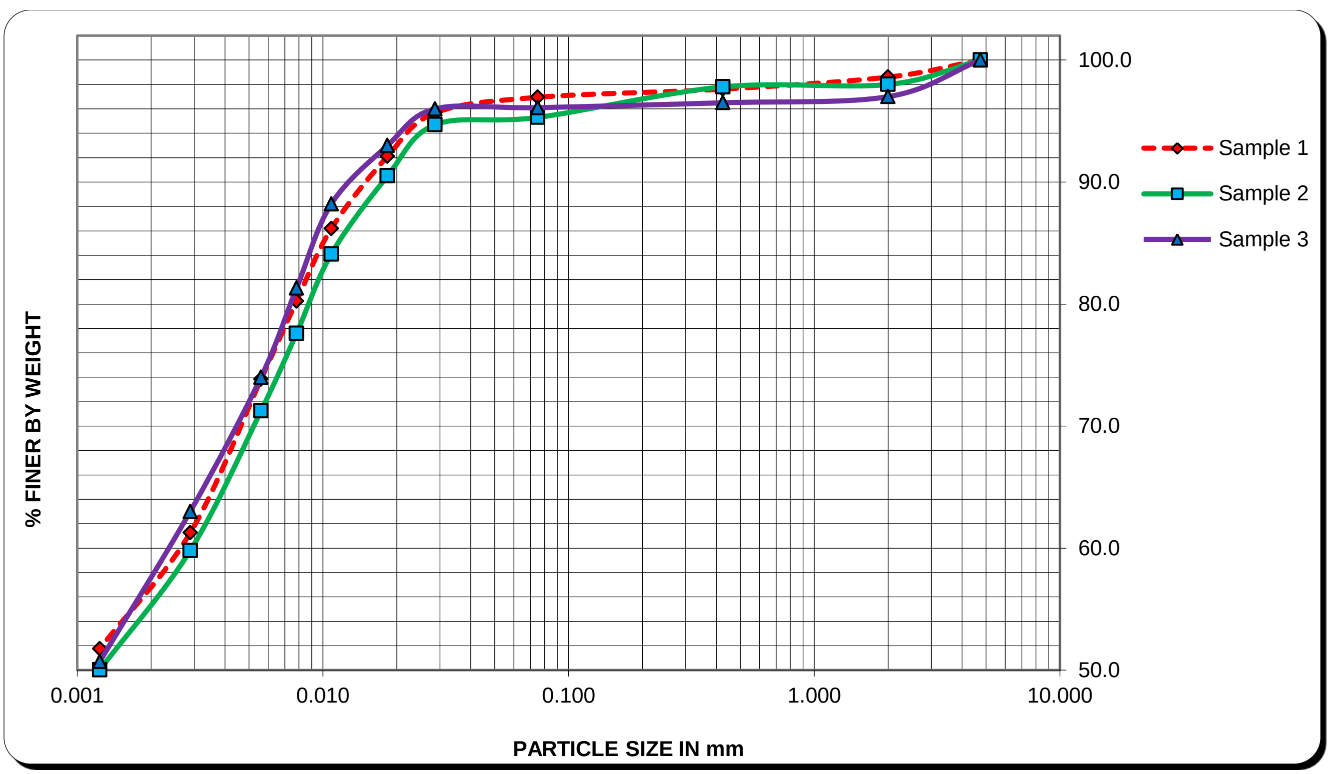


Figure 12: Particle Size Distributions for the Three Test pits of Black Cotton Soil

b) Specific Gravity

Specific gravity of the native black cotton soil were determined according to AASHTO T-100 and the specific gravity were determined to be 2.45, 2.47 and 2.51 for test pits one, two and three respectively which represents soils with clayey characteristics.

Figure 13: Specific Gravity test for the native Black Cotton Soil

c) Atterberg Limit

Atterberg limits were determined from the soil samples using the material passing through a No. 40 (0.425 mm) sieve. The results of the atterberg limit of the soil sample are presented on Table 9.

Figure 14: Atterberg Limit tests for the native Black Cotton Soil (Liquid Limit and Plastic Limit tests

Having determined the Atterberg limit tests and the grain size analysis tests, the soil samples were classified as A-7-6 according to the AASHTO Classification System.

Table 9: Atterberg Limit values for the three soil samples

	Atterberg Limit			%Passing 0.075mm	AASHTO Classification
	LL (%)	PL (%)	PI = LL-PL (%)		
Sample-1	89	49	40	96.1	A-7-6
Sample-2	84	41	43	95.3	A-7-6
Sample-3	81	39	42	96.9	A-7-6
Average	85	43	42	96.1	A-7-6

The soil samples tested to Atterberg Limits were plotted over the Casagrande's plasticity chart; Figure 15 shows the plot of plastic index against liquid limit to detect the potential swell of the soils in accordance with Casagrande's plasticity chart. The plot shows that all of the three samples of the native black cotton soil fall very close to the A-line, indicating that most of the samples are clays soils with High plasticity.

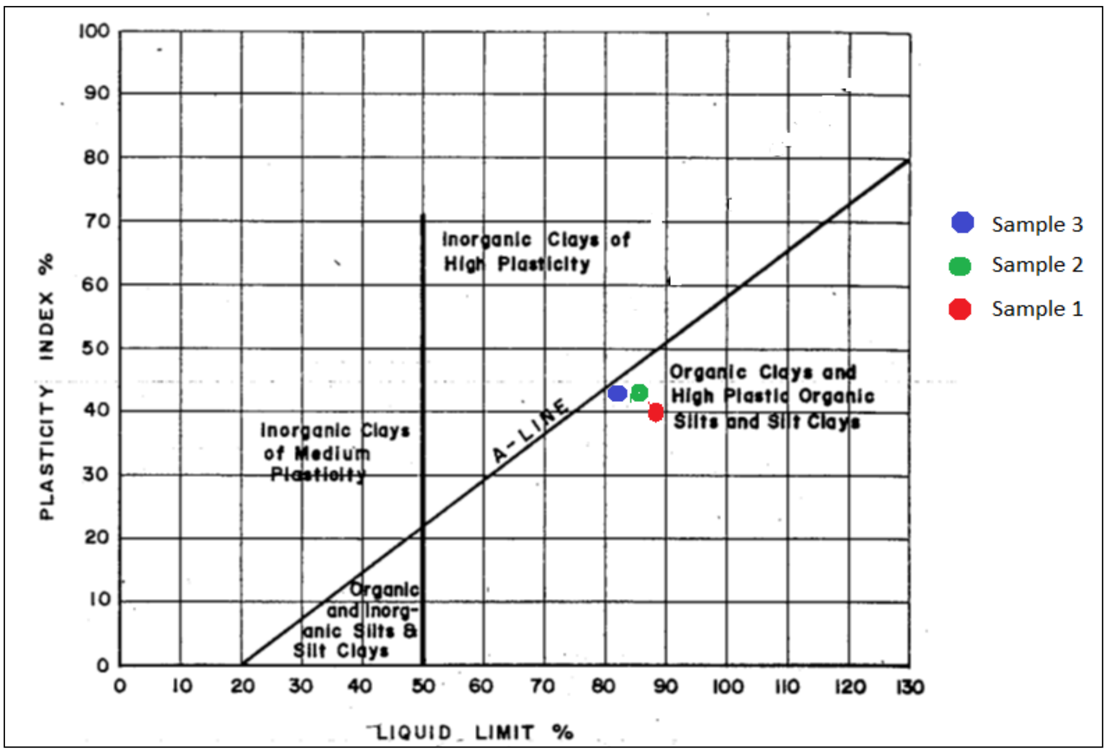


Figure 15: Plasticity of the Black Cotton Soil based on the Casagrande's plasticity chart

d) Linear Shrinkage

The Linear Shrinkage values of the native black cotton soil soils were determined in accordance with ASTM D 4943, and the resulted in 24.3%, 23.1% and 21.8% for test pits one, two and three respectively. It was suggested by (Altmeyer, 1955) as a guide to the determination of potential expansiveness for various values of shrinkage limits and linear shrinkage and reported that linear shrinkage greater than 8% is considered as soil with high degree of expansion. Based on (Altmeyer, 1955), the linear shrinkage values of all the three test pits could be categorized as expansive soils with a high range of volume fluctuations.

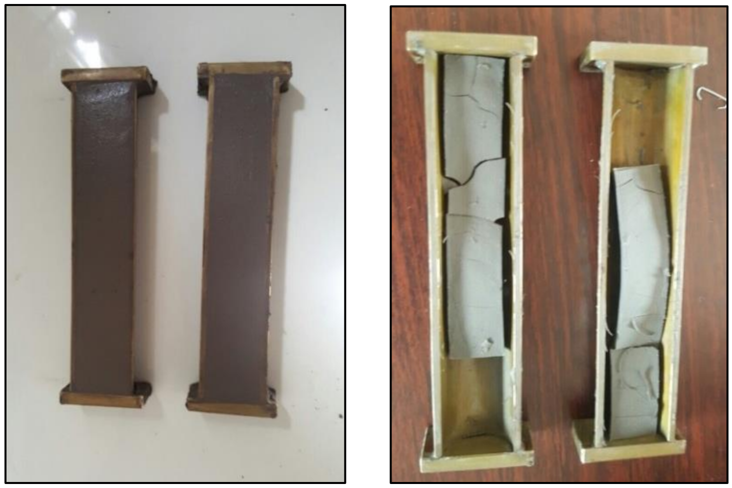


Figure 16: Linear Shrinkage test for the Native Black cotton soil

e) Free Swell Test

For each sample of soil, two 10gm ovens dry soil passing through a No. 40 (0.425 mm) sieve was taken. Each soil specimen was poured into each of two glass graduated cylinder. One cylinder was filled with kerosene oil and the other with distilled water up to 100 ml mark. Then after 24 hours the final volume of the soils in each cylinder was read and the free swell index of the soils was calculated.

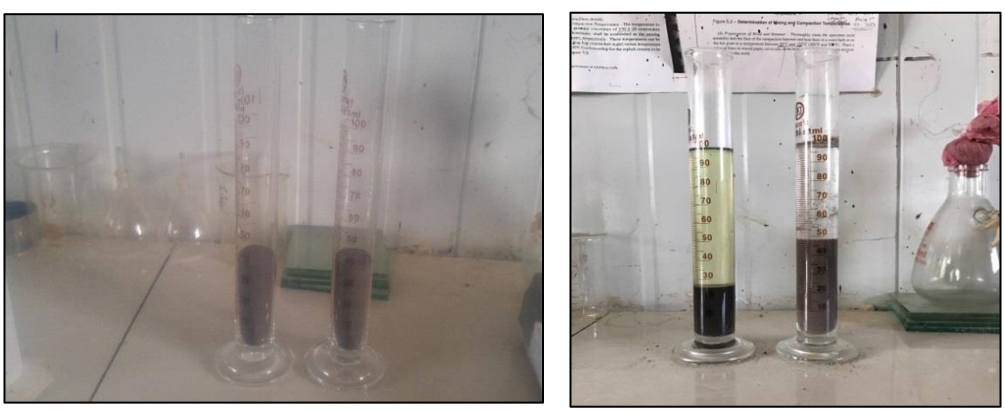


Figure 17: Free Swell test measurement for the native Black cotton soil sample

Based on the above, free swell values of 92%, 98% and 102% were recorded for test pits one, two and three respectively.

Holtz and Gibbs (1956) suggested that soils having free swell value as low as 100 % may exhibit considerable expansion in the field when wetted under light loading and soils having free swell value below 50% seldom exhibit appreciable volume change even under very light loading.

Therefore, based on the suggestion made by (Holtz and Gibbs, 1956), the recorded free swell values for all of the three test pits (i.e. 92%, 98% and 102%) are considered as highly expansive soils

f) Moisture Density Relations of the subgrade Soils

Modified Proctor tests were conducted on the native black cotton soils to determine the relationship between the moisture content and dry densities. The results of the maximum dry density and the respective optimum moisture content of the three samples of soil is presented on the following Table 10.

Figure 18: Modified Proctor compaction test preparation for the black cotton soil sample

Table 10: Maximum Dry Density and Optimum Moisture Content values of the soil

	Modified Proctor Test	
Black Cotton Soil	MDD (gm/cm3)	OMC (%)
Sample-1	1.48	23.7
Sample-2	1.50	26.0
Sample-3	1.53	22.3

g) California Bearing Ration (CBR) Values and CBR Percent Swell Values

Three point CBR and CBR Percent Swell tests were done according to AASHTO T-193 to determine the strength of the native black cotton sample soil. The compacted soil in CBR mold (molds for 10 blows, 30 blows and 65 blows) was soaked in water for 4 days with 4.5 kg annular surcharge discs load applied to it. A dial gauge mounted on a Tripod, having a travel of 25 mm and reading to 0.01 mm was fitted on the tripod for measuring CBR swell. The CBR values were calculated at penetration of 2.5 and 5.0 mm.

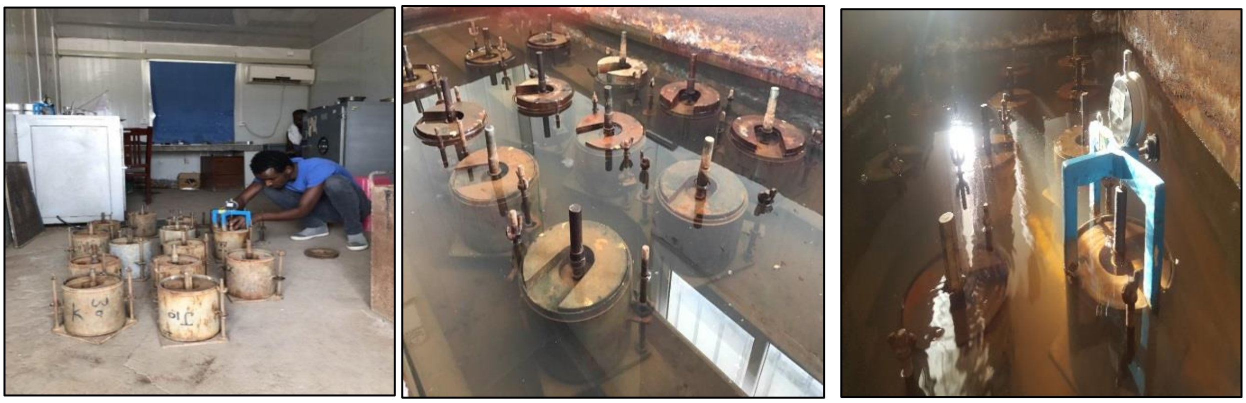


Figure 19: CBR and CBR Swell measurement for the native soil sample

The CBR test result values were determined at a density of 95% of the maximum dry density and the test results revealed that the native black cotton soil has very low CBR value. The test results of the soaked CBR Values and CBR Percent Swell Values for the native black cotton soil is presented in the following table:-

Table 11: CBR and CBR Swell values of the three soil samples

	CBR and CBR Swell					
Black Cotton Soil	Blows	CBR (%)	CBR Swell (%)	MDD	MDD (95%)	CBR at 95% MDD (%)
Sample-1	10	1	16	1.48	1.40	1.5
	30	1	14			
	65	2	18			
Sample-2	10	1	19	1.50	1.42	2.0
	30	2	17			
	65	2	18			
Sample-3	10	1	17	1.53	1.45	1.8
	30	1	16			
	65	2	19			

In most cases, CBR values at 2.5 mm are larger than CBR value at 5.0mm. According to AASHTO T-193, the CBR is generally selected at 2.5 mm penetration. If the ratio at 5.0 mm penetration is greater, the test shall be rerun. If the check test gives similar result, the value at 5.0 mm shall be selected. On the other hand, according to the British Standard (BS), the CBR value of the material is the higher percentage of the two calculated values at penetration of 2.5 and 5.0 mm, and the higher value was taken as CBR of the sample. For this research work the higher value is taken as the CBR of the soil.

According to (ERA, 2013c) subgrade soil with CBR values less than 5% are categorized as weak subgrade soils. Therefore, based on (ERA, 2013c), that CBR values for each of the three test pits are categorized as weak subgrade soil.

Furthermore, (ERA, 2013c) recommends CBR Percent Swell values of less than 2.0 % for sub-grade and embankment materials. In this regard, CBR Percent Swell values for all of the three test pits are well above the maximum threshold limits of 2.0 % for sub-grade soil materials.

h) Unconfined Compressive Strength (UCS)

The un-drained shear strength (Su) of clayey soils is usually determined from unconfined compression test. The un-drained shear strength (Su) of a cohesive soil is equal to one-half the unconfined compression strength (qu) when the soil's angle of internal friction is very minimum and/or zero (f=0 condition).

$$Su = C = \frac{qu}{2} \quad \text{………………………..} \quad \text{Eq. (6)}$$

Unconfined Compressive Strength (UCS) testing was done according to AASHTO T-208 and the un-drained shear strengths were calculated based on the above equation and the results are presented in Table 12.

Figure 20: UCS specimen preparation and strength measurement for the native black

Table 12: UCS and Cohesion (undrain shear strength) values for the three soil samples

Black Cotton Soil	UCS = q_u (KN/m2)	Cohesion = C= $q_u/2$ (KN/m2)	Moisture Content (%)
Sample-1	117.62	58.81	24.8
Sample-2	124.03	62.01	27.2
Sample-3	120.30	60.15	23.1

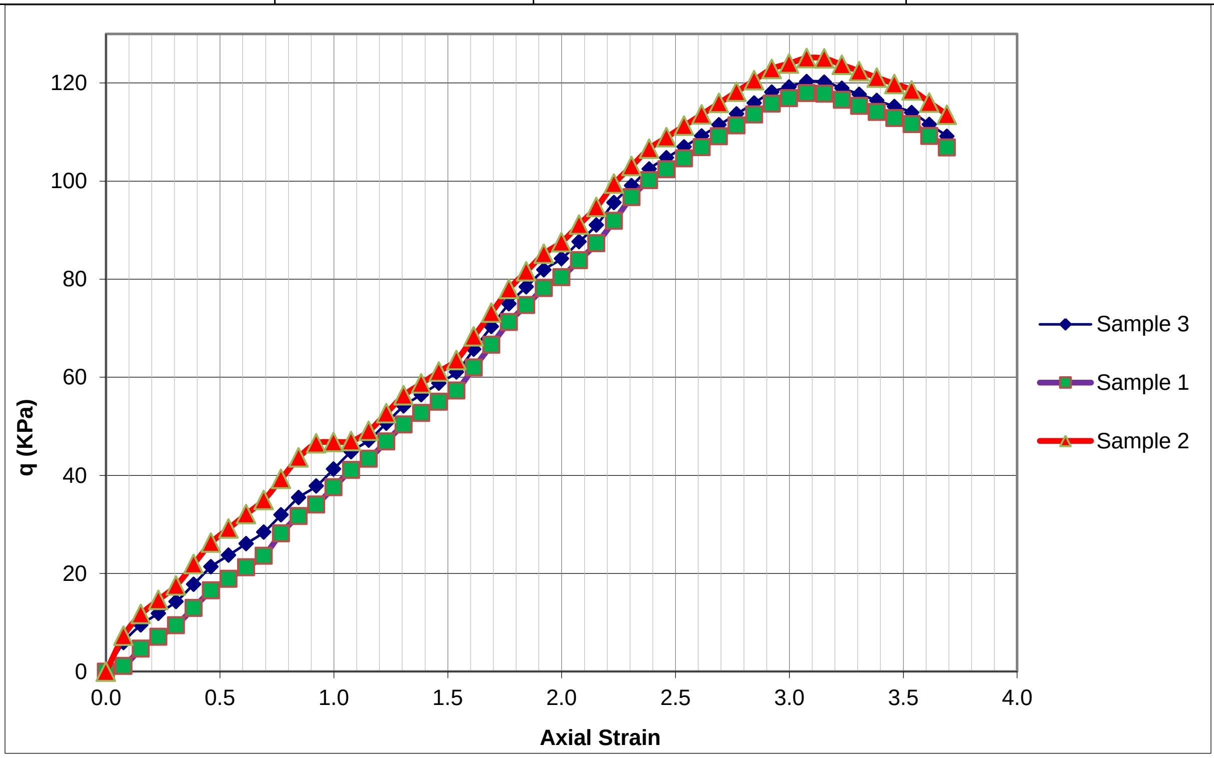


Figure 21: Stress – Strain distribution of the three soil samples

i) Indirect Estimation of Potential Swell

Potential swell is one of the most important parameter in characterizing expansive soils and this parameter is important to classify sub-grade soils based on their degree of expansion.

Potential swell can be measured either directly or indirectly. The indirect methods involve the use of soil properties and classification schemes to estimate swell potential, whereas the direct methods provide actual physical measurement of swelling. In this research, swelling potential of the soil is determined by index properties of the soil using indirect methods developed by Van Der Marwe's 1964 chart and Seed et al, 1962 model.

Swelling Potential based on Plasticity Index and Clay Fraction

The Van Der Marwe's chart measures swelling potential using plasticity index and percent of the clay fraction in the soil.

Based on the above, the native black cotton soil samples were plotted on the Van Der Marwe's 1964 chart as seen in Figure 22 and the result revealed that all of the three of the native black cotton soil samples fallen in the highly expansive soil region.

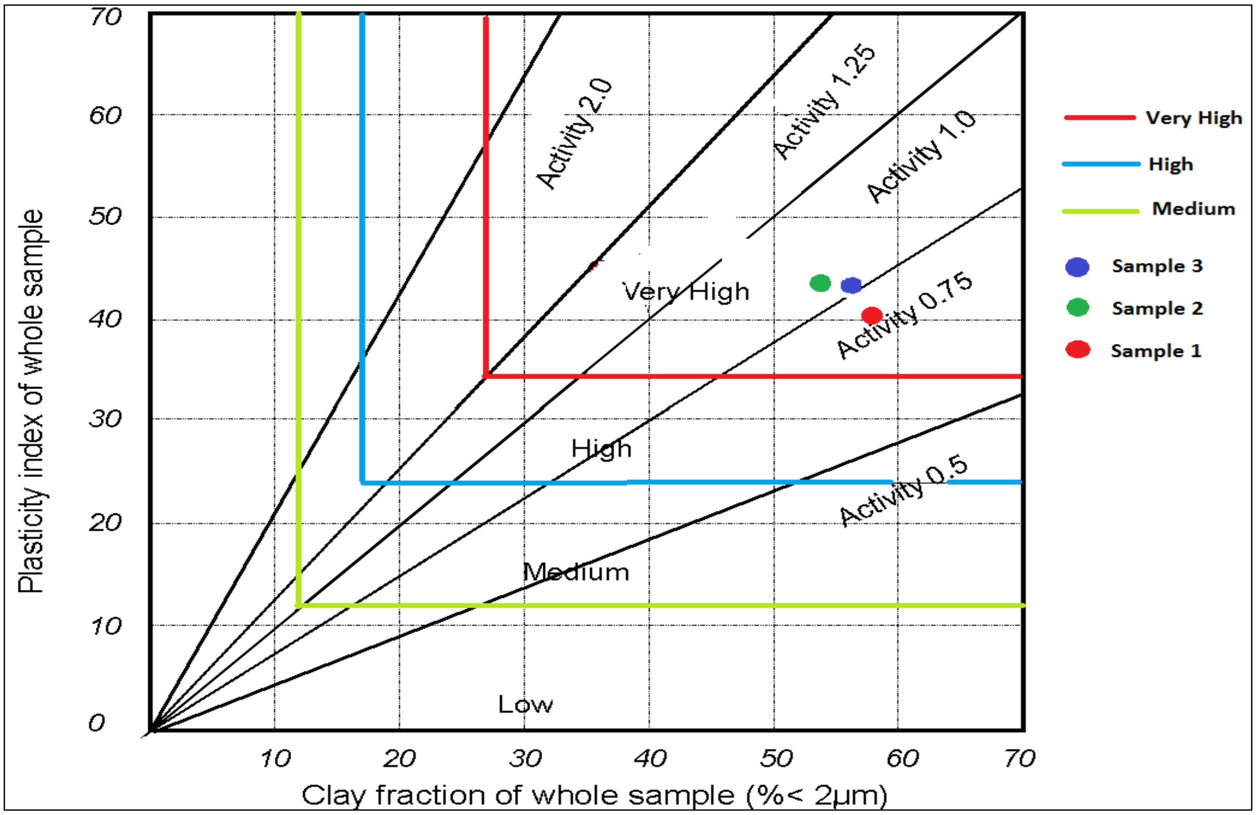


Figure 22: Classification chart for swelling potential of the native Black Cotton Soil proposed by (Van Der Merwe, 1964)

Swelling Potential based on Activity and Clay Fraction

The Seed et al, (1962) model calculates swelling potential using the activity of clay and percent of the clay fraction in the soil. The activity of a soil is taken as the dimensionless ratio of plasticity index to clay contents, both taken in percent. Activity can be calculated using Equation. (7),

$$A_C = \frac{PI}{C-5} \quad \text{.............................. Eq. (7)}$$

Table 13: Activity values of the sample soils (based on Seed et al 1962 model)

Black Cotton Soil	PI (%)	Clay Fraction (% < 2μm)	Activity $A_C = \frac{PI}{C-5}$
Sample-1	40	57	0.77
Sample-2	43	54	0.88
Sample-3	42	56	0.82

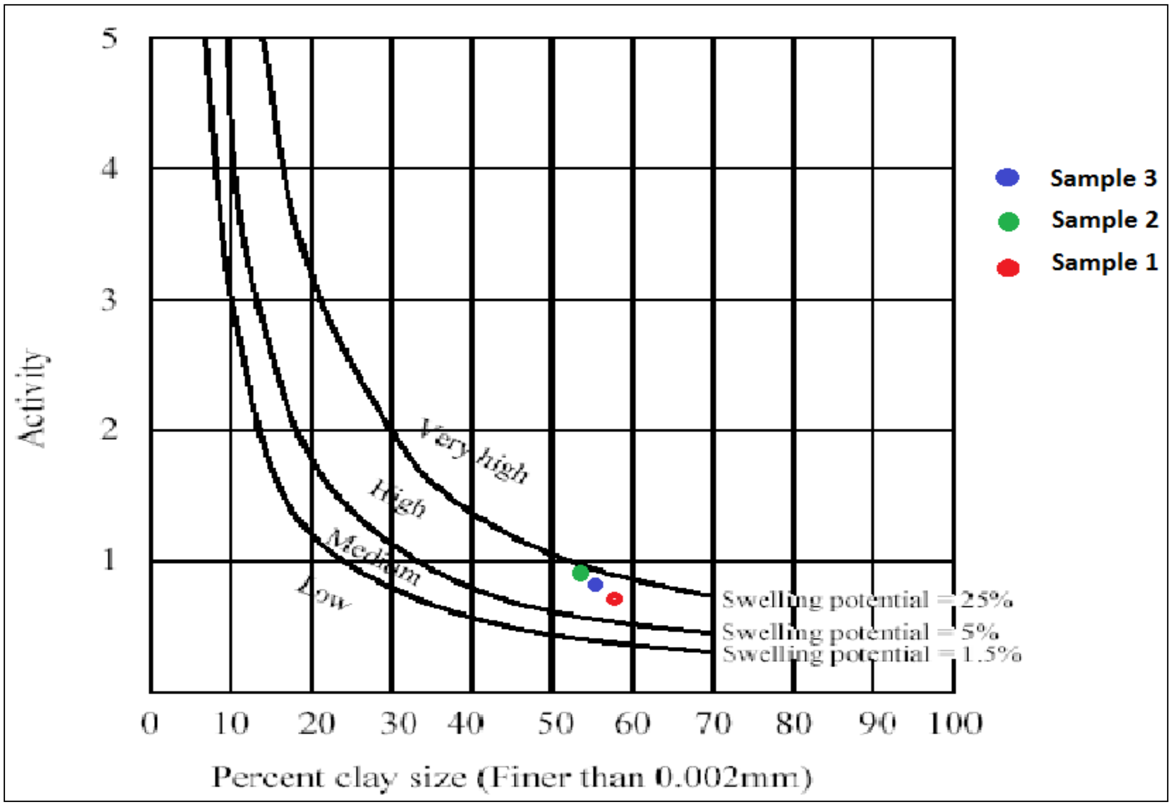


Figure 23: Swelling potential of the Native Black Cotton soil for the three test samples (Based on Seed et al, 1962 model)

Based on the above, the native black cotton soil samples were plotted on the Seed et al, 1962 model chart as seen in Figure 23 and the result revealed that all of the three of the native black cotton soil samples fallen in the high swelling potential region.

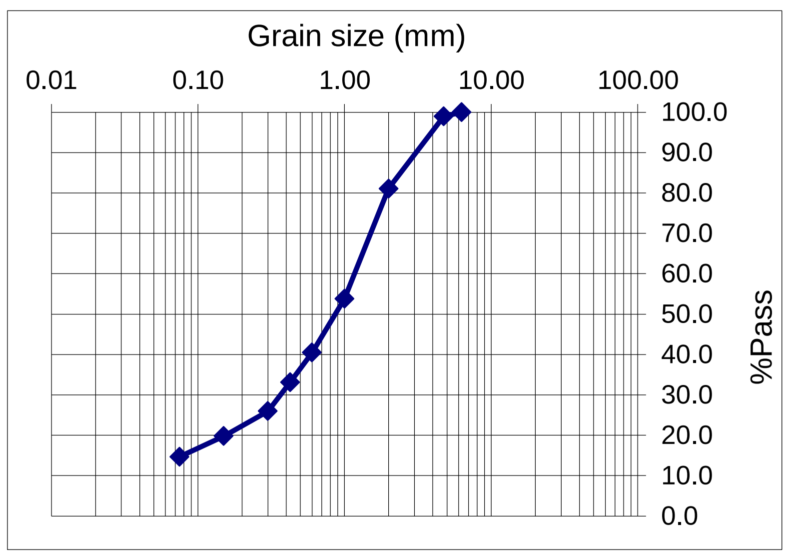
3.6.2. Quarry Dust

The Quarry dust utilized for this research work is a byproduct resulted from the crusher plant where aggregate crushing activities were performed from fresh Basalt rock quarries for producing Asphalt and Concrete aggregates that has been utilized during the construction of the Dire Dawa – Dewelle road project.

Once the Quarry dust has been brought from the crusher plant, it was dried with the atmospheric air, laboratory tests were carried out to determine the physical properties and engineering properties of the Quarry dust such as, Specific gravity, Gradation, Plasticity Index (%), compaction characteristics and CBR values were assessed.

The laboratory test results performed on the quarry dust were summarized and presented in Table 14.

Table 14: Summary of Laboratory Tests Results of the Quarry Dust

<table>
<tr><th colspan="2">Parameters</th><th>Value</th></tr>
<tr><td colspan="2">Specific Gravity</td><td>2.78</td></tr>
<tr><td colspan="2">Gradation</td><td rowspan="10">
</td></tr>
<tr><td>Sieve Size</td><td>Percent passing (%)</td></tr>
<tr><td>4.25mm</td><td>99.0</td></tr>
<tr><td>2.00mm</td><td>81.1</td></tr>
<tr><td>1.00mm</td><td>53.8</td></tr>
<tr><td>0.60mm</td><td>40.5</td></tr>
<tr><td>0.425mm</td><td>33.1</td></tr>
<tr><td>0.30mm</td><td>26.0</td></tr>
<tr><td>0.150mm</td><td>19.8</td></tr>
<tr><td>0.075mm</td><td>14.7</td></tr>
<tr><td colspan="2">Plasticity Characteristics (PI)</td><td>NP (Non-Plastic)</td></tr>
<tr><td colspan="2">Compaction Characteristics</td><td></td></tr>
<tr><td colspan="2">MDD</td><td>2.236 gm/cc</td></tr>
<tr><td colspan="2">OMC</td><td>6.75%</td></tr>
<tr><td colspan="2">CBR (%)</td><td>105</td></tr>
<tr><td colspan="2">CBR Swell (%)</td><td>Nil</td></tr>
</table>

3.6.3. Ordinary Portland cement

The cement used for this research is DANGOTE Ordinary Portland Cement (OPC) type-I cement purchased from the retailers found in Addis Ababa.

The physical and chemical properties of the DANGOTE Ordinary Portland Cement (OPC) such as oxide composition as Silica, Alumina, Iron Oxide, Calcium Oxide (Lime), and Magnesia, Sulphur Trioxide, free Lime (%), and Loss on ignition for the products which were manufactured at 2009 E.C, were obtained at DANGOTE Cement Factory Laboratory and the same has been shown on Figure 24.

The oxide composition result of the OPC showed that more than 60% lime (CaO) is present on the cement composition which in turn is the main compound causing a chemical reaction such as hydration reaction, cation exchange and pozzolanic reaction when it is mixed with the black cotton soil.

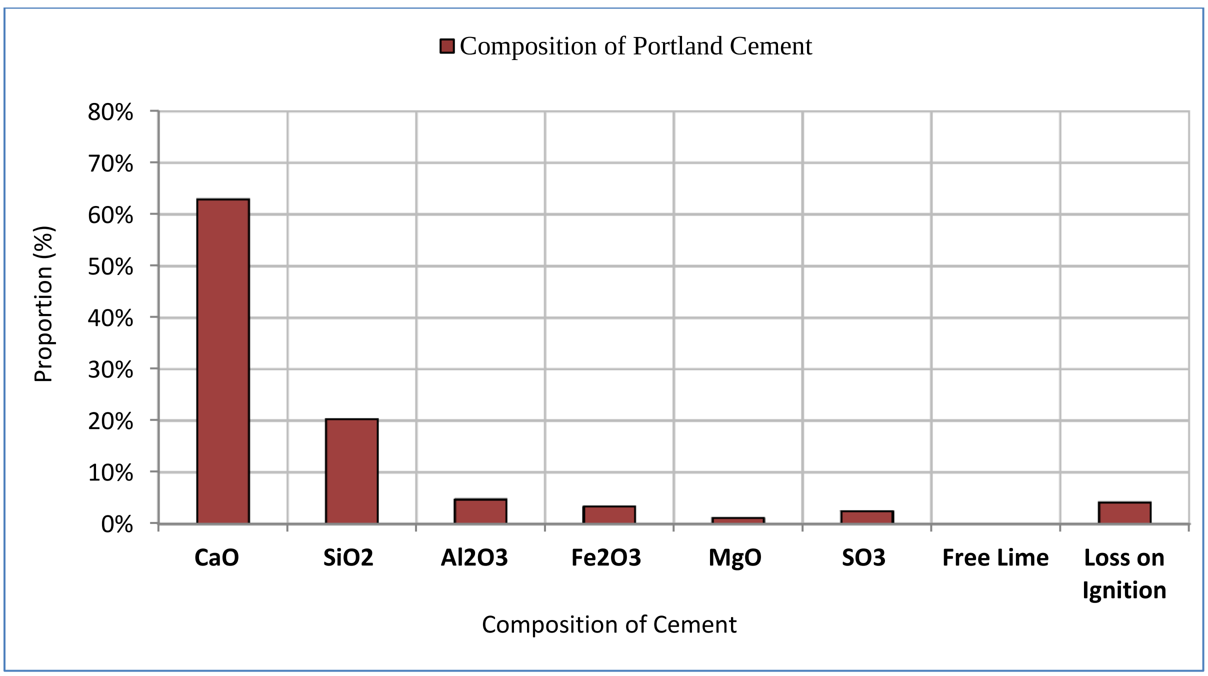


Figure 24: Composition of the Constituent Compounds of Ordinary Portland cement (OPC)

Chapter 4 Analysis and Discussion of Results

4.1. Foreword

In this chapter, analysis and discussion has been made on all the laboratory test results conducted for the treated Black Cotton soil with Portland cement only, Quarry Dust only, and Portland cement & Quarry Dust combinations for the different proportions of the additives/stabilizers utilized.

In doing so, the test results of the different proportions of the stabilizers on the engineering properties of the treated black cotton soil such as Atterberg Limits, Moisture-Density relation, CBR & CBR Swells, and Unconfined Compressive Strength (UCS) values were discussed and compared with the respective properties of the untreated/native Black Cotton soil.

Furthermore, discussion has been made on the outcome of the properties of the treated black cotton soil in line with 'Reviewed Literatures' as presented in Chapter-2 and also in vis-à-vis with the conclusions made by other scholars/researches regarding the effect of cement and quarry dust on treated expansive soils.

4.2. Atterberg Limits

In this sub-section, Atterberg limits i.e. Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) test results for the treated black cotton soil with cement only, quarry dust only, and with the combination of cement & quarry dust is discussed hereunder.

4.2.1. Atterberg Limits of Soil treated with Portland-cement

For the black cotton soil treated with cement only, the tests were carried out for the mixes that were prepared at 2%, 4%, 8% and 12% of Portland-cement by dry weight of the soil and for the samples cured for 7 days.

Hence, the addition of Portland cement in varying proportions with the soil and the effect of the same on the atterberg limit values of the mix and the changes made on the respective properties as compared to the native black cotton soil are discussed in hereunder.

Variation of liquid & plastic limits and the plasticity index for different cement content for treated black cotton soil is shown in Figure 25.

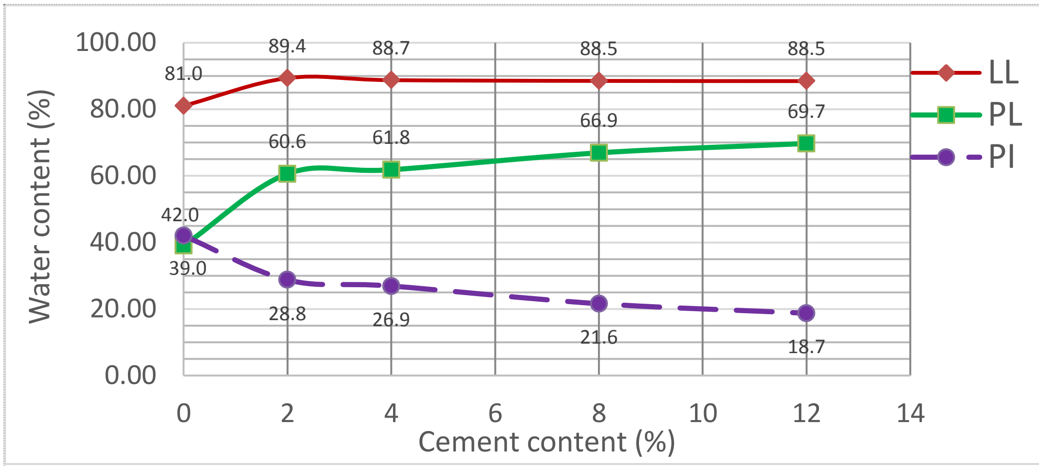


Figure 25: Variation of Atterberg Limit values of the soil treated with different cement content

The liquid limit (LL) of the native/untreated black cotton soil is determined as 81% whereas after the addition of Portland cement up to 12%, the liquid limit increased to 88%. From the figure above, it can be seen that the liquid limit (LL) increased initially and then decreased slightly with higher cement content.

The plastic limit (PL) of the native black cotton soil was found to be 39% and when cement is added, the plastic limit of the cement-treated soil increased to 69% with the addition of cement up to 12%. Consequently the Plasticity Index (PI) of the cement-treated black cotton soil decreases with the increase in cement content. The PI of the untreated soil (42%) is decreased to 18.4% with the addition of cement up to 12%.

Bergado et al. (1996) has also deduced the same conclusion and in doing so he has reported that reduction in Plasticity Index is due to an increasing of Plastic limit, which is highly affected by cement content and curing time.

The addition of cement was also found to increase optimum water content (OMC) and accordingly it could increase the liquid limit (LL) of the Cement-treated soil. The increase in Plastic limit (PL) of the Cement-treated soil could be attributed to the reduction in the permeability of the treated soil. The decrease in Plasticity Index (PI) of the cement treated soil is due to the cement hydration that is accompanied by an increase in P_H of the pore fluid and Ca^{++} ion concentration on the clay surface.

Similar conclusion has been made by Kauschinger et al. (1992). Kauschinger has reported that the permeability of the cement treated clay reduces with the increase of cement content and curing time. In addition to that, (Broderic and Daniel, 1990) reported that the permeability of the treated clay reduced to 1/4 or less than that of the untreated clay and they suggested that this reduction could be due to the Pozzolanic cement substances, which block the pores in the soil cement matrix.

All in all, the Atterberg limit values resulted on this research work is in synchronized with what it has been concluded by (Sridharan and Jayadeva, 1982; Sivapullaiah et al., 2000). They concluded that with the addition of cement, the plasticity index of Black Cotton Indian soil decreases. They found that immediately after the addition of cement, the liquid limit reduces significantly. This liquid limit was found to increase as the curing time increases to 7 days. On the other hand, the plastic limit increases with time.

4.2.2. Atterberg Limits of Soil treated with Quarry Dust

The Atterberg limit tests for black cotton soil treated with Quarry Dust only, were carried out by preparing mixes by varying the quarry dust content by 5% (i.e. 5%, 10%, 15% and 20%) by dry weight of the soil.

Variation of liquid limits, plastic limits and the plasticity index for the treated black cotton soil with different proportion of Quarry dust is shown in Figure 26. Even though there is no significant effect on the Plastic Index (PI) of soil treated with Quarry dust, there was a slight reduction in atterberg limits with increasing Quarry dust content.

Table 15: Atterberg limit values for Quarry Dust treated soil

Quarry Dust Proportion	LL (%)	PL (%)	PI = (LL-PL)	ΔPI (Change in PI)
0% (Native Soil)	81.0	39.0	42.0	--
5%	78.7	38.5	40.2	1.8
10%	74.9	36.7	38.2	3.8
15%	72.5	35.6	36.9	5.1
20%	71.1	35.6	35.5	6.5

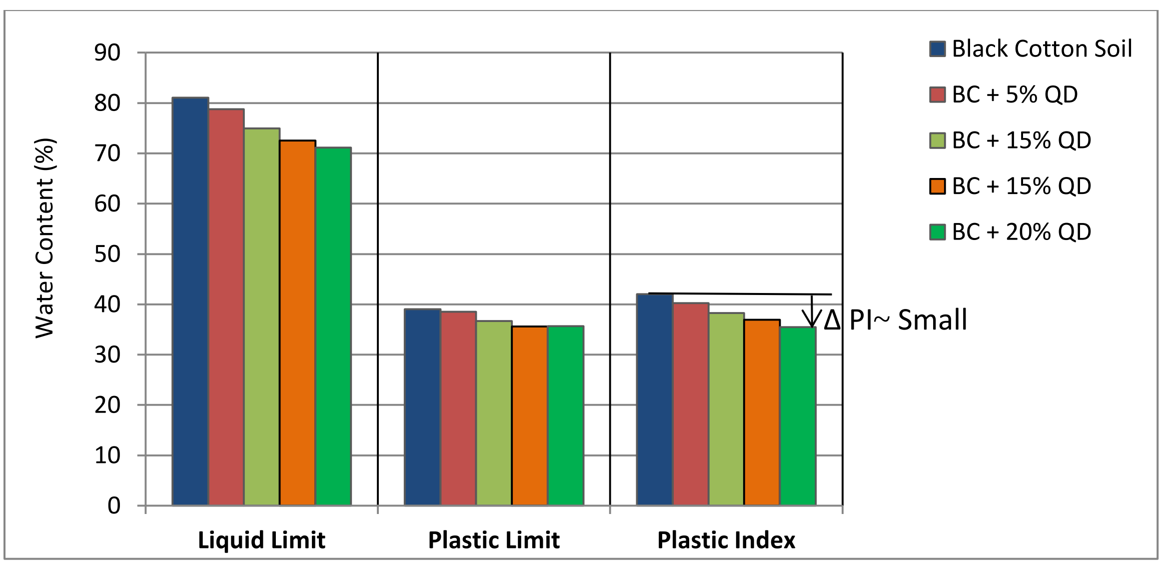


Figure 26: Distribution of Atterberg Limits for Quarry Dust treated soil

The addition of Quarry dust to the native black cotton soil, did not cause practical significant improvement on the Plasticity Index (PI) of the treated soil. This is due to the fact that the natural soil had very high clay content so that the addition of quarry dust only reinforced the sand size content of the soil-dust mixture with no textural and no chemical change of the clay particles of the black cotton soil.

The Plasticity Index (PI) of the treated black cotton soil decreases with the increase in Quarry dust content. The PI of the untreated soil (42%) is decreased gradually to 35% with the addition of Quarry dust up to 20%. This could be attributed to the partial reduction in clay content as the non-plastic Quarry dust is increased which in turn results in a reduction in water absorption capacity of the black cotton soil.

Eden (2017) reported that the plasticity of an expansive soil decreased by the addition of Quarry dust content. However, the observed decrement in the plasticity index of the treated soil is nominal.

As per AASHTO T- 89 (Method A) and AASHTO T- 90, particles passing through a No.40 (0.425mm) sieve are used for the determination of Atterberg Limits values of treated soils. In this regard, the sieve and hydrometer analysis test results showed that on average the native Black Cotton soil contained 4% sand (> 2.00mm), 40% silt (0.075mm-0.002mm) and 56% clay (< 0.002mm) by weight and from the constituent particles, 98% (% passing 0.425mm) of the native Black Cotton soil control the Plasticity characteristics of the Soil - Quarry dust mixture. On the other hand, as it can be shown in Figure 27, for the Soil - Quarry dust mixture, only 33.1% (% passing 0.425mm) of the added Quarry dust contribute for the improvement of the Plasticity characteristics of the soil.

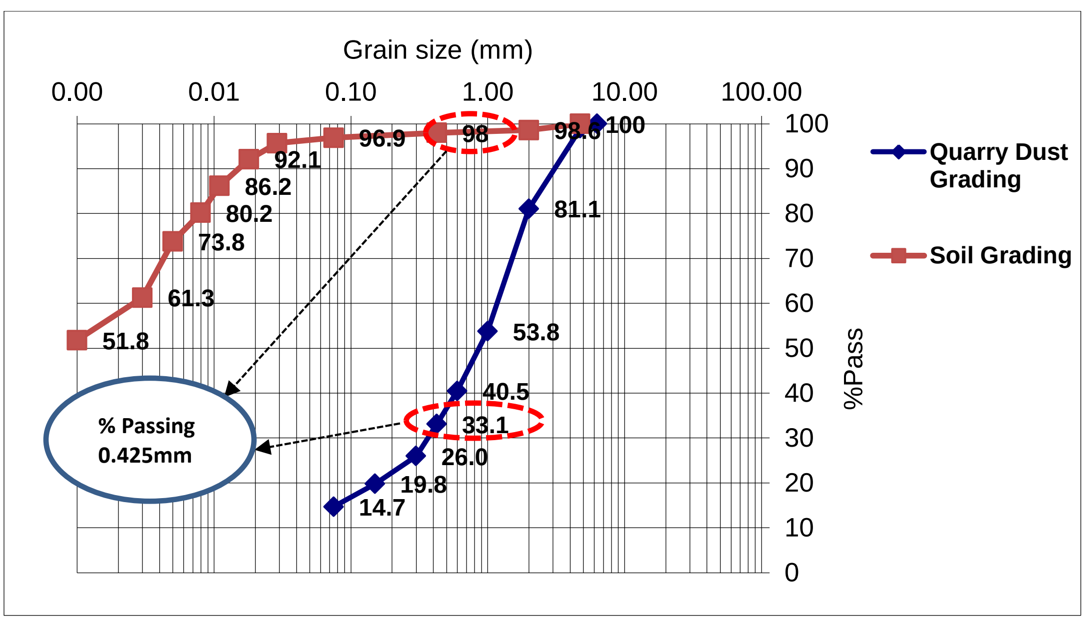


Figure 27: Particle Size Distributions of the Native Black Cotton soil and Quarry Dust

Hence, the more the fine the Quarry dust, then the better the improvement on the plasticity index of the treated soil. In general the gradation (especially % passing 0.425mm of the Quarry dust) has a great role on the anticipated degree of improvement/result of the atterberg limits of the Soil - Quarry dust mixture.

4.2.3. Atterberg Limits of Soil treated with Cement and Quarry Dust mixture

Atterberg limit tests for black cotton soil treated with Cement and Quarry Dust mixture were carried out by varying the Quarry Dust content by 5% (i.e. 5%, 10%, 15% and 20%) for 4%, 8% and 12% cement content and for each group of mixes, the samples were cured for 7 days.

Table 16: Atterberg Limit values for soil treated with Cement and Quarry Dust Mixture

Cement	Atterberg Limits	Quarry Dust			
		5%	10%	15%	20%
4%	LL (%)	86.3	86.0	84.0	84.0
	PL (%)	60.1	61.7	61.0	61.9
	PI (%)	26.3	24.3	23.0	22.3
8%	LL (%)	88.0	87.3	85.7	85.1
	PL (%)	66.3	66.3	65.4	66.0
	PI (%)	21.7	21.0	20.3	19.1
12%	LL (%)	87.4	87.1	84.1	83.1
	PL (%)	68.9	68.2	66.3	66.0
	PI (%)	18.4	18.9	17.8	17.1

It is noted that the liquid limit (LL) of the Cement-Quarry dust treated black cotton soil increased with increase in cement content. This initial increase in Liquid limit is attributed to the increase in optimum moisture content (OMC) with the addition of cement. However, as it has been discussed in section 4.2.2. as the Quarry dust content increased, there were an accompanied reduction in the Liquid limit (LL) of the treated soil due to the reduction in clay content of the soils as the non-plastic Quarry dust is increased.

The Plasticity Index (PI) of the Cement-Quarry dust treated black cotton soil decreases significantly with the increase in the stabilizer content. The PI of the untreated soil (42%) is decreased to 17% with the addition of 12% cement+20% Quarry dust.

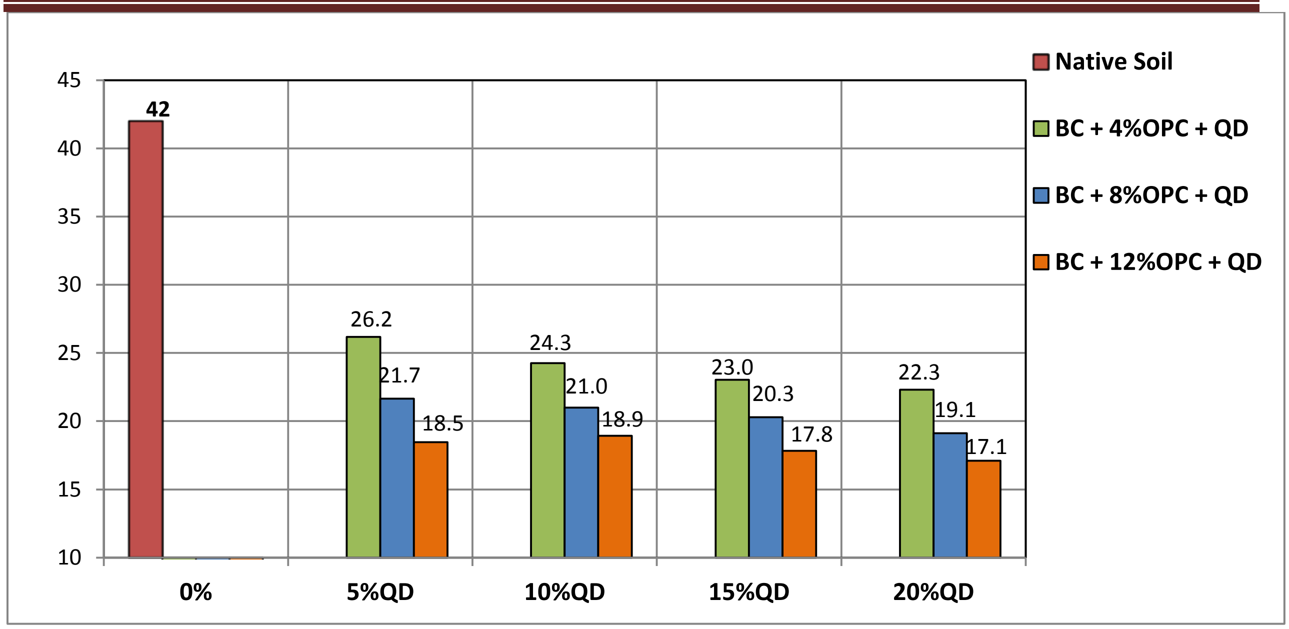


Figure 28: Variation of Plasticity Index values of the soil treated with Portland Cement & Quarry Dust

The Plasticity Index of the black cotton soil treated with Cement-Quarry dust mixture reduces further as compared to soil treated with Cement alone.

The addition of 4%cement, 8%cement and 12%cement alone reduces the PI of the untreated soil by 36%, 49% and 55% respectively. Whereas, with the addition 20% Quarry Dust, 4%cement+20%Quarrydust, 8%cement+20%Quarrydust and 12%cement+20%Quarrydust, the PI of the treated soil reduces by 47%, 54% and 59% respectively. This is due to the fact that when the Cement and Quarry dust are mixed together, the mixes of the two additives acts as a 'Cement-Mortar' which further reduces the Plasticity characteristics of the treated soil than the soil treated with Cement alone. **However, the observed reduction with increasing the Quarry dust content is not that much significant as compared to the effect of the Cement does in improving the plastic index of the treated soil**.

4.3. Compaction Characteristics (Dry Density and Moisture Content)

For determining the relationships between compacted dry density and soil moisture content, Modified Proctor Tests were done and accordingly the maximum dry density (MDD) and optimum moisture content (OMC) of the treated soil were determined according to AASHTO T-180.

The compaction characteristics for the treated black cotton soil with cement only, quarry dust only, and with the combination of cement & quarry dust is discussed hereunder.

4.3.1. Compaction Characteristics of Soil treated with Cement

For the black cotton soil treated with Portland cement at 2%, 4%, 8% and 12% of cement by dry weight of the soil, the respective compaction curves that shows the relationship between the Dry Density and Moisture Content were plotted against the 'dry density-moisture content' curve of the native black cotton soil and the comparison of the same with the untreated soil is presented in Figure 29.

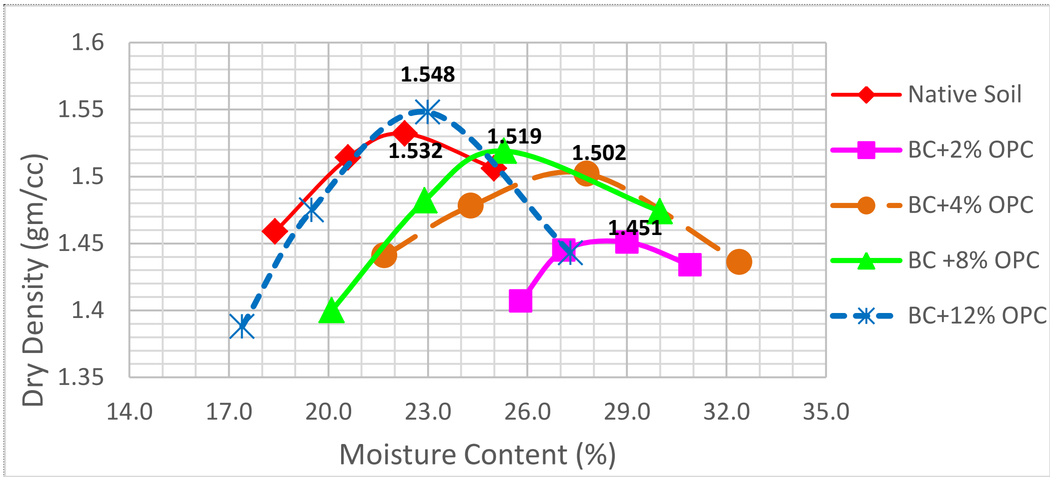


Figure 29: Dry Density Vs. Moisture Content for the Soil treated with Portland-cement

As it is shown in Figure 29, after the addition of Cement the MDD of the treated soil decreases with increasing the cement content up to 8% and reach 1.519gm/cm^3. Then after, the dry density of the treated soil increased slightly with further increasing the cement content to 12%.

The decrease in Maximum Dry Density of the Cement-treated soil could be attributed to the changes of clay particles towards more flocculated and agglomerated condition as the clay particles altering their arrangement after the addition of cement which in turn increases the pore size between the clay particles which leads to a corresponding reduction in the dry density of the treated soil.

At lower cement content (2% - 4%), the MDD of the treated soil reduced as compared to the soil treated with higher cement content. This could be attributed to the reason that at lower cement content, the formation of large size aggregated particles through agglomeration is lower. Whereas, at higher cement content (12%), the formation of large size aggregated particles through agglomeration is higher which allows higher compaction leads to increasing the dry density of the treated soil.

With regard to the optimum moisture content (OMC), there is a general increase in the OMC of the treated soil with the addition of Portland cement. The OMC of the treated soil increased significantly at lower cement content (29.0% with 2% cement added) and at higher cement content the optimum moisture content tends to decrease gradually but still higher than the OMC of the native soil. The observed increase in the optimum water content (OMC) of the cement treated soil is due to the hydration of cement in which the cement by itself utilizes the added water for the hydration reaction.

Muhunthan and Sariosseiri (2008) have reported that, generally, as cement content increased, optimum water content increased whereas maximum dry unit weight decreased. It can also be seen that, changes in compaction characteristics are significant at lower percentages of cement content. However at higher percentages of cement, the changes in compaction characteristics of treated soils are minimal. Furthermore, (Tabatabi, 1997) has reported that the addition of cement was found to increase optimum water content but decrease the maximum dry density.

However report by ACI committee 230 (1990) states that cement treatment causes changes in maximum dry density and optimum water content, but the direction of changes is not predictable.

4.3.2. Compaction Characteristics of Soil treated with Quarry Dust

For the sample soil treated with Quarry dust, the Maximum Dry Density (MDD) were determined to be 1.536gm/cm^3, 1.564gm/cm^3, 1.573gm/cm^3 and 1.617gm/cm^3 with the addition of 5%, 10%, 15% and 20% of Quarry dust by dry unit weight of the soil respectively.

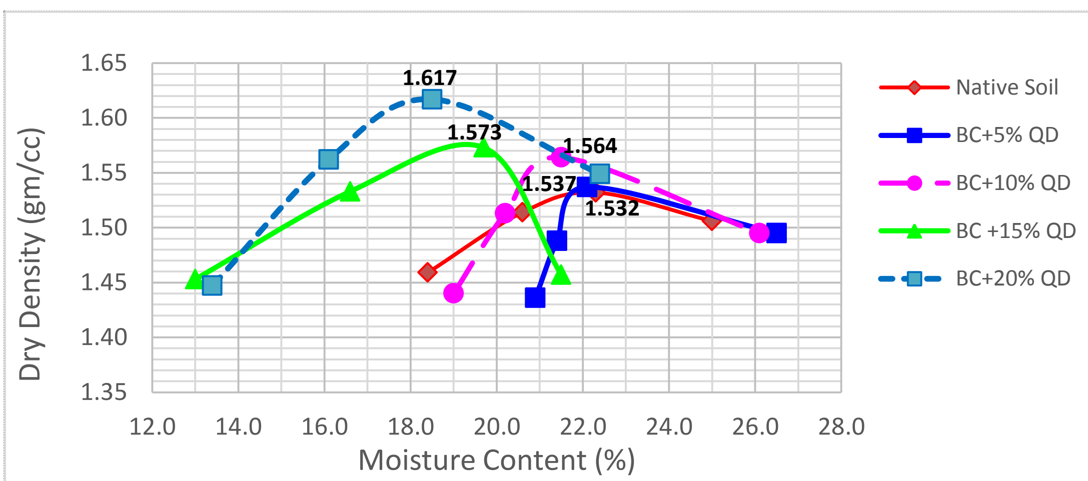


Figure 30: Dry Density Vs. Moisture Content for the Soil treated with Quarry Dust

Accordingly, with the addition of Quarry dust up to 20%, the Optimum Moisture Content (OMC) of the treated black cotton soil is decreased to 18.5% from 22.3% of the untreated soil. Here also, the OMC of the treated soil decreases continuously as the proportion of Quarry dust increases.

It is noted that as quarry dust content is increased, there is an increase in the maximum dry density (MDD) and a reduction in the optimum moisture content as demonstrated in Figure 30.

The increase in MDD and reduction in the OMC could be attributed to the fact that, as the low density particle black cotton soils (specific gravity of 2.45 up to 2.50) are replaced by a relatively high density Quarry dust (specific gravity of 2.78), an increase in the density of the composite material is expected.

The reduction in the OMC could also be due to the reduction in the clay content which causes a reduction in the water absorptive capacity of the composite material and subsequent increase in dry density (dry density is inversely proportional to moisture content).

Unlike to cement treated soil, from Figure 30 above, it can be seen that the bell shaped compaction curves of the Quarry dust treated soil shifted to the left with increasing the Quarry dust content as it is compared with the native soil which portrays the general decrease in the moisture content of the treated soil.

4.3.3. Compaction Characteristics of Soil treated with Cement and Quarry Dust Mixture

Soil treated with Cement & Quarry dust mixture has exhibited an increase in the Dry density of the soil accompanied by a reduction in the Optimum Moisture Content. The maximum dry density was recorded to be 1.671gm/cm^3 at 15.5% moisture content and 1.652gm/cm^3 at 19.6% moisture content for the soil treated with 8%OPC+20%QD and 12%OPC+20%QD respectively as it can be seen in Figure 31.

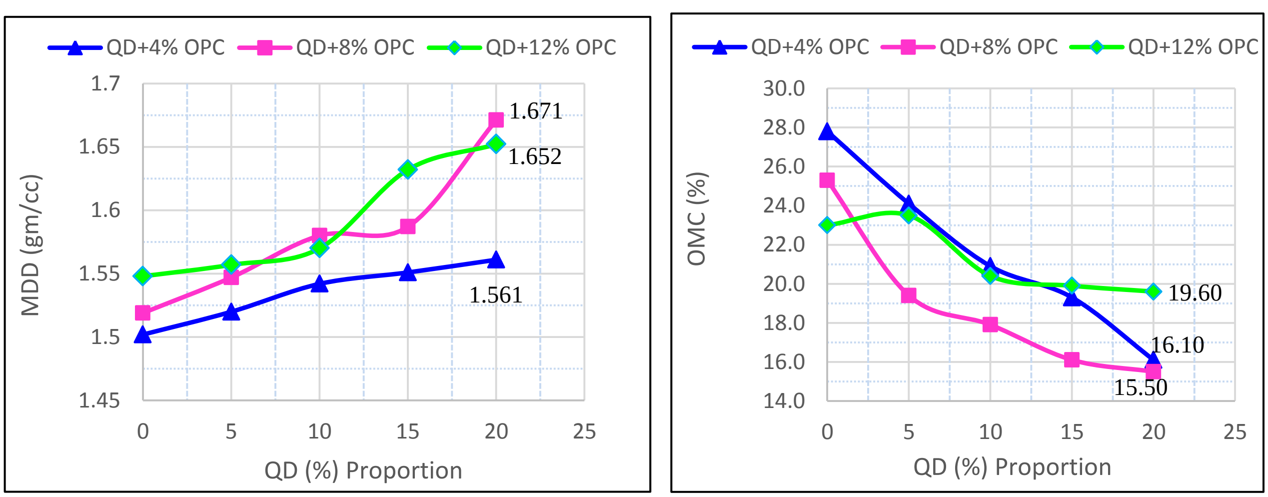
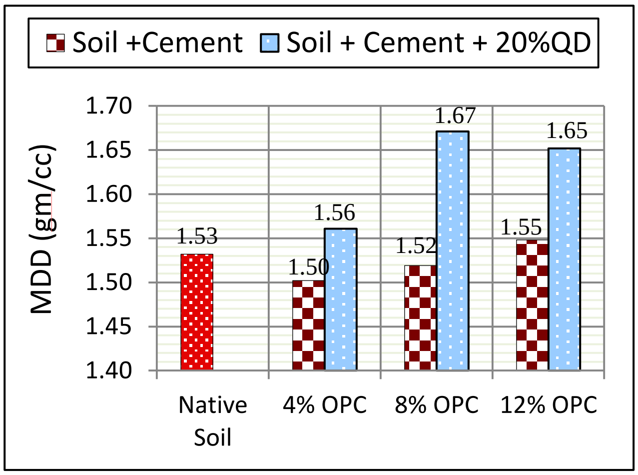


Figure 31: Variation of MDD and OMC for soil treated with Cement and Quarry Dust Mixture

As it has been discussed in section 4.3.1, the untreated black cotton soil has MDD of 1.532gm/cm³ and OMC of 22.3%. Whereas, for the soil treated with Cement only, the changes recorded on the MDD with the addition of 4% , 8% and 12% of OPC as compared to the native black cotton soil was recorded to be (-0.02), (-0.01), (+0.02) respectively (i.e. a general decrease in the MDD). However for soil treated with the mixture of Cement and Quarry dust up to 20%, the changes made on the MDD of the treated soil as compared with the untreated one were (+0.03) for 4%OPC+20%QD, (+0.14) for 8%OPC+20%QD, and (+0.12) for 12%OPC+20%QD.



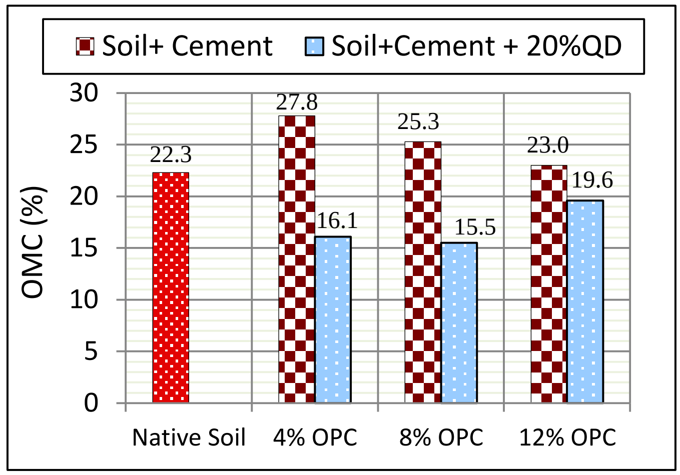


Figure 32: Comparison of MDD and OMC of soil treated with Mixture of Cement & Quarry Dust with soil treated with Cement alone

On the other hand, the maximum reduction in the OMC of the treated soil was recorded to be (-6.80%) i.e. reduction from 22.3% of the untreated soil to 15.5% for the soil treated with 8%OPC+20%QD. Hence, it is concluded that soil treated with 8%OPC+20%QD has given the maximum increase in the MDD and the maximum reduction in the OMC of the treated soil (i.e. 1.671gm/cm³ at 15.5% moisture content).

As it has been discussed before, soil treated with lower cement content results in a reduction in the Maximum Dry Density and an increase in the optimum moisture content of the treated soil. However, while keeping the Cement content constant and increasing the Quarry dust proportion, it has been observed that there is an increase in the maximum dry density (MDD) and a reduction in the optimum moisture content in all the case as shown in Figure 31.

- Though, the addition of cement cause a reduction in the dry density of the soil, the observed increase in the MDD of the treated soil with Cement & Quarry dust mixture may be associated with the increase in the size of the clay particles as the fine grained soil particles turned to a coarser one with the addition of cement and due to the addition of Quarry dust; the sand size content of the treated soil increased and accordingly the cement-dust mixture resulted in an increase in the skeleton of soil grains which in turn allows higher compaction. The observed reduction in the OMC of the treated soil could be attributed to the reduction in the clay content of the soil which causes a reduction in the water absorptive capacity of the composite soil-cement-dust material.

4.4. California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) values are considered as the very important strength parameters in the selection of road construction materials in terms of the load bearing capacity and suitable platform for the construction of the overlying pavement layers and it is a familiar indicator test used to evaluate the strength of soils.

CBR tests were carried out for the untreated/native black cotton soil as well as for the treated black cotton soil with Portland-cement only, Quarry dust only, and with the combination of Cement & Quarry dust mixtures with different proportions by applying different curing periods and soaked for 96 hours (4-days).

4.4.1. CBR values of Soil treated with Portland-Cement

For the black cotton soil treated with Portland cement, sample specimens were prepared at 2%, 4%, 8% and 12% of cement by dry weight of the soil.

The CBR values for the soil treated with Portland-cement were determined on soil samples compacted at OMC and cured for 7 days at room temperature by sealing the specimen in plastic bags and after 7 days of curing, soaked in water for 96 hours (4-days) by placing a 4.5kg annular surcharge load.

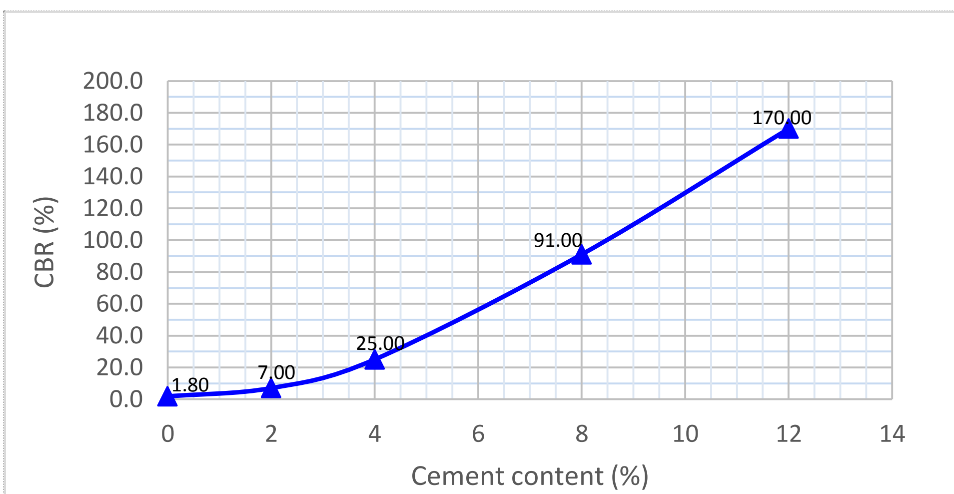


Figure 33: Distribution of Soaked CBR values for the Soil treated with Portland-Cement and cured for 7 days while increasing cement content

The CBR values of the native/untreated black cotton soil is determined as 1.8% after 4days soaking which indicate a total loss of strength of the untreated Black Cotton soil on soaking. Whereas after the addition of Portland cement, the CBR values of the treated soil increased with increasing the cement content and reach a maximum CBR value of 170% with 12% cement content. From Figure 33, it can be concluded that the CBR values of Cement treated soil increased with increasing cement content.

The reason for the improvement of the CBR values of the cement treated soil could be because of the cementing pozzolanic reaction between the soil grans and cement materials. The chemical hydration during the reaction, regarded as calcium hydroxide, or $Ca(OH)_2$, formed additional cementitous material that bound particles together and enhanced the strength of the soil (Gupta, 2016).

- The recorded CBR values of 7% for soil treated with 2% cement is categorized as subgrade strength class S-3 whereas the CBR value of 25% with 4% cement content is grouped as S-5 and the CBR values of 91%, and 170% for soil treated with 8% and 12% of Cement respectively categorized as S-6 subgrade strength class according to (ERA, 2002d).

Hence, it is concluded that soil treated with cement content of 4% and higher, fulfills the subgrade strength requirement stipulated in ERA 2002 Site Investigation Manual (i.e. for lime/cement stabilized soils, increase of the CBR to a minimum of 10% (after 7 days cure) with corresponding improvement of the subgrade strength class).

4.4.2. CBR values of Soil treated with Quarry Dust

For the Black cotton soil treated with Quarry dust only, sample specimens were prepared at 5%, 10%, 15% and 20% of Quarry dust by dry weight of the soil. The CBR values for the soil treated with quarry dust were determined on soil samples compacted at OMC and soaked in water for 4-days under a 4.5kg surcharge load. Then the CBR values were recorded after 4 days soaking.

The respective soaked CBR values for the soil treated with different proportion of Quarry dust is summarized in Figure 34.

The soaked CBR values of the treated soil increases slightly with increasing Quarry dust content. The maximum CBR value recorded to be 4.70% for the soil treated with 20% Quarry dust content. The slight increase in CBR values may be attributed because of the reason that the grains of the quarry dust form an interlocking system with the soil grains which results in an increase in resistance to penetration.

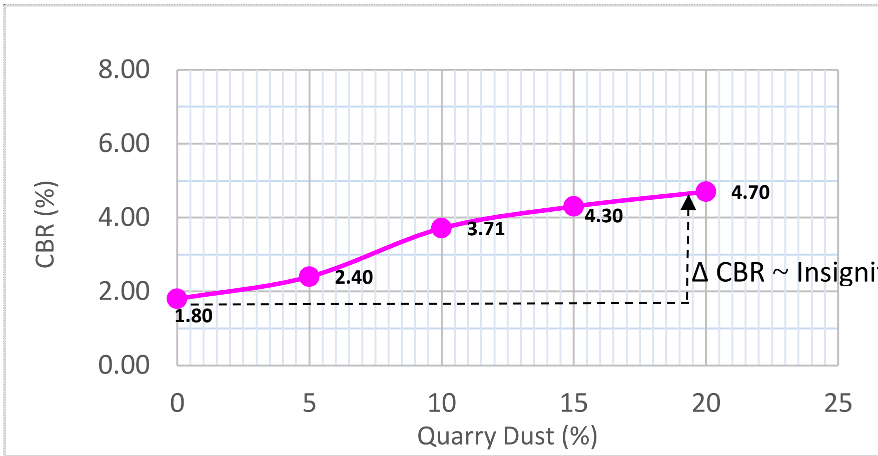


Figure 34: Distribution of Soaked CBR values for the Soil treated with Quarry Dust

The CBR values of soil treated with Quarry dust increased slightly with increasing the Quarry dust content. **However, the addition of Quarry dust to the native black cotton soil has not brought significant improvement on the strength (CBR values) of the treated soil.** This is due to the fact that the natural soil had very high clay content so that the addition of Quarry dust only reinforced the sand size content of the soil-dust mixture and form an interlocking system with no chemical change of the clay particles of the black cotton soil.

The recorded CBR values of 2.40% for soil with 5% Quarry dust is fall under subgrade strength class S-1. On the other hand recorded CBR values of 3.71%, 4.30 and 4.70% for soil treated with 10%, 15% and 20% Quarry dust respectively categorized as subgrade strength class S-2 according to (ERA, 2002b) which in turn do not fulfill the minimum strength requirement recommended for a road subgrade soil (i.e. CBR >5%).

4.4.3. CBR values of Soil treated with Cement and Quarry Dust mixture

CBR tests for Black Cotton soil treated with Cement and Quarry Dust mixture were carried out by varying the Quarry Dust content by 5% (i.e. 5%, 10%, 15% and 20%), while keeping 4% cement content constant as the 1st -group, 8% constant cement content as 2nd group and, 12% constant cement content as a 3rd group.

The CBR values of the treated soil increased when both the Cement and Quarry dust proportion increased as it is shown in Figure 35. For most of the mix proportions this increment is continued up to 15% Quarry dust content and beyond that (at higher Quarry dust content) the CBR value of the treated soil tends to decrease gradually at a smaller rate.

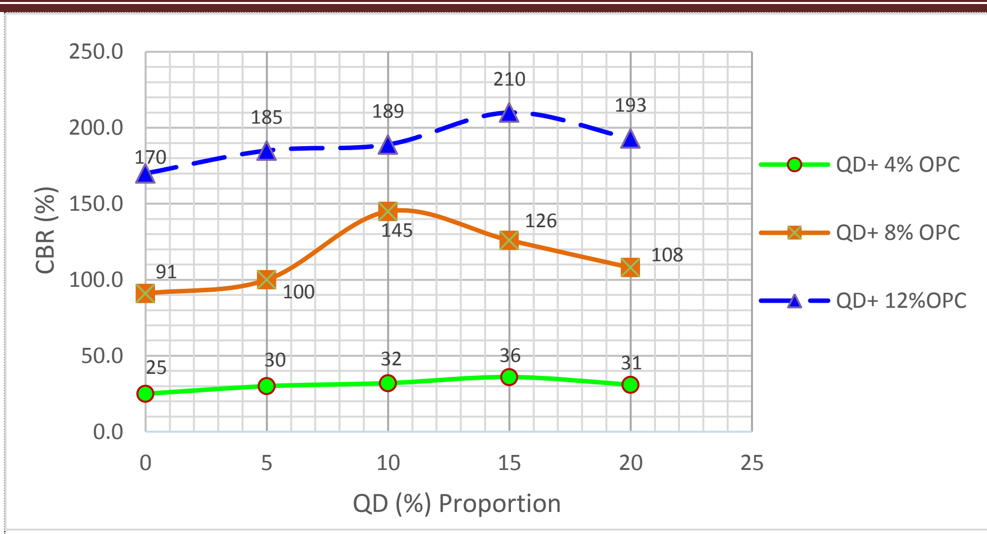


Figure 35: Distribution of Soaked CBR values for the Soil treated with Cement and Quarry Dust Mixture

The observed reduction in CBR value at the higher Quarry dust content (i.e. 20%) is may be due to the response of Cement at higher Quarry dust content. The proportion and the gradation of Quarry dust controlled the response of the soil-cement-dust mixture to compaction and resistance to penetration.

- When the proportion of the Quarry dust increased, then the amount of the finer particles of the Quarry dust increased. The increase of fine portion of the Quarry dust resulted in reduction of the Cement-Quarry dust ratio. Since, the fine portions of the Quarry dust interact easily with Cement than the larger size particles of the Quarry dust do with cement, the chance for the formation of large sized soil-cement-quarry dust skeleton is small as compared to the small sized soil-cement-quarry dust skeleton which intern reduce the expected resistance to penetration/strength.

Higher CBR values were recorded for the soil treated by Cement and Quarry Dust mixture than the soil treated with Cement alone. As an illustrative, for the soil treated with (4% OPC + 15% QD), (8% OPC+ 10% QD) and (12% OPC+ 15% QD) the recorded CBR values are 11%, 54% and 40% higher than the CBR values of the soil treated with only 4%, 8% and 12% cement respectively.

The observed higher CBR values for the soil treated by a mixture of Cement and Quarry Dust than the soil treated with Cement alone could be attributed to the fact that when Cement and Quarry dust are mixed together, the mixes of the two additives acts as a ‘Cement-Mortar’ which resulted in the formation of strong bond between the soil particles which in turn increases the resistance to penetration during the CBR test than the soil treated with Cement alone.

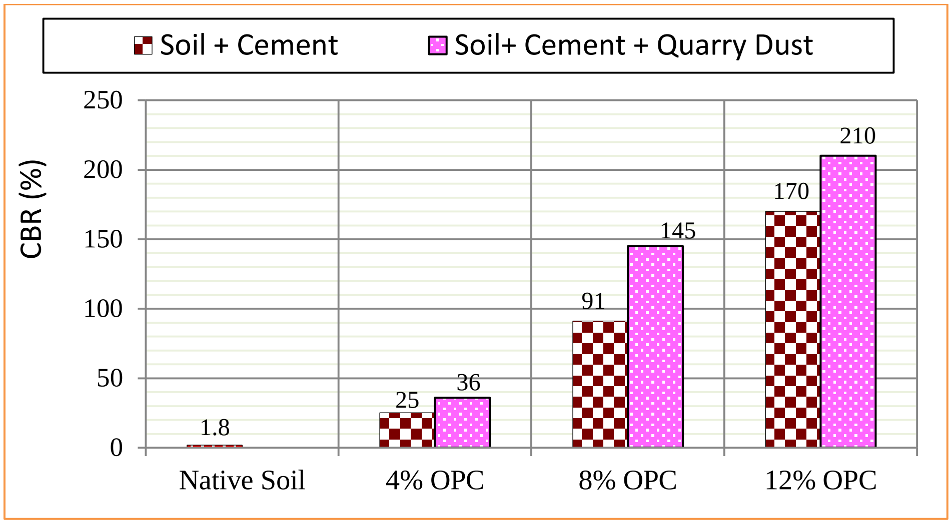


Figure 36: Comparison of CBR Values for the Soil treated with Cement only and with Cement and Quarry Dust Mixture

Hence, it is concluded that soil treated with the mixture of Cement and Quarry dust for all the mix proportion even at the smaller stabilizer content (4%OPC+5%QD) categorized as subgrade strength class S-6 (CBR>30%) according to ERA (2002b) and fulfills the subgrade strength requirement stipulated in ERA 2002 Site Investigation Manual (i.e. for lime/cement stabilized soils, increase of the CBR to a minimum of 10% (after 7 days cure) with corresponding improvement of the subgrade strength class).

4.5. CBR Swell Values

The CBR Swell values for the soil treated with different stabilizers were determined on the compacted soil in CBR mold and soaked in water for 4 days with 4.5 kg annular surcharge discs load applied to it.

The CBR Swell value of the native/untreated Black Cotton soil is determined as 17.61% after 4days soaking which indicates that the untreated Black Cotton soil has a high swelling potential and become very difficult to use it as a road sub-grade soil materials.

For the untreated Black Cotton soil, it has also been observed that even after 1-day of soaking, the swelling values of the soil are very high and after 4-days soaking, the 4.5 kg annular surcharge discs load applied to it is almost become outside/above the CBR molds.

As it can be shown below in Figure 37 (a), one can realize that the swelling value of the untreated/native Black Cotton soil are very high and after the soil is treated with Cement-Quarry dust mixture, Figure 37 (b), there is a substantial reduction in the swelling potential of the treated soil.

(a) Native Soil (**annular surcharge discs outside the CBR mold**)

(b) Cement-QD stabilized specimen (**annular surcharge discs inside the CBR mold**)

Figure 37: Comparision on the Swelling Potential of the untreated and treated soil specimen

4.5.1. CBR Swell of Soil treated with Portland-Cement

The CBR Swell value of the native/untreated black cotton soil is determined as 17.61% after 4days soaking. Whereas after the addition of Portland cement, the CBR Swell values of the treated soil decreased significantly with increasing the cement content.

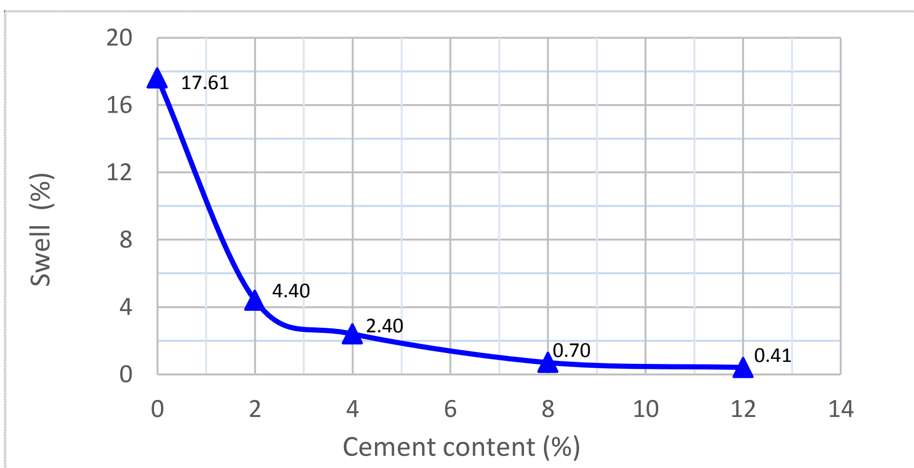


Figure 38: Distribution of CBR Swell values for the Soil treated with Cement

The reduction in the swelling values of the Cement treated soil could be attributed to the cement hydration that is accompanied by an increase in P_H of the the clay surface.

The Swelling potential of a clayey soil is determined by the amount of expansive clay (e.g. montmorillonite) present. Small quantities of cement have a greater effect on reducing swell or expansion than they do on improving the index properties. Since the index properties are only indices, the CBR swell test is a better, more direct measure of this soil property (Halsted et al., 2008).

As it has been discussed before, the addition of cement causes a substantial reduction of PI's and increase in shrinkage limit (SL) indicates an improvement in the volume change characteristics and modification of the soils into more stable and workable materials.

4.5.2. CBR Swell of Soil treated with Quarry Dust

The Black Cotton soil treated with Quarry dust showed a very small reduction in the CBR Swell values as compared to the 17.6% swell values of the untreated soil. Hence, the addition of Quarry dust in varying proportions with the soil and the effect of the same on the CBR Swell values of the mix as compared to the native black cotton soil are presented in Figure 39.

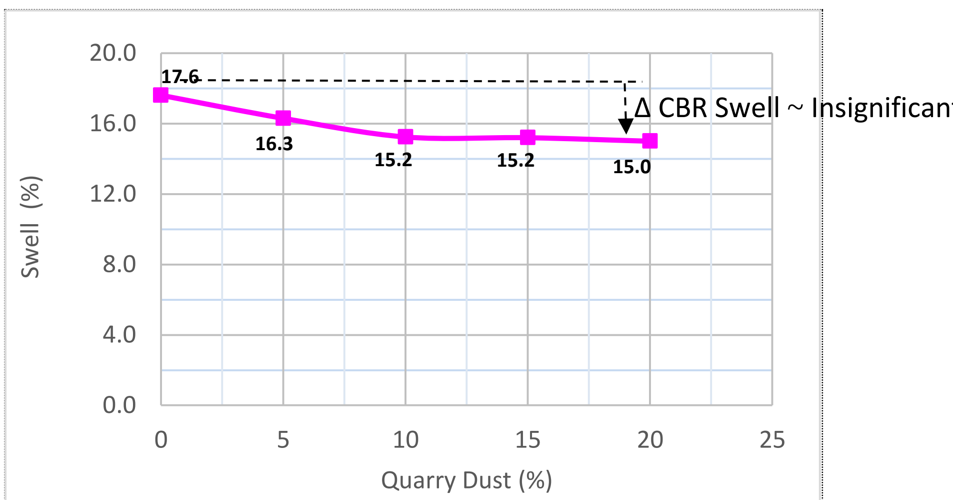


Figure 39: Distribution of CBR Swell values for the Soil treated with Quarry Dust

As it can be shown in Figure 39, **insignificant reduction is recorded in CBR Swell values of the Quarry dust treated soil with increasing the Quarry dust content**.

Similar to the findings of this research work, (Eden, 2017) has also reported that there is no significant reduction in the CBR Swell value of an expansive soil treated with Quarry dust even at higher quarry dust content up to 30%.

Though, there is no appreciable result observed on the CBR Swell values, the very slight reduction the black cotton soil with quarry dust from 17.6% to 15.0% is attributed due to the partial reduction of the swelling clay content and increase in the non–swelling Quarry dust.

4.5.3. CBR Swell of Soil treated with Cement and Quarry Dust mixture

Black Cotton soil treated with the mixture of Cement and Quarry Dust mixture significantly reduces the swelling potential of the native soil.

For the soil treated with 4%OPC+20%QD the maximum reduction in CBR Swell value is recorded to be 1.13% which is 1.27% swell lesser than the soil treated with 4% Cement alone (CBR swell of 2.40%). On the other hand for the soil treated by 8%OPC+10%QD and 12%OPC+15%QD, the maximum reduction in CBR Swell values were recorded to be 0.58% and 0.33% respectively.

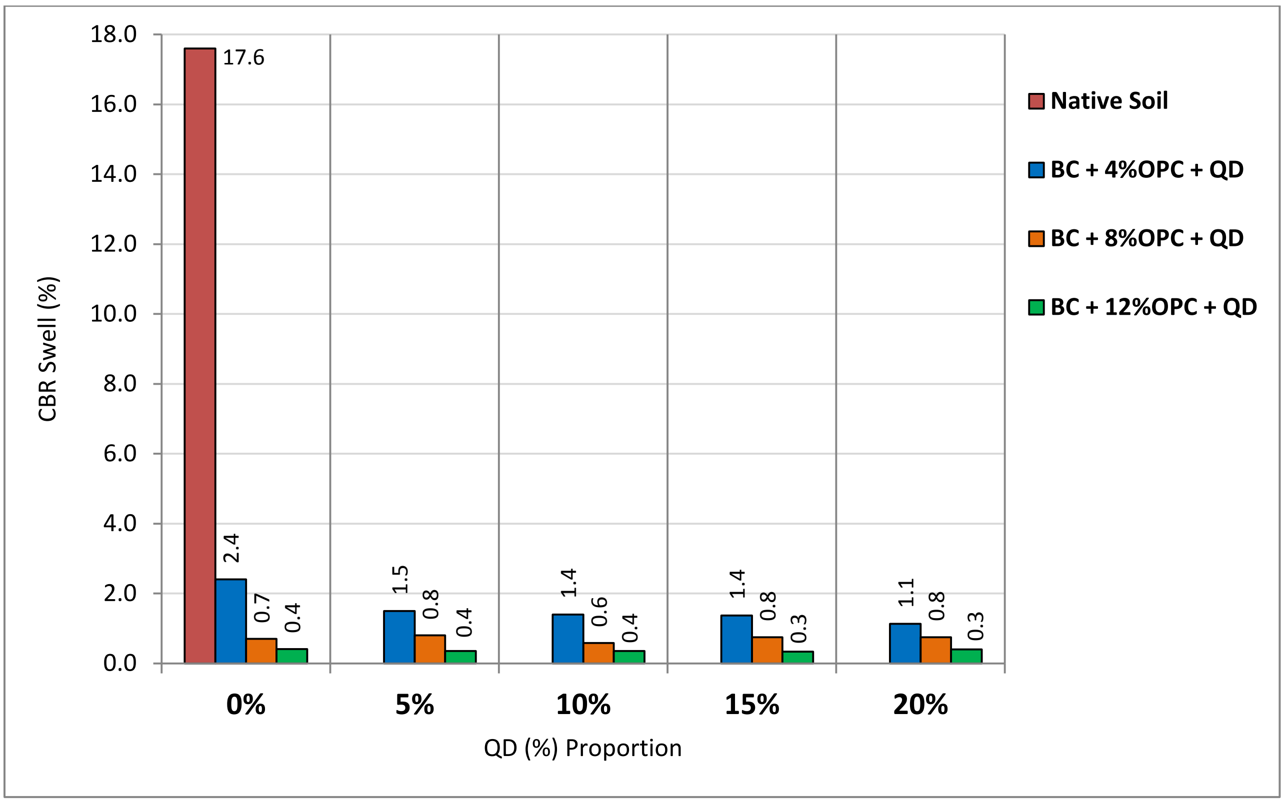


Figure 40: CBR Swell values for the Soil treated by Cement and Quarry Dust mixture

It is noted that, the swelling value of the soil treated with the Cement and Quarry dust mixture reduced further as compared to the swelling value of soil treated with Cement alone. **However, the observed reduction with increasing Quarry Dust proportion while keeping the Cement content constant is not significant.**

This is due to the fact that even at higher cement content, the rate of reduction in the swelling potential of the treated soil with changes in cement content is small as compared to the rate of reduction of the swelling potential of the treated soil at lower cement content with small change in proportion of cement content. Hence, the proportion of Cement has a pronounced effect than the proportion of Quarry dust. The soil treated with all the proportion of the mixture of Cement and Quarry dust meets the requirement stipulated in ERA 2002 Pavement Design Manual (i.e. CBR Swell value of less than 1.5%) for a road subgrade material.

4.6. Unconfined Compressive Strength (UCS)

The Unconfined Compression Strength test is one of the widely used laboratory tests in pavement application and soil stabilization application.

Unconfined compression test is used to determine the unconsolidated, un-drained strength of a cohesive soil for a cylinder of soil without lateral support which demonstrates evaluation of soils without later support like road embankment materials.

The unconfined compression strength is often used as an index to quantify the improvement of soils due to treatment. For example, ASTM D-4609 (Standard guide for evaluating effectiveness of admixture for soil stabilization) states that an increase in unconfined compressive strength of 345 KPa (50 psi) or more must be achieved for a treatment to be considered effective.

In this research work, Unconfined Compressive Strength (UCS) testing was done for remolded specimens according to ASTM D-5102, Procedure-A. UCS tests were carried out for the untreated/native Black Cotton soil as well as for the treated black cotton soil with Portland-cement only, Quarry dust only, and with the combination of Cement & Quarry dust mixtures with different proportions and different curing periods.

4.6.1. Unconfined Compressive Strength of Soil treated with Portland-Cement

The UCS values for the soil treated with Portland-cement were carried out on soil sample specimens prepared at 2%, 4%, 8% and 12% of cement by dry weight of the soil.

Specimens of the UCS test for the soil treated with Portland cement were prepared for two remolded samples at OMC and MDD with different curing periods applied:-

- **i.** Soil sample compacted and tested immediately after compaction (No curing)
- **ii.** Soil sample compacted and tested after 7 days curing

The UCS value of the native/untreated black cotton soil is determined as 120.3KN/m^2 indicating that the untreated Black Cotton soil has poor strength and shear resistance. Whereas after the addition of Portland cement, the UCS values of the treated soil increased with increasing the cement content. UCS values for the soil treated with different proportion of Cement with no curing and after 7 days curing of the soil sample are summarized in Table 17.

Table 17: UCS Values for the Soil treated with Portland-cement

Cement Content (%)	UCS (q_u) [KN/m^2]	
	Test #1	Test #2
	Immediately After Compaction (No Curing)	(After 7 Days Curing)
0% (Native Soil)	120.3	
2%	151.7	243
4%	183.6	305
8%	213.8	599
12%	309.6	1015

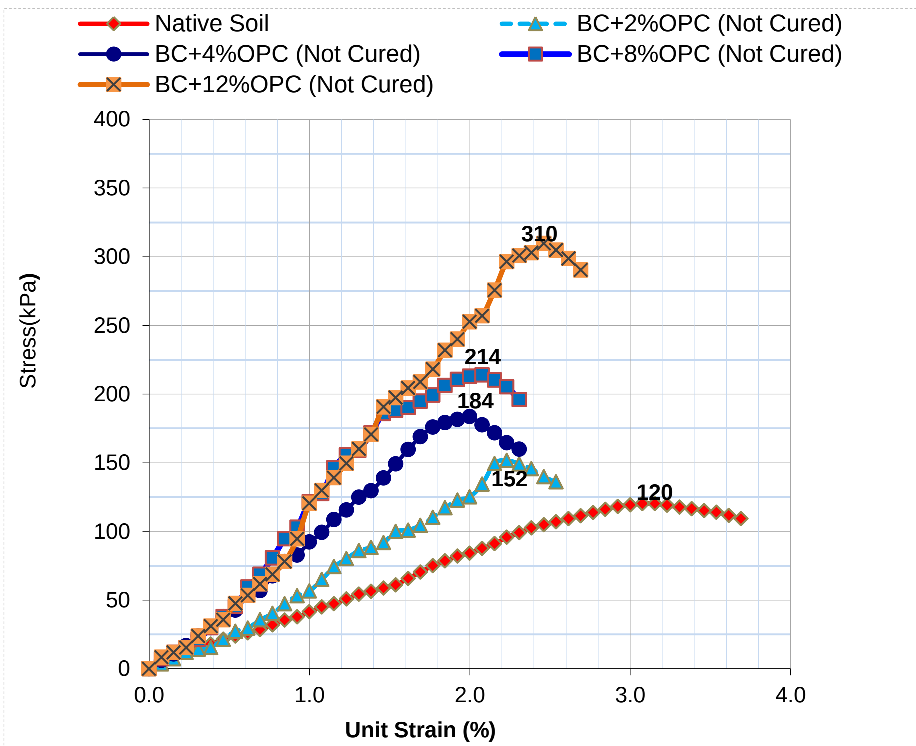


Figure 41: Stress-Strain curves for the untreated and treated soil with Cement for the tests carried out immediately after compaction (No Curing)

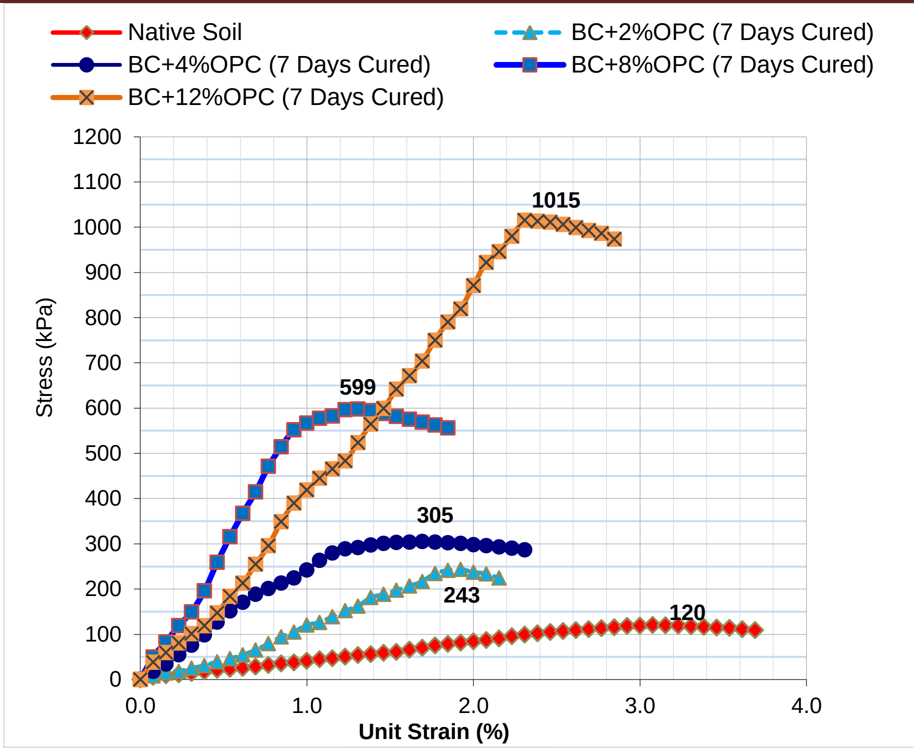


Figure 42: Stress-Strain curves for the untreated and treated soil with Cement for the tests carried out after 7 Days Curing

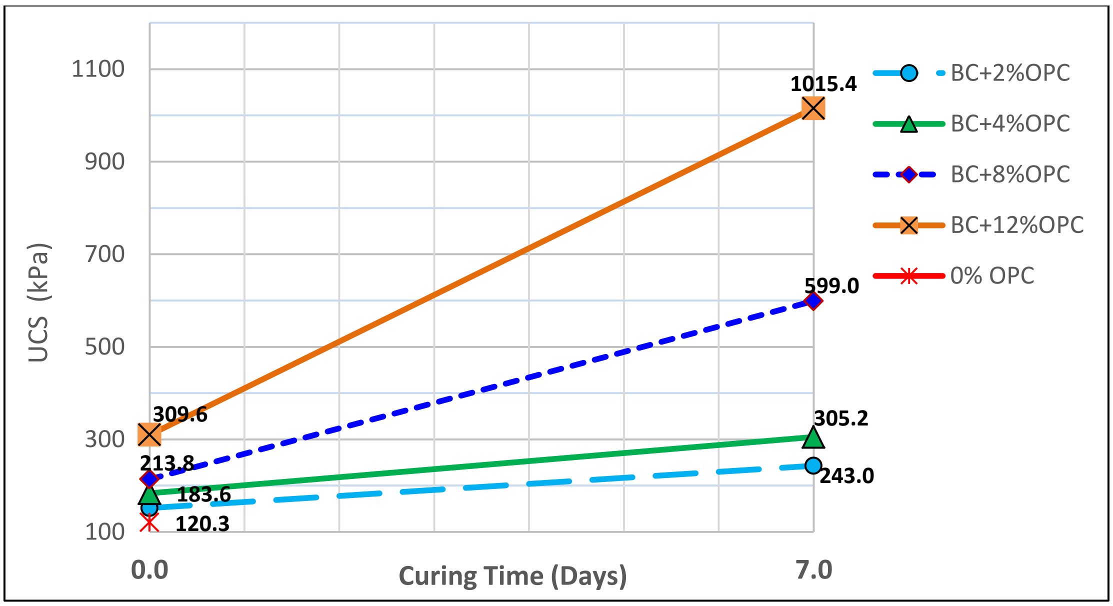


Figure 43: Comparison of Peak Failure Stress as a function of Curing Time for the soil treated with Cement

The addition of Cement increases the Unconfined Compressive Strength of the Black Cotton soil. As the cement content increased, the UCS value of the treated soil increased proportionally. However, after the addition of cement, the axial strain at peak failure stress get decreases as compared to the axial strain of the untreated soil.

As it can be shown on Figure 42, shown above, it is observed that soil samples treated with cement and cured for 7 Days shows significant improvement on UCS values than soil treated with the same amount of cement content with no curing applied (i.e. test immediately after compaction).

Figures 43 reveal the effect of curing time progress and cement content on the development of UCS. It can be seen from that the UCS strength increases with an increase in curing time. This is attributed to the fact that the strength of the cement-treated clay is expected to increase with time and this is due to the cement hydration and reaction of cement with soil silica.

From the comparison between the two factors shown above, it can be concluded that the Curing time influences the strength development more than the Cement Content. This is also in agreement with (Uddin et al, 1997), where it has been reported that the strength of the cement-treated clay soil increases with time.

- Typical stress-strain curves of the soil sample with different Cement content as presented in Figure 41 and Figure 42 indicated that the stress-strain curves shifted to the left side which in turn dictates that the strain at failure stress decreases with the addition of Cement and hence, **treatment of soil with Cement resulted in soil with brittle type failure mode**.

Figure 44: (a) Specimen before compression, (b) Failure mode for the Untreated-soil specimen after UCS test, (c) Failure mode for the soil treated with Cement after UCS test

Khitam, et al. (2014) through their study on physicochemical characterization of Cement treated Kaolin Clay have reported that UCS strength increases with an increase in curing time. This behavior is attributed to the fact that the strength of the cement-treated clay is increased with time as long as alkaline environment is present. However, the strength increase range during the late periods is different from strength values registered at early curing times.

Uddin et al. (1997) has reported that in the case of Unconfined Compressive Strength, failure strain reduces significantly with the increase of Cement content and Curing time. It was also found that up to a certain amount of cement content, the rate of reduction of failure strain is significant and thereafter reduces and the conclusion made by Uddin is similar to the findings of this research work.

4.6.2. Unconfined Compressive Strength of Soil treated with Quarry Dust

The UCS tests for black cotton soil treated with Quarry Dust only, were carried out by preparing remolded specimens for the mixes with varying quarry dust content by 5% (i.e. 5%, 10%, 15% and 20%) by dry weight of the soil.

For each of the proportion of the added Quarry Dust, two (2) sample specimens were prepared and the average UCS value for each of the respective mix proportion is taken to analyze the effect of Quarry dust on the treated soil.

Generally, the peak failure stress increases with increasing the added Quarry Dust proportion as it can be shown on Figure 45. **However, the addition of Quarry dust to the native black cotton soil has insignificant improvement on the UCS values of the treated soil**.

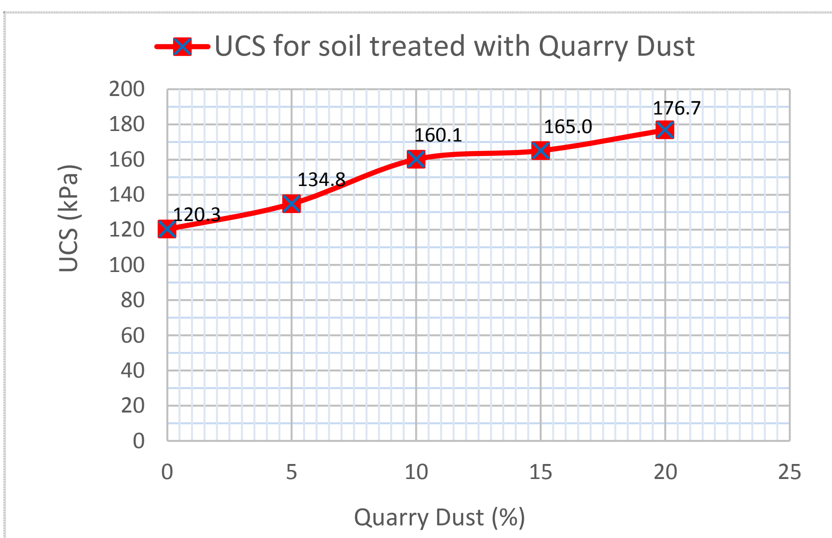


Figure 45: Effect of the proportion of Quarry Dust on UCS values

The observed slight increment on UCS values is because it is thought that the grains of the quarry dust form an interlocking system with the soil grains which results in an increase in shear resistance of the treated soil which in turn increase the unconfined compressive strength.

However, the UCS value of the black cotton soil treated with Quarry dust alone doesn't have practical significant improvement. This is due to the fact that the natural soil had very high clay content so that the addition of Quarry dust only reinforced the soil grains and form an interlocking system with no chemical change of the clay particles of the black cotton soil.

4.6.3. Unconfined Compressive Strength of Soil treated with Mixture of Cement and Quarry Dust

UCS tests for Black Cotton soil treated with Cement and Quarry Dust mixture were carried out by varying the Quarry dust content by 5% (i.e. 5%, 10%, 15% and 20%), while keeping 4% cement content constant as the 1st -group, 8% constant cement content as 2nd group and, 12% constant cement content as a 3rd group.

Similar to cement treated soil, specimens of the UCS test for the soil treated with mixture of Cement and Quarry dust were prepared for remolded samples at optimum moisture content and cured for 7 days.

UCS test results for the treated Black Cotton soil with Cement - Quarry Dust mixture for different proportion of the added stabilizers is presented in Figure 46.

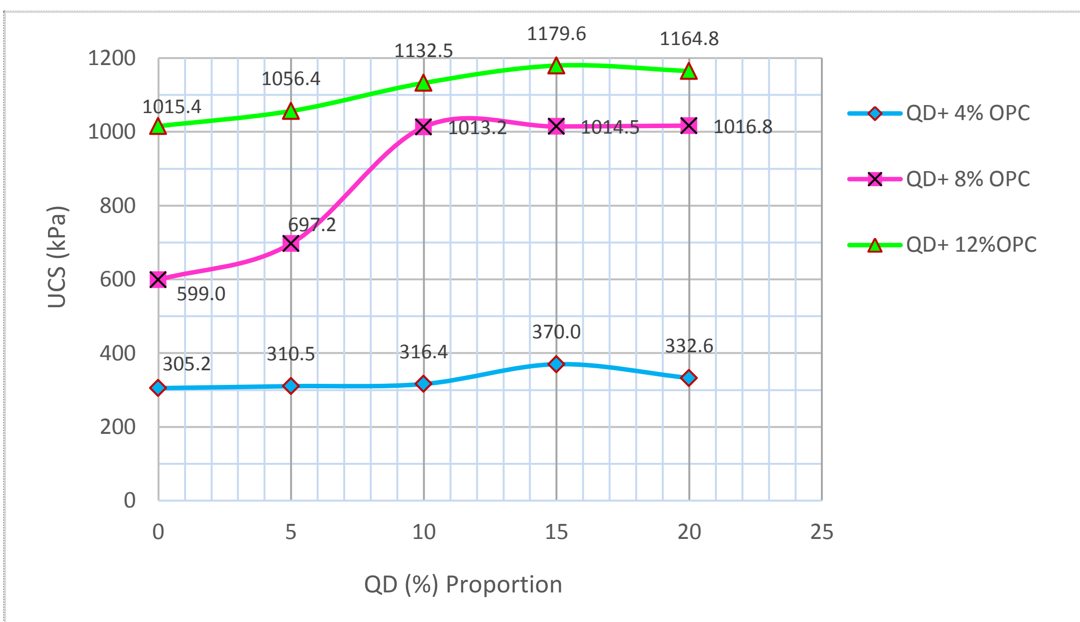


Figure 46: Effect of the proportion of Cement and Quarry Dust on UCS values of the Soil treated with Cement - Quarry Dust Mixture

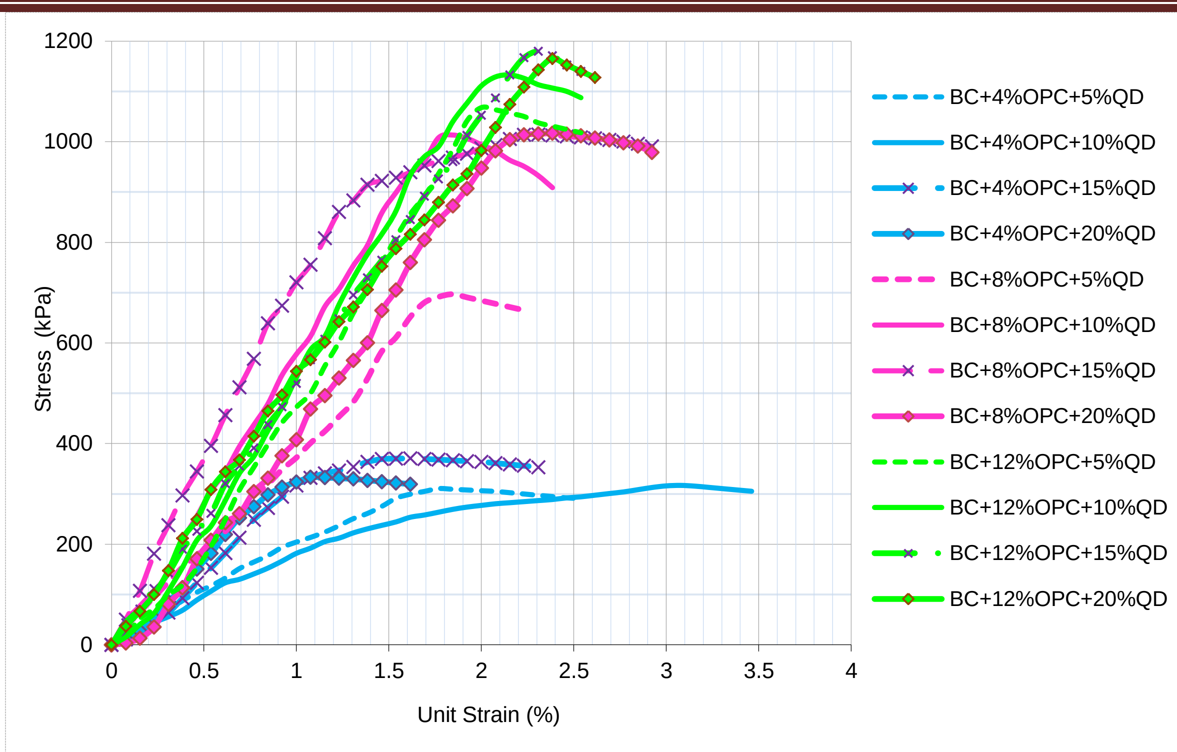


Figure 47: Stress-Strain curves for the Soil treated with Cement and Quarry Dust Mixture

Generally, the Unconfined Compressive Strength (UCS) values of the treated soil increased when both the Cement and Quarry dust proportion increased as it is shown in Figure 46.

In general, higher UCS values were recorded for the soil treated by Cement and Quarry Dust mixture than the soil treated with Cement alone.

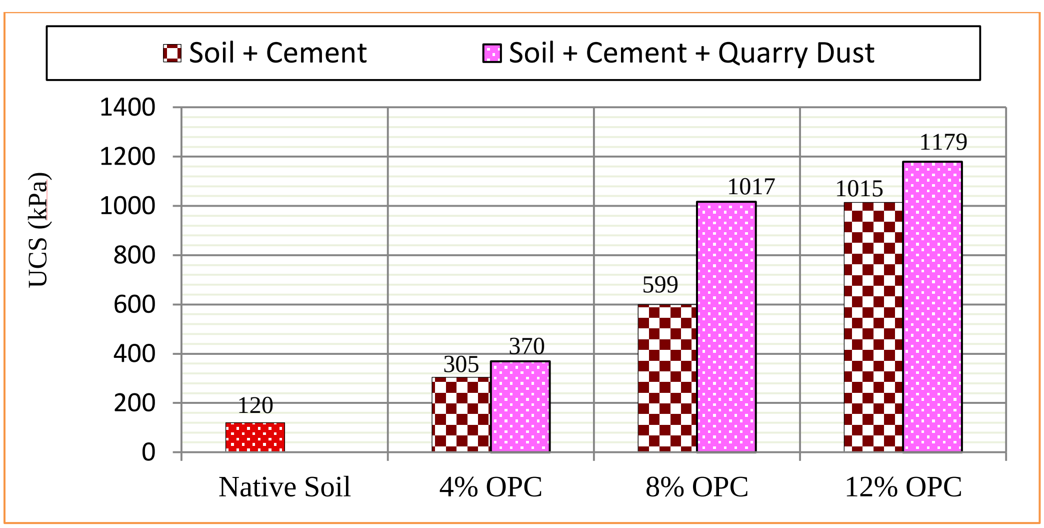


Figure 48: Comparison of UCS values of soil treated with Mixture of Cement & Quarry Dust with soil treated with Cement alone

The cementing reaction between the soil grans & cement materials contributed greatly for the improvement of the UCS values of the treated soil. In addition to that, when Cement and Quarry dust are mixed together, the mixes of the two additives form a strong bond within the soil grains which in turn increases the shear resistance of the treated soil that could not be possible for the soil treated with Cement alone.

Similar to soil treated with Portland cement, here also for the soil treated with mixture of Cement and Quarry dust, the strain at the failure stress decreases with the addition of both Cement and Quarry dust proportion as compared to the failure strain of the native/untreated soil as shown in Figure 47.

4.7. Statistical Evaluation of Laboratory Test Results

Through section 4.2 to 4.6, assessment/discussion has been made on all the laboratory test results conducted for the treated Black Cotton soil with Portland cement only, Quarry Dust only, and Portland cement & Quarry Dust combinations for the different proportions of the additives/stabilizers utilized. In doing so, the test results of the different proportions of the stabilizers on the engineering properties of the treated black cotton soil were discussed and compared with the respective properties of the untreated/native Black Cotton soil.

In addition to the interpretation and evaluation of the recorded laboratory test results, it has now become necessary to evaluate the recorded laboratory test results with respect to statistical point of view. Hence, an attempt was made to develop the basic concepts and methods of the **Two Factor Analysis of Variance, ANOVA** model in the context of the laboratory experiment to compare the different treatments.

In the laboratory experiments, there are two factors that are of simultaneous interest while evaluating the engineering properties and or performance indicators of the treated Black cotton Soil i.e.:-

- ✓ Factor ‘A’ (Proportion of Portland cement)
- ✓ Factor ‘B’ (Proportion of Quarry Dust).

Table 18: Possible combination of the engineering properties of the treated soil for Two-Factor ANOVA

Portland Cement (%)	Quarry Dust (%)			
	0	X%	Y%	Z%
0	a_{11}	a_{12}	a_{13}	a_{14}
A%	a_{21}	a_{22}	a_{23}	a_{24}
B%	a_{31}	a_{32}	a_{33}	a_{34}
C%	a_{41}	a_{42}	a_{43}	a_{44}

Where a_{11}, a_{11}, $a_{11\ldots}$, a_{44} are the values of the respective engineering properties of the treated Black cotton soil (i.e. PI, CBR, CBR Swell & UCS values) for the different proportions of stabilizers/additives.

Then there are 'IJ' possible combinations consisting of one level of 1st factor A (Cement) and one level of the 2nd factor B (Quarry dust).

Each such combination are the laboratory test results and/or values of the respective Engineering properties of the treated Black cotton soil with different proportion of Quarry Dust and Portland cement; so there are 'IJ' different treatments.

- "I "to denote the number of Proportions of Portland cement (α_1, α_2 α_3,…., α_I) and
- "J "to denote the number Proportions of Quarry Dust (β_1, β_2, $\beta_{3,}$ …… β_J)

Based on that, there will be two different **null hypotheses H_o** having considered the two-factors of the experiment **H_0A and H_0B**.

- **H_0A**, represents that the different proportions of Portland cement have no effect on the values of the respective engineering properties of the treated Black Cotton soil. (H_0A: $\alpha_1 = \alpha_2 = \ldots = \alpha_I = 0$).
- **H_0B**, represents that the different proportions of Quarry dust have no effect on the values of the respective engineering properties of the treated Black Cotton soil. (H_0B: $\beta_1 = \beta_2 = \ldots = \beta_J = 0$).

The **alternative hypothesis H_a** for the two-factors of the experiment **H_aA** and **H_aB**

- **H_aA**: at least one $\alpha_i \neq 0$ (i.e. H_0A is rejected at the considered significance level in favor of the assertion that the proportions of Portland cement has an effect on the values of the respective engineering properties of the treated Black Cotton soil)
- **H_aB:** at least one $\beta_j \neq 0$ (i.e. H_0B is rejected at the considered significance level in favor of the assertion that the proportions of Quarry Dust has an effect on the values of the respective engineering properties of the treated Black Cotton soil)

Based on the above statistical theory, **F- Test** ratio will be carried out so as to whether to accept or reject the null hypothesis.

Hypotheses	Test Statistic Value	Rejection Region
H_{0A} versus H_{aA}	$f_A = \dfrac{\text{MSA}}{\text{MSE}}$	$f_A \geq F_{\alpha,I-1,(I-1)(J-1)}$
H_{0B} versus H_{aB}	$f_B = \dfrac{\text{MSB}}{\text{MSE}}$	$f_B \geq F_{\alpha,J-1,(I-1)(J-1)}$

Where,

- MSA:- is the Mean Squares of Factor A (Proportion of Portland cement on the treated soil)
- MSB:- is the Mean Squares of Factor B (Proportion of Quarry Dust on the treated soil)
- MSE:- is the Mean Squares of Error of the treatment

a) Plasticity Index (PI) values

As it has been discussed in Section 4.2, the laboratory investigation on the Atterberg limit values of the Black Cotton soil has been made for the treated soil with Portland cement only, with Quarry Dust only, and Portland cement & Quarry Dust combinations for each of the different proportions. Based on the conducted laboratory tests, the Plasticity Index (PI) of the treated soil for each of the different proportion is summarized as shown here in Table 19.

Table 19: Summary of PI values

Plasticity Index (PI)					
Portland Cement (%)	Quarry Dust (%)				
	0	5	10	15	20
0	*42.02*	*40.22*	*38.25*	*36.95*	*35.49*
4	*26.91*	*26.19*	*24.26*	*23.03*	*22.31*
8	*21.60*	*21.66*	*21.00*	*20.30*	*19.12*
12	*18.74*	*18.47*	*18.93*	*17.82*	*17.10*

Based on the recorded Plastic Index (PI) values, Two Factor Analysis of Variance, ANOVA has been carried out to compare the effect of different treatments on the recorded PI values as shown in Table 20.

Table 20: ANOVA Table for PI values of the treated soil

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Factor A (OPC)	*1,239.87*	*3*	*413.29*	*446.79*	*0.0000*	*3.49*
Factor B (QD)	*38.13*	*4*	*9.53*	*10.31*	*0.0007*	*3.25*
Interaction	*11.10*	*12*	*0.925*	*1.00*	*0.5000*	*2.68*
	Level of significance					*0.05*

From Table 20, it has been noted that the Test Statistic Value for Factor A (Proportion of OPC on PI values) of the treated soil "f_A" is computed as 446.79. Whereas, the critical value for testing H_{0A} at level of significance 0.05 (i.e. $F_{\alpha, I-1, (I-1)(J-1)}$) is $F_{0.05, 3, 12}$ is 3.49.

Therefore, since $f_A = 446.79 > F_{\alpha, I-1, (I-1)(J-1)} = 3.49$, then H_{0A} is rejected at significance level 0.05 in favor of the assertion that the PI values varies with proportion of Portland Cement and this tells us that proportions of Portland cement has contributed on the observed reduction on the PI values of the treated Black Cotton soil.

The Test Statistic Value for Factor B (Proportion of QD on PI value) "f_B" is computed as 10.31. Whereas, the critical value for testing H_{0B} at level of significance 0.05 (i.e. $F_{\alpha, J-1, (I-1)(J-1)}$) is $F_{0.05, 4, 12}$ is 3.26.

Since $f_B = 10.31 > F_{\alpha, J-1, (I-1)(J-1)} = 3.26$, H_{0B} is rejected at significance level 0.05 in favor of the assertion that the PI values varies with proportion of Quarry Dust and hence, the proportions of Quarry dust has contributed on the observed improvement on the PI values of the treated Black Cotton soil.

Furthermore the plausibility of the test statistics is also evaluated based on the ***P*-value** (i.e. the probability, calculated assuming that the null hypothesis is true) at the considered significance level. Based on that, *P*-values of 0.000 and 0.0007 is computed for Factor-A (proportion of OPC) and Factor B (proportion of QD) respectively in which case both of the P-values are less than the considered significance level of 0.05.

- From the above discussion, similar conclusion as Section 4.2.3 is made that both the added Portland cement and Quarry dust have contributed for the recorded reduction on the PI values of the treated black cotton soil.

b) CBR values

Based on the conducted laboratory tests, the outcome of the treatment on CBR values of the treated soil for each of the different proportion of Cement and Quarry dust is summarized as shown in Table 21.

Table 21: Summary of CBR values

CBR (%)					
Portland Cement (%)	Quarry Dust (%)				
	0	5	10	15	20
0	*1.80*	*2.40*	*3.71*	*4.30*	*4.70*
4	*25.00*	*30.00*	*32.00*	*36.00*	*31.00*
8	*91.00*	*100.00*	*145.00*	*126.00*	*108.00*
12	*170.00*	*185.00*	*189.00*	*210.00*	*193.00*

So as to compare the effect of different treatments on the recorded CBR values, Two Factor Analysis of Variance, ANOVA has done based on the laboratory test results as shown on Table 22.

Table 22: ANOVA Table for CBR values of the treated soil

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Factor A (OPC)	*106,690.18*	*3*	*35,563.39*	*301.86*	*0.0000*	*3.49*
Factor B (QD)	*1,354.40*	*4*	*338.60*	*2.87*	*0.0698*	*3.25*
Interaction	*1,413.74*	*12*	*117.81*	*1.00*	*0.50*	*2.68*
	Level of significance					0.05

From the analysis of variance, it is noted that the Tests Statistic Value for Factor A (Proportion of OPC on CBR values) "f_A" is computed as 301.86. Whereas, the critical value for testing H_{0A} at level of significance 0.05 (i.e. $F_{\alpha,\ I-1,\ (I-1)\ (J-1)}$) is $F_{0.05,\ 3,\ 12}$ is 3.49.

Therefore, since f_A= 301.86 > $F_{\alpha,\ I-1,\ (I-1)\ (J-1)}$ = 3.49, then H_{0A} is rejected at significance level 0.05 in favor of the assertion that the CBR values varies with proportion of Portland Cement and this tells us that proportions of Portland cement has contributed on the observed increment on the CBR values of the treated Black Cotton soil.

On the other hand, the Test Statistic Value for Factor B (Proportion of Quarry dust on CBR values) of the treated soil "f_B" is computed as 2.87. Whereas, the critical value for testing H_{0B} at level of significance 0.05 (i.e. $F_{\alpha,\ J-1,\ (I-1)\ (J-1)}$) is $F_{0.05,\ 4,\ 12}$ is 3.26. Therefore, since f_B = 2.87 < $F_{\alpha,\ J-1,\ (I-1)\ (J-1)}$ = 3.26, H_{0B} **cannot** be rejected at significance level 0.05 which leads to the conclusion that the CBR values does not appear to depend on the proportion of Quarry Dust.

For Factor A (Proportion of OPC on CBR values*)*, *P*-value of 0.000 is computed which tells us that the probability calculated assuming that the null hypothesis (the hypothesis that Cement have no effect on CBR values is true) is **zero**. Despite to that, *P*-value of 0.069 is computed for Factor B (Proportion of QD on CBR values*)* which is higher than the 0.05 significance level and this shows that the probability calculated assuming that the null hypothesis (i.e. Quarry dust have no effect on CBR values of the treated soil) at 0.05 significance level is true.

- From the above discussion, similar conclusion as Section 4.4.1 and Section 4.4.2 is made that Portland cement has significant effect on the observed CBR values of the treated soil, however, the added Quarry dust have not brought significant improvement on CBR values of the treated black cotton soil.

c) CBR Swell values

The recorded CBR Swell values for the treated black cotton soil with Portland cement only, with Quarry Dust only, and Portland cement & Quarry Dust combinations for each of the different proportions is summarized on Table 23.

Table 23: Summary of CBR Swell values

CBR Swell (%)					
Portland Cement (%)	Quarry Dust (%)				
	0	5	10	15	20
0	*17.61*	*16.30*	*15.24*	*15.20*	*15.00*
4	*2.40*	*1.50*	*1.40*	*1.37*	*1.13*
8	*0.70*	*0.80*	*0.58*	*0.75*	*0.75*
12	*0.41*	*0.35*	*0.35*	*0.33*	*0.40*

Table 24: ANOVA Table for CBR Swell values of the treated soil

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Factor A (OPC)	*846.23*	*3*	*282.07*	*1035.59*	*0.000*	*3.49*
Factor B (QD)	*2.53*	*4*	*0.6339*	*2.32*	*0.115*	*3.25*
Interaction	*3.26*	*12*	*0.272*	*1.00*	*0.50*	*2.68*
					Level of significance	0.05

The 'Tests Statistic Value' for Factor A (Proportion of OPC on CBR Swell values) "f_A" is computed as 1035.6. Whereas, the critical value for testing H_{0A} at level of significance 0.05 (i.e. $F_{\alpha,\ I-1,\ (I-1)\ (J-1)}$) is $F_{0.05,\ 3,\ 12}$ is 3.49.

Therefore, since $f_A = 1035.6 > F_{\alpha,\ I-1,\ (I-1)\ (J-1)} = 3.49$, then H_{0A} is rejected at significance level 0.05 in favor of the assertion that the CBR Swell values varies with proportion of Portland Cement and this tells us that proportions of Portland cement has contributed on the observed reduction on the CBR Swell values of the soil.

The Test Statistic Value for Factor B (Proportion of Quarry dust on CBR Swell values) of the treated soil "f_B" is computed as 2.32. Whereas, the critical value for testing H_{0B} at level of significance 0.05 (i.e. $F_{\alpha,\ J-1,\ (I-1)\ (J-1)}$) is $F_{0.05,\ 4,\ 12}$ is 3.26. Therefore, since $f_B = 2.32 < F_{\alpha,\ J-1,\ (I-1)\ (J-1)} = 3.26$, H_{0B} **cannot** be rejected at significance level 0.05 which leads to the conclusion that the CBR Swell values does not appear to depend on the proportion of Quarry Dust.

P-value of 0.000 is computed for the effect of the Proportion of OPC on CBR values which tells us that the probability calculated assuming that the null hypothesis (the hypothesis that Cement have no effect on CBR Swell values is true) is zero. Despite to that, *P*-value of 0.115 is computed for Factor B (Proportion of QD on CBR Swell values) which is higher than the 0.05 significance level and this shows that the probability calculated assuming that the null hypothesis (i.e. Quarry dust have no effect on CBR Swell values of the treated soil) at 0.05 significance level is true.

- From the above discussion, similar conclusion as Section 4.5.1 and Section 4.5.2 is made that Portland cement has significant effect on the observed CBR swell values of the treated soil, however, the added Quarry dust have not brought significant improvement on CBR swell values of the treated black cotton soil.

d) UCS Values

The outcome of the treatment on UCS values of the treated black cotton soil for each of the different proportion of Cement and Quarry dust is summarized in Table 25.

Table 25: Summary of UCS values

UCS (Kpa)					
Portland Cement (%)	Quarry Dust (%)				
	0	5	10	15	20
0	*120.30*	*134.80*	*160.10*	*165.00*	*176.70*
4	*305.20*	*310.50*	*316.40*	*370.00*	*332.60*
8	*599.00*	*697.20*	*1013.20*	*1014.50*	*1016.80*
12	*1015.40*	*1056.40*	*1132.50*	*1179.60*	*1164.80*

Table 26: ANOVA Table for UCS values of the treated soil

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Factor A (OPC)	*3,033,829.92*	*3*	*1,011,276.64*	*131.73*	*0.000*	*3.49*
Factor B (QD)	*99,155.87*	*4*	*24,788.97*	*3.43*	*0.042*	*3.25*
Interaction	*92,123.33*	*12*	*7676.94*	*1.00*	*0.500*	*2.687*
	Level of significance					0.05

From Table 26, it has been noted that the Test Statistic Value for Factor A (Proportion of OPC on UCS values) of the treated soil "f_A" is computed as 131.73. Whereas, the critical value for testing H_{0A} at level of significance 0.05 (i.e. $F_{\alpha,\ I-1,\ (I-1)(J-1)}$) is $F_{0.05,\ 3,\ 12}$ is 3.49.

Since $f_A = 131.73 > F_{\alpha,\ I-1,\ (I-1)(J-1)} = 3.49$, H_{0A} is rejected at significance level 0.05 in favor of the assertion that the UCS values varies with proportion of Portland Cement and this tells us that proportions of Portland cement has contributed on the observed improvement/increase on the UCS values of the treated Black Cotton soil.

The Test Statistic Value for Factor B (Proportion of QD on UCS values) "f_B" is computed as 3.43. Whereas, the critical value for testing H_{0B} at level of significance 0.05 (i.e. $F_{\alpha,\ J-1,\ (I-1)\ (J-1)}$) is $F_{0.05,\ 4,\ 12}$ is 3.26.

Since $f_B = 3.43 > F_{\alpha,\ J-1,\ (I-1)\ (J-1)} = 3.26$, H_{0B} is rejected at significance level 0.05 in favor of the assertion that the UCS values varies with proportion of Quarry Dust and hence, the proportions of Quarry dust has contributed for improvement on the UCS values of the treated Black Cotton soil.

P-value of 0.000 is computed for the effect of the Proportion of OPC on UCS values which tells us that the probability calculated assuming that the null hypothesis (the hypothesis that Cement have no effect on UCS values is true) is zero.

On the other hand, although the *P*-value of 0.042 for Factor B (Proportion of QD on UCS values) is slightly lower than the 0.05 significance level, the two values are very close and hence, it can be concluded that the improvement on UCS values of with the addition of Quarry dust is not that much significant unlike to the effect of Cement on UCS values of the treated soil.

4.8. Economic Implication of Stabilized Soil Subgrade on Pavement Design

Pavement design is based on the premise that minimum specified structural quality will be achieved for each layer of material in the pavement system. Each layer must resist shearing, avoid excessive deflections that cause fatigue cracking within the layer or in overlying layers, and prevent excessive permanent deformation.

As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased so that a reduction in the required thickness of the soil and surface layers may be permitted. The minimum acceptable strength of a stabilized material depends on its position in the pavement structure and the level of traffic. It must be sufficiently strong to resist stresses coming from traffic loading.

As discussed in Chapter 2, on expansive soil subgrades the two (2) common construction techniques implemented for designing flexible pavement on expansive soil subgrade are "Cut-and-Replace" or "Stabilization".

- With cut-and-replace technique, the expansive soil is excavated to a reasonable depth of typically to a depth of 0.6 – 1.0meter and replaced with a more suitable/selected material with CBR on the order of more than 5%, and a non-swelling and not too pervious material.

- On the other hand, with stabilization technique, mostly 12" (30cm) thick of the expansive soil is stabilized with the suitable stabilizer and compacted to a much stronger roadbed than the untreated soil, making it capable of a stable working platform as well as pavement support.

According to ERA (2013c) for designing a flexible pavement, the selection of pavement structures is carried out using Structural Catalogue. Once the traffic class and the design subgrade are determined, then the recommended pavement thicknesses are read from the structural catalogue.

As an example, for a road project with traffic class T5 (CESAL of 3 - 6 million), an attempt has been made to evaluate the pavement structures/thicknesses recommended according to ERA (2013c) Structural Catalogue based on the subgrade classes determined for both 'Cut & Replaced Subgrade' and 'Stabilized Subgrade' techniques.

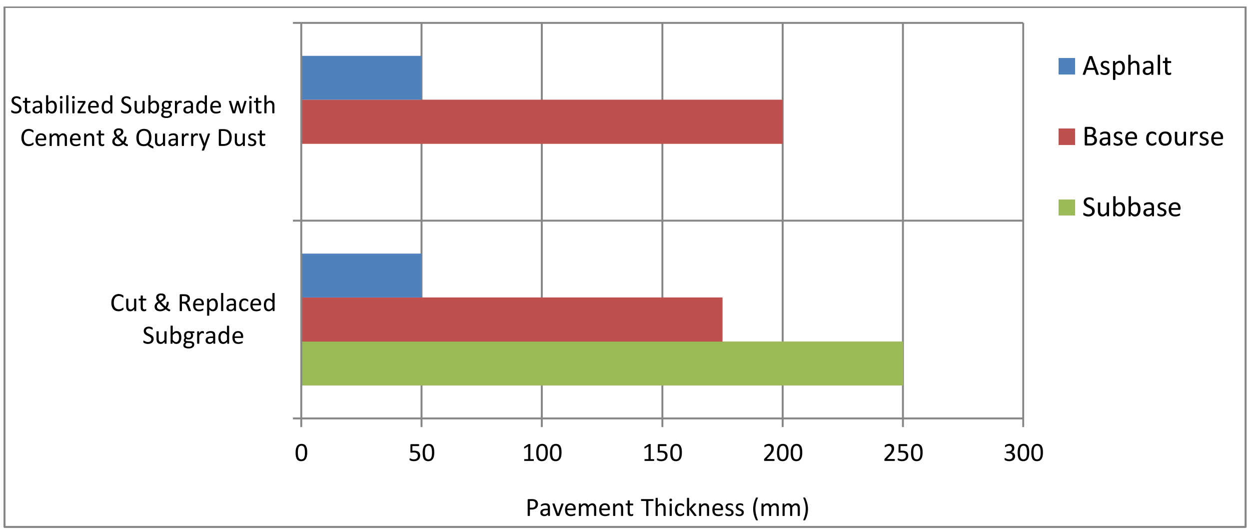


Figure 49: Comparison of Pavement Thicknesses based on cut-and-Replace Subgrade and Stabilized Subgrade

i. Cut and Replaced Subgrade:

While dealing with pavement design on expansive soil subgrade, determining the degree of expansiveness and swelling potential of the native soil has a paramount importance so as to determine the depth of excavation to implement 'remove-and-replace' technique.

Since the studied native black cotton soil has a very low bearing strength/CBR and high swelling potential, then it might be necessary to extend the depth of excavation up to 1.0meter and replaced with a borrow/selected material that has a CBR of more than 5% with a non-swelling characteristics. For example, if it has been decided to use a borrow material of CBR of 8-14%, then the subgrade soil formed with those borrow/selected material is classified as S-4 subgrade according to ERA (2013c).

Based on that, for a road with Traffic class of T5 and with subgrade made up of a borrow material of CBR of 8-14%, the pavement thicknesses recommended according to ERA (2013c) Structural Catalogue were, 250mm of Sub-base layer, 175mm Granular Base course and 50mm of HMA wearing course will be placed over the cut-and-replaced subgrade to carry the assumed traffic loading.

Apart from that, since sufficient surcharge is required to counterbalance the uplifting pressure arises from the swelling potential of the soil, huge embankment will be required till it reach the top subgrade level which in turn increases the total cost in addition to the costs of the construction of the pavement layers.

ii. Soil Subgrade Stabilized with Cement and Quarry dust:

From the results and discussion part, it is understood that soil treated with the mixture of Cement and Quarry dust for most of the mix proportion fulfills the requirement of a road subgrade material.

For all the mix proportion of Cement and Quarry dust mixture, even at the lower Cement and Quarry dust content (i.e. 4%OPC + 5%QD) the soaked CBR of the treated soil are greater than 30% and swell value of 1.5% which categorized as Subgrade class S-6 according to ERA (2013c).

Based on that, for a road with Traffic class of T5 and for a soil subgrade stabilized with Cement and Quarry dust mixture (i.e. Subgrade class of S-6), the pavement thicknesses recommended according to ERA (2013c) Structural Catalogue are a 200mm Granular Base course and 50mm of HMA wearing course are to be placed over the Cement and Quarry dust stabilized subgrade.

From the above, it can be noted that, for a 'Cut and Replaced Subgrade' a 250mm Sub-base layer is necessary beneath the Base course and Asphalt layer to withstand the assumed traffic load.

Unlike to 'cut and replaced subgrade', for a stabilized subgrade with Cement and Quarry dust mixture, there is no need for Sub-base course/layer and the assumed traffic load can be bear-up only by 200mm Granular Base course and 50mm of HMA wearing course layers.

And from this, it can be construed that, if someone is decided to construct the road over the subgrade that is stabilized with Cement and Quarry dust mixture of the studied soil than a subgrade made up of cut and replaced technique, then the costs for production, hauling and placing of a Sub-base material can be saved.

In general, for pavement subgrade many researches recommend that treating the soil with suitable stabilizer works better and costs less than soil removal and replacement technique.

However, both solutions can be effective for many projects, the better choice, in terms of cost and performance is not always obvious and needs valuable insight on each of the techniques is needed:

Which works better and costs less? The decision as to which technique to use to improve the soil at the construction site depends on a number of factors, including:

- Cost
- Project size
- Contractor capabilities and preferences
- Material availability
- Disposal options (for remove-and-replace)
- Equipment access or operating constraints
- Existing soil types and soil conditions

and should be evaluated on a case-by-case basis by the engineer, Neither solution is always best in all situations.

Chapter 5 Conclusion and Recommendations

5.1. Conclusion

Based on the study and results of the investigation, the following conclusions are drawn:

- The studied Black Cotton soil is classified as A-7-6 soil according to AASHTO classification system. Furthermore, the Plasticity Index, CBR & CBR Swell, Linear Shrinkage and Activity test results of the native soil revealed that the soil has a very low bearing capacity, high swelling potential and susceptible to volume change which makes it unsuitable to use it as a road subgrade soil unless it is treated with suitable stabilizer.

- Soil treated with Portland-Cement (OPC) alone by 2%, 4%, 8% and 12% by dry weight of the soil showed significant improvement in strength and reduce the swelling property of the native soil significantly and also improve the plasticity characteristics of the soil. Generally it was observed that with increasing the Cement content, strength of the treated soil improved, plasticity and swelling potential of the soil getting decreased.

- Soil treated with only Quarry Dust (QD), by 5%, 10%, 15% and 20% by dry weight of the soil showed slight/nominal improvement in the strength and plasticity characteristics of the soil and negligible result with respect to improving the swelling potential of the treated soil.

- **Treating Expansive soils with Quarry dust only has not brought significant improvement on the Strength, Plasticity and Swelling potential of the treated soil. And it is concluded that Quarry dust by itself is not an effective stabilizer for treating expansive soils.**

- Whereas, soil treated with Cement-Quarry dust mixture significantly improve the strength and profoundly reduce the swelling property and the plasticity characteristics of the treated soil.

- When Cement and Quarry dust are mixed together, the mixes of the two additives acts like a '*Cement-Mortar*'. Hence, holistic and significant improvements were recorded for the soil treated by Cement - Quarry Dust mixture than the soil treated with Cement alone.

- ❖ Soil treated with the mix proportion of (4%OPC + 15%QD) resulted in soaked CBR of 36%, CBR Swell value of 1.3%, Plasticity Index of 23 and UCS value of 370kPa after 7 days curing.

- ❖ According to ERA (2002d), the material forming the road subgrade shall have a minimum soaked Californian Bearing Ratio (CBR) of greater than 5% and a swell value of not more than 1.5%. Furthermore, according to ASTM D-4609 (Standard guide for evaluating effectiveness of admixture for soil stabilization) an increase in unconfined compressive strength of 345 kPa (50 psi) or more must be achieved after seven days curing for a treatment to be considered effective and as benchmark for long-term stabilization.

- ❖ Therefore, (4%OPC + 15%QD) was found to be the optimum stabilizer content for the studied soil to utilize it as a road subgrade soil and fulfills all the requirements stipulated for a road subgrade material according to ERA (2002d) and ASTM D-4609 (Standard guide for evaluating effectiveness of admixture for soil stabilization) requirements.

5.2. Recommendations

From the study it is recommended that:-

- ❖ The present work has attempted to evaluate and characterize the engineering properties of Black Cotton soil material collected from Lebu–Akaki-IT Park Outer Ring Road area. However, as the country is endowed with widely distributed Black Cotton soil deposit, it is recommendable to carry out investigation from samples collected from other areas in order to develop a guide-line.

- ❖ The Quarry Dust being utilized for this research is collected from aggregate processing quarries that have a Basaltic Rock nature. Due to time and capacity limitations, dust other than the ones originated from basalt rock type were not investigated. Therefore, it is recommended to investigate the effect of Stone Dust generated from other parental rock materials than 'Basalt rock' (like limestone, granite and others where applicable) on the treatment of Black cotton soils.

- ❖ The effect of curing time (longer curing periods) on the engineering properties of the Cement-Quarry Dust stabilized Black cotton soils shall be evaluated since hydration and pozzolanic reactions of cement are time bound.

- This research study was conducted on Black cotton soils treated with Cement alone, Quarry dust alone, and Cement and Quarry dust combination on laboratory basis and only empirical (index tests) such as PI, CBR and UCS tests are performed. Therefore in order to evaluate the actual performance of the treated soil on the actual field/site, it is recommended to carry out performance based tests such as Stiffness Modulus tests and other necessary tests.

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Appendices

Black Cotton Soil (Native Soil) Sample # 1

GRAIN SIZE ANALYSIS (WET SIEVE HYDROMETER ANALYSIS) AASHTO T88-02

Sieve Analysis

Sieve (mm)	% PASSED
9.50	100.0
4.750	100.0
2.000	97.3
0.425	96.5
0.075	96.1

Hydrometer Analysis

Smaller than (mm)	Percent
0.020	93.0
0.002	57.0
0.001	50.7

Combined	
Grain size	% Passed
4.75	100.0
2.00	97.3
0.425	96.5
0.075	96.1
0.029	96.0
0.018	93.0
0.011	88.2
0.008	81.3
0.006	74.0
0.003	63.0
0.001	50.7

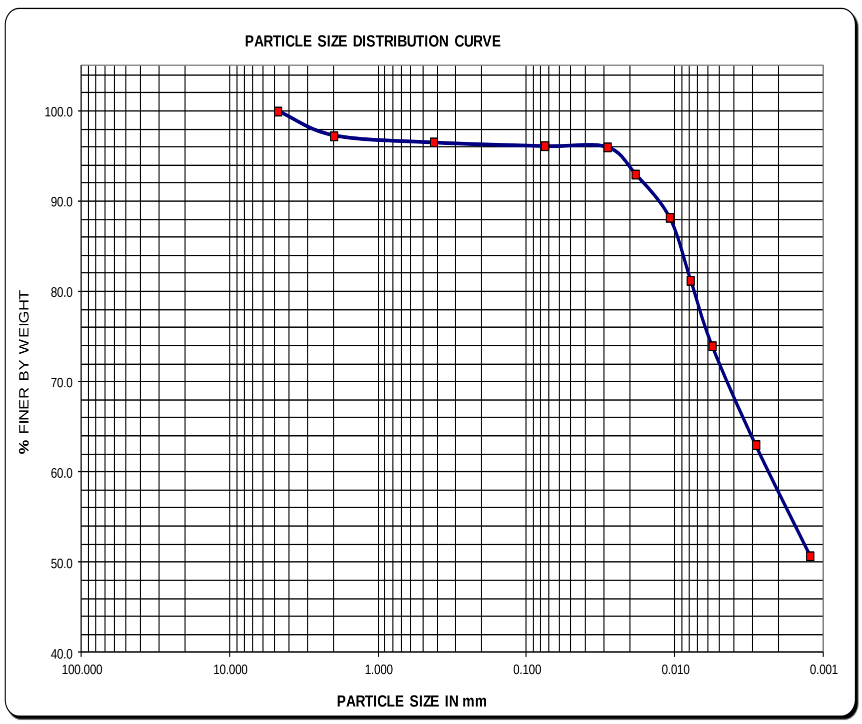
SIZE PROPORTIONS

Particle larger than 2.00 mm, % 2.7

Sand (2.00mm-0.075mm), % **1.2**

Silt (0.075mm-0.002mm), % **39.1**

Clay (less than 0.002), % **57.0**



Black Cotton Soil (Native Soil) Sample # 2

GRAIN SIZE ANALYSIS (WET SIEVE HYDROMETER ANALYSIS) AASHTO T88-02

Sieve Analysis

Sieve (mm)	% PASSED
9.50	100.0
4.750	100.0
2.000	98.0
0.425	97.8
0.075	95.3

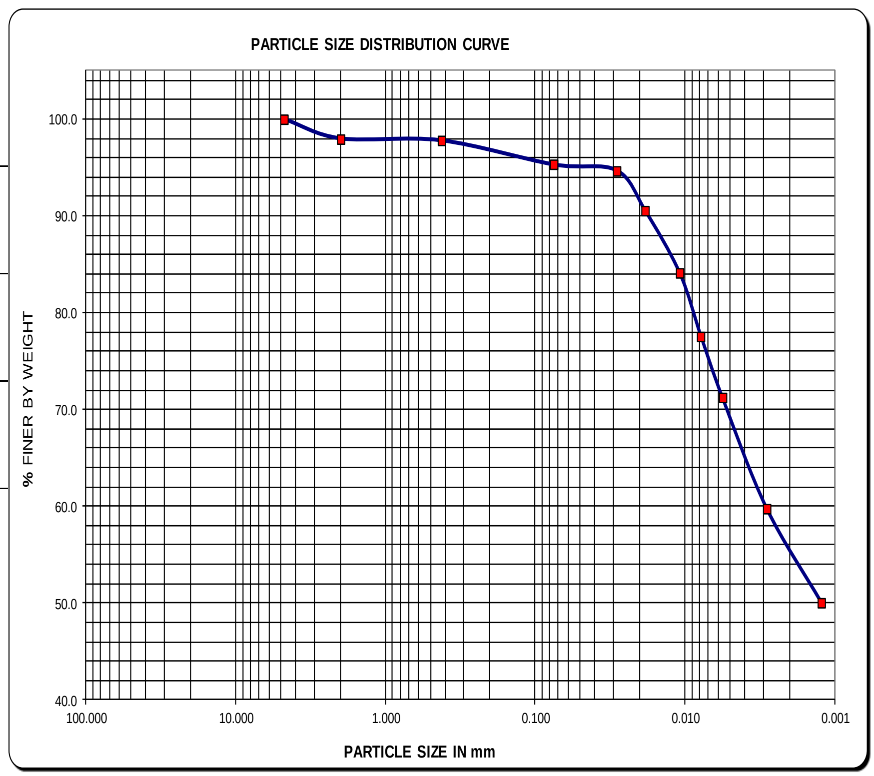
Hydrometer Analysis

Smaller than (mm)	Percent
0.020	90.5
0.002	54.0
0.001	50.0

Combined	
Grain size	% Passed
4.75	100.0
2.00	98.0
0.425	97.8
0.075	95.3
0.029	94.7
0.018	90.5
0.011	84.1
0.008	77.6
0.006	71.2
0.003	59.8
0.001	50.0

SIZE PROPORTIONS

Particle larger than 2.00 mm, %	2.0
Sand (2.00mm-0.075mm), %	**2.7**
Silt (0.075mm-0.002mm), %	**43.3**
Clay (less than 0.002), %	**54.0**



Black Cotton Soil (Native Soil) Sample # 3

GRAIN SIZE ANALYSIS (WET SIEVE HYDROMETER ANALYSIS) AASHTO T88-02

Sieve Analysis

Sieve (mm)	% PASSED
9.50	100.0
4.750	100.0
2.000	98.6
0.425	97.6
0.075	96.9

Hydrometer Analysis

Smaller than (mm)	Percent
0.020	92.1
0.002	56.0
0.001	51.8

Combined	
Grain size	% Passed
4.75	100.0
2.00	98.6
0.425	97.6
0.075	96.9
0.029	95.7
0.018	92.1
0.011	86.2
0.008	80.2
0.006	73.8
0.003	61.3
0.001	51.8

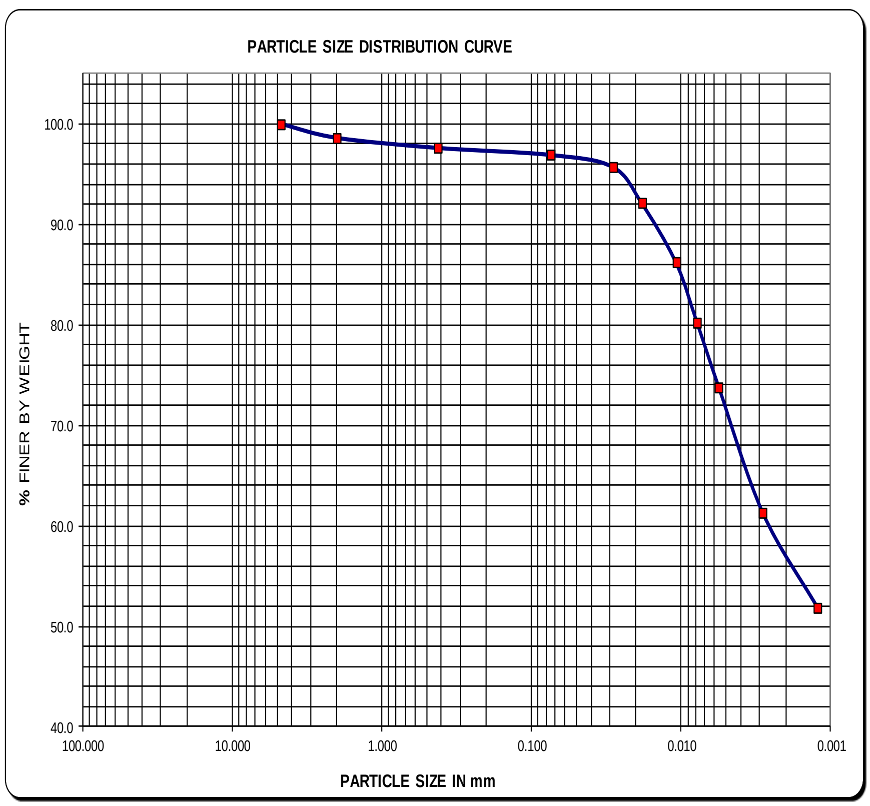
SIZE PROPORTIONS

Particle larger than 2.00 mm, % 1.4

Sand (2.00mm-0.075mm), % **1.7**

Silt (0.075mm-0.002mm), % **42.3**

Clay (less than 0.002), % **56.0**

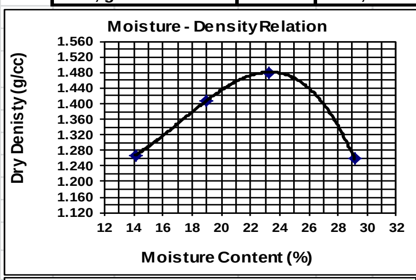


Black Cotton Soil (Native Soil) Sample # 1

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	7845	8310	8621	8210
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	2965	3430	3741	3330
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.45	1.67	1.82	1.62
Moisture Content Determination				
Weight of Wet soil + cont. (g)	425.5	311.4	375.0	415.0
Weight of Dry soil + cont. (g)	377.5	268.0	315.1	334.5
Weight of Container (g)	37.4	39.0	57.4	58.2
Weight of water (moisture) (g)	48	43.4	59.9	80.5
Weight of Dry soil (g)	340.1	229	257.7	276.3
Moisture content (%)	14.11	18.95	23.24	29.13
Dry Density (g / cm3)	1.267	1.407	1.481	1.258
MDD, g/cc	**1.480**	**OMC, %**	**23.7**	

Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9160	10213	9557	10670	9897	10988
Wt.of mould, g	W2	6200	6200	6406	6406	6156	6156
Wt.of wet sample, g	W3 = W1 - W2	2960	4013	3151	4264	3741	4832
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.39	1.89	1.48	2.01	1.76	2.27
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.21	1.20	1.29	1.25	1.54	1.38
Moisture Content Determination							
Wt. of wet sample + cont.	W3	367	217.2	320	228	354.6	225.7
Wt. of dry sample + cont.	W4	327.1	149.8	283.9	155.7	316.9	154.8
Wt. of water, g	W5 = W3 - W4	39.9	67.4	36.1	72.3	37.7	70.9
Wt. of container, g	W6	60.4	33.6	37	37.4	58.2	46
Wt. of dry sample, g	W7 = W4 - W6	266.7	116.2	246.9	118.3	258.7	108.8
% Moisture Content	W8 = W5/W7*100	15.0	58.0	14.6	61.1	14.6	65.2



SWELL DATA

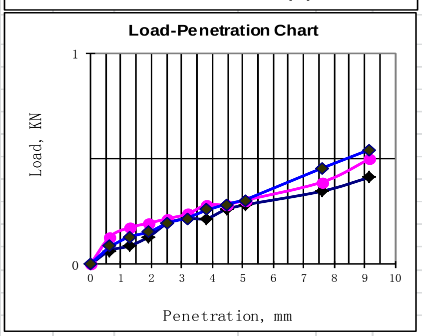
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	18.7	18.63	**16.01**	0.04	16.34	16.30	**14.00**	0.02	20.98	20.96	**18.01**

CBR DATA

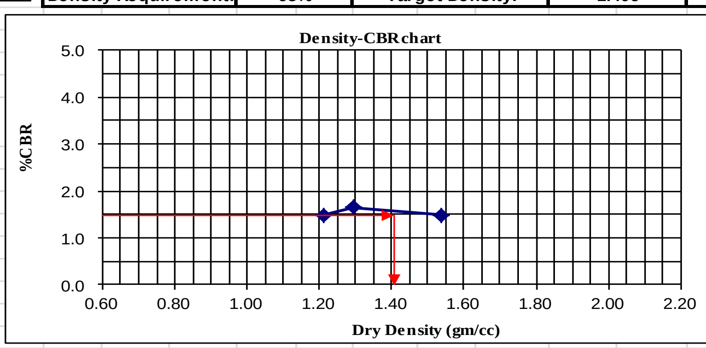
Penet-ration (mm)	Std load (KN)	Gauge reading (10)	Load KN (10)	Corrected CBR KN (10)	Corrected CBR % (10)	Gauge reading (30)	Load KN (30)	Corrected CBR KN (30)	Corrected CBR % (30)	Gauge reading (65)	Load KN (65)	Corrected CBR KN (65)	Corrected CBR % (65)
0		0	0			0	0			0	0		
0.64		3	0.065			6	0.13			4	0.09		
1.27		4	0.087			8	0.17			6	0.13		
1.91		6	0.13			9	0.20			7	0.15		
2.54	13.2	9	0.195	0.20	**1.5**	10	0.22	0.22	**1.64**	9	0.20	0.20	**1.5**
3.18		10	0.217			11	0.24			10	0.22		
3.81		10	0.217			13	0.28			12	0.26		
4.45		12	0.26			13	0.28			13	0.28		
5.08	20.4	13	0.282	0.28	**1.38**	14	0.30	0.30	**1.5**	14	0.30	0.30	**1.5**
7.62		16	0.347			18	0.39			21	0.46		
9.16		19	0.412			23	0.50			25	0.54		

	10	30	65
Soaked CBR,%	1.5	1.6	1.5
Dry Density, g/cc	1.21	1.29	1.54
Swell, %	16.01	14.00	18.01

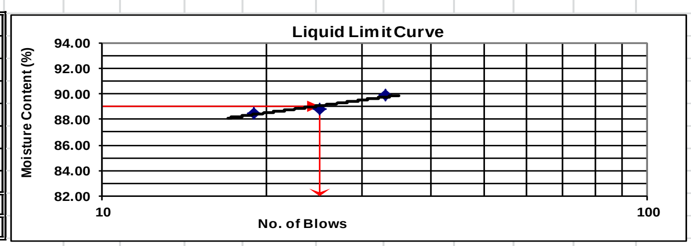
Density Requirement:	95%	Target Density:	1.406	CBR	1.50



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.21	1.5
30	1.29	1.6
65	1.54	1.5



	Liquid Limit			Plastic Limit	
No. of Blows	33	25	19		
Wt. of cont. + wet soil (g) = (w_1)	36.60	40.70	36.00	8.75	8.63
Wt. of cont. + dry soil (g.) = (w_2)	27.70	30.40	27.82	7.94	8.02
Wt. of container (g.) = (w_3)	17.80	18.80	18.58	6.38	6.70
Mass of moisture (g.) (w_1-w_2) = x	8.90	10.30	8.18	0.81	0.61
Wt. of dry soil (g.) (w_2-w_3) = y	9.90	11.60	9.24	1.56	1.32
Moisture Content (%) = (100x/y)	89.90	88.79	88.53	51.92	46.21
		89.07		49.07	
		Plasticity Index		40.00	



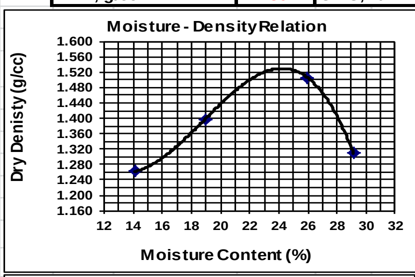
Black Cotton Soil (Native Soil) Sample # 2

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	7832	8289	8770	8344
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	2952	3409	3890	3464
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.44	1.66	1.90	1.69
Moisture Content Determination				
Weight of Wet soil +cont. (g)	425.5	311.4	370.0	415.0
Weight of Dry soil +cont. (g)	377.5	268.0	309.0	334.5
Weight of Container (g)	37.4	39.0	74.0	58.2
Weight of water (moisture) (g)	48	43.4	61	80.5
Weight of Dry soil (g)	340.1	229	235	276.3
Moisture content (%)	14.11	18.95	25.96	29.13
Dry Density (g / cm3)	1.262	1.398	1.507	1.309
MDD, g/cc	**1.502**	**OMC, %**		**26.0**

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9100	10205	9402	10662	9925	11030
Wt.of mould, g	W2	6310	6310	6403	6403	6204	6204
Wt.of wet sample, g	W3 = W1 - W2	2790	3895.2	2999	4259	3721	4826
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.31	1.83	1.41	2.01	1.75	2.27
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.09	1.10	1.26	1.19	1.73	1.38
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	383	226.7	307.6	237	320.7	225.7
Wt. of dry sample + cont.,	W4	327.1	149.8	278.1	155.7	316.9	154.8
Wt. of water, g	W5 = W3 - W4	55.9	76.9	29.5	81.3	3.8	70.9
Wt. of container, g	W6	60.4	33.6	37	37.4	58.2	46
Wt. of dry sample, g	W7 = W4 - W6	266.7	116.2	241.1	118.3	258.7	108.8
% Moisture Content	W8 = W5/W7*100	21.0	66.2	12.2	68.7	1.5	65.2

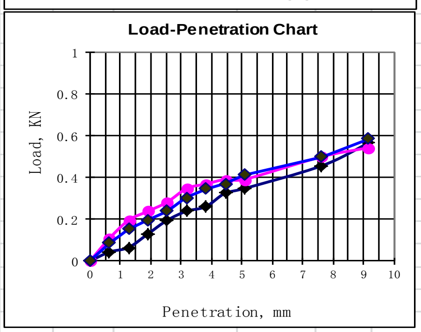


SWELL DATA

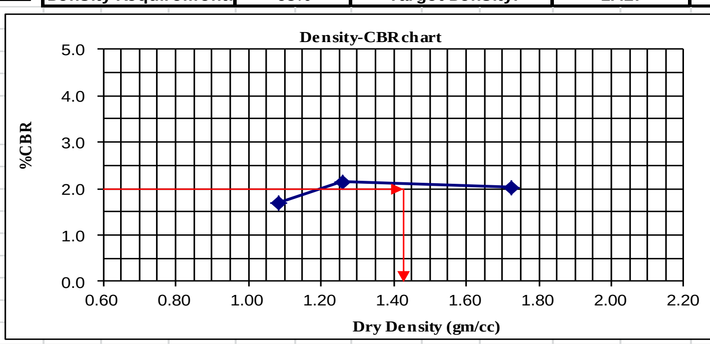
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.04	22.2	22.16	**19.04**	0.04	19.85	19.81	**17.02**	0.06	21.1	21.04	**18.08**

CBR DATA

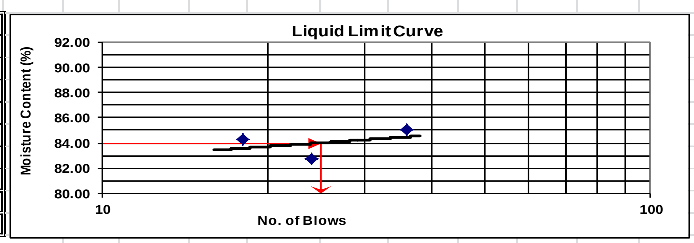
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		2	0.043			5	0.11			4	0.09		
1.27		3	0.065			9	0.20			7	0.15		
1.91		6	0.13			11	0.24			9	0.20		
2.54	13.2	9	0.195	0.20	**1.5**	13	0.28	0.28	**2.14**	11	0.24	0.24	**1.8**
3.18		11	0.239			16	0.35			14	0.30		
3.81		12	0.26			17	0.37			16	0.35		
4.45		15	0.326			18	0.39			17	0.37		
5.08	20.4	16	0.347	0.35	**1.70**	18	0.39	0.39	**1.9**	19	0.41	0.41	**2.0**
7.62		21	0.456			23	0.50			23	0.50		
9.16		26	0.564			25	0.54			27	0.59		
Soaked CBR,%	1.7					2.1				2.0			
Dry Density, g/cc	1.09					1.26				1.73			
Swell, %	19.04					17.02				18.08			
Density Requirement:	**95%**		**Target Density:**			**1.427**				**CBR**		**2.00**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.09	1.7
30	1.26	2.1
65	1.73	2.0



	Liquid Limit			Plastic Limit	
No. of Blows	36	24	18		
Wt. of cont. +wet soil (g) = (w_1)	37.02	39.97	35.44	8.14	8.62
Wt. of cont. +dry soil (g.) = (w_2)	27.50	29.98	27.76	7.62	8.07
Wt. of container (g.) = (w_3)	16.30	17.90	18.65	6.40	6.67
Mass of moisture (g.) (w_1-w_2) = x	9.52	9.99	7.68	0.52	0.55
Wt. of dry soil (g.) (w_2-w_3) = y	11.20	12.08	9.11	1.22	1.40
Moisture Content (%) = (100x/y)	85.00	82.70	84.30	42.62	39.29
	84.04			**40.95**	
	Plasticity Index			**43.09**	



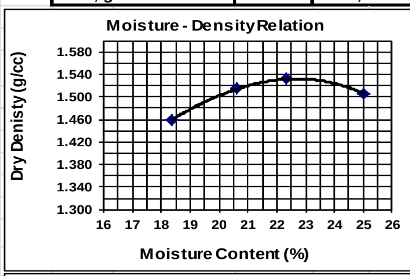
Black Cotton Soil (Native Soil) Sample # 3

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8420	8625	8721	8739
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3540	3745	3841	3859
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.73	1.83	1.87	1.88
Moisture Content Determination				
Weight of Wet soil + cont. (g)	252.2	284.5	216.9	243.0
Weight of Dry soil + cont. (g)	220.0	242.4	184.0	201.8
Weight of Container (g)	44.6	38.4	36.7	37.2
Weight of water (moisture) (g)	32.2	42.1	32.9	41.2
Weight of Dry soil (g)	175.4	204	147.3	164.6
Moisture content (%)	18.36	20.64	22.34	25.03
Dry Density (g / cm3)	1.459	1.514	1.532	1.506
MDD, g/cc	**1.532**	**OMC, %**		**22.3**

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9204	10390	9345	10658	9885	10976
Wt.of mould, g	W2	6339	6339	6205	6205	6252	6252
Wt.of wet sample, g	W3 = W1 - W2	2865	4051	3140	4453	3633	4724
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.35	1.91	1.48	2.10	1.71	2.22
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.17	1.20	1.29	1.30	1.49	1.35
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	365	215.2	318	226	352.6	223.7
Wt. of dry sample + cont.,	W4	325.3	148	282.1	153.9	315.1	153
Wt. of water, g	W5 = W3 - W4	39.7	67.2	35.9	72.1	37.5	70.7
Wt. of container, g	W6	58.3	35.2	39.2	37.4	56.8	44.7
Wt. of dry sample, g	W7 = W4 - W6	267	112.8	242.9	116.5	258.3	108.3
% Moisture Content	W8 = W5/W7*100	14.9	59.6	14.8	61.9	14.5	65.3



SWELL DATA

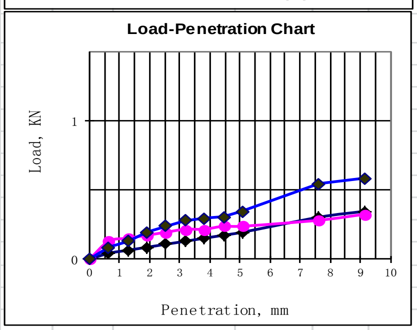
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	19.9	19.83	**17.04**	0.04	18.7	18.66	**16.03**	0	22.12	22.12	**19.00**

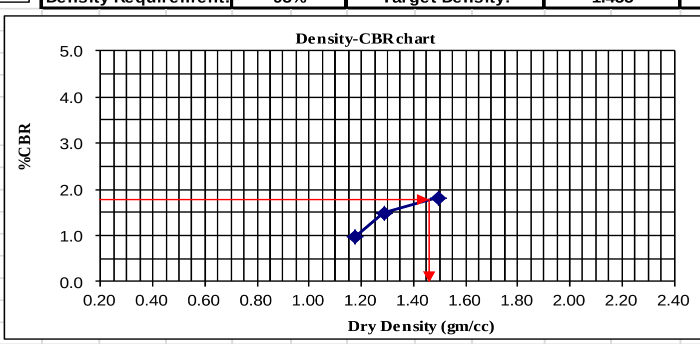
CBR DATA

Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		2	0.043			6	0.13			4	0.09		
1.27		3	0.065			7	0.15			6	0.13		
1.91		4	0.087			8	0.17			9	0.20		
2.54	13.2	5	0.109	0.11	**0.8**	9	0.20	0.20	**1.48**	11	0.24	0.24	**1.8**
3.18		6	0.13			10	0.22			13	0.28		
3.81		7	0.152			10	0.22			13.5	0.29		
4.45		8	0.174			11	0.24			14	0.30		
5.08	20.4	9	0.195	0.20	**0.96**	11	0.24	0.24	**1.2**	16	0.35	0.35	**1.7**
7.62		14	0.304			13	0.28			25	0.54		
9.16		16	0.347			15	0.33			27	0.59		

	10	30	65
Soaked CBR,%	1.0	1.5	1.8
Dry Density, g/cc	1.17	1.29	1.49
Swell, %	17.04	16.03	19.00

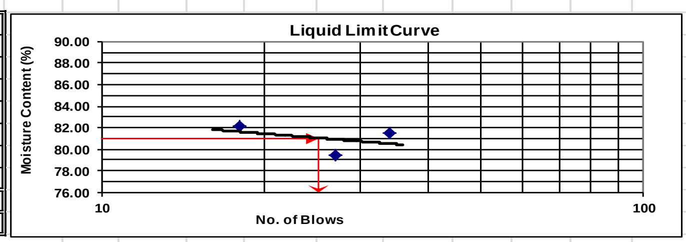
Density Requirement:	**95%**	**Target Density:**	**1.455**	**CBR**	**1.80**





No of Blows	DDBS (gm/cc)	CBR (%)
10	1.17	1.0
30	1.29	1.5
65	1.49	1.8

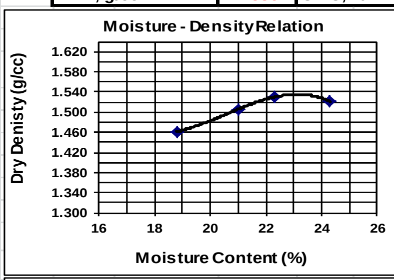
	Liquid Limit			Plastic Limit	
No. of Blows	34	27	18		
Wt. of cont. + wet soil (g) = (w_1)	35.80	39.80	35.27	8.57	8.63
Wt. of cont. + dry soil (g.) = (w_2)	27.76	30.55	27.67	7.98	8.02
Wt. of container (g.) = (w_3)	17.89	18.91	18.42	6.40	6.52
Mass of moisture (g.) (w_1-w_2) = x	8.04	9.25	7.60	0.59	0.61
Wt. of dry soil (g.) (w_2-w_3) = y	9.87	11.64	9.25	1.58	1.50
Moisture Content (%) = (100x/y)	81.46	79.47	82.16	37.34	40.67
		81.02		**39.00**	
		Plasticity Index		**42.02**	



BC+5%QD (Sample # 1)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8440	8615	8780	8756
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3560	3735	3900	3876
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.74	1.82	1.90	1.89
Moisture Content Determination				
Weight of Wet soil + cont. (g)	200.8	205.4	222.6	201.3
Weight of Dry soil + cont. (g)	169.5	171.5	183.6	163.5
Weight of Container (g)	19.8	20.3	20.3	20.6
Weight of water (moisture) (g)	31.3	33.9	39	37.8
Weight of Dry soil (g)	149.7	151.2	163.3	142.9
Moisture content (%)	18.81	21.00	22.30	24.30
Dry Density (g / cm3)	1.462	1.506	1.530	1.521
MDD, g/cc	**1.536**	**OMC, %**	**22.1**	



Unit Weight Determination

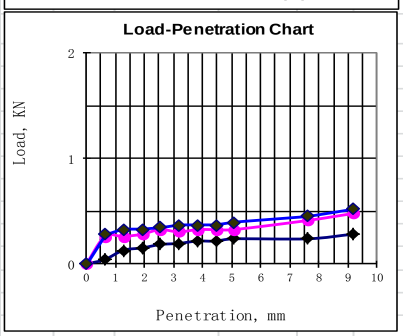
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9219	10224	9675	10473	10425	10853
Wt.of mould, g	W2	6239	6239	6092	6092	6302	6302
Wt.of wet sample, g	W3 = W1 - W2	2980	3985	3583	4381	4123	4551
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.40	1.88	1.69	2.06	1.94	2.14
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.18	1.26	1.42	1.37	1.64	1.41
Moisture Content Determination							
Wt. of wet sample + cont.	W3	334.2	284.3	298	288.8	353.9	240.2
Wt. of dry sample + cont.	W4	287	205.7	257	204.2	305	170.4
Wt. of water, g	W5 = W3 - W4	47.2	78.6	41	84.6	48.9	69.8
Wt. of container, g	W6	35.2	44.5	36	37.9	36.7	36
Wt. of dry sample, g	W7 = W4 - W6	251.8	161.2	221	166.3	268.3	134.4
% Moisture Content	W8 = W5/W7*100	18.7	48.8	18.6	50.9	18.2	51.9

SWELL DATA

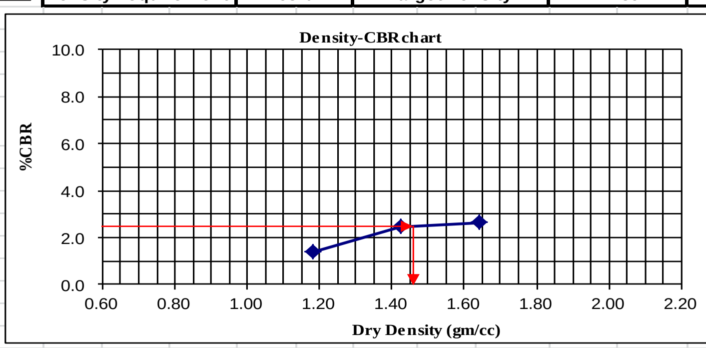
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.08	19.07	18.99	**16.31**	0.05	18.46	18.41	**15.82**	0.08	18.73	18.65	**16.02**

CBR DATA

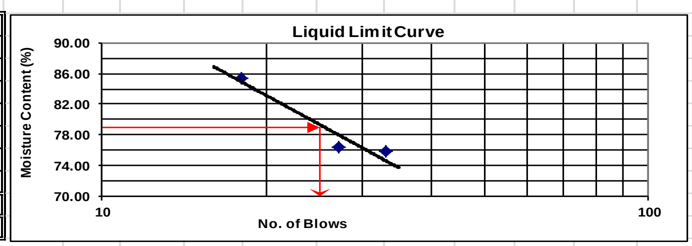
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		2	0.043			12	0.26			13	0.28		
1.27		6	0.13			12	0.26			15	0.33		
1.91		7	0.152			13	0.28			15	0.33		
2.54	13.2	9	0.184	0.18	**1.4**	15	0.33	0.33	**2.5**	16	0.35	0.35	**2.6**
3.18		9	0.195			14	0.30			17	0.37		
3.81		10	0.217			15	0.33			17	0.37		
4.45		10	0.217			15	0.33			17	0.37		
5.08	20.4	11	0.239	0.24	**1.2**	15	0.33	0.33	**1.6**	18	0.39	0.39	**1.9**
7.62		11	0.239			19	0.41			21	0.46		
9.16		13	0.282			22	0.48			24	0.52		
Soaked CBR,%		1.4				2.5				2.6			
Dry Density, g/cc		1.18				1.42				1.64			
Swell, %		16.31				15.82				16.02			
Density Requirement:		**95%**		**Target Density:**			**1.459**			**CBR**		**2.50**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.18	1.4
30	1.42	2.5
65	1.64	2.6



	Liquid Limit			Plastic Limit	
No. of Blows	33	27	18		
Wt. of cont. + wet soil (g) = (w_1)	44.50	42.90	41.62	28.60	27.90
Wt. of cont. + dry soil (g.) = (w_2)	34.80	33.42	31.75	24.00	23.50
Wt. of container (g.) = (w_3)	22.00	21.00	20.20	12.01	12.12
Mass of moisture (g.) (w_1-w_2) = x	9.70	9.48	9.87	4.60	4.40
Wt. of dry soil (g.) (w_2-w_3) = y	12.80	12.42	11.55	11.99	11.38
Moisture Content (%) = (100x/y)	75.78	76.33	85.45	38.37	38.66
		79.12		38.51	
		Plasticity Index		40.61	



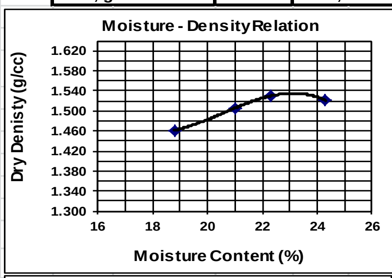
BC+5%QD (Sample #2)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould+Wet soil (g)	8440	8615	8780	8756
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3560	3735	3900	3876
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.74	1.82	1.90	1.89
Moisture Content Determination				
Weight of Wet soil+cont. (g)	200.8	205.4	222.6	201.3
Weight of Dry soil+cont. (g)	169.5	171.5	183.6	163.5
Weight of Container (g)	19.8	20.3	20.3	20.6
Weight of water (moisture) (g)	31.3	33.9	39	37.8
Weight of Dry soil (g)	149.7	151.2	163.3	142.9
Moisture content (%)	18.81	21.00	22.30	24.30
Dry Density (g / cm3)	1.462	1.506	1.530	1.521
MDD, g/cc	**1.536**	**OMC, %**	**22.1**	

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9118	10237	9710	10486	10550	10866
Wt.of mould, g	W2	6258	6258	6111	6111	6321	6321
Wt.of wet sample, g	W3 = W1 - W2	2860	3979	3599	4375	4229	4545
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.35	1.87	1.69	2.06	1.99	2.14
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.14	1.28	1.44	1.39	1.69	1.44
Moisture Content Determination							
Wt. of wet sample + cont.	W3	339.8	289.9	303.6	294.4	359.5	245.8
Wt. of dry sample + cont.	W4	293.3	212	263.3	210.5	311.3	176.7
Wt. of water, g	W5 = W3 - W4	46.5	77.9	40.3	83.9	48.2	69.1
Wt. of container, g	W6	35.2	44.5	36	37.9	36.7	36
Wt. of dry sample, g	W7 = W4 - W6	258.1	167.5	227.3	172.6	274.6	140.7
% Moisture Content	W8 = W5/W7*100	18.0	46.5	17.7	48.6	17.6	49.1

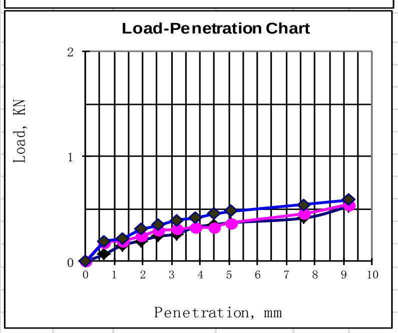


SWELL DATA

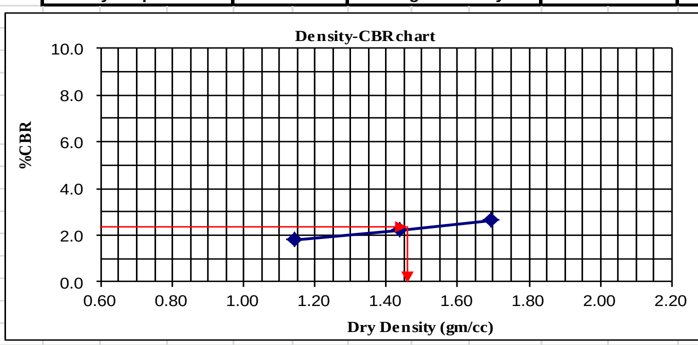
No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.08	19.07	18.99	**16.31**	0.05	18.46	18.41	**15.82**	0.08	18.73	18.65	**16.02**

CBR DATA

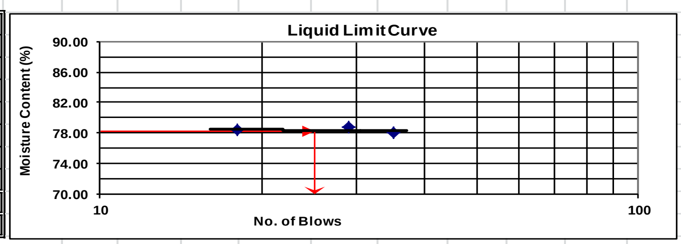
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		3	0.065			8	0.17			9	0.20		
1.27		7	0.152			9	0.20			10	0.22		
1.91		9	0.195			11	0.24			14	0.30		
2.54	13.2	11	0.239	0.24	**1.8**	14	0.29	0.29	**2.2**	16	0.35	0.35	**2.6**
3.18		12	0.26			14	0.30			18	0.39		
3.81		15	0.326			15	0.33			19	0.41		
4.45		16	0.347			15	0.33			21	0.46		
5.08	20.4	17	0.369	0.37	**1.8**	17	0.37	0.37	**1.8**	22	0.48	0.48	**2.3**
7.62		19	0.412			21	0.46			25	0.54		
9.16		24	0.521			25	0.54			27	0.59		
Soaked CBR,%	1.8					2.2				2.6			
Dry Density, g/cc	1.14					1.44				1.69			
Swell, %	16.31					15.82				16.02			
Density Requirement:	**95%**	**Target Density:**	**1.459**	**CBR**	**2.40**								



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.14	1.8
30	1.44	2.2
65	1.69	2.6



	Liquid Limit			Plastic Limit	
No. of Blows	35	29	18		
Wt. of cont. +wet soil (g) = (w_1)	42.69	41.37	38.97	28.58	27.88
Wt. of cont. +dry soil (g.) = (w_2)	33.60	32.50	30.90	23.96	23.50
Wt. of container (g.) = (w_3)	21.96	21.23	20.60	12.01	12.12
Mass of moisture (g.) (w_1-w_2) = x	9.09	8.87	8.07	4.62	4.38
Wt. of dry soil (g.) (w_2-w_3) = y	11.64	11.27	10.30	11.95	11.38
Moisture Content (%) = (100x/y)	78.09	78.70	78.35	38.66	38.49
	78.37			**38.57**	
	Plasticity Index			**39.80**	



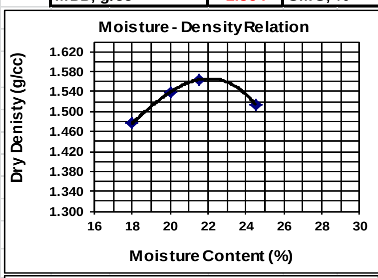
BC+10%QD (Sample # 1)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould+Wet soil (g)	8452	8666	8839	8745
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3572	3786	3959	3865
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g/cm3)	1.74	1.85	1.93	1.89
Moisture Content Determination				
Weight of Wet soil+cont. (g)	228.7	203.1	222.2	207.7
Weight of Dry soil+cont. (g)	192.5	169.9	183.7	168.9
Weight of Container (g)	19.8	19.2	19.8	20.2
Weight of water (moisture) (g)	36.2	33.2	38.5	38.8
Weight of Dry soil (g)	172.7	150.7	163.9	148.7
Moisture content (%)	18.00	20.00	21.50	24.50
Dry Density (g/cm3)	1.477	1.539	1.564	1.514
MDD, g/cc	**1.564**	**OMC, %**	**21.5**	

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9533	10450	10215	10924	9954	10747
Wt.of mould, g	W2	6262	6262	6610	6610	6095	6095
Wt.of wet sample, g	W3 = W1 - W2	3271	4188	3605	4314	3859	4652
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.54	1.97	1.70	2.03	1.82	2.19
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.28	1.33	1.42	1.35	1.53	1.51
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	297.9	261.5	346.1	316.9	278.5	281.1
Wt. of dry sample + cont.,	W4	253.3	188.5	295.5	230.6	241.2	211.5
Wt. of water, g	W5 = W3 - W4	44.6	73	50.6	86.3	37.3	69.6
Wt. of container, g	W6	36.6	38.3	39.2	57.7	44.5	55.5
Wt. of dry sample, g	W7 = W4 - W6	216.7	150.2	256.3	172.9	196.7	156
% Moisture Content	W8 = W5/W7*100	20.6	48.6	19.7	49.9	19.0	44.6

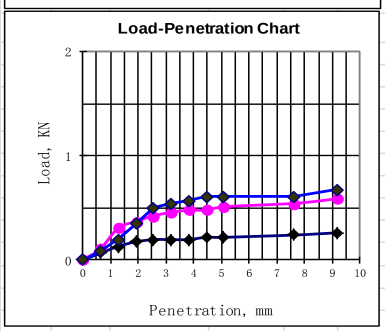


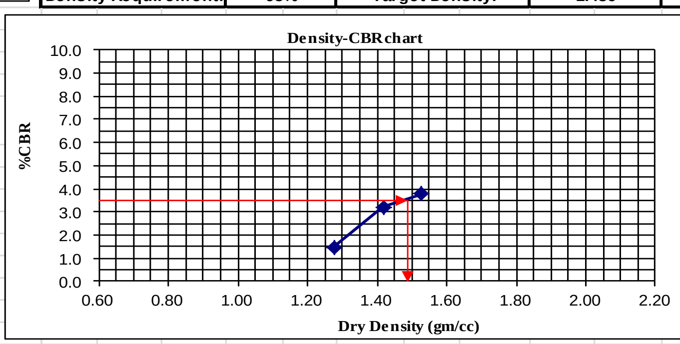
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.04	17.15	17.11	**14.70**	0.04	17.00	16.96	**14.57**	0.05	17.3	17.25	**14.82**

CBR DATA

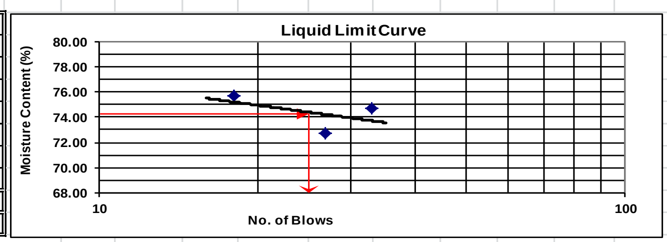
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		3	0.065			5	0.11			4	0.09		
1.27		6	0.13			14	0.30			9	0.20		
1.91		8	0.174			17	0.37			16	0.35		
2.54	13.2	9	0.195	0.20	**1.5**	20	0.42	0.42	**3.2**	23	0.50	0.50	**3.8**
3.18		9	0.195			21	0.46			25	0.54		
3.81		9	0.195			22	0.48			26	0.56		
4.45		10	0.217			22	0.48			28	0.61		
5.08	20.4	10	0.217	0.22	**1.1**	24	0.51	0.51	**2.5**	28	0.61	0.61	**3.0**
7.62		11	0.239			25	0.54			28	0.61		
9.16		12	0.26			27	0.59			31	0.67		
Soaked CBR,%		1.5				3.2				3.8			
Dry Density, g/cc		1.28				1.42				1.53			
Swell, %		14.70				14.57				14.82			
Density Requirement:		**95%**		**Target Density:**		**1.486**				**CBR**		**3.50**	





No of Blows	DDBS (gm/cc)	CBR (%)
10	1.28	1.5
30	1.42	3.2
65	1.53	3.8

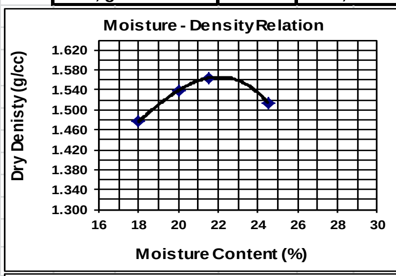
	Liquid Limit			Plastic Limit	
No. of Blows	33	27	18		
Wt. of cont.+wet soil (g) = (w_1)	38.97	39.45	41.25	29.45	28.65
Wt. of cont.+dry soil (g.) = (w_2)	31.35	31.45	33.15	24.88	24.31
Wt. of container (g.) = (w_3)	21.15	20.45	22.45	12.20	12.35
Mass of moisture (g.) (w_1-w_2) = x	7.62	8.00	8.10	4.57	4.34
Wt. of dry soil (g.) (w_2-w_3) = y	10.20	11.00	10.70	12.68	11.96
Moisture Content (%) = (100x/y)	74.71	72.73	75.70	36.04	36.29
		74.33		36.16	
		Plasticity Index		38.17	

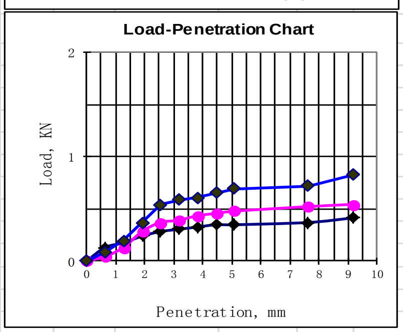


BC+10%QD (Sample # 2)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8452	8666	8839	8745
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3572	3786	3959	3865
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.74	1.85	1.93	1.89
Moisture Content Determination				
Weight of Wet soil + cont. (g)	228.7	203.1	222.2	207.7
Weight of Dry soil + cont. (g)	192.5	169.9	183.7	168.9
Weight of Container (g)	19.8	19.2	19.8	20.2
Weight of water (moisture) (g)	36.2	33.2	38.5	38.8
Weight of Dry soil (g)	172.7	150.7	163.9	148.7
Moisture content (%)	18.00	20.00	21.50	24.50
Dry Density (g / cm3)	1.477	1.539	1.564	1.514
MDD, g/cc	**1.564**	**OMC, %**	**21.5**	





Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	11248	11354	10090	11185	9900	10583
Wt.of mould, g	W2	9002	9002	7125	7125	6042	6042
Wt.of wet sample, g	W3 = W1 - W2	2246	2352	2965	4060	3858	4541
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.06	1.11	1.40	1.91	1.82	2.14
Dry unit weight, g/cc	Dw /(1+ W8/100)	0.88	0.75	1.17	1.28	1.53	1.48
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	297.9	261.5	346.1	316.9	278.5	281.1
Wt. of dry sample + cont.,	W4	253.3	188.5	295.5	230.6	241.2	211.5
Wt. of water, g	W5 = W3 - W4	44.6	73	50.6	86.3	37.3	69.6
Wt. of container, g	W6	36.6	38.3	39.2	57.7	44.5	55.5
Wt. of dry sample, g	W7 = W4 - W6	216.7	150.2	256.3	172.9	196.7	156
% Moisture Content	W8 = W5/W7*100	20.6	48.6	19.7	49.9	19.0	44.6

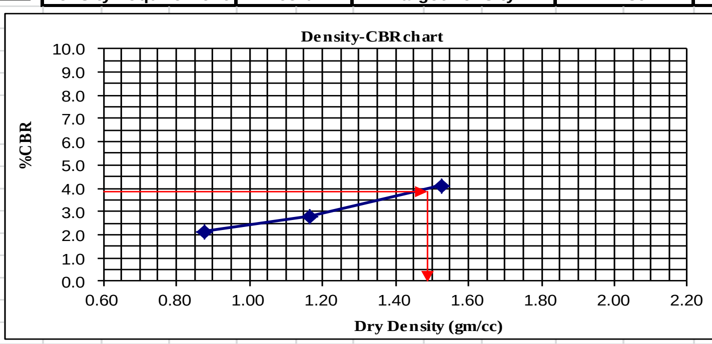
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.02	18.57	18.55	**15.94**	0.04	17.98	17.94	**15.41**	0.05	17.93	17.88	**15.36**

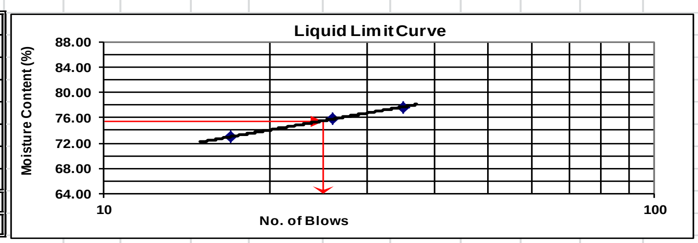
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		6	0.13			2	0.04			4	0.09		
1.27		8	0.174			6	0.13			9	0.20		
1.91		11	0.239			13	0.28			17	0.37		
2.54	13.2	13	0.282	0.28	**2.1**	17	0.37	0.37	**2.8**	25	0.54	0.54	**4.1**
3.18		14	0.304			18	0.39			27	0.59		
3.81		15	0.326			20	0.43			28	0.61		
4.45		16	0.347			21	0.46			30	0.65		
5.08	20.4	16	0.347	0.35	**1.7**	22	0.48	0.48	**2.3**	32	0.69	0.69	**3.4**
7.62		17	0.369			24	0.52			33	0.72		
9.16		19	0.412			25	0.54			38	0.82		
Soaked CBR,%	2.1					2.8				4.1			
Dry Density, g/cc	0.88					1.17				1.53			
Swell, %	15.94					15.41				15.36			
Density Requirement:	**95%**		**Target Density:**		**1.486**				**CBR**		**3.90**		

No of Blows	DDBS (gm/cc)	CBR (%)
10	0.88	2.1
30	1.17	2.8
65	1.53	4.1



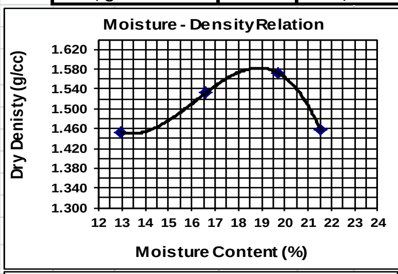
	Liquid Limit			Plastic Limit	
No. of Blows	35	26	17		
Wt. of cont. + wet soil (g) = (w_1)	37.19	38.87	41.24	29.53	29.01
Wt. of cont. + dry soil (g.) = (w_2)	30.56	30.82	33.25	24.92	24.31
Wt. of container (g.) = (w_3)	22.03	20.20	22.30	12.25	11.98
Mass of moisture (g.) (w_1-w_2) = x	6.63	8.05	7.99	4.61	4.70
Wt. of dry soil (g.) (w_2-w_3) = y	8.53	10.62	10.95	12.67	12.33
Moisture Content (%) = (100x/y)	77.73	75.80	72.97	36.39	38.12
		75.55		**37.25**	
		Plasticity Index		**38.30**	



BC+15%QD (Sample # 1)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8245	8545	8739	8511
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3365	3665	3859	3631
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.64	1.79	1.88	1.77
Moisture Content Determination				
Weight of Wet soil + cont. (g)	237.9	208.7	217.9	220.0
Weight of Dry soil + cont. (g)	212.9	182.0	185.4	184.6
Weight of Container (g)	19.9	21.4	20.3	20.2
Weight of water (moisture) (g)	25	26.7	32.5	35.4
Weight of Dry soil (g)	193	160.6	165.1	164.4
Moisture content (%)	12.95	16.63	19.69	21.53
Dry Density (g / cm3)	1.453	1.533	1.573	1.457
MDD, g/cc	**1.573**	**OMC, %**	**19.7**	



Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	11046	12062	9865	10896	10245	10911
Wt.of mould, g	W2	7935	7935	6450	6450	6338	6338
Wt.of wet sample, g	W3 = W1 - W2	3111	4127	3415	4446	3907	4573
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.46	1.94	1.61	2.09	1.84	2.15
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.26	1.30	1.39	1.43	1.59	1.44
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	246.2	215.3	300.1	238.5	364.5	281
Wt. of dry sample + cont.,	W4	216.7	151	265.2	169.4	319.6	201.3
Wt. of water, g	W5 = W3 - W4	29.5	64.3	34.9	69.1	44.9	79.7
Wt. of container, g	W6	37	20	37.7	21.1	37	39.2
Wt. of dry sample, g	W7 = W4 - W6	179.7	131	227.5	148.3	282.6	162.1
% Moisture Content	W8 = W5/W7*100	16.4	49.1	15.3	46.6	15.9	49.2

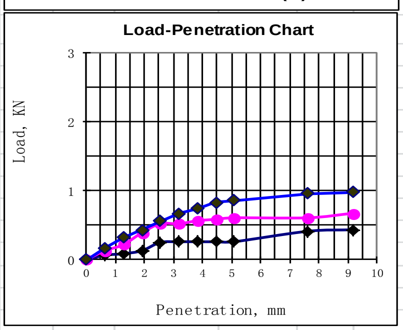
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.06	18.6	18.54	**15.93**	0.05	17.25	17.20	**14.78**	0.05	18.1	18.05	**15.51**

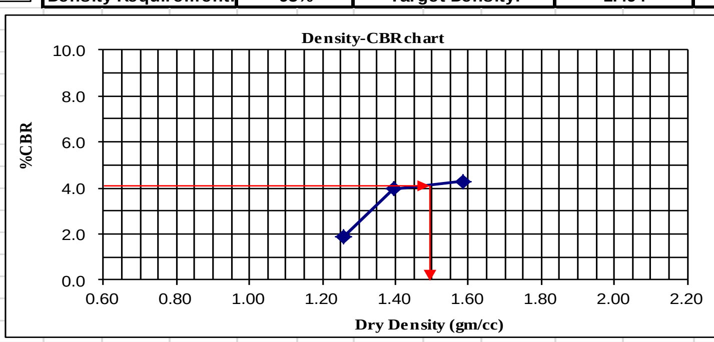
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		3	0.065			6	0.13			8	0.17		
1.27		4	0.087			10	0.22			15	0.33		
1.91		6	0.13			18	0.39			20	0.43		
2.54	13.2	12	0.25	0.25	**1.9**	24	0.52	0.52	**3.9**	26	0.56	0.56	**4.3**
3.18		12	0.26			24	0.52			31	0.67		
3.81		12	0.26			26	0.56			34	0.74		
4.45		12	0.26			27	0.59			38	0.82		
5.08	20.4	12	0.26	0.26	**1.3**	28	0.61	0.61	**3.0**	40	0.86	0.86	**4.2**
7.62		19	0.412			28	0.61			44	0.95		
9.16		20	0.434			31	0.67			45	0.98		
Soaked CBR,%	1.9				3.9				4.3				
Dry Density, g/cc	1.26				1.39				1.59				
Swell, %	15.93				14.78				15.51				

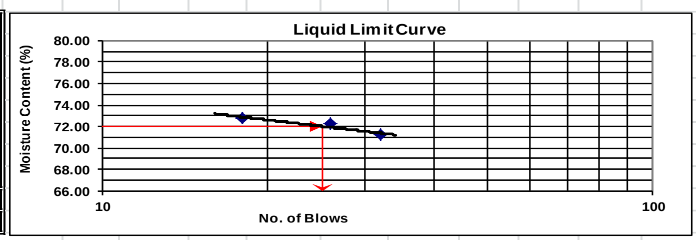
Density Requirement:	95%	Target Density:	1.494	CBR	4.10



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.26	1.9
30	1.39	3.9
65	1.59	4.3



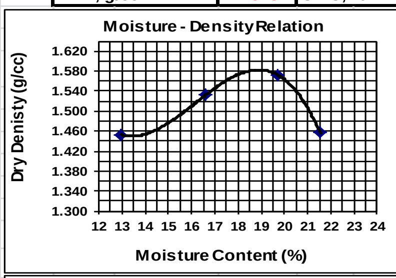
	Liquid Limit			Plastic Limit	
No. of Blows	32	26	18		
Wt. of cont. + wet soil (g) = (w1)	41.25	40.25	38.65	25.64	27.45
Wt. of cont. + dry soil (g.) = (w2)	32.60	32.24	31.70	22.10	23.50
Wt. of container (g.) = (w3)	20.45	21.15	22.15	12.11	12.44
Mass of moisture (g.) (w1-w2) = x	8.65	8.01	6.95	3.54	3.95
Wt. of dry soil (g.) (w2-w3) = y	12.15	11.09	9.55	9.99	11.06
Moisture Content (%) = (100x/y)	71.19	72.23	72.77	35.44	35.71
	72.06			**35.57**	
	Plasticity Index			**36.49**	



BC+15%QD (Sample # 2)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8245	8545	8739	8511
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3365	3665	3859	3631
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.64	1.79	1.88	1.77
Moisture Content Determination				
Weight of Wet soil +cont. (g)	237.9	208.7	217.9	220.0
Weight of Dry soil +cont. (g)	212.9	182.0	185.4	184.6
Weight of Container (g)	19.9	21.4	20.3	20.2
Weight of water (moisture) (g)	25	26.7	32.5	35.4
Weight of Dry soil (g)	193	160.6	165.1	164.4
Moisture content (%)	12.95	16.63	19.69	21.53
Dry Density (g / cm3)	1.453	1.533	1.573	1.457
MDD, g/cc	1.573	**OMC, %**		19.7



Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	10922	11878	9880	10712	10700	11012
Wt.of mould, g	W2	7842	7842	6493	6493	6800	6800
Wt.of wet sample, g	W3 = W1 - W2	3080	4036	3387	4219	3900	4212
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.45	1.90	1.59	1.99	1.84	1.98
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.19	1.27	1.37	1.40	1.64	1.42
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	247.3	210.6	294.3	228.9	356	277.6
Wt. of dry sample + cont.,	W4	210.2	147.5	258.4	167.6	321.2	210.5
Wt. of water, g	W5 = W3 - W4	37.1	63.1	35.9	61.3	34.8	67.1
Wt. of container, g	W6	37	20	37.7	21.1	37	39.2
Wt. of dry sample, g	W7 = W4 - W6	173.2	127.5	220.7	146.5	284.2	171.3
% Moisture Content	W8 = W5/W7*100	21.4	49.5	16.3	41.8	12.2	39.2

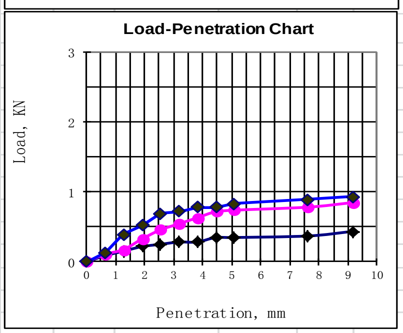
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.06	17.95	17.89	**15.37**	0.05	16.87	16.82	**14.45**	0.05	17.8	17.75	**15.25**

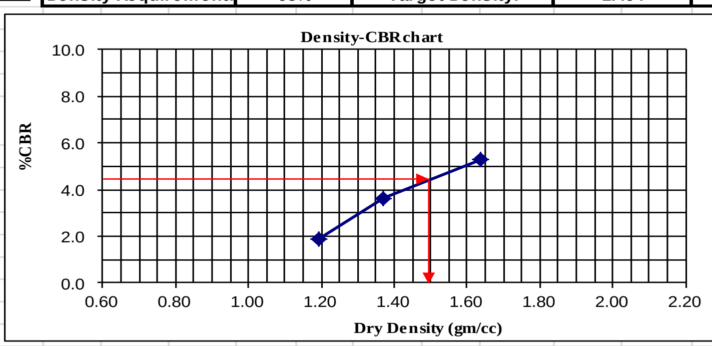
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		4	0.087			5	0.11			6	0.13		
1.27		7	0.152			8	0.17			18	0.39		
1.91		10	0.217			15	0.33			24	0.52		
2.54	13.2	12	0.25	0.25	**1.9**	21	0.46	0.46	**3.5**	32	0.69	0.69	**5.3**
3.18		13	0.282			25	0.54			33	0.72		
3.81		13	0.282			29	0.63			36	0.78		
4.45		16	0.347			33	0.72			36	0.78		
5.08	20.4	16	0.347	0.35	**1.7**	34	0.74	0.74	**3.6**	38	0.82	0.82	**4.0**
7.62		17	0.369			36	0.78			41	0.89		
9.16		20	0.434			39	0.85			43	0.93		
Soaked CBR,%	1.9					3.6				5.3			
Dry Density, g/cc	1.19					1.37				1.64			
Swell, %	15.37					14.45				15.25			

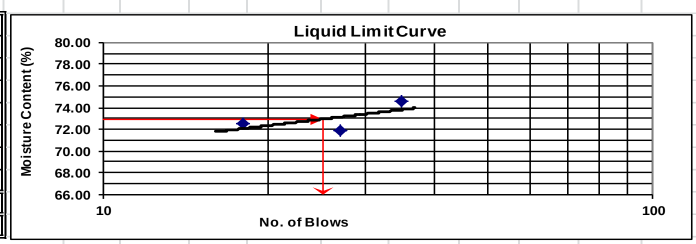
Density Requirement:	95%	Target Density:	1.494	CBR	4.50



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.19	1.9
30	1.37	3.6
65	1.64	5.3



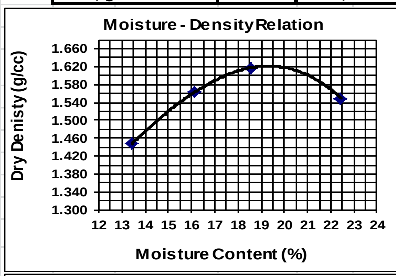
	Liquid Limit			Plastic Limit	
No. of Blows	35	27	18		
Wt. of cont. +wet soil (g) = (w_1)	40.20	39.60	38.50	26.20	26.91
Wt. of cont. +dry soil (g.) = (w_2)	32.00	31.88	31.55	22.90	22.73
Wt. of container (g.) = (w_3)	21.00	21.15	21.97	12.11	12.44
Mass of moisture (g.) (w_1-w_2) = x	8.20	7.72	6.95	3.30	4.18
Wt. of dry soil (g.) (w_2-w_3) = y	11.00	10.73	9.58	10.79	10.29
Moisture Content (%) = (100x/y)	74.55	71.95	72.55	30.58	40.62
	73.00			35.60	
	Plasticity Index			37.40	

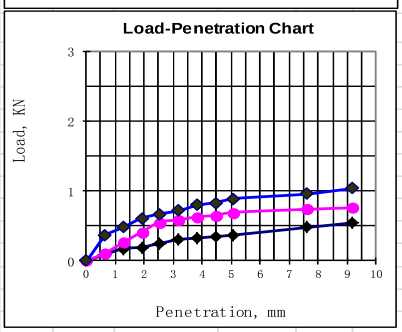


BC+20%QD (Sample # 1)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8245	8598	8809	8769
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3365	3718	3929	3889
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.64	1.81	1.92	1.90
Moisture Content Determination				
Weight of Wet soil + cont. (g)	211.1	373.2	356.8	301.7
Weight of Dry soil + cont. (g)	188.5	329.2	309.9	256.8
Weight of Container (g)	20.1	56.0	56.7	56.7
Weight of water (moisture) (g)	22.6	44	46.9	44.9
Weight of Dry soil (g)	168.4	273.2	253.2	200.1
Moisture content (%)	13.42	16.11	18.52	22.44
Dry Density (g / cm3)	1.447	1.562	1.617	1.549
MDD, g/cc	**1.617**	**OMC, %**	**18.5**	





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9698	10500	9725	10600	10310	10605
Wt.of mould, g	W2	6698	6698	6346	6346	6363	6363
Wt.of wet sample, g	W3 = W1 - W2	3000	3802	3379	4254	3947	4242
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.41	1.79	1.59	2.00	1.86	2.00
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.24	1.23	1.40	1.38	1.63	1.36
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	289.7	195	258.5	201.3	296.6	200.8
Wt. of dry sample + cont.,	W4	257.6	140.2	230.3	144.8	263.4	143.4
Wt. of water, g	W5 = W3 - W4	32.1	54.8	28.2	56.5	33.2	57.4
Wt. of container, g	W6	19.7	20.3	19.5	20.3	20.4	20.3
Wt. of dry sample, g	W7 = W4 - W6	237.9	119.9	210.8	124.5	243	123.1
% Moisture Content	W8 = W5/W7*100	13.5	45.7	13.4	45.4	13.7	46.6

SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.08	18.3	18.22	**15.65**	0.05	17.2	17.15	**14.73**	0.05	17.39	17.34	**14.90**

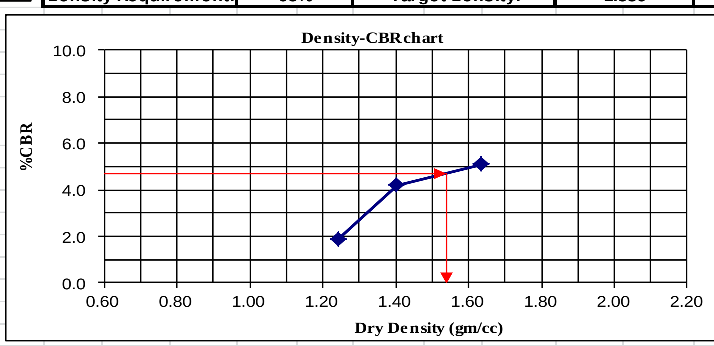
CBR DATA

Penetration (mm)	Std load (KN)	10: Gauge reading	10: Load KN	10: Corrected CBR KN	10: Corrected CBR %	30: Gauge reading	30: Load KN	30: Corrected CBR KN	30: Corrected CBR %	65: Gauge reading	65: Load KN	65: Corrected CBR KN	65: Corrected CBR %
0		0	0			0	0			0	0		
0.64		4	0.087			5	0.11			17	0.37		
1.27		8	0.174			12	0.26			22	0.48		
1.91		9	0.195			19	0.41			28	0.61		
2.54	13.2	12	0.25	0.25	**1.9**	26	0.55	0.55	**4.2**	31	0.67	0.67	**5.1**
3.18		14	0.304			27	0.59			33	0.72		
3.81		15	0.326			29	0.63			37	0.80		
4.45		16	0.347			30	0.65			38	0.82		
5.08	20.4	17	0.369	0.37	**1.8**	32	0.69	0.69	**3.4**	41	0.89	0.89	**4.4**
7.62		22	0.477			34	0.74			44	0.95		
9.16		25	0.543			35	0.76			48	1.04		

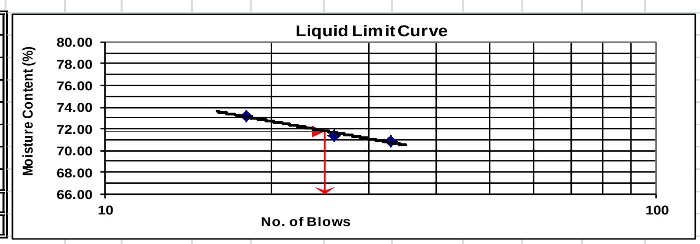
	10	30	65
Soaked CBR,%	1.9	4.2	5.1
Dry Density, g/cc	1.24	1.40	1.63
Swell, %	15.65	14.73	14.90

Density Requirement:	**95%**	**Target Density:**	**1.536**	**CBR**	**4.70**

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.24	1.9
30	1.40	4.2
65	1.63	5.1



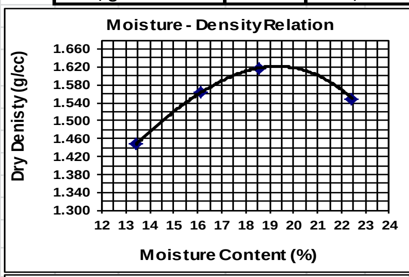
No. of Blows	Liquid Limit: 33	26	18		Plastic Limit	
Wt. of cont. + wet soil (g) = (w_1)	38.65	39.45	41.25		26.45	27.11
Wt. of cont. + dry soil (g.) = (w_2)	31.00	31.20	32.50		22.60	23.18
Wt. of container (g.) = (w_3)	20.21	19.65	20.55		12.05	12.22
Mass of moisture (g.) (w_1-w_2) = x	7.65	8.25	8.75		3.85	3.93
Wt. of dry soil (g.) (w_2-w_3) = y	10.79	11.55	11.95		10.55	10.96
Moisture Content (%) = (100x/y)	70.90	71.43	73.22		36.49	35.86
	71.85				**36.18**	
	Plasticity Index				**35.67**	

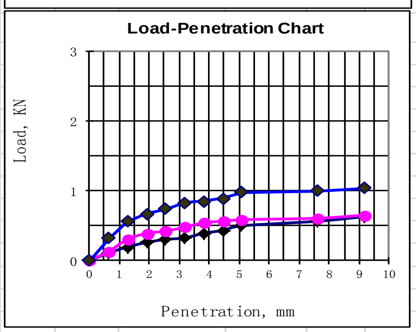


BC+20%QD (Sample # 2)

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8245	8598	8809	8769
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3365	3718	3929	3889
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g/cm3)	1.64	1.81	1.92	1.90
Moisture Content Determination				
Weight of Wet soil +cont. (g)	211.1	373.2	356.8	301.7
Weight of Dry soil +cont. (g)	188.5	329.2	309.9	256.8
Weight of Container (g)	20.1	56.0	56.7	56.7
Weight of water (moisture) (g)	22.6	44	46.9	44.9
Weight of Dry soil (g)	168.4	273.2	253.2	200.1
Moisture content (%)	13.42	16.11	18.52	22.44
Dry Density (g/cm3)	1.447	1.562	1.617	1.549
MDD, g/cc	1.617	**OMC, %**		18.5





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9725	10500	9765	10671	10312	10662
Wt.of mould, g	W2	7200	7200	6346	6346	6363	6363
Wt.of wet sample, g	W3 = W1 - W2	2525	3300	3419	4325	3949	4299
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.19	1.55	1.61	2.04	1.86	2.02
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.05	1.16	1.41	1.49	1.59	1.27
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	295	202	255	200.8	295	212
Wt. of dry sample + cont.,	W4	263	155.2	226.4	151.7	256.1	140.5
Wt. of water, g	W5 = W3 - W4	32	46.8	28.6	49.1	38.9	71.5
Wt. of container, g	W6	20.4	19.2	19.6	18.4	21.5	20.8
Wt. of dry sample, g	W7 = W4 - W6	242.6	136	206.8	133.3	234.6	119.7
% Moisture Content	W8 = W5/W7*100	13.2	34.4	13.8	36.8	16.6	59.7

SWELL DATA

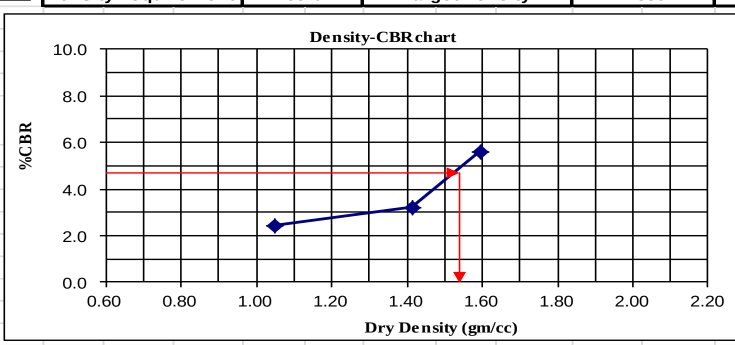
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.08	18.5	18.42	**15.82**	0.05	17	16.95	**14.56**	0.05	17.1	17.05	**14.65**

CBR DATA

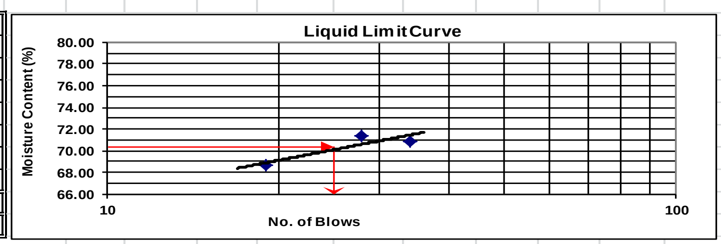
Penetration (mm)	Std load (KN)	Gauge reading (10)	Load KN (10)	Corrected CBR KN (10)	Corrected CBR % (10)	Gauge reading (30)	Load KN (30)	Corrected CBR KN (30)	Corrected CBR % (30)	Gauge reading (65)	Load KN (65)	Corrected CBR KN (65)	Corrected CBR % (65)
0		0	0			0	0			0	0		
0.64		5	0.109			6	0.13			15	0.33		
1.27		9	0.195			14	0.30			26	0.56		
1.91		12	0.26			18	0.39			31	0.67		
2.54	13.2	14	0.304	0.30	**2.3**	20	0.42	0.42	**3.2**	34	0.74	0.74	**5.6**
3.18		15	0.326			22	0.48			38	0.82		
3.81		18	0.391			25	0.54			39	0.85		
4.45		20	0.434			26	0.56			41	0.89		
5.08	20.4	23	0.499	0.50	**2.4**	27	0.59	0.59	**2.9**	45	0.98	0.98	**4.8**
7.62		26	0.564			28	0.61			46	1.00		
9.16		29	0.629			30	0.65			48	1.04		
Soaked CBR,%		2.4				3.2				5.6			
Dry Density, g/cc		1.05				1.41				1.59			
Swell, %		15.82				14.56				14.65			

Density Requirement:	95%	Target Density:	1.536	CBR	4.70

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.05	2.4
30	1.41	3.2
65	1.59	5.6



	Liquid Limit			Plastic Limit	
No. of Blows	34	28	19		
Wt. of cont. +wet soil (g) = (w_1)	38.65	39.45	40.70	26.23	27.11
Wt. of cont. +dry soil (g.) = (w_2)	31.00	31.20	32.50	22.60	23.18
Wt. of container (g.) = (w_3)	20.21	19.65	20.55	12.05	12.22
Mass of moisture (g.) (w_1-w_2) = x	7.65	8.25	8.20	3.63	3.93
Wt. of dry soil (g.) (w_2-w_3) = y	10.79	11.55	11.95	10.55	10.96
Moisture Content (%) = (100x/y)	70.90	71.43	68.62	34.41	35.86
	70.43			35.13	
	Plasticity Index			35.30	



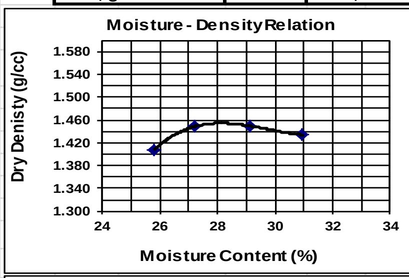
BC+2%OPC

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8510	8659	8717	8729
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3630	3779	3837	3849
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.77	1.84	1.87	1.88
Moisture Content Determination				
Weight of Wet soil + cont. (g)	435.6	462.5	431.7	440.5
Weight of Dry soil + cont. (g)	359.8	376.9	349.5	352.4
Weight of Container (g)	66.1	62.6	67.1	67.7
Weight of water (moisture) (g)	75.8	85.6	82.2	88.1
Weight of Dry soil (g)	293.7	314.3	282.4	284.7
Moisture content (%)	25.81	27.24	29.11	30.94
Dry Density (g / cm3)	1.407	1.449	1.450	1.434
MDD, g/cc	**1.451**	**OMC, %**	**29.0**	

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9711	10066	9973	10190	10515	10685
Wt.of mould, g	W2	6270	6270	6248	6248	6371	6371
Wt.of wet sample, g	W3 = W1 - W2	3441	3796	3725	3942	4144	4314
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.62	1.79	1.75	1.86	1.95	2.03
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.21	1.23	1.30	1.29	1.44	1.43
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	400.3	374.1	400.1	405	438	424
Wt. of dry sample + cont.,	W4	315	276.9	313.7	302.2	340.2	317.8
Wt. of water, g	W5 = W3 - W4	85.3	97.2	86.4	102.8	97.8	106.2
Wt. of container, g	W6	66	63.4	63.3	66	66.8	66.8
Wt. of dry sample, g	W7 = W4 - W6	249	213.5	250.4	236.2	273.4	251
% Moisture Content	W8 = W5/W7*100	34.3	45.5	34.5	43.5	35.8	42.3

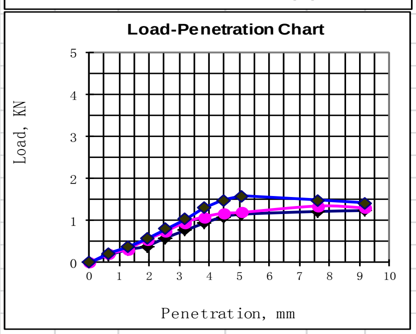


SWELL DATA

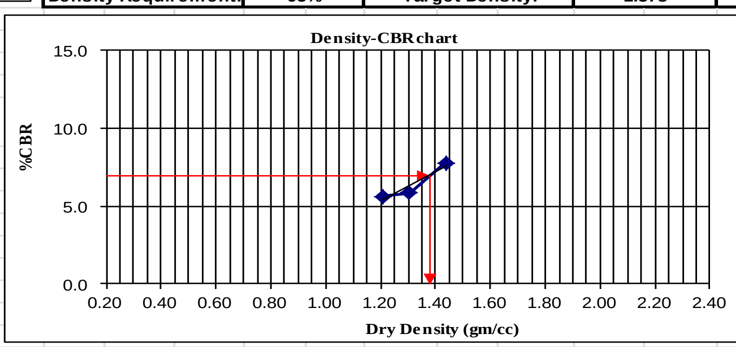
No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0	5.82	5.82	**5.00**	0	5.57	5.57	**4.79**	0	3.62	3.62	**3.11**

CBR DATA

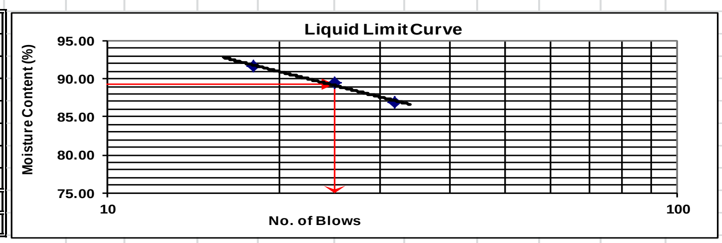
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		8	0.174			9	0.20			10	0.22		
1.27		14	0.304			15	0.33			17	0.37		
1.91		18	0.391			25	0.54			26	0.56		
2.54	13.2	27	0.586	0.59	**4.44**	34	0.74	0.74	**5.59**	37	0.80	0.80	**6.08**
3.18		35	0.76			44	0.95			48	1.04		
3.81		43	0.933			50	1.09			60	1.30		
4.45		50	1.085			54	1.17			68	1.48		
5.08	20.4	53	1.15	1.15	**5.64**	55	1.19	1.19	**5.85**	73	1.58	1.58	**7.77**
7.62		56	1.215			62	1.35			68	1.48		
9.16		57	1.237			60	1.30			65	1.41		
Soaked CBR,%		5.6				5.9				7.8			
Dry Density, g/cc		1.21				1.30				1.44			
Swell, %		5.00				4.79				3.11			
Density Requirement:		**95%**		**Target Density:**			**1.378**			**CBR**		**7.00**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.21	5.6
30	1.30	5.9
65	1.44	7.8



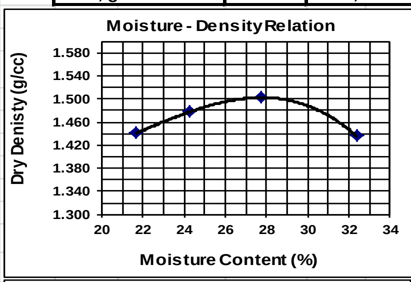
	Liquid Limit			Plastic Limit	
No. of Blows	32	25	18		
Wt. of cont. + wet soil (g) = (w_1)	35.17	33.67	33.77	9.06	9.40
Wt. of cont. + dry soil (g.) = (w_2)	27.33	26.27	26.18	8.05	8.27
Wt. of container (g.) = (w_3)	18.31	18.00	17.90	6.37	6.42
Mass of moisture (g.) (w_1-w_2) = x	7.84	7.40	7.59	1.01	1.13
Wt. of dry soil (g.) (w_2-w_3) = y	9.02	8.27	8.28	1.68	1.85
Moisture Content (%) = (100x/y)	86.92	89.48	91.67	60.12	61.08
		89.35		60.60	
		Plasticity Index		**28.75**	

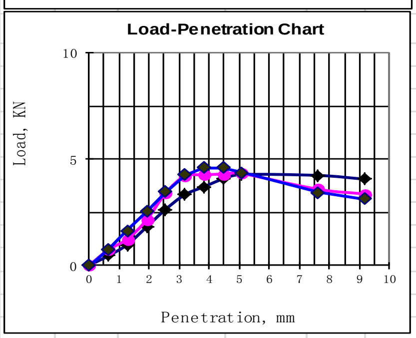


BC+4%OPC

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8475	8645	8815	8776
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3595	3765	3935	3896
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g/cm3)	1.75	1.84	1.92	1.90
Moisture Content Determination				
Weight of Wet soil + cont. (g)	322.3	314.6	336.5	284.5
Weight of Dry soil + cont. (g)	274.6	264.4	275.9	228.5
Weight of Container (g)	54.7	57.6	57.6	55.4
Weight of water (moisture) (g)	47.7	50.2	60.6	56
Weight of Dry soil (g)	219.9	206.8	218.3	173.1
Moisture content (%)	21.69	24.27	27.76	32.35
Dry Density (g/cm3)	1.441	1.478	1.502	1.436
MDD, g/cc	**1.502**	**OMC, %**	**27.8**	





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9539	9811	10082	10248	10645	10785
Wt.of mould, g	W2	6041	6041	6328	6328	6533	6533
Wt.of wet sample, g	W3 = W1 - W2	3498	3770	3754	3920	4112	4252
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.65	1.77	1.77	1.85	1.94	2.00
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.25	1.27	1.33	1.36	1.47	1.48
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	329.1	392.6	399	345.5	361	324.4
Wt. of dry sample + cont.,	W4	263.9	297.4	315	269.7	286.6	253.9
Wt. of water, g	W5 = W3 - W4	65.2	95.2	84	75.8	74.4	70.5
Wt. of container, g	W6	58.2	55.4	56	58.3	55	55.2
Wt. of dry sample, g	W7 = W4 - W6	205.7	242	259	211.4	231.6	198.7
% Moisture Content	W8 = W5/W7*100	31.7	39.3	32.4	35.9	32.1	35.5

SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.07	3.19	3.12	**2.68**	0.06	2.9	2.84	**2.44**	0.02	2.7	2.68	**2.30**

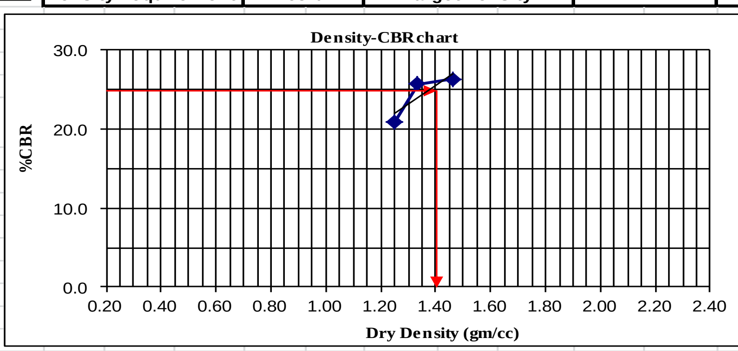
CBR DATA

Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		21	0.456			34	0.74			36	0.78		
1.27		45	0.977			57	1.24			75	1.63		
1.91		83	1.801			98	2.13			116	2.52		
2.54	13.2	121	2.626	2.63	**19.9**	156	3.39	3.39	**25.6**	160	3.47	3.47	**26.3**
3.18		153	3.32			193	4.19			196	4.25		
3.81		170	3.689			196	4.25			211	4.58		
4.45		187	4.058			198	4.30			212	4.60		
5.08	20.4	197	4.275	4.27	**20.96**	199	4.32	4.32	**21.17**	201	4.36	4.36	**21.4**
7.62		195	4.232			165	3.58			158	3.43		
9.16		187	4.058			155	3.36			145	3.15		

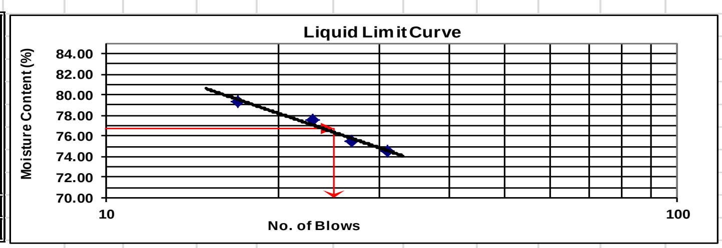
	10	30	65
Soaked CBR,%	21.0	25.6	26.3
Dry Density, g/cc	1.25	1.33	1.47
Swell, %	2.68	2.44	2.30

Density Requirement:	**95%**	**Target Density:**	**1.427**	**CBR**	**25.00**

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.25	21.0
30	1.33	25.6
65	1.47	26.3



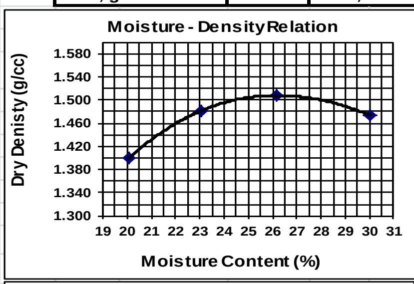
		Liquid Limit			Plastic Limit	
No. of Blows	31	27	23	17		
Wt. of cont. + wet soil (g) = (w_1)	35.53	33.80	35.58	38.44	15.72	15.84
Wt. of cont. + dry soil (g.) = (w_2)	28.12	27.22	28.72	31.61	14.77	14.99
Wt. of container (g.) = (w_3)	18.17	18.51	19.88	23.00	12.86	13.24
Mass of moisture (g.) (w_1-w_2) = x	7.41	6.58	6.86	6.83	0.95	0.85
Wt. of dry soil (g.) (w_2-w_3) = y	9.95	8.71	8.84	8.61	1.91	1.75
Moisture Content (%) = (100x/y)	74.47	75.55	77.60	79.33	49.74	48.57
		76.74			**49.15**	
		Plasticity Index			**27.59**	



BC+8%OPC

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8325	8615	8780	8809
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3445	3735	3900	3929
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.68	1.82	1.90	1.92
Moisture Content Determination				
Weight of Wet soil + cont. (g)	226.9	280.0	238.0	271.4
Weight of Dry soil + cont. (g)	195.2	234.4	196.5	216.9
Weight of Container (g)	37.3	36.4	37.9	35.5
Weight of water (moisture) (g)	31.7	45.6	41.5	54.5
Weight of Dry soil (g)	157.9	198	158.6	181.4
Moisture content (%)	20.08	23.03	26.17	30.04
Dry Density (g / cm3)	1.400	1.481	1.508	1.474
MDD, g/cc	**1.519**	**OMC, %**	**25.3**	



Unit Weight Determination

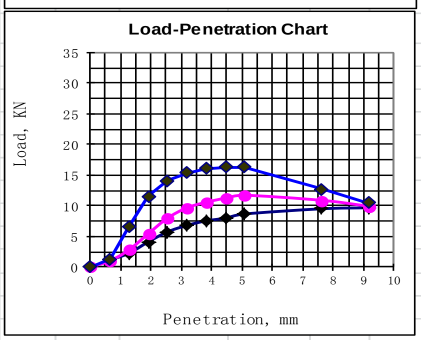
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9717	10045	10335	10547	10245	10355
Wt.of mould, g	W2	6293	6293	6711	6711	6140	6140
Wt.of wet sample, g	W3 = W1 - W2	3424	3752	3624	3836	4105	4215
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.61	1.77	1.71	1.81	1.93	1.98
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.25	1.26	1.32	1.34	1.50	1.52
Moisture Content Determination							
Wt. of wet sample + cont.	W3	367.1	296.7	364.6	338.2	457.3	340.9
Wt. of dry sample + cont.	W4	296.6	222.7	294.5	265.8	366.4	274.4
Wt. of water, g	W5 = W3 - W4	70.5	74	70.1	72.4	90.9	66.5
Wt. of container, g	W6	57.3	38.8	55.4	57.3	55.3	57.5
Wt. of dry sample, g	W7 = W4 - W6	239.3	183.9	239.1	208.5	311.1	216.9
% Moisture Content	W8 = W5/W7*100	29.5	40.2	29.3	34.7	29.2	30.7

SWELL DATA

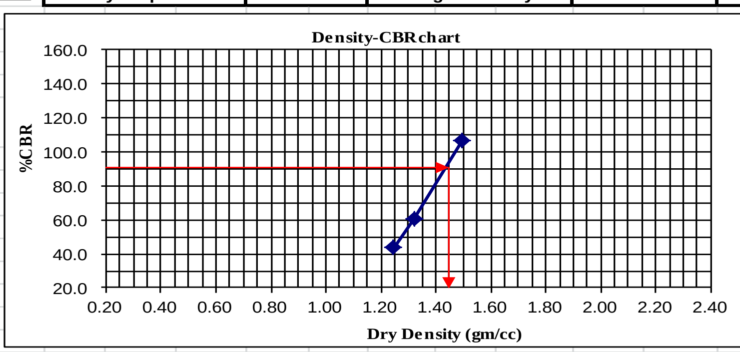
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	0.96	0.89	**0.76**	0.07	0.88	0.81	**0.70**	0.04	0.79	0.75	**0.64**

CBR DATA

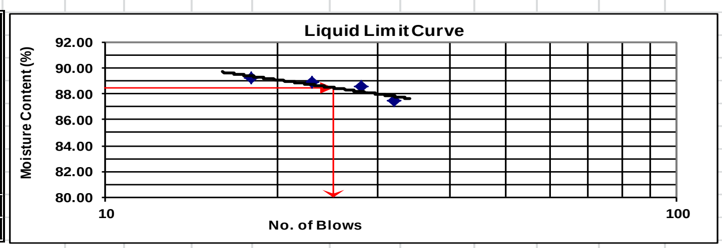
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		52	1.128			46	1.00			58	1.26		
1.27		103	2.235			128	2.78			299	6.49		
1.91		189	4.101			250	5.43			532	11.54		
2.54	13.2	264	5.729	5.73	**43.4**	367	7.96	7.96	**60.3**	650	14.11	14.11	**106.9**
3.18		313	6.792			445	9.66			710	15.41		
3.81		347	7.53			487	10.57			740	16.06		
4.45		368	7.986			518	11.24			749	16.25		
5.08	20.4	399	8.658	8.66	**42.4**	540	11.72	11.72	**57.4**	750	16.28	16.28	**79.8**
7.62		438	9.505			502	10.89			585	12.69		
9.16		446	9.678			458	9.94			484	10.50		
Soaked CBR,%		43.4				60.3				106.9			
Dry Density, g/cc		1.25				1.32				1.50			
Swell, %		0.76				0.70				0.64			
Density Requirement:		**95%**		**Target Density:**			**1.44**			**CBR**		**91.00**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.25	43.4
30	1.32	60.3
65	1.50	106.9



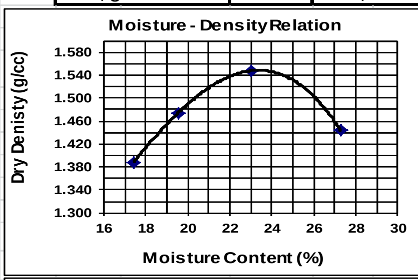
		Liquid Limit			Plastic Limit	
No. of Blows	32	28	23	18		
Wt. of cont. + wet soil (g) = (w₁)	35.55	33.10	33.30	37.07	8.86	14.48
Wt. of cont. + dry soil (g.) = (w₂)	27.68	25.99	26.27	29.16	7.85	13.45
Wt. of container (g.) = (w₃)	18.68	17.96	18.36	20.29	6.36	11.89
Mass of moisture (g.) (w₁-w₂) = x	7.87	7.11	7.03	7.91	1.01	1.03
Wt. of dry soil (g.) (w₂-w₃) = y	9.00	8.03	7.91	8.87	1.49	1.56
Moisture Content (%) = (100x/y)	87.44	88.54	88.87	89.18	67.79	66.03
		88.51			**66.91**	
		Plasticity Index			**21.60**	

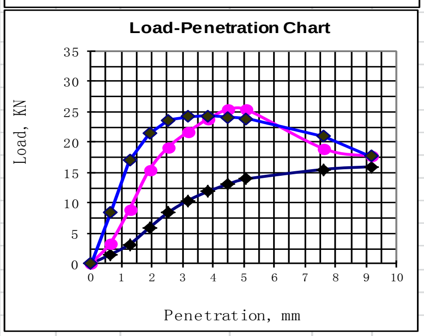


BC+12%OPC

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8222	8494	8784	8645
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3342	3614	3904	3765
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.63	1.76	1.90	1.84
Moisture Content Determination				
Weight of Wet soil + cont. (g)	234.3	333.6	308.5	305.7
Weight of Dry soil + cont. (g)	205.0	284.7	257.6	248.5
Weight of Container (g)	36.8	34.5	36.7	38.8
Weight of water (moisture) (g)	29.3	48.9	50.9	57.2
Weight of Dry soil (g)	168.2	250.2	220.9	209.7
Moisture content (%)	17.42	19.54	23.04	27.28
Dry Density (g / cm3)	1.388	1.475	1.548	1.443
MDD, g/cc	**1.548**	**OMC, %**		**23.0**





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9691	10074	10119	10366	10245	10356
Wt.of mould, g	W2	6317	6317	6460	6460	6142	6142
Wt.of wet sample, g	W3 = W1 - W2	3374	3757	3659	3906	4103	4214
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.59	1.77	1.72	1.84	1.93	1.98
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.25	1.29	1.35	1.39	1.53	1.55
Moisture Content Determination							
Wt. of wet sample + cont.	W3	445.8	305.7	380.1	243.4	345.1	280.8
Wt. of dry sample + cont.	W4	362.7	231.8	310.6	192.8	284.8	228.2
Wt. of water, g	W5 = W3 - W4	83.1	73.9	69.5	50.6	60.3	52.6
Wt. of container, g	W6	56.2	34.4	56.8	37.4	57	38.6
Wt. of dry sample, g	W7 = W4 - W6	306.5	197.4	253.8	155.4	227.8	189.6
% Moisture Content	W8 = W5/W7*100	27.1	37.4	27.4	32.6	26.5	27.7

SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.08	1.03	0.95	**0.82**	0.07	0.55	0.48	**0.41**	0.06	0.5	0.44	**0.38**

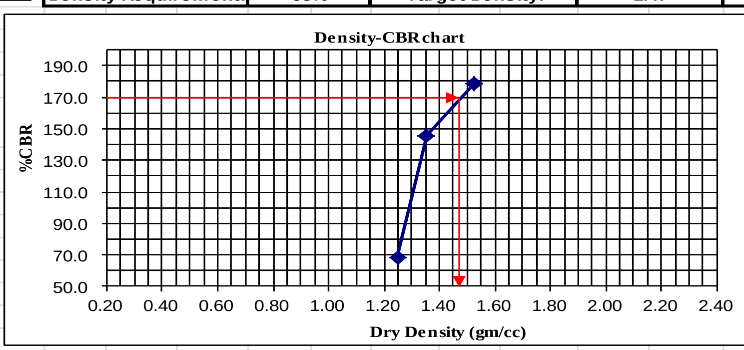
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		70	1.519			157	3.41			395	8.57		
1.27		148	3.212			415	9.01			782	16.97		
1.91		272	5.902			710	15.41			990	21.48		
2.54	13.2	390	8.463	8.46	**64.1**	885	19.20	19.20	**145.5**	1088	23.61	23.61	**178.9**
3.18		480	10.42			1001	21.72			1115	24.20		
3.81		546	11.85			1095	23.76			1120	24.30		
4.45		601	13.04			1168	25.35			1110	24.09		
5.08	20.4	643	13.95	13.95	**68.4**	1170	25.39	25.39	**124.5**	1100	23.87	23.87	**117.0**
7.62		716	15.54			872	18.92			965	20.94		
9.16		736	15.97			815	17.69			815	17.69		

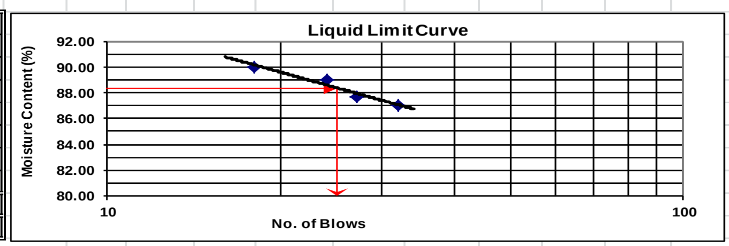
	10	30	65
Soaked CBR,%	68.4	145.5	178.9
Dry Density, g/cc	1.25	1.35	1.53
Swell, %	0.82	0.41	0.38

Density Requirement:	**95%**	**Target Density:**	**1.47**	**CBR**	**170.00**

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.25	68.4
30	1.35	145.5
65	1.53	178.9



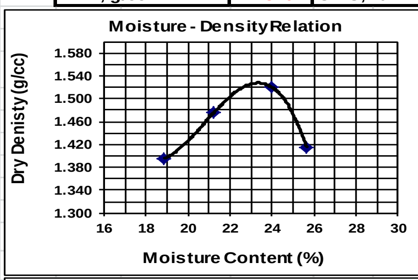
	Liquid Limit				Plastic Limit	
No. of Blows	32	27	24	18		
Wt. of cont. + wet soil (g) = (w_1)	34.81	35.78	35.72	34.84	8.58	13.46
Wt. of cont. + dry soil (g.) = (w_2)	27.76	28.12	28.51	28.87	7.70	12.75
Wt. of container (g.) = (w_3)	19.66	19.39	20.41	22.24	6.44	11.73
Mass of moisture (g.) (w_1-w_2) = x	7.05	7.66	7.21	5.97	0.88	0.71
Wt. of dry soil (g.) (w_2-w_3) = y	8.10	8.73	8.10	6.63	1.26	1.02
Moisture Content (%) = (100x/y)	87.04	87.74	89.01	90.05	69.84	69.61
	88.46				**69.72**	
	Plasticity Index				**19**	



BC+4%OPC+5%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould+Wet soil (g)	8279	8545	8745	8525
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3399	3665	3865	3645
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.66	1.79	1.89	1.78
Moisture Content Determination				
Weight of Wet soil+cont. (g)	238.0	241.0	218.0	192.2
Weight of Dry soil+cont. (g)	203.5	202.4	179.7	157.0
Weight of Container (g)	20.5	20.4	19.8	19.7
Weight of water (moisture) (g)	34.5	38.6	38.3	35.2
Weight of Dry soil (g)	183	182	159.9	137.3
Moisture content (%)	18.85	21.21	23.95	25.64
Dry Density (g / cm3)	1.395	1.475	1.521	1.415
MDD, g/cc	**1.520**	**OMC, %**		**24.1**



Unit Weight Determination

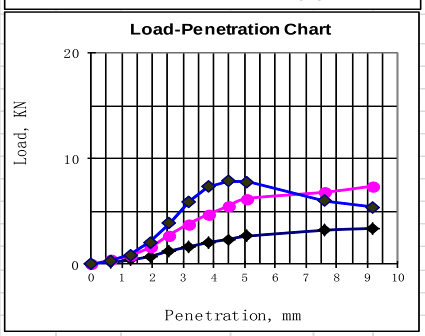
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	8857	9198	9768	10002	10455	10525
Wt.of mould, g	W2	5784	5784	6070	6070	6257	6257
Wt.of wet sample, g	W3 = W1 - W2	3073	3414	3698	3932	4198	4268
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.45	1.61	1.74	1.85	1.98	2.01
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.13	1.21	1.35	1.39	1.53	1.55
Moisture Content Determination							
Wt. of wet sample + cont.,	W3	278.3	217.8	258	300.7	270.6	269.3
Wt. of dry sample + cont.,	W4	225.6	172.5	208.2	235.5	217.6	215.4
Wt. of water, g	W5 = W3 - W4	52.7	45.3	49.8	65.2	53	53.9
Wt. of container, g	W6	37.8	36.8	37	36.9	37.3	35.6
Wt. of dry sample, g	W7 = W4 - W6	187.8	135.7	171.2	198.6	180.3	179.8
% Moisture Content	W8 = W5/W7*100	28.1	33.4	29.1	32.8	29.4	30.0

SWELL DATA

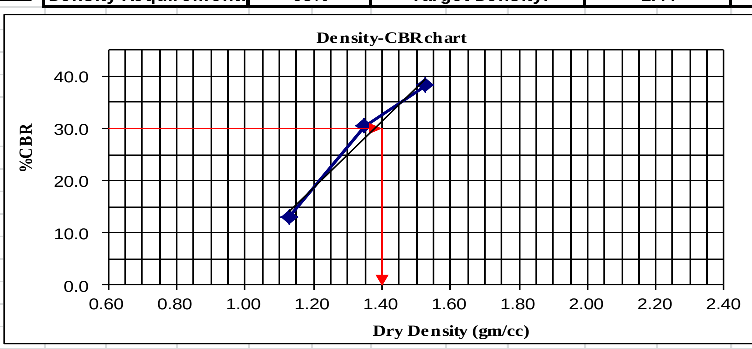
No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.05	1.72	1.67	**1.43**	0.07	1.82	1.75	**1.50**	0.1	1.88	1.78	**1.53**

CBR DATA

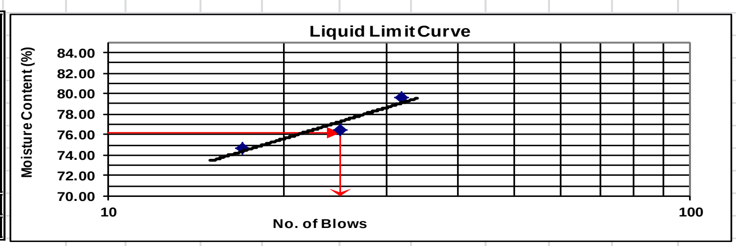
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		8	0.174			18	0.39			15	0.33		
1.27		18	0.391			39	0.85			41	0.89		
1.91		34	0.738			73	1.58			94	2.04		
2.54	13.2	57	1.237	1.24	**9.4**	127	2.76	2.76	**20.9**	177	3.84	3.84	**29.1**
3.18		76	1.649			176	3.82			273	5.92		
3.81		94	2.04			217	4.71			338	7.33		
4.45		108	2.344			252	5.47			363	7.88		
5.08	20.4	122	2.647	2.65	**12.98**	286	6.21	6.21	**30.42**	359	7.79	7.79	**38.2**
7.62		148	3.212			314	6.81			276	5.99		
9.16		156	3.385			340	7.38			250	5.43		
Soaked CBR,%		13.0				30.4				38.2			
Dry Density, g/cc		1.13				1.35				1.53			
Swell, %		1.43				1.50				1.53			
Density Requirement:		**95%**		**Target Density:**			**1.44**			**CBR**		**30.00**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.13	13.0
30	1.35	30.4
65	1.53	38.2



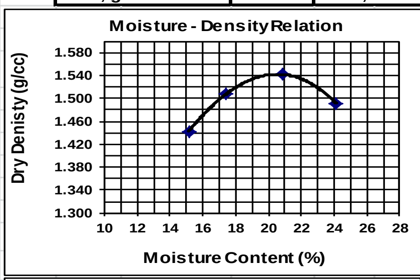
		Liquid Limit			Plastic Limit	
No. of Blows		32	25	17		
Wt. of cont.+wet soil (g) = (w_1)		27.11	28.92	26.89	5.51	13.13
Wt. of cont.+dry soil (g.) = (w_2)		20.48	21.55	20.02	5.00	12.48
Wt. of container (g.) = (w_3)		12.15	12.50	11.88	4.04	11.24
Mass of moisture (g.) (w_1-w_2) = x		6.63	7.37	6.87	0.51	0.65
Wt. of dry soil (g.) (w_2-w_3) = y		8.33	9.64	9.20	0.99	1.34
Moisture Content (%) = (100x/y)		79.59	76.45	74.67	51.52	48.51
			76.31		**50.12**	
			Plasticity Index		**26.19**	

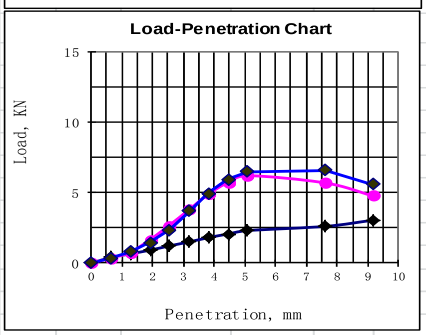


BC+4%OPC+10%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8286	8510	8701	8674
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3406	3630	3821	3794
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.66	1.77	1.86	1.85
Moisture Content Determination				
Weight of Wet soil +cont. (g)	318.0	310.0	248.0	265.0
Weight of Dry soil +cont. (g)	280.9	269.2	211.7	220.5
Weight of Container (g)	36.1	35.2	38.0	36.0
Weight of water (moisture) (g)	37.1	40.8	36.3	44.5
Weight of Dry soil (g)	244.8	234	173.7	184.5
Moisture content (%)	15.16	17.44	20.90	24.12
Dry Density (g / cm3)	1.443	1.508	1.542	1.491
MDD, g/cc	**1.542**	**OMC, %**	**20.9**	





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9410	9826	10063	10360	11846	11985
Wt.of mould, g	W2	6051	6051	6366	6366	7816	7816
Wt.of wet sample, g	W3 = W1 - W2	3359	3775	3697	3994	4030	4169
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.58	1.78	1.74	1.88	1.90	1.96
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.27	1.40	1.40	1.49	1.52	1.57
Moisture Content Determination							
Wt. of wet sample + cont.	W3	369.8	356.6	314.6	437.2	275.4	334.5
Wt. of dry sample + cont.	W4	304.1	292.5	259.8	358.5	227.5	279.8
Wt. of water, g	W5 = W3 - W4	65.7	64.1	54.8	78.7	47.9	54.7
Wt. of container, g	W6	36	57.2	34.5	55.5	36.7	58.3
Wt. of dry sample, g	W7 = W4 - W6	268.1	235.3	225.3	303	190.8	221.5
% Moisture Content	W8 = W5/W7*100	24.5	27.2	24.3	26.0	25.1	24.7

SWELL DATA

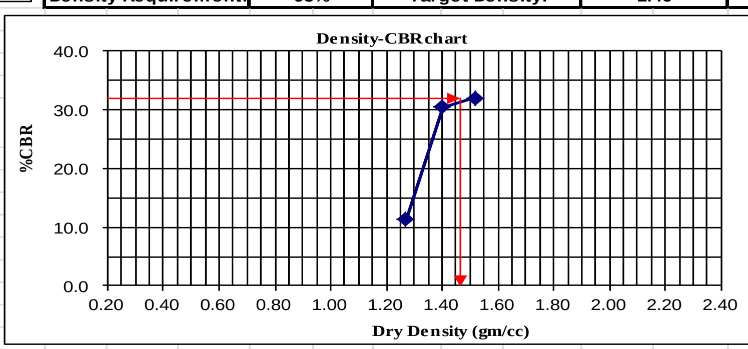
No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.03	1.62	1.59	**1.37**	0.1	1.73	1.63	**1.40**	0.09	2.28	2.19	**1.88**

CBR DATA

Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		18	0.391			16	0.35			16	0.35		
1.27		30	0.651			35	0.76			38	0.82		
1.91		42	0.911			76	1.65			67	1.45		
2.54	13.2	56	1.215	1.22	**9.2**	123	2.67	2.67	**20.2**	109	2.37	2.37	**17.9**
3.18		69	1.497			174	3.78			170	3.69		
3.81		83	1.801			225	4.88			227	4.93		
4.45		95	2.062			264	5.73			274	5.95		
5.08	20.4	106	2.3	2.30	**11.3**	286	6.21	6.21	**30.4**	300	6.51	6.51	**31.9**
7.62		120	2.604			262	5.69			303	6.58		
9.16		140	3.038			220	4.77			258	5.60		

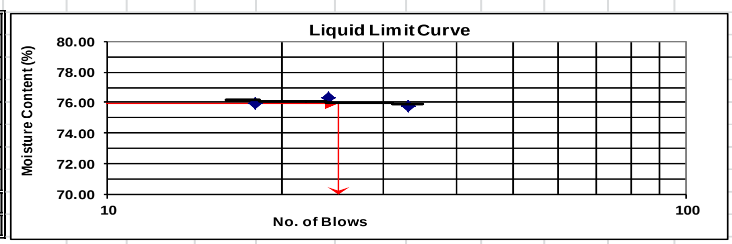
	10	30	65
Soaked CBR,%	11.3	30.4	31.9
Dry Density, g/cc	1.27	1.40	1.52
Swell, %	1.37	1.40	1.88

Density Requirement:	95%	Target Density:	1.46	CBR	32.00



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.27	11.3
30	1.40	30.4
65	1.52	31.9

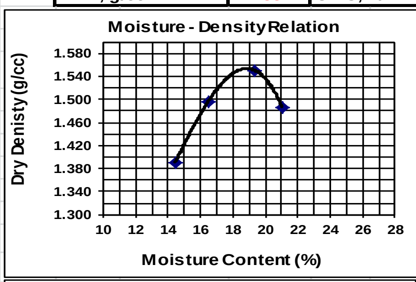
No. of Blows	Liquid Limit 33	24	18	Plastic Limit	
Wt. of cont. +wet soil (g) = (w_1)	26.69	28.56	34.75	8.35	14.23
Wt. of cont. +dry soil (g.) = (w_2)	20.40	21.62	28.33	7.73	13.66
Wt. of container (g.) = (w_3)	12.10	12.53	19.88	6.52	12.57
Mass of moisture (g.) (w_1-w_2) = x	6.29	6.94	6.42	0.62	0.57
Wt. of dry soil (g.) (w_2-w_3) = y	8.30	9.09	8.45	1.21	1.09
Moisture Content (%) = (100x/y)	75.78	76.35	75.98	51.24	52.29
		76.04		51.77	
		Plasticity Index		24.27	

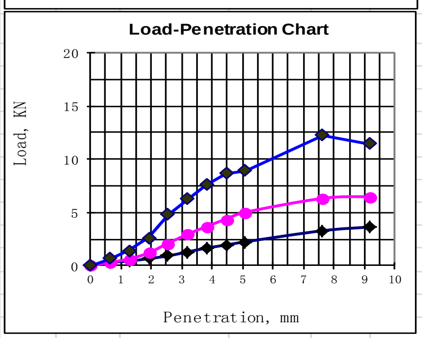


BC+4%OPC+15%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8142	8452	8673	8569
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3262	3572	3793	3689
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.59	1.74	1.85	1.80
Moisture Content Determination				
Weight of Wet soil +cont. (g)	466.7	340.1	229.1	331.9
Weight of Dry soil +cont. (g)	415.0	297.0	198.1	280.5
Weight of Container (g)	56.7	35.2	37.6	36.0
Weight of water (moisture) (g)	51.7	43.1	31	51.4
Weight of Dry soil (g)	358.3	261.8	160.5	244.5
Moisture content (%)	14.43	16.46	19.31	21.02
Dry Density (g / cm3)	1.391	1.496	1.551	1.487
MDD, g/cc	**1.551**	**OMC, %**	**19.3**	





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9670	10137	11434	11760	11428	11703
Wt.of mould, g	W2	6303	6303	7821	7821	7523	7523
Wt.of wet sample, g	W3 = W1 - W2	3367	3834	3613	3939	3905	4180
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.59	1.81	1.70	1.85	1.84	1.97
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.29	1.44	1.39	1.50	1.50	1.60
Moisture Content Determination							
Wt. of wet sample + cont.	W3	295.9	319	347	273.6	269.3	312.4
Wt. of dry sample + cont.	W4	247.8	265.5	291.3	228.5	226.7	260.5
Wt. of water, g	W5 = W3 - W4	48.1	53.5	55.7	45.1	42.6	51.9
Wt. of container, g	W6	38.7	56.2	37.7	38.8	38.4	35
Wt. of dry sample, g	W7 = W4 - W6	209.1	209.3	253.6	189.7	188.3	225.5
% Moisture Content	W8 = W5/W7*100	23.0	25.6	22.0	23.8	22.6	23.0

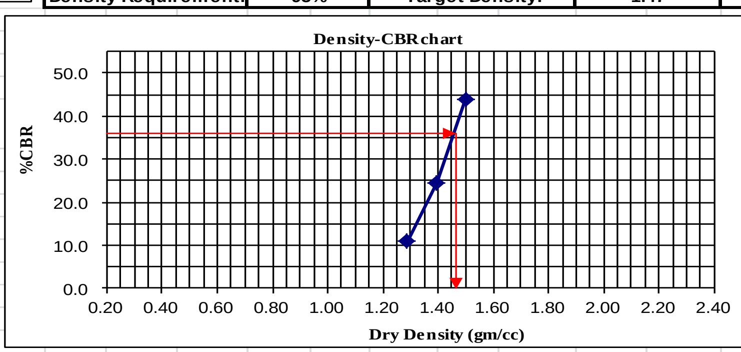
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	1.61	1.54	**1.32**	0.04	1.63	1.59	**1.37**	0.05	1.77	1.72	**1.48**

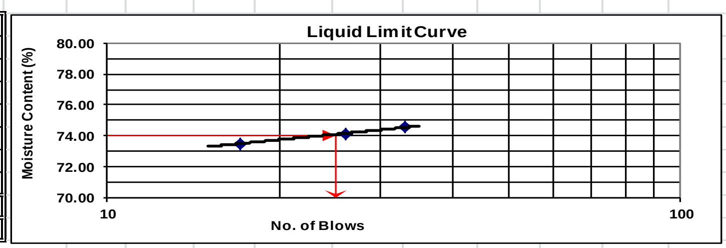
CBR DATA

Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		13	0.282			14	0.30			32	0.69		
1.27		20	0.434			29	0.63			64	1.39		
1.91		30	0.651			55	1.19			119	2.58		
2.54	13.2	42	0.911	0.91	**6.9**	96	2.08	2.08	**15.8**	220	4.77	4.77	**36.2**
3.18		59	1.28			135	2.93			290	6.29		
3.81		76	1.649			169	3.67			351	7.62		
4.45		89	1.931			201	4.36			398	8.64		
5.08	20.4	103	2.235	2.24	**11.0**	231	5.01	5.01	**24.6**	412	8.94	8.94	**43.8**
7.62		151	3.277			291	6.31			565	12.26		
9.16		167	3.624			299	6.49			527	11.44		
Soaked CBR,%		11.0				24.6				43.8			
Dry Density, g/cc		1.29				1.39				1.50			
Swell, %		1.32				1.37				1.48			
Density Requirement:		**95%**		**Target Density:**		**1.47**				**CBR**		**36.00**	

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.29	11.0
30	1.39	24.6
65	1.50	43.8



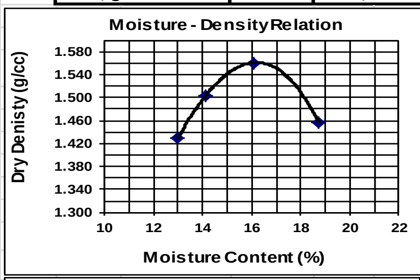
	Liquid Limit			Plastic Limit	
No. of Blows	33	26	17		
Wt. of cont. +wet soil (g) = (w_1)	34.09	37.07	28.10	6.08	8.60
Wt. of cont. +dry soil (g.) = (w_2)	27.55	29.28	21.55	5.41	7.86
Wt. of container (g.) = (w_3)	18.78	18.77	12.64	4.12	6.39
Mass of moisture (g.) (w_1-w_2) = x	6.54	7.79	6.55	0.67	0.74
Wt. of dry soil (g.) (w_2-w_3) = y	8.77	10.51	8.91	1.29	1.47
Moisture Content (%) = (100x/y)	74.57	74.12	73.51	51.71	50.34
		74.03		**51.02**	
		Plasticity Index		**23.01**	

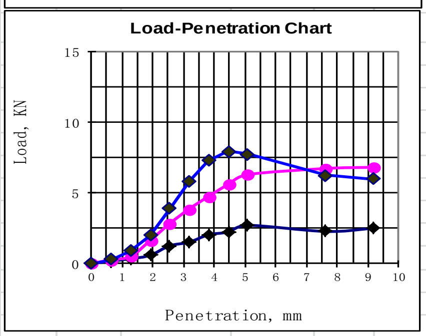


BC+4%OPC+20%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8190	8394	8593	8425
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3310	3514	3713	3545
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.61	1.71	1.81	1.73
Moisture Content Determination				
Weight of Wet soil + cont. (g)	306.6	328.8	347.1	336.6
Weight of Dry soil + cont. (g)	275.5	292.8	304.1	289.6
Weight of Container (g)	36.0	37.6	36.2	38.6
Weight of water (moisture) (g)	31.1	36	43	47
Weight of Dry soil (g)	239.5	255.2	267.9	251
Moisture content (%)	12.99	14.11	16.05	18.73
Dry Density (g / cm3)	1.429	1.502	1.561	1.457
MDD, g/cc	**1.561**	**OMC, %**		**16.1**





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9354	9974	9858	10247	11925	12063
Wt.of mould, g	W2	6096	6096	6165	6165	7882	7882
Wt.of wet sample, g	W3 = W1 - W2	3258	3878	3693	4082	4043	4181
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.53	1.83	1.74	1.92	1.90	1.97
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.29	1.48	1.46	1.59	1.60	1.65
Moisture Content Determination							
Wt. of wet sample + cont.	W3	322.3	255.2	294.6	328.8	321.9	324.3
Wt. of dry sample + cont.	W4	277	214.5	253.4	278.5	277.1	277.5
Wt. of water, g	W5 = W3 - W4	45.3	40.7	41.2	50.3	44.8	46.8
Wt. of container, g	W6	36.5	37.8	36.7	36	38.6	36.4
Wt. of dry sample, g	W7 = W4 - W6	240.5	176.7	216.7	242.5	238.5	241.1
% Moisture Content	W8 = W5/W7*100	18.8	23.0	19.0	20.7	18.8	19.4

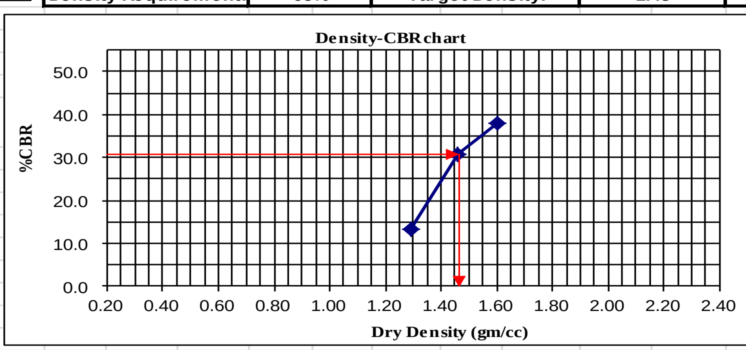
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.03	1.32	1.29	**1.11**	0.05	1.36	1.31	**1.13**	0.06	1.48	1.42	**1.22**

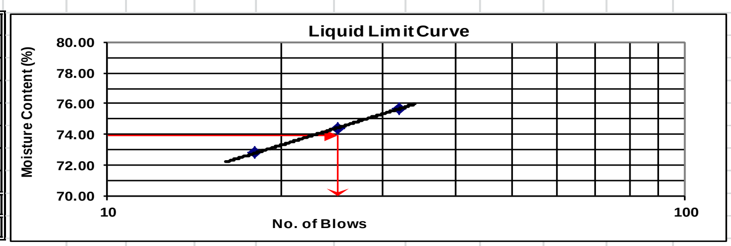
CBR DATA

Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		8	0.174			13	0.28			15	0.33		
1.27		16	0.347			23	0.50			41	0.89		
1.91		27	0.586			75	1.63			93	2.02		
2.54	13.2	58	1.259	1.26	**9.5**	130	2.82	2.82	**21.4**	180	3.91	3.91	**29.6**
3.18		70	1.519			178	3.86			270	5.86		
3.81		94	2.04			219	4.75			336	7.29		
4.45		103	2.235			258	5.60			365	7.92		
5.08	20.4	125	2.713	2.71	**13.3**	290	6.29	6.29	**30.8**	357	7.75	7.75	**38.0**
7.62		105	2.279			310	6.73			288	6.25		
9.16		115	2.496			314	6.81			276	5.99		
Soaked CBR,%		13.3				30.8				38.0			
Dry Density, g/cc		1.29				1.46				1.60			
Swell, %		1.11				1.13				1.22			
Density Requirement:		**95%**		**Target Density:**			**1.48**			**CBR**		**31.00**	

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.29	13.3
30	1.46	30.8
65	1.60	38.0



	Liquid Limit			Plastic Limit	
No. of Blows	32	25	18		
Wt. of cont. + wet soil (g) = (w_1)	31.40	33.00	27.00	14.38	6.17
Wt. of cont. + dry soil (g.) = (w_2)	25.83	26.60	20.98	13.59	5.43
Wt. of container (g.) = (w_3)	18.47	18.00	12.71	12.06	4.00
Mass of moisture (g.) (w_1-w_2) = x	5.57	6.40	6.02	0.79	0.74
Wt. of dry soil (g.) (w_2-w_3) = y	7.36	8.60	8.27	1.53	1.43
Moisture Content (%) = (100x/y)	75.68	74.42	72.79	51.63	51.75
		74.00		**51.69**	
		Plasticity Index		**22.31**	



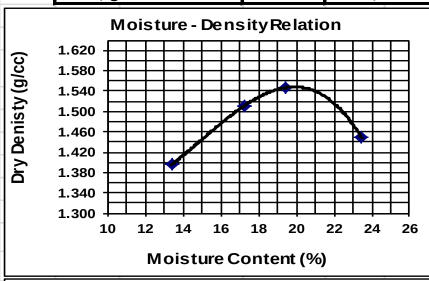
BC+8%OPC+5%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8125	8510	8666	8545
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3245	3630	3786	3665
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.58	1.77	1.85	1.79
Moisture Content Determination				
Weight of Wet soil + cont. (g)	284.8	399.1	337.9	300.3
Weight of Dry soil + cont. (g)	255.5	348.5	289.2	250.5
Weight of Container (g)	37.0	54.7	38.3	38.2
Weight of water (moisture) (g)	29.3	50.6	48.7	49.8
Weight of Dry soil (g)	218.5	293.8	250.9	212.3
Moisture content (%)	13.41	17.22	19.41	23.46
Dry Density (g / cm3)	1.396	1.511	1.547	1.448
MDD, g/cc	1.547	**OMC, %**	19.4	

Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9479	9825	10063	10272	10250	10355
Wt.of mould, g	W2	6013	6013	6229	6229	6163	6163
Wt.of wet sample, g	W3 = W1 - W2	3466	3812	3834	4043	4087	4192
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.63	1.79	1.81	1.90	1.92	1.97
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.30	1.30	1.44	1.46	1.53	1.53
Moisture Content Determination							
Wt. of wet sample + cont.	W3	495	359.6	344.5	385.6	518.1	370.9
Wt. of dry sample + cont.	W4	408.4	271.7	287.3	305.7	425	296.3
Wt. of water, g	W5 = W3 - W4	86.6	87.9	57.2	79.9	93.1	74.6
Wt. of container, g	W6	67	38.2	63.3	44.5	68	35.4
Wt. of dry sample, g	W7 = W4 - W6	341.4	233.5	224	261.2	357	260.9
% Moisture Content	W8 = W5/W7*100	25.4	37.6	25.5	30.6	26.1	28.6

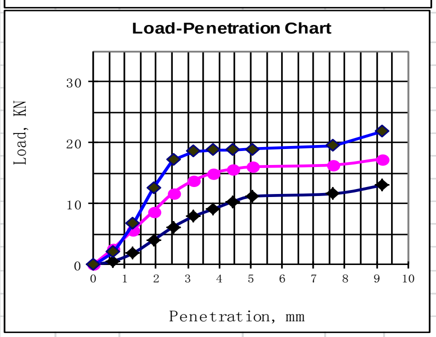


SWELL DATA

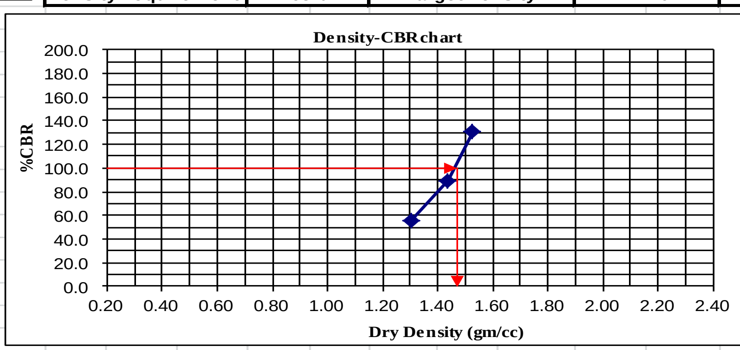
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	1	0.93	**0.80**	0.09	0.97	0.88	**0.76**	0.04	1.04	1.00	**0.86**

CBR DATA

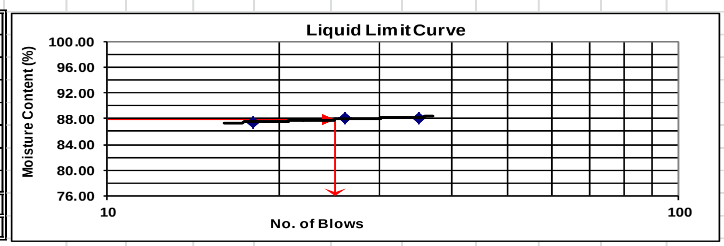
Penet-ration (mm)	Std load (KN)	Gauge reading (10)	Load KN (10)	Corrected CBR KN (10)	Corrected CBR % (10)	Gauge reading (30)	Load KN (30)	Corrected CBR KN (30)	Corrected CBR % (30)	Gauge reading (65)	Load KN (65)	Corrected CBR KN (65)	Corrected CBR % (65)
0		0	0			0	0			0	0		
0.64		28	0.608			125	2.71			100	2.17		
1.27		88	1.91			265	5.75			310	6.73		
1.91		186	4.036			405	8.79			580	12.59		
2.54	13.2	286	6.206	6.21	**47.0**	545	11.83	11.83	**89.6**	795	17.25	17.25	**130.7**
3.18		365	7.921			637	13.82			860	18.66		
3.81		421	9.136			695	15.08			869	18.86		
4.45		478	10.37			725	15.73			870	18.88		
5.08	20.4	518	11.24	11.24	**55.1**	741	16.08	16.08	**78.8**	875	18.99	18.99	**93.1**
7.62		537	11.65			755	16.38			900	19.53		
9.16		600	13.02			800	17.36			1010	21.92		
Soaked CBR,%		55.1				89.6				130.7			
Dry Density, g/cc		1.30				1.44				1.53			
Swell, %		0.80				0.76				0.86			
Density Requirement:		**95%**		**Target Density:**			**1.470**		**CBR**		**100.00**		



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.30	55.1
30	1.44	89.6
65	1.53	130.7



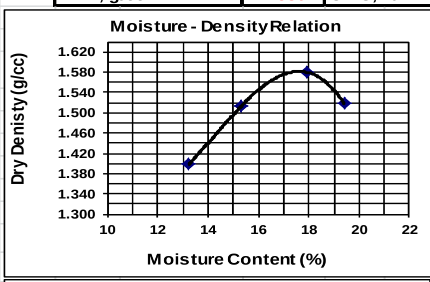
	Liquid Limit			Plastic Limit	
No. of Blows	35	26	18		
Wt. of cont. + wet soil (g) = (w_1)	32.59	35.94	37.83	8.01	14.22
Wt. of cont. + dry soil (g.) = (w_2)	26.40	28.41	30.48	7.36	13.48
Wt. of container (g.) = (w_3)	19.38	19.86	22.07	6.35	12.40
Mass of moisture (g.) (w_1-w_2) = x	6.19	7.53	7.35	0.65	0.74
Wt. of dry soil (g.) (w_2-w_3) = y	7.02	8.55	8.41	1.01	1.08
Moisture Content (%) = (100x/y)	88.18	88.07	87.40	64.36	68.52
		88.00		**66.34**	
		Plasticity Index		**21.66**	

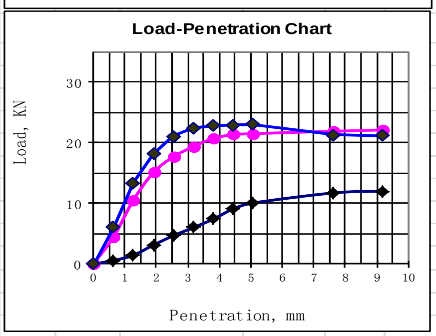


BC+8%OPC+10%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8125	8455	8699	8595
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3245	3575	3819	3715
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.58	1.74	1.86	1.81
Moisture Content Determination				
Weight of Wet soil + cont. (g)	236.0	396.5	332.5	264.1
Weight of Dry soil + cont. (g)	210.8	351.5	287.4	224.5
Weight of Container (g)	20.3	57.4	35.3	20.4
Weight of water (moisture) (g)	25.2	45	45.1	39.6
Weight of Dry soil (g)	190.5	294.1	252.1	204.1
Moisture content (%)	13.23	15.30	17.89	19.40
Dry Density (g / cm3)	1.398	1.512	1.580	1.518
MDD, g/cc	**1.580**	**OMC, %**		**17.9**





Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9771	10115	10450	10646	10355	10422
Wt.of mould, g	W2	6138	6138	6614	6614	6243	6243
Wt.of wet sample, g	W3 = W1 - W2	3633	3977	3836	4032	4112	4179
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.71	1.87	1.81	1.90	1.94	1.97
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.38	1.42	1.46	1.47	1.56	1.53
Moisture Content Determination							
Wt. of wet sample + cont.	W3	443.8	302.5	454	319.1	387.5	365.7
Wt. of dry sample + cont.	W4	370.2	238.3	378.8	259.7	324.8	297.1
Wt. of water, g	W5 = W3 - W4	73.6	64.2	75.2	59.4	62.7	68.6
Wt. of container, g	W6	65	38.2	62.9	56	67.8	56.7
Wt. of dry sample, g	W7 = W4 - W6	305.2	200.1	315.9	203.7	257	240.4
% Moisture Content	W8 = W5/W7*100	24.1	32.1	23.8	29.2	24.4	28.5

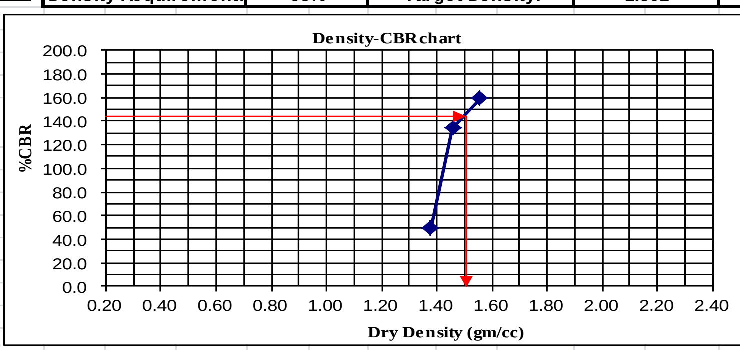
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.03	0.63	0.60	**0.52**	0.07	0.74	0.67	**0.58**	0.07	0.69	0.62	**0.53**

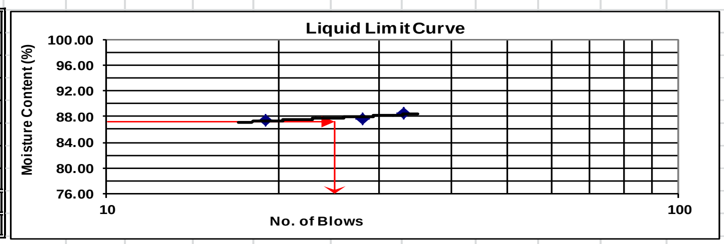
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		27	0.586			205	4.45			280	6.08		
1.27		67	1.454			485	10.52			615	13.35		
1.91		145	3.147			697	15.12			840	18.23		
2.54	13.2	216	4.687	4.69	**35.5**	815	17.69	17.69	**134.0**	970	21.05	21.05	**159.5**
3.18		278	6.033			894	19.40			1038	22.52		
3.81		342	7.421			955	20.72			1050	22.79		
4.45		421	9.136			985	21.37			1055	22.89		
5.08	20.4	465	10.09	10.09	**49.5**	992	21.53	21.53	**105.5**	1060	23.00	23.00	**112.8**
7.62		541	11.74			1010	21.92			980	21.27		
9.16		555	12.04			1020	22.13			975	21.16		
Soaked CBR,%		49.5				134.0				159.5			
Dry Density, g/cc		1.38				1.46				1.56			
Swell, %		0.52				0.58				0.53			
Density Requirement:		**95%**		**Target Density:**			**1.501**			**CBR**		**145.00**	

No of Blows	DDBS (gm/cc)	CBR (%)
10	1.38	49.5
30	1.46	134.0
65	1.56	159.5



	Liquid Limit			Plastic Limit	
No. of Blows	33	28	19		
Wt. of cont. + wet soil (g) = (w_1)	36.20	36.80	35.40	12.40	13.63
Wt. of cont. + dry soil (g.) = (w_2)	28.72	29.99	28.23	11.75	12.92
Wt. of container (g.) = (w_3)	20.28	22.21	20.03	10.74	11.88
Mass of moisture (g.) (w_1-w_2) = x	7.48	6.81	7.17	0.65	0.71
Wt. of dry soil (g.) (w_2-w_3) = y	8.44	7.78	8.20	1.01	1.04
Moisture Content (%) = (100x/y)	88.63	87.53	87.44	64.36	68.27
	87.31			**66.31**	
	Plasticity Index			**21.00**	

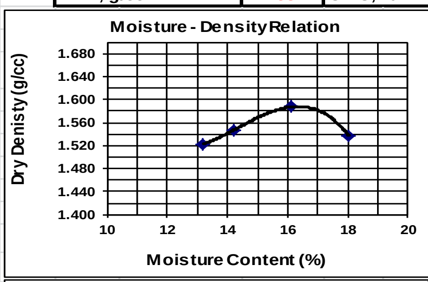


BC+8%OPC+15%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8413	8500	8658	8600
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3533	3620	3778	3720
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.72	1.77	1.84	1.81
Moisture Content Determination				
Weight of Wet soil +cont. (g)	469.8	457.3	464.9	531.4
Weight of Dry soil +cont. (g)	421.5	408.3	409.7	460.5
Weight of Container (g)	55.5	62.9	66.9	67.2
Weight of water (moisture) (g)	48.3	49	55.2	70.9
Weight of Dry soil (g)	366	345.4	342.8	393.3
Moisture content (%)	13.20	14.19	16.10	18.03
Dry Density (g / cm3)	1.522	1.546	1.587	1.537
MDD, g/cc	1.587	**OMC, %**	16.1	

Unit Weight Determination		10		30		65	
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9819	10225	10125	10346	10391	10534
Wt.of mould, g	W2	6242	6242	6266	6266	6269	6269
Wt.of wet sample, g	W3 = W1 - W2	3577	3983	3859	4080	4122	4265
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.68	1.88	1.82	1.92	1.94	2.01
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.38	1.47	1.49	1.51	1.60	1.61
Moisture Content Determination							
Wt. of wet sample + cont.	W3	348.4	357.8	346.3	468.3	368.4	512.4
Wt. of dry sample + cont.	W4	296	295.2	295.1	380.9	313.1	425
Wt. of water, g	W5 = W3 - W4	52.4	62.6	51.2	87.4	55.3	87.4
Wt. of container, g	W6	55.4	67.2	57.5	63	56	71.1
Wt. of dry sample, g	W7 = W4 - W6	240.6	228	237.6	317.9	257.1	353.9
% Moisture Content	W8 = W5/W7*100	21.8	27.5	21.5	27.5	21.5	24.7



SWELL DATA

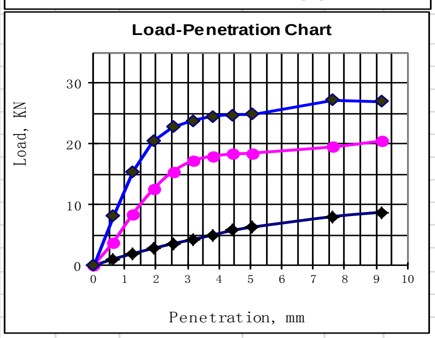
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.07	1.2	1.13	**0.97**	0.04	0.8	0.76	**0.65**	0.05	0.87	0.82	**0.70**

CBR DATA

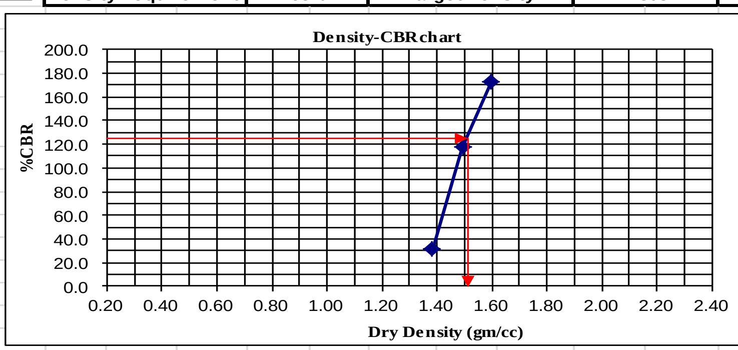
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		50	1.085			180	3.91			378	8.20		
1.27		92	1.996			395	8.57			712	15.45		
1.91		131	2.843			579	12.56			943	20.46		
2.54	13.2	167	3.624	3.62	**27.5**	715	15.52	15.52	**117.5**	1052	22.83	22.83	**172.9**
3.18		199	4.318			796	17.27			1100	23.87		
3.81		233	5.056			831	18.03			1134	24.61		
4.45		268	5.816			847	18.38			1144	24.82		
5.08	20.4	293	6.358	6.36	**31.2**	854	18.53	18.53	**90.8**	1148	24.91	24.91	**122.1**
7.62		372	8.072			901	19.55			1255	27.23		
9.16		405	8.789			945	20.51			1245	27.02		

	10 blows	30 blows	65 blows
Soaked CBR,%	31.2	117.5	172.9
Dry Density, g/cc	1.38	1.49	1.60
Swell, %	0.97	0.65	0.70

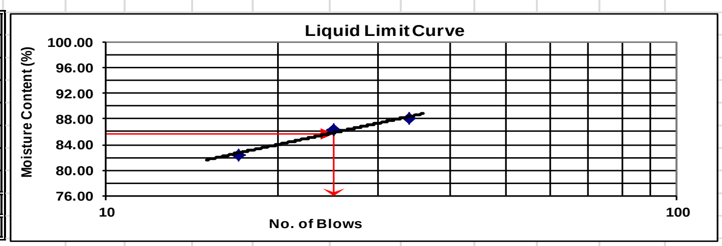
Density Requirement:	**95%**	**Target Density:**	**1.508**	**CBR**	**126.00**



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.38	31.2
30	1.49	117.5
65	1.60	172.9



	Liquid Limit			Plastic Limit	
No. of Blows	34	25	17		
Wt. of cont. +wet soil (g) = (w_1)	36.10	27.50	35.00	14.36	14.13
Wt. of cont. +dry soil (g.) = (w_2)	29.39	20.50	27.50	13.76	13.41
Wt. of container (g.) = (w_3)	21.77	12.40	18.40	12.85	12.30
Mass of moisture (g.) (w_1-w_2) = x	6.71	7.00	7.50	0.60	0.72
Wt. of dry soil (g.) (w_2-w_3) = y	7.62	8.10	9.10	0.91	1.11
Moisture Content (%) = (100x/y)	88.06	86.42	82.42	65.93	64.86
		85.70		65.40	
		Plasticity Index		20.30	

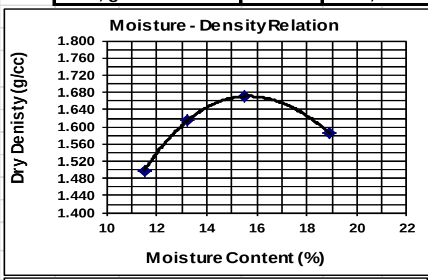


BC+8%OPC+20%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8304	8625	8835	8745
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3424	3745	3955	3865
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.67	1.83	1.93	1.89
Moisture Content Determination				
Weight of Wet soil + cont. (g)	458.1	367.3	435.1	325.0
Weight of Dry soil + cont. (g)	416.8	328.8	384.5	280.4
Weight of Container (g)	57.7	37.4	57.5	44.6
Weight of water (moisture) (g)	41.3	38.5	50.6	44.6
Weight of Dry soil (g)	359.1	291.4	327	235.8
Moisture content (%)	11.50	13.21	15.47	18.91
Dry Density (g / cm3)	1.498	1.614	1.671	1.585
MDD, g/cc	1.671	OMC, %	15.5	

Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	9802	10257	10029	10299	10497	10696
Wt.of mould, g	W2	6355	6355	6176	6176	6381	6381
Wt.of wet sample, g	W3 = W1 - W2	3447	3902	3853	4123	4116	4315
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.62	1.84	1.81	1.94	1.94	2.03
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.36	1.38	1.51	1.54	1.62	1.64
Moisture Content Determination							
Wt. of wet sample + cont.	W3	370.5	430.7	519.2	462.2	426	352.7
Wt. of dry sample + cont.	W4	319.7	339.2	442.4	380.3	365.7	297.2
Wt. of water, g	W5 = W3 - W4	50.8	91.5	76.8	81.9	60.3	55.5
Wt. of container, g	W6	56.8	65	55.6	68.2	57.1	63.4
Wt. of dry sample, g	W7 = W4 - W6	262.9	274.2	386.8	312.1	308.6	233.8
% Moisture Content	W8 = W5/W7*100	19.3	33.4	19.9	26.2	19.5	23.7

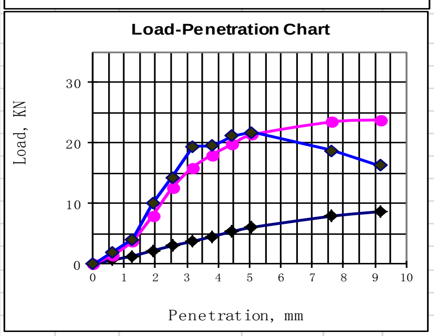


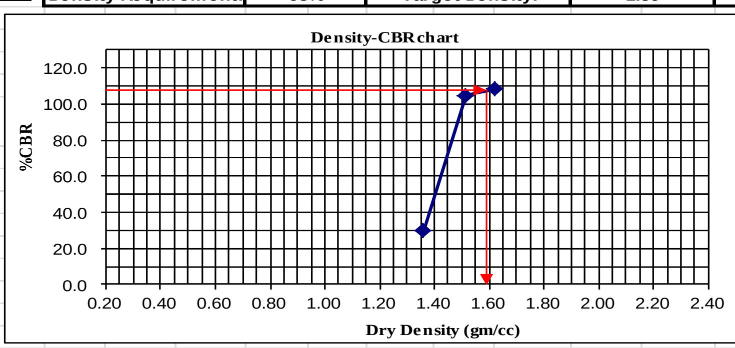
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.03	1.2	1.17	**1.01**	0.05	1.03	0.98	**0.84**	0.06	0.92	0.86	**0.74**

CBR DATA

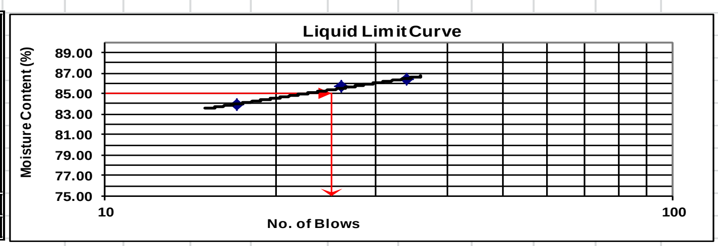
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		32	0.694			70	1.52			92	2.00		
1.27		62	1.345			178	3.86			190	4.12		
1.91		102	2.213			370	8.03			464	10.07		
2.54	13.2	140	3.038	3.04	**23.0**	583	12.65	12.65	**95.8**	658	14.28	14.28	**108.2**
3.18		173	3.754			735	15.95			894	19.40		
3.81		210	4.557			834	18.10			900	19.53		
4.45		248	5.382			913	19.81			975	21.16		
5.08	20.4	280	6.076	6.08	**29.8**	985	21.37	21.37	**104.8**	1004	21.79	21.79	**106.8**
7.62		365	7.921			1083	23.50			865	18.77		
9.16		400	8.68			1099	23.85			754	16.36		
Soaked CBR,%		29.8				104.8				108.2			
Dry Density, g/cc		1.36				1.51				1.62			
Swell, %		1.01				0.84				0.74			
Density Requirement:		**95%**		**Target Density:**		**1.59**				**CBR**		**108.00**	





No of Blows	DDBS (gm/cc)	CBR (%)
10	1.36	29.8
30	1.51	104.8
65	1.62	108.2

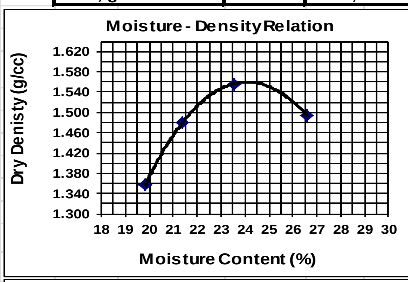
	Liquid Limit			Plastic Limit	
No. of Blows	34	26	17		
Wt. of cont. + wet soil (g) = (w_1)	32.70	35.80	33.20	13.87	12.94
Wt. of cont. + dry soil (g.) = (w_2)	27.20	28.40	26.80	13.21	12.18
Wt. of container (g.) = (w_3)	20.83	19.77	19.17	12.20	11.04
Mass of moisture (g.) (w_1-w_2) = x	5.50	7.40	6.40	0.66	0.76
Wt. of dry soil (g.) (w_2-w_3) = y	6.37	8.63	7.63	1.01	1.14
Moisture Content (%) = (100x/y)	86.34	85.75	83.88	65.35	66.67
	85.12			**66.01**	
	Plasticity Index			**19.11**	



BC+12%OPC+5%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8213	8565	8822	8756
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3333	3685	3942	3876
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.63	1.80	1.92	1.89
Moisture Content Determination				
Weight of Wet soil + cont. (g)	378.2	384.5	400.2	420.5
Weight of Dry soil + cont. (g)	326.1	328.5	336.9	343.8
Weight of Container (g)	63.3	66.8	67.9	55.6
Weight of water (moisture) (g)	52.1	56	63.3	76.7
Weight of Dry soil (g)	262.8	261.7	269	288.2
Moisture content (%)	19.82	21.40	23.53	26.61
Dry Density (g / cm3)	1.357	1.481	1.557	1.493
MDD, g/cc	**1.557**	**OMC, %**		**23.5**



Unit Weight Determination

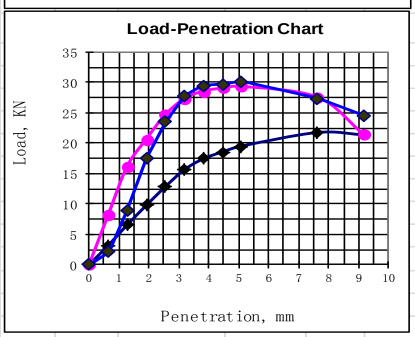
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	11157	11453	11568	11762	11888	12007
Wt.of mould, g	W2	7641	7641	7752	7752	7911	7911
Wt.of wet sample, g	W3 = W1 - W2	3516	3812	3816	4010	3977	4096
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.66	1.79	1.80	1.89	1.87	1.93
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.30	1.33	1.41	1.43	1.47	1.49
Moisture Content Determination							
Wt. of wet sample + cont.	W3	501.3	297.1	451.1	323.3	447.1	308.6
Wt. of dry sample + cont.	W4	406.7	229.7	368.5	253.5	366	247
Wt. of water, g	W5 = W3 - W4	94.6	67.4	82.6	69.8	81.1	61.6
Wt. of container, g	W6	66.1	37.2	66.7	38.3	67.6	38.3
Wt. of dry sample, g	W7 = W4 - W6	340.6	192.5	301.8	215.2	298.4	208.7
% Moisture Content	W8 = W5/W7*100	27.8	35.0	27.4	32.4	27.2	29.5

SWELL DATA

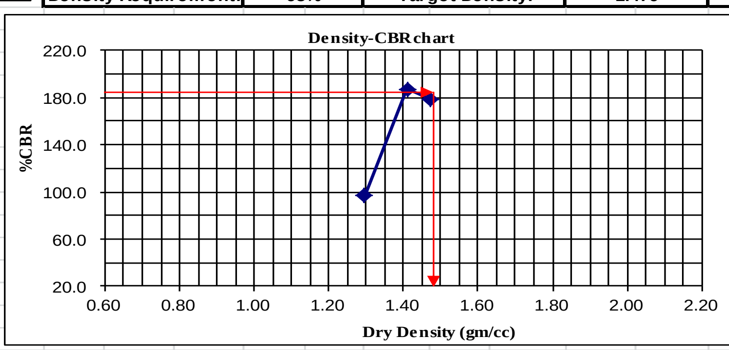
No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.08	0.55	0.47	**0.40**	0.05	0.46	0.41	**0.35**	0.05	0.44	0.39	**0.34**

CBR DATA

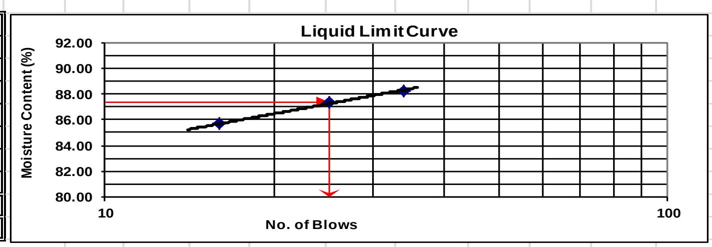
Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		146	3.168			378	8.20			95	2.06		
1.27		301	6.532			745	16.17			406	8.81		
1.91		450	9.765			952	20.66			805	17.47		
2.54	13.2	590	12.8	12.80	**97.0**	1137	24.67	24.67	**186.9**	1085	23.54	23.54	**178.4**
3.18		720	15.62			1260	27.34			1285	27.88		
3.81		803	17.43			1317	28.58			1355	29.40		
4.45		855	18.55			1340	29.08			1366	29.64		
5.08	20.4	899	19.51	19.51	**95.6**	1353	29.36	29.36	**143.9**	1390	30.16	30.16	**147.9**
7.62		1003	21.77			1272	27.60			1260	27.34		
9.16		985	21.37			990	21.48			1130	24.52		
Soaked CBR,%		97.0				186.9				178.4			
Dry Density, g/cc		1.30				1.41				1.47			
Swell, %		0.40				0.35				0.34			
Density Requirement:		**95%**		**Target Density:**		**1.479**		**CBR**		**185.00**			



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.30	97.0
30	1.41	186.9
65	1.47	178.4



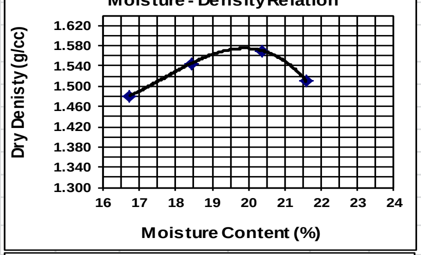
	Liquid Limit			Plastic Limit	
No. of Blows	34	25	16		
Wt. of cont. + wet soil (g) = (w_1)	31.86	35.60	32.30	14.56	8.64
Wt. of cont. + dry soil (g.) = (w_2)	25.61	29.73	25.97	13.86	7.79
Wt. of container (g.) = (w_3)	18.53	23.01	18.58	12.85	6.55
Mass of moisture (g.) (w_1-w_2) = x	6.25	5.87	6.33	0.70	0.85
Wt. of dry soil (g.) (w_2-w_3) = y	7.08	6.72	7.39	1.01	1.24
Moisture Content (%) = (100x/y)	88.28	87.35	85.66	69.31	68.55
	87.40			**68.93**	
	Plasticity Index			**18.47**	

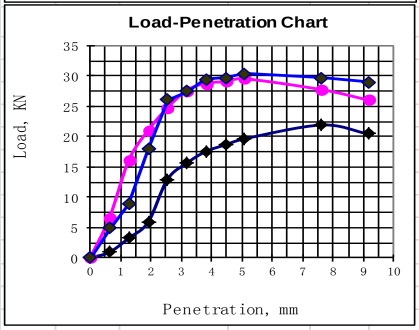


BC+12%OPC+10%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8425	8630	8755	8645
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3545	3750	3875	3765
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.73	1.83	1.89	1.84
Moisture Content Determination				
Weight of Wet soil + cont. (g)	452.9	362.4	277.0	322.7
Weight of Dry soil + cont. (g)	397.3	312.0	236.3	271.9
Weight of Container (g)	65.1	38.3	36.7	36.5
Weight of water (moisture) (g)	55.6	50.4	40.7	50.8
Weight of Dry soil (g)	332.2	273.7	199.6	235.4
Moisture content (%)	16.74	18.41	20.39	21.58
Dry Density (g / cm3)	1.481	1.545	1.570	1.511
MDD, g/cc	**1.570**	**OMC, %**	**20.4**	





Unit Weight Determination

No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	11390	11784	9698	9958	11864	11950
Wt.of mould, g	W2	7924	7924	5875	5875	7693	7693
Wt.of wet sample, g	W3 = W1 - W2	3466	3860	3823	4083	4171	4257
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.63	1.82	1.80	1.92	1.96	2.00
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.32	1.37	1.45	1.50	1.58	1.58
Moisture Content Determination							
Wt. of wet sample + cont.	W3	525.9	311.7	537.6	295.9	425.4	378.7
Wt. of dry sample + cont.	W4	437.5	245.1	446.2	240.7	356.1	306
Wt. of water, g	W5 = W3 - W4	88.4	66.6	91.4	55.2	69.3	72.7
Wt. of container, g	W6	65.8	38.1	67.9	44.6	68.8	34.5
Wt. of dry sample, g	W7 = W4 - W6	371.7	207	378.3	196.1	287.3	271.5
% Moisture Content	W8 = W5/W7*100	23.8	32.2	24.2	28.1	24.1	26.8

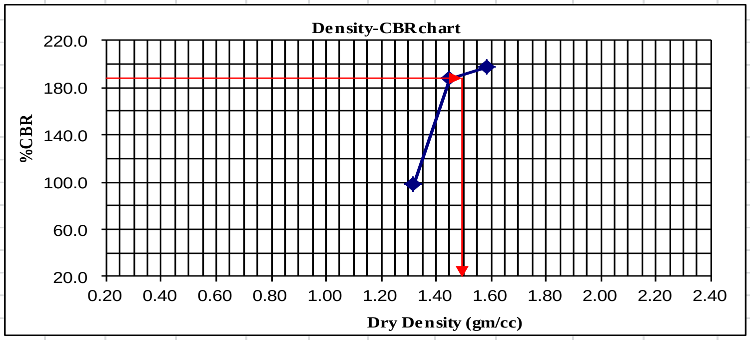
SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample:	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
116.4mm	0.1	0.6	0.50	**0.43**	0.04	0.45	0.41	**0.35**	0.05	0.43	0.38	**0.33**

CBR DATA

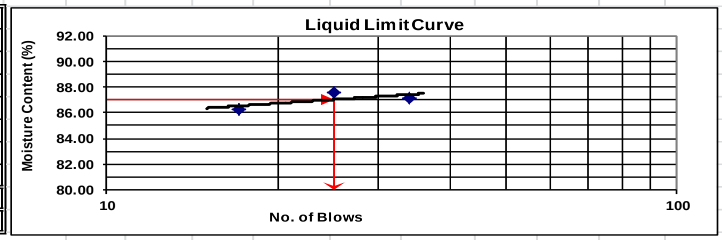
Penet-ration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		44	0.955			309	6.71			225	4.88		
1.27		150	3.255			742	16.10			410	8.90		
1.91		272	5.902			970	21.05			825	17.90		
2.54	13.2	595	12.91	12.91	**97.8**	1140	24.74	24.74	**187.4**	1200	26.04	26.04	**197.3**
3.18		720	15.62			1273	27.62			1264	27.43		
3.81		809	17.56			1328	28.82			1360	29.51		
4.45		859	18.64			1340	29.08			1370	29.73		
5.08	20.4	905	19.64	19.64	**96.3**	1362	29.56	29.56	**144.9**	1400	30.38	30.38	**148.9**
7.62		1010	21.92			1279	27.75			1370	29.73		
9.16		942	20.44			1200	26.04			1335	28.97		
Soaked CBR,%		97.8				187.4				197.3			
Dry Density, g/cc		1.32				1.45				1.58			
Swell, %		0.43				0.35				0.33			

Density Requirement:	**95%**	**Target Density:**	**1.492**	**CBR**	**189.00**



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.32	97.8
30	1.45	187.4
65	1.58	197.3

	Liquid Limit			Plastic Limit	
No. of Blows	34	25	17		
Wt. of cont. + wet soil (g) = (w_1)	33.40	35.10	33.56	15.43	13.27
Wt. of cont. + dry soil (g.) = (w_2)	26.31	27.88	26.90	14.55	12.44
Wt. of container (g.) = (w_3)	18.17	19.64	19.18	13.24	11.24
Mass of moisture (g.) (w_1-w_2) = x	7.09	7.22	6.66	0.88	0.83
Wt. of dry soil (g.) (w_2-w_3) = y	8.14	8.24	7.72	1.31	1.20
Moisture Content (%) = (100x/y)	87.10	87.62	86.27	67.18	69.17
		87.10		**68.17**	
		Plasticity Index		**18.93**	

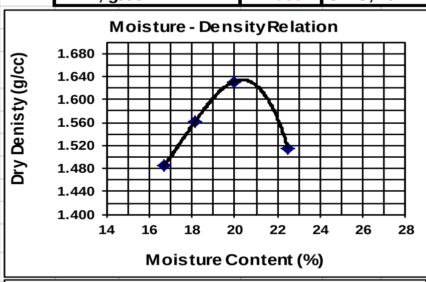


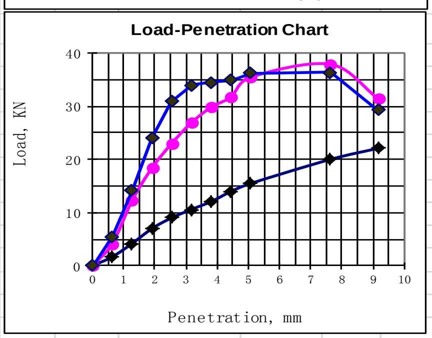
BC+12%OPC+15%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould + Wet soil (g)	8430	8659	8890	8685
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3550	3779	4010	3805
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.73	1.84	1.96	1.86
Moisture Content Determination				
Weight of Wet soil + cont. (g)	348.3	448.0	445.5	483.0
Weight of Dry soil + cont. (g)	303.8	387.6	382.7	406.5
Weight of Container (g)	36.8	54.3	68.0	66.4
Weight of water (moisture) (g)	44.5	60.4	62.8	76.5
Weight of Dry soil (g)	267	333.3	314.7	340.1
Moisture content (%)	16.67	18.12	19.96	22.49
Dry Density (g / cm3)	1.484	1.561	1.631	1.515
MDD, g/cc	1.635	**OMC, %**	19.9	

Unit Weight Determination							
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt. of wet sample + mould	W1	9793	10153	9984	10197	10125	10245
Wt. of mould, g	W2	6278	6278	6100	6100	5935	5935
Wt. of wet sample, g	W3 = W1 - W2	3515	3875	3884	4097	4190	4310
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.65	1.82	1.83	1.93	1.97	2.03
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.34	1.38	1.48	1.51	1.60	1.62
Moisture Content Determination							
Wt. of wet sample + cont.	W3	552.9	481.6	577.3	592.3	605.5	502.6
Wt. of dry sample + cont.	W4	461	381.3	480.1	478.1	502.9	414.8
Wt. of water, g	W5 = W3 - W4	91.9	100.3	97.2	114.2	102.6	87.8
Wt. of container, g	W6	67.8	67	67.6	63.4	67.7	65
Wt. of dry sample, g	W7 = W4 - W6	393.2	314.3	412.5	414.7	435.2	349.8
% Moisture Content	W8 = W5/W7*100	23.4	31.9	23.6	27.5	23.6	25.1





SWELL DATA

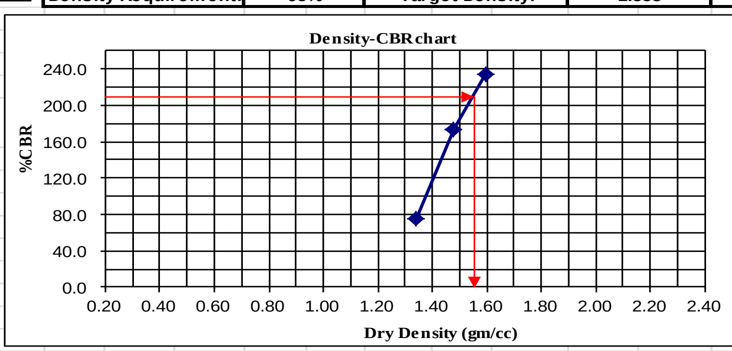
No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.23	0.75	0.52	**0.45**	0.16	0.55	0.39	**0.34**	0.1	0.48	0.38	**0.33**

CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		78	1.693			192	4.17			253	5.49		
1.27		192	4.166			563	12.22			652	14.15		
1.91		322	6.987			847	18.38			1103	23.94		
2.54	13.2	415	9.006	9.01	**68.2**	1058	22.96	22.96	**173.9**	1420	30.81	30.81	**233.4**
3.18		488	10.59			1240	26.91			1564	33.94		
3.81		556	12.07			1373	29.79			1590	34.50		
4.45		644	13.97			1463	31.75			1605	34.83		
5.08	20.4	713	15.47	15.47	**75.8**	1633	35.44	35.44	**173.7**	1665	36.13	36.13	**177.1**
7.62		920	19.96			1745	37.87			1675	36.35		
9.16		1017	22.07			1448	31.42			1350	29.30		

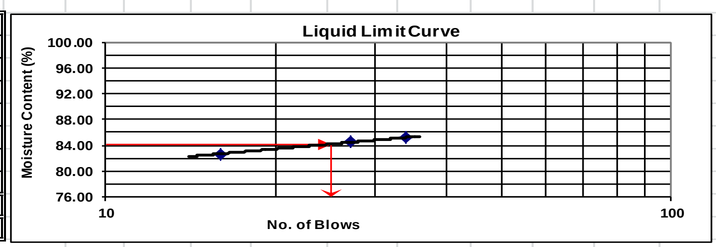
	10 blows	30 blows	65 blows
Soaked CBR,%	75.8	173.9	233.4
Dry Density, g/cc	1.34	1.48	1.60
Swell, %	0.45	0.34	0.33

Density Requirement: 95% **Target Density:** 1.553 **CBR** 210.00



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.34	75.8
30	1.48	173.9
65	1.60	233.4

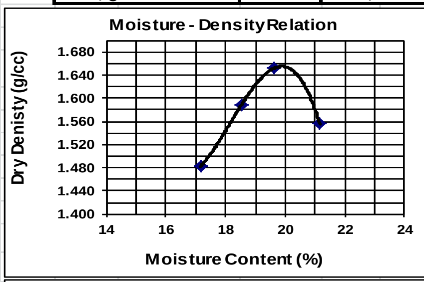
	Liquid Limit			Plastic Limit	
No. of Blows	34	27	16		
Wt. of cont. + wet soil (g) = (w_1)	31.97	35.64	33.30	14.41	12.53
Wt. of cont. + dry soil (g.) = (w_2)	25.39	27.85	26.54	13.68	11.79
Wt. of container (g.) = (w_3)	17.66	18.64	18.36	12.60	10.66
Mass of moisture (g.) (w_1-w_2) = x	6.58	7.79	6.76	0.73	0.74
Wt. of dry soil (g.) (w_2-w_3) = y	7.73	9.21	8.18	1.08	1.13
Moisture Content (%) = (100x/y)	85.12	84.58	82.64	67.59	65.04
	84.15			66.32	
	Plasticity Index			17.83	

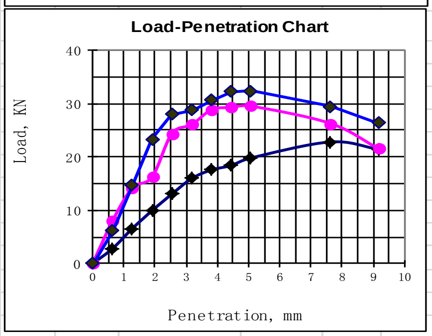


BC+12%OPC+20%QD

Moisture Density Relation AASHTO: T 180, 3-Point Californian Bearing Ratio (CBR) AASHTO: T 193 & Atterberg Limit AASHTO : T 89-90 Tests

Trial No.	1	2	3	4
Weight of Mould +Wet soil (g)	8440	8742	8932	8745
Weight of Mould (g)	4880	4880	4880	4880
Weight of Wet soil (g)	3560	3862	4052	3865
Volume of Mould (cc)	2050	2050	2050	2050
Wet density (g / cm3)	1.74	1.88	1.98	1.89
Moisture Content Determination				
Weight of Wet soil +cont. (g)	305.7	339.5	315.4	339.5
Weight of Dry soil +cont. (g)	266.4	292.0	269.3	286.6
Weight of Container (g)	37.4	35.7	34.5	36.5
Weight of water (moisture) (g)	39.3	47.5	46.1	52.9
Weight of Dry soil (g)	229	256.3	234.8	250.1
Moisture content (%)	17.16	18.53	19.63	21.15
Dry Density (g / cm3)	1.482	1.589	1.652	1.556
MDD, g/cc	**1.652**	**OMC, %**		**19.6**





Unit Weight Determination

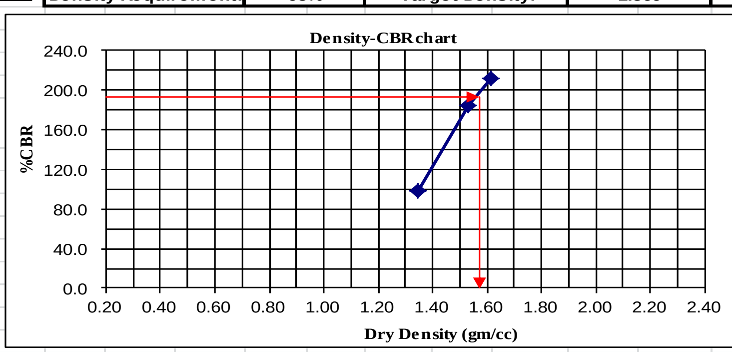
No. of Blows per Layer		10		30		65	
CONDITION OF SAMPLE		Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample + mould	W1	11512	11946	10459	10692	10415	10565
Wt.of mould, g	W2	8065	8065	6502	6502	6253	6253
Wt.of wet sample, g	W3 = W1 - W2	3447	3881	3957	4190	4162	4312
Volume of mould, cc	V	2124	2124	2124	2124	2124	2124
Wet unit weight, g/cc	Dw = W3 / V	1.62	1.83	1.86	1.97	1.96	2.03
Dry unit weight, g/cc	Dw /(1+ W8/100)	1.35	1.40	1.53	1.57	1.62	1.64
Moisture Content Determination							
Wt. of wet sample + cont.	W3	458.3	539.7	396.5	576	351	486.4
Wt. of dry sample + cont.	W4	390	430.5	336.1	473.2	296.4	405.9
Wt. of water, g	W5 = W3 - W4	68.3	109.2	60.4	102.8	54.6	80.5
Wt. of container, g	W6	55.3	71.1	56.8	67.6	38.7	66.1
Wt. of dry sample, g	W7 = W4 - W6	334.7	359.4	279.3	405.6	257.7	339.8
% Moisture Content	W8 = W5/W7*100	20.4	30.4	21.6	25.3	21.2	23.7

SWELL DATA

No. of Blows	10				30				65			
Initial Height of Sample: 116.4mm	Dial reading		Swell		Gauge reading		Swell		Gauge reading		Swell	
	Initial	Final	mm	%	Initial	Final	mm	%	Initial	Final	mm	%
	0.08	0.7	0.62	**0.53**	0.1	0.56	0.46	**0.40**	0.08	0.38	0.30	**0.26**

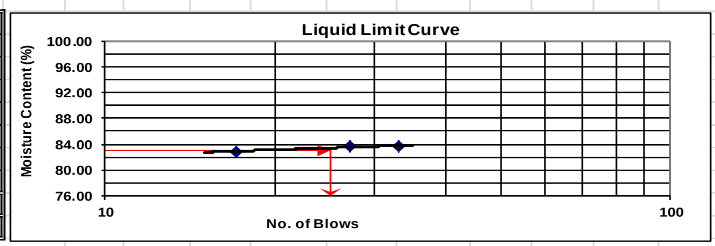
CBR DATA

Penetration (mm)	Std load (KN)	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %	Gauge reading	Load KN	Corrected CBR KN	Corrected CBR %
0		0	0			0	0			0	0		
0.64		130	2.821			370	8.03			285	6.18		
1.27		302	6.553			652	14.15			675	14.65		
1.91		458	9.939			748	16.23			1075	23.33		
2.54	13.2	600	13.02	13.02	**98.6**	1123	24.37	24.37	**184.6**	1290	27.99	27.99	**212.1**
3.18		735	15.95			1200	26.04			1325	28.75		
3.81		808	17.53			1328	28.82			1410	30.60		
4.45		847	18.38			1348	29.25			1486	32.25		
5.08	20.4	912	19.79	19.79	**97.0**	1359	29.49	29.49	**144.6**	1493	32.40	32.40	**158.8**
7.62		1050	22.79			1210	26.26			1358	29.47		
9.16		987	21.42			993	21.55			1215	26.37		
Soaked CBR,%		98.6				184.6				212.1			
Dry Density, g/cc		1.35				1.53				1.62			
Swell, %		0.53				0.40				0.26			
Density Requirement:		**95%**		**Target Density:**			**1.569**			**CBR**		**193.00**	



No of Blows	DDBS (gm/cc)	CBR (%)
10	1.35	98.6
30	1.53	184.6
65	1.62	212.1

	Liquid Limit			Plastic Limit	
No. of Blows	33	27	17		
Wt. of cont. +wet soil (g) = (w_1)	36.80	34.53	32.20	14.13	16.12
Wt. of cont. +dry soil (g.) = (w_2)	28.87	27.86	25.90	13.30	15.17
Wt. of container (g.) = (w_3)	19.40	19.88	18.30	12.06	13.72
Mass of moisture (g.) (w_1-w_2) = x	7.93	6.67	6.30	0.82	0.95
Wt. of dry soil (g.) (w_2-w_3) = y	9.47	7.98	7.60	1.24	1.45
Moisture Content (%) = (100x/y)	83.74	83.58	82.89	66.53	65.52
		83.10		**66.02**	
		Plasticity Index		**17.08**	



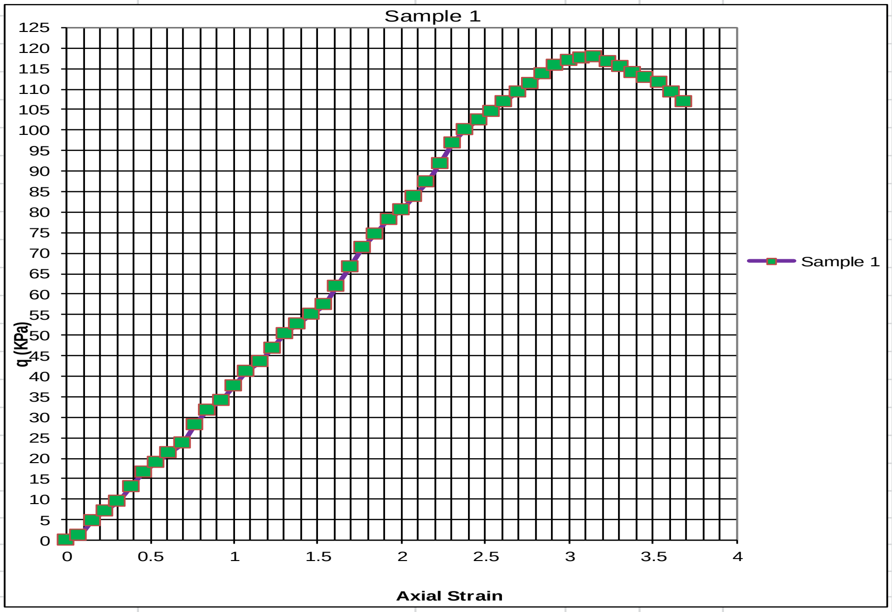
Native Soil (Sample # 1)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	**Native Soil (Sample # 1)**
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.781
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1811.4
Bulk Unit Weight(kN/m3)	18.11
NMC %	31.85
Dry Density (kg/m3)	1373.84
Dry Unit Weight(kN/m3)	13.74

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	1.14
0.1538	4.71
0.2308	7.09
0.3077	9.46
0.3846	13.01
0.4615	16.56
0.5385	18.92
0.6154	21.27
0.6923	23.62
0.7692	28.22
0.8462	31.75
0.9231	34.09
1.0000	37.60
1.0769	41.11
1.1538	43.43
1.2308	46.93
1.3077	50.43
1.3846	52.74
1.4615	55.05
1.5385	57.35
1.6154	62.00
1.6923	66.64
1.7692	71.28
1.8462	74.73
1.9231	78.18
2.0000	80.45
2.0769	83.89
2.1538	87.33
2.2308	91.92
2.3077	96.77
2.3846	100.18
2.4615	102.43
2.5385	104.67
2.6154	106.91
2.6923	109.15
2.7692	111.38
2.8462	113.61
2.9231	115.84
3.0000	116.90
3.0769	117.63
3.1538	117.87
3.2308	116.62
3.3077	115.37
3.3846	114.12
3.4615	112.88
3.5385	111.63
3.6154	109.24
3.6923	106.86



q (Kpa)	117.60
C(Kpa)	58.80

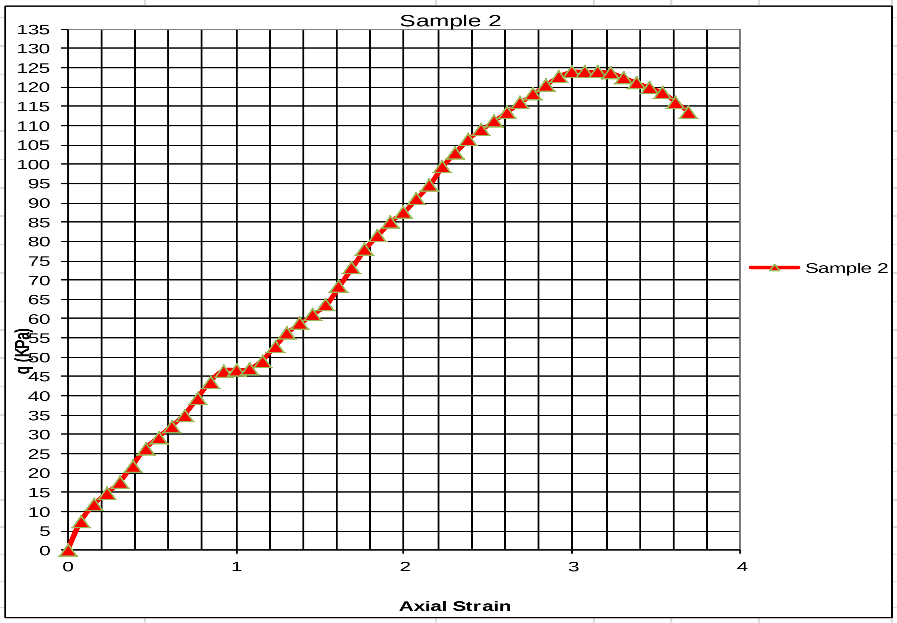
Native Soil (Sample # 2)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	**Native Soil (Sample # 2)**
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.781
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1811.4
Bulk Unit Weight(kN/m3)	18.11
NMC %	31.85
Dry Density (kg/m3)	1373.84
Dry Unit Weight(kN/m3)	13.74

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	7.33
0.1538	11.72
0.2308	14.64
0.3077	17.56
0.3846	21.93
0.4615	26.30
0.5385	29.20
0.6154	32.09
0.6923	34.98
0.7692	39.33
0.8462	43.66
0.9231	46.54
1.0000	46.80
1.0769	47.00
1.1538	49.07
1.2308	52.71
1.3077	56.34
1.3846	58.75
1.4615	61.15
1.5385	63.55
1.6154	68.38
1.6923	73.21
1.7692	78.03
1.8462	81.62
1.9231	85.21
2.0000	87.57
2.0769	91.15
2.1538	94.72
2.2308	99.50
2.3077	103.06
2.3846	106.61
2.4615	108.95
2.5385	111.28
2.6154	113.61
2.6923	115.94
2.7692	118.26
2.8462	120.58
2.9231	122.89
3.0000	124.00
3.0769	124.03
3.1538	123.95
3.2308	123.70
3.3077	122.41
3.3846	121.11
3.4615	119.82
3.5385	118.52
3.6154	116.04
3.6923	113.55



q (Kpa)	124.03
C(Kpa)	62.02

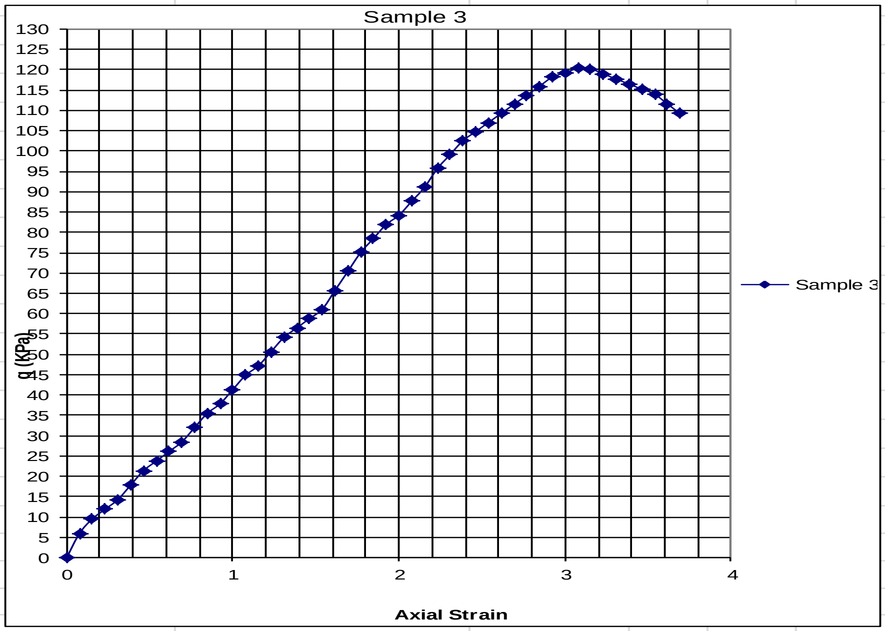
(Native Soil (Sample # 3

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	**Native Soil (Sample # 3)**
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.781
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1811.4
Bulk Unit Weight(kN/m3)	18.11
NMC %	31.85
Dry Density (kg/m3)	1373.84
Dry Unit Weight(kN/m3)	13.74

Axial Strain	**Comp. Str (q,kpa)**
0	0
0.0769	5.96
0.1538	9.53
0.2308	11.91
0.3077	14.28
0.3846	17.83
0.4615	21.38
0.5385	23.74
0.6154	26.09
0.6923	28.44
0.7692	31.97
0.8462	35.50
0.9231	37.84
1.0000	41.35
1.0769	44.86
1.1538	47.18
1.2308	50.68
1.3077	54.18
1.3846	56.49
1.4615	58.80
1.5385	61.10
1.6154	65.75
1.6923	70.39
1.7692	75.03
1.8462	78.48
1.9231	81.93
2.0000	84.20
2.0769	87.64
2.1538	91.08
2.2308	95.67
2.3077	99.10
2.3846	102.51
2.4615	104.76
2.5385	107.00
2.6154	109.24
2.6923	111.48
2.7692	113.71
2.8462	115.94
2.9231	118.17
3.0000	119.23
3.0769	120.29
3.1538	120.20
3.2308	118.95
3.3077	117.70
3.3846	116.45
3.4615	115.21
3.5385	113.96
3.6154	111.57
3.6923	109.19



q (Kpa)	120.30
C(Kpa)	60.15

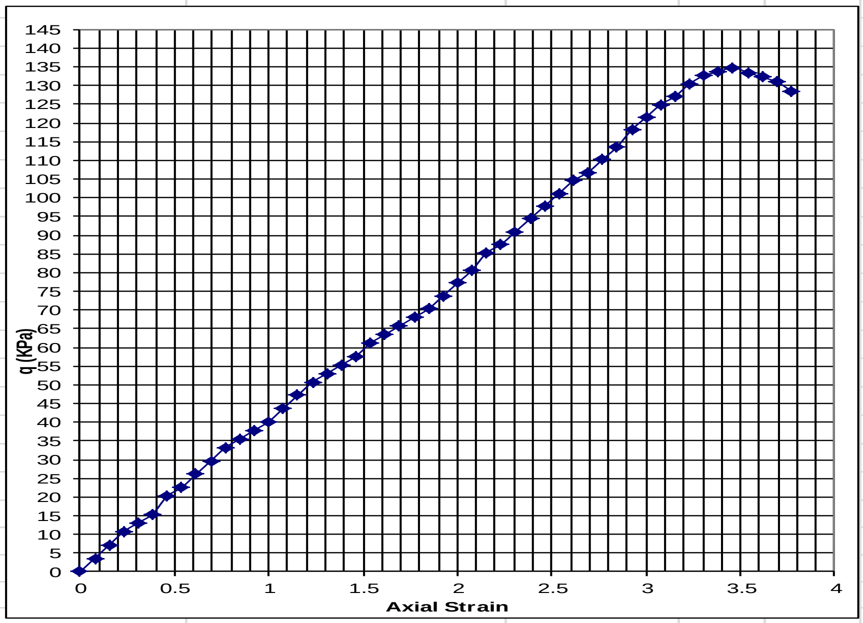
BC + 5%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC + 5%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.763
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1768.4
Bulk Unit Weight(kN/m3)	17.68
NMC %	32.70
Dry Density (kg/m3)	1332.57
Dry Unit Weight(kN/m3)	13.33

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	3.58
0.1538	7.15
0.2308	10.72
0.3077	13.09
0.3846	15.45
0.4615	20.19
0.5385	22.55
0.6154	26.09
0.6923	29.63
0.7692	33.16
0.8462	35.50
0.9231	37.84
1.0000	40.17
1.0769	43.68
1.1538	47.18
1.2308	50.68
1.3077	53.00
1.3846	55.31
1.4615	57.62
1.5385	61.10
1.6154	63.40
1.6923	65.70
1.7692	67.99
1.8462	70.28
1.9231	73.74
2.0000	77.19
2.0769	80.63
2.1538	85.24
2.2308	87.51
2.3077	90.94
2.3846	94.36
2.4615	97.78
2.5385	101.19
2.6154	104.60
2.6923	106.84
2.7692	110.23
2.8462	113.62
2.9231	118.17
3.0000	121.55
3.0769	124.92
3.1538	127.13
3.2308	130.50
3.3077	132.70
3.3846	133.75
3.4615	134.79
3.5385	133.53
3.6154	132.28
3.6923	131.02
3.7692	128.62



q (Kpa)	134.80
C(Kpa)	67.40

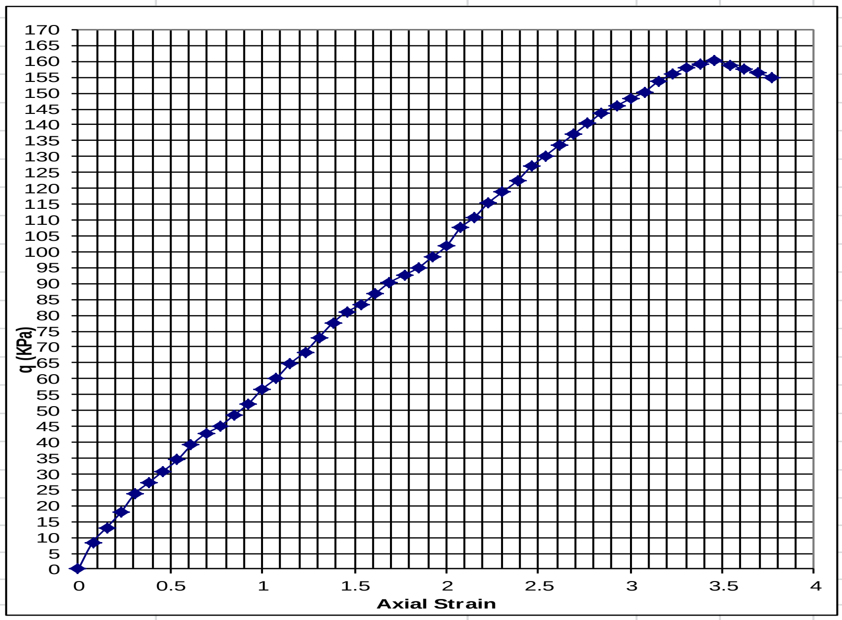
BC + 10%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	**BC + 10% QD**
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.760
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1761.1
Bulk Unit Weight(kN/m3)	17.61
NMC %	29.47
Dry Density (kg/m3)	1360.17
Dry Unit Weight(kN/m3)	13.60

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	8.35
0.1538	13.11
0.2308	17.86
0.3077	23.79
0.3846	27.34
0.4615	30.88
0.5385	34.42
0.6154	39.14
0.6923	42.66
0.7692	45.00
0.8462	48.51
0.9231	52.02
1.0000	56.71
1.0769	60.21
1.1538	64.88
1.2308	68.36
1.3077	73.02
1.3846	77.67
1.4615	81.14
1.5385	83.43
1.6154	86.88
1.6923	90.34
1.7692	92.61
1.8462	94.88
1.9231	98.32
2.0000	101.75
2.0769	107.51
2.1538	110.93
2.2308	115.51
2.3077	118.92
2.3846	122.32
2.4615	126.88
2.5385	130.27
2.6154	133.65
2.6923	137.03
2.7692	140.40
2.8462	143.77
2.9231	145.97
3.0000	148.17
3.0769	150.37
3.1538	153.71
3.2308	155.90
3.3077	158.09
3.3846	159.11
3.4615	160.14
3.5385	158.86
3.6154	157.58
3.6923	156.31
3.7692	155.03



q (Kpa)	160.10
C(Kpa)	80.05

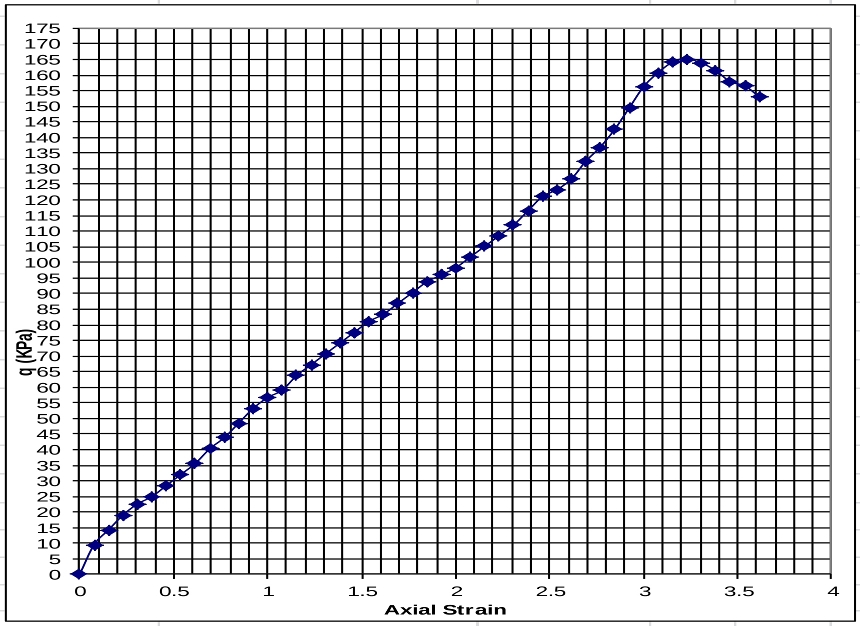
BC + 15%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC + 15%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.789
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1828.9
Bulk Unit Weight(kN/m3)	18.29
NMC %	24.66
Dry Density (kg/m3)	1467.07
Dry Unit Weight(kN/m3)	14.67

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	9.54
0.1538	14.30
0.2308	19.05
0.3077	22.60
0.3846	24.96
0.4615	28.51
0.5385	32.05
0.6154	35.58
0.6923	40.29
0.7692	43.82
0.8462	48.51
0.9231	53.21
1.0000	56.71
1.0769	59.03
1.1538	63.70
1.2308	67.19
1.3077	70.67
1.3846	74.14
1.4615	77.61
1.5385	81.08
1.6154	83.36
1.6923	86.82
1.7692	90.26
1.8462	93.71
1.9231	95.98
2.0000	98.24
2.0769	101.67
2.1538	105.09
2.2308	108.51
2.3077	111.92
2.3846	116.49
2.4615	121.06
2.5385	123.29
2.6154	126.68
2.6923	132.38
2.7692	136.92
2.8462	142.61
2.9231	149.45
3.0000	156.27
3.0769	160.78
3.1538	164.12
3.2308	165.14
3.3077	163.85
3.3846	161.42
3.4615	157.83
3.5385	156.56
3.6154	152.98
0.0000	0.00
0.0000	0.00



q (Kpa)	165.14
C(Kpa)	82.57

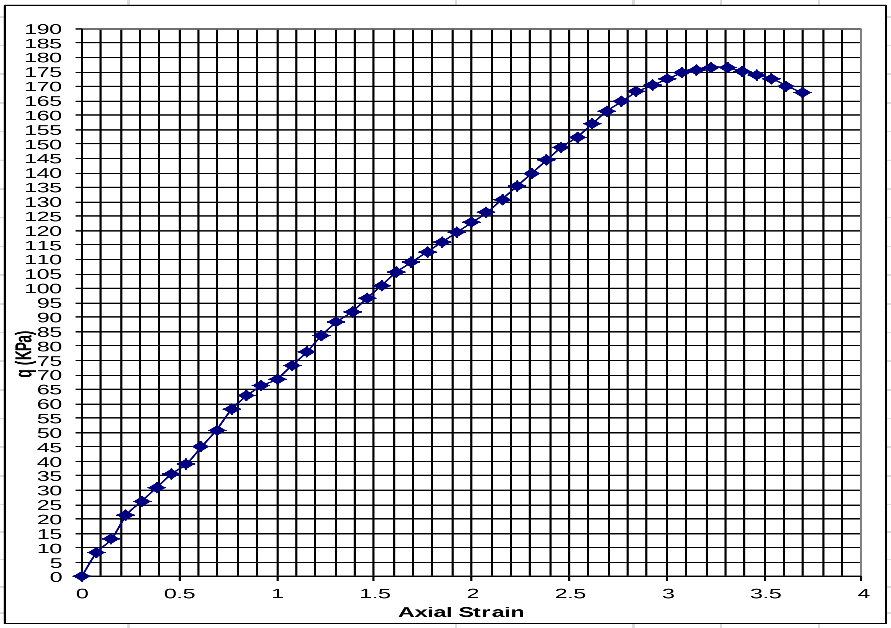
BC + 20%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC + 20% QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.789
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1827.9
Bulk Unit Weight(kN/m3)	18.28
NMC %	24.95
Dry Density (kg/m3)	1462.89
Dry Unit Weight(kN/m3)	14.63

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	8.35
0.1538	13.11
0.2308	21.43
0.3077	26.17
0.3846	30.91
0.4615	35.64
0.5385	39.17
0.6154	45.07
0.6923	50.96
0.7692	58.03
0.8462	62.71
0.9231	66.21
1.0000	68.52
1.0769	73.19
1.1538	77.85
1.2308	83.69
1.3077	88.33
1.3846	91.79
1.4615	96.43
1.5385	101.05
1.6154	105.67
1.6923	109.11
1.7692	112.54
1.8462	115.96
1.9231	119.38
2.0000	122.80
2.0769	126.21
2.1538	130.78
2.2308	135.34
2.3077	139.90
2.3846	144.45
2.4615	148.99
2.5385	152.36
2.6154	156.89
2.6923	161.41
2.7692	164.77
2.8462	168.12
2.9231	170.30
3.0000	172.48
3.0769	174.66
3.1538	175.67
3.2308	176.69
3.3077	176.55
3.3846	175.25
3.4615	173.96
3.5385	172.67
3.6154	170.23
3.6923	167.80



q (Kpa)	176.60
C(Kpa)	88.30

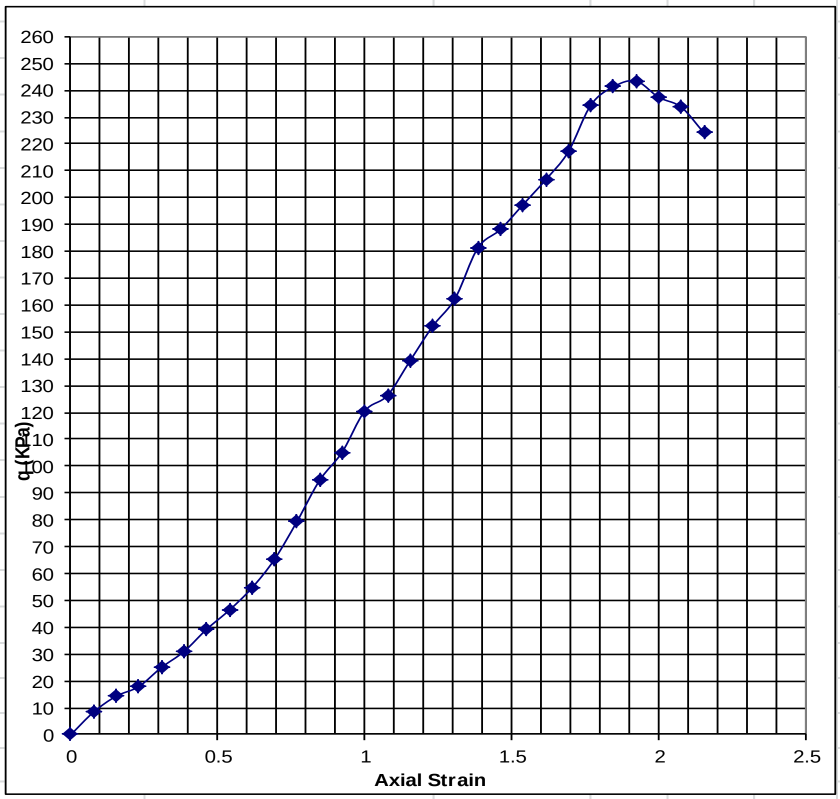
BC+2%OPC (After 7 Days Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+2%OPC (After 7 Days Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.825
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1912.2
Bulk Unit Weight(kN/m3)	19.12
NMC %	35.86
Dry Density (kg/m3)	1407.46
Dry Unit Weight(kN/m3)	14.07

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	8.35
0.1538	14.30
0.2308	17.86
0.3077	24.98
0.3846	30.91
0.4615	39.20
0.5385	46.29
0.6154	54.56
0.6923	65.18
0.7692	79.34
0.8462	94.66
0.9231	105.23
1.0000	120.51
1.0769	126.32
1.1538	139.19
1.2308	152.05
1.3077	162.53
1.3846	181.24
1.4615	188.15
1.5385	197.40
1.6154	206.64
1.6923	217.04
1.7692	234.45
1.8462	241.30
1.9231	243.45
2.0000	237.41
2.0769	233.72
2.1538	224.19
0.0000	0.00
0.0000	0.00



q (Kpa)	243.40
C(Kpa)	121.70

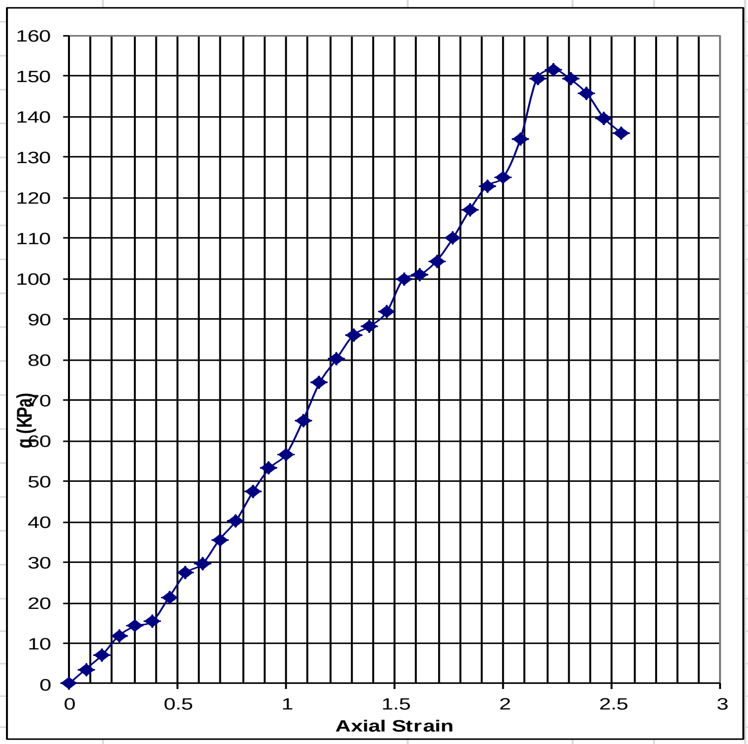
BC+2%OPC (Test Immediately After Compaction/No Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+2%OPC (Test Immediately After Compaction/No Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.825
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1912.2
Bulk Unit Weight(kN/m3)	19.12
NMC %	35.86
Dry Density (kg/m3)	1407.46
Dry Unit Weight(kN/m3)	14.07

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	3.58
0.1538	7.15
0.2308	11.91
0.3077	14.28
0.3846	15.45
0.4615	21.38
0.5385	27.30
0.6154	29.65
0.6923	35.55
0.7692	40.26
0.8462	47.33
0.9231	53.21
1.0000	56.71
1.0769	64.93
1.1538	74.32
1.2308	80.15
1.3077	85.98
1.3846	88.26
1.4615	91.72
1.5385	99.88
1.6154	100.97
1.6923	104.41
1.7692	110.19
1.8462	117.13
1.9231	122.90
2.0000	125.14
2.0769	134.39
2.1538	149.46
2.2308	151.68
2.3077	149.23
2.3846	145.62
2.4615	139.68
2.5385	136.08



q (Kpa)	151.68
C(Kpa)	75.84

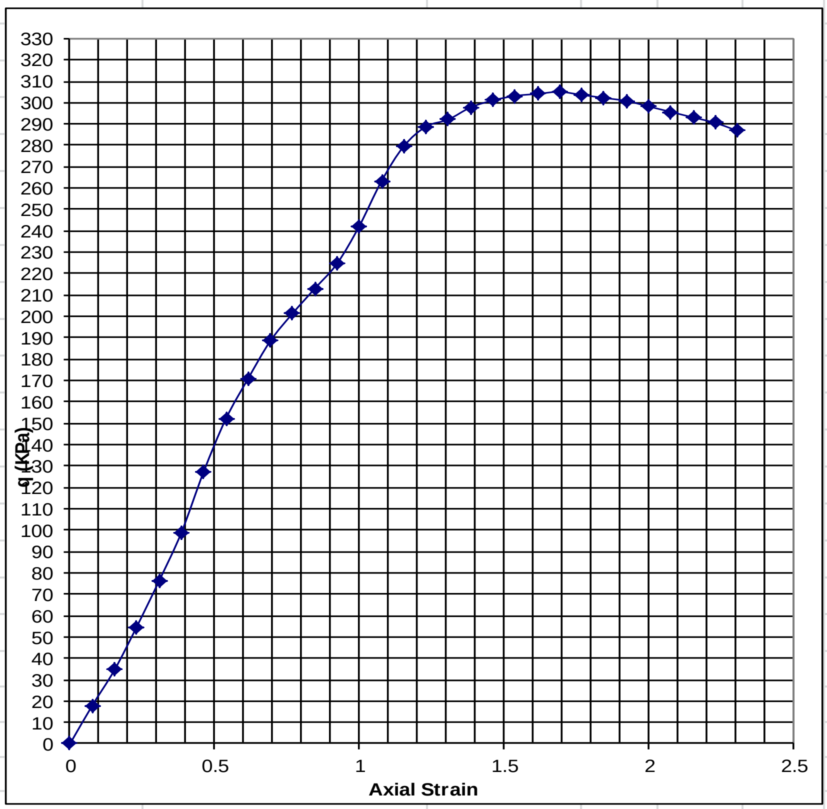
BC+4%OPC (After 7 Days Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+4%OPC (After 7 Days Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hiegth (m)	0.13
Mass (Kg)	0.825
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1912.2
Bulk Unit Weight(kN/m3)	19.12
NMC %	35.86
Dry Density (kg/m3)	1407.46
Dry Unit Weight(kN/m3)	14.07

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	17.89
0.1538	34.55
0.2308	54.77
0.3077	76.14
0.3846	98.67
0.4615	127.10
0.5385	151.93
0.6154	170.79
0.6923	188.43
0.7692	201.31
0.8462	212.99
0.9231	224.65
1.0000	242.20
1.0769	263.26
1.1538	279.57
1.2308	288.78
1.3077	292.09
1.3846	297.74
1.4615	301.04
1.5385	303.16
1.6154	304.09
1.6923	305.03
1.7692	303.62
1.8462	302.21
1.9231	300.80
2.0000	298.23
2.0769	295.65
2.1538	293.09
2.2308	290.52
2.3077	286.80



q (Kpa)	305.20
C(Kpa)	152.60

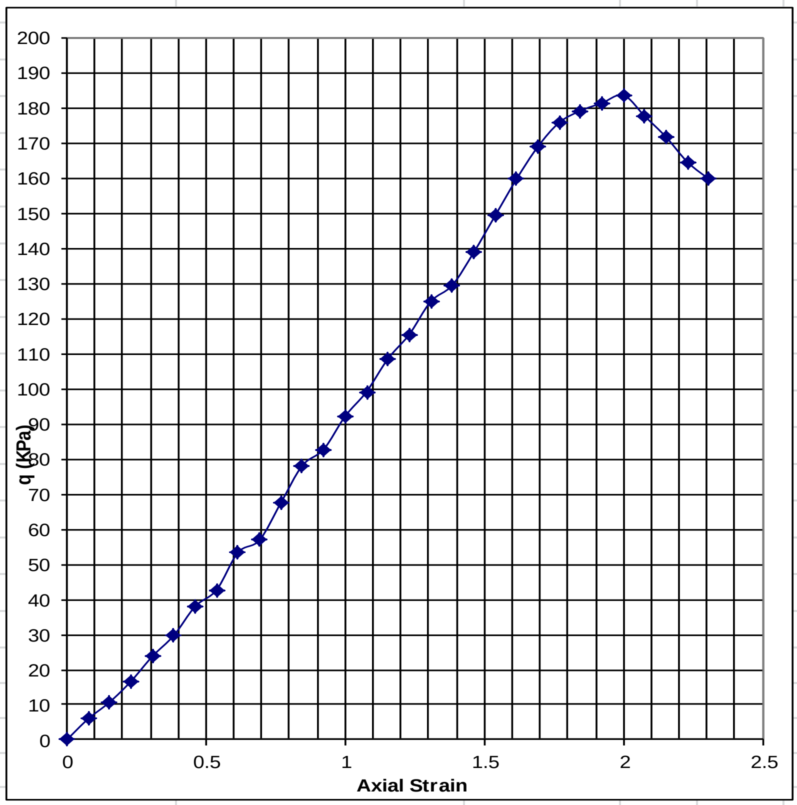
BC+4%OPC (Test Immediately After Compaction/No Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+4%OPC (Test Immediately After Compaction/No Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.825
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1912.2
Bulk Unit Weight(kN/m3)	19.12
NMC %	35.86
Dry Density (kg/m3)	1407.46
Dry Unit Weight(kN/m3)	14.07

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	5.96
0.1538	10.72
0.2308	16.67
0.3077	23.79
0.3846	29.72
0.4615	38.01
0.5385	42.73
0.6154	53.37
0.6923	56.89
0.7692	67.50
0.8462	78.10
0.9231	82.77
1.0000	92.15
1.0769	99.16
1.1538	108.52
1.2308	115.51
1.3077	124.84
1.3846	129.45
1.4615	138.76
1.5385	149.23
1.6154	159.68
1.6923	168.94
1.7692	175.84
1.8462	179.22
1.9231	181.42
2.0000	183.61
2.0769	177.63
2.1538	171.65
2.2308	164.51
2.3077	159.72



q (Kpa)	183.60
C(Kpa)	91.80

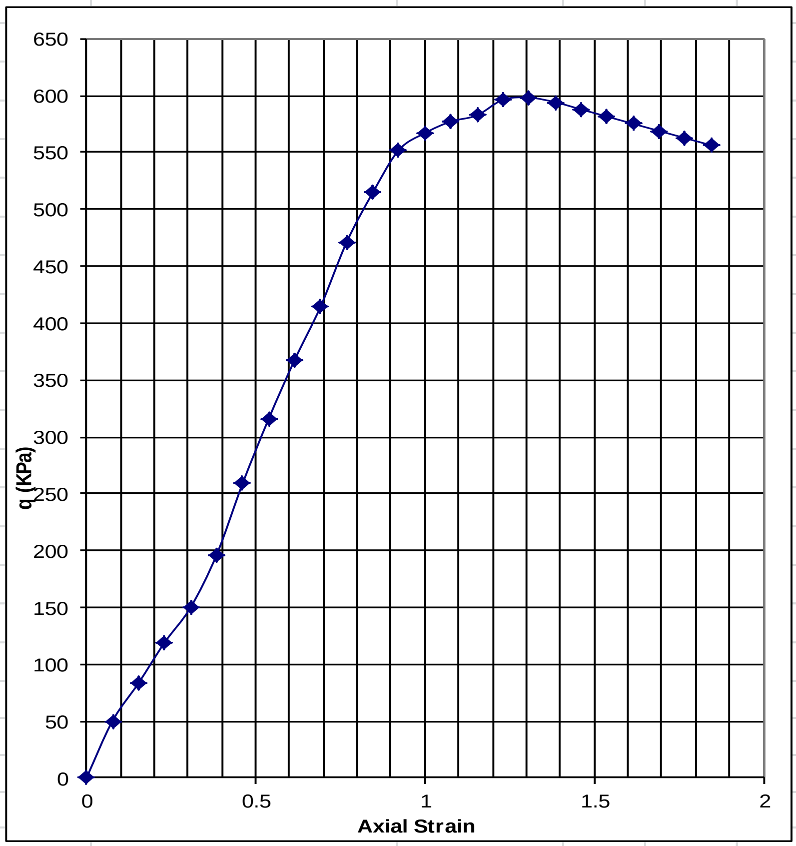
BC+8%OPC (After 7 Days Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+8%OPC (After 7 Days Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.822
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1904.4
Bulk Unit Weight(kN/m3)	19.04
NMC %	31.87
Dry Density (kg/m3)	1444.12
Dry Unit Weight(kN/m3)	14.44

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	50.08
0.1538	83.41
0.2308	119.06
0.3077	149.90
0.3846	196.15
0.4615	258.96
0.5385	315.73
0.6154	367.67
0.6923	414.79
0.7692	471.31
0.8462	514.73
0.9231	552.16
1.0000	567.09
1.0769	577.28
1.1538	582.73
1.2308	596.42
1.3077	598.31
1.3846	594.31
1.4615	587.97
1.5385	581.63
1.6154	575.31
1.6923	568.99
1.7692	562.69
1.8462	556.39



q (Kpa)	599.00
C(Kpa)	299.50

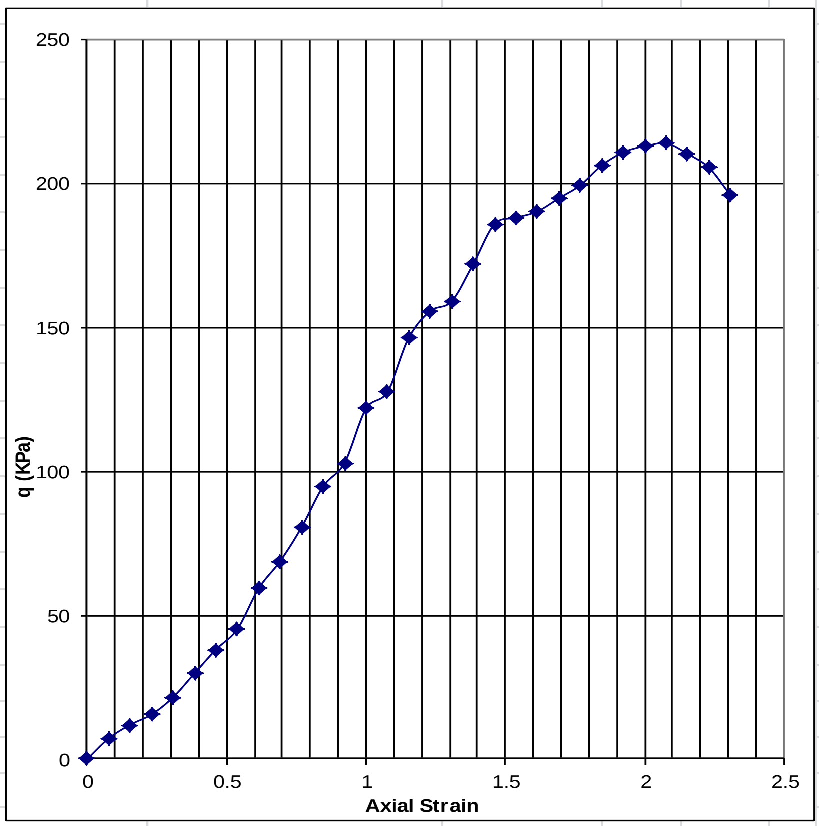
BC+8%OPC (Test Immediately After Compaction/No Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	**BC+8%OPC (Test Immediately After Compaction/No Curing)**
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.822
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1904.4
Bulk Unit Weight(kN/m3)	19.04
NMC %	31.87
Dry Density (kg/m3)	1444.12
Dry Unit Weight(kN/m3)	14.44

Axial Strain	**Comp. Str (q,kpa)**
0	0
0.0769	7.15
0.1538	11.92
0.2308	15.48
0.3077	21.41
0.3846	29.72
0.4615	38.01
0.5385	45.10
0.6154	59.30
0.6923	68.74
0.7692	80.53
0.8462	94.66
0.9231	102.87
1.0000	121.69
1.0769	127.50
1.1538	146.27
1.2308	155.59
1.3077	159.00
1.3846	171.82
1.4615	185.80
1.5385	188.00
1.6154	190.20
1.6923	194.75
1.7692	199.29
1.8462	206.16
1.9231	210.68
2.0000	212.85
2.0769	213.85
2.1538	210.18
2.2308	205.35
2.3077	195.86



q (Kpa)	213.80
C(Kpa)	106.90

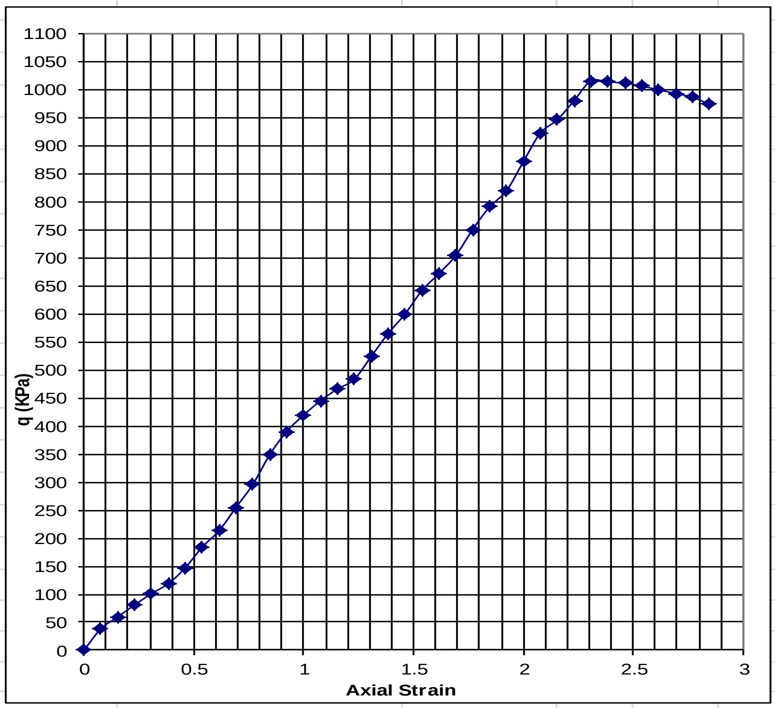
BC+12%OPC (After 7 Days Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+12%OPC (After 7 Days Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.835
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1936.6
Bulk Unit Weight(kN/m3)	19.37
NMC %	30.28
Dry Density (kg/m3)	1486.49
Dry Unit Weight(kN/m3)	14.86

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	38.16
0.1538	59.58
0.2308	80.96
0.3077	101.13
0.3846	118.88
0.4615	147.30
0.5385	183.98
0.6154	213.49
0.6923	254.80
0.7692	296.05
0.8462	349.07
0.9231	390.18
1.0000	419.41
1.0769	445.06
1.1538	465.95
1.2308	483.26
1.3077	524.11
1.3846	564.89
1.4615	599.73
1.5385	641.56
1.6154	671.59
1.6923	703.91
1.7692	750.25
1.8462	790.66
1.9231	819.30
2.0000	871.29
2.0769	922.02
2.1538	945.82
2.2308	980.08
2.3077	1015.45
2.3846	1013.48
2.4615	1011.52
2.5385	1006.07
2.6154	999.46
2.6923	992.87
2.7692	986.28
2.8462	973.91



q (Kpa)	1015.40
C(Kpa)	507.70

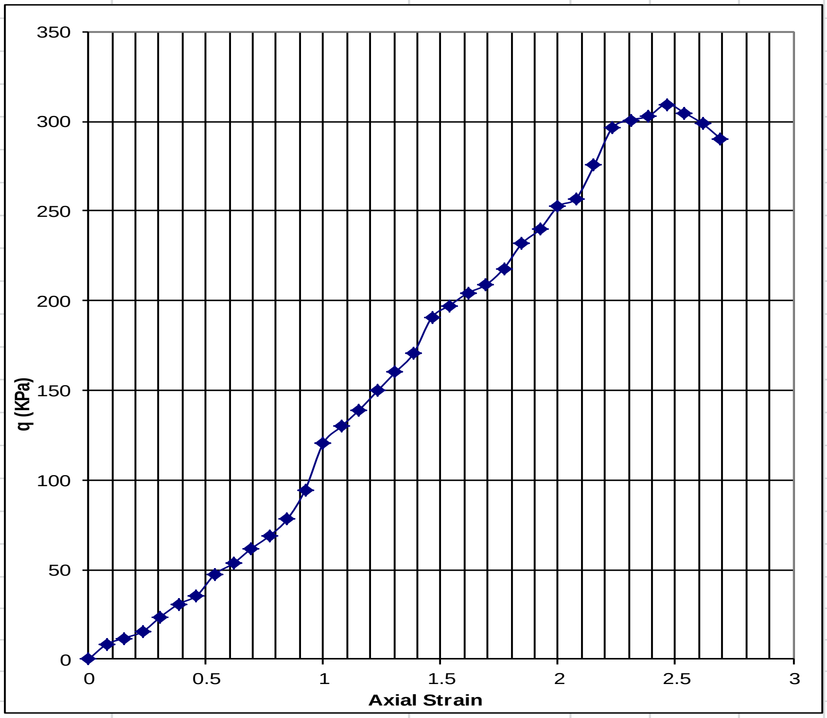
BC+12%OPC (Test Immediately After Compaction/No Curing)

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+12%OPC (Test Immediately After Compaction/No Curing)
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.835
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1936.6
Bulk Unit Weight(kN/m3)	19.37
NMC %	30.28
Dry Density (kg/m3)	1486.49
Dry Unit Weight(kN/m3)	14.86

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	8.35
0.1538	11.92
0.2308	15.48
0.3077	23.79
0.3846	30.91
0.4615	35.64
0.5385	47.48
0.6154	53.37
0.6923	61.63
0.7692	68.68
0.8462	78.10
0.9231	94.59
1.0000	120.51
1.0769	129.86
1.1538	139.19
1.2308	149.69
1.3077	160.18
1.3846	170.64
1.4615	190.50
1.5385	197.40
1.6154	204.29
1.6923	208.83
1.7692	218.04
1.8462	231.93
1.9231	239.94
2.0000	252.61
2.0769	257.09
2.1538	275.57
2.2308	296.36
2.3077	300.79
2.3846	302.88
2.4615	309.63
2.5385	304.73
2.6154	298.68
2.6923	290.31
0.0000	0.00
0.0000	0.00



q (Kpa)	309.60
C(Kpa)	154.80

BC+4%OPC+5%QD

Unconfind Compressive Strength Test, ASTM D2166

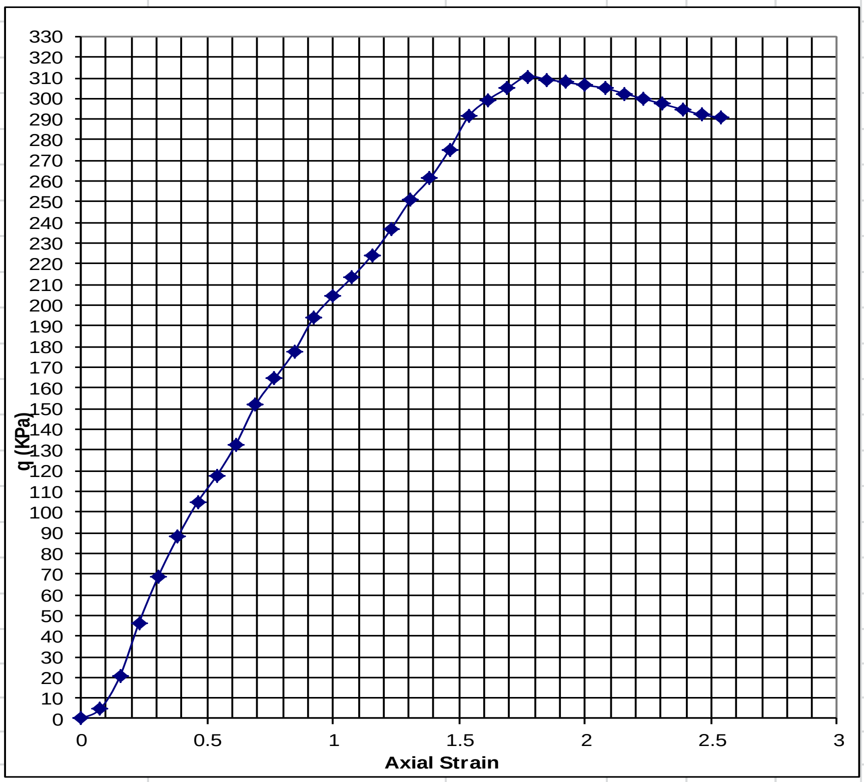
TP-ID: BC+4%OPC+5%QD

Depth(m): -

Sample : Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.828
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1919.0
Bulk Unit Weight(kN/m3)	19.19
NMC %	37.62
Dry Density (kg/m3)	1394.36
Dry Unit Weight(kN/m3)	13.94

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	4.77
0.1538	20.26
0.2308	46.43
0.3077	69.00
0.3846	87.97
0.4615	104.53
0.5385	117.51
0.6154	132.84
0.6923	151.70
0.7692	164.60
0.8462	177.49
0.9231	193.91
1.0000	204.39
1.0769	213.68
1.1538	224.13
1.2308	236.92
1.3077	250.87
1.3846	261.26
1.4615	275.17
1.5385	291.40
1.6154	299.40
1.6923	305.03
1.7692	310.65
1.8462	309.24
1.9231	307.82
2.0000	306.41
2.0769	305.00
2.1538	302.43
2.2308	299.86
2.3077	297.29
2.3846	294.73
2.4615	292.17
2.5385	290.77



q (Kpa)	310.50
C(Kpa)	155.25

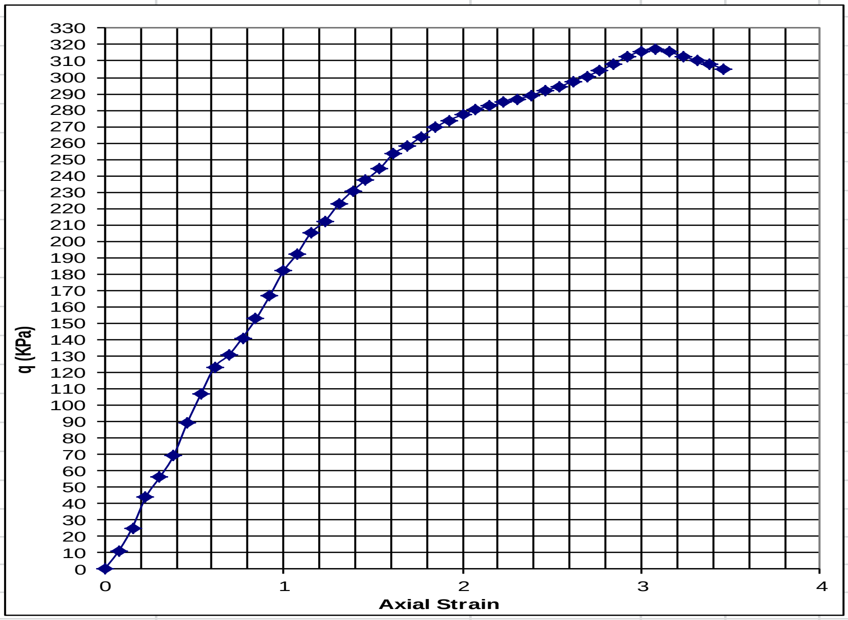
BC+4%OPC+10%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+4%OPC+10%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.854
Area (m^2)	0.00332
Volume,m3	0.00043
Bulk density (kg/m3)	1979.7
Bulk Unit Weight(kN/m3)	19.80
NMC %	34.40
Dry Density (kg/m3)	1472.98
Dry Unit Weight(kN/m3)	14.73

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	10.73
0.1538	25.02
0.2308	44.05
0.3077	55.92
0.3846	68.95
0.4615	89.09
0.5385	106.83
0.6154	123.35
0.6923	130.36
0.7692	140.92
0.8462	152.64
0.9231	166.71
1.0000	181.94
1.0769	192.43
1.1538	205.25
1.2308	212.16
1.3077	222.60
1.3846	230.66
1.4615	237.54
1.5385	244.40
1.6154	253.61
1.6923	258.10
1.7692	263.76
1.8462	269.41
1.9231	273.88
2.0000	277.17
2.0769	280.46
2.1538	282.58
2.2308	284.69
2.3077	286.80
2.3846	288.90
2.4615	292.17
2.5385	294.26
2.6154	297.52
2.6923	300.76
2.7692	304.01
2.8462	308.40
2.9231	312.79
3.0000	316.02
3.0769	316.92
3.1538	315.52
3.2308	312.96
3.3077	310.40
3.3846	307.85
3.4615	305.30



q (Kpa)	316.40
C(Kpa)	158.20

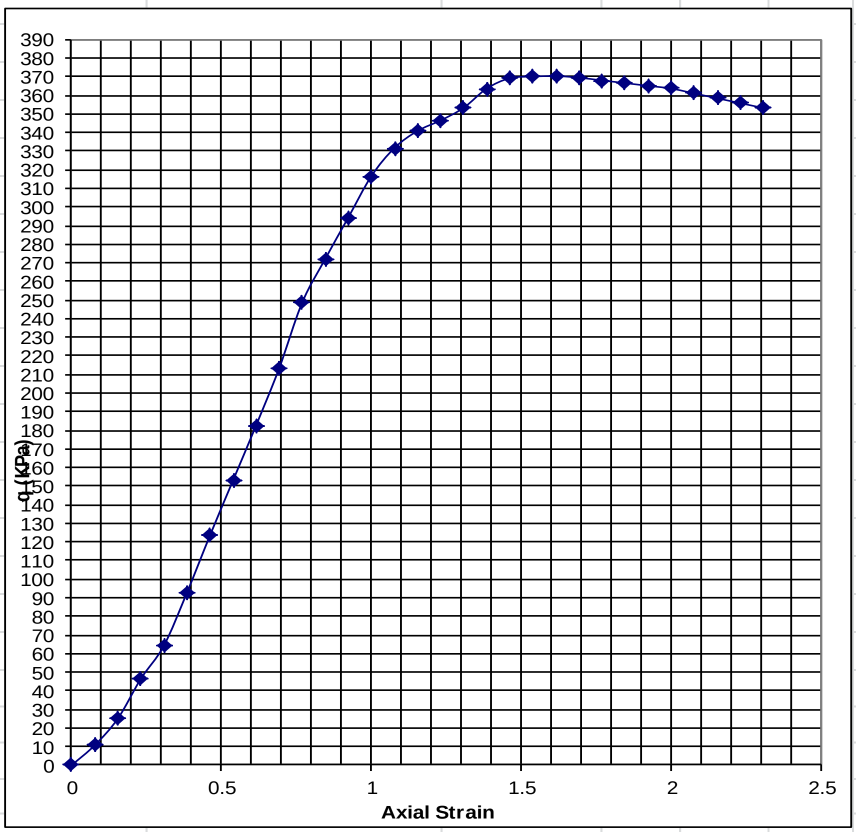
BC+4%OPC+15%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+4%OPC+15%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.867
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	2009.8
Bulk Unit Weight(kN/m3)	20.10
NMC %	31.68
Dry Density (kg/m3)	1526.32
Dry Unit Weight(kN/m3)	15.26

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	10.73
0.1538	25.02
0.2308	46.43
0.3077	64.24
0.3846	92.73
0.4615	123.54
0.5385	153.12
0.6154	182.65
0.6923	213.32
0.7692	248.68
0.8462	272.15
0.9231	294.41
1.0000	316.63
1.0769	331.73
1.1538	340.91
1.2308	346.54
1.3077	353.33
1.3846	363.65
1.4615	369.24
1.5385	370.13
1.6154	370.43
1.6923	369.55
1.7692	368.09
1.8462	366.63
1.9231	365.17
2.0000	363.72
2.0769	361.10
2.1538	358.48
2.2308	355.86
2.3077	353.25



q (Kpa)	370.00
C(Kpa)	185.00

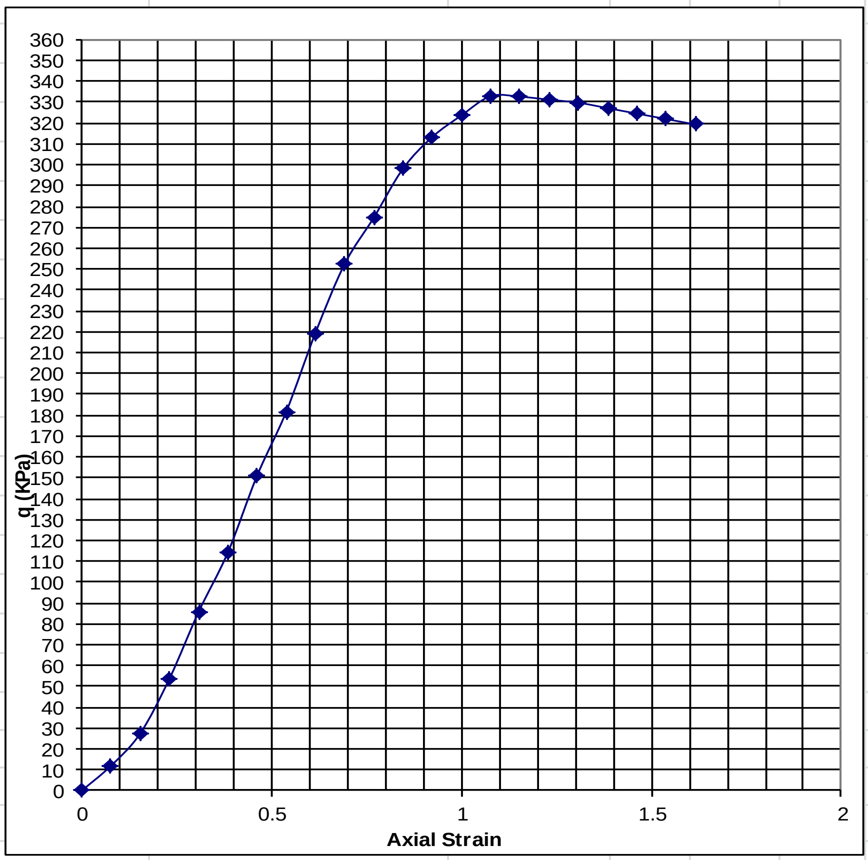
BC+4%OPC+20%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID: BC+4%OPC+20%QD
Depth(m): -
Sample : Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.883
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	2046.5
Bulk Unit Weight(kN/m3)	20.46
NMC %	32.12
Dry Density (kg/m3)	1548.95
Dry Unit Weight(kN/m3)	15.49

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	11.92
0.1538	27.41
0.2308	53.58
0.3077	85.66
0.3846	114.12
0.4615	150.86
0.5385	181.60
0.6154	219.42
0.6923	252.43
0.7692	274.73
0.8462	298.19
0.9231	313.33
1.0000	323.72
1.0769	332.91
1.1538	332.65
1.2308	331.21
1.3077	329.78
1.3846	327.17
1.4615	324.56
1.5385	321.96
1.6154	319.36



q (Kpa)	332.60
C(Kpa)	166.30

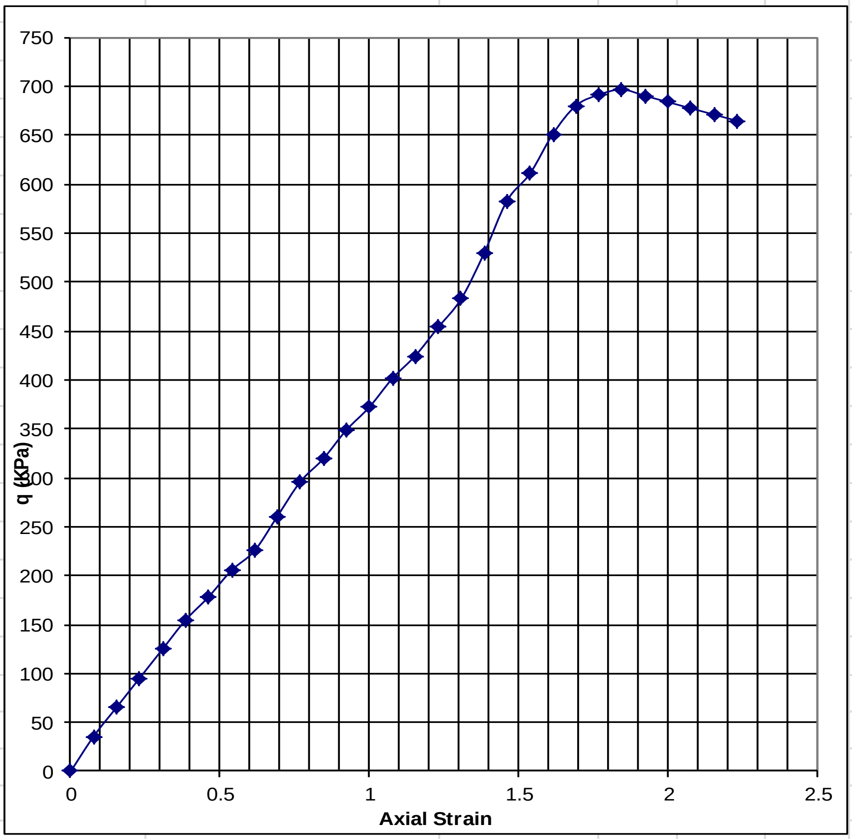
BC+8%OPC+5%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+8%OPC+5%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.852
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1975.1
Bulk Unit Weight(kN/m3)	19.75
NMC %	30.18
Dry Density (kg/m3)	1517.18
Dry Unit Weight(kN/m3)	15.17

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	35.77
0.1538	65.53
0.2308	95.25
0.3077	124.92
0.3846	154.54
0.4615	178.18
0.5385	205.34
0.6154	225.35
0.6923	260.73
0.7692	296.05
0.8462	319.49
0.9231	348.80
1.0000	372.16
1.0769	401.38
1.1538	424.66
1.2308	453.80
1.3077	482.89
1.3846	529.59
1.4615	583.27
1.5385	611.01
1.6154	651.63
1.6923	680.45
1.7692	691.64
1.8462	696.95
1.9231	690.55
2.0000	684.16
2.0769	677.78
2.1538	671.41
2.2308	665.05



q (Kpa)	697.20
C(Kpa)	348.60

BC+8%OPC+10%QD

Unconfind Compressive Strength Test, ASTM D2166

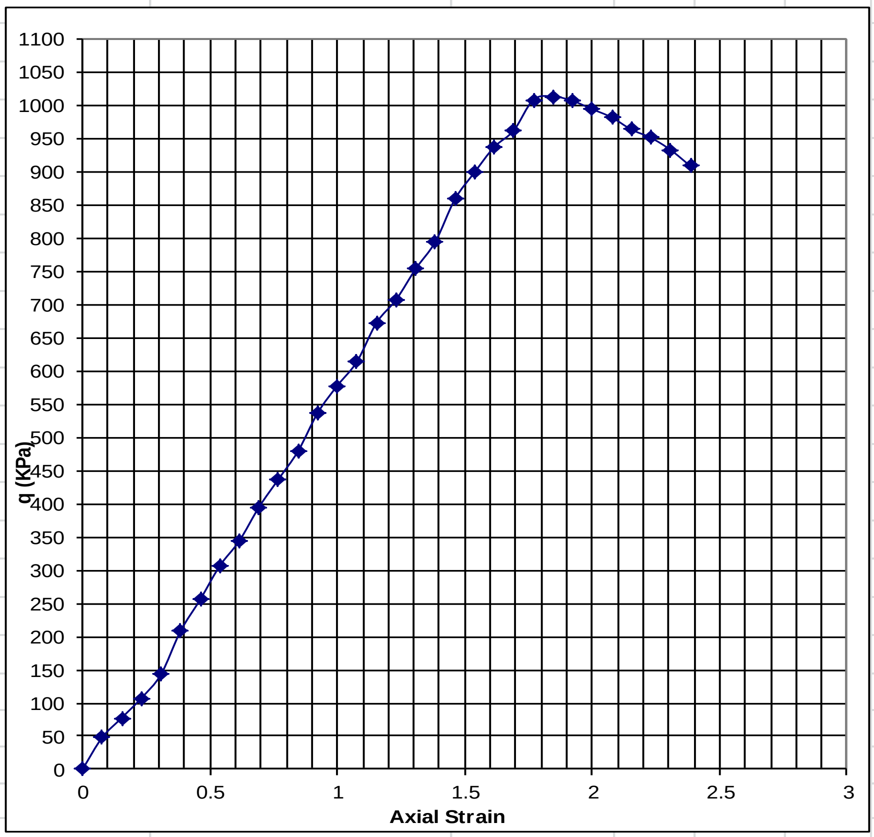
TP-ID: BC+8%OPC+10%QD

Depth(m): -

Sample : Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.846
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1961.1
Bulk Unit Weight(kN/m3)	19.61
NMC %	33.98
Dry Density (kg/m3)	1463.72
Dry Unit Weight(kN/m3)	14.64

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	47.70
0.1538	77.45
0.2308	107.16
0.3077	142.76
0.3846	208.04
0.4615	255.39
0.5385	306.23
0.6154	343.95
0.6923	394.64
0.7692	436.97
0.8462	479.23
0.9231	536.79
1.0000	577.73
1.0769	613.87
1.1538	672.38
1.2308	707.22
1.3077	753.78
1.3846	794.38
1.4615	858.43
1.5385	898.89
1.6154	936.93
1.6923	962.01
1.7692	1008.15
1.8462	1013.22
1.9231	1006.57
2.0000	994.09
2.0769	981.62
2.1538	963.33
2.2308	950.91
2.3077	932.67
2.3846	908.64



q (Kpa)	1013.20
C(Kpa)	506.60

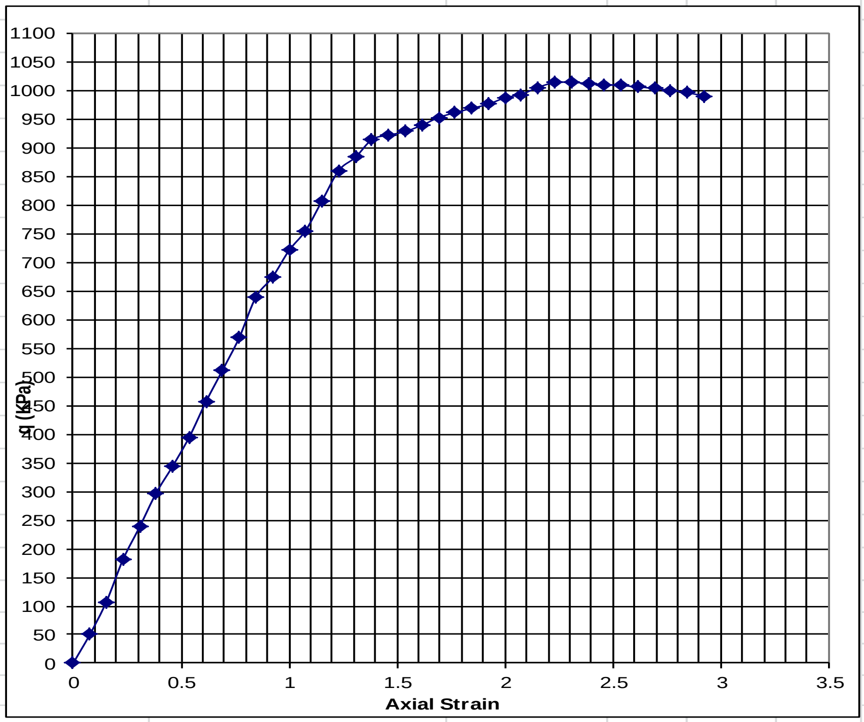
BC+8%OPC+15%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+8%OPC+15%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.852
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1976.0
Bulk Unit Weight(kN/m3)	19.76
NMC %	31.01
Dry Density (kg/m3)	1508.27
Dry Unit Weight(kN/m3)	15.08

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	50.08
0.1538	107.24
0.2308	180.98
0.3077	237.94
0.3846	297.20
0.4615	344.48
0.5385	395.26
0.6154	456.62
0.6923	511.97
0.7692	568.42
0.8462	638.97
0.9231	673.95
1.0000	720.68
1.0769	755.54
1.1538	808.03
1.2308	860.45
1.3077	883.33
1.3846	914.42
1.4615	921.94
1.5385	928.27
1.6154	939.28
1.6923	952.63
1.7692	961.26
1.8462	968.70
1.9231	976.14
2.0000	987.07
2.0769	993.30
2.1538	1005.37
2.2308	1013.91
2.3077	1014.28
2.3846	1012.32
2.4615	1010.36
2.5385	1008.40
2.6154	1006.44
2.6923	1003.32
2.7692	1000.21
2.8462	995.94
2.9231	990.51



q (Kpa)	1014.50
C(Kpa)	507.25

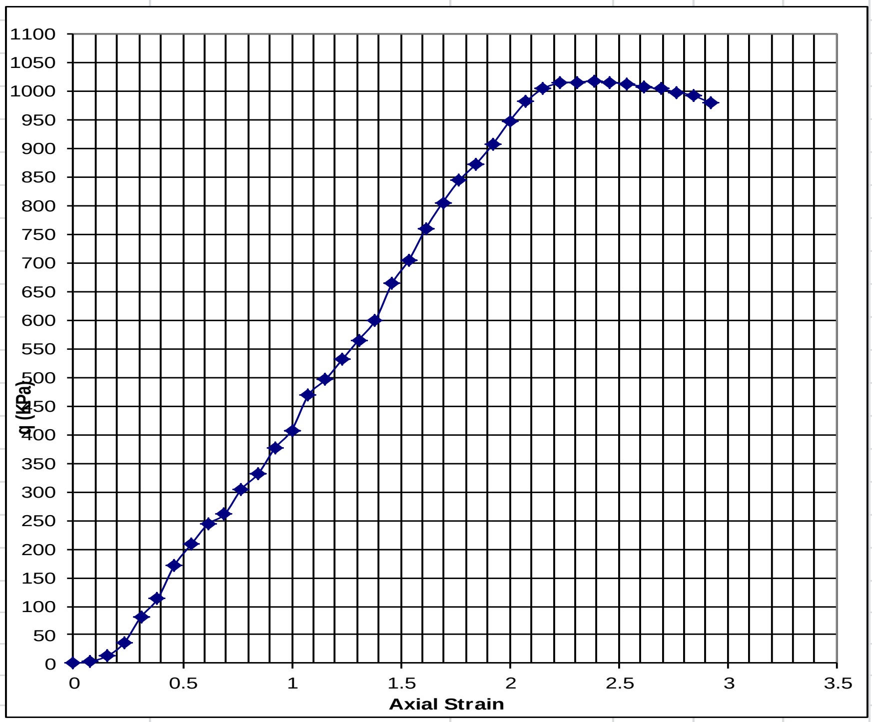
BC+8%OPC+20%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+8%OPC+20%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.857
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1987.6
Bulk Unit Weight(kN/m3)	19.88
NMC %	29.58
Dry Density (kg/m3)	1533.88
Dry Unit Weight(kN/m3)	15.34

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	3.58
0.1538	13.11
0.2308	35.72
0.3077	80.90
0.3846	112.94
0.4615	171.05
0.5385	207.72
0.6154	243.14
0.6923	260.73
0.7692	304.34
0.8462	331.32
0.9231	375.99
1.0000	407.60
1.0769	468.67
1.1538	495.44
1.2308	530.41
1.3077	565.33
1.3846	600.20
1.4615	664.40
1.5385	705.01
1.6154	759.64
1.6923	804.80
1.7692	844.03
1.8462	872.65
1.9231	907.08
2.0000	947.30
2.0769	981.62
2.1538	1004.20
2.2308	1013.91
2.3077	1015.45
2.3846	1016.98
2.4615	1015.01
2.5385	1011.88
2.6154	1007.60
2.6923	1003.32
2.7692	997.89
2.8462	991.30
2.9231	978.93



q (Kpa)	1016.80
C(Kpa)	508.40

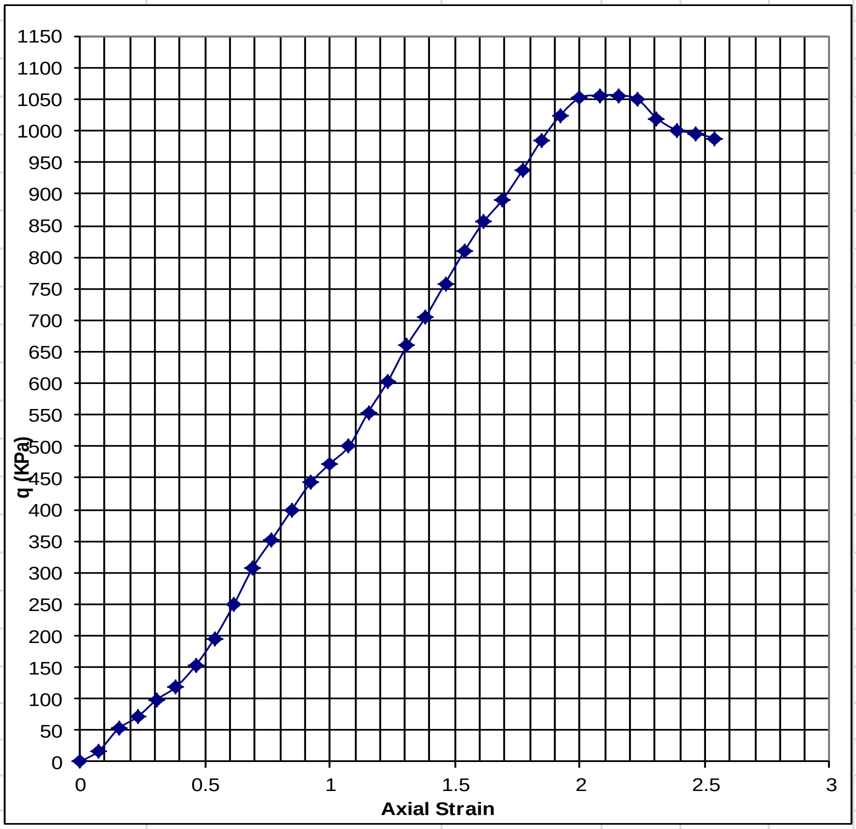
BC+12%OPC+5%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+12%OPC+5%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.787
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1825.1
Bulk Unit Weight(kN/m3)	18.25
NMC %	34.68
Dry Density (kg/m3)	1355.11
Dry Unit Weight(kN/m3)	13.55

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	17.89
0.1538	52.43
0.2308	71.44
0.3077	98.75
0.3846	118.88
0.4615	152.05
0.5385	195.85
0.6154	249.07
0.6923	308.13
0.7692	352.89
0.8462	398.77
0.9231	442.20
1.0000	472.58
1.0769	500.54
1.1538	554.42
1.2308	602.31
1.3077	659.55
1.3846	706.11
1.4615	758.48
1.5385	809.59
1.6154	855.92
1.6923	891.62
1.7692	936.64
1.8462	985.10
1.9231	1025.30
2.0000	1052.56
2.0769	1056.41
2.1538	1056.75
2.2308	1050.08
2.3077	1020.11
2.3846	1001.83
2.4615	996.39
2.5385	988.62



q (Kpa)	1056.40
C(Kpa)	528.20

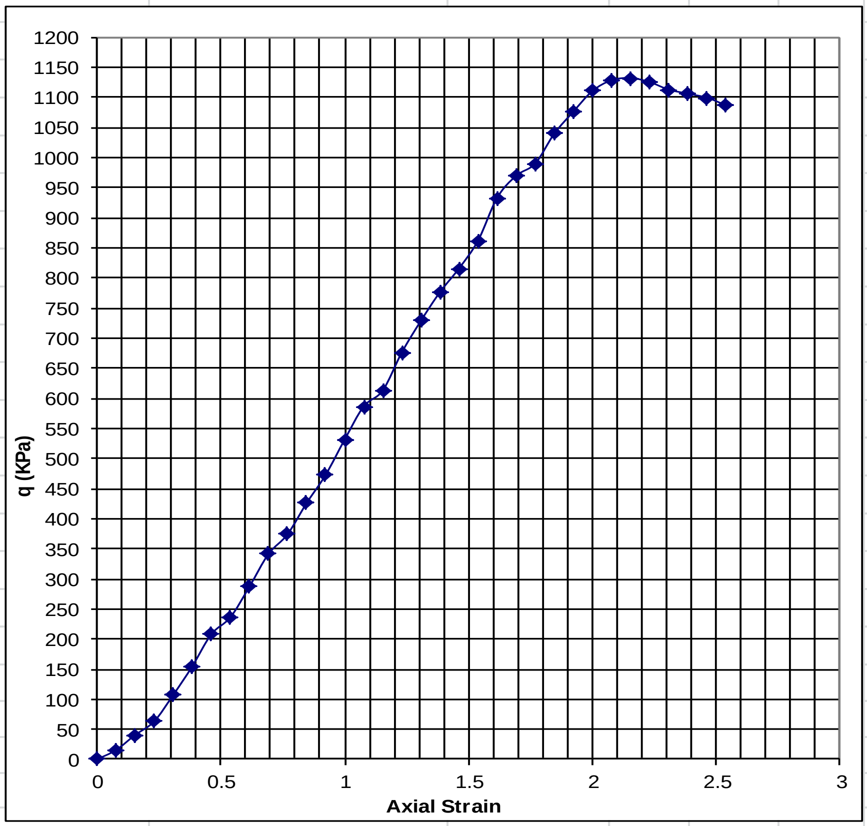
BC+12%OPC+10%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID: BC+12%OPC+10%QD
Depth(m): -
Sample : Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.840
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1947.2
Bulk Unit Weight(kN/m3)	19.47
NMC %	30.49
Dry Density (kg/m3)	1492.24
Dry Unit Weight(kN/m3)	14.92

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	15.50
0.1538	40.51
0.2308	63.10
0.3077	107.07
0.3846	154.54
0.4615	207.88
0.5385	236.20
0.6154	287.02
0.6923	341.31
0.7692	374.21
0.8462	425.98
0.9231	472.95
1.0000	531.65
1.0769	586.72
1.1538	613.40
1.2308	676.57
1.3077	729.04
1.3846	776.72
1.4615	816.10
1.5385	862.46
1.6154	933.41
1.6923	970.22
1.7692	990.56
1.8462	1040.16
1.9231	1076.80
2.0000	1111.04
2.0769	1128.86
2.1538	1132.65
2.2308	1125.92
2.3077	1113.38
2.3846	1106.68
2.4615	1099.98
2.5385	1087.49



q (Kpa)	1132.50
C(Kpa)	566.25

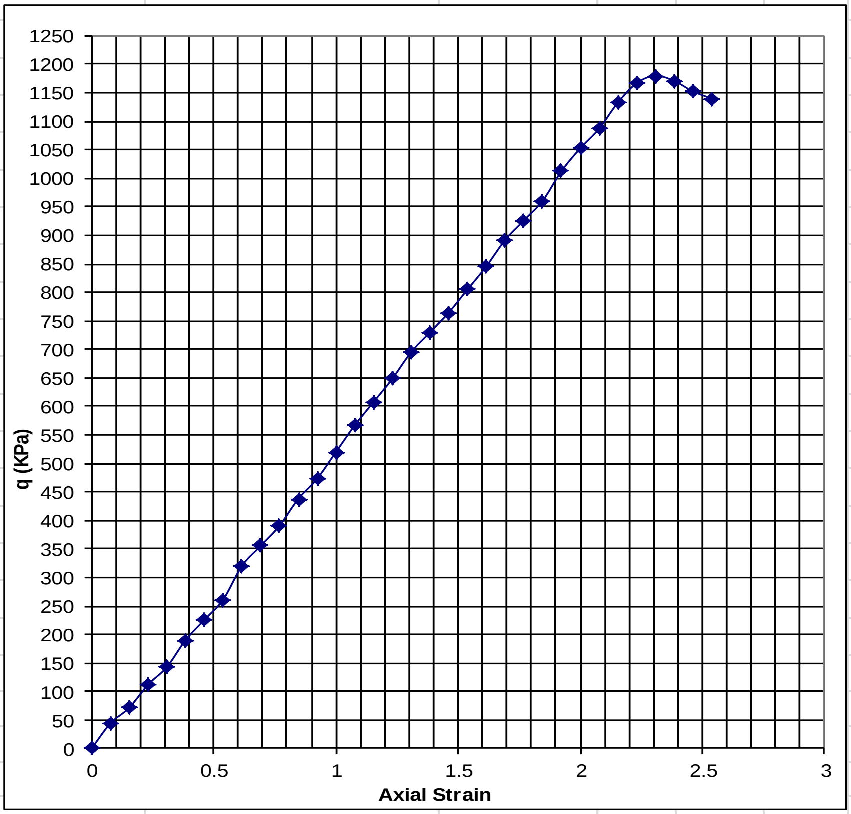
BC+12%OPC+15%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+12%OPC+15%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.841
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	1949.3
Bulk Unit Weight(kN/m3)	19.49
NMC %	30.88
Dry Density (kg/m3)	1489.45
Dry Unit Weight(kN/m3)	14.89

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	44.12
0.1538	71.49
0.2308	111.92
0.3077	142.76
0.3846	190.21
0.4615	225.70
0.5385	261.13
0.6154	320.23
0.6923	355.54
0.7692	390.79
0.8462	437.81
0.9231	472.95
1.0000	519.84
1.0769	566.65
1.1538	607.50
1.2308	648.28
1.3077	694.89
1.3846	729.65
1.4615	764.36
1.5385	804.89
1.6154	845.35
1.6923	891.62
1.7692	926.09
1.8462	960.51
1.9231	1012.42
2.0000	1052.56
2.0769	1086.79
2.1538	1132.65
2.2308	1166.76
2.3077	1179.83
2.3846	1170.75
2.4615	1152.36
2.5385	1139.82



q (Kpa)	1179.60
C(Kpa)	589.80

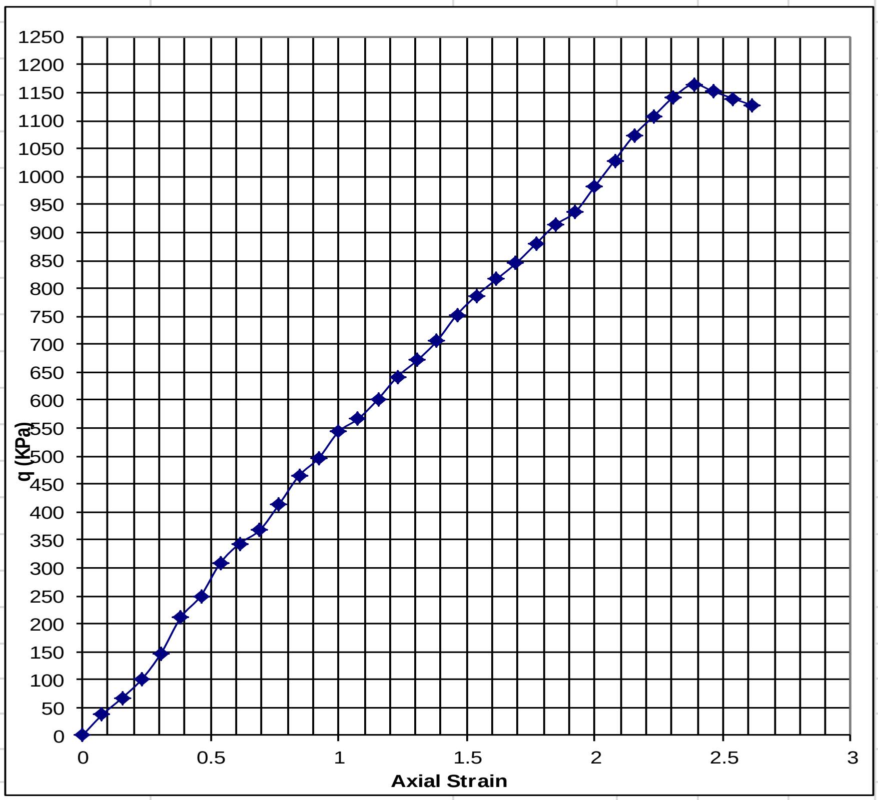
BC+12%OPC+20%QD

Unconfind Compressive Strength Test, ASTM D2166

TP-ID:	BC+12%OPC+20%QD
Depth(m):	-
Sample :	Disturbed Sample

Unit Weight	
Diameter (m)	0.065
Hieght (m)	0.13
Mass (Kg)	0.879
Area (m^2)	0.00332
Volume,m3	0.0004
Bulk density (kg/m3)	2038.1
Bulk Unit Weight(kN/m3)	20.38
NMC %	30.19
Dry Density (kg/m3)	1565.52
Dry Unit Weight(kN/m3)	15.66

Axial Strain	Comp. Str (q,kpa)
0	0
0.0769	36.97
0.1538	66.73
0.2308	100.01
0.3077	147.52
0.3846	211.60
0.4615	249.45
0.5385	308.61
0.6154	343.95
0.6923	367.39
0.7692	414.47
0.8462	465.03
0.9231	496.59
1.0000	543.47
1.0769	566.65
1.1538	601.60
1.2308	642.39
1.3077	671.33
1.3846	706.11
1.4615	752.60
1.5385	787.26
1.6154	816.00
1.6923	844.69
1.7692	879.20
1.8462	913.65
1.9231	936.34
2.0000	982.39
2.0769	1028.36
2.1538	1074.26
2.2308	1108.42
2.3077	1142.52
2.3846	1164.92
2.4615	1152.36
2.5385	1139.82
2.6154	1127.30



q (Kpa)	1164.80
C(Kpa)	582.40