JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GEOTECHINICAL ENGINEERING

Correlation of California Bearing Ratio with Soil Index Properties for Subgrade Soil in Jimma Town

A thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirements for the Degree of Master of Science in Geotechnical Engineering

By: - Gifti Hailu

Jimma, Ethiopia

January, 2018

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GEOTECHNICAL ENGINEERING

Correlation of California Bearing Ratio with Soil Index Properties for Subgrade Soil in Jimma Town

A thesis submitted to the School of Graduate Studies of Jimma institute of technology, in Partial Fulfilment of the Requirements for the Degree of Master of Science in Geotechnical Engineering

By: - Gifti Hailu

Advisor:

Main Advisor: - Dr. Yoseph Birru

Co Advisor: - Mr. Damtew Tsige

DECLARATION

This research is my original work and has not been presented for a degree in any other university.

Gifti Hailu

Signature__________________________ Date_____________________

This research proposal has been submitted for examination with my approval as university supervisor.

Advisor

Main advisor: - Dr.Yoseph Birru

Signature________________________ Date_____________________

Co Advisor: - Mr. Damtew Tsige

Signature________________________ Date_____________________

Acknowledgement

First and most of all, I would like to thank almighty God for blessing and being with me in every steps.

I would like to express my warmest thanks my advisor Dr.Yoseph Birru for immense guidance and supervision all the way throughout this research work with good heart and patient. Also I am very grateful for my research co- advisor Mr.Damtew Tsige Who has encouraged, directed, and given me academic advisory throughout my work.

A special thanks address to Jimma University, Institute of Technology, Geotechnical chair Staffs and Ethiopian Roads Authority (ERA) my sponsor deserves thank for its financial support until the completion of the study.

A special thank goes to all my friends and my family especially my sister husband Mr. Danial Alemayehu for their support and encouragement during the development of thesis research.

Table of Contents

List of Symbols

c	Cohesion of Soil
Cu	Undrained Cohesion of Soil
D60	Diameter on the Cumulative Size Distribution Curve Where 60 percent of Particles are fines
IP	Plasticity Index
m_w	mass of water contained in soil
ms	mass of dry soil
P200	Percent Passing Sieve No. 200 (0.075mm Sieve Size)
R	Pearson Product Moment Correlation Coefficient
R2	Coefficient of Determination
R	Value Resistance Value
P	Standard Significant Error
α1, α2, α3, αn	Coefficients of the Single Linear Regression Equation
β1, β2, β3, βn	Coefficients of the Multiple Linear Regression Equation
ε	Statistical Random Error

List of Abbreviation and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AC	Agricultural Campus
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CH	High Plasticity Clay
DCP	Dynamic Cone Penetrometer
GC	Clayey Gravels
GI	Group Index
GP	Poorly Graded Gravels
GW	Well Graded Gravel
HM	Honeyland to Michael
SB	Shanan gibe to Bore
KF	Kitto Furdisa Campus
MR	Merewa Road project
ST	Seto Area
LL	Liquid Limit
MDD	Maximum Dry Density
ML	Inorganic Silts of Low Plasticity
MH	Inorganic Silts of High Plasticity
NCHRP	National Cooperative Highway Research Program of United States of America
OMC	Optimum Moisture Content
PI	Plasticity Index

PL	Plasticity Limit
SPSS	Statistical Package for Social Science Software
TA	Tilehun shed to Kera hospital
USCS	Unified Soil Classification System
WA	Weigh bridge to Ajip

List of Tables

List of Figures

Abstract

CBR is a commonly used indirect method to assess the stiffness modulus and shear strength of subgrade soils in pavement design. However; it is always difficult and time taking to obtain representative CBR value for design of pavements. In this study a method is proposed for correlating CBR values with the liquid limit, plastic limit, plasticity index, optimum moisture content, and maximum dry density of cohesive soils of various zones of Jimma city.

With the objective of predicting CBR value from index properties of soil, having all the associated test results with corresponding CBR values collected from laboratory tests and Ethiopia road authority's archival secondary data analysis were carried out. As a result, these study has examined the feasibility of single linear regression analysis and multiple linear regression analysis in correlating CBR value with soil index properties.

Specific to this research, statistical software (SPSS) is employed to investigate the significance of individual independent variables. The correlation is developed in the form of an equation of CBR as a function of grain size parameter, Atterberg limits and compaction parameters by considering the effect of an individual soil properties and effect of a combination of soil properties on the CBR value.

The developed correlation entailed a moderate determination coefficient of R^2 *= 0.462 using single regression analysis, while multiple regression analysis generated relatively an improved correlation of* R^2 *= 0.604, for a sample size of fifty. After validating the developed correlation with control test results, it was noted that the correlation of CBR value with soil index properties is more applicable for preliminary characterizing the strength of subgrade soil in Jimma town.*

Keywords: *California Bearing Ratio (CBR), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Plasticity index (PI)*

CHAPTER ONE

Introduction

1.1 Background

Soil has diverse information and character. Therefore accurate prediction of its engineering behaviour is of research interest in civil engineering area. The engineering behaviour of soils varies from place to place and also with time. Index properties of cohesive soils are used to characterize the physical and mechanical behaviour of soils by making use of parameters such as moisture content, specific gravity, particle size distribution, Atterberg limits and moisture-density relationships. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [1]

Roads are necessary for transportation and economic development of the country. Most of the road network in the country is consisting of flexible pavement of difference layers such as subgrade, subbase, base course and surface layer. Subgrade is the bottom most layer. Design and performance of flexible pavement mainly depends on the strengths of subgrade material. The load from the pavement surface is ultimately transferred to sub-grade and to the sub-base. The subgrade is designed such that the stress transferred should not exceed elastic limit. Hence, the suitability and stability of subgrade material is evaluated before construction of pavement. Soaked CBR value percent is considered as strength parameter in design of subgrade. The thickness of subgrade is mainly depends on CBR value, if the CBR value is higher, then the designed thickness of the subgrade is thinner and vice versa.

The soil sample will be compacted as required in a standard mould and then a plunger is made to penetrate the soil at a specified penetration rate. Load versus penetration curve will be plotted from the result of the penetration and will be compared with the bearing resistance of standard crush rock [1]. Apart from CBR test carried out in laboratory, engineers frequently conduct in direct measurement of CBR value at project site. Various attempts, which take less time and are easier to perform as compared to the standard procedure of CBR testing, have been made to predict the CBR of a particular type of soil.

1.2 Statement of the Problem

Soil has numerous mineralogical contents and subsequently diversified characteristics, thus the correct prediction of its engineering behaviour is of research interest in civil engineering field. The engineering behaviour of soils varies from place to place and also with time. To predict the CBR value many an attempts are made from the index properties of soil. Hence determining of things that influence the soil strength and finding out their relationship with CBR value on stratified soil sample could be considered nearly as good insight of soil behaviour. [1]

The CBR is the well-known, common and trustful penetration test currently used in road pavement design. The test is being used for many years and is familiar to organization's involved in the interpretation of results, consequent road design and construction. The socked CBR test require large quantity of soil sample and the soil is remoulded to maximum dry density and time consuming. Therefore it's very difficult to carry out to entire stretch of the road in short duration and leads to serious delay in the project and increase its cost. To overcome this problem a simple and less time consuming method is necessary by correlating soaked CBR value with easily determining soil parameters.

Different investigations are conducted on this correlation by different scholars in our country, for instance by Yared Leliso in 2013 for the case study of Addis Ababa city. In Jimma there are no such studies conducted so far. Hence determining of factors that influence the soil strength and studying their-relationship with CBR value may be considered as good insight of soil behaviour.

1.3 Objective of the Study

1.3.1 General Objective

- The general objective of the research is to predict CBR values from correlation of index properties of soil.

1.3.2 Specific Objectives

- To investigate the index properties parameter and CBR.
- To come up with the correlation between CBR and index properties of typical subgrade soils in Jimma town.
- To check and validate the developed correlation using a control test results.

1.4 Significance of the study

In Ethiopia many road construction projects and railway constructions are undertaking. For this reasons, the output of the proposed correlation will provide road authorities, railway authorities, consultants, contractors and stakeholders preliminary background information on the value of CBR, for a localized subgrade material, from soil index properties with a benefit of timesaving and without incurring any additional cost for carrying out laboratory CBR test.

This study will enhance the researcher additional knowledge and improve his/her skill on the correlation of CBR with soil index properties in practical way.

1.5 Scope of the study

As mentioned above, this research investigates the correlation of CBR with soil index properties. Focusing only on typical Jimma subgrade soils .With regard to the regression analysis the required correlation carried out by applying a single linear regression model and multiple linear regression models with the aid of SPSS software.

1.6 Organization of the study

The thesis is organized and presented under six Chapters. The first Chapter high lights introduction of the subject study. Chapter two deals with review of published literature. In Chapter three, discussions on sample collection and on test results were made. In Chapter four, correlation and regression analyses were conducted and Chapter five focuses on validating and evaluating the obtained correlation. Under Chapter six, the conclusion and recommendation were presented. At the end, details of the regression and laboratory test results enclosed under appendix section.

CHAPTER TWO

Literature Review

2.1 California Bearing Ratio (CBR)

2.1.1 General

The California bearing ratio test was first developed by California division of highways in 1929 as a means of classifying the suitability of a soil for use as subgrade or base course material in highway construction. During World War II, the US corps of engineers adopted the test for use in airfield construction [2].

To measure the stiffness modulus and shear strength of subgrade soil a simple test that can be used as an index test was devised. This is where CBR test comes into frame in measurement of subgrade strength. The CBR test is a simple strength test that compares the bearing capacity of a material with that of a well graded standard crushed stone base kept in California Division of Highways Laboratory [2]. This means that the standard crushed stone material should have a CBR value of 100%. The resistance of the crushed stone under standardized conditions is well established. Therefore, the purpose of a CBR test is to determine the relative resistance of the subgrade material under the same conditions. The test is an index test, thus it is not a direct measure of stiffness modulus or shear strength. In equation form

$$CBR= \frac{test unit load}{stadared unit load} * 100 \qquad (2.1)$$

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

2.1.2 Applications of California Bearing Ratio

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

2.2 CBR Laboratory Test Methods

California bearing ratio (CBR) test can be done at both field and laboratory according to the test method ASTM D 4429 and ASTM D1883-73 respectively.

Samples may be prepared in three different ways. Accordingly,

(i) The test can be performed on a remoulded sample in laboratory.

(ii) On undisturbed sample carefully extracted from field and trimmed to closely fit the standard mould in laboratory.

(iii) An in-situ sample which is entirely tested on field.

The CBR test taken in this research is socked CBR test. CBR tests are usually made on test specimens at the optimum moisture value for the soil as determined using the standard or modified compaction test using method 2 or 4 of ASTM D 69870 or of D155770 (for the 15.2cm diam. mould)[3].

The sample which is taken from the terrain must be purposive disturbed soil samples were collected. Two moulds of soil are often compacted one for immediate penetration testing and one for testing after soaking for a period of 96 hr. The second specimen is soaked for a period of 96hr with a surcharge approximately equal to the pavement weight used in the field but in no case the surcharge weight is less than 4.5kg. Swell readings are taken during this period at arbitrary selected times. At the end of the soaking period, the CBR penetration test is made to obtain a CBR value for the soil in saturated condition.

In both penetration tests for the CBR values, a surcharge of the same magnitude as for the swell test is placed on the soil sample. The test on soaked sample accomplishes two things:

I) It gives information concerning expected soil expansion beneath the pavement when the soil become saturated.

II) It gives an indication of strength loss from field saturation.

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

Using the corrected value taken from the load-penetration curve for 2.54 mm and 5.08 mm penetration, the bearing ratio is calculated by dividing the corrected load by the corresponding standard load, multiplied by 100. Its value ranges from 0 (worst) to 100 (best). If the bearing ratio of 2.54 mm is greater than that of 5.08 mm, the bearing ratio that should be reported for the soil is normally the one at 2.54 mm penetration. When the ratio at 5.08 mm penetration is greater, the test is entirely repeated on a fresh specimen. If the repeated result of 5.08 mm is again greater, the design bearing ratio will be that of 5.08 mm or else, if the bearing ratio of 2.54 mm is greater the design bearing ratio will be that of 2.54 mm penetration [3].

A typical laboratory CBR testing apparatus found in ERA from jimma district is shown in Figure 2.1.

Figure 2.1: California Bearing Ratio laboratory Testing Apparatus

2.3 Index Properties of Soil Test

Index properties are the properties of soil that help in identification and classification of soil. Water content, specific gravity, Particle size distribution, in situ density (Bulk Unit weight of soil), Consistency Limit and relative density are the index properties of soil. These properties are generally determined in the laboratory. In situ density and relative density require undisturbed sample extraction while other quantities can be determined from disturbed soil sampling. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [4].

2.3.1 Textural classification

In a general sense, texture of soil refers to its surface appearance. Soil texture is influenced by the size of the individual particles present in it. In most cases, natural soils are mixtures of particles from several size groups. In the textural classification system, the soils are named after their principal components, such as sandy, clay, silty clay, and so forth [4].

Although the textural classification of soil is relatively simple, it is based entirely on the particle-size distribution. Currently, two more elaborate classification systems are commonly used by soils engineers. Both systems take in to consideration the particle-size distribution and Atterberg limits. They are the American Association of State Highway and Transportation Officials (AASHTO) classification system and the Unified Soil Classification System (USCS). The AASHTO classification system is used mostly by state and section highway departments. Geotechnical engineers generally prefer the Unified system. Both are used to specify a certain soil type that is best suitable for a specific application. These classification systems divide the soil into two groups: cohesive or fine-grained soils and cohesion-less or coarse-grained soils [5].

The Unified Soil Classification System is a standardized technique for classifying soils for engineering purposes. Within this system, soils are classified based on the distribution of their grain sizes and the plasticity characteristics of the cohesive material. The original form of this system was proposed by Casagrande in 1942 for use in the airfield construction works undertaken by the Army Corps of Engineers during World War .II. In cooperation with the U.S. Bureau of Reclamation, this system was revised in 1952.At present, it is used widely by engineers (ASTM Test Designation D-2487) [6].

This system classifies soils into three broad categories:

1. Coarse-grained soils that are gravelly and sandy in nature with less than 50% passing through the No.200 sieve. The group symbols start with a prefix of G or S.G stands for gravel or gravelly soil and S for sand or sandy soil.
2. Fine-grained soils are with 50% or more passing through the No. 200 sieve. The group symbols start with prefixes of M, which stands for inorganic silt, C for inorganic clay,

or O for organic silts and clays. The symbol Pt is used for peat, muck, and other highly organic soils.

3. Highly organic soil.

Table 2.1: Symbols in the Unified Soil Classification System

Soil groups	Symbol
Gravel	G
Sand	S
Silt	M
Clay	C
Soil Characteristics	***Symbol***
Well-graded	W
Poorly-graded	P
Low plasticity (liquid limit under 50)	L
High plasticity (liquid limit over 50)	H
Organic (silts and clays)	O
Organic (peat)	Pt

2.3.2 Atterberg Limit

When clay minerals are present in fine-grained soil, the soil can be remoulded in the presence of some moisture without crumbling. This cohesive nature is caused by the adsorbed water surrounding the clay particles. In the early1900s, a Swedish scientist named Atterberg developed a method to describe the consistency of fine-grained soils with varying moisture contents.

At a very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Hence, on an arbitrary basis, depending on the moisture content, the behaviour of soil can be divided into four basic state solid, semisolid, plastic and liquid as shown in Figure 2.2.The moisture content, in percent, at which the transition from solid to semisolid state takes place is defined as the shrinkage limit. The moisture content at the point of transition from semisolid to plastic state is the plastic limit, and from plastic to liquid state is the liquid limit. These parameters are also known as Atterberg limits [6].

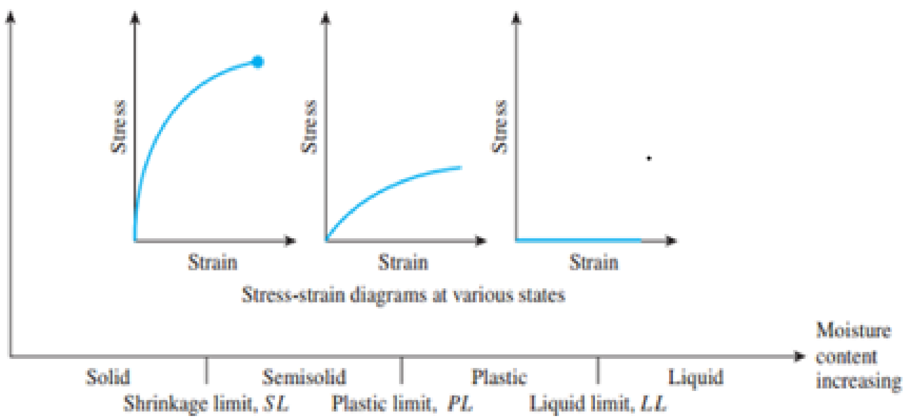


Figure 2.2: Atterberg limits [6]

This limit describes the plasticity and consistency of fine grained soils with varying degrees of water content. For the portion of soil passing 425mm (no 40) sieve, the moisture content is varied to determine the three stages of soil behaviour in terms of consistency. These stages are generally known as liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) of soils.

2.3.2.1 Liquid Limit

The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state and principally it is defined as the water content at which the soil pat cut using standard groove closes for about a distance of 13cm (1/2 in.) at 25 blows of the liquid limit machine (Casagrande Apparatus). The liquid limit of a soil highly depends upon the clay mineral present. The conventional liquid limit test is carried out in accordance of test procedures of AASHTO T 89 or ASTM D 4318. A soil containing high water content is in the liquid state and it offers no shearing resistance.

2.3.2.2 Plastic Limit

The moisture at which soil has the smallest plasticity is known as the plastic limit. Which the soil stops behaving as a plastic material Just after plastic limit the soil displays the properties of a semi-solid. For determination purpose, the plastic limit is defined as the water content at which soil will just begin to crumble when rolled into a thread of 3mm in diameter.

2.3.2.3 Plastic Index

The amount of water which must be added to change a soil from its plastic limit to liquid limit is an indication of the plasticity of the soil. The degree of plasticity is measured by the plasticity index (PI), which is the numerical difference between liquid limit and plastic limit (PI=LL – PL). The greater the plasticity index means that the soil is more plastic, compressible and the greater volume change characteristic of the soil.

2.3.3.4 Sieve Analysis

Sieve analysis is done to determine the percentage of various grain sizes. The grain size distribution helps in determining the textural classification of soils whether it is gravel, sand, silt, clay, etc. which is then useful in evaluating the engineering characteristics such as permeability, strength, swelling potential and susceptibility to frost action. The sieves for soil tests used are 4.75 mm to 75mm. Particle size analysis tests are carried out in accordance to ASTM D 422-63[7].

2.3.4 Moisture Content

Moisture content of soil describes the amount of water present in a quantity of soil in terms of its dry weight.

In equation form

$$W = \frac{m_w}{m_s} * 100 \text{----------in percent} \qquad (2.2)$$

Where:

m_w =mass of water contained in soil.

M_S =mass of dry soil

The purpose of moisture content test is to determine the amount of water present in a quantity of soil in terms of its dry weight and to provide general correlations with strength, settlement, workability and other properties. The moisture content test is carried out in the laboratory as per the procedure of AASHTOT 265 or ASTM D 2216 and in the field according to AASHTO T217.

2.3.5 Moisture Density Relationship (Compaction Test)

It is the process of densification of soils. Compaction is the application of mechanical energy to a soil so as to rearrange its particles. It is applied to improve the engineering properties it means it increases the shear strength of the soil and hence, the bearing capacity. It increases the stiffness and thus, reduces future settlement, void ratio and permeability of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, runways, earth dams, and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings [8].

Compaction tests are performed using disturbed, prepared soils with or without additives. Normally, soil passing the No. 4 (4.75mm) or 19mm sieve is mixed with water to form samples at various moisture contents ranging from the dry state to wet state. These samples are compacted in layers in a mold by a hammer in accordance with specified nominal compaction energy. Dry density is determined based on the moisture content and the unit weight of compacted soil. The test is done in the laboratory according to AASHTO T 99 (Standard Proctor), T 180 (Modified Proctor) or ASTM D 698 (Standard Proctor), D1557 (Modified Proctor).

2.4 Existing Correlations

2.4.1 Relationship Specific to a region and soil type

A number of studies and investigations such as in-situ or laboratory tests have previously been carried out to make correlations between the CBR and other soil properties. Most of the correlations were applied according to the particular circumstances of the soil such as soil type, dry density, Soil consistency and degree of saturation. A few of these methods take a general approach and attempt to encompass many or all possible soil types however most attempts have been limited in scope to a specific soil and only apply to one region, soil type, or specialized material. Some of the correlations are presented as follows:

Scala was one of the first investigators who developed the correlation between the CBR and soil strength. He undertook a considerable number of test in Australia for obtaining the CBR, using static or dynamic cone penetrometer (DCP) [9]. Other than Scala, studies regarding the CBR and DCP impact on various types of soil have also been conducted by researchers such as kleyn (1975), Smith and Pratt (1983), Harrison (1986) and Webster et al. (1992). The scala correlations was presented below in Eq (2.3):

$$\log CBR = 2.465 - 1.12 \log (DCP) \quad (2.3)$$

Venkatasubramania proposed a method for correlating CBR values with the liquid limit, plastic limit, plasticity index, optimum moisture content, Maximum dry density, values of various soils taken from in and around three different district in Tamil-Naidu's [10].The relation was made with the help of artificial neural network system and multiple regression analysis. The tests were performed as per IS. Code specification. The result showed that the specific gravity for 15 sample varied from 1.609 to 2.55 and plasticity index varied from 5 to 9. All samples had good amount of sand content which ranged from 28% to 86%.Unsoaked CBR value is around 2-3 times the soaked CBR value. Unconfined compressive strength varied from 66.2 KN/m^2 to 183.90 KN/m^2 for different samples. From the results it was observed that samples 1, 2, 5, 8, 9, 10, 11, 12 and 15 multiple linear regression analysis under estimates actual CBR values and for remaining Samples it over estimates. Similarly for samples1, 2, 4, 5, 6, 9, 11, 14 and 15 neural network model under estimates CBR value and for remaining samples it over estimated.

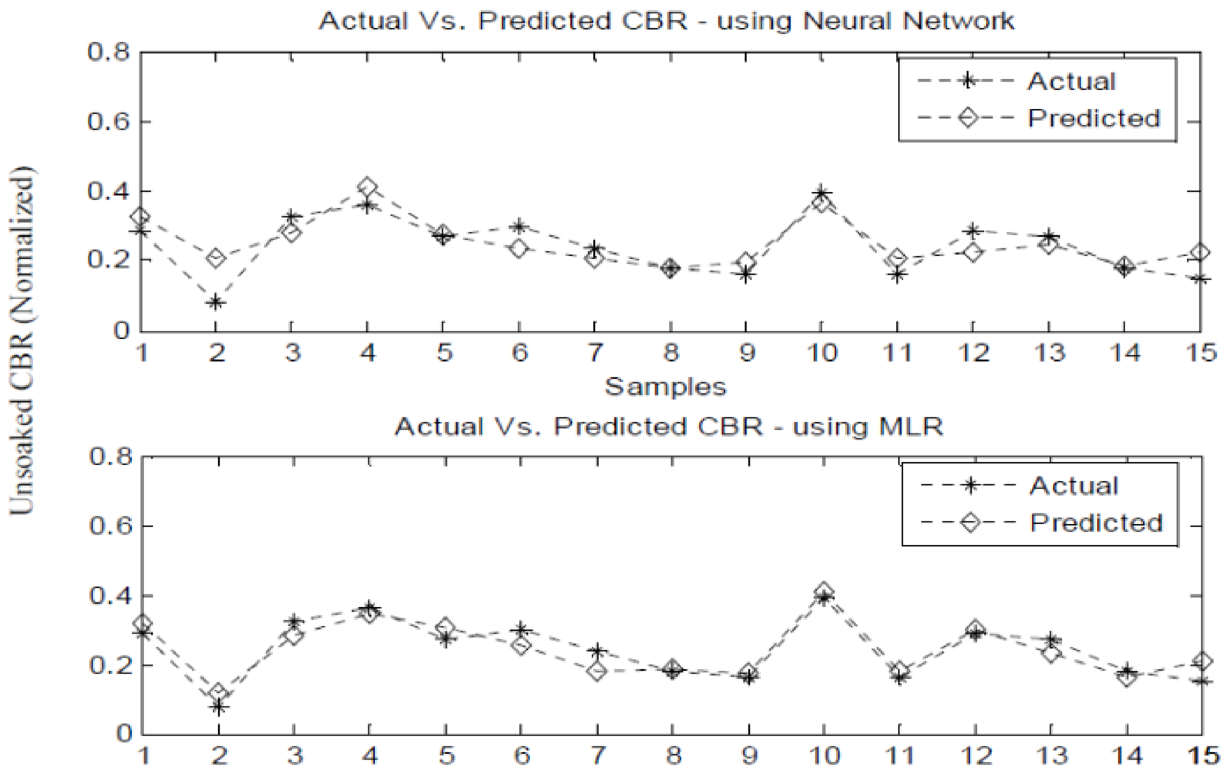


Figure 2.3 (a): Comparison of un-soaked CBR actual vs. predicted CBR. [10]

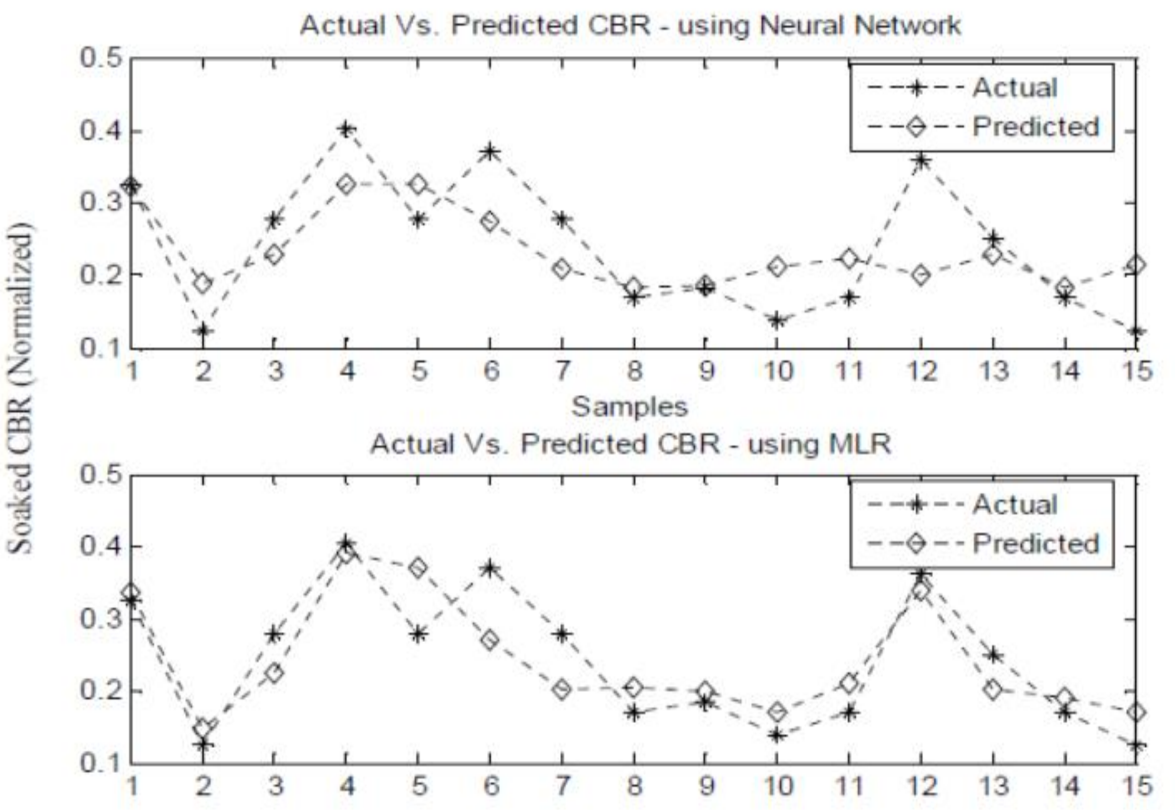


Figure 2.3 (b): Comparison of soaked CBR actual vs. predicted CBR

It was also concluded from this research that the CBR prediction model based on multiple linear regression performs better than neutral network model and hence recommended to predict CBR values.

De Graft-Johnson and Bhatia on the Ghana lateritic soil developed a correlation of CBR with plasticity and grading using the concept of suitability index [11].

$$SI=\frac{A}{LL(LogPI\ )} \qquad (2.4)$$

Where: - SI Suitability Index value of de Graft-Johnson and Bhatia

- A Percentage passing 2.0mm sieve size

- LL Liquid Limit

- PI Plasticity Index

It is worth to note that the soil samples were compacted to maximum dry density at optimum moisture content and soaked for 4 days according to the Ghana standard of compaction. This specifies the use of a standard CBR mould and a 4.5kg hammer with 450mm drop height to compact the soil in 5 layers using 25 blows per layer. The developed relationship is presented in Figure 2.4.

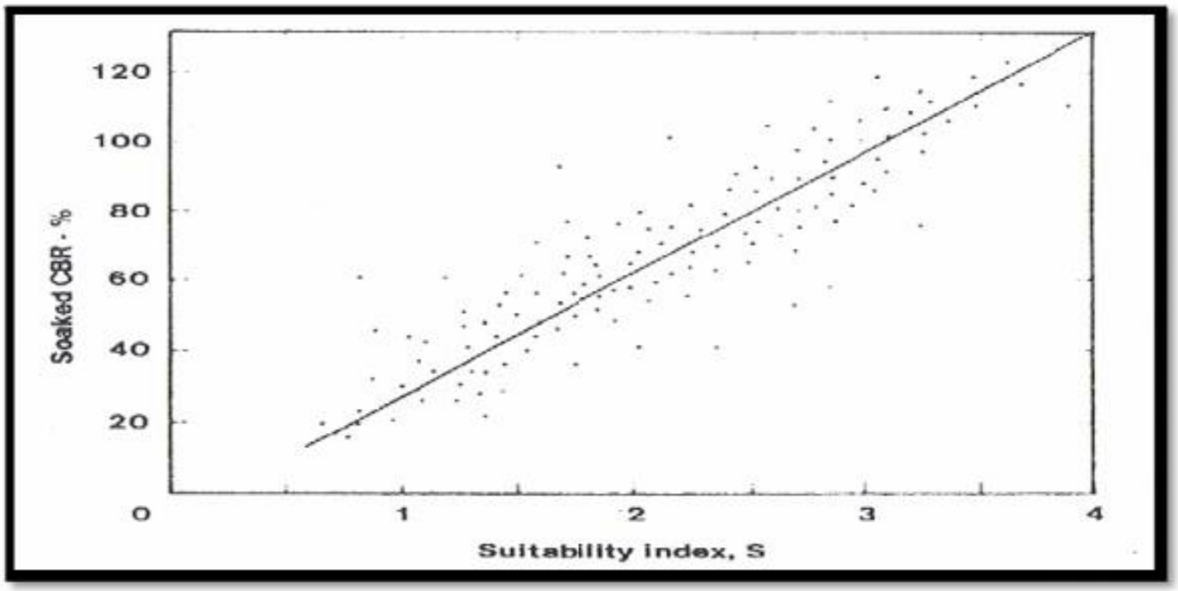


Figure 2.4: Relationship between socked CBR test and suitability index

Aggarwal and Ghanekar performed their research on 48 samples of fine grained soils found in India, on the basis of which they had tried to develop a correlation between CBR values and either liquid limit, plastic limit or plasticity index [12]. But in that case they failed to find any strong or significant correlation between them. Instead, they found a better correlation when they include the optimum moisture content and liquid limit. The correlation developed is as below:

$$CBR = 2 - \log(OMC) + 0.07 * L.L. \qquad (2.5)$$

OMC-optimum moisture content, LL=Liquid limit

The 48 soil samples tested by them had CBR values not exceeding 9% and the standard deviation obtained was 1.8. Hence, they suggested that the correlation is only of sufficient accuracy for preliminary identification of material. They also recommended that this correlation may be of more use of derived for specific geological regions.

2.4.2 Universal Approaches Based on Soil Classification Systems

2.4.2.1 Typical Values Based on Unified Soil Classification System

Guidelines for choosing CBR values based solely on USCS soil type are found throughout different literature. A variety of USCS class soils are associated with a range of CBR values by different researchers and research institutes. A summary of reported values from several of these sources is shown in Table 2.1. Generally, these are consistent for each soil type, with minor differences among the reported values. Part of this variation may be due to the fact that some refer to compacted soils, others refer to field-measured CBR values, while some do not specify test conditions [13].

Table 2.2: Typical California Bearing Ratio Values based on Unified Soil Classification [13].

USCS Soil Type	USACE, US Army and Air Force	Yoder & Witczalk	US Army, Air Force and Navy and PCA	Rollings & Rollings	NCHRP*
GW	40 - 80	60 - 80	60 - 80	60 - 80	60 – 80
GP	30 - 60	35 - 60	25 - 60	35 - 60	35 – 60
GM	20 - 60	40 - 80	20 - 80	40 - 80	30 – 80
GC	20 - 40	20 - 40	20 - 40	20 - 40	20 – 40
SW	20 - 40	20 - 40	20 - 40	20 - 50	20 – 40
SP	10 - 40	15 - 25	10 - 25	10 - 25	15 – 30
SM	10 - 40	20 - 40	10 - 40	20 - 40	20 – 40
SC	5 - 20	10 - 20	10 - 20	10 - 20	10 – 20
ML	15 or less	5 - 15	5 - 15	5 - 15	8 – 16
CI	15 or less	5 - 15	5 - 15	5 - 15	5 – 15
OL	5 or less	4 - 8	4 - 8	4 - 8	--
MH	10 or less	4 - 8	4 - 8	4 - 8	2 - 8
CH	15 or less	3 - 5	3 - 5	3 - 5	1 - 5
OH	5 or less	3 - 5	3 - 5	3 - 5	--
Pt	- -	- -	- -	< 1	- -
CL-ML	- -	- -	- -	- -	- -

GW-GM	- -	- -	- -	- -	35 - 70
GW-GC	- -	- -	- -	- -	20 - 60
GP-GM	- -	- -	- -	- -	25 - 60
GP-GC	- -	- -	- -	- -	20 - 50
GC-GM	- -	- -	- -	- -	
SW-SM	- -	- -	- -	- -	15 - 30
SW-SC	- -	- -	- -	- -	10 - 25
SP-SM	- -	- -	- -	- -	15 - 30
SP-SC	- -	- -	- -	- -	10 - 25
SC-SM	- -	- -	- -	- -	- -

* NCHRP: represents National Cooperative Highway Research Program of United States

2.4.2.2 Mechanistic-Empirical Design Guide

Another general approach to the problem of estimating CBR has been developed as a part of the highway pavement community's recently released *Mechanistic-Empirical Design Guide for New and Rehabilitated Pavement Structures* [14]. The design guide methodology includes three levels of confidence in the resulting pavement designs, depending on the quality of input data provided to the model. This ranges from the highest level, where the design is based on a detailed, project-specific series of laboratory characterization tests on the construction materials, to the lowest level where default values based on simple material characterization tests and/or regional norms are used as model inputs. One of the parameters needed to perform a flexible pavement design using this system is the resilient modulus, which is "a specific type of modulus of elasticity that is based on their coverable strain instead of total strain" [14]. Also, the resistance value test (r-value) is used to measure the frictional resistance of a material to deformation under saturated condition. Its test is conducted using the HveemStabilo meter in accordance to ASTM D 2844.

In addition to the above, the National Cooperative Highway Research Program of United States of America through the "Guide for Mechanical-Empirical Design of New and Rehabilitated Pavement Structures" had developed some correlations that describe the relationship between soil index properties and CBR values based on a simple regression approach. The CBR values were selected by choosing average values for each USCS soil type based up on sources that provide typical CBR values by classification, as illustrated in the previous section.

The index property values were selected by examining the USCS classification criteria for each soil type, and choosing a typical value for that USCS soil type. The index properties chosen to correlate with CBR included:

$$wPI = P_{200} * PI \qquad \text{(If PI > 0)} \qquad (2.6)$$

w = Percent passing No. 200 Sieve

PI = Plasticity Index

For the clean, coarse-grained, non-plastic soils where *wPI*= 0, the CBR were correlated with D_{60}. The best-fitted equation proposed by NCHRP for clean, coarse-grained soil provides the following prediction relationship:

$$\text{CBR} = \begin{cases} 5 & \left(if \quad D_{60} \le 0.01mm\right) \\ 28.09\left(D_{60}\right)^{0.358} & \left(if \quad 0.01mm < D_{60} < 30mm\right) \\ 95 & \left(if \quad D_{60} \ge 30mm\right) \end{cases}$$

Where: - D60 Diameter on the cumulative size distribution curve where 60 percent of

Particles are finer (in millimetres)

- P200 Percent passing (finer than) the number 200 sieve size (in decimal form)

In cases where the soil has fine content, percent passing sieve No. 200 greater than twelve percent and the weighted plasticity index (*wPI)* value is different from zero, the prediction equation will be:

$$\text{CBR}=\frac{75}{1+0.728(wPI)} \qquad (2.7)$$

wPI = Weighted Plasticity Index

PI = Plasticity index

CHAPTER THREE

Methods, Data Collection and Laboratory Results

3.1 General

In order to accomplish the proposed objectives of the study, Books, journal and published reports has been thoroughly studied and reviewed at early stage of the study to keep up to date on the published correlation of CBR and soil index properties.

To have satisfactory data for utilizing the correlations, laboratory tests were conducted by the researcher on sample collected from different localities of Jimma town and also records of already tested results of CBR values together with associated soil indices (sieve analysis results, moisture-density relationship and Atterberg limit) were collected from selected road material.

3.2 Study Area

The Jimma Town is one of the biggest towns located in the Oromia National Regional State. The town is a Centre for large trunk roads passing different part of Ethiopia; Due to this reason the town is a meeting place for different nationalities, languages and a place for marketing. The town is located in western part of Ethiopia 7°40′N 36°50′E latitude and longitude. Jimma has a tropical rainforest climate (Af) under the Köppen climate classification. It features a long annual wet season from March to October. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), this Zone has a total population of 120,960, of whom 60,824 are men and 60,136 women with an area of 50.52 square kilometres. Temperatures at Jimma are in a comfortable range, with the daily mean staying between 20°C and 25°C year-round.

3.3 Data Collection and Test Results

3.3.1 Primary Data

In order to have sufficient and reliable data for the target analysis, laboratory tests were conducted on soil samples obtained from different localities of Jimma Town. One of the samples collected from undergoing road construction projects during the excavation stage. A total of twenty test pit disturbed samples were gathered within a reasonable sampling interval. The representative samples selected on the basis of visual identification of a subgrade soil, as such a diversified samples acquired from areas such as; Merawa road project, Jimma university institution of technology (KittoFurdisa) construction site, Agricultural University Jimma branch and Seto area.

3.3.2 Secondary Data

The twenty disturbed sample conducted in the laboratory which is not enough for correlation purpose. However, additional thirty tests are obtained from secondary data. The secondary data has been collected from records of CBR and Index property test results found in Ethiopia road authority. The data consist of subgrade three point CBR with corresponding consequent Atterberg limit test, Compaction test, Sieve analysis and necessary classification based on AASHTO standard for various geographical locations in Jimma. All the tests are conducted based on the standard compaction with corresponding socked CBR test. The secondary data acquired from area such as; Weigh Bridge to Ajip road, Honey land to Michael road, Tilehun Shed to Kera road, Kera to Bore road, Bore to Qofe road.

Figure 3.1 Map showing Jimma Area and regional setting (Google Earth)

The result graph of detailed for sample 1 of cohesive soil is presented from Figure 3.2 to Figure 3.5. For the rest of the samples summary of tests with detailed sample demonstrations have been attached at appendix part of this thesis.

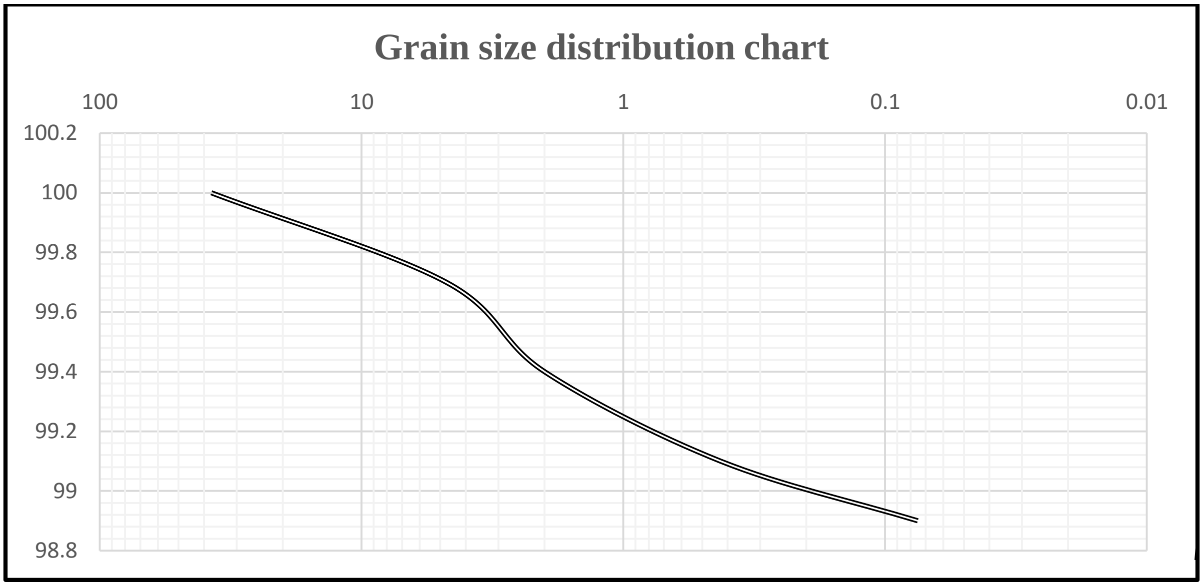


Figure 3.2: Typical Grain Size Analysis Graph

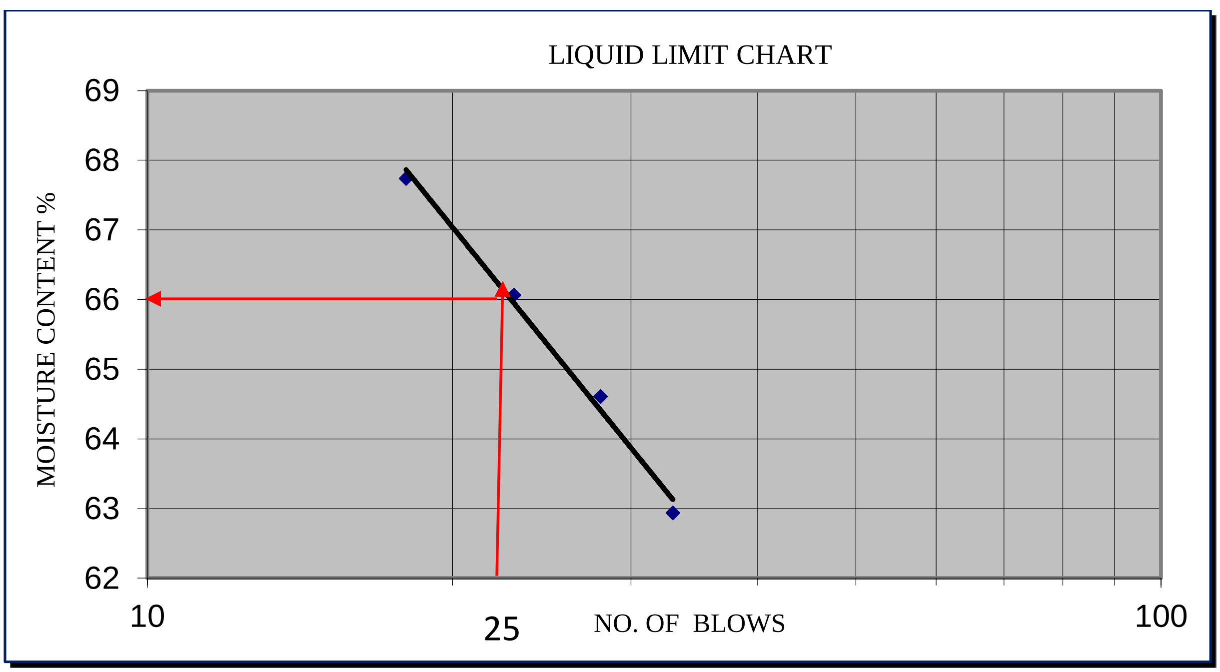


Figure 3.3: Typical Liquid Limit Graph (Flow Curve)

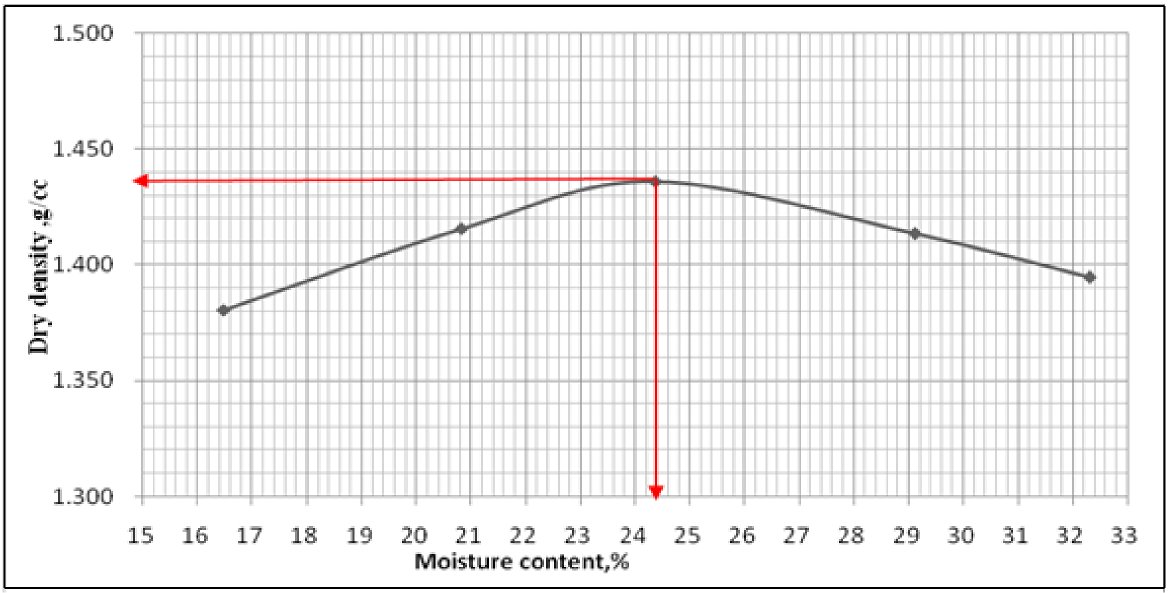


Figure 3.4: Typical Density vs. Moisture Content Relationship Graph

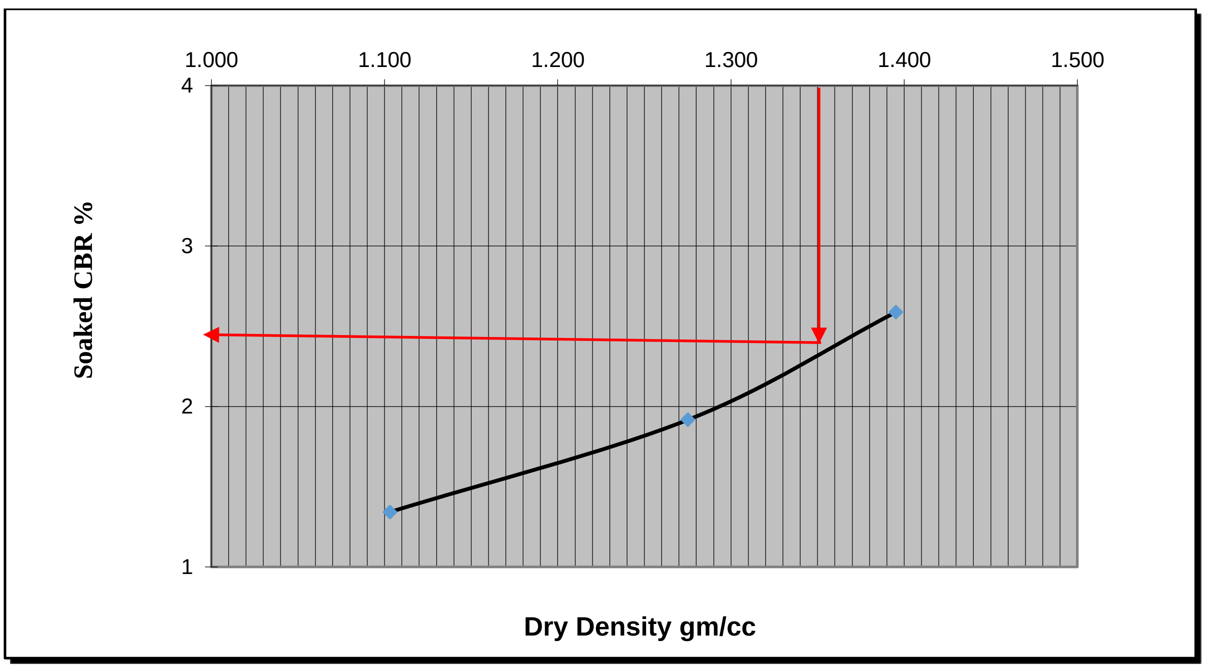


Figure 3.5: Typical Density vs. CBR Graph

3.4 Discussion on Laboratory Tests

The following different kinds of tests have been performed both primary data (laboratory test) and secondary data (already exist test result)

- Liquid Limit Test (ASTM D 4318)
- Plastic Limit Test (ASTM D4318-III)
- Grain size Analysis Test (ASTM D 422-63)
- Standard Proctor Test (AASHTO T 180)
- Three-point CBR Test (AASHTO T 193)

The above conventional tests were conducted on the fifty soil samples and a range of test results achieved. Based on the obtained test results of plasticity and grain size distribution the soil classification was made and the result shows that all the sample are classified as fine grained soil. In accordance to the AASHTO classification system the soil is mainly classified as A-7-5 and A-7-6 from the conventional Atterberg limit tests, The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state, a liquid limit value ranging from 44 up to 77, The moisture at which soil has the smallest plasticity is known as the plastic limit, plasticity limit value of 18 up to 45 and the degree of plasticity is measured by the plasticity index (PI), which is the numerical difference between liquid limit and plastic limit (PI=LL – PL). A plasticity index value of 17 up to 50 were obtained.

A Standard proctor test conducted as per AASHTO T 180 D, through which samples compacted at five layers each compacted by 25 uniform blows using 4.54 kg weight of hammer. From the standard proctor test, after plotting moisture-density curve, a range of maximum dry density along with the optimum moisture content were obtained. Similarly, the CBR test was carried out, on samples remoulded with OMC using 10, 30 and 65 blows of standard proctor density and soaked for four days. Consequently, after the penetration test were carried out a CBR value ranging from 1.8 up to 9.5 is obtained at 95% MDD of standard AASHTO proctor density.

Table 3.1 Summary of all laboratory test result

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
1	MR- 1	100	99.7	99.4	99.1	98.9	66	32	33	A-7-5(28)	1.435	24.4	10	1.103	0.18	0.29	2.3
													30	1.275	0.2	0.4	
													65	1.395	0.35	0.5	
2	MR- 2	100	100	92	80.6	70.8	67	35	32	A-7-5(25)	1.451	26.3	10	1.102	0.24	0.40	2.6
													30	1.199	0.3	0.4	
													65	1.322	0.47	0.87	
3	MR - 3	100	99.3	97.3	94.9	88.1	63	24	39	A-7-6(37)	1.468	27.3	10	1.440	0.56	0.77	4.9
													30	1.599	0.7	0.9	
													65	1.634	0.82	1.10	
4	MR - 4	100	48.3	82.9	76.6	63.1	52	32	20	A-7-5(9)	1.360	26.8	10	1.162	0.96	1.41	8.0
													30	1.302	1.1	1.6	
													65	1.372	1.25	2.12	
5	MR - 5	100	85.2	71.9	67.6	61.1	63	24	39	A-7-5(25)	1.468	27.3	10	1.243	0.77	1.01	7.6
													30	1.357	1.0	1.4	
													65	1.510	1.06	1.51	
6	MR - 6	100	98.1	95.7	94.1	91.7	59	28	32	A-7-6(29)	1.470	28	10	1.049	0.41	0.67	5.3
													30	1.411	0.7	0.74	
													65	1.529	0.74	1.15	
7	MR - 7	100	84.7	71.9	67.9	65.3	61	25	32	A-7-6(20)	1.653	22.6	10	1.129	0.4	0.61	9.5
													30	1.303	1.0	1.5	
													65	1.378	1.88	2.43	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 Mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
8	KF - 1	100	94.8	91.3	87.3	85.0	58	31	27	A-7-5(26)	1.486	28	10	1.275	0.51	0.73	8.5
													30	1.364	0.9	1.3	
													65	1.479	1.47	2.2	
9	KF - 2	100	98.3	97.1	95.0	91.9	59	24	35	A-7-5(36)	1.521	24.3	10	1.317	0.31	0.5	3.9
													30	1.462	0.4	0.5	
													65	1.555	0.47	0.63	
10	KF - 3	100	96.4	92.0	89.0	85.6	66	32	34	A-7-5(34)	1.505	25.8	10	1.409	0.19	0.33	2.5
													30	1.428	0.3	0.5	
													65	1.499	0.4	0.84	
11	KF - 4	100	98.8	91.6	87.4	84.3	66	32	34	A-7-5(33)	1.503	28.9	10	1.384	0.22	0.38	2.7
													30	1.430	0.4	0.7	
													65	1.537	0.51	0.84	
12	AC -1	100	96.3	88.6	78.3	73.4	74	30	44	A-7-5(26)	1.420	27.2	10	1.242	0.2	0.37	3.0
													30	1.372	0.2	0.5	
													65	1.419	0.4	0.61	
13	AC - 2	100	98.8	97.5	87.0	74.9	60	23	37	A-7-6(29)	1.505	26.7	10	1.305	0.59	0.84	5.0
													30	1.456	0.7	0.9	
													65	1.532	0.83	1.04	
14	AC - 3	100	96.3	84.3	79.7	70.0	66	28	38	A-7-6(27)	1.458	28.8	10	1.256	0.33	0.56	3.2
													30	1.408	0.4	0.7	
													65	1.490	0.51	0.79	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
15	AC - 4	100	96	85	80	72	68	32	36	A-7-5(27)	1.661	18	10	1.430	0.6	0.74	4.5
													30	1.600	0.65	0.69	
													65	1.682	0.7	0.98	
16	AC- 5	82.8	71.9	67.5	61.9	56.6	60	22	38	A-7-6(18)	1.443	29	10	1.252	0.22	0.46	2.3
													30	1.407	0.3	0.6	
													65	1.490	0.41	0.68	
17	ST- 1	100	100	98.8	93.3	87.3	65	24	41	A-7-6(17)	1.480	25	10	1.018	1.05	1.41	7.0
													30	1.395	1.46	1.73	
													65	1.492	1.48	2.03	
18	ST- 2	100	100	98.6	94.1	88.3	65	30	36	A-7-6(35)	1.42	31.7	10	1.234	0.41	0.69	6.5
													30	1.343	0.9	1.2	
													65	1.407	0.92	1.28	
19	ST- 3	100	100	97.8	86.8	72.8	74	34	40	A-7-5(31)	1.393	31.9	10	1.214	0.62	1.13	4.0
													30	1.378	1.03	1.31	
													65	1.390	1.05	1.33	
20	ST- 4	100	93.8	85.8	82.7	79.3	65	31	34	A-7-5(16)	1.433	26.8	10	1.241	0.62	1.13	9.5
													30	1.347	0.24	1.99	
													65	1.431	1.71	2.57	
21	WA-1	100	100	99.5	96.2	84.9	72	32	40	A-7-5(19)	1.393	31.6	10	1.018	1.05	1.41	3.9
													30	1.395	1.46	1.73	
													65	1.492	1.48	2.03	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
22	WA -2	100	88.5	85.3	81.9	78.6	62	27	35	A-7-5(29)	1.435	25.5	10	1.225	0.22	0.37	2.5
													30	1.336	0.3	0.4	
													65	1.439	0.45	0.61	
23	WA -3	100	99.1	98.4	93.7	87.6	68	30	38	A-7-5(38)	1.315	38.5	10	1.178	0.18	0.31	4.0
													30	1.236	0.3	0.4	
													65	1.366	0.29	0.45	
24	WA -4	100	92.5	89.8	84.5	77.4	60	30	30	A-7-5(25)	1.435	31.2	10	1.233	0.18	0.31	1.8
													30	1.376	0.3	0.4	
													65	1.440	0.29	0.45	
25	WA -5	100	98.6	97.8	95.2	90.5	64	31	33	A-7-5(34)	1.405	28	10	1.230	0.32	0.5	3.0
													30	1.372	0.4	0.6	
													65	1.443	0.43	0.61	
26	WA -6	100	99.4	98.3	96.4	88.8	59	27	37	A-7-6(37)	1.640	22	10	1.426	0.14	0.26	6.9
													30	1.587	0.2	0.3	
													65	1.652	0.2	0.37	
27	WA -7	100	99.3	98.9	98.2	95.3	73	30	43	A-7-5(42)	1.410	27.4	10	1.226	0.14	0.22	3.3
													30	1.373	0.2	0.2	
													65	1.456	0.19	0.27	
28	HM -1	100	95.9	90.4	84.5	79.2	77	27	50	A-7-6(35)	1.390	34.4	10	1.198	0.19	0.31	5.1
													30	1.336	0.3	0.4	
													65	1.410	0.36	0.58	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
29	HM -2	100	91.9	88.6	73.3	65.9	52	18	34	A-7-6(20)	1.496	22	10	1.198	0.29	0.47	3
													30	1.336	0.41	0.61	
													65	1.410	0.45	0.70	
30	HM -3	100	98.3	96.7	93.9	87.4	67	32	35	A-7-5(36)	1.427	27	10	1.225	0.27	0.55	4
													30	1.380	05	0.8	
													65	1.455	0.56	0.86	
31	HM -4	100	97.1	94.2	90.4	84.9	62	28	34	A-7-6(32)	1.470	25.6	10	1.267	0.42	0.67	3.5
													30	1.408	0.5	0.8	
													65	1.495	0.52	0.88	
32	HM -5	100	100	91.5	86.2	76.8	62	25	37	A-7-6(30)	1.495	24.7	10	1.290	0.18	0.4	2.0
													30	1.446	0.3	0.5	
													65	1.531	0.41	0.69	
33	HM -6	100	99.2	90.1	82.3	77.4	64	32	32	A-7-5(27)	1.485	23.2	10	1.405	0.38	1.3	6.0
													30	1.435	1.3	2.2	
													65	1.512	2.01	3.29	
34	TK -1	100	99.2	90.6	83.2	78.6	62	34	38	A-7-6(31)	1.566	19.4	10	1.434	0.46	0.90	4.5
													30	1.503	0.5	1.0	
													65	1.604	0.6	1.22	
35	TK -2	100	90.9	88.2	81.6	66.9	57	25	32	A-7-6(20)	1.540	22.4	10	1.312	0.38	0.54	3.4
													30	1.479	0.5	0.6	
													65	1.539	0.52	0.81	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
36	TK -3	100	100	90.3	85.1	73.2	70	27	43	A-7-6(32)	1.423	30.5	10	1.240	0.19	0.29	2.2
													30	1.378	0.3	0.4	
													65	1.478	0.32	0.43	
37	TK -4	100	98.2	95.6	89.7	81.7	44	26	18	A-7-6(16)	1.560	22	10	1.468	0.46	0.74	3.8
													30	1.525	0.6	0.9	
													65	1.557	0.69	1.02	
38	TK -5	100	100	99.0	97.3	88.5	63	36	28	A-7-5(29)	1.455	27.7	10	1.254	0.29	0.52	3.5
													30	1.397	0.5	0.8	
													65	1.478	0.58	0.9	
39	KB -1	100	98.0	95.8	92.6	83.0	70	33	37	A-7-5(35)	1.433	31.2	10	1.244	0.37	0.56	3.8
													30	1.385	0.5	0.7	
													65	1.450	0.59	0.86	
40	KB -2	100	95.4	91.9	85.6	82.0	59	34	25	A-7-5(24)	1.533	26.6	10	1.317	0.68	1.00	5.4
													30	1.323	0.7	1.1	
													65	1.537	0.77	1.3	
41	KB -3	100	97.1	95.7	94.5	93.9	60	28	32	A-7-6(35)	1.456	29	10	1.254	1.82	1.93	3.8
													30	1.409	2.73	3.13	
													65	1.465	4.73	4.43	
42	KB -4	100	100	97.5	90.5	84.4	57	31	26	A-7-5(25)	1.413	31.5	10	1.245	0.33	0.47	4.0
													30	1.364	0.49	0.78	
													65	1.441	0.69	1.15	

It. No.	Sample Code	Grain size analysis Present passing					Atterberg limits			Soil Classification	Standard Proctor Test		CBR Tests				
		9.5 mm	4.75 Mm	2.00 Mm	0.475 Mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load in (MPa) at 2.54 mm	Load in (MPa) at 5.08 mm	CBR at 95% MDD (%)
43	KB -5	100	95.4	90.2	85.6	80.9	66	32	33	A-7-5(30)	1.468	26.4	10	1.349	0.22	0.38	2.8
													30	1.393	0.4	0.6	
													65	1.495	0.46	0.72	
44	BQ -1	100	94.2	86.8	83.5	81.9	62	45	17	A-7-5(19)	1.480	30.8	10	1.283	3.93	4.75	7.0
													30	1.425	7.77	9.91	
													65	1.487	11.03	11.7	
45	BQ -2	100	99.5	98.6	97.1	96.3	59	35	24	A-7-5(29)	1.504	25.5	10	1.315	0.77	1.24	8.0
													30	1.423	1.0	1.8	
													65	1.623	1.36	1.85	
46	BQ -3	100	89.1	75.3	69.4	67.8	63	31	32	A-7-5(22)	1.630	24	10	1.511	0.37	0.59	4.9
													30	1.533	0.6	0.9	
													65	1.619	0.81	1.23	
47	BQ -4	100	99.9	99.8	99.3	98.6	66	32	34	A-7-5(41)	1.503	25	10	1.408	0.18	0.28	2.3
													30	1.433	0.4	0.7	
													65	1.527	0.45	0.74	
48	BQ -5	100	97.9	96.7	93.9	91.7	57	27	30	A-7-6(31)	1.527	25.4	10	1.423	0.55	1.05	4.4
													30	1.478	0.7	1.2	
													65	1.569	0.87	1.41	
49	BQ -6	100	98.8	97.0	88.1	77.8	66	35	31	A-7-5(27)	1.456	30.3	10	1.233	0.51	0.84	2.2
													30	1.380	0.3	0.7	
													65	1.428	0.22	0.42	
50	BQ -7	100	97.3	96.8	94.9	93.2	54	28	26	A-7-6(28)	1.459	29.7	10	1.324	0.15	0.31	2.4
													30	1.462	0.3	0.6	
													65	1.544	0.32	0.7	

CHAPTER FOUR

REGRESSION ANALYSIS AND CORRELATIONS

4.1 Introduction

Regression analysis is a statistical technique for modelling and investigating the relationship between two or more variables. Many problems in engineering and science involve exploring and making use of the relationships between two or more variables. Regression analysis the best fit model could be in the form of linear, parabolic, and logarithmic and so on, depending on the trend that may exist between the dependent and independent variables.

Regression analysis divided into either simple regression or multiple regression analysis pertinent to the number of variables involved in the system. A regression model that contains more than one regression variable is called multiple regression model. Alternatively, a regression model containing one independent variable or regression is termed as simple regression model. [15]

A variable whose value is predicted is called dependent variable or response. A variable(s) used to predict the value of dependent variable is termed independent or regression variable (s).The development and subsequent Fitting of a regression model requires several assumptions. The method of least squares is used in order to choose the best fitting line for a set of data. Estimation of the model parameters requires the assumption that, the residuals (actual values less estimated values) corresponding to different observations are uncorrelated random variables with zero mean and constant variance (σ_2). In most practical situation, the variance (σ_2) of the random error (ε) will be unknown and must be estimated from the sample data [15]. The standard error of an estimate gives some idea about the precision of an estimate. During modelling, a variable that shows the least standard error of estimates is the one to be chosen.

This is indeed fundamental assumption of any tests of hypothesis and interval estimation.

A number of techniques can be used to indicate the adequacy of a multiple regression model, some of which are standard error, the multiple regression R-squared values. The standard error of a statistic gives some idea about the precision of an estimate. Estimated standard errors are computed based on sample estimates, as population values are not obtainable using sample surveys. The estimated standard error of a variable with mean $\bar{x}$ and standard deviation of SD is given by

$$\sigma = SD/\sqrt{n} \tag{4.1}$$

σ = Estimated standard error of a sample.

n=sample size

During modelling, a variable that shows the least standard error of estimates is the one to be relatively chosen.

A convenient way of measuring how well the regression model performs as a predictor of the dependent variable is to compute the reduction in the sum of squares of deviations that can be attributed to regress or variables and this quantity termed the coefficient of determination, R2. The value of R^2 is always between 0 and 1, because R^2 is between -1 and +1, whereby a negative value of R^2 indicates inversely relationship and positive value implies direct relationship. Many problems in engineering require that we decide whether to accept or reject a statement about some correlations. A number of techniques can be used to judge the adequacy of a regression model some of which are standard error (α), R-squared value (R_2), R-adjusted. [16]

4.2 Scatter Plot

In this work, the California Bearing Ratio value is taken as the dependent variable whereas the percent passing 0.075mm sieve size, liquid limit, plastic limit, plasticity index, maximum dry density and optimum moisture content are independent variables

In carrying out the whole statistical analysis, statistical software programs called SPSS software were used. Using the 50 soil samples, different kinds of relationships between CBR and other soil index properties were studied. The scatter plot of the dependent variable CBR with the regression variable for the case of Jimma soils is shown below from Figure 4.1 to Figure 4.6

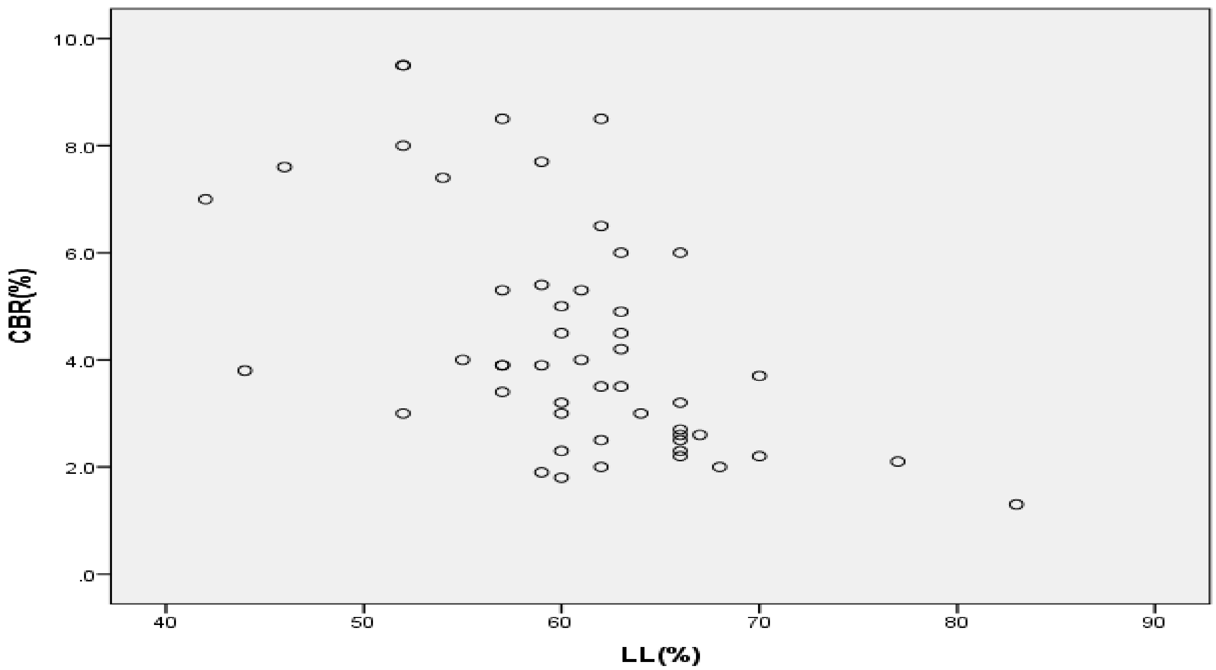


Figure 4.1: Scatter diagram of LL versus CBR

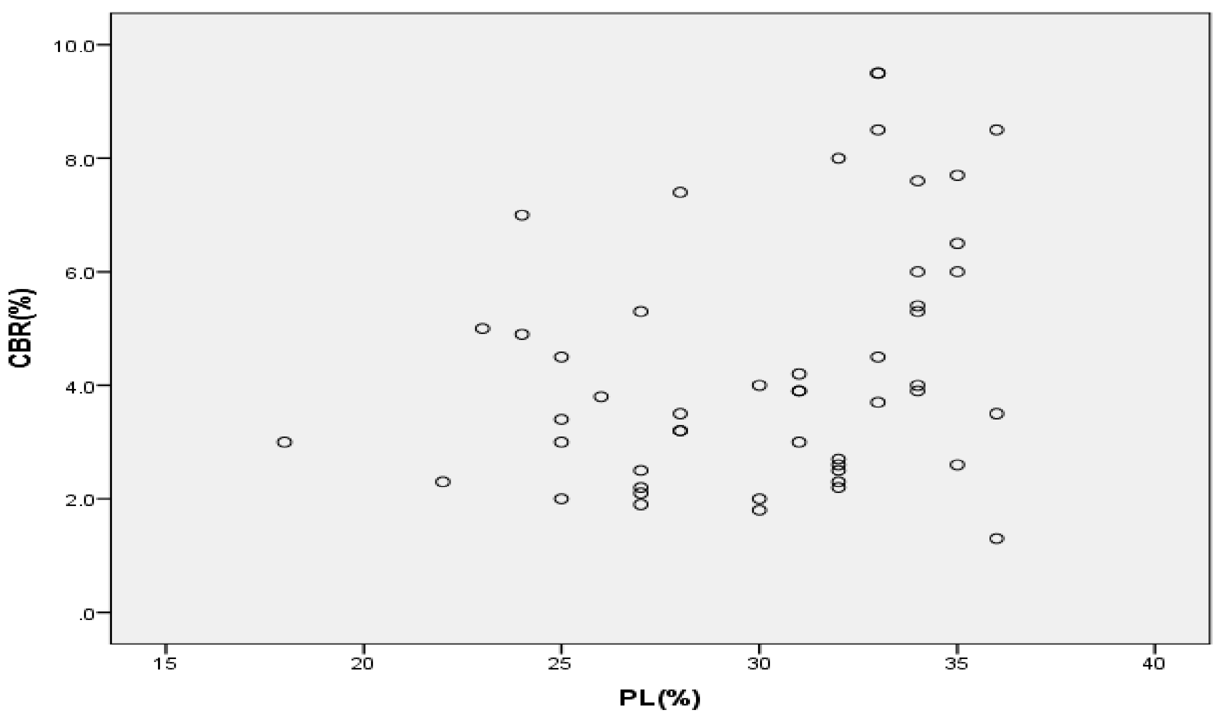


Figure 4.2: Scatter diagram of PL versus CBR

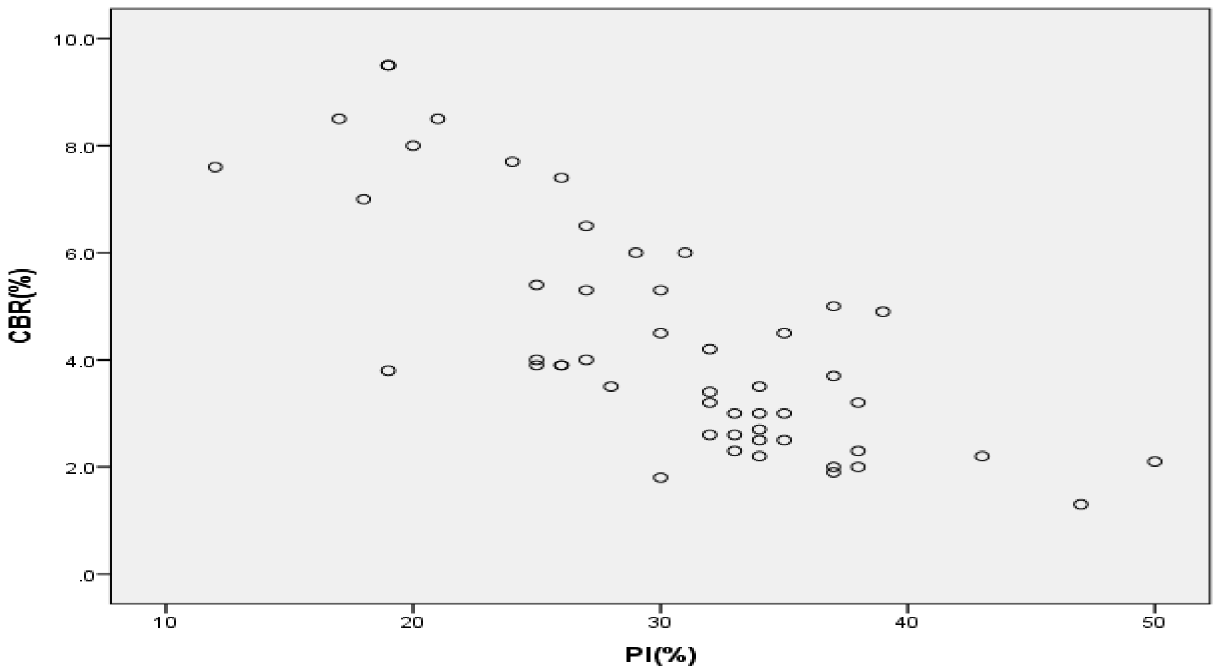


Figure 4.3: Scatter diagram of PI versus CBR

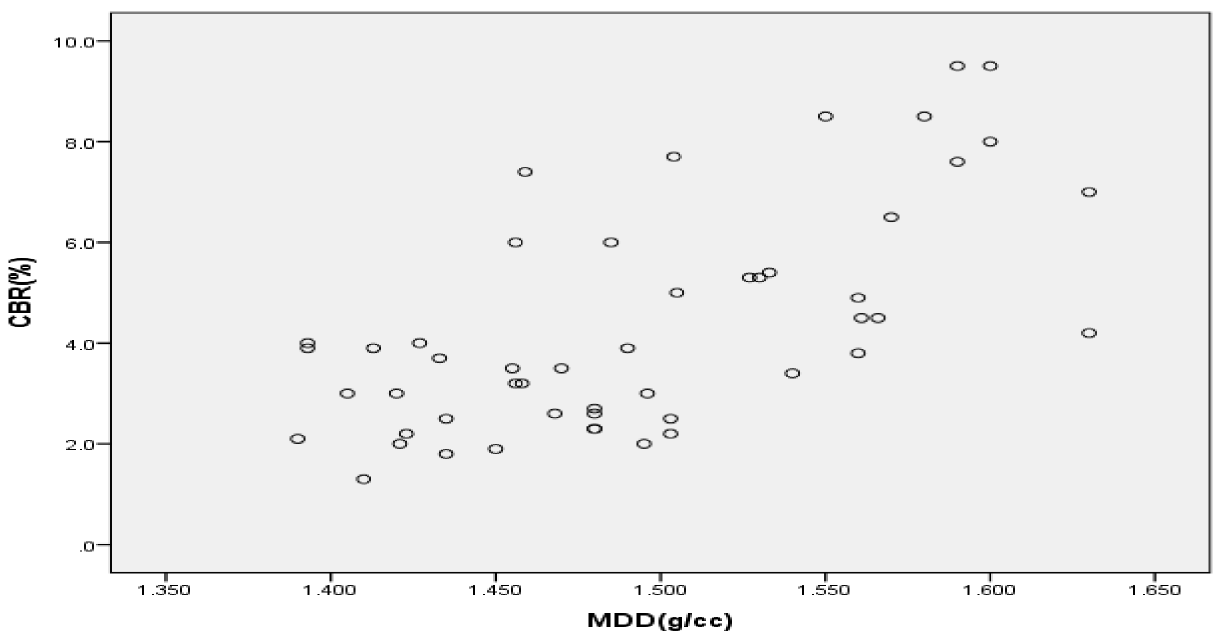


Figure 4.4: Scatter diagram of MDD versus CBR

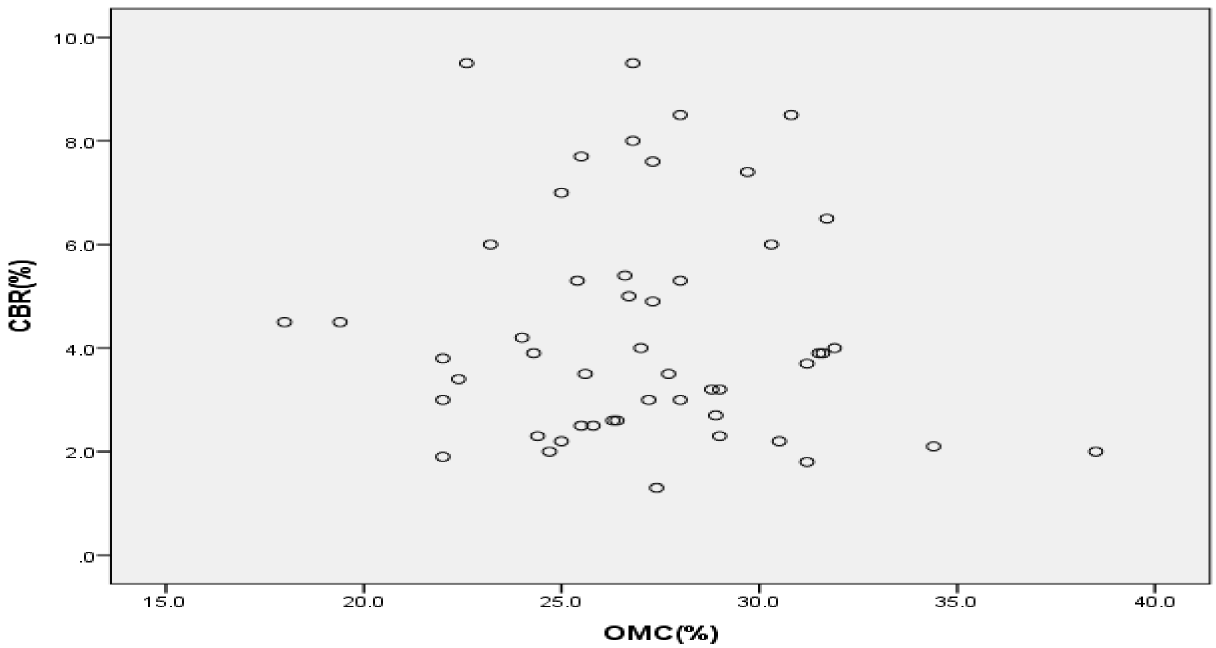


Figure 4.5: Scatter diagram of OMC versus CBR

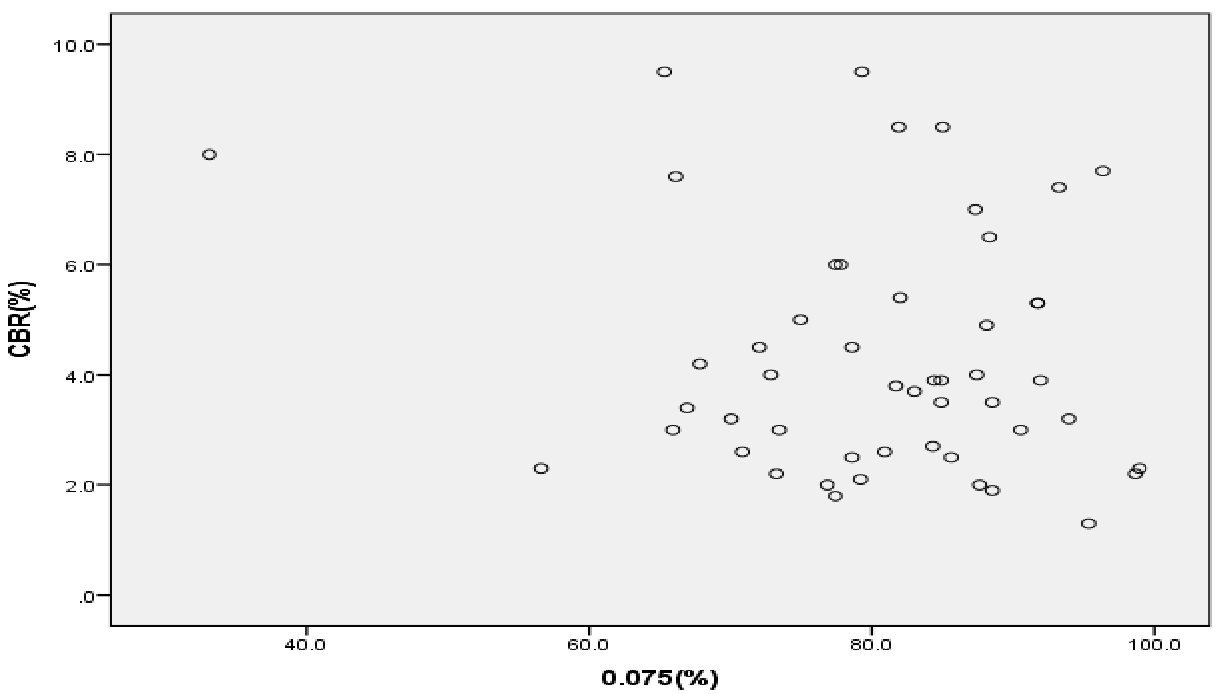


Figure 4.6: Scatter diagram of P200 versus CBR

4.3 Regression Analysis

Regression an analysis one of the most important statistical techniques for engineering applications. It's a conceptually simple method for involving functional relationship among or between variable. The regression results show whether this relationship is valid.

In this research work, an attempt is made to apply single linear regression model and multiple linear regression models to characterize the strength of subgrade soil from soil index parameters using a statistical approach. In simple linear regression a single independent variables used to predict the value of a dependent variable. In multiple linear regressions two or more independent variables are used to predict the value of a dependent variable. The difference between the two is the number of independent variables.

The general representation of a probabilistic single and multiple linear regression models are presented in the following forms:

$$Y = \alpha_0 + \alpha_1 x + \varepsilon \tag{4.2}$$

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots\dots\dots + \beta_n x_n + \varepsilon \tag{4.3}$$

Where the slope α_0 and α_1 of the single linear regression model are called regression coefficients. Similarly, coefficients $\beta_{0,} \beta_{1,} \beta_{2,} and \beta_n$ are termed multiple regression coefficients.

The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the random error term, ε [16]. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method. Specific to this research, a statistical package for social science software (SPSS) is employed to investigate the significance of individual regress or variables. Accordingly, the forty two laboratory test results of the independent and dependent variables are used in the following regression analysis. The statistical information's of the test results are presented in Table 4.1

Table 4.1: Statistical Information of Dependent and Independent Variable

Variable Type	Variable type	Unit of Measurement	No of sample	Range	Minimum	Maximum	Std. Deviation
Independent	0.075	%	50	65.8	56.6	98.9	11.78
	LL	%	50	41	44	77	7.35
	PL	%	50	27	18	45	4.72
	PI	%	50	38	17	50	7.74
	MDD	g/cc	50	0.34	1.31	1.66	0.07
	OMC	%	50	20.5	18.0	38.5	3.75
Dependent	CBR	%	50	8.2	1.8	9.5	2.0

In order to know the influence of one variable on the other, a stepwise linear regression has been analysed and as a result correlation coefficients and level of significance have been calculated, as shown in Table 4.2 the Pearson correlation coefficient matrix.

Table 4.2: correlation on matrix of Pearson Correlation Coefficient

Correlations

Pearson Correlation	CBR	0.075	LL	PL	PI	MDD	OMC
CBR	1.000	-0.162	-0.554	0.270	-0.563	0.662	-0.084
0.075	-0.162	1.000	0.238	0.213	0.101	-0.028	0.118
LL	-0.554	0.238	1.000	0.233	0.789	-0.277	0.347
PL	0.270	0.213	0.233	1.000	-0.405	-0.140	0.261
PI	-0.563	0.101	0.789	-0.405	1.000	-0.140	0.149
MDD	0.662	-0.028	-0.277	-0.140	-0.140	1.000	-0.777
OMC	-0.084	0.118	0.347	0.261	0.149	-0.777	1.000

From the above linear relationships, it is shown that the correlation between CBR with liquid limit, plasticity index and maximum dry density has relatively moderate correlation coefficient. Basically, the strength of fine grained soil has a greater association with the consistency of the soil. As a result, liquid limit, plasticity index and maximum dry density has resulted relatively a better correlation with the strength parameter. However, the correlation with plastic limit, optimum moisture content, grain size shows a weak relationship, this is may be due to the inconsistency in conducting laboratory test and inadequacy of the number of trials considered in the test procedures. Further to the above correlation analysis, a number of alternative linear regression analyses that best fits the obtained test results have been carried out. The summarized correlation results are presented hereinafter:

4.3.1 Single Linear Regression Analysis

Model 1: Correlation between CBR and Liquid Limit (LL)

After correlating CBR with LL the resulting regression analysis is expressed by the following single linear equation with its corresponding correlation coefficients:

CBR = 14.528 - 0.168*LL, with $R^2 = 0.316$, n = 50

The details of the statistical out-put indicates that the relationship developed between LL and CBR is significant ($p<0.05$) as shown in Model-1 of Appendix A.

Model 2: Correlation Between CBR and Plastic Limit (PL)

The resulting regression analysis after correlating CBR with PL is expressed by the following single linear equation with its corresponding correlation coefficients:

CBR = -0.875 + 0.172*PL, with $R^2 = 0.137$, n = 50

The details of the statistical out-put indicates that the relationship developed between PL and CBR is not significant ($p>0.05$) as shown in Model-1 of Appendix A.

Model 3: Correlation Between CBR and Plasticity Index (PI)

The resulting regression analysis after correlating CBR with PI is expressed by the following single linear equation with its corresponding correlation coefficients:

CBR = 10.995 - 0.218*PI with $R^2 = 0.462$, n = 50

The details of the statistical out-put indicates that the relationship developed between PI and CBR is significant ($p<0.05$) as shown in Model-3 of Appendix A.

From the above developed correlation liquid limit and plastic index has good correlation than plastic limit it means PI=LL-PL, PI and LL direct relation but with PL inverse relation so the above correlation show that PI and LL better correlation than PL.

Model 4: Correlation Between CBR and Maximum Dry Density (MDD)

The resulting regression analysis after correlating CBR with MDD is expressed by the following single linear equation with its corresponding correlation coefficients:

CBR = -12.276 + 11.172*MDD, with R^2 = 0.458, n = 50

The details of the statistical out-put indicates that the relationship developed between MDD and CBR is significant ($p<0.05$) as shown in Model-4 of Appendix A.

Model 5: Correlation Between CBR and Optimum Moisture Content (OMC**)**

The resulting regression analysis after correlating CBR with OMC is expressed by the following single linear equation with its corresponding correlation coefficients:

CBR = 5.682 - 0.0490*OMC, with R^2 = 0.007, n = 50

The details of the statistical out-put indicates that the relationship developed between OMC and CBR is not significant ($p>0.05$) and also a weak relationship exists between correlation variables.

Model 6: Correlation Between CBR and Percent Passing Sieve No. 200 (P_{200})

The resulting regression analysis after correlating CBR with P_{200} is expressed by the following linear equation with its corresponding correlation coefficients:

CBR = 6.771 - 0.030*P_{200}, with R^2 = 0.026, n = 50

The details of the statistical out-put indicates that the relationship developed between P_{200} and CBR is not significant ($p>0.05$) and also a weak relationship exists between correlation variables.

From the above developed single linear regression models, based on the significant standard error (p) and coefficient of determination (R^2), it was noted that the CBR value correlates relatively better with liquid limit, plasticity index and maximum dry density which is an indication for these variables to form the multiple regression variables that could yield a better correlation result. While the remaining parameters showed a weak relationship with CBR.

4.3.2 Multiple Linear Regression Analysis

Model A: Correlation between CBR with PL and LL

CBR=9.339-0.205LL+0.245PL, with R^2 =0.570, n=50

The details of the statistical out-put of Model A indicates that the relationship developed between CBR with LL and PL is significant ($p<0.05$). Besides, the R^2 value of the multiple regression analysis is improved than the R^2 value of the individual parameters, i.e. PI and PL. For further reference, the detail of Model A is shown in Appendix A.

Model B: Correlation between CBR with PI and P_{200}

CBR=12.204-0.116P_{200}-0.216PI, with R^2 =0.589, n=50

The statistical out-put of Model B indicates that the relationship developed between CBR with PI and P_{200} is significant ($p<0.05$). Besides, the R^2 value of the multiple regression analysis is improved than the R^2 value of the individual parameters, i.e. PI and P_{200}. For further reference, the detail of Model B is shown in Appendix A.

Model C: Correlation between CBR with LL, PL and MDD

CBR=2.838+3.673MDD+0.246PL-0.14LL, with R^2 =0.604, n=50

The details of the statistical out-put of Model C indicates that the relationship developed between CBR with LL, PL and MDD is significant ($p<0.05$) and CBR with LL, PL and MDD. Besides, the R^2 value of Model C is better than all the above stated models. Furthermore, the detail of Model C is shown in Appendix A.

4.4 Discussion on correlation results

4.4.1 Comparisons between the Existing and the Developed Equations

These control test results were obtained from soil samples collected from different localities of Jimma. The validation of the developed correlation is conducted by using five known test results which follows similar testing procedures with that of current research. Depending on the relative significance order.

Model C (CBR = 2.838 +3.673*MDD + 0.246*PL - 0.14*LL is preferably selected among the different alternative correlations for further verifications. Subsequently, using the control test results and the developed correlation equation, the predicted CBR is determined so as to compare it with the actual CBR value as shown in Table5.1:

Table 4.3: Validation of the developed correlation

Sample No.		Control Test Results						Developed CBR value	Variation (%)
	P_{200}	LL (%)	PL (%)	PI (%)	MDD (g/cc)	OMC (%)	Actual CBR value		
Mr 1	77.8	76	31	45	1.455	30.3	6	5.2	-15.4
Mr 2	93.5	92	36	56	1.362	33.8	5	3.82	-24
Kb3	89.4	67	31	36	1.420	28.8	6.6	6.0	-9
Da4	85.2	66	29	37	1.339	29	7.0	5.7	18.57
Da5	89.0	74	26	48	1.52	33	4.0	4.46	11.25
Avg.							5.6	5.21	15.4

From the above performed result it was determined that a significant correlation can be developed between among the actual and predicted CBR value

4.5 Evaluation of the Developed and Existing Correlations

The suitability of existing correlations particularly the Yared Liliso correlation and Agarwal and Ghanekar's correlation along with the developed correlation is examined using a control test results obtained from the subject study area. The calculated results of the correlations which are obtained by using the control test results are shown in Table 4.4:

Table 4.4 Comparisons between actual value, newly developed and Mechanistic-Empirical method for cohesive soils.

Sample No.	Actual CBR Value [A]	Developed Correlation		Yared Liliso Correlation	
		Predicted CBR Value [B]	Variation (%) [B-A]*100/A	Predicted CBR Value [C]	Variation (%) [C-A]*100/A
1	6.0	5.2	-15.4	2.83	-52.8
2	5.0	3.82	-24	1.92	-61.6
3	6.6	6.0	-9	1.68	-74.54
4	7.0	5.7	18.57	2.5	-64.8
5	4.0	4.45	11.25	2.34	-41.5
Avg.	**5.6**	**5.21**	**15.4**	**2.6**	**59.0**

As shown in Tables 4.4, the Yared Liliso correlation resulted an average variation of 59.0% from the actual CBR values.

Table 4.5 comparisons between actual value, newly developed and Agarwal and Ghanekar

Sample No.	Actual CBR Value [A]	Developed Correlation		Agarwal and Ghanekar	
		Predicted CBR Value [B]	Variation (%) [B-A]*100/A	Predicted CBR Value [D]	Variation (%) [D-A]*100/A
1	6.0	5.2	-13.3	-28.14	-169
2	5.0	3.8	-24	-28.9	-278
3	6.6	6.0	-9.1	-26.0	193.9
4	7.0	5.7	-18.57	-28.0	-100
5	4.0	4.45	11.25	-27.5	-187.5
Avg.	**5.72**	**5.09**	**15.4**	**20.2**	**104**

The Agarwal and Ghanekar's correlation resulted average variation of 104 % by entirely under estimating the actual CBR value. The Agarwal and Ghanekar correlation has been evaluated and the result shows that a negative predicted CBR value, which is impractical, is obtained. This is may be due to the difference in test procedures and also the unique properties of the geological material where this correlation was developed. In light of the above, it is worth to note that the test results obtained from the subject study area are not suited by the above existing correlations.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This research is carried out to predict the CBR of cohesive soil from soil index properties in terms of P200, LL, PL, PI, MDD and OMC. The laboratory test were conducted on samples taken from different geographical area of Jimma and secondary data of the same town is also included. The total of 50 sample test results are obtained and analysed using single and multiple linear regression. In general from the statistical analysis made, the following conclusions are drawn.

- Among the single linear regression analysis the correlation between CBR and liquid limit has resulted the following relationship:

  CBR = 10.995 – 0.218*PI, with R^2 = 0.462, n = 50

  As it can be observed from the following expression, relatively an improved correlation is obtained when multiple regression is used.

  CBR=2.838+3.673MDD+0.246PL-0.14LL, with R^2 =0.604, n=50

  These indicate that the multiple regression is better correlation than single regression analysis.

- From the comparisons made between the newly developed, Yared Liliso and Agarwal and Ghanekar method, the newly developed one approximates CBR value of cohesive soils in a better way.
- For preliminary design purpose the above correlation might be used, if the predicted CBR value is within the range of 1.8 % to 9.5%. Otherwise, a detailed laboratory test should be carried out to obtain the actual CBR value.

5.2 Recommendations

From the research conducted, the following recommendations are given:

1. It is recommended to further carry out this correlation works using a different geographical areas in Jimma which are not covered by this research.

2. The correlations made in this study were developed for locally used sub grade soils. The applicability of the CBR – soil index properties for other pavement layers such as sub base and base courses are also should be investigated.

References

[1] Fredrics, M., Standard Hand Book for Civil Engineers, McGraw-Hill Book Company, New York, 1983.

[2] Yang, H., Pavement Design and Analysis, Pearson Education Inc., New Saddle River, NJ, 2004.

[3] American Society for Testing and Materials, Designation: D 1883 – 99, Laboratory CBR Testing, Annual Book of ASTM Standards, Volume 04.08, West Conshohocken, Pennsylvania, 2000.

[4] Bowles Joseph E, Engineering Properties of Soils and Their Measurement, McGraw-Hill, Singapore, second edition, 1984

[5] Mittal, S. and Shukla, J.P., Soil Testing for Engineers, Romesh Chander Khanna Publishers Delhi (India), 2000.

[6] Braja M. Das, principals of geotechnical engineering seventh edition, 2001.

[7] Prasad, index properties of soil, S. J. College of Engineering, Mysore, 2000.

[8] Arora, K.R., Soil Mechanics and Foundation Engineering, Re-print Standard Publishers Distributer, Niagara, Delhi, 2004.

[9] Carter, M. and Bentley, S.P., correlation of soil properties, Pentech Press, London, 1991

[10] Venkata, S., Correlation of index properties of soil, India institution of technology, 2011

[11] De. Graft – Johnson. J.W.S and Bhatia the engineering characteristics of the lateritic gravel soil of Ghana, 1969.

[12] Agarwal, K.B and Ghanekar, K.D., prediction of CBR from plasticity characteristics of soil, south East Asia, 1970.

[13] US Army and Air Force (1983), Soils and Geology Procedures for Foundation Design Of Buildings and Other Structures, US Army Technical Manual 5-818-1, Washington DC, 1983. Available Online /http: //www.usace.army.mil/inet/usacedocs/.

[14] National Cooperative Highway Research Program, Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Correlation of CBR Values With Soil Index Properties, NCHRP, Transportation Research Board, National Research Council, Washington DC, 2004.

[15] Douglas C. M. George C. Runger, Applied Statistics and Probability for Engineers, John Wiley & Sons, Inc.USA,third edition ,2003.

[16] Perry R.Hinton, Charlotte Brownlow, SPSS Explained, Taylor and Francis e-Library, 2005

APPENDIX A: Details of the SPSS Regression Analysis Outputs

Appendix A-1: Single Linear Regression Analysis

Model 1: Correlation between CBR and Liquid Limit (LL)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.562[a]	.316	.302	1.8337

a. Predictors: (Constant), LL

b. Dependent Variable: CBR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	14.528	2.177		6.672	.000
	LL	-.168	.036	-.562	-4.709	.000

a. Dependent Variable: CBR

Model 2: Correlation between CBR and Plastic Limit (PL)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.370[a]	.137	.119	2.0602

a. Predictors: (Constant), PL

b. Dependent Variable: CBR

Coefficientsa

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.875	1.917		-.457	.650
	PL	.172	.062	.370	2.756	.08

a. Dependent Variable: CBR

Model 3: Correlation between CBR and Plastic Index (PI)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.679[a]	.462	.413	1.4333

a. Predictors: (Constant), PI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.995	.838		13.120	.000
	PI	-.218	.027	-.763	-8.177	.000

a. Dependent Variable: CBR

Model 4: Correlation between CBR and MDD

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.676	.458	.408	1.65072

a. Predictors: (Constant), MDD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-12.276	6.418		-1.913	.042
	MDD	11.172	4.309	.350	2.593	.013

a. Dependent Variable: CBR

Model 5: Correlation between CBR and OMC

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.084[a]	.007	-.014	2.2094

a. Predictors: (Constant), OMC

b. Dependent Variable: CBR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.682	2.298		2.472	.017
	OMC	-.049	.084	-.084	-.587	.560

a. Dependent Variable: CBR

Model 6: Correlation between CBR and Grain Size

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.162[a]	.026	.016	2.1881

a. Predictors: (Constant), 0.075

b. Dependent Variable: CBR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.771	2.159		3.136	.003
	0.075	-.030	.027	-.162	-1.135	.262

a. Dependent Variable: CBR

Appendix A-2: Multiple Linear Regression Analysis

Model 1 CBR with LL, PL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.755[a]	.570	.552	1.4689

a. Predictors: (Constant), PL, LL

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	9.339	2.017		4.631	.000
1	LL	-.205	.030	-.677	-6.886	.000
	PL	.245	.046	.528	5.366	.000

a. Dependent Variable: CBR

Model 2 CBR with PI, 0.075

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.768[a]	.589	.572	1.4359

a. Predictors: (Constant), PI, 0.075

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	12.204	1.570		7.772	.000
1	0.075	-.116	.071	-.286	-2.443	.036
	PI	-.216	.027	-.754	-8.029	.000

a. Dependent Variable: CBR

Model 3 CBR with MDD, PL, and LL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.777[a]	.604	.579	1.4246

a. Predictors: (Constant), MDD, PL, LL

Coefficients[a]

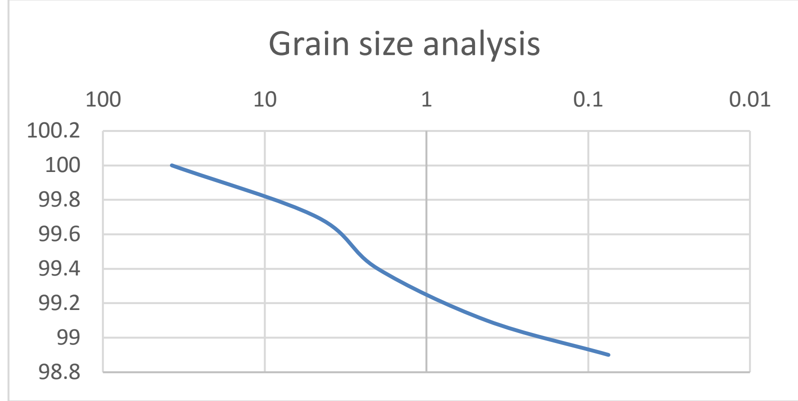
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.616	5.580		1.186	.242
	LL	-.201	.031	-.664	-6.477	.000
	PL	.247	.046	.532	5.349	.000
	MDD	.136	.5123	.053	.524	.006

a. Dependent Variable: CBR

APPENDIX B: Details of the Laboratory Test Results

Sample No.: 1 Location of Sample: Merewa Road Project, MR - 1

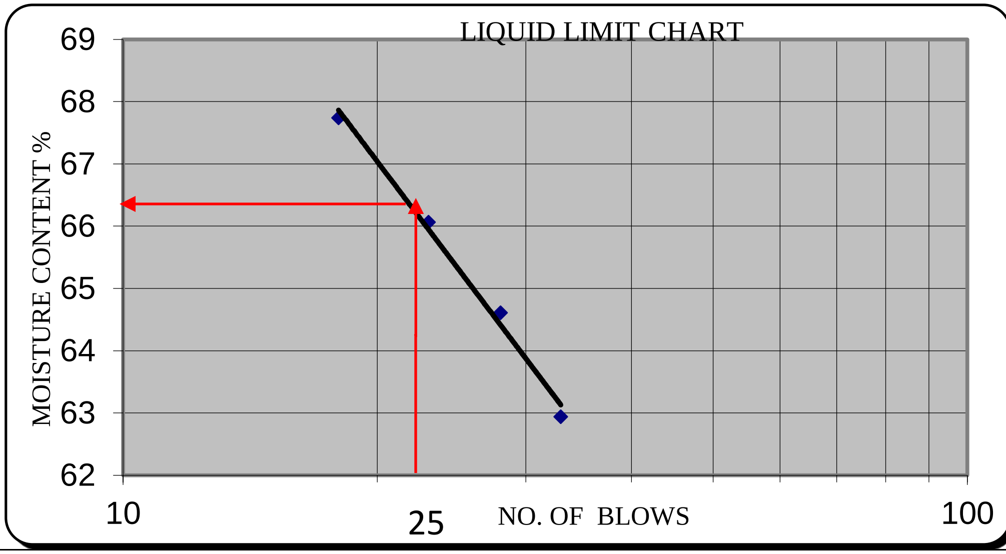
1.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing1316gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	2.8	0.3	99.7
2	2.8	0.3	99.4
0.425	2.1	0.2	99.1
0.075	1.9	0.2	98.9
Pan	0.0	0.0	



1.1.2 Subgrade Soil Classification — ASSHTO A-7-5(20)

Descriptions	1.2.1 Liquid Limit				1.2.2 Plastic Limit	
Container	AD	13	A-66	Z-40	25	B-30
Wt wet soil + con	38.88	41.05	39.89	40.35	24.38	24.15
Wt dry soil + con	31.34	32.67	32.20	31.95	23.45	23.22
Wt of water	7.54	8.38	7.69	8.40	0.93	0.93
Wt of container	19.36	19.70	20.56	19.55	20.58	20.34
Wt of dry soil	11.98	12.97	11.64	12.40	2.87	2.88
Water content,%	62.94	64.61	66.07	67.74	32.40	32.29
No of blows	33	28	23	18		

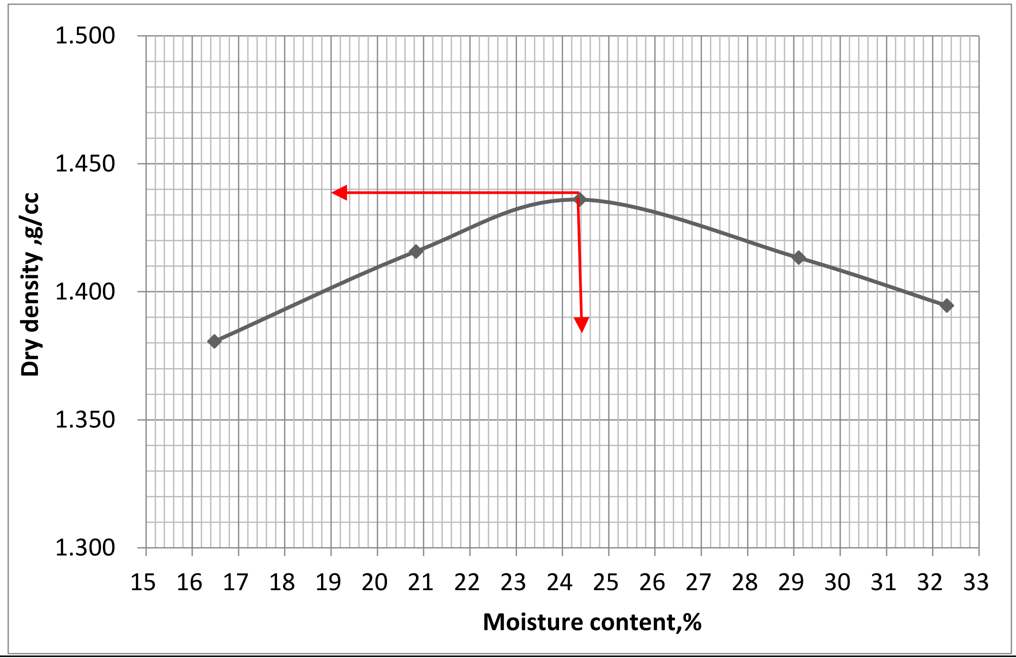
1.2.3 Plasticity Index = LL – PL = 66-32=33



1.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

1.3.1 Dry Density Determination	No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9326.4	9544.0	9704.0	9786.0
Mold (gm)	5912.4	5912.4	5912.4	5912.4
Wet soil(gm)	3414.0	3631.6	3791.6	3873.6
Volume(cm3)	2123.0	2123.0	2123.0	2123.0
Wet Density (g/cm3)	1.608	1.711	1.786	1.825
1.3.2 Moisture Content Determination				
Container No.	B-8	PH	EP	A-2
Wet Soil + Con. (g)	168.4	161.4	154.6	160.9
Dry Soil +Con. (g)	149.4	139.3	131.4	132.7
Mass of water	19.0	22.1	23.2	28.2
Mass of Con. (g)	34.1	33.2	36.2	35.8
Mass of dry soil	115.3	106.1	95.2	96.9
Moisture Content(g/cm3)	16.5	20.8	24.4	29.1
Dry density	1.381	1.416	1.436	1.413



From the compaction curve: MDD = 1.435 g/cm3 and OMC = 24.4%

1.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

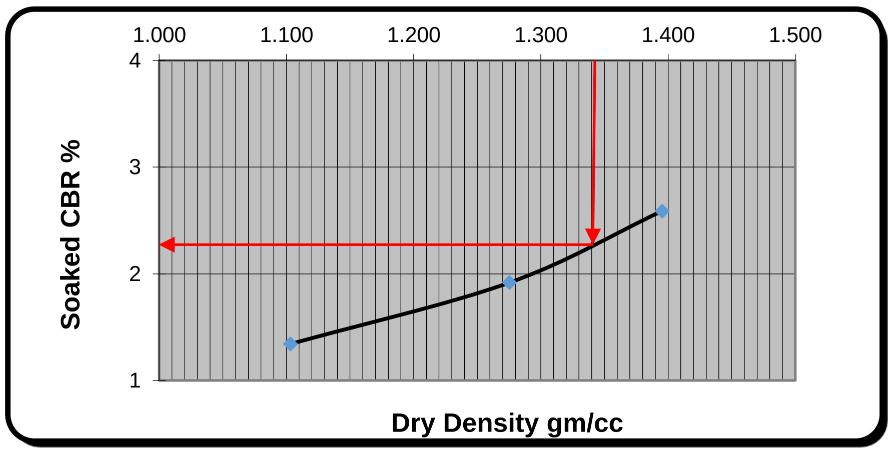
1.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00		0.0		0.00
0.64	**5**	0.06	**8**	0.1	**17**	0.22
1.27	**9**	0.12	**11**	0.1	**21**	0.27
1.96	**13**	0.17	**15**	0.2	**24**	0.31
2.54	**14**	0.18	**19**	0.2	**27**	0.35
3.18	**15**	0.19	**24**	0.3	**31**	0.40
3.81	**19**	0.24	**27**	0.3	**36**	0.46
4.45	**22**	0.28	**30**	0.4	**37**	0.47
5.08	**23**	0.29	**34**	0.4	**39**	0.50

1.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 Mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.103	0.18	0.29	13.2	20	1.34	1.47	1.34
30	1.275	0.2	0.4	13.2	20	1.92	2.17	1.92
65	1.395	0.35	0.5	13.2	20	2.59	2.49	2.59

Before soaking the three samples were remolded with OMC =24.4%

No. of Blows	10	30	65
DD (g/cm3)	1.103	1.275	1.395
CBR (%)	1.34	1.92	2.59

Density - CBR Curve



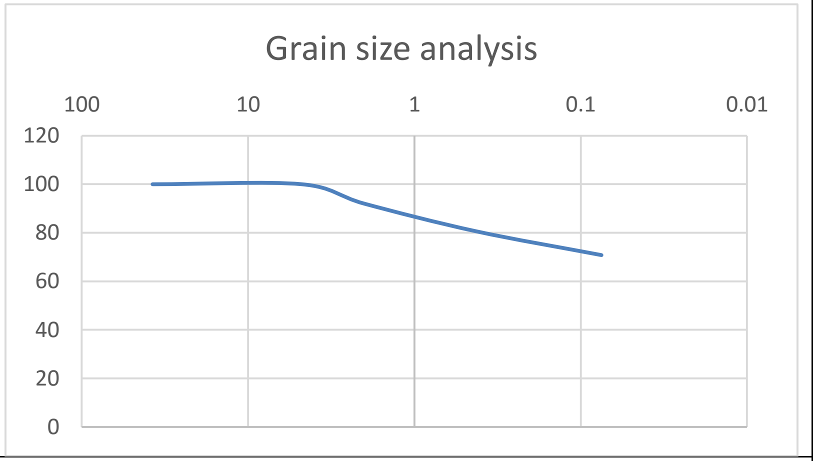
Dry density at 95% of MDD=1.363

Sample No 2.1. 1 Location of Sample: Merewa Road Project, MR - 2

2.1.1GRAIN SIZE ANALYSIS (ASTM D422)

Total Weight of dry soil before washing 815gm

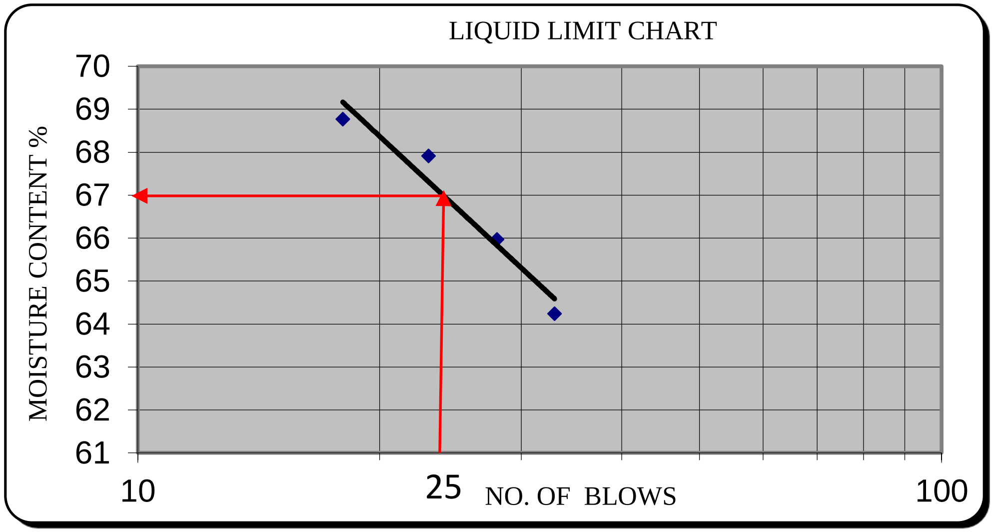
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	0.0	0.0	100.0
2	65.0	8.0	92.0
0.425	93.0	11.4	80.6
0.075	80.0	9.8	70.8
Pan	0.0	0.0	100.0



2.1.2 Subgrade Soil Classification: ASSHTO A-7-5(19)

Descriptions	2.2.1 Liquid Limit				2.2.2 Plastic Limit	
Container	C-68	A-66	AZ	U	C-3	D-4
Wt wet soil + con	33.72	31.68	32.52	31.49	27.47	27.35
Wt dry soil + con	29.30	27.26	28.16	27.02	25.56	25.55
Wt of water	4.42	4.42	4.36	4.47	1.91	1.80
Wt of container	22.42	20.56	21.74	20.52	20.21	20.34
Wt of dry soil	6.88	6.70	6.42	6.50	5.35	5.21
Water content,%	64.24	65.97	67.91	68.77	35.70	34.55
No of blows	33	28	23	18		

2.2.3 Plasticity Index = LL – PL = 67-35=32



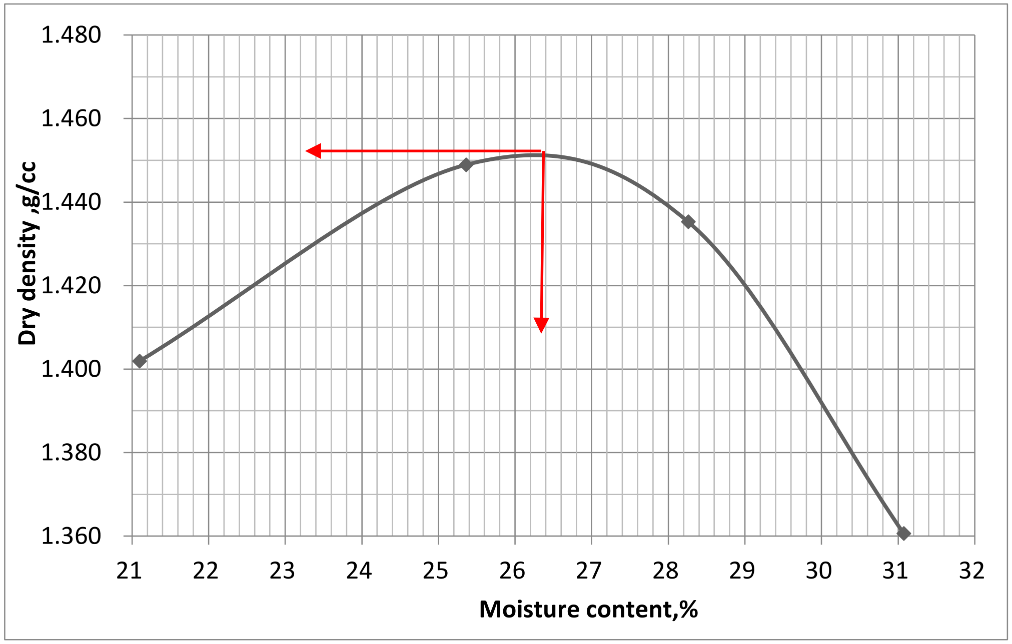
2.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

2.3.1 Dry Density Determination	No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9898.0	10150.0	10202.0	10080.0
Mold (gm)	6292.0	6292.0	6292.0	6292.0
Wet soil(gm)	3606.0	3858.0	3910.0	3788.0
Volume(cm3)	2124.0	2124.0	2124.0	2124.0
Wet Density (g/cm3)	1.698	1.816	1.841	1.783

2.3.2 Moisture Content Determination

Container No.	BN	CU	AQ	N-30
Wet Soil + Con. (g)	616.7	473.4	515.3	434.5
Dry Soil +Con. (g)	522.3	392.3	418.6	350.7
Mass of water	94.4	81.1	96.7	83.8
Mass of Con. (g)	74.9	72.5	76.4	81.0
Mass of dry soil	447.4	319.8	342.2	269.7
Moisture Content(g/cm3)	21.1	25.4	28.3	31.1
Dry density	1.402	1.449	1.435	1.361



From the compaction curve: MDD = 1.456 g/cm3 and OMC = 26.3%

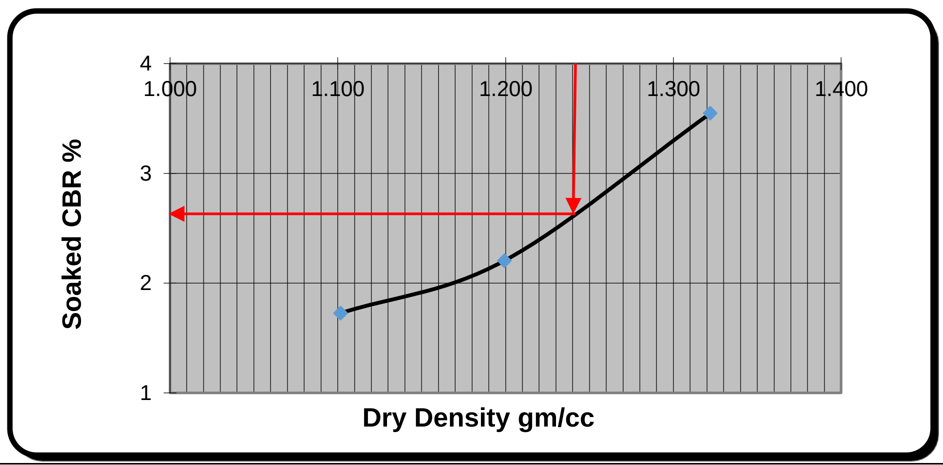
2.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

2.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00	**0**	0.0		0.00
0.64	**9**	0.12	**10**	0.1	**11**	0.14
1.27	**12**	0.15	**16**	0.2	**16**	0.20
1.96	**15**	0.19	**18**	0.2	**23**	0.29
2.54	**19**	0.24	**21**	0.3	**37**	0.47
3.18	**22**	0.28	**26**	0.3	**44**	0.56
3.81	**25**	0.32	**30**	0.4	**55**	0.70
4.45	**28**	0.36	**32**	0.4	**63**	0.81
5.08	**31**	0.40	**35**	0.4	**68**	0.87

2.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.102	0.24	0.40	13.2	20	1.82	1.98	1.82
30	1.199	0.3	0.4	13.2	20	2.01	2.24	2.01
65	1.322	0.47	0.87	13.2	20	3.55	4.35	3.55
Before soaking the three samples were remolded with OMC =24.4%								

No. of Blows	10	30	65
DD (g/cm3)	1.102	1.199	1.322
CBR (%)	1.82	2.01	3.55

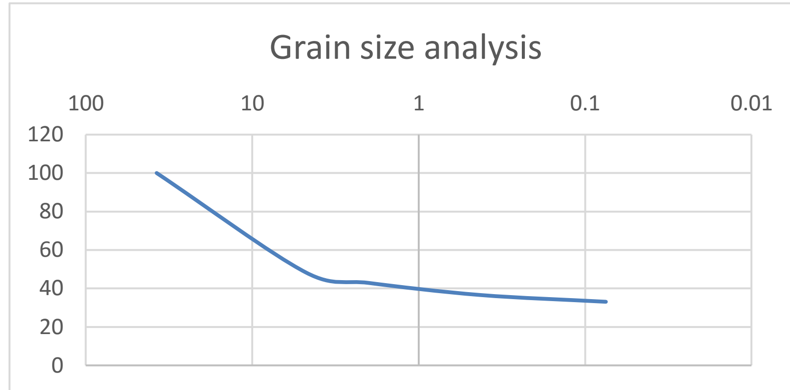
Density - CBR Curve



Dry density at 95% of MDD=1.240

Sample No 4: 1 Location of Sample: Merewa Road Project, MR - 4

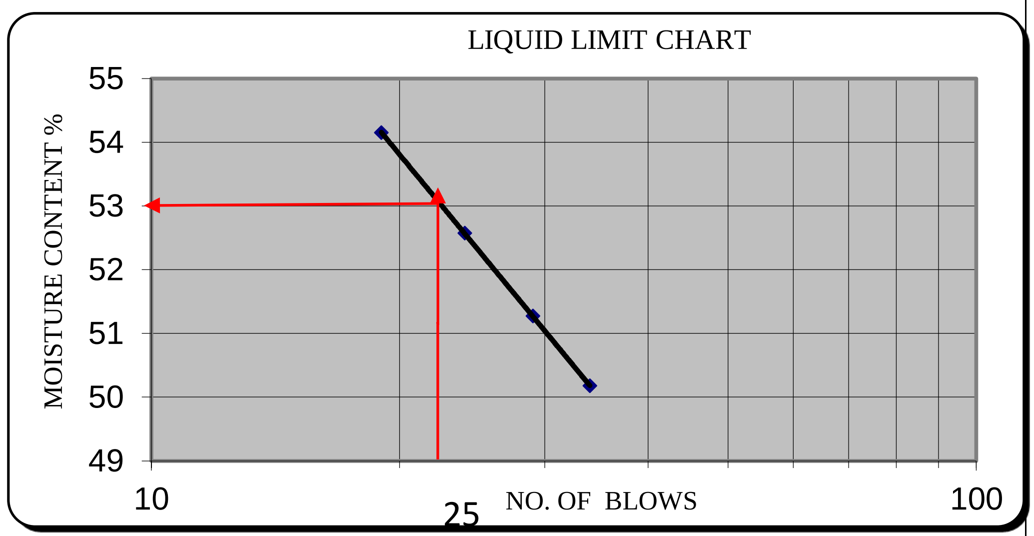
4.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing1316gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	680.0	51.7	48.3
2	72.0	5.5	42.9
0.425	82.0	6.2	36.6
0.075	46.0	3.5	33.1
Pan	0.0	0.0	



4.1.2 Subgrade Soil Classification: ASSHTO A-7-5(20)

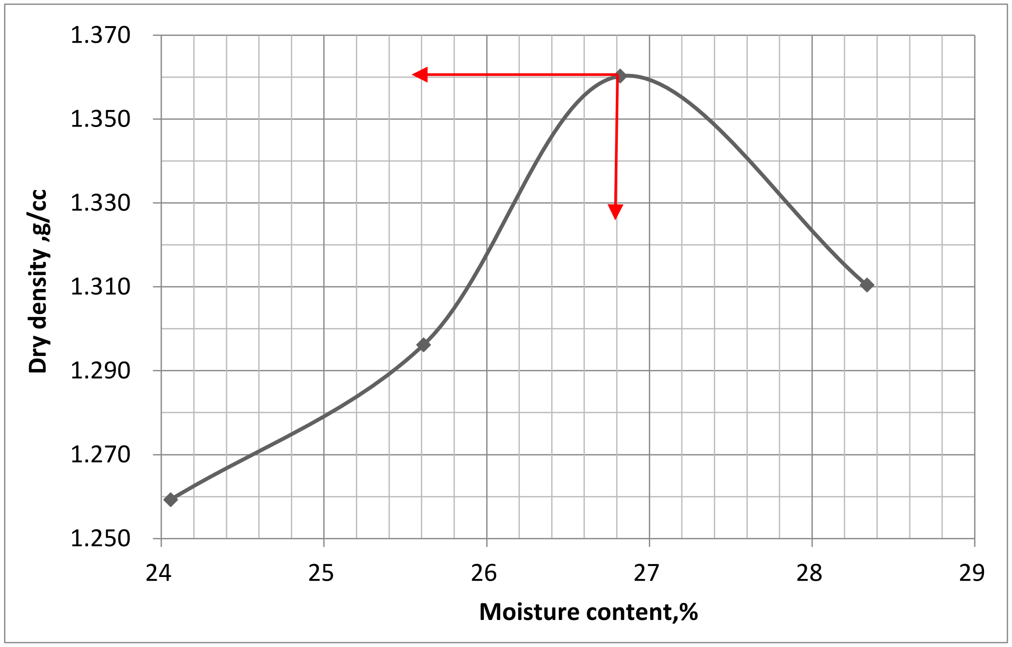
Descriptions	4.2.1 Liquid Limit				4.2.2 Plastic Limit	
Container	B-65	BM	A-29	ZL	Z-40	A-38
Wt wet soil + con	28.54	31.37	29.78	32.68	22.46	22.46
Wt dry soil + con	25.69	27.34	26.10	28.57	21.75	21.84
Wt of water	2.85	4.03	3.68	4.11	0.71	0.62
Wt of container	20.01	19.48	19.10	20.98	19.55	19.92
Wt of dry soil	5.68	7.86	7.00	7.59	2.20	1.92
Water content,%	50.18	51.27	52.57	54.15	32.27	32.29
No of blows	34	29	24	19	Z-40	A-38

4.2.3 Plasticity Index = LL – PL = 52-32=20



4.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

4.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9536.0	9676.0	9882.0	9790.0					
Mold (gm)	6218.0	6218.0	6218.0	6218.0					
Wet soil(gm)	3318.0	3458.0	3664.0	3572.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.562	1.628	1.725	1.682					
4.3.2 Moisture Content Determination									
Container No.	E	A-4	A-3	P					
Wet Soil + Con. (g)	481.2	521.4	500.8	473.3					
Dry Soil +Con. (g)	398.4	427.0	408.3	380.5					
Mass of water	82.8	94.4	92.5	92.8					
Mass of Con. (g)	54.2	58.4	63.4	53.0					
Mass of dry soil	344.2	368.6	344.9	327.5					
Moisture Content(g/cm3)	24.1	25.6	26.8	28.3					
Dry density	1.259	1.296	1.360	1.310	From the compaction curve: MDD = 1.360 g/cm3 and OMC = 26.8 %				



From the compaction curve: MDD = 1.360 g/cm3 and OMC = 26.8 %

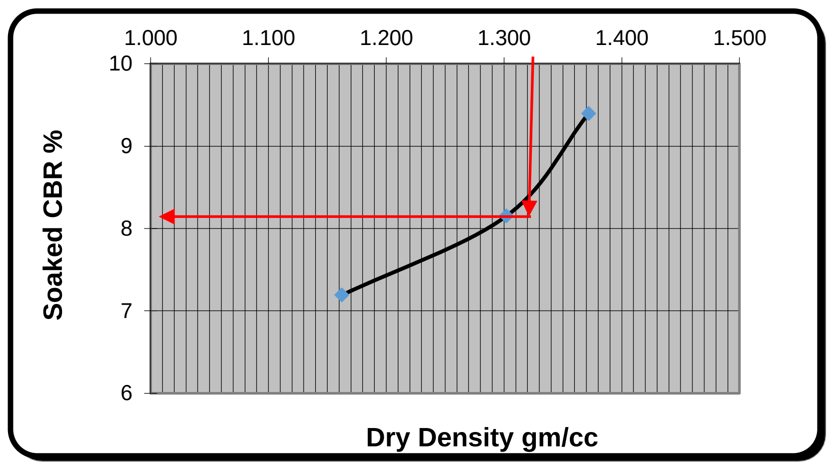
4.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

4.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	23.0	0.29	23.0	0.3	25.0	0.32
1.27	47.0	0.60	47.0	0.6	58.0	0.74
1.96	67.0	0.86	67.0	0.9	77.0	0.98
2.54	75.0	0.96	85.0	1.1	98.0	1.25
3.18	88.0	1.13	95.0	1.2	109.0	1.39
3.81	97.0	1.24	105.0	1.3	120.0	1.53
4.45	105.0	1.34	117.0	1.5	145.0	1.85
5.08	110.0	1.41	126.0	1.6	166.0	2.12

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.162	0.96	1.41	13.2	20	7.19	7.03	7.19
30	1.302	1.1	1.6	13.2	20	8.15	8.06	8.15
65	1.372	1.25	2.12	13.2	20	9.40	10.62	9.40

Before soaking the three samples were remolded with OMC=24.3%

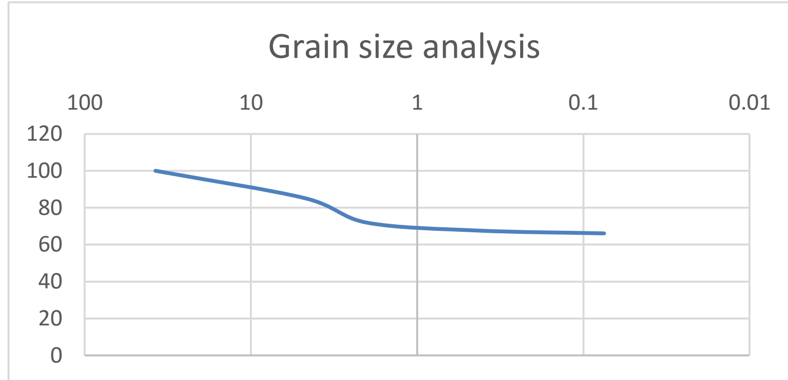
No. of Blows	10	30	65
DD (g/cm3)	1.162	1.302	1.372
CBR (%)	7.19	8.15	9.40



Dry density at 95% of MDD=1.298

Sample No.: 5 Location of Sample: Merewa Road Project, MR - 5

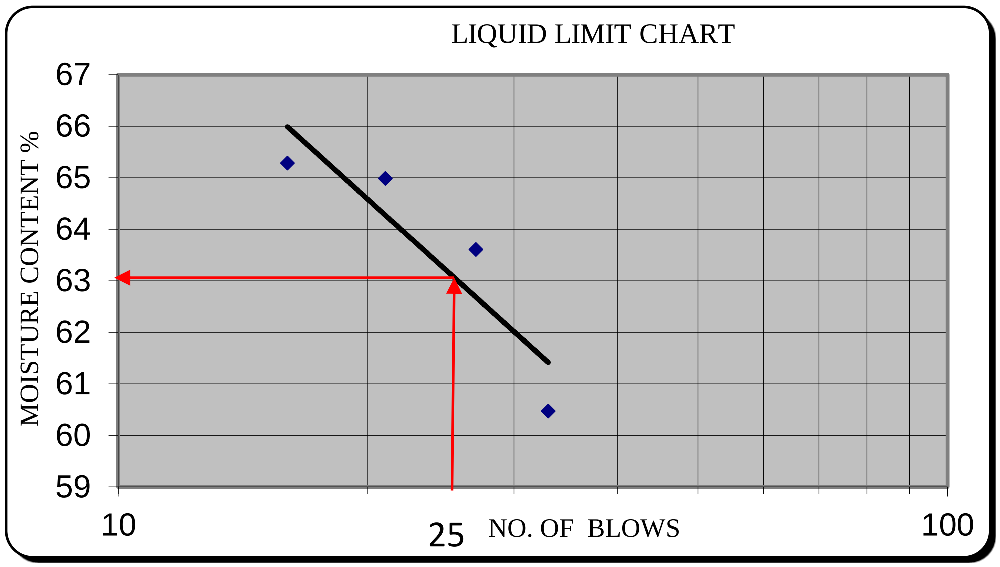
5.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 652gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	96.6	14.8	85.2
2	86.6	13.3	71.9
0.425	28.0	4.3	67.6
0.075	10.0	1.5	66.1
Pan	0.0	0.0	



5.1.2 Subgrade Soil Classification: ASSHTO A-7-6(17)

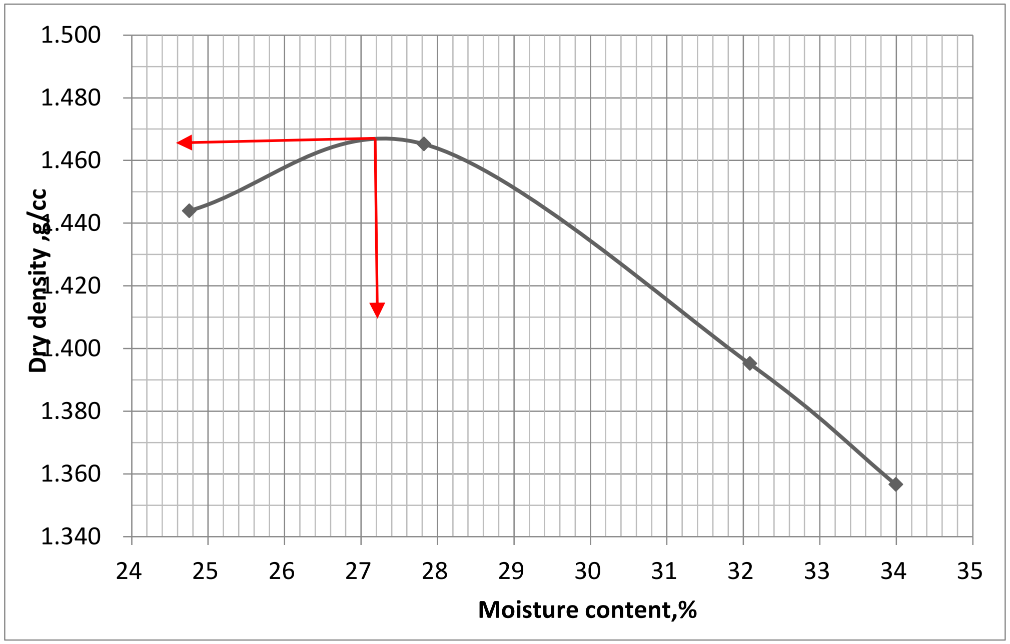
Descriptions	5.2.1 Liquid Limit				5.2.2 Plastic Limit	
Container	Z-50	YS	MM	ZM	C-68	GT
Wt wet soil + con	30.07	31.63	30.64	31.29	25.82	25.02
Wt dry soil + con	26.75	27.40	26.78	27.36	25.17	24.41
Wt of water	3.32	4.23	3.86	3.93	0.65	0.61
Wt of container	21.26	20.75	20.84	21.34	22.42	21.90
Wt of dry soil	5.49	6.65	5.94	6.02	2.75	2.51
Water content,%	60.47	63.61	64.98	65.28	23.64	24.30
No of blows	33	27	21	16		

5.2.3 Plasticity Index = LL – PL = 63-24=39



5.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

5.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	10014.0	10166.0	10102.0	10049.0					
Mold (gm)	6188.0	6188.0	6188.0	6188.0					
Wet soil(gm)	3826.0	3978.0	3914.0	3861.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.801	1.873	1.843	1.818					
5.3.2 Moisture Content Determination									
Container No.	EP	PH	B-17	B-12					
Wet Soil + Con. (g)	459.6	456.3	446.0	379.6					
Dry Soil +Con. (g)	379.9	369.5	350.4	296.9					
Mass of water	79.7	86.8	95.6	82.7					
Mass of Con. (g)	57.9	57.5	52.4	53.6					
Mass of dry soil	322.0	312.0	298.0	243.3					
Moisture Content(g/cm3)	24.8	27.8	32.1	34.0					
Dry density	1.444	1.465	1.395	1.357	From the compaction curve: MDD = 1.468 g/cm3 and OMC = 27.3%				



5.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

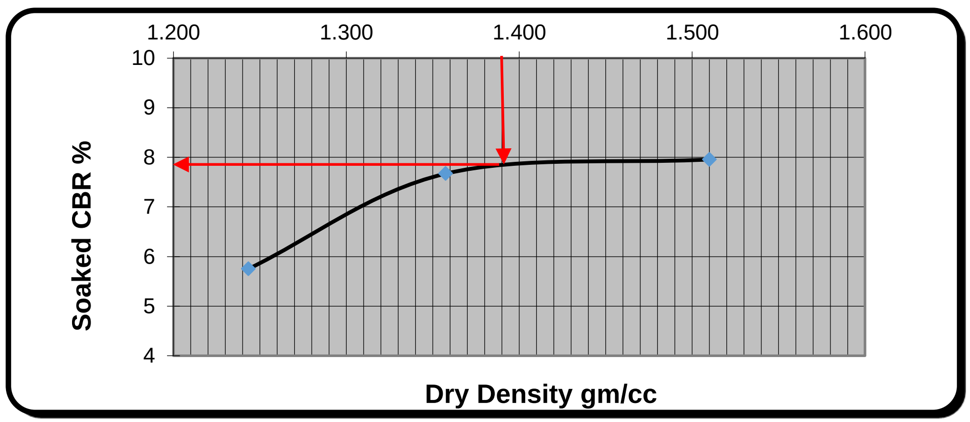
5.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	21.0	0.27	16.0	0.2	27.0	0.35
1.27	40.0	0.51	42.0	0.5	46.0	0.59
1.96	53.0	0.68	65.0	0.8	67.0	0.86
2.54	60.0	0.77	80.0	1.0	83.0	1.06
3.18	67.0	0.86	89.0	1.1	95.0	1.22
3.81	72.0	0.92	94.0	1.2	104.0	1.33
4.45	77.0	0.98	100.0	1.3	111.0	1.42
5.08	79.0	1.01	110.0	1.4	118.0	1.51

5.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.243	0.77	1.01	13.2	20	5.75	5.05	5.75
30	1.357	1.0	1.4	13.2	20	7.67	7.03	7.67
65	1.510	1.06	1.51	13.2	20	7.96	7.55	7.96

Before soaking the three samples were remolded with OMC =27.3%

No. of Blows	10	30	65
DD (g/cm3)	1.243	1.357	1.510
CBR (%)	5.75	5.67	7.96

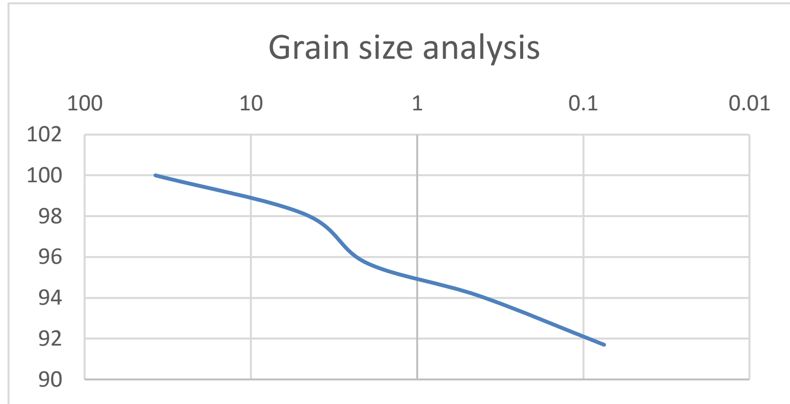
Density - CBR Curve



Dry density at 95% of MDD=1.395

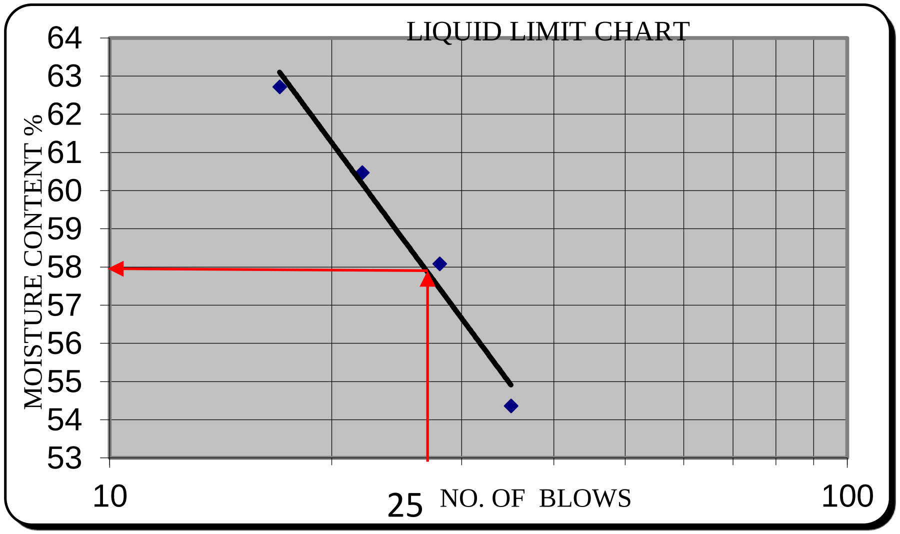
Sample No 6: Location of Sample: Merewa Road Project, MR - 6

6.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 659.4gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	12.3	1.9	98.1
2	15.9	2.4	95.7
0.425	10.6	1.6	94.1
0.075	16.1	2.4	91.7
Pan	0.0	0.0	



6.1.2 Subgrade Soil Classification: ASSHTO A-7-6(20)

Descriptions	6.2.1 Liquid Limit				6.2.2 Plastic Limit	
Container	A-38	A-36	BF	Q	XY	DN
Wt wet soil + con	29.99	32.01	30.96	30.26	25.96	25.98
Wt dry soil + con	26.44	27.84	26.86	26.61	24.79	24.79
Wt of water	3.55	4.17	4.10	3.65	1.17	1.19
Wt of container	19.91	20.66	20.08	20.79	20.53	20.50
Wt of dry soil	6.53	7.18	6.78	5.82	4.26	4.29
Water content,%	54.36	58.08	60.47	62.71	27.46	27.74
No of blows	35	28	22	17		
1.2.3 Plasticity Index = LL – PL = 59-28=31						



6.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

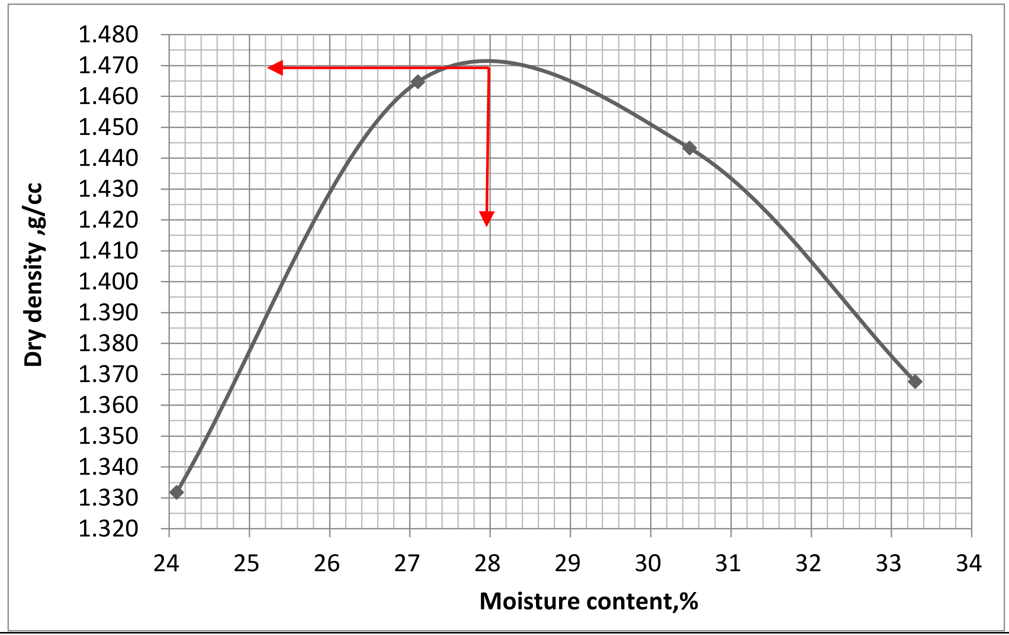
No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

6.3.1 Dry Density Determination

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9694.0	10138.0	10184.0	10056.0
Mold (gm)	6184.0	6184.0	6184.0	6184.0
Wet soil(gm)	3510.0	3954.0	4000.0	3872.0
Volume(cm3)	2124.0	2124.0	2124.0	2124.0
Wet Density (g/cm3)	1.653	1.862	1.883	1.823

6.3.2 Moisture Content Determination

Container No.	AO	AL	AG	BE
Wet Soil + Con. (g)	436.5	408.3	405.3	416.7
Dry Soil +Con. (g)	366.2	335.6	326.5	332.5
Mass of water	70.3	72.7	78.8	84.2
Mass of Con. (g)	74.4	67.3	68.0	79.6
Mass of dry soil	291.8	268.3	258.5	252.9
Moisture Content(g/cm3)	24.1	27.1	30.5	33.3
Dry density	1.332	1.465	1.443	1.368



From the compaction curve: MDD = 1.470 g/cm3 and OMC = 28.0%

6.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

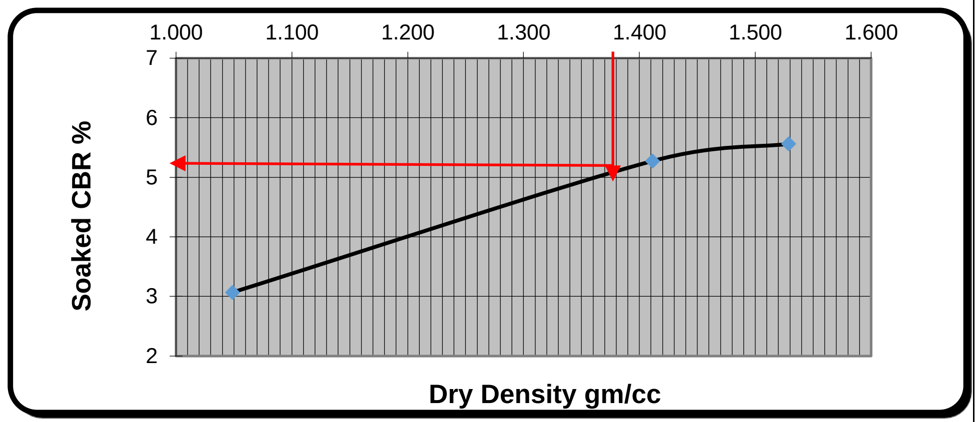
6.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00	**0**	0.0		0.00
0.64	**10**	0.13	**17**	0.2	**10**	0.13
1.27	**17**	0.22	**35**	0.4	**30**	0.38
1.96	**25**	0.32	**47**	0.6	**48**	0.61
2.54	**32**	0.41	**55**	0.7	**58**	0.74
3.18	**38**	0.49	**60**	0.8	**69**	0.88
3.81	**45**	0.58	**62**	0.8	**75**	0.96
4.45	**49**	0.63	**65**	0.8	**83**	1.06
5.08	**52**	0.67	**69**	0.9	**90**	1.15

6.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.049	0.41	0.67	13.2	20	3.3	3.07	3.3
30	1.411	0.7	0.74	13.2	20	5.27	4.41	5.27
65	1.529	0.74	1.15	13.2	20	5.56	5.76	5.56

Before soaking the three samples were remolded with OMC =28%

No. of Blows	10	30	65
DD (g/cm3)	1.049	1.411	1.529
CBR (%)	3.07	5.27	5.56

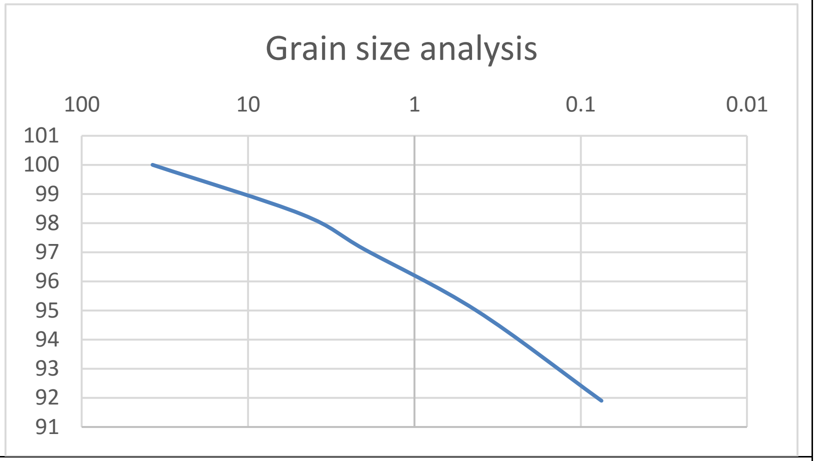
Density - CBR Curve



Dry density at 95% of MDD=1.397

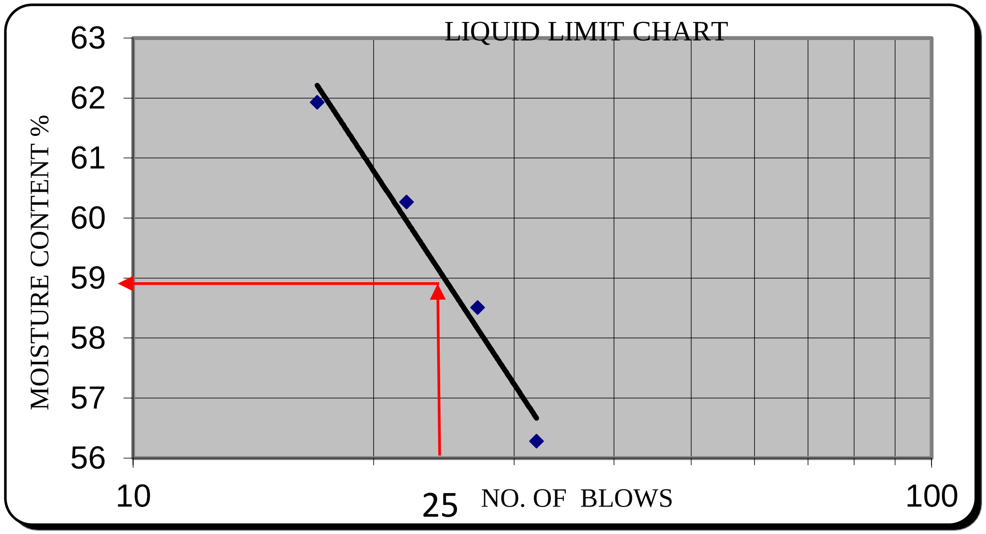
Sample No 9: Location of Sample: Kitto Furdisa, KF - 9

9.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 628gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	10.9	1.7	98.3
2	7.2	1.1	97.1
0.425	13.3	2.1	95.0
0.075	19.4	3.1	91.9
Pan	0.0	0.0	
9.1.2 Subgrade Soil Classification	ASSHTO A-7-6(20)		



9.2 ATTERBERG LIMIT TEST (ASTM D 4318)

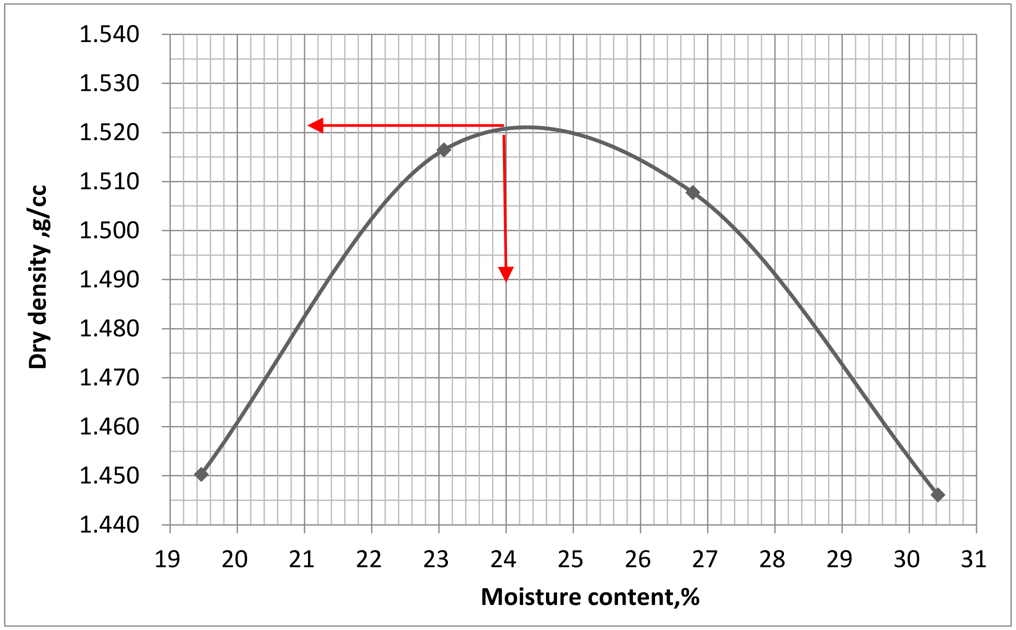
Descriptions	9.2.1 Liquid Limit				9.2.2 Plastic Limit	
Container	SB	MS	A-36	F	BD	B-30
Wt wet soil + con	33.42	31.00	37.45	32.65	25.62	24.22
Wt dry soil + con	28.76	26.46	31.14	28.16	24.81	23.46
Wt of water	4.66	4.54	6.31	4.49	0.81	0.76
Wt of container	20.48	18.70	20.67	20.91	21.50	20.34
Wt of dry soil	8.28	7.76	10.47	7.25	3.31	3.12
Water content,%	56.28	58.51	60.27	61.93	24.47	24.36
No of blows	32	27	22	17		
9.2.3 Plasticity Index = LL – PL = 59-24=35						



9.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

9.3.1 Dry Density Determination				
Mold No.	1	2	3	4
Mold + Wet soil (gm)	9872.0	10156.0	10252.0	10198.0
Mold (gm)	6192.0	6192.0	6192.0	6192.0
Wet soil(gm)	3680.0	3964.0	4060.0	4006.0
Volume(cm3)	2124.0	2124.0	2124.0	2124.0
Wet Density (g/cm3)	1.733	1.866	1.911	1.886
9.3.2 Moisture Content Determination				
Container No.	CM	AL	AG	BE
Wet Soil + Con. (g)	550.0	486.5	437.4	413.9
Dry Soil +Con. (g)	473.2	407.9	359.4	335.9
Mass of water	76.8	78.6	78.0	78.0
Mass of Con. (g)	78.6	67.2	68.1	79.5
Mass of dry soil	394.6	340.7	291.3	256.4
Moisture Content(g/cm3)	19.5	23.1	26.8	30.4
Dry density	1.450	1.516	1.508	1.446



From the compaction curve: MDD = 1.521 g/cm3 and OMC = 24.0%

9.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

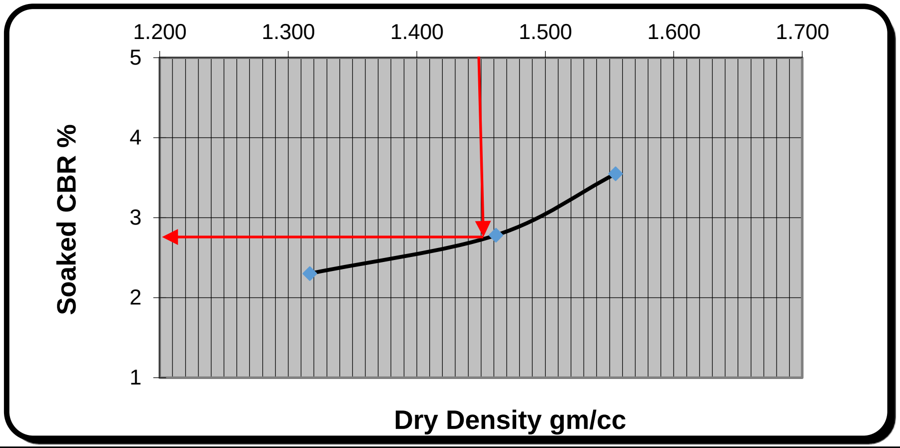
9.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.01279		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00		0.0		0.00
0.64	**5**	0.06	**8**	0.1	**17**	0.22
1.27	**9**	0.12	**11**	0.1	**21**	0.27
1.96	**16**	0.20	**15**	0.2	**24**	0.31
2.54	**24**	0.31	**29**	0.4	**37**	0.47
3.18	**28**	0.36	**33**	0.4	**39**	0.50
3.81	**31**	0.40	**36**	0.5	**43**	0.55
4.45	**36**	0.46	**40**	0.5	**46**	0.59
5.08	**39**	0.50	**42**	0.5	**49**	0.63

9.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.317	0.31	0.5	13.2	20	3.55	3.13	3.55
30	1.462	0.4	0.5	13.2	20	2.78	2.69	2.78
65	1.555	0.47	0.63	13.2	20	2.49	2.3	2.49

Before soaking the three samples were remolded with OMC =24.3%

No. of Blows	10	30	65
DD (g/cm3)	1.317	1.462	1.555
CBR (%)	3.13	2.69	2.3

Density - CBR Curve

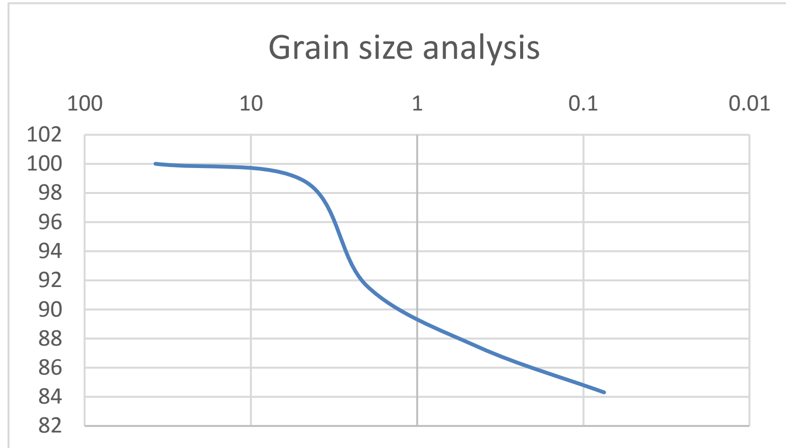


Dry density at 95% of MDD=1.445

11.1 GRAIN SIZE ANALYSIS (ASTM D422)

Total Weight of dry soil before washing 532.0gm

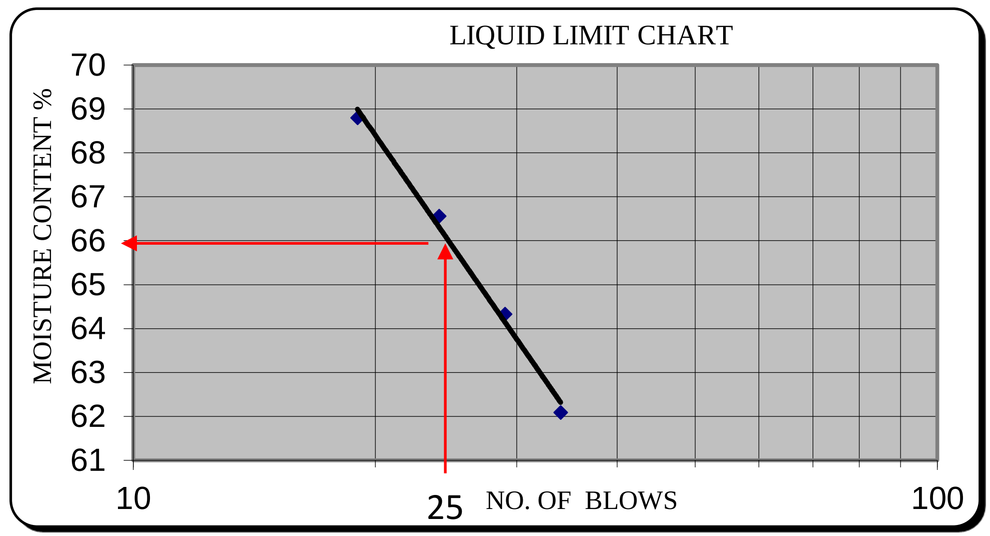
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	6.4	1.2	98.8
2	38.3	7.2	91.6
0.425	22.3	4.2	87.4
0.075	16.7	3.1	84.3
Pan	0.0	0.0	



11.1.2 Subgrade Soil Classification: ASSHTO A-7-5(20)

Descriptions	11.2.1 Liquid Limit				11.2.2 Plastic Limit	
Container	A-66	13	D-4	AE	34	A-99
Wt wet soil + con	36.72	38.91	41.43	43.05	26.68	26.06
Wt dry soil + con	30.53	31.39	32.99	34.01	25.46	24.78
Wt of water	6.19	7.52	8.44	9.04	1.22	1.28
Wt of container	20.56	19.70	20.31	20.87	21.68	20.78
Wt of dry soil	9.97	11.69	12.68	13.14	3.78	4.00
Water content,%	62.09	64.33	66.56	68.80	32.28	32.00
No of blows	34	29	24	19		

11.2.3 Plasticity Index = LL – PL = 66-32=34



11.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

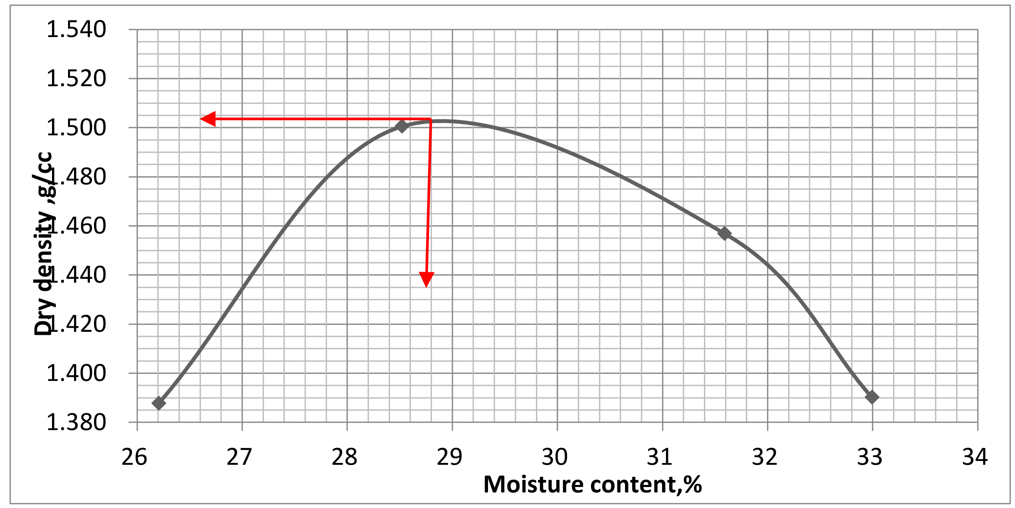
No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

11.3.1 Dry Density Determination

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9908.0	10284.0	10260.0	10115.0
Mold (gm)	6188.0	6188.0	6188.0	6188.0
Wet soil(gm)	3720.0	4096.0	4072.0	3927.0
Volume(cm3)	2124.0	2124.0	2124.0	2124.0
Wet Density (g/cm3)	1.751	1.928	1.917	1.849

11.3.2 Moisture Content Determination

Container No.	AG	BE	AF	BF
Wet Soil + Con. (g)	513.1	474.9	460.4	478.1
Dry Soil +Con. (g)	420.7	387.2	368.7	378.1
Mass of water	92.4	87.7	91.7	100.0
Mass of Con. (g)	68.1	79.7	78.4	75.0
Mass of dry soil	352.6	307.5	290.3	303.1
Moisture Content(g/cm3)	26.2	28.5	31.6	33.0
Dry density	1.388	1.500	1.457	1.390



From the compaction curve: MDD = 1.503 g/cm3 and OMC = 28.9%

11.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

11.4.1 Penetration Data (After 4-day soaking)

Ring Factor=0.01279

Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	7.0	0.09	10.0	0.1	16.0	0.20
1.27	12.0	0.15	18.0	0.2	22.0	0.28
1.96	15.0	0.19	24.0	0.3	30.0	0.38
2.54	17.0	0.22	32.0	0.4	40.0	0.51
3.18	20.0	0.26	37.0	0.5	47.0	0.60
3.81	22.0	0.28	42.0	0.5	51.0	0.65
4.45	25.0	0.32	47.0	0.6	58.0	0.74
5.08	30.0	0.38	52.0	0.7	66.0	0.84

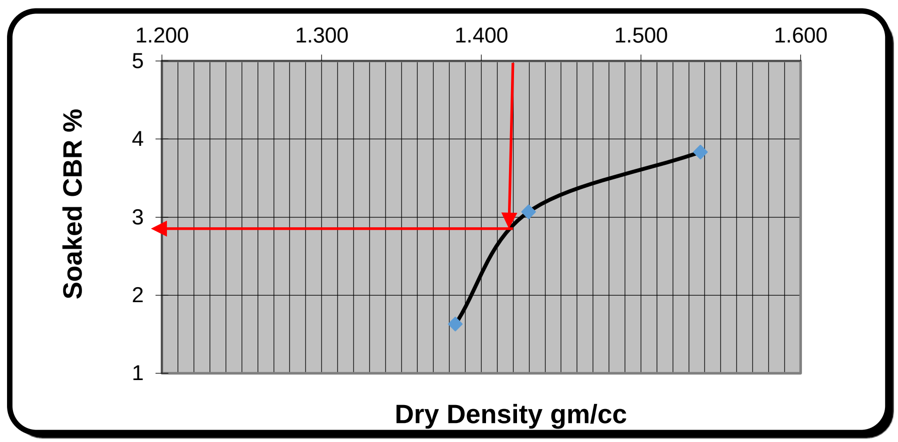
11.4.2 CBR Value at Standard Loads and CBR Test Summary

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.384	0.22	0.38	13.2	20	3.84	4.22	3.84
30	1.430	0.4	0.7	13.2	20	3.07	3.33	3.07
65	1.537	0.51	0.84	13.2	20	1.63	1.92	1.63

Before soaking the three samples were remolded with OMC =28.9%

No. of Blows	10	30	65
DD (g/cm3)	1.384	1.430	1.537
CBR (%)	3.84	3.07	1.63

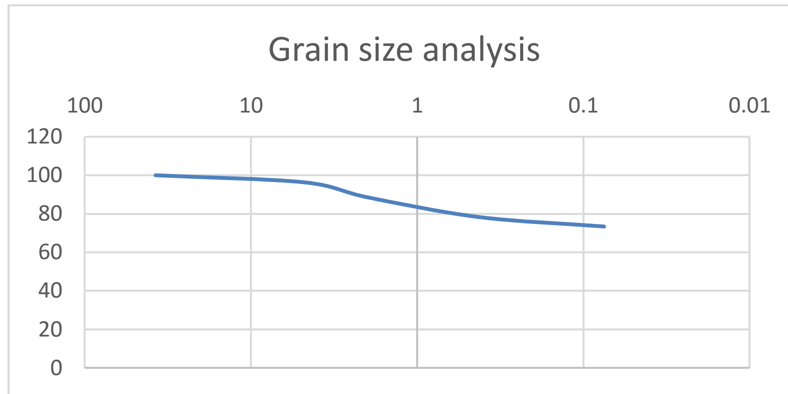
Density - CBR Curve



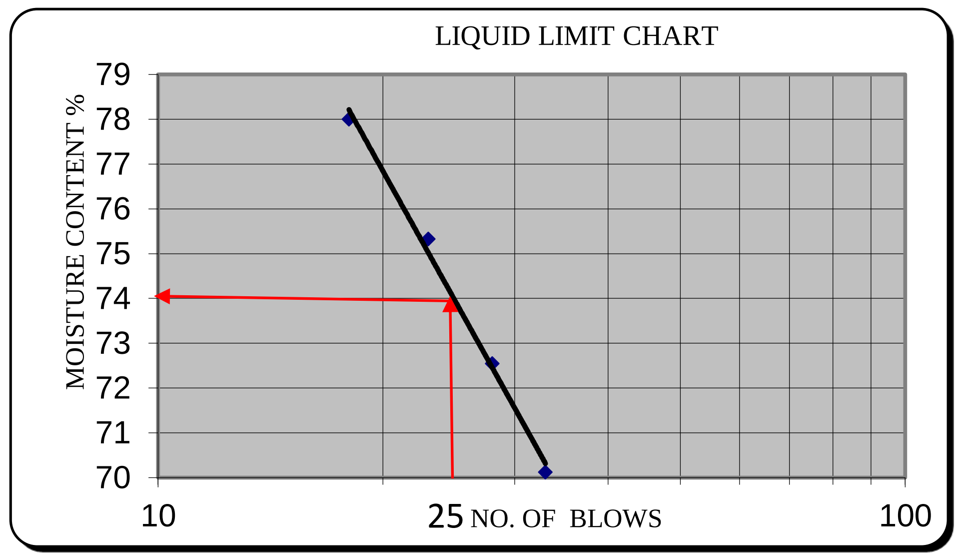
Dry density at 95% of MDD=1.428

Sample No 12: Location of Sample: Agricultural campus AC - 1

12.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 798.0gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	29.5	3.7	96.3
2	61.4	7.7	88.6
0.425	82.2	10.3	78.3
0.075	39.1	4.9	73.4
Pan	0.0	0.0	
12.1.2 Subgrade Soil Classification	ASSHTO A-7-5(20)		



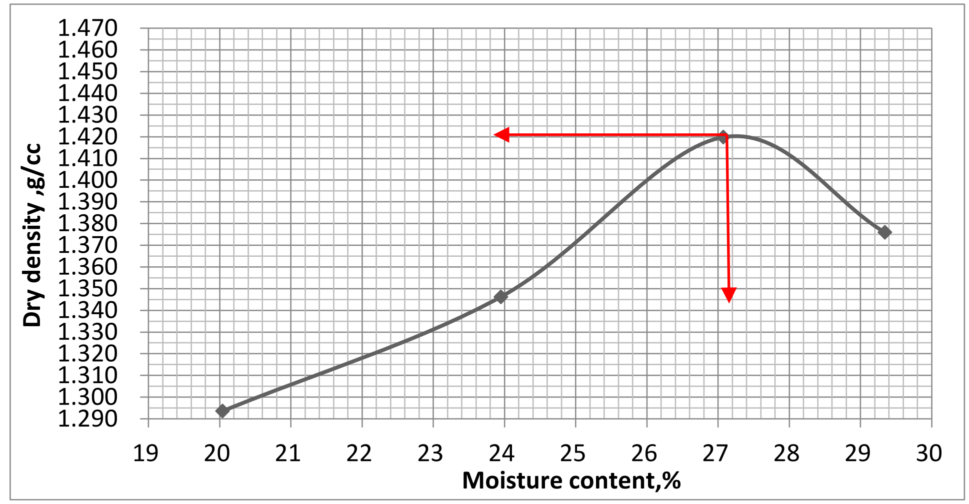
Descriptions	12.2.1 Liquid Limit				12.2.2 Plastic Limit	
Container	Z-3	Z-40	Z-2	Z-1	Z-50	Z-60
Wt wet soil + con	30.65	31.69	34.10	32.83	27.36	27.25
Wt dry soil + con	24.97	26.59	28.39	27.44	25.95	25.79
Wt of water	5.68	5.10	5.71	5.39	1.41	1.46
Wt of container	16.87	19.56	20.81	20.53	21.27	20.87
Wt of dry soil	8.10	7.03	7.58	6.91	4.68	4.92
Water content,%	70.12	72.55	75.33	78.00	30.13	29.67
No of blows	33	28	23	18		
12.2.3 Plasticity Index = LL – PL = 74-30=44						



12.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

12.3.1 Dry Density Determination	No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9624.0	9870.0	10158.0	10106.0
Mold (gm)	6326.0	6326.0	6326.0	6326.0
Wet soil(gm)	3298.0	3544.0	3832.0	3780.0
Volume(cm3)	2124.0	2124.0	2124.0	2124.0
Wet Density (g/cm3)	1.553	1.669	1.804	1.780
12.3.2 Moisture Content Determination				
Container No.	AL	BG	AQ	N-30
Wet Soil + Con. (g)	567.4	500.9	455.0	437.1
Dry Soil +Con. (g)	483.9	419.0	374.3	356.3
Mass of water	83.5	81.9	80.7	80.8
Mass of Con. (g)	67.2	77.0	76.2	80.9
Mass of dry soil	416.7	342.0	298.1	275.4
Moisture Content(g/cm3)	20.0	23.9	27.1	29.3
Dry density	1.294	1.346	1.420	1.376



From the compaction curve: MDD = 1.420 g/cm3 and OMC = 27.2%

12.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

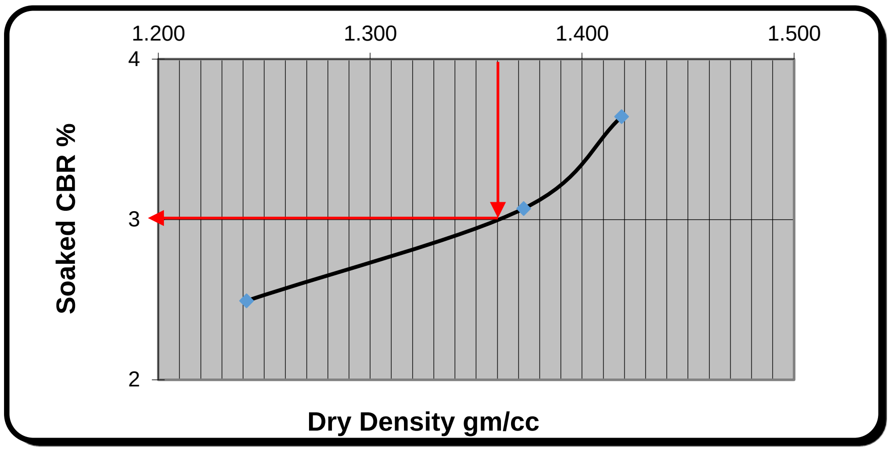
12.4.1 Penetration Data (After 4-day soaking)					Ring Factor=0.01279	
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00		0.0		0.00
0.64	**4**	0.05	**6**	0.1	**12**	0.15
1.27	**6**	0.08	**9**	0.1	**20**	0.26
1.96	**8**	0.10	**11**	0.1	**30**	0.38
2.54	**26**	0.33	**32**	0.4	**38**	0.49
3.18	**30**	0.38	**35**	0.4	**43**	0.55
3.81	**33**	0.42	**39**	0.5	**49**	0.63
4.45	**38**	0.49	**44**	0.6	**54**	0.69
5.08	**42**	0.54	**53**	0.7	**58**	0.74

12.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.242	0.33	0.54	13.2	20	2.49	2.59	2.49
30	1.372	0.4	0.7	13.2	20	3.07	3.39	3.07
65	1.419	0.49	0.74	13.2	20	3.64	3.71	3.64

Before soaking the three samples were remolded with OMC =27.2%

No. of Blows	10	30	65
DD (g/cm3)	1.242	1.372	1.419
CBR (%)	2.49	3.07	3.64

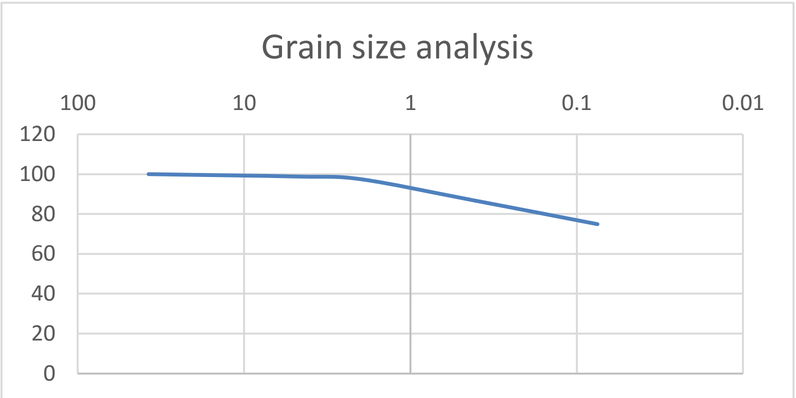
Density - CBR Curve



Dry density at 95% of MDD=1.349

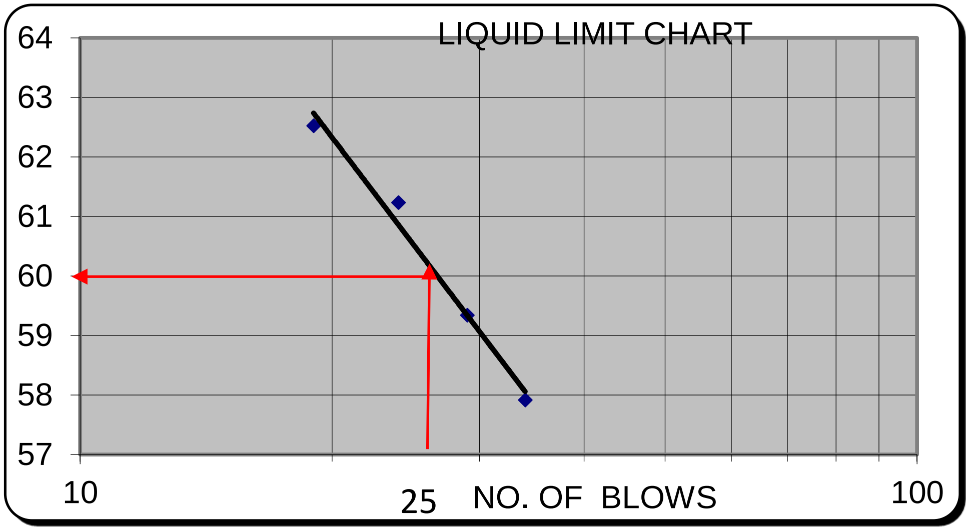
Sample No 13: Location of Sample: Agricultural campus AC - 2

13.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 504.0gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	7.1	1.2	98.8
2	8.3	1.3	97.5
0.425	64.8	10.5	87.0
0.075	74.5	12.1	74.9
Pan	0.0	0.0	
13.1.2 Subgrade Soil Classification	ASSHTO A-7-5(18)		



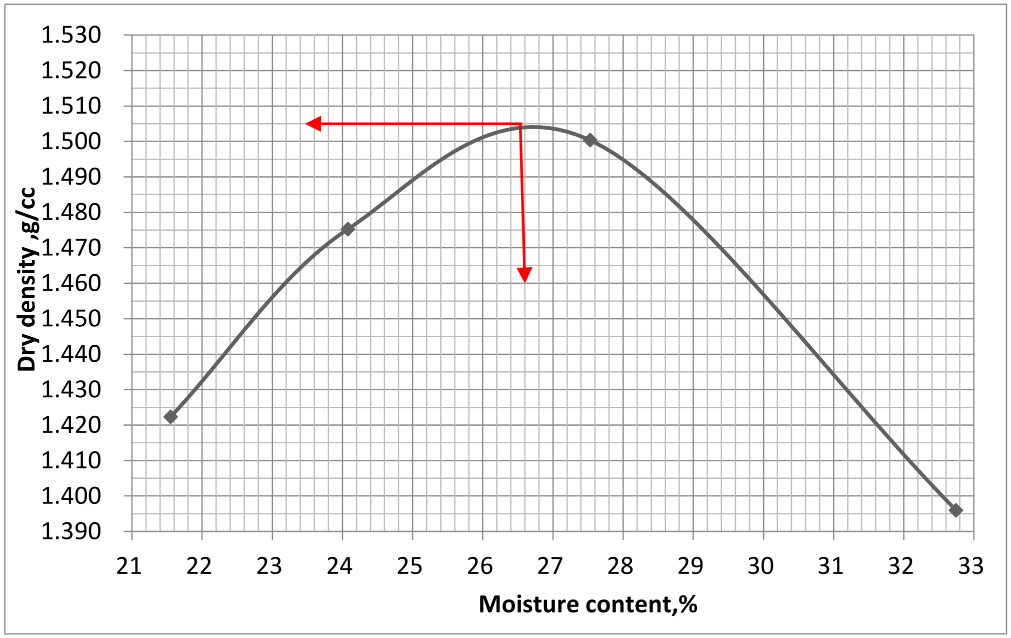
13.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	13.2.1 Liquid Limit				13.2.2 Plastic Limit	
Container	GT	13	D-4	BM	BN	BZ
Wt wet soil + con	31.58	29.78	31.88	30.58	25.91	24.78
Wt dry soil + con	28.03	26.03	27.49	26.31	24.88	24.05
Wt of water	3.55	3.75	4.39	4.27	1.03	0.73
Wt of container	21.90	19.71	20.32	19.48	20.50	20.91
Wt of dry soil	6.13	6.32	7.17	6.83	4.38	3.14
Water content,%	57.91	59.34	61.23	62.52	23.52	23.25
No of blows	33	28	23	18		
13.2.3 Plasticity Index = LL – PL = 60-23=37						



13 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

13.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9998.0	10214.0	10390.0	10262.0					
Mold (gm)	6326.0	6326.0	6326.0	6326.0					
Wet soil(gm)	3672.0	3888.0	4064.0	3936.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.729	1.831	1.913	1.853					
13.3.2 Moisture Content Determination									
Container No.	AB	CQ	CP	BN					
Wet Soil + Con. (g)	504.3	505.8	478.6	450.5					
Dry Soil +Con. (g)	424.5	418.9	386.6	357.8					
Mass of water	79.8	86.9	92.0	92.7					
Mass of Con. (g)	54.2	58.0	52.4	74.7					
Mass of dry soil	370.3	360.9	334.2	283.1					
Moisture Content(g/cm3)	21.6	24.1	27.5	32.7					
Dry density	1.422	1.475	1.500	1.396	From the compaction curve: MDD = 1.505 g/cm3 and OMC = 26.67%				



13.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

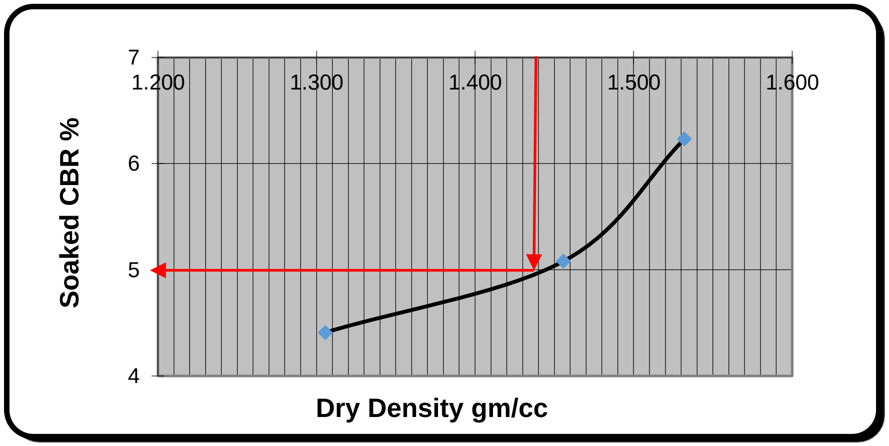
13.4.1 Penetration Data (After 4-day soaking)					Ring Factor=0.01279	
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	16.0	0.20	18.0	0.2	20.0	0.26
1.27	22.0	0.28	33.0	0.4	36.0	0.46
1.96	39.0	0.50	42.0	0.5	55.0	0.70
2.54	46.0	0.59	53.0	0.7	65.0	0.83
3.18	49.0	0.63	56.0	0.7	69.0	0.88
3.81	55.0	0.70	60.0	0.8	74.0	0.95
4.45	59.0	0.75	68.0	0.9	78.0	1.00
5.08	66.0	0.84	72.0	0.9	81.0	1.04

13.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.305	0.59	0.84	13.2	20	4.41	4.22	4.41
30	1.456	0.7	0.9	13.2	20	5.08	4.60	5.08
65	1.532	0.83	1.04	13.2	20	6.23	5.18	6.23

Before soaking the three samples were remolded with OMC =26.7%

No. of Blows	10	30	65
DD (g/cm3)	1.305	1.456	1.532
CBR (%)	5.08	5.27	5.08

Density - CBR Curve



Dry density at 95% of MDD=1.430

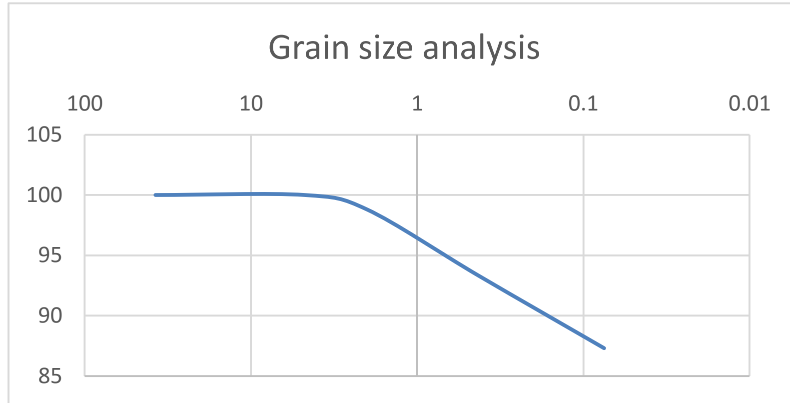
Sample No 17: Location of Sample: Seto Area SA - 1

1.7 Particle size distribution AASHTO T-11/T27

Total Weight of dry soil before washing = 513gm

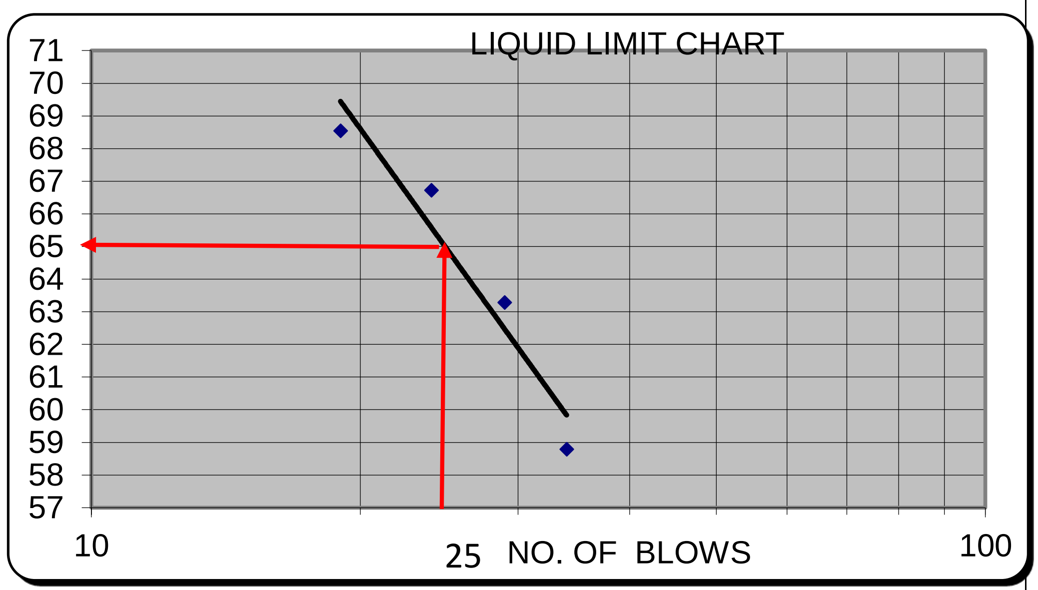
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0	0	100
4.75	0	0	100
2	6.2	1.2	98.8
0.425	28.2	5.5	93.3
0.075	30.6	6	87.3
Pan	0	0	

17.1.2 Subgrade Soil Classification AASHTO = A-7-5(13)



Descriptions	17.2.1 Liquid Limit				17.2.2 Plastic Limit	
Container	WO	SQ	CP	4U	A-100	PA
Wt wet soil + con	28.46	30.03	31.39	31.84	23.6	26.25
Wt dry soil + con	25.65	26.41	27.52	27.7	22.59	25.39
Wt of water	2.81	3.62	3.87	4.14	1.01	0.86
Wt of container	20.87	20.69	21.72	21.66	18.39	21.79
Wt of dry soil	4.78	5.72	5.8	6.04	4.2	3.6
Water content,%	58.79	63.29	66.72	68.54	24.05	23.89
No of blows	34	29	24	19	24	

1.2.3 Plasticity Index = LL – PL =65-24=41



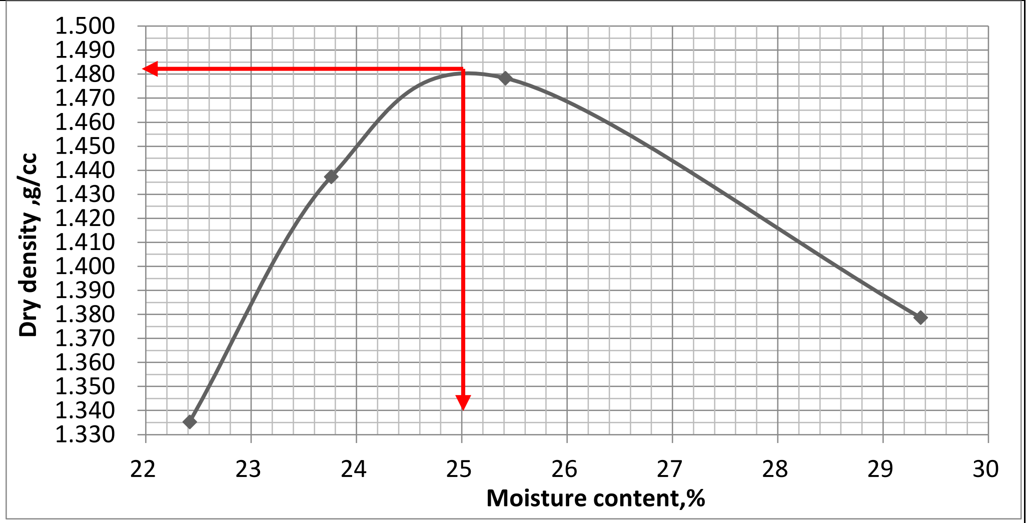
17.3 STANDARD PROCTOR TEST (AASHTO T-181, Method D)

17.3.1 Dry Density Determination	No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9630	9870	10128	10010
Mold (gm)	6158	6158	6158	6158
Wet soil(gm)	3404	3712	3970	3852
Volume(cm3)	2124	2124	2124	2124
Wet Density (g/cm3)	1.603	1.748	1.869	1.814

17.3.2 Moisture Content Determination

Container No.	B-8	PH	EP	A-2
Wet Soil + Con. (g)	383.5	375.5	309.0	360.1
Dry Soil +Con. (g)	323.2	308.7	248.5	284
Mass of water	60.3	66.8	60.5	76
Mass of Con. (g)	57.7	57.8	57.6	52
Mass of dry soil	265.5	250.9	190.9	232
Moisture Content(g/cm3)	22.7	26.6	31.7	32.8
Dry density	1.306	1.308	1.419	1.366



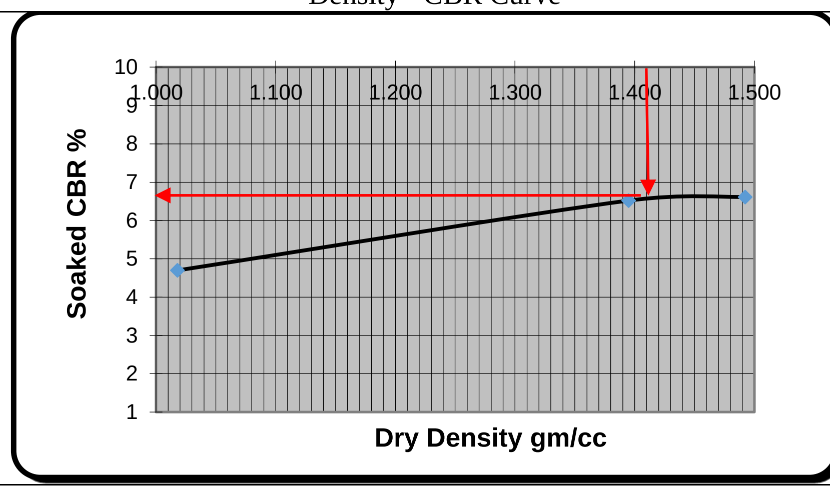
17.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

17.4.1 Penetration Data (After 4-day soaking)					Ring Factor=0.01279	
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0	0	0	0	0	0
0.64	16	0.34	25	0.54	15	0.32
1.27	29	0.62	46	0.98	31	0.66
1.96	40	0.86	60	1.28	55	1.18
2.54	49	1.05	68	1.46	69	1.48
3.18	55	1.18	73	1.56	78	1.67
3.81	60	1.28	76	1.63	85	1.82
4.45	64	1.37	79	1.69	90	1.93
5.08	66	1.41	81	1.73	95	2.03

17.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.018	1.05	1.41	13.2	20	1.05	1.41	1.05
30	1.395	1.46	1.73	13.2	20	1.46	1.73	1.46
65	1.492	1.48	2.03	13.2	20	1.48	2.03	1.48
Before soaking the three samples were remolded with OMC = 25%								

No. of Blows	10	30	65
DD (g/cm3)	1.018	1.395	1.492
CBR (%)	4.72	6.52	6.62

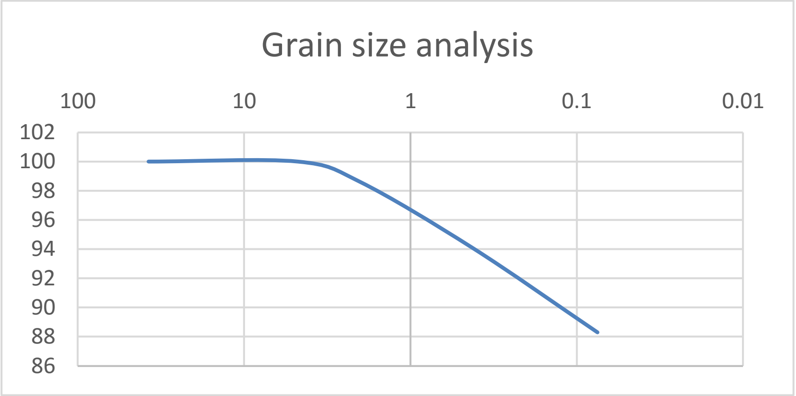
Density - CBR Curve



Dry density at 95% of MDD=1.406

Sample No 18: Location of Sample: Kitto Furdisa, ST - 2

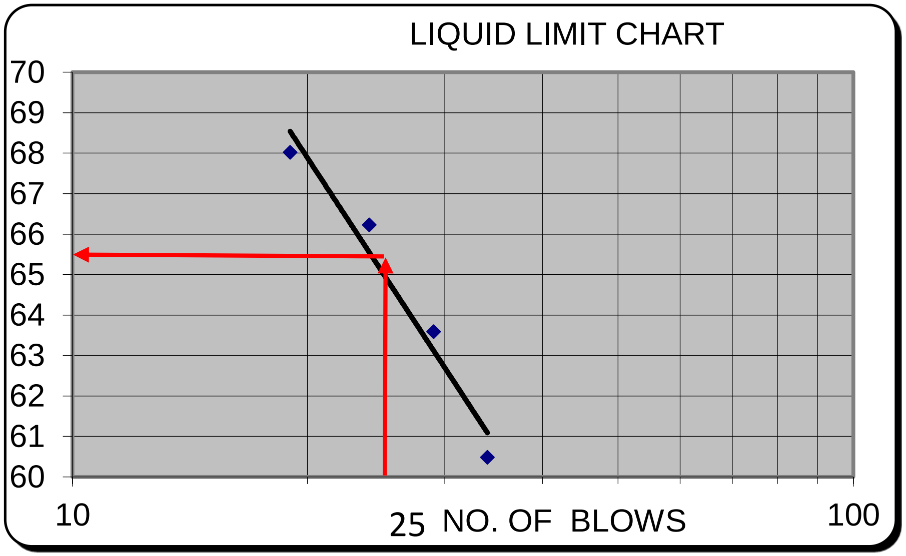
18.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing = 884gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0	0	100
4.75	0	0	100
2	7.4	1.4	98.6
0.425	22.7	4.4	94.1
0.075	30.1	5.9	88.3
Pan	0	0	



18.1.2 Subgrade Soil Classification — AASHTO = A-7-6(20)

Descriptions	18.2.1 Liquid Limit				18.2.2 Plastic Limit	
Container	K	Z-1	JQ	23	LL	BK
Wt wet soil + con	32.4	29.75	30.96	29.91	24.64	24.69
Wt dry soil + con	27.9	26.17	26.98	26.38	23.64	23.77
Wt of water	4.54	3.58	3.98	3.53	1.00	0.92
Wt of container	20.46	20.54	20.97	21.19	20.24	20.68
Wt of dry soil	7.44	5.63	6.01	5.19	3.4	3.09
Water content,%	61.02	63.59	66.22	68.02	29.41	29.77
No of blows	34	29	24	19		

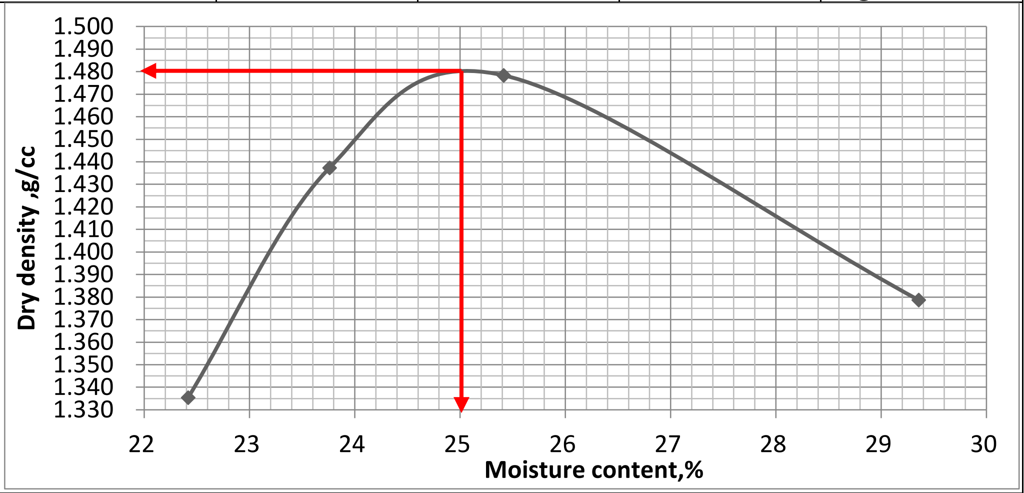
18.2.3 Plasticity Index = LL – PL =65-30=35



18.3 STADARD PROCTOR TEST (AASHTO T-181, Method D)

18.3.1 Dry Density Determination	No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9630	9870	10128	10010
Mold (gm)	6158	6158	6158	6158
Wet soil(gm)	3404	3712	3970	3852
Volume(cm3)	2124	2124	2124	2124
Wet Density (g/cm3)	1.603	1.748	1.869	1.814
18.3.2 Moisture Content Determination				
Container No.	B-8	PH	EP	A-2
Wet Soil + Con. (g)	383.5	375.5	309.0	360.1
Dry Soil +Con. (g)	323.2	308.7	248.5	284
Mass of water	60.3	66.8	60.5	76
Mass of Con. (g)	57.7	57.8	57.6	52
Mass of dry soil	265.5	250.9	190.9	232
Moisture Content(g/cm3)	22.7	26.6	31.7	32.8
Dry density	1.306	1.308	1.419	1.366



From the compaction curve: MDD = 1.480 g/cm3 and OMC = 25 %

18.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

18.4.1 Penetration Data (After 4-day soaking)					Ring Factor =0.01279	
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0	0	0	0	0	0
0.64	16	0.34	25	0.54	15	0.32
1.27	29	0.62	46	0.98	31	0.66
1.96	40	0.86	60	1.28	55	1.18
2.54	49	1.05	68	1.46	69	1.48
3.18	55	1.18	73	1.56	78	1.67
3.81	60	1.28	76	1.63	85	1.82
4.45	64	1.37	79	1.69	90	1.93
5.08	66	1.41	81	1.73	95	2.03

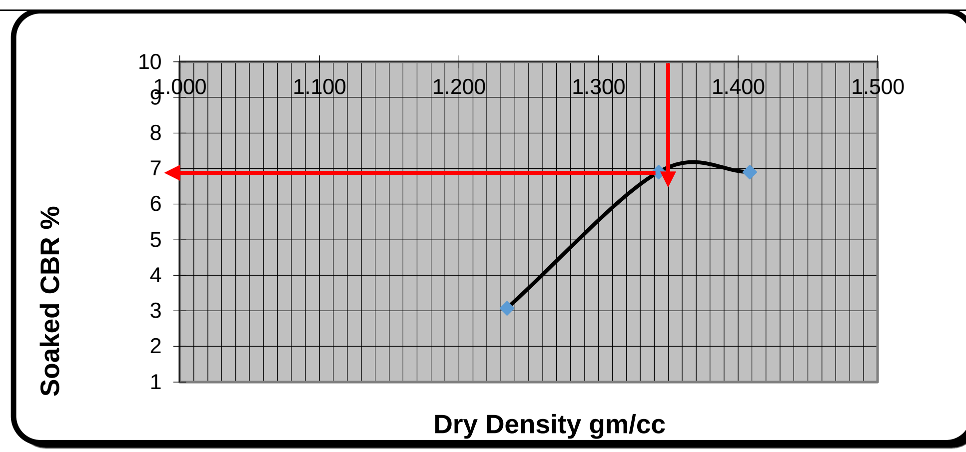
18.4.2 CBR Value at Standard Loads and CBR Test Summary

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10		0.41	0.69	13.2	20	3.07	3.45	3.07
30		0.9	1.2	13.2	20	6.9	5.76	6.9
65		0.92	1.28	13.2	20	6.9	6.4	6.9

Before soaking the three samples were remolded with OMC = 25%

No. of Blows	10	30	65
DD (g/cm3)	1.234	1.343	1.408
CBR (%)	3.07	6.9	6.9

Density - CBR Curve

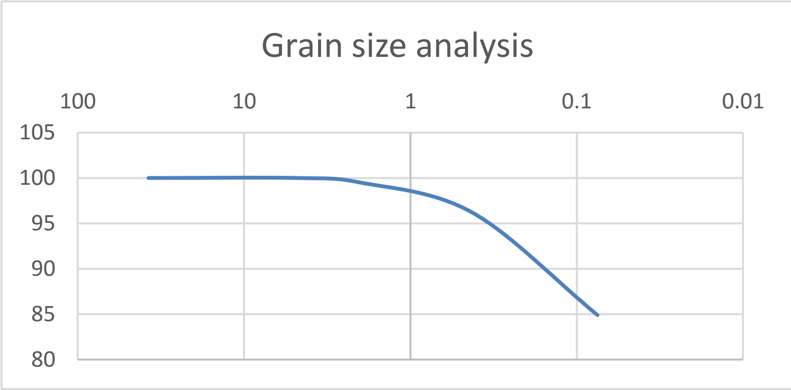


Dry density at 95% of MDD=1.406

APPENDIX C: Details of the Secondary Data Laboratory Test Results

Sample No 21: Location of Sample: Weight bridge - Ajip Road, WA – 1, Depth 40-100cm

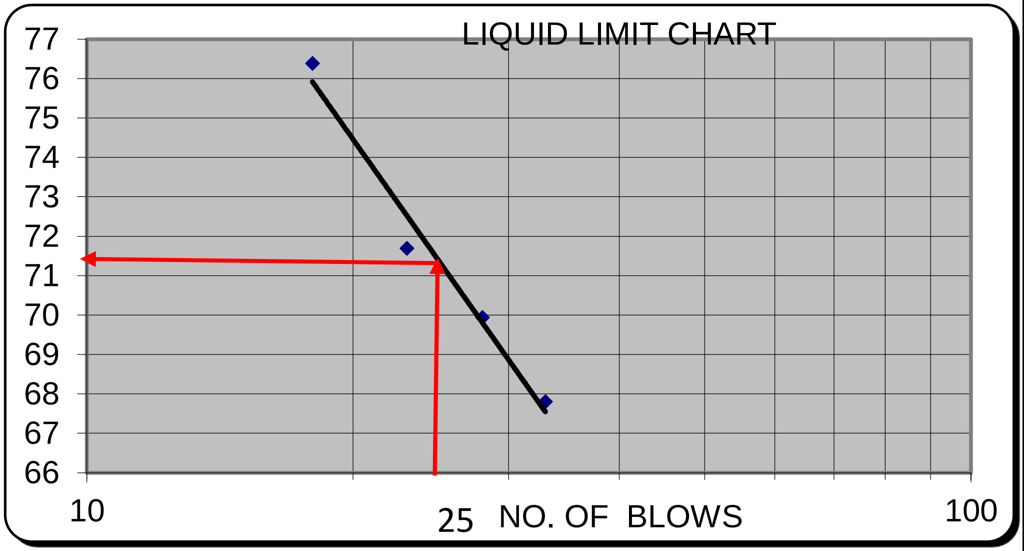
21.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing = 678gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0	0	100
4.75	0	0	100
2	4.6	0.5	99.5
0.425	28.9	3.2	96.2
0.075	99	11.4	84.9
Pan	0	0	



21.1.2 Subgrade Soil Classification: ASSHTO A-7-(20)

Descriptions	21.2.1 Liquid Limit				21.2.2 Plastic Limit	
Container	140	128	121	O	C-68	MB
Wt wet soil + con	46.44	49.71	46.16	31.66	26.12	23.89
Wt dry soil + con	41.45	44.5	42.21	26.97	25.22	23.01
Wt of water	4.99	5.21	3.95	4.69	0.9	0.88
Wt of container	34.09	37.05	36.7	20.83	22.42	20.26
Wt of dry soil	7.36	7.45	5.51	6.14	2.8	2.75
Water content,%	67.8	69.93	71.69	76.38	32.14	32
No of blows	33	28	23	18		

21.2.3 Plasticity Index = LL – PL = 72 - 32 = 40



21.3 STANDARED PROCTOR TEST (AASHTO T-181, Method D)

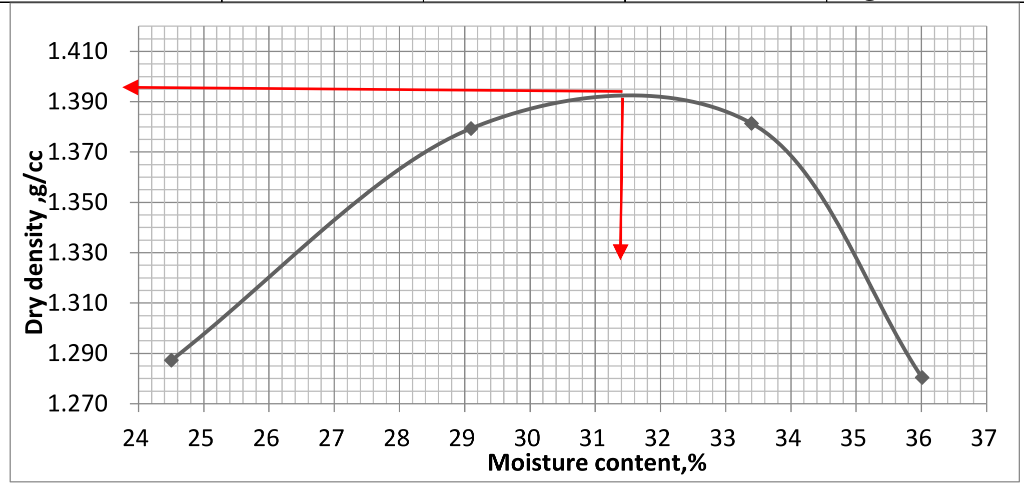
No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg

21.3.1 Dry Density Determination

Mold No.	1	2	3	4
Mold + Wet soil (gm)	9592	9970	10102	9887
Mold (gm)	6188	6188	6188	6188
Wet soil(gm)	3404	3782	3914	3699
Volume(cm3)	2124	2124	2124	2124
Wet Density (g/cm3)	1.603	1.787	1.843	1.742

21.3.2 Moisture Content Determination

Container No.	B-19	BJ	N-30	B-16
Wet Soil + Con. (g)	540.3	523.2	445.1	447.1
Dry Soil +Con. (g)	445.7	423.5	353.9	344.3
Mass of water	94.6	99.7	91.2	102.8
Mass of Con. (g)	59.6	80.8	80.8	58.8
Mass of dry soil	386.1	342.7	273.1	285.5
Moisture Content(g/cm3)	24.5	29.1	33.4	36
Dry density	1.287	1.379	1.381	1.280



From the compaction curve: MDD = 1393 g/cm3 and OMC = 31.6 %

21.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

21.4.1 Penetration Data (After 4-day soaking)					Ring Factor =0.02148	
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00	**0**	0.0		0.00
0.64	**11**	0.14	**18**	0.2	**21**	0.27
1.27	**24**	0.31	**28**	0.4	**27**	0.35
1.96	**30**	0.38	**34**	0.4	**38**	0.49
2.54	**36**	0.46	**40**	0.5	**47**	0.60
3.18	**44**	0.56	**49**	0.6	**56**	0.72
3.81	**49**	0.63	**53**	0.7	**65**	0.83
4.45	**55**	0.70	**58**	0.7	**72**	0.92
5.08	**58**	0.74	**66**	0.8	**77**	0.98

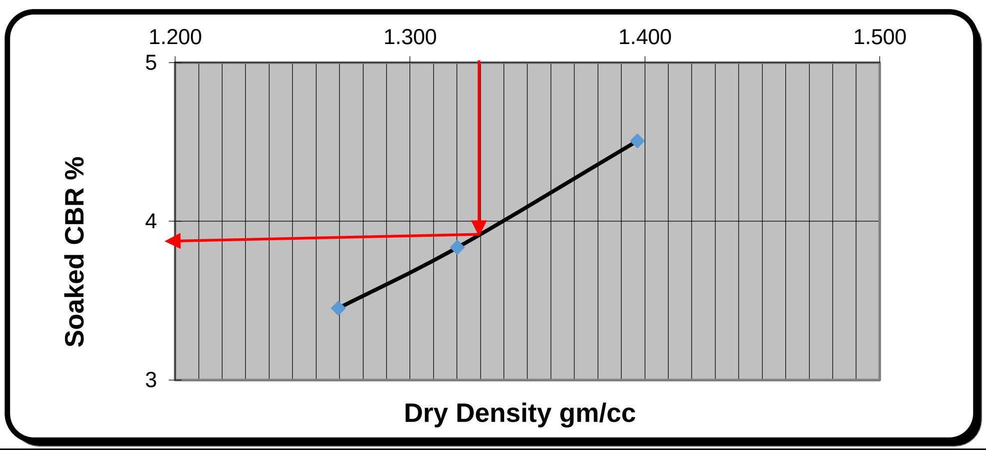
21.4.2 CBR Value at Standard Loads and CBR Test Summary

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.269	0.62	1.13	13.2	20	3.45	3.71	3.45
30	1.320	0.24	1.99	13.2	20	3.84	4.22	3.84
65	1.397	1.71	2.57	13.2	20	4.51	4.92	4.51

Before soaking the three samples were remolded with OMC = 31.6 %

No. of Blows	10	30	65
DD (g/cm3)	1.269	1.320	1.397
CBR (%)	3.45	3.84	4.51

Density - CBR Curve



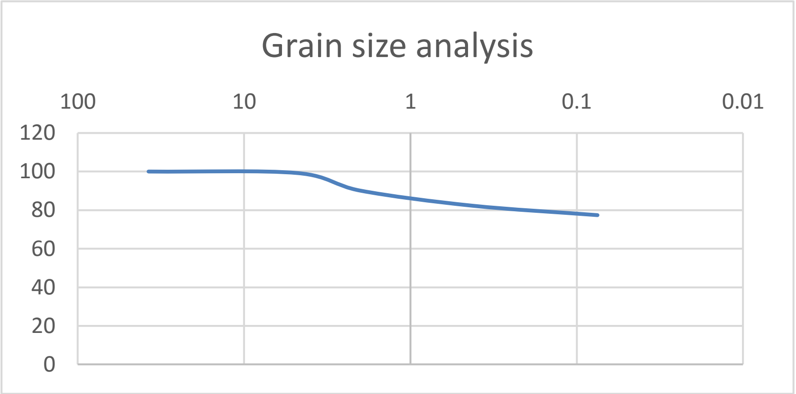
Dry density at 95% of MDD=1.323

Sample No 33: Location of Sample Honeyland – Michahel, HM-6, Depth 40-100cm

33.1 GRAIN SIZE ANALYSIS (ASTM D422)

Total Weight of dry soil before washing 668.0gm

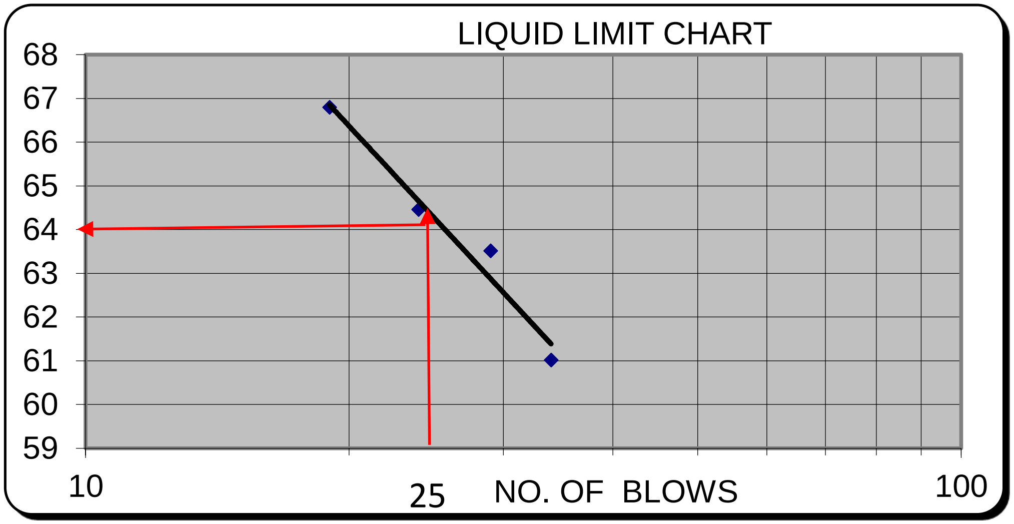
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	4.3	0.8	99.2
2	49.1	9.1	90.1
0.425	42.1	7.8	82.3
0.075	26.5	4.9	77.4
Pan	0.0	0.0	100.0



33.1.2 Subgrade Soil Classification: ASSHTO A-7-6(20)

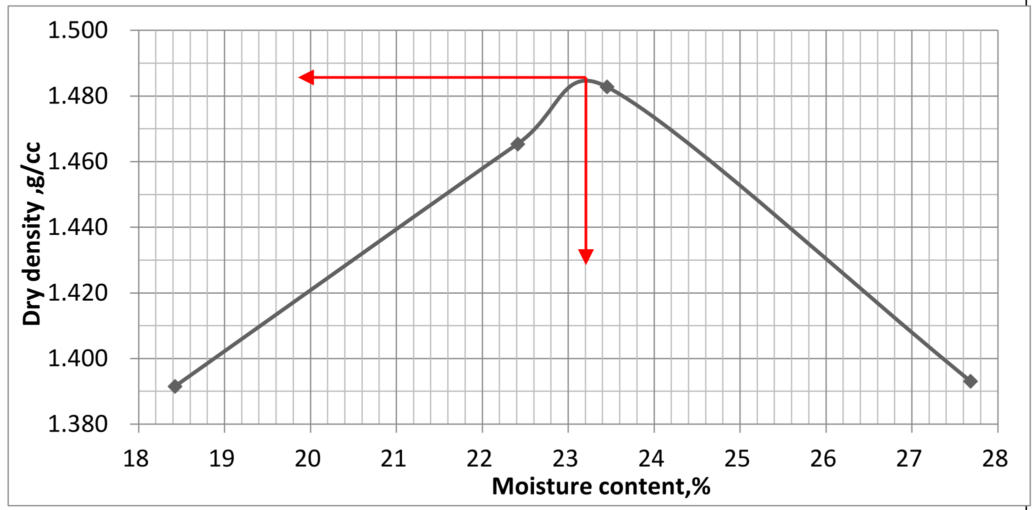
Descriptions	33.2.1 Liquid Limit				33.2.2 Plastic Limit	
Container	25	BK	A-18	AB	YS	A-2
Wt wet soil + con	41.65	40.89	39.96	41.05	25.45	24.54
Wt dry soil + con	33.67	33.04	32.29	32.32	24.32	23.86
Wt of water	7.98	7.85	7.67	8.73	1.13	0.68
Wt of container	20.59	20.68	20.39	19.25	20.75	21.73
Wt of dry soil	13.08	12.36	11.90	13.07	3.57	2.13
Water content,%	61.01	63.51	64.45	66.79	31.65	31.92
No of blows	34	29	23	18		

33.2.3 Plasticity Index = LL – PL = 64-32=32



33.3 STANDARED PROCTOR TEST (AASHTO T-181, Method D)

33.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9682.0	9992.0	10070.0	9960.0					
Mold (gm)	6182.0	6182.0	6182.0	6182.0					
Wet soil(gm)	3500.0	3810.0	3888.0	3778.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.648	1.794	1.831	1.779					
33.3.2 Moisture Content Determination									
Container No.	AL	B-12	EP	A-2					
Wet Soil + Con. (g)	505.6	496.2	485.9	464.6					
Dry Soil +Con. (g)	435.1	415.1	404.5	375.1					
Mass of water	70.5	81.1	81.4	89.5					
Mass of Con. (g)	52.4	53.2	57.4	51.8					
Mass of dry soil	382.7	361.9	347.1	323.3					
Moisture Content(g/cm3)	18.4	22.4	23.5	27.7					
Dry density	1.391	1.465	1.483	1.393	From the compaction curve: MDD = 1.485 g/cm3 and OMC = 23.2%				



33.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

33.4.1 Penetration Data (After 4-day soaking)				Ring Factor=0.02148		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	11.0	0.14	27.0	0.3	30.0	0.38
1.27	16.0	0.20	54.0	0.7	70.0	0.90
1.96	23.0	0.29	79.0	1.0	115.0	1.47
2.54	30.0	0.38	103.0	1.3	157.0	2.01
3.18	35.0	0.45	130.0	1.7	190.0	2.43
3.81	40.0	0.51	147.0	1.9	219.0	2.80
4.45	43.0	0.55	160.0	2.0	240.0	3.07
5.08	48.0	0.61	170.0	2.2	257.0	3.29

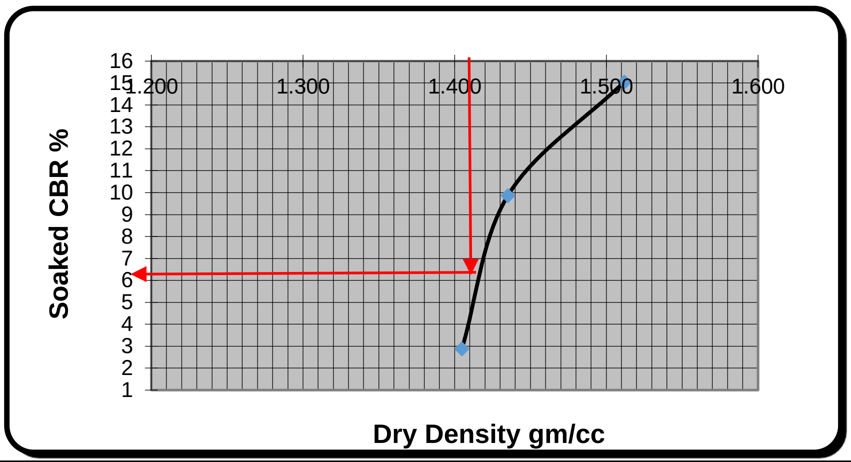
33.4.2 CBR Value at Standard Loads and CBR Test Summary

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.405	0.38	1.3	13.2	20	3.22	3.32	3.22
30	1.435	1.3	2.2	13.2	20	9.88	10.8	9.88
65	1.512	2.01	3.29	13.2	20	15.05	16.4	15.05

Before soaking the three samples were remolded with OMC = 22%

No. of Blows	10	30	65
DD (g/cm3)	1.405	1.435	1.512
CBR (%)	3.22	9.88	15.05

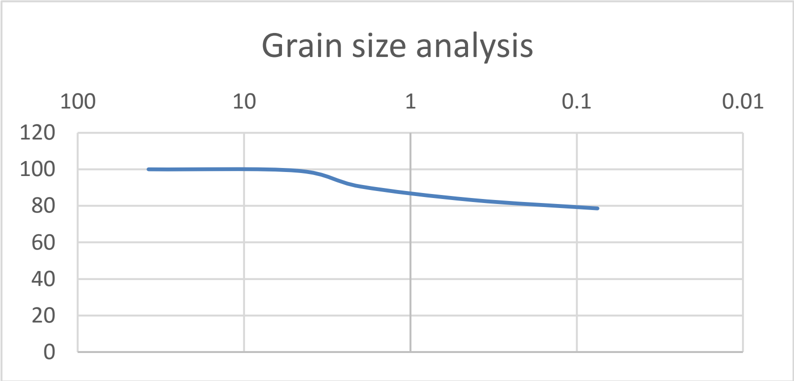
Density - CBR Curve



Dry density at 95% of MDD=1.404

Sample No 34: Location of Sample Tilahunshed – Kerahospital, TK-1, Depth 40-100cm

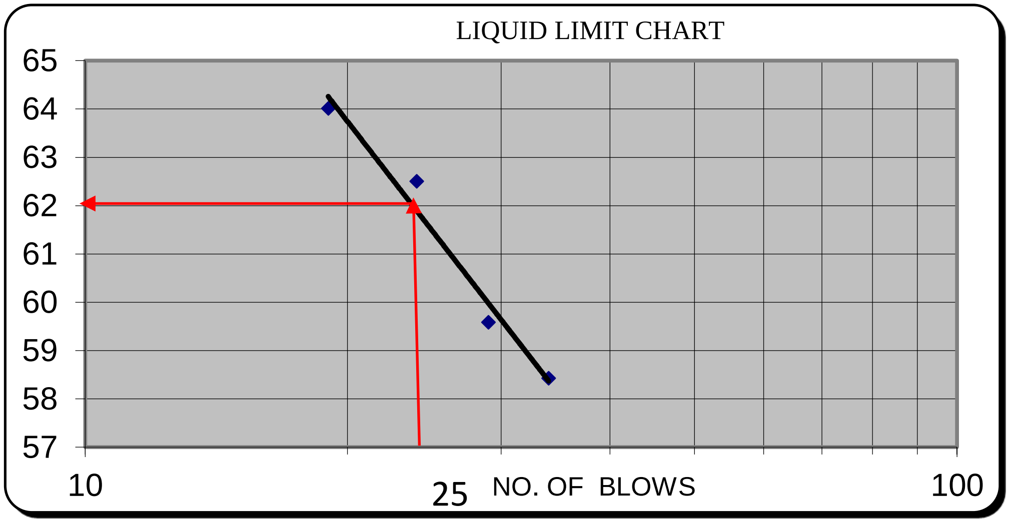
34.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing 570.0gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	4.3	0.8	99.2
2	49.1	8.6	90.6
0.425	42.1	7.4	83.2
0.075	26.5	4.6	78.6
Pan	0.0	0.0	



34.1.2 Subgrade Soil Classification: ASSHTO A-7-6(20)

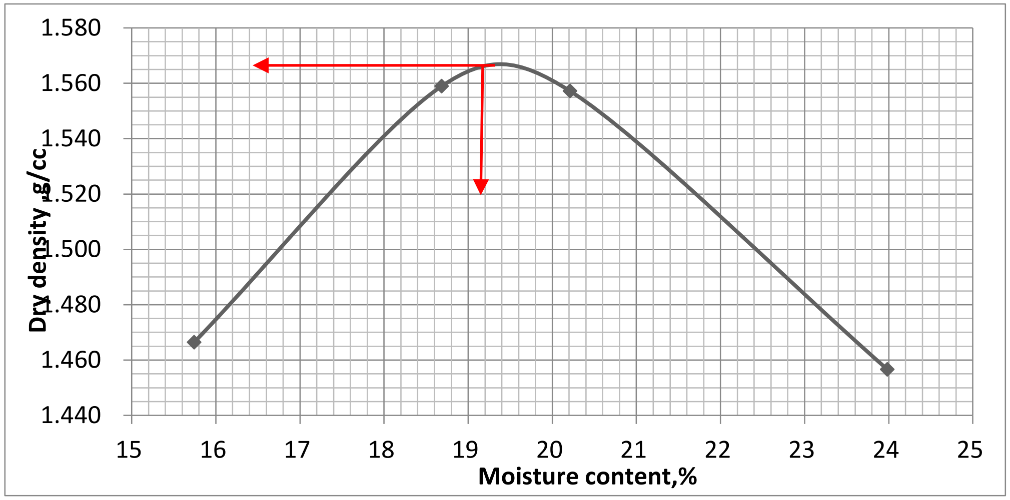
Descriptions	34.2.1 Liquid Limit				34.2.2 Plastic Limit	
Container	BM	G-5	B-65	B-30	W	24
Wt wet soil + con	28.13	32.16	29.77	30.41	24.60	22.77
Wt dry soil + con	24.94	27.90	26.02	26.48	23.68	21.89
Wt of water	3.19	4.26	3.75	3.93	0.92	0.88
Wt of container	19.48	20.75	20.02	20.34	20.94	19.29
Wt of dry soil	5.46	7.15	6.00	6.14	2.74	2.60
Water content,%	58.42	59.58	62.50	64.01	33.58	33.85
No of blows	33	28	24	19		

34.2.3 Plasticity Index = LL – PL = 62-34=28



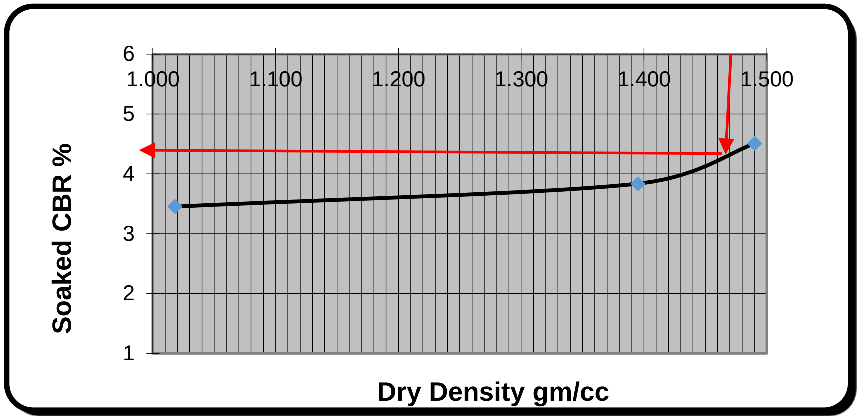
34.3STANDARED PROCTOR TEST (AASHTO T-181, Method D)

34.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9789.0	10114.0	10160.0	10020.0					
Mold (gm)	6184.0	6184.0	6184.0	6184.0					
Wet soil(gm)	3605.0	3930.0	3976.0	3836.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.697	1.850	1.872	1.806					
34.3.2 Moisture Content Determination									
Container No.	AB	AI	AF	AL					
Wet Soil + Con. (g)	491.7	506.9	510.3	550.5					
Dry Soil +Con. (g)	435.5	438.1	437.6	456.9					
Mass of water	56.2	68.8	72.7	93.6					
Mass of Con. (g)	78.5	69.9	77.9	66.6					
Mass of dry soil	357.0	368.2	359.7	390.3					
Moisture Content(g/cm3)	15.7	18.7	20.2	24.0					
Dry density	1.466	1.559	1.557	1.457	From the compaction curve: MDD = 1.566 g/cm3 and OMC = 19.4%				



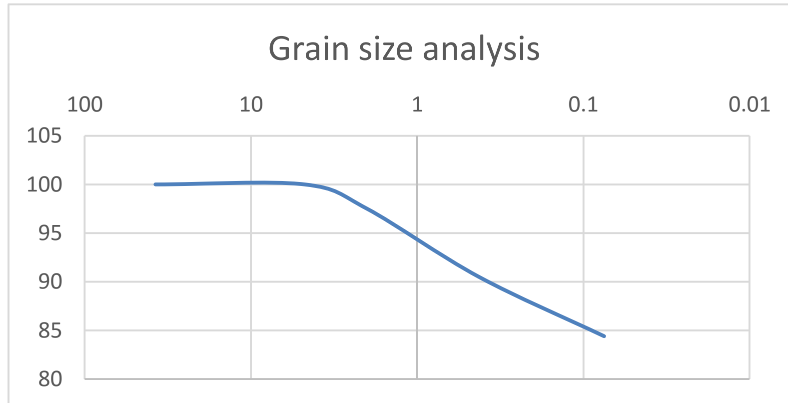
34.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

34.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 0.02148		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.0	0.0	0.00
0.64	10.0	0.13	13.0	0.2	15.0	0.19
1.27	18.0	0.23	20.0	0.3	25.0	0.32
1.96	28.0	0.36	31.0	0.4	35.0	0.45
2.54	36.0	0.46	40.0	0.5	47.0	0.60
3.18	49.0	0.63	52.0	0.7	58.0	0.74
3.81	58.0	0.74	61.0	0.8	68.0	0.87
4.45	64.0	0.82	76.0	1.0	82.0	1.05
5.08	70.0	0.90	80.0	1.0	95.0	1.22

34.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.434	0.46	0.90	13.2	20	3.45	4.48	3.45	
30	1.503	0.5	1.0	13.2	20	3.84	5.21	3.84	
65	1.604	0.6	1.22	13.2	20	4.51	6.08	4.51	
Before soaking the three samples were remolded with OMC = 22%									
No. of Blows		10		30		65			
DD (g/cm3)		1.434		1.503		1.604			
CBR (%)		3.45		3.84		4.51			Dry density at 95% of MDD=1.488

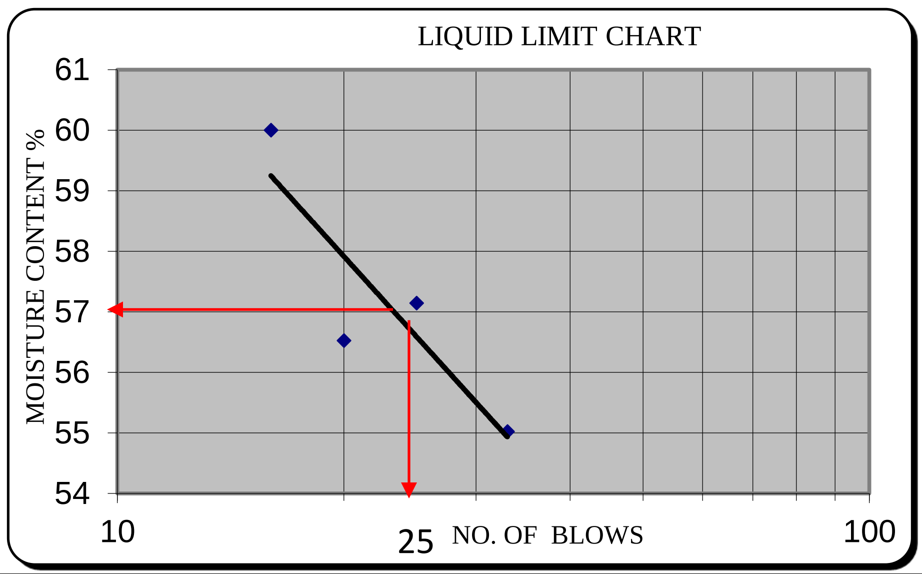
Sample No 42: Location of Sample, Kera – Bore, KB4, and Depth 40-100cm

42.1 GRAIN SIZE ANALYSIS (ASTM D422)			
Total Weight of dry soil before washing1316gm			
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	0.0	0.0	100.0
2	20.0	2.5	97.5
0.425	57.0	7.0	90.5
0.075	49.0	6.0	84.4
Pan	0.0	0.0	
42.1.2 Subgrade Soil Classification			ASSHTO A-7-5(20)



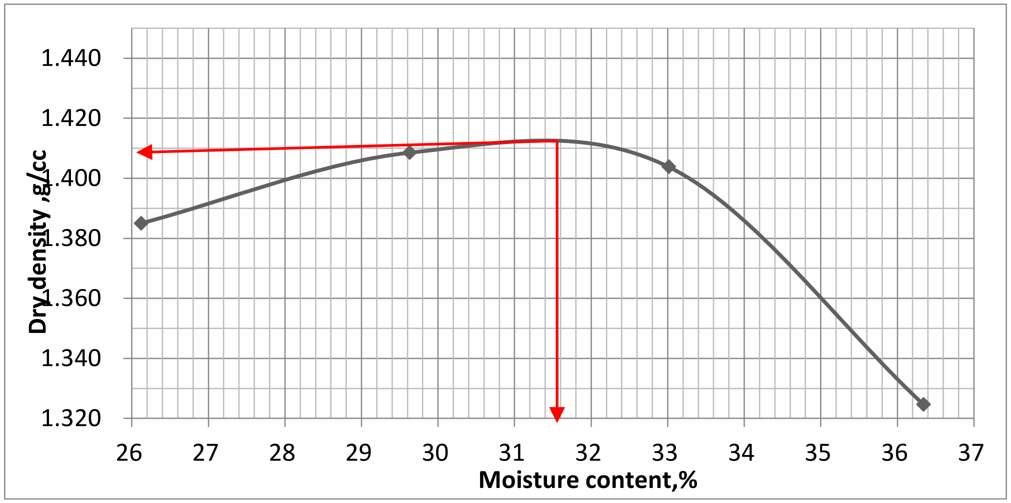
Descriptions	42.2.1 Liquid Limit				42.2.2 Plastic Limit	
Container	47.10	50.00	51.50	48.00	13.89	13.87
Wt wet soil + con	34.50	36.00	36.50	35.00	13.35	13.32
Wt dry soil + con	11.60	11.50	11.50	12.00	11.59	11.58
Wt of water	12.60	14.00	15.00	13.00	0.54	0.55
Wt of container	22.90	24.50	25.00	23.00	1.76	1.74
Wt of dry soil	55.0	57.1	60.0	56.5	30.7	31.6
Water content,%	47.10	50.00	51.50	48.00	13.89	13.87
No of blows	33	25	16	20		

42.2.3 Plasticity Index = LL – PL = 57-31=26



42.3 STANDARED PROCTOR TEST (AASHTO T-181, Method D)

42.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9994.0	10162.0	10250.0	10120.0					
Mold (gm)	6284.0	6284.0	6284.0	6284.0					
Wet soil(gm)	3710.0	3878.0	3966.0	3836.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.747	1.826	1.867	1.806					
42.3.2 Moisture Content Determination									
Container No.	PH	P	B-8	CK					
Wet Soil + Con. (g)	483.5	433.9	402.5	433.6					
Dry Soil +Con. (g)	395.3	346.8	316.8	336.5					
Mass of water	88.2	87.1	85.7	97.1					
Mass of Con. (g)	57.6	52.8	57.2	69.3					
Mass of dry soil	337.7	294.0	259.6	267.2					
Moisture Content(g/cm3)	26.1	29.6	33.0	36.3					
Dry density	1.385	1.409	1.404	1.325	From the compaction curve: MDD = 1.413 g/cm3 and OMC 31.5%				



From the compaction curve: MDD = 1.413 g/cm3 and OMC 31.5%

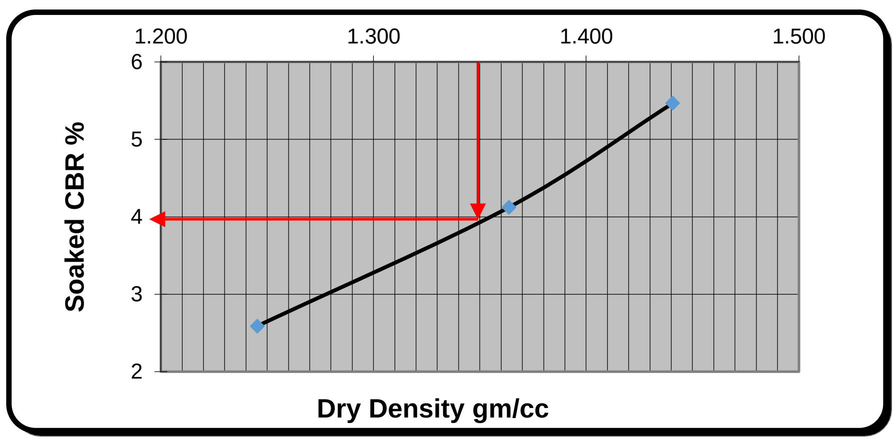
42.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

42.4.1 Penetration Data (After 4-day soaking)				Ring Factor= 0.02148		
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.0	0.00	0.0	0.00	0.0	0.00
0.64	10.0	0.12	14.0	0.17	17.0	0.21
1.27	16.0	0.19	26.0	0.31	32.0	0.39
1.96	23.0	0.28	34.0	0.41	45.0	0.54
2.54	27.0	0.33	41.0	0.49	57.0	0.69
3.18	30.0	0.36	46.0	0.56	68.0	0.82
3.81	33.0	0.40	54.0	0.65	78.0	0.94
4.45	36.0	0.43	60.0	0.72	87.0	1.05
5.08	39.0	0.47	65.0	0.78	95.0	1.15

42.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.245	0.33	0.47	13.2	20	5.46	6.08	5.46
30	1.364	0.49	0.78	13.2	20	4.12	4.16	4.12
65	1.441	0.69	1.15	13.2	20	2.59	2.49	2.59
Before soaking the three samples were remolded with OMC =31.0%								

No. of Blows	10	30	65
DD (g/cm3)	1.245	1.364	1.441
CBR (%)	5.46	4.12	2.59

Density - CBR Curve



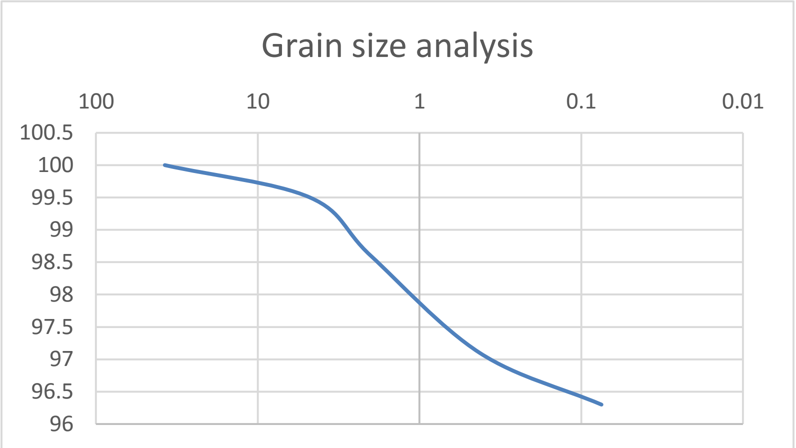
Dry density at 95% of MDD=1.363

Sample No 44: Location of Sample Bore – Qofe, BQ-1, Depth 40-100cm

44.1 GRAIN SIZE ANALYSIS (ASTM D422)

Total Weight of dry soil before washing = 720gm

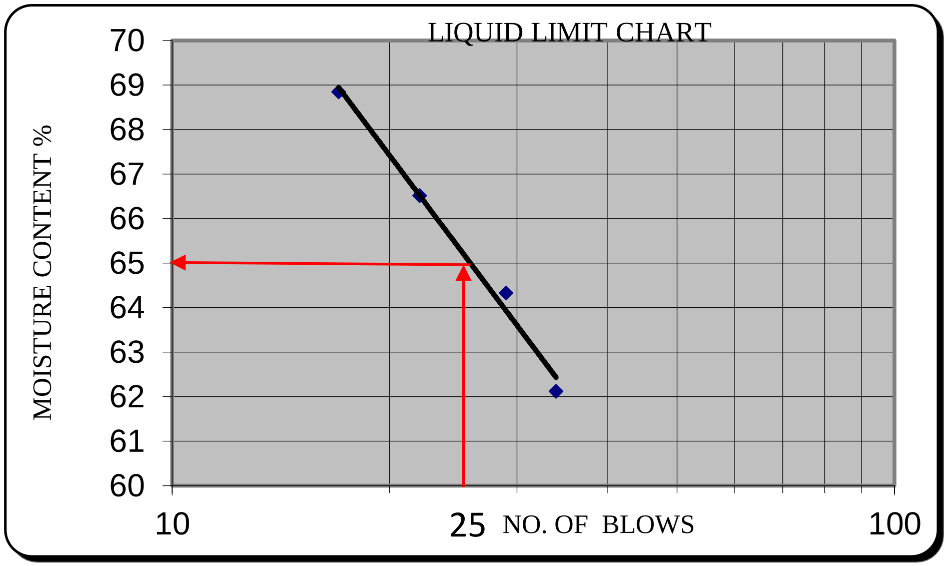
Sieve opening	Weight retained	Percent retained (%)	% age Passing
9.5	0.0	0.0	100.0
4.75	3.6	0.5	99.5
2	6.7	0.9	98.6
0.425	10.5	1.5	97.1
0.075	5.8	0.8	96.3
Pan	0.0	0.0	



44.1.2 Subgrade Soil Classification

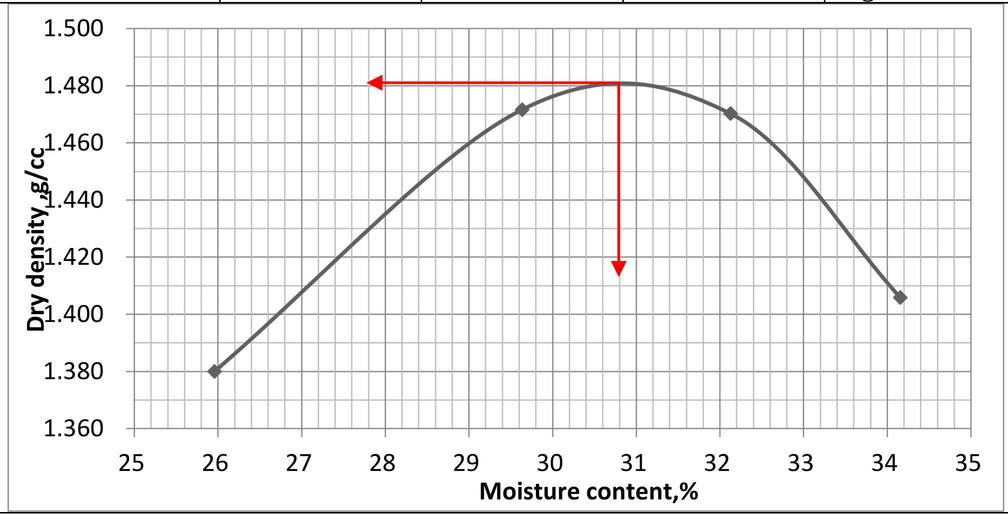
Descriptions	44.2.1 Liquid Limit				44.2.2 Plastic Limit	
Container	K	Z-1	JQ	23	LL	BK
Wt wet soil + con	42.64	41.38	43.74	41.69	24.73	23.69
Wt dry soil + con	33.62	33.39	34.46	32.67	23.79	22.95
Wt of water	9.02	7.99	9.28	9.02	0.94	0.74
Wt of container	19.10	20.97	20.51	19.57	20.87	20.66
Wt of dry soil	14.52	12.42	13.95	13.10	2.92	2.29
Water content,%	62.12	64.33	66.52	68.85	32.19	32.31
No of blows	34	29	22	17		

44.2.3 Plasticity Index = LL – PL =65-30=35



44.3 STANDARED PROCTOR TEST (AASHTO T-181, Method D)

44.3.1 Dry Density Determination					No. of Blows=56	No. of Layers=5	Method of Compaction	Volume of Mold=2124	Weight of Hammer=4.5 Kg
Mold No.	1	2	3	4					
Mold + Wet soil (gm)	9976.0	10336.0	10410.0	10290.0					
Mold (gm)	6284.0	6284.0	6284.0	6284.0					
Wet soil(gm)	3692.0	4052.0	4126.0	4006.0					
Volume(cm3)	2124.0	2124.0	2124.0	2124.0					
Wet Density (g/cm3)	1.738	1.908	1.943	1.886					
44.3.2 Moisture Content Determination									
Container No.	BF	CQ	B-13	A-3					
Wet Soil + Con. (g)	567.7	441.4	458.7	454.7					
Dry Soil +Con. (g)	466.1	353.8	361.2	355.0					
Mass of water	101.6	87.6	97.5	99.7					
Mass of Con. (g)	74.7	58.2	57.7	63.1					
Mass of dry soil	391.4	295.6	303.5	291.9					
Moisture Content(g/cm3)	26.0	29.6	32.1	34.2					
Dry density	1.380	1.472	1.470	1.406	From the compaction curve: MDD = 1.480 g/cm3 and OMC 30.8%				



44.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

44.4.1 Penetration Data (After 4-day soaking) — Ring Factor =0.02148

Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0		0.00	**0**	0.0		0.00
0.64	**11**	0.14	**10**	0.1	**15**	0.19
1.27	**23**	0.29	**27**	0.3	**47**	0.60
1.96	**31**	0.40	**54**	0.7	**85**	1.09
2.54	**41**	0.52	**81**	1.0	**115**	1.47
3.18	**48**	0.61	**115**	1.5	**138**	1.77
3.81	**56**	0.72	**128**	1.6	**157**	2.01
4.45	**61**	0.78	**142**	1.8	**172**	2.20
5.08	**68**	0.87	**155**	2.0	**184**	2.35

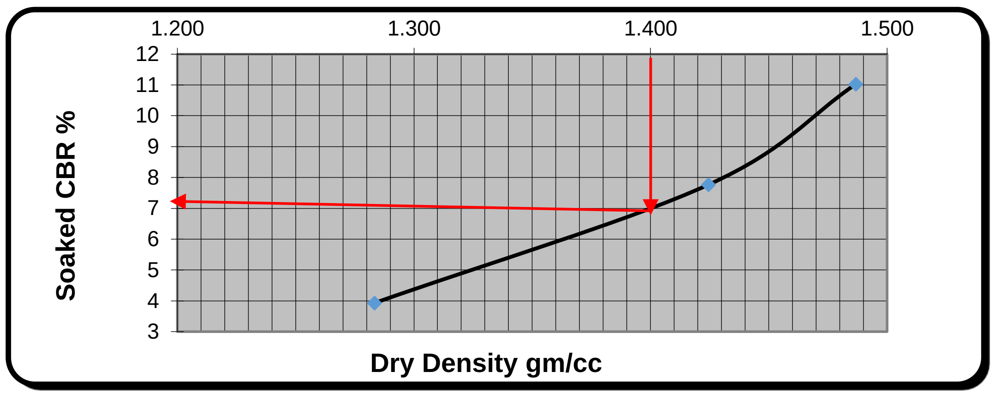
44.4.2 CBR Value at Standard Loads and CBR Test Summary

No. of Blows	Dry Density (g/cm3)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
10	1.283	0.52	0.87	13.2	20	3.93	4.75	3.93
30	1.425	1.0	2.0	13.2	20	7.77	9.91	7.77
65	1.487	1.47	2.35	13.2	20	11.03	11.7	11.03

Before soaking the three samples were remolded with OMC = 25%

No. of Blows	10	30	65
DD (g/cm3)	1.283	1.425	1.487
CBR (%)	3.93	7.77	11.03

Density - CBR Curve



Dry density at 95% of MDD=1.406