

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY**



**CORRELATION OF CBR VALUE WITH SOIL
INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS**

**A Thesis Submitted to the School of Graduate Studies of
Addis Ababa University in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Civil Engineering (Geotechnical Engineering)**

By

Yared Leliso

Advisor

Professor Alemayehu Teferra

December 2013

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF CIVIL ENGINEERING**

**CORRELATION OF CBR VALUE WITH SOIL
INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS**

By

Yared Leliso

**A Thesis Submitted to the School of Graduate Studies of
Addis Ababa University in Partial Fulfillment of the Requirements for
The Degree of
Master of Science in Civil Engineering
(Geotechnical Engineering)**

Approved by Board of Examiners

Prof. Alemayehu Teferra
Advisor


Signature

12 / 5 / 14
Date

Dr. Ing. Samuel Tadesse
External Examiner


Signature


12 / 05 / 14
Date

Dr. Messele Haile
Internal Examiner


Signature

18 / 05 / 14
Date

Dr. Bikila Teklu
Chairman


Signature

19 / 05 / 14
Date



ACKNOWLEDGEMENTS

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

I would like to express my warmest thanks to my advisor Professor Alemayehu Teferra for immense guidance and supervision all the way through this research work.

A special thanks address to Addis Ababa University Institute of Technology Geotechnical Department Staffs, Ethiopian Roads Authority Staffs, Bako-Nekempt Road Project Supervision Staffs, Manabenga-Lemlem Bereha Road Project Staffs and Gondwana Consulting Engineers for their support during the preparation of this thesis.

Last but not least, my heartfelt gratitude goes to those who assisted me this research work to reach final, particularly my beloved family and friends for their unreserved support and encouragement throughout my journey.

TABLE OF CONTENTS

<u>Title</u>	<u>Page</u>
ACKNOWLEDGEMENTS	i
TABLE OF CONTENTS.....	ii
LIST OF SYMBOLS.....	iiv
LIST OF ABBREVIATIONS AND ACRONYMS.....	v
LIST OF TABLES	vi
LIST OF FIGURES	vii
ABSTRACT	vii
Chapter 1: Introduction	
1.1 Background	1
1.2.1 General Objective.....	2
1.2.2 Specific Objectives.....	2
1.3 Scope of the Study.....	2
1.4 Methodology	3
1.5 Organization of the Study	4
Chapter 2 : Literature Review	
2.1 California Bearing Ratio (CBR).....	5
2.1.1 General.....	5
2.1.2 Applications of California Bearing Ratio	6
2.1.3 Test Methods.....	6
2.1.3.1 In-Situ Field Testing	6
2.1.3.2 Laboratory Testing.....	8
2.2 Index Property Tests	10
2.2.1 Soil Classification	10
2.2.1.1 Grain Size Analysis.....	10
2.2.1.2 Moisture Content	11
2.2.1.3 Atterberg Limits.....	11
2.2.2 Moisture - Density Relationship	13

2.3 Existing Correlations	14
2.3.1 Universal Approaches Based on Soil Classification Systems	14
2.3.1.1 Typical Values Based on Unified Soil Classification System	14
2.3.1.2 Mechanistic-Empirical Design Guides	16
2.3.2 Relationships Specific to a Region and Soil Type	19
2.3.3 Relationship Between CBR and Shear Strength of a Soil	21
2.3.4 AASHTO Group Index Value as Indicator of Suitability of Subgrade	22
Chapter 3 : Sample Collection and Test Results	
3.1 Sample Collection.....	23
3.2 Laboratory Tests and Results	24
3.2.1 Discussion on Laboratory Tests	24
3.2.2 Summary of Laboratory Test Results.....	27
Chapter 4 : Regression Analysis and Correlations	
4.1 Introduction	33
4.2 Scatter Plot	34
4.3 Regression Analysis.....	38
4.3.1 Single Linear Regression Analysis	40
4.3.2 Multiple Linear Regression Analysis	42
Chapter 5 : Discussion on Correlation Results	
5.1 The Developed Correlation	44
5.2 Evaluation of the Developed and Existing Correlations	45
Chapter 6 : Conclusion and Recommendation	
6.1 Conclusions	47
6.2 Recommendations.....	48
References	
APPENDIX A: Details of the SPSS Regression Analysis Outputs	
Appendix A-1: Single Linear Regression Analysis	
Appendix A-2: Multiple Linear Regression Analysis	
APPENDIX B: Details of the Laboratory Test Results	

LIST OF SYMBOLS

A	Percent Passing Sieve No. 10 (2mm Sieve Size)
B	Diameter of Plunger or Width of Foundation
c	Cohesion of Soil
c_u	Undrained Cohesion of Soil
D_{60}	Diameter on the Cumulative Size Distribution Curve where 60 percent of Particles are fines
I_P	Plasticity Index
M_R	Resilient Modulus
N_c	Terzaghi's Bearing Capacity Cohesion Coefficient
N_q	Terzaghi's Bearing Capacity Surcharge Coefficient
N_γ	Terzaghi's Bearing Capacity Dry Unit Weight Coefficient
P_o	Overburden or Surcharge Load
P_{200}, F	Percent Passing Sieve No. 200 (0.075mm Sieve Size)
q_u	Bearing Capacity
R	Pearson Product Moment Correlation Coefficient
R^2	Coefficient of Determination
R-Value	Resistance Value
τ	Shear Strength of Soil
w_l	Liquid Limit
w	Moisture Content
α	Standard Significant Error
$\alpha_1, \alpha_2, \alpha_3, \alpha_n$	Coefficients of the Multiple Linear Regression Equation
γ	Bulk density of Soil
$\beta_1, \beta_2, \beta_3, \beta_n$	Coefficients of the Single Linear Regression Equation
σ_n	Normal Stress
σ^2	Statistical Variance
ϕ	Internal Friction Angle
ε	Statistical Random Error

LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CH	High Plasticity Clay
CL	Inorganic Silts of Low to Medium Plasticity
DCP	Dynamic Cone Penetrometer
FCBR	Field California Bearing Ratio
FDD	Field Dry Density
GC	Clayey Gravels
GI	Group Index
GM	Silty Gravels
GP	Poorly Graded Gravels
GW	Well Graded Gravel
LI	Liquidity Index
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
S1	ERA Subgrade class with a CBR Range of 0 to 2
S2	ERA Subgrade class with a CBR Range of 3 to 4
S3	ERA Subgrade class with a CBR Range of 5 to 7
S4	ERA Subgrade class with a CBR Range of 8 to 14
SPSS	Statistical Package for Social Science Software
SI	Suitability Index of de-Graft Johnson Equation
USCS	Unified Soil Classification System

LIST OF TABLES

Table 2.1 Symbols in the Unified Soil Classification System.....	15
Table 2.2 Typical California Bearing Ratio Values based on Unified Soil Classification.....	15
Table 3.1 Summary of All Laboratory Test Results.....	28
Table 4.1 Statistical Information of Dependent and Independent Variables.....	38
Table 4.2 Correlation Matrix of Pearson Correlation Coefficient.....	39
Table 4.3 Summary of the Regression Analysis.....	43
Table 5.1 Validation of the Developed Correlation	44
Table 5.2 Developed and Existing Correlations.....	46

LIST OF FIGURES

Figure 1.1 Flow Chart of the Study.....	4
Figure 2.1 CBR Testing Apparatus.....	7
Figure 2.2 Typical CBR Load-Penetration Curve Correction Graphs.....	9
Figure 2.3 Descriptions of Phases of Soil-Water System.....	12
Figure 2.4: Modified Graphical Correlation of CBR, M_r with USCS and AASHTO Systems.....	16
Figure 2.5 CBR and “Suitability Index” for Ghanaian Lateritic Soil	19
Figure 3.1 Location Map of Collected Samples.....	23
Figure 3.2 Typical Grain Size Analyses Curve.....	25
Figure 3.3 Typical Flow Curve.....	25
Figure 3.4 Typical Density-Moisture Content Relationship Graph.....	26
Figure 3.5 Typical Load-Penetration Depth Graph.....	26
Figure 3.6 Typical Density-CBR Graph.....	27
Figure 4.1 Scatter diagram of CBR vs. Percent Passing Sieve No. 200.....	34
Figure 4.2 Scatter diagram of CBR vs. Liquid Limit.....	35
Figure 4.3 Scatter diagram of CBR vs. Plastic Limit.....	35
Figure 4.4 Scatter diagram of CBR vs. Plasticity Index.....	36
Figure 4.5 Scatter diagram of CBR vs. Maximum Dry Density.....	36
Figure 4.6 Scatter diagram of CBR vs. Optimum Moisture Content.....	37
Figure 5.1 Actual CBR vs. Predicted CBR Value	45

ABSTRACT

The unique nature of soil properties as it appears naturally is that being divergent spatially and seasonally beyond the designer's control. Geotechnical engineers usually attempts to develop empirical equations specific to a certain region and soil type. However, these empirical equations are more reliable for the type of soil where the correlation is origin. Hence, it is important to develop empirical equations that best fit for the local area that we can access.

As a result, this study evolved to find the correlation between CBR values with soil index properties specific to Addis Ababa subgrade soils. The study has examined the feasibility of single linear regression analysis and multiple linear regression analysis in correlating CBR value with soil index properties. Accordingly, forty two disturbed samples collected from different parts of Addis Ababa and the required laboratory tests have been conducted in order to achieve the intended correlations.

Specific to this research, statistical software (SPSS) is employed to investigate the significance of individual independent variables. The correlation is established 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 $R^2 = 0.458$ using single regression analysis, while multiple regression analysis generated relatively an improved correlation of $R^2 = 0.629$, for a sample size of forty two. 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 soils.

Chapter-1

Introduction

1.1 Background

California Bearing Ratio (CBR) is a common and comprehensive test currently practiced in the design of pavement to assess the stiffness modulus and shear strength of subgrade material so as to determine the thickness of overlying pavement layers. In road construction civil engineers always encounter difficulties in obtaining representative CBR value for design of pavement. The type of soil is not the only parameter which affects the CBR value, but it also varies with different soil properties possessed by the soil.

California Bearing Ratio (CBR) is actually an indirect measure which represents comparison of the strength of subgrade, sub-base and base-course material to the strength of standard crushed rock quoted in percentage values. Laboratory CBR test requires relatively large effort to conduct the test and it is time consuming. The alternate method could be to correlate CBR with simpler test results such as soil index properties. These tests are much economical and rapid than CBR test. This thesis gives an overview to obtain a correlation between CBR value with soil index properties that is suited for Addis Ababa subgrade soil. Previous researches and investigations on Addis Ababa soil indicates that weathered and hard rock, black cotton soil and non-expansive soil are dominantly found as a natural subgrade soil in Addis Ababa. Hence, this thesis deeply focuses on developing the intended correlation for different distributions of suitable subgrade soils, specifically non-expansive fine grained soils, which represents the study area.

Currently, many road construction projects and railway constructions are undergoing in the country. In light of this, the output of the proposed correlation will provide road authorities, railway authorities, consultants and contractors preliminary background information on the value of CBR, for a localized subgrade material, from soil index properties with a benefit of time saving and without incurring any additional cost for carrying out laboratory CBR test.

1.2 Objective of the Study

1.2.1 General Objective

The main objective of this thesis is to give more attention to find correlation between California Bearing Ratio with soil index properties for representative soil samples recovered from different localities of Addis Ababa.

1.2.2 Specific Objectives

- ❖ To check and come up with a correlation between CBR values and soil index properties for Addis Ababa subgrade soils.

- ❖ To validate and evaluate the developed correlation using a control test results.

1.3 Scope of the Study

The subject study is desired to conduct a localized research particularly on samples recovered from Addis Ababa city. In order to conduct the proposed correlation forty two laboratory test results are used in this research work.

With regard to the regression analysis, depending on the trends of the scattering of test results the correlation is analyzed using a linear regression model. The required correlation is carried out by applying a single linear regression model and multiple linear regression models with the aid of SPSS Software. Furthermore, the scope of the developed correlation is limited to the test procedures followed in the subject research work.

1.4 Methodology

Primarily, in order to address the intended objectives of the study, basic theories and descriptions of CBR test in general and in relation to soil index property of subgrade soil is reviewed. Subsequently, previous works of different researchers with regard to prediction of CBR value from basic soil index properties were assessed.

In order to have satisfactory data for utilizing the correlations, laboratory tests were conducted by the researcher on samples collected from different localities of Addis Ababa, so as to get records of test results of CBR values along with the associated soil indices particularly the grain size analysis, Atterberg limits, moisture-density relationships. Then, discussions on sample collection and summary of laboratory test results were presented.

Statistical regression analyses of test results were carried out and correlations were developed and also analyzed to fit the test results. Under the discussions of the obtained results the suitability of the developed correlations were examined. Finally, a generalized conclusion and recommendation were made.

1.5 Organization of the Study

The thesis is organized and presented under six Chapters. The first Chapter highlights 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. Organization of the thesis work is presented with a flow chart as follows:

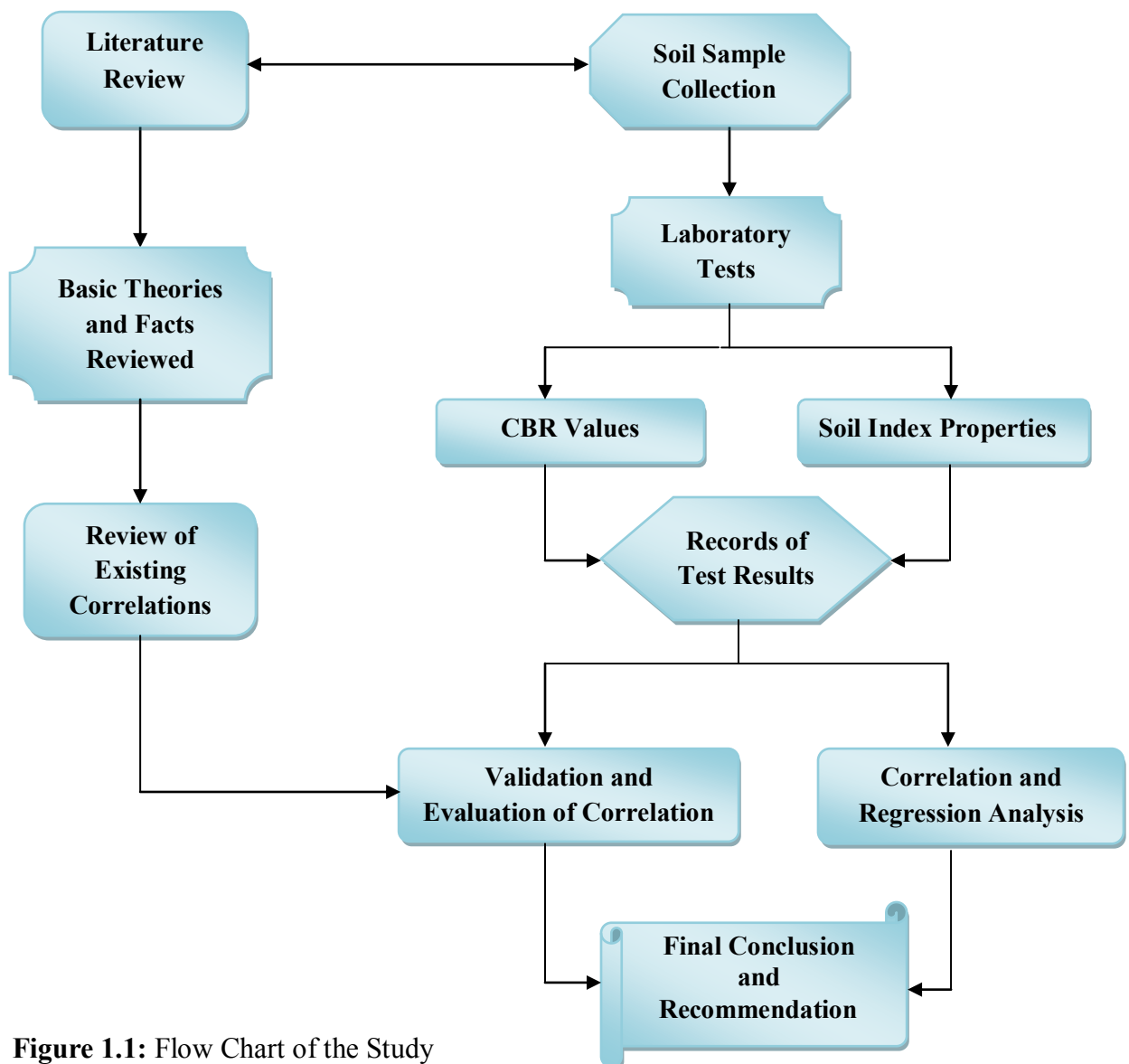


Figure 1.1: Flow Chart of the Study

Chapter-2

Literature Review

2.1 California Bearing Ratio (CBR)

2.1.1 General

The California Bearing Ratio (CBR), defined as the ratio of the resistance to penetration of a material to the penetration resistance of a standard crushed stone base material. California Bearing Ratio is the main design input in pavement construction to assess the stiffness modulus and shear strength of subgrade material. The method was developed by the California Division of Highways as part of their study in pavement failure at World War II [1].

With an intention to adopt a more simplified test method to measure the stiffness modulus and shear strength of subgrade soil a simple test that can be used as an index test was devised. This is where CBR test comes into frame in measurement of subgrade strength. The CBR test is a simple strength test that compares the bearing capacity of a material with that of a well graded standard crushed stone base kept in California Division of Highways Laboratory [1]. 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.

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 design of pavement thickness in road construction requires the strength of subgrade soil, sub-base and base-course material to be expressed in terms of California Bearing Ratio, so that a stable and economic design achieved. A road section for which a pavement design is undertaken should be sub-divided into subgrade areas where the subgrade CBR can be reasonably expected to be delineated uniform, i.e. without significant variations, in order to utilize it in the design of pavement thickness [2]. It is also used to rate the conditions of an existing pavement layers.

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

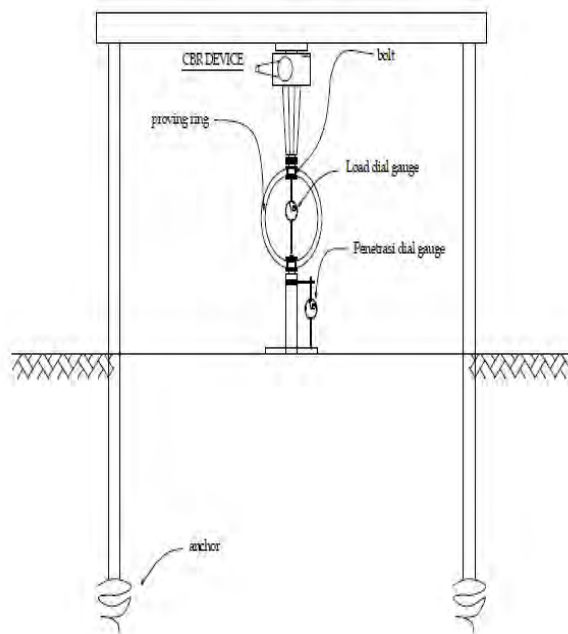
2.1.3 Test Methods

The California Bearing Ratio (CBR) test can be carried out both in laboratory and in field. The samples may be prepared in three different ways. Accordingly, (i) the test can be performed on a remolded sample in laboratory, (ii) on undisturbed sample carefully extracted from field and trimmed to closely fit the standard mould in laboratory and finally (iii) an in-situ sample which is entirely tested on field.

2.1.3.1 In-Situ Field Testing

Field in-place tests are used to determine the relative strength of soils, sub-base and some base materials in the condition at which they exist at the time of testing. Field in-place CBR tests are used for the design of flexible pavement components and for other applications in which CBR is the desired strength parameter. If field CBR is to be used directly for evaluation or design without consideration for variation due to change in water content, the test should be conducted under one of the conditions stated in ASTM D 4429-93 [3].

In the field study, once a set of field CBR tools are setup for carrying out the penetration test, the cylindrical plunger is allowed to penetrate the soil at a given rate. The force required to cause the plunger to penetrate the in-situ soil with respect to the penetration depth would be recorded by means of a calibrated proving ring. Later, the results of the in-situ soil shall be compared with the relationship between force and penetration to that of a standard load of a crushed stone base material. A typical in-situ CBR testing apparatus is shown in Figure 2.1 (a).



a. Field CBR Apparatus



b. Laboratory CBR Apparatus

Figure 2.1: California Bearing Ratio Testing Apparatus

In order to get a reliable result care measures shall be taken for any construction test activities, such as grading or compacting carried out subsequent to the field in-situ test which will probably invalidate the results of the test. It should be further noted that during in-situ testing the removal of larger-sized particles which may adversely affects the test result is not possible [4]. Therefore, the in-situ test is likely to encounter such problems in coarser types of in-situ material, whereas the laboratory CBR test is limited to particles passing 3/4 inch (19 mm) sieve size [5].

2.1.3.2 Laboratory Testing

Laboratory CBR test is carried out as per the procedure outlined in AASHTO T 193-63 or ASTM D 1883-73. This test method provides the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry density from the compaction tests of either standard proctor test (ASTM D 698) or modified proctor test (ASTM D 1557). A typical laboratory CBR apparatus is shown in Figure 2.1 (b).

The Laboratory CBR test procedure is based on the principle of a plunger of standard area advancing into a remolded sample at a specified rate of penetration. Prior to the penetration test the soil sample is remolded in laboratory at a desired moisture content and density. The remolded sample may be soaked for 96 hour with a surcharge load not less than 4.52 kg/10 lb that is a representative of the pavement weight in the field. Swell readings are taken during this period at arbitrary selected times. It is worth nothing that the soaking requirement depends on the climate of the study area and on the specifications requirement to be applied in the design [5].

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 will be recorded with respect to the standard penetration depths at each 0.5mm penetration, including the load value at 2.54 mm and 5.08 mm until the total penetration is 12.7mm. The penetration resistance load is then plotted against the penetration depth and correction is made for the load-penetration curve. A typical load-penetration curve correction graph is presented in Figure 2.2.

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 [5].

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

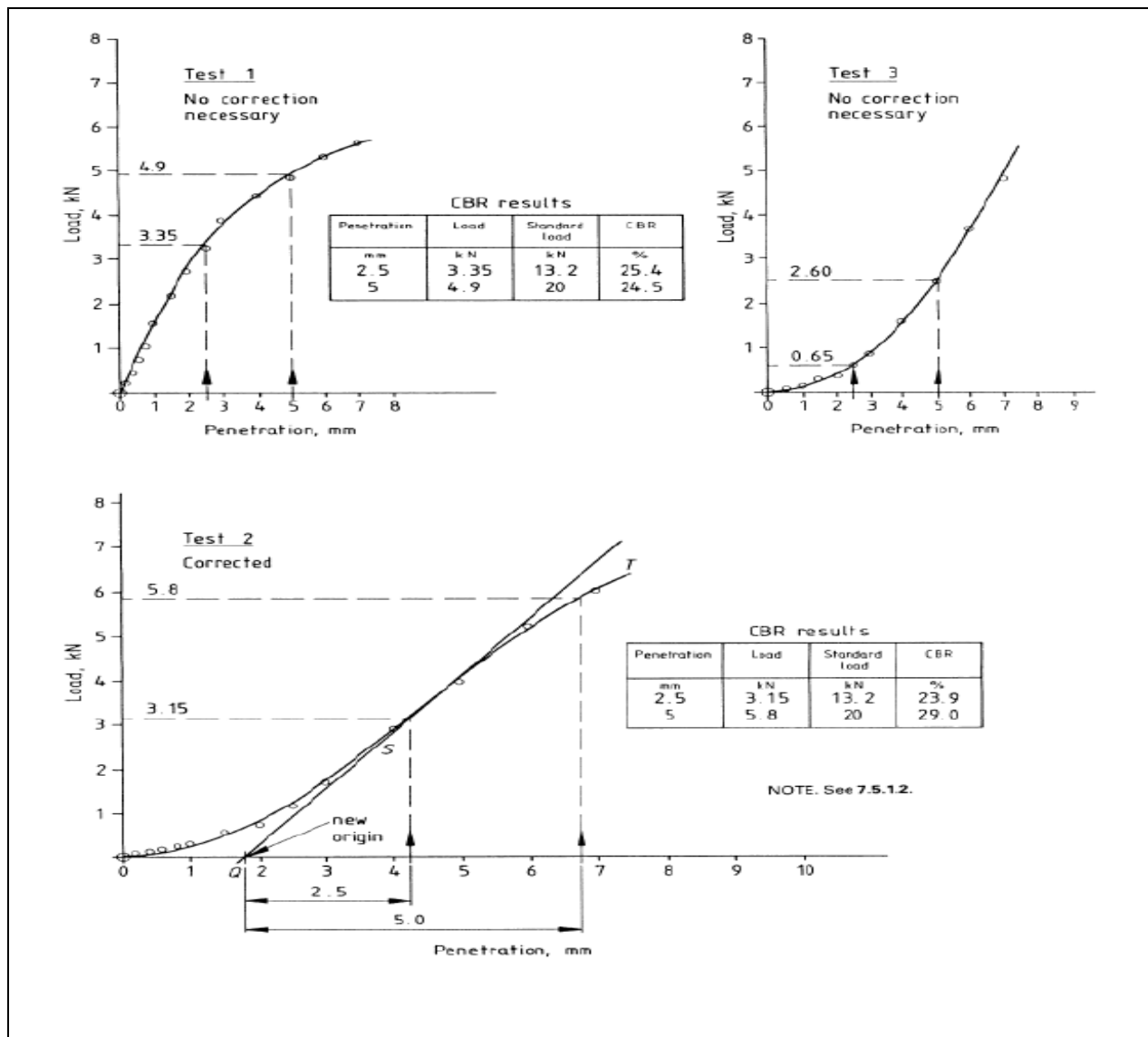


Figure 2.2: Typical CBR Load-Penetration Correction Graphs [6]

2.2 Index Property Tests

In nature soil occurs in a large variety. Engineers are continually searching for simplified tests that will increase their knowledge of soils by employing a simple and rapid soil tests. These simplified tests which are indicative of the engineering properties of soils are called index properties [7]. Index properties of cohesive soils are used to characterize the physical and mechanical behavior 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 [8].

2.2.1 Soil Classification

Soils exhibiting similar behavior can be grouped together to form a particular group under different standardized classification systems. A classification scheme provides a method of identifying soils in a particular group that would likely exhibit similar characteristics. There are different classification devises such as USCS and AASHTO classification systems, which 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.

2.2.1.1 Grain Size Analysis

For coarse grained materials, the grain size distribution is determined by passing soil sample either by wet or dry shaken through a series of sieves placed in order of decreasing standard opening sizes and a pan at the bottom of the stock. Then the percent passing on each sieve is used for further identifying the distribution and gradation of different grain sizes [10]. Particle size analysis tests are carried out in accordance to ASTM D 422-63. Besides, the distribution of different soil particles in a given soil is determined by a sedimentation process using hydrometer test for soil passing 0.075mm sieve size. For a given cohesive soil having the same moisture content, as the percentage of finer material or clay content decreases the shear strength of the soil possibly increases.

2.2.1.2 Moisture Content

Change in moisture content is the most influential parameter that affects the property of soils. Moisture content is defined as the ratio expressed as a percentage of mass of water to mass of soil solids. The moisture content test is carried out in laboratory as per the procedures of AASHTO T 265 or ASTM D 2216 and in field according to AASHTO T 217.

2.2.1.3 Atterberg Limits

Based on their mode of formation and mineralogical composition different soils respond differently for the same moisture content. Albert Atterberg, a Swedish Scientist in 1911 gave an idea of the consistency limit of cohesive soils and proposed a number of tests for defining their properties. The three Atterberg limits which are liquid limit, plastic limit and shrinkage limits are the boundary between each of the two consecutive states of the soil-water phases. Their test is performed only on that portion of a soil which passes the 425mm (No. 40) sieve [9]. A description of phases of soil-water system is shown with schematic diagram in Figure 2.3.

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.

Plastic Limit: The plastic limit (PL) is the water content, expressed in percentage, below which the soil stops behaving as a plastic material and it begin to crumble when rolled into a thread of soil of 3.0mm diameter. The conventional plastic limit test is carried out as per the procedure of AASHTO T 90 or ASTM D 4318. The soil in the plastic state can be remolded into different shapes. When the water content is reduced the plasticity of the soil decreases changing into semisolid state and it cracks when remolded.

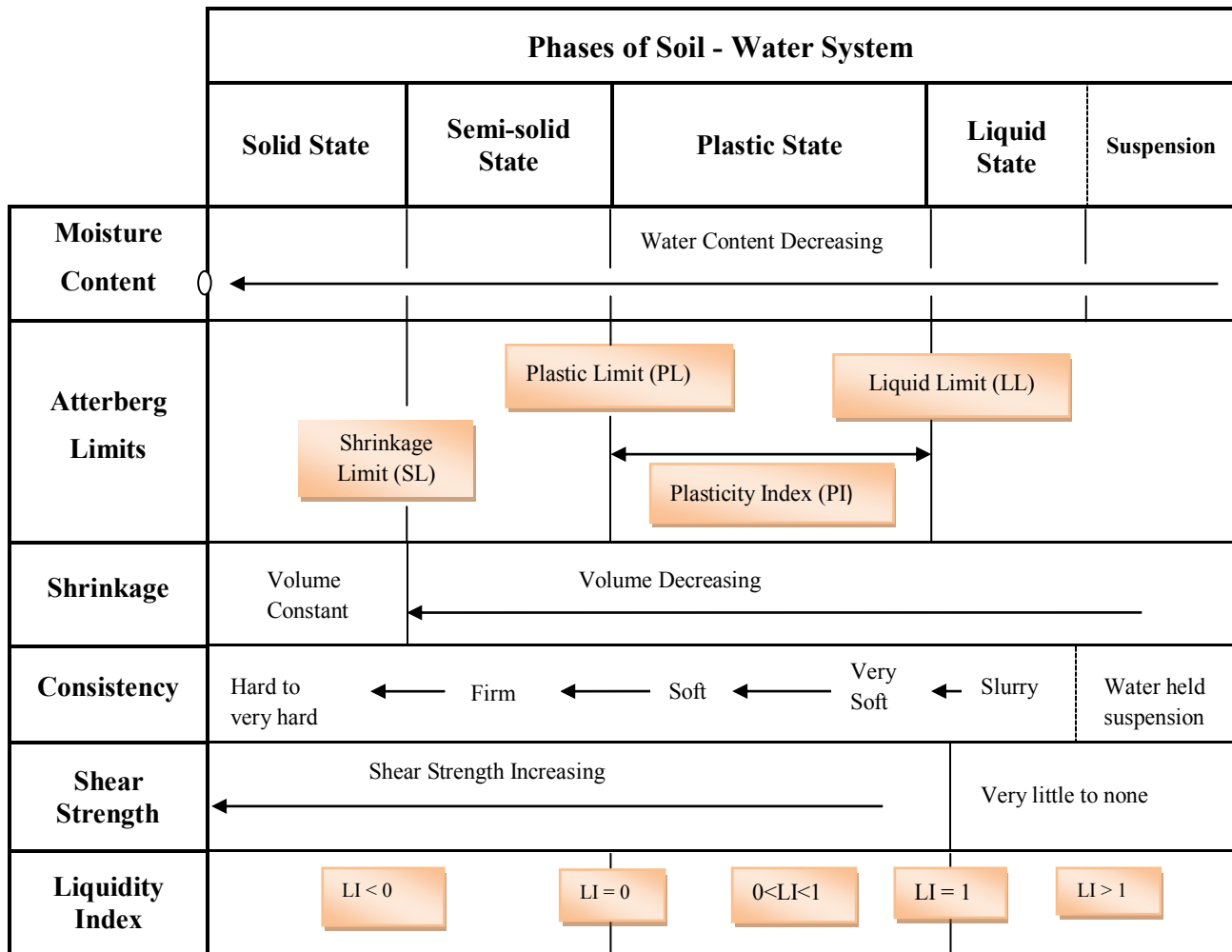


Figure 2.3: Description of Phases of Soil-Water System

Shrinkage Limit: Is defined as the water content in which the soil changes from semi-solid state to solid state. In other word, it is the moisture content below which no soil volume change occurs with further reduction of water content. The test is carried out as per the procedure of AASHTO T 92 or ASTM D 427.

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.

The liquid limit, plastic limit and plasticity index parameters are an integral part of several engineering properties and characterize the fine grained fractions of construction materials. The shear strength of a fine grained soil mainly depends on the consistency of the soil. As shown in Figure 2.3, the shear strength of fine grained soil increases as the moisture content in the soil decreases from the liquid state up to the solid state.

2.2.2 Moisture - Density Relationship

Compaction of a soil improves the engineering properties, i.e. 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. At lower water content than the optimum the soil is rather stiff and has a lot of void spaces and hence, the dry density is low. On the other hand, at water content more than the optimum the additional water reduces the dry density as it occupies the space that might have been occupied by solid particles [7].

The laboratory standard proctor and modified proctor tests are performed as per (AASHTO T 99 or ASTM D 698) and (AASHTO T 180 or ASTM D 1557) respectively. The tests are performed on disturbed samples of soil particles passing sieve sizes 4.75mm or 19mm mixed with water to form samples at various moisture contents ranging from the dry state to wet state. These samples are compacted in three or five layers at 25 blows per layer in accordance with the specified nominal compaction energy of standard or modified proctor test respectively. Dry density is determined based on the moisture content and the unit weight of compacted soil. The corresponding water content at which the maximum dry density occurs is termed as the optimum moisture content [10].

Grading and Atterberg limits alone are not sufficient to qualify the performance of construction materials since variation of moisture content and density play a considerable role. Different researches show that the moisture content and density conditions have a greater influence, on the value of shear strength of a soil, on coarser materials than fine grained materials.

2.3 Existing Correlations

Many researchers and agencies developed relationships between CBR with soil index parameters on the basis of samples obtained from a specific region and soil type. General relationships are also developed using universally accepted soil classification systems, basically based on the Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) systems. These correlation methods take a general approach and attempt to encompass many or all possible soil types.

2.3.1 Universal Approaches Based on Soil Classification Systems

2.3.1.1 Typical Values Based on Unified Soil Classification System

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. It should be stressed that the unified soil classification system is a systematic and repeatable classification strictly based on test measurement values defined in the ASTM standard. As such, the USCS class of a soil is inherently tied to the soil properties by which it is defined [11]. In the USCS system, soils are divided in three categories; coarse-grained (either gravel or sand), fine-grained (either silt or clay) and highly organic soils as shown in Table 4.1.

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 2.2. 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 [12].

Table 2.1: Symbols in the Unified Soil Classification System

Symbol	G	S	M	C	O	Pt	H	L	W	P
Description	Gravel	Sand	Silt	Clay	Organic Clay/Silt	Peat	High Plastic	Low Plastic	Well Graded	Poorly Graded

Table 2.2: Typical California Bearing Ratio Values based on Unified Soil Classification

USCS Soil Type	USACE, US Army and Air Force	Yoder & Witzalk	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

2.3.1.2 Mechanistic-Empirical Design Guides

An appendix to the Mechanistic-Empirical Design Guide was developed that relates resilient modulus to much simpler soil characterization tests by way of CBR as an intermediary step. In order to provide an estimate of the resilient modulus parameter for the lower tiers of the system where it is not measured directly a graphical correlation is developed by utilizing the AASHTO and USCS classification systems [13]. Consequently, a modified graphical correlation of CBR, M_R with USCS and AASHTO classification systems is shown in Figure 2.4:

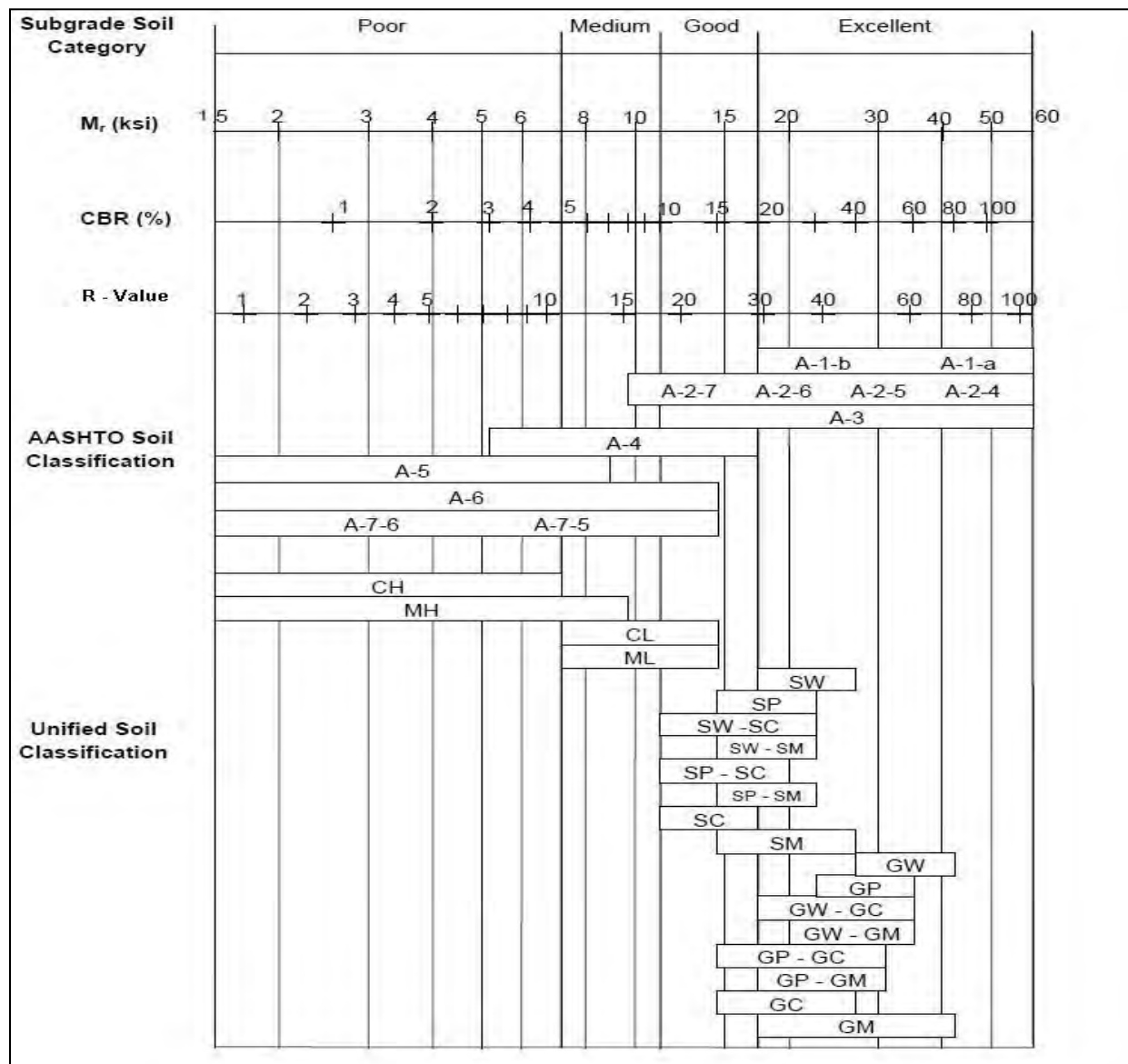


Figure 2.4: Modified Graphical Correlation of CBR, M_R with USCS and AASHTO Systems

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 the recoverable strain instead of total strain” [13]. 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 Hveem Stabilometer in accordance to ASTM D 2844.

The design guide methodology includes three tiers 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 used as model inputs [13].

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. Separate relationships were determined for coarse-grained soils that exhibit non-cohesive behavior (GW, GP, SW, and SP) and for soils with more than 12 percent fines that exhibit plastic behavior (GM, GC, SM, SC, ML, MH, CL, and CH) [13].

The CBR values were selected by choosing average values for each USCS soil type based upon 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 percent passing sieve number 200 and the plasticity index parameters were combined into a composite index called the weighted plasticity index. This term, denoted by wPI , is defined as shown in equation (2.2):

$$wPI = (\text{Percent passing No. 200 Sieve}) \times (\text{Plasticity Index}) = P_{200} \times PI \quad (2.1)$$

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:

$$CBR = \begin{cases} 5 & \text{(if } D_{60} \leq 0.01mm) \\ 28.09(D_{60})^{0.358} & \text{(if } 0.01mm < D_{60} < 30mm) \\ 95 & \text{(if } D_{60} \geq 30mm) \end{cases} \quad (2.2)$$

Where: - D_{60} Diameter on the cumulative size distribution curve where 60 percent of particles are finer (in millimeters)
 - P_{200} Percent passing (finer than) the number 200 sieve size (in decimal form)

For the second group of soils that exhibit plastic behavior, a different correlation for CBR was determined. 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:

$$CBR = \frac{75}{1 + 0.728(wPI)} \quad (2.3)$$

Where: - wPI Weighted Plasticity Index
 - PI Plasticity index (in percent)

The coefficient of determination, R^2 , values of the above stated two equations were reported as 0.84 for the coarse-grained materials of equation (2.3) and 0.67 for the fine grained materials of equation (2.4) [13].

2.3.2 Relationships Specific to a Region and Soil Type

Currently, several attempts at predicting the California Bearing Ratio of soils for a specific soil or geographic location can be found in different literature. The following are published correlations targeting to correlate the CBR value with soil index properties specific to a certain region and soil type.

A correlation of CBR with plasticity and grading using the concept of suitability index was developed by de Graft-Johnson and Bhatia (1969) on the Ghana lateritic soil. In this case, the relationship between CBR and suitability index is shown as follows [14]:

$$\text{CBR} = (35 \cdot \text{SI}) - 8 \quad (2.4)$$

$$\text{SI} = \frac{A}{LL(\text{LogPI})} \quad (2.5)$$

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 rammer with 450mm drop height to compact the soil in 5 layers using 25 blows per layer. The developed relationship is presented in Figure 2.5.

In addition to the de Graft-Johnson and Bhatia correlation, based on their research on 48 samples of fine-grained soils found in India, Agarwal and Ghanekar (1970) had developed an improved correlation between CBR values with liquid limit and optimum moisture content as shown in equation 2.7 [14].

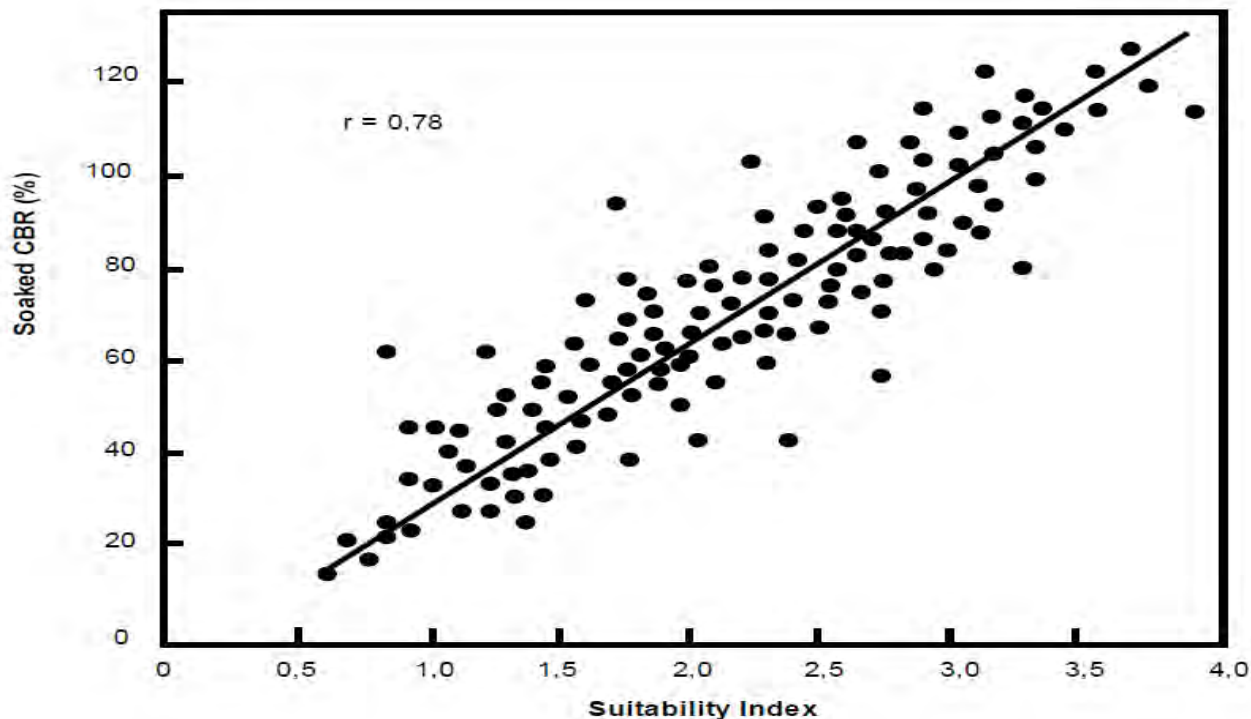


Figure 2.5: CBR and “Suitability Index” for Ghanaian Lateritic Soil

The correlation developed by Agarwal and Ghanekar is defined as follows:

$$\text{CBR} = 2 - 16\text{Log}(\text{OMC}) + 0.07\text{LL} \quad (2.6)$$

Where: - OMC Optimum Moisture Content of the soil
 - LL Liquid Limit of the soil

The 48 soil samples tested by them had CBR values not more than 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 [14].

Further to the above existing correlations, to figure out the association of soil strength parameter with soil index properties the following fundamental theories and concepts are revised in section 2.3.3 and 2.3.4 hereinafter:

2.3.3 Relationship Between CBR and Shear Strength of a Soil

The CBR is essentially a measure of the shear strength of a material at a known density and moisture content. As described in fundamental soil mechanics books, the shear strength of a soil can generally be considered in terms of Coulomb's Law. The relationship between shear strength of a soil (τ) and its cohesion (c), normal stress (σ_n) and angle of internal friction (ϕ) is shown as follows:

$$\tau = c + \sigma_n \tan(\phi) \quad (2.7)$$

It is well known that the shear strength of fine grained soils varies mainly with cohesion ($\tau = c$). A clay which is at liquid limit has very little shearing strength, whereas the same clay at lower moisture content may have considerable shearing strength [15]. Assuming the CBR test as a bearing capacity problem in which standard plunger acts as a circular foundation the following relation considered. By using Terzaghi's bearing capacity equation for circular foundation:

$$q_u = 1.3cN_c + p_0N_q + 0.3\gamma BN_\gamma \quad (2.8)$$

Where: - q_u , c , γ , p_0 and B ; Represents; bearing capacity (kN/m^2), cohesion of soil (kN/m^2), bulk unit weight of soil (kN/m^3), overburden load (kN) and diameter of plunger (m) respectively and N_c , N_q , N_γ are Terzaghi's bearing capacity factors.

For saturated clay in undrained condition, the angle of shearing resistance (ϕ) is zero. For $\phi = 0$ the bearing capacity factors will be $N_c = 5.14$, $N_q = 1$ and $N_\gamma = 0$, thus the N_γ term in the equation is zero. Also the overburden pressure, p_0 , which is relatively light pressure exerted by the surcharge weights which is negligible. Thus, the above equation reduces to $q_u = 6.68c_u$. To convert the measurement of CBR value out of 100%, the standard load of CBR at 2.54mm penetration which is 6900kN/m^2 is considered and the relationship is simplified as follows:

$$CBR = \frac{6.68xc_u}{6900} \times 100 = 0.097c_u \quad (2.9)$$

Where: CBR in % and c_u in kN/m^2

2.3.4 AASHTO Group Index Value as Indicator of Suitability of Subgrade

Group index value (GI) is an indicator of suitability of subgrade soil for highway construction. Different soil class under AASHTO classification are generally rated for subgrade suitability from excellent to good for coarse graded material and good to poor for fine graded soil [7]. This parameter used as a general guide to the load bearing capacity of a soil. The group index is a function of the liquid limit, the plasticity index and the amount of material passing 0.075mm sieve size.

$$GI = (F-35) [0.2 + 0.005(w_1 - 40)] + 0.01(F - 15) (I_p - 10) \quad (2.10)$$

Where:

- F Percentage passing sieve No. 200 (size 0.075mm), whole number
- w_1 Liquid Limit, expressed as a whole number
- I_p Plasticity Index, expressed as a whole number

While calculating the GI from the above equation, if the computed value is negative, the group index is reported as zero. In addition, the GI value is rounded off to the nearest whole number. The smaller the value of the group index, the better is the soil in that category. A group index of zero indicates a good subgrade, whereas a group index of 20 or greater shows a very poor subgrade.

In other way, increasing the value of the group index within each basic soil group reflect the combined effect of increase in liquid limit and plasticity index and also decreasing percentage of coarser material resulting in decrease in the load-carrying capacity of subgrade. In this regard, the idea of Group Index is similar to CBR in a way that both are an indicator of the suitability of subgrade soil. Since, Group Index value by itself is obtained by empirical relationship, correlating GI with CBR might misrepresent the association between them. Subsequently, it is important to correlate CBR value with soil index properties as far as the Group Index value is a parameter that obtained by empirical relationship to measure the performance of the subgrade soil by taking into account of the plasticity and gradation of soil.

Chapter-3

Sample Collection and Test Results

3.1 Sample Collection

In order to have sufficient and reliable data for the target analysis, laboratory tests conducted on soil samples obtained from different localities of Addis Ababa city. Most of the samples collected from undergoing road construction projects during the excavation stage. A total of forty two disturbed samples were gathered within a reasonable sampling interval. The representative samples selected on the basis of visual identification of a suitable subgrade soil, as such a diversified samples acquired from areas such as; Megenanga-Lamberet road, Winget-Yohannes road, Winget-Addisugebeya ring-road, Total-Addisugebeya road, Kolfe building construction site and Lideta Condominium construction site. The location of collected soil samples site is shown with the aid of map in Figure 3.1:

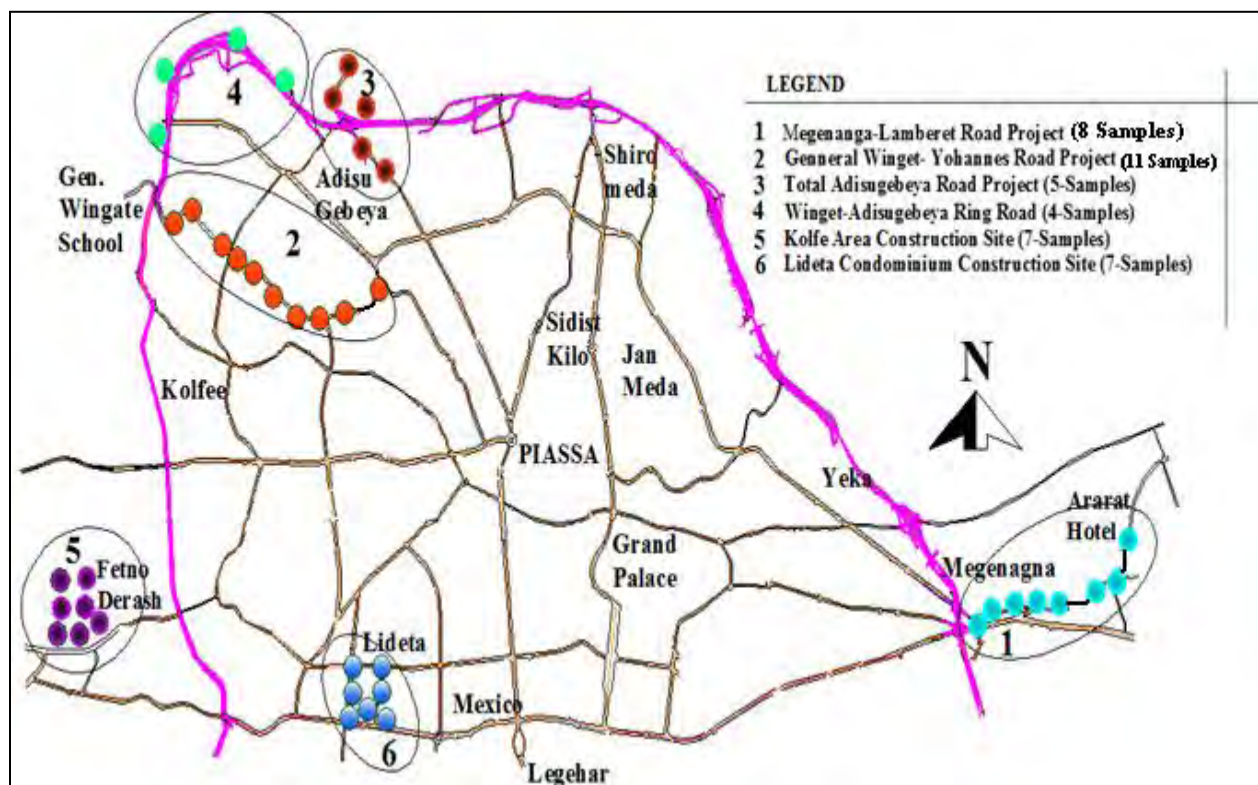


Figure 3.1: Sample Collection from Different Localities of Addis Ababa [16]

3.2 Laboratory Tests and Results

3.2.1 Discussion on Laboratory Tests

Based on the samples retrieved from the sites, laboratory tests on the forty two samples were conducted in the geotechnical and highway laboratories of Addis Ababa Institute of Technology. In addition, by staying about one month on Bako-Nekempt road construction project, some tests were carried out in the joint material testing laboratory of Mouchel and CWCE Supervision Consultants. Accordingly, the following different kinds of tests have been performed:

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

The above conventional tests were conducted on the forty two 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 and also pursuant to USCS classification system about 26 samples have been classified as MH and the remaining soils classified as CL, ML and CH. From the conventional Atterberg limit tests, a liquid limit value ranging from 42 up to 72, plasticity limit value of 20 up to 45 and a plasticity index value of 12 up to 52 were obtained.

A modified 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 modified 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 remolded with OMC using 10, 30 and 65 blows of modified proctor density and soaked for four days. Consequently, after the penetration test were carried out a CBR value ranging from 2.2 up to 10 is obtained at 95% MDD of modified ASHTO proctor density.

For the sake of illustration and easy of reference, the typical test results of a soil sample have been demonstrated hereunder from Figures 3.2 up to 3.6:

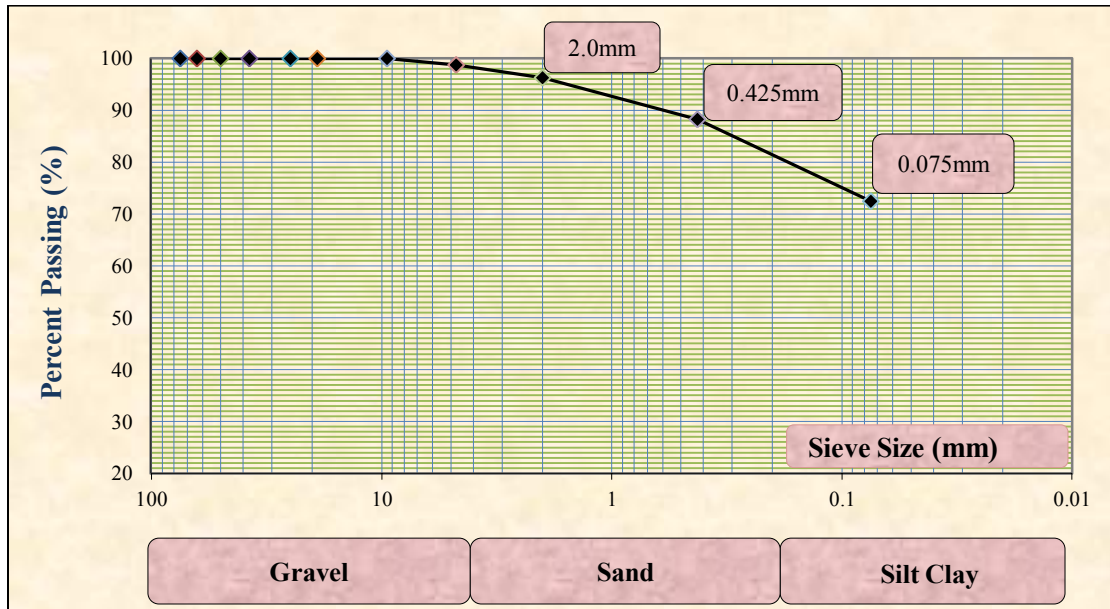


Figure 3.2: Typical Grain Size Analysis Graph

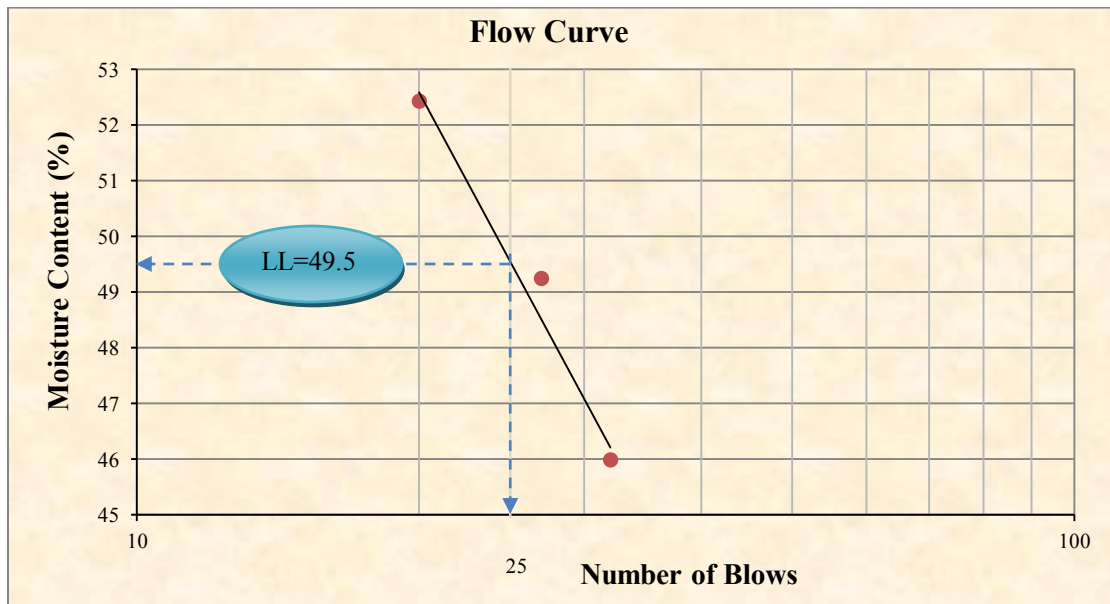


Figure 3.3: Typical Liquid Limit Graph (Flow Curve)

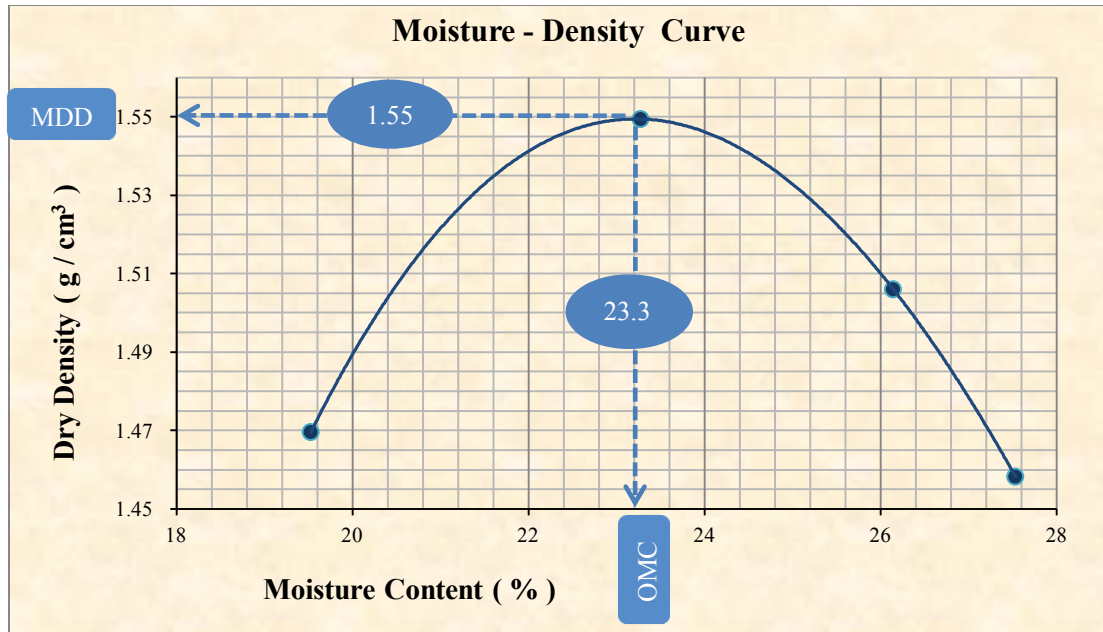


Figure 3.4: Typical Density vs. Moisture Content Relationship Graph

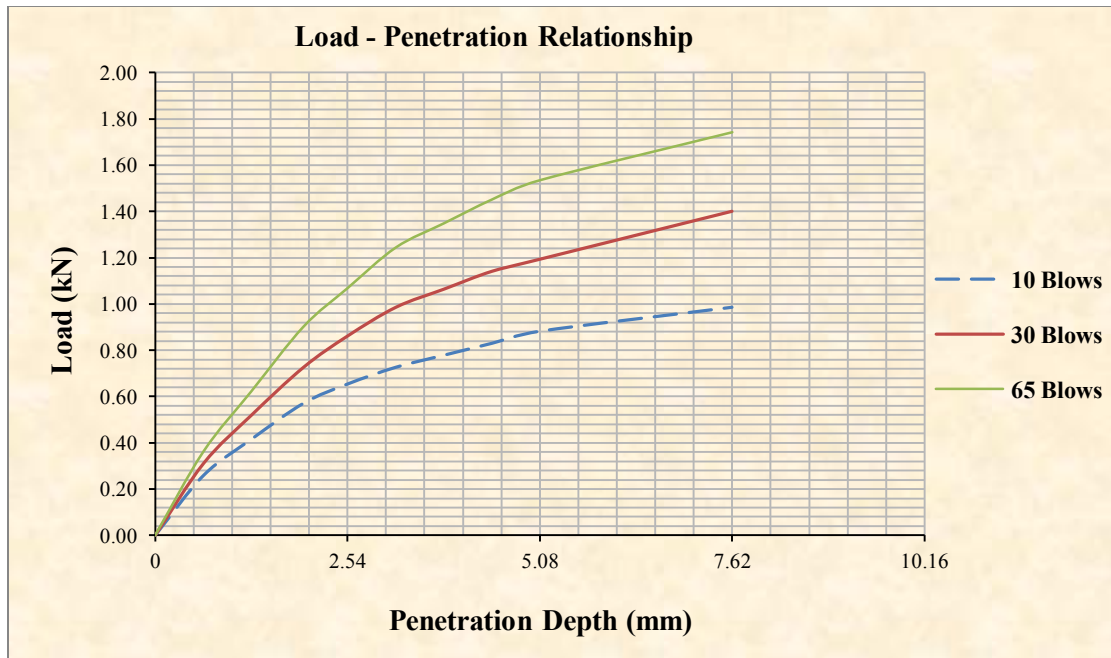


Figure 3.5: Typical Penetration Load vs. Penetration Depth Graph

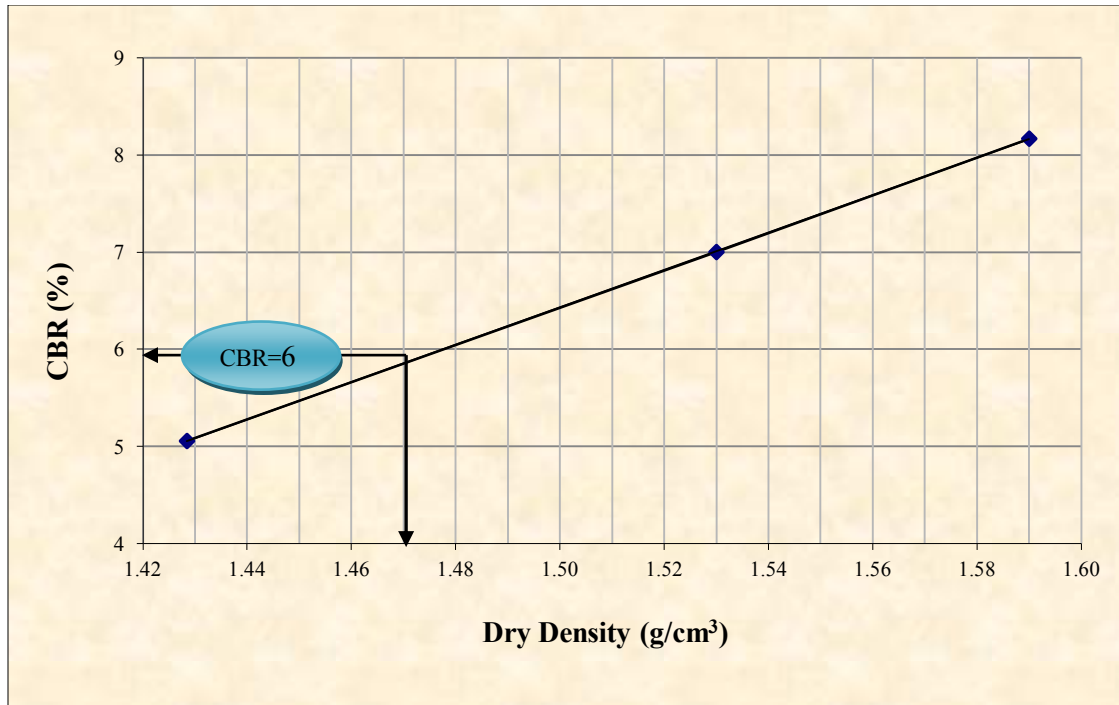


Figure 3.6: Typical Density vs. CBR Graph

For further reference, the details of all the laboratory tests results of the forty two soil samples and related calculations including graphs have been enclosed under Appendix B of this thesis.

3.2.2 Summary of Laboratory Test Results

In order to analyze the intended correlation, the test results were compiled and summarized in a way that the SPSS Software inputs the data as shown in Table 3.1.

Table 3.1: Summary of All Laboratory Test Results

It. No.	Sample Code	Grain Size Analysis Percent Passing (%)					Atterberg Limits			Soil Classification		Modified Proctor Test		CBR Test				
		9.5 mm	4.75 mm	2.00 mm	0.475 mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	USCS 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	ML - 1	100	99.0	96.0	88.0	72.4	50	34	16	A-7-5 (13)	MH	1.55	23.3	10	1.43	5.06	4.41	6
														30	1.53	7.00	5.97	
														65	1.59	8.17	7.78	
2	ML - 2	100	99.5	98.1	94.2	86.1	43	29	14	A-7-6 (14)	ML	1.60	21.9	10	1.40	8.60	8.30	10
														30	1.56	10.7	10.38	
														65	1.59	12.4	11.41	
3	ML - 3	100	100	98.0	91.7	78.7	53	33	20	A-7-5 (18)	MH	1.57	20.9	10	1.38	5.44	5.20	9.2
														30	1.5	9.72	9.10	
														65	1.56	11.30	10.90	
4	ML - 4	100	99.9	97.1	87.5	75.1	48	30	18	A-7-5 (14)	ML	1.56	20.6	10	1.41	5.06	4.67	6.2
														30	1.52	6.61	5.97	
														65	1.6	7.78	6.74	
5	ML - 5	100	99.3	96.6	91.0	80.2	55	32	23	A-7-5 (21)	MH	1.54	20.4	10	1.43	5.72	5.19	6.4
														30	1.55	7.8	6.74	
														65	1.60	8.86	8.04	
6	ML - 6	100	99.0	97.0	88.0	72.1	46	34	12	A-7-5 (10)	ML	1.59	20.2	10	1.46	6.61	5.71	7.4
														30	1.57	8.17	6.74	
														65	1.63	9.33	7.78	
7	ML - 7	100	99.9	99.3	93.0	80.8	60	28	32	A-7-6 (28)	CH	1.51	24.3	10	1.31	2.72	2.33	3.3
														30	1.47	3.50	2.85	
														65	1.54	4.28	3.63	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

It. No.	Sample Code	9.5 mm	4.75 mm	2.00 mm	0.475 mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	USCS Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load at 2.54 mm	Load at 5.08 mm	CBR at 95% MDD
8	ML - 8	100	100	99.1	96.2	88.2	66	35	31	A-7-5 (33)	MH	1.50	29.2	10	1.28	3.50	2.80	6.1
														30	1.41	5.70	4.80	
														65	1.48	7.00	5.90	
9	WY-1	100	100	98.6	94.6	84.1	61	34	27	A-7-5 (27)	MH	1.53	27.8	10	1.39	4.72	4.30	5.4
														30	1.48	5.85	5.15	
														65	1.52	6.82	5.75	
10	WY-2	100	100	98.8	95.1	87.8	63	34	29	A-7-5 (30)	MH	1.53	29.2	10	1.29	2.40	2.30	6.1
														30	1.42	4.70	4.20	
														65	1.48	6.70	5.50	
11	WY-3	100	100	97.1	90.9	80.9	54	28	26	A-7-6 (23)	CH	1.59	23.2	10	1.45	6.67	6.15	7.3
														30	1.54	7.50	6.60	
														65	1.58	8.17	7.25	
12	WY-4	100	100	98.2	94.5	84.1	59	35	24	A-7-5 (24)	MH	1.55	23.8	10	1.42	4.60	4.30	7.8
														30	1.46	7.50	6.50	
														65	1.56	9.30	7.80	
13	WY-5	100	100	99.2	93.3	87.3	52	33	19	A-7-5 (20)	MH	1.53	27.6	10	1.38	8.30	6.40	9.4
														30	1.47	9.70	7.80	
														65	1.52	10.50	8.20	
14	WY-6	100	100	98.4	90.5	77.5	57	36	21	A-7-5 (19)	MH	1.50	24.2	10	1.39	7.83	6.49	8.4
														30	1.48	8.83	6.91	
														65	1.52	10.17	8.05	
15	WY-7	100	100	98.0	92.0	81.0	61	34	27	A-7-5 (25)	MH	1.58	23.3	10	1.46	3.64	3.32	4.1
														30	1.52	4.46	4.15	
														65	1.58	6.03	5.45	
16	WY-8	100	100	97.0	87.0	73.0	70	32	38	A-7-5 (22)	CH	1.48	27.8	10	1.38	1.99	1.77	2.2
														30	1.48	2.52	2.30	
														65	1.67	3.47	3.14	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

It. No.	Sample Code	9.5 mm	4.75 mm	2.00 mm	0.475 mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	USCS Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load at 2.54 mm	Load at 5.08 mm	CBR at 95% MDD
17	WY-9	100	100	99.0	94.0	82.0	56	29	27	A-7-6 (25)	CH	1.64	22.2	10	1.39	6.18	5.58	7.3
														30	1.47	6.99	6.65	
														65	1.67	8.02	7.28	
18	WY-10	100	100	100	95.0	81.0	60	37	23	A-7-5 (22)	MH	1.53	26	10	1.4	4.49	3.68	5.2
														30	1.49	5.92	4.97	
														65	1.67	9.27	7.20	
19	WY-11	100	100	99.0	92.0	80.0	63	33	30	A-7-5 (27)	MH	1.56	27.7	10	1.42	3.06	3.16	4.6
														30	1.49	4.73	4.40	
														65	1.57	7.57	6.91	
20	TA-1	100	100	100	97.0	91.0	54	32	22	A-7-5 (24)	MH	1.61	23.4	10	1.4	3.77	3.13	8.4
														30	1.46	5.49	4.79	
														65	1.56	9.45	7.36	
21	TA-2	100	100	99.0	95.0	89.0	59	28	31	A-7-6 (31)	CH	1.58	24.5	10	1.46	4.06	4.47	4.7
														30	1.58	6.12	5.84	
														65	1.63	9.00	7.53	
22	TA-3	100	100	97.0	89.0	78.0	61	40	21	A-7-5 (20)	MH	1.57	19	10	1.42	3.73	3.40	4.3
														30	1.52	4.60	3.98	
														65	1.56	5.24	4.40	
23	TA-4	100	100	97	91.7	78.6	67	38	29	A-7-5 (27)	MH	1.54	22	10	1.39	4.43	3.87	6.2
														30	1.44	5.75	4.75	
														65	1.5	7.26	5.75	
24	TA-5	100	100	97.8	89.7	75.7	62	35	27	A-7-5 (23)	MH	1.57	30.2	10	1.4	4.71	4.14	6.4
														30	1.5	6.5	5.33	
														65	1.59	8.12	6.41	
25	KA-1	100	100	99.1	92.9	79.5	72	35	37	A-7-5 (33)	MH	1.48	30.2	10	1.32	2.37	2.3	2.8
														30	1.39	2.77	2.56	
														65	1.46	3.16	2.82	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

It. No.	Sample Code	9.5 mm	4.75 mm	2.00 mm	0.475 mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	USCS Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load at 2.54 mm	Load at 5.08 mm	CBR at 95% MDD
26	KA-2	100	100	99.6	92.8	81.4	60	35	25	A-7-5 (24)	MH	1.52	24.2	10	1.32	3.27	2.72	5.8
														30	1.42	5.14	4.36	
														65	1.51	7.23	5.96	
27	KA-3	99	100	97.5	92.3	81.7	68	44	24	A-7-5 (25)	MH	1.50	28.4	10	1.36	2.39	2.05	3.6
														30	1.42	3.29	3.09	
														65	1.49	4.50	4.34	
28	KA-4	100	100	98.4	94.1	81.5	63	40	23	A-7-5 (23)	MH	1.49	29.3	10	1.33	3.71	3.19	5.3
														30	1.38	4.71	4.00	
														65	1.49	6.21	5.01	
29	KA-5	100	100	97.9	92.6	80.0	59	34	25	A-7-5 (23)	MH	1.50	22.9	10	1.38	2.6	2.6	3.7
														30	1.41	3.41	3.21	
														65	1.52	4.42	3.83	
30	KA-6	100	100	97.2	91.3	83.0	65	31	34	A-7-5 (32)	CH	1.48	24.1	10	1.35	2.76	2.65	3.2
														30	1.4	3.15	3.07	
														65	1.49	3.82	3.46	
31	KA-7	100	100	98.0	90.3	80.5	53	33	20	A-7-5 (19)	MH	1.50	21.4	10	1.38	4.01	3.80	5.1
														30	1.42	5.07	4.32	
														65	1.52	6.05	4.90	
32	WARR-1	100	100	99.2	95.6	87.5	70	31	39	A-7-5 (39)	CH	1.52	20.2	10	1.38	2.48	2.38	3.4
														30	1.43	3.26	2.89	
														65	1.53	4.05	3.4	
33	WARR-2	100	100	98.5	96.2	82.8	43	28	15	A-7-6 (14)	ML	1.61	24	10	1.41	4.75	4.53	9.0
														30	1.5	7.96	7.51	
														65	1.63	12.07	9.91	
34	WARR-3	100	100	100	97.7	87.2	49	27	22	A-7-6 (21)	CL	1.60	23.4	10	1.41	4.68	4.15	8
														30	1.50	7.47	6.76	
														65	1.61	10.11	8.56	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

It. No.	Sample Code	9.5 mm	4.75 mm	2.00 mm	0.475 mm	0.075 mm	LL (%)	PL (%)	PI (%)	AASHTO Class.	USCS Class.	MDD (g/cc)	OMC (%)	No. of Blows	Density (g/cc)	Load at 2.54 mm	Load at 5.08 mm	CBR at 95% MDD
35	WARR-4	100	100	100	97.9	88.2	45	26	19	A-7-6 (19)	CL	1.65	22.1	10	1.52	8.4	7.01	9.5
														30	1.61	10.38	8.63	
														65	1.65	12.83	10.47	
36	LC-1	100	100	97.8	91.5	83.4	54	32	22	A-7-5 (21)	MH	1.55	19.7	10	1.35	3.32	3.09	5.3
														30	1.42	4.79	4.16	
														65	1.56	6.02	5.22	
37	LC-2	100	100	100	95.4	85.0	42	24	18	A-7-6 (16)	CL	1.63	18.8	10	1.47	3.32	3.09	7
														30	1.57	4.79	4.16	
														65	1.64	6.02	5.22	
38	LC-3	100	100	98.4	95.4	88.7	60	25	35	A-7-6 (35)	CH	1.48	24.1	10	1.33	1.58	1.37	2.8
														30	1.37	2.31	1.95	
														65	1.47	3.32	2.66	
39	LC-4	100	100	98.2	90.8	79.2	55	30	25	A-7-5 (39)	MH	1.52	23.3	10	1.29	3.54	3.35	5.1
														30	1.4	4.68	4.27	
														65	1.47	5.43	5.03	
40	LC-5	100	100	99.1	94.4	84.0	57	31	26	A-7-5 (19)	MH	1.49	25.9	10	1.33	2.71	2.35	3.9
														30	1.42	3.92	3.46	
														65	1.5	4.6	4.08	
41	LC-6	100	100	98.5	95.2	82.5	72	20	52	A-7-6 (45)	CH	1.62	17.8	10	1.47	2.99	2.53	4.8
														30	1.51	4.31	3.72	
														65	1.58	5.38	4.6	
42	LC-7	100	100	98.9	97.5	90.0	62	45	17	A-7-5 (22)	MH	1.55	18	10	1.38	5.22	4.52	8.4
														30	1.45	7.86	7.02	
														65	1.53	9.72	8.30	

Where:

ML= Megenanga-Lamberet (Ararat Hotel) Road Project

WY = Winget-Yohanes Road Project

TA = Total Adisugebeya Road Project

LC=Lideta Condominium Building and Road Construction Site

WARR = Winget-Adisugebeya Ring Road

KA = Kolfe Area Construction Site

Chapter-4

Regression Analysis and Correlations

4.1 Introduction

Regression analysis is a statistical technique that is very useful in the field of engineering and science in modeling and investigating relationships between two or more variables. The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticated nonlinear multiple regressions. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

Fitting 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 [17]. The standard error of an estimate gives some idea about the precision of an estimate. During modeling, a variable that shows the least standard error of estimates is the one to be 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 regressor variables and this quantity termed the coefficient of determination, R^2 . The value of R^2 is always between 0 and 1, because R is between -1 and +1, whereby a negative value of R 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 and the t-test [18].

4.2 Scatter Plot

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

Prior to carrying out the regression analysis using the forty two test results, a scatter diagram is generated by applying the Excel Spreadsheet, in order to study the relationships developed between the dependent variable and the regressor variables so as to determine the model that best suits the test results. Consequently, the scatter plot of the same is presented from Figure 4-1 up to Figure 4-6:

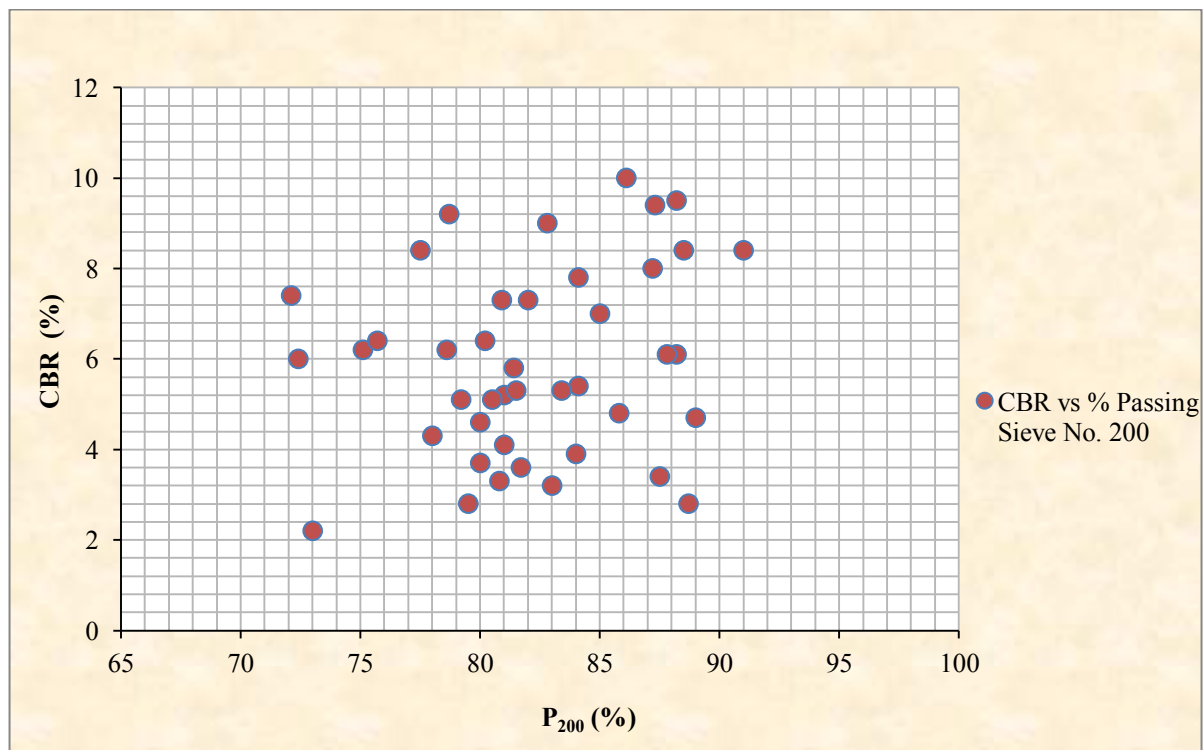


Figure 4-1: Scatter Diagram of Percent Passing Sieve No. 200 vs. CBR

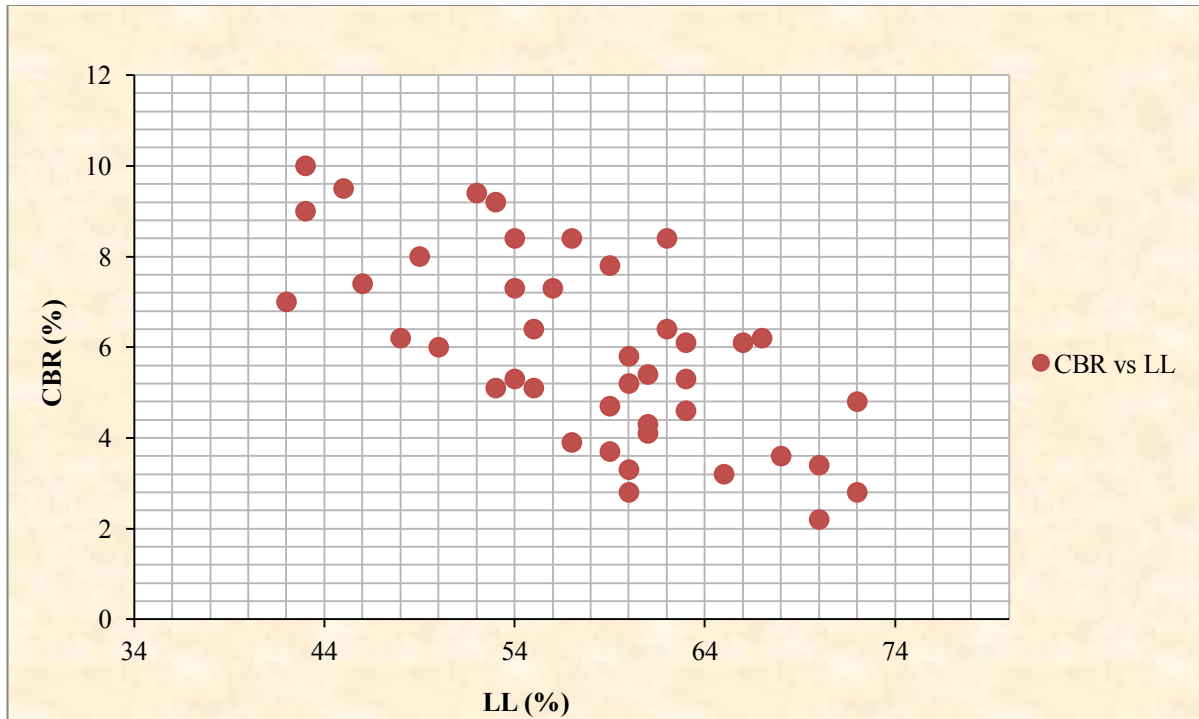


Figure 4-2: Scatter Diagram of Liquid Limit vs. CBR

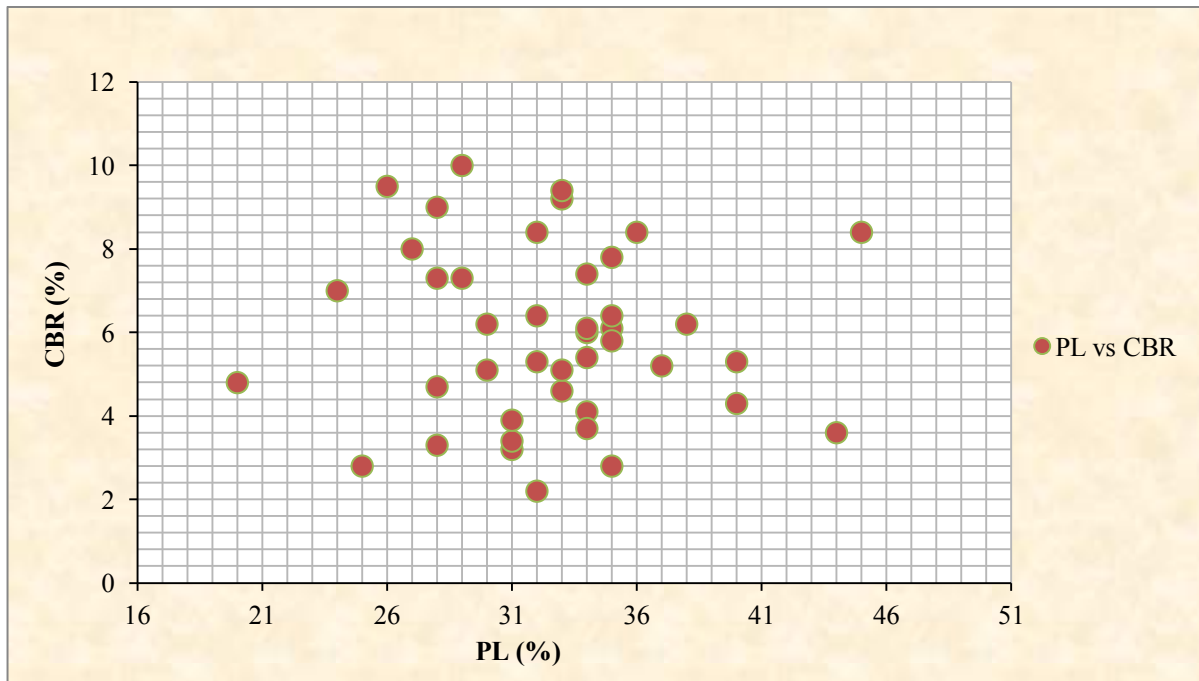


Figure 4-3: Scatter Diagram of Plastic Limit vs. CBR

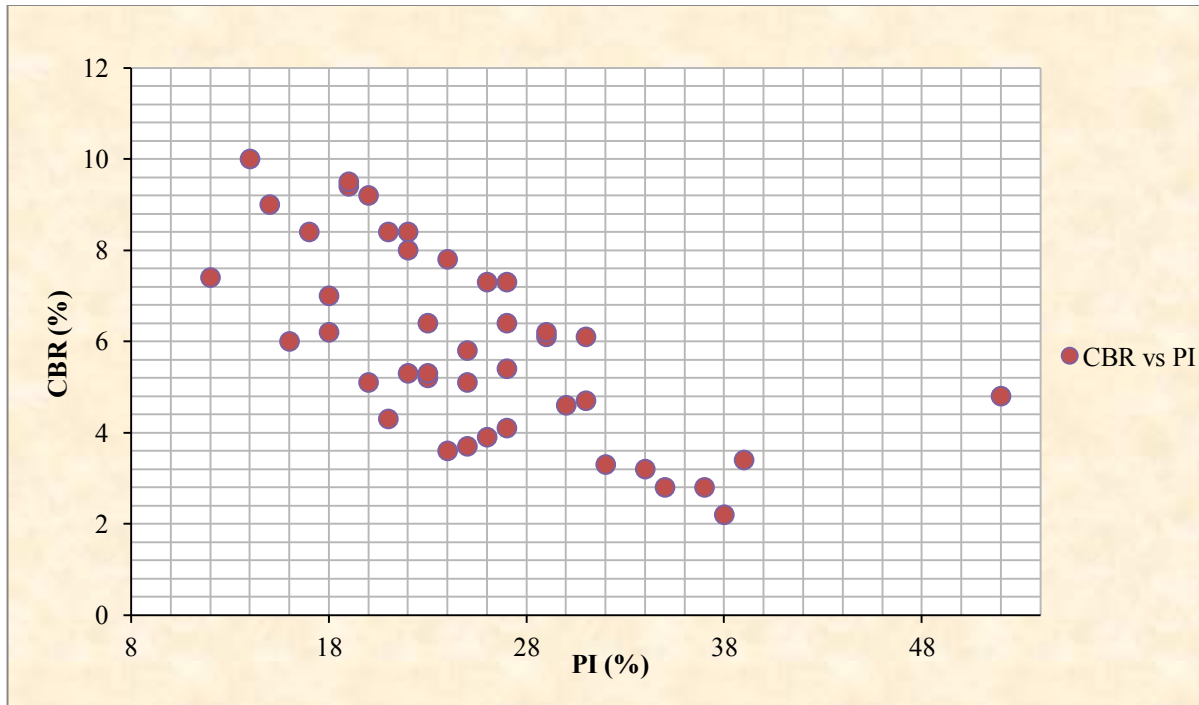


Figure 4-4: Scatter Diagram of Plasticity Index vs. CBR

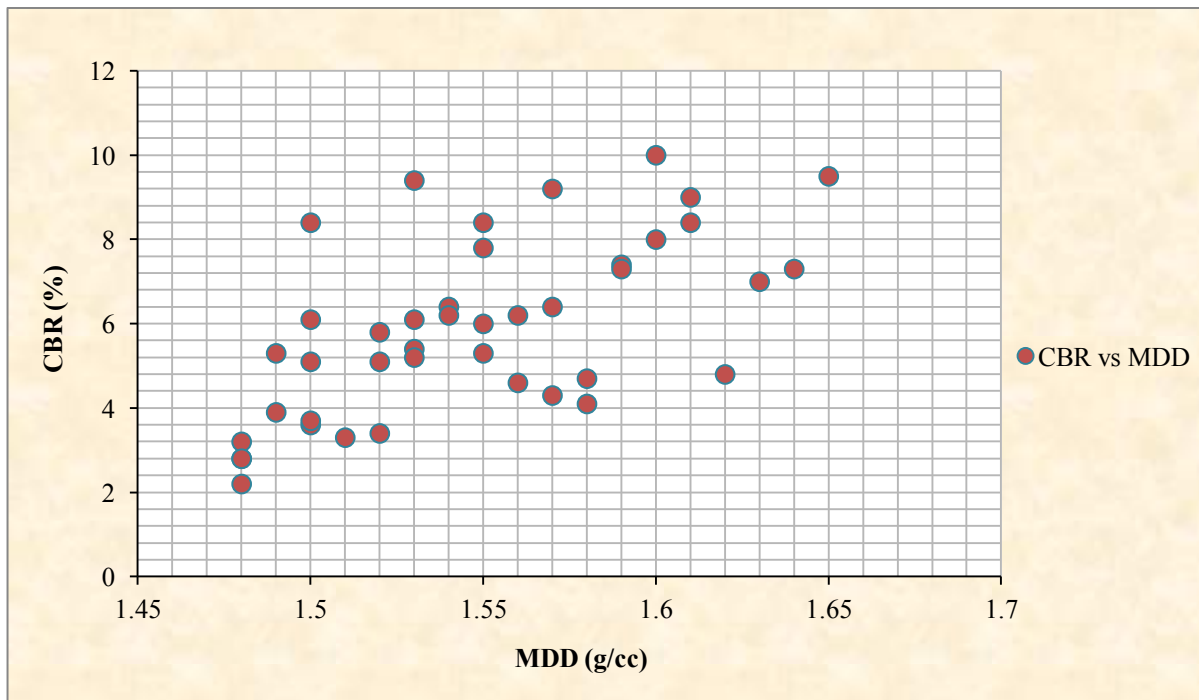


Figure 4-5: Scatter Diagram of Maximum Dry Density vs. CBR

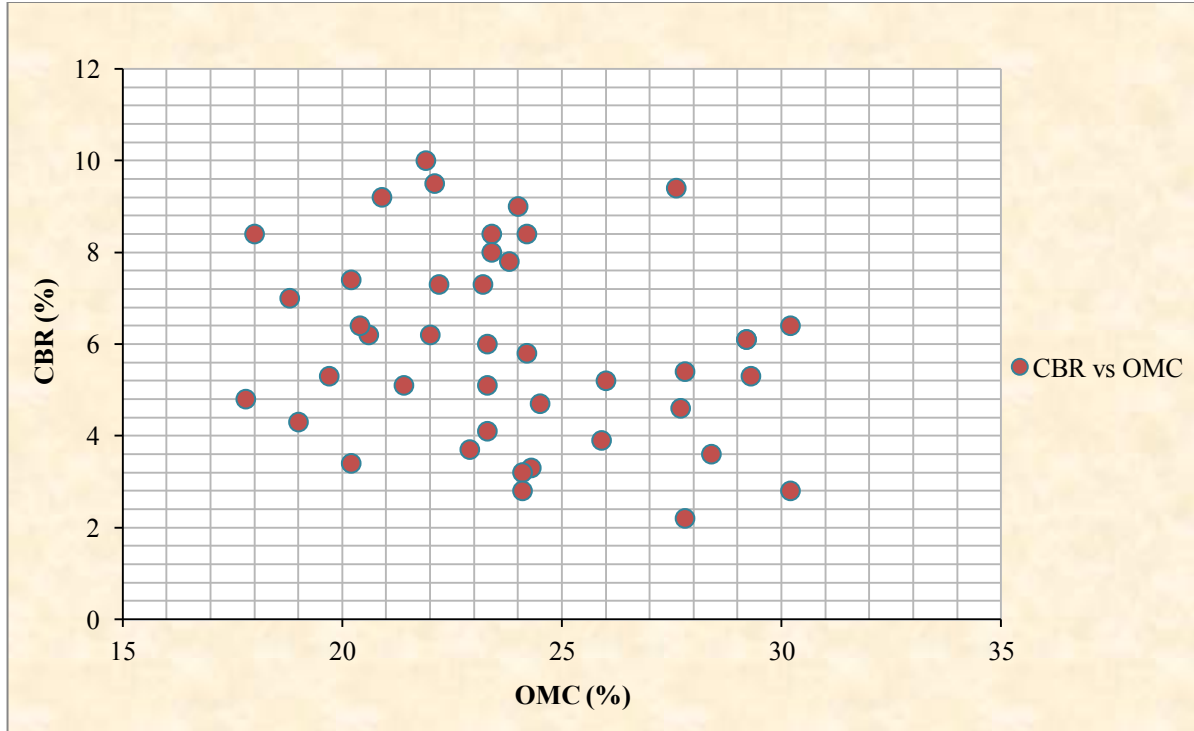


Figure 4-6: Scatter Diagram of Optimum Moisture Content vs. CBR

The above scatter diagrams provide a visual method of displaying a relationship between variables as plotted in a two dimensional coordinate system. Inspection of the scatter diagrams indicate that, although no simple curve will pass exactly through all the points, there is a reasonable indication that the points lie scattered randomly around a straight line, particularly for the liquid limit, plasticity index and maximum dry density.

While the remaining independent variables such as percent passing 0.075mm sieve size, plastic limit and optimum moisture content test results outliers away from the possible straight line. Relatively the above scatter plot shows a linear response and hence, a linear regression model expresses the association between the subject parameters.

4.3 Regression Analysis

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

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad (4.1)$$

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 \dots + \alpha_n X_n + \varepsilon \quad (4.2)$$

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_0 , α_1 , α_2 and α_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 [17]. 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 regressor 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 Variables

Variable Type	Variable Name	Unit of Measurement	No. of Samples	Ranges		Mean	Standard Deviation
				Min.	Max.		
Dependent	CBR	%	42	2.2	10.0	5.99	2.08
Independent	P ₂₀₀	%	42	72.1	91.0	82.20	4.73
	LL	%	42	42.0	72.0	57.83	7.88
	PL	%	42	20.0	45.0	32.48	4.92
	PI	%	42	12.0	52.0	25.36	7.71
	MDD	g/cc	42	1.48	1.65	1.55	0.05
	OMC	%	42	17.8	30.2	23.82	3.40

To identify the influence of one variable on the other, a stepwise linear regression has been analyzed and as a result, the respective correlation coefficients and level of significance determined. Hereunder, the Pearson correlation coefficient matrix is shown in Table 4.2:

Table 4.2: Correlation Matrix of Pearson Correlation Coefficient

Pearson Correlation (R)	CBR	P₂₀₀	LL	PL	PI	MDD	OMC
CBR	1.000	0.202	-0.677	-0.059	-0.655	0.620	-0.245
P₂₀₀	0.202	1.000	0.007	-0.251	0.168	0.179	-0.027
LL	-0.677	0.007	1.000	0.347	0.801	-0.555	0.374
PL	-0.059	-0.251	0.347	1.000	-0.284	-0.429	0.278
PI	-0.655	0.168	0.801	-0.284	1.000	-0.294	0.205
MDD	0.620	0.179	-0.555	-0.429	-0.294	1.000	-0.479
OMC	-0.245	-0.027	0.374	0.278	0.205	-0.479	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 and plasticity index has resulted relatively a better correlation with the strength parameter. However, the correlation with plastic limit shows a weak relationship, this is may be due to the inconsistency in conducting laboratory plastic limit test and inadequacy of the number of trials considered in the test procedures. Besides, in this research work the maximum dry density has resulted a moderate correlation coefficient with the strength parameter for fine grained soil, this is due to the presence of more silty soils and some granular materials blended with the fine soils.

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 detail outputs of the SPSS Software for the single and multiple linear regression analysis is presented under Appendix A of this thesis and also the summarized correlation results are presented hereinafter:

4.3.1 Single Linear Regression Analysis

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

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

$$\text{CBR} = 16.270 - 0.179 * \text{LL}, \quad \text{with } R^2 = 0.458, \quad n = 42$$

The details of the statistical out-put indicates that the relationship developed between LL and CBR is significant ($\alpha < 0.05$) 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:

$$\text{CBR} = 6.737 - 0.025 * \text{PL}, \quad \text{with } R^2 = 0.003, \quad n = 42$$

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

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:

$$\text{CBR} = 10.413 - 0.177 * \text{PI} \quad \text{with } R^2 = 0.429, \quad n = 42$$

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

Model 4: Correlation Between CBR and Percent Passing Sieve No. 200 (P₂₀₀)

The resulting regression analysis after correlating CBR with P₂₀₀ is expressed by the following linear equation with its corresponding correlation coefficients:

$$\text{CBR} = -1.366 + 0.089 * P_{200}, \quad \text{with } R^2 = 0.041, \quad n = 42$$

The details of the statistical out-put indicates that the relationship developed between P₂₀₀ and CBR is not significant ($\alpha > 0.05$) and also a weak relationship exists between correlation variables.

Model 5: 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:

$$\text{CBR} = -35.966 + 27.072 * \text{MDD}, \quad \text{with } R^2 = 0.384, \quad n = 42$$

The details of the statistical out-put indicates that the relationship developed between MDD and CBR is significant ($\alpha < 0.05$) as shown in Model-5 of Appendix A.

Model 6: 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:

$$\text{CBR} = 9.499 - 0.150 * \text{OMC}, \quad \text{with } R^2 = 0.06, \quad n = 42$$

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

From the above developed single linear regression models, based on the significant standard error (α) 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

During analyzing the multiple linear regressions, after going through a number of alternative combinations of predictors the following results are obtained for the forty two samples and the significant relationships are presented hereunder:

Model A: Correlation Between CBR with PL and PI

The resulting regression analysis after correlating CBR with PL and PI is expressed by the following multiple linear equations with its corresponding correlation coefficients:

$$\text{CBR} = 14.580 - 0.197 \cdot \text{PI} - 0.112 \cdot \text{PL}, \quad \text{with } R^2 = 0.494, \quad \text{Adj. } R^2 = 0.468, \quad n = 42$$

The details of the statistical out-put of Model A indicates that the relationship developed between CBR with PL and PI is significant ($\alpha < 0.05$). 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}

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

$$\text{CBR} = 8.302 - 0.190 \cdot \text{PI} + 6.33 \cdot P_{200}^5, \quad \text{with } R^2 = 0.533, \quad \text{Adj. } R^2 = 0.510, \quad n = 42$$

Where: P_{200} expressed in decimal

The statistical out-put of Model B indicates that the relationship developed between CBR with PI and P_{200} is significant ($\alpha < 0.05$). 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, PI and MDD or (LL, PL and MDD)

The resulting regression analysis after correlating CBR with LL, PI and MDD and also with LL, PL and MDD is expressed by the following multiple linear equations with its corresponding correlation coefficients:

$$\text{CBR} = -21.734 - 0.003 \cdot \text{LL} - 0.137 \cdot \text{PI} + 20.244 \cdot \text{MDD}, \text{ with } R^2 = 0.629, \text{ Adj. } R^2 = 0.599, n = 42$$

Or

$$\text{CBR} = -21.522 - 0.141 \cdot \text{LL} + 0.137 \cdot \text{PI} + 20.244 \cdot \text{MDD}, \text{ with } R^2 = 0.629, \text{ Adj. } R^2 = 0.599, n = 42$$

The details of the statistical out-put of Model C indicates that the relationship developed between CBR with LL, PL and MDD is significant ($\alpha < 0.05$). 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.

The above correlations result is summarized and presented in Table 4.3 as shown below:

Table 4.3: Summary of the Regression Analysis

Regression Type	Model Name	R	R^2	Std. Error (α)	Significance Order Depending on α and R^2
Single Linear Regression Model	Model 1	- 0.677	0.458	< 0.05	1
	Model 2	- 0.059	0.003	>0.05	6
	Model 3	- 0.655	0.429	< 0.05	2
	Model 4	0.202	0.041	>0.05	5
	Model 5	0.620	0.384	< 0.05	3
	Model 6	- 0.245	0.060	>0.05	4
Multiple Linear Regression Model	Model A	0.703	0.494	< 0.05	3
	Model B	0.730	0.533	< 0.05	2
	Model C	0.793	0.629	< 0.05	1

Chapter-5

Discussion on Correlation Results

5.1 The Developed Correlation

The validation of the developed correlation is conducted by using ten known test results which follows similar testing procedures with the subject research. These control test results were obtained from Gondwana Consulting Engineers material testing laboratory for soil samples collected from different localities of Addis Ababa. Depending on the relative significance order, Model C ($CBR = -21.734 - 0.003*LL - 0.137*PI + 20.244*MDD$) 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 Table 5.1:

Table 5.1: Validation of the Developed Correlation

Sample No.	Control Test Results						Developed CBR Value
	P ₂₀₀ (%)	LL (%)	PI (%)	MDD (g/cc)	OMC (%)	Actual CBR Value	
1.	69	57	29	1.50	19	3	4.6
2.	70	58	36	1.64	20	7	6.7
3.	89	81	36	1.65	32	6	6.2
4.	73	73	33	1.55	23	3	4.7
5.	67	52	26	1.68	19	9	8.8
6.	89	55	25	1.56	18	6	6.3
7.	56	51	21	1.59	20	5	7.5
8.	71	53	24	1.66	22	8	8.6
9.	88	56	23	1.53	21	6	5.9
10.	89	74	48	1.52	33	3	2.5

Further to the above, in order to figure out and verify the suitability of the developed correlation using a control test results, a comparison graph is plotted between the actual CBR (CBR_{Actual}) and predicted CBR ($CBR_{Predicted}$) as shown in Figure 5.1:

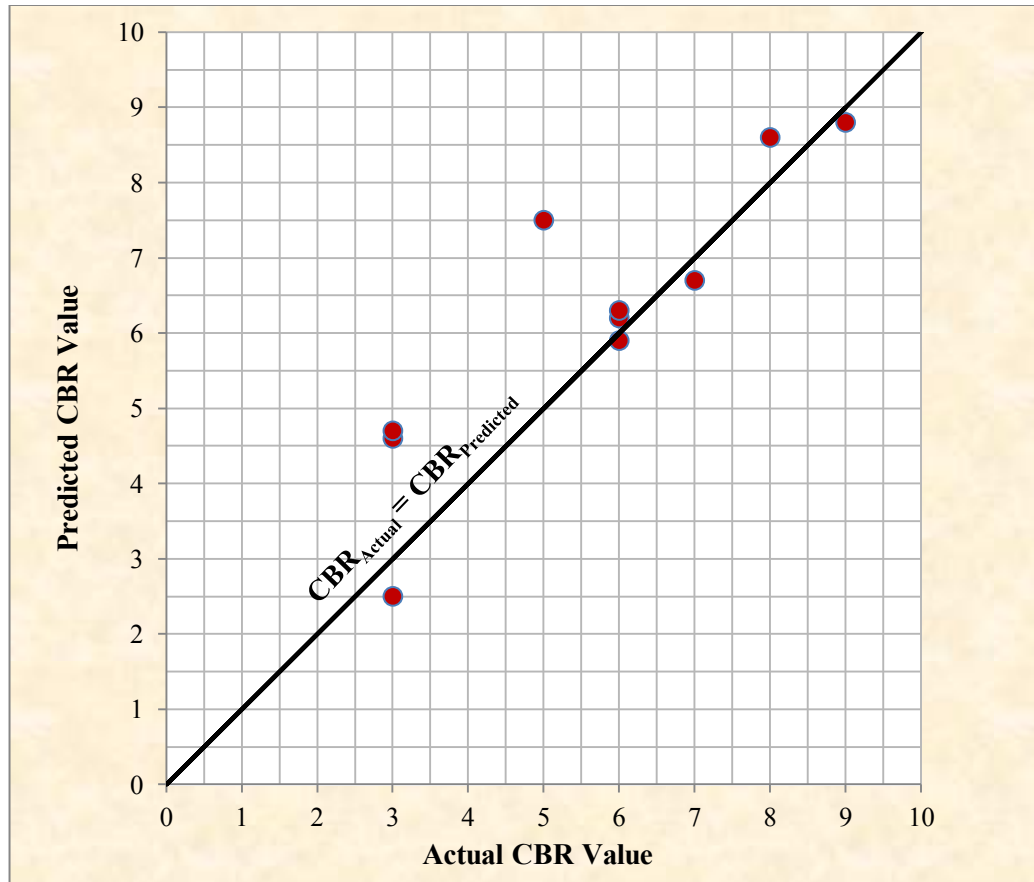


Figure 5.1: Actual CBR Value vs. Predicted CBR Value

As shown in Figure 5.1, about seven samples predicted CBR value scatters near the straight line, through which the actual and predicted CBR value is equal, whereas relatively three test results slightly deviated from the possible straight line having variation from the actual CBR value between 50% up to 60%. By investigating the accuracy of the predicted CBR values, the developed correlation might be applied for preliminary characterization of the strength of subgrade soil into uniform section.

5.2 Evaluation of the Developed and Existing Correlations

The suitability of existing correlations particularly the NCHRP's 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 5.2:

Table 5.2: The Developed and Existing Correlations

Sample No.	Actual CBR Value [A]	Developed Correlation		NCHRP		Agarwal and Ghanekar	
		Predicted CBR Value [B]	Variation (%) [B-A]*100/A	Predicted CBR Value [C]	Variation (%) [C-A]*100/A	Predicted CBR Value [D]	Variation (%) [D-A]*100/A
1.	3	4.6	53	4.8	61	-14.5	- 582
2.	7	6.7	-4	3.9	-45	-14.9	- 312
3.	6	6.2	3	3.1	-49	-16.4	- 374
4.	3	4.7	57	4.0	35	-14.7	- 589
5.	9	8.8	-2	5.5	-39	-14.8	- 265
6.	6	6.3	5	4.4	-27	-14.2	- 337
7.	5	7.5	50	7.8	57	-15.2	- 405
8.	8	8.6	8	5.6	-31	-15.8	- 297
9.	6	5.9	-2	4.8	-21	-15.2	- 354
10.	3	2.5	-17	2.3	-22	-17.1	- 671
Avg.	5.6	6.18	20	4.62	39	-15.28	419

As shown in Tables 5.2, the NCHRP's correlation resulted an average variation of 39% from the actual CBR values. Similarly, the Agarwal and Ghanekar's correlation resulted average variation of 419% by entirely underestimating the actual CBR value. On the other hand, the developed correlation predicted the CBR value with average variation of 20% from the actual CBR value.

As depicted above, by using a control test results that are obtained from different localities of Addis Ababa, 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-6

Conclusion and Recommendation

6.1 Conclusions

The research was conducted to find a localized correlation between CBR value and soil index properties within the scope of the study. Accordingly, the required laboratory tests were conducted on samples retrieved from different geographical area of Addis Ababa. Using the obtained forty two test results a single and multiple linear regressions were analyzed and a relationship was developed that predict CBR value in terms of P_{200} , LL, PL, PI, MDD and OMC.

The suitability of the developed correlation is evaluated by utilizing a separate control test results. From the results of this study the following conclusions are drawn:

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

$$\text{CBR} = 16.270 - 0.179 \cdot \text{LL} \quad R^2 = 0.458, \quad n = 42$$

2. Relatively an improved correlation than the single regression is obtained when multiple regression is used as given below:

$$\text{CBR} = -21.734 - 0.003 \cdot \text{LL} - 0.137 \cdot \text{PI} + 20.244 \cdot \text{MDD}, \quad R^2 = 0.629 \quad n = 42$$

3. In light of the above, a combination of soil index properties correlates better with strength characteristic of CBR than individual soil properties.
4. For preliminary design purpose the above correlation might be used, if the predicted CBR value is within the range of 2.2% to 10%. Otherwise, a detailed laboratory test should be carried out to obtain the actual CBR value.

6.2 Recommendations

The exposure encountered in trying to conduct the current research has revealed areas where further efforts may be proved in the future. Following are some of the recommendations in relation to the subject study:

1. It is recommended to carry out this correlation with a large number of samples including geographical areas in Addis Ababa which are not covered by this research.
2. It is also recommended to carry out such a study in other parts of Ethiopia especially in regions where lateritic soil abundantly to be found.
3. It is advisable to conduct comparative correlations between soaked and unsoaked CBR value with soil index properties.
4. Further, it is advisable to develop correlation between CBR with resilient modulus (M_R) for different types of soil.
5. It would be of interest to investigate the effect of compaction and moisture content on the value of CBR under varying density and moisture conditions for coarse grained materials.

References

- [1] - Yang, H., *Pavement Design and Analysis*, Pearson Education Inc., New Saddle River, NJ, 2004.
 - [2] - Ethiopian Road Authority, *Pavement Design Manual Volume 1, chapter 3 Subgrade*, Brehanena Selam Printing Enterprise, Addis Ababa, 2002.
 - [3] - American Society for Testing and Materials, Designation: D 4429-93, *In-situ CBR Testing*, Annual Book of ASTM Standards, Volume 04.08, West Conshohocken, Pennsylvania, 2000.
 - [4] - Peter, M. Semen, U.S. Army Engineer Research and Development Center, *A Generalized Approach to Soil Strength Prediction with Machine Learning Methods*, ERDC/CRREL Technical Report 06-15, Engineer Research and Development Center, Hanover, NH, USA, 2006.
 - [5] - 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.
 - [6] - Martin R., *Highway Engineering*, Blackwell Publishing Ltd Editorial Offices, Ireland, 2003.
 - [7] - Arora, K.R., *Soil Mechanics and Foundation Engineering*, Re-print Standard Publishers Distributer, Nai Sarak, Delhi, 2004.
 - [8] - Fredrics, M., *Standard Hand Book for Civil Engineers*, McGraw-Hill Book Company, New York, 1983.
 - [9] - Mittal, S. and Shukla, J.P., *Soil Testing for Engineers*, Romesh Chander Khanna Publishers Delhi (India), 2000.
 - [11] - American Society for Testing and Materials, D 2487–00, *Standard Practice for classification of Soils for Engineering Purposes (Unified Soil Classification System)*, Annual Book of ASTM Standards, Volume 04.08, West Conshohocken, Pennsylvania, 2000.
 - [12] - 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/>.
-

- [13] - 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.
- [14] - Carter, M. and Bentley, S.P., *correlation of soil properties*, Pentech Press, London, 1991.
- [15] - Alemayehu Teferra and Mesfin Leikun, *Soil Mechanics*, Faculty of Technology Addis Ababa University, 1999.
- [16] - Source of Map: City Government of Addis Ababa Works and Urban Development Bureau.
- [17] - Douglas, C.M. and George, C.R., *Applied Statistics and Probability for Engineers*, Third Edition John Wiley & Sons Inc., USA, 2003.

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	.677(a)	.458	.445	1.55082

a. Predictors: (Constant), LL

b. Dependent Variable: CBR

Coefficients (a)

Model 1		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	16.270	1.793		9.075	.000
	LL	-.179	.031	-.677	-5.819	.000

a. Dependent Variable: CBR

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

Model Summary (b)

Model 2	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	.059(a)	.003	-.021	2.10368

a. Predictors: (Constant), PL

b. Dependent Variable: CBR

Coefficients (a)

Model 2		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
2	(Constant)	6.737	2.193		3.072	.004
	PL	-.025	.067	-.059	-.371	.712

a. Dependent Variable: CBR

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

Model Summary (b)

Model 3	R	R Square	Adjusted R Square	Std. Error of the Estimate
3	.655(a)	.429	.414	1.59274

a. Predictors: (Constant), PI

b. Dependent Variable: CBR

Coefficients (a)

Model 3		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
3	(Constant)	10.413	.854		12.191	.000
	PI	-.177	.032	-.655	-5.479	.000

a. Dependent Variable: CBR

Model 4: Correlation Between CBR and Percent Passing Sieve No. 200 (P₂₀₀)

Model Summary (b)

Model 4	R	R Square	Adjusted R Square	Std. Error of the Estimate
4	.202(a)	.041	.017	2.06395

a. Predictors: (Constant), P₂₀₀

b. Dependent Variable: CBR

Coefficients (a)

Model 4		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
4	(Constant)	-1.366	5.608		-.244	.809
	P ₂₀₀	0.89	0.68	.202	1.303	.200

a. Dependent Variable: CBR

Model 5: Correlation Between CBR and Maximum Dry Density (MDD)

Model Summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
5	.620(a)	.384	.369	1.65341

a. Predictors: (Constant), MDD

b. Dependent Variable: CBR

Coefficients (a)

Model	5	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
5	(Constant)	-35.966	8.387		-4.288	.000
	MDD	27.072	5.417	.620	4.998	.000

a. Dependent Variable: CBR

Model 6: Correlation Between CBR and Optimum Moisture Content (OMC)

Model Summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
6	.245(a)	.060	.036	2.04315

a. Predictors: (Constant), OMC

b. Dependent Variable: CBR

Coefficients (a)

Model	6	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
6	(Constant)	9.499	2.256		4.211	.000
	OMC	-.150	.094	-.245	-1.597	.118

a. Dependent Variable: CBR

Appendix A-2: Multiple Linear Regression Analysis

Model A: Correlation Between CBR with PL and PI

Model Summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
A	.703(a)	.494	.468	1.51860

a. Predictors: (Constant), PI, PL

b. Dependent Variable: CBR

Coefficients (a)

Model A		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	14.580	2.033		7.170	.000
	PI	-.197	.032	-.730	-6.145	.000
	PL	-.112	.050	-.266	-2.236	.031

a. Dependent Variable: CBR

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

Model Summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
B	.730(a)	.533	.510	1.45770

a. Predictors: (Constant), $(P_{200})^5$, PI

b. Dependent Variable: CBR

Coefficients (a)

Model B		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	8.302	1.058		7.844	.000
	PI	-.190	.030	-.705	-6.367	.000
	$(P_{200})^5$	6.33E-010	.000	.327	2.959	.005

a. Dependent Variable: CBR

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

Model Summary (b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
C	.793(a)	.629	.599	1.31746

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

b. Dependent Variable: CBR

Coefficients (a)

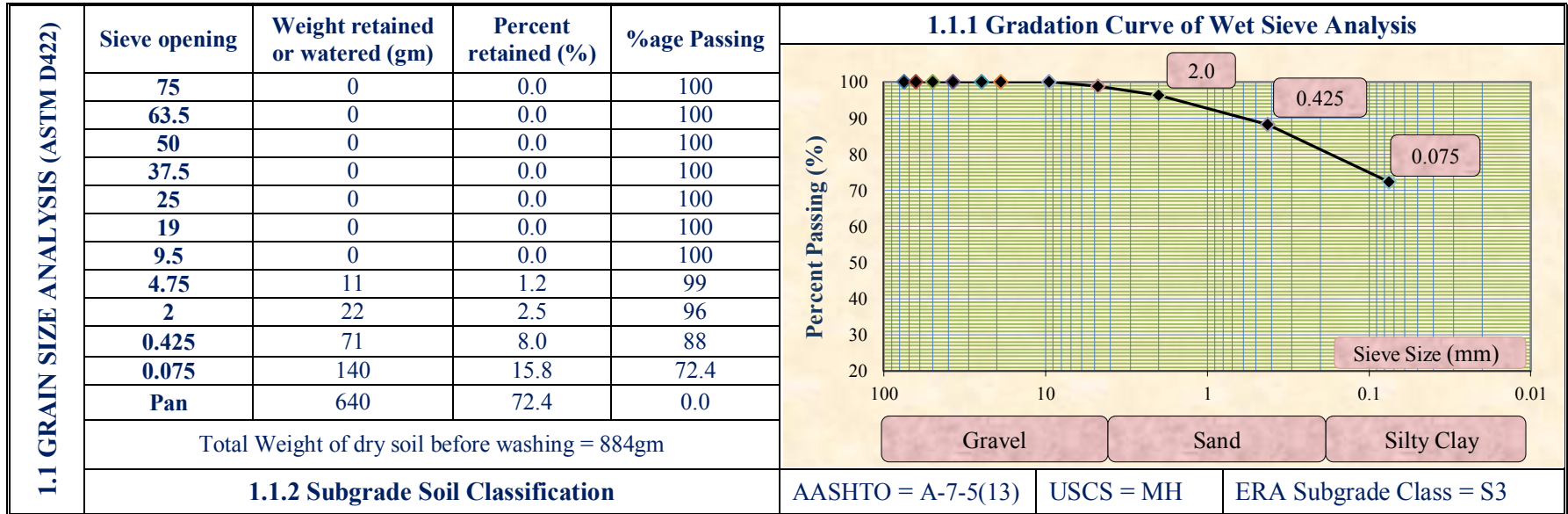
Model C		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
C	(Constant)	-21.734	9.927	-.532	-2.189	.035
	LL	-.141	.032	.325	-4.429	.000
	PL	.137	.047	.464	2.936	.006
	MDD	20.244	5.446		3.717	.001

a. Dependent Variable: CBR

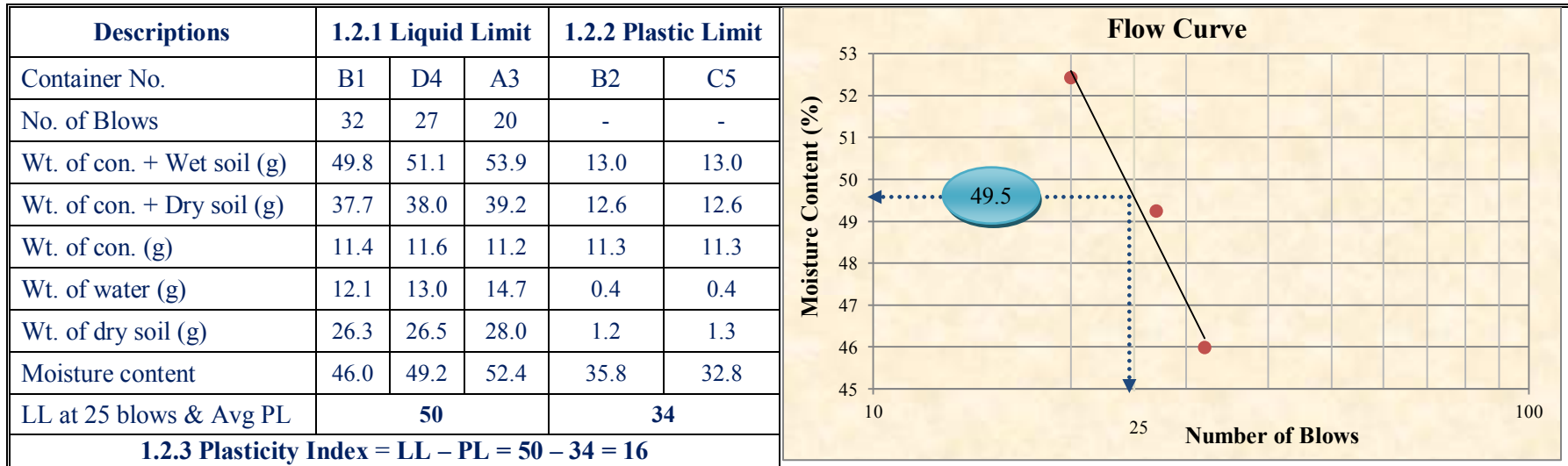
APPENDIX B: Details of the Laboratory Test Results

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 1 /ML-1/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 1.2m, **Soil Description:** Light brown clay soil



1.2 ATTERBERG LIMIT TEST (ASTM D 4318)



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

1.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	F2	B16	C2	B5	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	182.73	225.3	222.27	214.08	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.55 g/cm³ and OMC = 23.3 %</p>				
Dry Soil + Con. (g)	159.87	190.59	185.94	177.43					
Mass of Con. (g)	42.81	41.46	46.97	44.31					
Mass of Moisture (g)	22.86	34.71	36.33	36.65					
Dry Soil (g)	117.06	149.13	138.97	133.12					
Moisture cont. (g/cm ³)	19.53	23.27	26.14	27.53					
1.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9164	9490	9468	9383					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3731	4057	4035	3950					
Wet Density (g/cm ³)	1.76	1.91	1.90	1.86					
Dry Density (g/cm ³)	1.47	1.55	1.51	1.46					

1.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

1.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00	<p>Legend: 10 Blows (dashed blue), 30 Blows (solid red), 65 Blows (solid green)</p>		
0.64	5	0.26	6	0.31	7	0.36			
1.27	8	0.42	10	0.52	12	0.62			
1.96	11	0.57	14	0.73	17	0.90			
2.54	13	0.65	17	0.86	21	1.07			
3.18	14	0.73	19	0.99	24	1.25			
3.81	15	0.78	21	1.06	26	1.35			
4.45	16	0.83	22	1.14	28	1.45			
5.08	17	0.88	23	1.19	30	1.54			
7.62	19	0.99	27	1.40	34	1.74			

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

1.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	DD (g/cm ³)	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	1.43	0.67	0.88	13.2	20.0	5.06	4.41	5.06
30	1.53	0.93	1.19	13.2	20.0	7.00	5.97	7.00
65	1.59	1.09	1.56	13.2	20.0	8.17	7.78	8.17
Before soaking the three samples were remolded with OMC = 23.3%.								
No. of Blows	10		30		65			
DD (g/cm ³)	1.43		1.53		1.59			
CBR (%)	5.06		7.00		8.17			

Density - CBR Curve

From the Density-CBR Curve at 95% MDD (1.47 g/cm³): **CBR = 6.0**

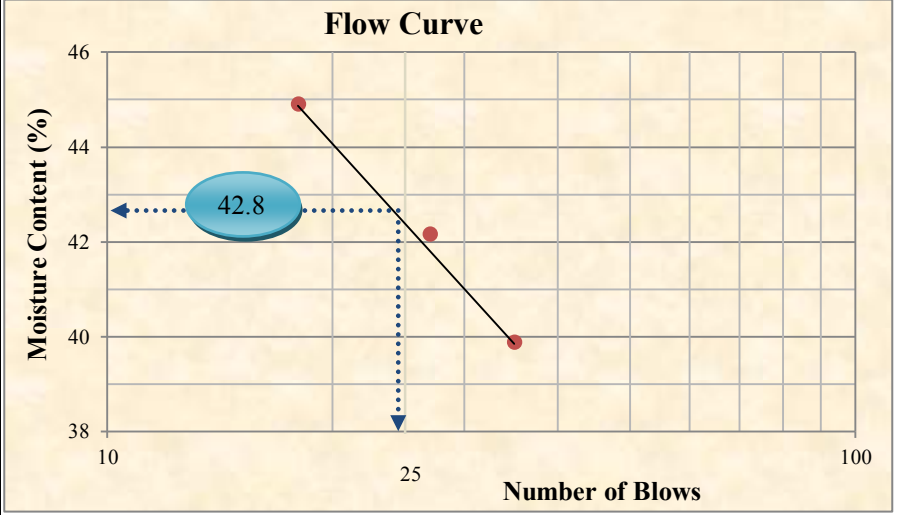
Sample No.: 2 /ML-2/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 0.8m, **Soil Description:** Red clay soil

2.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing
	75	0	0.0	100.0
	63.5	0	0.0	100.0
	50	0	0.0	100.0
	37.5	0	0.0	100.0
	25	0	0.0	100.0
	19	0	0.0	100.0
	9.5	0	0.0	100.0
	4.75	4	0.5	99.5
	2	12	1.4	98.1
	0.425	34	3.9	94.2
	0.075	70	8.1	86.1
	Pan	744	86.1	-
Total Weight of dry soil before washing = 864gm				
2.1.2 Subgrade Soil Classification				
AASHTO = A-7-6(14)		USCS = ML		ERA Subgrade Class = S4

2.1.1 Gradation Curve of Wet Sieve Analysis

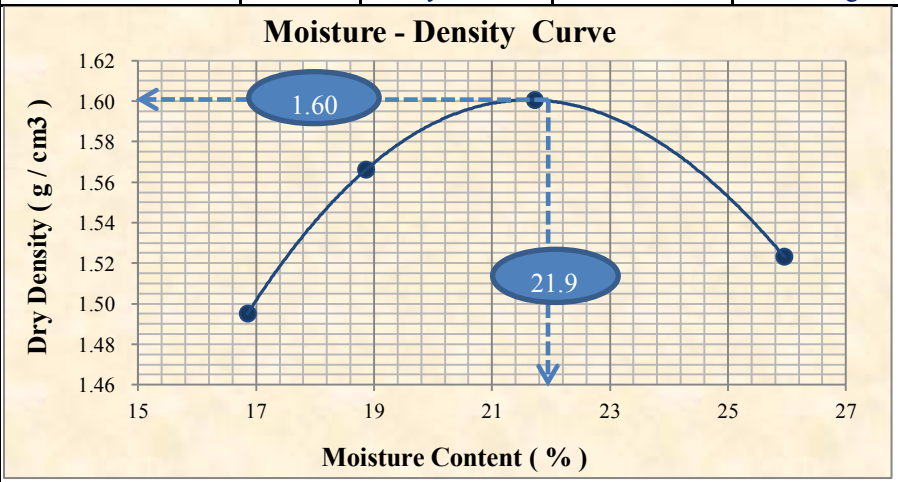
2.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	2.2.1 Liquid Limit			2.2.2 Plastic Limit	
	A1	D1	D5	A2	B2
Container No.	A1	D1	D5	A2	B2
No. of Blows	35	27	18	-	-
Wt. of con. + Wet soil (g)	40.8	45.2	45.9	13.0	13.0
Wt. of con. + Dry soil (g)	32.4	35.2	35.2	12.7	12.7
Wt. of con. (g)	11.4	11.4	11.5	11.3	11.3
Wt. of water (g)	8.4	10.0	10.7	0.4	0.4
Wt. of dry soil (g)	21.0	23.7	23.7	1.3	1.3
Moisture content	39.9	42.2	44.9	29.8	28.0
LL at 25 blows & Avg. PL	43			29	
2.2.3 Plasticity Index = LL – PL = 43 – 29 = 14					



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

2.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B13	B12	B9	B11	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	218.65	219.14	219.2	219.65					
Dry Soil + Con. (g)	193.74	191.06	187.46	182.97					
Mass of Con. (g)	45.96	42.19	41.35	41.64					
Mass of Moisture (g)	24.91	28.08	31.74	36.68					
Dry Soil (g)	147.78	148.87	146.11	141.33					
Moisture cont. (g/cm ³)	16.86	18.86	21.72	25.95					
2.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9144	9387	9571	9508					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3711	3954	4138	4075					
Wet Density (g/cm ³)	1.75	1.86	1.95	1.92					
Dry Density (g/cm ³)	1.50	1.57	1.60	1.52					



From the compaction curve: **MDD = 1.60 g/cm³** and **OMC = 21.9 %**

2.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

2.4.1 Penetration Data (After 4-day soaking)						Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	8	0.42	13	0.67	17	0.88		
1.27	13	0.67	18	0.93	22	1.14		
1.96	18	0.93	23	1.19	27	1.40		
2.54	22	1.14	27	1.42	32	1.66		
3.18	25	1.30	31	1.61	36	1.87		
3.81	28	1.45	34	1.76	39	2.02		
4.45	31	1.61	37	1.92	42	2.18		
5.08	32	1.65	40	2.08	44	2.28		
7.62	34	1.76	43	2.23	47	2.44		

2.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	DD (g/cm ³)	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	1.40	1.14	1.66	13.2	20.0	8.6	8.30	8.6
30	1.56	1.45	2.08	13.2	20.0	10.7	10.38	10.9
65	1.59	1.66	2.28	13.2	20.0	12.4	11.41	12.4

Before soaking the three samples were remolded with OMC = 21.9%.

No. of Blows	10	30	65
DD (g/cm ³)	1.40	1.56	1.59
CBR (%)	8.56	10.65	12.44

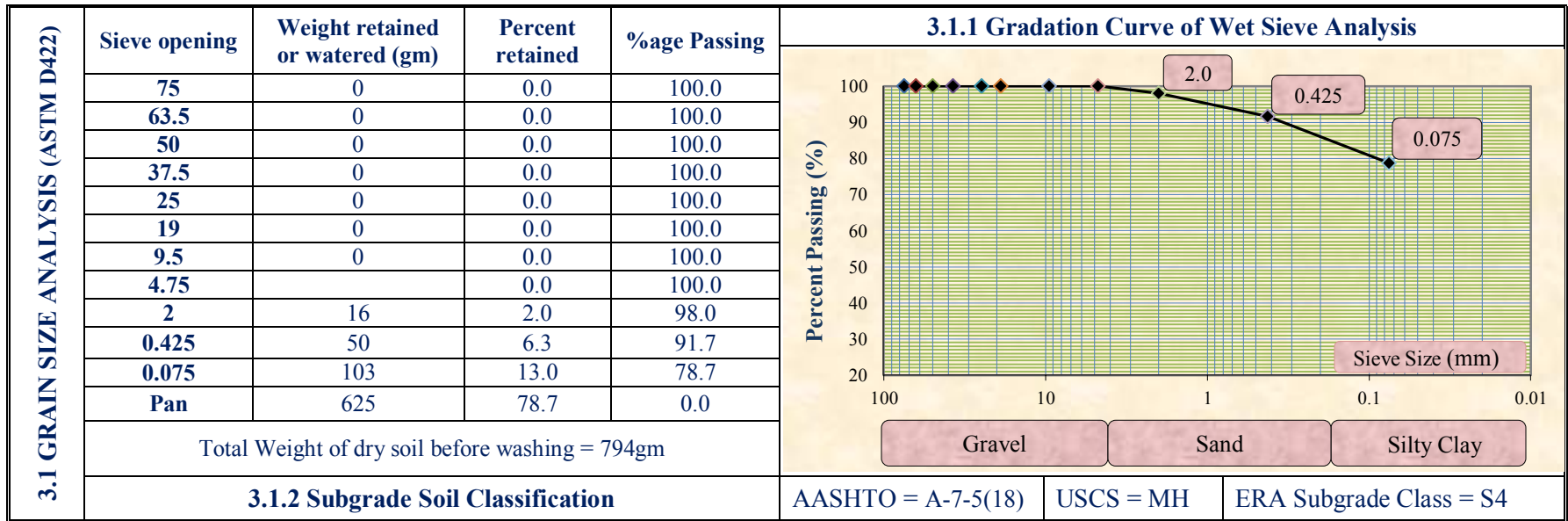
Load - Penetration Relationship

Density - CBR Curve

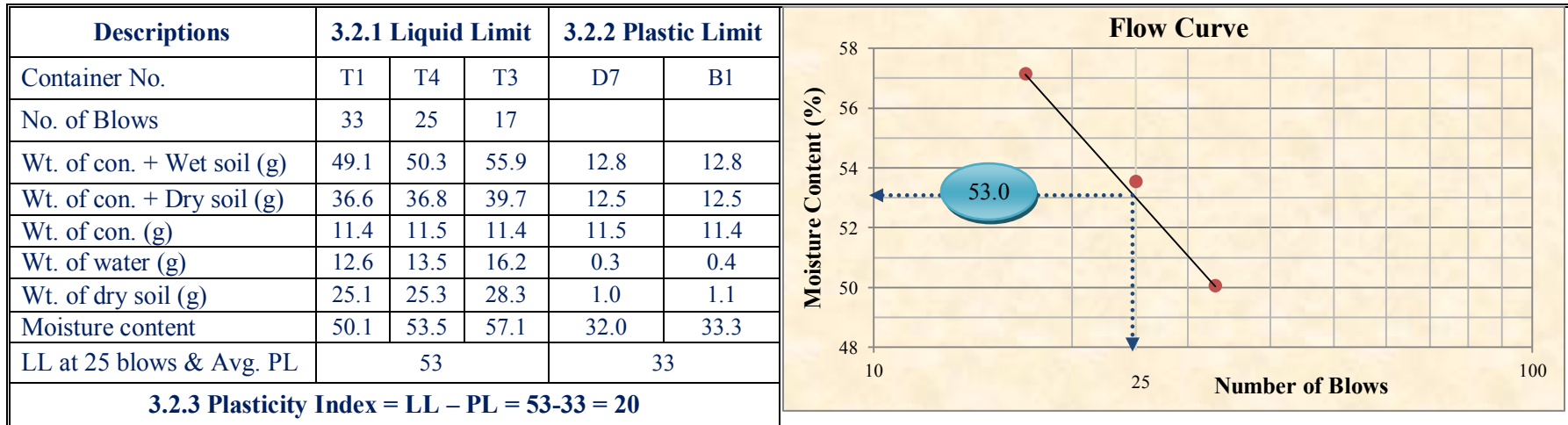
From the Density-CBR Curve at 95% MDD (1.52 g/cm³): **CBR = 10**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 3 /ML-3/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 0.6m, **Soil Description:** Red clay soil



3.2 ATTERBERG LIMIT TEST (ASTM D 4318)



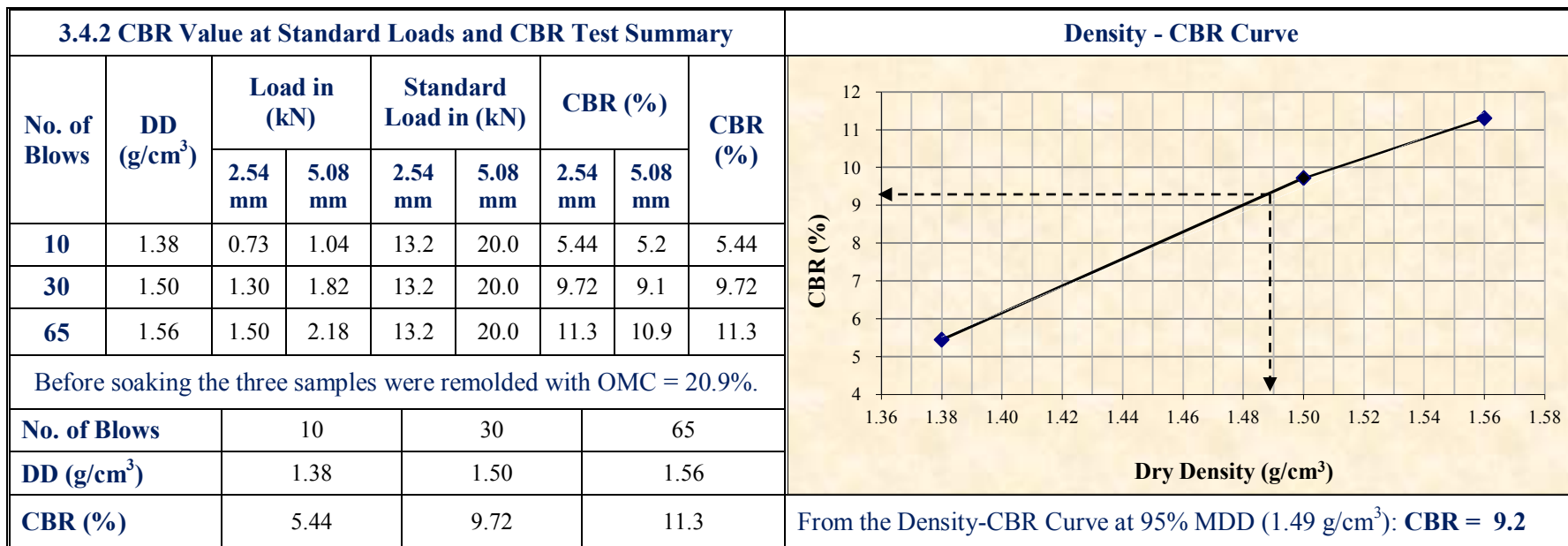
3.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

3.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B16	C2	B4	B6	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	210.7	210.56	210.74	210.87	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.57 g/cm³ and OMC = 20.90 %</p>				
Dry Soil + Con. (g)	185.45	182.52	178.04	174.11					
Mass of Con. (g)	41.47	46.95	44.49	45.03					
Mass of Moisture (g)	25.25	28.04	32.7	36.76					
Dry Soil (g)	143.98	135.57	133.55	129.08					
Moisture cont. (g/cm ³)	17.54	20.68	24.49	28.48					
3.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9074	9425	9462	9355					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3641	3992	4029	3922					
Wet Density (g/cm ³)	1.71	1.88	1.90	1.85					
Dry Density (g/cm ³)	1.46	1.56	1.52	1.44					

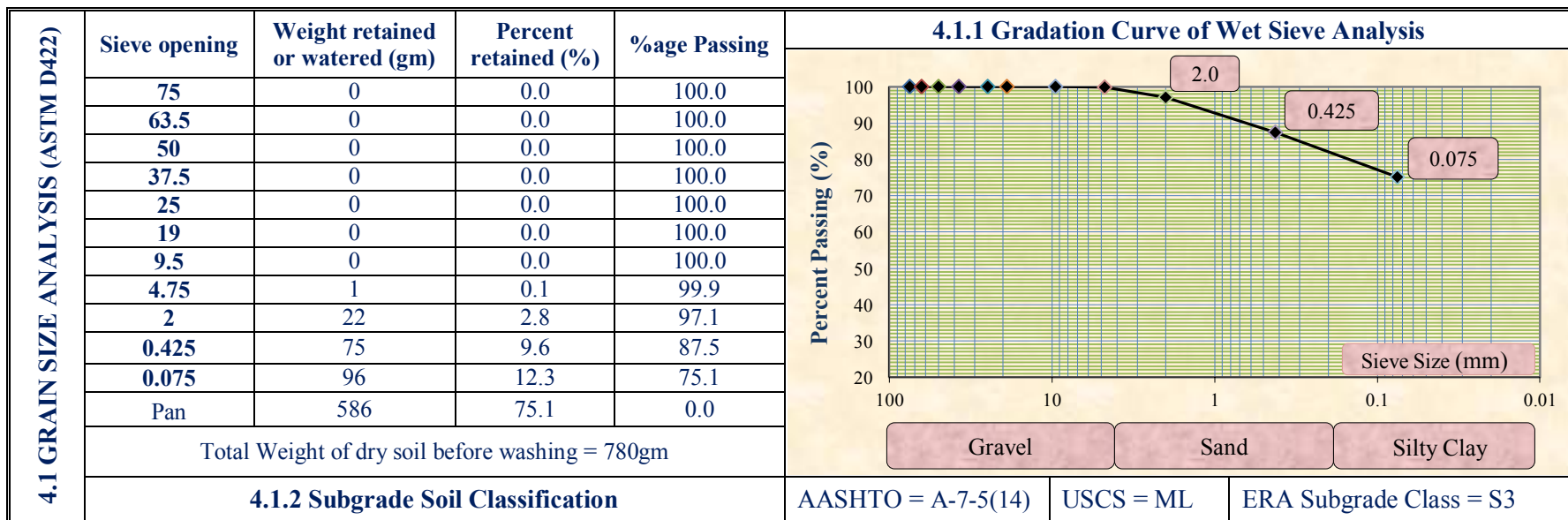
3.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

3.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	<p align="center">Load - Penetration Relationship</p>
0.64	6	0.31	8	0.42	12	0.62	
1.27	9	0.47	16	0.83	20	1.04	
1.96	12	0.62	21	1.11	25	1.30	
2.54	14	0.73	25	1.30	29	1.50	
3.18	16	0.83	27	1.40	33	1.71	
3.81	18	0.93	30	1.54	35	1.82	
4.45	19	0.99	32	1.66	39	2.02	
5.08	20	1.04	35	1.82	42	2.18	
7.62	22	1.14	40	2.08	47	2.44	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

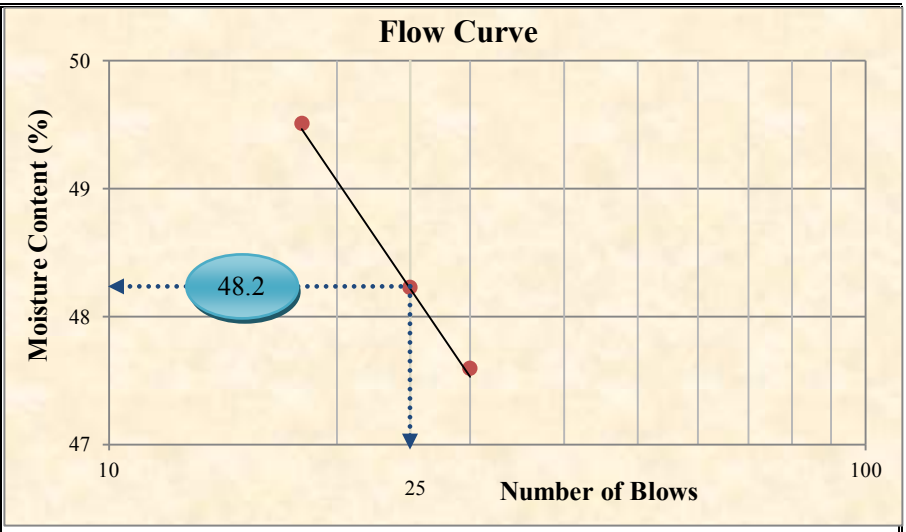


Sample No.: 4 /ML-4/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 1.2m, **Soil Description:** Dark Brown silty clay soil



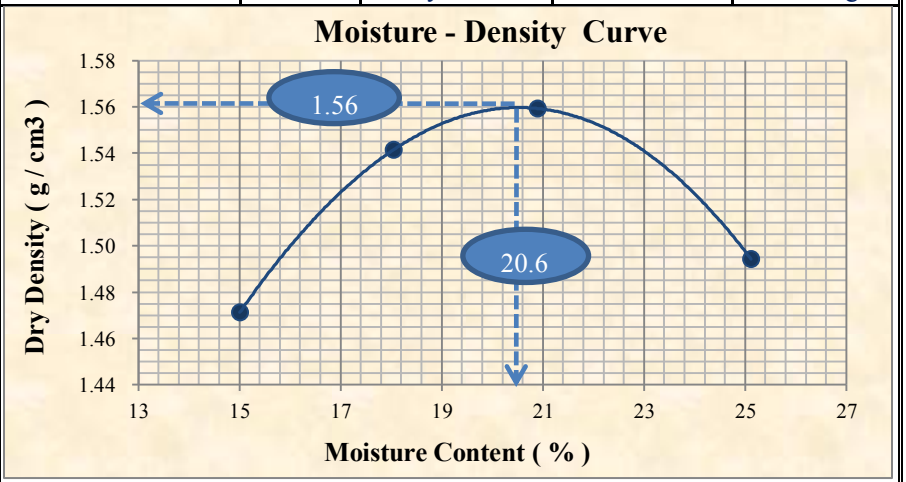
4.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	4.2.1 Liquid Limit			4.2.2 Plastic Limit	
	D4	A5	A6	D7	T1
Container No.	D4	A5	A6	D7	T1
No. of Blows	30	25	18		
Wt. of con. + Wet soil (g)	53.0	53.4	54.2	12.8	12.8
Wt. of con. + Dry soil (g)	39.6	39.8	40.0	12.5	12.5
Wt. of con. (g)	11.6	11.6	11.5	11.4	11.4
Wt. of water (g)	13.4	13.6	14.1	0.3	0.3
Wt. of dry soil (g)	28.1	28.2	28.5	1.1	1.1
Moisture content	47.6	48.2	49.5	30.3	30.3
LL at 25 blows & Avg. PL	48			30	
4.2.3 Plasticity Index = LL – PL = 48 – 30 = 18					



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

4.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C1	M1	B7	B19	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	216.48	216.3	216.79	216.62					
Dry Soil + Con. (g)	194.1	190.12	186.75	182.5					
Mass of Con. (g)	44.99	45.06	42.98	46.64					
Mass of Moisture (g)	22.38	26.18	30.04	34.12					
Dry Soil (g)	149.11	145.06	143.77	135.86					
Moisture cont. (g/cm ³)	15.01	18.05	20.89	25.11					
4.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9027	9298	9437	9404					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3594	3865	4004	3971					
Wet Density (g/cm ³)	1.69	1.82	1.89	1.87					
Dry Density (g/cm ³)	1.47	1.54	1.56	1.49					



From the compaction curve: **MDD = 1.56 g/cm³** and **OMC = 20.6 %**

4.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

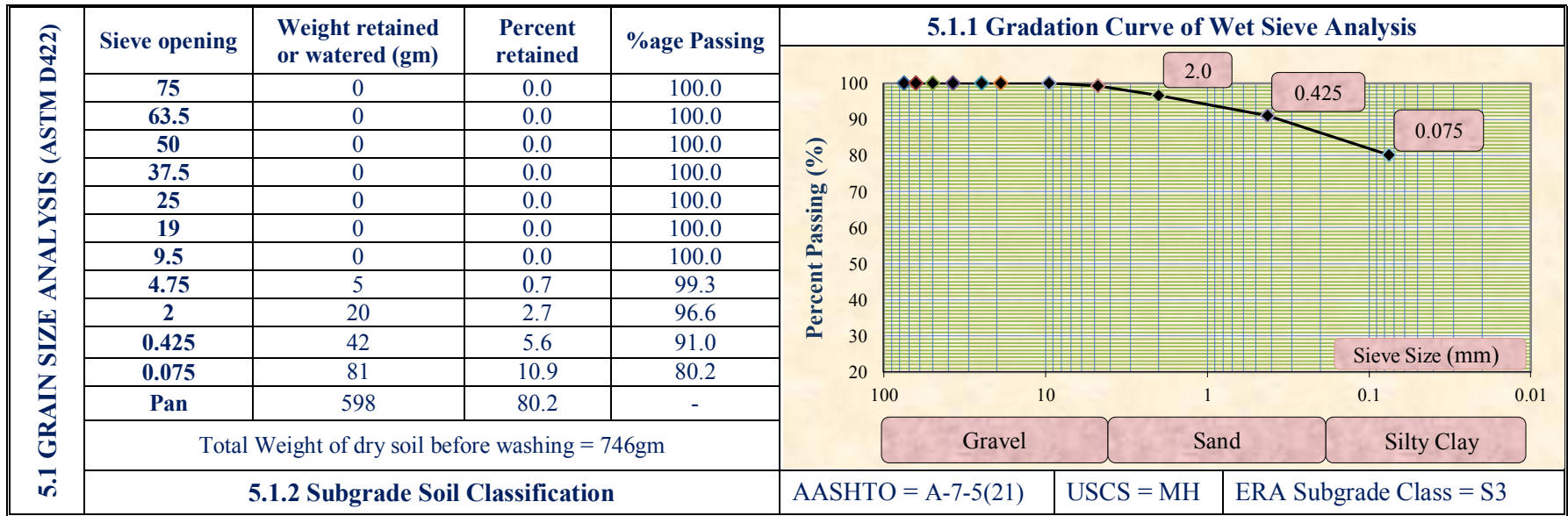
4.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0	0	0.00			
0.64	5	0.26	8	0.42	11	0.57			
1.27	8	0.42	11	0.57	14	0.73			
1.96	10	0.52	14	0.73	17	0.88			
2.54	13	0.67	17	0.88	20	1.04			
3.18	15	0.78	19	0.99	22	1.14			
3.81	16	0.83	21	1.09	24	1.25			
4.45	17	0.88	22	1.14	25	1.30			
5.08	18	0.93	23	1.19	26	1.35			
7.62	20	1.04	25	1.30	28	1.45			

4.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	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	1.41	0.67	0.93	13.2	20.0	5.06	4.67	5.06		
30	1.52	0.88	1.19	13.2	20.0	6.61	5.97	6.61		
65	1.60	1.04	1.35	13.2	20.0	7.78	6.74	7.78		
Before soaking the three samples were remolded with OMC = 20.6%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.41		1.52		1.60				
CBR (%)		5.06		6.61		7.78				

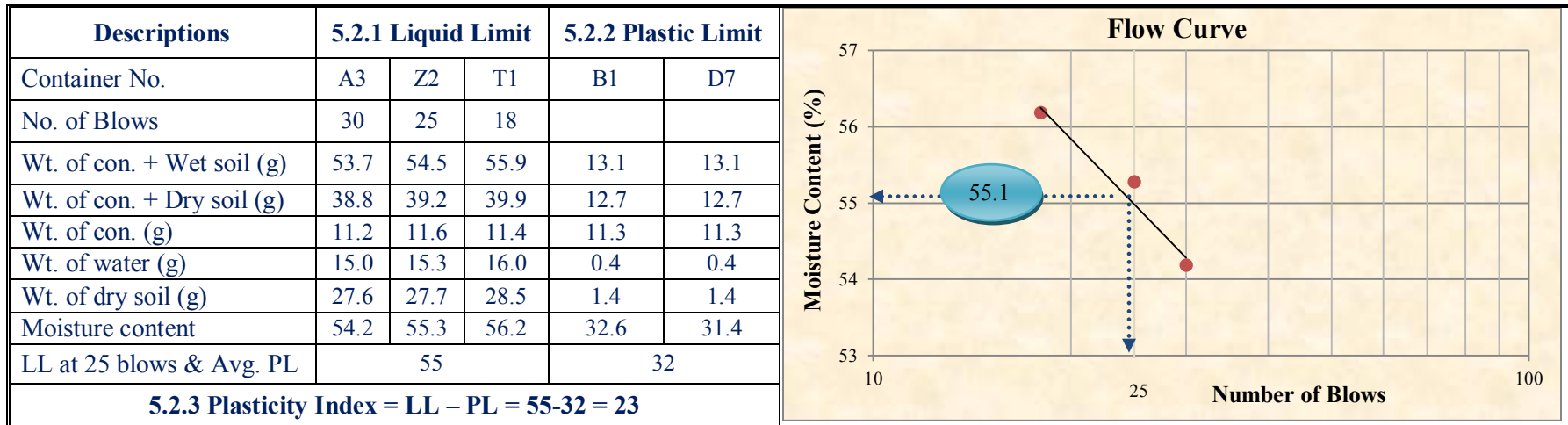
From the Density-CBR Curve at 95% MDD (1.49g/cm³): **CBR = 6.2**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 5 /ML-5/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 1.0m, **Soil Description:** Dark Brown clay soil



5.2 ATTERBERG LIMIT TEST (ASTM D 4318)

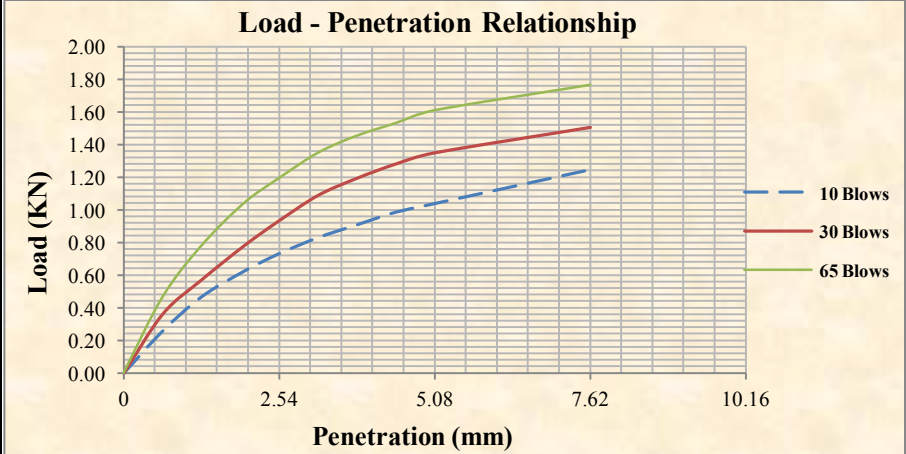


5.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

5.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B5	C3	B14	B8	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	210.39	211.7	210.5	210.83	<p>Moisture - Density Curve</p> <p>Dry Density (g/cm³)</p> <p>Moisture Content (%)</p> <p>From the compaction curve: MDD = 1.54 g/cm³ and OMC = 20.04 %</p>				
Dry Soil +Con. (g)	187.95	184.58	180.67	177.65					
Mass of Con. (g)	44.3	41.49	44.16	40.96					
Mass of Moisture (g)	22.44	27.12	29.83	33.18					
Dry Soil (g)	143.65	143.09	136.51	136.69					
Moisture cont. (g/cm ³)	15.62	18.95	21.85	24.27					
5.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9000	9339	9420	9410					
Mold (gm)	5447	5447	5447	5447					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3553	3892	3973	3963					
Wet Density (g/cm ³)	1.67	1.83	1.87	1.87					
Dry Density (g/cm ³)	1.45	1.54	1.54	1.50					

5.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

5.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0	0.00	0	0.00	0	0.00
0.64	5	0.26	7	0.36	9	0.47
1.27	9	0.47	11	0.57	15	0.78
1.96	12	0.62	15	0.78	20	1.04
2.54	14	0.73	18	0.93	23	1.19
3.18	16	0.83	21	1.09	26	1.35
3.81	18	0.91	23	1.19	28	1.45
4.45	19	0.99	25	1.28	30	1.53
5.08	20	1.04	26	1.35	31	1.61
7.62	24	1.25	29	1.50	34	1.76



CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

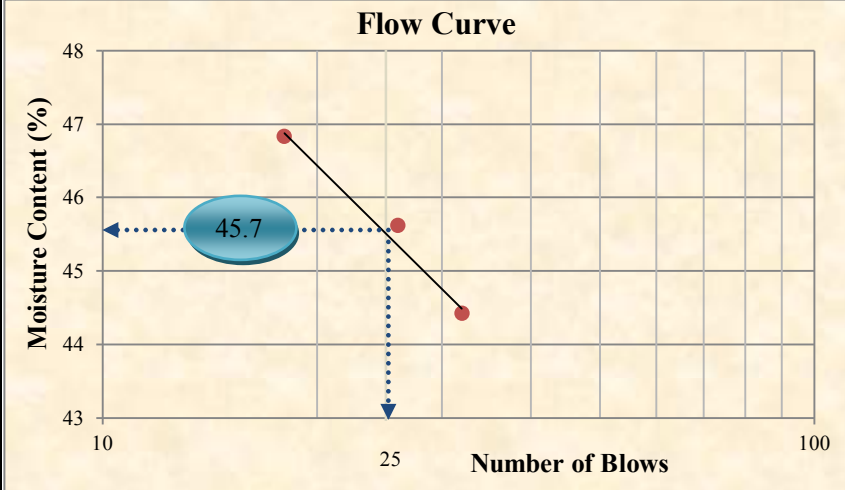
5.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.43	0.76	1.04	13.2	20.0	5.72	5.19	5.72	From the Density-CBR Curve at 95% MDD (1.46 g/cm ³): CBR = 6.4
30	1.55	1.04	1.35	13.2	20.0	7.80	6.74	7.80	
65	1.60	1.18	1.61	13.2	20.0	8.86	8.04	8.86	
Before soaking the three samples were remolded with OMC = 20.40%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.43		1.55		1.60			
CBR (%)		5.44		7		8.56			

Sample No.: 6 /ML-6/, Location of Sample: Megenanga-Lamberet, Depth of Sampling: 0.6m, Soil Description: Light brown clay soil

6.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	6.1.1 Gradation Curve of Wet Sieve Analysis
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	1	0.1	99.9	
	2	25	2.9	97.0	
	0.425	78	9.0	88.0	
	0.075	139	16.0	72.1	
Pan	627	72.1	-		
Total Weight of dry soil before washing = 870 gm					AASHTO = A-7-5(10) USCS = ML ERA Subgrade Class = S3
6.1.2 Subgrade Soil Classification					

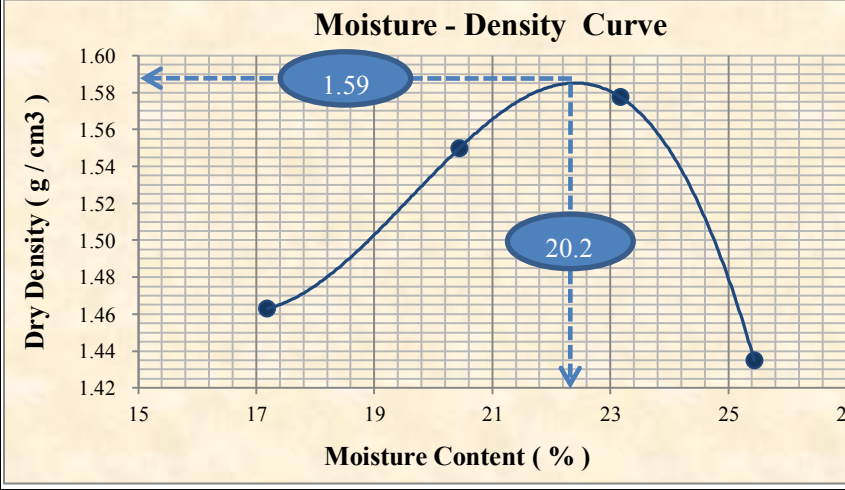
6.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	6.2.1 Liquid Limit			6.2.2 Plastic Limit	
	C2	T3	T5	D1	T2
Container No.	C2	T3	T5	D1	T2
No. of Blows	32	26	18	-	-
Wt. of con. + Wet soil (g)	52.8	53.6	54.4	13.0	13.0
Wt. of con. + Dry soil (g)	40.1	40.4	40.7	12.6	12.6
Wt. of con. (g)	11.5	11.4	11.4	11.5	11.4
Wt. of water (g)	12.7	13.2	13.7	0.4	0.4
Wt. of dry soil (g)	28.6	29.0	29.3	1.2	1.2
Moisture content	44.4	45.6	46.8	33.9	33.6
LL at 25 blows & Avg. PL	46			34	
6.2.3 Plasticity Index = 46 – 34 = 12					



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

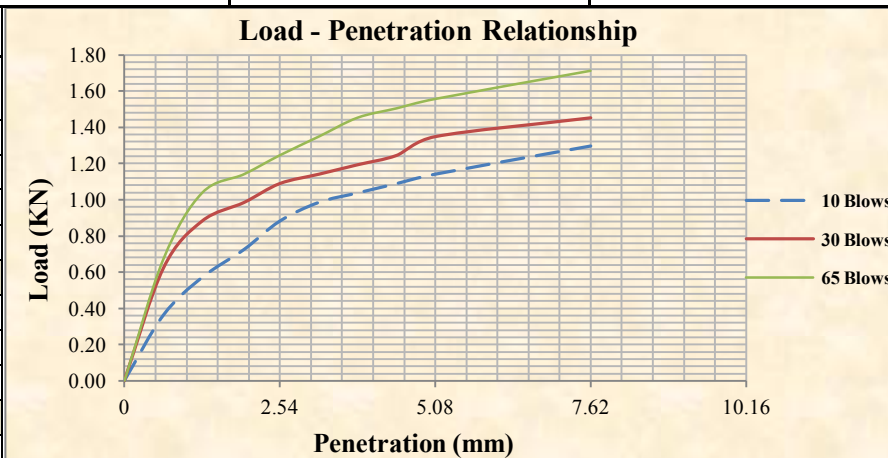
6.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C1	B8	B17	B9	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	239	237.78	227.57	227.62					
Dry Soil + Con. (g)	212.38	210.74	195.7	190.82					
Mass of Con. (g)	44.16	40.97	44.51	41.34					
Mass of Moisture (g)	26.62	27.04	31.87	36.8					
Dry Soil (g)	168.22	169.77	151.19	149.48					
Moisture cont. (g/cm ³)	15.82	15.93	21.08	24.62					
6.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9027	9244	9485	9226					
Mold (gm)	5428	5428	5428	5428					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3599	3816	4057	3798					
Wet Density (g/cm ³)	1.69	1.80	1.91	1.79					
Dry Density (g/cm ³)	1.46	1.55	1.58	1.43					



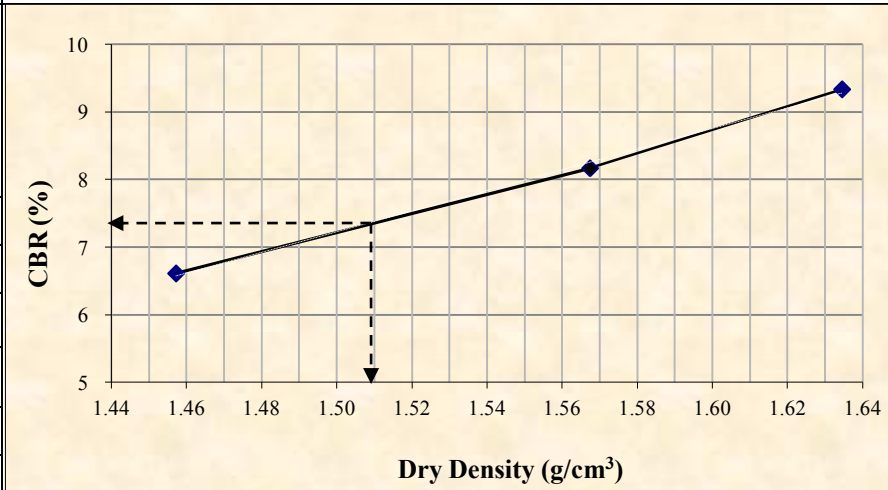
From the compaction curve: **MDD = 1.59 g/cm³** and **OMC = 20.2 %**

6.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

6.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	7	0.36	12	0.62	13	0.67
1.27	11	0.57	17	0.88	20	1.04
1.96	14	0.73	19	0.99	22	1.14
2.54	17	0.88	21	1.09	24	1.25
3.18	19	0.99	22	1.14	26	1.35
3.81	20	1.04	23	1.19	28	1.45
4.45	21	1.09	24	1.25	29	1.50
5.08	22	1.14	26	1.35	30	1.56
7.62	25	1.30	28	1.45	33	1.71



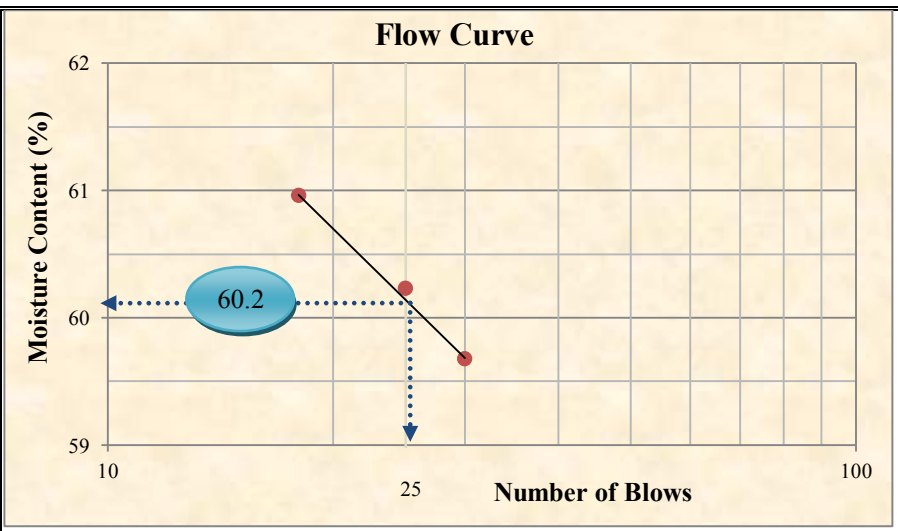
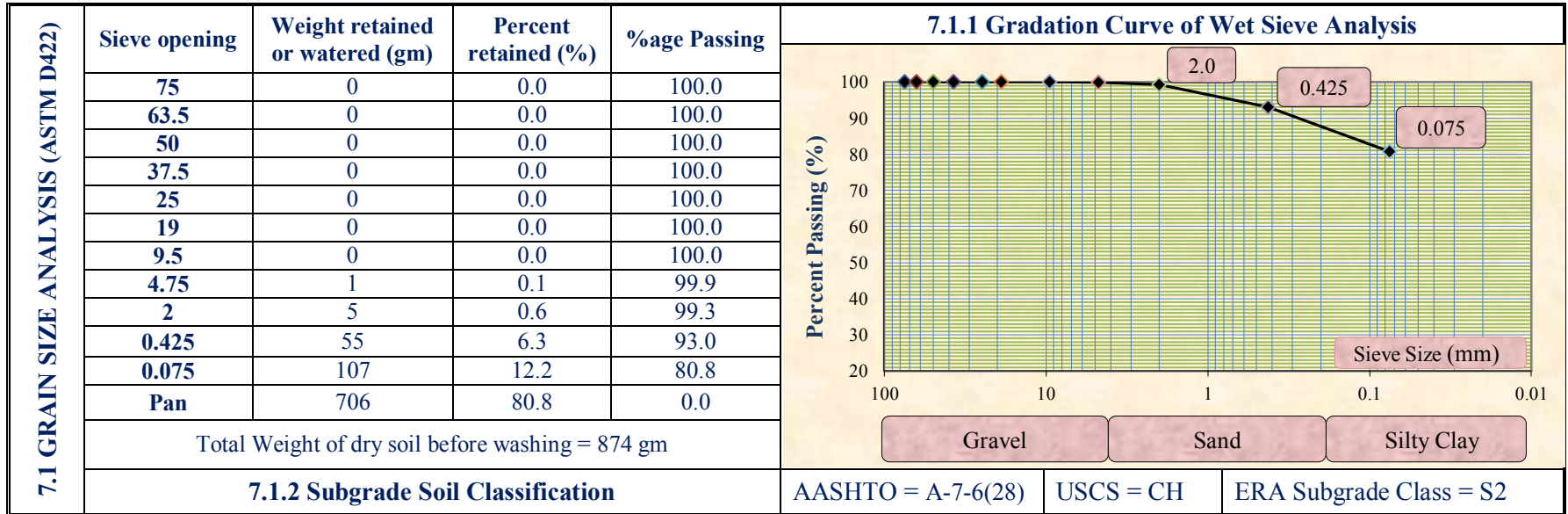
6.4.2 CBR Value at Standard Loads and CBR Test Summary								Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.46	0.88	1.14	13.2	20.0	6.61	5.71	6.61	
30	1.57	1.09	1.35	13.2	20.0	8.17	6.74	8.17	
65	1.63	1.25	1.56	13.2	20.0	9.33	7.78	9.33	
Before soaking the three samples were remolded with OMC = 20.20%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.46		1.57		1.63			
CBR (%)		6.61		8.17		9.33			



From the Density-CBR Curve at 95% MDD (1.51 g/cm³): **CBR = 7.4**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 7 /ML-7/, **Location of Sample:** Megenanga-Lamberet, **Depth of Sampling:** 1.2m - 1.5m, **Soil Description:** Dark gray clay soil



7.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

7.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C4	F1	B2	B9	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	220.18	214.48	224.94	227.62	<p>Moisture - Density Curve</p> <p>Dry Density (g/cm³)</p> <p>Moisture Content (%)</p> <p>From the compaction curve: MDD = 1.51 g/cm³ and OMC = 24.3 %</p>				
Dry Soil + Con. (g)	190.44	180.98	186.42	184.82					
Mass of Con. (g)	46.15	44.17	45.58	41.34					
Mass of Moisture (g)	29.74	33.5	38.52	42.8					
Dry Soil (g)	144.29	136.81	140.84	143.48					
Moisture cont. (g/cm ³)	20.61	24.49	27.35	29.83					
7.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9177	9421	9428	9326					
Mold (gm)	5431	5431	5431	5431					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3746	3990	3997	3895					
Wet Density (g/cm ³)	1.76	1.88	1.88	1.83					
Dry Density (g/cm ³)	1.46	1.51	1.48	1.41					

7.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

7.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p>Load - Penetration Relationship</p> <p>Load (KN)</p> <p>Penetration (mm)</p> <p>10 Blows</p> <p>30 Blows</p> <p>65 Blows</p>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0	0	0	0	0			
0.64	3	0.16	5	0.26	7	0.36			
1.27	5	0.26	7	0.36	8	0.42			
1.96	6	0.31	8	0.42	10	0.52			
2.54	7	0.36	9	0.47	11	0.57			
3.18	7	0.36	10	0.52	12	0.62			
3.81	8	0.42	10	0.52	12	0.62			
4.45	8	0.42	11	0.57	13	0.67			
5.08	9	0.47	11	0.57	14	0.73			
7.62	10	0.52	12	0.62	16	0.83			

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

7.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	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	1.31	0.36	0.47	13.2	20.0	2.72	2.33	2.72	
30	1.47	0.47	0.57	13.2	20.0	3.50	2.85	3.50	
65	1.54	0.57	0.73	13.2	20.0	4.28	3.63	4.28	
Before soaking the three samples were remolded with OMC = 24.3%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.31		1.47		1.54			
CBR (%)		2.72		3.5		4.28			

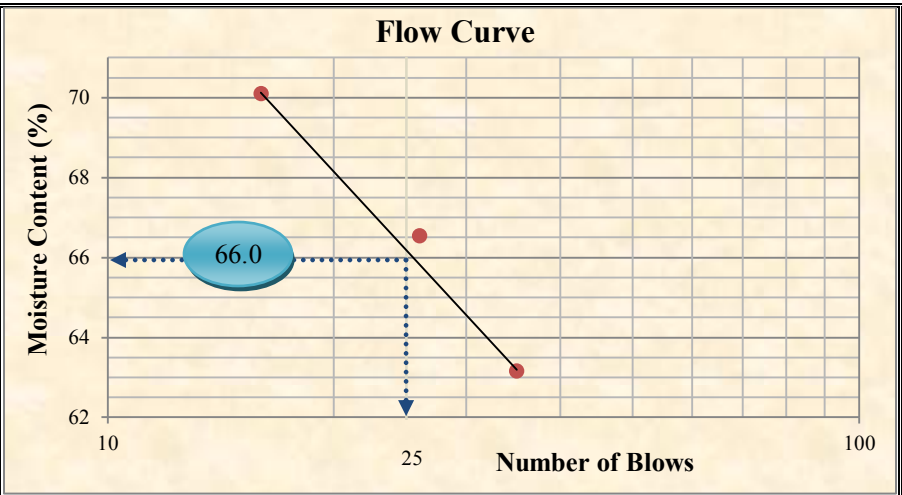
From the Density-CBR Curve at 95% MDD (1.42 g/cm³): **CBR = 3.3**

Sample No.: 8 /ML-1/, Location of Sample: Megenanga-Lamberet, Depth of Sampling: 0.5m, Soil Description: Light Brown clay soil

8.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	8.1.1 Gradation Curve of Wet Sieve Analysis 		
	75	0	0.0	100.0			
	63.5	0	0.0	100.0			
	50	0	0.0	100.0			
	37.5	0	0.0	100.0			
	25	0	0.0	100.0			
	19	0	0.0	100.0			
	9.5	0	0.0	100.0			
	4.75	0	0.0	100.0			
	2	12	0.9	99.1			
	0.425	39	2.9	96.2			
	0.075	107	8.0	88.2			
Pan					1181	88.2	0.0
Total Weight of dry soil before washing = 1339 gm							
8.1.2 Subgrade Soil Classification					AASHTO = A-7-5(33)	USCS = MH	ERA Subgrade Class = S3

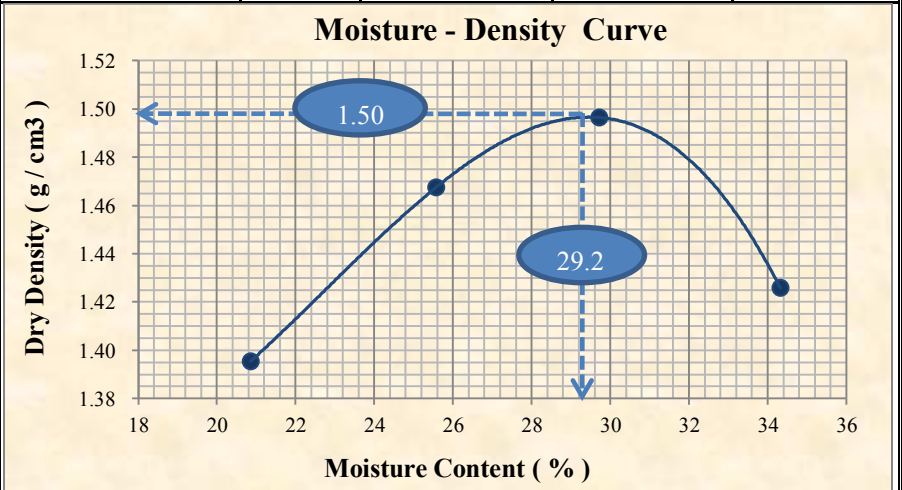
8.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	8.2.1 Liquid Limit			8.1.2 Plastic Limit	
	C14	C9	C8	C7	C1
Container No.	C14	C9	C8	C7	C1
No. of Blows	35	26	16	0	0
Wt. of con. + Wet soil (g)	47.3	46.7	47.0	24.91	23.98
Wt. of con. + Dry soil (g)	35.4	34.7	34.4	22.76	22.04
Wt. of con. (g)	16.5	16.6	16.4	16.56	16.57
Wt. of water (g)	11.9	12.0	12.6	2.2	1.9
Wt. of dry soil (g)	18.9	18.1	18.0	6.2	5.5
Moisture content	63.2	66.5	70.1	34.7	35.5
LL at 25 blows & Avg. PL	66			35	
8.2.3 Plasticity Index = LL – PL = 66 – 35 = 31					



8.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

8.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	D5	E2	C2	A8	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	144.47	122.97	115.34	122.51					
Dry Soil + Con. (g)	123.22	102.24	93.68	96.35					
Mass of Con. (g)	21.33	21.17	20.79	20.13					
Mass of Moisture (g)	21.25	20.73	21.66	26.16					
Dry Soil (g)	101.89	81.07	72.89	76.22					
Moisture cont. (g/cm ³)	20.86	25.57	29.72	34.32					
8.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8564	8896	9105	9050					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3582	3914	4123	4068					
Wet Density (g/cm ³)	1.69	1.84	1.94	1.92					
Dry Density (g/cm ³)	1.40	1.47	1.50	1.43					



From the compaction curve: **MDD = 1.50 g/cm³** and **OMC = 29.2 %**

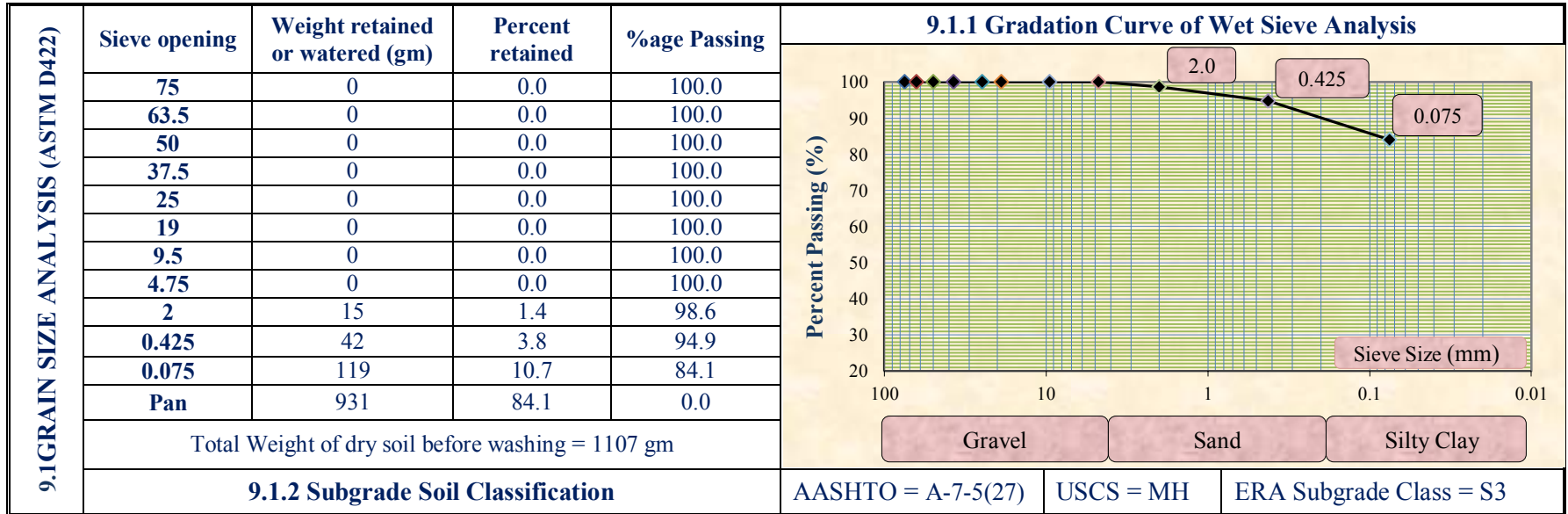
8.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

8.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	10	0.21	14	0.30	18	0.38			
1.27	16	0.34	23	0.49	29	0.62			
1.96	20	0.43	31	0.66	38	0.81			
2.54	22	0.47	36	0.77	44	0.94			
3.18	23	0.49	40	0.85	48	1.02			
3.81	24	0.51	42	0.89	51	1.09			
4.45	25	0.53	44	0.94	53	1.13			
5.08	26	0.55	45	0.96	55	1.17			
7.62	29	0.62	53	1.13	66	1.41			

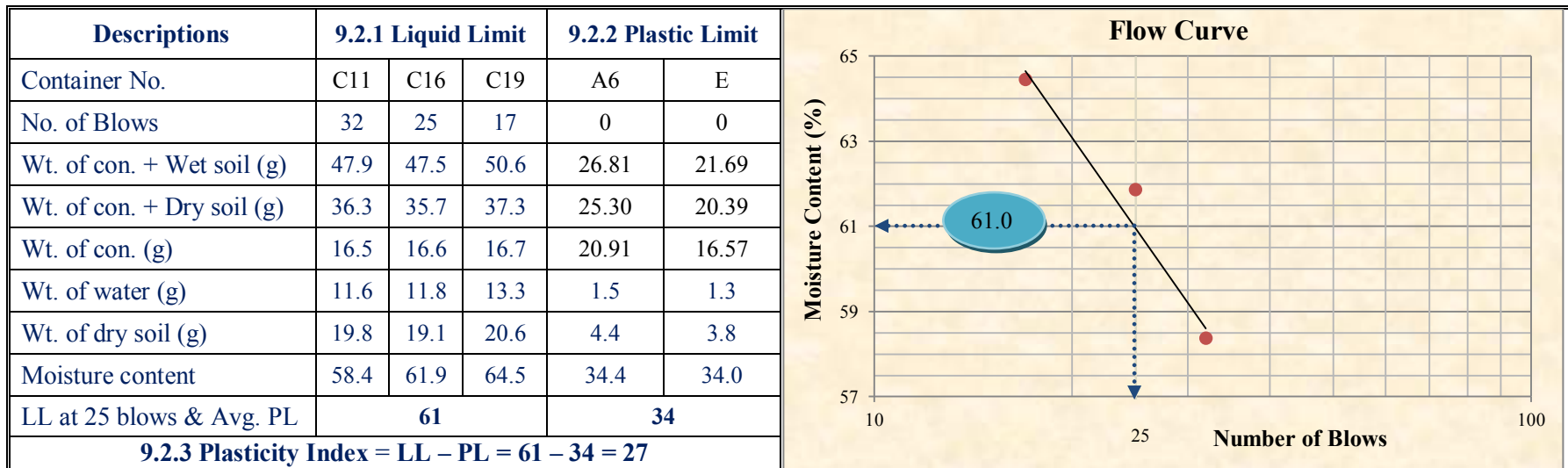
8.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)		
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.28	0.47	0.55	13.2	20.0	3.5	2.8	3.5		
30	1.41	0.77	0.96	13.2	20.0	5.7	4.8	5.7		
65	1.48	0.94	1.17	13.2	20.0	7.0	5.9	7.0		
Before soaking the three samples were remolded with OMC = 29.2%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.28		1.41		1.48				
CBR (%)		3.5		5.7		7.0				
									From the Density-CBR Curve at 95% MDD (1.43 g/cm ³): CBR = 6.1	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 9 /WY-1/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 1.5m, **Soil Description:** Light Brown clay soil



9.2 ATTERBERG LIMIT TEST (ASTM D 4318)



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

9.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C5	D3	B1	A4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	121.95	103.19	122.36	111.92	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.53 g/cm³ and OMC = 27.8%</p>				
Dry Soil + Con. (g)	104.82	87.02	99.71	90.29					
Mass of Con. (g)	20.37	20.99	19.92	22.27					
Mass of Moisture (g)	17.13	16.17	22.65	21.63					
Dry Soil (g)	84.45	66.03	79.79	68.02					
Moisture cont. (g/cm ³)	20.28	24.49	28.39	31.80					
9.3.2 Dry Density Determination									
Trial No.	1	2	3	4	<p align="center">Load - Penetration Relationship</p>				
Mold + Wet soil (gm)	8621	8923	9146	9017					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3639	3941	4164	4035					
Wet Density (g/cm ³)	1.71	1.86	1.96	1.90					
Dry Density (g/cm ³)	1.42	1.49	1.53	1.44					

9.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

9.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	<p align="center">Load - Penetration Relationship</p>		
0.64	8	0.17	12	0.25	18	0.38			
1.27	16	0.35	24	0.50	30	0.64			
1.96	23	0.50	31	0.65	39	0.83			
2.54	29	0.63	37	0.78	43	0.91			
3.18	32	0.69	40	0.84	47	1.00			
3.81	35	0.75	45	0.95	50	1.06			
4.45	38	0.82	47	0.99	52	1.10			
5.08	40	0.86	49	1.03	54	1.15			
7.62	45	0.97	55	1.16	65	1.38			

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

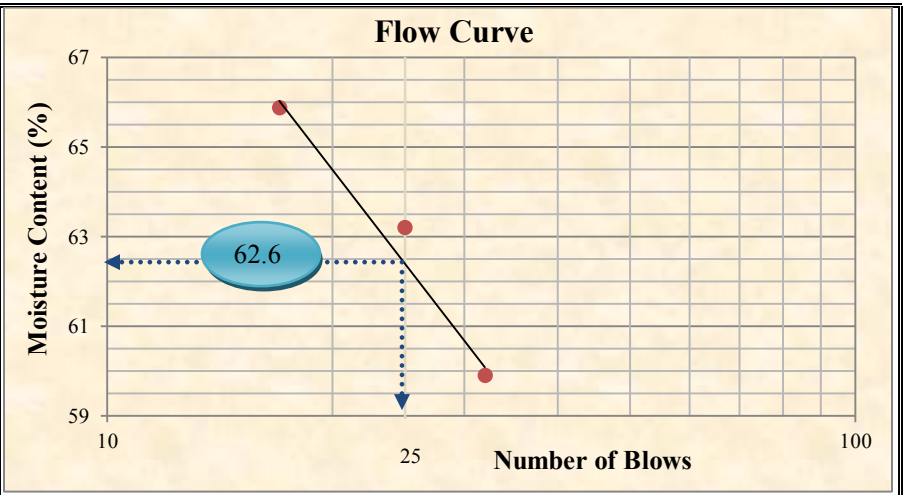
9.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.39	0.63	0.86	13.2	20.0	4.72	4.30	4.72	From the Density-CBR Curve at 95% MDD (1.45 g/cm ³): CBR = 5.4
30	1.48	0.78	1.03	13.2	20.0	5.85	5.15	5.85	
65	1.52	0.91	1.15	13.2	20.0	6.82	5.75	6.82	
Before soaking the three samples were remolded with OMC = 27.8%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.39		1.48		1.52			
CBR (%)		4.72		5.85		6.82			

Sample No.: 10 /WY-2/, Location of Sample: Winget – Yohanes Road, Depth of Sampling: 0.8m, Soil Description: Light brown clay soil

10.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	10.1.1 Gradation Curve of Wet Sieve Analysis
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	16	1.2	98.8	
	0.425	50	3.7	95.1	
	0.075	98	7.3	87.8	
	Pan	1181	87.8	0.0	
Total Weight of dry soil before washing = 1345 gm					
10.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(30)		USCS = MH		ERA Subgrade Class = S3	

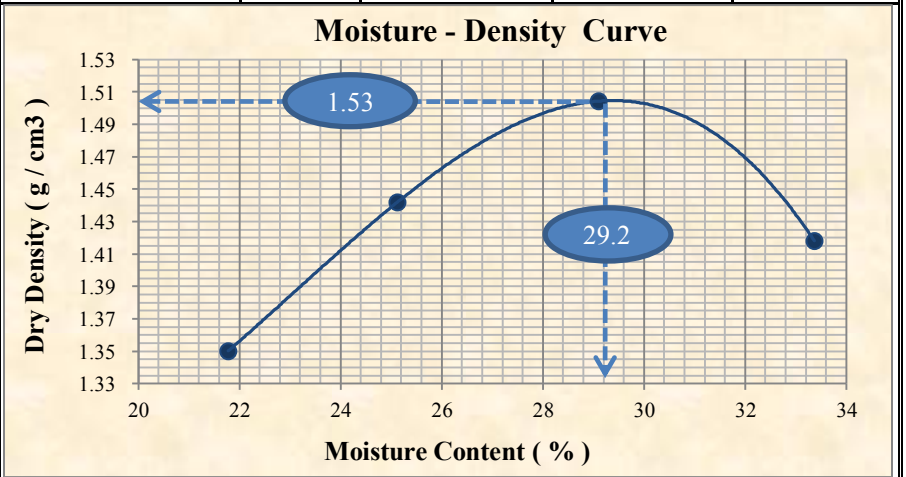
10.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	10.2.1 Liquid Limit			10.1.2 Plastic Limit	
	G	C11	C12	A3	A6
Container No.	G	C11	C12	A3	A6
No. of Blows	32	25	17	-	-
Wt. of con. + Wet soil (g)	43.9	45.5	48.0	28.30	28.24
Wt. of con. + Dry soil (g)	33.7	34.2	35.6	26.49	26.29
Wt. of con. (g)	16.6	16.5	16.7	21.08	20.49
Wt. of water (g)	10.2	11.2	12.4	1.8	2.0
Wt. of dry soil (g)	17.1	17.8	18.9	5.4	5.8
Moisture content	59.9	63.2	65.9	33.5	33.6
LL at 25 blows & Avg. PL	63			34	
10.2.3 Plasticity Index = LL – PL = 63-34 = 29					



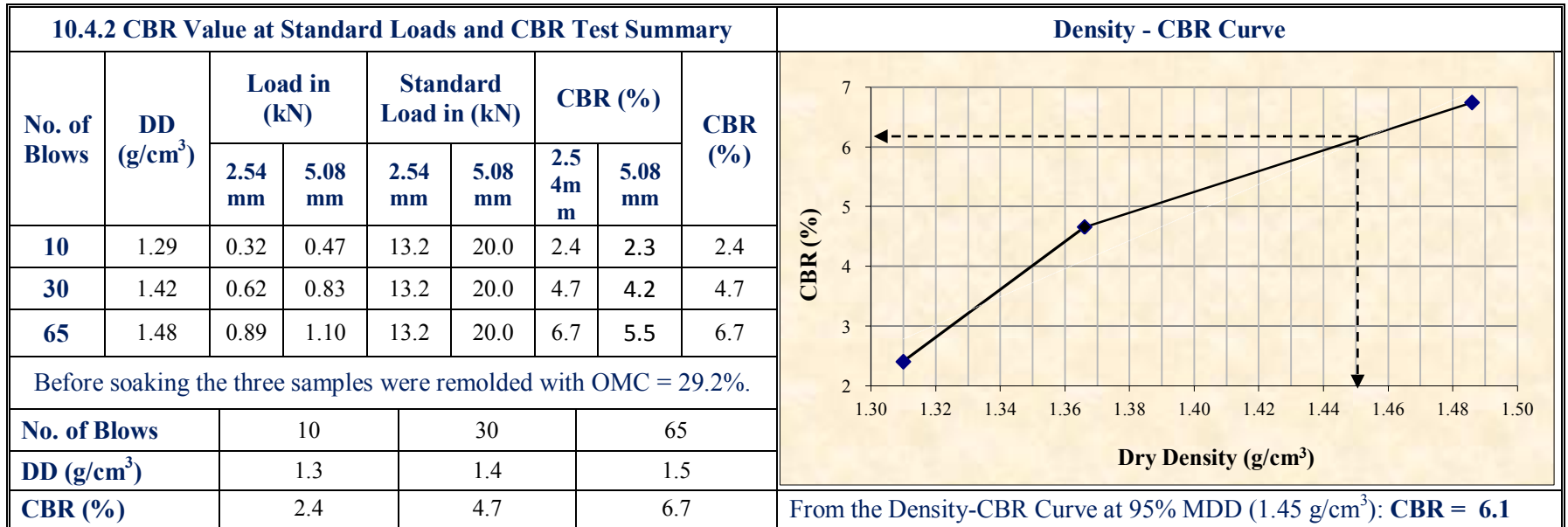
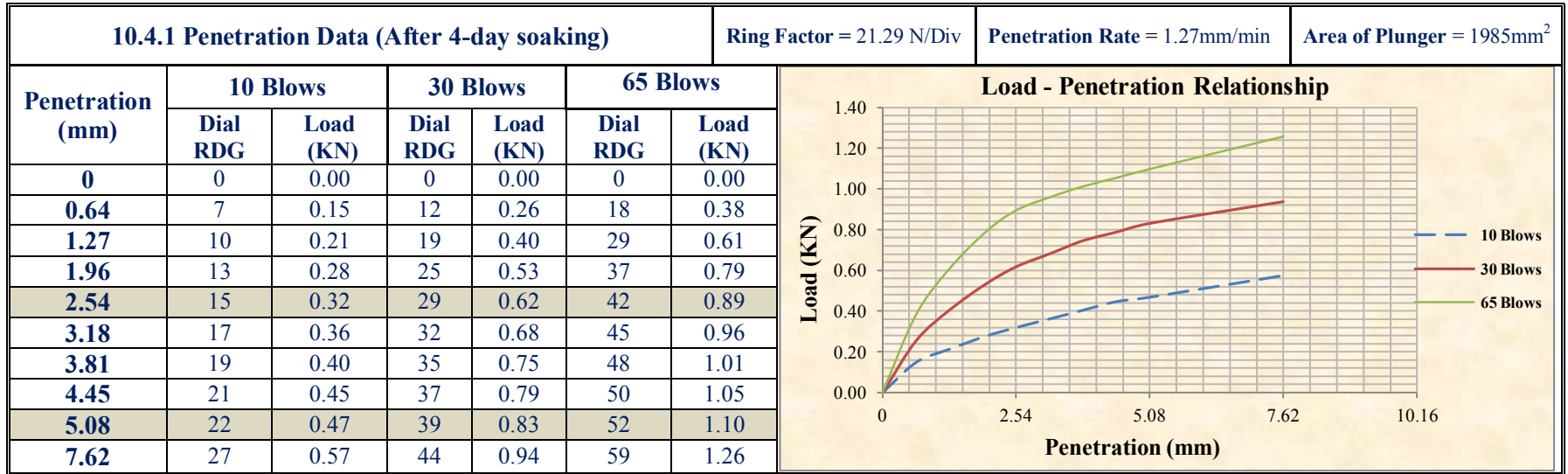
10.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

10.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	1A	2A	3A	4A	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	180.54	140.97	121.68	121.98					
Dry Soil + Con. (g)	153.77	118.79	101.31	99.01					
Mass of Con. (g)	30.84	30.5	31.31	30.17					
Mass of Moisture (g)	26.77	22.18	20.37	22.97					
Dry Soil (g)	122.93	88.29	70	68.84					
Moisture cont. (g/cm ³)	21.78	25.12	29.10	33.37					
10.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8474	8814	9107	8999					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3492	3832	4125	4017					
Wet Density (g/cm ³)	1.64	1.80	1.94	1.89					
Dry Density (g/cm ³)	1.35	1.44	1.50	1.42					



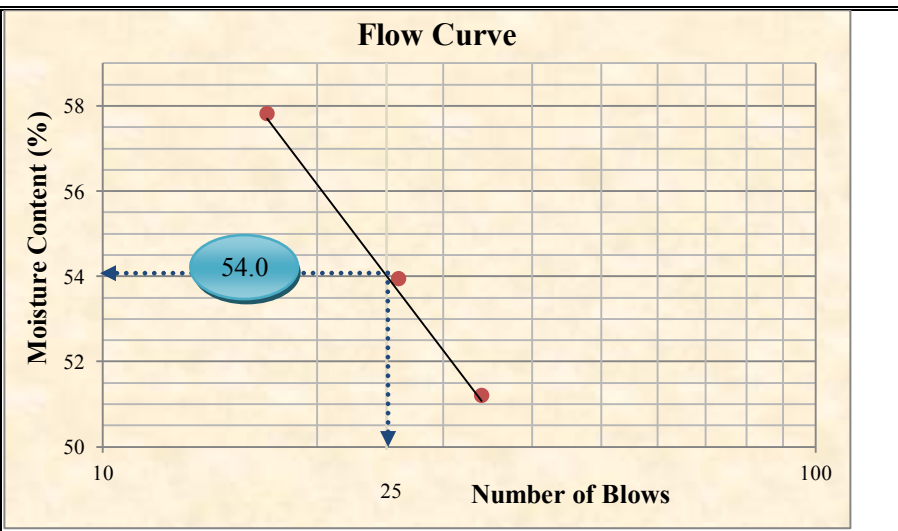
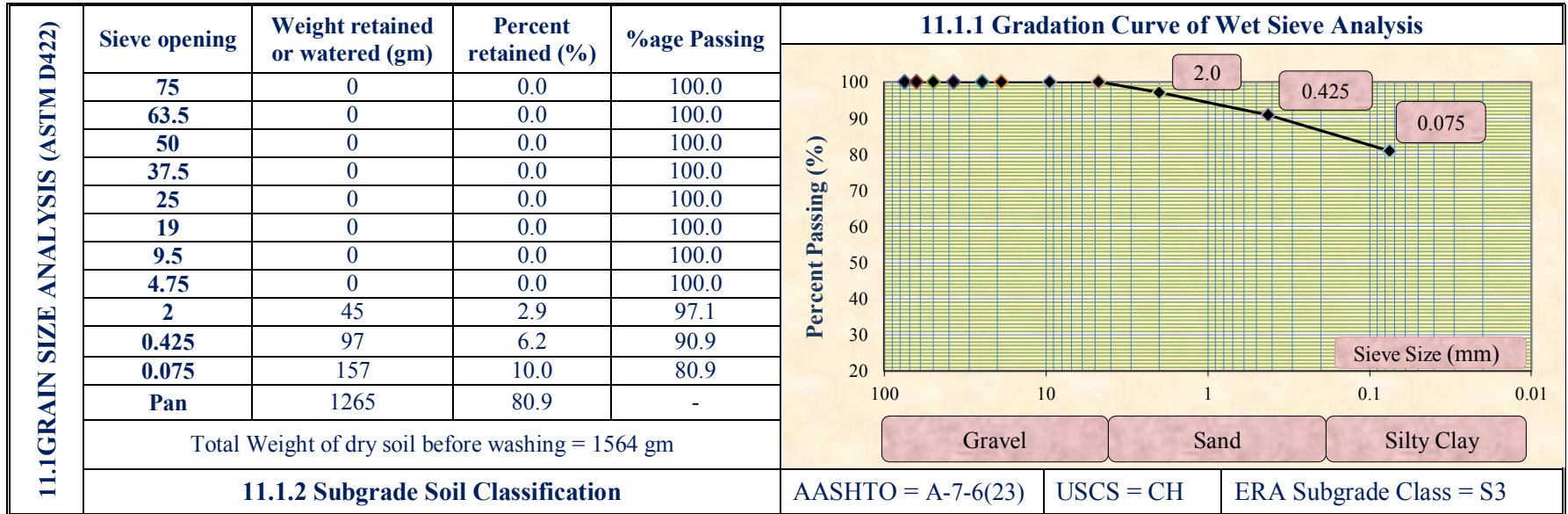
From the compaction curve: **MDD = 1.53 g/cm³** and **OMC = 29.2 %**

10.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)



CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 11 /WY-3/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 1.2m, **Soil Description:** Light Brown clay soil



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

11.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	9A	6A	7A	8A	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	135.41	129.46	122.14	130.89	<p align="center">Moisture - Density Curve</p>				
Dry Soil + Con. (g)	119.08	112.3	103.82	109.01					
Mass of Con. (g)	30.81	30.98	31.04	31.09					
Mass of Moisture (g)	16.33	17.16	18.32	21.88					
Dry Soil (g)	88.27	81.32	72.78	77.92					
Moisture cont. (g/cm ³)	18.50	21.10	25.17	28.08					
11.3.2 Dry Density Determination									
Trial No.	1	2	3	4	<p>From the compaction curve: MDD = 1.59 g/cm³ and OMC = 23.2 %</p>				
Mold + Wet soil (gm)	8600	9011	9147	9089					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3618	4029	4165	4107					
Wet Density (g/cm ³)	1.70	1.90	1.96	1.93					
Dry Density (g/cm ³)	1.44	1.57	1.57	1.51					

11.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

11.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0	0	0	0	0	<p>Legend: --- 10 Blows, --- 30 Blows, --- 65 Blows</p>		
0.64	11	0.23	16	0.34	22	0.47			
1.27	23	0.49	27	0.57	34	0.72			
1.96	35	0.75	38	0.81	44	0.94			
2.54	42	0.89	47	1.00	51	1.09			
3.18	49	1.04	53	1.13	58	1.23			
3.81	53	1.13	56	1.19	63	1.34			
4.45	55	1.17	59	1.26	65	1.38			
5.08	58	1.23	62	1.32	68	1.45			
7.62	65	1.38	71	1.51	79	1.68			

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

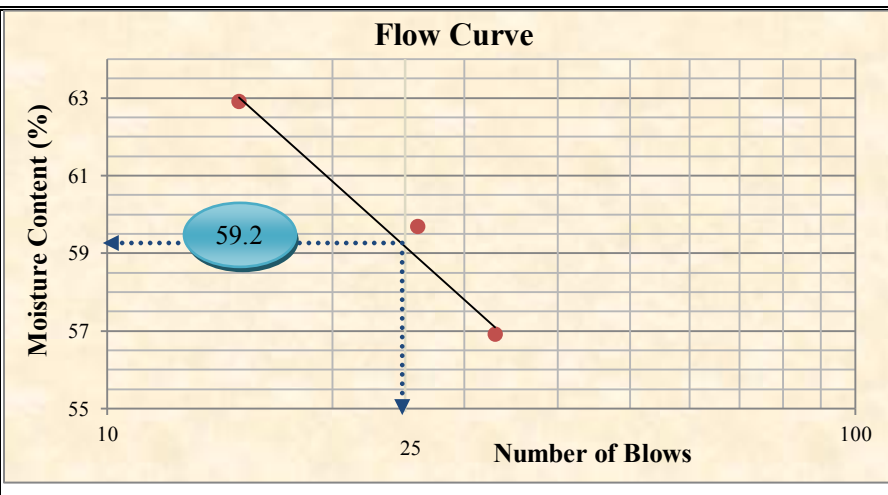
11.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.45	0.89	1.23	13.2	20.0	6.67	6.15	6.67	
30	1.54	1.00	1.32	13.2	20.0	7.50	6.60	7.50	
65	1.58	1.09	1.45	13.2	20.0	8.17	7.25	8.17	
Before soaking the three samples were remolded with OMC = 23.2%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.45		1.54		1.58			
CBR (%)		6.7		7.5		8.2			
From the Density-CBR Curve at 95% MDD (1.51g/cm ³): CBR = 7.3									

Sample No.:12 /WY-4/, Location of Sample: Winget – Yohanes Road, Depth of Sampling: 1.2m, Soil Description: Light Brown clay soil

12.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	12.1.1 Gradation Curve of Wet Sieve Analysis
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	20	1.8	98.2	
	0.425	43	3.8	94.5	
	0.075	118	10.3	84.1	
Pan	960	84.1	-		
Total Weight of dry soil before washing = 1141 gm					
12.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(24)		USCS = MH		ERA Subgrade Class = S4	

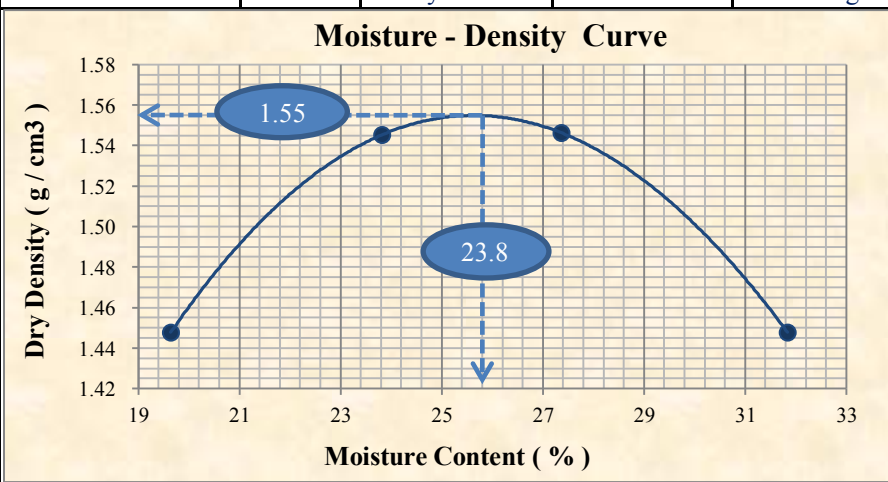
12.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	12.2.1 Liquid Limit			12.1.2 Plastic Limit	
	P1	C11	C13	C7	C13
Container No.	P1	C11	C13	C7	C13
No. of Blows	33	26	15	-	-
Wt. of con. + Wet soil (g)	43.8	49.1	47.8	27.93	26.57
Wt. of con. + Dry soil (g)	34.0	37.0	35.7	26.28	25.18
Wt. of con. (g)	16.7	16.7	16.6	21.53	21.20
Wt. of water (g)	9.8	12.1	12.0	1.65	1.39
Wt. of dry soil (g)	17.3	20.3	19.1	4.75	3.98
Moisture content	56.9	59.7	62.9	34.74	34.92
LL at 25 blows & Avg. PL	59			35	
12.2.3 Plasticity Index = 59 – 35 = 24					



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

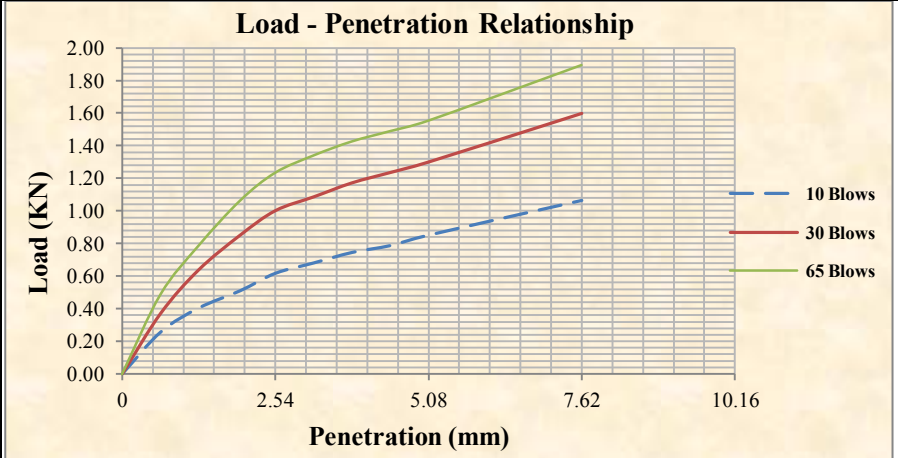
12.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	2B	4B	8B	9B	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	136.17	123.19	128.55	114.22					
Dry Soil + Con. (g)	117.23	103.41	105.44	91.45					
Mass of Con. (g)	20.81	20.37	20.99	19.93					
Mass of Moisture (g)	18.94	19.78	23.11	22.77					
Dry Soil (g)	96.42	83.04	84.45	71.52					
Moisture cont. (g/cm ³)	19.64	23.82	27.37	31.84					
12.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8661	9046	9165	9036					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3679	4064	4183	4054					
Wet Density (g/cm ³)	1.73	1.91	1.97	1.91					
Dry Density (g/cm ³)	1.45	1.55	1.55	1.45					



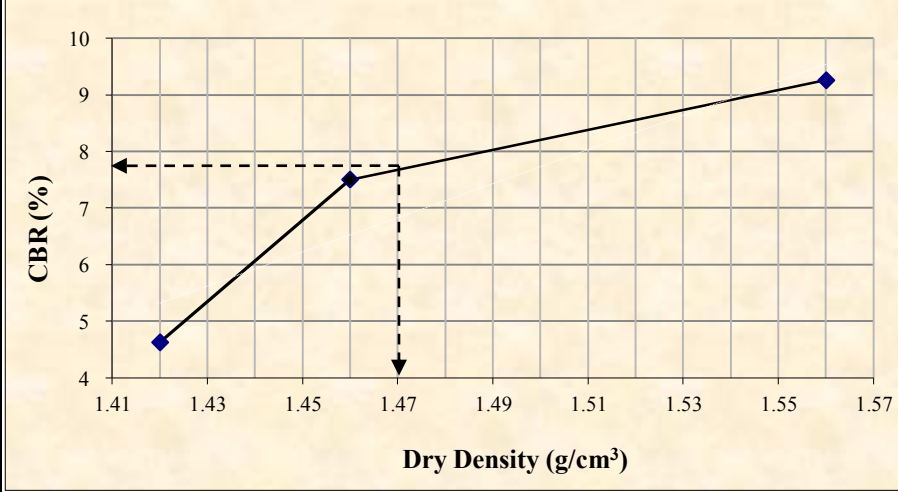
From the compaction curve: **MDD = 1.55 g/cm³** and **OMC = 25.8 %**

12.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

12.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	14	0.30	19	0.40	23	0.49
1.27	19	0.40	30	0.64	37	0.79
1.96	24	0.51	40	0.85	50	1.06
2.54	29	0.62	47	1.00	58	1.23
3.18	32	0.68	51	1.09	63	1.34
3.81	35	0.75	55	1.17	67	1.43
4.45	37	0.79	58	1.23	70	1.49
5.08	40	0.85	61	1.30	73	1.55
7.62	50	1.06	75	1.60	89	1.89



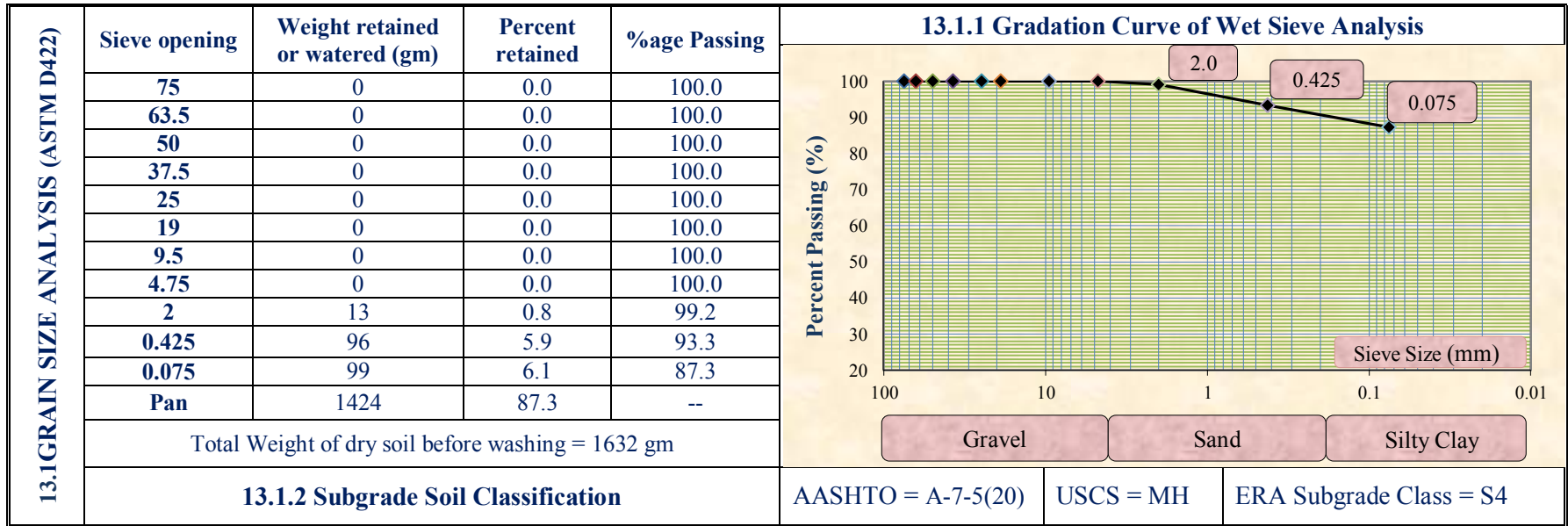
12.4.2 CBR Value at Standard Loads and CBR Test Summary								Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.42	0.62	0.85	13.2	20.0	4.6	4.3	4.6	
30	1.46	1.00	1.30	13.2	20.0	7.5	6.5	7.5	
65	1.56	1.23	1.55	13.2	20.0	9.3	7.8	9.3	
Before soaking the three samples were remolded with OMC = 25.8%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.42		1.46		1.56			
CBR (%)		4.6		7.5		9.3			



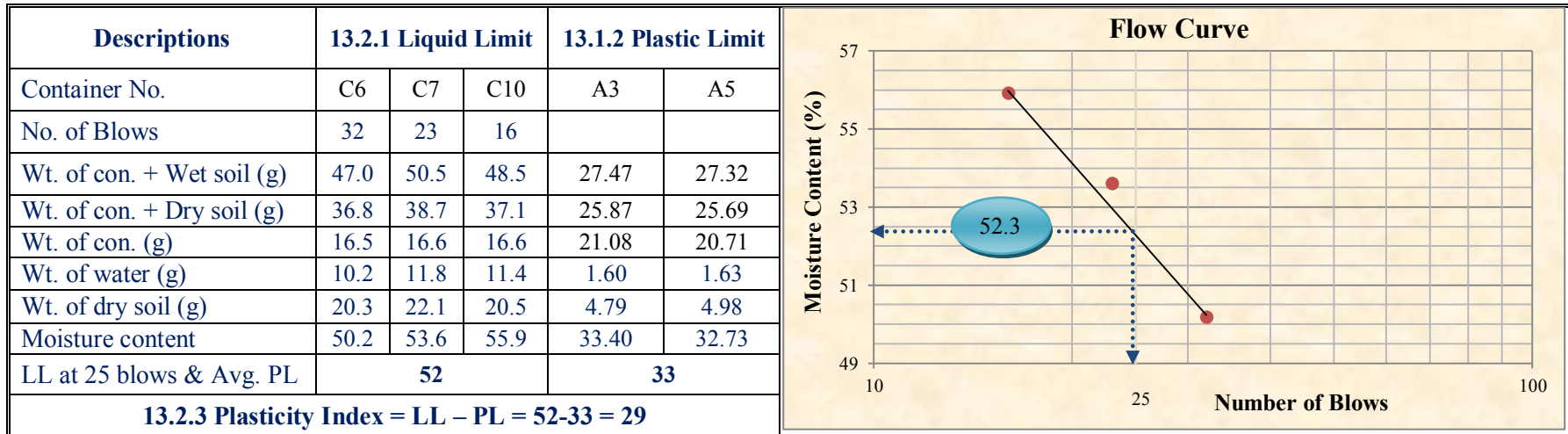
From the Density-CBR Curve at 95% MDD (1.47 g/cm³): **CBR = 7.8**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 13 /WY-5/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 1.2m, **Soil Description:** Red clay soil



13.2 ATTERBERG LIMIT TEST (ASTM D 4318)



13.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

13.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	1A	2A	3A	4A	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	126.03	159.35	133.07	126.86	<p>Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.53 g/cm³ and OMC = 27.6 %</p>				
Dry Soil +Con. (g)	110.26	135.07	111.03	103.58					
Mass of Con. (g)	30.85	30.51	31.31	30.17					
Mass of Moisture (g)	15.77	24.28	22.04	23.28					
Dry Soil (g)	79.41	104.56	79.72	73.41					
Moisture cont. (g/cm ³)	19.86	23.22	27.65	31.71					
13.3.2 Dry Density Determination									
Trial No.	1	2	3	4	<p>Load - Penetration Relationship</p>				
Mold + Wet soil (gm)	8240	8758	9130	9060					
Mold (gm)	4982	4982	4982	4982					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3258	3776	4148	4078					
Wet Density (g/cm ³)	1.53	1.78	1.95	1.92					
Dry Density (g/cm ³)	1.28	1.44	1.53	1.46					

13.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

13.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
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	26	0.55	32	0.68	37	0.79	
1.27	38	0.81	47	1.00	53	1.13	
1.96	46	0.98	56	1.19	60	1.28	
2.54	52	1.11	61	1.30	66	1.41	
3.18	54	1.15	64	1.36	70	1.49	
3.81	56	1.19	68	1.45	73	1.55	
4.45	58	1.23	70	1.49	75	1.60	
5.08	60	1.28	73	1.55	77	1.64	
7.62	74	1.58	84	1.79	92	1.96	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

13.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	CBR (%)	Dry Density (g/cm ³)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.38	1.11	1.28	13.2	20.0	8.3	6.4	8.3		
30	1.47	1.30	1.55	13.2	20.0	9.7	7.8	9.7		
65	1.52	1.41	1.64	13.2	20.0	10.5	8.2	10.5		
Before soaking the three samples were remolded with OMC = 27.6%.										
No. of Blows	10	30	65							
DD (g/cm ³)	1.38	1.47	1.52							
CBR (%)	8.3	9.7	10.5							

Density - CBR Curve	
From the Density-CBR Curve at 95% MDD (1.45 g/cm ³):	CBR = 9.4

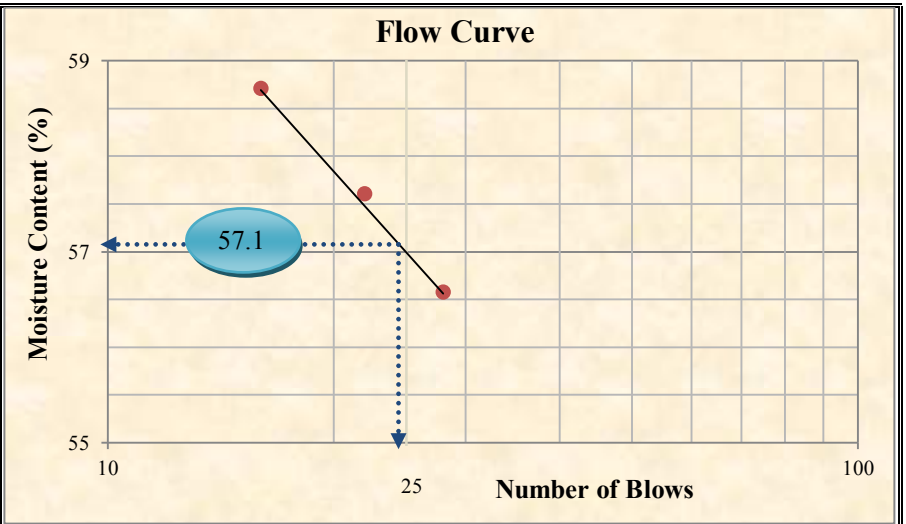
Sample No.: 14 /WY-6/, Location of Sample: Winget – Yohanes Road, Depth of Sampling: 1.0m, Soil Description: Red clay soil

14.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing
	75	0	0.0	100.0
	63.5	0	0.0	100.0
	50	0	0.0	100.0
	37.5	0	0.0	100.0
	25	0	0.0	100.0
	19	0	0.0	100.0
	9.5	0	0.0	100.0
	4.75	0	0.0	100.0
	2	13	1.6	98.4
	0.425	66	7.9	90.5
	0.075	108	13.0	77.5
	Pan	644	77.5	-
Total Weight of dry soil before washing = 831 gm				
14.1.2 Subgrade Soil Classification				
AASHTO = A-7-5(19)		USCS = MH		ERA Subgrade Class = S4

14.1.1 Gradation Curve of Wet Sieve Analysis	
Percent Passing (%)	Sieve Size (mm)
100	2.0
90.5	0.425
77.5	0.075
Gravel Sand Silty Clay	

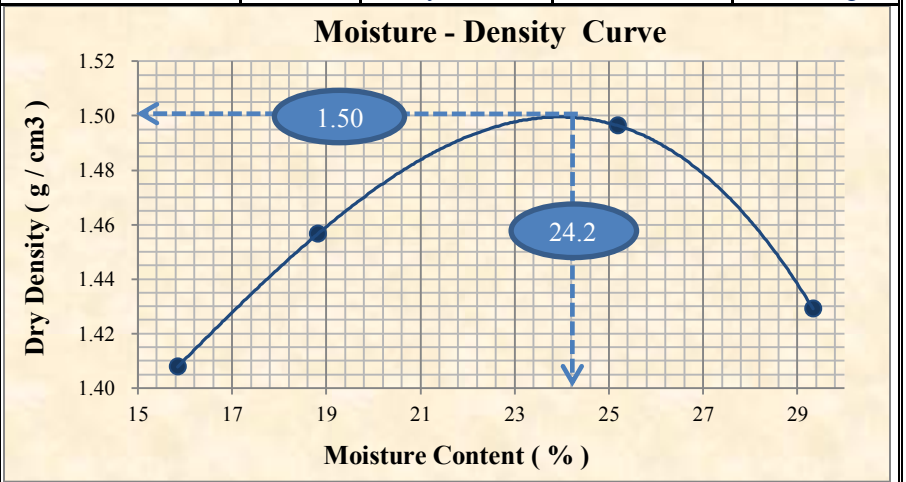
14.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	14.2.1 Liquid Limit			14.2.2 Plastic Limit	
	C4	C5	C12	D3	D2
Container No.	C4	C5	C12	D3	D2
No. of Blows	28	22	16	-	-
Wt. of con. + Wet soil (g)	80.0	74.0	75.1	63.54	64.23
Wt. of con. + Dry soil (g)	69.8	65.4	64.4	60.25	61.03
Wt. of con. (g)	51.7	50.6	46.1	51.23	52.04
Wt. of water (g)	10.2	8.6	10.7	3.29	3.20
Wt. of dry soil (g)	18.1	14.9	18.3	9.02	8.99
Moisture content	56.6	57.6	58.7	36.47	35.60
LL at 25 blows & Avg. PL	57			36	
14.2.3 Plasticity Index = LL – PL = 57 – 36 = 21					



14.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

14.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	1E	2E	3E	4E	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	426.5	330	507	526.5					
Dry Soil + Con. (g)	380	295	422.5	427.5					
Mass of Con. (g)	86.5	109	87	90					
Mass of Moisture (g)	46.5	35	84.5	99					
Dry Soil (g)	293.5	186	335.5	337.5					
Moisture cont. (g/cm ³)	15.84	18.82	25.19	29.33					
14.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8897	9109	9412	9359					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3464	3676	3979	3926					
Wet Density (g/cm ³)	1.63	1.73	1.87	1.85					
Dry Density (g/cm ³)	1.41	1.46	1.50	1.43					



From the compaction curve: **MDD = 1.50 g/cm³** and **OMC = 24.2 %**

14.3 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

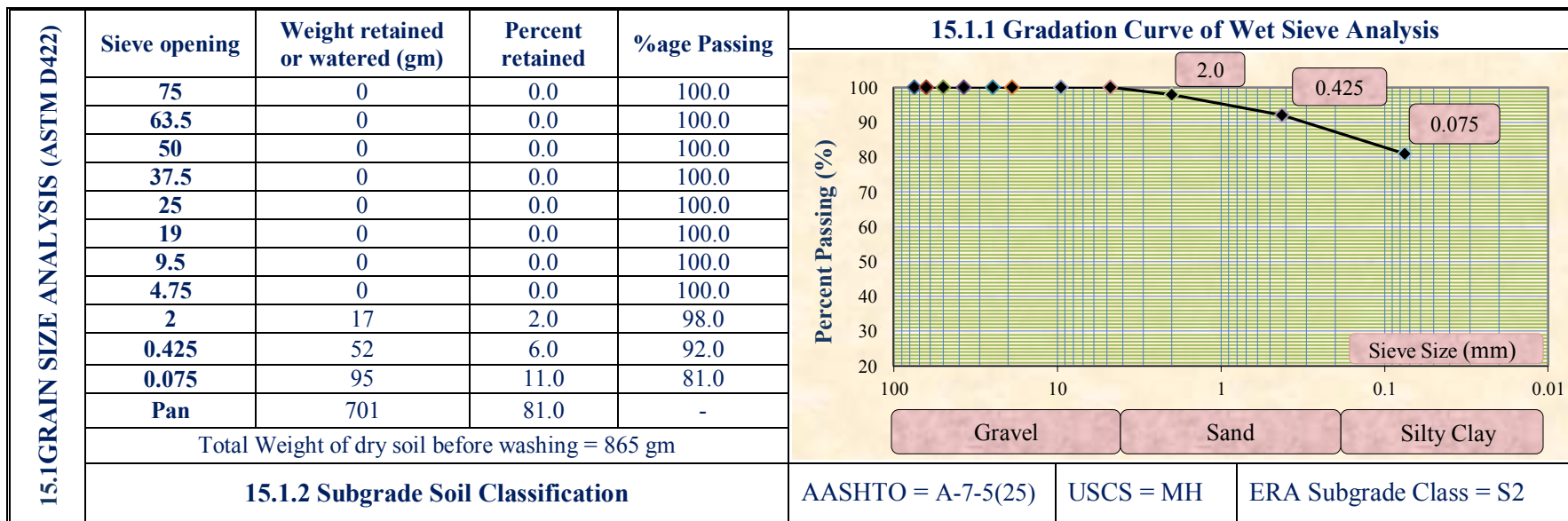
14.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<div style="text-align: center;"> Load - Penetration Relationship </div>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0	0.00	0	0	0			
0.64	0.64	4	0.21	6	0.33	10			
1.27	1.27	10	0.52	14	0.71	18			
1.96	1.96	16	0.83	19	1.00	23			
2.54	2.54	20	1.04	20	1.17	26			
3.18	3.18	22	1.14	24	1.25	28			
3.81	3.81	23	1.19	25	1.30	29			
4.45	4.45	24	1.25	26	1.35	30			
5.08	5.08	25	1.30	27	1.38	31			
7.62	7.62	27	1.40	30	1.54	34			

14.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	<div style="text-align: center;"> </div>	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.39	1.04	1.30	13.2	20.0	7.83	6.49	7.83		
30	1.48	1.17	1.38	13.2	20.0	8.83	6.91	8.83		
65	1.52	1.35	1.61	13.2	20.0	10.17	8.05	10.17		
Before soaking the three samples were remolded with OMC = 24.2%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.39		1.48		1.52				
CBR (%)		7.83		8.83		10.17				

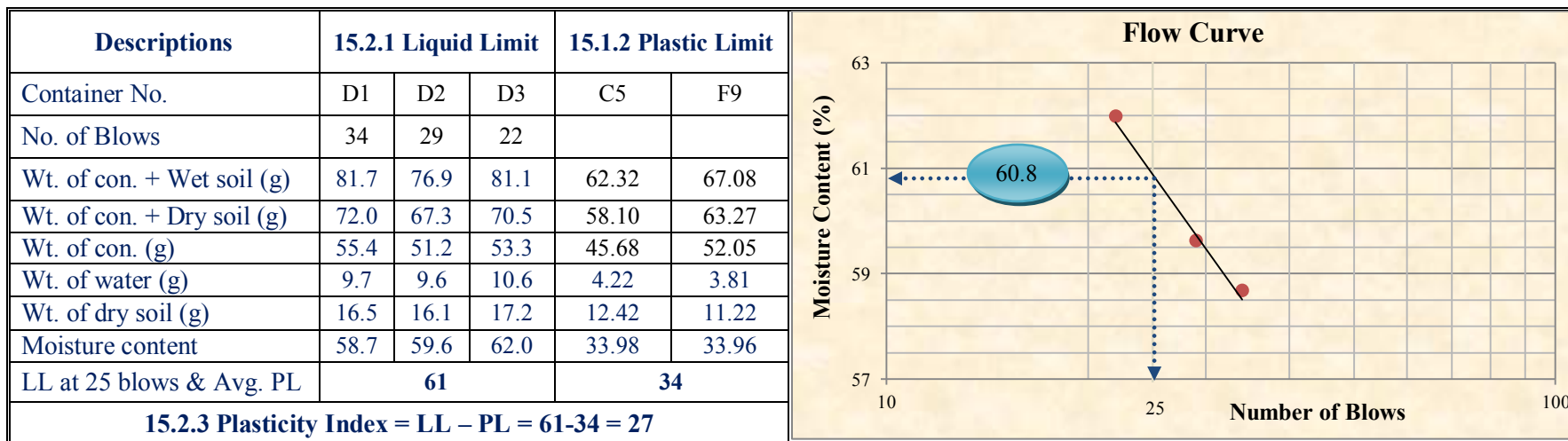
From the Density-CBR Curve at 95% MDD (1.43 g/cm³): **CBR = 8.4**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 15 /WY-7/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 0.8m, **Soil Description:** Dark Brown clay soil



15.2 ATTERBERG LIMIT TEST (ASTM D 4318)



15.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

15.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	F1	G4	B3	T9	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	398	448.5	442.5	436.5	<div style="text-align: center;"> Moisture - Density Curve </div>				
Dry Soil + Con. (g)	348	384	375	358.5					
Mass of Con. (g)	87	86	89	87					
Mass of Moisture (g)	50	64.5	67.5	78					
Dry Soil (g)	261	298	286	271.5					
Moisture cont. (g/cm ³)	19.16	21.64	23.60	28.73					
15.3.2 Dry Density Determination					From the compaction curve: MDD = 1.58 g/cm³ and OMC = 23.3%				
Trial No.	1	2	3	4	<div style="text-align: center;"> Load - Penetration Relationship </div>				
Mold + Wet soil (gm)	9200	9464	9575	9528					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3767	4031	4142	4095					
Wet Density (g/cm ³)	1.77	1.90	1.95	1.93					
Dry Density (g/cm ³)	1.49	1.56	1.58	1.50					

15.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

15.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 21.29 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<div style="text-align: center;"> Load - Penetration Relationship </div>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00			
0.64	3	0.16	5	0.26	7	0.36			
1.27	6	0.31	8	0.42	11	0.57			
1.96	8	0.42	10	0.53	14	0.73			
2.54	9	0.48	11	0.59	15	0.80			
3.18	10	0.52	13	0.67	17	0.90			
3.81	11	0.57	14	0.73	19	0.99			
4.45	12	0.61	15	0.78	20	1.04			
5.08	13	0.66	16	0.83	21	1.09			
7.62	16	0.83	21	1.09	26	1.35			

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

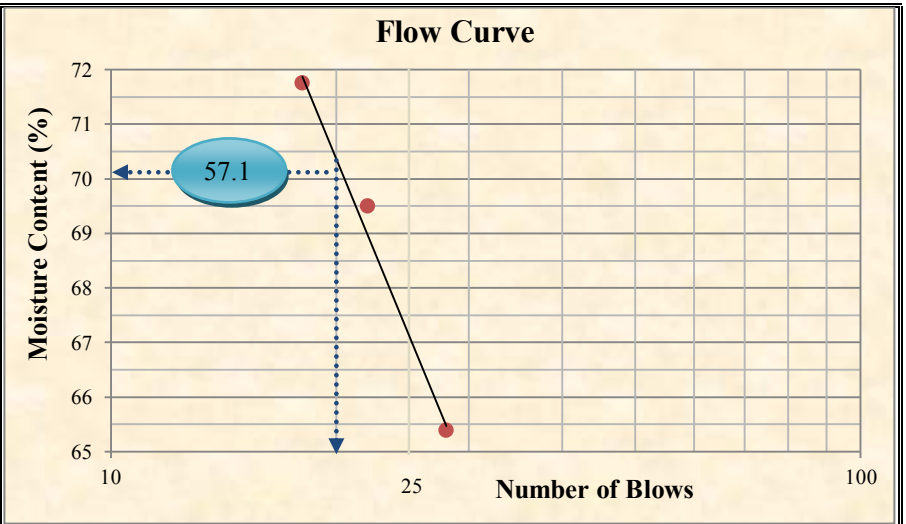
15.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	CBR (%)	CBR (%)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.46	0.48	0.66	13.2	20.0	3.64	3.32	3.64		
30	1.52	0.59	0.83	13.2	20.0	4.46	4.15	4.46		
65	1.58	0.80	1.09	13.2	20.0	6.03	5.45	6.03		
Before soaking the three samples were remolded with OMC = 23.3%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.46		1.52		1.58				
CBR (%)		3.64		4.46		6.03				
									From the Density-CBR Curve at 95% MDD (1.50 g/cm ³): CBR = 4.1	

Sample No.: 16 /WY-8/, Location of Sample: Winget – Yohanes Road, Depth of Sampling: 0.6m, Soil Description: Dark clay soil

16.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	16.1.1 Gradation Curve of Wet Sieve Analysis		
	75	0	0.0	100.0			
	63.5	0	0.0	100.0			
	50	0	0.0	100.0			
	37.5	0	0.0	100.0			
	25	0	0.0	100.0			
	19	0	0.0	100.0			
	9.5	0	0.0	100.0			
	4.75	0	0.0	100.0			
	2	27	3.0	97.0			
	0.425	89	10.0	87.0			
	0.075	124	14.0	73.0			
Pan	649	73.0	-				
Total Weight of dry soil before washing = 889gm					AASHTO = A-7-5(22) USCS = CH ERA Subgrade Class = S1		
16.1.2 Subgrade Soil Classification							

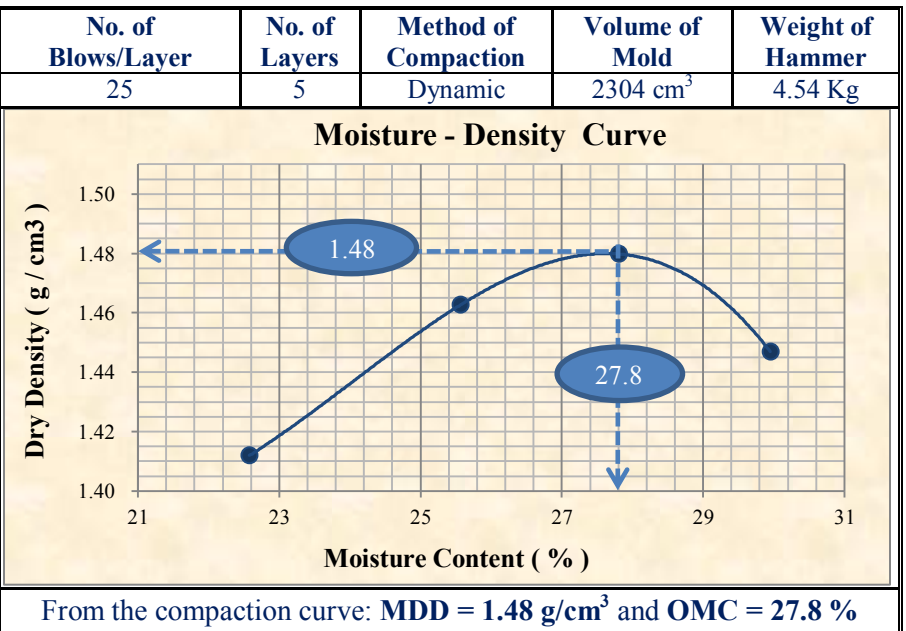
16.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	16.2.1 Liquid Limit			16.2.2 Plastic Limit	
	G5	B11	G3	D4	C2
Container No.	G5	B11	G3	D4	C2
No. of Blows	28	22	18	-	-
Wt. of con. + Wet soil (g)	82.3	83.3	86.3	73.64	74.45
Wt. of con. + Dry soil (g)	71.0	71.0	73.4	68.25	69.05
Wt. of con. (g)	53.7	53.4	55.5	51.32	52.02
Wt. of water (g)	11.3	12.3	12.8	5.39	5.40
Wt. of dry soil (g)	17.3	17.6	17.9	16.93	17.03
Moisture content	65.4	69.5	71.8	31.84	31.71
LL at 25 blows & Avg. PL	70			32	
16.2.3 Plasticity Index = LL – PL = 70 – 32 = 38					



16.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

16.3.1 Moisture Content Determination				
Container No.	F1	G4	B3	T9
Wet Soil + Con. (g)	348.2	531	460	503
Dry Soil + Con. (g)	300	440.5	379.5	407
Mass of Con. (g)	86.5	86.5	90	86.5
Mass of Moisture (g)	48.2	90.5	80.5	96
Dry Soil (g)	213.5	354	289.5	320.5
Moisture cont. (g/cm ³)	22.58	25.56	27.81	29.95
16.3.2 Dry Density Determination				
Trial No.	1	2	3	4
Mold + Wet soil (gm)	9109	9334	9450	9427
Mold (gm)	5433	5433	5433	5433
Volume (cm ³)	2124	2124	2124	2124
Wet Soil (gm)	3676	3901	4017	3994
Wet Density (g/cm ³)	1.73	1.84	1.89	1.88
Dry Density (g/cm ³)	1.41	1.46	1.48	1.45

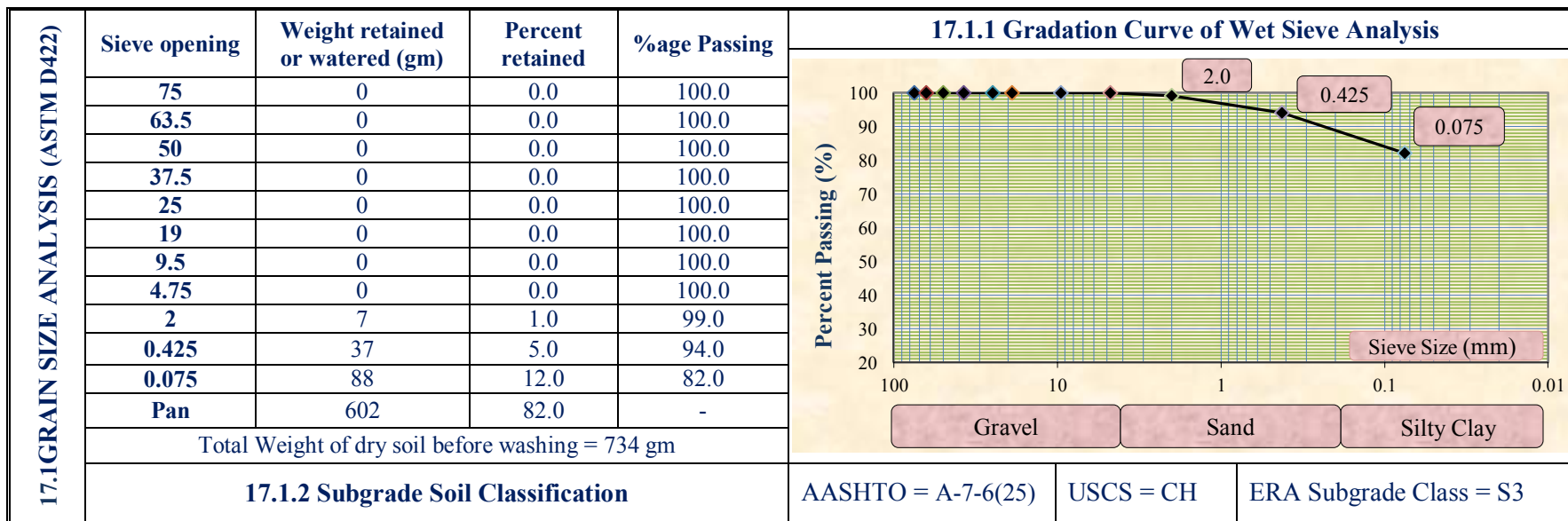


16.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

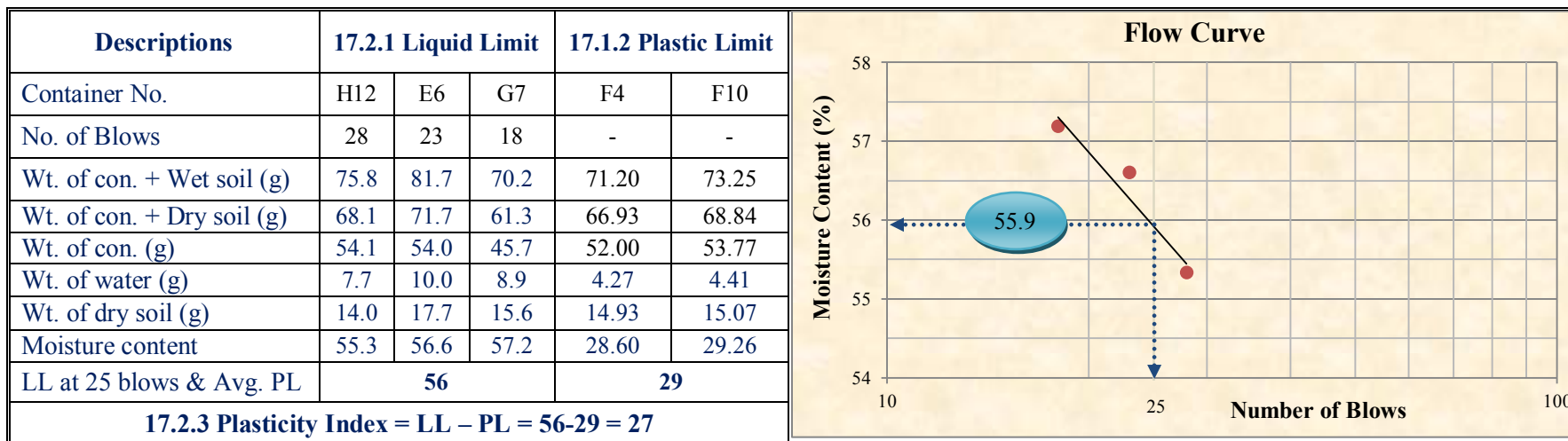
16.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00			
0.64	3	0.13	4	0.19	5	0.26			
1.27	3	0.18	5	0.25	7	0.36			
1.96	4	0.23	6	0.29	8	0.42			
2.54	5	0.26	6	0.33	9	0.46			
3.18	6	0.29	7	0.38	10	0.50			
3.81	6	0.31	8	0.41	10	0.54			
4.45	7	0.34	8	0.44	11	0.59			
5.08	7	0.35	9	0.46	12	0.63			
7.62	9	0.46	11	0.59	15	0.80			
16.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve		
No. of Blows	DD (g/cm ³)	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	1.38	0.26	0.35	13.2	20.0	1.99	1.77	1.99	
30	1.48	0.33	0.46	13.2	20.0	2.52	2.30	2.52	
65	1.67	0.46	0.63	13.2	20.0	3.47	3.14	3.47	
Before soaking the three samples were remolded with OMC = 27.8%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.38		1.48		1.67			
CBR (%)		1.99		2.52		3.47			
							From the Density-CBR Curve at 95% MDD (1.41 g/cm ³): CBR = 2.2		

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 17 //WY-9/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 0.8m, **Soil Description:** Dark Brown clay soil



17.2 ATTERBERG LIMIT TEST (ASTM D 4318)



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

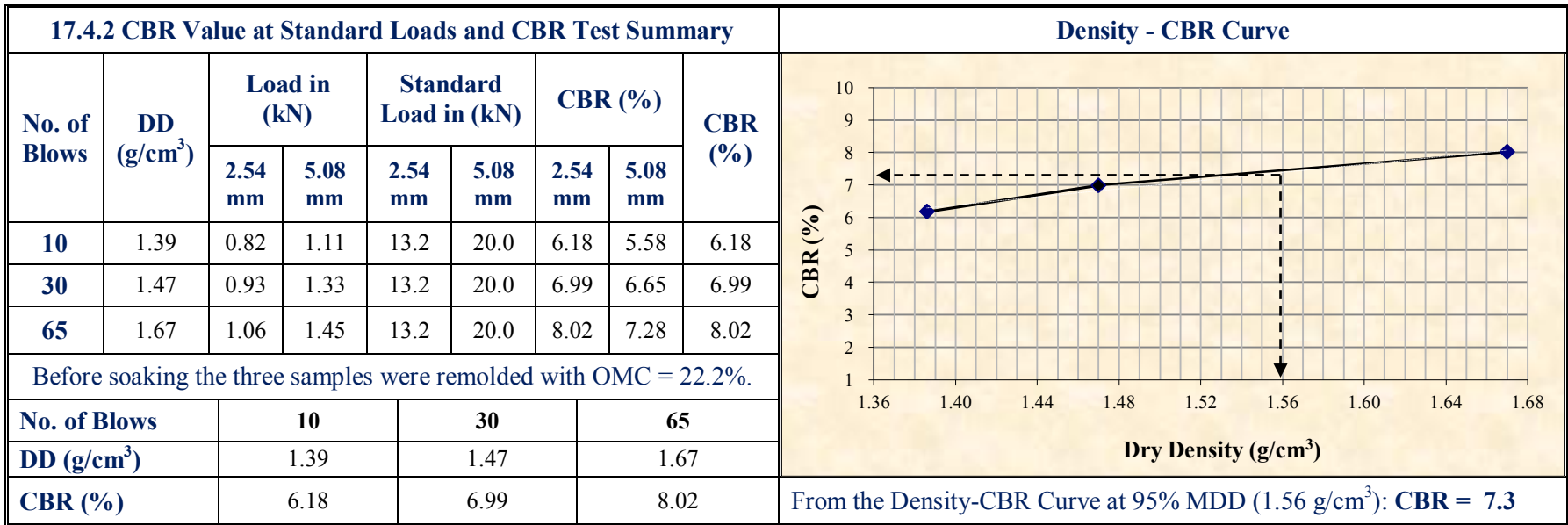
17.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	F1	G4	B3	T9	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	348.2	295.45	304	323	<p>Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.64 g/cm³ and OMC = 22.2 %</p>				
Dry Soil + Con. (g)	310.22	264	269.19	281.12					
Mass of Con. (g)	106.32	107.05	113.01	108.31					
Mass of Moisture (g)	37.98	31.45	34.81	41.88					
Dry Soil (g)	203.9	156.95	156.18	172.81					
Moisture cont. (g/cm ³)	18.63	20.04	22.29	24.23					
17.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9109	9395	9683	9561					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3676	3962	4250	4128					
Wet Density (g/cm ³)	1.73	1.87	2.00	1.94					
Dry Density (g/cm ³)	1.46	1.55	1.64	1.56					

17.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

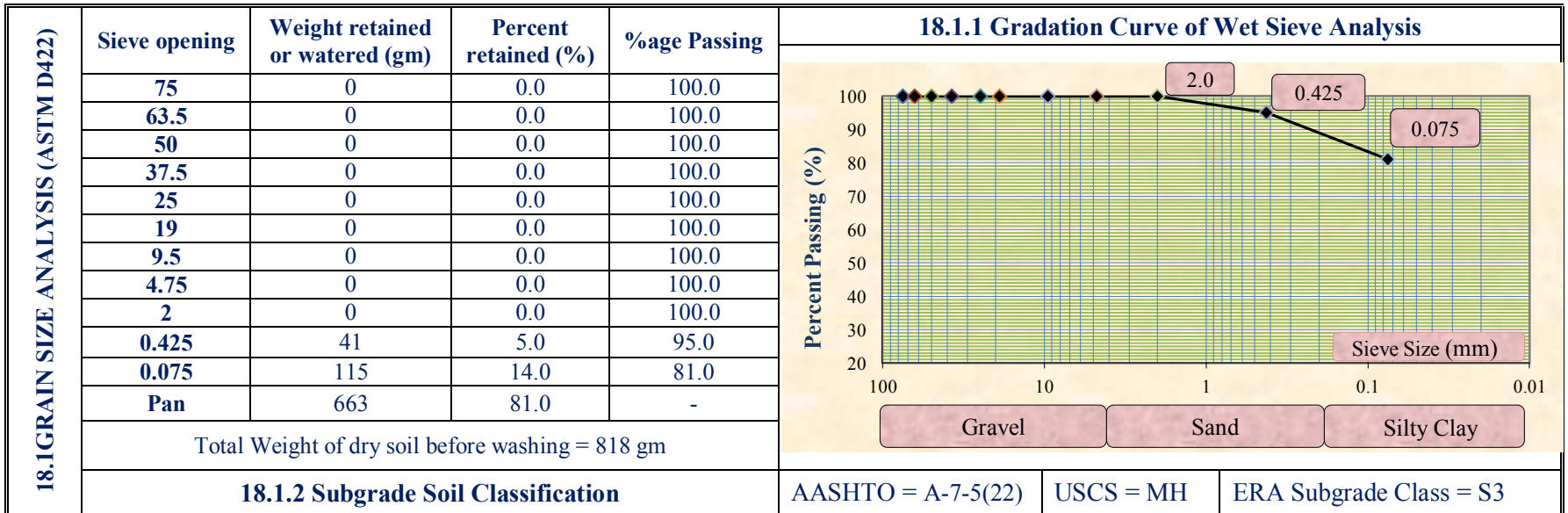
17.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0.00	0	0.00	0	0.00	0.00
0.64	0.26	7	0.36	9	0.45	0.26
1.27	0.52	12	0.62	14	0.73	0.52
1.96	0.71	16	0.83	18	0.94	0.71
2.54	0.82	18	0.93	21	1.06	0.82
3.18	0.93	20	1.04	23	1.19	0.93
3.81	0.99	22	1.16	25	1.31	0.99
4.45	1.06	24	1.25	27	1.40	1.06
5.08	1.11	26	1.33	28	1.45	1.11
7.62	1.24	28	1.45	31	1.61	1.24

Load - Penetration Relationship

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

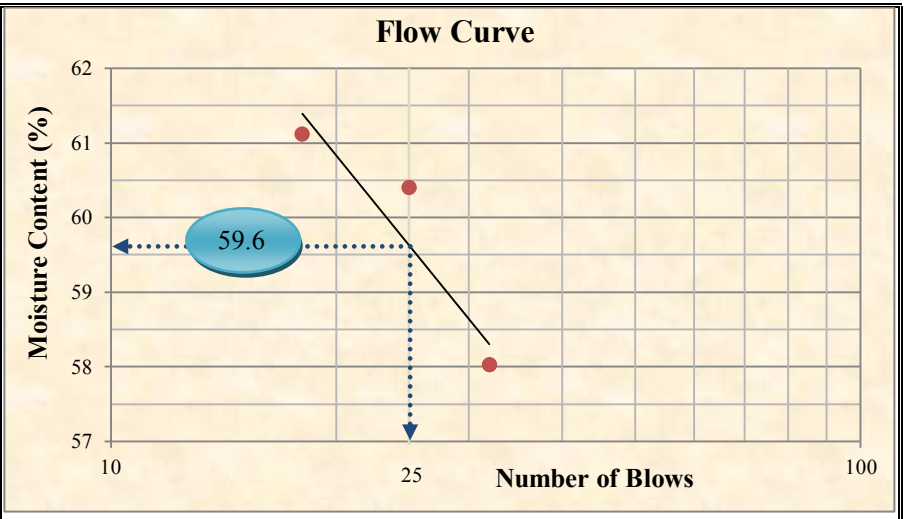


Sample No.: 18 /WY-10/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 0.6m, **Soil Description:** Dark Brown clay soil



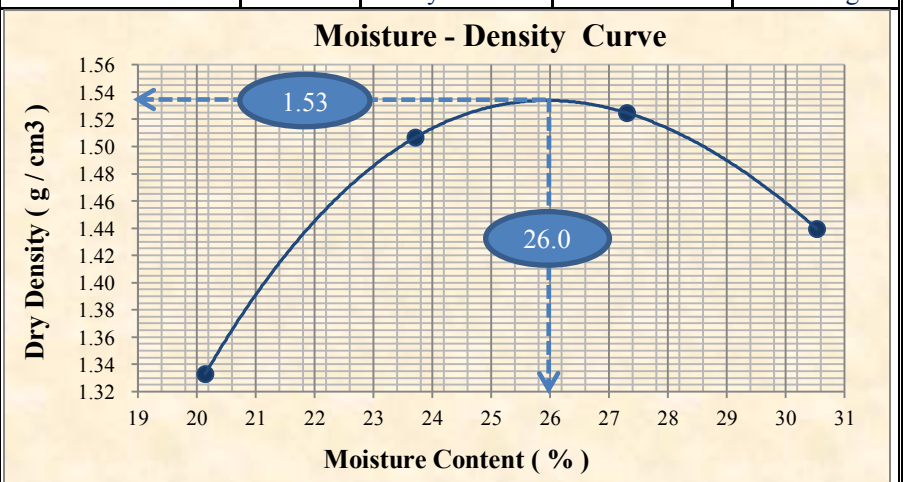
18.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	18.2.1 Liquid Limit			18.2.2 Plastic Limit	
	F8	D14	J1	G11	G5
Container No.	F8	D14	J1	G11	G5
No. of Blows	32	25	18		
Wt. of con. + Wet soil (g)	81.6	82.7	79.4	72.40	74.45
Wt. of con. + Dry soil (g)	74.6	73.3	70.3	66.93	68.84
Wt. of con. (g)	62.4	57.8	55.4	52.00	53.77
Wt. of water (g)	7.0	9.4	9.1	5.47	5.61
Wt. of dry soil (g)	12.2	15.5	14.9	14.93	15.07
Moisture content	58.0	60.4	61.1	36.64	37.23
LL at 25 blows & Avg. PL	60			37	
18.2.3 Plasticity Index = LL – PL = 60 – 37 = 23					



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

18.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H1	C2	D5	H4	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	426.5	446.5	445.5	466.5					
Dry Soil + Con. (g)	369.5	377.5	368.5	377.5					
Mass of Con. (g)	86.5	86.5	86.5	86					
Mass of Moisture (g)	57	69	77	89					
Dry Soil (g)	283	291	282	291.5					
Moisture cont. (g/cm ³)	20.14	23.71	27.30	30.53					
18.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8834	9392	9556	9424					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3401	3959	4123	3991					
Wet Density (g/cm ³)	1.60	1.86	1.94	1.88					
Dry Density (g/cm ³)	1.33	1.51	1.52	1.44					



From the compaction curve: **MDD = 1.53 g/cm³** and **OMC = 26.0 %**

18.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

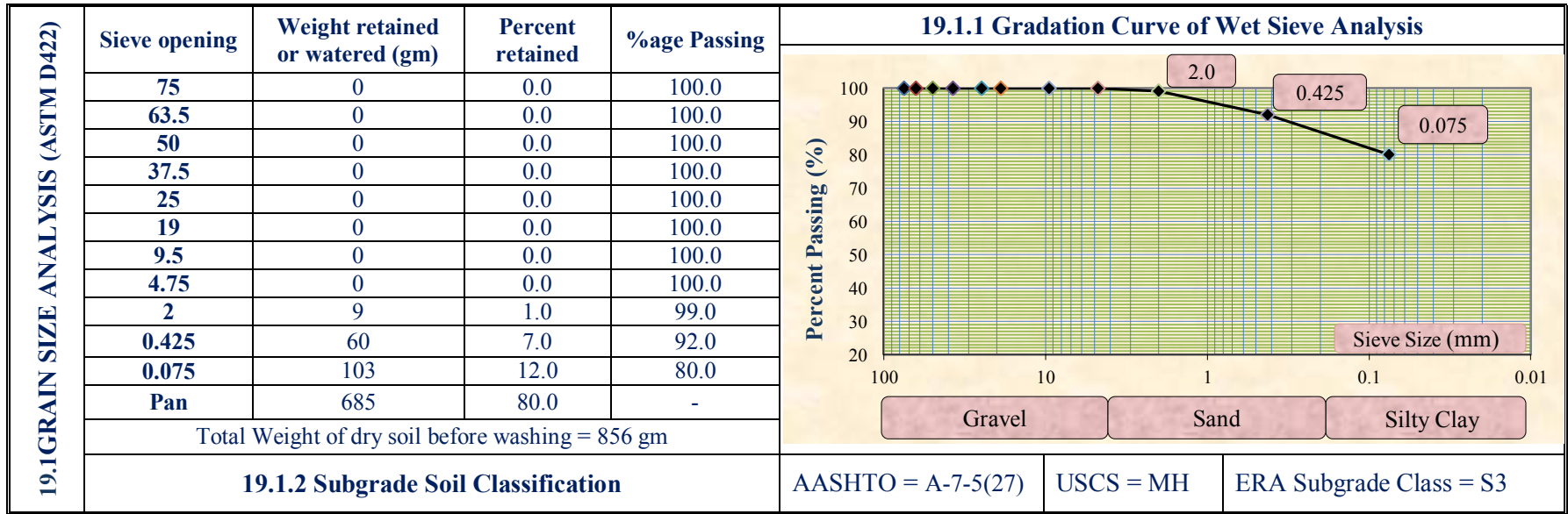
18.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0.00	0	0.00			
0.64	4	0.22	7	0.38	15	0.75			
1.27	7	0.39	12	0.62	19	1.00			
1.96	10	0.51	14	0.73	22	1.14			
2.54	11	0.60	15	0.78	24	1.23			
3.18	12	0.61	17	0.87	25	1.29			
3.81	13	0.66	18	0.91	26	1.35			
4.45	14	0.70	18	0.95	27	1.38			
5.08	14	0.74	19	0.99	28	1.44			
7.62	16	0.81	22	1.15	31	1.59			

18.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	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	1.40	0.60	0.74	13.2	20.0	4.49	3.68	4.49		
30	1.49	0.78	0.99	13.2	20.0	5.92	4.97	5.92		
65	1.67	1.23	1.44	13.2	20.0	9.27	7.20	9.27		
Before soaking the three samples were remolded with OMC = 26.0%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.40		1.49		1.67				
CBR (%)		4.49		5.92		9.27				

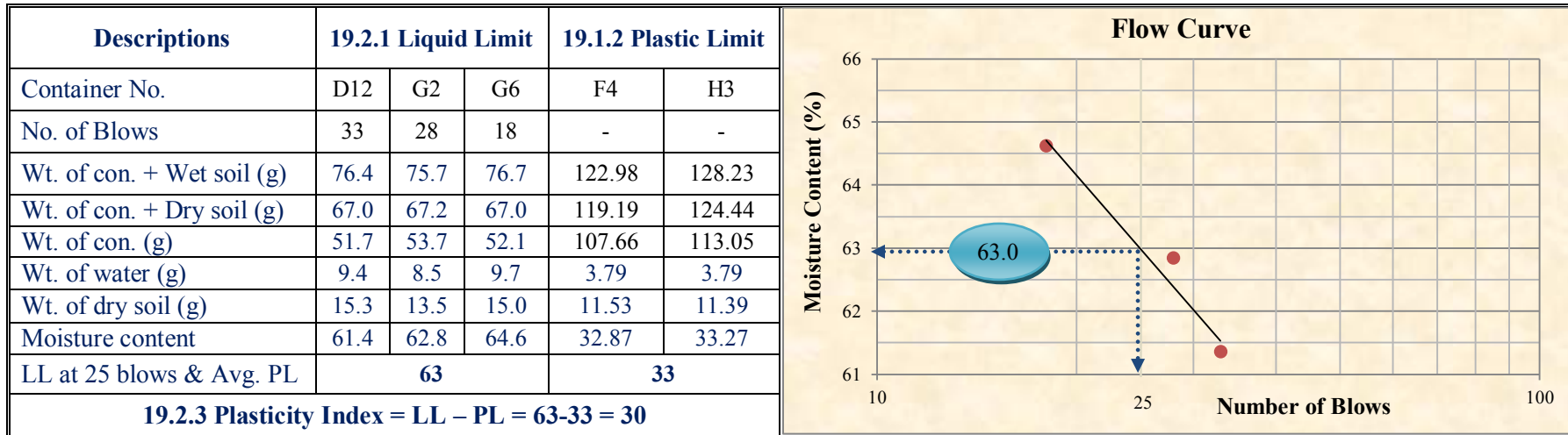
From the Density-CBR Curve at 95% MDD (1.45 g/cm³): CBR = 5.2

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 19 /WY-11/, **Location of Sample:** Winget – Yohanes Road, **Depth of Sampling:** 0.7m, **Soil Description:** Dark Brown clay soil



19.2 ATTERBERG LIMIT TEST (ASTM D 4318)



19.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

19.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H1	C2	D5	H4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	297.77	277.56	267.84	270.12	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.56 g/cm³ and OMC = 27.7 %</p>				
Dry Soil + Con. (g)	262.95	243.19	233.42	232.88					
Mass of Con. (g)	109.31	105.84	107.05	111.73					
Mass of Moisture (g)	34.82	34.37	34.42	37.24					
Dry Soil (g)	153.64	137.35	126.37	121.15					
Moisture cont. (g/cm ³)	22.66	25.02	27.24	30.74					
19.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9186	9439	9624	9489					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3753	4006	4182	4056					
Wet Density (g/cm ³)	1.77	1.89	1.97	1.91					
Dry Density (g/cm ³)	1.44	1.51	1.55	1.46					

19.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

19.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	3	0.14	5	0.28	8	0.42	
1.27	5	0.25	8	0.42	13	0.67	
1.96	7	0.35	10	0.54	16	0.84	
2.54	8	0.41	12	0.63	19	1.00	
3.18	9	0.46	14	0.71	21	1.09	
3.81	11	0.55	15	0.79	23	1.21	
4.45	11	0.59	16	0.84	25	1.30	
5.08	12	0.63	17	0.88	27	1.38	
7.62	16	0.84	21	1.09	30	1.55	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

19.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	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	1.42	0.41	0.63	13.2	20.0	3.06	3.16	3.06	
30	1.49	0.63	0.88	13.2	20.0	4.73	4.40	4.73	
65	1.57	1.00	1.38	13.2	20.0	7.57	6.91	7.57	
Before soaking the three samples were remolded with OMC = 27.7%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.42		1.49		1.57			
CBR (%)		3.06		4.73		7.57			

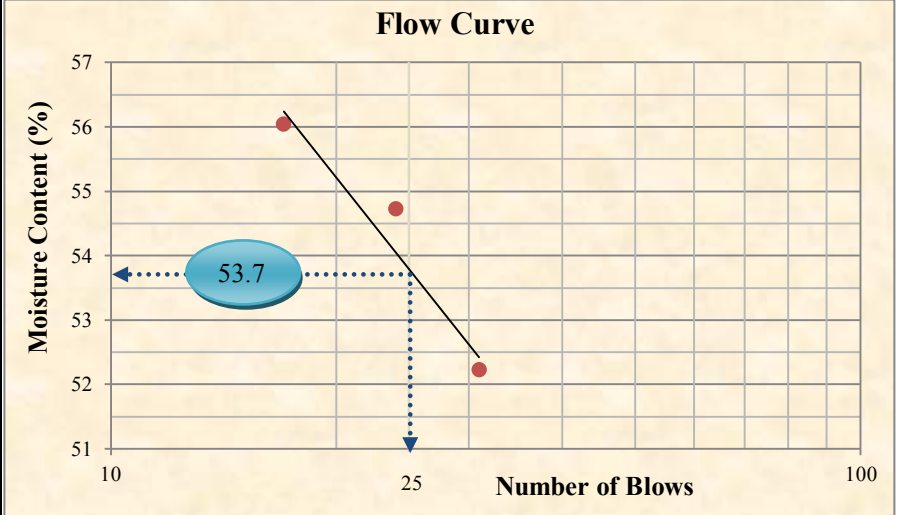
From the Density-CBR Curve at 95% MDD (1.48 g/cm³): **CBR = 4.6**

Sample No.: 20 /TA-1/, **Location of Sample:** Total-Addisugebeya, **Depth of Sampling:** 1.0m, **Soil Description:** Red clay soil

20.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	<p align="center">20.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	0	0.0	100.0	
	0.425	24	3.0	97.0	
	0.075	48	6.0	91.0	
Pan		730	91.0	-	
Total Weight of dry soil before washing = 802 gm					
20.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(24)		USCS = MH		ERA Subgrade Class = S4	

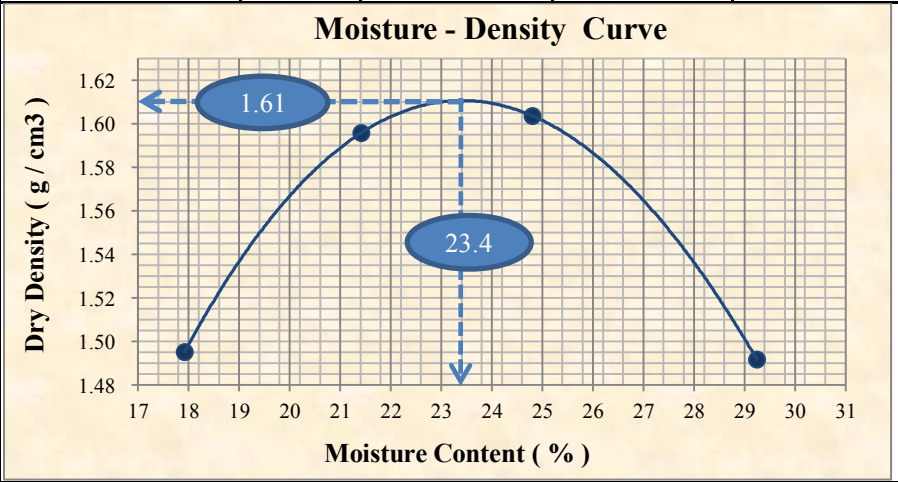
20.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	20.2.1 Liquid Limit			20.2.2 Plastic Limit	
	J6	N9	N2	D4	F6
Container No.	J6	N9	N2	D4	F6
No. of Blows	31	24	17	-	-
Wt. of con. + Wet soil (g)	77.0	80.6	82.3	119.10	87.15
Wt. of con. + Dry soil (g)	69.6	73.4	73.7	117.62	85.53
Wt. of con. (g)	55.5	60.1	58.3	113.05	80.49
Wt. of water (g)	7.4	7.2	8.6	1.48	1.62
Wt. of dry soil (g)	14.2	13.2	15.4	4.57	5.04
Moisture content	52.2	54.7	56.0	32.39	32.14
LL at 25 blows & Avg. PL	54			32	
20.2.3 Plasticity Index = LL – PL = 54 – 32 = 22					



20.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

20.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H1	C2	D5	H4	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	309	295.59	324.62	309.44					
Dry Soil + Con. (g)	278.5	263.27	281.51	265					
Mass of Con. (g)	108.3	112.35	107.7	113.05					
Mass of Moisture (g)	30.5	32.32	43.11	44.44					
Dry Soil (g)	170.2	150.92	173.81	151.95					
Moisture cont. (g/cm ³)	17.92	21.42	24.80	29.25					
20.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9178	9548	9684	9528					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3745	4115	4251	4095					
Wet Density (g/cm ³)	1.76	1.94	2.00	1.93					
Dry Density (g/cm ³)	1.50	1.60	1.60	1.49					



From the compaction curve: **MDD = 1.61 g/cm³** and **OMC = 23.4 %**

20.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

20.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²			
Penetration (mm)	10 Blows		30 Blows		65 Blows		<div style="text-align: center;"> Load - Penetration Relationship </div>					
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)						
0	0	0.00	0	0.00	0	0.00						
0.64	3	0.17	6	0.31	10	0.53						
1.27	6	0.31	9	0.49	16	0.84						
1.96	9	0.44	12	0.64	22	1.12						
2.54	10	0.50	14	0.73	24	1.25						
3.18	11	0.55	15	0.80	25	1.31						
3.81	11	0.57	16	0.85	26	1.37						
4.45	11	0.59	17	0.90	27	1.41						
5.08	12	0.62	18	0.96	28	1.47						
7.62	14	0.73	21	1.09	31	1.59						
20.4.2 CBR Value at Standard Loads and CBR Test Summary												
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	<div style="text-align: center;"> Density - CBR Curve </div>			
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm					
10	1.40	0.50	0.62	13.2	20.0	3.77	3.13	3.77				
30	1.46	0.73	0.96	13.2	20.0	5.49	4.79	5.49				
65	1.56	1.25	1.47	13.2	20.0	9.45	7.36	9.45				
Before soaking the three samples were remolded with OMC = 23.4%.												
No. of Blows		10		30		65						
DD (g/cm ³)		1.4		1.46		1.56						
CBR (%)		3.77		5.49		9.45						
From the Density-CBR Curve at 95% MDD (1.53 g/cm ³): CBR = 8.4												

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 21 /TA-2/, **Location of Sample:** Total-Addisugebeya, **Depth of Sampling:** 1.2m - 1.5m, **Soil Description:** Dark brown clay soil

21.1.GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	<p align="center">21.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	8	1.0	99.0	
	0.425	33	4.0	95.0	
	0.075	49	6.0	89.0	
	Pan	729	89.0	-	
	Total Weight of dry soil before washing = 819 gm				
21.1.2 Subgrade Soil Classification				AASHTO = A-7-6(31) USCS = CH ERA Subgrade Class = S3	

21.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	21.2.1 Liquid Limit			21.1.2 Plastic Limit	
	G10	N6	B2	G4	F1
Container No.	G10	N6	B2	G4	F1
No. of Blows	34	22	17	-	-
Wt. of con. + Wet soil (g)	72.3	63.4	68.5	57.11	52.26
Wt. of con. + Dry soil (g)	65.6	56.8	62.1	55.70	50.92
Wt. of con. (g)	54.1	45.7	51.7	50.59	46.14
Wt. of water (g)	6.7	6.6	6.4	1.41	1.34
Wt. of dry soil (g)	11.6	11.1	10.5	5.11	4.78
Moisture content	57.7	60.0	61.0	27.59	28.03
LL at 25 blows & Avg. PL	59			28	
21.2.3 Plasticity Index = LL - PL = 59-28 = 31					

Flow Curve	
Moisture Content (%)	Number of Blows
62	10
61	
60	
59.2	25
58	
57	
56	100

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

21.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H1	C2	D5	H4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	309	300	351	340	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.58 g/cm³ and OMC = 24.5 %</p>				
Dry Soil + Con. (g)	278.5	268.23	303.5	288.5					
Mass of Con. (g)	108.3	117.8	112.5	110					
Mass of Moisture (g)	30.5	31.77	47.5	51.5					
Dry Soil (g)	170.2	150.43	191	178.5					
Moisture cont. (g/cm ³)	17.92	21.12	24.87	28.85					
21.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9178	9422	9630	9524					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3745	3989	4197	4091					
Wet Density (g/cm ³)	1.76	1.88	1.98	1.93					
Dry Density (g/cm ³)	1.50	1.55	1.58	1.49					

21.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

21.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	3	0.14	5	0.26	10	0.52	
1.27	6	0.29	10	0.49	17	0.89	
1.96	8	0.43	13	0.69	21	1.09	
2.54	10	0.54	16	0.81	23	1.19	
3.18	13	0.67	18	0.95	25	1.32	
3.81	15	0.78	20	1.05	27	1.40	
4.45	16	0.84	21	1.11	28	1.45	
5.08	17	0.89	23	1.17	29	1.50	
7.62	21	1.07	26	1.35	32	1.64	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

21.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	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	1.46	0.54	0.89	13.2	20.0	4.06	4.47	4.06	
30	1.58	0.81	1.17	13.2	20.0	6.12	5.84	6.12	
65	1.63	1.19	1.50	13.2	20.0	9.00	7.53	9.00	
Before soaking the three samples were remolded with OMC = 27.6%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.46		1.58		1.63			
CBR (%)		4.06		6.12		9.00			

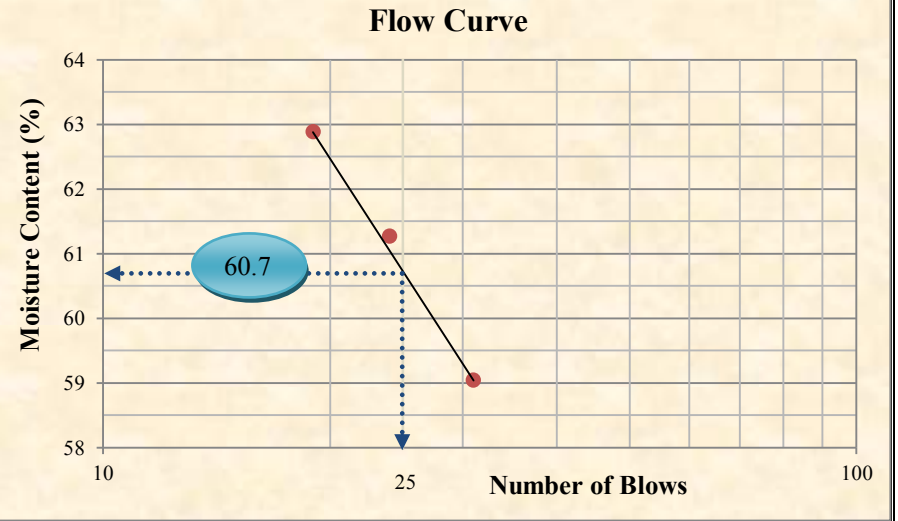
From the Density-CBR Curve at 95% MDD (1.45 g/cm³): **CBR = 4.7**

Sample No.: 22 /TA-3/, **Location of Sample:** Total-Addisugebeya, **Depth of Sampling:** 0.8m, **Soil Description:** Dark Brown Clay soil

22.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	<p align="center">22.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	25	3.0	97.0	
	0.425	68	8.0	89.0	
	0.075	93	11.0	78.0	
Pan	658	78.0	-		
Total Weight of dry soil before washing = 844 gm					
22.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(20)		USCS = MH		ERA Subgrade Class = S2	

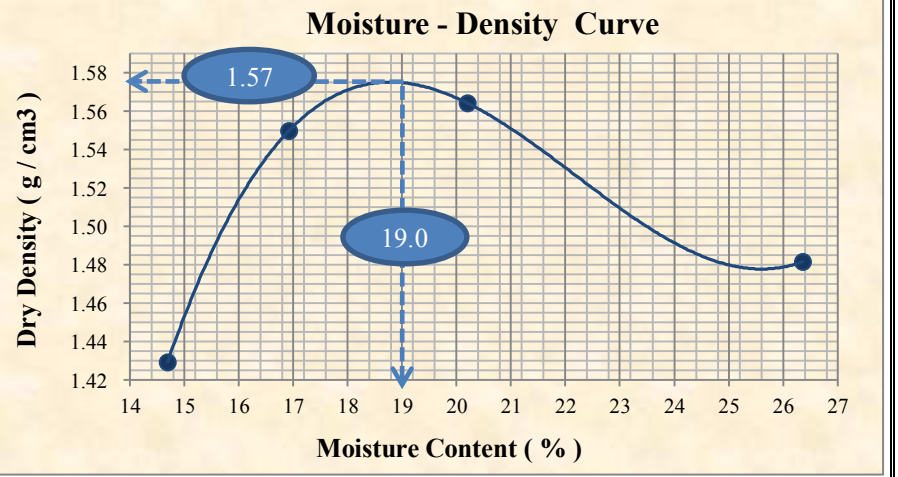
22.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	22.2.1 Liquid Limit			22.2.2 Plastic Limit	
	G10	N6	B2	G4	F1
Container No.	G10	N6	B2	G4	F1
No. of Blows	31	24	19	-	-
Wt. of con. + Wet soil (g)	81.3	75.8	76.8	70.49	70.39
Wt. of con. + Dry soil (g)	71.7	66.2	66.9	65.76	65.57
Wt. of con. (g)	55.4	50.6	51.2	53.92	53.39
Wt. of water (g)	9.6	9.6	9.9	4.73	4.82
Wt. of dry soil (g)	16.3	15.6	15.7	11.84	12.18
Moisture content	59.0	61.3	62.9	39.95	39.57
LL at 25 blows & Avg. PL	61			40	
22.2.3 Plasticity Index = LL – PL = 61 – 40 = 21					



22.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

22.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C3	D4	C8	A2	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	575	557	566	515					
Dry Soil + Con. (g)	512.5	484.5	485.5	425.5					
Mass of Con. (g)	87	56	87	86					
Mass of Moisture (g)	62.5	72.5	80.5	89.5					
Dry Soil (g)	425.5	428.5	398.5	339.5					
Moisture cont. (g/cm ³)	14.69	16.92	20.20	26.36					
22.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8915	9281	9426	9410					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3482	3848	3993	3977					
Wet Density (g/cm ³)	1.64	1.81	1.88	1.87					
Dry Density (g/cm ³)	1.43	1.55	1.56	1.48					



From the compaction curve: **MDD = 1.57 g/cm³** and **OMC = 19.0 %**

22.3 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

22.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p>Load - Penetration Relationship</p>		
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0.00	0	0.00			
0.64	3	0.17	5	0.25	6	0.33			
1.27	6	0.30	8	0.42	10	0.52			
1.96	8	0.43	10	0.54	12	0.63			
2.54	10	0.49	12	0.61	13	0.69			
3.18	11	0.55	13	0.67	15	0.75			
3.81	11	0.60	14	0.71	15	0.79			
4.45	12	0.64	15	0.75	16	0.84			
5.08	13	0.68	15	0.79	17	0.88			
7.62	17	0.89	19	1.00	21	1.09			

22.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	<p>Density - CBR Curve</p>	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.42	0.49	0.68	13.2	20.0	3.73	3.40	3.73		
30	1.52	0.61	0.79	13.2	20.0	4.60	3.98	4.60		
65	1.56	0.69	0.88	13.2	20.0	5.24	4.40	5.24		
Before soaking the three samples were remolded with OMC = 19.0%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.42		1.52		1.56				
CBR (%)		3.73		4.60		5.24				

From the Density-CBR Curve at 95% MDD (1.49 g/cm³): **CBR = 4.3**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 23 /TA-4/, **Location of Sample:** Total-Addisugebeya, **Depth of Sampling:** 1.0m, **Soil Description:** Light Brown clay soil

23.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	<p>23.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	31	2.5	97.5	
	0.425	71	5.8	91.7	
	0.075	163	13.2	78.6	
	Pan	970	78.6	0.0	
	Total Weight of dry soil before washing = 1235gm				
23.1.2 Subgrade Soil Classification					
		AASHTO = A-7-5(27)		USCS = MH	ERA Subgrade Class = S3

23.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	23.2.1 Liquid Limit			23.1.2 Plastic Limit	
	C1	C4	C11	C17	C18
Container No.	C1	C4	C11	C17	C18
No. of Blows	34	27	18		
Wt. of con. + Wet soil (g)	48.5	57.6	56.9	24.1	24.8
Wt. of con. + Dry soil (g)	36.4	41.2	39.9	22.0	22.6
Wt. of con. (g)	16.6	16.7	16.5	16.5	16.7
Wt. of water (g)	12.1	16.4	17.0	2.07	2.22
Wt. of dry soil (g)	19.8	24.5	23.4	5.52	5.89
Moisture content	61.1	66.7	72.4	37.50	37.69
LL at 25 blows & Avg. PL	67			38	
23.2.3 Plasticity Index = LL – PL = 67-38= 37					

Flow Curve

23.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

23.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H1	C2	D5	H4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	296	317	329	327	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.54g/cm³ and OMC = 22 %</p>				
Dry Soil +Con. (g)	262	273	276	269					
Mass of Con. (g)	61	52	58	54					
Mass of Moisture (g)	34	44	53	58					
Dry Soil (g)	201	221	218	215					
Moisture cont. (g/cm ³)	16.92	19.91	24.31	26.98					
23.3.2 Dry Density Determination									
Trial No.	1	2	3	4	<p align="center">Load - Penetration Relationship</p>				
Mold + Wet soil (gm)	9125	9328	9418	9249					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3692	3895	3985	3816					
Wet Density (g/cm ³)	1.74	1.83	1.88	1.80					
Dry Density (g/cm ³)	1.49	1.53	1.51	1.41					

23.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

23.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	5	0.25	7	0.36	9	0.48	
1.27	8	0.40	11	0.55	14	0.70	
1.96	10	0.51	13	0.68	17	0.86	
2.54	11	0.59	15	0.76	19	0.96	
3.18	12	0.64	16	0.81	19	1.00	
3.81	13	0.69	17	0.86	20	1.06	
4.45	14	0.73	17	0.91	21	1.11	
5.08	15	0.77	18	0.95	22	1.15	
7.62	19	1.00	23	1.17	26	1.37	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

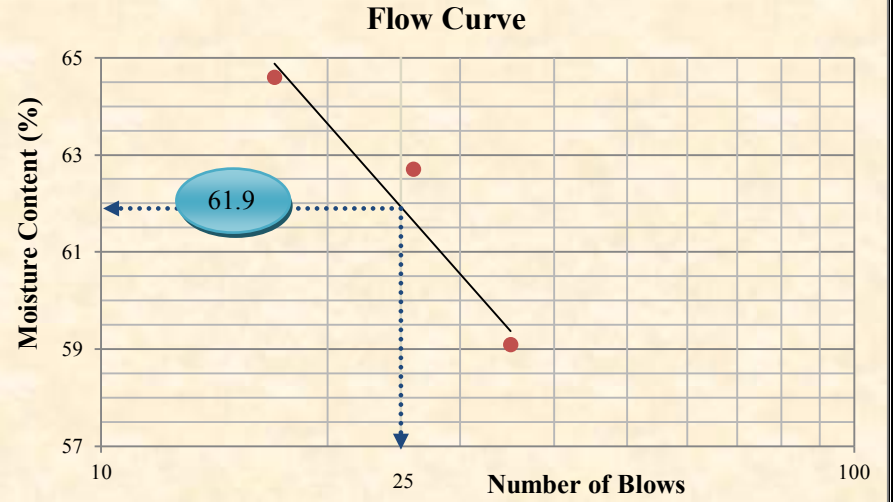
23.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.39	0.59	0.77	13.2	20.0	4.43	3.87	4.43	
30	1.44	0.76	0.95	13.2	20.0	5.75	4.75	5.75	
65	1.50	0.96	1.15	13.2	20.0	7.26	5.75	7.26	
Before soaking the three samples were remolded with OMC = 22.0%.									
No. of Blows	10	30		65					
DD (g/cm ³)	1.39	1.44		1.50					
CBR (%)	4.43	5.75		7.26					
From the Density-CBR Curve at 95% MDD (1.46g/cm ³): CBR = 6.2									

Sample No.: 24 /TA-5/, **Location of Sample:** Total-Addisugebeya, **Depth of Sampling:** 0.8m, **Soil Description:** Light Brown clay soil

24.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	<p align="center">24.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	19	2.2	97.8	
	0.425	70	8.1	89.7	
	0.075	121	14.0	75.7	
Pan	656	75.7	-		
Total Weight of dry soil before washing = 866 gm					
24.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(23)		USCS = MH		ERA Subgrade Class = S3	

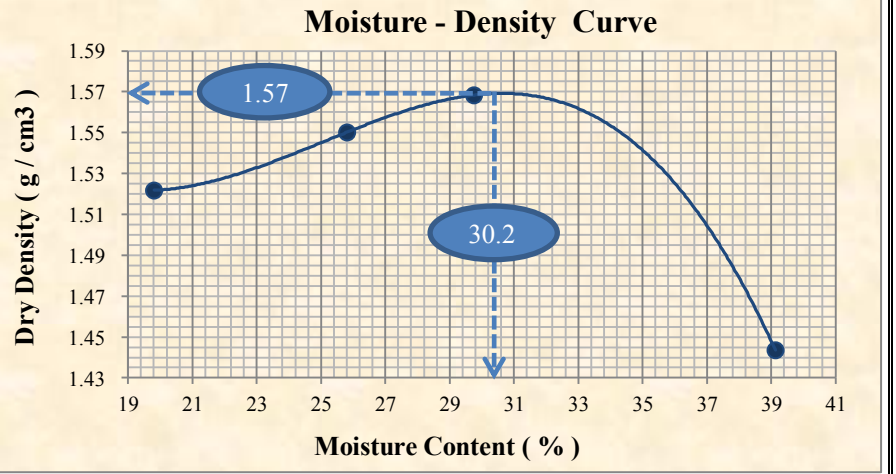
24.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	24.2.1 Liquid Limit			24.2.2 Plastic Limit	
	P1	C7	C15	C19	A5
Container No.	P1	C7	C15	C19	A5
No. of Blows	35	26	17		
Wt. of con. + Wet soil (g)	57.7	52.4	58.2	29.0	34.0
Wt. of con. + Dry soil (g)	42.5	38.6	41.9	25.9	30.5
Wt. of con. (g)	16.7	16.6	16.7	16.7	20.7
Wt. of water (g)	15.3	13.8	16.3	3.15	3.43
Wt. of dry soil (g)	25.8	22.0	25.2	9.22	9.81
Moisture content	59.1	62.7	64.6	34.16	34.96
LL at 25 blows & Avg. PL	62			35	
24.2.3 Plasticity Index = LL - PL = 62 - 35 = 27					



24.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

24.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	D2	B4	B3	H4	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	176	210	212	216					
Dry Soil + Con. (g)	156	178	176	171					
Mass of Con. (g)	55	54	55	56					
Mass of Moisture (g)	20	32	36	45					
Dry Soil (g)	101	124	121	115					
Moisture cont. (g/cm ³)	19.80	25.81	29.75	39.13					
24.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9305	9575	9755	9699					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3872	4142	4322	4266					
Wet Density (g/cm ³)	1.82	1.95	2.03	2.01					
Dry Density (g/cm ³)	1.52	1.55	1.57	1.44					



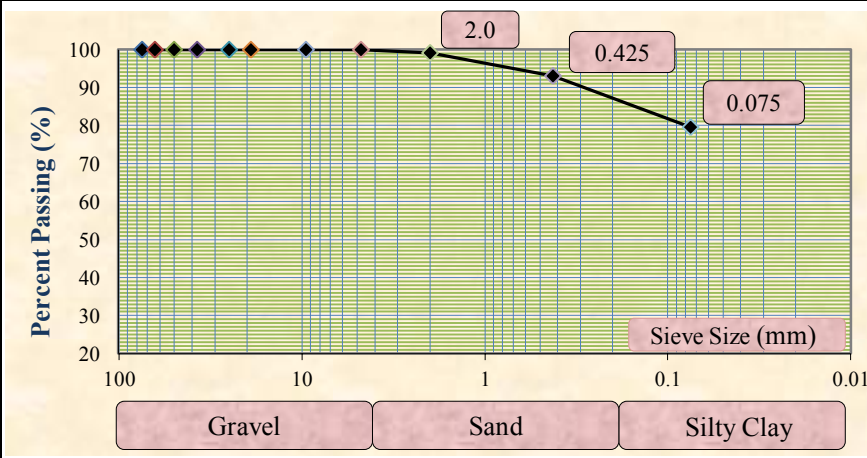
From the compaction curve: **MDD = 1.57 g/cm³** and **OMC = 30.2 %**

24.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

27.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00			
0.64	5	0.26	7	0.35	9	0.48			
1.27	8	0.41	11	0.58	14	0.75			
1.96	10	0.54	14	0.73	18	0.93			
2.54	12	0.62	17	0.86	21	1.08			
3.18	14	0.72	18	0.96	23	1.17			
3.81	15	0.77	19	1.01	24	1.22			
4.45	15	0.79	20	1.03	24	1.24			
5.08	16	0.83	21	1.07	25	1.28			
7.62	18	0.92	22	1.16	26	1.37			
24.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve		
No. of Blows	DD (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	1.40	0.62	0.83	13.2	20.0	4.71	4.14	4.71	
30	1.50	0.86	1.07	13.2	20.0	6.50	5.33	6.50	
65	1.59	1.08	1.28	13.2	20.0	8.12	6.41	8.12	
Before soaking the three samples were remolded with OMC = 30.2%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.40		1.50		1.59			
CBR (%)		4.71		6.5		8.12			
From the Density-CBR Curve at 95% MDD (1.49 g/cm ³): CBR = 6.4									

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

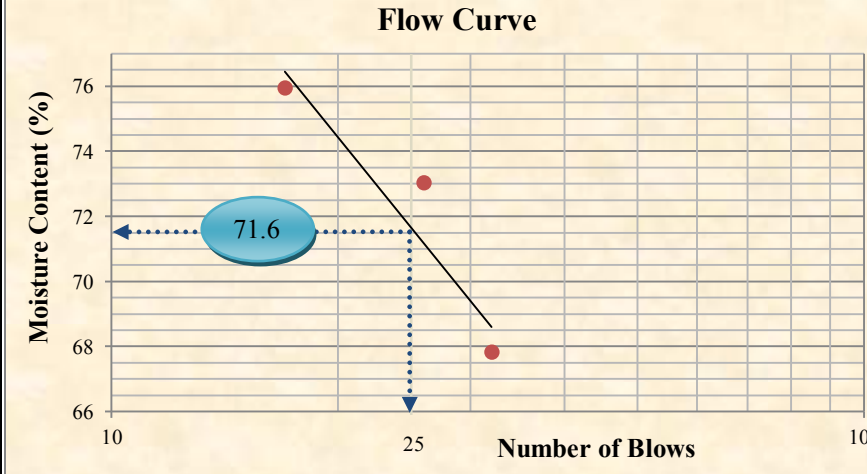
Sample No.: 25 /KA-1/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 1.5m, **Soil Description:** Dark clay soil

25.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	<p>25.1.1 Gradation Curve of Wet Sieve Analysis</p> 
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	8	0.9	99.1	
	0.425	59	6.2	92.9	
	0.075	128	13.4	79.5	
	Pan	759	79.5	0.0	
	Total Weight of dry soil before washing = 954 gm				
25.1.2 Subgrade Soil Classification					
		AASHTO = A-7-5(33)		USCS = MH	ERA Subgrade Class = S2

25.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	25.2.1 Liquid Limit			25.1.2 Plastic Limit	
	A3	A2	A1	A5	A6
Container No.	A3	A2	A1	A5	A6
No. of Blows	32	26	17	-	-
Wt. of con. + Wet soil (g)	53.3	57.2	52.8	31.6	31.2
Wt. of con. + Dry soil (g)	40.1	42.1	39.1	28.8	28.5
Wt. of con. (g)	20.8	21.4	21.1	20.8	20.9
Wt. of water (g)	13.1	15.1	13.7	2.80	2.68
Wt. of dry soil (g)	19.4	20.7	18.0	8.00	7.62
Moisture content	67.8	73.0	75.9	35.00	35.17
LL at 25 blows & Avg. PL	72			35	
25.2.3 Plasticity Index = LL – PL = 72-35 = 29					

Flow Curve



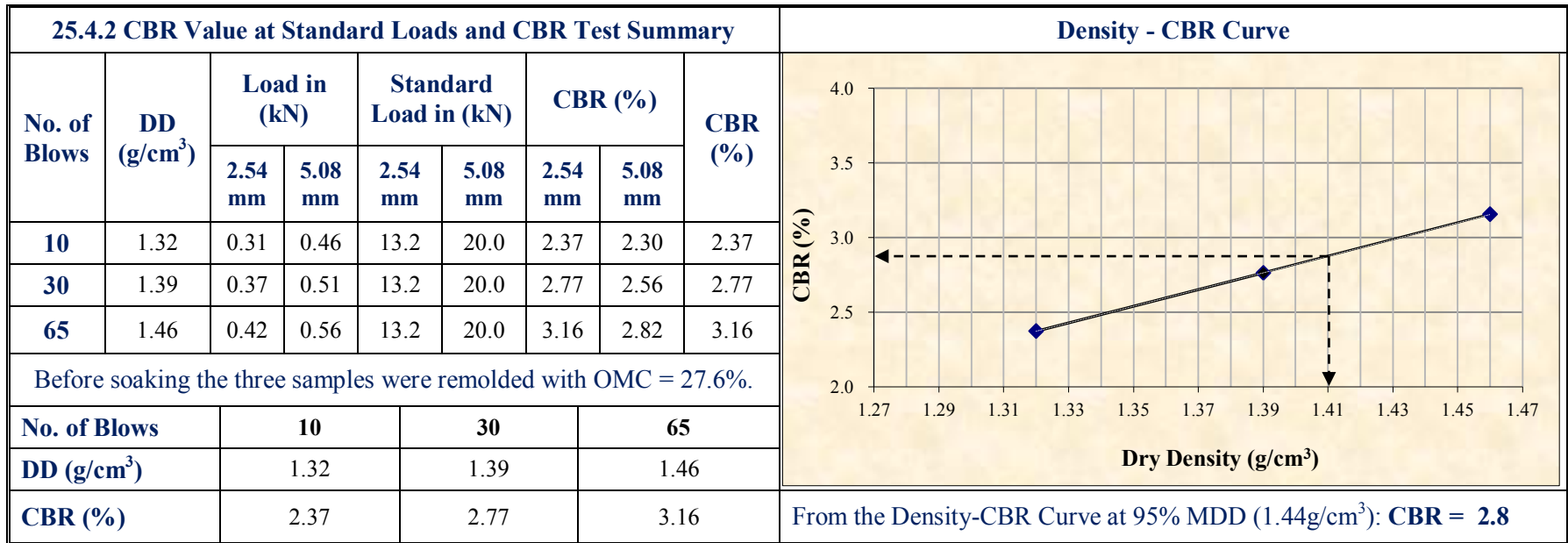
25.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

25.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	H5	H3	G1	H11	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	363.5	414.5	386	377.5	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.48 g/cm³ and OMC = 30.2 %</p>				
Dry Soil + Con. (g)	309	332	312.4	298					
Mass of Con. (g)	64	68	59	63					
Mass of Moisture (g)	54.5	82.5	73.6	79.5					
Dry Soil (g)	245	264	253.4	235					
Moisture cont. (g/cm ³)	22.24	31.25	29.04	33.83					
25.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8745	9532	9465	9240					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3312	4100	4032	3807					
Wet Density (g/cm ³)	1.56	1.93	1.90	1.79					
Dry Density (g/cm ³)	1.28	1.47	1.47	1.34					

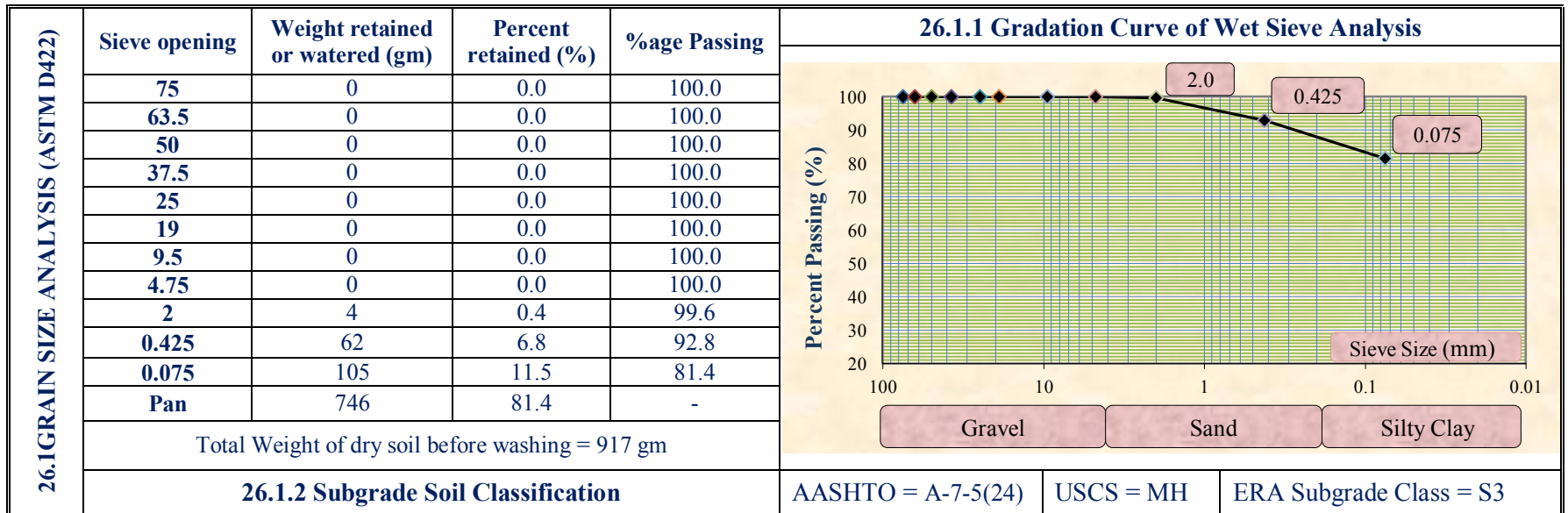
25.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

25.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	<p align="center">Load - Penetration Relationship</p>
0.64	2	0.09	3	0.14	3.7	0.19	
1.27	3	0.17	4	0.23	5.5	0.28	
1.96	5	0.25	6	0.32	7.2	0.37	
2.54	6	0.31	7	0.37	8.1	0.42	
3.18	7	0.36	8	0.41	8.9	0.46	
3.81	7	0.39	8	0.44	9.5	0.49	
4.45	8	0.42	9	0.48	10.2	0.53	
5.08	9	0.46	10	0.51	10.9	0.56	
7.62	11	0.56	12	0.61	12.7	0.66	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

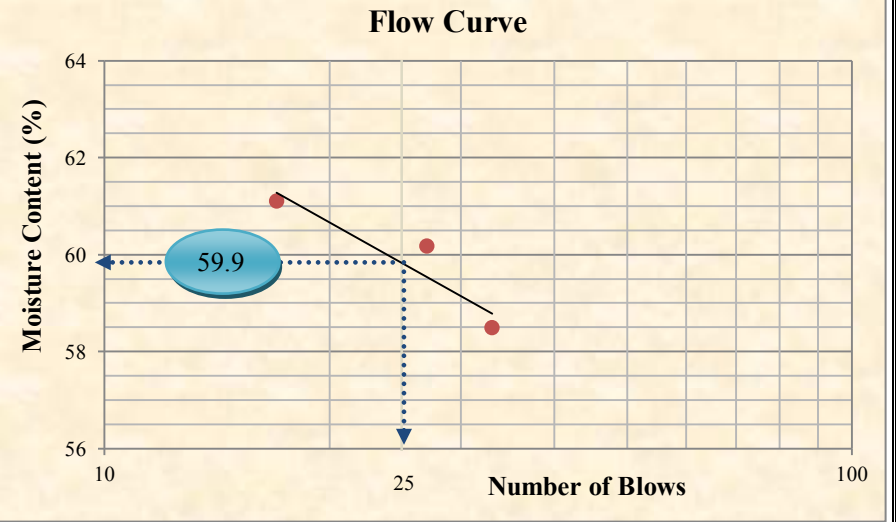


Sample No.: 26 /KA-2/, Location of Sample: Kolfe Area, Depth of Sampling: 1.2m - 1.5m, Soil Description: Light Brown clay soil



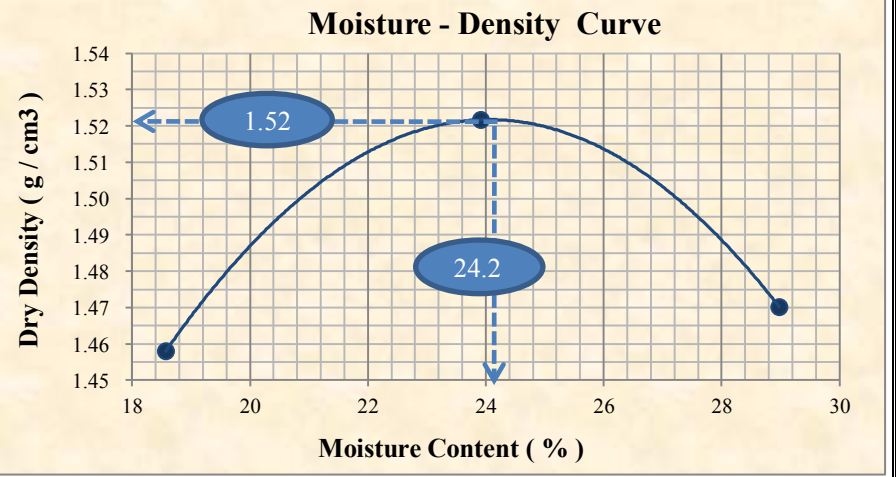
26.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	26.2.1 Liquid Limit			26.2.2 Plastic Limit	
	C14	C2	C9	C13	C20
Container No.	C14	C2	C9	C13	C20
No. of Blows	33	27	17	-	-
Wt. of con. + Wet soil (g)	48.6	51.9	50.0	26.5	26.8
Wt. of con. + Dry soil (g)	36.8	38.6	37.3	24.0	24.1
Wt. of con. (g)	16.5	16.6	16.6	16.6	16.4
Wt. of water (g)	11.9	13.3	12.7	2.58	2.70
Wt. of dry soil (g)	20.3	22.1	20.7	7.38	7.65
Moisture content	58.5	60.2	61.1	34.96	35.29
LL at 25 blows & Avg. PL	60			35	
26.2.3 Plasticity Index = LL – PL = 60 – 35 = 25					



26.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

26.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	D6	D3	F4	H12	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	345.5	392.5	368	359.5					
Dry Soil + Con. (g)	300	316	307.4	289					
Mass of Con. (g)	55	52	54	54					
Mass of Moisture (g)	45.5	76.5	60.6	70.5					
Dry Soil (g)	245	264	253.4	235					
Moisture cont. (g/cm ³)	18.57	28.98	23.91	30.00					
26.3.2 Dry Density Determination									
Trial No.	1	3	4	2					
Mold + Wet soil (gm)	9105	9460	9438	9465					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3672	4028	4005	4032					
Wet Density (g/cm ³)	1.73	1.90	1.89	1.90					
Dry Density (g/cm ³)	1.46	1.47	1.52	1.46					



From the compaction curve: **MDD = 1.52 g/cm³** and **OMC = 24.2 %**

26.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

26.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0.00	0	0.00			
0.64	3	0.15	5	0.27	7	0.39			
1.27	5	0.24	9	0.45	13	0.66			
1.96	7	0.36	11	0.59	16	0.82			
2.54	8	0.43	13	0.68	18	0.96			
3.18	9	0.48	14	0.74	20	1.03			
3.81	10	0.50	15	0.78	21	1.10			
4.45	10	0.52	16	0.82	22	1.15			
5.08	10	0.54	17	0.87	23	1.19			
7.62	12	0.63	19	0.99	26	1.36			

26.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	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	1.32	0.43	0.54	13.2	20.0	3.27	2.72	3.27		
30	1.42	0.68	0.87	13.2	20.0	5.14	4.36	5.14		
65	1.51	0.96	1.19	13.2	20.0	7.23	5.96	7.23		
Before soaking the three samples were remolded with OMC = 24.2%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.32		1.42		1.51				
CBR (%)		3.27		5.14		7.23				

From the Density-CBR Curve at 95% MDD (1.44 g/cm³): CBR = 5.8

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 27 /KA-3/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 1.2m - 1.5m, **Soil Description:** Light gray soil

27.1GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	<p>27.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	25	2.5	97.5	
	0.425	52	5.2	92.3	
	0.075	105	10.6	81.7	
	Pan	810	81.7	-	
	Total Weight of dry soil before washing =992 gm				
27.1.2 Subgrade Soil Classification					
		AASHTO = A-7-5(25)		USCS = MH	ERA Subgrade Class = S2

27.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	27.2.1 Liquid Limit			27.1.2 Plastic Limit	
	C13	A6	C7	A9	C10
Container No.	C13	A6	C7	A9	C10
No. of Blows	31	25	17	-	-
Wt. of con. + Wet soil (g)	58.7	58.7	61.0	29.6	28.6
Wt. of con. + Dry soil (g)	43.8	43.2	44.7	25.6	24.9
Wt. of con. (g)	21.2	20.5	21.5	16.5	16.6
Wt. of water (g)	15.0	15.5	16.4	4.00	3.64
Wt. of dry soil (g)	22.6	22.7	23.1	9.11	8.31
Moisture content	66.2	68.4	70.7	43.91	43.80
LL at 25 blows & Avg. PL	68			44	
27.2.3 Plasticity Index = LL - PL = 68-44 = 24					

Flow Curve	
Moisture Content (%)	Number of Blows

27.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

27.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B4	B8	C5	B1	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	346	359	359	353	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.50 g/cm³ and OMC = 28.4 %</p>				
Dry Soil +Con. (g)	286	294	287.5	279					
Mass of Con. (g)	51	54	52	52					
Mass of Moisture (g)	60	65	71.5	74					
Dry Soil (g)	235	240	235.5	227					
Moisture cont. (g/cm ³)	25.53	27.08	30.36	32.60					
27.3.2 Dry Density Determination									
Trial No.	1	3	4	2	<p align="center">Load - Penetration Relationship</p>				
Mold + Wet soil (gm)	9098	9418	9503	9391					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3665	3985	4070	3958					
Wet Density (g/cm ³)	1.73	1.88	1.92	1.86					
Dry Density (g/cm ³)	1.37	1.48	1.47	1.41					

27.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

27.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	2	0.11	3	0.17	5	0.23	
1.27	4	0.20	5	0.28	7	0.38	
1.96	5	0.28	7	0.39	10	0.51	
2.54	6	0.32	8	0.44	12	0.60	
3.18	7	0.35	9	0.49	13	0.69	
3.81	7	0.37	10	0.53	15	0.77	
4.45	8	0.39	11	0.58	16	0.81	
5.08	8	0.41	12	0.62	17	0.87	
7.62	10	0.49	14	0.73	19	0.99	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

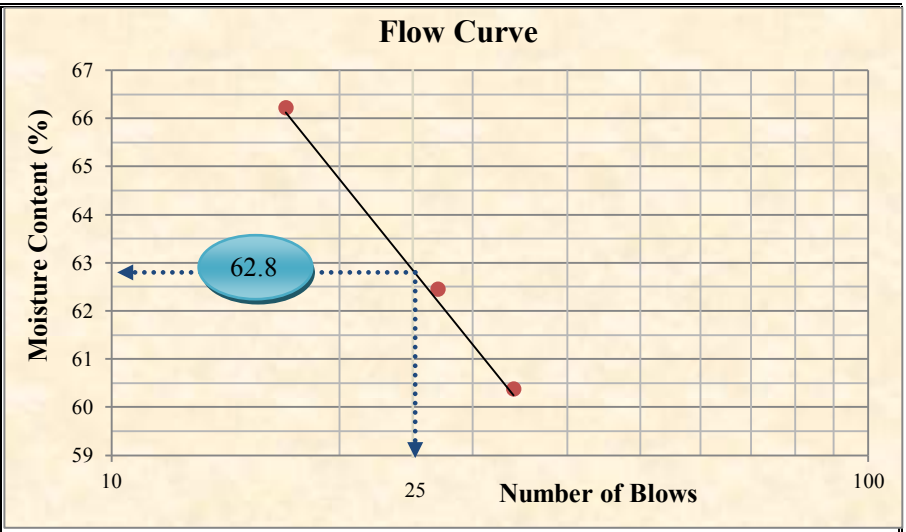
27.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)		
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.36	0.32	0.41	13.2	20.0	2.39	2.05	2.39		
30	1.42	0.44	0.62	13.2	20.0	3.29	3.09	3.29		
65	1.49	0.60	0.87	13.2	20.0	4.50	4.34	4.50		
Before soaking the three samples were remolded with OMC = 28.4%.										
No. of Blows	10	30	65							
DD (g/cm³)	1.36	1.42	1.49							
CBR (%)	2.39	3.29	4.50							
From the Density-CBR Curve at 95% MDD (1.43 g/cm ³): CBR = 3.6										

Sample No.: 28 /KA-4/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 1.2m, **Soil Description:** Light Brown clay soil

28.1GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	15	1.6	98.4	
	0.425	42	4.3	94.1	
	0.075	121	12.6	81.5	
	Pan	781	81.5	0.0	
	Total Weight of dry soil before washing =958 gm				
28.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(23)		USCS = MH		ERA Subgrade Class = S3	

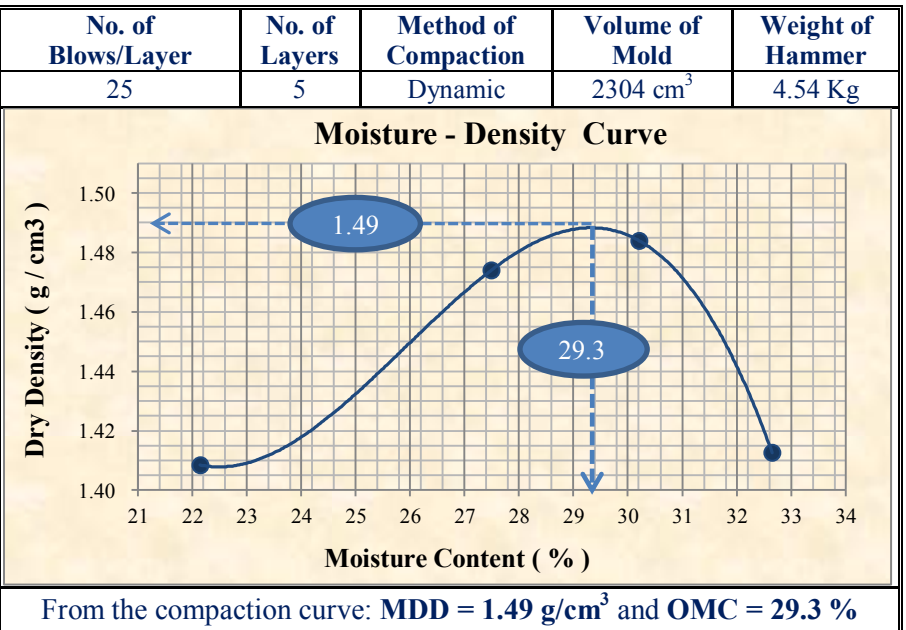
28.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	28.2.1 Liquid Limit			28.2.2 Plastic Limit	
	C5	C6	C8	C12	C16
Container No.	C5	C6	C8	C12	C16
No. of Blows	34	27	17		
Wt. of con. + Wet soil (g)	55.3	54.4	58.1	31.2	30.9
Wt. of con. + Dry soil (g)	40.7	39.8	41.5	27.2	26.7
Wt. of con. (g)	16.6	16.5	16.4	16.7	16.6
Wt. of water (g)	14.6	14.6	16.6	4.02	4.21
Wt. of dry soil (g)	24.2	23.3	25.1	10.49	10.17
Moisture content	60.4	62.4	66.2	38.32	41.40
LL at 25 blows & Avg. PL	63			40	
28.2.3 Plasticity Index = LL – PL = 63 – 40 = 23					



28.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

28.3.1 Moisture Content Determination				
Container No.	D3	D2	D6	C2
Wet Soil + Con. (g)	406	437	439	455
Dry Soil + Con. (g)	344	357	352	359
Mass of Con. (g)	64	66	64	65
Mass of Moisture (g)	62	80	87	96
Dry Soil (g)	280	291	288	294
Moisture cont. (g/cm ³)	22.14	27.49	30.21	32.65
28.3.2 Dry Density Determination				
Trial No.	1	3	4	2
Mold + Wet soil (gm)	9087	9425	9537	9413
Mold (gm)	5433	5433	5433	5433
Volume (cm ³)	2124	2124	2124	2124
Wet Soil (gm)	3654	3992	4104	3980
Wet Density (g/cm ³)	1.72	1.88	1.93	1.87
Dry Density (g/cm ³)	1.41	1.47	1.48	1.41



28.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

28.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0	0	0			
0.64	4	0.22	6	0.30	8	0.44			
1.27	7	0.35	9	0.45	12	0.63			
1.96	8	0.43	11	0.56	15	0.76			
2.54	9	0.49	12	0.62	16	0.82			
3.18	11	0.55	13	0.68	17	0.89			
3.81	11	0.58	14	0.73	18	0.94			
4.45	12	0.60	15	0.77	19	0.98			
5.08	12	0.64	15	0.80	19	1.00			
7.62	13	0.69	16	0.85	20	1.05			
28.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve		
No. of Blows	DD (g/cm ³)	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	1.33	0.49	0.64	13.2	20.0	3.71	3.19	3.71	
30	1.38	0.62	0.80	13.2	20.0	4.71	4.00	4.71	
65	1.49	0.82	1.00	13.2	20.0	6.21	5.01	6.21	
Before soaking the three samples were remolded with OMC = 29.3%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.33		1.38		1.49			
CBR (%)		3.71		4.71		6.21			
From the Density-CBR Curve at 95% MDD (1.42 g/cm ³): CBR = 5.3									

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 29 /KA-5/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 2.0m, **Soil Description:** Dark clay soil

29.1GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing
	75	0	0.0	100.0
	63.5	0	0.0	100.0
	50	0	0.0	100.0
	37.5	0	0.0	100.0
	25	0	0.0	100.0
	19	0	0.0	100.0
	9.5	0	0.0	100.0
	4.75	0	0.0	100.0
	2	19	2.1	97.9
	0.425	47	5.3	92.6
	0.075	113	12.6	80.0
	Pan	715	80.0	-
	Total Weight of dry soil before washing = 894 gm			
29.1.2 Subgrade Soil Classification				
		AASHTO = A-7-5(23)	USCS = MH	ERA Subgrade Class = S2

29.1.1 Gradation Curve of Wet Sieve Analysis

29.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	29.2.1 Liquid Limit			29.1.2 Plastic Limit	
	C17	C18	C19	A5	A6
Container No.	C17	C18	C19	A5	A6
No. of Blows	35	27	18	-	-
Wt. of con. + Wet soil (g)	54.1	51.5	51.5	34.0	33.7
Wt. of con. + Dry soil (g)	41.0	38.6	37.7	30.7	30.4
Wt. of con. (g)	16.5	16.7	16.7	20.7	20.9
Wt. of water (g)	13.2	12.9	13.8	3.36	3.27
Wt. of dry soil (g)	24.5	21.9	21.1	9.96	9.52
Moisture content	53.7	58.9	65.4	33.73	34.35
LL at 25 blows & Avg. PL	59			34	
29.2.3 Plasticity Index = LL – PL = 59-34 = 25					

Flow Curve

29.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

29.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	C3	C5	C10	C1	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	403	420	425	424	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.50 g/cm³ and OMC = 22.9 %</p>				
Dry Soil + Con. (g)	350	360	358	353					
Mass of Con. (g)	68	71	65	69					
Mass of Moisture (g)	53	60	67	71					
Dry Soil (g)	282	289	293	284					
Moisture cont. (g/cm ³)	18.79	20.76	22.87	25.00					
29.3.2 Dry Density Determination									
Trial No.	1	3	4	2					
Mold + Wet soil (gm)	8907	9159	9346	9188					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3474	3726	3913	3755					
Wet Density (g/cm ³)	1.64	1.75	1.84	1.77					
Dry Density (g/cm ³)	1.38	1.45	1.50	1.41					

29.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

29.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	<p align="center">Load - Penetration Relationship</p>
0.64	3	0.14	4	0.19	5	0.27	
1.27	4	0.22	6	0.30	8	0.41	
1.96	6	0.29	7	0.39	10	0.51	
2.54	7	0.35	9	0.45	11	0.59	
3.18	8	0.40	10	0.53	12	0.64	
3.81	9	0.45	11	0.57	13	0.70	
4.45	9	0.49	12	0.61	14	0.74	
5.08	10	0.52	12	0.64	15	0.76	
7.62	11	0.57	14	0.70	16	0.82	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

29.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	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	1.38	0.35	0.52	13.2	20.0	2.60	2.60	2.60	
30	1.41	0.45	0.64	13.2	20.0	3.41	3.21	3.41	
65	1.52	0.59	0.76	13.2	20.0	4.42	3.83	4.42	
Before soaking the three samples were remolded with OMC = 22.9%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.38		1.41		1.52			
CBR (%)		2.6		3.41		4.42			

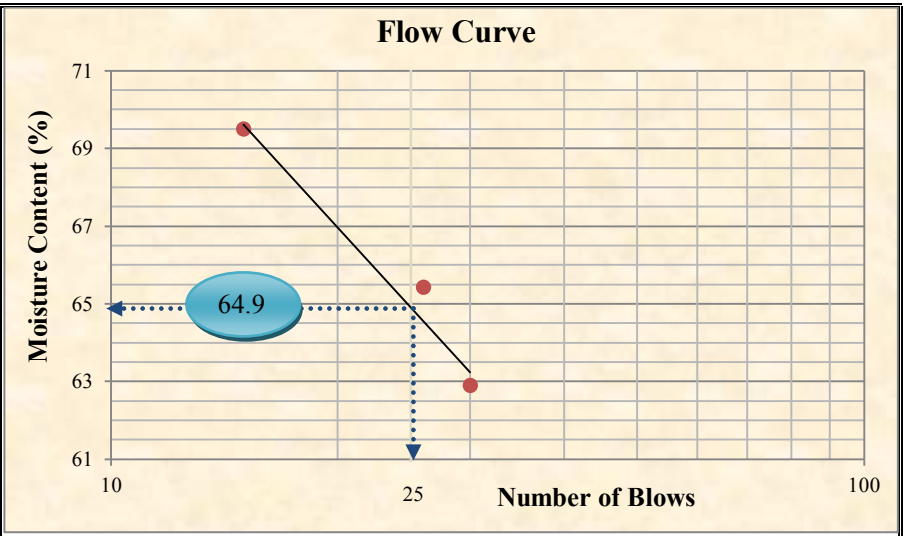
From the Density-CBR Curve at 95% MDD (1.43 g/cm³): **CBR = 3.7**

Sample No.: 30 /KA-6/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 2.5m, **Soil Description:** Dark clay soil

30.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	27	2.8	97.2	
	0.425	56	5.8	91.3	
	0.075	80	8.4	83.0	
	Pan	791	83.0	-	
Total Weight of dry soil before washing = 953 gm					
30.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(32)		USCS = CH		ERA Subgrade Class = S2	

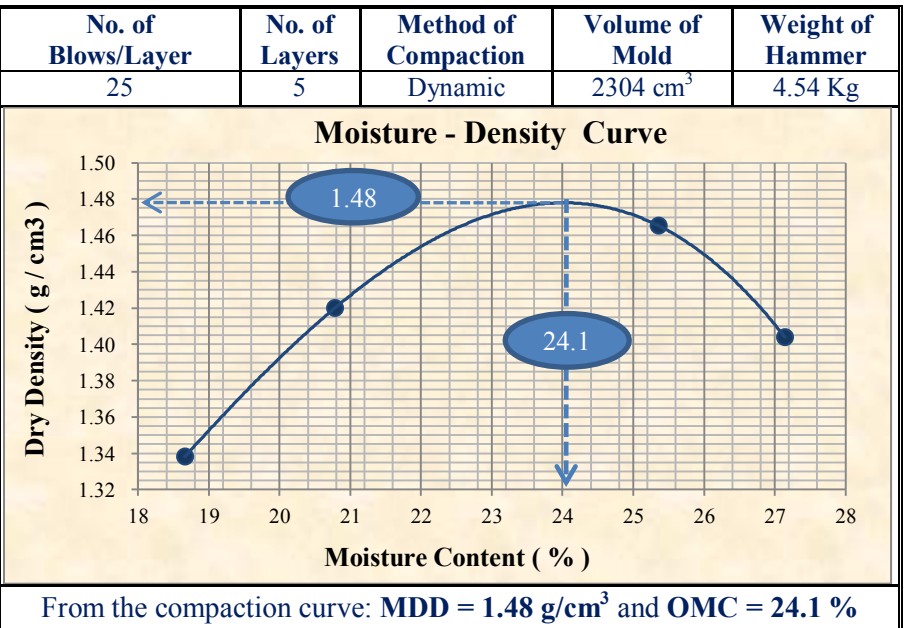
30.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	30.2.1 Liquid Limit			30.2.2 Plastic Limit	
	A7	A33	G4	X22	K11
Container No.	A7	A33	G4	X22	K11
No. of Blows	30	26	15	-	-
Wt. of con. + Wet soil (g)	44.6 5	41.7	36.19	24.35	24.01
Wt. of con. + Dry soil (g)	33.6	31.6	27.8	22.5	22.2
Wt. of con. (g)	16.0	16.1	15.8	16.4	16.3
Wt. of water (g)	11.1	10.1	8.4	1.89	1.82
Wt. of dry soil (g)	17.6	15.5	12.0	6.09	5.86
Moisture content	62.9	65.4	69.5	31.03	31.06
LL at 25 blows & Avg. PL	65			31	
30.2.3 Plasticity Index = LL - PL = 65 - 31 = 34					



30.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

30.3.1 Moisture Content Determination				
Container No.	F9	G4	F6	F3
Wet Soil + Con. (g)	392	395	407	410
Dry Soil + Con. (g)	339	336.5	336	334
Mass of Con. (g)	55	55	56	54
Mass of Moisture (g)	53	58.5	71	76
Dry Soil (g)	284	281.5	280	280
Moisture cont. (g/cm ³)	18.66	20.78	25.36	27.14
30.3.2 Dry Density Determination				
Trial No.	1	2	3	4
Mold + Wet soil (gm)	8806	9076	9335	9224
Mold (gm)	5433	5433	5433	5433
Volume (cm ³)	2124	2124	2124	2124
Wet Soil (gm)	3373	3643	3902	3791
Wet Density (g/cm ³)	1.59	1.72	1.84	1.78
Dry Density (g/cm ³)	1.34	1.42	1.47	1.40



30.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

30.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0.00	0	0.00			
0.64	2	0.12	3	0.16	4	0.22			
1.27	4	0.22	5	0.27	7	0.35			
1.96	6	0.31	7	0.36	9	0.44			
2.54	7	0.37	8	0.42	10	0.51			
3.18	8	0.42	9	0.48	11	0.57			
3.81	9	0.46	10	0.53	12	0.62			
4.45	10	0.50	11	0.57	13	0.66			
5.08	10	0.53	12	0.61	13	0.69			
7.62	12	0.62	14	0.71	15	0.80			
30.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve		
No. of Blows	DD (g/cm ³)	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	1.35	0.37	0.53	13.2	20.0	2.76	2.65	2.76	
30	1.40	0.42	0.61	13.2	20.0	3.15	3.07	3.15	
65	1.49	0.51	0.69	13.2	20.0	3.82	3.46	3.82	
Before soaking the three samples were remolded with OMC = 24.1%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.35		1.40		1.39			
CBR (%)		2.76		3.15		3.82			
							From the Density-CBR Curve at 95% MDD (1.41g/cm ³): CBR = 3.2		

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 31 /KA-7/, **Location of Sample:** Kolfe Area, **Depth of Sampling:** 1.5m, **Soil Description:** Dark Brown clay soil

31.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	<p>31.1.1 Gradation Curve of Wet Sieve Analysis</p>
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	16	2.0	98.0	
	0.425	62	7.7	90.3	
	0.075	79	9.8	80.5	
	Pan	653	80.5	-	
	Total Weight of dry soil before washing =811 gm				
	31.1.2 Subgrade Soil Classification				

31.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	31.2.1 Liquid Limit			31.1.2 Plastic Limit	
	C7	C4	C11	C1	A2
Container No.	C7	C4	C11	C1	A2
No. of Blows	34	24	16	-	-
Wt. of con. + Wet soil (g)	55.1 5	56.4 1	55.23	29.48	34.23
Wt. of con. + Dry soil (g)	42.2	42.5	41.4	26.3	31.0
Wt. of con. (g)	16.6	16.7	16.5	16.6	21.4
Wt. of water (g)	13.0	13.9	13.9	3.23	3.19
Wt. of dry soil (g)	25.6	25.8	24.9	9.68	9.61
Moisture content	50.7	53.9	55.6	33.37	33.19
LL at 25 blows & Avg. PL	53			33	
31.2.3 Plasticity Index = LL – PL = 53-33 = 20					

Flow Curve

31.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

31.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	G5	F2	F8	F4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	385	390	412	403					
Dry Soil + Con. (g)	341	340	352	335					
Mass of Con. (g)	58	57	58	56					
Mass of Moisture (g)	44	50	60	68					
Dry Soil (g)	283	283	294	279					
Moisture cont. (g/cm ³)	15.55	17.67	20.41	24.37					
31.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8858	9017	9249	9173					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3425	3584	3816	3740					
Wet Density (g/cm ³)	1.61	1.69	1.80	1.76					
Dry Density (g/cm ³)	1.40	1.43	1.49	1.42					

From the compaction curve: **MDD = 1.50 g/cm³** and **OMC = 21.4 %**

31.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

31.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	3	0.14	4	0.22	7	0.37	
1.27	6	0.29	9	0.44	11	0.57	
1.96	9	0.45	11	0.59	14	0.72	
2.54	10	0.53	13	0.67	15	0.80	
3.18	12	0.62	14	0.75	16	0.85	
3.81	13	0.67	15	0.79	17	0.90	
4.45	14	0.72	16	0.83	18	0.95	
5.08	15	0.76	17	0.86	19	0.98	
7.62	16	0.81	19	0.97	21	1.08	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

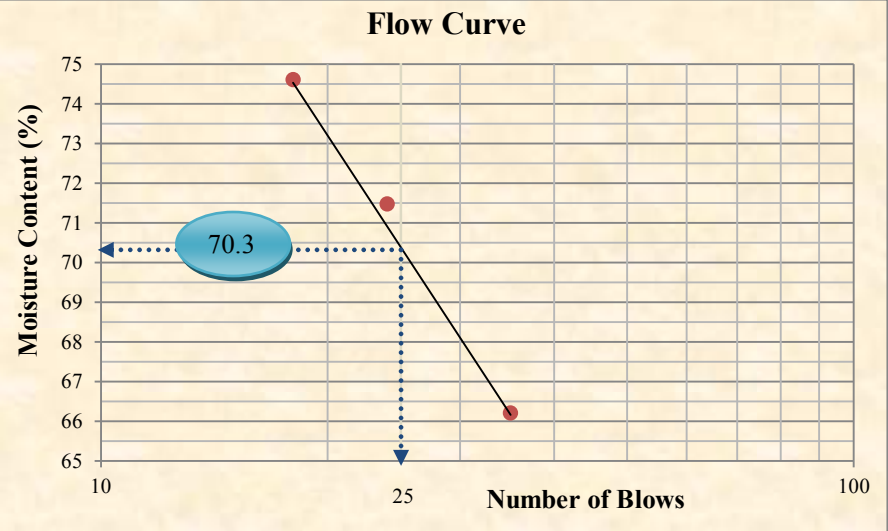
31.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.38	0.53	0.76	13.2	20.0	4.01	3.80	4.01	From the Density-CBR Curve at 95% MDD (1.43g/cm ³): CBR = 5.1
30	1.42	0.67	0.86	13.2	20.0	5.07	4.32	5.07	
65	1.52	0.80	0.98	13.2	20.0	6.05	4.90	6.05	
Before soaking the three samples were remolded with OMC = 21.4%.									
No. of Blows		10		30		65			
DD (g/cm ³)		1.38		1.42		1.52			
CBR (%)		4.01		507		6.05			

Sample No.: 32 /WARR-1/, Location of Sample: Winget-Adisugebeya RR, Depth of Sampling: 1.5m, Soil Description: Dark clay soil

32.1.GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	32.1.1 Gradation Curve of Wet Sieve Analysis
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	7	0.8	99.2	
	0.425	31	3.6	95.6	
	0.075	70	8.1	87.5	
Pan	757	87.5	0.0		
Total Weight of dry soil before washing = 865 gm					
32.1.2 Subgrade Soil Classification					AASHTO = A-7-5(39) USCS = CH ERA Subgrade Class = S2

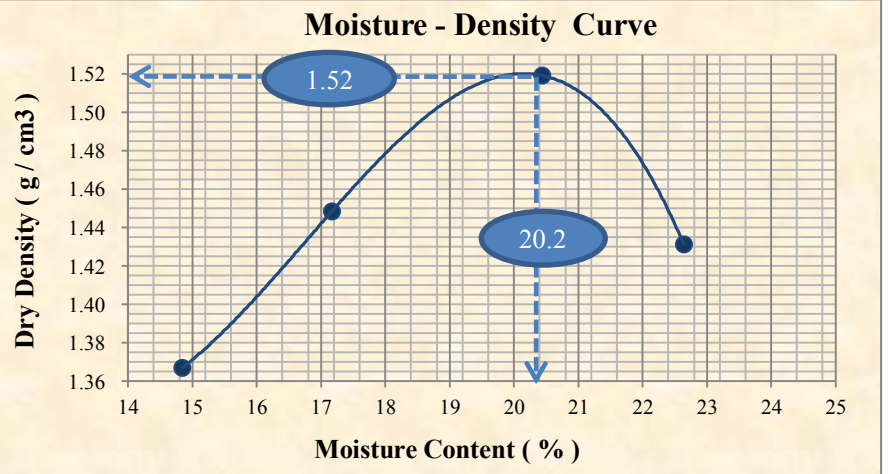
32.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	32.2.1 Liquid Limit			32.2.2 Plastic Limit	
	A4	G7	H4	E4	F5
Container No.	A4	G7	H4	E4	F5
No. of Blows	35	24	18		
Wt. of con. + Wet soil (g)	56.7	57.8	56.73	29.58	30.33
Wt. of con. + Dry soil (g)	40.2	40.0	39.4	26.3	26.8
Wt. of con. (g)	15.3	15.1	16.1	15.5	15.8
Wt. of water (g)	16.5	17.8	17.4	3.33	3.49
Wt. of dry soil (g)	24.9	24.9	23.3	10.75	11.04
Moisture content	66.2	71.5	74.6	30.98	31.61
LL at 25 blows & Avg. PL	70			31	
32.2.3 Plasticity Index = LL - PL = 70 - 31 = 39					



32.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

32.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	F6	D8	B10	F11	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	384	389	389	382					
Dry Soil + Con. (g)	342	340.5	333	322					
Mass of Con. (g)	59	58	59	57					
Mass of Moisture (g)	42	48.5	56	60					
Dry Soil (g)	283	282.5	274	265					
Moisture cont. (g/cm ³)	14.84	17.17	20.44	22.64					
32.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	8768	9038	9319	9161					
Mold (gm)	5433	5433	5433	5433					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3335	3605	3886	3728					
Wet Density (g/cm ³)	1.57	1.70	1.83	1.76					
Dry Density (g/cm ³)	1.37	1.45	1.52	1.43					



From the compaction curve: **MDD = 1.52 g/cm³** and **OMC = 20.2 %**

32.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

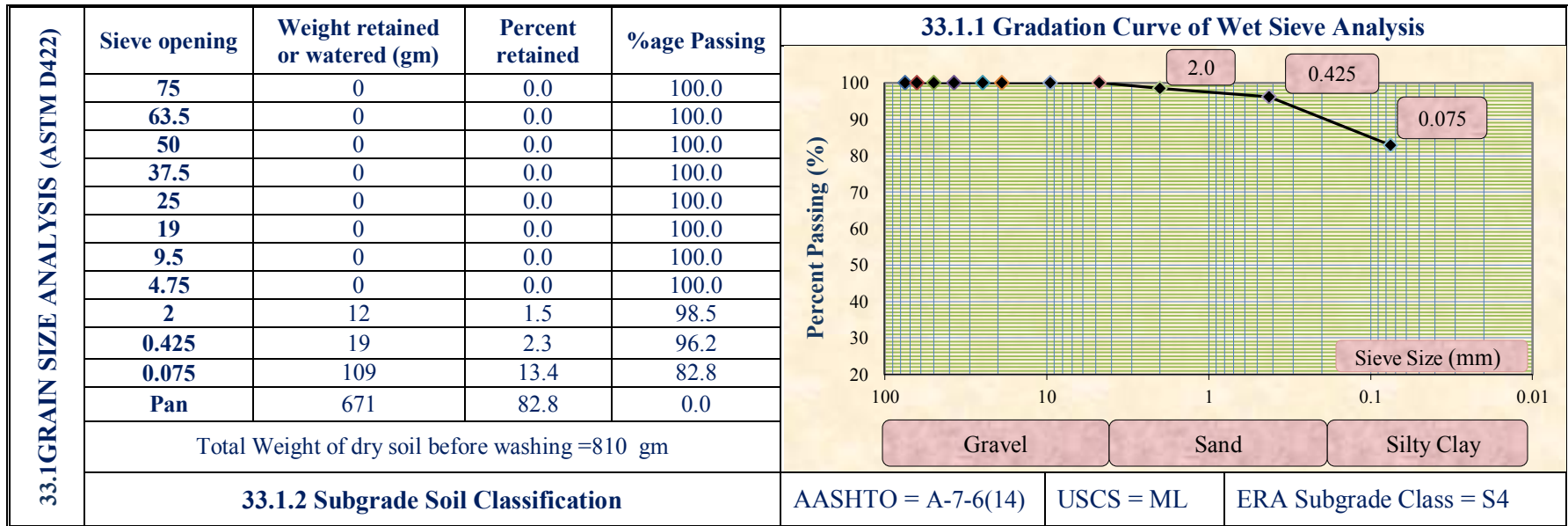
32.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)			
0	0	0.00	0	0.00	0	0.00			
0.64	2	0.12	4	0.19	5	0.24			
1.27	4	0.20	6	0.29	7	0.37			
1.96	5	0.28	7	0.37	9	0.48			
2.54	6	0.33	8	0.43	10	0.54			
3.18	7	0.38	9	0.48	11	0.58			
3.81	8	0.42	10	0.52	12	0.62			
4.45	9	0.45	11	0.56	13	0.66			
5.08	9	0.48	11	0.58	13	0.68			
7.62	11	0.56	13	0.67	15	0.78			

32.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	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	1.38	0.33	0.48	13.2	20.0	2.48	2.38	2.48		
30	1.43	0.43	0.58	13.2	20.0	3.26	2.89	3.26		
65	1.53	0.54	0.68	13.2	20.0	4.05	3.40	4.05		
Before soaking the three samples were remolded with OMC = 20.2%.										
No. of Blows		10		30		65				
DD (g/cm ³)		1.38		1.43		1.53				
CBR (%)		2.48		3.26		4.05				

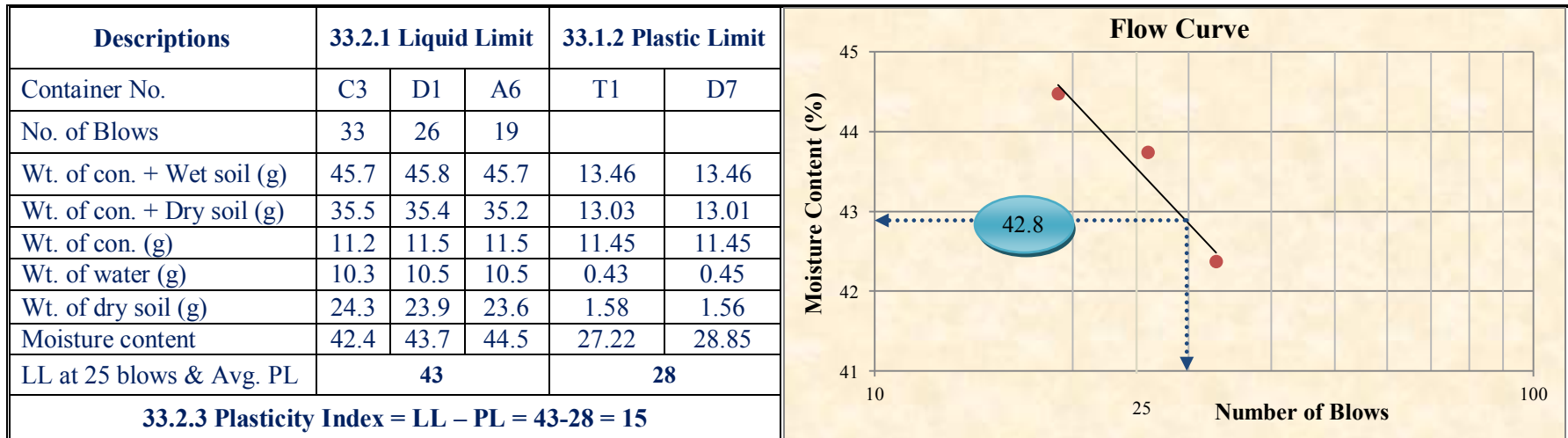
From the Density-CBR Curve at 95% MDD (1.52 g/cm³): **CBR = 3.4**

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 33 /WAARR-2/, **Location of Sample:** Winget-Adisugebeya Ring Road, **Depth of Sampling:** 1.5m, **Soil Description:** Red clay soil



33.2 ATTERBERG LIMIT TEST (ASTM D 4318)



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

33.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B12	F3	B15	F2	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	212	178	227	212	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.61 g/cm³ and OMC = 24.0 %</p>				
Dry Soil + Con. (g)	187	156	190	173					
Mass of Con. (g)	42	42	45	43					
Mass of Moisture (g)	25	22	37	38					
Dry Soil (g)	145.12	114.33	145.27	130.3					
Moisture cont. (g/cm ³)	17.17	19.20	25.22	29.52					
33.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9238	9380	9675	9460					
Mold (gm)	5408	5408	5408	5408					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3830	3972	4267	4052					
Wet Density (g/cm ³)	1.80	1.87	2.01	1.91					
Dry Density (g/cm ³)	1.54	1.57	1.60	1.47					

33.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

33.4.1 Penetration Data (After 4-day soaking)						Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)		
0	0	0.00	0	0.00	0	0.00		
0.64	5	0.26	9	0.47	14	0.72		
1.27	8	0.40	14	0.73	21	1.09		
1.96	10	0.52	18	0.91	27	1.39		
2.54	12	0.63	20	1.06	31	1.60		
3.18	13	0.69	23	1.19	33	1.71		
3.81	15	0.77	25	1.30	35	1.82		
4.45	16	0.83	27	1.40	37	1.93		
5.08	17	0.91	29	1.50	38	1.98		
7.62	24	1.25	35	1.82	45	2.31		

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

33.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/cm ³)	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	1.41	0.63	0.91	13.2	20.0	4.75	4.53	4.75	
30	1.50	1.06	1.50	13.2	20.0	7.96	7.51	7.96	
65	1.63	1.60	1.98	13.2	20.0	12.07	9.91	12.07	
Before soaking the three samples were remolded with OMC = 24.0%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.41		1.50		1.63			
CBR (%)		4.75		7.96		12.07			

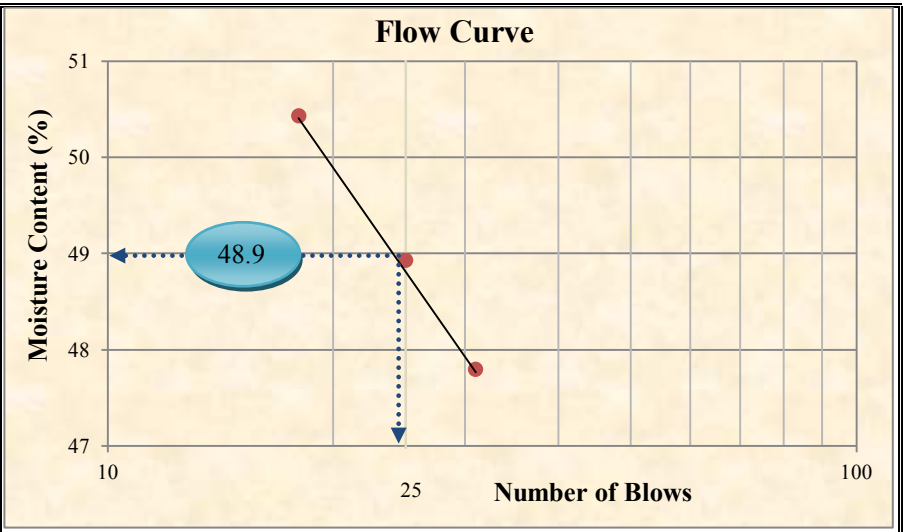
From the Density-CBR Curve at 95% MDD (1.53 g/cm³): **CBR = 9.0**

Sample No: 34 /WARR-3/, Location of Sample: Winget-Adisugebeya RR, Depth of Sampling: 2m, Soil Description: Light Brown Silty clay soil

34.1.GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing	
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	0	0.0	100.0	
	0.425	19	2.3	97.7	
	0.075	87	10.5	87.2	
	Pan	726	87.2	-	
Total Weight of dry soil before washing = 832 gm					<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px;">Gravel</div> <div style="border: 1px solid black; padding: 2px;">Sand</div> <div style="border: 1px solid black; padding: 2px;">Silty Clay</div> </div>
34.1.2 Subgrade Soil Classification					

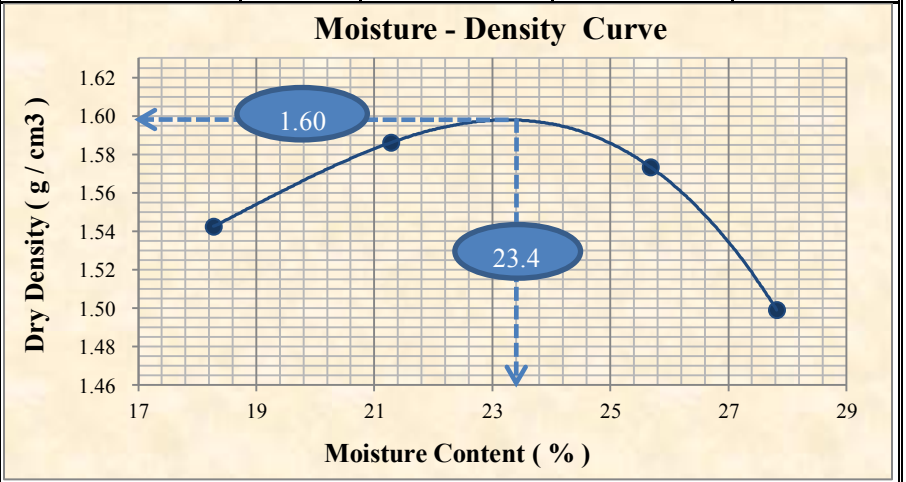
34.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	34.2.1 Liquid Limit			34.2.2 Plastic Limit	
	D1	C3	A6	D7	T1
Container No.	D1	C3	A6	D7	T1
No. of Blows	31	25	18	-	-
Wt. of con. + Wet soil (g)	42.7	42.7	43.0	14.78	14.76
Wt. of con. + Dry soil (g)	32.6	32.5	32.4	14.06	14.05
Wt. of con. (g)	11.5	11.5	11.4	11.45	11.45
Wt. of water (g)	10.1	10.3	10.6	0.72	0.71
Wt. of dry soil (g)	21.1	21.0	21.0	2.61	2.60
Moisture content	47.8	48.9	50.4	27.59	27.31
LL at 25 blows & Avg. PL	49			27	
34.2.3 Plasticity Index = LL – PL = 49 – 27 = 22					



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

34.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B1	B16	B6	B2	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	187	182	185	183					
Dry Soil + Con. (g)	165.26	157.25	156.41	152.87					
Mass of Con. (g)	45.11	41.53	45.05	45.58					
Mass of Moisture (g)	21.96	24.63	28.6	29.85					
Dry Soil (g)	120.15	115.72	111.36	107.29					
Moisture cont. (g/cm ³)	18.28	21.28	25.68	27.82					
34.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9327	9528	9642	9512					
Mold (gm)	5452	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3875	4086	4200	4070					
Wet Density (g/cm ³)	1.82	1.92	1.98	1.92					
Dry Density (g/cm ³)	1.54	1.59	1.57	1.50					



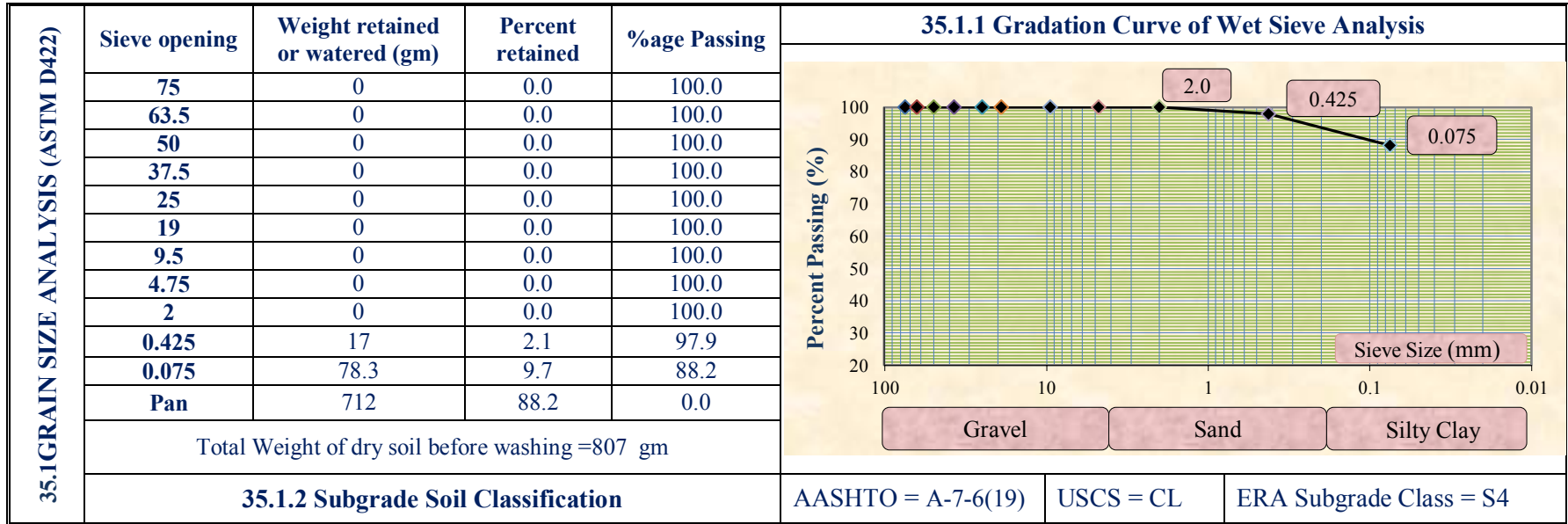
From the compaction curve: **MDD = 1.60 g/cm³** and **OMC = 23.4%**

34.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

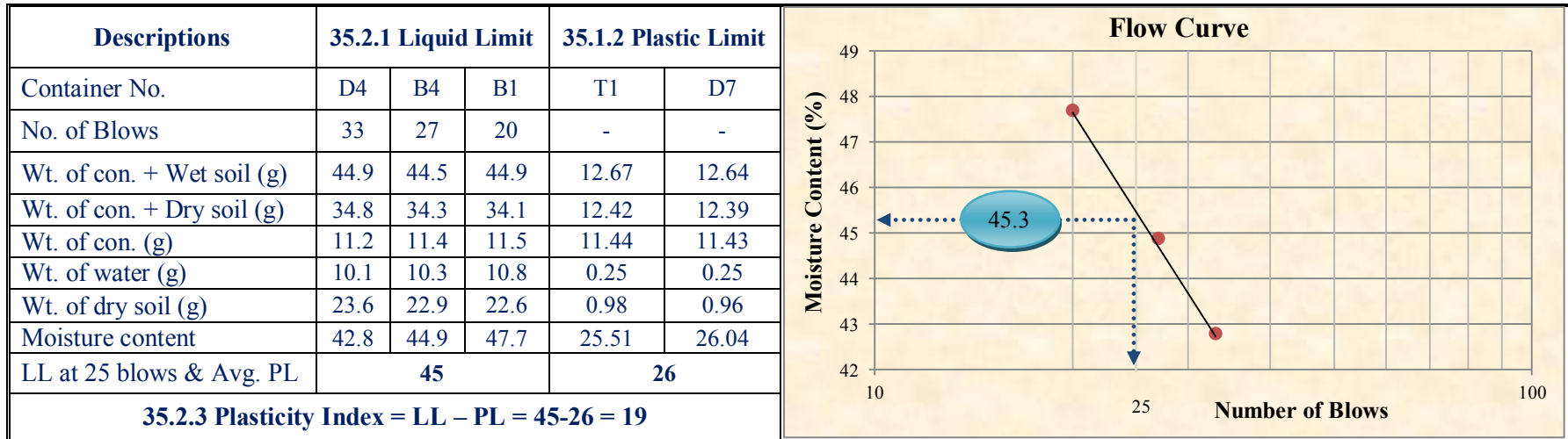
34.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²		
Penetration (mm)	10 Blows		30 Blows		65 Blows						
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)					
0	0	0.00	0	0.00	0	0.00					
0.64	5	0.23	6	0.34	12	0.62					
1.27	8	0.42	11	0.57	18	0.95					
1.96	10	0.54	16	0.83	23	1.22					
2.54	12	0.62	19	0.99	26	1.34					
3.18	13	0.67	21	1.11	28	1.45					
3.81	14	0.73	23	1.19	29	1.52					
4.45	15	0.78	25	1.30	31	1.63					
5.08	16	0.83	26	1.35	33	1.71					
7.62	20	1.04	29	1.52	39	2.00					
34.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve				
No. of Blows	DD (g/c m ³)	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	1.41	0.62	0.83	13.2	20.0	4.68	4.15	4.68			
30	1.50	0.99	1.35	13.2	20.0	7.47	6.76	7.47			
65	1.61	1.34	1.71	13.2	20.0	10.11	8.56	10.11			
Before soaking the three samples were remolded with OMC = 23.4%.											
No. of Blows		10		30		65					
DD (g/cm ³)		1.41		1.50		1.61					
CBR (%)		4.68		7.47		10.11					
From the Density-CBR Curve at 95% MDD (1.52 g/cm ³): CBR = 8.0											

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No: 35 /WARR-4/, Location of Sample: Winget-Adisugebeya RR, Depth of Sampling: 2m, Soil Description: Light Brown Silty clay soil



35.2 ATTERBERG LIMIT TEST (ASTM D 4318)



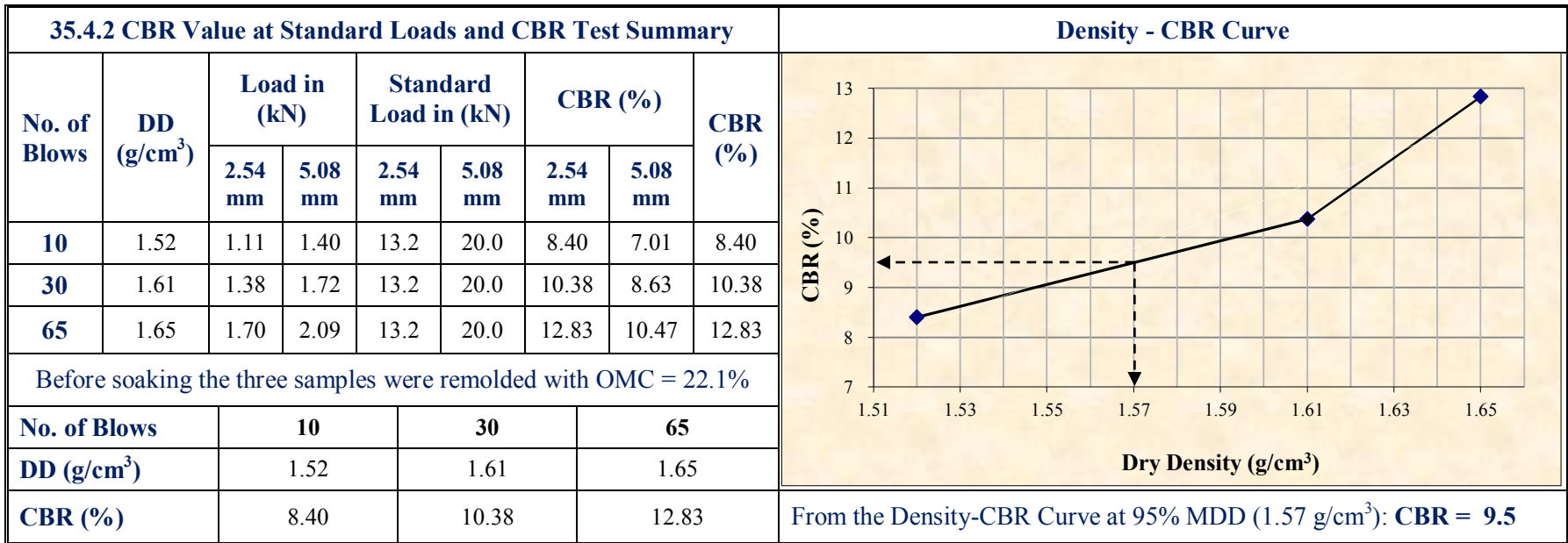
35.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

35.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B3	B20	B11	B4	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	198	204	180	195	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.65 g/cm³ and OMC = 22.1%</p>				
Dry Soil + Con. (g)	177.94	176.08	151.95	160.98					
Mass of Con. (g)	43.18	40.73	41.66	44.51					
Mass of Moisture (g)	19.56	27.83	28.05	34.36					
Dry Soil (g)	134.76	135.35	110.29	116.47					
Moisture cont. (g/cm ³)	14.51	20.56	25.43	29.50					
35.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9017	9613	9691	9399					
Mold (gm)	5408	5408	5408	5408					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3609	4205	4283	3991					
Wet Density (g/cm ³)	1.70	1.98	2.02	1.88					
Dry Density (g/cm ³)	1.48	1.64	1.61	1.45					

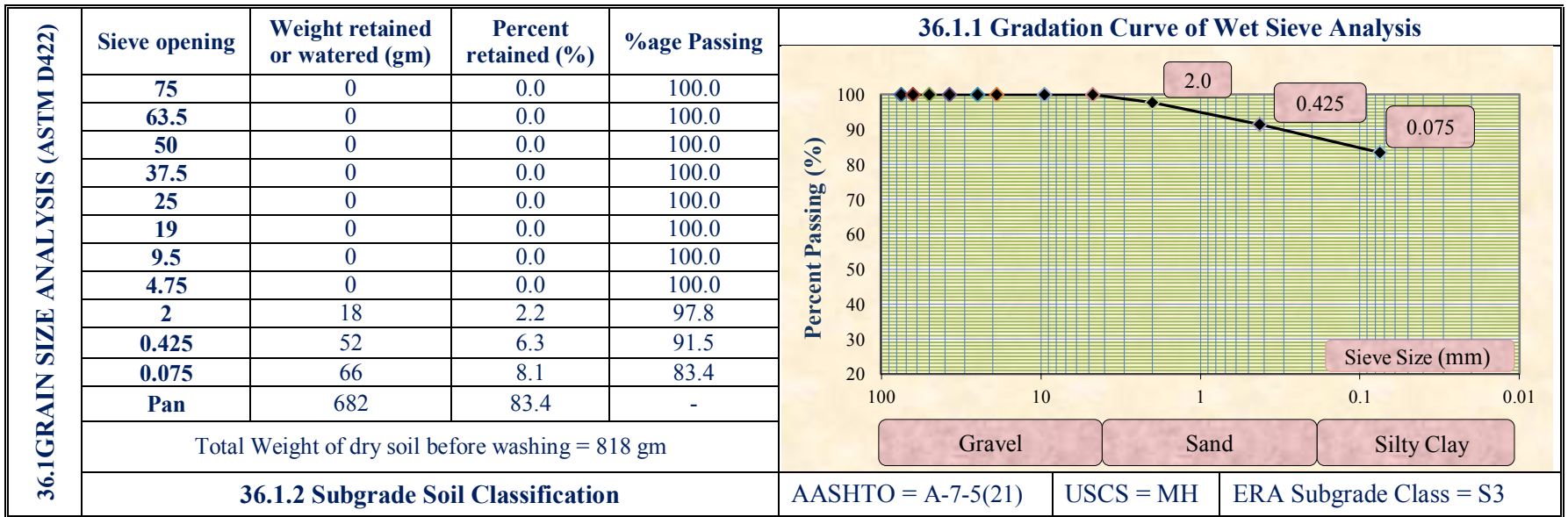
35.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

35.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p align="center">Load - Penetration Relationship</p>
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	
0.64	7	0.38	11	0.57	16	0.84	
1.27	14	0.73	17	0.91	23	1.21	
1.96	19	0.99	22	1.16	29	1.49	
2.54	21	1.11	27	1.38	33	1.70	
3.18	24	1.22	29	1.52	35	1.81	
3.81	25	1.30	32	1.64	37	1.91	
4.45	26	1.35	33	1.72	38	1.99	
5.08	27	1.40	35	1.81	40	2.09	
7.62	32	1.66	39	2.03	45	2.33	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

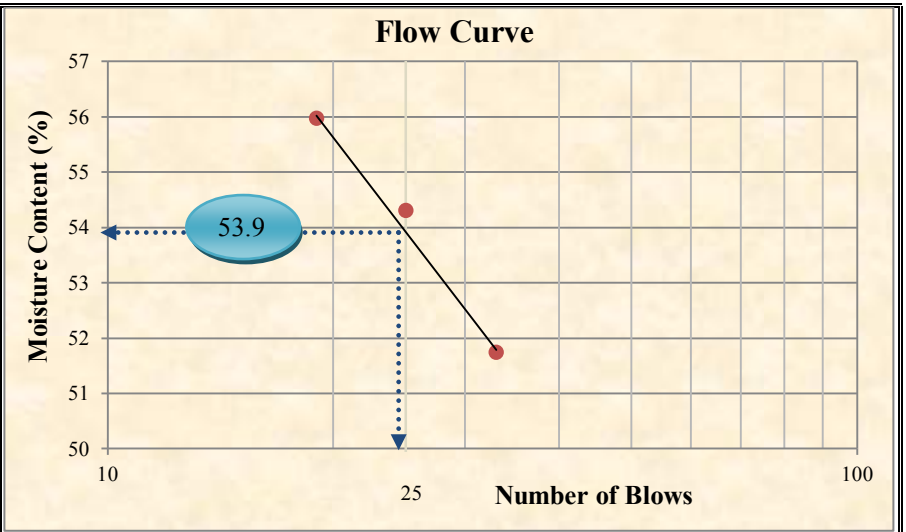


Sample No.: 36 /LC-1/, Location of Sample: Lideta Condominium site, Depth of Sampling: 1.5m, Soil Description: Light Brown clay soil



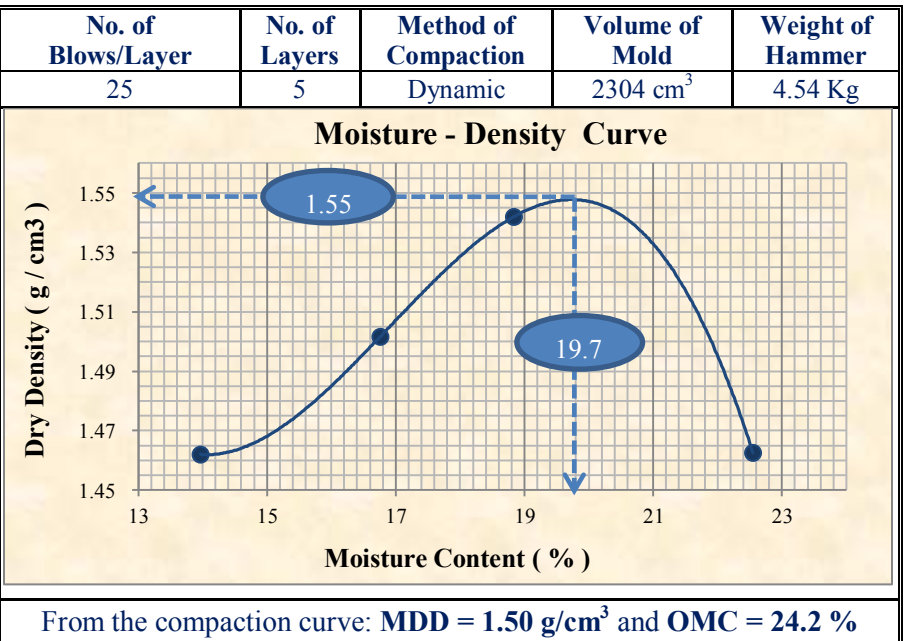
36.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	36.2.1 Liquid Limit			36.2.2 Plastic Limit	
	A2	T3	C1	B5	D4
Container No.	A2	T3	C1	B5	D4
No. of Blows	33	25	19		
Wt. of con. + Wet soil (g)	55.8	57.1	58.0	13.81	13.81
Wt. of con. + Dry soil (g)	40.7	41.0	41.3	13.28	13.27
Wt. of con. (g)	11.4	11.4	11.5	11.59	11.60
Wt. of water (g)	15.2	16.1	16.7	0.53	0.54
Wt. of dry soil (g)	29.3	29.6	29.8	1.69	1.67
Moisture content	51.7	54.3	56.0	31.36	32.34
LL at 25 blows & Avg. PL	54			32	
36.2.3 Plasticity Index = LL – PL = 54 – 32 = 22					



36.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

36.3.1 Moisture Content Determination				
Container No.	C5	C4	B9	B5
Wet Soil + Con. (g)	226	235	208	226
Dry Soil + Con. (g)	204	208	183	193
Mass of Con. (g)	45.59	46.18	46.24	44.35
Mass of Moisture (g)	22.15	27.09	25.71	33.5
Dry Soil (g)	158.6	161.64	136.51	148.57
Moisture cont. (g/cm ³)	13.97	16.76	18.83	22.55
36.3.2 Dry Density Determination				
Trial No.	1	2	3	4
Mold + Wet soil (gm)	8981	9166	9334	9249
Mold (gm)	5442	5442	5442	5442
Volume (cm ³)	2124	2124	2124	2124
Wet Soil (gm)	3539	3724	3892	3807
Wet Density (g/cm ³)	1.67	1.75	1.83	1.79
Dry Density (g/cm ³)	1.46	1.50	1.54	1.46

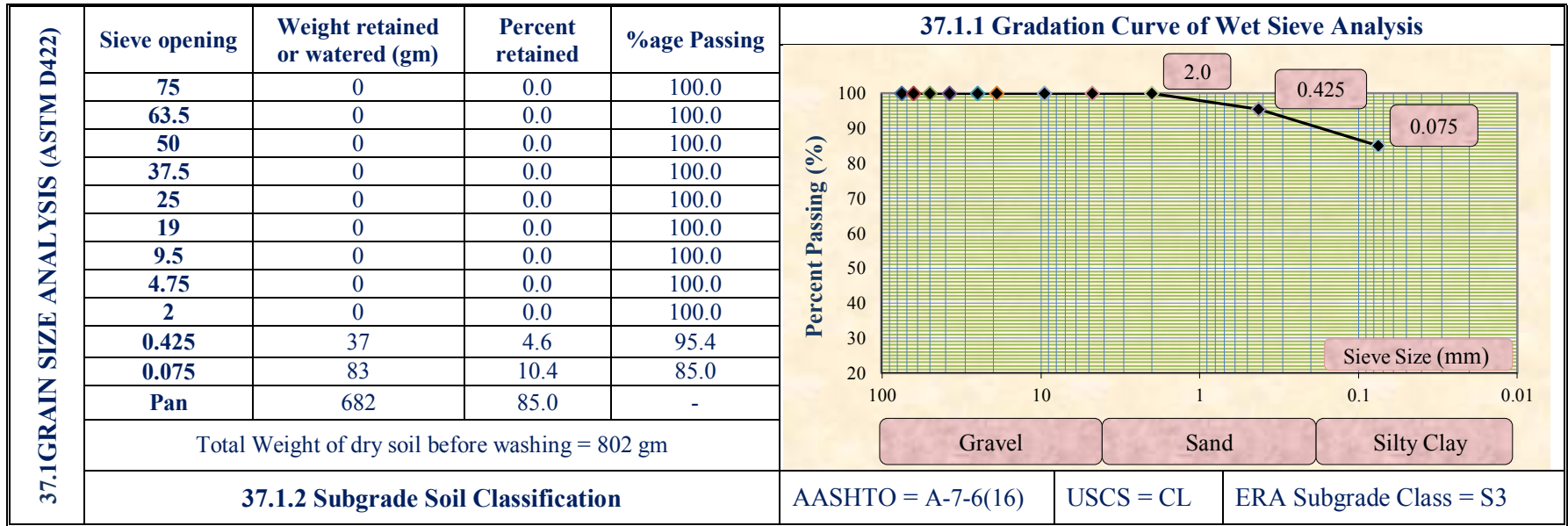


36.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

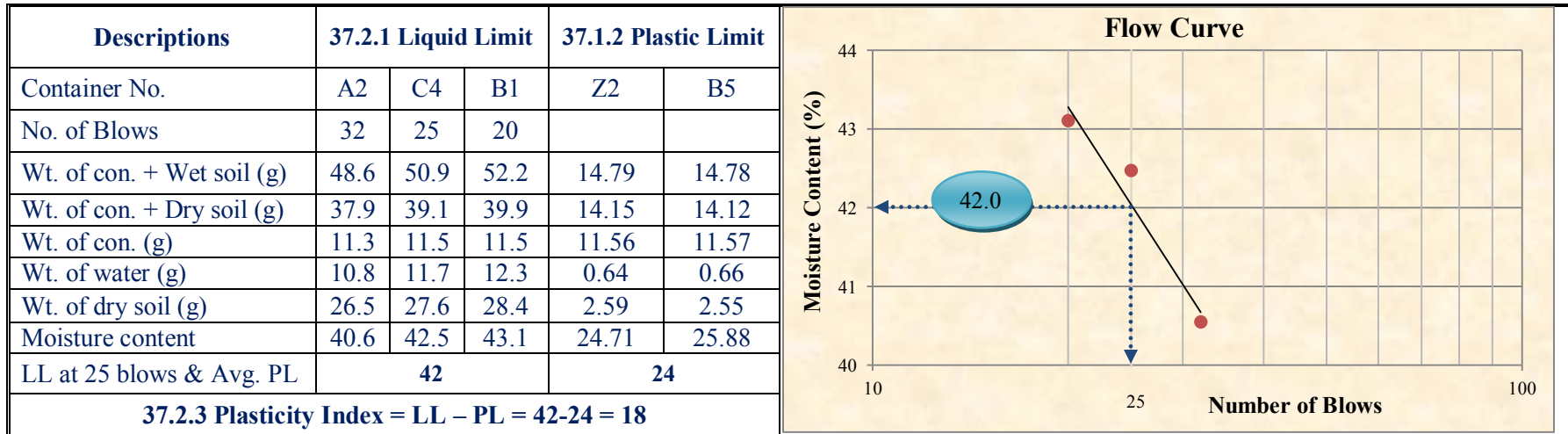
36.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²		
Penetration (mm)	10 Blows		30 Blows		65 Blows						
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)					
0	0	0.00	0	0.00	0	0.00					
0.64	3	0.18	5	0.24	7	0.36					
1.27	6	0.31	8	0.42	10	0.54					
1.96	8	0.40	11	0.55	13	0.68					
2.54	8	0.44	12	0.64	15	0.80					
3.18	9	0.49	13	0.70	17	0.87					
3.81	10	0.53	14	0.75	18	0.94					
4.45	11	0.57	15	0.80	19	0.99					
5.08	12	0.62	16	0.83	20	1.04					
7.62	14	0.73	19	0.98	23	1.19					
36.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve				
No. of Blows	DD (g/cm ³)	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	1.35	0.44	0.62	13.2	20.0	3.32	3.09	3.32			
30	1.42	0.64	0.83	13.2	20.0	4.79	4.16	4.79			
65	1.56	0.80	1.04	13.2	20.0	6.02	5.22	6.02			
Before soaking the three samples were remolded with OMC = 19.7%.											
No. of Blows		10		30		65					
DD (g/cm ³)		1.35		1.42		1.56					
CBR (%)		3.32		4.79		6.02					
From the Density-CBR Curve at 95% MDD (1.47 g/cm ³): CBR = 5.3											

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 37 /LC-2/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 1.2m, **Soil Description:** Light Brown clay soil



37.2 ATTERBERG LIMIT TEST (ASTM D 4318)



37.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

37.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B7	B17	B10	C2	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	226	219	207	266	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.63 g/cm³ and OMC = 18.8 %</p>				
Dry Soil + Con. (g)	206	194	178	219					
Mass of Con. (g)	43.02	44.53	41.53	46.99					
Mass of Moisture (g)	20.24	24.65	28.52	46.66					
Dry Soil (g)	163.08	149.8	136.86	171.96					
Moisture cont. (g/cm ³)	12.41	16.46	20.84	27.13					
37.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9202	9464	9606	9519					
Mold (gm)	5442	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3760	4022	4164	4077					
Wet Density (g/cm ³)	1.77	1.89	1.96	1.92					
Dry Density (g/cm ³)	1.57	1.63	1.62	1.51					

37.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

40.4.1 Penetration Data (After 4-day soaking)					Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)	
0	0	0.00	0	0.00	0	0.00	<p align="center">Load - Penetration Relationship</p>
0.64	5	0.28	9	0.47	14	0.74	
1.27	10	0.49	13	0.69	21	1.11	
1.96	12	0.63	17	0.87	25	1.32	
2.54	14	0.73	19	0.99	29	1.49	
3.18	15	0.80	21	1.10	31	1.60	
3.81	17	0.88	23	1.18	33	1.71	
4.45	18	0.95	24	1.25	35	1.80	
5.08	19	0.99	25	1.30	36	1.87	
7.62	20	1.04	26	1.35	37	1.93	

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

37.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve
No. of Blows	DD (g/c m ³)	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	1.35	0.44	0.62	13.2	20.0	3.32	3.09	3.32	
30	1.42	0.64	0.83	13.2	20.0	4.79	4.16	4.79	
65	1.56	0.80	1.04	13.2	20.0	6.02	5.22	6.02	
Before soaking the three samples were remolded with OMC = 18.8%.									
No. of Blows	10	30	65						
DD (g/cm³)	1.47	1.57	1.64						
CBR (%)	5.51	7.47	11.24						

Density - CBR Curve								
From the Density-CBR Curve at 95% MDD (1.55 g/cm ³): CBR = 7.0								

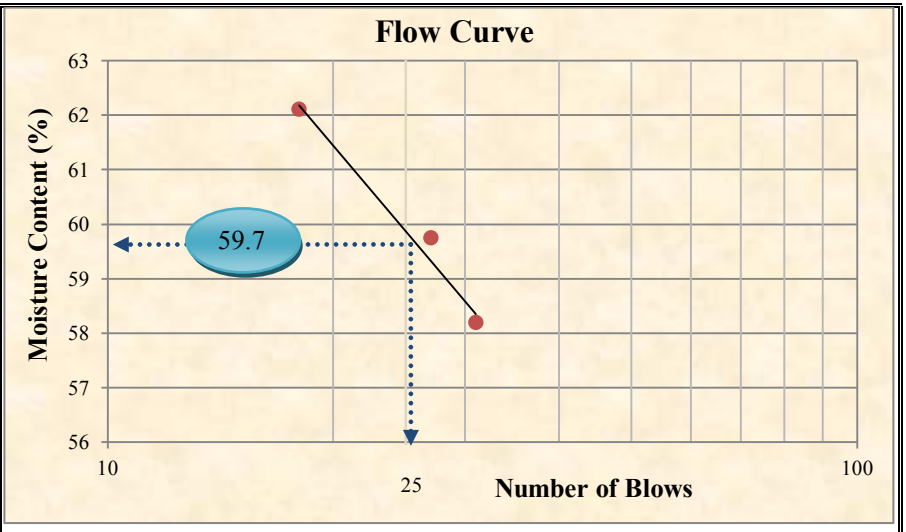
Sample No.: 38 /LC-3/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 2.0m, **Soil Description:** Dark clay soil

38.1 GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained (%)	%age Passing
	75	0	0.0	100.0
	63.5	0	0.0	100.0
	50	0	0.0	100.0
	37.5	0	0.0	100.0
	25	0	0.0	100.0
	19	0	0.0	100.0
	9.5	0	0.0	100.0
	4.75	0	0.0	100.0
	2	13	1.6	98.4
	0.425	24	3.0	95.4
	0.075	54	6.7	88.7
	Pan	716	88.7	-
Total Weight of dry soil before washing = 807 gm				
38.1.2 Subgrade Soil Classification				

38.1.1 Gradation Curve of Wet Sieve Analysis		
AASHTO = A-7-6(35) USCS = CH ERA Subgrade Class = S2		

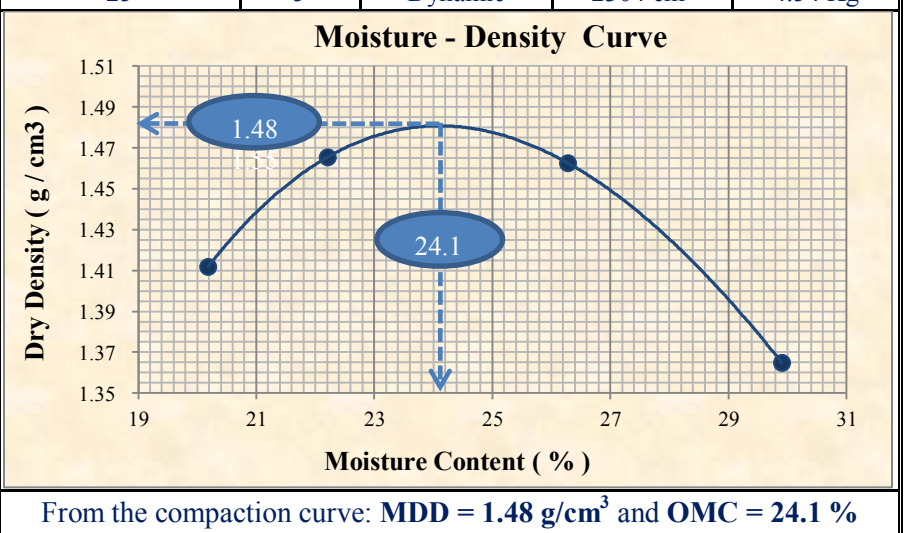
38.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	38.2.1 Liquid Limit			38.2.2 Plastic Limit	
	B2	T3	A7	C5	A2
Container No.	B2	T3	A7	C5	A2
No. of Blows	31	27	18	-	-
Wt. of con. + Wet soil (g)	52.0	58.0	59.6	13.78	13.81
Wt. of con. + Dry soil (g)	37.0	40.6	41.1	13.29	13.32
Wt. of con. (g)	11.3	11.4	11.2	11.35	11.36
Wt. of water (g)	15.0	17.4	18.5	0.49	0.49
Wt. of dry soil (g)	25.7	29.2	29.8	1.94	1.96
Moisture content	58.2	59.7	62.1	25.26	25.00
LL at 25 blows & Avg. PL	60			25	
38.2.3 Plasticity Index = LL – PL = 60 – 25 = 35					



38.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

38.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B12	F3	B15	F2	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	199	212	202	262					
Dry Soil + Con. (g)	173	182	169	212					
Mass of Con. (g)	42.97	46.93	45.02	46.11					
Mass of Moisture (g)	26.26	30.06	32.68	49.62					
Dry Soil (g)	130.11	135.35	124.35	165.91					
Moisture cont. (g/cm ³)	20.18	22.21	26.28	29.91					
38.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9046	9246	9365	9208					
Mold (gm)	5442	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3604	3804	3923	3766					
Wet Density (g/cm ³)	1.70	1.79	1.85	1.77					
Dry Density (g/cm ³)	1.41	1.47	1.46	1.36					

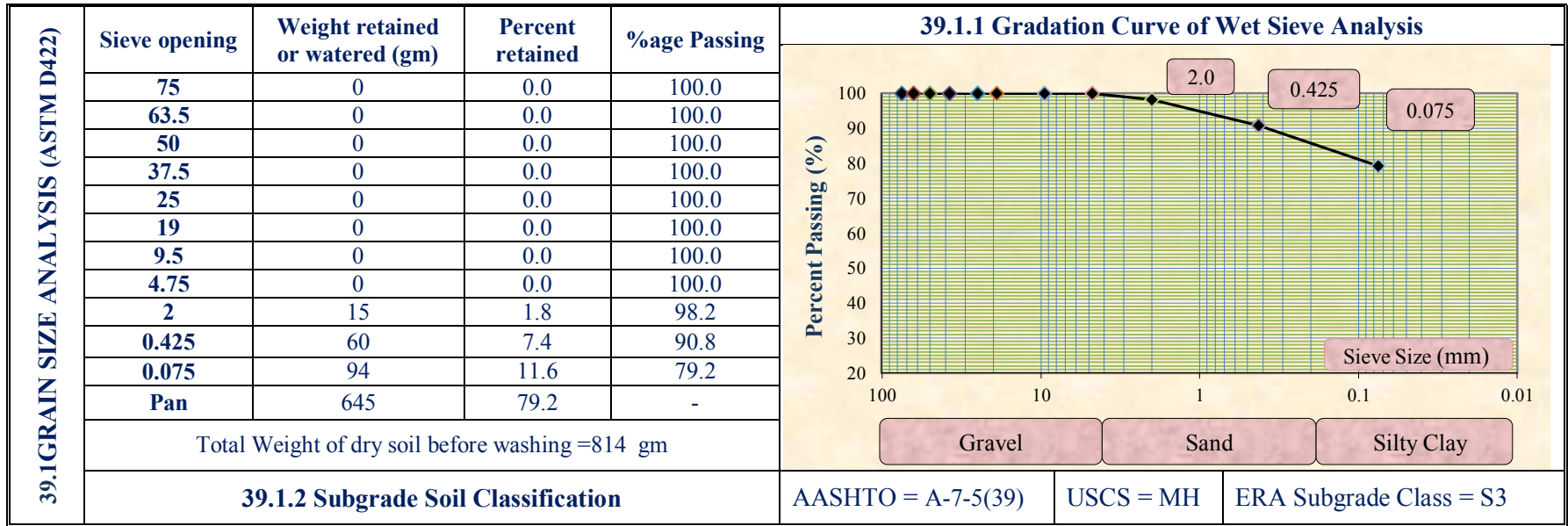


38.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

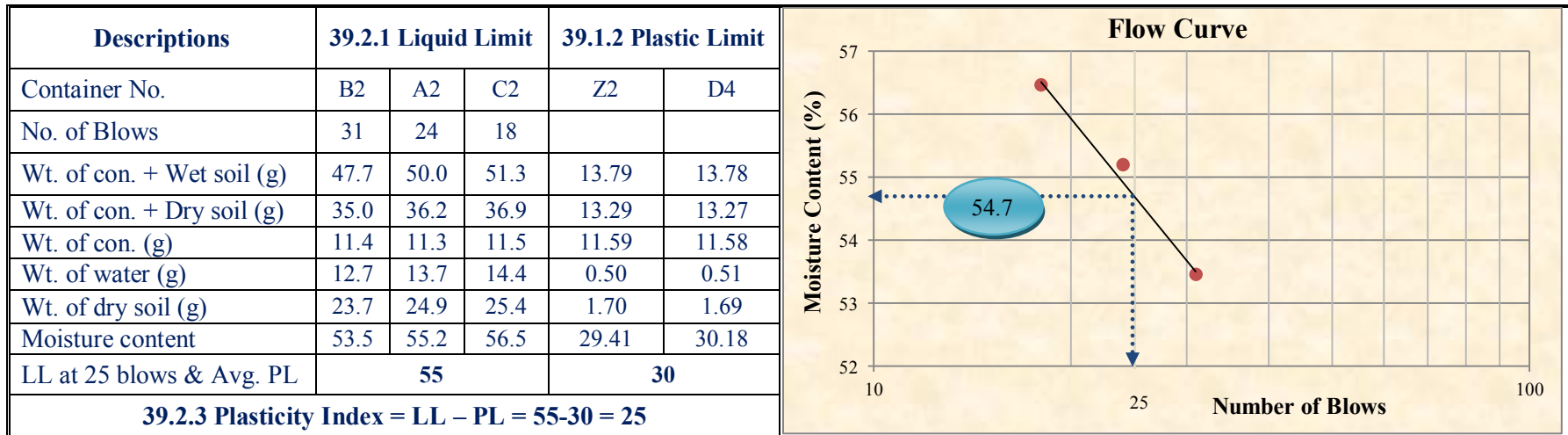
41.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows				
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00			
0.64	2	0.10	3	0.17	5	0.24			
1.27	3	0.16	5	0.24	6	0.33			
1.96	4	0.19	6	0.29	8	0.40			
2.54	4	0.21	6	0.31	8	0.44			
3.18	4	0.23	6	0.33	9	0.48			
3.81	5	0.24	7	0.35	10	0.49			
4.45	5	0.26	7	0.37	10	0.52			
5.08	5	0.27	7	0.39	10	0.53			
7.62	6	0.31	9	0.45	12	0.60			
38.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve		
No. of Blows	DD (g/c m³)	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	1.33	0.21	0.27	13.2	20.0	1.58	1.37	1.58	
30	1.37	0.31	0.39	13.2	20.0	2.31	1.95	2.31	
65	1.47	0.44	0.53	13.2	20.0	3.32	2.66	3.32	
Before soaking the three samples were remolded with OMC = 24.1%.									
No. of Blows		10		30		65			
DD (g/cm³)		1.33		1.37		1.47			
CBR (%)		1.58		2.31		3.32			
From the Density-CBR Curve at 95% MDD (1.41 g/cm ³): CBR = 2.8									

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 39 /LC-4/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 1.5m, **Soil Description:** Light Brown clay soil



39.2 ATTERBERG LIMIT TEST (ASTM D 4318)



39.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

39.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	B9	B11	B4	B20	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	212.29	241.21	186.18	172.47	<p>Moisture - Density Curve</p> <p>Dry Density (g/cm³)</p> <p>Moisture Content (%)</p> <p>From the compaction curve: MDD = 1.52 g/cm³ and OMC = 23.3 %</p>				
Dry Soil +Con. (g)	187	207.08	156.21	139.68					
Mass of Con. (g)	41.28	41.59	44.41	40.65					
Mass of Moisture (g)	25.29	34.13	29.97	32.79					
Dry Soil (g)	145.72	165.49	111.8	99.03					
Moisture cont. (g/cm ³)	17.36	20.62	26.81	33.11					
39.3.2 Dry Density Determination									
Trial No.	1	2	3	4	<p>Load - Penetration Relationship</p> <p>Load (KN)</p> <p>Penetration (mm)</p> <p>10 Blows 30 Blows 65 Blows</p>				
Mold + Wet soil (gm)	8850	9261	9412	9271					
Mold (gm)	5442	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3408	3819	3970	3829					
Wet Density (g/cm ³)	1.60	1.80	1.87	1.80					
Dry Density (g/cm ³)	1.37	1.49	1.47	1.35					

39.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

39.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows		<p>Load - Penetration Relationship</p> <p>Load (KN)</p> <p>Penetration (mm)</p> <p>10 Blows 30 Blows 65 Blows</p>		
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)			
0	0	0.00	0	0.00	0	0.00			
0.64	3	0.16	4	0.21	5	0.28			
1.27	5	0.27	7	0.38	9	0.46			
1.96	8	0.40	10	0.52	12	0.61			
2.54	9	0.47	12	0.62	14	0.72			
3.18	10	0.52	13	0.69	16	0.82			
3.81	11	0.57	14	0.74	17	0.90			
4.45	12	0.62	15	0.80	18	0.96			
5.08	13	0.67	16	0.85	19	1.01			
7.62	16	0.83	20	1.04	23	1.20			

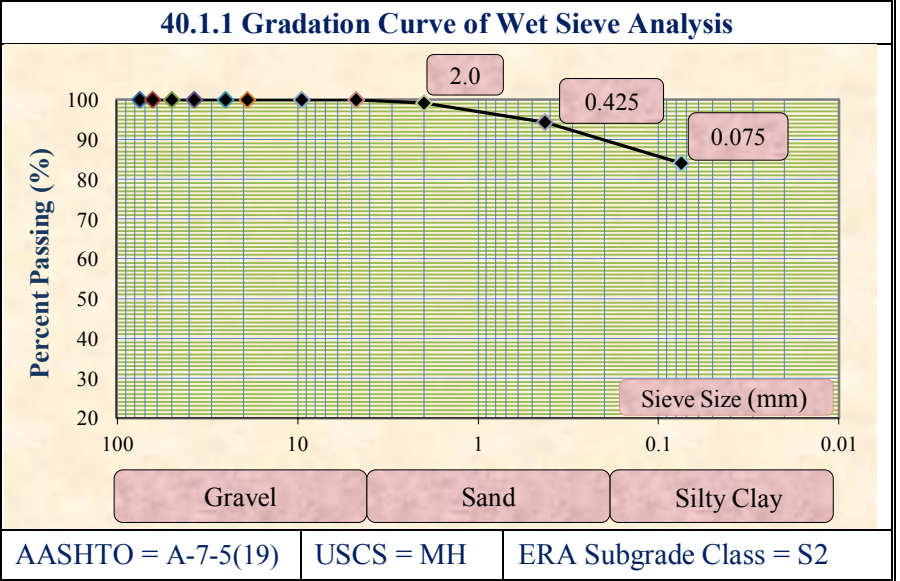
CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

39.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/c m ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	CBR (%)	Dry Density (g/cm ³)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.29	0.47	0.67	13.2	20.0	3.54	3.35	3.54		
30	1.40	0.62	0.85	13.2	20.0	4.68	4.27	4.68		
65	1.47	0.72	1.01	13.2	20.0	5.43	5.03	5.43		
Before soaking the three samples were remolded with OMC = 23.3%.										
No. of Blows		10		30		65				
DD (g/cm³)		1.29		1.40		1.47				
CBR (%)		3.54		4.68		5.43				

40.1GRAIN SIZE ANALYSIS (ASTM D422)	
Sieve opening	Weight retained or watered (gm)
75	0
63.5	0
50	0
37.5	0
25	0
19	0
9.5	0
4.75	0
2	7
0.425	22
0.075	102
Pan	693
Total Weight of dry soil before washing = 825 gm	
40.1.2 Subgrade Soil Classification	

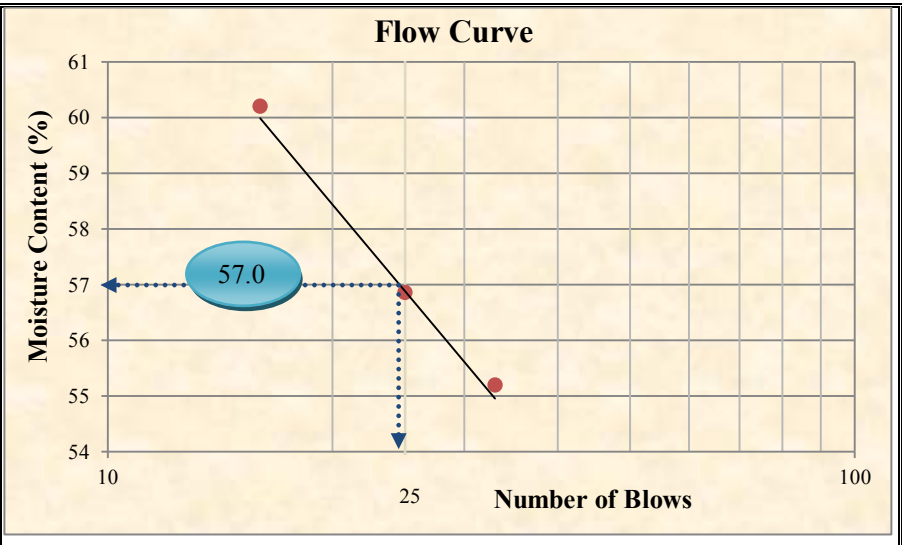
From the Density-CBR Curve at 95% MDD (1.43g/cm³): **CBR = 5.1**

Sample No.: 40 /LC-5/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 1.2m, **Soil Description:** Dark brown clay soil



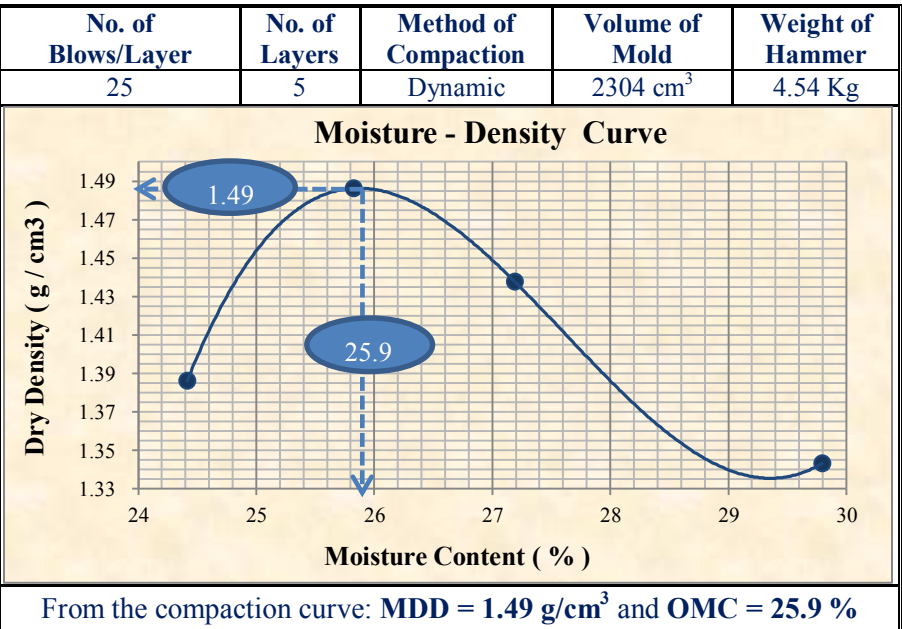
40.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	40.2.1 Liquid Limit			40.2.2 Plastic Limit	
	D2	T4	D1	A1	B4
Container No.	D2	T4	D1	A1	B4
No. of Blows	33	25	16		
Wt. of con. + Wet soil (g)	47.1	50.0	51.5	13.89	13.87
Wt. of con. + Dry soil (g)	34.5	36.0	36.5	13.35	13.32
Wt. of con. (g)	11.6	11.5	11.5	11.59	11.58
Wt. of water (g)	12.6	13.9	15.1	0.54	0.55
Wt. of dry soil (g)	22.9	24.5	25.0	1.76	1.74
Moisture content	55.2	56.9	60.2	30.68	31.61
LL at 25 blows & Avg. PL	57			31	
40.2.3 Plasticity Index = LL – PL = 57 – 31 = 26					



40.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

40.3.1 Moisture Content Determination				
Container No.	B9	B11	B4	B20
Wet Soil + Con. (g)	224.95	221.32	170.87	163.65
Dry Soil + Con. (g)	190.03	184.74	144.21	135.58
Mass of Con. (g)	47.00	43.09	46.16	41.37
Mass of Moisture (g)	34.92	36.58	26.66	28.07
Dry Soil (g)	143.03	141.65	98.05	94.21
Moisture cont. (g/cm ³)	24.41	25.82	27.19	29.80
40.3.2 Dry Density Determination				
Trial No.	1	2	3	4
Mold + Wet soil (gm)	9105	9414	9326	9145
Mold (gm)	5442	5442	5442	5442
Volume (cm ³)	2124	2124	2124	2124
Wet Soil (gm)	3663	3972	3884	3703
Wet Density (g/cm ³)	1.72	1.87	1.83	1.74
Dry Density (g/cm ³)	1.39	1.49	1.44	1.34

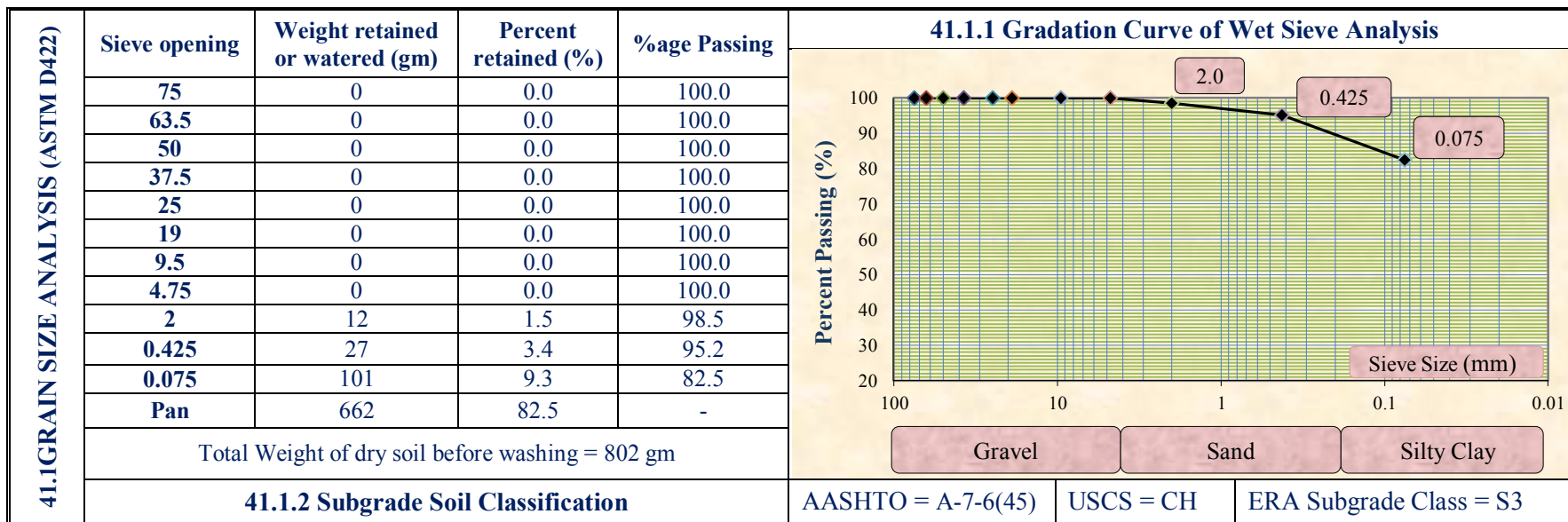


40.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

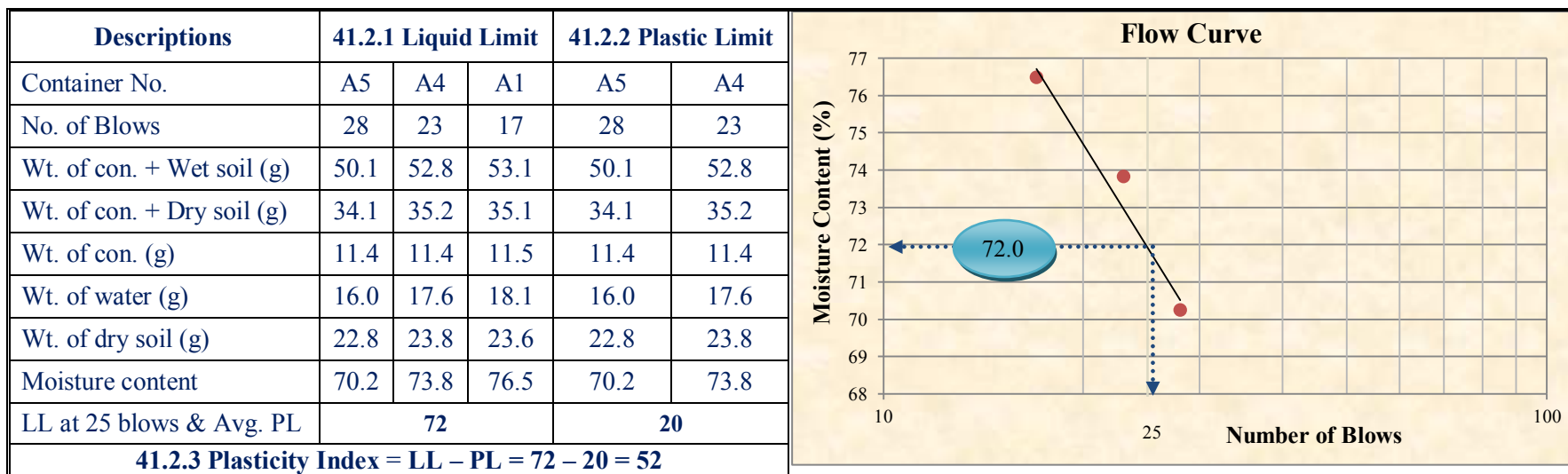
40.4.1 Penetration Data (After 4-day soaking)							Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²		
Penetration (mm)	10 Blows		30 Blows		65 Blows						
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)					
0	0	0.00	0	0.00	0	0.00					
0.64	4	0.18	5	0.24	6	0.32					
1.27	5	0.26	7	0.36	9	0.45					
1.96	6	0.32	9	0.46	11	0.55					
2.54	7	0.36	10	0.52	12	0.61					
3.18	8	0.39	11	0.57	13	0.67					
3.81	8	0.42	12	0.62	14	0.73					
4.45	9	0.45	13	0.66	15	0.78					
5.08	9	0.47	13	0.69	16	0.82					
7.62	11	0.57	15	0.78	18	0.94					
40.4.2 CBR Value at Standard Loads and CBR Test Summary							Density - CBR Curve				
No. of Blows	DD (g/c m ³)	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	1.33	0.36	0.47	13.2	20.0	2.71	2.35	2.71			
30	1.42	0.52	0.69	13.2	20.0	3.92	3.46	3.92			
65	1.50	0.61	0.82	13.2	20.0	4.60	4.08	4.60			
Before soaking the three samples were remolded with OMC = 25.9%.											
No. of Blows		10		30		65					
DD (g/cm ³)		1.33		1.42		1.50					
CBR (%)		2.71		3.92		4.60					
From the Density-CBR Curve at 95% MDD (1.47 g/cm ³): CBR = 3.9											

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

Sample No.: 41 /LC-6/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 2.0m, **Soil Description:** Dark Gray soil



41.2 ATTERBERG LIMIT TEST (ASTM D 4318)



41.3 MODIFIED PROCTOR TEST (AASHTO T-181, Method D)

41.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	D5	D4	C3	B4	25	5	Dynamic	2304 cm ³	4.54 Kg
Wet Soil + Con. (g)	188	203	192	246	<p align="center">Moisture - Density Curve</p> <p>From the compaction curve: MDD = 1.62 g/cm³ and OMC = 17.8%</p>				
Dry Soil + Con. (g)	173	182	169	209					
Mass of Con. (g)	41.86	43.27	43.59	42.84					
Mass of Moisture (g)	14.92	20.72	22.63	36.98					
Dry Soil (g)	131.22	139.01	125.78	166.18					
Moisture cont. (g/cm ³)	11.37	14.91	17.99	22.25					
41.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9136	9356	9505	9368					
Mold (gm)	5442	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3694	3914	4063	3926					
Wet Density (g/cm ³)	1.74	1.84	1.91	1.85					
Dry Density (g/cm ³)	1.56	1.60	1.62	1.51					

41.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

41.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (KN)	Dial RDG	Load (KN)	Dial RDG	Load (KN)
0	0	0.00	0	0.00	0	0.00
0.64	4	0.22	6	0.29	8	0.42
1.27	6	0.29	8	0.41	11	0.55
1.96	7	0.36	10	0.52	13	0.65
2.54	8	0.40	11	0.57	14	0.71
3.18	8	0.43	12	0.62	15	0.77
3.81	9	0.46	13	0.67	16	0.83
4.45	9	0.49	14	0.71	17	0.88
5.08	10	0.51	14	0.74	18	0.92
7.62	12	0.61	16	0.83	20	1.05

Load - Penetration Relationship

CORRELATION OF CBR WITH SOIL INDEX PROPERTIES FOR ADDIS ABABA SUBGRADE SOILS

41.4.2 CBR Value at Standard Loads and CBR Test Summary									Density - CBR Curve	
No. of Blows	DD (g/cm ³)	Load in (kN)		Standard Load in (kN)		CBR (%)		CBR (%)	CBR (%)	Dry Density (g/cm ³)
		2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm			
10	1.47	0.40	0.51	13.2	20.0	2.99	2.53	2.99		
30	1.51	0.57	0.74	13.2	20.0	4.31	3.72	4.31		
65	1.58	0.71	0.92	13.2	20.0	5.38	4.60	5.38		
Before soaking the three samples were remolded with OMC = 17.8%.										
No. of Blows		10		30		65				
DD (g/cm³)		1.47		1.51		1.58				
CBR (%)		2.99		4.31		5.38				

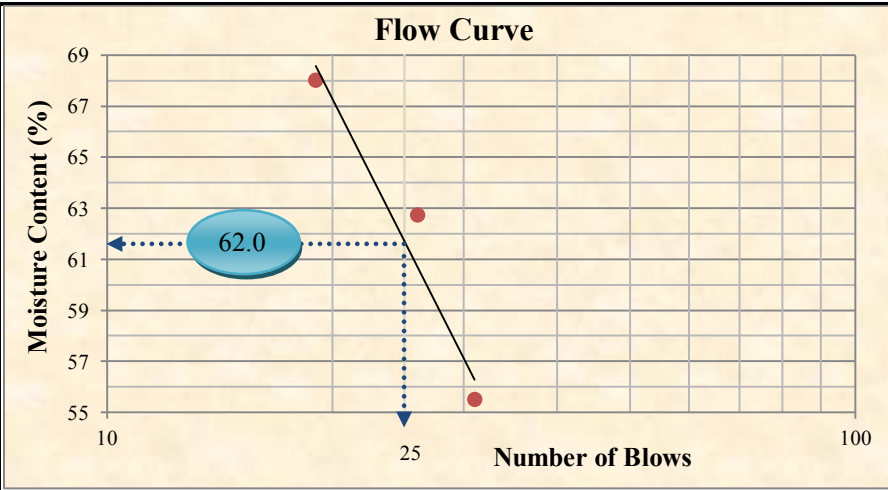
From the Density-CBR Curve at 95% MDD (1.54 g/cm³): **CBR = 4.8**

Sample No.: 42 /LC-7/, **Location of Sample:** Lideta Condominium site, **Depth of Sampling:** 1.5m, **Soil Description:** Light Brown clay soil

42.1GRAIN SIZE ANALYSIS (ASTM D422)	Sieve opening	Weight retained or watered (gm)	Percent retained	%age Passing	42.1.1 Gradation Curve of Wet Sieve Analysis
	75	0	0.0	100.0	
	63.5	0	0.0	100.0	
	50	0	0.0	100.0	
	37.5	0	0.0	100.0	
	25	0	0.0	100.0	
	19	0	0.0	100.0	
	9.5	0	0.0	100.0	
	4.75	0	0.0	100.0	
	2	9	1.1	98.9	
	0.425	12	1.4	97.5	
	0.075	63	7.5	90.0	
Pan	761	90.0	-		
Total Weight of dry soil before washing =845 gm					
42.1.2 Subgrade Soil Classification					
AASHTO = A-7-5(22)		USCS = MH		ERA Subgrade Class = S4	

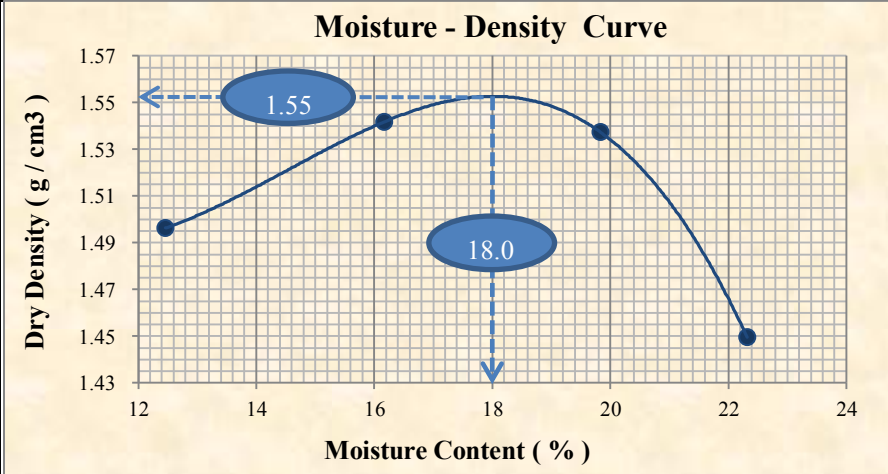
42.2 ATTERBERG LIMIT TEST (ASTM D 4318)

Descriptions	42.2.1 Liquid Limit			42.1.2 Plastic Limit	
	C2	C5	F2	F1	B3
Container No.	C2	C5	F2	F1	B3
No. of Blows	31	26	19		
Wt. of con. + Wet soil (g)	42.8	45.5	46.0	13.95	13.89
Wt. of con. + Dry soil (g)	31.3	32.0	31.6	13.17	13.12
Wt. of con. (g)	10.5	10.4	10.4	11.42	11.42
Wt. of water (g)	11.5	13.5	14.4	0.78	0.77
Wt. of dry soil (g)	20.8	21.6	21.2	1.75	1.70
Moisture content	55.5	62.7	68.0	44.57	45.29
LL at 25 blows & Avg. PL	62			45	
42.2.3 Plasticity Index = LL – PL = 62 – 45 = 17					



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

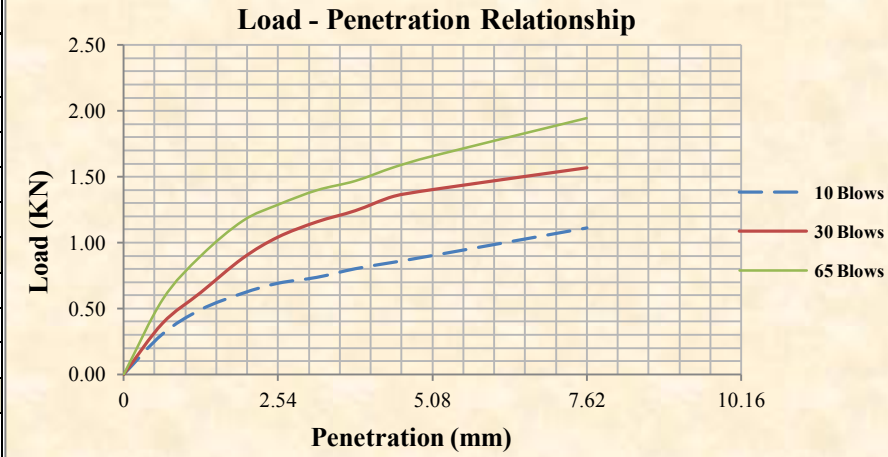
42.3.1 Moisture Content Determination					No. of Blows/Layer	No. of Layers	Method of Compaction	Volume of Mold	Weight of Hammer
Container No.	A7	F4	C1	C6	25	5	Dynamic	2124 cm ³	4.54 Kg
Wet Soil + Con. (g)	199	218	207	224					
Dry Soil + Con. (g)	182	194	180	191					
Mass of Con. (g)	43.52	45.44	45.83	44.86					
Mass of Moisture (g)	17.26	24.06	27	32.62					
Dry Soil (g)	138.56	148.84	134.54	146.16					
Moisture cont. (g/cm ³)	12.46	16.17	19.83	22.32					
42.3.2 Dry Density Determination									
Trial No.	1	2	3	4					
Mold + Wet soil (gm)	9016	9246	9355	9208					
Mold (gm)	5442	5442	5442	5442					
Volume (cm ³)	2124	2124	2124	2124					
Wet Soil (gm)	3574	3804	3913	3766					
Wet Density (g/cm ³)	1.68	1.79	1.84	1.77					
Dry Density (g/cm ³)	1.50	1.54	1.54	1.45					



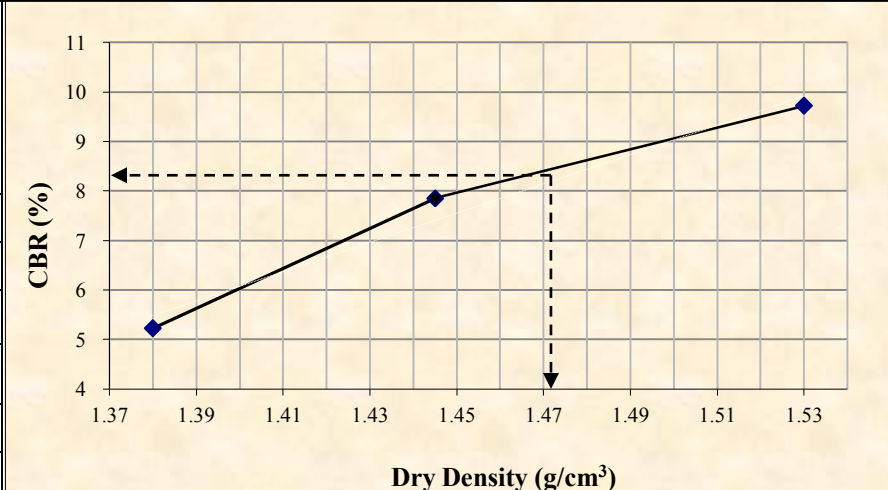
From the compaction curve: **MDD = 1.55 g/cm³** and **OMC = 18 %**

42.4 CALIFORNIA BEARING RATIO TEST (AASHTO T-193)

42.4.1 Penetration Data (After 4-day soaking)				Ring Factor = 51.88 N/Div	Penetration Rate = 1.27mm/min	Area of Plunger = 1985mm ²
Penetration (mm)	10 Blows		30 Blows		65 Blows	
	Dial RDG	Load (kN)	Dial RDG	Load (kN)	Dial RDG	Load (kN)
0	0	0.00	0	0.00	0	0.00
0.64	6	0.31	7	0.39	11	0.57
1.27	9	0.49	12	0.62	17	0.90
1.96	12	0.62	17	0.88	22	1.17
2.54	13	0.69	20	1.04	25	1.29
3.18	14	0.74	22	1.16	27	1.40
3.81	15	0.80	24	1.24	28	1.47
4.45	16	0.85	26	1.35	30	1.57
5.08	17	0.90	27	1.40	32	1.66
7.62	21	1.11	30	1.57	38	1.95



42.4.2 CBR Value at Standard Loads and CBR Test Summary								
No. of Blows	DD (g/cm ³)	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	1.38	0.69	0.90	13.2	20.0	5.22	4.52	5.22
30	1.45	1.04	1.40	13.2	20.0	7.86	7.02	7.86
65	1.53	1.29	1.66	13.2	20.0	9.72	8.30	9.72
Before soaking the three samples were remolded with OMC = 18 %								
No. of Blows		10		30		65		
DD (g/cm ³)		1.38		1.45		1.53		
CBR (%)		5.22		7.86		9.72		



From the Density-CBR Curve at 95% MDD (1.47g/cm³): **CBR = 8.4**