A PROJECT FOR PARTIAL FULFILLMENT OF MASTER OF ENGINEERING IN CIVIL ENGINEERING (GEOTECHNICAL ENGINEERING STREAM)

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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

“Developing Correlation Between Index properties and California Bearing Ratio, CBR of Soils: A Case Study on Guliso Cheliya Dilla Kondala Begi Road Project, Lot 2”

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Advisor: - Dr. Ing.Henok Fikre

“A project Submitted for the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Engineering in Civil Engineering (Geotechnical Engineering)”

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ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING

MASTER OF ENGINEERING PROJECT APPROVAL SHEET

"Developing Correlation Between Index Properties and California Bearing Ratio, CBR of Soils: A Case Study on Guliso Cheliya Dilla Kondala Begi Road Project, Lot 2"

By: Gudata Mokonon

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DECLARATION

I, the under signed, declare to the senate of Addis Ababa University that this project is solely my own original work and it has not been submitted to any university for an academic award. In accordance with internationally accepted practices, I have acknowledged and referenced all materials used in this project work.

ACKNOWLEDGEMENT

First and foremost, I want to thank the Almighty God for being with me throughout this project work and in all aspects of my life. Next, I want to express my gratitude to Dr. Ing. Henok Fikre, my esteemed adviser, for taking the time to encourage and direct me to complete this project from beginning to end. Also, I would like to thank the Ethiopian Roads Authority which funded my university fees. In addition, I would like to thank White Knight Construction Management Consultants and Best Consulting Engineers Private Limited Company for giving me all project information and geotechnical test results respectively. At last, but not least, I would like to thank my classmates, family, friends and senior students who have directly or indirectly contributed to this project work

ABSTRACT

Soil properties are specific to a region and alter greatly from place to place based on climatic and geographic conditions. Geotechnical engineers often attempt to develop empirical methods specific to particular regions and soil types. However, empirical equations are more consistent for soil types where the correlation is developed. Therefore, it is extremely important to develop a correlation between CBR and subsoil index properties specific to different soil types.

This project comprises developing the relationship between CBR values and soil index properties specific to the Guliso Cheliya Dilla Kandalama Begi road project. When finding the correlations, both simple and multiple regression analyzes were considered. Accordingly, one hundred and ten secondary data sets were collected from Best Consulting engineers, consulting firm, to attain the intended correlations. Using SPSS, the CBR correlation is constructed as a function of Atterberg limits, percentage grain size, and moisture-density relationship parameters.

After evaluating developed correlation, it was found that CBR values and soil index properties are well correlated and this is advantageous for the preliminary detection of the geotechnical characteristics of the soil in the investigation area. Finally, a reliable correlation is derived from correlation work with a coefficient of determination of 0.691 using multiple linear regression analysis.

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LIST OF ABBBRIVATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation
ASTAM	American Society for Testing and Materials.
BS	British Standards
CBR	California Bearing Ratio in %
LL	Liquid limit in %
MDD	Maximum Dry Density in g/cm^3
OMC	Optimum Moisture content in %
PI	Plasticity Index in %
PL	Plasticity Limit in %
SPSS	Statistical Package for Social Science Software
PP40	Percent Passing sieve number 40
PP200	Percent Passing sieve number 200
F	Modal Parameter on Anova table
dfl	Number of excluded sample
df2	Number of non-excluded sample
b1	Coefficient of the first term in the mentioned equation
b2	Coefficient of the second term in the mentioned equation
b3	Coefficient of the third term in the mentioned equation
R	Regression coefficient
R^2	Regression coefficient square
n	Number of input data(sample)

CHAPTER 1

INTRODUCTION

1.1 Background

The California Bearing Ratio test, one of several tests used in civil engineering, is frequently performed to determine the stiffness modulus and shear strength of the subgrade materials used to construct flexible pavements.

It is the ratio of the penetration resistance of a material to the penetration resistance of a standard gravel base material. The subsoil strength is therefore related to the CBR value of the soil. However, it is always difficult for engineers to obtain accurate CBR values of a soil, and it is also tedious and laborious to conduct the test.

To overcome these problems, researchers have attempted to establish a relationship between various soil index properties and the CBR value in order to obtain accurate CBR values in less time and effort by using various analysis techniques such as the regression method. The CBR value obtained in such a correlation is a function of several factors affecting soil properties such as maximum dry density, optimum moisture content, plasticity index, liquid limit, plastic limit, percentage of fines and other soil properties. It is therefore a good representative of the subsoil character in situ in pavement design.

In this project, correlation in the form of an equation of CBR as a function of different soil properties is established. Since correlations are specific to the place where they were made, it is better to have correlations of different areas of our country to provide a more feasible relationship between index properties and CBR values, which is the principal goal of this project.

The subgrade soils along the route are predominantly reddish silty clay soils as indicated in the White Knight Construction Management Consultant Private Limited Company soil extent report. Construction of this project has not yet started. In the analysis, one hundred and ten data points were used with the corresponding soil indices, specifically grain size analysis, Atterberg limits, and moisture-density relationships for both simple and multiple linear regression analyses. Statistical Package for Social Science Software is used to apply single linear, single nonlinear, and multiple linear regression models.

1.2 Statement of problem

In designing of different pavements, engineers consistently encounter difficulties to obtain representative CBR value of subgrade materials. Because laboratory CBR test requires comparatively larger soil sample and it is time consuming task. Obtained results sometimes are also not accurate due to the poor quality of handling and laboratory testing on the soil samples. Thus, identification of factors that control the CBR value such as index properties of the soil can be used as a basis of judgement on the validity of the CBR values obtained in the field. This is done by developing correlation for CBR value as function of different index properties of a soil from localized subgrade materials with the advantage of time, labor and cost savings for conducting laboratory CBR tests.

1.3 Objectives

1.3.1 General Objective

The basic objective of this project is to develop a correlation between CBR and index properties of soils using laboratory test results of representative soil samples collected in different sections of Guliso Cheliya Dilla Kondala Begi road project.

1.3.2 Specific objectives

To differentiate soil properties that significantly affect CBR values.
To establish the model that can most accurately estimate CBR values from index properties.
To develop correlation of CBR values with different soil parameters from single linear and nonlinear and also multiple linear regression analysis.
To analyze obtained results of linear and multiple regression analysis and recommend the most fit model to estimate CBR value from index characteristics of soil.
To compare and contrast the CBR-Index properties test values relations of soils in Guliso Cheliya Dilla Kondala Begi areas with other local and international existing correlations.

1.3 Scope of the Project

To establish the correlation, one hundred and ten data from laboratory test results of soil index properties are used and the required correlation is performed by applying regression analysis using SPSS. This study is specific to soil samples collected from different sections of Guliso Cheliya Dilla Kondala Begi road project.

All data used for this project are sampled by White Knight Construction Management Consultants Private Limited Company and Geotechnical test results of CBR and Index properties of soils are received from Best Consulting Engineers private limited company.

As briefly discussed in literature review, the project work is evidenced by various secondary resources such as multiple researches and relevant published articles. The correlation evolved represents only soils on Guliso Cheliya Dilla Kondala Begi road and is for academic purposes only.

1.5 Significance of the project.

In this work, CBR index properties of soil correlations are developed aiming to minimize the effort and time expended under normal CBR test conditions, specifically for the Guliso Cheliya Dilla Kondala Begi road project and generally for soils around the areas from Guliso to Begi. Accordingly, different models are developed by performing both single linear, non-linear and multiple linear regression of CBR with different soil parameters such as liquid limit, plastic limit, optimal moisture content, maximum dry density and plastic index. In addition, the study provided the reader with a valuable concept of the different engineering properties of soils of the investigation area.

1.6 Project Organization

The project is divided into five chapters. In the first chapter, Introduction, the aim, scope and significance of the project are briefly explained. The second chapter, literature review, provides a summary of the existing information that was used to develop the expected correlation in this project. In the third chapter, Methodology, the methods and procedures for determining the correlation, the project location, the project description and general information of investigation area are briefly described.

In Chapter Four, Regression Analysis, Developed Correlation and Discussion, the result of the analyzed data is examined in detail using the proposed technique and it is checked whether the desired goal is surely achieved. The fifth chapter, Conclusion and Recommendation, summarizes the findings of this project and provide conclusions and recommendations to the readers for further study.

CHAPTER 2

LITRATURE REVIEW

2.1 General

Most of constructed roads in our country, Ethiopia, are flexible pavement. Flexible pavement consists of different layers such as sub-grade, sub-base and base course. According to Ethiopian Roads Authority Pavement Design Manual Volume1(2013), Design and performance of flexible pavement mainly depends on the strength of sab-grade materials. The California Bearing Ratio is one of the methods for determining the material strength of the subgrade and is treated as a strength parameter in the design and construction of the pavement structure.

However, since CBR testing is so tedious and time-consuming to perform, it is very important to find a simple method for a quick estimate of the CBR value. Consequently, various local and international scholars have endeavored to correlate the CBR value with simple index property tests. As stated in the Ethiopian Roads Authority Pavement Design Manual, the index test is an indirect measure of stiffness modulus or shear strength.

2.2 Index Property Tests

Soil index properties are properties used in identification and classification of soils for engineering purposes. Water content is very important soil index property of fine-grained soils since their behavior largely changes with water concentration variations and it is clear that strength and compressibility characteristics of cohesive soils are a function of water content. Thus, water content is a key component in understanding the aggregate behavior of such soil types and a crucial element in conducting index property tests.

As of American Society for Testing and Materials (2000), the index property of cohesive soils is used to characterize the soil's physical and mechanical behavior using parameters such as moisture content, particle size distribution, Atterberg limits and moisture density relationship.

2.3 California Bearing Ratio (CBR)

California Bearing Ratio is defined as the ratio of the penetration resistance of a material to the penetration resistance of a standard gravel base material. The Ethiopian Roads Authority Pavement Design Manual, Volume 1 (2013) states that the California Bearing Ratio is the most important design input in pavement design to assess the stiffness modulus and shear strength of the subgrade material. With an intension to adopt a more simplified test method to measure the stiffness modulus and shear strength of sub grade soil, 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 **(Fredric .M,1983)**

The resistance of crushed stone under standardized conditions is well recognized and should have a CBR value of one hundred percent. Therefore, the intent of the California Bearing Ratio test is to determine the relative resistance of the subgrade material under similar conditions. The test is an index test; therefore, it is not a direct measure of stiffness modulus or shear strength.

2.4 Existing Correlation

Currently, many researchers and organizations have developed and relationships between the California Bearing Ratio and soil index parameters based on samples collected from a specific region. General relationships are also developed using generally accepted soil classification systems, like based on the Unified Classification System and the official systems of the American Association of State Highway and Transportation. These correlations methods take a general approach and attempt to incorporate many or all possible soil types **(Leliso Y,2013).**

For such correlations to be accepted in general practice, it is necessary to demonstrate their validity and applicability. So predicted and experimental CBR values of different soils were used to check the relevance and limitations of available methodologies

Agarwal and Ghanekar (1970) analyzed fine-grained soils from forty-eight samples collected in India and attempted to establish a correlation between CBR values and liquid limit, plastic limit, and plastic index. Later on, they included OMC in their analysis and obtained a much better correlation than before as it is shown below;

$CBR=2-16\log OMC + 0.07LL$ with $R=0.82$, $R^2=0.67$

Katte et al (2018) developed another stronger correlation as;

$CBR= -175.006+99.869MDD$ with $R=0.879$, $R^2=0.772$

$CBR = 99.086-5.162OMC$ with $R=0.861$, $R2=0.741$.

Okon Bassey (2002) also developed the following correlations

$CBR=0.0071PI_2-0.4403PI+10.303$, $R^2=0.923$

$CBR=3.6197OMC_2+91.121OMC-564$, $R^2=0.988$

Ms. Avani Kaushik, Aakash Rawer, Mayank Chhoker and Mohd. Kaif (2022)

$CBR=1.9636*OMC-23.678$

Faisal Iqbal (2018)

$CBR=11.2525LL-26.4144PI-0.3024PP_{200}+153.7175$, $R^2=0.984$

$CBR=17.3174LL-42.5467PI-102.9336MDD+455.5159$, $R^2=0.971$

Leliso Y. (2013) worked on correlation of CBR value with index properties of Northern, North East and North West parts of Addis Ababa subgrade soils as;

CBRs=f (F, S, G, LL, MDD and OMC) and developed the following models from single and multiple linear regression analysis.

Developed single linear regression equations are;

Correlation between CBR and PL

$CBR=6.737-0.025*PL$, R2=0.003, n=42

Correlation between CBR and LL

$CBR=16.270-0.179*LL$, $R^2=0.458$, n=42

Correlation between CBR and PI

$CBR=10.413-0.177*PI$, $R^2=0.429$, n=42

Correlation between CBR and percent passing sieve No.200

$CBR=-1.366+0.089*P200$, $R^2=0.041$, n=4

Correlation between CBR and OMC

$CBR=G.499-0.150*OMC$, $R^2=0.06$, n=42

Correlation between CBR and MDD

$CBR=-35.966+27.072*MDD$, R2=0.384, n=42

Developed multiple linear regression analysis equations are;

Correlation between CBR with PL and P200

CBR=8.302-0.190*PI+6.33*P200, R^2=0.533, n=42

Correlation between CBR with PL and PI

CBR=14.580-0.197*Pl-0.112*Pl, R2=0.494, n=42

Correlation between CBR with LL, PI and MDD or (LL, Pl and MDD)

CBR=-21.734-0.003*LL-0.137*PI +20.244*MDD, R^2=0.629, n=42 or

CBR=-21.522-0.141*LL+0.137*PI+20.244*MDD, R^2=0.629, n=42

According to him, the proposed model should only be applicable with support of sound judgment and technical experience for that particular area in order to provide a quick and cost effective method of determining CBR of sub-grade soil. From the individual linear regression models developed by the researcher, based on the R2 value, CBR correlates relatively better with the liquid limit and the plasticity index. In multiple linear regressions, the correlation between CBR with LL, PI and MDD or (LL, PI and MDD) is more moderately correlated than all other models.

Solomon A. (2021) Conducted correlation between Index properties of red clay and brawn clay soil with CBR values of Gedo Mana Begna upgrading road project which links West Showa with Horo Guduru wollega along the road from Gedo to Fincha and developed the following correlation.

CBR=989.798+4.04PP200-1.223LL-1.19PI-9.961OMC-527.282MDD+0.019P40

R2=0.915, n=73 (for red clay soil) and

CBR=3178.89+0.035LL-10.57PI-469.578MDD+17.567OMC-33.017PP40-15.274PI +7.756PP200

R2=0.838, N=37 (for brown clay soil)

This correlation is more genuine than that of Leliso’s as coefficient of determination value is more approached to unity.

In addition to individual researchers, different universal approaches have developed the estimation of CBR from index properties of soil.

For example, National Cooperative Highway Research Program of united states (NCHRP)developed estimation of CBR for finer soils having percent passing sieve No. 200 greater than twelve percent and the weighted plasticity index (wPI) value is different from zero, as;

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

Where; wPI is Weighted plasticity index

PI is Plasticity Index (percent)

wPI = (Percent passing No. 200 Sieve) x (Plasticity Index) = P200 x PI

Generally, although various foreign and local researchers have done correlations of CBR with index properties for fine grained soils on different investigation areas, it is not sufficiently conducted on different soil types where various projects undertaken in Ethiopia. Therefore, this project attempted to play a significant role by performing correlations of CBR with index properties of fine-grained soils on Guliso Cheliya Dilla Kondala Begi road project with relatively large number of data, higher number of independent variables, better regression coefficient value and all possible types regression analysis.

CHAPTER 3

METHODOLOGY

3.1 General

To have enough data to perform the correlation, secondary laboratory test results were collected from Best Consulting Engineers office which was sampled from different sections of Guliso Cheliya Dilla Kondala Begi Lot 2 road project by White Knight Construction Management Consultant Private Limited Company. One hundred ten soil data samples were collected with the analogous soil index, specifically the Atterberg limits, grain size analysis and moisture density relationships for single linear, nonlinear and multiple linear regression analysis.

The investigation area report is briefly outlined below and a summary of the laboratory test data is also presented in Appendix B

3.2 Description of Investigation Area

3.2.1 Project Location

Guliso Cheliya Dilla Kondala Begi Road Project is located in the Western part of Ethiopia and it lies entirely in Oromia National Regional State, particularly in West Wollega Zone. Accordingly, Lot 2 is an extension of this project and it starts at Shimel Toke kebele located 60 km away from Nejo town along the existing Nejo Jarso Begi gravel road and ends at Begi town. Its length is estimated to be seventy kilometers.

The project route creates access to Babo Gambel, Kondala and Begi Woredas of West Wollega zone and connects towns like Shimel Toke, Chala Dabus, Likiti, Geba Defino and Begi.

Table 3.1 Project Description

Project Name	**Guliso Cheliya Dilla Kondala Road Project, Lot 2**
Road No:	S/02/NCB/RFP/GOE/2012EFY
Region/Zone	Oromia National Regional State of the Federal Democratic Republic of Ethiopia, West Wollega Zone
Starting Point Description	Shimel Toke kebele located 60km away from Nejo town along Nejo Jarso Begi gravel road
Ending Point Description	Begi Town is located along Nejo Jarso Begi Road after travelling 148km from Nejo town
Length (km)	Approximately 70 km
Road Functional Classification	Link Road
Climate Classification	Weina Dega and Kola
Elevation (m) (min – max)	1370 - 1730
Traffic Volume vpd	1282

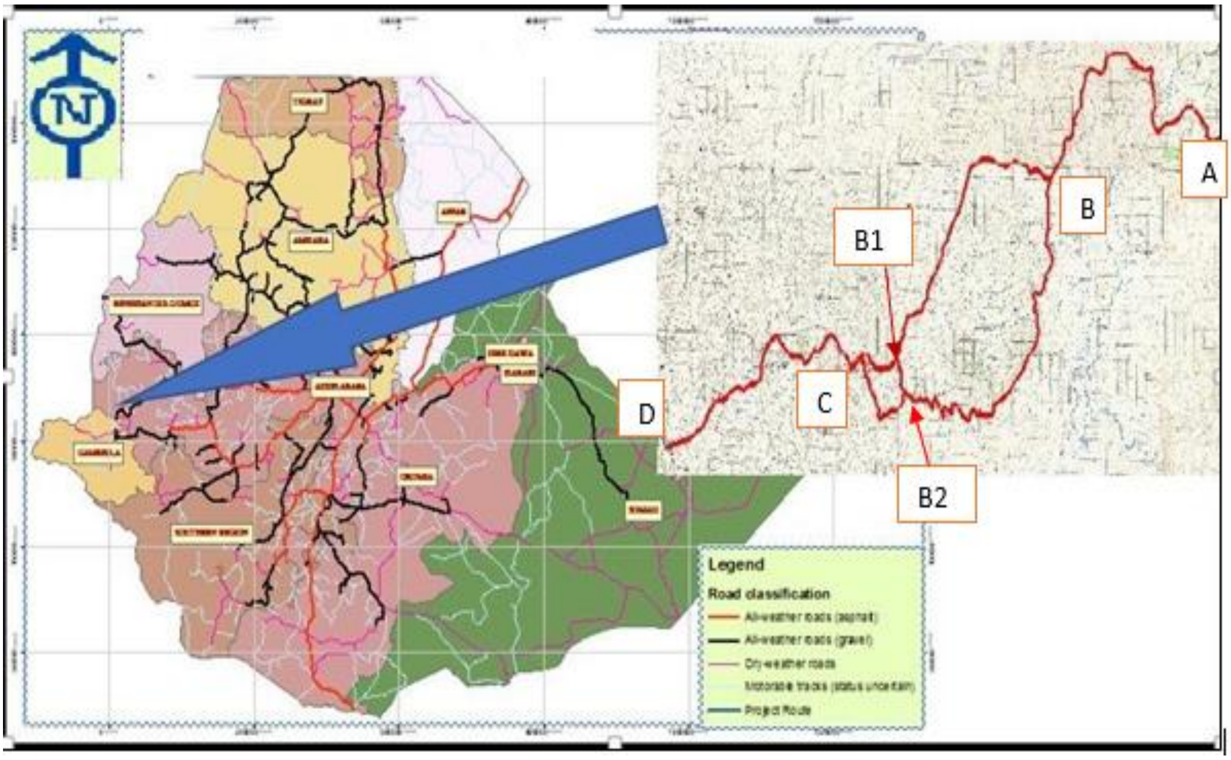

Figure 3-1: Location Map of Guliso Cheliya Dilla Kondala Begi Road Project [Ethiopian Geological Survey]

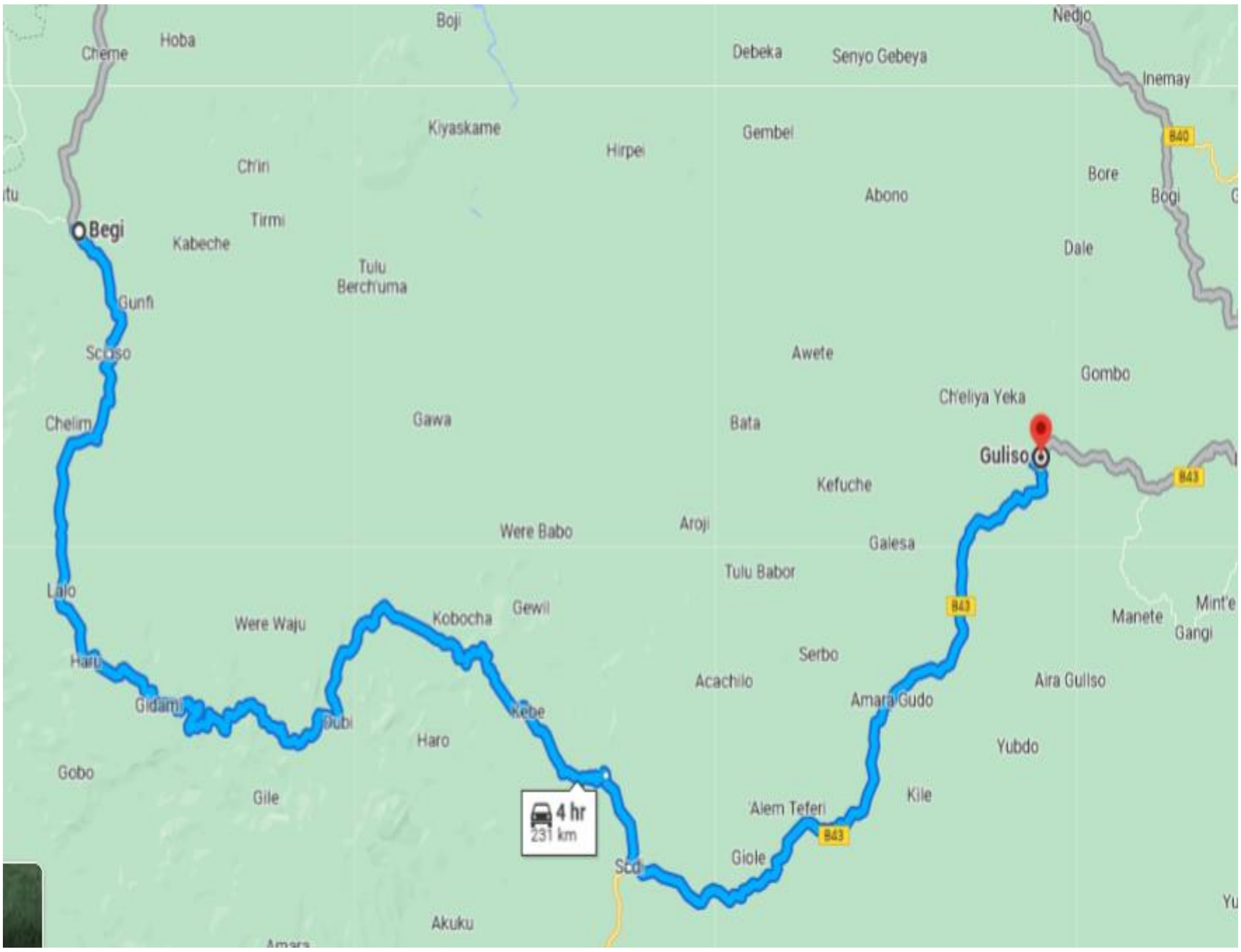

Figure 3-2: Project Location

3.3 Laboratory Test Results for the Regression Analysis and Correlation

A liquid limit value ranging from 30% to 69% with an average of 52% and a plasticity index value of 8% to 23% with an average of 14% were obtained from the Atterberg limit tests.

Strength of the soil along project alignment is accessed through 3-point 4-day soaked CBR tests (AASHTO, T-193-93 at T-180 modified compaction). CBR values, which correspond to 95% of the MDD, are in the range of 3.5% up to 71%, with an overall average of 25%. These laboratory test results are clearly outlined in appendix B.

CHAPTER 4

REGRESSION ANALYSIS, DEVELOPED CORRELATIONS AND DISCUSSION

4.1 General

The analysis is carried out statistically, and single linear, non-linear, and multiple linear regression models are attempted to be applied in order to characterize the strength of subgrade soil in terms of soil index parameters.

Specifically, to examine the significance of each regression variable for this study, SPSS is used. The equation with the highest R^2 value is chosen from these sets of equations and the CBR of the soil of the study area is formulated as dependent variable in the equation.

4.2 Single Linear and Nonlinear Regression Analysis

The correlation of CBR is developed with each individual property of soil index parameters both linearly and nonlinearly as shown in following scatter plots and tables in appendix A

4.3 Scatter Plot and Best-Fit-Curve of Single linear and nonlinear Regression Analysis

Throughout developed equations in this project work, CBR is taken as the dependent variable, while LL, PL, PI, PP40, PP200, MMD, and OMC are independent variables.

However, regression analysis is used and SPSS is thought to be the most efficient and descriptive tool when more than two variables are needed to determine the relationship, i.e. when the dependent variable requires more than two independent variables. In appendix A, detail linear and nonlinear regression outputs are briefly presented.

4.3.1 Scatter Plot

4.3.1.1 California Bearing Ratio versus Percent Passing Sieve No. 40

The correlation between the CBR and the percent passing sieve no. 40 for the tested samples is shown in figure 4-1.

The equation that best fits the correlation between CBR and % passing sieve No. 40 is quadratic equation and shown as;

CBR = $24.307+1.469*PP_{40}-0.034*PP_{40}^{2,}$ R^2= 0.498

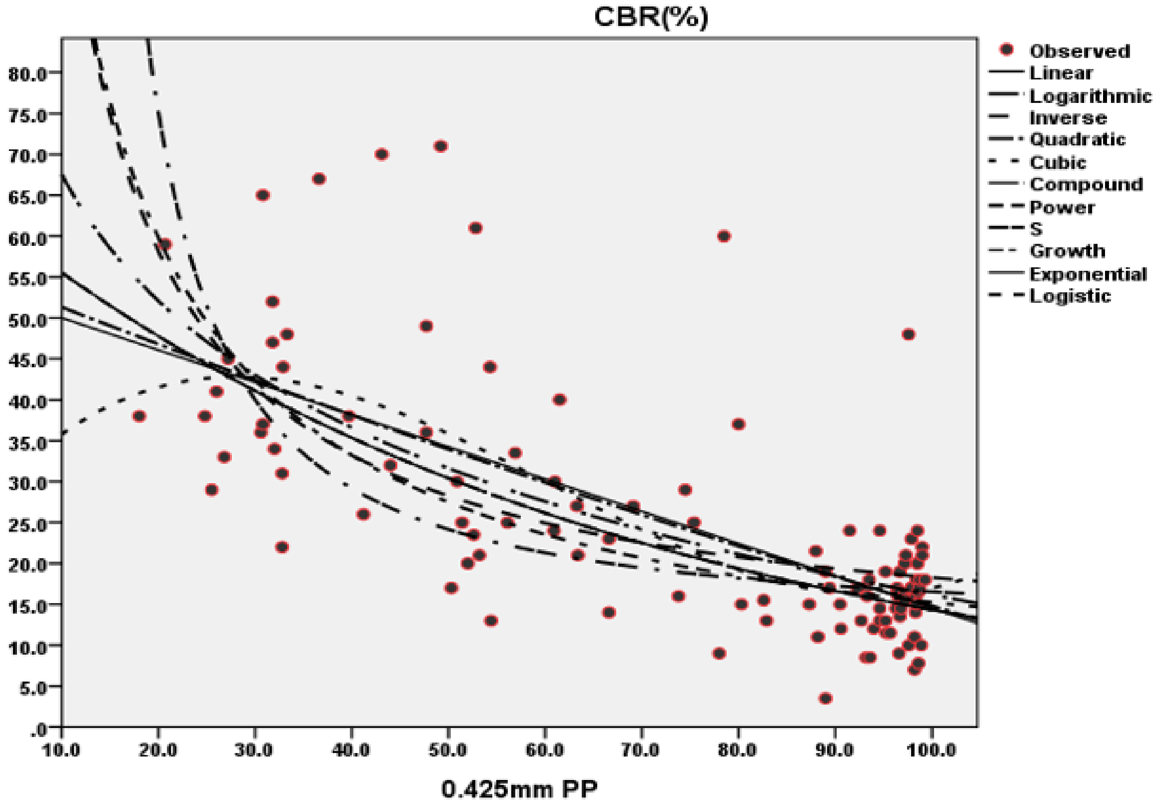

Figure 4-1: Scatter Diagram of California bearing ratio versus percent passing sieve no. 40

4.3.1.2 California Bearing Ratio versus Percent Passing Sieve No. 200

The correlation between the CBR and the percent passing sieve no. 200 for the tested samples is shown in figure 4-2.

The equation that most fits the correlation between CBR and % passing sieve No. 200 is again quadratic equation and shown as;

$CBR = 30.29+1.18*PP_{200}-0.032*PP_{200}^{2,}$ has $R^2= 0.509$

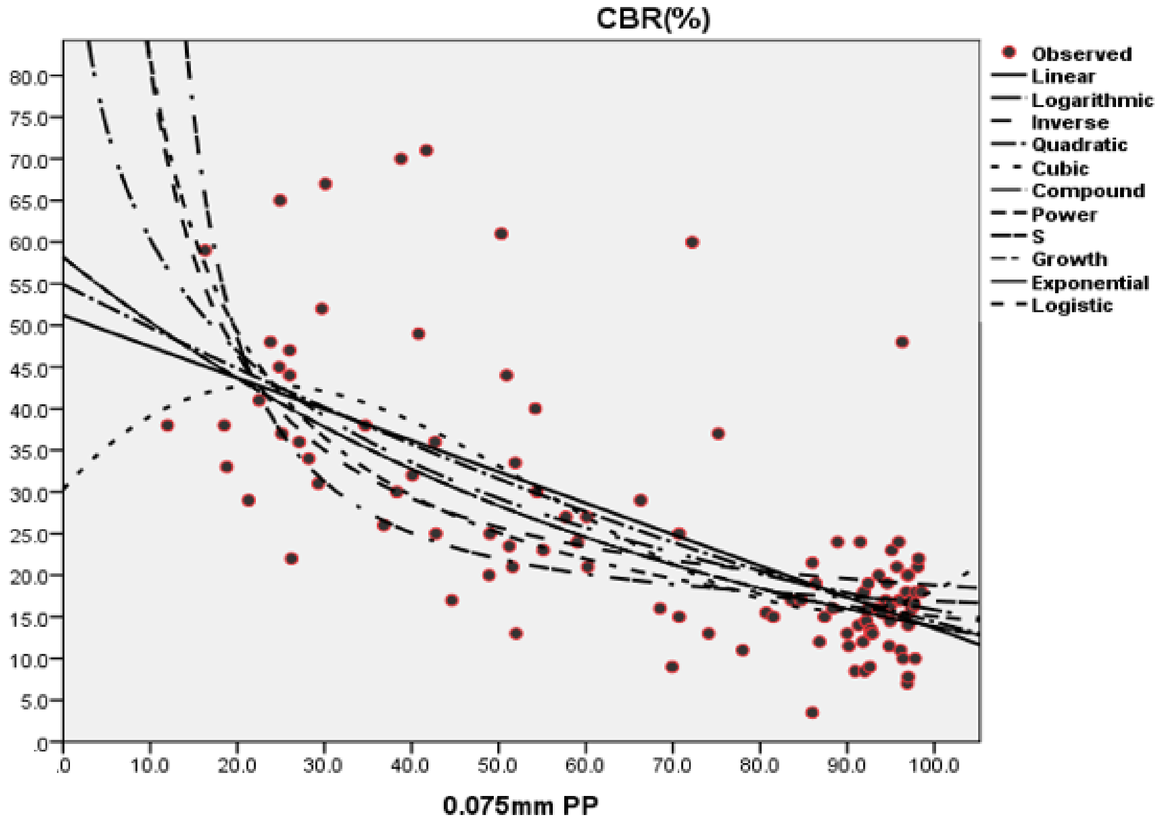

Figure 4-2: Scatter Diagram of California bearing ratio versus percent passing sieve no. 200

4.3.1.3 California Bearing Ratio (CBR) versus Liquid Limit (LL)

The correlation between the CBR and LL for the tested samples is shown in figure 4-3.

The equation that best fits the correlation between CBR and LL is also quadratic.

CBR = 114.503-2.262*LL+0.01*LL^2, R^2= 0.400

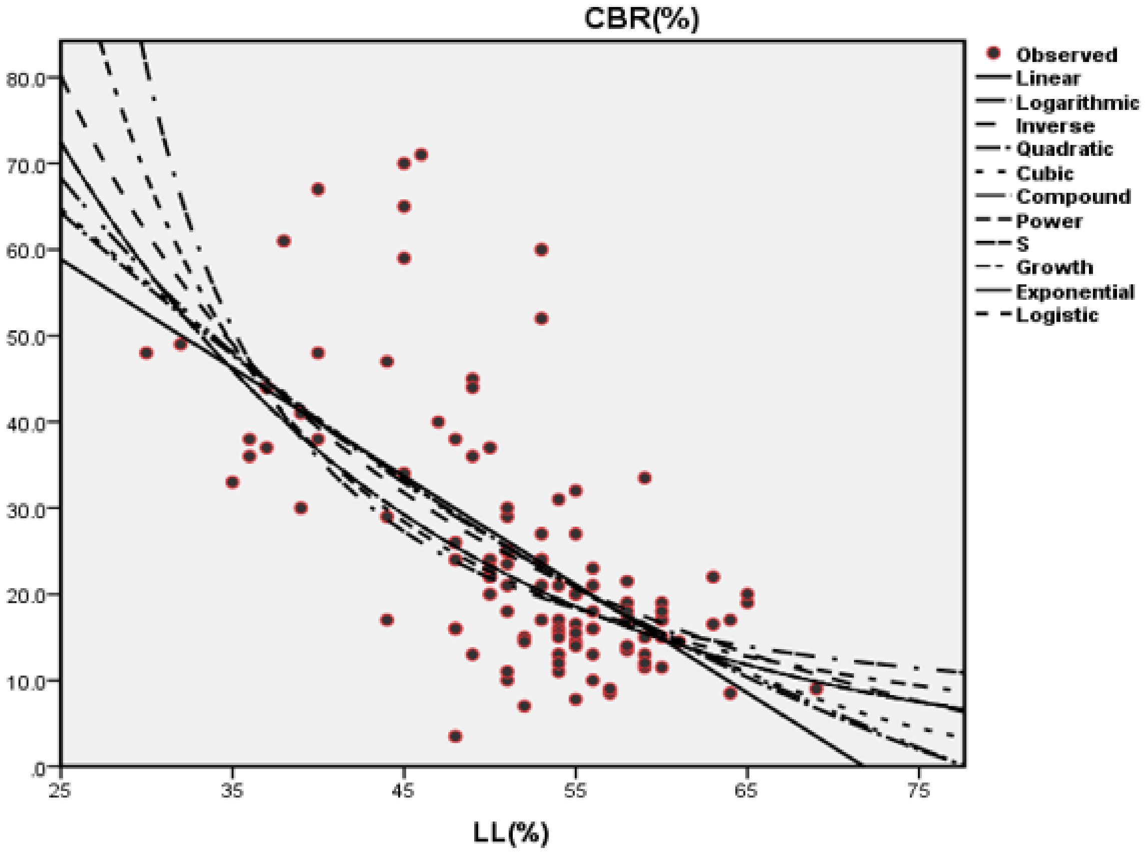

Figure 4-3: Scatter Diagram of California bearing ratio versus Liquid limit

4.3.1.4 California Bearing Ratio (CBR) versus Plastic Limit (PL)

The correlation between the CBR and PL for the tested samples is shown in figure 4-4.

The equation that best fits the correlation between CBR and PL is linear equation.

CBR = 98.024-2.186*PL R^2= 0.317

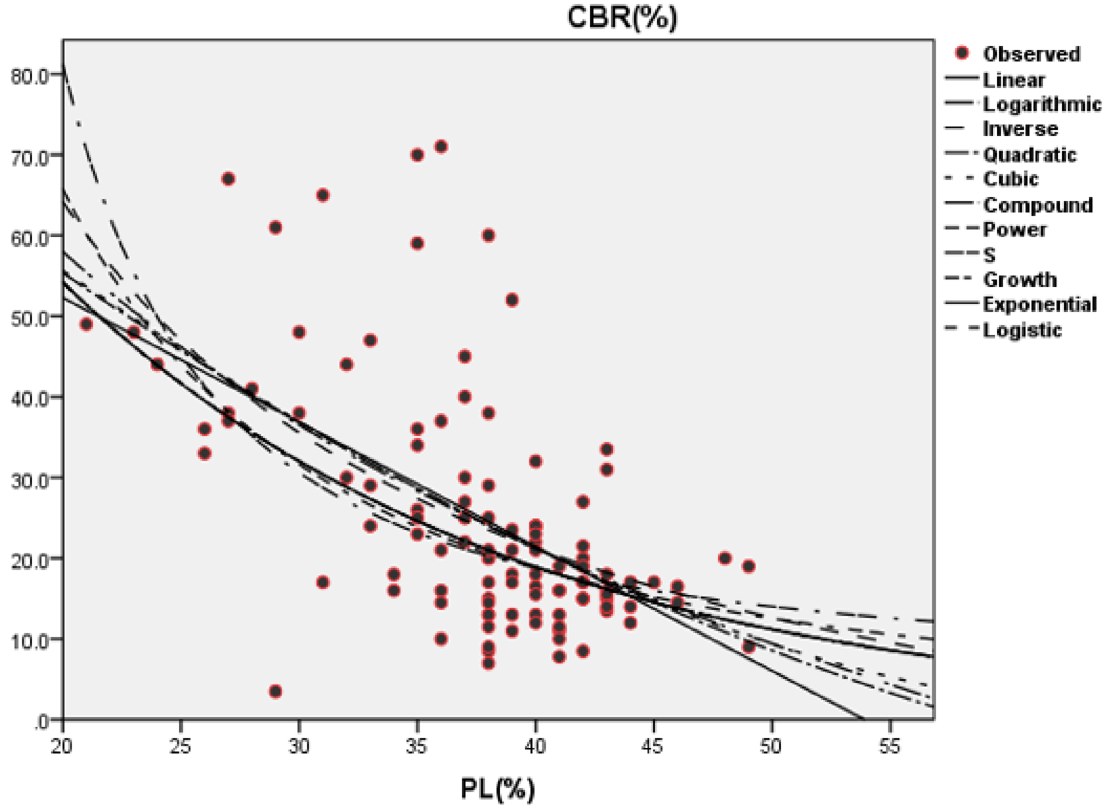

Figure 4-4: Scatter Diagram of California bearing ratio versus Plastic limit

4.3.1.5 California Bearing Ratio (CBR) versus Plastic Index (PI)

The relationship between the CBR and PI for the tested samples is shown in figure 4-5.

The equation that best fits the correlation between CBR and PI is quadratic equation.

$CBR = 115.06-10.176*PI+0.258*PI^{2,}$ R^2= 0.336.

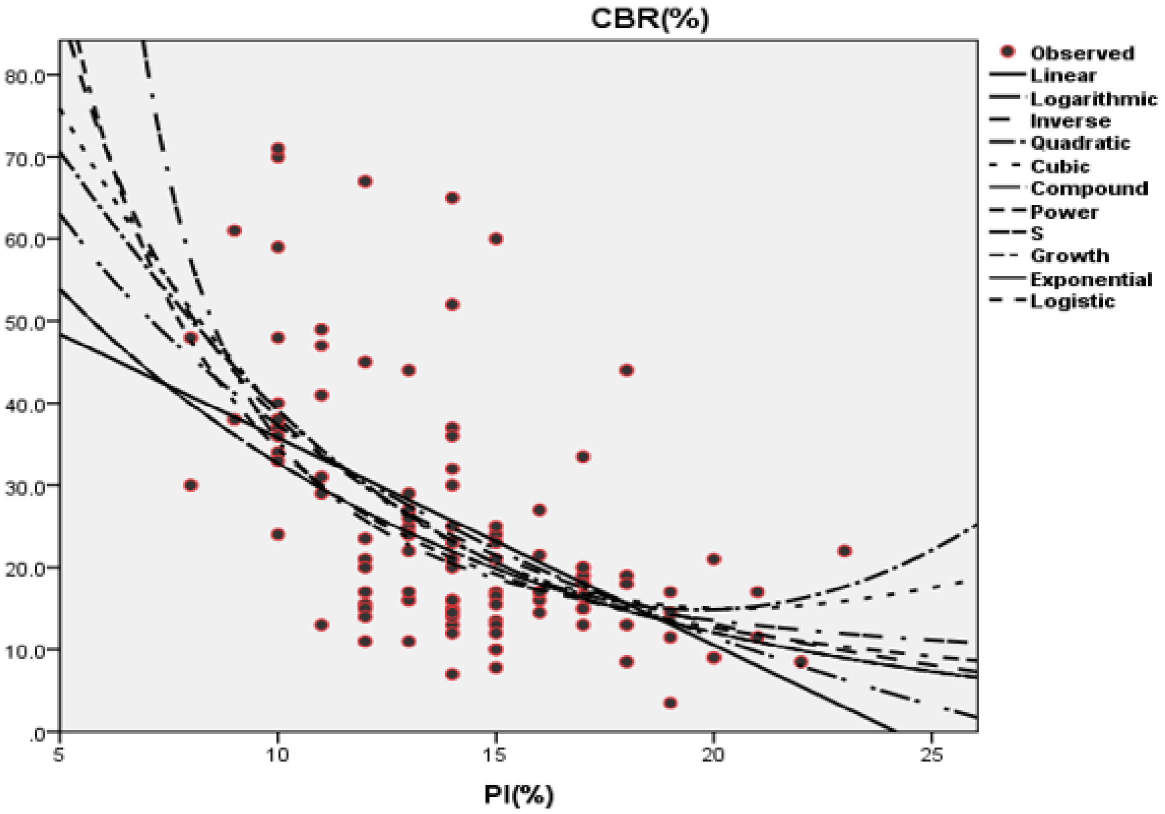

Figure 4-5: Scatter Diagram of California bearing ratio versus Plastic Index

4.3.1.6 California Bearing Ratio (CBR) versus Maximum Dry Density (MDD)

The correlation between the CBR and MDD for the tested samples is shown in figure 4-6.

The equation that best fits the correlation between CBR and MDD is again quadratic.

CBR = 24.023-58.222*MDD+36.055*MDD^2, R^2= 0.667.

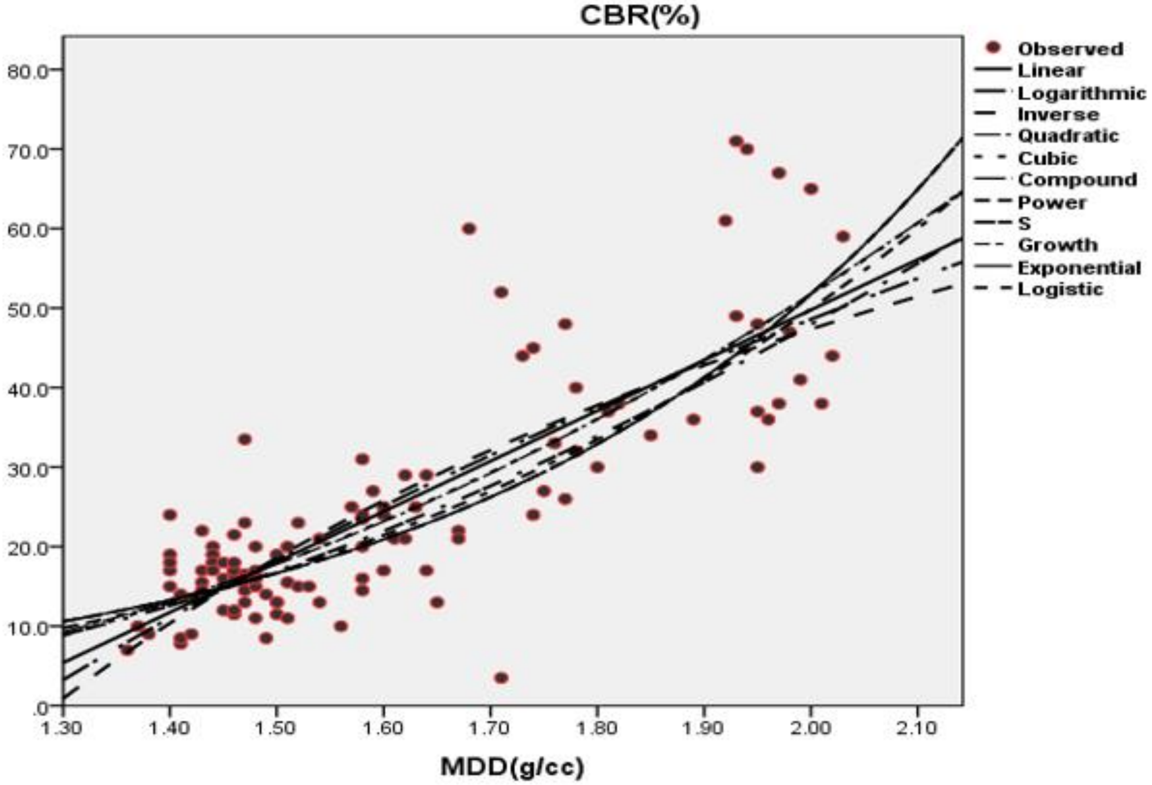

Figure 4-6: Scatter Diagram of California bearing ratio versus Maximum Dry Density

4.3.1.7 California Bearing Ratio (CBR) versus Optimum Moisture Content (OMC)

The correlation between the CBR and OMC for the tested samples is shown in figure 4-7.

The equation that best fits the correlation between them is cubic equation.

CBR = 116.241-5.367*OMC+ 0.002*OMC^3, R^2= 0.580.

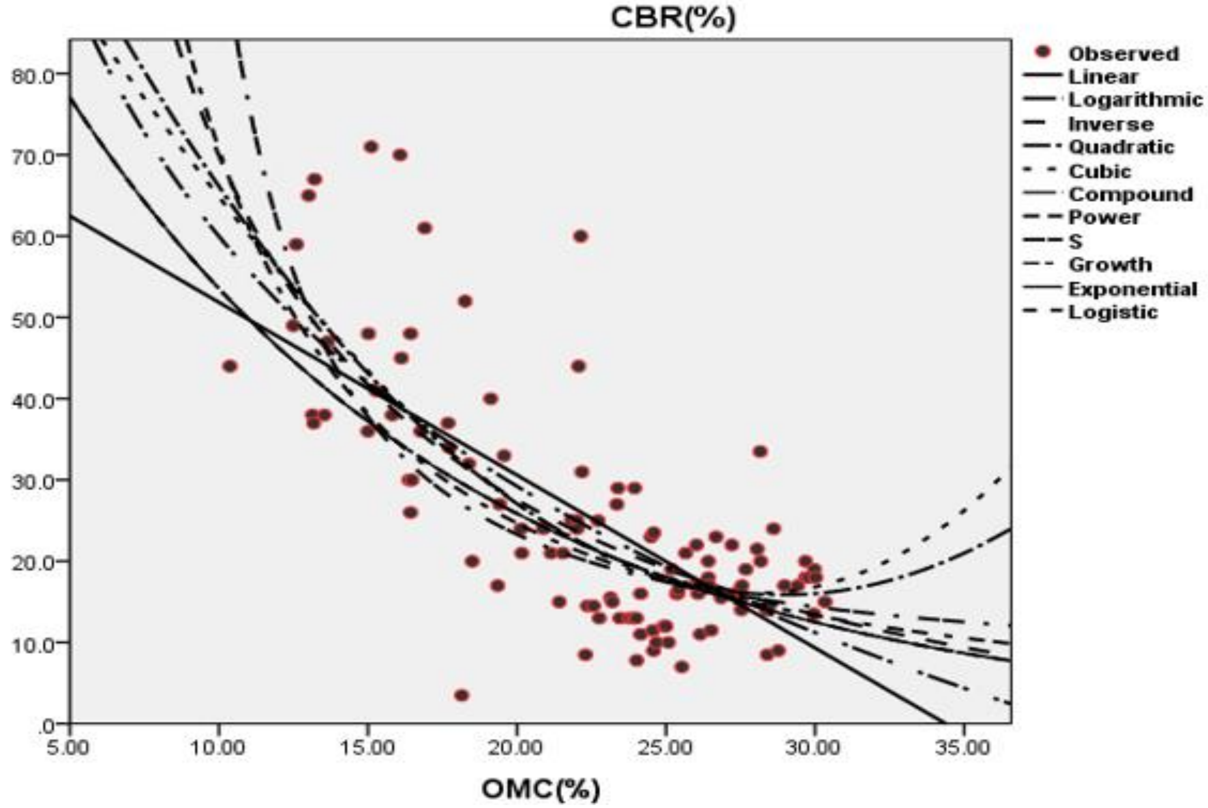

Figure 4-7: Scatter Diagram of California bearing ratio versus Optimum moisture content

According to the coefficient of regression from the aforementioned single-linear and single-non-linear regression models of sub grade, CBR has a strong correlation with soil index properties. Details of the output are provided in appendix A.

4.4 Multiple Linear Regression Analysis

Probable empirical equations are established by taking one or more of these independent variables (PP_{40}, PP_{200}, LL, PL, PI, MDD, and OMC) in different arrangements as summarized in below table.

Table 4.1: Summary of developed possible empirical equations

Equt. No.	Equations	R	R^2
1	$CBR = 73.728-0.575LL-0.27PP_{200}$	0.730	0.532
2	$CBR = 59.76-0.316PP_{200}-0.891PI$	0.715	0.511
3	$CBR = -51.665-0.102PP_{200}+52.085MDD$	0.822	0.675
4	$CBR = 68.216-0.19PP_{200}-1.323OMC$	0.755	0.570
5	$CBR = 52.232-0.131PP_{40}-0.252PP_{200}$	0.699	0.489
6	$CBR = 88.788-1.073LL-0.565PI$	0.635	0.403
7	$CBR = -76.748-0.002LL+63.312MDD$	0.812	0.660
8	$CBR = 81.264-0.32LL-1.752OMC$	0.727	0.528
9	$CBR = 76.267-0.589LL-0.282PP_{40}$	0.730	0.531
10	$CBR = 61.986-0.331PP_{40}-0.887PI$	0.712	0.508
11	$CBR = 77.039-0.7PI-1.857OMC$	0.730	0.532
12	$CBR = -63.7850.444PI+59.118MDD$	0.816	0.666
13	$CBR = 69.857-1.335OMC-0.199PP_{40}$	0.755	0.571
14	$CBR = -103.435+0.43OMC+73.776MDD$	0.814	0.663

15	CBR = -51.334+52.282MDD-0.106PP_{40}	0.824	0.675
16	CBR = 73.371-0.268PP_{200}-0.519LL-0.194PI	0.730	0.533
17	CBR = 73.327-0.181PP_{200}-0.192LL-1.136*OMC*	0.757	0.573
18	CBR = -59.256-0.108PP_{200}+0.088LL+54.185MDD	0.822	0.676
19	CBR = 74.864-0.137PP_{200}-0.576LL-0.141PP_{40}	0.729	0.533
20	CBR = 79.825-0.144LL-0.544PI-1.749*OMC*	0.730	0.534
21	CBR = -79.99+0.244LL-0.724PI63.808MDD	0.818	0.669
22	CBR = 75.999-0.547LL-0.143PI-0.279PP_{40}	0.730	0.533
23	CBR = -97.625-0.564PI+72.665MDD+0.608*OMC*	0.820	0.672
24	CBR = 72.261-0.389PI-1.241*OMC*-0.185PP_{40}	0.758	0.575
25	CBR = -89.344+0.7*OMC*-0.127PP40+67.017MDD	0.827	0.683
26	CBR = -46.37-0.092PP_{200}+50.695MDD-0.266PI	0.823	0.677
27	CBR = 70.851-0.177PP_{200}-1.222OMC-0.41PI	0.758	0.574
28	CBR = 60.283-0.243PP_{200}-0.882PI-0.079PP_{40}	0.715	0.511
29	CBR = -91.415-0.126PP_{200}+0.739OMC+67.398MDD	0.827	0.684
30	CBR = 69.413-0.048PP_{200}-1.325OMC-0.15*OMC*	0.756	0.571
31	CBR = -99.655-0.07LL+0.482OMC+72.935MDD	0.815	0.664
32	CBR = 74.928-0.19PP_{40}-0.194LL-1.145OMC	0.758	0.573
33	CBR = -46.224-0.095PP_{40}-0.264PI+50.931MDD	0.823	0.678
34	CBR = -51.402-0.08PP_{200}+52.045MDD-0.024PP_{40}	0.822	0.675
35	CBR = -58.308-0.111PP_{40}+54.235MDD0.08LL	0.821	0.673

36	CBR = 72.755-0.176PP$_{200}$-0.096LL-0.308PI-1.153OMC	0.758	0.575
37	CBR = -63.762-0.096PP$_{200}$+0.272LL-0.571PI+55.593MDD	0.826	0.682
38	CBR = 74.469-0.145PP$_{200}$-0.527LL-0.167PI-0.131PP$_{40}$	0.731	0.534
39	CBR = -88.611-0.113PP$_{200}$-0.389PI+0.831OMC+67.268MDD	0.830	0.688
40	CBR = 71.741-0.059PP$_{200}$-0.393PI-1.228OMC-0.125PP$_{40}$	0.758	0.575
41	CBR = -91.811-0.143PP$_{200}$+0.743OMC+67.502MDD+0.019PP$_{40}$	0.827	0.684
42	CBR = -105.467+0.181LL-0.757PI+0.533OMC+74.47MDD	0.821	0.674
43	CBR = 74.397-0.109LL-0.273-1.162OMC-0.184PP$_{40}$	0.759	0.575
44	CBR = -63.087+0.259LL-0.557PI+55.741MDD-0.097PP$_{40}$	0.825	0.681
45	CBR = -89.059-0.006LL+0.703*OMC*+66.96MDD-0.127PP$_{40}$	0.827	0.683
46	CBR = -86.902-0.113PP$_{40}$-0.385PI+0.792OMC+66.989MDD	0.829	0.687
47	CBR = -91.433-0.126PP$_{200}$+0.739OMC+67.402MDD	0.827	0.684
48	CBR = -58.996-0.091PP$_{200}$+0.087LL+54.138MDD-0.018PP$_{40}$	0.822	0.676
49	CBR = 74.538-0.039PP$_{200}$-0.192LL-1.139OMC-0.151PP$_{40}$	0.758	0.574
50	CBR = -46.272-0.082PP$_{200}$-0.265PI-0.011P$_{40}$+50.683MDD	0.823	0.677
51	CBR = 73.872-0.051PP$_{200}$-0.133PP$_{40}$-0.105LL-0.281PI-1.154OMC	0.759	0.576
52	CBR = -64.135-0.177PP$_{200}$+0.023PP$_{40}$+0.275LL-0.576PI+55.66MDD	0.826	0.682
53	CBR = -89.493-0.154PP$_{200}$-0.394PI+0.044PP$_{40}$+0.841OMC+67.51MDD	0.830	0.689
54	**CBR = -96.73-0.114PP$_{200}$+0.188LL-0.588PI+0.754OMC+69.122MDD**	**0.831**	**0.691**

Generally, Potential empirical equations for the subgrade silty clay soil of the investigation area are typically created by carefully analyzing a reasonable number of laboratory test results with all probable combinations of independent variables.

The best regression coefficient value, $R^2=0.691$, is obtained when all possible independent variable parameters are used, as is clearly demonstrated in the above table. Regression coefficient square value increases as the number of independent variables increases.

Multiple parameter regression analysis shows a higher regression coefficient square value than single parameter regression analysis. As a result, the correlation analysis carried out by multiple regression analysis is more trustworthy and accurate.

4.5 Evaluation of Developed Correlation

4.5.1 Comparison of Regression coefficient square value Range with existing Correlations

To develop proposed equations, different literatures regarding correlations of CBR with index properties of soils has been thoroughly studied and reviewed at the early stage of the study and its summary is presented in previous chapter. Finally, from all output of single nonlinear, single linear and multiple linear regression analysis, an improved correlation is obtained from multiple linear regression analysis with regression coefficient square value of **0. 691** and obtained equation is;

CBR = -96.73-0.114PP200+0.188LL-0.588PI+0.754OMC+69.122MDD, R2= 0.691, n = 110.

To check the validity of this equation and to keep up to date on the published correlations, different post-graduation thesis, journals and published reports were reviewed. This is done by comparing regression coefficient square value (R^2) of this work with previously developed correlations that were correlated soaked CBR value with different soil index properties as summarized below.

Regression Coefficient square is the measures of how well the least-square regression line (best-fit line) fits the sample data. Value of R= 1 or -1 ($R^2=1$) shows that there is a perfect linear correlation and also perfect linear regression, where by a negative value of R indicates inversely relationship and positive value implies a direct relationship. On the other hand, R = 0 or approaches to zero shows, no valid relationship can be obtained between the variables **(Douglas, C.M. and George, C.R,2003)**

According to the principles of multiple linear regressions, the value of regression coefficient square (R^2) should approach to unity for the perfect fit **(Zohib Shahzad Janjua and Jagdish Chand ,2016).**

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 regression variables and this quantity termed as the coefficient of determination, R^2.

The value of R^2 is always between 0 and 1, because R is between -1 and +1. A negative value of R indicates inversely relationship and a positive value implies direct relationship **(Yared L.2013)**

Accordingly, the regression Coefficient square value of different authors are summarized in the next table.

Table 4.2: Regression Coefficient square value of existing correlations.

Developed Correlation for CBR(soaked)	**R^2 value**	**Number of data points**	**CBR is correlated with**	**Author name and year**	**soil types used in correlation**	**Awarded**	**Institute and Country**
CBR = -76.65 + 0.22LL - 0.5PI - 0.219P_{200} + 72.867MDD	R^2=0.768	n=115	LL, PI, PP 200 & MDD	Getachew Baro (2022)	Laterite Soils	Meng in civil Engineering	Addis Ababa University, Ethiopia
CBR = -21.734 – 0.003*LL – 0.137*PI + 20.244*MDD	R^2 =0.629	n= 42	LL,PI & MDD	Yared Leliso (2013)	Fine grain soil(A-7-5&6)-as AASHTO	MSc in civil Engineering	Addis Ababa University, Ethiopia
CBR=3.591-0.031PP200+63.707MDD-0.098PI	R^2=0.731	n=30	PP_{200},MDD &PI	Dino A. ,Tadesse A. &Prof. Emer T.(2017)	Fine grained soils	Global Scientific Journal	Jimma University,
CBR=15.84MDD-0.36LL+0.218PL-4.08	R^2=0.9306 (Fine Grained)	n=14	MDD,LL & PL	Dereje Bogale(2019)	Fine graine (A-7-5)-as AASHTO	MSc in civil Engineering	Addis Ababa University, Ethiopia
CBR=0.137-0.078LL-0.028PL-.0.441OMC+9.127MDD	R^2=0.958	n=45	LL, PL, OMC ,PL&MDD	Arunav Ch.and Anasuya G.(2021)	Fine grained soil(silt+clay)	Geotechnical Engineering Journal	Tezpur University,India
CBR = 0.142 PP_{200}+ 0.0262 L.L + 0.0283 OMC+ 1.043 MDD - 17.029	R^2=0.836	n=33	PP200,LL,OMC &MDD	Zohib Sh.Janjua and Agdish Chand (2016)	Well graded sand containing silt) soil	MSc. in Civil Engineering	Chandigarh University, India.

CBR=989.798+4.04PP200-1.223LL-1.19PI-9.961OMC-527.282MDD+0.019P_{40}	R^2=0.915	n=73 (for red clay soil)	PP20, LL PI, OMC, MDD & P_{40}	Abiyu Solomon (2021)	Red clay soil	Meng in civil Engineering	Addis Ababa University, Ethiopia
CBR= 3178.89+0.035LL-10.57PI-469.578MDD+17.567OMC-33.017PP40-15.274PI+7.756PP_{200}	R^2=0.838	n=37 (for brown clay soil)	PP20, LL PL,MDD ,OMC ,PP40 &PI		Brown clay soil		
CBR=-0.05LL-0.5LI+0.021PP_{200}+4.625	R^2=0.319	n=18(for red clay soil)	LL, LI & PP_{200}	Alemayehu Bekele(2017)	Red Clay	MSc in civil Engineering	Addis Ababa University, Ethiopia
CBR=-0.049LL-0.91LI-0.015PP_{200}+8.205	R^2=0.72	n=9 (for gray clay soil)			Black/ gray Soil		
CBR=29.17MDD+0.2365OMC+0.225PI-38.975	R^2=0.866 (course grained)	n=23	MDD, OMC &PI	Dereje Bogale (2019)	Coarse Grain(A-2-7)-as AASHTO	MSc in civil Engineering	Addis Ababa University, Ethiopia
CBR = -21.734 – 0.003*LL – 0.137*PI + 20.244*MDD,	R^2 =0.629	n = 42	LL,PI & MDD	Yared Leliso (2013)	Fine grain soil(A-7-5&6)-as AASHTO	MSc in civil Engineering	Addis Ababa University, Ethiopia

As it is observed from the table, the regression coefficient square value of these authors' ranged from **0.319 to 0.958** and the obtained value from the finding is **0.691** which is in range of previously developed correlations.

4.5.2 Validity Checking of Developed Correlation with Actual (Measured) CBR Values

The validation of developed correlation is conducted by using seven known test results which follows similar testing procedures with the subject study. These control test results were obtained from Best Consulting Engineers P.L.C testing laboratory for soil samples collected from different sections of Guliso Cheliya Dilla Kondala Begi Road Project.

Depending on the relative value of regression coefficient square and considering numbers of independent variables included in the developed equations, **CBR = -96.73-0.114PP200+0.188LL-0.588PI+0.754OMC+69.122MDD** is preferably selected among the different developed alternative correlations for further verifications.

Accordingly, Predicted and actual CBR values with all independent variables are summarized in the following table and its detail is presented in **Appendix C**

Table 4.3: Actual (Measured) Test Results and Predicted CBR values

No	Actual (measured) Test Results								Predicted CBR Value (%) (B)	Differenc	Variation (%) [(A-B)/A] *100
1	PP_{40} (%)	PP_{200} (%)	LL (%)	PL (%)	PI (%)	MDD (g/cc)	OMC (%)	Measured CBR Values (%) (A)			
2	53.2	50.4	57	46	10	1.58	16.46	**18.0**	**23.62**	-5.62	**-31%**
3	74.0	67.2	54	42	13	1.65	19.52	**23.0**	**27.18**	4.18	**-18%**
4	75.5	67.7	47	36	11	1.60	21.13	**29.0**	**24.26**	-4.74	**16%**
5	42.3	38.2	53	40	13	1.80	17.61	**36.5**	**38.80**	2.30	**-6%**
6	85.5	79.1	48	33	15	1.63	10.20	**16.0**	**15.02**	-0.98	**6%**
7	44.7	38.1	54	39	15	1.73	20.73	**33.0**	**35.64**	2.64	**-8%**
8	45.4	41.6	49	36	13	1.77	17.27	**17.0**	**35.59**	18.59	**-109%**
Av										**2.34**	**-22%**

As it is observed from the table, the average predicted CBR value obtained from developed correlation shows 78% accuracy when compared with actual CBR value.

4.5.3 Comparison of Developed Correlation with Existing Correlations

To evaluate the developed correlations, different existing correlations along with the developed correlation is examined using actual test results and the variations are calculated as it is briefly presented in below table.

Table 4.4: Comparison of developed and existing correlations

No	**Actual CBR value (%)**	**Developed Correlation**			**Bogale D.(fine g)**		**Leliso Y.**		**Baro G.**		**Bogale D.(course g.)**	
		Predicted CBR	Difference	Variation (%)	Predicted CBR	Variation (%)	Predicted CBR	Variation (%	Predicted CBR	Variation (%	Predicted CBR	Variation (%)
1	18.0	23.62	-5.62	-31%	10.628	41%	8.640	52%	34.637	-92%	13.318	26%
2	23.0	27.18	4.18	-18%	11.597	50%	9.788	57%	34.527	-50%	16.671	28%
3	29.0	24.26	-4.74	16%	12.162	58%	8.949	69%	29.737	-3%	15.020	48%
4	36.5	38.80	2.30	-6%	14.034	62%	12.729	65%	51.175	-40%	20.603	44%
5	16.0	15.02	-0.98	6%	11.625	27%	9.110	43%	28.094	-76%	14.482	9%
6	33.0	35.64	2.64	-8%	12.479	62%	11.125	66%	45.603	-38%	19.755	40%
7	17.0	35.59	18.59	-109%	14.213	16%	12.196	28%	47.596	-180%	19.596	-15%
Av			**2.34**	**-22%**		**45%**		**54%**		**-68%**		**26%**
Soil type					Fie Gr. (A-7-5)-as AASHTO		Fine grain soil (A-7-5&6)-as AASHTO		Laterite soil		Coarse Grain(A-2-7)-as AASHTO	

No	**Actual CBR value (%)**	**Developed Correlation**			**NCHRP**		**Zahib Sh.&Agdish Ch.**		**Arunav Ch. &Anasuya G.**		**Agarwa and Ghanekar**	
		Predicted CBR	Difference	Variation (%)	Predicted CBR	Variation (%	Predicted CBR	Variation(%	Predicted CBR	Variation (%)	Predicted CBR	Variation (%)
1	18.0	23.62	-5.62	-31%	30.53	-70%	27.783	-54%	1.582	91%	-13.498	175%
2	23.0	27.18	4.18	-18%	22.20	3%	30.268	-32%	1.206	95%	-14.849	165%
3	29.0	24.26	-4.74	16%	24.65	15%	30.137	-4%	0.709	98%	-15.907	155%
4	36.5	38.80	2.30	-6%	31.39	14%	26.215	28%	3.539	90%	-14.220	139%
5	16.0	15.02	-0.98	6%	17.32	-8%	31.526	-97%	5.843	63%	-10.754	167%
6	33.0	35.64	2.64	-8%	29.24	11%	26.234	21%	1.509	95%	-15.299	146%
7	17.0	35.59	18.59	-109%	30.33	-78%	26.550	-56%	3.834	77%	-14.368	185%
Av.			**2.34**	**-22%**		**-16%**		**-28%**		**87%**		**162%**
Soil type					Fine Grained (plastic) soil		Well graded sand containing silt) soil		Fine grained soil(silt clay)		Fine Grained soil	

As it is shown in table 4.4 above, developed correlation is compared with eight different equations developed by different researchers conducted at different places. Accordingly, correlations developed by NCHRP, Zahib Sh.and Agdish Ch. And Bogale D $_{\text{(course grain)}}$ are suited better with developed correlation with an average variation of -16%, -28% and 26% respectively. This is because of soil types used in actual CBR test is relatively similar with that of the authors' soil type. But equations developed by Bogale D $_{\text{(fine grain)}}$, Leliso Y, Baro G and Arunav Ch. and Anasuya G. shows relatively poor relation with developed correlation with average variation of 45%, %54% -68% and 87 % respectively. Surprisingly, the Agarwal and Ghanekar correlations resulted negative predicted CBR values, which is impractical, when evaluated with the actual test results of the study area. This may be due to the difference in test procedures and also the unique properties of the geological material where the correlations were developed. On the other hand, developed correlation predicted the CBR value with average difference of 2.34 or average percentage variation of -22% from the actual CBR value.

In general, the regression analysis targeted to predict CBR value from index properties of soil in this work provided 78 percent accuracy in evaluating CBR value when conducted on soils with similar properties and test procedures kept uniform throughout the correlation work. But to use for Practical purpose, this correlation must be investigated with different soils and seasons before being used. It also has to be modified with a large number of samples an advanced methodology instead of only correlation analysis.

CHAPTER 5

CONCLUSION AND RECOMMENATIONS

5.1 Conclusion

The goal of this project work is to establish a relationship between the CBR value and the soil index characteristics of the Guliso Cheliya Dilla Kondala Begi Lot 2 road project. To achieve the objectives of the study, 110 secondary laboratory test results were collected from Best Consulting Engineers office which was collected from different sections of the road. Single linear, non-linear and multiple linear regressions analysis methods were used to analyze the laboratory test data and expected correlation is developed that estimates the CBR values in terms of LL, PL, PI, PP_{40}, PP_{200}, MDD and OMC.

Generally, the following conclusions are noted from the regression analysis results.

a. From the output of single nonlinear, single linear and multiple linear regression analysis, an improved correlation is obtained from multiple linear analysis and it is summarized as follows;

$$CBR = -96.73-0.114PP_{200}+0.188LL-0.588PI+0.754OMC+69.122MDD,$$

$$R^2 = 0.691,\ n = 110$$

As observed from the developed equation, R^2 value is 0.691 and this clearly shows that the conducted correlation analysis is reliable and approached to accuracy.

b. Regression coefficient square value is more approached to unity when maximum dry density and optimum moisture content are incorporated in the regression analysis which means that CBR value is more related with MMD and OMC than other soil index properties. So controlling of compaction and moisture content R^2 during subgrade preparation in road construction is very important to get required strength.

c. Compared to single linear and nonlinear regressions, multiple linear regression analysis reveals higher regression coefficient square value. So, combination of soil index properties correlates more favorably with CBR values than individual soil properties.

d. From Single Linear Regression analysis, Correlation of CBR with MDD, OMC and PP_{200} provide strong relation with R^2 = 0.667, R^2 =0.58 and R^2 =0.509 respectively.

This shows that the reliability of these three equations, with a single test result, is almost the same with that of selected MLRA result.

So these three equations; i.e. $CBR = 24.023-58.222*MDD+36.055*MDD^2, \quad R^2= 0.667$

$$CBR = 116.241-5.367*OMC+ 0.002*OMC^3, \quad R^2= 0.580$$

$$CBR = 30.29+1.18*PP200-0.032*PP200^2, \quad R^2= 0.509$$

can be used in absence of LL, PL and PP_{400} test results to use developed MLRA equation to save time and effort.

5.2 Recommendations

With respect to the topic under study, the following recommendations are proposed.

a. Due to the fact that soil properties differ from place to place on surface and layer to layer deep, it is advised to conduct frequent research in various types of soils.

b. Comparative correlation studies between soaked and unoaked CBR values and soil index properties are important in establishing more reliable correlations.

c. To confirm the equation holds true for other types of soil, more researches must be done on different soil types.

d. It is advised to use one of alternative equation developed in Single linear regression analysis from MDD, OMC and PP_{200} respectively in the absence of LL, PL and PP400 test results to use developed MLRA equation.

e. Instead of using a straightforward regression analysis method, it is essential to study Ethiopian soil using advanced techniques like Artificial Neural Network method and develop national soil data base system.

f. Finally, obtained regression coefficient square value from the developed correlation is little far from unity and it should be more improved by collecting more data points and conducting similar regression analysis around the investigation area.

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APPENDIX A

Details of the SPSS Regression Analysis Outputs

Appendix A1: Summary of Single Linear and Non-Linear Regression

Model Summary and Parameter Estimates for California bearing ratio versus percent passing sieve no. 40

Model Summary and Parameter Estimates

Dependent Variable: CBR (%)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.485	101.604	1	108	.000	53.950	-.394		
Logarithmic	.467	94.641	1	108	.000	118.926	-22.315		
Inverse	.403	72.767	1	108	.000	8.301	997.461		
Quadratic	.485	50.397	2	107	.000	55.944	-.468	.001	
Cubic	.498	35.068	3	106	.000	24.307	1.469	-.034	.000
Compound	.494	107.307	1	108	.000	64.547	.985		
Power	.476	98.244	1	108	.000	761.454	-.849		
S	.408	74.290	1	108	.000	2.428	37.812		
Growth	.491	107.307	1	108	.000	4.167	-.015		
Exponential	.493	107.307	1	108	.000	64.547	-.015		
Logistic	.491	107.307	1	108	.000	.015	1.015		

The independent variable is PP_{40} (0.425mm PP).

Model Summary and Parameter Estimates for California bearing ratio versus percent passing sieve no. 200

Model Summary and Parameter Estimates									
Dependent Variable: CBR (%)									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.488	102.827	1	108	.000	51.216	-.376		
Logarithmic	.466	94.332	1	108	.000	104.823	-19.322		
Inverse	.369	63.261	1	108	.000	11.865	694.491		
Quadratic	.490	51.320	2	107	.000	54.919	-.529	.001	
Cubic	.509	36.561	3	106	.000	30.290	1.180	-.032	.000
Compound	.502	108.938	1	108	.000	58.186	.986		
Power	.476	98.144	1	108	.000	446.077	-.736		
S	.375	64.883	1	108	.000	2.563	26.374		
Growth	.502	108.938	1	108	.000	4.064	-.014		
Exponential	.502	108.938	1	108	.000	58.186	-.014		
Logistic	.502	108.938	1	108	.000	.017	1.014		
The independent variable is PP_{200} (0.075mm PP).									

Model Summary and Parameter Estimates for California bearing ratio versus Liquid Limit

Model Summary and Parameter Estimates

Dependent Variable: CBR (%)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.397	71.043	1	108	.000	90.298	-1.258		
Logarithmic	.395	70.651	1	108	.000	262.132	-60.214		
Inverse	.381	66.380	1	108	.000	-28.758	2723.974		
Quadratic	.400	35.610	2	107	.000	114.503	-2.262	.01	
Cubic	.400	35.842	2	107	.000	110.727	-1.893	.00	8.458E-5
Compound	.364	61.796	1	108	.000	225.309	.956		
Power	.362	61.359	1	108	.000	110481.41	-2.171		
S	.349	57.884	1	108	.000	1.122	98.258		
Growth	.364	61.796	1	108	.000	5.417	-.045		
Exponential	.364	61.796	1	108	.000	225.309	-.045		
Logistic	.364	61.796	1	108	.000	.004	1.046		

The independent variable is LL.

Model Summary and Parameter Estimates for California bearing ratio versus Plastic Limit

Model Summary and Parameter Estimates									
Dependent Variable: CBR (%)									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.315	49.588	1	108	.000	83.136	-1.542		
Logarithmic	.314	49.331	1	108	.000	216.855	-53.027		
Inverse	.302	46.717	1	108	.000	-21.708	1717.716		
Quadratic	.316	24.759	2	107	.000	101.151	-2.581	.015	
Cubic	.317	24.853	2	107	.000	98.024	-2.186	.000	.000
Compound	.258	37.574	1	108	.000	155.250	.949		
Power	.257	37.321	1	108	.000	14809.216	-1.808		
S	.247	35.505	1	108	.000	1.468	58.580		
Growth	.258	37.574	1	108	.000	5.045	-.053		
Exponential	.258	37.574	1	108	.000	155.250	-.053		
Logistic	.258	37.574	1	108	.000	.006	1.054		
The independent variable is PL.									

Model Summary and Parameter Estimates for California bearing ratio versus Plastic Index

Model Summary and Parameter Estimates

Dependent Variable: CBR (%)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.286	43.212	1	108	.000	61.018	-2.524		
Logarithmic	.314	49.347	1	108	.000	122.942	-37.189		
Inverse	.328	52.648	1	108	.000	-11.971	501.895		
Quadratic	.336	26.973	2	107	.000	115.060	-10.176	.258	
Cubic	.335	17.857	3	106	.000	135.692	-14.613	.563	-.007
Compound	.314	49.497	1	108	.000	88.640	.905		
Power	.335	54.310	1	108	.000	965.761	-1.447		
S	.334	55.720	1	108	.000	1.642	19.270		
Growth	.314	49.497	1	108	.000	4.485	-.100		
Exponential	.314	49.497	1	108	.000	88.640	-.100		
Logistic	.314	49.497	1	108	.000	.011	1.105		

The independent variable is PI.

Model Summary and Parameter Estimates for California bearing ratio versus Maximum Dry Density

Model Summary and Parameter Estimates									
Dependent Variable: CBR (%)									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.660	209.537	1	108	.000	-76.993	63.385		
Logarithmic	.652	202.381	1	108	.000	-24.377	105.278		
Inverse	.641	192.715	1	108	.000	133.658	-172.587		
Quadratic	.667	106.463	2	107	.000	24.023	-58.222	36.055	
Cubic	.665	106.313	2	107	.000	-10.327	.000	3.563	5.974
Compound	.594	158.113	1	108	.000	.557	9.641		
Power	.594	157.924	1	108	.000	3.618	3.785		
S	.591	155.844	1	108	.000	6.992	-6.242		
Growth	.594	158.113	1	108	.000	-.585	2.266		
Exponential	.594	158.113	1	108	.000	.557	2.266		
Logistic	.594	158.113	1	108	.000	1.795	.104		
The independent variable is MDD.									

Model Summary and Parameter Estimates for California bearing ratio versus Optimum moisture density

Model Summary and Parameter Estimates

Dependent Variable: CBR (%)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.519	116.333	1	108	.000	73.127	-2.126		
Logarithmic	.548	130.767	1	108	.000	162.188	-44.383		
Inverse	.551	132.537	1	108	.000	-14.814	847.454		
Quadratic	.575	72.315	2	107	.000	133.191	-8.105	.140	
Cubic	.580	73.840	2	107	.000	116.241	-5.367	.000	.002
Compound	.428	80.789	1	108	.000	110.884	.930		
Power	.452	88.947	1	108	.000	2332.956	-1.518		
S	.454	89.665	1	108	.000	1.700	28.970		
Growth	.428	80.789	1	108	.000	4.708	-.073		
Exponential	.428	80.789	1	108	.000	110.884	-.073		
Logistic	.428	80.789	1	108	.000	.009	1.075		

The independent variable is OMC

Appendix A-2: Analysis of Single and Multiple Regressions

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), 0.075mm PP [b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.822[a]	.675	.669	8.5829

a. Predictors: (Constant), MDD (g/cc), 0.075mm PP

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16378.488	2	8189.244	111.167	.000[b]
	Residual	7882.258	107	73.666		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), 0.075mm PP

Coefficients [a]

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.

		B	Std. Error	Beta		
1	(Constant)	-51.665	13.285		-3.889	.000
	0.075mm PP	-.102	.046	-.190	-2.239	.027
	MDD(g/cc)	52.085	6.630	.668	7.855	.000

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), PI(%) [b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.816[a]	.666	.659	8.7057

a. Predictors: (Constant), MDD (g/cc), PI (%)

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16151.317	2	8075.658	106.554	.000[b]
	Residual	8109.430	107	75.789		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), PI (%)

Coefficients [a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

1	(Constant)	-63.785	11.956		-5.335	.000
	PI (%)	-.444	.324	-.094	-1.369	.174
	MDD (g/cc)	59.118	5.360	.758	11.029	.000

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), 0.425mm PP, ,OMC(%)[b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.827[a]	.683	.674	8.5145

a. Predictors: (Constant), MDD (g/cc), 0.425mm PP, OMC (%)

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16576.135	3	5525.378	76.216	.000[b]
	Residual	7684.612	106	72.496		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), 0.425mm PP, OMC (%)

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-89.344	26.218		-3.408	.001
	0.425mm PP	-.127	.049	-.224	-2.583	.011
	OMC (%)	.700	.415	.237	1.688	.094
	MDD(g/cc)	67.017	10.919	.859	6.138	.000

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), PI(%), 0.075mm PP[b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.823[a]	.677	.668	8.5975

a. Predictors: (Constant), MDD (g/cc), PI (%), 0.075mm PP

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16425.481	3	5475.160	74.071	.000[b]
	Residual	7835.266	106	73.918		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), PI (%), 0.075mm PP

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-46.370	14.873		-3.118	.002
	0.075mm PP	-.092	.048	-.171	-1.926	.057
	PI (%)	-.266	.333	-.056	-.797	.427
	MDD(g/cc)	50.695	6.867	.650	7.383	.000

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	0.425mm PP, PI(%), MDD(g/cc), LL(%)[b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.825[a]	.681	.669	8.5887

a. Predictors: (Constant), 0.425mm PP, PI (%), MDD (g/cc), LL (%)

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16515.335	4	4128.834	55.972	.000[b]
	Residual	7745.412	105	73.766		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), 0.425mm PP, PI (%), MDD (g/cc), LL (%)

Coefficients [a]

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.

		B	Std. Error	Beta		
1	(Constant)	-63.087	20.871		-3.023	.003
	LL (%)	.259	.223	.130	1.163	.248
	PI (%)	-.557	.419	-.118	-1.331	.186
	MDD (g/cc)	55.741	7.987	.714	6.979	.000
	0.425mm PP	-.097	.050	-.171	-1.934	.056

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), PI(%), 0.425mm PP, OMC(%)[b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.829[a]	.687	.675	8.5022

a. Predictors: (Constant), MDD (g/cc), PI (%), 0.425mm PP, OMC (%)

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16670.506	4	4167.627	57.653	.000[b]
	Residual	7590.241	105	72.288		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), PI (%), 0.425mm PP, OMC (%)

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-86.902	26.268		-3.308	.001
	0.425mm PP	-.113	.051	-.200	-2.242	.027
	PI (%)	-.385	.337	-.081	-1.143	.256
	OMC (%)	.792	.422	.268	1.878	.063
	MDD(g/cc)	66.989	10.903	.859	6.144	.000

a. Dependent Variable: CBR (%)

Variables Entered/Removed [a]

Model	Variables Entered	Variables Removed	Method
1	MDD(g/cc), PI(%), 0.075mm PP, LL(%), OMC(%)[b]	.	Enter

a. Dependent Variable: CBR (%)

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.831[a]	.691	.676	8.4968

a. Predictors: (Constant), MDD (g/cc), PI (%), 0.075mm PP, LL (%), OMC (%)

ANOVA [a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16752.396	5	3350.479	46.408	.000[b]
	Residual	7508.350	104	72.196		
	Total	24260.747	109			

a. Dependent Variable: CBR (%)

b. Predictors: (Constant), MDD (g/cc), PI (%), 0.075mm PP, LL (%), OMC (%)

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-96.730	27.865		-3.471	.001
	0.075mm PP	-.114	.048	-.211	-2.351	.021
	LL (%)	.188	.226	.094	.832	.408
	PI (%)	-.588	.412	-.125	-1.426	.157
	OMC (%)	.754	.434	.255	1.736	.085
	MDD (g/cc)	69.122	11.073	.886	6.242	.000

a. Dependent Variable: CBR (%)

APPENDIX B

Laboratory Test Results of Subgrade material used in Correlation work

Description of Material	Station, km	Depth, cm	Percentage Passing Sieve Sizes			Atterberg Limits			AASHTO Classification	Proctor Density,		CBR, %	Swell, %
			2.00 mm	0.425 mm	0.075 mm	LL (%)	PL (%)	PI (%)		MDD, g/cc	OMC, %		
Reddish silty Clay	0+000	50-152	100.0	98.4	96.6	60	43	17	A - 7 - 5(15)	1.48	30.34	15.0	0.28
Reddish silty Clay with gravel	1+000	50-150	77.6	69.1	57.7	55	42	13	A - 7 - 5(8)	1.59	23.35	27.0	0.31
Reddish silty Clayey Gravel	2+000	40-130	40.2	32.8	29.3	54	43	11	A - 2 - 7(0)	1.58	22.18	31.0	0.15
Reddish silty Clay	3+000	40-160	99.8	99.0	98.2	63	40	23	A - 7 - 5(15)	1.67	27.21	22.0	0.58
Reddish silty Clay	4+000	20-150	94.6	90.5	87.4	52	38	14	A - 7 - 5(12)	1.40	27.51	15.0	0.54
Reddish silty Clay	5+000	50-150	97.5	95.2	92.9	54	40	14	A - 7 - 5(12)	1.65	22.76	13.0	0.64
Reddish silty Clayey Gravel	6+000	30-110	33.0	27.2	24.8	49	37	12	A - 2 - 7(0)	1.74	16.12	45.0	0.45
Reddish silty Clay	7+000	40-160	99.3	97.9	96.2	54	42	12	A - 7 - 5(12)	1.40	25.97	17.0	0.91
Reddish Silty Clay with gravel	7+500	110-160	81.9	73.8	68.5	48	34	14	A - 7 - 5(11)	1.58	26.08	16.0	0.69
Reddish Silty Clayey Gravel	8+000	0-30	40.9	31.8	26.0	44	33	11	A - 2 - 7(0)	1.98	13.65	47	0.22
Reddish silty Clay	8+000	30-150	89.1	80.0	75.2	50	36	14	A - 7 - 5(12)	1.81	17.69	37.0	0.58

Reddish silty Clay with gravel	8+500	50-86	85.7	74.5	66.3	51	38	13	A - 7 - 5(10)	1.62	23.95	29.0	0.58
Reddish Silty Clayey Gravel	9+000	50-152	39.3	32.0	28.2	45	35	10	A - 2 - 5(0)	1.85	17.73	34.0	0.20
Reddish silty Clay	10+000	20-154	95.6	91.5	88.9	50	40	10	A - 7 - 5(10)	1.60	22.02	24.0	0.28
Reddish silty Clay	11+000	40-150	100.0	96.7	92.7	58	43	15	A - 7 - 5(14)	1.42	29.96	13.5	0.42
Reddish silty Clayey Gravel	12+000	0-50	33.8	24.8	18.5	36	27	9	A - 2 - 4(0)	2.01	13.14	38	0.23
Reddish silty Clay	12+000	50-152	98.0	92.7	90.0	49	38	11	A - 7 - 5(10)	1.47	23.77	13.0	0.72
Reddish silty Clay with gravel	13+000	28-110	61.0	54.3	50.9	49	32	18	A - 7 - 5(7)	1.73	22.07	44.0	0.29
Reddish silty Clay	14+000	40-160	99.4	98.3	97.4	54	41	13	A - 7 - 5(12)	1.48	25.35	16.0	0.46
Reddish silty Clay	15+000	30-160	84.4	78.5	72.2	53	38	15	A - 7 - 5(12)	1.68	22.14	60.0	0.34
Reddish silty Clayey Gravel	16+000	0-38	43.2	30.8	25.1	37	27	10	A - 2 - 4(0)	1.95	13.18	37	0.56
Reddish silty Clay	16+000	56-160	98.7	96.7	94.6	58	41	17	A - 7 - 5(15)	1.50	27.68	19.0	0.70
Reddish silty Clay with gravel	17+000	70-162	60.1	51.4	49.0	51	37	14	A - 7 - 5(6)	1.60	22.72	25.0	0.77
	17+500	30-85	73.2	61.5	54.2	47	37	10	A - 5(5)	1.78	19.12	40	0.53
Reddish silty Clay	18+000	20-162	99.9	98.5	96.9	55	38	17	A - 7 - 5(14)	1.51	28.18	20.0	0.36
Reddish silty Clay	19+000	70-164	80.2	75.4	70.7	51	38	13	A - 7 - 5(10)	1.57	22.01	25.0	0.36
Reddish silty clayey Gravel	20+000	0-30	40.9	26.8	18.8	35	26	10	A - 2 - 4(0)	1.76	19.57	33	0.24

Reddish silty Clay with gravel	20+000	61-162	70.1	63.3	60.1	53	37	16	A - 7 - 5(9)	1.75	19.42	27.0	0.44
Reddish silty Clay	21+000	35-164	95.5	89.0	86.0	48	29	19	A - 7 - 5(14)	1.71	18.15	3.5	1.45
Reddish silty Clay	22+000	80-160	54.8	43.1	38.8	45	35	10	A - 5(1)	1.94	16.08	70.0	0.11
Reddish silty Clay with gravel	23+000	30-160	57.4	52.6	51.2	51	39	12	A - 7 - 5(5)	1.58	24.59	23.5	0.75
	24+000	0-35	57.6	47.7	40.8	32	21	11	A - 6(1)	1.93	12.50	49	0.15
	24+000	71-120	71.4	61.0	54.4	51	37	14	A - 7 - 5(7)	1.80	16.38	30.0	0.41
Reddish silty clayey Gravel	25+000	35-164	33.4	25.5	21.3	44	33	11	A - 2 - 7(0)	1.64	23.39	29.0	0.25
	25+500	25-77	36.9	30.6	27.1	49	35	14	A - 2 - 7(0)	1.89	16.77	36	0.22
Reddish silty Clay with gravel	26+000	70-165	65.5	60.9	59.0	53	40	13	A - 7 - 5(8)	1.74	20.89	24.0	0.23
Reddish silty clayey Gravel	27+000	30-160	36.0	31.8	29.7	53	39	14	A - 2 - 7(0)	1.71	18.26	52.0	0.64
	28+000	35-110	25.0	18.0	12.0	48	38	10	A - 2 - 5(0)	1.82	15.82	38.0	0.27
Reddish silty Clay	29+000	50-165	99.6	98.2	96.9	52	38	14	A - 7 - 5(12)	1.36	25.53	7.0	0.72
Reddish silty Clay	30+000	30-164	100.0	97.2	93.6	55	42	14	A - 7 - 5(13)	1.44	26.42	20.0	0.41
Reddish silty Clay	31+000	30-162	99.6	94.6	91.5	48	33	15	A - 7 - 5(12)	1.58	20.14	24.0	0.45
Reddish silty Clay with gravel	32+000	0-30	59.1	47.7	42.7	36	26	10	A - 4(1)	1.96	15.00	36	0.06
	32+000	30-155	99.1	88.2	78.0	54	41	13	A - 7 - 5(12)	1.51	24.15	11.0	0.63
Reddish silty Clay	33+000	30-156	100.0	98.5	95.9	53	40	13	A - 7 - 5(12)	1.40	28.61	24.0	0.84
	34+000	40-154	99.3	97.6	96.4	51	36	15	A - 7 - 5(13)	1.37	25.08	10.0	0.91
Reddish silty Clayey Gravel	35+000	50-150	44.6	32.9	26.0	37	24	13	A - 2 - 7(0)	2.02	10.37	44.0	0.35
	36+000	0-30	48.2	33.3	23.8	30	23	8	A - 2 - 4(0)	1.77	16.43	48	0.28

Reddish silty Clay with gravel	36+000	75-155	69.1	63.4	60.2	51	39	12	A - 7 - 5(7)	1.62	21.54	21.0	0.72
	36+500	30-90	47.0	41.2	36.8	48	35	13	A - 7 - 5(1)	1.77	16.43	26	0.37
Reddish silty Clay	37+000	30-160	99.6	97.9	95.1	56	40	15	A - 7 - 5(13)	1.47	26.68	23.0	0.57
Reddish silty Clay	38+000	30-160	100.0	98.2	96.1	51	39	12	A - 7 - 5(12)	1.48	26.15	11.0	0.55
Reddish silty Clay	39+000	43-160	99.8	98.7	97.3	53	38	15	A - 7 - 5(13)	1.60	27.55	17.0	0.30
Reddish silty Clay	40+000	68-160	99.7	97.1	92.5	48	36	13	A - 7 - 5(15)	1.46	25.39	16.0	0.61
Reddish silty clayey Gravel	41+000	58-150	47.5	32.8	26.2	50	37	13	A - 2 - 7(0)	1.43	26.02	22.0	0.49
Reddish silty Clay with gravel	42+000	25-130	57.8	54.4	52.0	56	38	17	A - 7 - 5(7)	1.50	24.01	13.0	1.13
Reddish silty Clay	43+000	40-120	99.6	98.3	97.0	58	44	14	A - 7 - 5(14)	1.41	28.38	14.0	0.58
Reddish silty Clayey Gravel	44+000	0-40	45.8	36.6	30.1	40	27	12	A - 2 - 6(0)	1.97	13.21	67	0.38
Reddish silty Clay	44+000	40-145	99.4	98.6	97.7	55	40	15	A - 7 - 5(13)	1.46	25.42	16.5	0.92
Reddish silty Clay	45+000	58-130	98.9	96.5	93.5	56	41	16	A - 7 - 5(13)	1.45	24.15	16.0	0.76
Reddish silty Clay	46+000	45-140	98.3	95.2	92.4	65	49	17	A - 7 - 5(15)	1.40	29.98	19.0	0.65
Reddish silty Clay	47+000	50-148	99.8	96.7	95.0	63	46	17	A - 7 - 5(15)	1.47	27.48	16.5	0.60
Reddish silty Clay with gravel	48+000	28-145	91.8	78.0	69.9	69	49	20	A - 7 - 5(14)	1.38	24.58	9.0	0.81
Reddish silty Clay	50+000	30-142	98.8	97.2	94.0	54	40	15	A - 7 - 5(13)	1.43	26.85	15.5	0.87
Reddish silty Clay with gravel	51+000	25-65	58.3	52.0	48.9	50	38	12	A - 7 - 5(4)	1.58	18.50	20.0	0.44

Reddish silty clayey Gravel	52+000	0-35	35.0	26.0	22.5	39	28	11	A - 2 - 6(0)	1.99	15.27	41.0	0.60
Reddish silty Clay	52+000	35-110	96.1	93.5	91.9	56	39	17	A - 7 - 5(14)	1.45	26.42	18.0	0.42
Reddish silty Clay	53+000	25-152	93.9	89.0	86.4	60	42	18	A - 7 - 5(16)	1.44	25.19	19.0	1.00
Reddish silty Clay	54+000	30-146	96.8	93.2	90.9	57	38	18	A - 7 - 5(15)	1.49	22.30	8.5	0.72
Reddish silty Clay	55+000	15-148	98.5	96.3	94.9	61	46	16	A - 7 - 5(14)	1.43	28.46	14.5	0.63
Reddish silty Clayey Gravel	56+000	0-20	52.5	39.7	34.7	40	30	10	A - 2 - 4(0)	1.97	13.54	38	0.26
Reddish silty Clay	56+000	20-135	99.5	97.3	95.7	56	36	20	A - 7 - 5(15)	1.54	25.66	21.0	0.75
Reddish silty Clay	57+000	15-138	99.4	95.3	90.2	59	38	21	A - 7 - 5(17)	1.46	26.51	11.5	1.24
Reddish silty Clay	58+000	20-90	95.8	89.4	83.6	58	42	16	A - 7 - 5(14)	1.43	26.11	17	0.95
Reddish silty Clay	58+000	90-144	99.9	98.6	97.0	55	41	15	A - 7 - 5(13)	1.41	24.02	7.8	1.27
Reddish silty Clay	59+000	35-148	97.4	94.6	92.1	55	36	19	A - 7 - 5(15)	1.58	22.57	14.5	0.59
Reddish silty Clay	60+000	0-20	99.0	97.6	96.3	40	30	10	A - 4(8)	1.95	15.02	48	0.11
Reddish silty Clay	60+000	20-140	98.5	96.4	94.4	60	44	16	A - 7 - 5(14)	1.46	29.42	17.0	0.87
Reddish silty Clay with gravel	61+000	20-80	57.3	50.3	44.6	44	31	13	A - 7 - 5(3)	1.64	19.35	17.0	0.68
	61+000	80-146	94.4	82.9	74.1	54	39	15	A - 7 - 5(13)	1.54	23.45	13	1.01
Reddish silty Clay	62+000	39-148	90.6	80.3	70.7	59	42	17	A - 7 - 5(14)	1.53	21.42	15.0	0.78
Reddish silty Clay with gravel	63+000	35-165	64.6	56.9	51.9	59	43	17	A - 7 - 5(7)	1.47	28.16	33.5	0.63
	64+000	0-30	40.4	30.8	24.9	45	31	14	A - 2 - 7(0)	2.00	13.01	65	0.10
Reddish silty Clay	64+000	30-145	100.0	98.4	96.8	51	34	17	A - 7 - 5(13)	1.44	29.68	18.0	0.55
Reddish silty Clay	65+000	50-142	95.9	93.6	92.0	64	42	22	A - 7 - 5(17)	1.41	28.40	8.5	0.93

Reddish silty Clay	66+000	20-140	99.8	98.5	97.0	65	48	17	A - 7 - 5(15)	1.48	29.68	20.0	1.06
Reddish silty Clay with gravel	67+000	40-148	55.5	53.2	51.6	53	38	15	A - 7 - 5(6)	1.61	21.14	21.0	0.92
	68+000	0-25	68.3	56.1	42.8	51	35	15	A - 7 - 5(3)	1.63	21.83	25	0.69
Reddish silty Clay	68+000	25-150	93.5	88.0	86.0	58	42	16	A - 7 - 5(16)	1.46	28.06	21.5	0.93
Reddish silty Clay	69+000	30-150	100.0	96.8	92.2	52	38	14	A - 7 - 5(12)	1.47	22.37	14.5	0.58
Reddish silty Clay	69+500	30-110	99.8	97.9	95.9	60	39	21	A - 7 - 5(16)	1.44	26.45	17	0.88
Reddish silty Clay	70+000	30-148	96.6	92.3	84.7	64	45	19	A - 7 - 5(16)	1.48	28.98	17.0	0.76
Reddish silty Clay	71+000	40-150	100.0	93.3	88.3	56	43	14	A - 7 - 5(13)	1.47	27.33	16.0	0.44
Reddish silty Clay with gravel	72+000	0-40	62.2	49.2	41.7	46	36	10	A - 5(1)	1.93	15.11	71	0.29
Reddish silty Clay	72+000	68-150	95.5	90.6	86.8	54	40	14	A - 7 - 5(16)	1.45	25.00	12.0	1.07
Reddish silty Clay	73+000	35-146	99.8	99.3	98.5	58	40	18	A - 7 - 5(15)	1.40	29.80	18.0	0.43
Reddish silty Clay	74+000	35-145	96.6	94.6	92.7	59	41	18	A - 7 - 5(15)	1.50	23.91	13.0	1.06
Reddish silty Clay	75+000	50-150	84.6	82.6	80.7	55	43	12	A - 7 - 5(13)	1.51	23.14	15.5	0.91
Reddish silty Clay with gravel	76+000	0-25	60.5	52.8	50.3	38	29	9	A - 4(4)	1.92	16.91	61	0.18
Reddish silty Clay	76+000	43-160	99.6	98.8	97.9	60	43	17	A - 7 - 5(15)	1.46	30.02	18.0	0.61
Reddish silty Clay	77+000	30-150	99.6	99.0	98.1	54	40	14	A - 7 - 5(14)	1.67	20.16	21.0	0.92
Reddish silty Clay	78+000	30-150	92.1	87.3	81.5	54	42	12	A - 7 - 5(12)	1.52	23.20	15.0	0.80
Reddish silty Clay with gravel	79+000	48-150	50.5	44.0	40.1	55	40	14	A - 7 - 5(7)	1.78	18.38	32.0	0.63
	80+000	0-25	66.8	50.9	38.3	39	32	8	A - 4(1)	1.95	16.48	30	0.46
Reddish silty Clay	80+000	25-152	96.6	95.7	94.8	60	41	19	A - 7 - 5(16)	1.50	24.56	11.5	0.94

Reddish silty Clay	81+000	55-160	77.8	66.6	91.3	55	43	12	A - 7 - 5(13)	1.49	27.53	14.0	0.60
Reddish silty Clay	82+000	40-160	99.9	96.6	92.6	57	38	20	A - 7 - 5(16)	1.42	28.77	9.0	0.93
Reddish silty Clay with gravel	83+000	40-65	77.8	66.6	55.1	50	35	14	A - 7 - 5(7)	1.52	24.50	23	0.46
Reddish silty Clay	83+000	65-150	99.8	98.9	97.8	56	41	15	A - 7 - 5(13)	1.56	24.68	10.0	0.64
Reddish silty Clay	84+000	15-150	96.9	94.0	91.8	59	44	15	A - 7 - 5(14)	1.46	24.92	12.0	0.88
Reddish silty clayey Gravel	85+000	7-35	30.9	20.7	16.3	45	35	10	A - 2 - 5(0)	2.03	12.60	59.0	0.34

APPENDIX C

Actual (Measured) Laboratory Test Results Data of Subgrade materials used in Validity checking of the Correlation Work.

No	Material Description	Station, km	Depth, cm	Percentage Passing Sieve Sizes			Atterberg Limits			AASHTO Classification	Proctor Density,		**CBR**	Swell
				2.00 mm	0.425 mm	0.075 mm	LL (%)	PL (%)	PI (%)		MDD g/cc	OMC %		
1	Reddish silty Clay with gravel	1+900	20-85	56.0	53.2	50.4	57	46	10	A - 5(1)	1.58	16.46	**18.0**	0.23
2	Reddish silty Clay with sand	8+400 LHS	30-110	88.2	74.0	67.2	54	42	13	A - 7 - 5(11)	1.65	19.52	**23.0**	1.23
3	Reddish silty Clay with sand	19+050 RHS	20-100	83.8	75.5	67.7	47	36	11	A - 7 - 5(3)	1.60	21.13	**29.0**	0.67
4	Reddish silty Clay with gravel	27+000 LHS	0-80	51.5	42.3	38.2	53	40	13	A - 7 - 5(2)	1.80	17.61	**36.5**	0.33
5	Reddish silty Clay with sand	39+390 RHS	40-110	92.9	85.5	79.1	48	33	15	A - 7 - 5(11)	1.63	10.20	**16.0**	0.68
6	Reddish silty Clay with gravel	56+200 RHS	30-100	56.8	44.7	38.1	54	39	15	A - 7 - 5(3)	1.73	20.73	**33.0**	1.43
7	Reddish silty Clay with sand	78+780 LHS	60-130	52.1	45.4	41.6	49	36	13	A - 7 - 5(9)	1.77	17.27	**17.0**	1.30