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"Developing Correlation between Index Properties and California Bearing Ratio, CBR of soils: A Case Study on Gedo Menabegna Road Upgrading Project; on the Way from Gedo to Fincha"

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DECLARATION

I hereby declare to senate of Addis Ababa University that this project is entirely original work and all other materials are duly acknowledged. This work has not been submitted for academic award at any University.

_____

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LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CBR_u	Un-soaked California Bearing Ratio
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plasticity Limit
SPSS	Statistical Package for Social Science Software
USCS	Unified Soil Classification System
PP 40	Percent passing sieve no 40
PP 200	Percent passing sieve no 200
F	Modal parameter on Anova table
df1	Number of excluded sample
df2	Number of non-excluded sample
constant	constant term in the mentioned equation
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

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Abstract

California Bearing Ratio (CBR) is a very common test to determine the thickness of overlying pavement layers in pavement design and to assess potential strength of subgrade, sub base and base course material. Engneers are continually searching for simplified tests with the view to increase their knowledge of soils via using a simple and rapid soil tests. These simplified tests which are indicative of the engineering properties of soils are called index properties.

In road construction, civil engineers constantly come upon difficulties in obtaining representative CBR value for pavement design. 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 project gives an overview to obtain a correlation between CBR values with soil index properties for Gedo-Manabegna road upgrading project.

Primarily, in order to address the intended objectives of the study, basic theories and descriptions of CBR test in general and in relation to 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, conducted laboratory tests are collected from Gedo-Manabegna road upgrading project 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 are presented. Statistical regression analyses of test results carried out, correlations are developed and analyzed to fit the test results with a reliable accuracy with a higher regression coefficient that approaches to unity. Finally, a generalized conclusion and recommendation is made.

CHAPTER 1

INTRODUCTION

1.1. Background

The California Bearing Ratio (CBR) is an important parameter to determine the bearing capacity of earth structures, such as earth dams, road embankments, airport runways, bridge abutments and pavements. It is essential parameter that measures the strength of subgrade for design of pavement to assess the stiffness modulus and shear strength of subgrade material.

In road construction, civil engineers repeatedly encounter difficulties and challenges in obtaining a representative CBR value for road design. A laboratory CBR test requires a relatively large amount of effort to perform and 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 project gives an overview to obtain a correlation between CBR values with soil index properties that is suited for Gedo-Manabegna road upgrading project.

Currently, many road construction projects and railway constructions are undergoing in the country. In light of this, the output of the proposed correlation 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 Statement of the Problem

Laboratory CBR test requires relatively large effort to conduct the test and it is time consuming. As a result, the goal of this project is to establish a correlation between California Bearing Ratio and soil index properties for representative soil samples recovered in order to provide preliminary background information on the value of CBR for a localized subgrade material with the benefit of time savings and without incurring any additional cost for conducting laboratory CBR tests.

1.3 Objective of the study

1.3.1 General objective

The main objective of this project is to make keen effort to establish correlation between California Bearing Ratio with soil index properties for representative soil samples recovered from different sections of Gedo-Manabegna Road upgrading project.

1.3.2 Specific objectives

- To undertake Co-relationship between CBR with each independent variables.
- To identify soil properties that have significance influence on CBR values.
- To establish the model that can best predict CBR values from index properties.

1.4 Scope

The subject study is desired to conduct a localized research particularly on samples accrued from Gedo-Manabegna road upgrading project. With a purpose to conduct the proposed correlation reasonably adequate laboratory test results are used in this project.

In regard to the regression analysis, depending on the trends of the scattering of test results the correlation is analyzed using both linear and multiple regression model.

1.5 Methodology

To begin, basic ideas and descriptions of CBR tests in general and in relation to soil index property of subgrade soil are reviewed in order to fulfill the study's intended objectives.

Laboratory tests are collected from various sections of the Gedo-Manabegna road upgrading project in order to obtain records of test results of CBR values as well as associated soil indices such as grain size analysis, Atterberg limits, and moisture-density relationships, in order to have sufficient data for using the correlations.

The specified correlation is carried out by applying a single linear regression model and multiple linear regression models with the aid of SPSS Software.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Roads are necessary for transportation and financial improvement of a country. Most of the road network in our country is consisting of flexible pavement. Flexible pavement consists of different layers such as sub-grade, sub-base, base course and surface layer. [5]

California Bearing Ratio (CBR) is one of the methods to determine the sub grade strength. Design and performance of flexible pavement mainly depends on the strength of sub-grade material. The load from the pavement surface is ultimately transferred to sub-grade. The sub-grade is designed such that the stress transferred should not exceed elastic limit. [5]

Hence, the suitability and stability of sub-grade material is evaluated before construction of pavement. California bearing ratio (CBR*)* value is considered as strength parameter in design of pavement Structure. [5]

Among the various methods of evaluating the subgrade strength, quick estimate of CBR is very important for a highway engineer so a simple test that can be used as an index test was devised. Thus index test is an indirect measure of stiffness modulus or shear strength. [5]

2.2 Index Property Tests

The strength and compressibility characteristics of cohesive soils are functions of water content. As such water content is a crutial factor in understanding the aggregate behavior of cohesive soils [1]. Index properties of cohesive soils are used to characterize the physical and mechanical behavior of via utilising parameters such as moisture content, specific gravity, particle size distribution, Atterberg limits and moisture-density relationships. [2]

2.2.1 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]

2.2.2 Atterberg Limits

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.

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. [6]

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. [6]

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. [6]

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 1, 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.

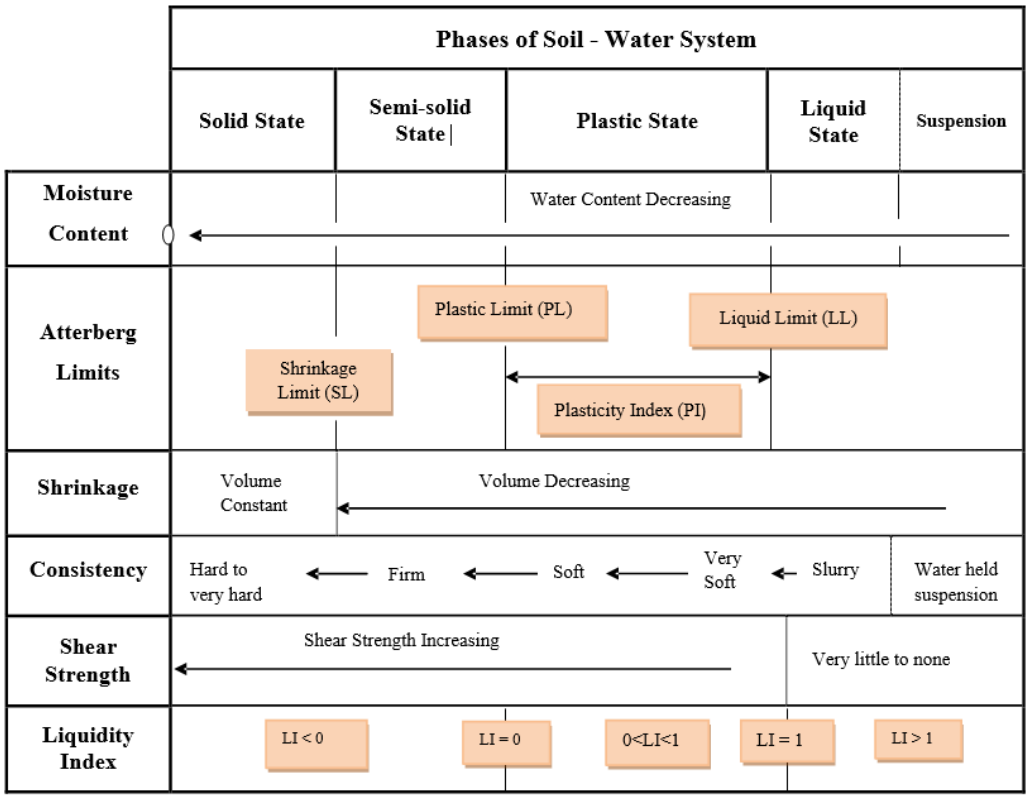

Figure 1: Description of Phases of Soil-Water System

2.2.3 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 [2].

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.

2.3 California Bearing Ratio (CBR)

2.3.1 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. [5]

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 [6].

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 [6]. 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 [6]. 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.

2.4 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. [7]

However, the validity and applicability of such correlations need to be established for their acceptances in general practice. The predicted and experimental values of CBR of various soils have been used to check the applicability and limitations of available methods.

The models developed from Simple and Multiple Regression Analysis is given by different investigators as;

CBRs = f (F, S, G, LL, PL, MDD, and OMC) and a typical Model equation is as follows:

CBRs=0.064F+0.082S+0.033G-0.069LL+0.157PL-1.810MDD-0.061OMC [7]

Where; F is Fines (%), S is Sand (%), G is Gravel (%), LL is Liquid Limit, PL is Plastic Limit, MDD is maximum dry density and OMC is optimum moisture content.

Agarwal and Ghanekar(1970) performed their analysis on fine grained soils over 48 samples found in India.On the basis of their analysis,they tried to develop a correlation between CBR values and Liquid Limit,Plastic Limit/Plasticity index.Instead a much better correlation was found when they included the liquid limit and optimum moisture content(OMC).

CBR=2-logOMC+0.07 with R=0.82, R^2=0.67

Katte et al-2018-Geotechnical and Geological Engineering

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

CBR=99.086-5.162OMC with R=0.861, R^2=0.741

Okon Bassey Bassey(2002)

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

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

Faisal Iqbal(2018)

$CBR=11.2525LL-26.4144PI-0.3024PP200+153.7175$, $R^2=0.984$

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

Correlation between CBR values and Index properties of subgrade soils in Northern, north-east and north-west parts of Addis Ababa was carried by Leliso Y.[4].

The proposed model should only be used along with good judgment and engineering experience for that particular area to provide a rapid and cost-effective method of determining CBR of subgrade soil. [7]

The previous researcher [7] Performed his research on 42 samples of fine grained soils found in Addis Ababa, on the basis of which he has developed a correlation between CBR values and Index properties (liquid limit, plastic limit, plasticity index, grain size).

2.4.1 Single Linear Regression Analysis

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

CBR = 16.270 - 0.179*LL, with $R^2 = 0.458$, n = 42 [7]

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

CBR = 6.737 - 0.025*PL, with $R^2 = 0.003$, n = 42 [7]

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

CBR = 10.413 - 0.177*PI with $R^2 = 0.429$, n = 42 [7]

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

CBR = -1.366 + 0.089*P200, with $R^2 = 0.041$, n = 42 [7]

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

CBR = -35.966 + 27.072*MDD, with $R^2 = 0.384$, n = 42 [7]

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

CBR = 9.499 - 0.150*OMC, with $R^2 = 0.06$, n = 42 [7]

From the developed single linear regression models by the researcher, based on coefficient of determination (R^2), CBR value correlates relatively better with liquid limit and plasticity index.

2.4.2 Multiple Linear Regression Analysis

Model A: Correlation between CBR with PL and PI

CBR = 14.580 - 0.197*PI - 0.112*PL, with R^2 = 0.494, n = 42 [7]

Model B: Correlation between CBR with PI and P200

CBR = 8.302 - 0.190*PI + 6.33*P2005, with R^2 = 0.533, n = 42 [7]

Model C: 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, with R^2 = 0.629, n = 42 [7]

Or CBR = -21.522 - 0.141*LL + 0.137*PI + 20.244*MDD, with R^2 = 0.629, n = 42 [7]

From the researcher's findings, Model C indicated that the relationship developed between CBR with LL, PL and MDD is moderately correlated than all the rest models.

Various foreign and some local researchers have done correlations of CBR with index properties for fine grained soils on different study areas. However, correlation between CBR and index properties is not sufficiently made on various projects undertaken in Ethiopia.

Hence, this project tried to deliver some role by making correlations of CBR with index properties on fine grained soils of on Gedo-Manabegna road upgrading project with a relatively large no of data, higher number of independent variables, better regression coefficient value and all possible types of equations.

CHAPTER 3

METHODOLOGY

3.1 General

In order to have satisfactory data for utilizing the correlations, conducted laboratory tests are collected on samples collected from different sections of Gedo-Manabegna Road upgrading project, 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.

Around 73 samples for red clay soil part and 37 samples for brown clay soil part is collected with the corresponding soil indices particularly the grain size analysis, Atterberg limits, moisture-density relationships for single and multiple regression analysis is to be made.

The description of the study area and summary of laboratory test data for both of the red clay and brown clay soil part are presented as following section.

3.2 Description of the study area

3.2.1 Project location

The Gedo - Mana Begna road is located in West Shewa and Horogudru zone, Jimma Rarrea wereda of the Oromia National Regional State. The project road starts at the junction on the Addis - Nekempt - Assosa trunk road at Gedo town. Gedo town is about 175 km west of the capital, Addis Ababa. The project road then proceeds in a northerly direction towards a Junction to Kombolcha (Locally known as 'Mana Begna', Kombolcha Mazoria).

Gedo-Manabegna Road section (80.5km) is the first contract of Gedo-Fincha-Lemelem Bereha Road Upgrading project, the construction of which is awarded to HAWK International Finance and Construction Ltd., the construction contract had been signed on March 2014.

The topography of this section of the road is rolling terrain. The rolling terrain spans from the start of the project road up to Mana Begna.

Ethiopian Roads Authority (ERA) is the Executing Agency for the project, while the Central Region Contract Management Directorate Office (CRCMDO) is monitoring & coordinating the project activities on behalf of ERA. CRCMDO designated an officer in charge for the project, who is the first point of contact for the Consultant as well as the Contractor. Galander Engineering Consultants of Sudan in JV with Beza Consulting Engineers of Ethiopia has been appointed as the responsible authority for managing the overall construction supervision and contract administration in the role of the Engineer. The Team Leader has full responsibility for delivery of the services as defined in the Consultancy contract. He is assisted by a team of Technical, Social and Environmental Specialists. The project location is given in the figure below.

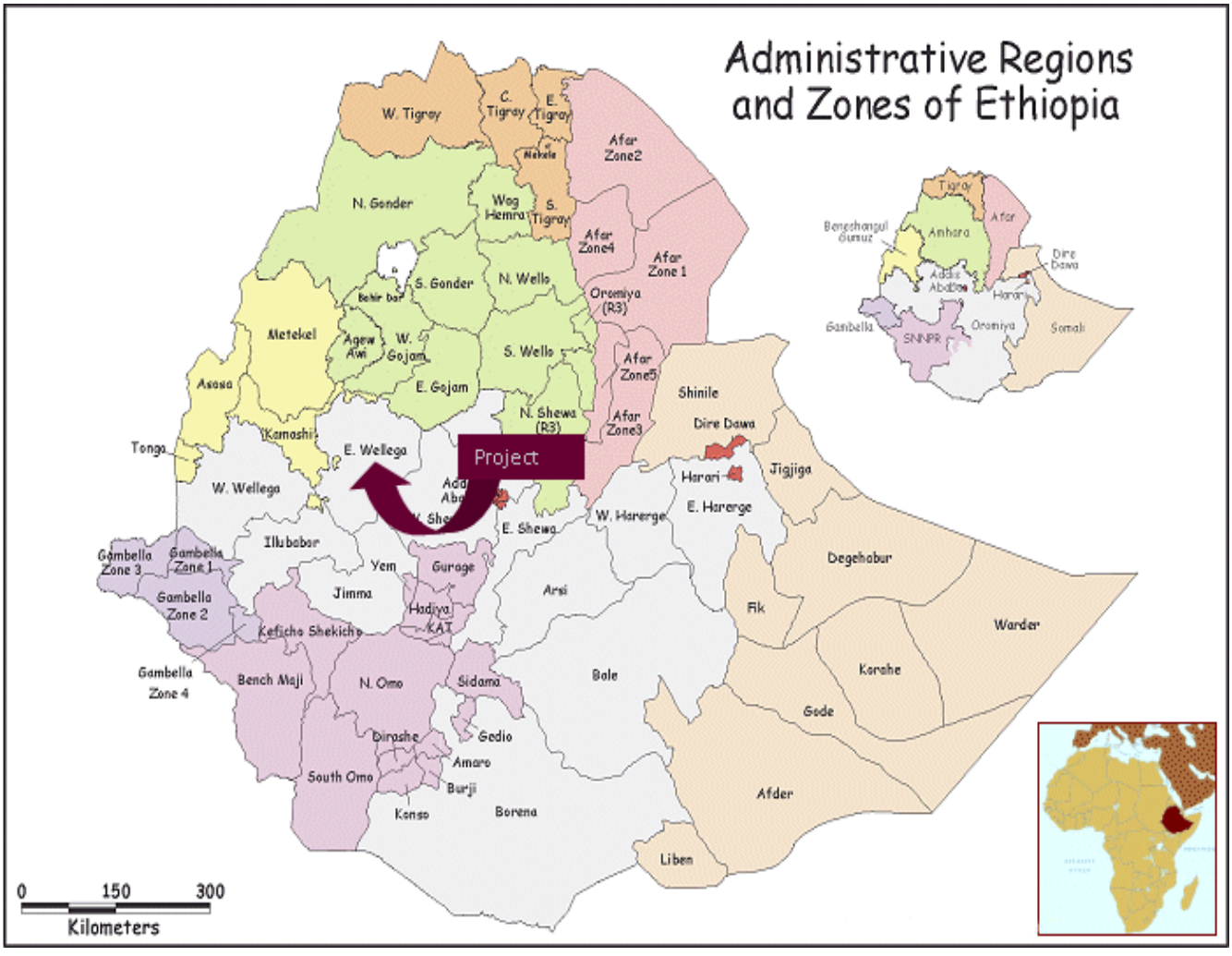

Figure 2: Administrative regions and zones of Ethiopia

***Project stretch(Gedo-Wayu- Mana-begna*)**

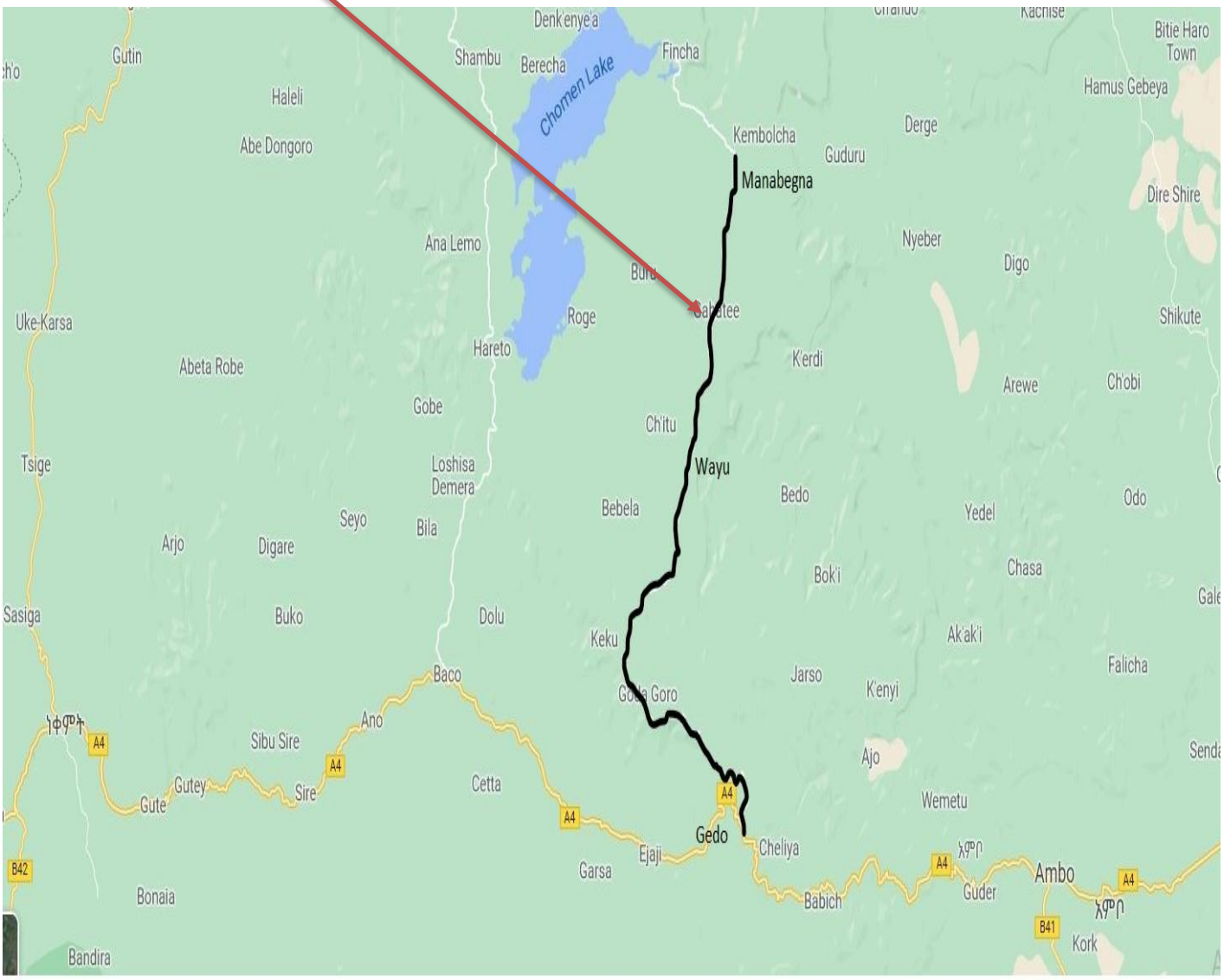

Figure 3*:* Project location

3.3.1 Input data for the regression analysis and Correlations

3.3.1.1 Summary of all laboratory test data for the existing subgrade, red Clay Soil

Table 1: Summary of all laboratory test data for the existing subgrade

Description of Material	Location/Chainage		Percentage Passing Sieve size			Classification	LL	PL	PI	MDD	OMC	CBR	Swell ≤ 2%
	From	To	2mm	0.425mm	0.075mm		(%)	(%)	(%)	(gm/cc)	(%)	(%)	(%)
Red clay Soil	50+000	50+250	100.00	71.12	42.50	A-2-7	50.00	23.09	26.91	1.56	23.50	5.60	0.36
Red clay Soil	50+250	50+500	100.00	69.33	23.92	A-2-7	50.00	28.30	21.70	1.46	23.00	4.30	3.80
Red clay Soil	50+750	51+000	98.40	73.62	47.08	A-7-6	51.80	22.22	29.58	1.51	27.80	10.40	1.57
Red clay Soil	51+000	51+250	100.00	76.40	20.51	A-2-7	44.40	17.84	26.56	1.48	20.25	6.40	1.43
Red clay Soil	51+250	51+500	100.00	73.10	35.68	A-2-7	38.50	20.00	18.50	1.57	23.00	9.20	1.38
Red clay Soil	51+750	52+000	100.00	73.28	28.55	A-2-7	51.60	23.53	28.07	1.47	23.25	4.60	1.53
Red clay Soil	52+000	52+250	100.00	75.00	19.58	A-7-6	54.90	28.57	26.33	1.35	25.50	6.15	1.84
Red clay Soil	52+250	52+500	100.00	71.28	42.95	A-2-7	54.20	27.27	26.93	1.51	26.80	6.00	1.77
Red clay Soil	53+000	53+250	100.00	74.25	24.76	A-2-7	53.50	30.91	22.59	1.46	22.50	7.80	1.56
Red clay Soil	53+250	53+500	100.00	75.70	33.32	A-2-7	53.30	28.30	25.00	1.49	24.50	3.70	1.70
Red clay Soil	53+500	53+750	100.00	72.77	20.32	A-2-7	49.00	32.14	16.86	1.46	22.00	3.75	1.52
Red clay Soil	53+750	54+000	100.00	69.49	29.03	A-2-7	51.00	31.58	19.42	1.51	22.50	5.00	3.28
Red clay Soil	54+000	54+250	100.00	75.03	32.77	A-2-7	57.00	33.74	23.26	1.47	24.50	7.20	1.33
Red clay Soil	54+750	55+000	100.00	77.05	39.12	A-2-7	45.80	23.86	21.94	1.56	24.00	8.20	0.90
Red clay Soil	55+250	55+500	100.00	81.61	37.55	A-7-5	48.10	37.20	10.90	1.56	24.00	11.80	1.71

Table 1: Summary of all laboratory test data for the existing subgrade, red Clay Soil

Red clay Soil	55+500	55+750	100.00	88.63	44.00	A-7-6	46.30	28.80	17.50	1.57	25.50	12.40	0.51
Red clay Soil	55+750	56+000	100.00	90.40	36.20	A-7-5	53.80	31.03	22.77	1.49	25.50	7.60	1.71
Red clay Soil	56+000	56+250	100.00	73.41	18.74	A-2-7	49.40	24.00	25.40	1.37	25.00	4.80	0.93
Red clay Soil	56+250	56+500	100.00	98.25	28.60	A-7-5	54.10	37.20	16.90	1.56	19.50	6.10	1.90
Red clay Soil	56+500	56+750	100.00	96.18	38.93	A-2-7	53.60	37.20	16.40	1.59	21.50	11.00	1.85
Red clay Soil	56+750	57+000	100.00	97.71	51.55	A-2-7	59.40	29.80	29.60	1.62	23.25	6.40	2.57
Red clay Soil	57+000	57+250	100.00	75.74	41.69	A-2-7	53.00	30.43	22.57	1.53	25.50	7.20	1.35
Red clay Soil	57+250	57+500	100.00	80.00	36.75	A-2-7	51.20	32.84	18.36	1.52	24.50	12.60	0.52
Red clay Soil	57+500	57+750	100.00	68.54	39.32	A-2-7	54.80	37.20	17.60	1.50	26.50	6.80	1.43
Red clay Soil	58+000	58+250	100.00	78.26	37.15	A-7-6	58.00	37.37	20.63	1.56	22.00	6.80	1.07
Red clay Soil	58+250	58+500	100.00	77.30	33.21	A-7-5	51.10	37.20	13.90	1.49	25.00	14.40	0.93
Red clay Soil	58+500	58+750	100.00	70.99	40.21	A-2-7	56.00	27.83	28.17	1.50	25.50	10.00	1.32
Red clay Soil	58+750	59+000	100.00	75.79	42.63	A-7-5	49.00	31.78	17.22	1.69	18.50	7.60	1.07
Red clay Soil	59+000	59+250	100.00	74.29	35.75	A-2-7	46.75	24.72	22.03	1.51	25.00	6.90	0.70
Red clay Soil	59+250	59+500	100.00	74.70	31.49	A-2-7	50.00	25.00	25.00	1.44	26.25	6.80	0.96
Red clay Soil	59+500	59+750	100.00	69.85	48.60	A-2-7	55.80	38.29	17.51	1.62	23.70	6.90	1.22
Red clay Soil	59+750	60+000	100.00	75.63	36.96	A-2-7	50.00	31.58	18.42	1.57	22.25	10.80	1.47
Red clay Soil	60+000	60+250	100.00	72.95	39.67	A-2-7	48.00	31.78	16.22	1.52	26.25	13.20	0.64
Red clay Soil	60+250	60+500	100.00	81.84	29.50	A-2-7	53.60	30.71	22.89	1.47	23.75	5.90	1.33
Red clay Soil	60+500	60+750	100.00	68.60	32.56	A-2-7	46.70	21.92	24.78	1.50	24.00	6.20	1.18
Red clay Soil	60+750	61+000	100.00	68.68	33.07	A-2-7	49.20	24.59	24.61	1.53	22.00	10.00	1.27
Red clay Soil	62+000	62+250	100.00	69.77	33.42	A-2-7	47.00	26.67	20.33	1.54	22.00	14.00	1.37
Red clay Soil	62+250	62+500	100.00	71.86	48.86	A-2-7	44.30	26.67	17.63	1.59	26.25	15.50	0.32
Red clay Soil	62+500	62+750	100.00	73.45	32.68	A-2-7	53.20	30.23	22.97	1.45	26.00	10.20	0.68

Table 1: Summary of all laboratory test data for the existing subgrade, red Clay Soil

Red clay Soil	63+000	63+250	100.00	70.76	36.64	A-2-7	47.00	32.33	14.67	1.54	24.25	10.50	1.54
Red clay Soil	64+750	65+000	99.00	72.74	38.83	A-7-6	45.30	25.96	19.34	1.56	23.50	13.40	1.79
Red clay Soil	65+000	65+250	100.00	78.49	43.97	A-7-6	46.20	26.75	19.45	1.58	25.00	9.70	1.96
Red clay Soil	65+250	65+500	98.00	94.29	40.73	A-7-6	49.20	24.45	24.75	1.50	27.00	9.10	1.81
Red clay Soil	65+500	65+750	98.00	85.34	44.97	A-7-6	53.20	28.63	24.58	1.49	28.75	5.30	1.94
Red clay Soil	66+000	66+250	99.80	81.59	48.08	A-7-6	51.20	25.53	25.67	1.60	24.30	9.70	1.68
Red clay Soil	67+500	67+750	100.00	73.60	42.39	A-7-5	45.20	30.50	14.70	1.56	25.30	18.20	1.29
Red clay Soil	67+750	68+000	100.00	75.88	44.43	A-7-6	49.40	26.42	22.98	1.58	24.30	10.80	1.88
Red clay Soil	68+000	68+250	100.00	81.27	44.93	A-7-5	52.40	34.78	17.62	1.55	26.40	7.00	1.95
Red clay Soil	68+500	68+750	100.00	80.83	27.82	A-2-7	50.00	30.61	19.39	1.48	23.50	4.50	1.69
Red clay Soil	68+750	69+000	100.00	83.49	38.11	A-2-7	49.00	27.45	21.55	1.62	19.70	7.80	1.34
Red clay Soil	69+000	69+250	100.00	58.33	36.91	A-2-7	48.50	32.61	15.89	1.54	24.25	8.20	1.79
Red clay Soil	69+250	69+500	100.00	74.01	33.93	A-2-7	46.00	24.72	21.28	1.51	24.25	9.00	1.43
Red clay Soil	69+750	70+000	100.00	66.87	37.24	A-2-7	47.40	30.00	17.40	1.55	24.00	6.20	1.38
Red clay Soil	70+250	70+500	99.84	73.61	44.53	A-7-6	47.60	29.69	17.91	1.59	24.30	11.20	1.85
Red clay Soil	70+500	70+750	99.63	86.42	50.11	A-7-6	49.20	26.75	22.45	1.61	24.80	10.00	2.00
Red clay Soil	70+750	71+000	100.00	71.70	27.04	A-7-6	52.60	27.63	24.97	1.46	22.80	10.00	1.67
Red clay Soil	71+000	71+250	100.00	80.97	58.38	A-7-5	49.40	30.00	19.40	1.66	25.60	14.20	1.46
Red clay Soil	71+250	71+500	100.00	90.64	58.10	A-7-5	47.00	31.33	15.67	1.65	26.60	15.00	1.40
Red clay Soil	71+500	71+750	100.00	80.27	42.45	A-7-6	46.00	29.30	16.69	1.59	24.20	9.60	1.67
Red clay Soil	72+000	72+250	100.00	81.59	37.23	A-7-6	51.20	25.53	25.67	1.57	21.50	9.70	1.68
Red clay Soil	72+750	73+000	100.00	75.88	47.28	A-7-6	49.40	26.42	22.98	1.65	21.50	10.80	1.88
Red clay Soil	73+000	73+250	100.00	76.21	29.82	A-7-6	48.20	25.73	22.47	1.54	20.70	8.00	1.92
Red clay Soil	74+000	74+250	100.00	76.16	51.73	A-7-6	50.80	25.67	25.13	1.67	21.80	10.00	1.73
Red clay Soil	74+500	74+750	100.00	81.71	38.52	A-7-6	47.20	26.01	21.19	1.59	21.80	11.40	1.97
Red clay Soil	75+000	75+250	100.00	77.42	35.39	A-7-5	48.20	30.35	17.85	1.54	23.75	4.90	1.09
Red clay Soil	75+250	75+500	100.00	84.21	38.52	A-7-5	51.10	31.48	19.62	1.47	28.00	8.30	1.52

Table 1: Summary of all laboratory test data for the existing subgrade, red Clay Soil

Red clay Soil	76+000	76+250	100.00	88.55	55.22	A-7-6	51.00	26.92	24.08	1.67	23.75	6.20	1.23
Red clay Soil	76+500	76+750	100.00	79.66	43.66	A-7-5	50.40	30.61	19.79	1.66	20.00	8.00	1.99
Red clay Soil	77+250	77+500	100.00	94.47	46.94	A-7-6	50.80	25.73	25.07	1.59	24.70	7.30	1.78
Red clay Soil	77+500	77+750	100.00	93.19	41.94	A-7-6	50.90	26.14	24.76	1.53	25.50	8.40	1.76
Red clay Soil	78+250	78+500	100	78.65	38.3632	A-7-5	49.70	31.20	18.50	1.535	24.00	15.50	1.67

3.3.1.2 Summary of all laboratory test data for the existing subgrade, brown Clay Soil

Table 2: Summary of all laboratory test data for the existing subgrade

Description of Material	Location/Chainage					Classification	LL ≤ 60%	PL	PI ≤30%	MDD	OMC	CBR	Swell ≤ 2%
	From	To	2mm	0.425mm	0.075mm		(%)	(%)	(%)	(gm/cc)	(%)	(%)	(%)
Brown Clay Soil	50+500	50+750	100.00	70.66	22.38	A-2-7	48.50	26.90	21.60	1.71	23.00	7.40	0.55
Brown Clay Soil	51+500	51+750	100.00	73.28	21.87	A-2-7	47.60	23.33	24.27	1.56	24.00	4.10	1.59
Brown Clay Soil	52+500	52+750	100.00	70.70	20.13	A-2-7	45.80	24.50	21.30	1.61	19.50	3.70	2.27
Brown Clay Soil	52+750	53+000	100.00	73.14	19.41	A-2-7	45.90	23.90	22.00	1.49	21.50	6.20	1.68
Brown Clay Soil	54+250	54+500	100.00	75.90	33.93	A-2-7	51.70	36.71	14.99	1.53	23.00	8.00	1.71
Brown Clay Soil	54+500	54+750	100.00	75.72	24.59	A-2-7	50.30	37.27	13.03	1.46	23.50	5.20	1.71
Brown Clay Soil	57+750	58+000	100.00	71.39	26.77	A-2-7	58.80	36.50	22.30	1.58	25.25	9.00	0.94
Brown Clay Soil	61+000	61+250	100.00	77.73	42.61	A-7-5	54.80	26.92	27.88	1.51	27.50	6.20	2.29
Brown Clay Soil	61+250	61+500	100.00	69.20	35.17	A-7-6	60.20	26.92	33.28	1.61	22.25	10.60	1.70
Brown Clay Soil	61+500	61+750	100.00	80.65	57.41	A-7-5	46.00	24.70	21.30	1.59	21.80	14.20	1.08
Brown Clay Soil	61+750	62+000	100.00	69.37	10.26	A-2-7	45.70	24.72	20.98	1.64	22.25	10.70	1.61
Brown clay soil	62+750	63+000	100.00	76.38	24.63	A-2-7	49.70	30.00	19.70	1.47	26.50	7.50	1.50
Brown Clay Soil	63+250	63+500	100.00	79.27	47.75	A-7-5	49.40	32.08	17.32	1.58	24.00	10.80	1.95
Brown clay soil	63+500	63+750	100.00	73.84	43.82	A-2-7	49.20	21.66	27.54	1.68	21.00	12.25	1.11
Brown Clay Soil	63+750	64+000	100.00	80.68	42.68	A-2-7	46.70	28.81	17.89	1.47	24.50	9.60	1.90
Brown Clay Soil	64+000	64+250	98.85	78.89	51.97	A-7-6	43.00	21.11	21.89	1.65	21.00	15.00	1.33
Brown Clay Soil	64+250	64+500	99.00	74.57	37.52	A-7-6	45.60	29.17	16.43	1.65	19.00	7.30	1.72
Brown Clay Soil	64+500	64+750	100.00	80.89	52.00	A-7-6	43.00	24.44	18.56	1.61	22.75	14.20	1.60
Brown Clay Soil	65+750	66+000	99.00	79.74	51.53	A-7-6	46.40	24.80	21.60	1.57	22.50	16.00	1.11
Brown Clay Soil	67+000	67+250	100.00	76.07	39.07	A-7-5	45.40	28.85	16.55	1.61	20.00	8.00	1.53
Brown Clay Soil	67+250	67+500	99.81	78.42	39.13	A-7-5	48.00	30.00	18.00	1.56	25.00	6.80	1.65

Table 2: Summary of all laboratory test data for the existing subgrade, brown Clay Soil

Brown Clay Soil	68+250	68+500	100.00	75.85	32.67	A-7-5	53.40	36.73	16.67	1.53	25.00	5.00	1.77
Brown Clay Soil	69+500	69+750	100.00	77.56	45.93	A-2-7	49.90	28.25	21.65	1.60	23.70	14.20	1.35
Brown Clay Soil	70+000	70+250	99.81	73.16	42.35	A-7-6	55.20	28.73	26.47	1.64	22.70	13.20	1.48
Brown Clay Soil	71+750	72+000	100.00	76.23	37.25	A-7-5	47.20	30.33	16.87	1.63	22.60	6.00	1.72
Brown Clay Soil	72+250	72+500	100.00	76.78	39.18	A-7-6	47.40	24.53	22.87	1.61	24.00	7.00	1.48
Brown Clay Soil	72+500	72+750	100.00	78.22	43.91	A-7-6	49.90	25.49	24.41	1.47	23.00	13.00	1.83
Brown Clay Soil	73+250	73+500	100.00	75.78	36.37	A-7-6	52.40	23.08	29.32	1.46	24.30	8.50	1.92
Brown Clay Soil	73+500	73+750	100.00	75.38	32.97	A-7-6	50.80	27.96	22.84	1.48	22.70	6.00	1.86
Brown Clay Soil	73+750	74+000	100.00	81.41	55.60	A-7-6	48.00	26.53	21.47	1.57	25.00	18.00	1.64
Brown Clay Soil	74+250	74+500	100.00	78.86	49.51	A-7-6	45.60	24.00	21.60	1.59	21.80	14.50	1.24
Brown Clay Soil	74+750	75+000	100.00	77.11	41.98	A-7-6	48.60	23.08	25.52	1.57	24.00	9.80	1.64
Brown Clay Soil	76+250	76+500	100.00	78.50	51.48	A-7-5	49.00	29.41	19.59	1.70	24.70	14.80	1.49
Brown Clay Soil	76+750	77+000	99.00	75.13	40.20	A-7-6	53.00	29.55	23.45	1.62	24.50	9.80	1.91
Brown Clay Soil	77+000	77+250	100.00	75.66	34.66	A-7-6	50.20	26.23	23.97	1.50	23.00	6.60	1.87
Brown Clay Soil	77+750	78+000	100.00	79.72	44.30	A-7-6	51.00	29.21	21.79	1.500	26.50	11.40	1.68
Brown Clay Soil	78+000	78+250	100.00	82.0097	50.45	A-7-6	36.30	21.11	15.19	1.660	21.80	10.20	1.66
Brown Clay Soil	78+500	78+750	100.00	78.8065	48.23	A-2-7	48.00	24.45	22.55	1.575	23.00	14.20	1.56

CHAPTER 4

REGRESSION ANALYSIS, CORRELATIONS AND DISCUSSION

4.0 General

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.

Specific to this research, a statistical package for social science software (SPSS) is employed to investigate the significance of individual regression variables. Out of these equations, equations with higher R^2 values were selected and using these equations the CBR of the study area was calculated.

4.1 Scatter Plot and Best-Fit Curve (Single regression analysis)

In the subject study, the California Bearing Ratio is taken as the dependent variable whereas the liquid limit, plastic limit, plasticity index, liquidity index and grain size (PP40,PP200) are independent variables. However, when determination of the relationships among more than two variables are required (the dependent variable requires two or more independent variables) regression analysis is used and the SPSS software is found to be the most powerful and descriptive tool.

Consequently, soils are classified in to red and black or/gray by using Munsell chart. The scatter plot of the same is presented for the Red clay and Brown clay respectively.

4.1.1 Scatter plot for red clay soil

4.1.1.1 California bearing ratio versus percent Passing Sieve No.200

The relationship between the CBR and the percent passing sieve no 200 for the tested samples is shown in figure 5.The equation that best fits for the correlation between CBR and % passing sieve No.200 is CBR = 2.786-23.804*($1/PP_{200}$), has R^2= 0.252.

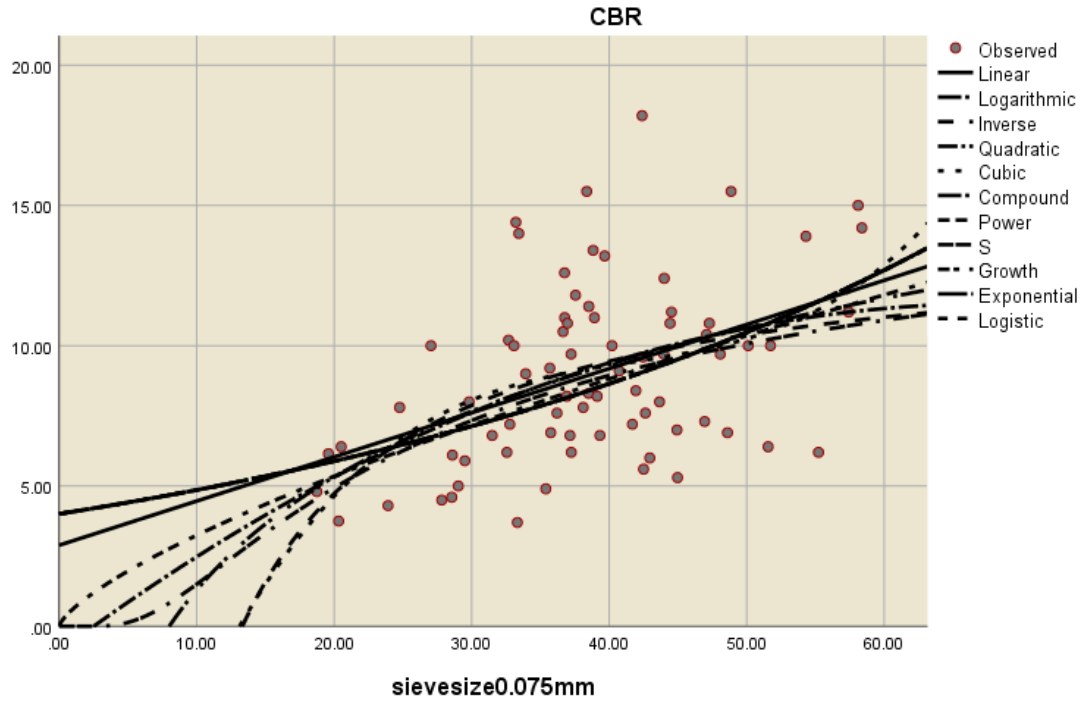

Figure 4: Scatter Diagram of California bearing ratio versus percent passing sieve no 200 (red clay soil)

Table 3: Model Summary and Parameter Estimates for California bearing ratio versus percent passing sieve no 200 (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df 1	df2	Sig.	Constant	b1	b2	b3
Linear	.196	17.575	1	72	.000	2.891	.157		
Logarithmic	.207	18.768	1	72	.000	-12.077	5.805		
Inverse	.205	18.593	1	72	.000	14.163	-188.683		
Quadratic	.205	9.148	2	71	.000	-.897	.364	-.003	
Cubic	.219	6.548	3	70	.001	-16.537	1.729	-.040	.000
Compound	.225	20.941	1	72	.000	4.010	1.019		
Power	.246	23.491	1	72	.000	.616	.721		
S	.252	24.221	1	72	.000	2.786	-23.804		
Growth	.225	20.941	1	72	.000	1.389	.019		
Exponential	.225	20.941	1	72	.000	4.010	.019		
Logistic	.225	20.941	1	72	.000	.249	.981		
The independent variable is PP200.									

4.1.1.2 California bearing ratio versus percent Passing Sieve No.40 (red clay soil)

The relationship between the CBR and the percent passing sieve no 40 for the tested samples is shown in figure 6.The equation that best fits for the correlation between CBR and % passing sieve No.40 is CBR = -18.173+0.641*PP_{40}-0.004*PP_{40}^2, has R^2= 0.02 and CBR = -11.22+0.36*PP_{40}-1.617E-5*PP_{40}^3, has R^2= 0.02.

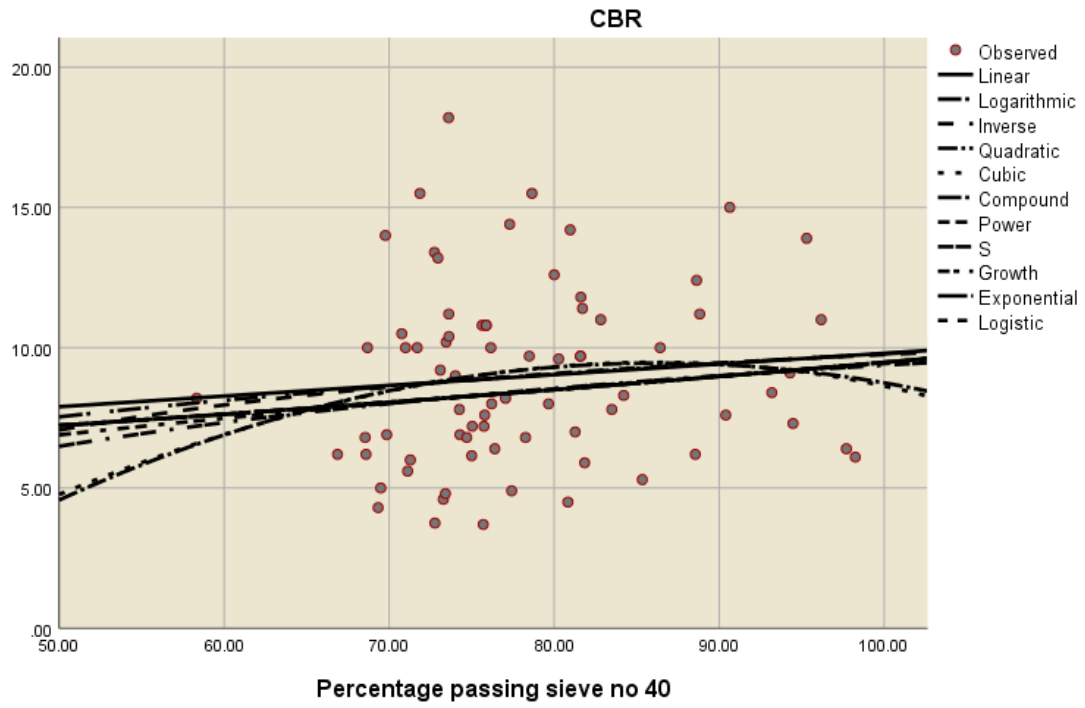

Figure 5: Scatter Diagram of California bearing ratio versus percent passing sieve no 40 (red clay soil)

Table 4: Model Summary and Parameter Estimates for California bearing ratio versus percent passing sieve no 40 (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df 2	Sig.	Constant	b1	b2	b3
Linear	.009	.690	1	72	.409	5.992	.038		
Logarithmic	.011	.781	1	72	.380	-5.158	3.245		
Inverse	.012	.865	1	72	.355	12.447	-269.180		
Quadratic	.020	.708	2	71	.496	-18.173	.641	-.004	
Cubic	.020	.736	2	71	.483	-11.220	.360	.000	-1.617E-5
Compound	.015	1.083	1	72	.301	5.512	1.005		
Power	.016	1.179	1	72	.281	1.173	.453		
S	.017	1.254	1	72	.266	2.606	-36.829		
Growth	.015	1.083	1	72	.301	1.707	.005		
Exponential	.015	1.083	1	72	.301	5.512	.005		
Logistic	.015	1.083	1	72	.301	.181	.995		
The independent variable is PP40.									

4.1.1.3 California bearing ratio versus liquid limit (red clay soil)

The relationship between the CBR and LL for the tested samples is shown in figure 7 .The equation that best fits for the correlation between CBR and LL is CBR = 23.559-0.291 * LL, as the strength of this correlation is only 10.4% or has R^2= 0.104. It is deemed not reliable enough to be used as a predictor for the estimation of the CBR.

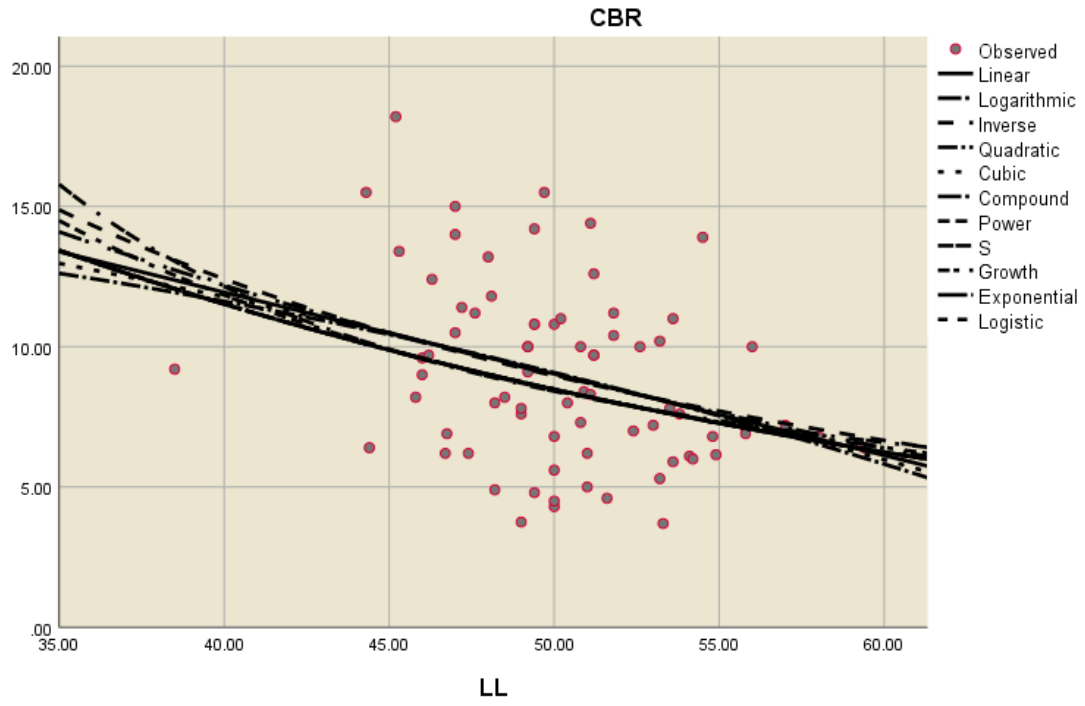

Figure 6: Scatter Diagram of California bearing ratio versus Liquid Limit (red clay soil)

Table 5: Model Summary and Parameter Estimates for California bearing ratio versus Liquid Limit (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.104	8.321	1	72	.005	23.559	-.291		
Logarithmic	.102	8.159	1	72	.006	64.921	-14.295		
Inverse	.099	7.871	1	72	.006	-4.848	690.466		
Quadratic	.104	4.127	2	71	.020	14.542	.071	-.004	
Cubic	.104	4.128	2	71	.020	17.253	.000	-.004	1.454E-5
Compound	.089	7.027	1	72	.010	39.279	.970		
Power	.088	6.946	1	72	.010	3155.831	-1.514		
S	.086	6.764	1	72	.011	.662	73.424		
Growth	.089	7.027	1	72	.010	3.671	-.031		
Exponential	.089	7.027	1	72	.010	39.279	-.031		
Logistic	.089	7.027	1	72	.010	.025	1.031		
The independent variable is LL.									

4.1.1.4 California bearing ratio versus plastic limit (red clay soil)

The relationship between the CBR and PL for the tested samples is shown in figure 8.The equation that best fits for the correlation between CBR and PL is CBR = -6.252+0.993* PL -0.016*PL^2, has R^2= 0.024.

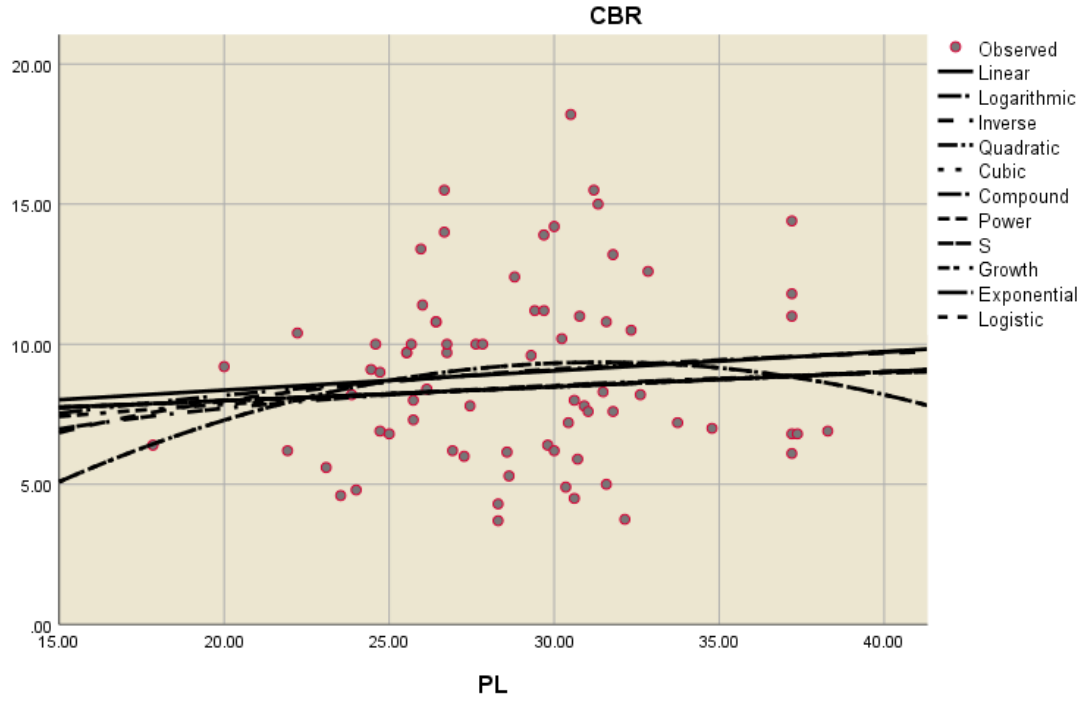

Figure 7: Scatter Diagram of California bearing ratio versus Plastic Limit (red clay soil)

Table 6: Model Summary and Parameter Estimates for California bearing ratio versus Plastic Limit (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.008	.611	1	72	.437	6.988	.069		
Logarithmic	.011	.799	1	72	.374	1.487	2.233		
Inverse	.014	.994	1	72	.322	11.382	-68.090		
Quadratic	.024	.881	2	71	.419	-6.252	.993	-.016	
Cubic	.024	.881	2	71	.419	-6.252	.993	-.016	.000
Compound	.005	.364	1	72	.548	7.074	1.006		
Power	.007	.477	1	72	.492	4.354	.197		
S	.008	.600	1	72	.441	2.345	-6.043		
Growth	.005	.364	1	72	.548	1.956	.006		
Exponential	.005	.364	1	72	.548	7.074	.006		
Logistic	.005	.364	1	72	.548	.141	.994		
The independent variable is PL.									

4.1.1.5 California bearing ratio Versus Plasticity Index (red clay soil)

The relationship between the CBR and PI for the tested samples is shown in figure 8.The equation that best fits for the correlation between CBR and PI is CBR = 23.195-1.069*PI+0.018*PI^2, has R^2= 0.155.

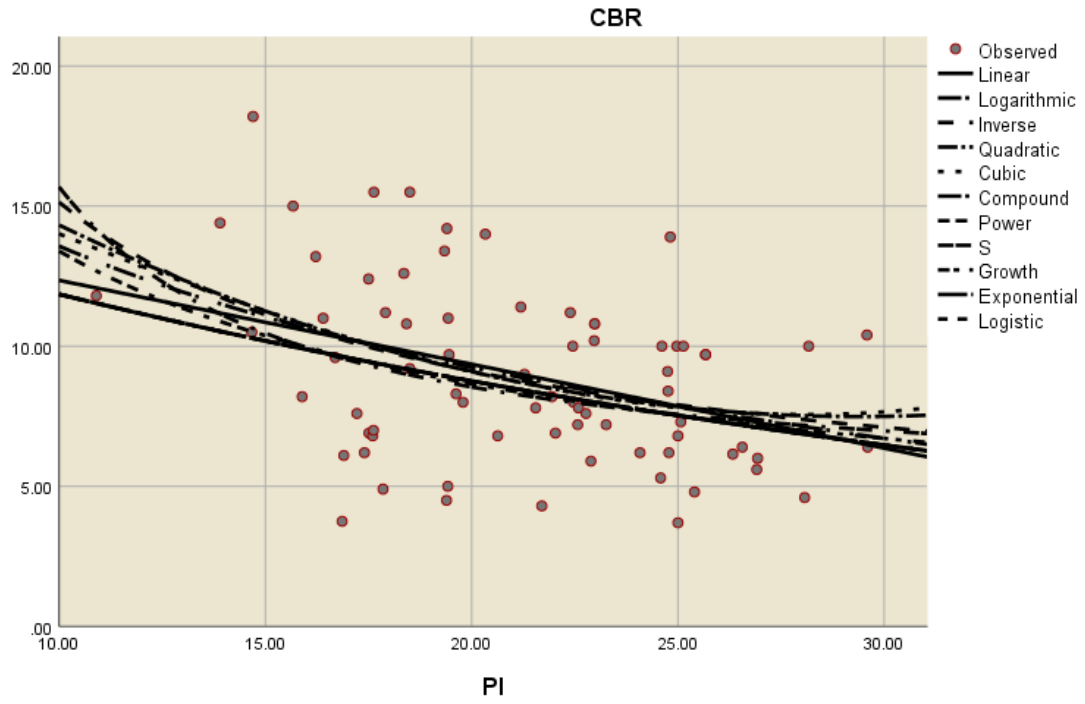

Figure 8: Scatter Diagram of California bearing ratio versus Plasticity Index (red clay soil)

Table 7: Model Summary and Parameter Estimates for California bearing ratio versus Plasticity Index (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.143	12.054	1	72	.001	15.343	-.299		
Logarithmic	.151	12.788	1	72	.001	27.949	-6.244		
Inverse	.152	12.921	1	72	.001	3.085	120.558		
Quadratic	.155	6.517	2	71	.003	23.195	-1.069	.018	
Cubic	.155	4.289	3	70	.008	20.136	-.598	-.005	.000
Compound	.113	9.164	1	72	.003	16.042	.970		
Power	.118	9.641	1	72	.003	57.060	-.629		
S	.119	9.729	1	72	.003	1.538	12.148		
Growth	.113	9.164	1	72	.003	2.775	-.030		
Exponential	.113	9.164	1	72	.003	16.042	-.030		
Logistic	.113	9.164	1	72	.003	.062	1.031		
The independent variable is PI.									

4.1.1.6 California bearing ratio versus Maximum dry density (red clay soil)

The relationship between the CBR and MDD for the tested samples is shown in figure 10.The equation that best fits for the correlation between CBR and MDD is CBR = 5.403-5.032*(1/MDD), has R^2= 0.164.

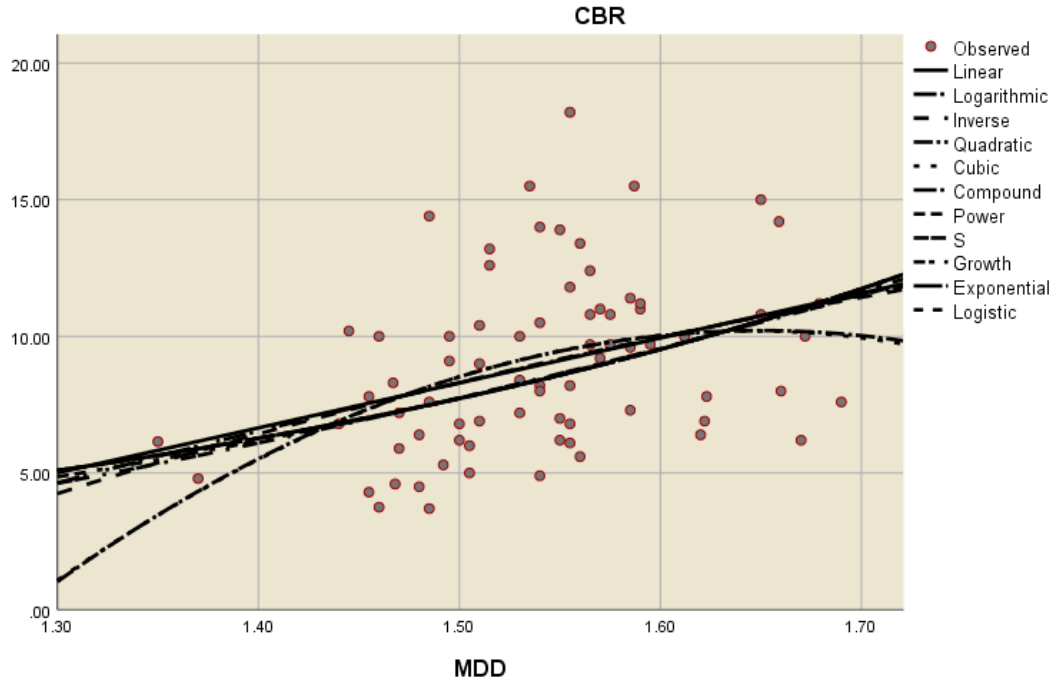

Figure 9: Scatter Diagram of California bearing ratio versus Maximim dry density (red clay soil)

Table 8: Model Summary and Parameter Estimates for California bearing ratio versus Maximum dry density (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.125	10.323	1	72	.002	-16.354	16.434		
Logarithmic	.129	10.658	1	72	.002	-2.076	25.603		
Inverse	.132	10.961	1	72	.001	34.774	-39.685		
Quadratic	.152	6.351	2	71	.003	-193.614	247.020	-74.842	
Cubic	.153	6.410	2	71	.003	-138.505	135.600	.000	-16.704
Compound	.156	13.321	1	72	.000	.337	8.076		
Power	.160	13.729	1	72	.000	2.072	3.250		
S	.164	14.093	1	72	.000	5.403	-5.032		
Growth	.156	13.321	1	72	.000	-1.088	2.089		
Exponential	.156	13.321	1	72	.000	.337	2.089		
Logistic	.156	13.321	1	72	.000	2.969	.124		
The independent variable is MDD.									

4.1.1.7 California bearing ratio Versus Optimum moisture content (red clay soil)

The relationship between the CBR and OMC for the tested samples is shown in figure 11.The equation that best fits for the correlation between CBR and OMC is CBR = -0.515+0.47*(OMC), has R^2= 0.029. This shows that the relationship is weak.

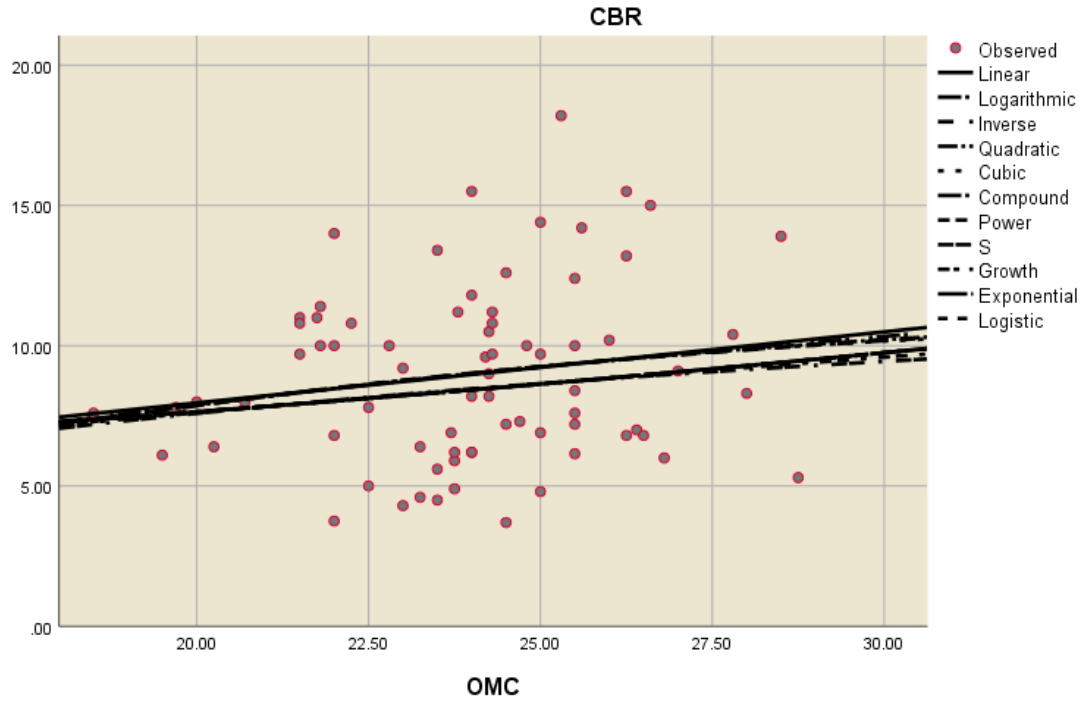

Figure 10: Scatter Diagram of California bearing ratio versus Optimum moisture content (red clay soil)

Table 9: Model Summary and Parameter Estimates for California bearing ratio versus optimum moisture content (red clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.028	2.091	1	72	.153	2.897	.253		
Logarithmic	.028	2.104	1	72	.151	-10.025	5.986		
Inverse	.028	2.097	1	72	.152	14.819	-139.142		
Quadratic	.028	1.041	2	71	.359	-1.692	.642	-.008	
Cubic	.029	1.043	2	71	.358	-.515	.470	.000	.000
Compound	.020	1.472	1	72	.229	4.702	1.025		
Power	.020	1.454	1	72	.232	1.383	.569		
S	.019	1.421	1	72	.237	2.682	-13.107		
Growth	.020	1.472	1	72	.229	1.548	.024		
Exponential	.020	1.472	1	72	.229	4.702	.024		
Logistic	.020	1.472	1	72	.229	.213	.976		
The independent variable is OMC.									

4.1.2 Scatter plot for brown clay soil

4.1.2.1 California bearing ratio versus percent Passing Sieve No.200

The relationship between the CBR and PP_{200} for the tested samples is shown in figure 12. The equation that best fits for the correlation between CBR and % Passing Sieve No.200 is CBR =22.259-1.538*PP_{200}+0.042 PP_{200}^2.

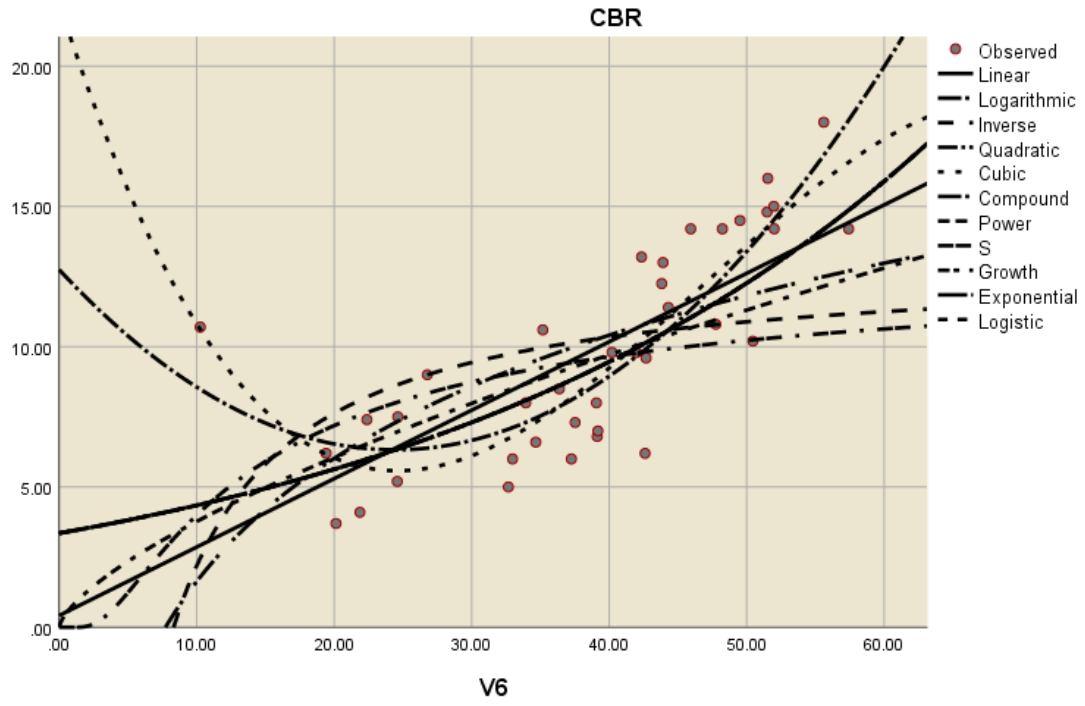

Figure 11: Scatter Diagram of CBR versus percent Passing Sieve No.200 (brown clay soil)

Table 10: Model Summary and Parameter Estimates California bearing ratio versus percent Passing Sieve No.200 (brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df 1	df2	Sig.	Constant	b1	b2	b3
Linear	.244	42.999	1	36	.000	.420	.244		
Logarithmic	.176	21.647	1	36	.000	-12.953	6.334		
Inverse	.179	7.863	1	36	.008	13.062	-108.716		
Quadratic	.125	46.088	2	35	.000	12.747	-.526	.011	
Cubic	.151	34.101	3	34	.000	22.259	-1.538	.042	.000
Compound	.127	40.186	1	36	.000	3.355	1.026		
Power	.234	21.472	1	36	.000	.784	.682		
S	.179	7.870	1	36	.008	2.560	-11.744		
Growth	.227	40.186	1	36	.000	1.210	.026		
Exponential	.227	40.186	1	36	.000	3.355	.026		
Logistic	.227	40.186	1	36	.000	.298	.974		
The independent variable is %Passing Sieve No.200.									

4.1.2.2 California bearing ratio versus percent Passing Sieve No 40 (brown clay soil)

The equation that best fits for the correlation between CBR and % Passing Sieve No.40 is CBR =564.492-15.253*PP_{40} +0.104*PP_{40}^2.The strength of this equation in predicting an outcome from the % Passing Sieve No.40 is around 37% or has R^2= 0.37.

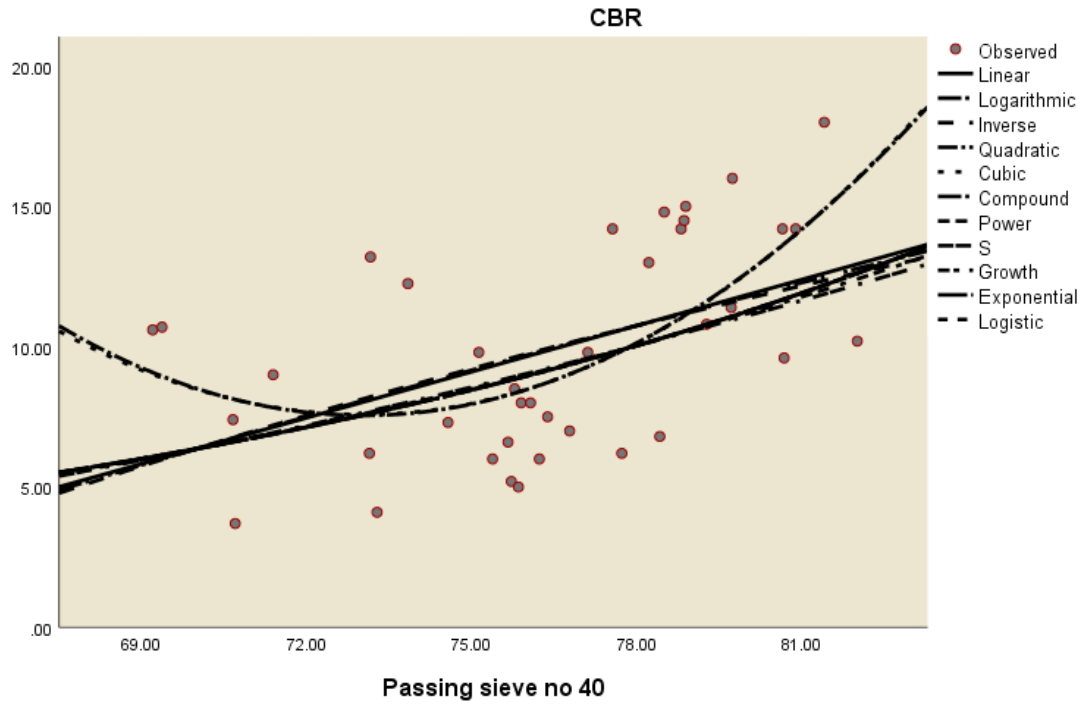

Figure 12: Scatter Diagram of California bearing ratio versus percent Passing Sieve No.40 (brown clay soil)

Table 11: Model Summary and Parameter Estimates California bearing ratio versus percent Passing Sieve No.40 (brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.242	11.513	1	36	.002	-31.927	.547		
Logarithmic	.233	10.952	1	36	.002	-165.849	40.536		
Inverse	.224	10.390	1	36	.003	49.121	-2992.729		
Quadratic	.370	10.267	2	35	.000	564.492	-15.253	.104	
Cubic	.368	10.179	2	35	.000	363.252	-7.306	.000	.000
Compound	.225	10.478	1	36	.003	.118	1.059		
Power	.217	9.984	1	36	.003	1.027E-7	4.223		
S	.209	9.485	1	36	.004	6.305	-311.834		
Growth	.225	10.478	1	36	.003	-2.139	.057		
Exponential	.225	10.478	1	36	.003	.118	.057		
Logistic	.225	10.478	1	36	.003	8.488	.945		
The independent variable is %Passing Sieve No.40.									

4.1.2.3 California bearing ratio versus liquid limit (brown clay soil)

The equation that best fits for the correlation between CBR and LL is CBR =27.668-0.481 LL -0.0538 * LL+4.769*10^{-5} LL^2, has R^2= 0.027.

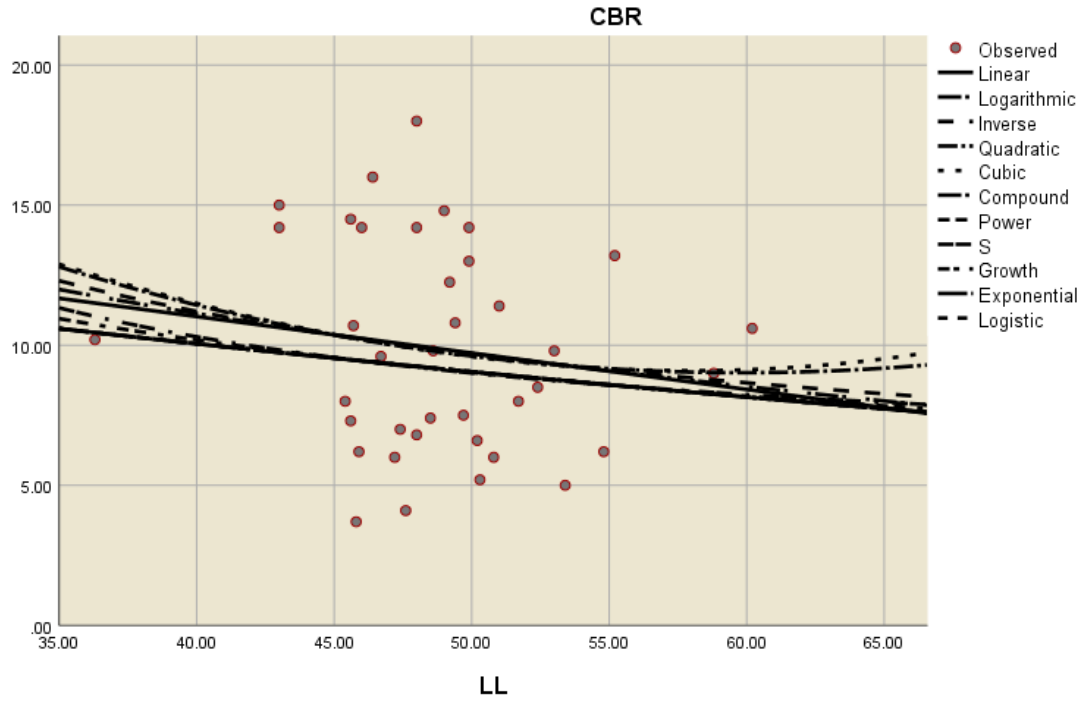

Figure 13: Scatter Diagram of California bearing ratio versus Liquid limit (brown clay soil)

Table 12: Model Summary and Parameter Estimates California bearing ratio versus Liquid limit(brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.023	.843	1	36	.365	16.226	-.130		
Logarithmic	.024	.878	1	36	.355	34.847	-6.429		
Inverse	.024	.884	1	36	.353	3.561	305.881		
Quadratic	.026	.471	2	35	.628	30.954	-.733	.006	
Cubic	.027	.488	2	35	.618	27.668	-.481	.000	4.769E-5
Compound	.013	.465	1	36	.500	15.294	.990		
Power	.014	.528	1	36	.472	74.890	-.541		
S	.016	.577	1	36	.452	1.662	26.798		
Growth	.013	.465	1	36	.500	2.727	-.010		
Exponential	.013	.465	1	36	.500	15.294	-.010		
Logistic	.013	.465	1	36	.500	.065	1.011		
The independent variable is LL.									

4.1.2.4 California bearing ratio versus plastic limit (brown clay soil)

The relationship between CBR and the plastic limit for the tested samples is shown in figure 15. The best fitting trend line for this relationship is CBR = $11.071+0.004PL^2$, the strength of this equation in predicting an outcome from the plastic Limit is around 10.5 % or has R^2= 0.105.This Shows that the relationship is weak.

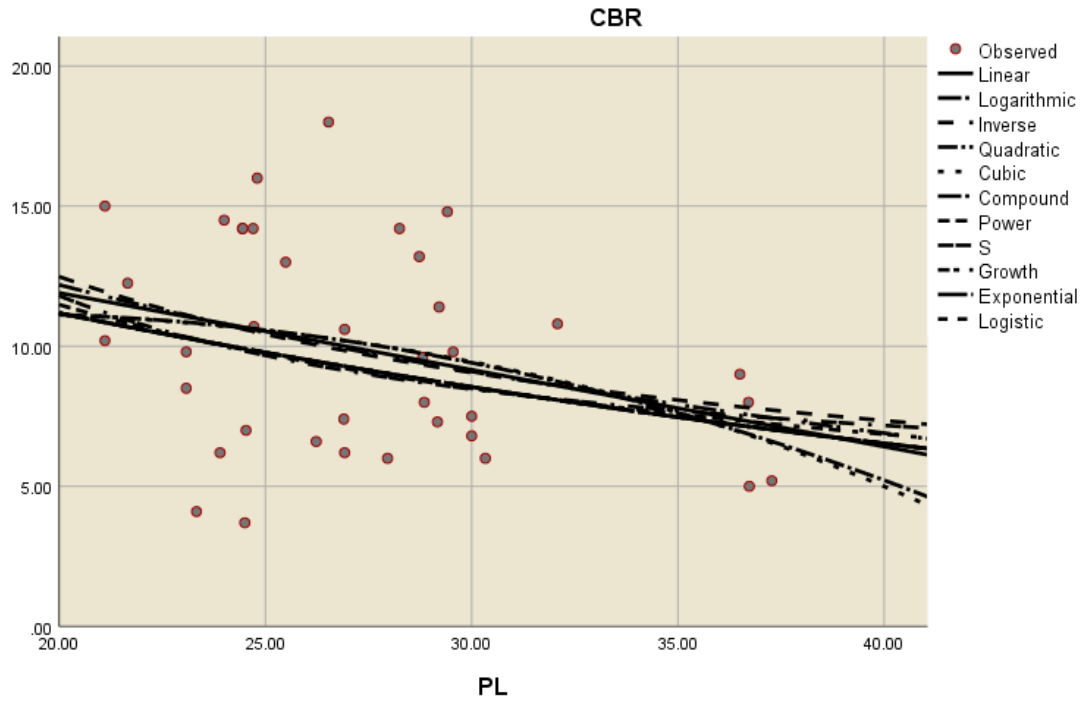

Figure 14 : Scatter Diagram of California bearing ratio versus Plastic limit (brown clay soil)

Table 13: Model Summary and Parameter Estimates California bearing ratio versus Plastic limit (brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.099	3.944	1	36	.055	17.390	-.274		
Logarithmic	.094	3.743	1	36	.061	35.067	-7.636		
Inverse	.089	3.502	1	36	.069	2.207	205.529		
Quadratic	.104	2.034	2	35	.146	7.109	.448	-.012	
Cubic	.105	2.044	2	35	.145	11.071	.000	.004	.000
Compound	.081	3.187	1	36	.083	19.142	.973		
Power	.077	2.984	1	36	.093	106.479	-.743		
S	.071	2.767	1	36	.105	1.472	19.916		
Growth	.081	3.187	1	36	.083	2.952	-.027		
Exponential	.081	3.187	1	36	.083	19.142	-.027		
Logistic	.081	3.187	1	36	.083	.052	1.027		
The independent variable is PL.									

4.1.2.5 California bearing ratio Versus Plasticity Index (brown clay soil)

The equation that best fits for the correlation between CBR and PI is CBR =-59.476 +8.691PI+5-0.351PI^2+0.005 PI^3 the strength of this equation in predicting an outcome from the Plasticity index is around 11.2% or has R^2= 0.112.

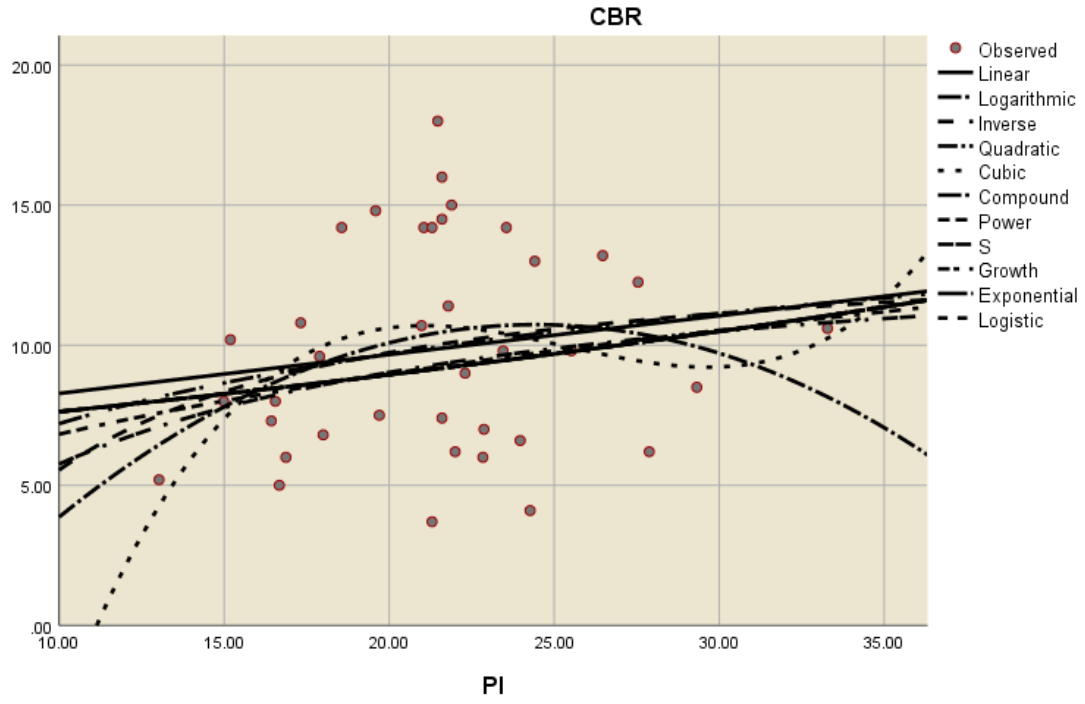

Figure 15: Scatter Diagram of California bearing ratio versus Plasticity index (brown clay soil)

Table 14: Model Summary and Parameter Estimates California bearing ratio versus Plasticity index (brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.026	.970	1	36	.331	6.806	.143		
Logarithmic	.038	1.431	1	36	.239	-1.299	3.664		
Inverse	.051	1.940	1	36	.172	13.996	-85.281		
Quadratic	.080	1.526	2	35	.232	-9.058	1.618	-.033	
Cubic	.112	1.432	3	34	.251	-59.476	8.691	-.351	.005
Compound	.030	1.096	1	36	.302	6.449	1.016		
Power	.040	1.487	1	36	.231	2.682	.403		
S	.050	1.913	1	36	.175	2.657	-9.147		
Growth	.030	1.096	1	36	.302	1.864	.016		
Exponential	.030	1.096	1	36	.302	6.449	.016		
Logistic	.030	1.096	1	36	.302	.155	.984		
The independent variable is PI.									

4.1.2.6 California bearing ratio Versus Maximum dry density (brown clay soil)

The equation that best fits for the correlation between CBR and MDD is CBR =-151.366+146.22MDD-17.572MDD^3 the strength of this equation in predicting an outcome from the Maximum dry density is around 10.1% or has R^2= 0.101.

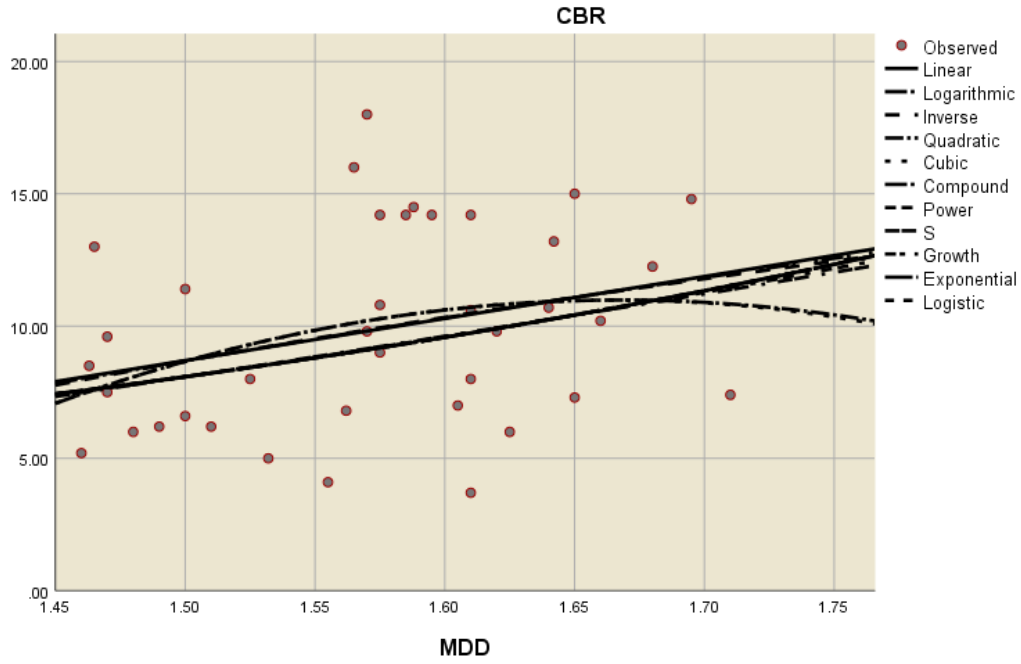

Figure 16: Scatter Diagram of California bearing ratio versus Maximum dry density (brown clay soil)

Table 15: Model Summary and Parameter Estimates California bearing ratio versus Maximim dry density(brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.088	3.477	1	36	.070	-15.145	15.894		
Logarithmic	.089	3.538	1	36	.068	-1.505	25.136		
Inverse	.091	3.595	1	36	.066	35.109	-39.645		
Quadratic	.100	1.954	2	35	.157	-218.458	275.174	-82.505	
Cubic	.101	1.959	2	35	.156	-151.366	146.220	.000	-17.572
Compound	.085	3.353	1	36	.075	.643	5.410		
Power	.086	3.387	1	36	.074	2.748	2.661		
S	.087	3.415	1	36	.073	4.878	-4.183		
Growth	.085	3.353	1	36	.075	-.442	1.688		
Exponential	.085	3.353	1	36	.075	.643	1.688		
Logistic	.085	3.353	1	36	.075	1.556	.185		
The independent variable is MDD.									

4.1.2.7 California bearing ratio Versus Optimum moisture Content (brown clay soil)

The equation that best fits for the correlation between CBR and OMC is CBR =-95.029 +9.181OMC-0.2*OMC^2 the strength of this equation in predicting an outcome from the Optimum moisture content is around 7% or has R^2= 0.07.

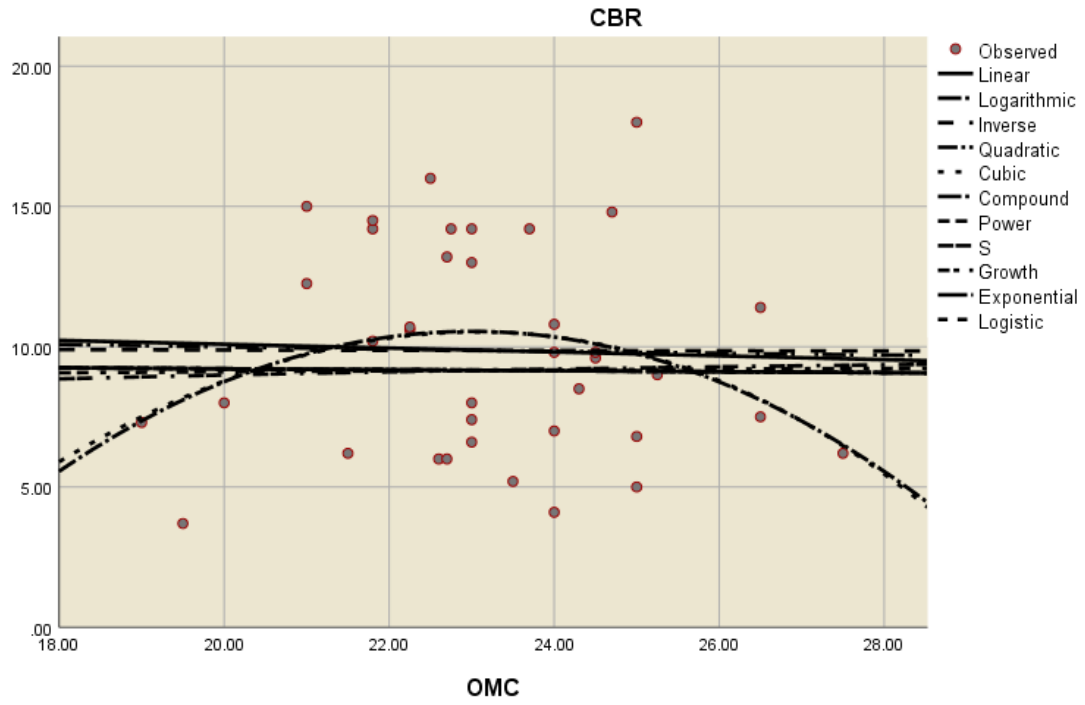

Figure 17: Scatter Diagram of California bearing ratio versus Optimum moisture content (brown clay soil)

Table 16: Model Summary and Parameter Estimates California bearing ratio versus Optimum moisture content (brown clay soil)

Model Summary and Parameter Estimates									
Dependent Variable: CBR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.001	.043	1	36	.838	11.467	-.069		
Logarithmic	.000	.013	1	36	.911	12.572	-.861		
Inverse	.000	.000	1	36	.989	9.761	2.451		
Quadratic	.070	1.320	2	35	.280	-95.029	9.181	-.200	
Cubic	.067	1.264	2	35	.295	-58.418	4.483	.000	-.003
Compound	.000	.003	1	36	.959	9.568	.998		
Power	.000	.002	1	36	.964	8.138	.038		
S	.001	.022	1	36	.884	2.335	-2.768		
Growth	.000	.003	1	36	.959	2.258	-.002		
Exponential	.000	.003	1	36	.959	9.568	-.002		
Logistic	.000	.003	1	36	.959	.105	1.002		
The independent variable is OMC.									

4.2 Multiple Linear Regression Analysis

The following possible empirical formulas are developed by taking one or more of important parameters (PP200, LL, PL,PI, OMC and MDD) in different combination as shown in table 17.

4.2.1 Multiple Linear Regression Analysis for red clay soil

Table 17: Summary of newly developed possible empirical equations (red clay soil)

Equt. No	Equations (Red clay soil)	R	R^2
1	CBR=17.957-0.303LL+0.16PP200	0.556	0.309
2	CBR=9.19+0.153PP200-0.289PI	0.574	0.33
3	CBR=1.655+0.153PP200+0.058OMC	0.445	0.198
4	CBR=2.175+0.154PP200+0.547MDD	0.443	0.196
5	CBR=5.017+0.169PP200-0.033P40	0.450	0.203
6	CBR=23.528-0.189LL-0.237PI	0.425	0.181
7	CBR=17.123-0.312LL+0.313OMC	0.382	0.146
8	CBR=-0.846-0.242LL+14.246MDD	0.442	0.195
9	CBR=-19.898+0.074P40-0.333LL	0.370	0.137
10	CBR=8.141-0.316PI+0.315OMC	0.432	0.187
11	CBR=-5.864-0.248PI+13.044MDD	0.467	0.218
12	CBR=11.547-0.308PI+0.051P40	0.400	0.160
13	CBR=-35.042+0.475OMC+21.158MDD	0.463	0.214
14	CBR=0.442+0.245OMC+0.034P40	0.189	0.036
15	CBR=-16.268+16.562MDD-0.004P40	0.354	0.125
16	CBR=18.072+0.157PP200-0.209LL-0.221PI	0.613	0.376
17	CBR=15.811+0.153PP200-0.31LL+0.119OMC	0.560	0.314
18	CBR=30.926+0.214PP200-0.337LL-8.638MDD	0.566	0.320
19	CBR=17.809+0.16PP200-0.305LL+0.004P40	0.556	0.309
20	CBR=16.501-0.208LL-0.25PI+0.342OMC	0.482	0.232
21	CBR=2.55-0.165LL-0.197PI+12.248MDD	0.496	0.246
22	CBR=19.925+0.073P40-0.232LL-0.236PI	0.462	0.213
23	CBR=-24.82-0.255PI+0.49OMC+17.814MDD	0.559	0.312
24	CBR=4.916+0.046P40+0.305OMC-0.314PI	0.448	0.201
25	CBR=-35.142-0.026P40+0.494OMC+22.276MDD	0.467	0.218
26	CBR=6.644+0.144PP200-0.296PI+0.127OMC	0.580	0.336
27	CBR=23.116+0.214PP200-0.325PI-10.052MDD	0.588	0.346
28	CBR=10.226+0.159PP200-0.286PI-0.017P40	0.576	0.332
29	CBR=-63.109-0.125PP200+0.805OMC+37.377MDD	0.467	0.218

Table 17: Summary of newly developed possible empirical equations (red clay soil)

30	CBR=3.874+0.165PP200+0.051OMC-0.032P40	0.451	0.203
31	CBR=-19.482-0.26LL+0.504OMC+19.087MDD	0.543	0.295
32	CBR=13.822+0.071P40+0.303OMC-0.352LL	0.421	0.177
33	CBR=-6.034+0.017P40+12.347MDD-0.253PI	0.469	0.220
34	CBR=4.332+0.166PP200+0.523MDD-0.033P40	0.450	0.203
35	CBR=-0.069+0.035P40+12.792MDD-0.267LL	0.449	0.202
36	CBR=15.302+0.146PP200-0.215LL-0.227PI+0.153OMC	0.620	0.384
37	CBR=40.2+0.246PP200-0.509LL+0.26PL-14.726MDD	0.638	0.407
38	CBR=17.892+0.155PP200-0.211LL-0.221PI+0.005P40	0.613	0.376
39	CBR=187.459+0.897PP200-0.545PI-1.852OMC-101.945MDD	0.628	0.394
40	CBR=7.618+0.15PP200-0.293PI+0.124OMC-0.015P40	0.581	0.338
41	CBR=-57.363-0.099PP200+0.751OMC+34.89MDD-0.021P40	0.470	0.221
42	CBR=-16.159-0.182LL-0.199PI+0.507OMC+17.096MDD	0.589	0.347
43	CBR=13.276-0.248LL-0.248PI+0.332OMC+0.069P40	0.511	0.261
44	CBR=3.548-0.192LL-0.202PI+-10.49MDD+0.041P40	0.505	0.255
45	CBR=-18.937-0.268LL+0.496OMC+18.512MDD+0.012P40	0.543	0.295
46	CBR=-24.907-0.253PI+0.494OMC+18.06MDD-0.005P40	0.559	0.312
47	CBR=141.504+0.658PP200-0.491LL-1.202OMC-67.804MDD	0.587	0.345
48	CBR=30.814+0.212PP200-0.342LL-8.767MDD+0.008P40	0.566	0.320
49	CBR=15.513+0.15PP200-0.314LL+0.121OMC+0.007P40	0.561	0.315
50	CBR=23.913+0.218PP200-0.322PI-9.956MDD-0.015P40	0.589	0.347
51	CBR=14.93+0.143PP200-0.22LL-0.228PI+0.156OMC+0.009P40	0.621	0.386
52	CBR=40.064+0.243PP200-0.256LL-0.261PI-14.937MDD+0.012P40	0.630	0.397
53	CBR=141.247+0.656PP200-0.495LL-1.2OMC-67.835MDD+0.007P40	0.587	0.345
54	CBR=200.614+0.955PP200-0.552PI-1.98OMC-108.08MDD-0.035P40	0.634	0.402
55	CBR=-15.302-0.194LL-0.201PI+0.495OMC+16.207MDD+0.018P40	0.591	0.349
56	CBR=988.837+4.04PP200-1.211LL-1.188PI-9.949OMC-526.326MDD	0.956	0.913
57	CBR=989.798+4.04PP200-1.223LL-1.19PI-9.961OMC-527.282MDD+0.019P40	0.957	0.915

On the above table, Summary of newly developed possible empirical equations for red clay soil is made by rigorously analyzing for reasonably adequate number of samples with all possible independent variable combinations.

On the above table, it is crystal clear that regression coefficient value increases as the number of independent variable increases. Best regression coefficient value , R^2=0.915 is obtained when all possible independent variable parameters are used.

It's is very clear that multiple parameter regression analysis shown a higher regression coefficient value than single parameter regression analysis. The higher regression coefficient is near to unity. Hence, the correlation analysis undertaken is reliable and had a better accuracy.

4.2.2 Multiple Linear Regression Analysis for brown clay soil

The following possible empirical formulas are developed by taking one or more of important parameters (PP200, PP40, LL, PL, PI, OMC and MDD) in different combination as shown in table 18.

Table 18: Summary of newly developed possible empirical equations (brown clay soil)

Equt. No	Equations (Brown clay soil)	R	R^2
1	CBR=-0.011+0.08LL+0.245PP200	0.738	0.545
2	CBR=-2.329+0.243PP200+0.129PI	0.752	0.566
3	CBR=3.372+0.245PP200-0.129OMC	0.741	0.549
4	CBR=-13.689+0.233PP200+9.217MDD	0.757	0.573
5	CBR=23.823+0.328PP200-0.349P40	0.760	0.578
6	CBR=16.692-0.266LL+0.275PI	0.308	0.095
7	CBR=-14.983-0.149LL+0.093OMC	0.158	0.025
8	CBR=-10.609-0.066LL+15.048MDD	0.311	0.097
9	CBR=-39.286+0.593P40+0.078LL	0.499	0.249
10	CBR=9.33+0.143PI-0.108OMC	0.164	0.027
11	CBR=-18.724+0.14PI+16.244MDD	0.324	0.105
12	CBR=-49.597+0.324PI+0.687P40	0.601	0.361
13	CBR=-25.442+18.897MDD+0.239OMC	0.321	0.103
14	CBR=-27.692-0.327OMC+0.591P40	0.518	0.268
15	CBR=-71.869+0.627P40+21.492MDD	0.632	0.399
16	CBR=0.993+0.236PP200-0.081LL+0.172PI	0.756	0.572
17	CBR=2.12+0.249PP200+0.047LL-0.181OMC	0.742	0.551
18	CBR=-17.088+0.237PP200+0.046LL+9.877MDD	0.759	0.576
19	CBR=35.187+0.344PP200-0.093LL-0.447P40	0.766	0.587
20	CBR=14.479-0.309LL+0.287PI+0.187OMC	0.319	0.102
21	CBR=-6.546+0.051LL-0.246PI+13.127MDD	0.392	0.154
22	CBR=-44.312+0.657P40-0.074LL+0.354PI	0.605	0.366
23	CBR=-26.645+0.13PI+0.197OMC+18.511MDD	0.353	0.125
24	CBR=-45.815+0.779P40-0.514OMC+0.377PI	0.648	0.420
25	CBR=-72.203+0.626P40+0.01OMC+21.6MDD	0.632	0.399
26	CBR=1.311+0.244PP200+0.138PI-0.167OMC	0.757	0.573
27	CBR=-16.687+0.233PP200+0.132PI+9.346MDD	0.772	0.596
28	CBR=18.437-0.284P40+0.05PI+0.312PP200	0.430	0.185
29	CBR=-14.97+0.233PP200-+0.0O31MC+9.592MDD	0.757	0.573
30	CBR=23.823+0.329PP200+0.004OMC-0.351P40	0.760	0.578
31	CBR=-21.319-0.125LL+0.366OMC+18.301MDD	0.346	0.120
32	CBR=-52.146+0.844P40-0.79OMC+0.325LL	0.574	0.330

33	CBR=-94.405+0.788P40+23.157MDD+0.357PI	0.737	0.543
34	CBR=8.729+0.297PP200+5.253MDD-0.244P40	0.764	0.584
35	CBR=-108.491+0.809P40+27.5MDD+0.272LL	0.683	0.466
36	CBR=2.317+0.24PP200-0.051LL+0.162PI-0.117OMC	0.758	0.575
37	CBR=-14.41+0.23PP200-0.037LL+0.151PI+8.838MDD	0.772	0.596
38	CBR=28.501+0.319PP200-0.12LL+0.092PI-0.355P40	0.770	0.593
39	CBR=-16.185+0.233PP200+0.132PI-0.012OMC+9.195MDD	0.772	0.596
40	CBR=17.152+0.305PP200+0.061PI-0.05OMC-0.252P40	0.762	0.581
41	CBR=6.887+0.298PP200+0.065OMC+5.892MDD-0.253P40	0.765	0.585
42	CBR=-18.886-0.272LL+0.259PI+-0.429OMC-16.845MDD	0.426	0.181
43	CBR=-55.719+0.16LL+0.333PI-0.72OMC+0.882P40	0.658	0.433
44	CBR=-108.41+0.126LL+0.309PI+-14.726MDD+0.851P40+25.727MDD	0.745	0.555
45	CBR=-111.072+0.422LL-0.538OMC+25.046MDD+0.96P40	0.709	0.503
46	CBR=-89.504+0.373PI-0.179OMC+21.305MDD+0.812P40	0.741	0.549
47	CBR=-16.415+0.237PP200+0.05LL-0.024OMC+9.65MDD	0.759	0.576
48	CBR=27.232+0.329PP200-0.072LL+1.888MDD-0.387P40	0.766	0.587
49	CBR=57.887+0.413PP200-0.278LL+0.485OMC-0.807P40	0.777	0.604
50	CBR=-20.001+0.224PP200+0.141PI+9.903MDD+0.034P40	0.772	0.596
51	CBR=52.434+0.394PP200-0.272LL+0.044PI+0.436OMC-0.728P40	0.775	0.601
52	CBR=-4.779+0.252PP200-0.054LL+0.135PI+7.159MDD-0.087P40	0.773	0.600
53	CBR=114.147+0.531PP200-0.492LL+0.747OMC-10.431MDD-1.332P40	0.781	0.600
54	CBR=-20.328+0.221PP200+0.146PI-0.023OMC+9.834MDD+0.047P40	0.772	0.596
55	CBR=-110.763+0.268LL+0.298PI+23.555MDD-0.49OMC+0.987P40	0.764	0.584
56	CBR=-15.15-0.042LL+0.152PI+9.087MDD+0.027OMC+0.229PP200	0.772	0.596
57	CBR=3178.89+0.035LL-10.57PL-469.578MDD+17.567OMC-33.017P40-15.274PI+7.756PP200	0.915	0.838

On the above table Summary of newly developed possible empirical equations for brown clay soil is made by rigorously analyzing for reasonably adequate number of samples with all possible independent variables combinations.

On the above table, it is crystal clear that regression coefficient value increases as the number of independent variable increases. Best regression coefficient value that is R^2=0.838 is obtained when all possible independent variable parameters are used.

It’s is very clear that multiple parameter regression analysis shown a higher regression coefficient value than single parameter regression analysis.The higher regression coefficient is near to unity. Hence, the correlation analysis undertaken is reliable and had a better accuracy.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

4.1.1 Conclusion

The research was conducted to find a localized correlation between CBR value and soil index properties within the scope of the study. Using the obtained 112 test results, single and multiple linear regressions were analyzed and Correlations are developed that predicts CBR value in terms of PP200, LL, PI, P40, OMC and MDD.

From the results of this study the following conclusions are drawn:

1. From the results of linear and multiple regression analysis, an improved correlation of multiple regression is summarized as follows;

   CBR= 989.798+4.04PP200-1.223LL-1.19PI-9.961OMC-527.282MDD+0.019P40
   R^2=0.915, n = 73 (**for red clay soil**)

   CBR=3178.89+0.035LL-10.57PI-469.578MDD+17.567OMC-33.017PP40-15.274PI
   R^2=0.838, n = 37 (**for brown clay soil**)

2. It's observed that multiple parameter regression analysis shown a higher regression coefficient value than single parameter regression analysis. In light of the above results, a combination of soil index properties correlates better with strength characteristic of CBR than individual soil properties.
3. Correlations developed are different spatially due to difference in soil types in different locations which is clearly elaborated in various literatures in addition to this study.

4.1.2 Recommendation

1. The equation developed may be further improved by increasing the number and range of samples.

2. It is far really useful to conduct comparative correlations between soaked and unsoaked CBR value with soil index properties

3. Further studies have to be carried out to check the applicability of the equation for other types of soil.

4. It is also endorsed to carry out similar research in other parts of Ethiopia since Correlations vary spatially due to difference in soil type.

Reference

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[3] - American Society for Testing and Materials, Designation. (2000). D 2487-00.2000Standard Price for classification of Soils for Engineering Purposes (Unified Soil Classification System), Annual Book of ASTM Standards Volume 04.08,WestConshohocken:Pennsylvania

[4] - Dereje Bogale(2019),Prediction of Soaked CBR value from Index properties and compaction characteristics of subgrade soil for the case of Jinka-Mendir Design and Build Road project,M.Sc thesis, AAU,AAiT

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[6] - Fredrics, M. (1983). Standard Hand Book for Civil Engineers,McGraw-Hill Book Company:New York

[7] - Leliso Y. (2013). Correlation of CBR value with soil index properties for Addis Ababa,M.Sc thesis, AAU,AAiT

Appendix

Brown Clay soil

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	MDD, PI, PP200, 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	.772[a]	.597	.548	2.50183

a. Predictors: (Constant), MDD, PI, PP200, LL

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	305.429	4	76.357	12.199	.000[b]
	Residual	206.553	33	6.259		
	Total	511.981	37			

a. Dependent Variable: CBR
b. Predictors: (Constant), MDD, PI, PP200, LL

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-14.410	12.083		-1.193	.242
	PP200	.230	.038	.696	6.041	.000
	LL	-.037	.118	-.042	-.308	.760
	PI	.151	.115	.171	1.306	.201
	MDD	8.838	6.222	.166	1.420	.165

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	PP40, PI, LL, PP200[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	.770[a]	.592	.543	2.51441

a. Predictors: (Constant), PP40, PI, LL, PP200

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	303.347	4	75.837	11.995	.000[b]
	Residual	208.635	33	6.322		
	Total	511.981	37			

a. Dependent Variable: CBR
b. Predictors: (Constant), PP40, PI, LL, PP200

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.501	21.961		1.298	.203
	PP200	.319	.075	.966	4.281	.000
	LL	-.120	.119	-.139	-1.011	.320
	PI	.092	.130	.105	.709	.483
	PP40	-.355	.275	-.319	-1.292	.205

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	MDD, PI, PP200, 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	.772[a]	.595	.546	2.50535

a. Predictors: (Constant), MDD, PI, PP200, OMC

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	304.848	4	76.212	12.142	.000[b]
	Residual	207.133	33	6.277		
	Total	511.981	37			

a. Dependent Variable: CBR
b. Predictors: (Constant), MDD, PI, PP200, OMC

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-16.185	13.943		-1.161	.254
	PP200	.233	.038	.705	6.198	.000
	PI	.132	.099	.150	1.342	.189
	OMC	-.012	.251	-.006	-.050	.961
	MDD	9.195	6.733	.172	1.366	.181

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	PP40, OMC, PI, PP200[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	.762[a]	.580	.529	2.55171

a. Predictors: (Constant), PP40, OMC, PI, PP200

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	297.110	4	74.278	11.408	.000[b]
	Residual	214.871	33	6.511		
	Total	511.981	37			

a. Dependent Variable: CBR
b. Predictors: (Constant), PP40, OMC, PI, PP200

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	17.152	21.048		.815	.421
	PP200	.305	.086	.922	3.549	.001
	PI	.061	.140	.070	.437	.665
	OMC	-.050	.272	-.025	-.185	.855
	PP40	-.252	.323	-.227	-.781	.440

a. Dependent Variable: CBR

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Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	PI, PP200[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	.574[a]	.330	.311	2.63986

a. Predictors: (Constant), PI, PP200

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	243.441	2	121.720	17.466	.000[b]
	Residual	494.791	71	6.969		
	Total	738.231	73			

a. Dependent Variable: CBR
b. Predictors: (Constant), PI, PP200

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.190	2.164		4.248	.000
	PP200	.153	.035	.432	4.443	.000
	PI	-.289	.077	-.366	-3.761	.000

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	PP200, PP200[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	.450[a]	.202	.180	2.88015

a. Predictors: (Constant), PP200, PP200

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	149.269	2	74.634	8.997	.000[b]
	Residual	588.962	71	8.295		
	Total	738.231	73			

a. Dependent Variable: CBR
b. Predictors: (Constant), PP200, PP200

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.017	3.271		1.534	.130
	PP200	.169	.041	.475	4.141	.000
	PP200	-.033	.045	-.084	-.731	.467

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	LL, PP200[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	.370[a]	.137	.113	2.99518

a. Predictors: (Constant), LL, PP200

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	101.282	2	50.641	5.645	.005[b]
	Residual	636.949	71	8.971		
	Total	738.231	73			

a. Dependent Variable: CBR
b. Predictors: (Constant), LL, PP200

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	19.898	5.470		3.638	.001
	PP200	.074	.044	.189	1.663	.101
	LL	-.333	.103	-.369	-3.242	.002

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	OMC, 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	.432[a]	.187	.164	2.90813

a. Predictors: (Constant), OMC, PI

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	137.769	2	68.885	8.145	.001[b]
	Residual	600.462	71	8.457		
	Total	738.231	73			

a. Dependent Variable: CBR
b. Predictors: (Constant), OMC, PI

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.141	4.136		1.969	.053
	PI	-.316	.085	-.400	-3.718	.000
	OMC	.315	.162	.209	1.942	.056

a. Dependent Variable: CBR

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
1	OMC, PL, sievesize0.075mm, LL, MDD[b]	.	Enter

a. Dependent Variable: CBR
b. Tolerance = .000 limit reached.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.956[a]	.913	.907	.96934

a. Predictors: (Constant), OMC, PL, sievesize0.075mm, LL, MDD

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	674.336	5	134.867	143.532	.000[b]
	Residual	63.895	68	.940		
	Total	738.231	73			

a. Dependent Variable: CBR
b. Predictors: (Constant), OMC, PL, sievesize0.075mm, LL, MDD

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	988.921	47.815		20.682	.000
	sievesize0.075mm	4.040	.192	11.373	21.093	.000
	LL	-2.400	.103	-2.658	-23.322	.000
	PL	1.188	.056	1.586	21.152	.000
	MDD	-526.368	25.828	-11.342	-20.380	.000
	OMC	-9.950	.499	-6.600	-19.940	.000

a. Dependent Variable: CBR

Excluded Variables[a]						
Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	PI	-6.965[b]	-.079	.937	-.010	1.650E-7

a. Dependent Variable: CBR

b. Predictors in the Model: (Constant), OMC, PL, sievesize0.075mm, LL, MDD