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Regression Analysis of Index Properties of Soil as Strength Determinant for California Bearing Ratio (CBR)

Dino Abdella [1], Tadesse Abebe [2], Prof. Emer Tucay Quezon[3]

[1]*Geotechnical Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia*

[2]*Geotechnical Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia*

[3]*Construction Engineering and Management Stream, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia*

Email address:
tadewree@yahoo.com (T. Abebe), quezonet09@yahoo.com (E. T. Quezon), quezonet09@gmail.com (E.T. Quezon)

ABSTRACT

Investigation of the variation in different soil types and origins is an essential task for Geotechnical engineers. To overcome the effects of this change, the Geotechnical engineers, as well as other professionals, attempted to develop empirical equations unique to a region and soil type to use the soil for its intended purpose. However, these empirical equations are more reliable for the kind of soil where there is the strong relationship of parameters is developed. Hence, it is good practice to develop empirical equations that best fit in the soil available in the location that we can access. On the flexible pavement, subgrade is considered to be an ideal layer to resist wheel load, and its CBR value is considered as the strength measuring a parameter. Conducting CBR test is an expensive and time-consuming procedure. Also, it is challenging to mold the sample at a desired in-situ density in the laboratory. Furthermore, if the available soil is of poor quality, suitable additives are mixed with soil, and resulting strength of soil is assessed by the CBR value which is cumbersome. To overcome such problem, statistical approach such as regression-based models are used. This can be used for quick and easily determined parameters. Relative to this, the study has been conducted to develop an equation to show the relationship between the index properties and CBR values precisely located along Welkite- Arekit –Hosanna Road of about 121km stretches. It was carried out using thirty samples retrieved from this road and tested in a laboratory. The test result of the regression based statistical analysis was used to develop the predetermined relationship. The relationship development was performed in the form of an equation of CBR as a function of grain size parameters, Atterberg's liquid limits and compaction parameters by considering the effect of individual soil properties as well as the effect of a combination of soil properties on the CBR value. Based on the results of the study for both linear and multiple linear regression analyses, it was revealed that there was relatively fair relationship obtained by combining plasticity index, the percentage of fine content and maximum dry density which are strength determinant of fine-grained soils. Also, the results showed that the coefficient of determination for multiple linear regression is R^2=0. 731, while for single linear regression is R2=0. 682. Therefore, it is concluded that the index properties of soils are sufficiently accurate in determining the CBR values, of which it can be utilized for preliminary characterization.

Keywords: Atterberg Limits, CBR Values, Compaction Parameters, Empirical Equations, Flexible pavements, Index Properties, Grain Size Parameters, Regression anlaysis, Strenght determinant.

1 INTRODUCTION

The California Bearing Ratio (CBR), defined as the ratio of the resistance to penetration of material to the penetration resistance of a standard crushed stone base material. CBR is one of the primary parameters used in pavement design to assess the stiffness modulus and shear strength of subgrade material. During the early 1920s, the CBR test was developed by O. J. Porter for the California Highway Department to evaluate the bearing capacity of pavement materials in laboratory conditions. Starting from then, many countries, including Ethiopia have developed or adopted pavement design methods based on the CBR value of the materials [1].

The CBR test is essentially a measure of the shearing resistance of soil at a known moisture and density conditions. The method of evaluating CBR is standardized in AASHTO T 193 and ASTM D 1883.The value of CBR is an indicator of the suitability of natural subgrade soil as a construction material. If the CBR value of the subgrade is high, it means that the subgrade is firm and as a result, the design of pavement thickness can be reduced in conjunction with the stronger subgrade. Conversely, if the subgrade soil has little CBR value, it indicates that the thickness of pavement shall be increased in order to spread the traffic load over a greater area of the weak subgrade or, the subgrade soil shall be subjected to treatment or stabilization [7].

CBR test is expensive, time-consuming and laborious. Obtaining a proper idea about the soaked CBR of subgrade materials over the total length of the road is very difficult. So, it is not possible to take a large number of samples. Also, CBR test in the laboratory requires a large soil sample. This would result in the serious delay in the progress of the project since in most situations the materials for earthwork construction come from highly varied sources. Any delay in construction inevitably leads to the rise of the project cost. To overcome this issue, it is better to predict the CBR value of subgrade soil with readily determinable parameters. To exercise the right judgment during various phases of professional activities, the engineer is constantly required to predict a situation. In fact, the prediction was an integral component of practice in the past developed models for estimating the CBR value by low cost, less time consuming and easy to perform tests. Other investigators used soft computing systems like Artificial Neural Networks for correlating CBR values with Liquid Limit, Plastic Limit, Plasticity Index, Optimum Moisture Content, Maximum Dry Density, and Unconfined Compressive strength values of various soils [5].

Even though various attempts have been made to predict the CBR value by different researchers from samples of their respective localities, adapting those developed prediction models without adjustment leads to misinterpretation of soil behavior. Therefore, identification of factors that influence the soil strength, studying their relationship with CBR value and performing necessary tests on local representative soil sample would give a rational basis in speculating soil behavior, which ultimately minimizes both cost and time dedicated to carrying out the actual laboratory test.

The primary objective of the research is to develop empirical relationships between soil index properties (indices related to gradation characteristics, maximum dry density, optimum moisture content, plastic limit, liquid limit, and plasticity index) that can be used for the prediction of CBR values. Specifically, this study aims to establish a relationship between CBR values and soil index properties for Welkite to Hossana road subgrade soils, to validate and evaluate the developed equations using a control test results, and to compare the developed equations with previous studies.

2 RESEARCH METHODOLOGY

2.1 Study Area

The start of the road at Welkiteis located at 8° 16.6´Latitude and 37° 46.4´ Longitude, and it is found 158 km from Addis Ababa, on the Addis Ababa – Jimma trunk road. The destination point of the project, Hosana is located at 7° 33 latitudes, and 37° 51´Longitude is 260 km away from Addis Ababa, which along Addis Ababa –Butajira – Wolayita trunk road.

The project road connects three Zones and traverses five rural Woredas and two special Woredas; namely Wolkitie special Woreda, Chaha and Gummer Woredas in Gurage Zone, MirabAzernetWoreda in Silte zone and Limo Woreda and Hossana special Woreda in Hadya zone.

2.2 Source of Data

Soil samples were collected along Welkite-Arekite-Hossana road at a different stretch of the roads using borrowed pit. The road is 121 km long and located in Southern Nations, Nationalities and Peoples Regional State of Ethiopia. The dominant soil type on the road is red clay and brown to dark clay. The samples tested for different parameters like Atterberg's limit test, compaction test, and sieve analysis, CBR tests based on AASHTO standard. The tests carried out with their respective standard numbers are presented below.

□ Sieve analysis (AASHTO T27)

□ Atterberg limit test (AASHTO T89-90)
□ Compaction test (modified proctor test AASHTO T180 D)
□ California bearing ratio test (AASHTO T193)

2.3 Laboratory Test

The sieve analysis is done according to AASHTO T 27, Sieve Analysis of Fine and Coarse Aggregates. For sampling, the procedure outlined on AASHTO T2 is strictly followed. Accurate determination was of material better than the No. 200 sieve cannot be achieved by using this method alone. Therefore, test procedure, ND T 11/ AASHTO T11 for material finer than the No. 200 sieve by washing is employed. When working with mixed materials that are coated, lumpy, or baked together, the material is pulverized carefully so as not to break soil grain particles.

Atterberg limit tests carried out according to AASHTO T 89 for determination of the liquid limit of the soil and AASHTO T 90 used for Determination of plastic limit of the soil. Before the test is undertaken the sample made to pass No.40 (0.425mm) sieve according to sample preparation outlined on AASHTO T 87. For determining the water content in the laboratory AASHTO T 265 is used.

A modified proctor test conducted as per AASHTO T 180D, through which samples compacted at five layers, each compacted by 25 uniform blow using 4.54kg weight of the hammer. From the modified proctor test, after plotting moisture-density curve, a range of maximum dry density along with the optimum moisture content obtained. Similarly, the three point CBR test was carried out, on samples remolded with OMC using 10, 30 and 65 blows of modified proctor density and soaked for four days.

3 ANALYSIS, RESULTS, AND DISCUSSION

3.1 Regression Analysis

3.1.1 General Overview

Regression analysis is a statistical technique that is very useful in the field of engineering and science in modeling and investigating relationships between two or more variables. The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticated nonlinear multiple regressions. The best fit model could be in the form of a linear, parabolic or logarithmic trend. A direct relationship is usually practiced in solving different engineering problems because of its simplicity [7].

3.1.2 Regression analysis

In this research work, an attempt is made to apply the single linear regression model and multiple linear regression models to characterize the strength of subgrade soil from soil index parameters using a statistical approach. The general representation of a probabilistic single and multiple linear regression models are presented in the following forms:

$$Y = \beta_0 + \beta_1 x + \varepsilon \quad (1)$$

$$Y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 \ldots + \alpha_n x_n + \varepsilon \quad (2)$$

Where the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_0, α_1, α_2 and α_n are termed multiple regression coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the random error term, ε [2]. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method. For data analysis of this study, commercially available software MINITAB and, a statistical package for social science software (SPSS) is employed to investigate the significance of individual regressor variables. In this study, about 30 sample laboratory test results of the independent and dependent variables are used in the following regression analysis. The statistical information's of the test results are presented in Table 3.1.

Table 3.1: Statistical Information of Dependent and Independent Variables

	Measurment	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
F	(%)	30	54.9	41	95.9	72.55	2.77	15.15	229.46
PI	(%)	30	25	14	39	23.07	1.21	6.61	43.72
OMC	(%)	30	22.2	14.6	36.8	23.93	1.03	5.65	31.92
G	(%)	30	26	0	26	4.19	1.23	6.74	45.37
LL	(%)	30	54	30	84	50.67	2.57	14.05	197.40
PL	(%)	30	36	16	52	27.60	1.74	9.51	90.46
MDD	g/cc	30	0.67	1.23	1.9	1.56	0.03	0.16	0.03
S	(%)	30	54.9	4.1	59	23.28	2.59	14.20	201.60
CBR	(%)	30	5.8	2.2	8	4.87	0.29	1.59	2.54
Valid N (listwise)		30							

For determining the influence of one variable on the other, a stepwise linear regression both forward selection and backward methods using both MINITAB and SPSS software have been used, and the following coefficients and level of significance determined. Hereunder, the Pearson correlation coefficient matrix is shown in Table 3.2.

Table 3.2: Matrix of Pearson Correlation Coefficient

Correlations

		CBR	PI	MDD	F	OMC	G	LL	PL	S
Pearson Correlation	CBR	1.000	-.743	.724	-.522	-.701	.672	-.713	-.537	.238
	PI	-.743	1.000	-.646	.306	.779	-.535	.811	.503	-.073
	MDD	.724	-.646	1.000	-.272	-.863	.685	-.824	-.769	-.036
	F	-.522	.306	-.272	1.000	.240	-.361	.199	.081	-.896
	OMC	-.701	.779	-.863	.240	1.000	-.640	.860	.729	.048
	G	.672	-.535	.685	-.361	-.640	1.000	-.653	-.592	-.091
	LL	-.713	.811	-.824	.199	.860	-.653	1.000	.914	.099
	PL	-.537	.503	-.769	.081	.729	-.592	.914	1.000	.196
	S	.238	-.073	-.036	-.896	.048	-.091	.099	.196	1.000
Sig. (1-tailed)	CBR		.000	.000	.002	.000	.000	.000	.001	.102
	PI	.000		.000	.050	.000	.001	.000	.002	.351
	MDD	.000	.000		.073	.000	.000	.000	.000	.426
	F	.002	.050	.073		.100	.025	.146	.334	.000
	OMC	.000	.000	.000	.100		.000	.000	.000	.401
	G	.000	.001	.000	.025	.000		.000	.000	.317
	LL	.000	.000	.000	.146	.000	.000		.000	.302
	PL	.001	.002	.000	.334	.000	.000	.000		.149
	S	.102	.351	.426	.000	.401	.317	.302	.149	

Based on Table 3.2, using Pearson correlation coefficient and the significance level of the parameters, there is a linear relationship between CBR and liquid limit, plasticity index and maximum dry density, optimum moisture content, and gravel content has a relatively higher correlation coefficient with a significant value less than 0.05. The negative sign (-) before the Pearson coefficient indicates that the assumed parameters have the opposite effect on the other parameters. For instance, the correlation coefficient between CBR and PI it is negative 0.743. That means for 1- unit increase in the value of PI, the response will be 74.3% decrease in the value of CBR. The strength of fine-grained soil has a greater association with the consistency of the soil. As a result, liquid limit and plasticity index has occurred from relatively a better relationship with the strength parameter.

However, the correlation with plastic limit shows relatively a weak relationship, this is may be due to the inconsistency in conducting laboratory plastic limit test and inadequacy of the number of trials considered in the trial procedures. Besides, in this research work, the percentage of gravel content and maximum dry density has resulted from relatively higher positive correlation coefficient with the strength parameter for fine-grained soil, this is due to the presence of more silty soils and some granular materials blended with the fine soils.

3.1.2.1 Single Linear Regression Analysis

Model A- 1: Correlation Between CBR and Percentage of Fine (F)

Based on the resulting regression analysis for correlating CBR with F is expressed by the following single linear equation with its corresponding correlation coefficients:

$$CBR = 8.849-0.55F \quad (3)$$

With R^2= 0.272, for N=30

Model A- 2: Correlation Between CBR and Percentage of Sand (S)

Based on the resulting regression analysis after correlating CBR with sand content (s), it is observed that the result is statistically not significant (α>0.05)

Error! Bookmark not defined.with R^2=0.057, for N=30

Model A- 3: Correlation Between CBR and Percentage of Gravel (G)

After correlating CBR with a percentage of gravel, the following relationship developed. It is observed that the correlation coefficient is positive. It indicates there is a positive relationship between them. Even though the soil under study is mainly fine-grained soil, there might be a granular soil blended during sampling since it is extracted from the road subgrade. The correlation developed is presented below.

$$\mathbf{CBR = 4.201 + 0.159G} \quad (4)$$

With, R^2=0. 451, for N=30

Model A- 4: Correlation Between CBR and Plastic Limit (PL)

Based on the resulting regression analysis for correlating CBR with PL, it is observed that the best fit between CBR and PL is using linear polynomial regression and the result obtained is presented below.

$$\mathbf{CBR = 37.696 - 3.133PL + 0.094PL^2 - 0.001PL^3} \quad (5)$$

With R^2=0. 627, for N=30

The details of the statistical output indicate that the relationship developed between fine content (F) and CBR are significant (α<0.05).

Model A- 5: Correlation Between CBR and Plasticity Index (PI)

The resulting regression analysis after correlating CBR with PI is expressed by the following Quadratic Linear Regression Model with its corresponding correlation coefficients:

$$\mathrm{CBR} = 17.227\text{-}\ 0.867{*}\mathrm{PI} + 0.013\mathrm{PI}^2 \quad (6)$$

With, R^2= 0.682, for N = 30

The details of the statistical output indicate that the relationship developed between PI and CBR is significant (α<0.05).

Model A- 6: Correlation Between CBR and Liquid Limit (LL)

The resulting regression analysis after correlating CBR with LL is expressed by the following two linear equations which are almost approaching each other and the corresponding correlation with coefficients presented below.

$$\mathbf{CBR = 21.125 - 4.182\ Ln(LL)} \quad (7)$$

With R^2=0.543

And $$\mathbf{CBR = 8.967 - 0.081LL} \quad (8)$$

With R^2=0. 503; for N=30

The details of the statistical output indicate that the relationship developed between LL and CBR is significant in both cases (α<0.05).

Model A- 7: Correlation Between CBR and Maximum Dry Density (MDD)

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

$$\mathbf{CBR = -6.087 + 7.029 * MDD} \quad (9)$$

With R2= 0.524, for N = 30

The details of the statistical output indicate that the relationship developed between MDD and CBR is significant (α<0.05)

Model A- 8: Correlation Between CBR and Optimum Moisture Content (OMC)

The resulting regression analysis after correlating CBR with OMC is expressed by the following Quadratic Linear Regression Equation with its corresponding correlation coefficients:

$$\mathbf{CBR = 18.369 - 0.934OMC + 0.015OMC^2} \quad (10)$$

withR^2=0.582, for N=30

The details of the statistical output indicate that the relationship developed between OMC and CBR is statistically significant (α<0.05).

From the above developed single linear regression models, based on the significant standard error (α) and coefficient of determination (R^2). It was found out that the CBR value correlates relatively better with Gravel content, Optimum moisture content, Liquid limit, Plasticity index, Plastic limit and Maximum dry density, which is an indication of these variables to form the multiple regression variables that could yield a better correlation result. While the remaining parameters showed a weak relationship with CBR.

3.1.2.2 Multiple Linear Regression Analysis

On the other hand, to develop multiple linear regression models for the study, stepwise regression analysis is used using commercially available software MINITAB, SPSS and MICROSOFT EXCEL (Analysis tool pack VBA). After going through some alternative combinations of predictors, the following correlation results are obtained as presented below:

Model B-1: Correlation Between CBR with and Grain Size Analysis

The resulting regression analysis after correlating CBR with Percentage of gravel (G), a percentage of sand (s) and proportion of fine (F) is expressed by the following multiplicative linear equations with its corresponding correlation coefficients:

$$\mathbf{CBR = 0.121G + 0.068S + 0.034F} \tag{11}$$

With R2=0. 956, R2=0. 916, for N=30

The details of the statistical output of the Model A indicates that the relationship developed between CBR with grain size analysis is significant (α<0.05) and all predictor variables are significant (α<0.05). Besides, the R2 value of the multiple regression analysis is better than the R2value of the individual parameters. For instance, the prediction capacity of sand on single linear analysis was not significant but now has become significant when combined with parameters F and G.

Model B-2: Correlation Between CBR with Atterberg Limit

The resulting regression analysis after correlating CBR with Atterberg limit (PI, LL, and PL) was found to be not significant (α<0.05). The individual, predicting capacity for single linear regression analysis is now changed, which may be a combination effect of the other parameter. The only significant term while combining PI with PL and PI with LL is PI. The relationship using PL and LL is also not important. The statistical output of Model B indicates that the relationship developed between CBR with PI and LL, LL and PL, and PL and LL is not significant. Because α values of the individual predictor are not highly important rather than PI.

Model B-3: Correlation Between CBR with Compaction Parameters

The resulting regression analysis after correlating CBR with optimum moisture content and maximum dry density are expressed by the following multiple linear equations with its corresponding correlation coefficients:

$$\mathbf{CBR = 4.450MDD - 0.086OMC} \tag{12}$$

With R^2=0. 957 and Adj. R^2=0.920, N=30

The details of the statistical output of Model B-3 indicates that the relationship developed between CBR with OMC and MDD is significant (α<0.05) for both predictors. Besides, the R2 value of single linear regression analysis is also improved for the developed multiple regression models using MDD and OMC.

Model B-4: Correlation Between CBR with Grain Size Analysis, Atterberg Limit and Compaction Parameters (G, F, S, LL, PI, PL, OMC, and MDD)

After going through a number of alternative combinations of predictors from Grain size analysis, compaction parameters, and Atterberg limit the following correlation results are obtained , and The resulting regression analysis after correlating CBR with LL, PL, PI, OMC, G, S, F and MDD which are significant are summarized as shown in Table 3.3.

Table 3.1: The developed correlation of CBR and Index properties of soil

Model No.	Predictors	Equation Developed	R^2	Adj. R^2	Standard Deviation
B-4-1	F, MDD, PI	CBR=5.34MDD-0.026F-0.069PI	0.973	0.933	0.885
B-4-2	F, MDD, PI	CBR=3.591-0.031F+3.707MDD-0.098PI	0.731	0.701	0.873
B-4-3	S, LL	CBR=0.084S+0.048LL	0.798	0.756	2.374

B-4-4		CBR=8.329+0.035S-0.084LL	0.604	0.575	1.039
B-4-5	MDD, PI	CBR=4.634MDD-0.102PI	0.967	0.93	0.973
B-4-6		CBR=1.15+4.069MDD-0.114PI	0.653	0.628	0.972
B-4-7	S, OMC	CBR=8.974+0.036S-0.201 OMC	0.564	0.532	1.089
B-4-8		CBR=0.150S +0.114OMC	0.817	0.775	2.263
B-4-9	G, OMC	CBR=0.15G+0.258OMC	0.903	0.864	1.643
B-4-10		CBR=7.59-0.129OMC+0.89G	0.575	0.543	1.07
B-4-11	G, S, OMC	CBR=6.75+0.033S-0.128OMC+0.097G	0.662	0.623	0.97
B-4-12		CBR=0.054S+0.102 OMC+0.239G	0.927	0.884	1.45
B-4-13	MDD, F	CBR=5.171-0.044F	0.965	0.962	0.990

From the above results, the following correlation that is fitted with constant (intercept) are grouped in the same category and the other relationships without including intercept grouped in the other category. Based on the coefficient of determination and standard error the following equations selected with the R^2 decreasing order for models fitted with including intercept:

1. $\mathrm{CBR} = 3.591 - 0.031\mathrm{F} + 3.707\mathrm{MDD} - 0.098\mathrm{PI}$ (13)
   With with R^2 = 0.73
2. $\mathrm{CBR} = 6.75 + 0.033\mathrm{S} - 0.128\mathrm{OMC} + 0.097\mathrm{G}$ (14)
   With R^2 = 0.662
3. $\mathrm{CBR} = 1.15 + 4.069\mathrm{MDD} - 0.114\mathrm{PI}$ (15)
   With R^2 = 0.653
4. $\mathrm{CBR} = 8.329 + 0.035\ \mathrm{S} - 0.084\mathrm{LL}$ (16)
   With R^2 = 0.604
5. $\mathrm{CBR} = 7.59 - 0.129\mathrm{OMC} + 0.89\mathrm{G}$ (17)
   With R^2 = 0.575
6. $\mathrm{CBR} = 0.15\mathrm{G} + 0.258\mathrm{OMC}$ (18)
   With R^2 =0.564

From models fitted without intercept model B-4-1, B-4-5, and model B-3 takes one to the third rank. From those models, Model B-4-1 without intercept and model B-4-2 with intercept is selected.

3.2 Results and Discussion

3.2.1 The Developed Correlation

From the regression analysis, it is observed that multiple linear regression has a relatively good coefficient of determination than single linear regression analysis. Two models selected from the developed correlation that has a higher coefficient of determination and based on relative significance order using standard error for further verifications.

The selected models are:

Model B-4-1

$$\mathbf{CBR = 5.34MDD - 0.026F - 0.069PI} \quad (19)$$

With R2 =0.973 and standard error =0.885

Model B-4-2

$$\mathbf{CBR = 3.591 - 0.031F + 3.707MDD - 0.098PI} \quad (20)$$

With R2=0.731 and standard error =0. 873)

Both equations contain grain size distribution parameters (F), compaction parameter (MDD), and Atterberg limit parameter (PI). The difference between this two model is the method of data fitting used. The first model is fitted without including the constant (intercept), while the latter includes. The validation of the correlation developed with the actual test data was studied and presented in Table 3.4.

Table 3.4: Validation of CBR from Relationship Developed With The Actual Test Data

Sample code	G	S	F	PI	MDD	OMC	CBR	CBR From Model B-4-1	CBR From Model B-4-2
AR01	2	8	90	18	1.61	21.9	4.5	5.02	5.01
BO03	6	22	72	17	1.71	18.5	6.4	6.09	6.03
BS01	0	17	83	32	1.48	26.2	3.4	3.54	3.37
DE02	0	46	54	28	1.64	27.4	5	5.42	5.25
DO10	0	16	84	39	1.53	26.5	2.8	3.30	2.84
RE-18	16	22	62	14	1.9	17.2	8	7.57	7.34
DO22	13	29	58	17	1.8	17.4	5.4	6.93	6.80
EM02	2	11	87	20	1.58	20.7	4.3	4.80	4.79
FE01	4	14	82	16	1.69	19.2	6.8	5.79	5.75
GE01	0.3	7.6	92.3	32	1.3	36.8	2.5	2.33	2.41
GU01	0	13.6	86.4	26	1.46	32	3.8	3.76	3.78
GU02	0	43.7	56.7	19	1.53	22	6.7	5.39	5.64
HO01	17	13	70	16	1.7	17.9	7.1	6.15	6.15
HO02	12	16	72	17	1.72	18.4	6.5	6.14	6.07
KE-02	3.2	36.4	60.45	27	1.23	32.8	4	3.13	3.63
KB01	0.2	29	70.8	23	1.37	29.5	5.6	3.89	4.22
JO-20	0	35	65	37	1.41	33	4.4	3.29	3.18
LR01	0	4.1	95.9	28	1.44	26	4	3.26	3.21
LR20	26	17	57	19	1.7	17.6	7	6.29	6.26
WE01	0	27	73	21	1.49	26.3	5	4.61	4.79
WE20	0	42	58	22	1.38	28	4.5	4.34	4.75
NF04	0	59	41	20	1.54	25.5	4.3	5.78	6.07
NF05	8	14	78	21	1.6	21.2	3.5	5.07	5.05
MU01	2	11	87	20	1.6	20.6	4.2	4.90	4.87
SE01	1	9	90	22	1.6	22	3.7	4.69	4.58
SE02	13	46	41	17	1.9	14.6	8	7.91	7.70
SE28	0	41	59	21	1.39	20.9	4.2	4.44	4.86
DO-11	0	15	85	20	1.6	20	5.4	4.95	4.93
TS20	0	19	81	33	1.46	27.7	2.8	3.41	3.26
TS4	0	15	85	30	1.39	30	2.2	3.14	3.17

In addition to the above tabular comparison, a scatter plot of the actual CBR Versus the two chosen model is done using commercially available software MINITAB and the output is shown in the following consecutive figures.

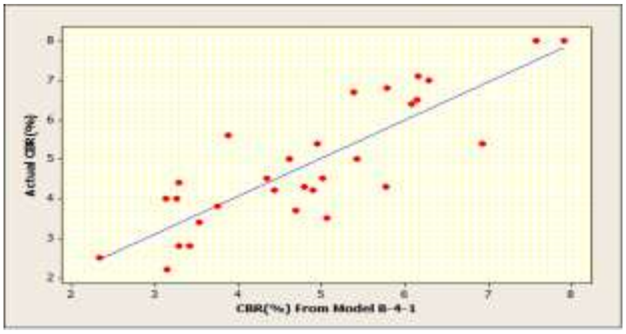

Figure 3. 1: Scatter diagram of CBR versus gravel content of the tested soil samples

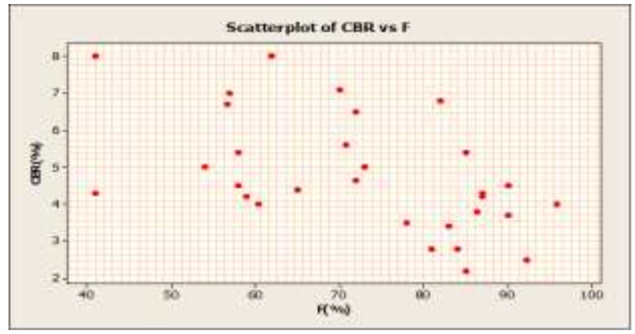

Figure 3. 2: Scatter diagram of CBR versus fine content of the tested soil samples

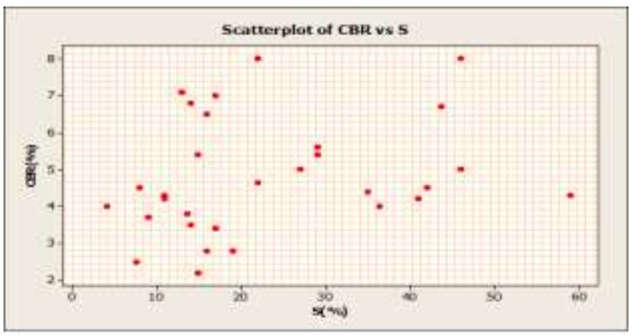

Figure 3. 3: Scatter diagram of CBR versus sand content of the tested soil samples

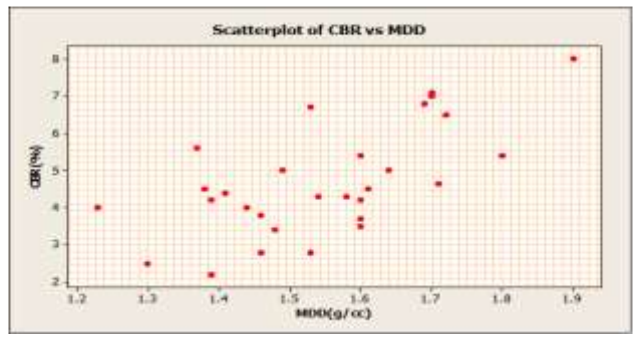

Figure 3. 4: Scatter diagram of CBR versus MDD of the tested soil samples

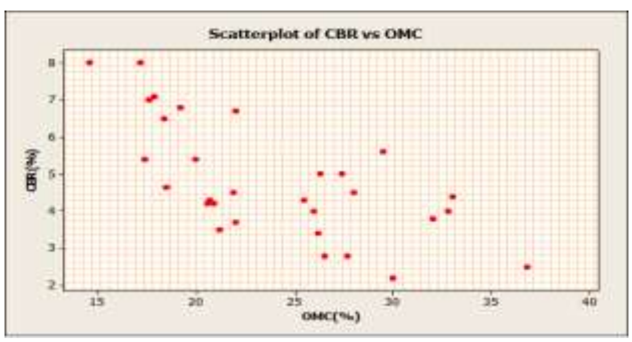

Figure 3. 5: Scatter diagram of CBR versus OMC of the tested soil samples

The first two numbers were drawn to relate as an individual effect to CBR. While the latter is drawn from comparing side by side if the relationship is valid. The statistical output from MINITAB indicates the Model B-4-2 perform well in fitting the actual CBR with a coefficient of determination (R^2=73. 4%), while model B-4-1 fits with R^2=71. 2. %. From these results, it can be concluded that Model B-4-2 is better in representing the subject under study. Hence, from now on the discussion on the next parts are based on this model. To clarify this, the linear relationship between the developed and actual CBR is given below by the following equations:

$$\textbf{Actual CBR} = \mathbf{0.0132 + 0.9990} \text{ Predicted CBR from Model B} - 4 - 2 \quad (21)$$

withR^2 = 0.734

$$\textbf{Actual CBR} = \mathbf{0.1894 + 0.9657} \text{ Predicted CBR from Model B} - 4 - 1 \quad (22)$$

With R^2 =0. 712

3.2.2 Evaluation of the Developed Relationship

3.2.2.1 Evaluation of the Developed Correlation with Control Tests

In this study, about seven separate control samples prepared and tested in the laboratory to check the suitability of the model developed from other soil samples extracted from the road under study other than using the example used in model development. The control samples, laboratory result details, and the CBR obtained from the developed model is given in the following table. For more clarification graphical comparison of the CBR value of the model developed and the actual CBR is also shown below following the table.

Table 3.5: Evaluation of the Developed Relationsgip with Control Tests

Sample code	G	S	F	PI	MDD	OMC	CBR	CBR From Model B-4-2	VARIATION %
cs1	13	41	46	37	1.405	31.7	4.8	3.75	/-21.93/
cs2	8	39	53	23	1.523	23.2	2.9	5.34	84.13
cs3	7	40	53	26	1.38	33.3	7.9	4.52	/-42.84/
cs4	2	16	82	17	1.703	19.2	3.7	5.70	53.95
cs5	22	18	60	15	1.8	16.9	5.7	6.93	21.64
cs6	0	9	91	25	1.51	25.1	3.2	3.92	22.42
cs7	1	15	84	43	1.535	19.8	3.4	2.46	/-27.55/
Average(%)		39.2							

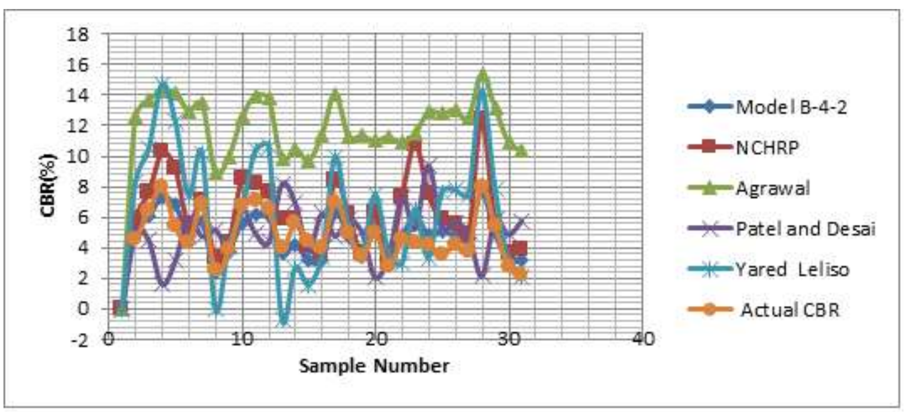

Figure 3.6: Graphical comparison of CBR of control samples with CBR from developed model

As shown in Figure 3.6, it can be concluded that the control samples actual CBR have 12.83% variation from the newly developed model CBR value. This shows the new design may approximate the value of CBR with the lesser error for rough estimation for the soils that have the same range of Atterberg, compaction and gradation values which are used in the correlation development.

In dealing the soil samples used in model development, the newly developed model B-4-2 have a CBR value with a variation of 3% compared to actual CBR value. Next model B-4-2, Patel and Desai 2010 [6], YaredLeliso [7], NCHRP's have a relatively good relationship to the Actual CBR. However, CBR predicted from Agrawal [20] is higher than the actual. It is magnified about 170%; it almost entirely overestimates the actual CBR value. Even though this CBR is greater, it almost exactly follows the trend line of actual CBR. Both Patel and NCHRP have a real relationship to actual CBR regarding following the trend line of actual CBR. However the CBR predicted from Yared [4] fluctuates much even though the average variation found to be 27%, the NCHRP's, correlation resulted from an average variation of 33% from the actual CBR values. Similarly, Patel [6] relationship resulted from average difference of 20%.

As observed above, the predicted CBR from Yared [7] correlation shows about three samples have negative value. This is may be due to the difference in test procedures and also the unique properties of the geological material where this correlation was developed. In light of the above, it is worth to note that the test results obtained from the subject study area are relatively situated better to Patel and Desai 2010 [6] in addition to developed correlation. There is a correlation of the above-discussed model other than Agrawal [3], after which it followed the trend line showing a very high CBR value.

3.2.2.2 Evaluation of the Development and Existing Relationships

The suitability of existing relationships particularly YaredLeliso [7] for a CBR value of 2.2% to 10%, NCHRP's correlation for plastic soils and more than 12% fines passing the 0.075 mm sieve. While, Agarwal and Ghanekar's fine grained soil, Patel and Desai 2010 [6], were chosen in this study because it will perform well for Ethiopian soil as reviewed by Kumar et al. (2014) [4]. Therefore, in this study, the comparison of calculated results of the correlations which are obtained by using the test results are shown in Table 3.6.

Table 3.6: Comparison of calculating result of different correlation methods

Sample No.	Actual CBR	CBR B-4-2		NCHRP[7]		Agarwal and Ghanekar,1970)[20]		(Patel &Desai,2010)[21]		Yared Leliso, 2013[4]	
		Pridicted CBR	variation(%)	Pridicted CBR	variation(%)	Pridicted CBR	variation(%)	Pridicted CBR	variation(%)	Pridicted CBR	variation(%)
1	4.5	5.01	11.23	5.86	30.22	12.58	179.58	5.25	16.66	8.27	83.84
2	6.4	6.03	-5.75	7.57	18.24	13.75	114.84	4.51	-29.49	10.45	63.27
3	8	7.34	-8.25	10.25	28.09	14.25	78.16	1.62	-79.70	14.72	84.02
4	5.4	6.80	25.92	9.17	69.83	14.18	162.51	3.16	-41.46	12.27	127.24
5	4.3	4.79	11.42	5.49	27.62	12.97	201.70	6.00	39.46	7.39	71.83
6	6.8	5.75	-15.50	7.11	4.53	13.49	98.39	4.77	-29.92	10.19	49.81
7	2.5	2.41	-3.49	3.33	33.32	9.01	260.21	5.18	107.16	-0.05	-102.11
8	3.8	3.78	-0.61	4.32	13.73	9.96	162.13	4.21	10.82	4.07	7.22
9	6.7	5.64	-15.78	8.48	26.59	12.56	87.46	6.63	-1.07	6.47	-3.41
10	7.1	6.15	-13.31	8.19	15.40	13.98	96.87	4.98	-29.89	10.39	46.34
11	6.5	6.07	-6.63	7.57	16.42	13.79	112.11	4.36	-32.99	10.65	63.87
12	4	3.63	-9.23	5.82	45.55	9.79	144.68	8.19	104.77	-0.71	-117.75
13	5.6	4.22	-24.63	5.83	4.19	10.52	87.86	6.95	24.12	2.69	-51.96
14	4.4	3.18	-27.80	4.05	-7.90	9.75	121.56	3.82	-13.21	1.55	-64.79
15	4	3.21	-19.70	3.65	-8.75	11.41	185.27	6.25	56.23	3.37	-15.87
16	7	6.26	-10.52	8.44	20.60	14.10	101.42	4.79	-31.55	9.96	42.30
17	5	4.79	-4.13	6.17	23.35	11.32	126.38	5.87	17.38	5.39	7.75
18	3.4	3.37	-0.93	3.69	8.47	11.35	233.94	5.06	48.95	3.64	7.12
19	5	5.25	5.05	6.25	24.92	11.04	120.72	2.06	-58.76	7.46	49.18
20	2.8	2.84	1.31	3.02	7.79	11.28	302.70	3.38	20.78	3.69	31.87
21	4.5	4.75	5.61	7.29	61.98	10.89	142.05	7.32	62.62	2.99	-33.61
22	4.3	6.07	41.13	10.76	150.26	11.53	168.25	5.27	22.54	6.53	51.95
23	4.2	4.86	15.64	7.49	78.22	12.92	207.59	9.41	124.06	3.35	-20.21
24	3.5	5.05	44.18	5.80	65.80	12.81	265.94	5.37	53.55	7.65	118.67
25	4.2	4.87	15.84	5.49	30.66	13.01	209.69	5.65	34.57	7.79	85.56
26	3.7	4.58	23.68	4.87	31.50	12.55	239.28	5.03	36.08	7.50	102.82
27	8	7.70	-3.78	12.35	54.34	15.39	92.44	2.15	-73.18	14.30	78.70
28	5.4	4.93	-8.76	5.61	3.83	13.21	144.67	5.84	8.09	7.79	44.32
29	2.8	3.26	16.37	3.67	30.92	10.96	291.46	4.88	74.46	3.13	11.69
30	2.2	3.17	44.03	3.83	74.25	10.41	373.03	5.77	162.26	2.12	-3.58
Average(%)			2.75		32.80		170.43		20.11		27.20

4 CONCLUSION

The research conducted to study the correlation between California bearing ratio (CBR) value and index properties of soil. To achieve the objectives of the study, soil samples retrieved from different areas along Welkite-Arekit- Hosana road of Southern Nation Nationalities Peoples and Regional State of Ethiopia. About thirty samples extracted from the road section and different laboratory tests were carried out. Using this test result, a statistical analysis was used. A single and multiple linear regressions were applied, and a relationship was developed that would predict the CBR values of soil regarding percentage of fine (F), Sand (s), gravel content (G), LL, PL, PI, MDD, and OMC. From the results of this study, the following conclusions are drawn:

- From the single linear regression, it was observed that the effect of fine, plasticity index, liquid limit, plastic limit and optimum moisture content have an adverse effect on CBR. This means if fine content, liquid limit, plastic limit, plasticity index, optimum moisture content tends to increase, the CBR value also tends to decrease.
- While the increase in maximum dry density and percentage of gravel content revealed a positive effect on CBR value. For instance, if MDD or G increases, the CBR value tends to increase.
- Among the single linear regression analysis, the correlation between CBR value and plasticity index has a better relationship than other predicting parameters which is expressed in the following equations:

$$CBR = 17.227 - 0.867 * PI + 0.013PI^2 \quad (23)$$

With R2 = 0.682 For N = 30

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

$$CBR = 3.591 - 0.031F + 3.707MDD - 0.098PI \quad (24)$$

withR2 = 0.731, n=30

• In addition to the above, a combination of soil index properties (grain size analysis, Atterberg limit, and compaction parameters) correlates better than individual soil properties.

• From independent parameters (predictors) F, MDD, and PI show better relationship when combined in predicting CBR value.

• For preliminary design purpose, the high correlation could be used, if the range of soil samples under considerations is within the range of data used in this study, in determining CBR values from the study parameters. Otherwise, a detailed laboratory test should be carried out to obtain the actual CBR value.

•From existing correlations by Patel and Desai 2010 [6], NCHRP [7] demonstrated a better estimation, and followed the trend line of actual CBR value, while correlations by Agrawal [3] showed overestimation.

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