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Empirical Correlation of Hossaena Town Soil Index Properties with California Bearing Ratio (CBR) Values

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ABSTRACT

California bearing ratio (CBR) is a key input factor in pavement structural design that is used to determine character size, the strength of unbound materials, and subgrade soils. The construction of a straightforward and logical regression model to forecast the CBR of unbound materials as a function of the index properties of the material. This work explains the relationship between compaction parameters and Atterberg limit tests. A laboratory test was conducted to get the independent (percent finer, liquid limit, plastic limit, plastic index, maximum dry density, and moisture content), and dependent variables (CBR). A statistical package for social science software (SPSS) used to develop the mathematical model both in single and multiple regression. The viability of using multiple linear regression analysis to relate CBR values to soil index features was investigated. In this study, SPSS is used to examine each independent variable's significance individually. The multiple linear regression analysis was used to create the correlation, which had an eighteen-person sample size and a modest determination coefficient of R2 = 0.821. The CBR has a good relation with maximum dry density and optimum moisture content compared to other parameters. This model is applicable for small structures in the specified soil type, MH.

1. Introduction

California Bearing Ratio (CBR) is a popular and thorough test used in pavement design nowadays to evaluate the stiffness modulus and shear strength of subgrade material to establish the thickness of underlying pavement layers (Abdella et al., 2017; Patel & Desai, 2010). The soil type is different from the Welkitie to Hossaena road section, so civil engineers always struggle to obtain representative CBR values for the design of pavement in road construction from Welkitie to Hossaena road project, but it only covers the road section and this study only covers the road in the town of Hossaena (Abdella et al., 2017). The CBR value is affected by several factors, including the kind of soil, but also by the various soil properties that the soil possesses (George, 2004). The values of CBR differ when the soil types are different at two different locations (Jafer et al., 2016; Omar, 2017). The CBR compares the strength of subgrade, sub-base, and base course materials to the strength of typical crushed rock and is expressed as a percentage number (González Farias et al., 2018; Waqas & Ahmed, 2020). The laboratory CBR test is time-consuming and requires a fair amount of work to conduct. The alternative approach can involve correlating CBR with simpler test outcomes like soil index features (Janjua & Chand, 2016).

Compared to the CBR test, these tests are far more affordable and efficient. In order to obtain a link between CBR values and soil index parameters suitable for Hossaen subgrade soil, this work provides an outline. According to earlier studies and analyses of the soil in Hossaena town, clay soil predominates as a natural subgrade soil there (Anil et al., 2023; BIRHAN-MESKEL, 2020). The development of the anticipated correlation for a varied distribution of acceptable sub-grade soils, notably non-expansive fine-grained soils, which characterize the study area, is therefore the emphasis of this study (BIRHAN-MESKEL, 2020; Cabalar & Karabash, 2014; Katte et al., 2019a).

The output of the proposed correlation will give road authorities, consultants, and contractors preliminary background information on the value of CBR, for a localized subgrade material, from soil index properties with the benefit of saving time and without incurring any additional costs for performing laboratory CBR tests. Currently, many infrastructure projects and railway constructions are underway in the nation (Khasawneh et al., 2022).

When planning and building infrastructure projects like bridges, highways, airports, seaports, and railroads, soil characterization is a great resource (Ghanizadeh & Rahrovan, 2019). Construction engineering research is interested in accurate predictions of soil's engineering behavior since soil is variable in shape and character (Mishra & Tegar, 2019). The number of representative samples that are taken relies on how accurately the engineering behavior of soils can be predicted because it changes from location to location and even over time (Kadhim, 2014).

For the design of flexible pavements and runways at airports, CBR value is a crucial soil characteristic (Datta & Chottopadhyay, 2011). By employing correlation, it may also be utilized to determine the modulus of soil's subgrade reaction (Bassey et al., 2017). It is among the most crucial engineering characteristics of soil for the proposed roads' design subgrade. Maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), plastic limit (PL), plasticity index (PI), type of soil analyzed, soil permeability, and soil shear strength are just a few of the variables that may affect a soil's CBR rating (Mousavi et al., 2021).

Additionally, whether the soil is wet or dry affects the value which means the CBR value decreases when the moisture content is above optimum moisture content and the dry density is below maximum dry density its value also decreases (Bassey et al., 2017). The procedure of determining CBR is quite drawn-out, difficult, and time-consuming. There is no properly calibrated laboratory equipment used in Hossaen to calculate the California Bearing Ratio (Mousavi et al., 2021). Therefore, this study develops empirical Correlations between LL, PL, PI, OMC, and MDD (Patel & Desai, 2010).

This model will help to construct infrastructure without doing laboratory tests only for the selected and the classified soil type in the laboratory during the development of the empirical correlation of CBR values.

The study is concerned with conducting localized research, particularly on samples that are recovered from Hossaena town for achieving the objective of the study, different laboratory tests that possibly influence CBR values were carried out on eighteen samples collected the Hossaena town. This research was used to find the value of CBR for small structures like gravel roads and cobble stones. Some literature empirical correlation of CBR with other index tests is given in Table 1. The main objective of this study is to establish a correlation between the California Bearing Ratio with soil index properties and compaction parameters for representative soil samples recovered from different localities of Hossaena.

2. Materials and Methods

To have sufficient and reliable data for the target analysis, laboratory tests were conducted on soil samples obtained from different localities of Hossaana town. All samples are collected by the excavation of the existing road on the right and left sides of the roads at a depth of a minimum of one and a half meters. Eighteen disturbed samples were gathered within an interval of the one-kilometer sampling interval.

Sampling Procedure: Based on the sample retrieved from the site, Laboratory tests on eighteen samples were conducted in Jimma Industrial Park. Accordingly, the following tests have been performed: Sieve analysis (AASHTO T27), Atterberg limit test (AASHTO T89-90), Compaction test (modified proctor test AASHTO T180 D), and California bearing ratio test (AASHTO T193).
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 of material finer than the No. 200 sieve cannot be achieved by using this method alone. Therefore, test method 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.

Table 1. Some Empirical equations of CBR with index tests

Equation	R^2	Country	Reference
$CBR_s=0.767(CBR_{us})^{0.9362}$	0.9174	Bangladesh	(Ahmed et al., 2016)
CBR=11.969(MDD)-0.1807(OMC)+0.1274(P075)-0.2048(P425)	0.8000	Sri Lanka	(Jayamali & Nawagamuwa, 2015)
CBR=-175.006+99.869*MDD	0.772	Congo	(Katte et al., 2019b)
CBR=4.3408-(0.0427*LL) +(0.0085*PI)	0.799	India	(Korde & Yadav, 2015)
CBR=8.76D60+10.834	0.860	Pakistan	(Ul-Rehman et al., 2015)

Atterberg limit tests were carried out according to AASHTO T 89 for the determination of the liquid limit of the soil and AASHTO T 90 was used for the determination of the plastic limit of the soil. Before the test is undertaken, the sample is made to pass the 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 was conducted as per AASHTO T 180 D, through which samples were compacted at five layers each compacted by 56 uniform blows using a 4.54 kg weight of the hammers. From the modified proctor test, after plotting the moisture-density curve, a range of maximum dry density along with the optimum moisture content was 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. Data Processing and Analysis: For data processing and analysis of this work, Microsoft Excel and, a statistical package for social science software (SPSS) is employed to investigate the significance of individual regressor variables.

3. Results

3.1 Regression Analysis

After laboratory tests, the soil was classified as an MH group according to the Unified soil classification system, which contains sandy silt, clayey silts, and inorganic silts, with relatively low plasticity. According to AASHTO soil classification, A-7-5 (28), A-7-5(25), A-7-5 (24), A-7-5(24), A-7-5 (27), A-7-5(26), A-7-5 (21, A-7-5(23), A-7-5 (20), A-7-5(22), A-7-5 (27), A-7-5(28), A-7-5 (9), A-7-5(13), A-7-5 (11), A-7-5(12), A-7-5 (20), A-7-5(27). The value in the bracket indicates the material strength indicator. When greater than zero, its strength decreases.

In this research work, an attempt is made to apply a 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 statistical analysis is shown in Table 2. For determining the influence of one variable on the other, a stepwise linear regression both forward selection and backward methods using SPSS software has been used and the following correlation coefficients and level of significance determined. Hereunder, the Pearson correlation coefficient matrix is shown in Table 3.

Based on the above correlation result, using the Pearson correlation coefficient and significance level of the parameters, there is a linear relationship between CBR and liquid limit, plasticity index, maximum dry density, optimum moisture content, and gravel content has a relatively higher correlation coefficient with significance 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 reason correlation coefficient between CBR and PI it is negative 0.758.

That means for a one-unit increase in the value of PI, the response will be a 75.8 percent decrease in the value of CBR based on this statistical result. The strength of fine-grained soil has a greater association with the consistency of the soil. As a result, the liquid limit and plasticity index have resulted in relatively a better correlation with the strength parameter. However, the correlation with plastic limit shows relatively a weak relationship, CBR values have good correlations with MDD and OMC but increasing the liquid limit and increasing the plastic limit affect the subgrade strength material. Besides, in this research work the percentage of gravel content and maximum dry density has resulted 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. some granular materials blended with the fine soils. Different alternatives and analysis procedures were used during data analysis to develop the correlation using regression methods. For this specific work linear regression analyses that best fits the obtained test results have been considered.

3.3.1 Single Linear Regression Analysis

Model A-1: Correlation Between CBR and Percentage of Finer (P200)

Based on the resulting regression analysis for correlating CBR with F is expressed by the following single linear equation with its corresponding correlation coefficients: For all equations, N means number of samples, and P200 mean percent passing in sieve number 200. MDD in g/cc and CBR, OMC, P200, LL, PL, and PI in %.

$$CBR=28.46-0.282*P200, \text{ with } R2=0.268 \quad (1)$$

The negative sign indicates that if the percentage of fine content increases the value of CBR tends to decrease. The details of the statistical output indicate that the relationship developed between fine content(P200) and CBR is significant ($\alpha<0.05$).

Model A-2: Correlation Between CBR and Liquid Limit (LL).

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

$$CBR=12.736-0.143*LL, \text{ with } R2=0.485 \quad (2)$$

The positive sign indicates that if the Plastic limit increases the value of CBR tends to increase. The details of the statistical output indicate that the relationship developed between the Plastic Index (PI) and CBR is significant(α>0.05). The negative sign indicates that if Liquid Limit increases the value of CBR tends to decrease. The detail of the statistical output indicates that the relationship developed between Liquid Limit (LL) and CBR is significant (α<0.05).

Model A-3: Correlation Between CBR and Plastic Limit (PL)

Based on the resulting regression analysis for correlating CBR with Plastic limit is expressed by the following single linear equation with its corresponding correlation coefficients: The model is shown in Table 4.

CBR=-1.276+0.173*PL, with R2=0.0.118 (3)

Where df is degree of freedom, R is Pearson's coefficient of relation, F is F test

Model A-4: Correlation Between CBR and Plastic Index (PI)

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

CBR=7.783-0.141*PI, with R2=0.575 (4)

The negative sign indicates that if Plastic Index increases the value of CBR tends to decrease. The details of the statistical output indicate that the relationship developed between the Plastic Index (PI) and CBR is significant (α<0.05). The model is shown in Table 5.

Table 2. Statistical Information of Dependent and Independent Variables

Types of Variables	Variable Name	Unit of measurement	No of Sample	Ranges		Mean	Standard Deviation
				Max.	Min.		
Dependent	CBR	%	18	3.2	6.7	4.65	1.24
	P_{200}	%	18	78.4	86.86	84.44	2.28
	LL	%	18	44	62	56.50	6.07
	PL	%	18	32	42	34.33	2.47
Independent	PI	%	18	7	29	22.16	6.69
	MDD	g/cc	90	1.34	1.75	1.59	0.11
	OMC	%	90	11.2	18.4	14.18	2.13

Table 3. Correlation Matrix of Pearson Correlation Coefficient

Pearson Correlation(R)	CBR	LL	PL	PI	P_{200}	MDD	OMC
CBR	1.000	-0.697	0.343	-0.758	-0.517	0.790	-0.174
LL	-0.697	1.000	-0.063	0.930	0.756	-0.544	0.572
PL	0.343	-0.063	1.000	-0.426	0.349	0.393	-0.325
PI	-0.758	0.930	-0.426	1.000	0.556	-0.639	0.638
P_{200}	-0.517	0.756	0.349	0.556	1.000	-0.311	0.306
MDD	0.790	-0.544	0.393	-0.639	-.311	1.000	-0.231
OMC	-0.174	0.572	-0.325	0.638	0.306	-0.231	1.000

Table 4. Model Summary

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.517[a]	0.268	0.222	1.099396	0.268	5.846	1	16	0.028

[a] Predictors: (Constant), Percent Passing

Table 5. Model Summary

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.790[a]	0.624	0.600	0.788197	0.624	26.502	1	16	0.000
a. Predictors: (Constant), Maximum Dry Density									

Table 6. Model Summary

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.758[a]	0.575	0.548	0.837776	0.575	21.620	1	16	0.000
[a.] Predictors: (Constant), Plastic Index									

The positive sign indicates that if maximum dry density increases the value of CBR tends to increase. The details of the statistical output indicate that the relationship developed between maximum dry density (MDD) and CBR is significant (α<0.05).

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

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

CBR=6.099-0.102*OMC, with R2=0.0.030 (5)

The negative sign indicates that if optimum moisture content increases the value of CBR tends to decrease. The details of the statistical output indicate that the relationship developed between optimum moisture (OMC) and CBR is significant (α>0.05).

3.3.2 Multiple Linear Regression Analysis

To develop multiple linear regression model for the subject study, stepwise regression analysis is used using commercially available software's SPSS. After going through several alternative combinations of predictors the following correlation results are obtained as presented below.

Model B-1: Correlation Between CBR with Atterberg Limit and Percent Finer

The resulting regression analysis after correlating CBR with the Atterberg limit (PI, LL, and PL) is found to be not significant for the assumed significant level(α<0.05). The individual predicting capacity on single linear regression analysis has now changed. that 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 significant. Therefore, the developed relationship is not presented here.

The statistical output

of Model B indicates that the relationship developed between CBR with PI and LL, LL and PL, and PL and LL are not significant. Because α values for individual predictors are not significant rather to PI. It is shown in Table 6.

Model B-2: Correlation Between CBR with Compaction Parameter and Percent Finer

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

The details of the statistical out-put of Model B-2 indicates that the relationship developed between CBR with MDD is significant (α<0.05) but not significant for optimum moisture content and percent finer.

Model B-3: Correlation Between CBR with Atterberg Limit, Compaction Parameter and Percent Finer

The resulting regression analysis after correlating CBR with optimum moisture content, plastic limit, plastic index, liquid limit, percent finer, and maximum dry density (among these predictors are only optimum moisture content, plastic index, and maximum dry density is significant). It is expressed by the following multiple linear equations with corresponding correlation coefficients.

CBR=4.426*MDD-0.142*PI+0.237*OMC, with R2=0.821 (6)

Table 7. Model Summary

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.790[a]	.624	.600	.788197	.624	26.502	1	16	.000
2	.856[b]	.732	.697	.686507	.109	6.091	1	15	.026
3	.906[c]	.821	.783	.581027	.089	6.941	1	14	.020
a. Predictors: (Constant), Maximum Dry Density									
b. Predictors: (Constant), Maximum Dry Density, Plastic Index									
c. Predictors: (Constant), Maximum Dry Density, Plastic Index, Optimum Moisture Content									

Table 8. Comparative of Laboratory soaked CBR and CBR from Mathematical Equation

Sample Code	MDD (g/cc)	PI	OMC (%)	CBR from LAB	CBR From Model
1	1.64	26	17.2	4.5	7.6
2	1.57	25	13.6	3.6	6.6
8	1.72	27	18.4	6.5	8.1
17	1.64	17	13	5.6	7.9
18	1.48	27	17	3.6	6.7
16	1.71	13	13.4	6.3	8.8
15	1.64	12	11.2	6.4	6.4
13	1.75	7	14.2	6.7	9.4

Table 9. Evaluation of the Developed Correlation with Control Tests

Sample Code	MDD (g/cc)	PI	OMC (%)	CBR from LAB	CBR From Model	Variation
CS1	1.57	33	14	5.10	5.58	9.41
CS2	1.48	36	13.6	4.20	4.66	10.95
CS3	1.65	28	13.5	5.25	6.53	24.38
CS4	1.58	25	14	5.10	6.76	32.54
CS5	1.41	30	17	4.90	6.00	22.44
CS6	1.62	30	13.4	5.20	6.08	16.92
CS7	1.55	25	14	5.50	6.62	20.36
CS8	1.55	20	14.2	6.15	7.38	20
					Average (%)	19.6

4. Discussion

4.1 The Developed Correlation

Based on this result, a correlation of CBR with index properties of the soil (LL, PL, PI, MDD, Percent of Fines, and OMC) was developed using statistical regression (Barham et al., 2020). Based on the trends of the scatter plot of test results the correlation was analyzed using a linear regression model. The proposed correlation is carried out by applying a single linear regression model and multiple linear regression models with the help of Microsoft Excel and SPSS Software (Shakoor & Barefield, 2009). Different alternatives have been tried with the help of stated software (Arslan et al., 2008).

From the regression analysis it is observed that multiple linear regression has fairly good coefficient of determination than single linear regression analysis. Different scholars underscore the use of CBR for different projects is vital(Patel et al., 2023). To get this value laboratory tests, and field tests are the major ones but other correlation is good to with factors of CBR like MDD, OMC, PL, PI, Soil type, LL, and percent finer(Janjua & Chand, 2016; Khatti & Grover, 2023). This developed model is used for similar soil types and small structures. One model selected from the developed correlation has have higher coefficient of determination and is based on relative significance order using standard error for further verifications.

The selected model is Model B-3 CBR=4.426*MDD - 0.142*PI + 0.237*OMC, with R2=0.821, Adj.R2=0.783). This model contains Atterberg limit parameters and compaction parameters. It is shown in Table 7. The comparable results from the mathematical model and soaked CBR value are shown in Table 8.

4.2 Evaluation of the Developed Correlation

4.2.1 Evaluation of the Developed Correlation with Control Tests

In this work about eight separate control samples were prepared and tested in the laboratory to check the suitability of the developed model from other soil samples extracted from the road under study other than using the sample used in model development. The control samples laboratory result details and the CBR obtained from the developed model is given in the following Table 9.

The above control tests data taken from the Hossaena for validation purposes. The sample's location is like the samples used for this study. From the above table, control sample two shows a similar variation (19.6 %) compared to the predicted value. This may be due to the location of the test pit being similar to the samples considered in the correlation. Since the soil varies from place to place and season to season, it may have different properties. On the other hand, CS1, CS5, CS6, and CS7 have a variation of 9-32%. This may be due to the location of sampling approaches to where the samples recovered and have nearly the same properties with the samples considered in the regression analysis. This indicates the correlation can be used for rough estimation purposes only.

In general, we can conclude that even though the statistical regression analysis shows the correlation may give 82.1% accuracy in the determination of the CBR, there must be a detail study in using the correlation for practical purpose and as a reference. Before using this correlation, it must be checked with different soil and seasons. It also needs modification with large number of samples and advanced methods rather than simple correlation analysis.

5. Conclusions

The research was conducted to find a localized correlation between CBR values and soil index properties within the scope of the study. Accordingly, the required laboratory tests were conducted on samples collected from different locations in Hossaena town. Using the obtained eighteen test results, multiple linear regressions were analyzed, and a relationship was developed that predicts CBR value in terms of PI, MDD, and OMC.

The suitability of the developed correlation is evaluated by comparing the significance of the independent variables. From the results of this study, the following conclusions are drawn.

A unity change of maximum dry density affects the values of CBR at least four times the present value. From control tests, the predicted CBR has an average variation of 19.6% compared to the actual CBR. This indicates the correlation can be used for rough estimation purposes only and it can be concluded that even though the statistical regression analysis shows the correlation may give 82.1% accuracy in the determination of the CBR, there must be a detailed study using the correlation for practical purpose and as a reference. Before using this correlation, it must be checked with different soil and seasons.

The empirical relations CBR=4.426(MDD)-0.142(PI) + 0.237(OMC), (R2=0.821) obtained from multiple linear regression analysis (MLRA) show good relation to predicting CBR values from MDD and OMC.

This work is used to predict for small structures like cobblestone, double bituminous surface treatment flexible roads, and gravel roads without conducting CBR tests for the specified soil type and location. It saves time and any other costs related to laboratory work. The limitations of the study depend on the location of the data source, and it is only used for Hossaena town for small structures like roads that carry low loads. The number of tests and the distance between the boreholes has impact on the values of CBR. Future studies will consider detailed investigations of the town using both field tests and laboratory tests. It will help to predict CBR values for large-volume structures and loads.

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