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Correlation of California Bearing Ratio with Index Properties of Sub-Grade Soil: A Case Study On Thankot Chitlang Road Section

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Abstract
Value of California Bearing Ratio is often required for geotechnical solutions of engineering road structures. For area development projects using fillings requires placement of such fillings in proper order for high strength and low compressibility. Huge quantity of filling material is used for construction of sub grade and California Bearing Ratio value for all such fills is very important parameter and need to be assessed. But due to high cost and time requirement for such testing it generally becomes difficult to map the variation in their value along the alignment. Correlations of California Bearing Ratio from different index properties have been made by different researchers. However the validity and applicability of such correlation need to be established for their acceptances in general practice. The predicted and tested values of California Bearing Ratio of various soils have been used to check the applicability and limitations of available methods and are presented in this paper. As a result, this study evolved to find the correlation between California Bearing Ratio values with soil index properties of sub-grade soils. The study has examined the feasibility of single linear regression analysis and multiple linear regression analysis in correlating California Bearing Ratio value with soil index properties. Accordingly, 36 disturbed samples collected from different parts of Thankot chitlang Road project and the required laboratory tests have been conducted in order to achieve the intended correlations.

Keywords
California Bearing Ratio, Compressibility, Subgrade, correlation, soil index properties

1. Introduction

Nepal's economic and social development cannot be seen separately from its geography and accessibility. Adequate road connectivity and quality of road are directly related with the country's productive sector like agriculture, market, commerce, industry, and social sector like education, health, communication, livelihood and quality of life. The sub grade is the foundation or underneath native material of the pavement structure which ultimately disperses the pavement load to the earth mass. It is also called formation level. The Indian Road Congress,[1] (IRC:37, 2001) provides the exact procedures for the pavement layers design which based upon the sub-grade strength. It is a fact that weaker sub-grade needs thicker layers whereas stronger sub-grade needs thinner pavement layers for the sub-grade without getting over stressed. So, investigation of sub-grade materials for pavement design works becomes necessary to optimize structural safety and economy aspects of the road infrastructures. One of the activities during the site investigation is determination of sub-grade material strength with different in-situ and laboratory tests such as the California Bearing Ratio (CBR) test. California Bearing Ratio (CBR) is a common and comprehensive test currently practiced in the design of pavement to assess the stiffness modulus and shear strength of sub-grade material so as to determine the thickness of overlying pavement layers. In road construction civil engineers always encounter difficulties in obtaining representative CBR value for design of pavement. The type of soil is not the only parameter which affects the CBR value, but it also varies with different soil properties possessed by the soil. California Bearing Ratio (CBR) is actually an indirect measure which represents comparison of the strength of sub-grade, sub-base and base-course material to the strength of standard crushed rock quoted in percentage values. Laboratory CBR test requires relatively large effort to conduct the test and it is time consuming. The alternate method could be to correlate CBR with simpler test results such as soil index properties. These tests are much economical and rapid than CBR test. This thesis gives an overview to obtain a correlation between CBR values with soil index properties that is suited for Thankot chitlang Road sub-grade soil. Hence, this thesis deeply focuses on developing the intended correlation for different distributions of suitable sub-grade soils.

2. Research Objectives

This research considers a laboratory analysis and correlation of the

1. To check and come up with a correlation between CBR values and soil index properties for subgrade soils.
2. To validate and evaluate the developed correlation using a control test results.
3. To find the linear correlation equation which is use for find necessary properties of sub-grade soils for other place.

3. Literature Review

This chapter reviews the existing research which meets the objective and scope of the study, as literature review plays the vital role for gaining new idea and concepts which helps to gear up the research work effectively. It is basic homework that is assumed to have been done vigilantly, and a given fact in all research papers. It not only surveys what research has been done in the past on my topic, but it also appraises, encapsulates, compares and contrasts, and correlates various scholarly books, research articles, and other relevant sources that are directly related to the current research(3)[2]. As a student, we may not be an expert in a given field however, by listing a thorough review in the research paper, we are telling the audience, in essence, that we know what you are talking about. As a result, the more books, articles, and other sources can be listed in the literature review.

3.1 Review of Existing Correlations

Aggarwal and Ghanekar (1970)
Performed their research on 48 samples [3] (Yared Leliso) of fine grained soils found in India, on the basis of which they had tried to develop a correlation between CBR values and either liquid limit, plastic limit or plasticity index. But in that case they failed to find any strong or significant correlation between them. Instead, they found a better correlation when they include the optimum moisture content and liquid limit. The correlation developed is as below:
CBR= 2-log (OMC) + 0.07* L.L.
OMC-optimum moisture content, L.L=Liquid limit
Patel et al. (2010)
Proposed a method for correlating[4] vi (VIKARAN MAHAJAN) CBR values with the LL, PL,PI, OMC and Maximum dry density of cohesive soils of various zones of Surat city of Gujarat state. The correlation is established in the form of an equation of CBR as a function of different soil properties by the method of regression analysis (Scala, 1959).
CBR (Unsoak) = 54.247 - 212.216 (LL) + 212.18 (PL) +211.937 (Ip) - 0.467 (SL) -20.903 (MDD) + 0.159 (OMC)
CBR (Soak) = 53.783 - 103.571 (LL) + 103.447 (PL) +103.443 (Ip) - 0.077 (SL) -21.782 (MDD) - 0.304 (OMC)
CBR (Unsoak) = 17.009 - 0.0696 (Ip) - 6.296 (MDD) +0.0648 (OMC)
CBR (Soak) = 43.907 - 0.093 (Ip) - 18.78 (MDD) - 0.3081(OMC)
OMC-Optimum Moisture content, MDD-Maximum dry density, Ip-Plasticity index, LL-liquid limit, PL-Plastic limit
Datta and Chottopadhyay (2011) Checked the validity and applicability of [4] (VIKARAN MAHAJAN) correlation which were used for prediction of CBR for their acceptance in general practice. The predicted and tested values of CBR of various soils were used to check the applicability and limitations of available methods and were presented in this research. It was found that the correlation given by Vinod and Cletus (2008) seems to give good agreement of tested values and predicted values of CBR for CI soils but in case of CL soils, the predicted values are much higher than the experimental values.
CBR=-0.889(LL)+ 45.616
Katte et al-2018-Geotechnical and Geological Engineering(Valentine Yato Katte)
Correlation between CBR and Maximum Dry Density (MDD)
CBR=-175.006+99.869*MDD With R = 0.879, R2 = 0.772
Correlation between CBR and Optimum moisture content (OMC)
CBR=99.086-5.162*OMC with R=0.861, R2=0.741

Correlation between CBR and Liquid limit (LL)
CBR=24.377+0.151*LL with R=0.189, R2=0.036

4. Methodology

This study covers only the Thankot chitlang Road sections sub-grade soil compacted to Maximum Dry density (MDD) and Optimum Moisture Content (OMC) obtained according to different field test and lab test using standard effort in predicting CBR values that could be obtained according CBR test machine. The data on CBR value and its index properties of sub-grade soil were collected from number of sample of different section to compare with the published correlations and to develop new regression based models and also plot the graph between different index properties of sub-grade soil with CBR value and find out the correlation equation. From the collected data, several parameters of CBR(%), MDD(g/cm3), OMC(%), % Liquid Limit (LL), % Plastic Limit (PL), % Plasticity Index of sub-grade soil and diameters (in mm) corresponding to 60%, 30% and 10% finer in the grain size distribution respectively denoted as D60,D30 and D10 were included into the database.

4.1 Research Design

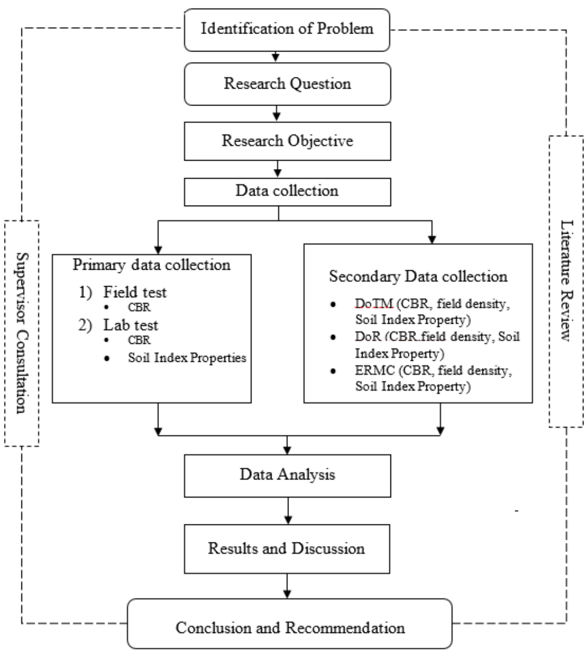

Figure 1: Flow Chart of Research Methodology

5. Results and Discussion

Table 1: Summary of All Laboratory Test Results

S. No.	CH	Types of Soil	Sieve Analysis in %			Atterberg Limit, %			Fines %	Compaction		Average CBR%
			Gravel %	Sand %	Silt+ Clay %	LL	PL	PI		OMC (%)	MDD (gm/cc)	
1	13+000	SM	0.23	56.78	43	38.2	28.83	9.37	43	9.66	2.11	35.85
2	13+250	SM	0.7	55	44.31	44.15	36.19	7.97	44.31	10.63	2.08	37.56
3	13+500	SM	0.2	75.87	23.93	50.1	43.54	6.56	23.93	11.59	2.04	24.76
4	13+750	SM	1.11	76.55	22.35	47.5	40.21	7.29	22.35	13.7	2.02	21.17
5	14+000	SM	2.01	77.23	20.76	44.9	36.88	8.02	20.76	15.8	2	24.76
6	14+250	SM	1.01	67.01	31.88	41.55	32.86	8.7	31.88	12.73	2.06	12.00
7	14+500	GW	56.78	35.53	7.7	38.2	28.83	9.37	7.7	9.66	2.11	35.85
8	14+750	GW	30.49	55.7	13.82	44.15	36.19	7.97	13.82	10.63	2.08	37.00
9	15+000	SM	4.2	75.87	19.93	50.1	43.54	6.56	19.93	11.59	2.04	24.76
10	15+500	SM	15.24	72.26	12.5	44.1	34.36	9.74	12.5	13.24	2.05	17.00
11	15+750	SM	21.93	66.25	11.83	43.35	34.77	8.59	11.83	12.63	2	40.00
12	16+000	GW	28.62	60.24	11.15	42.6	35.17	7.43	11.15	12.01	1.95	35.85
13	16+250	GM	40.54	51.13	8.35	42.55	36.3	6.25	8.35	10.99	2.05	30.00
14	16+500	GM	52.45	42.01	5.54	42.5	37.43	5.07	5.54	9.97	2.15	15.00
15	16+750	GM	52.6	40.85	6.56	46.15	39.72	6.43	6.56	9.82	2.17	10.00
16	17+000	GW	52.74	39.69	7.58	49.8	42.01	7.79	7.58	9.67	2.18	17.00
17	17+250	GW	53.48	39.69	6.83	50.95	43.28	7.67	6.83	9.51	2.17	10.00
18	17+500	GW	54.22	40	6.08	52.1	44.55	7.55	6.08	9.35	2.15	16.00
19	17+750	GW	54.83	39.64	5.53	50.95	42.23	8.72	5.53	9.2	2.17	25.61
20	18+000	GW	55.44	39.58	4.98	49.8	39.91	9.89	4.98	9.04	2.19	16.00
21	18+250	GM	56.11	37.56	6.34	44	34.37	9.63	6.34	9.35	2.15	12.00
22	18+500	GM	56.78	35.53	7.7	38.2	28.83	9.37	7.7	9.66	2.11	35.85
23	18+750	SM	0.49	55.7	43.82	44.15	36.19	7.97	43.82	10.63	2.08	37.00
24	19+000	SM	1.93	75.87	22.2	50.1	43.54	6.56	22.2	11.59	2.04	24.76
25	19+250	SM	0.11	76.55	23.35	47.5	40.21	7.29	23.35	13.7	2.02	20.00
26	19+500	SM	2.01	77.23	20.76	44.9	36.88	8.02	20.76	15.8	2	24.76
27	19+750	SM	0.51	60.22	39.28	46.25	37.87	8.38	39.28	12.85	2.08	24.76
28	20+000	SM	47.01	43.2	9.79	47.6	38.86	8.74	9.79	9.9	2.16	14.17
29	20+250	GW	64.23	29.96	5.82	47.2	38.34	8.87	5.82	12.63	2.05	16.48
30	20+500	GW	81.45	16.71	1.84	46.8	37.81	8.99	1.84	15.4	1.93	18.78
31	20+750	GW	59.97	33.9	6.14	43.9	35.43	8.47	6.14	14.09	1.92	18.78
32	21+000	GM	38.48	51.08	10.44	41	33.05	7.95	10.44	12.8	1.9	17.78
33	21+250	GM	46.05	45.29	8.67	43.8	37.78	6.02	8.67	10.74	2.01	22.15
34	21+500	GM	53.62	39.49	6.89	46.6	42.51	4.09	6.89	8.7	2.12	24.76
35	21+750	GW	66.81	28.35	4.85	46.8	41.06	5.74	4.85	8.71	2.12	36.71
36	22+000	GM	79.99	17.21	2.81	47	39.61	7.39	2.81	8.77	2.12	30.00

The resulting regression analysis after correlating CBR with G%, S%, C%, LL, PL, PI, MDD and OMC is expressed by the following Multi and single linear equation with its corresponding correlation coefficients are presented in table

Table 2: Linear Regression Analysis For All soil

SN	Correlations	Num.of Samples	R Value	R^2 Value	ά
a)	CBR = -0.57LL+0.23PI+0.23Fines%-3.26OMC-73.92MDD+0.04Sand%+232.66	36	0.62	0.40	0.019
b)	CBR = -0.56LL+0.12PI+0.27Fines%-3.07OMC-72.69MDD+229.75	36	0.62	0.40	0.009
c)	CBR = -0.77LL+0.03PI-2.35OMC-60.16MDD+209.91	36	0.54	0.30	0.041
d)	CBR = -0.77LL-2.34OMC-59.88MDD+209.58	36	0.53	0.30	0.018
e)	CBR=-LL+69.59	36	0.42	0.20	0.014
f)	CBR=-0.75PL+52.38	36	0.35	0.12	0.037

Table 3: Linear Regression Analysis for Silty Gravels-GM soil of Thankot Chitlang Road Section

SN	Correlations	Num.of Samples	R Value	R^2 Value	ά
a)	CBR = -2.59LL-1.45PI-0.59Fines%-8.80OMC-121.81MDD-0.21Sand%+500.60	9	0.80	0.70	0.72
b)	CBR = -2.63LL-1.13PI-1.46Fines%-9.97OMC-138.77MDD+544.58	9	0.80	0.70	0.49
c)	CBR = -1.95LL-10.72OMC-127.75MDD+481.48	9	0.77	0.60	0.20
d)	CBR = -0.97LL+64.27	9	0.32	0.10	0.42
e)	CBR=-0.56PL+42.58	9	0.30	0.10	0.50

Table 4: Linear Regression Analysis for Well Graded Gravels-GW soil of Thankot Chitlang Road Section

SN	Correlations	Num.of Samples	R Value	R^2 Value	ά
a)	CBR = -0.05LL+1.97PI+2.99Fines%-9.86OMC-201.84MDD-0.78S%+546.35	12	0.90	0.80	0.13
b)	CBR = -1.41LL-1.39PI+0.26Fines%-4.22OMC-71.86MDD+294.74	12	0.88	0.80	0.07
c)	CBR = -1.49LL-1.48PI-4.43OMC-74.23MDD+308.51	12	0.87	0.80	0.28
d)	CBR = -1.24LL-5.89OMC-108.25MDD+371.35	12	0.86	0.74	0.01
e)	CBR=-1.98LL-1.82OMC+136.22	12	0.79	0.62	0.01
f)	CBR=-1.67LL+101.85	12	0.69	0.47	0.01

Table 5: Linear Regression Analysis for Silty Sand-SM soil of Thankot Chitlang Road Section

SN	Correlations	Num. of Samples	R Value	R^2 Value	ά
a)	CBR = 0.28LL+1.52PI-4.05OMC-362.08MDD-0.29G%-1.13S%+872.37	15	0.90	0.80	0.02
b)	CBR = 0.15LL+3.48PI+0.34Fines%-4.85OMC-230.63MDD+515.46	15	0.77	0.60	0.10
c)	CBR = -3.30LL+1.83PL-4.25OMC-161.94MDD+492.46	15	0.72	0.52	0.09
d)	CBR = -0.38LL+0.29Fines%+35.14	15	0.48	0.23	0.20
e)	CBR=-0.81LL+62.62	15	0.32	0.10	0.25

6. Conclusion and Recommendations

6.1 Conclusion

The research was conducted to find a localized correlation between CBR value and soil index properties within the scope of the study. Accordingly, required laboratory tests were conducted on samples retrieved from different geographical area of Nepal. Using the obtained 36 test results, a single and multiple linear regressions were analyzed and a relationship was developed that predict CBR value in terms of G%, S%, C%, LL, PL, PI, Fines%, MDD and OMC. For the study 36 samples were collected at Thankot - Chitlang road section (9 km.) at an interval of 250 m. The suitability of the developed correlation is validated by utilizing a separate control test results. From the results of this study the following single linear and multiple linear regressions relationship conclusions are drawn

1. For all type of soil only two equation are fair i.e.
   CBR = -0.57LL+0.23PI+0.23Fines%-3.26OMC-73.92MDD+0.04S%+232.66
   for R2=0.40 and
   CBR = -0.56LL+0.12PI+0.27Fines%-3.07OMC-72.69MDD+229.75
   for R2=0.40 other result are Poor

2. For Silty Gravel Soil-GM two equation are good i.e.
   CBR = -2.59LL-1.45PI-0.59Fines%-8.80OMC-121.81MDD-0.21S%+500.60 for R2=0.70 and
   CBR = -2.63LL-1.13PI-1.46Fines%-9.97OMC-138.77MDD+544.58 for R2=0.70 and
   one equation fair i.e.
   CBR = -1.95LL-10.72OMC-127.75MDD +481.48 for R2=0.60 other relation are poor

3. For Well Graded Gravel Soil-GW four equation are good i.e.
   CBR = -0.05LL+1.97PI+2.99Fines%-9.86 OMC-201.84MDD-0.78S%+546.35
   for R2=0.80
   CBR = -1.41LL-1.39PI+0.26Fines%-4.22OMC-71.86MDD+294.74 for R2=0.80
   CBR = -1.49LL-1.48PI-4.43OMC-74.23MDD+ 308.51 for R2=0.80 and
   CBR = -1.24LL-5.89OMC-108.25MDD+ 371.35 for R2=0.74
   two equation are fair and other are poor resullt

4. For Silty Sand Soil-SM only one equation is good i.e.
   CBR = 0.28LL+1.52PI-4.05OMC-362.08MDD-0.29G%-1.13S%+872.37 for R2=0.80
   two result are fair and other result are poor
   The result shows that we should use two equation for Silty Gravel, four equation for Well Graded Gravel and one equation for Silty Sand are used to predict the CBR value by knowing the the index properties of soil.

6.2 Recommendations

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

1. It is recommended to carry out CBR and DCPI correlation which are not covered by this research.

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

3. Further, it is advisable to develop correlation between CBR with resilient modulus (MR) for different types of soil.

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