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Correlation Between CBR Value and Plasticity Index of Base Course Material in Flexible Pavement

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Abstract

The California Bearing Ratio (CBR) serves as a crucial indicator of base course strength, informing the thickness design of the pavement. It signifies the material's capacity to withstand loads and resist deformation. Plasticity Index (PI) is another pivotal parameter guiding engineers in assessing the suitability of the base course for pavement design. A larger PI implies a higher clay content, potentially compromising the base course's strength and stability. This prompts researchers to explore the potential relationship between CBR and PI. Twenty-one samples of base course were gathered from Lalitpur, Makwanpur, and Dhading, ensuring compliance with the Standard Specifications for Road and Bridge Works, 2016 (SSRBW). In assessing CBR, Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are also considered. Thus, OMC, MDD, and PI are treated as independent variables to formulate an expression for estimating CBR. Utilizing Multiple Linear Regression in Excel, a predictive model for CBR was established, demonstrating a strong correlation between predicted and observed CBR, with an R^2-value of 0.82. This model streamlines testing procedures by facilitating the determination of CBR values for base courses without extensive testing. Laboratory tests indicate that even with a PI exceeding 6 (e.g., PI = 8), the CBR value remains above 80% . This underscores the negative correlation between CBR and PI, suggesting that as PI increases, the CBR value tends to decrease. Moreover, during the validation of the research, Root Mean Square Error (RMSE) values for the estimated CBR compared to the observed CBR were determined as 4.49. This underlines the model's effectiveness in CBR determination and underscores its potential to save time and resources. Adopting this model could significantly enhance its reliability for practical application in road construction projects.

Keywords

CBR, PI, MDD, OMC, Base, SSRBW, Correlation

1. Introduction

The majority of the roads in Nepal are made of flexible pavement. The flexible pavement consists four layers such as Sub-grade, Sub-base, Base and finally Wearing courses. Base course is also most important layer to bear load that coming from vehicle to the pavement. Normally cost of base course is 15 – 20% of road cost per length of construction. Most of the flexible pavement designed based on the using a theoretical or empirical approach that consider California bearing ratio (CBR) value mainly.

The CBR is a measure of the strength of the base course material. It indicates the material's ability to withstand loads and resist deformation. Typically, a higher CBR value implies a stronger base course material, which can handle higher loads without significant deformation.

In Nepal, there are so many sources of base courses. But physical properties vary places to places. In Nepal most of base material contain lot of soil that causes plasticity property. Plasticity property may be expressed in plasticity index. In pavement design, the relation between the California Bearing Ratio (CBR) and the Plasticity Index (PI) of the base course is used to assess the strength and suitability of the material for supporting the pavement structure. A lower PI value indicates lower clay content and better drainage properties, which contribute to the stability of the base course material. Ideally, a good base course material for pavement design should have a high CBR value and a low PI value. This combination ensures that the material can bear heavy loads without deformation while also having good drainage characteristics. However, the specific design requirements may vary depending on factors such as traffic volume, climate conditions, and soil properties in the project area.

Determining the CBR is a demanding, time-consuming, and labor-intensive task essential for pavement design and construction. Typically, this process takes an average of four days to complete. However, due to the lack of trained labor, there's a risk of inaccuracies in CBR test results, making it difficult to conduct tests at the required frequency for road projects. Furthermore, various soil properties such as plasticity index, optimum moisture content (OMC), and maximum dry density (MDD) can influence CBR values, adding complexity to the assessment. To overcome these challenges, the objective is to establish a correlation between the CBR value of the base course with PI, MDD and OMC.

In Nepal, despite the extensive construction of roads, ensuring proper design, quality control, and methodology remains a persistent challenge. One of the most crucial and demanding tasks is the construction of the base course layer following the completion of the sub-grade and sub-base layers. The materials available for this layer can vary widely in quality, presenting both opportunities and obstacles for pavement construction. In accordance with the 2016 Standard Specification of Road and Bridge Work, as amended in 2022 by the Department of Road, a plasticity index of up to 6 is allowed, while the California Bearing Ratio (CBR) must surpass 80 for the base course. Therefore, the goal is to investigate whether the CBR value can still exceed 80 after the plasticity index exceeds 6, effectively addressing this challenge.

1.1 Objective of the Study

The main objective of the study is to determine the relationship between CBR value and Plasticity index of Base Course. The specific objectives are enlisted as below:

1. To correlate the CBR and Plasticity index of base courses.
2. To check and verify the minimum threshold of PI value for acceptable CBR (80%) criteria as per SSRBW 2016.

1.2 Limitation of the Study

For this research, only twenty-one samples were prepared and tested for analysis. Constraints such as limited funds, time, and other resources prevented further testing and analysis for more robust results. The project report was prepared under following limitations:

1. The test sample collected from Dhading, Makwanpur, Lalitpur district of Nepal.
2. All the required test was conducted from Laboratory of Department of Road (DOR).
3. Increase in PI value of base course not considering the binding effect between wearing and sub-base layer.

2. Literature Review

Rehman et al. (2017) formulated predictive models utilizing 59 sets of soil samples comprising both fine-grained and coarse-grained soil. They developed three separate models, each tailored to specific soil types, and assessed their accuracy using 25 distinct soil sample sets. The authors differentiated between coarse- and fine-grained soils, creating individual models for each. These models were established based on parameters such as liquid limit and plasticity index for fine-grained soil, and coefficient of uniformity and maximum dry density for coarse-grained soil[1].

Rani and Nagaraj et al. (2017) established a correlation between CBR values and soil index properties specific to the Yadadri region. Soil index properties encompassed sieve analysis, Atterberg limits, and compaction tests. The study involved gathering eighteen samples from various parts of Yadadri and subjecting them to comprehensive laboratory testing to establish this correlation. The analysis employed both single linear regression and multiple linear regression techniques using SPSS software. It was observed that considering multiple variables such as liquid limit (LL), plastic limit (PL), maximum dry density (MDD), optimum moisture content (OMC), and plasticity index (PI) resulted in a notably improved correlation. Overall, the study concluded that soil index properties demonstrate a stronger association with CBR strength quality compared to individual soil properties. The predicted CBR values closely matched the laboratory values, with the coefficient of correlation R^2 for CBR value ranging from 0.801 to 0.692 as determined through SPSS analysis[2].

Pall and Pal (2019) have done very large number of test results on soil samples collected from different sites in Kolkata been used. By using the approach of graphical analysis, the correlation is established as an equation of CBR as a function of Percentage Finer and Plasticity Index, and the validity of the suggested method has been confirmed for a significant number of tested values. The use of additional properties for predicting CBR value, such as Liquid Limit, Plastic Limit, and Grain Size Analysis, which are acquired from low-cost and less time-consuming tests, can be stressed given that the CBR value test of soil is laborious and time-consuming. In the current investigation, it has been found that the projected CBR values are more similar to the measured CBR values. This model forecasts the soaked CBR values based on soil PI Value and grain size analyses. The capacity to anticipate the soaking CBR value and to confirm the accuracy of CBR values obtained in laboratories will both be greatly aided by this for geotechnical engineers[3].

Roksana et al. (2017) collected five soil samples from Mirpur, Gazipur, Noakhali, Hatirpool, and Nawabganj to estimate soil properties. Subsequently, a regression analysis was conducted using SPSS 16.0 software based on correlation coefficients to predict unsoaked CBR values, which were then compared with actual CBR values. For CBR with Plastic Limit, the coefficient of determination (R) ranged from 0.86 to 0.99, while for Maximum Dry Density (MDD), it ranged from 0.06 to 0.2. It was concluded that unsoaked CBR values exhibit a strong linear association with Plastic Limit (PL) and a weak linear relationship with MDD. PL was found to significantly impact CBR values, whereas MDD had minimal impact on the CBR values of subgrade soil. Regression equations illustrating the relationship between CBR and each measured soil parameter were developed through SPSS 16.0 software analysis. CBR values obtained from the regression equations considering LL, PL, SL, PI, MDD, and OMC as independent variables closely matched those obtained from laboratory tests. However, the study's primary limitations include the use of disturbed soil samples and a small sample size. It is suggested that undisturbed soil samples be used for optimal results and a larger sample size be employed for more robust findings. Additionally, investigating soaked and unsoaked CBR values may lead to a better understanding of the relationship[4].

Naeini et.al. (2008) collects three types of soil with various plasticity indexes of 10, 16 and 23 that it is achieved by adding different percents of bentonite (10 and 20%) to original clay soil are used. The samples were initially tested without geogrid in soaked and unsoaked conditions. Then by placing a single layer of geogrid at the second layer of the sample, CBR tests were performed on the reinforced soil. Consequently, geogrid was placed at the first and the third layer and CBR tests were repeated[5].

Shirur et. al. (2017) based on the analysis of experimental data and SLRA (Single Linear Regression Analysis), there is no significant correlation observed for predicting CBR values based on liquid limit and plastic limit alone. However, a linear relationship was identified between the plasticity index and CBR value, yielding a coefficient of correlation (R^2) of 0.72. Furthermore, empirical equations derived through SLRA revealed strong predictive capabilities when utilizing maximum dry density (MDD) and optimum moisture content

(OMC) to estimate CBR values. Specifically, Additionally, a multiple linear regression analysis (MLRA) produced an empirical relation, CBR= −4.8353 − 1.56856(OMC)+4.6351(MDD) (R^2 = 0.82), which exhibited a robust correlation for predicting CBR values based on MDD and OMC simultaneously. However, it's important to note that despite these predictive models, significant discrepancies between experimental and predicted CBR values were observed, particularly concerning high compressible clays (CH), as indicated by correlation analysis[6].

Talukdar (2014) explored the correlation between CBR and various soil index properties. Utilizing Linex statistics in Microsoft Excel (version 13.0), a linear multiple regression model was constructed to ascertain CBR values. The following conclusions were drawn: For fine-grained soil types, including those with low compressibility (ML) and silts of intermediate compressibility (MI), significant correlations were found between CBR values and parameters such as plasticity index (PI), maximum dry density (MDD), and optimum moisture content(OMC). Analysis revealed a trend wherein CBR values tend to decrease with increasing plasticity index and optimum moisture content of the soil. Conversely, CBR values demonstrate an increase with rising maximum dry density. A slight variance was observed between laboratory-determined CBR values and those computed through the multiple linear regression model, which incorporated parameters such as liquid limit (LL), plastic limit (PL), plasticity index (PI), maximum dry density (MDD), and optimum moisture content (OMC). The study primarily focused on soil types ML and MI. Future research endeavors may explore additional soil types to broaden the scope of understanding in this area [7].

Kaushik et. al. (2022) concludes that time-consuming nature of conducting CBR tests on soil samples, there is a notable advantage in exploring alternative properties, such as liquid limit, plastic limit, optimum moisture content, and maximum dry density. These properties, which can be determined through more cost-effective and less time-intensive tests, hold promise for estimating CBR values. In the current investigation, experimental findings indicate that the predicted CBR values closely align with measured CBR values. This development offers a valuable tool for Geotechnical Engineering, enabling the prediction of soaked CBR values through the correlation established in this study[8].

Gudeta et. al. (2018) collects several soil samples sourced from diverse regions of Pakistan were collected with the aim of formulating predictive models tailored to the country's locally available soils. These models specifically target the prediction of CBR Soaked values for both fine-grained and coarse-grained soils. For fine-grained soil, a single model was devised, while two distinct models were developed for coarse-grained soil. The robustness of these models was assessed based on their correlation coefficient (R value) and their applicability to real-scale data. Additionally, simplified predictive curves were introduced to facilitate the determination of CBR Soaked values for both fine-grained and coarse-grained soils, derived from the multiple regression models proposed in this study. it's essential to note that they cannot serve as a substitute for actual tests[9].

According to "STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE WORKS 2016 (Second amendment 2022)" for Crusher run Base types of test parameter guided the study clearly[10]. The association between CBR and PI has been thoroughly explored within the field of geotechnical engineering. Numerous researchers have examined this connection through various testing approaches, both in controlled laboratory settings and in the field. Here are the principal discoveries drawn from these investigations: Multiple laboratory inquiries have demonstrated a significant negative correlation between CBR and PI. Additionally, CBR might be influenced by factors such as OMC and MDD. Overall, the findings suggest that determining CBR and PI values is crucial and also no any studied found correlation between CBR and PI for granular base course material, particularly for base courses, and can pose significant challenges in construction projects.

3. Methodology

3.1 Study area

The study seeks to establish the connection between the California Bearing Ratio (CBR) and Plasticity Index (PI) of the Base course in flexible pavement. Samples were gathered from Dhading, Makwanpur, and Lalitpur districts of Nepal. Comprehensive tests were carried out to investigate the correlation between CBR and PI. The samples were selected in accordance with the specifications outlined in SSRBW, 2016.

3.2 Data Collection and extraction

The study exclusively utilizes primary data gathered directly rather than from secondary sources. Initially, the samples are subjected to oven drying to prepare them for subsequent tests. These oven-dried samples are then assessed for fundamental properties including LAA, AIV, Combined Index (CI), Flakiness Index (FI), Elongation Index (EI), Water Absorption, LL, PL, and PI. For analysis, 15 distinct samples are prepared and tested with varying PI values, resulting in diverse CBR, MDD, and OMC values for different sources, as presented in the Table 1.

Table 1: Lab Test Result by varying PI and their Corresponding CBR, MDD and OMC of Base Sample

S.N.	CBR (%)	PI	MDD (gm/cm^3)	OMC (%)
1	93	8	2.245	5.85
2	96	7	2.262	6
3	97	6.5	2.28	4.8
4	110	5	2.22	5
5	120	4	2.256	4.8
6	124	2	2.268	6.1
7	140	0	2.264	6.4
8	219	0	2.231	5.4
9	185	1	2.215	5.8
10	190	2	2.219	5.9
11	142	4.08	2.22	6.15
12	122	5.6	2.224	5.5
13	115	6	2.214	5.6
14	114	6.6	2.22	5.7
15	94	8	2.236	5.4

3.3 Graph and its nature

There are plotted some Graph and its nature of CBR, PI, MDD and OMC from Table 1.

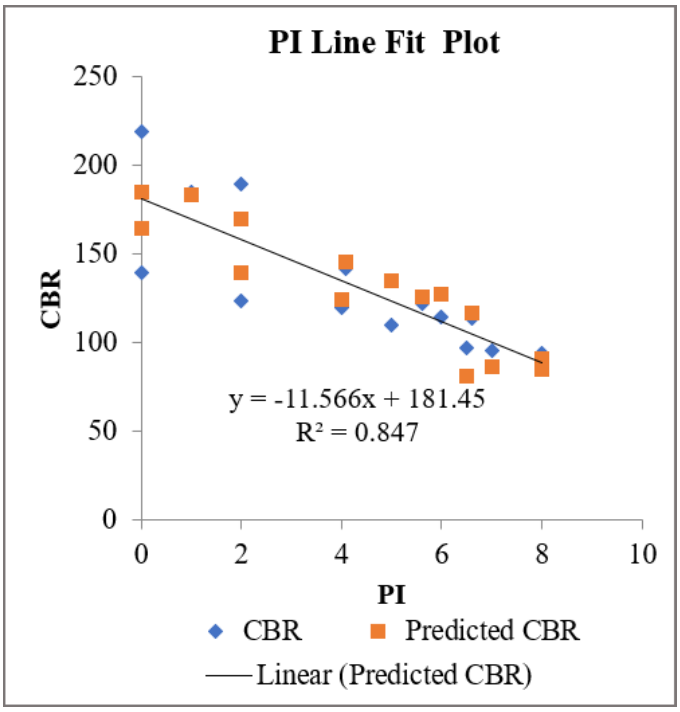

Figure 1: Plot of CBR value and PI

The graph in Figure 1 shows that lower the PI value results in high value of CBR and vice-versa. The equation from graph is given below:

$$CBR_p = -11.566 \times PI + 181.45 \quad (1)$$

4. Results and Discussion

4.1 Model interpretation

OMC have P-value greater than 0.05. There may not be a significant linear relationship between the independent variable corresponding to that coefficient and the dependent variable if the p-value is greater than 0.05, which indicates that the coefficient is not statistically significant at the selected significance level. Therefore, after taking into consideration other factors in the model, for practical conclusion that the independent variable (OMC) has no discernible impact on the dependent variable. Again, after analysis of Multiple Linear Regression was done with the help of Excel Software. Following equation shows the relation of predicted CBR (i.e. Dependent Variable) with PI and MDD (i.e. Independent Variable).

$$CBP_p = 1552.91 - 11.40 \times PI - 613.06 \times MDD \quad (2)$$

With the help of above equation, we get the graph as shown in Figure 2.

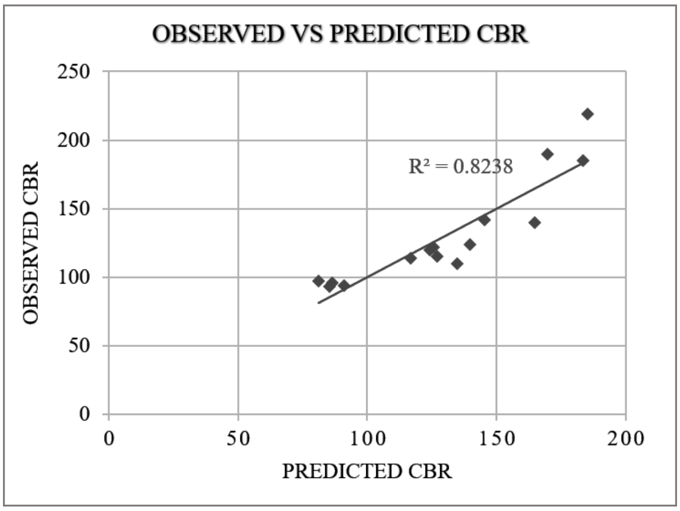

Figure 2: Plot of Observed CBR value and Predicted CBR value

with the help of equation (2), get Predicted CBR and tabulated below with Observed CBR

Predicted CBR	Observed CBR
85.39	93
86.37	96
81.03	97
134.92	110
124.25	120
139.69	124
164.94	140
185.17	219
183.58	185
169.73	190
145.40	142
125.62	122
127.20	115
116.68	114
90.91	94

Table 2: Predicted CBR and Observed CBR after analysis

4.2 Validation

Validation is done for the sample collected from Dhading and tested. Error Percentage of Predicted CBR and Estimated CBR with observed CBR are tabulated below:

Observed CBR	Predicted CBR	Error in % of Predicted CBR from Observed CBR
180	117.82	1.21
146	150.37	-2.99
135	135.28	-0.21
122	119.59	1.98
115	111.26	3.26
96	87.23	9.14

Table 3: Error % of observed CBR with estimated CBR and predicted CBR

From above model maximum and minimum difference in observed CBR and predicted CBR are 9.14% and 0.21% respectively. Root Mean Square Error was observed 4.49 and R^2 – value 0.987 while validate from Dhading data.

5. Conclusion and Recommendation

5.1 Conclusion

Samples of base material collected from three districts - Lalitpur, Makwanpur, and Dhading were subjected to testing as per the specifications outlined in "SSRBW 2016" for sample preparation. A total of 21 samples were prepared from the tested base material, varying in Plasticity Index (PI), leading to different values of Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) respectively.

For the analysis in this study, 15 sample test data were utilized, collected from Lalitpur and Makwanpur districts. Additionally, six samples prepared and tested data obtained from Dhading were employed to validate the findings of this research.

It was noted that the correlation between California Bearing Ratio (CBR) and Plasticity Index (PI) was more pronounced compared to other variables such as Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The correlation coefficients (R-value, R^2-value) between CBR and PI, CBR and MDD, CBR and OMC were observed as (-0.84, 0.71), (-0.38, 0.14), and (0.2, 0.04) respectively. Despite efforts to establish a stronger relationship between CBR and PI, OMC, and MDD through multiple linear regression modeling, it was found that the-values exceeded 0.05 (for OMC variable), indicating no statistical significance. Consequently, a model considering only CBR with PI and MDD was developed. Utilizing Multiple Linear Regression in Excel, a predictive model for CBR ($CBR_p = 1552.91 - 11.40 \times PI - 613.06 \times MDD$) was derived, showing a strong correlation between predicted and observed CBR with an R-value of 0.91 and an R^2-value of 0.82. This equation facilitates the determination of CBR for base courses without the need for time-consuming tests.

Based on comprehensive lab tests, it was determined that even when PI exceeds 6 (e.g., PI = 8), the CBR value remains above 80%. It was concluded that there exists a negative correlation between CBR and PI, indicating that as PI increases, the CBR value tends to decrease.

5.2 Recommendation

Given the significant correlation observed between California Bearing Ratio (CBR) and Plasticity Index (PI), it is advisable to prioritize further investigation into this relationship for enhanced understanding and potential practical applications. Additionally, considering the robust predictive model derived from the Multiple Linear Regression analysis, which incorporates CBR, PI, and Maximum Dry Density (MDD), it is recommended to utilize this model for efficient determination of CBR values for base courses, thereby streamlining testing procedures and saving time. Moreover, the validation of research findings through data collected from Dhading reinforces the reliability and applicability of the developed model across different districts, enhancing its credibility for practical implementation in pavement construction projects.

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