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Association between CBR and Soil Index Properties: Empirical Analysis from Chitwan and Makwanpur District Soil Samples

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ABSTRACT

The California Bearing Ratio (CBR) value is a crucial soil parameter in road construction and design. Obtaining representative CBR values is challenging, requiring time-consuming and expensive testing procedures. To address this issue, regression equations were developed to establish correlations between CBR and soil index properties. Laboratory tests were conducted to determine the soaked CBR, Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) of soil samples. Regression models were then created between CBR and different sets of soil index properties using Microsoft Excel 2007. Strong correlations were observed between soaked CBR, PL, PI, OMC, and MDD (R2 = 0.744); CBR, LL, PL, OMC, and MDD (R2 = 0.702); CBR, PI, OMC, and MDD (R2 = 0.643); CBR, LL, OMC, and MDD (R2 = 0.621); and CBR, OMC, and MDD (R2 = 0.602). Among all equations, the relation CBR = 0.72 PL – 1.22 PI + 2.34 OMC + 106.97 MDD – 222.46 exhibited the strongest correlation with a P-value of 0.005 and R2 of 0.744.

Keywords: California Bearing Ratio, LL, PL, PI, Soil Strength Parameters, Regression analysis

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INTRODUCTION

The California Bearing Ratio (CBR) value is a crucial parameter used to evaluate the strength of subgrade in flexible pavement construction. It is considered an ideal layer for resisting wheel loads. Conducting CBR tests is expensive and time-consuming, and it can be challenging to achieve the desired in-situ density of samples in the laboratory. Additionally, when the soil quality is poor, additives need to be mixed to enhance soil strength, and CBR values are used to assess the resulting strength, further complicating the process. To overcome these difficulties, mathematical models have been developed to estimate CBR values more efficiently. These models correlate CBR values with various soil parameters and index properties using regression analysis (Raklaradi & Gomarsi, 2015). Soil properties such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Optimum Moisture Content (OMC), and Maximum Dry Density (MDD) are determined for soil samples collected from different areas of Chitwan and Makwanpur districts, and regression models are developed to establish correlations with CBR values. The thickness of the subgrade in road construction depends on the CBR value, with lower CBR values requiring thicker pavement compared to higher CBR values (Bassey et al., 2017). In the case of road construction, the compaction test will be conducted at each layer of soil, and index properties are also determined for finding out the other engineering properties. The index properties can easily be found in lab tests. The CBR value can be predicted from these index properties and soil parameters (Roy and Bhalla, 2017).

OBJECTIVES

The main objective of the research is to identify the possibility of finding the CBR value from the index property of soil. The relation thus would reasonably reduce the test time and help for a quick decision on the pavement design and construction of the road.

LITERATURE REVIEW

The performance of pavement depends upon the quality of the subgrade. A subgrade should be prepared to provide firm support for the construction of pavement layers. The required pavement thickness is determined based on the subgrade strength. Accurate characterization of the strength of the in-situ subgrade soil is therefore critical for the long-term performance of the pavement section (Rushema, 2021). Some correlations do exist to estimate the CBR of soil, based on soil classification, other index property values, and/or physical property measurement of soil. Aggarwal & Ghanekar, 1970 performed the analysis of fine-grained soils of 48 samples found in India. Based on the study, a correlation between CBR values and Liquid Limit, Plastic Limit/Plasticity Index was produced. However, the analysis failed to determine any strong correlation. Instead, a much better correlation was found including the liquid limit and optimum moisture content (OMC). The relationship between OMC, LL, and CBR found during the study is given as: "CBR=2-log(OptimumMoistureConte nt)+0.07×(LiquidLimit" Venkatasubramanian et al., 2011 proposed a technique to correlate CBR values with the soil parameters of various types of soils taken from the three different districts of Tamil-Naidu. A relation was developed with the help of an Artificial Neural Network System (ANN) and Multiple Linear Regression Analysis (MLRA). Korde and Ydadav, 2015, proposed a correlation to determine the CBR value of some soils collected from different parts of Jabalpur city based on index properties like Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), and compaction characteristics i.e. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Their developed equation is given below; "CBR=-0.258-(0.014×LL)-(0.015×PI)+(0.011×OMC)+(2.100×MDD") Patel and Desai, 2010 proposed a correlation between the plasticity index, maximum dry density, and optimum moisture content. The proposed equation is, "CBR=43.907-0.093×PI-18.78×MDD-0.3081×OMC" The literature

review you provided highlights the importance of accurately characterizing the strength of the subgrade soil for the performance of pavement. It also mentions several correlations proposed by different researchers to estimate the California Bearing Ratio (CBR) of soil based on index properties and soil parameters.

Aggarwal and Ghanekar (1970) conducted an analysis of fine-grained soils in India and found a correlation between CBR values and Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). However, they observed a stronger correlation when including the liquid limit and optimum moisture content (OMC) in the relationship.

Venkatasubramanian et al. (2011) used Artificial Neural Network System (ANN) and Multiple Linear Regression Analysis (MLRA) to correlate CBR values with soil parameters from different districts in Tamil-Nadu.

Korde and Ydadav (2015) proposed a correlation for determining the CBR value based on index properties such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Optimum Moisture Content (OMC), and Maximum Dry Density (MDD) for soils collected from different parts of Jabalpur city.

Patel and Desai (2010) proposed a correlation between the plasticity index (PI), maximum dry density (MDD), and optimum moisture content (OMC) to estimate the CBR value.

These correlations provide relationships between CBR and various index properties and soil parameters. By utilizing these correlations, it is possible to estimate the CBR value of soil, which can help in making quicker decisions regarding pavement design and road construction.

METHODOLOGY

Sample Collection

Total fifteen disturbed soil samples were collected from the site. The Soil samples were collected from a depth of 0.5m. Ravichandra et al., 2019 suggested that samples at a depth smaller than 0.5 m have to be discarded because of the presence of organic matter. Figure 1 d shows the collection of sample from 0.5m depth from different site.

Sample Size

Due to accessibility, availability and time constraint fifteen soil samples were collected for this study from different location. Roksana et al. 2018 collected five samples, Janjua and Chand, 2016 collected eleven samples for developing the relationship between CBR and index properties of soil.

Index properties of soil

(i) Consistency limit: Liquid Limit (LL) and Plastic Limit (PL) are determined by Casagrande's apparatus according to IS: 2720 (part V)-1985. Soil sample passing through a 425-micron sieve, weighing 200g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casagrande's apparatus cup with a groove created and the number of blows to achieve 12.5mm closure at varying moisture contents was recorded. Moisture content corresponding to 25 numbers of blows is taken as the Liquid Limit (LL). Similarly, for the plastic limit determination, the soil sample weighing 200g was taken from the material passing the 425-micron sieve and then was mixed with water till it become homogeneous and plastic to be shaped into a ball. The ball of soil was rolled on a glass plate to form threads that cracked at approximately 3mm in diameter. The moisture content of the thread-like soil was taken as the Plastic Limit (PL).

(ii) Plasticity Index (PI) is a measure of the plasticity of the soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and plastic limit (PI = LL-PL). Figure 4.1 b shows the casagrnde device to performed the liquid limit.

Compaction test

Air dried soil sample was sieved from a 20mm sieve size and a 2500 gm soil sample was taken

for further testing. Initially, 5% of the water was mixed thoroughly. The standard proctor test was conducted with the help of sample preparation. Sample preparation of compaction test involved the preparation of 3 layers of soil in a mold (capacity of 1 liter) where each layer was compacted with 25 blows of a 2.5 kg hammer falling from a height of 310 mm (IS: 2720 (part VII), 1980). Simultaneously, the water content (w) was determined from the oven drying method as per standard IS: 2720 (part II)-1973. This process was repeated for various moisture content and the dry densities were determined for each. The graphical relationship of the dry density to moisture content was then plotted to establish the compaction curve. The maximum dry density was finally obtained from the peak point of the curve and its corresponding moisture content; also known as the optimum moisture content was observed.

California Bearing Ratio Test

The California Bearing Ratio (CBR) test was carried out in this study where 5 Kg air-dried soil sieved through a 20mm sieve size was mixed with a suitable amount of water 7.5% of its weight. The sample was then placed in CBR mold in 3 layers where each layer was compacted with 56 blows with a 4.89 Kg hammer dropping from a 470mm height. The compacted soil and mold were weighed and allowed for soaking for 96 hrs (4 days). After completing the soaking, the sample was placed under the CBR machine. The test followed IS: 2720 (part-16) - 1987. The loads were recorded with the help of a calibrated proving ring at different penetrations 0, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 7.5, 10, and 12.5mm of soil sample. Figure 4.1a shows the testing in progress of sample for CBR value and figure 1 (c) c is soaking the sample up to 96 hours and expansion of soil sample also recorded at different time interval.

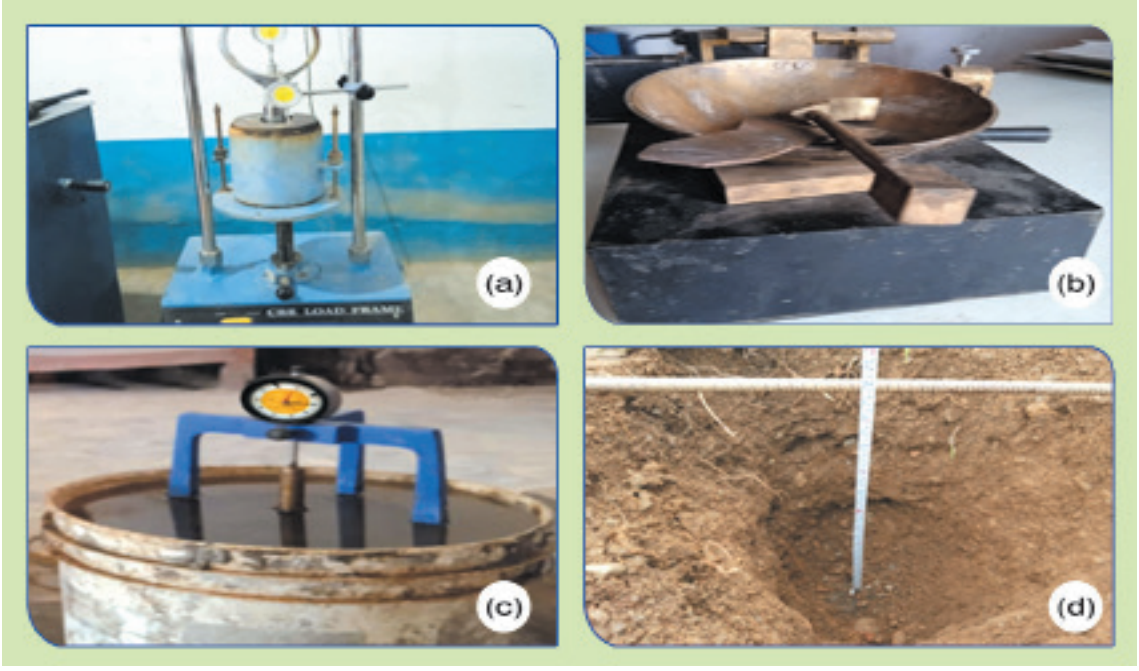

Figure 1: Sampling and Testing. (a) CBR testing of samples, (b) Casagrande testing devices, (c) Soaking of Sample, (d) Sample taking from site,

RESULT AND DISCUSSION

Summary of the experiments

Table 1 shows the summary of all the tests of all the samples performed. The detail multiple regression analysis was done by using these variables.

Table 1: Summary of All Laboratory Test Results

Sample No.	Liquid Limit %	Plastic limit %	Plasticity Index %	OMC %	MDDgm/cc	CBR%
1	30.46	23.42	7.04	19.00	1.66	2.04
2	22.92	20.95	1.97	14.00	1.84	20.44
3	34.06	27.61	6.45	13.00	1.82	12.17
4	30.248	21.84	8.40	15.00	1.86	19.46
5	33.49	27.07	6.42	15.00	1.92	29.19
6	36.79	27.47	9.32	23.00	1.52	7.055
7	26.78	25.88	0.90	22.00	1.54	7.542
8	31.86	24.40	7.46	18.00	1.63	3.406
9	35.1	29.12	5.98	21.00	1.57	8.759
10	25.33	20.65	4.68	15.00	1.73	7.056
11	23.08	19.74	3.34	14.00	1.86	21.411
12	23.2	21.42	1.78	15.00	1.76	10.706
13	20.41	19.75	0.66	14.00	1.77	18.979
14	27.96	20.60	7.36	15.00	1.81	3.309
15	30.06	23.59	6.47	16.00	1.79	21.411

Source: (Lab test, 2022)

Regression Analysis and Correlations

The strategy for relapse investigation was utilized to create the direct or bend relationship which gives the best fit through a bunch of data of interest. Relapse and connection is areas of strength for a method, which is utilized in the field of designing examination and researching the connection between at least two factors. This essential methodology is appropriate in circumstances going from single straight relapse to more sophisticate non-direct numerous relapses. All that fit model could be as a straight, explanatory, or logarithmic pattern. A direct relationship was typically rehearsed in tackling different designing issues in view of effortlessness. Fitting a regression model requires several assumptions. The method of least squares is used to choose the best-fitting line for a set of data.

The regression model performs as a predictor of the dependent variable. The regression is to compute the reduction in the sum of squares of deviations that can be attributed to regressor variables and this quantity is termed as the coefficient of determination, R2. The value of R2 is always between 0 and 1 because R is between -1 to +1, whereby a negative value of R indicates an inverse relationship and a positive value implies a direct relationship. Some problems in engineering require that we decide whether to accept or reject a statement about some correlations. Several techniques are available to judge the adequacy of a regression model some are significant level P-value, R-squared value (R2), R2-adjusted, and the t-test.

Regression Between CBR and MDD

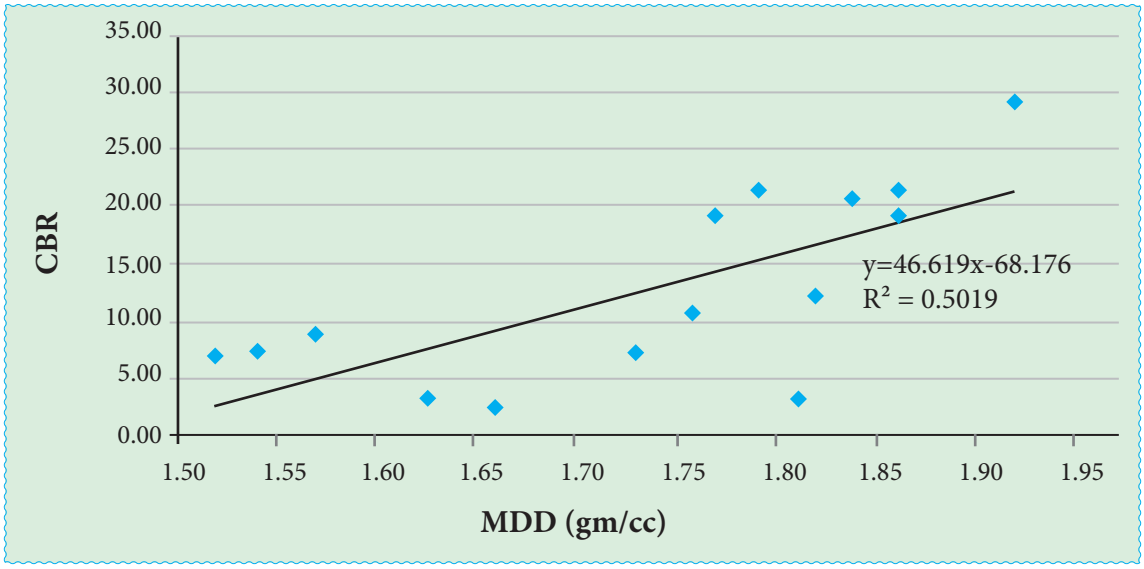

Figure 2: Overall MDD and CBR Relationships

From Figure 2 CBR vs. MDD graph, it can be stated that there exists a direct linear relationship between the CBR and MDD. The coefficient of determination R2= 0.501 between variables means that the regression line moderately fits with the collected data. From the observation of the data the CBR value and MDD value of the collected soil sample are 50.1% related. Thus, the relation 46.61 MDD – 68.17 = CBR, holds moderately.

Correlation Between Lab CBR and Predicted CBR.

The correlation between the lab-tested CBR and predicted CBR is shown in Figure 3. In which a strong correlation between Lab tested CBR values and predicted CBR values with a coefficient of determination of 0.869 is observed. Thus, the prediction of the actual lab CBR can be made with an equation:

Lab CBR = 0.996 CBRPredicted- 0.279.

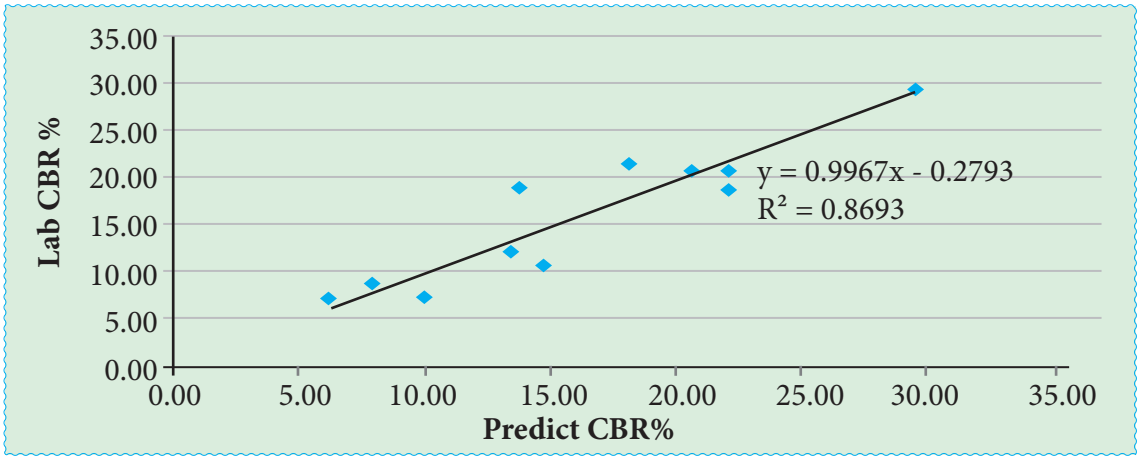

Figure 3: Lab CBR and Predicted CBR Relationships

Multiple Correlation and Regression

Table 2: Multiple Linear Regression Analysis

SN	Correlation	Total sample	R	R2	P-value
1	CBR = 0.72PL-1.22PI+2.34OMC+106.97MDD-222.46	15	0.862	0.744	0.005
2	CBR =-1.22LL+1.94PL+2.34OMC+106.97MDD-222.46	15	0.862	0.744	0.005
3	CBR = -1.01PI+2.86OMC+110.87MDD-222.05	15	0.838	0.702	0.003
4	CBR = 1.14PL-0.95PI+57.95MDD-108.86	15	0.801	0.643	0.008
5	CBR = -0.27LL+2.5OMC+100.79MDD-196.06	15	0.788	0.621	0.011
6	CBR = 2.01OMC+93.15MDD-182.45	15	0.776	0.602	0.004

Using the data analysis tools on the recorded data, the different multiple regression equations were developed. Table 2 presents different sets of regression equations between different soil parameters and CBR values. The Plasticity Index is dependent on the Liquid Limit and Plastic Limit since the plasticity index is the difference between the liquid limit and plastic limit. Thus, no relation is produced with all these three variables together, liquid limit, plastic limit, and plasticity index. As per Table 2 the regression equation CBR = 0.72PL-1.22PI+2.34OMC+10 6.97MDD-222.46, which was the best-fitted model equation. In this model, the value of R is 0.862 which means there exists a strong linear correlation between the independent variable CBR value and other dependent variables PL, PI, OMC, and MDD. The coefficient of determination R2 is 0.744 and the level of significance P-value is 0.005 for the equation. Because the plasticity index is dependent on the liquid limit and plastic limit, the regression equation provided in SN 2, i.e., CBR = -1.22LL+1.94PL+2.34OMC+106.97 MDD-222.46, gives the same value of R, R2and significance level P-value of 0.005 as that of the equation provided in SN 1 of the table i.e., CBR = 0.72PL-1.22PI+2.34OMC+106.97MDD-222.46.

The multiple regression equation between the dependent variable CBR and independent variables Plasticity Index, Optimum Moisture Content, and Maximum Dry Density was found as CBR = -1.01PI+2.86OMC+110.87MDD-222.05, which depicts the strong relationship between dependent and independent variables. This is shown by the value of linear correlation coefficient R of 0.838, R2of 0.702, and significance level, P-value of 0.003.

The regression equation, CBR = 1.14PL- 0.95PI+ 57.95MDD -108.86, where the independent variables are Plastic Limit, Plasticity Index, and Maximum Dry Density whereas the dependent variable is CBR. This equation is another best-fit model equation. The linear correlation coefficient R is 0.801, whereas R2 is found to be 0.643, and the significance level, a p-value is 0.008 for the equation.CBR = -0.27LL+2.5 OMC+100.79MDD-196.06, in this regression equation the value of R is0.788, R2is 0.621, and the significance level, P-value was 0.011. It means that this fitted model gives a moderate linear relationship between the dependent and independent variables.

A relation produced, CBR = 2.01OMC +93.15MDD-182.45 equation, the value of R of 0.776, R2of 0.602 and significance level, P-value of 0.004 was observed. It means that this fitted model gives a moderate linear relationship between the dependent and independent variables, where the independent variables are OMC and MDD.

CONCLUSION

California Bearing Ratio (CBR) is the numerical parameter of soil, which is obtained from the laboratory test. CBR value plays important role for the analysis of stability and durability of the flexible pavements. Finding the soaked CBR value for the design of flexible pavement with collected soil samples are always more time consuming and laborious. Thus, to predict CBR with soil index properties with a regression equation, this study was conducted. Different laboratory tests were conducted on collected soil samples from different places of Chitwan, and Makwanpur district. From the result of this study, the following conclusions can be drawn:

- The multiple correlations between the CBR and PL, PI, OMC, and MDD observed a strong correlation. The multiple linear regression equation that can be utilized for predicting was observed as CBR = 0.72PL – 1.22PI + 2.34OMC + 106.97MDD - 222.46. The coefficient of determination value R2 was 0.744 and the significant level, P-value was observed as 0.005 for the equation.
- The multiple correlations between the CBR and PI, OMC, and MDD was strong and observed as CBR= -1.01PI+2.86OMC+110.87MDD-222.05as well. The coefficient of determination value R2was 0.702 and the significant level, P-value was 0.003. Hence, this result could also be utilized for determining the CBR value.
- The multiple correlations between the CBR and PL, PI, and MDD were seen as strong and the correlation equation was CBR = 1.14PL-0.95PI+57.95MDD-108.86. The coefficient of determination value R2 was 0.643 and a significant level, P-value was observed as 0.008. Hence, this result could also be utilized for determining the CBR value.
- The multiple correlations between the CBR and LL, OMC, and MDD was observed as CBR =-0.27LL+2.5OMC+100.79MDD-196.06 were seen as strong with the value R2 was 0.621 and a significant level, P-value was observed as 0.011. Hence, this result could also be utilized for determining the CBR value.
- The multiple correlations between the CBR and OMC, and MDD were also seen strong. And the regression equation was CBR = 2.01OMC+93.15MDD-182.45. The coefficient of determination value R2 was 0.602 and the significant level, P-value was 0.004. Hence, this result can also be utilized for predicting the CBR value.

RECOMMENDATIONS

After carrying out this study, the following suggestions and recommendations are suggested for further study:

- The multiple regression equation between CBR and soil index properties can be used to determine the CBR value for different types of soil.
- It is advisable to conduct a comparative correlation between the soaked and unsoaked sample's CBR value with soil index properties.
- The number of soil samples was small due to time constraints. Further, it is recommended to develop the correlation between CBR with index properties for different types of soil collecting and the number of samples more than 15.
- There may exist a relationship between DCPT and other soil parameters. So, the study on these aspects is recommended for further study.
- Based on regression and correlation analysis, it is recommended that a good measure of quality control in PI, MDD, OMC, and LL tests is significant in producing an estimate of CBR.

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