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Prediction of California Bearing Ratio from Consistency and Compaction Characteristics of Fine-grained Soils

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Abstract

Soil's characteristics are essential for the successful design of projects such as airports runway and flexible pavement. CBR (California Bering Ratio) is one of the significant soil characteristics for highways and airports projects. Thus, the CBR property can be used to determine the subgrade reaction of soil through correlations. Many of the soil geotechnical parameters such as compaction characteristics (Maximum Dry Density, MDD; Optimum Moisture Content, OMC), and consistency parameters (Liquid Limit, LL; Plastic Limit, PL; Plasticity Index, PI) can be in charge of changes that happen in soil CBR value. Soaked and/or non-soaked conditions of soils also affect CBR value. Hence, testing soils in a laboratory for CBR calculation is time-consuming that needs notable effort. Therefore, this study aims to generate some useful correlations for soil's CBR with compaction and consistency parameters for 85 samples of fine-grained soils. The study trials were applied on natural soil samples of various places in Sulaimani Governorate, Northern Iraq. Statistical analysis has been carried out by using SPSS software (Version 28). Soaked CBR is counted, which is important for conditions such as rural roads that remain prone to water for few days. Based on the statistical analysis, there is a significant correlation between LL, PL, PI, MDD, and OMC with CBR as the dependent variable as a single variable equation with R^2 of 0.7673, 0.5423, 0.5192, 0.6489, and 0.51, respectively. In addition, the highest value of R^2 correlation was obtained between CBR value with consistency and compaction properties as a multiple regression equation with R^2 of 0.82. The obtained equations for correlation purposes are successfully achieved and can be used, notably, to estimate CBR value.

Keywords: California Bearing Ratio, Geotechnical Properties, Correlation, Fine-grained Soils.

التنبؤ بنسبة تحمل كاليفورنيا من خصائص الاتساق والضغط للتربة ذات الحبيبات الدقيقة

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الخلاصة:

تعتبر خصائص التربة ضرورية للتصميم الناجح للمشاريع مثل مدارج المطارات والتبليط المرن. CBR (Bering Ratio) California هي إحدى خصائص التربة المهمة لمشاريع الطرق السريعة والمطارات. وبالتالي، يمكن استخدام خاصية CBR لتحديد رد فعل التربة من خلال الارتباطات. العديد من المعلمات الجيوتقنية للتربة مثل خصائص الرص (أقصى كثافة جافة، MDD، محتوى الرطوبة الأمثل، OMC)، ومعلمات القوام (حد السيولة، LL، حد اللدونة، PL، مؤشر اللدونة، PI) يمكن أن تكون مسؤولة عن التغييرات التي تحدث في قيمة CBR للتربة. تؤثر ظروف التربة المبللة و/ أو غير مغمورة أيضًا على قيمة CBR. ومن ثم، فإن اختبار التربة في المختبر لحساب CBR يستغرق وقتًا طويلاً ويحتاج إلى جهد ملحوظ. لذلك، تهدف هذه الدراسة إلى إنشاء بعض ارتباطات المفيدة ل CBR التربة مع معاملات الضغط والاتساق ل 85 عينة من التربة ذات الحبيبات الدقيقة. تم

تطبيق تجارب الدراسة على عينات تربة طبيعية من مناطق مختلفة في محافظة السليمانية شمال العراق. تم إجراء التحليل الأحصائي باستخدام برنامج SPSS (الإصدار 28) . يتم احتساب CBR المغمور، وهو أمر مهم لظروف مثل الطرق الريفية التي تظل عرضة للمياه لبضعة أيام. بناءً على التحليل الإحصائي، هناك ارتباط هام بين LL و PL و PI و MDD و OMC مع CBR كمتغير تابع كمعادلة ذات متغير واحد مع قيم ارتباط R^2 من 0.7673 و 0.5423 و 0.5192 و 0.6489 و 0.51 على التوالي. بالإضافة إلى ذلك، تم الحصول على أعلى قيمة ارتباط R2 بين قيمة CBR مع خصائص الاتساق والضغط كمعادلة انحدار متعددة مع R^2 بقيمة 0.82. تم تحقيق المعادلات التي تم الحصول عليها لاغراض الارتباط بنجاح ويمكن استخدامها، على وجه الخصوص، لتقدير قيمة CBR.

1. Introduction

A stable foundation is essential for successful sustainable projects such as buildings, roads and highways, dams, and other projects that utilize great earthwork. So, having reliable approaches are essential to obtain the required engineering properties for such projects. For the conduction of the current study, natural samples of soil of Sulaimani Governorate, Northern Iraq were gathered. Although the laboratory calculation of CBR is consuming of long time, tedious, and expensive, multiple tests need to be performed through the distance of pavement to obtain proper insight into the strength of the subgrade. This issue delays projects and increases their cost. Therefore, CBR values need to be predicted on the basis of simply determined and basic soil properties to save time and money.

Finding some empirical relationships to predict Soil's CBR property by utilizing the soil's consistency and compaction parameters is the aim of the current study. Most of the used soil data were obtained from Sulaimani Central laboratories for testing materials. Many researchers have studied soil CBR, for instant, Danistan and Vipulanandan [9] , Nugroho et al. [18], Maghdi and Zumrawi [15] studied clayey soils CBR property (soaked and non-soaked) as a function of some soils index parameters, namely: PI, natural moisture content, dry density, and void ratio. Their finding yielded in a good relation for CBR and PI.

The prediction of CBR of fine-grained soil as a function of Soil's consistency properties was considered in many studies such as Talukdar [29], and Saklecha et al. [25], Roy [23], Bassey et al. [7], Farias et al. [10], and Torgano et al. [35], their results reveal that correlations of CBR with LL, PL, and PI as a single variable were concluded to be relatively negative in the prediction of the real CBR value cannot be from those limits. However, good correlations for prediction of CBR value from LL, PL, PI, OMC, and MDD with as a single variable equation were achieved by Kumar et al. [13], Prashanth et al. [21], Gudeta and Patel [11], Mishra and Tegar [16], Priya et al. [31], and Katte et al. [12]. Moreover, various indx parameters such as specific gravity (G), coefficient of uniformity (Cu), coefficient of curvature (Cc), liquid limit (LL), plastic limit (PL), plasticity index (PI), optimum moisture content (OMC) and maximum dry density (MDD) for alluvial soil were correlated with CBR in the study of Alam et al. [1]. The study considered both soaked and un-soaked CBR values as a function of those index properties by utilizing Genetic Expression Programming (GEP), artificial neural network (ANN), and kriging methods. The study outcomes clearly reveal that for prediction of both soaked and un-soaked CBR values by using soil's index properties, the GEP, ANN, and kriging methods can be effectively employed. Singh [27] Utilized 16 natural soil samples from the Nagaon district of Assam for the purpose of soil properties correlation. CBR property was correlated with MDD, OMC, LL, PL, and PI. CBR value correlation with the soil index properties was conducted by multiple linear regression analysis (MLRA).

Patel and Desai [20] developed correlations between various soils' geotechnical properties such as MDD, OMC and CBR in soaked conditions. So, from multiple variable regression analysis, empirical correlations were developed, which were gained as results of soil's laboratory testing collected from different places in Gujarat, India. In addition, Muley and Jain [17] studied the poor soil's CBR after mixed with a stone dust. The study performed to obtain a correlation to predict the soil CBR. Moreover on correlation purposes, MLRA models were developed to determine correlations between CBR with soil index properties [6, 8, 21, 26, 27, 28 and 33].

This study aims to achieve valuable correlations between soil's CBR and other geotechnical properties, namely consistency and compaction parameters of locally available fine particles soils in Sulaimani Governorate, Northern Iraq. Hence, the allocated objectives of current work are:

- Development of equations for correlation purpose for soil's CBR with consistency and compaction parameters
- To compare the predicted CBR values (by developed regression equation) with the laboratory-determined CBR values.
- To find the linear correlation equation which is use for find necessary properties of sub-grade soils for other place.

2. Materials and Methods

Eighty-five natural samples of soil were taken from various selected parts of Sulaimani Governorate. Many Laboratory experiments were carried out such as those to obtain LL, PL, compaction characteristics and CBR. All these conducted experiments were followed the instructions for each test from the global ASTM specifications (Table 1). Both of linear regression analysis (simple) and MLRA are chosen and utilized to gain the required equation for prediction of CBR (soaked) from consistency and compaction parameters. So, for MLRA conduction, the values of soil's CBR considered as a dependent variable, while PI, PL, LL, OMC and MDD as the independent variables. Coefficient of determination (R^2) and root minimum square error (RMSE) are used as evaluation criteria to check the calculated empirical correlations between compaction characteristics versus index properties.

Table (1): Soil test standards used for testing the soil samples in this study.

Soil Test	Specification
Atterberg Limits	[3]
Modified Proctor Compaction	[4]
CBR	[5]

3. Results and Discussions

The studied soil samples of Sulaimaniyah governorate were found to be clayey or silty soil with low to high plasticity, which can be defined as low plasticity soil (CL) considering the Unified Soil Classification System (USCS) ASTM D-2487 [2]. Table 2 gives a list of the obtained statistical parameters and database results from the experimental work performed on 85 soil samples from Sulaimani City.

Table 2: Statistical parameters for the calculated geotechnical characteristics.

	Atterberg Limits			**Compaction**		**CBR value**
	LL	PL	PI	MDD	OMC	
Maximum value	49	34	19	2.122	21.2	17
Minimum Value	24	15	2	1.625	7.2	1.4
Range	25	19	17	0.497	14	15.6
Mean	39.76	26.96	12.73	1.79	15.5	4.82
Median	42	27	14	1.778	16	3.3
Mode	44	30	14	1.794	15.4	3
Standard dev.	6.41	4.473	3.473	0.105	3.12	3.53
Units	%	%	%	gm/cm^3	%	%

3.1 Linear Regression Analysis (Simple)

Figure 1 represents a graph, shows the soaked CBR significantly correlated with the liquid limit as a single variable. This is noticed from the achieved values of R^2 and RMSE, which were 0.767 and 1.69 respectively. Figure 1 clearly indicates that the higher LL caused a lower CBR. A higher LL value means that the clay fractions content is notable and active for water absorption naturally, which may cause the load-bearing capability of the soil to decrease. Therefore, for smaller LL, higher CBR was obtained. The mathematical relation between the two parameters is shown in Equation (1). Similarly, the mentioned relation are also reported in several studies, however current study's results are higher than the results of developed relations by Talukdar [28], Saklecha et al. [25], Roy [23], Farias et al. [10], Bassey et al. [7], and Torgano et al. [30]. In those studies, it is concluded that the CBR and liquid limit correlations are relatively negative, in addition to prediction of the real CBR value, the limit cannot be utilized. In contrast, the result of Prashanth et al. [21], and Mishra and Tegar [16] were higher compare with the result of this study. Those studies outcomes were proved by depending on mathematical modeling through using practically-determined CBR value. Moreover, the considered soils in the current study have low to medium plasticity characteristics representing the real field states of those soils available in general in Sulaimani Governorate, Northern Iraq. Therefore, the achieved good correlations with CBR means that those obtained equations can be successfully working for CBR values determination for low to medium plasticity soils.

CBR (soaked) = -0.4829 LL+24.018……….. (1)

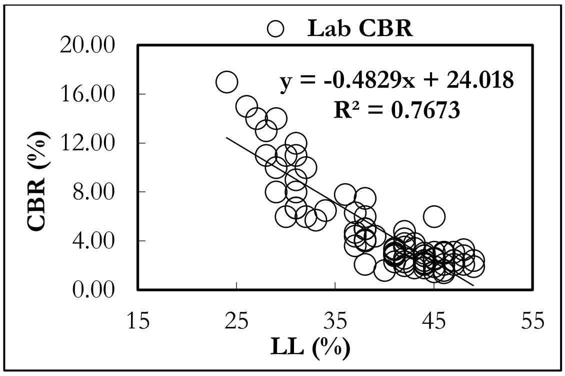

Figure 1: Relationship of CBR with LL of the soil samples.

The relation between CBR and PL is also considered and given in Figure 2, which can be represented by the following equation with coefficient of determination (R^2) and the lower value of RMSE equal to 0.58423 and 2.37, respectively. The mathematical relation between the two parameters is shown in Equation (2). Clay mineral types and percent may be responsible for this type of relationship. The testing procedure and methods may affect the accuracy of the collected data and correlation success. Other factors, such as particle size and shapes, distribution of voids and availability of various minerals, may play a notable role. This study result is larger than the result obtained in the study of Roy [23], Bassey et al. [7], Priya et al. [31], and Torgano et al. [30], negative correlations between plasticity index and CBR was observed. The present study outcome is less than the achieved result by Prashanth et al. [21], Mishra and Tegar [16], which were achieved R^2 values of 0.757 and 0.934, respectively.

CBR (Soaked) = -0.5815 PL + 20.497 ………… (2)

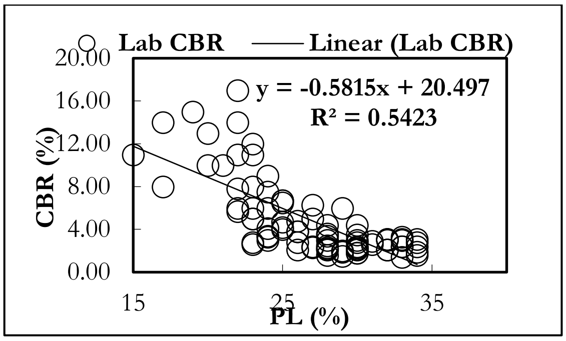

Figure 2: The soil samples CBR and PL relationship.

The variation of PI with CBR values as a single variable shown in Figure 3. The obtained correlation is weak and CBR value is not proposed to be computed from PI. This weak relation may be due to clay mineral types and percent. The testing procedure and methods may affect the accuracy of the collected data and the correlation success. The availability of various types' minerals may also play a notable role. From Figure 3 it has been observed that CBR value decreases with increase in the value of plasticity index of soil. R^2 values for Eq. 3 (see Table 3 for statistical parameters) was 0.5192, which is above 50% implies that a notable correlation between independent and dependent variables in this study. This achievement agrees with the achieved results in the studies of Prashanth et al. [21], Mishra and Tegar [16], Gudeta and Patel [11], and Priya et al. [31]. However, several studies' outcomes showed that the relationship by utilizing plasticity index parameter cannot be accurately used to predict the values of soaked CBR (Roy [23], Bassey et al. [7], and Torgano et al. [30]).

CBR (Soaked) = - 0.7331PI + 14.148 …….. (3)

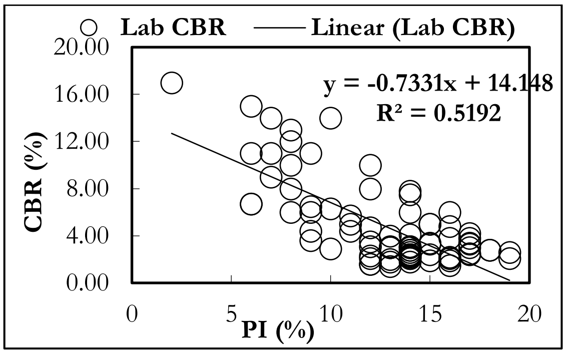

Figure 3: Relationship of the soil samples CBR and PI.

Reliable correlations between the soil samples CBR values and OMC were obtained and shown in Figure 4 and Equation (4). The correlation for this figure can be given by the linear equation with the value of R^2 and RMSE equal to 0.51 and 2.46, respectively. The correlation between CBR and optimum moisture content was found significant (Figure 4) indicating that density influences the CBR value with the increase in the required OMC to obtain a reliable dry density. This indication is important for the foundations of construction projects; the soil sample provides a vast room for water absorption due to the available clay fractions in the soil sample, that way saving plenty of water in the diffuse layers of the soil sample. Hence, if the soil sample absorbs a large amount of water, then a high degree of particle lubrication and weak resistance to applied forces are possible, as noted in the correlation with CBR values. A negative correlation by several studies (Bassey et al. [7], Farias et al. [10], Torgano et al. [30] and Priya et al. [31]) was found for OMC and CBR values, and OMC cannot be utilized accurately in the prediction of the CBR value, which disagrees with the outcomes of the current study. The results of this study were compiled with the achievements of several studies such as Lakshmi et al. [14], Prashanth et al. [21], Roy [23], Mishra, and Tegar [16].

CBR (Soaked) = - 0.8079 OMC + 17.338 …….. (4)

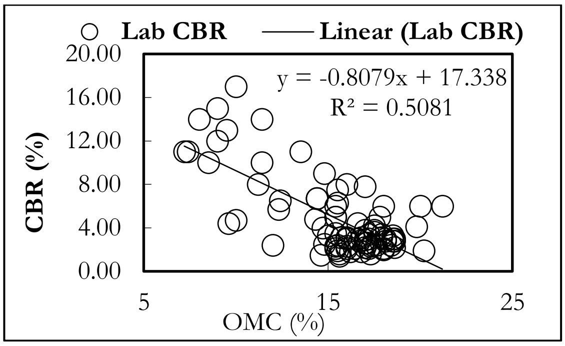

Figure 4: Relationship of CBR and OMC of the soil samples.

To focus on the required correlations for CBR values of the soil samples with the other geotechnical parameters, Figure 5 was prepared, which presents the correlated CBR values with MDD obtained from modified Proctor compaction test. From the figure and according to the good values of R^2 and RMSE (add values of R^2 and RSME), there is an acceptable correlation was obtained between MDD and CBR as a single variable equation. Logically, with the increase in MDD, the compacted sample is more capable of resisting the application of load, especially vertical ones. Thus, the resistance increases as the density increases. However, the value of R^2 is not very high, which may be caused by some factors such as availability of clay minerals, their types and percent, testing procedure and methods, particle size and shapes, distribution of voids and availability of various minerals. Such factors may play a role in decreasing the accuracy of the obtained relationship. The findings of several studies such as Lakshmi et al. [14], Roy [23], Prashanth et al. [21], Mishra and Tegar [16] are in line with the achieved relationship shown in Figure 5, and Equation 5 of the current study. While, the mentioned relationship disagrees with the achievements of other studies such as Bassey et al. [7], Farias, et al. [10], Torgano et al. [30], Priya et al. [31], which concluded that there is no correlation between MDD and CBR values.

CBR (Soaked) = 27.094 MDD – 43.714 ……….. (5)

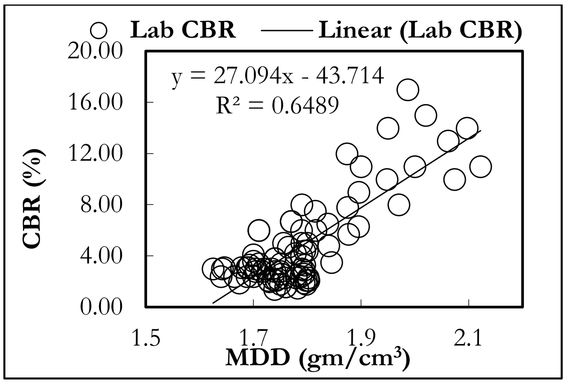

Figure 5: CBR values correlation with the soil samples MDD.

3.2 Multiple regression analysis

To achieve the more on the required objectives of current study, Tool Pak of Microsoft Excel was utilized for the data analysis purpose to gain a regression model (multiple).

Therefore, the following gained equation represents the successful outcome of the conducted analysis:

CBR = 4.32 - 0.13662 PI - 0.01607 PL + 0.26614 LL - 0.13504 OMC + 8.563 MDD ……………. (6)

The coefficient of correlation (R^2) and RMSE for the above equation are 0.82 and 1.47 respectively. Hence, the equation effectively correlates the CBR value with other soil properties. In order to validate and check the successfulness of the obtained equation, Figure 6 was prepared. The determined CBR values obtained from the experiments carried out in a soil laboratory and the computed CBR values from Equation (6) were notably have similar behavior. A good correlation for CBR determination from five other geotechnical properties was obtained; thus, CBR cannot be predicted without testing. The testing accuracy seems to be significantly controlled. Thus, the soil type may work smoothly with the addition of water for those tests. The CBR values that calculated from the laboratory experiments are generally in agreement with the computed ones from the proposed Equation 6. However, a few points showed less agreement. This condition means that the CBR value can be determined from empirical equations successfully, which is the main goal of this study. Table 3 shows the summary of the developed empirical equations between consistency and compaction characteristics to predict the CBR value carried out in this study.

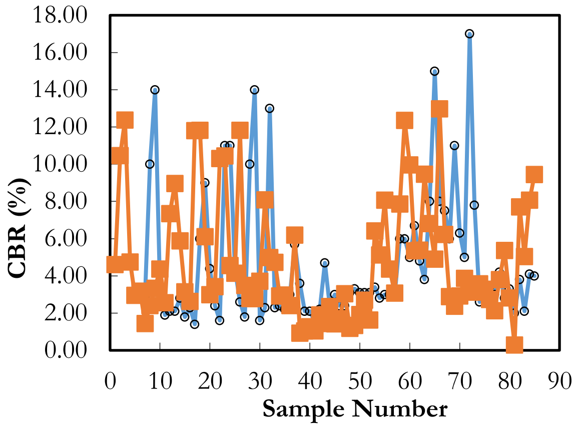

Figure 6: Comparison between predicted and computed CBR values of the soil samples.

Table 3: Summary of the developed single and multi linear regression analysis to evaluate the CBR value.

Equation	*R^2*	*MAE*	*RMSE*	*MSE*	*MAPE*
CBR= - 0.4829 LL+24.018	*0.7673*	*1.35*	*1.69*	*2.86*	*35.74*
CBR = - 0.5815 PL+20.497	*0.5423*	*1.84*	*2.37*	*5.64*	*48.52*
CBR = - 0.7331PI + 14.148	*0.5192*	*2*	*2.4*	*5.92*	*55.4*
CBR = - 0.8079 OMC + 17.338	*0.5081*	*1.85*	*2.46*	*6.1*	*51.37*
CBR = 27.094 MDD – 43.714	*0.6489*	*1.66*	*2.1*	*4.3*	*48.88*
CBR = 4.32 - 0.13662 PI - 0.01607 PL + 0.26614 LL - 0.13504 OMC + 8.563 MDD	*0.82*	*1.19*	*1.47*	*2.16*	*34.63*

4. Conclusions

Eighty-five natural samples of soil were taken from various selected parts of Sulaimani Governorate and utilized for soil's CBR correlation with consistency and compaction parameters. The following conclusions can be drawn based on the outcomes of current study:

- Consistency parameters (LL, PL, and PI) have a notable impact on CBR values, which yielded in CBR decrease with increases of those parameters. Significantly, the correlations are suitable for low to medium plasticity soils.
- Compaction parameters (MDD and OMC) have also significant influences on the CBR values. OMC increase decreases CBR. While, MDD increase increases CBR values.
- A slight difference exists between the laboratory CBR and multiple linear regression models' CBR obtained from correlations of CBR values with consistency and compaction parameters.

- Significant coefficient of variation (adjusted R^2) can be achieved (0.81) when CBR correlated with consistency and compaction parameters.
- From the utilized data and obtained equations, the obtain correlation equation can be used successfully to evaluate different values of soil's CBR, especially for low to medium plasticity soils.

Table 3: List of symbols/Abbreviations.

Symbol	Description
ASTM	American Society for Testing and Materials
LL	Liquid limit (%)
MDD	Maximum dry density (gm/cm^3)
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MSE	Mean Squared Error
OMC	Optimum moisture content (%)
PL	Plastic limit (%)
PI	Plasticity index (%)
R^2	Coefficient of determination
RMSE	Root mean square error
CBR	California bearing ratio (%)

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