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Predicting California Bearing Ratio (CBR) Value of a Selected Subgrade Material

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Abstract. The subgrade bearing capacity is an important parameter in flexible pavement design, and it is largely influenced by the variation of subgrade moisture. California Bearing Ratio (CBR) is the most popular method of assessing the subgrade bearing capacity. It compares the load required to make a particular penetration on a given subgrade with the load to make the same penetration on standard material. Although it would be beneficial to perform CBR tests at more frequent intervals on a road section to design, it would not be practical in certain instances owing to the laborious and time-consuming CBR test process. In that case, developing a method to predict the subgrade CBR based on the variation of moisture would be an advantage. Accordingly, this study aims to assess the influence of moisture content and the compacted density on the subgrade CBR value. Hence, the possibility of developing a model to predict subgrade CBR was investigated. A series of standard CBR tests were performed for different combinations of moisture and compaction densities, and standard CBR values were estimated. Thereafter, a statistical model was developed to predict the CBR value for the selected clay material and validated with laboratory test results.

Keywords: Pavement Engineering, Pavement materials, Unsaturated soils, California Bearing Ratio, Subgrade, Subgrade Moisture.

1 Introduction

A well-connected transportation network plays a vital role in the economic development of a country[1-3]. In such networks, road and rail links establish connections between major cities to facilitate logistics and to commute. These networks should be constructed not to fail before the end of design life and, therefore, need a strong subgrade as the foundation of constructing resilient roads and rail lines[4]. Overestimation of subgrade condition would develop an inadequate design to bear traffic loads and, as a result, will induce early pavement distresses. Underestimation of the subgrade condition would lead to the decision that the subgrade is weak and hence, would recommend weak subgrade improvements, such as geogrid reinforcement and increasing granular cover[5-8], which could create unnecessary demand for resources[9, 10]. Therefore, an accurate subgrade assessment will ensure a long-lasting pavements and railroads.

California Bearing Ratio(CBR) test is the most popular method being used to assess the bearing capacity of subgrades[11, 12]. This was first developed by the California Division of Highways in 1920 and subsequently adopted by most of the transportation agencies for subgrade assessment [13, 14]. In some instances, researchers have used the CBR test to assess the stability of recycled concrete aggregates[15]and stress-strain stage of railroad subgrades[16, 17]. Although CBR is not a fundamental material property that can be incorporated in mechanistic-empirical road design methods, its simplicity and inexpensiveness have made it a popular test for subgrade assessment[13]. Moreover, Austroads pavement design guidelines assume tenfold of subgrade CBR as the resilient modulus in the absence of experimentally estimated subgrade resilient modulus for mechanistic-empirical pavement design[18].

Usually, the CBR test is performed multiple times and obtain the average to eliminate test errors. Also, in order to assess the existing subgrade condition of a road section to be designed, the CBR test has to be performed at multiple locations with a reasonable gap. Despite doing CBR tests at more frequent intervals with repetitions would be beneficial, number of tests must be limited owing to the time and labour requirement. In that case, a prediction model could be helpful to assess the subgrade while reducing the number of CBR trials[19]. Moreover, prediction models could also be helpful to estimate the variation of CBR with changes to soil properties. Subgrade conditions drastically change with the variation of groundwater height and the presence of expansive clay type soil[20, 21]. This condition is prominent in Queensland, Australia [22-28], and as a result, weak subgrades have become a frequent challenge in road construction[29]. With the support of prediction models, variation of CBR can be pre-assessed for design processes while estimating the current condition with laboratory experiments[13].

In literature, researchers have found that subgrade CBR depends on soil properties: such as optimum moisture content, liquid limit, plastic limit, plastic index, shrinkage limit and density[13, 14, 30-32]. Even though the relationship between the CBR and the soil properties is complex to be defined, studies have reported that multiple linear regression method and the Artificial Neural Network(ANN) method can effectively be used to predict subgrade CBR from soil properties with reasonable accuracy[11, 13, 19, 33]. However, the developed models have their own limitations and needs to be calibrated for different conditions if required to be used.

This study has been conducted as a part of a large-scale laboratory plate load testing project to evaluate the performance of geogrid reinforced flexible pavements. In order to create a subgrade of a predetermined bearing capacity, it is required to know the relationship between the bearing capacity of the subgrade and its properties. Otherwise, a large number of standard CBR trials has to be performed to determine required subgrade properties for desired bearing capacity. Accordingly, this paper reports the development of a statistical model to predict unsoaked CBR by considering subgrade soil properties as input variables. The scope of the study is limited to one clay type soil. Moreover, only the moisture content of subgrade soil and the Degree of Compaction

(DOC) of the subgrade have been selected as independent variables to develop a prediction model.

2 Materials and Testing

2.1 Subgrade Soil

The subgrade soil was collected from a road construction site in Queensland, Australia. Standard procedures specified in the Material Testing Manual(MTM) of Queensland Department of Transport and Main Roads[34] were followed to determine the basic soil properties listed in Table 1. This subgrade soil can be classified as high plastic silt as per the Unified Soil Classification System (USCS). Furthermore, it also matches with classification A-7-6 of the AASHTO soil classification method.

Table 1: Properties of subgrade soil

Soil Property	Value
Soil Particle Density	2.62
Maximum Dry Density (g/cm^3)	1.316
Optimum Moisture Content (%)	32
Liquid Limit (%)	73
Plastic Limit (%)	53
Shrinkage Limit (%)	20
D_{10}(mm)	0.00081
D_{30}(mm)	0.0085
D_{60}(mm)	0.041
Coefficient of Curvature (Cc)	50.62
Coefficient of Uniformity (Cu)	2.18
USCS Classification	**MH**

The standard proctor compaction test was conducted, following Q142A standard procedure stipulated in MTM[34], aiming to estimate the relationship between the dry density and the moisture content for the selected subgrade soil. Figure 1 illustrates the compaction curve of the subgrade soil. Moreover, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the subgrade soil was determined as 1.3 g/cm^3 and 33%, respectively.

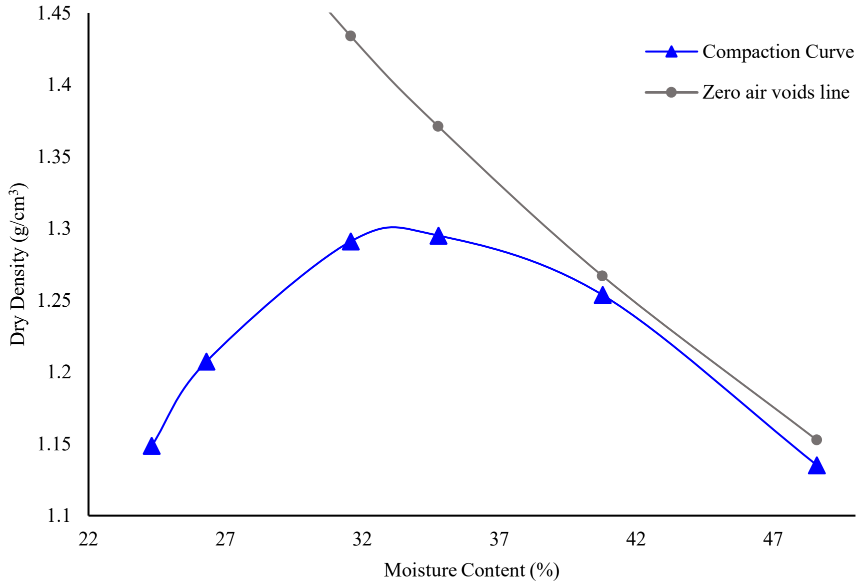

Figure 1: Dry density vs moisture content of subgrade soil

2.2 Standard CBR Testing

The subgrade soil was oven-dried at 60 degrees of Celsius for three days to remove the moisture. Thereafter, subgrade soil was mixed with water in small batches, and water content for each batch was changed to achieve different soil moisture contents. In this study, the moisture content was varied between 30% and 50%. The mixed soil was sealed in polythene bags and cured for 7 days as considerable time is required for clay type soil to equalise moisture throughout the bulk.

The prepared clay soil was used to create subgrades, with known moisture content and density, inside the standard CBR mould. The DOC was maintained between 80% and 100%. First, as the moisture content of the subgrade soil and the volume of the standard CBR mould is known, the required weight of the mixed subgrade soil to achieve the desired degree of compaction was calculated. Then, the measured soil was compacted inside the CBR mould in three equally thick layers. Thereafter, annular weights were placed on the top surface, and the sample was tested in Instron machine as shown in Figure 2. The CBR of each trial was calculated based on standard calculation procedure of Q113A in TMR specification[34] using the load-deformation data recorded from testing. The results of the 26 trials are listed in Table 2.

Figure 2: Performing standard CBR test using Instron machine.

Table 2: Results of CBR trials

Test No	Moisture (%)	Density(g/cm^3)	D.O.C. (%)	Measured CBR (%)
1	30.9	1.33	102	7.4
2	37.0	1.04	80	3.5
3	37.0	1.11	85	3.8
4	37.0	1.17	90	5.7
5	37.0	1.24	95	6
6	37.6	1.10	85	4
7	37.6	1.17	90	3.5
8	37.6	1.23	95	4.5
9	37.6	1.29	100	6.8
13	41.9	1.12	86	4.3
14	41.9	1.19	91	4.7
15	41.9	1.25	96	5.1
10	43.0	1.10	84	4.3
11	43.0	1.16	89	3.6
12	43.0	1.23	94	5.1
16	43.7	1.12	86	3.4
17	43.7	1.19	91	3.4
18	43.7	1.26	97	5
19	47.9	1.11	85	2.6
20	47.9	1.17	90	3.5
21	47.9	1.24	95	4.1
22	48.9	1.11	86	2.6
23	48.9	1.18	91	3
24	48.9	1.24	96	3.5
25	50.3	1.13	87	2
26	50.3	1.20	92	1.9

3 Statistical Analysis

The results from CBR trials were analysed using the regression method to understand the correlations between selected subgrade soil properties and subgrade bearing capacity. Hence, a bearing capacity prediction model was estimated. Initially, simple linear regression was applied, selecting one subgrade property as an exogenous variable and the estimated CBR value as an endogenous variable. Thereafter, the multiple linear regression method was considered selecting both subgrade moisture(%) and DOC(%) as independent variables while subgrade bearing capacity (CBR) as dependent variable. All 26 observations in Table 2 were used for both simple and multiple linear regression analysis.

3.1 Simple Linear Regression Models

First, the moisture content was selected as the independent variable and the estimated subgrade CBR as the dependent variable. The model equation is expressed by Eq. 1 and also illustrated in Figure 3. This model estimated a linear relationship between subgrade CBR and the moisture content with Multiple R=0.7404 and R^2=0.5482. Multiple R > 0.5 implies that moisture content has a strong relationship with subgrade bearing capacity. The p-values of all mode coefficients are less than 0.05, which indicates that the estimated linear model is statistically significant (α<0.05). However, R^2 value confirms that this model can only explain 54.8% of subgrade CBR variance only.

$$CBR = 12.23 - 0.19(Moisture) \quad (1)$$

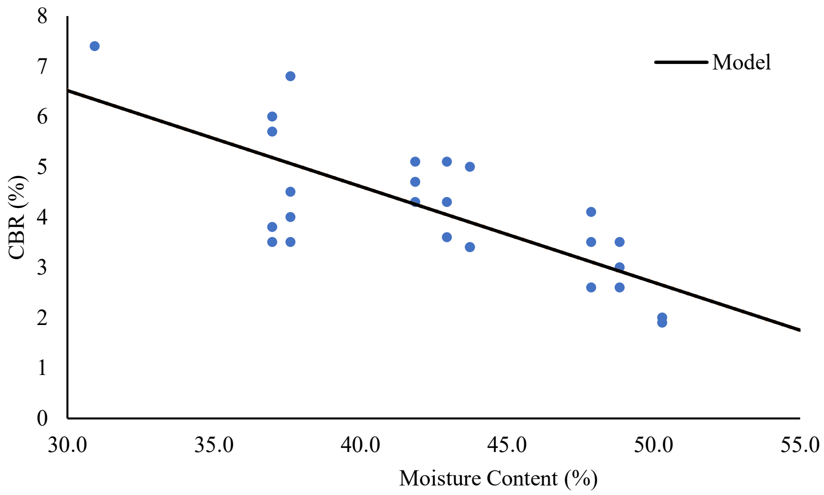

Figure 3: CBR (%) vs Moisture Content (%)

In the second analysis, the DOC and subgrade bearing capacity were selected as independent and dependent variables, respectively. Eq. 2 defines the model equation with Multiple R=0.6329 and R^2=0.4006 and the linear relationship between two variables are illustrated in Figure 4. All model coefficients are statistically significant with p-value < 0.05. Although DOC has a great correlation with subgrade bearing capacity (Multiple R>0.5), the R^2 indicate that the DOC itself could explain 40% of the subgrade CBR only.

$$CBR = -10.42 + 0.16(DOC) \quad (2)$$

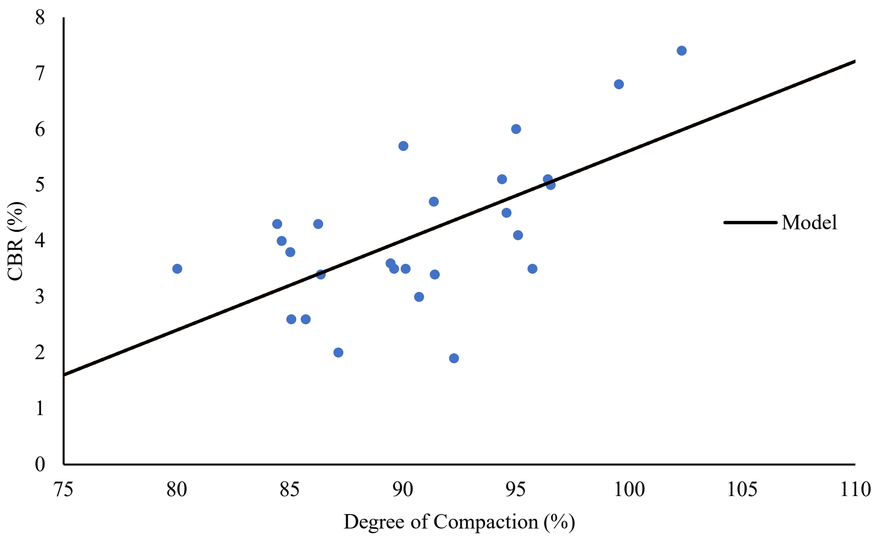

Figure 4: CBR (%) vs Degree of Compaction(%)

3.2 Multiple Linear Regression Model

The simple linear regression analysis in section 3.1 confirms that all estimated models are statistically significant and both moisture content and DOC have greater correlation with subgrade CBR. However, aforementioned estimation considered only one subgrade property as exogenous variable and hence, does not result powerful statistical models that can predict the subgrade bearing capacity with greater accuracy. This is due to the fact that subgrade CBR is dependent on both moisture content and DOC. Accordingly, multiple linear regression was applied by considering both moisture content and the DOC as independent variables while considering subgrade CBR as the dependent variable. The model equation is given in Eq 3 and the regression statistics are listed in Table 3. Accordingly, the MLM model can explain 82.4% of the CBR variation, which is high in accuracy compared to the case of simple linear regression models. Moreover, p values of the two independent variables estimated below 0.05 confirmed that both variables are statistically significant in MLM model.

$$CBR = -4.468 + 13.531(DOC) – 20.069(Moisture\ Content)^2 \quad (3)$$

Table 3: MLM Model Statistics

Regression Statistics		
Multiple R		0.9077
R Square		0.8239

Variable	Coefficients	P-value
Intercept	-4.4682	5.08E-02
D.O.C. (%)	13.5314	3.72E-06
Moisture Content (%)	-20.0692	1.47E-07

The estimated MLM model was further validated by performing Analysis of Variance (ANOVA) on regression results. The analysis compares the null hypothesis: subgrade CBR not related to the subgrade moisture content and the DOC, to the alternative hypothesis of subgrade CBR is dependent on these two variables. Table 4 summarises the results of ANOVA test. As the Significance F value records 2.11E-09, which is exceedingly lower than 0.01, the null hypothesis can be rejected with 99% confidence, supporting that the subgrade CBR is greatly dependent on moisture content and DOC. Hence, the developed multiple linear regression model is a valid prediction of subgrade CBR against moisture content and DOC.

Table 4: Results of ANOVA test

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	37.4654	18.7327	53.8177	2.11E-09
Residual	23	8.0058	0.3481		
Total	25	45.4712			

4 Validation

The developed subgrade CBR prediction model was validated by conducting another CBR test series with 10 experimental trials. The combination of the moisture content and the DOC for those trials are listed in Table 5. The Figure 5 illustrates the experimentally estimated CBR and the predicted CBR for the ten trials. The straight line represents the points where predicted CBR and experimental CBR are exactly same. Almost all points are closer to the straight line depicts that predicted CBR value is closer to the experimentally estimated value. Furthermore, the standard error of the predicted vs experimental CBR was estimated as 0.5141.

Table 5: CBR trials for validation

Test	Moisture Content (%)	DOC (%)	Predicted CBR (y)	Estimated CBR (y')	$(y-y')^2$
1	41.6%	95.3%	4.9	4.8	0.0205
2	38.4%	89.8%	4.7	4.4	0.1036
3	44.9%	94.4%	4.3	4.8	0.2901
4	46.0%	78.9%	2.0	2.7	0.5380
5	45.8%	90.1%	3.5	3.5	0.0003
6	47.3%	90.5%	3.3	3.5	0.0460
7	49.0%	84.4%	2.1	2.1	0.0016
8	52.5%	83.7%	1.3	2.6	1.6367
9	51.4%	85.9%	1.9	1.9	0.0021
10	49.2%	81.7%	1.7	1.8	0.0041
				Standard Error	0.5141

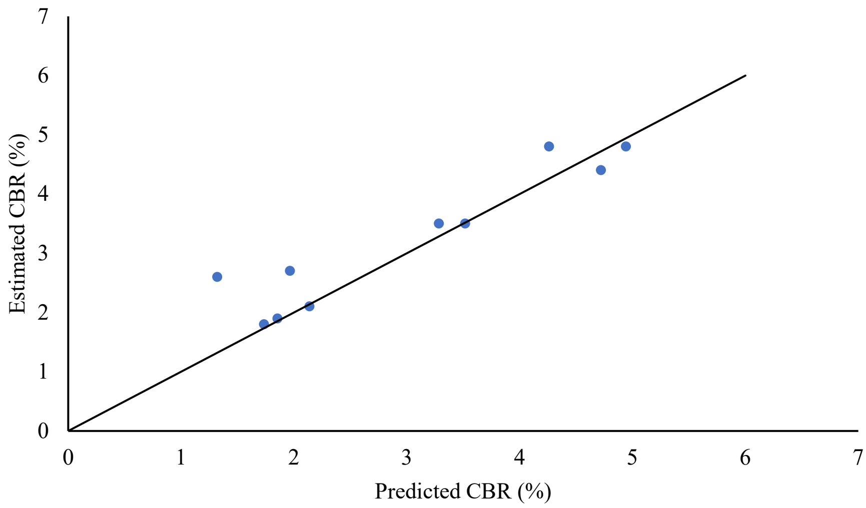

Figure 5: Estimated vs Predicted CBR

5 Conclusion

This study was aimed to develop a relationship between the subgrade moisture content and DOC with its unsoaked CBR value. The simple linear regression analysis indicated that moisture content and the DOC has a significant correlation with the unsoaked CBR of subgrade soil. A multiple linear regression model was developed with R^2=0.8239, selecting subgrade moisture and the DOC as independent variables to predict the unsoaked CBR of the subgrade. Additional 10 CBR trials were performed and obtained data to validate the proposed CBR prediction model, and it was confirmed that the proposed MLM model can predict CBR value with a standard error of 0.5141. Therefore, it can be concluded that MLM can successfully be used to develop statistical models to predict the unsoaked CBR of subgrades. Moreover, the proposed model could be used to estimate the unsoaked CBR of a subgrade, given that the subgrade soil moisture and the DOC are known. In addition, the prediction model could also be used to determine the required moisture content and the degree of compaction to create a subgrade of a known CBR value for laboratory testing purposes.

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