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Investigation of the correlation between California bearing ratio and shear strength of pavement subgrade material with different water contents

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Highlights

- CBR and shear strength of subgrade soil were found experimentally
- The effect of the water content on CBR and shear strength of subgrade soil
- A new correlation is proposed between CBR and shear strength values
- Prediction of CBR using the Hand Vane Shear test and existing correlations
- Comparison between experimental results and existing correlations

Abstract

In this study, CBR and Shear Vane tests, which are common test methods used in determining the bearing capacity and shear strength of the highway pavement subgrade material, were applied and the effect of the changing water content on the test results was investigated. It is aimed to determine the accuracy of these expressions by obtaining the bearing capacity parameters of the subgrade material with different water contents from laboratory experiments and comparing the results obtained with the empirical expressions in the literature. Shear strength and CBR values of five samples prepared at 15%, 16%, 17%, 18%, and 20% water contents were obtained experimentally. The experimental results obtained and the results calculated using the correlations found in the literature were compared. As a result of the study, the shear strength values obtained from the shear vane test, which is recommended to be preferred in terms of ease of application, were used in the selected correlation relations and CBR values were calculated. By comparing the experimental and calculated CBR values, the approximation accuracies of the existing correlation expressions were presented and it was seen that it was possible to find the CBR value with a maximum accuracy of 90%. In addition, this study presents a new correlation that gives the relationship between shear strength and CBR using the data obtained from the experimental results. With the new equation created; After the shear strength value was obtained experimentally, it was seen that the CBR value could be found with 96% accuracy.

Information

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1. Introduction

In recent years, considering the increase in road construction, the design of road pavements has become a widely studied problem, especially in terms of time and cost. For this reason, the analysis and characterization of the subgrade, which is one of the determining parameters in the characteristics of the pavement, continues to be the area of interest for many researchers [1-3].

The bearing capacity of the subgrade is determined by the California Bearing Ratio (CBR) Test method, which can be performed both in situ and in the laboratory. Determination of the mechanical properties of the subgrade, its bearing capacity, and another important parameter, the shear strength; Due to the properties of the material, it requires the solution of a problem in which complex behaviours are combined. For this reason, in this study, while determining the bearing capacity of the subgrade with the CBR test method, a second test method, the shear vane test, was applied to determine the shear strength.

In addition to being a test method that is generally applied in the field, the shear vane test has been widely used in recent years due to its ease of application and the fact that laboratory equipment is economical compared to CBR test equipment [4]. In the case of combined stress caused by the anisotropic nature of the subgrade and the loads it is exposed to, it is necessary to know the values

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that determine its behaviour against shear in calculating the bearing capacity [5]. For this reason, the shear vane test method, which is very convenient to be applied in laboratory conditions, was chosen and the shear strength of the subgrade was found.

Knowing the relationship between shear strength and bearing capacity becomes very important when considering the subgrade, whose properties are defined by the need for many experimental data. For this reason, many researchers have developed correlation expressions that give the relationship between bearing capacity and shear strength [6-8]. The creation of these correlations is very important in terms of easily calculating the sought value in cases where experimental studies cannot be performed. However, considering the subgrade whose behavioural characteristics change depending on many variables, the validity of the correlations requires the selection of the correct correlation and the minimum level of experimental data that can provide confirmation.

Considering that the California bearing ratio (CBR), which is directly related to the bearing capacity of a soil, varies depending on the moisture content and saturation level of the soil [9], 5 soil samples with different water content were tested in this study. Both CBR and shear vane tests of these prepared samples were performed and some of the correlation relations found in the literature and suitable for the material used in the study were selected, and the approximation percentages of the relations were calculated in the light of the experimental data. In addition, it has been seen that the shear vane test method can be used in cases where the CBR test cannot be performed, allowing the CBR value to be found through the relevant correlation relation.

2. Existing Correlations

For the design and analysis of road pavements, it is necessary to know the mechanical properties of the subgrade material. For this purpose, correlations between CBR and other soil properties have been developed as an alternative to many material tests by researchers [4,10,11]. Relationships between in-situ or laboratory CBR test and ultimate bearing capacity [9,12], CBR - modulus of elasticity relations [1,13], and CBR-shear strength relations [6,7,14] can be established through widely used correlations as a result of many studies developed and conducted. Therefore, the use of correlation relations developed instead of performing experiments that are difficult and costly in terms of implementation has been preferred by many researchers to determine soil parameters.

Since the soil has many variables due to its material structure, each correlation may not be suitable for a soil sample located in another region. For this reason, researchers working on this subject have carried out experiments using as many different variables as possible and obtained different correlations. One of the most important variables here; is the limit values of the soil sample studied [15, 16].

Correlations suitable for the classification and limit values of the soil sample used in this study were selected from the literature and these are mentioned below.

The first of the relations chosen is the correlation relation between shear strength and CBR (Equation 1), developed by Black [6] for remolded clay soil and based on the theoretical bearing capacity of the soil.

Giroud and Han [8] worked on the determination of the theoretically developed base layer thickness related to the failure modes of reinforced, unpaved roads and presented the equation given in Equation 2.

In the study by Rushema [16], some of the relationships between shear strength and CBR are discussed on the established accuracy rates. One of the correlation relations in this study, USCOE (US Army Corps of Engineers) was chosen and presented in Equation 3.

The statement developed by Gregory and Cross [7] and based on the theory of bearing capacity equality has been obtained by performing the triaxial shear test and CBR tests for cohesive inorganic soil material (See Equation 4).

$$\text{CBR}=0.043C_u \quad (1)$$

$$\text{CBR}=0.033C_u \quad (2)$$

$$\text{CBR}=0.0087C_u^{1.3723} \quad (3)$$

$$\text{CBR}=0.09C_u \quad (4)$$

The term C_u in the above equations is shear strength and is expressed in kPa.

3. Material and Methods

3.1. Material properties

In this study, low plasticity clay material obtained from the Isparta Airport region was used. The results obtained by performing Atterberg limit tests for the classification of this material taken from the subgrade and the material class determined accordingly are presented in Table 1.

As seen in Table 1, it was determined that the soil class of the selected material was low plasticity inorganic clay (CL).

Wet sieve analysis has been performed to determine the granulometry of the material and the results are shown in Table 2 and Figure 1.

Table 1. Subgrade soil Atterberg Limits

Liquid limit	46%	(TS 1900-1 AASHTO T-89)
Plastic limit	17%	(TS 1900-1 AASHTO T-90)
Plastic index	29%	(PI = LL - PL)
Soil classification	CL	Unified Soil Classification

Table 1. Sieve analysis results of subgrade soil (ASTM D1140).

Sieve No	Sieve Opening (mm)	Percent Passing (%)
3/8''	9.53	100.00
No 4	4.760	99.48
No 10	2.000	99.18
No 40	0.425	94.93
No 200	0.075	56.35

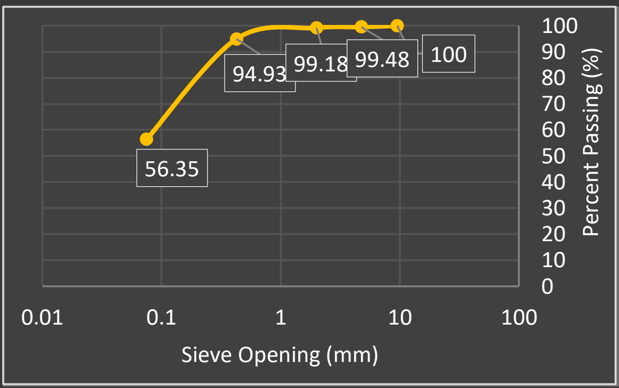

Figure 1. Granulometry curve of subgrade material

To determine the optimum water content of the material used in the tests, the Proctor test was performed and the dry unit weights (γ_k) at different water contents (ω) were determined (Figure 2).

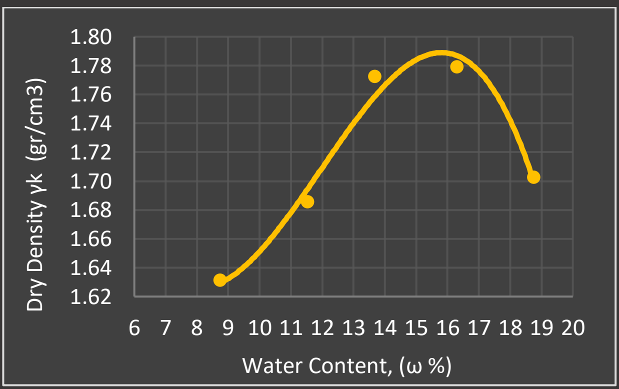

Figure 2. Moisture content-dry density relationship from standard Proctor tests

The results obtained from the Proctor test were taken into account while determining the water content of the samples that were subjected to CBR and shear vane tests.

3.2. Test Methods

In this study, two different test methods, CBR and shear vane test were used to determine the bearing capacity and shear strength of the soil sample at different water contents.

3.2.1. CBR (California bearing ratio) test

The CBR test is used to evaluate the bearing capacity of the subgrade, base and subbase layer materials in the road pavement. CBR is a test method that gives the ratio of the bearing capacity of the material to the bearing capacity of the standard crushed stone as a percentage [17].

Determining the CBR value in a construction zone requires a lot of effort in terms of sample supply. In addition, to carry out the test in a laboratory environment, it is necessary to know the soil class of the material and the parameters such as optimum water content. To determine these parameters, a series of pre-tests are required. All these situations create a disadvantage in terms of time and cost [18]. CBR test is a common test method that gives reliable results in the bearing capacity calculation. However, the disadvantages mentioned above have revealed the need to find alternative methods to CBR testing.

In this study, the above-mentioned preliminary experiments were carried out to perform the CBR test and the relevant parameters were obtained. Samples prepared in five different water contents were compressed into CBR molds by ASTM D1883-16 standard and tests were carried out (Figure 3).

Figure 3. Automatic CBR test machine

3.2.2. Hand vane shear test

This test method can be used in the field directly on the ground or in the laboratory on specimens compressed into molds to certain standards. The hand vane shear tester is a simple and portable test kit (ASTM D8121/D8121M-19) for measuring the undrained shear strength of saturated, fine-grained, cohesive soils. The method of obtaining the results found with this device; may differ according to the calculation methods of the companies producing the hand vane shear test device. This test method is very easy to perform and the equipment costs are more economical compared to the CBR test [16]. In addition, in terms of applicability, the shear vane test can be performed in a shorter time than the CBR test method [19,20].

The device (Geonor-H-60 Hand Vane Tester) used in this study can directly give the shear strength of the material in pascal. There are 3 different diameter torque blades in the test kit, which can be measured in 3 different strength ranges (Figure 4). The torque blade was selected depending on the rigidity of the sample to be tested, and tests were carried out by the ASTM D8121/D8121M-19 standard on the samples that were compressed into the CBR mold.

Figure 4. Hand vane shear tester

It is known that the shear vane test is a test method that can be applied to soft ground materials [21]. On the other hand, in the study, preliminary tests were carried out on samples with a water content lower than the optimum value. However, since healthy measurements could not be made, the results of the pre-trial test were not included in this study.

4. Results and Discussions

In this study, the results obtained from two separate experiments with different water contents are presented in this section. Then, the relationship between two separate parameters obtained from the experiments was expressed as a correlation. In addition, CBR values obtained from 4 different correlation relations and experimental results are compared and presented below as a graphic and table.

4.1. Laboratory test results

The CBR and shear vane tests performed in the laboratory were performed for each of the 5 samples with different water content, and the changes in the bearing capacity and shear strength values according to the water content are presented in Figure 5 and Figure 6, respectively. In addition, in Table 3, percentage changes in CBR and shear strength results according to water content are shown.

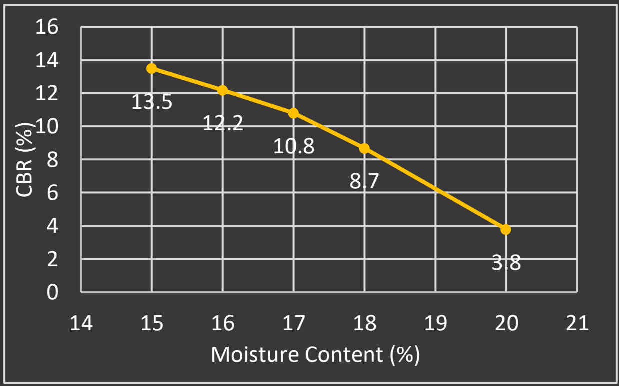

Figure 5. Moisture Content vs. CBR values

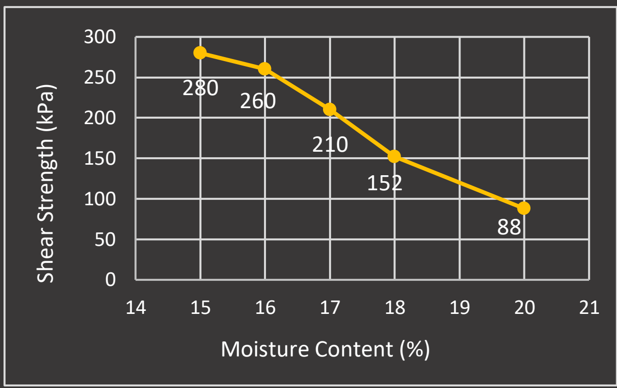

Figure 6. Moisture Content vs. Shear Strength

In the graphs given in Figures 5 and 6, CBR and shear strength values decrease with exceeding the optimum content. Due to the mineralogical structure of the clay, as the water content increases, the distance between the grains increases, and the attractive forces decrease.

Table 3. Tendencies to decrease in Cu and CBR values according to water content.

Water Content (%)	CBR (%)	Shear Vane Test	C_u Decreasing Trend (%)	CBR Decreasing Trend (%)
15	13.5	280	7.14	9.63
16	12.2	260	19.23	11.48
17	10.8	210	27.62	19.44
18	8.7	152	42.11	56.32
20	3.8	88	-	-

As can be seen from the experimental results and percentages of change given in Table 3, as the water content increases, the CBR and shear strength decrease, and the rate of decrease of the values increases after the optimum water content is exceeded. This behavior is also consistent with the results of the Proctor test presented in Figure 2.

To determine the relations between the data obtained by the two test methods, the values in the same water contents were compared and the changes in the values obtained from the CBR and shear vane tests in the same water contents were presented in Figure 7.

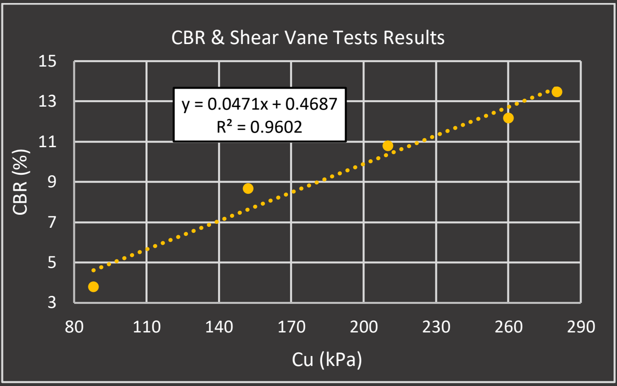

Figure 7. CBR vs Shear Strength

The correlation between the experimental results presented in Figure 7 was established using a linear equation and this correlation was expressed with the function given in Equation 5.

$$CBR=0.0471*C_u+0.4687 \tag{5}$$

The R-squared value, which expresses the compatibility of the linear function with the experimental results, was found to be 0.9602. This value shows that the proposed linear relationship can be used to calculate the corresponding values for similar subgrade materials.

4.2. The Existing Correlation Results

CBR values were calculated by using the shear strength result values obtained using the hand shear vane test kit in the laboratory and the equations given in the existing correlation section. The results obtained from the CBR and shear vane tests and equations performed at different water contents are presented in Table 4. In Figure 8, the CBR values obtained from the equations and experiments are shown comparatively.

According to the numerical results presented in Table 4, it is seen that Equation 1 gives the closest result to the experimental results among 5 samples. Accordingly, the closest values were seen in sample 5, the experimental and correlated CBR values were found to be 3.8 and 3.79, respectively.

When the results given in Table 4 and Figure 8 are examined, it is seen that the closest CBR value to the results of the experimental study was obtained with Equation 1 suggested by Black [6]. In addition, it was observed that the other two relations gave very close results at low CBR values. It has been seen that the equations giving the highest and lowest values out of the four selected equations are Equation 4 and Equation 2, respectively, which is important in terms of determining the limit values.

5. Conclusions

In this study, two different test methods were applied to determine the design parameters of the cohesive fine-grained subgrade material. For each test, samples with 5 different water contents were tested and the selected water contents were determined by considering the results of the Proctor test.

Tablo 4. CBR values from experiments and correlations

Sample No	Moisture Content (%)	Cu (kPa) (Exp)	CBR (From Correlations)				CBR (%) (Exp)
			Eq-1	Eq-2	Eq-3	Eq-4	
1	15	280	12.04	9.24	19.85	25.2	13.5
2	16	260	11.18	8.58	17.93	23.4	12.2
3	17	210	9.03	6.93	13.38	18.9	10.8
4	18	152	6.54	5.02	8.58	13.68	8.7
5	20	88	3.79	2.90	4.05	7.92	3.8

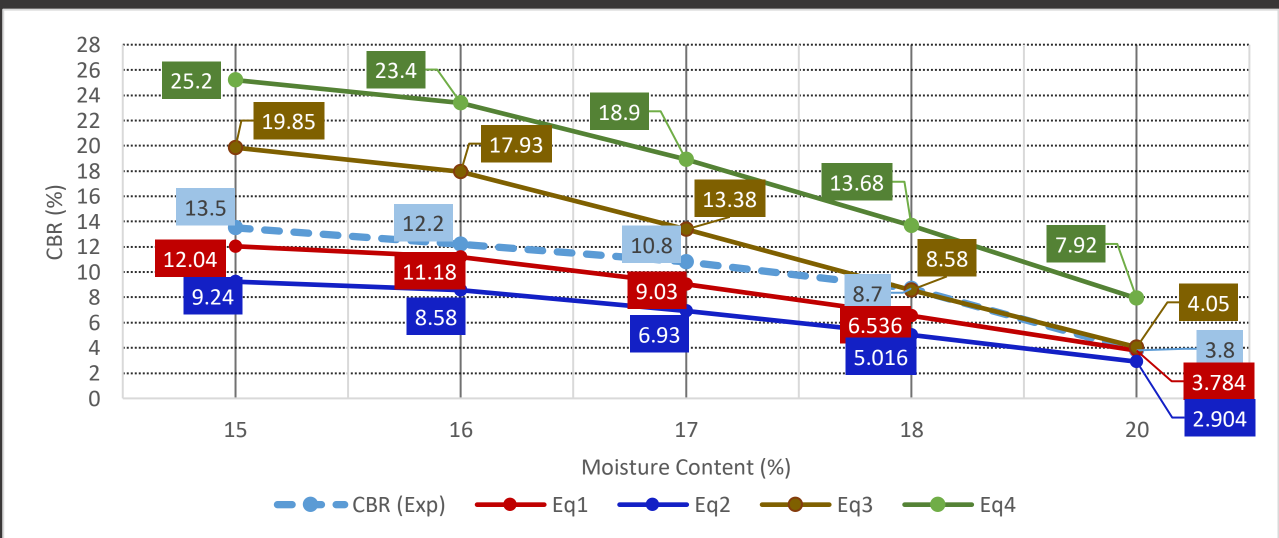

Figure 8. Comparison between correlated and experimental CBR values

In addition, since the CBR and shear vane test methods will be associated in the study, the applicability of the shear vane test on soft soil material has been decisive in the selection of values above the optimum value. As expected in the test results, it was observed that CBR and shear strength values decreased as the water content increased, and there was a significant decrease in both values (CBR and Cu), especially at rates above 18% water content.

In addition, in this study, a new equation is proposed by establishing a linear relationship between the experimentally obtained CBR and shear strength results. Using this new proposed equation, the CBR value can be found with 96% accuracy after the shear strength of the CL type subgrade material is obtained experimentally.

In the next stage of the study, CBR values were calculated by using the results obtained from the shear vane test in 4 different correlation relations found in the literature. The approximation tendencies of the selected correlation relations were determined by comparing the calculated values with the experimental results. Thus, in cases where it is not possible to perform the CBR test, it has been determined that the shear vane test, which is easier and less costly in terms of application, can be performed as an alternative. It has been seen that it is possible to calculate the CBR value with 90% accuracy by using the obtained shear strength values in the correlation expression (Equation 1), the accuracy of which was determined as a result of the study. These results provide a fast, reliable, and economical method to determine the bearing capacity of the subgrade, which is one of the important parameters in pavement design.

Declaration of Interest Statement

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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