

Prediction of the Granular Materials Strength

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Abstract

California bearing ratio (CBR) is an important property used to express the quality and strength of the unbound granular materials. Moreover, it is one of the material inputs for the empirical pavement design procedure. CBR is also conducted on the unbound materials for the quality control/quality assurance during construction. Because of its importance, this paper presents a mathematical approach to the problem of estimating the strength of local sand-aggregate material usually obtained from riverbed and banks and used as subbase layer for road construction. Based on simple and easy to determine physical parameters such as particles size distribution, modified proctor dry density (MDD), and moisture content, such estimation could be determined. The study can help in understanding the nature and the properties of sand-aggregate mixture and provide a reasonable and simple statistical method for assessing the strength from simple physical tests, and assist in considerable reduction of the bulk testing of samples on a project, thus affect economy, choice of material and quality control. The model obtained is capable to explain 73% of the variation in log CBR predicted from gradation and density parameters.

Keywords: Granular materials; Density; Gradation; Strength; Modeling; Subbase; Bearing.

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INTRODUCTION

The design of pavement structure is essentially based on the strength characteristics of the sub grade soil and other materials constituting it. The CBR (California bearing ratio) method of pavement design is still commonly adopted to evaluate the strength properties of such materials as reported by UL-Rehman, [1]. Field Engineer responsible for construction of roads have always been on the lookout for a simple method for estimating strength of the subbase layer material which can be easy for adoption and accurate enough for practical purposes, [2]. A review of the available literature about predicting strength value indicates that density, gradation, and index properties have a grate influence on the predicted CBR value [3]. Vinod and Cletus [4] studied the possibility of prediction of CBR values of lateritic soils from the gradation and liquid limit data, while UL-Rehman *et al.* [5] studied California bearing ratio (CBR) and compaction characteristics of granular soils. An attempt has been made by Taha *et al.* [6] to develop a simple and reliable CBR model based on routine material properties such as gradation, Atterberg limits and compaction properties using regression analysis. Data of CBR values was collected from the quality control reports. The collected CBR values were found to range between

26 and 98%. The developed model correlates CBR values with maximum dry density and diameter at 60% passing (D60). The prediction accuracy in terms of coefficient of determination (R^2) for the developed CBR model was excellent, and the validation of the suggested model was satisfactory. NCHRP [7], in their assessment, stated the possibility of incorporating the predicted CBR values from soil index properties into the suggested mechanistic empirical design method for pavement structures. Aderinola *et al.* [8] explored a number of combinations involving the variables of particles size distribution and dry density, they concluded that liquid and plastic limits show no direct visible correction with CBR, and the best trend is seen to be between CBR and dry density for clay soil. Araya *et al.* [9] stated that characterization of unbound granular road base and subbase materials in developing countries is still done using empirical methods such as California Bearing Ratio (CBR) testing. The CBR does not provide information on the mechanical behavior such as the resilient and permanent deformation characteristics of the material although it is widely applicable. Singh *et al.* [10] evaluated the CBR of sub grade soil depending on the particle size distribution, dry density, and moisture content. A linear correlation between such variables was developed. Araujo and Ruiz [11] developed the strength index depending on

the dry density, moisture content, percent sand content and percentage fines for sub grade soil. They concluded that dry density and moisture content are sufficient to identify a group of strength index value. Ahmed *et al.* [12] stated that in Egypt, California Bearing Ratio (CBR) is the main strength parameter used for characterization of the unbound materials and subgrade soils due to its availability and simplicity. A comprehensive experimental testing program was conducted on different unbound granular base/subbase materials typically used in pavement construction projects in Egypt. The testing program includes Resilient Modulus MR, CBR, and basic material properties. The effect of aggregate gradation on MR is investigated. A model predicting MR as a function of the basic material properties is proposed. The MR–CBR relationship adopted in the current Egyptian Code of Practice is verified based on the testing results. Roy

[13], developed a model for computing soaked CBR values from sieve analysis data for soil, it was concluded that a simple linear expression has been developed for the computation of maximum dry density and soaked CBR value. Esfahani and Goli [14], stated that resilient modulus and California Bearing Ratio (CBR) in unbound granular materials are the key technical characteristics of layers in a flexible pavement design. Among the factors affecting these two parameters, the aggregate gradation is the most important. It was concluded that strength is highest in the lower limit of gradation. Therefore, the use of well-graded coarse-grained aggregates could significantly increase the strength. Many researchers have developed simple regression equations correlating the CBR value of the soil or granular materials with their physical properties. Table 1 demonstrates such predicted correlations.

Table-1: Predicted models of soil and granular materials strength

Model	Researcher
CBR = 50.28 (MDD) -70.22	Bello, [15]
CBR = 21.101 (MDD) -30.56	Bhatt <i>et al.</i> [16]
CBR = 0.025(P.200) ⁴ +30.130(MDD) -25.813	Taha <i>et al.</i> [17]
CBR = 2- 16 log (OMC) + 0.07 L.L	Breytenbach <i>et al.</i> [18]
CBR = 114.7(MDD) -170.57	Taha <i>et al.</i> [19]

Where:

CBR = California bearing ratio (%)

MDD = Maximum dry density

P.200 = Percent passing sieve No. 200 (75 microns)

OMC = Optimum moisture content

L. L. = Liquid limit (%)

In Iraq, the local sand-aggregate mixes is readily available at the river banks, and bed either on the surface itself, or at shallow depth; however, quality of this material varies from place to another and thus required to be evaluated as reported by Sarsam, [20].

METHODOLOGY

The aim of the present investigation is to develop a simple and rapid method for estimating the soaked CBR value for the subbase layer material from gradation analysis and modified proctor density. The methodology presented is based on data on engineering properties collected from the analysis of 80 subbase material samples obtained from various highway projects executed at Mosul city.

Laboratory Investigation

Sand-aggregate mixture samples were obtained from different highway projects at Mosul city using the standard sampling method as per AASHTO. The samples were obtained from the roadway after spreading the material and before compaction. Samples were subjected to wet grain size analysis [21], modified proctor density test [22], CBR value determination [23] and liquid and plastic limits test as per AASHTO [24].

A total of 80 samples were collected and tested as explained above.

ANALYSIS OF TEST RESULTS AND DISCUSSION

Analysis of test results was conducted using the stepwise multiple regression analysis software, it shows that the strength characteristics of the material at the soaked condition were influenced by the maximum dry density, optimum moisture content and gradation parameters, therefore, significant correlation could be established, and the mathematical model could be written based on the regression analysis as follows in equation 1.:

$$F(\text{CBR}) = A + aX_1 + bX_1^2 + cX_2 + dX_2^2 + eX_3 + fX_3^2 + gX_4 \quad (1)$$

Where

F (CBR) = some function of soaked CBR at 95% compaction

A, a, b, c, d, e, f, g = multiple regression analysis constant

X₁ = modified maximum dry density (lb/ft³)

X₂ = optimum moisture content (%)

X₃, X₄ = some functions of grain size distribution

The gradation of material was converted into two parameters known as the coefficients of uniformity (Cu) and coefficient of curvature (Cc). Atterberg limits shows no direct visible correlation with CBR, since most of the tested samples were either non-plastic or have very low value of plasticity index (lower than 5%), it was felt that such behavior was considered in the low plasticity index requirements of 6% in the specification as demonstrated in Table 2.

Table 2: Specification requirements for subbase material –SCRB, [25]

Sieve size (mm)	Percentage finer by weight			
	Type A	Type B	Type C	Type D
75	100	100	100	100
50	95-100	100	100	100
25	-----	75-95	100	100
9.5	30-65	40-75	50-85	60-100
4.75	25-55	30-60	35-65	50-85
2.36	16-42	21-47	26-52	42-72
0.30	7-18	14-28	14-28	23-42
0.075	2-8	5-15	5-15	5-20
CBR (%)	-----	35	30	25
Liquid limit (%)	25	25	25	25
Plasticity index (%)	6	6	6	6

Numerous multiple regression analysis was conducted to determine the function of CBR that would correlate best with selected form of the variables X_1, X_2, X_3, X_4 . Of all the multiple regression analysis investigated, the one that resulted in the highest correlation coefficient was as follows in equation 2.

$$F (\%CBR) = \log (\%CBR) \tag{2}$$

X_1 = modified maximum dry density (lb/ft³)

X_2 = optimum moisture content (%)

X_3 = Coefficient of curvature (Cc)

X_4 = Coefficient of uniformity (Cu)

A = 2.2587; a = -0.019 ; b = 0.00012 ; c = 0.0574;

d = 0.00371; e = -0.00375 ; f = -0.00003 ; g = 0.00014

This resulted in the following equation:

$$\log (\%CBR) = 2.2587 - 0.019X_1 + 0.00012X_1^2 - 0.0574X_2 + 0.00371X_2^2 + 0.00375X_3 - 0.00003X_3^2 + 0.00014X_4 \tag{3}$$

This multiple regression equation resulted in a correlation coefficient ($R^2=0.7312$) which means that the equation explains 73% of the variation in log CBR. This is further evidenced in that the standard error of estimate (SEE) of log CBR is 0.1652. Similar

regression models were reported by Shirur, and Hiremath, [26]; Yashas *et al.*, [27]. Figure 1 presents the relationship between observed and predicted CBR values.

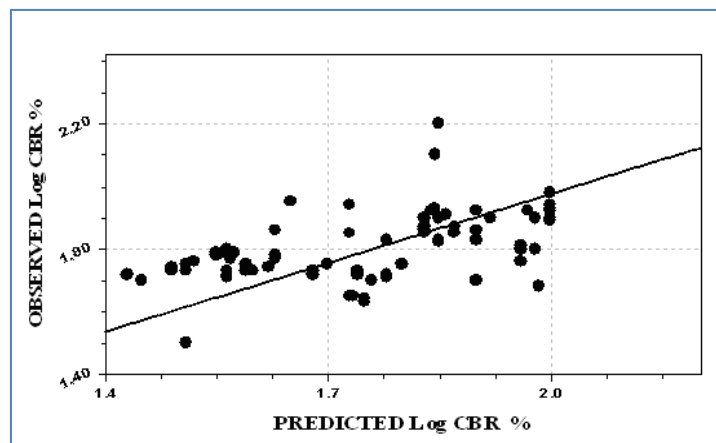


Fig-1: Observed and predicted Log CBR relationship

The figure shows that such values agree quite well and shows considerable scatter about the expected regression line. This, however, is to be expected since

the effect of particle shape and roundness may have a marked influence on the strength. Table 3 shows the range of various test results studied.

Table-3: Range of various test results analyzed

Variable	Maximum value	Minimum value
%CBR @ 95% compaction (AASHTO T-180-74)	98	26
Maximum dry density (lb/ft ³), [gm/cm ³]	147, [2.355]	128, [2.051]
Optimum moisture content (%)	8	3
Coefficient of uniformity (Cu)	0.250	1733
Coefficient of curvature (Cc)	0.067	115.2

CONCLUSIONS

Based on the limitations of materials and testing program, the following conclusions may be drawn:

- The strength of the sand-aggregate mix which is usually used for subbase layer construction can be estimated satisfactorily from its physical characteristics by the mathematical approach suggested.
- The soaked CBR value at 95% compaction obtained on a statistical basis, such as that resulting from the equation presented in this paper should provide a reasonably satisfactory estimate for a given sub base material by comparing this with the difficulty of obtaining a reliable CBR value from a single test.
- Such an approach might possibly be used for estimating the strength of other types of subbase material and assist in considerable reduction of the bulk testing of samples on a project, and thus affect economy, choice of material and quality control.
- The obtained multiple regression model resulted in a correlation coefficient ($R^2=0.7312$) which means that the equation explains 73% of the variation in log CBR.

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