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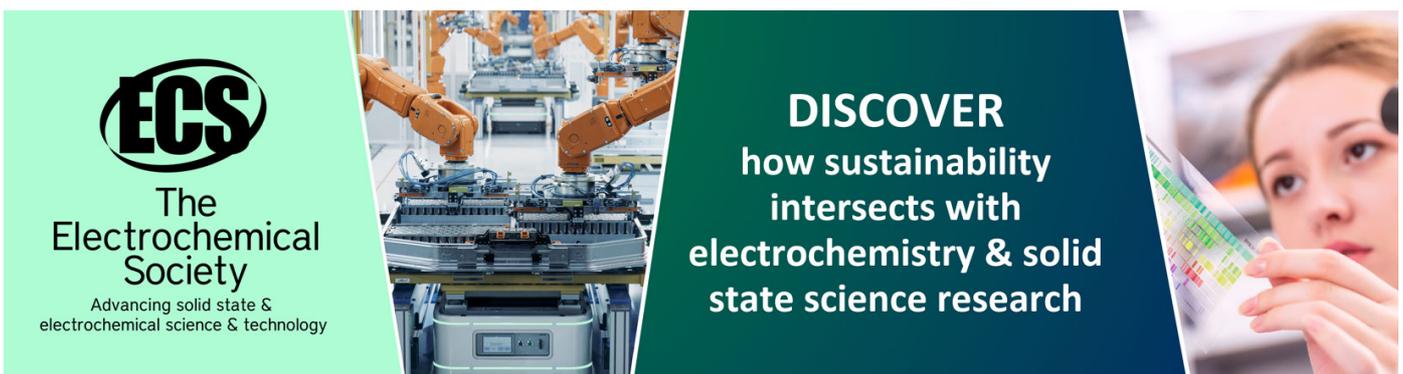
Determining field bearing resistance of subgrade soils using physical characteristics

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Determining field bearing resistance of subgrade soils using physical characteristics

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Abstract. In highway design, subgrade strength is mostly affected in pavement layers' thickness. California Bearing Ratio (CBR) is one of the simple testing methods that is commonly used to determine the strength of unbounded paving materials; i.e., subgrade, subbase, and base course materials of highways and airfield pavement. In-situ CBR test is intended to determine the static properties of unbound pavement layers represented by bearing capacity of subgrade soils without requiring the digging of test pits. The in-situ CBR test is laborious, time-consuming, and relatively expensive, therefore an alternative methodology is proposed for correlating CBR value with physical properties of subgrade soils such as field density and moisture content. Three testing methods were used: in-situ CBR test, sand replacement method for determining the field density and moisture content of granular soils and clayey soils, respectively. Selected types of soils were nominated from the local area having soil's type of A-1-b, A-3, and A-6-7. Statistical analyses were performed to evaluate bearing resistance of subgrade soils depending on water content and dry density obtained from field density tests. The results of two statistical models indicated that both field density and water content correlate well with the bearing ratio for various subgrade soils.

Keywords: Core cutter method; In-situ (CBR); subgrade soils; field density; statistical analysis

1. Introduction

A pavement system is conventionally composed of several well compacted hard courses or layers which constructed over a natural subgrade soil. The structural performance of these systems depends mainly on the strength characteristics of the granular pavement materials such as stiffness modulus, density, California Bearing Ratio (CBR), etc. CBR value is an important soil parameter for the design of flexible highway and airport pavements. The CBR test was originally developed by the California State Highway Department and was thereafter incorporated by the Army Corps of Engineers for the design of flexible pavements [1]. It has become so globally popular that it is incorporated in many international standards such as the American Association of State Highway and Transportation Officials AASHTO T193 [2]. The standard CBR test can be carried out in the laboratory or on-site under standard test methods, namely ASTM D1883[3], and ASTM D4429[4], respectively.

The CBR value of soil depends on many factors such as soil physical characteristics like maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), plastic limit (PL), plasticity index (PI), grain size distribution, permeability of soil etc., and testing condition like soaked or unsoaked soil



condition [5-7]. The correlation was tried extensively by many researches works for estimating bearing resistance of soils from its physical properties.

Based on experimental results and simple linear regression analysis (SLRA) of subgrade soils with an average liquid limit (20% to 70%), there is no significant relation exists to predict CBR value from liquid limit and plastic limit, but there is a good empirical relation obtained by SLRA to predict CBR value from MDD and OMC [5-8]:

$$\text{CBR}=4.99 \text{ MDD}- 5.711 \quad (\text{R}^2=0.78) \quad (1)$$

$$\text{CBR}=-0.2443 \text{ OMC}+7.5264 \quad (\text{R}^2=0.71) \quad (2)$$

While CBR value of fine-grained silty soil of low compressibility (ML) and silts of intermediate compressibility (MI) bears significant correlation with PI, MDD and OMC, and observed CBR value decreases with the increase in the plasticity index and optimum moisture content of soil but increases with the increase in the maximum dry density[5-8] and there is a slight difference between the CBR value determined in the laboratory and computed by using multiple linear regression model involving LL, PL, PI, MDD and OMC [6]:

$$\text{CBR}_{\text{soaked}} = 0.127(\text{LL}) + 0.00 (\text{PL}) - 0.1598(\text{PI}) +1.405 (\text{MDD}) - 0.259 (\text{OMC}) + 4.618 \quad (3)$$

There is a suggested other empirical relation obtained from multiple linear regression analysis (MLRA) of fine-grained soils shows good relation to predict CBR value from a combination of MDD and OMC [6]:

$$\text{CBR}= -4.8353-1.56856(\text{OMC}) +4.6351(\text{MDD}) \quad (\text{R}^2=0.82) \quad (4)$$

The main purpose of this study is to develop statistical models for predicting the bearing resistance of local subgrade soils properties depending on their physical properties This prediction process could facilitate the understanding of the role of these parameters in general soil characteristics. Therefore, this paper will discuss the analysis process to build prospective models.

2. Soils characterization:

The evaluated subgrade soils in this paper were collected from three roadway projects in Karbala city. Standardized laboratory tests according to ASTM and AASHTO procedures were conducted on each soil type to define the basic soil properties including sieve analysis, Atterberg limits, standard and modified Proctor tests, and laboratory California bearing ratio test (CBR). In addition, chemical tests were included to investigate the main chemical elements in subgrade soil. The grain size distribution of the selected subgrade soils is presented in Figure (1). The laboratory test results including physical and chemical tests were summarized in Table (2).

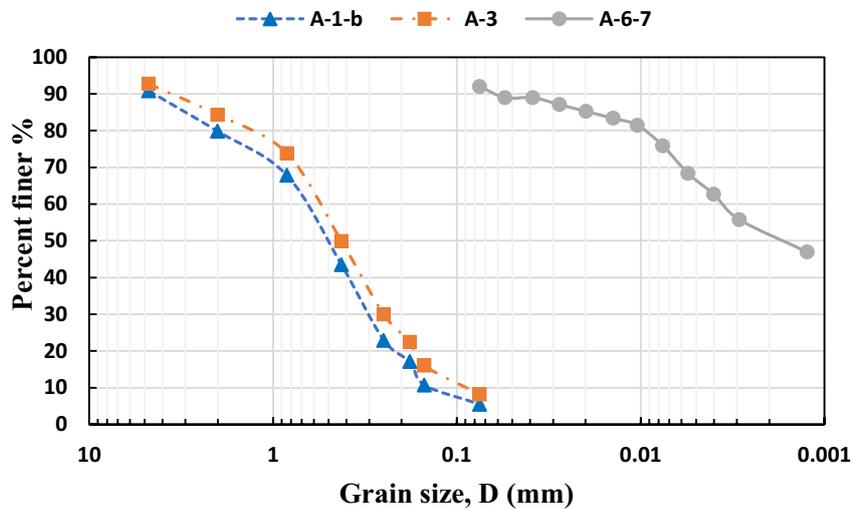


Figure 1. Grain size distribution system for selected types of soil

Table 1. Average physical and chemical properties of selected types of subgrade soils

| Property | Subgrade Soil type | | | Specification |
|---|--|----------------------------|---|-------------------|
| | AL-Meelad | AL-Fares | AL-Rofaee | |
| Site coordination | 409911.538, 3604114.561 | 406139.763, 3604069.317 | 406073.683, 3617974.787 | / |
| USCS classification | poorly graded sand with silt (SP-SM) | poorly graded sand (SP) | Non-organic elastic silt with high of plasticity (MH) | ASTM D2487[9] |
| AASHTO classification | A-1-b | A-3 | A-6-7 | AASHTO M145[10] |
| Dry Unit Weight | 16.87 kN/m ³ | 20.94 kN/m ³ | 16.87 kN/m ³ | ASTM D1557[11] |
| O.M.C | 15.5% | 8.75% | 18 % | ASTM D4643[12] |
| G. S | 2.72 | 2.74 | 2.55 | ASTM D891[13] |
| D10, D30, D60 | 0.13, 0.30, 0.62 | 0.17, 0.29, 0.72 | / | ASTM D2487[9] |
| Uniformity Coefficient, Cu | 4.77 | 2.47 | / | ASTM D2487[9] |
| Curvature Coefficient, Cc | 1.11 | 1.18 | / | ASTM D2487[9] |
| Gravel Fraction, GF | 9.20% | 1.52 % | / | ASTM D2487[9] |
| Fine Content | 5.50% | 4.01 % | 90.20 % | ASTM D2487[9] |
| Lab. CBR – Un soaked | 61.5% | 99 % | 22.2 % | ASTM D1883[3] |
| Lab. CBR – Soaked | 27.2% | 50.5% | 5.2 % | ASTM D1883[3] |
| Liquid limit | 0 | 0 | 64.90 % | ASTM D4318[14] |
| Plasticity Index | N. P | N. P | 25.96 | ASTM D4318[14] |
| Sulfate (SO ₃) | 4.409 | 4.959 | 1.86 | BS1377-3:1990[15] |
| gypsum content (CaSO ₄ 2H ₂ O) | 9.48 | 10.66 | 3.99 | BS1377-3:1990[15] |
| Total Soluble Salts | 1.56 | 1.10 | 3.53 | BS1377-3:1990[15] |

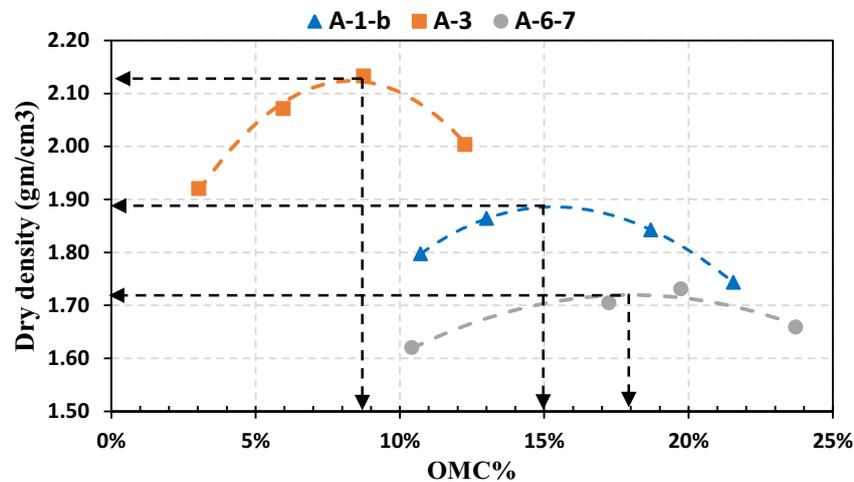


Figure 2. Modified proctor test for selected types of soils.

3. Experimental Program, Testing Conditions and Methods.

3.1 Experimental Program.

A 3.0 x 1.2 x 1.0 m laboratory testing model was designed and manufactured to simulate in-situ conditions of subgrade soils. The experimental program was designed to accommodate the main aim of the study, which is to develop a reliable and acceptable relation between the bearing ratio of subgrade soils, field dry density and moisture content. The samples were prepared under the following objective:

- Preparing three types of soil classified according to USCS and AASHTO for compression purpose to detect the effect of their physical properties and main chemical elements in testing results
- Adapting three degrees of compaction (low, medium, high) level that achieved by identifying the numbers of compactor passes on soil layers. The purpose of using three compaction efforts was to achieve a variety of densities for each soil type and identify the extent of compaction impact on the results of the tests.

Table 2. Abbreviations of the designation Names for soil samples

| NO. | Abbreviations of soil samples | Soil samples details | Number of compactors passes (NOP) | test point (P _n) |
|-----|-------------------------------|--|-----------------------------------|------------------------------|
| 1 | A-1-b, 8 NOP, P _n | Poorly graded sand with silt, | 8 | 1-6 |
| 2 | A-1-b, 12 NOP, P _n | Poorly graded sand with silt | 12 | 1-6 |
| 3 | A-1-b, 16 NOP, P _n | Poorly graded sand with silt | 16 | 1-6 |
| 4 | A-3, 8 NOP, P _n | Poorly graded sand | 8 | 1-6 |
| 5 | A-3, 12 NOP, P _n | Poorly graded sand | 12 | 1-6 |
| 6 | A-3, 16 NOP, P _n | Poorly graded sand | 16 | 1-6 |
| 7 | A-6-7, 8 NOP, P _n | Non-organic elastic silt with high of plasticity | 8 | 1-6 |
| 8 | A-6-7, 12 NOP, P _n | Non-organic elastic silt with high of plasticity | 12 | 1-6 |
| 9 | A-6-7, 16 NOP, P _n | Non-organic elastic silt with high of plasticity | 16 | 1-6 |

3.1.1 Soil preparation.

In this study, three collected subgrade soils were tested by field density tests using two test methods, i.e., core cutter method (C.C.M) and sand replacement method (S.R.M), further to in-situ CBR test. To achieve the research work goal, a special testing apparatus and other accessories were designed and manufactured. The apparatus has the capability of containing soil about 2 m³ and applying different static and dynamic loads. The general views are shown in Figure (3). The apparatus consists of a loading steel frame, axial loading system, Steel box, and Data acquisition.

The specimen's preparation comprising several steps as follows:

- The moisture content of prepared samples was the optimum moisture content obtained by the Modified Proctor Test according to ASTM D1557[11].
- The soil was moistened with optimum moisture content using a drum mixer of 0.25 m³ capacity. For each mixture 150 kg of soil was used and divided into containers every 25 kg for easy soil transfer to the mixer, and to ensure effective mixing process. Six rounds in the amount of 0.25 m³ were required to prepare one layer with a thickness of 20 cm
- Three layers of subgrade soils were adopted with thickness 20 cm each, which means each layer was 1.5 m³ with approximately 900 kg of soil and the total weight of the testing sample equal 2.7 ton.
- Before placing the soil sample in the steel box, the inner walls of the steel box were covered with a light insulation plastic sheet to prevent soil sticking to the walls of the mold.
- Three degrees of compaction were adopted for preparing samples depending on the numbers of compactor passes, i.e., 8,12 and 16NOP.
- Each soil layer was compacted to increase the density of the soil by packing the particles closer together. The compacted effort was achieved by using a compactor (model: petrol engine with power 6.0 Kw, weight 160 kg and frequency 4000 VPM)
- Six test points were selected for each test type included the CBR test according to ASTM D4429[4]. In addition, field dry density which conducted by either sand replacement method for granular soils according to ASTM D1556[16] or core cutter method for clayey.

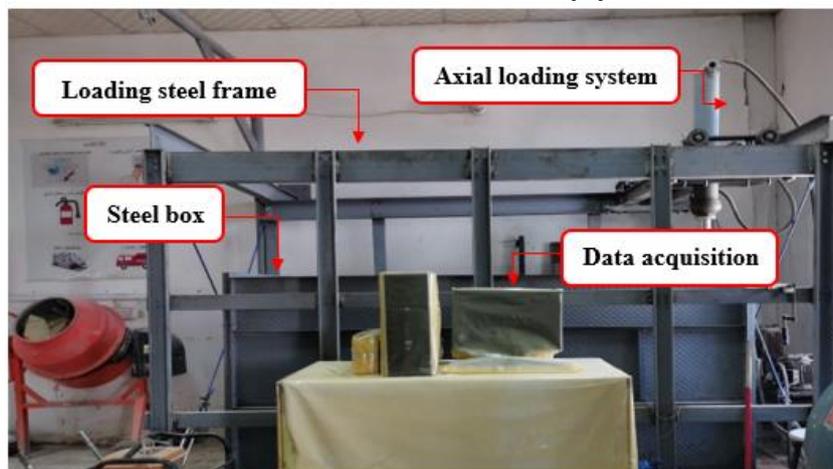


Figure 3. General view of the test device.

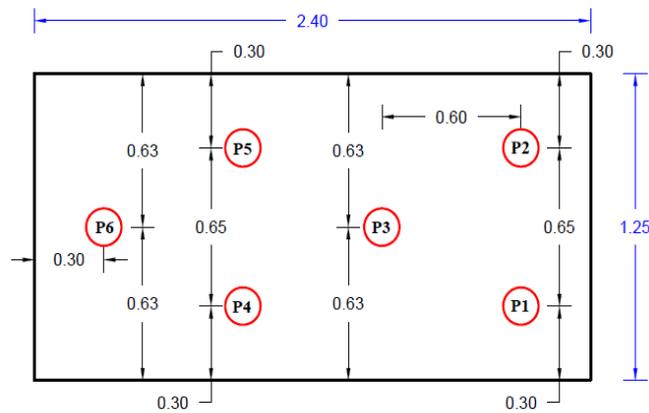
3.2 Laboratory tests.

After completing the preparation of the soil sample in the steel box with a total thickness of 60 cm and ensuring the top surface is leveled to get as near as possible a flat surface. The soil surface is divided into six testing zones as shown in Figure (4). In each testing zone, several testes were implemented including:

1) the in-situ CBR test, 2) core cutter method (CCM), 3) sand replacement method (SRM), and 4) moisture content. (MC).



(a): Laboratory testing zones.



(b): Test points diagram

Figure 4. (a): Laboratory testing zones and (b): Test points details.

3.2.1 In-Situ CBR Test.

The California Bearing Ratio (CBR) test, is used to estimate the load-bearing capacity and mechanical strength of unbound pavement layers. This test is carried out on laboratory remolded soil specimens according to ASTM D 1883 and field (in-situ) subgrade soil according to ASTM D4429 to determine their bearing capacity.

In-situ CBR instruments consist of many apparatuses which were prepared in the line with the recommendations of ASTM D4429[3], as shown in Figure (5), such as:

- Mechanical screw jack equipped with a special swivel head for applying the load to the penetration piston provided a uniform load penetration rate of 0.05 in. (1.3 mm)/min, and designed with a maximum capacity of (3000 kg) and minimum lift of 2 in. (50 mm).
- LVDT considered as a dial gauge in conventional in-situ CBR test for measuring penetration reading.
- Load cell considered as a proving ring in the conventional in-situ CBR test for measuring deflection reading.
- Surcharge plates to simulate overburden pressure of upper pavement layers.
- Hydraulic Jack (reaction) was considered as a truck (or piece of heavy equipment) used in the field in place CBR to achieve loading sufficiently and provide a reaction of approximately (31 kN)[4] for forcing the penetration piston into the soil.



Figure 5. apparatuses of in-situ CBR test.

3.2.2 Determination of In-situ density.

3.2.2.1 Sand replacement method.

This test is performed to determine the field density and field moisture content of soil according to ASTM D1556[16]. Sand replacement method is applicable for soils without appreciable amounts of rock or coarse materials that exceeds 1.5 in. (38 mm), but it is also suitable for organic, saturated, or highly plastic soils that would deform or compress during the excavation of the test hole [16]. Six test points were selected to conduct this test for granular soils which represented by A-1-b and A-3 for the three degrees of compaction.

3.2.2.2 Core cutter method

Field density and field moisture content can be determined using a core cutter test method according to AASHTO T191[17]. This method can be used successfully whenever soil conditions permit pushing of cutter for sampling and taking it out in the laboratory without much disturbance. AASHTO was restricted C.C.M for determining the in-place density in soils containing particles not larger than 50 mm (2 in.) in diameter. For this reason, this test method was adopted to determine field density for clayey soil which is represented in this study by A-6-7 subgrade soil type.

4. Laboratory test results and discussion.

4.1 in-situ CBR test results.

The relation between CBR and numbers of compactor passing on subgrade soil for the three types of soil are summarized in Figure (6). The granular soils exhibit higher bearing resistance, also, the Figure (6) shows that the increase in compaction effort from 8 to 12 then to 16, lead to an increase in the degree of compaction and record higher CBR values. A-3 subgrade soil shows more influence with the increasing of compaction effort than A-1-b, and lastly A-6-7. The increment in bearing resistance for A-3 subgrade soil might be further to physical characteristics, is due to the effect of gypsum content in this type of soil as shown in Table (1) that agreed completely with Ahmed[18] reported that the compressive strength values for poorly graded sandy soil samples stabilized with recycled gypsum increased from 14.42 kPa to 25.43, 81.99 and 331.18 kPa due to adding 5%, 10% and 20% content of recycled gypsum, respectively. This can

be explained by the addition of recycled gypsum to the soil causing cementation or hardening of soil particles; thus, cohesion strength between soil particles is developed.

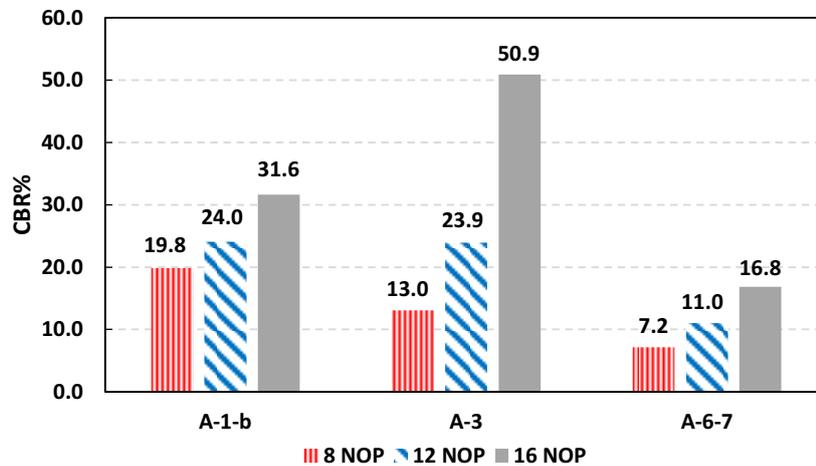


Figure 6. CBR results verses compaction effort

4.2 In-situ density results.

The relation between field density and numbers of compactor passing on subgrade soil for the three types of soil are summarized in Figure (7). The figure shows that the increase in compaction effort leads to an increase in the degree of compaction and record higher density value for the three types of soils. similar to CBR results, A-3 subgrade soil exhibits more influence with the increasing of compaction effort, the reason of this increase is due to the effect of gypsum content in subgrade soil that agreed with Ahmed [18] attributed this behavior to the role of gypsum particles as a filling material to the intergranular voids of the soil matrix, and Kuttah[19] claimed that adding gypsum to soil is increase the maximum dry unit weight of the soil and decrease the optimum moisture content, but only for gypsum content ranging between 0% to 15%. After investigation can observe the field moisture content had an average 5.90% and record decreased 0.3 than optimum moisture content, that means complete agreement with the previous finding.

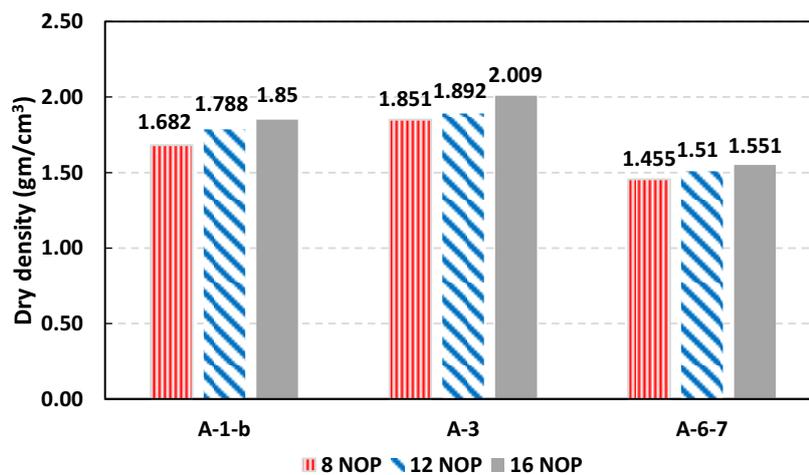


Figure 7.: field dry density results verses compaction effort.

5. Statistical analysis modals.

5.1 Prediction modals.

SPSS software was used to analyze and build predictive models. For the simplification purposes, linear models were firstly tested, unfortunately, all linear models were failed to represent the observations, for many trails it was found that all models were nonlinear. Two models were selected to correlate bearing ratio to basic physical properties with reference to subgrade soil type, i.e., the 1st model presents the correlation of bearing ratio to field dry density and moisture content among other basic physical properties for granular soils, while the 2nd model is represented for clayey soils.

5.2 Building of CBR-physical properties model.

This selection is based on the most important parameters and their impact on the bearing capacity of the soils. The results were divided randomly 70% to generate the models while 30% is selected randomly for validation. The analysis results for both soils types are explained as follow:

5.2.1 Correlation CBR – basic physical properties for granular soils:

Correlating CBR for granular soils with (MC), and (γ_{df}) was performed. The results of the regression analysis are shown in Tables (3-5). The bivariate Pearson correlation between variables is shown in Table (3) and demonstrates that dry density (γ_{df}) has the most significant correlation to CBR value than moisture content (MC). While the parameter of the developed nonlinear model for predicted CBR value and its limitation with confidence interval the most common being 95% are shown in Table (4). The sum of regression is higher than the sum of residue which is sustained the significant of the model. And R-Square with value (0.801) indicates an acceptable prediction model. See Table (5). From these results can conclude and draw the developed model for CBR- physical properties parameters for granular soil is acceptable. Figure (8) indicates that acceptable scatter can be recognized between predicted and observed operability values with R^2 of (0.735), furthermore, almost all value except one value out the significant level boundaries, while Figure (9) shows the scatter plot for residual (difference between the observed CBR value and the predicted CBR value and each data point has one residual) and independent variable (γ_{df}).

Table 3. Correlation between Variables CBR-basic physical properties-granular soils

| | | Correlation | | |
|---------------------------------|---------------------|-------------|--------|---------------|
| | | CBR | MC | γ_{df} |
| CBR | Pearson Correlation | 1 | -.109 | .751** |
| | Sig. (2-tailed) | / | .527 | .000 |
| | N | 36 | 36 | 36 |
| MC | Pearson Correlation | -.109 | 1 | -.416* |
| | Sig. (2-tailed) | .527 | / | .012 |
| | N | 36 | 36 | 36 |
| γ_{df} | Pearson Correlation | .751** | -.416* | 1 |
| | Sig. (2-tailed) | .000 | .012 | / |
| | N | 36 | 36 | 36 |

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 4. Nonlinear model of CBR-physical properties-granular soils parameters

| Developed model | | CBR = $b_0 + (b_1 * MC) + (b_2 * \gamma d_f^2) + (b_3 * \gamma d_f^3)$ | | |
|---------------------|----------|--|-------------------------|-------------|
| Parameter Estimates | | | | |
| Parameter | Estimate | Std. Error | 95% Confidence Interval | |
| | | | Lower Bound | Upper Bound |
| b_0 | 767.523 | 211.132 | 333.535 | 1201.510 |
| b_1 | 56.757 | 25.438 | 4.469 | 109.046 |
| b_2 | 274.774 | 63.136 | 144.996 | 404.552 |
| b_3 | -911.870 | 231.298 | -1387.309 | -436.431 |

Table 5. ANOVA for nonlinear (CBR- physical properties-granular soils parameters) model

| ANOVA ^a | | | |
|--------------------|----------------|----|--------------|
| Source | Sum of Squares | df | Mean Squares |
| Regression | 27460.656 | 4 | 6865.164 |
| Residual | 851.069 | 26 | 32.733 |
| Uncorrected Total | 28311.725 | 30 | |
| Corrected Total | 4266.909 | 29 | |

Dependent variable: CBR

a. R squared = $1 - (\text{Residual Sum of Squares}) / (\text{Corrected Sum of Squares}) = 0.801$

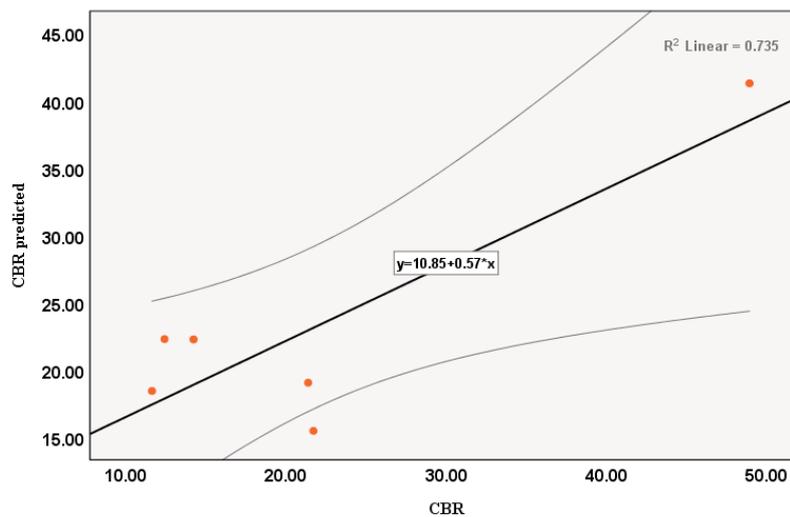


Figure 8. Comparisons between Measured and Predicted CBR for granular soils

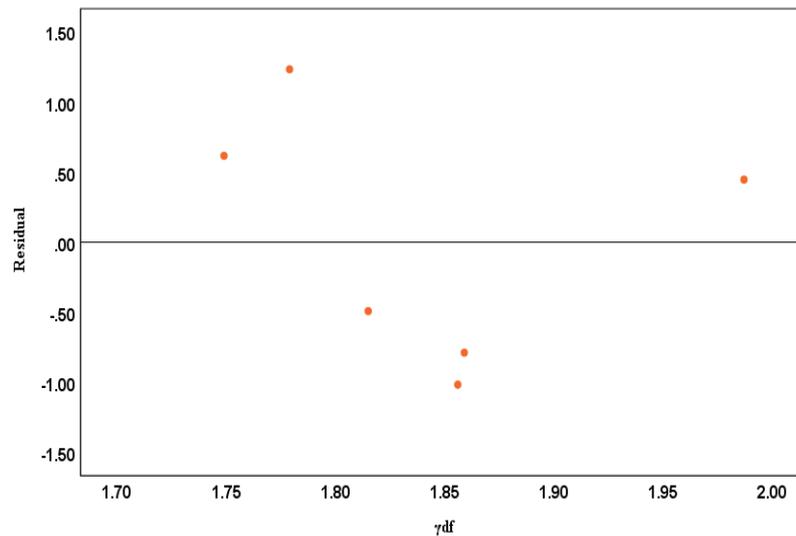


Figure 9. Scatter plot for residual and predicted CBR – granular soils

5.2.2 Correlation CBR – basic physical properties for clayey soils:

Correlating bearing ratio for clayey soils to moisture content (Mc), and field density (γ_{df}) was conducted. The analysis results of the correlation are shown in Tables (6-8). The bivariate Pearson correlation between variables is explained in Table (6) and it shows that the dry density (γ_{df}) has the most significant correlation to CBR value than the (MC), and the parameters of the developed model and its limitation with Confidence Interval of 95% are shown in Table (7). While Table (8) states that the MSE is low, which is good for the significant of the model, and R-Square with value (0.949) indicates a perfect prediction. A conclusion can draw that the developed model for CBR-basic physical properties parameters for clayey soil is acceptable. Figure (10) indicates that acceptable scatter can be recognized between predicted and observed operability values with $R^2(0.95)$, furthermore, almost all value within the significant level boundaries and the difference between the observed CBR value and the predicted CBR value as known the residual versus independent variable (γ_{df}) are illustrated in Figure (11).

Table 6. Correlation between CBR and basic physical properties of clayey soils.

| | | Correlations | | |
|---------------|---------------------|--------------|---------------|--------|
| | | MC | γ_{df} | CBR |
| MC | Pearson Correlation | 1 | .435 | .507 |
| | Sig. (2-tailed) | / | .157 | .093 |
| | N | 12 | 12 | 12 |
| γ_{df} | Pearson Correlation | .435 | 1 | .930** |
| | Sig. (2-tailed) | .157 | / | .000 |
| | N | 12 | 12 | 12 |
| CBR | Pearson Correlation | .507 | .930** | 1 |
| | Sig. (2-tailed) | .093 | .000 | / |
| | N | 12 | 12 | 12 |

** . Correlation is significant at the 0.01 level (2-tailed).

Table 7. Nonlinear CBR-physical properties-clayey soils parameters modeling

| Developed model | | CBR = $b_0 + b_1 * Wc^2 + b_2 * \gamma d_f^2 + b_3 * \gamma d_f + b_4 * Wc + b_5 * Wc * \gamma d_f$ | | |
|---------------------|-----------|---|-------------------------|-------------|
| Parameter Estimates | | | | |
| Parameter | Estimate | Std. Error | 95% Confidence Interval | |
| | | | Lower Bound | Upper Bound |
| b ₀ | 1093.977 | 1328.394 | -3133.566 | 5321.520 |
| b ₁ | 12175.854 | 6457.954 | -8376.239 | 32727.948 |
| b ₂ | 697.661 | 1109.237 | -2832.425 | 4227.747 |
| b ₃ | -1457.857 | 2019.526 | -7884.891 | 4969.177 |
| b ₄ | -635.058 | 12973.836 | -41923.595 | 40653.480 |
| b ₅ | -2758.476 | 8161.748 | -28732.800 | 23215.847 |

Table 8. ANOVA for nonlinear (CBR- physical properties-clayey soils parameters) modeling

| ANOVA ^a | | | |
|--------------------|----------------|----|--------------|
| Source | Sum of Squares | df | Mean Squares |
| Regression | 1496.159 | 6 | 249.360 |
| Residual | 8.639 | 3 | 2.880 |
| Uncorrected Total | 1504.799 | 9 | |
| Corrected Total | 170.789 | 8 | |

Dependent variable: CBR

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = 0.949

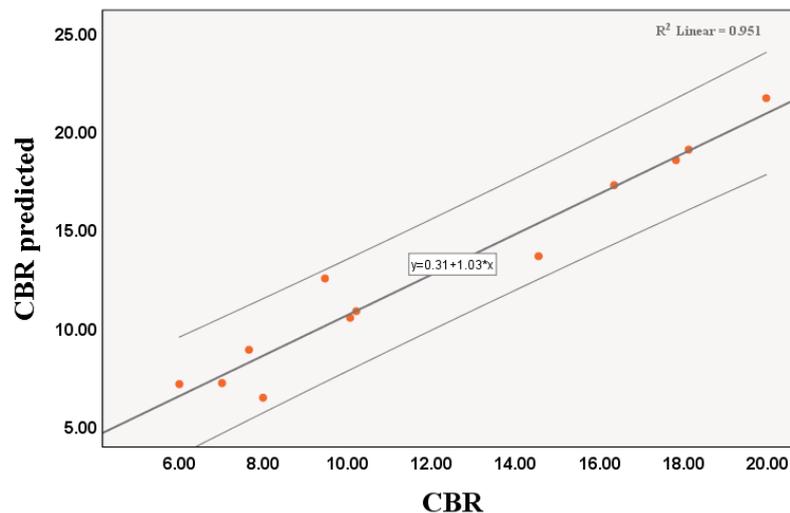


Figure 10. Comparisons between Measured and Predicted CBR for clayey soils

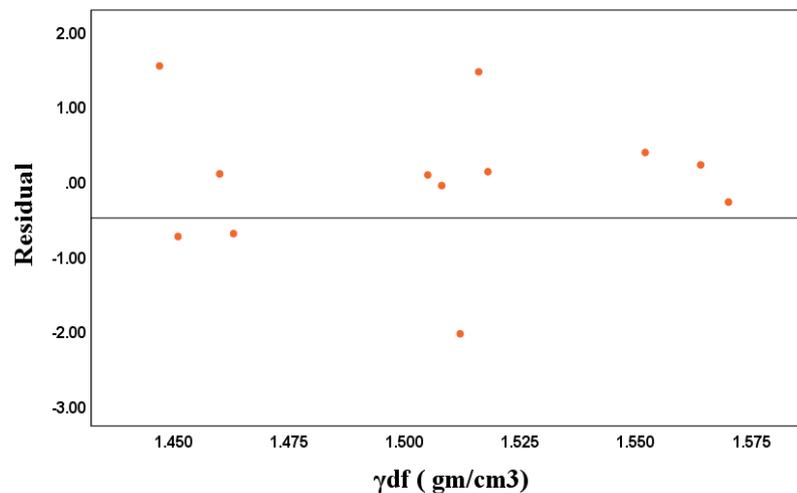


Figure 11. Scatter plot for residual and predicted CBR –clayey soils

6. Conclusion.

From experimental works and statistical analysis of this research study, the following can be concluded:

1. Gypsum content in A-3 subgrade soils was caused to increase in bearing resistance of subgrade soils and max dry unit weight while a decrease in moisture content than the optimum value.
2. Modeling the CBR value for both granular and clayey soils with reference to the soil's physical parameters inputs is achievable and satisfactory in terms of prediction and the significance of input parameters with multi nonlinear models.
3. The statistical results show that the field density has the most significant correlation than moisture content to predict bearing resistance of subgrade soils.

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