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The Effect of California bearing ratio (CBR) on the soil properties value and then the thickness of the rigid pavement layer in the Egyptian context

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ABSTRACT

In the realm of street building engineering, the California Bearing Ratio (CBR) is an essential criterion for determining the size of stiff pavements in tropical locations. The ability to compute the modulus of subgrade soil layers using installed correlations is critical when developing both flexible and stiff road layouts. The Atterberg limits, maximum dry density (MDD), and optimal moisture content (OMC) of the soil all have a significant impact on CBR values. Using one hundred soil samples gathered from different. Both single and multiple linear regression models were used to examine the relationship between CBR values and soil index properties. CBR and MDD were found to be directly related, with a coefficient of willpower (R2) of 0.96. With an R2 of 0.87, a comparable association between CBR and OMC% was found. Nonetheless, there was a weaker negative correlation between CBR values and the plasticity index (PI). Additionally, the data analysis revealed that, although soil types A-2-4 and A-2-6 showed considerable differences, soil types A-1-a, A-1-b, and A-3 showed only slight differences between laboratory-derived and projected CBR values. The findings demonstrate the possibility of cutting down on the time and effort required for CBR estimation. The study also investigated the effects of soil power beneath concrete slabs on pavement thickness. In the AASHTO layout equation, soil strength is represented by the modulus of subgrade response. Using approximated values of subgrade response in accordance with the AASHTO designs technique made it easy to estimate slab thickness for different scenarios. The evaluation of the findings offers some understanding of how well soil power can be increased beneath rigid pavements, which can help guide pavement design and construction methods.

1. Introduction

The California Bearing Ratio is one measure that is calculated indirectly. According to Khatri, D. P. et al. (2019) [1], laboratory CBR testing is time-consuming and labor-intensive. The laboratory has received thirty-three soil samples for analysis, in compliance with Katte, V. Y. et al. (2019)[2]. They discovered a connection between soil properties and CBR. According to Roksana et al. (2018)[3], CBR was impacted by the subgrade soil's plastic limitation and maximum dry density. According to their analysis, CBR values have an inverse relationship with MDD, SL, PL, and OMC but are proportionate to LL and PI. According to F. Iqbal et al. (2017)[4], the stiffness modulus and shear power of subgrade soils are measured using the California Bearing Ratio cost. Yadav, R. All OK. Furthermore, the high association between the CBR fee for coarse soil and MDD and OMC was confirmed by V. Chandrakar (2016)[5]. Most geotechnical solutions for engineering avenue developments require a CBR cost.

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Rehman, Z. U., et al. (2017)[6] used 59 soil samples, each of which included both excellent and coarse-grained soil samples, to develop prediction models. A distinct set of twenty-five soil samples was used to evaluate the validity of each of the three models that were created.

To classify soils based on their mechanical, physical, and chemical properties, several categorization schemes have been established. AASHTO and USCCS categorization systems are the two most commonly used systems. The distribution of grain sizes and the soil's fluidity are used to classify plants. B. M. Das (2014) [7]. I. M. Ramadan et al. (2018)[8] provided an inquiry into the effect of reinforcing the soil beneath a concrete slab on its thickness. They concluded that increasing the (CBR percent) value, which lowers the thickness of the concrete slab, increases the strength of the subgrade soil by increasing the (K) value.

For all soil samples gathered from various sites around Egypt, this paper aimed to establish a relationship between CBR values and the Soil Plasticity Index, Optimal Moisture Content, and Maximum Dry Density. The difference between these soil samples' projected and laboratory CBR values must be evaluated as the second factor. As this study explains, the results demonstrate a high degree of agreement between the predicted and laboratory values of CBR.

2. Laboratory Investigations

There was a thorough experimental plan mentioned in this publication. As illustrated in Fig. 1, experiments were carried out on one hundred (100) soil samples that were gathered from twelve different locations throughout Egypt. The results of the tests and observations made during the experiments are analyzed and reported in this paper..

Fig. 1 Map of Egypt showing sample site locations.

1- Wady Natrun. 2- El-Sadat City.
3- 6th October City. 4- Wady El-Rayyan.
5- El-Maady. 6- New Cairo City.
7- Badr City. 8- El-Obour City.
9- Abu-Zabel City. 10- Talkha City.
11- Damitta El-Gededa. 12- Sharm Al-Skeikh.

3. Program of Study

3.1. Properties of the Soil Index.

The Atterberg limits for each soil sample were obtained using the Atterberg technique (ECP 202-2001)[10].

3.2. Soil Classification and Particle Size Estimation

Different soil samples were classified using AASHTO method M14.5. The percentages of different fractions were established by analysing the different sizes of particles in all soil samples.

3.3. CBR Value Determination

Three kilograms of air-dried soil and a tiny amount of water were mixed. The sample was done in accordance with the standard protocol (ECP 104- 2008) [9]. The mold and compacted dirt were weighed and positioned below the CBR apparatus as per standard procedure. Table 1 provides a summary of all the test results.

4. Results

4.1. . CBR Values, Compaction Characteristics, and Soil Properties

The results of all the testing are compiled in Table1. Multiple linear regression analysis (MLRA) and simple linear regression analysis (SLRA) were developed to determine the CBR values. Table 2 demonstrates the various regression correlation coefficients between CBR levels and other soil metrics. The link between CBR and several soil metrics (PI, OMD, and MDD) is depicted in Figures 2 through 13.

Table 1. Soil properties, Compaction Characteristics and CBR values.

Soil Type	Gravel (%)	Sand (%)	Fine (%)	L.L. (%)	P.L. (%)	Com. Characteristics		CBR (%)
						MDD (%)	OMC (%)	
A-1-a	84	14.5	1.5	11	3	2.09	7.76	95.8
A-1-b	57	23	20	14	4	2.06	8.24	35.6
A-2-4	29	45	26	21	10	2.07	6.8	38.0
A-2-6	23	60	17	26	14	1.91	9.39	23.9
A-3	0	100	0	16	16	1.77	12.9	24.3

Table 2. The coefficient of correlation between CBR values and other soil characteristics.

Soil Type	Correlation Coefficient (R2) CBR & MDD	Correlation Coefficient (R2) CBR &OMC	Correlation Coefficient (R2) CBR & PI
A-1-a	0.60	-0.53	---
A-1-b	0.11	-0.44	---
A-2-4	-0.06	-0.6	0.23
A-2-6	0.32	-0.08	-0.11
A-3	-0.95	0.87	---

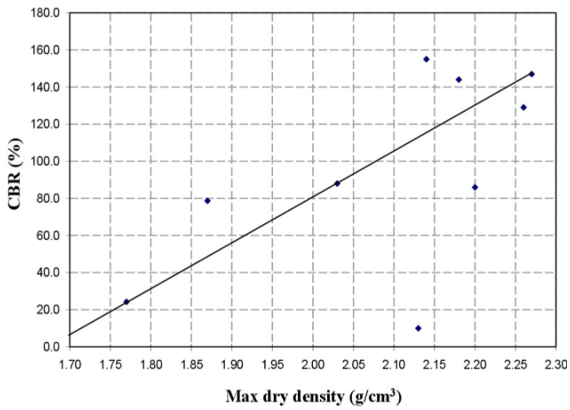

Fig. 2 Relationship between MDD and CBR in the (A-1-a) soil

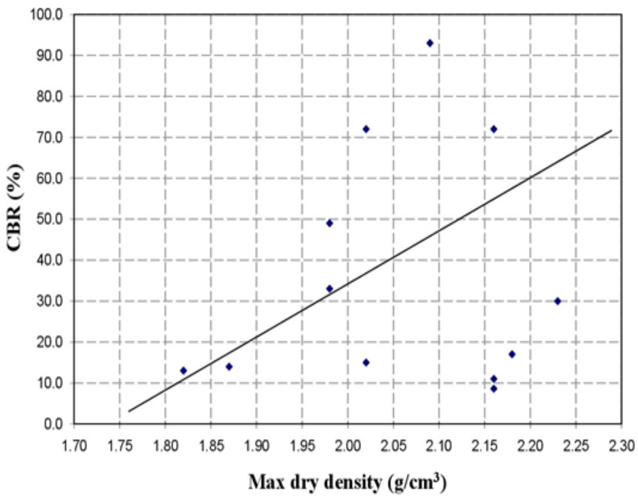

Fig. 3 MDD and CBR relationships in the (A-1-b) soil.

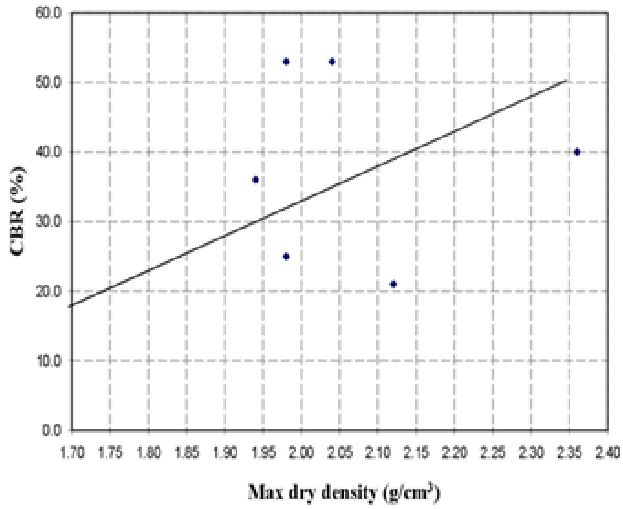

Fig. 4 MDD and CBR relationships in the (A-2-4) soil.

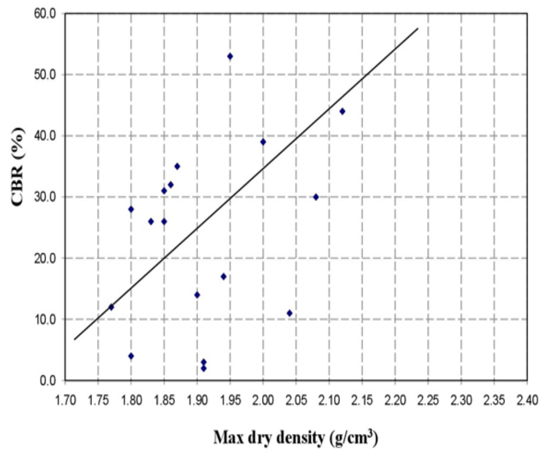

Fig. 5 MDD and CBR relationships in the (A-2-6) soil

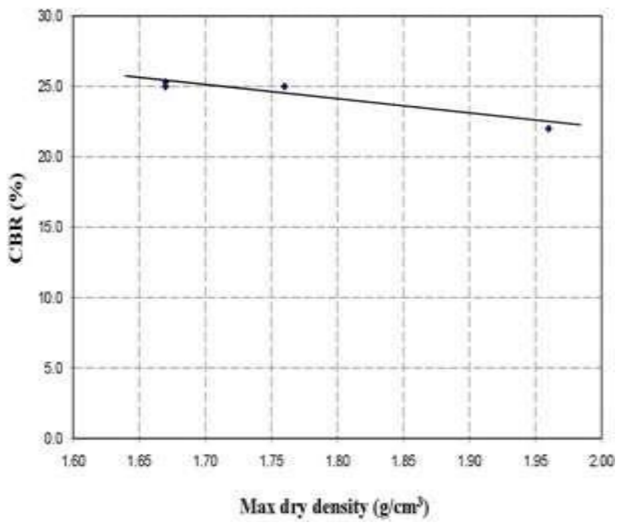

Fig. 6 MDD and CBR relationships in the (A-3) soil

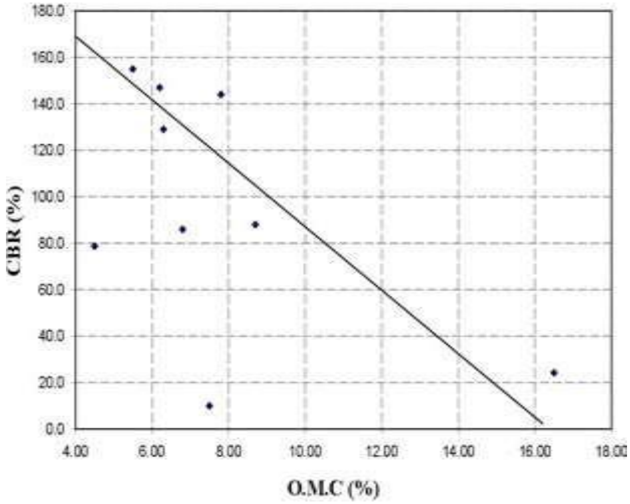

Fig. 7 OMC and CBR relationships in the (A-1-a) soil.

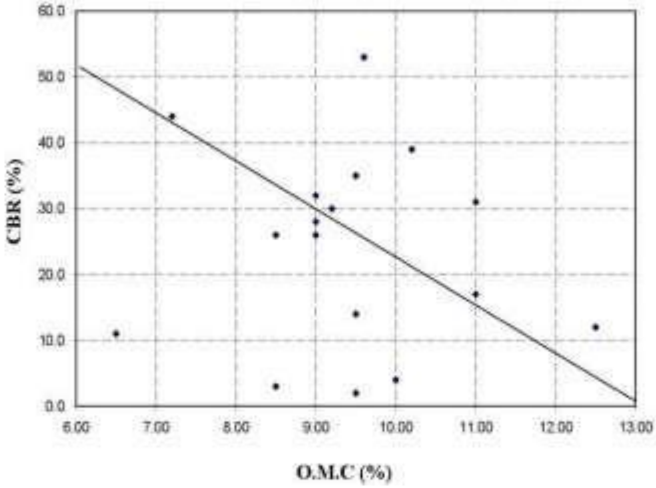

Fig. 10 OMC and CBR relationships in the (A-2-6) soil.

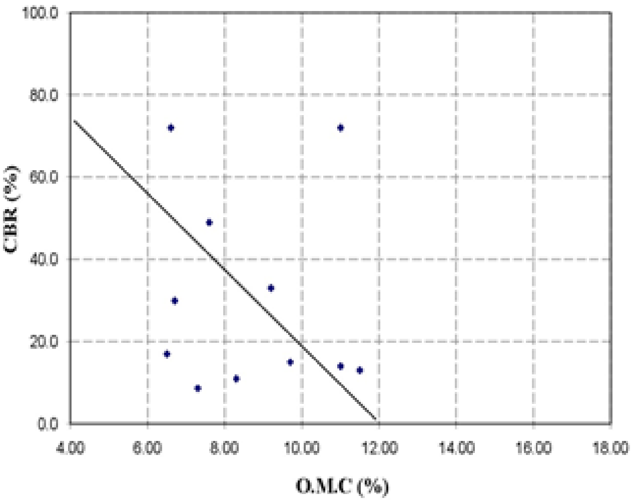

Fig. 8 OMC and CBR relationships in the (A-1-b) soil.

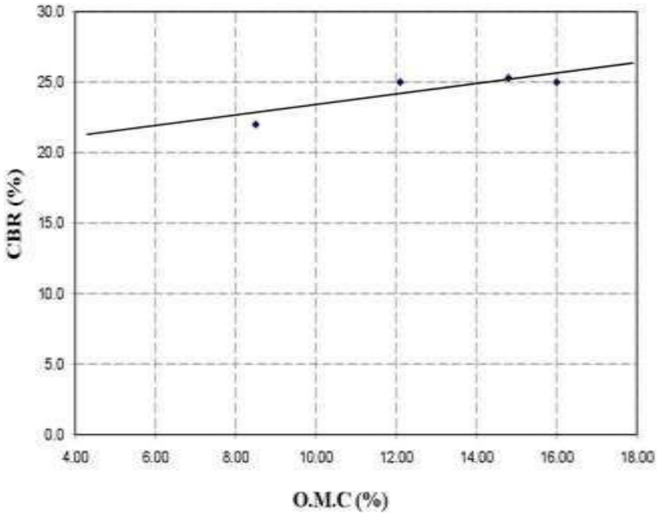

Fig. 11 OMC and CBR relationships in the (A-3) soil.

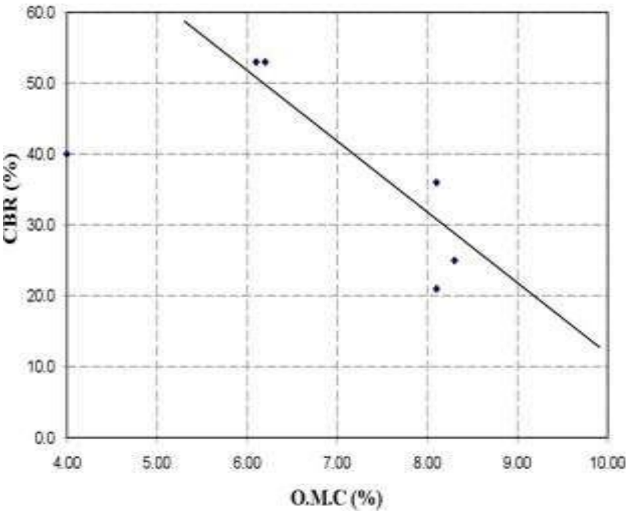

Fig. 9 OMC and CBR relationships in the (A-2-4) soil.

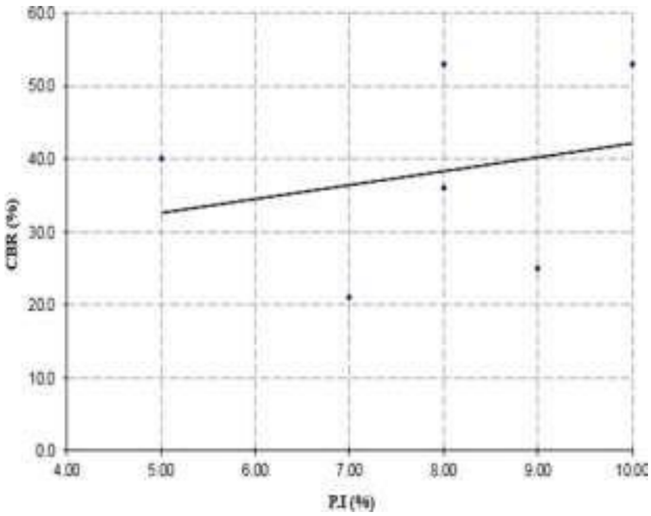

Fig. 12 PI and CBR relationships in the (A-1-4) soil.

4.2. Correlation between Max. Dry Density (MDD) and CBR (%) for Various Soil Types.

Table 2 displays the correlation coefficients between (MDD) and CBR for the various soil types. An outstanding significant positive connection between CBR and MDD was found for the soil A-1-a type; this implies that CBR rises as the MDD value does, as shown in Fig. 2. The regression analysis shows that curve fitting has a coefficient of determination (R2 = 0.61). For A-1-b, A-2-4, and A-1, however, there was almost no correlation between CBR% and MDD, as shown in Figs. 3 and 4. The A-2-6 kind of soil was found to have a relatively positive correlation with a coefficient of determination (R2 = 0.33), as illustrated in Figure 5. Nevertheless, significantly negative correlation was discovered in the A-3 kind of soil indicating that as the value of MDD grew, the value of CBR increased linearly (R2 = -0.96), which matched the results in Fig. 6.

4.3. Correlation between (OMC) and (CBR) for Various Soil Types.

Additionally, Table 2 shows an additional correlation coefficient between OMC (%) and CBR (%) for various soil types. In the A-1-a, A-1-b, and A- 2-4 types of soil, as illustrated in Figs. 7 to 9, there was a highly significant negative correlation, which means that as the value of CBR dropped, the value of OMC rose. Figure 10 shows a weak negative correlation for soil type A-2-6. But as Fig. 11 illustrates, in the A-3 kind of soil, there was a very high significant positive correlation between OMC (%) and CBR (%), with a coefficient of determination of 0.87.

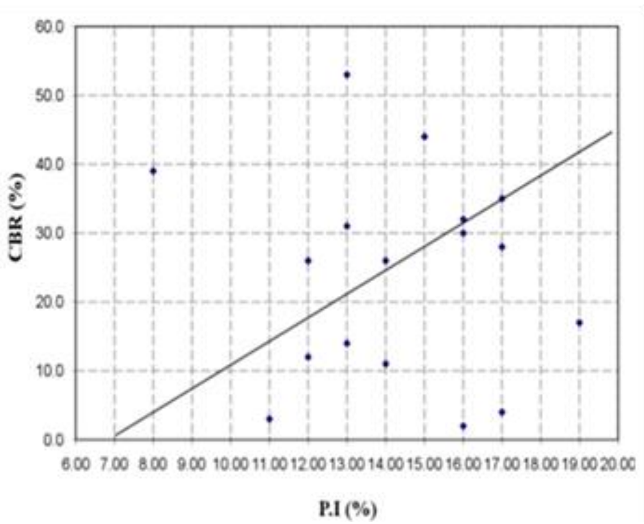

Fig. 13 PI and CBR relationships in the (A-2-6) soil.

4.4. Correlation between the CBR percentage and the Plasticity Index (PI%) for

As Fig. 12 shows, the results for the A-2-4 soil type indicated a weakly positive correlation between PI (%) and CBR (%). The negative (non-significant) correlation between CBR and PI for the A-2-6 type is seen in Fig. 13.

In the end, regression analyses were conducted using soil characteristics as the independent variable and the CBR value as the dependent variable. An overview of all the relationships discovered is given in Table 3. It is evident that the (MDD) and (OMC) have a direct effect on the CBR value. Nevertheless, the Plasticity Index (PI) had no discernible impact on the CBR value.

Table 3. CBR regression formulae for various soil types.

Soil Type	Correlation	Regression Model
A-1-a	CBR vs. PI	= - 411.7 + 246.2 × PI
	CBR vs. OMC	= 210.41 - 12.9 × O.M.C
	CBR vs. MDD & OMC	= - 100.6 + 123.1 × MDD - 6.6 × O.M.C
	CBR vs. MDD	= - 224.52 + 129.01 × MDD
A-1-b	CBR vs. PI	= 108.457 - 9.114 × PI
	CBR vs. MDD & OMC	- 58.03 + 64.52 × MDD - 4.5 × O.M.C
	CBR vs. MDD	= - 67.5 + 50 × MDD
	CBR vs. OMC	= 110 - 9.8 × O.M.C
A-2-4	CBR vs. PI	= - 11 + 6.25 × P.I
	CBR vs. MDD & MOC & PI	= 50.3 × MDD – 70.2
	CBR vs. MDD	= - 165 + 100 × MDD
	CBR vs. OMC	= 99 - 7.7 × O.M.C
A-2-6	CBR vs. PI	= - 24.2 + 3.5 × P.I
	CBR vs. MDD & OMC & PI	= - 45.1 + 50 × MDD - 3.8 × O.M.C + 1.73 × P.I
A-3	CBR vs. MDD	= 49.8 – 14 × MDD
	CBR vs. OMC	= 19.4 + 0.4 × O.M.C
	CBR vs. MDD & OMC	= 34.6 – 7 × MDD + 0.2 × O.M.C

5. Discussion

5.1. Comparison between Predicted and Field value CBR (%) for Various Soil Types.

As mentioned earlier, the results demonstrated that the CBR value is directly impacted by the (MDD) and (OMC) for different soil types. This suggests that the regression analysis-based CBR value prediction model closely matches test findings for different soil types. Consequently, the CBR value was computed directly using the soil's characteristics. Table 4 and Figs. 14–18 illustrate the comparison between the field and expected values of CBR for different soil types using the following equation:

$$\textbf{Predicted CBR} = -45.1 + 50 \times \textbf{MDD} - 3.8 \times \textbf{O.M.C} + 1.73 \times \textbf{P.I}$$

When contrasting the results, In the A-1a, A-1-b, and A-3 types of soil, the field and expected CBR vary somewhat, as shown in Figs. 14 to 16. In the A-2-4 and A-2-6 types of soil, however, Figs. 17 and 18 show a notable difference between the two values. Since the results showed a high degree of agreement between the field and anticipated values of CBR, the predicted model may be used to compute the value of CBR by knowing the soil properties like (MDD) and (OMC). Furthermore, the expected values of CBR are a little lower than

the field value; therefore, using the predicted value will raise the (K) for soil, which will cause the thickness of the pavement and subbase to decrease.

Table 4. Comparison between field and predicted values of CBR for different soil types.

Soil Type	Field CBR (%)	Predicted CBR (%)
A-1-a	95.8	107.0
A-1-b	35.6	37.1
A-2-4	38	58.8
A-2-6	23.9	39.1
A-3	24.3	24.8

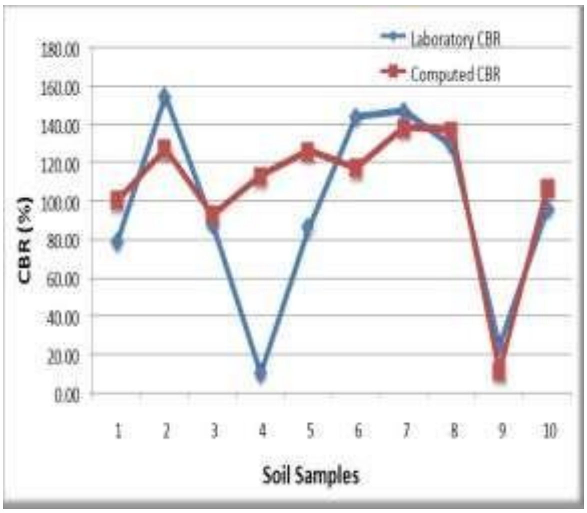

Fig 14 Field and predicted CBR values for soil A-1-a type.

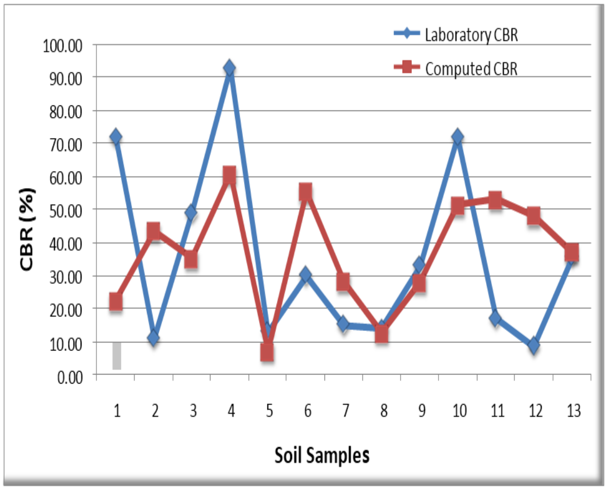

Fig. 15 Field and predicted CBR value for soil A-1-b type.

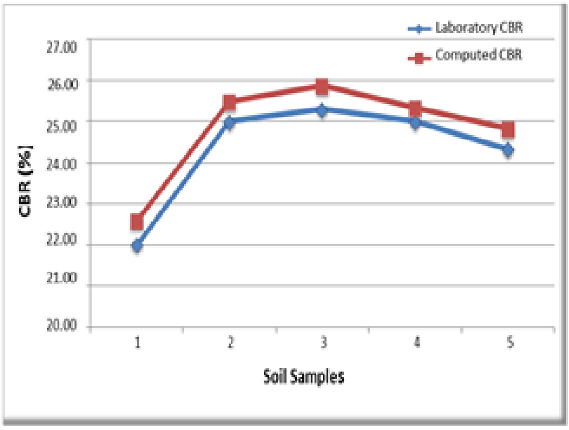

Fig. 16 Field and predicted CBR value for soil A-3 type.

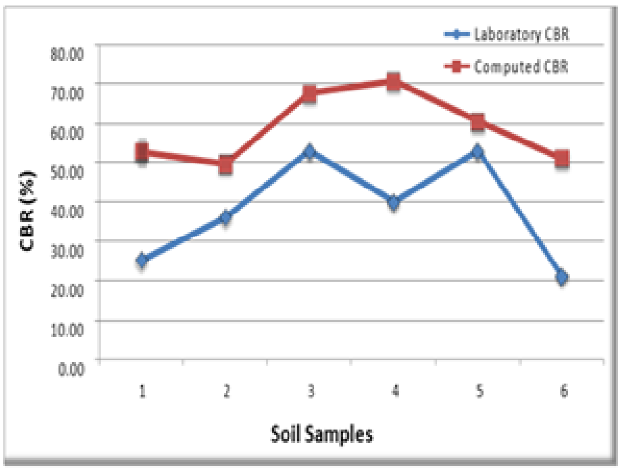

Fig. 17 Feld and predicted CBR value for soil A-2-4 type.

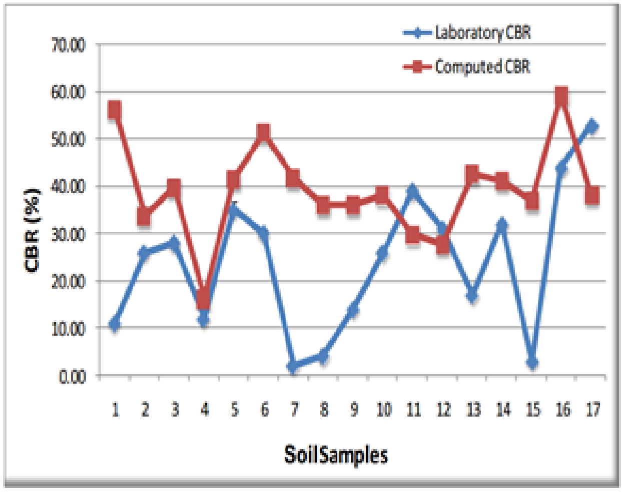

Fig. 18 Field and predicted CBR value for soil A-2-6 type.

5.2. The Effect of the Strength of the Soil on the Slab Thickness.

Finding the modulus of subgrade response (K) values, which can be done from CBR values using a number of formulas and figures in (ECP 1998), is the first step in figuring out the link between k values and CBR values. With the exception of D and K, which will remain the only two variable values showing the effect of growing sub-grade reaction value on dropping slab depth, the AASHTO Design Equation for Rigid Pavement shows that all of the parameters are constant. The slab thickness comparison utilizing field and expected CBR values is displayed in Table 5.

$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35 \cdot \log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624\cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \cdot p_t)\cdot \log\left[\frac{S_c \cdot C_d \cdot (D^{0.75} - 1.132)}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

<u>These values for equation parameters are used:</u>

Zr = -1.282 S= 0.35 Po= 4.5 Pt = 3 DPSI= 1.5
Sc = 600 Cd= 1 J= 2.7
Ec= 4000000. From these parameters an equation can be concluded as follows:
Slab depth (in) = 9.3207 - 0.0016 K (Psi/in)

Table 5. Comparison between field and predicted values of the slab thickness**.**

Soil Type	Field CBR (%)	K Psi/in	D inch	Predicted CBR (%)	K Psi/in	D inch	% Decrease
A-1-a	95.8	780	**8.1**	107.0	845	**8.00**	**1.24**
A-1-b	35.6	360	**8.8**	37.1	375	**8.7**	**1.24**
A-2-4	38	380	**8.7**	58.8	565	**8.4**	**3.45**
A-2-6	23.9	270	**8.85**	39.1	390	**8.7**	**1.70**
A-3	24.3	288	**8.9**	24.8	290	**8.85**	**1.7**

Any research project should aim for technical assistance, advancement, and improvement, but in cases of financial difficulty, the economic impact is still the most important factor. Governments can reduce the amount of money they spend on infrastructure projects by using scientific research. To illustrate the economic implications of the research, the following stiff pavement design is used:

The value of the reduction in slab depth × road length × number of lanes × lane width equals the concrete saving (m3) for a 100-kilometer highway with two ways in each direction. For instance, with soil type A-3:
= (1.7/100)× (100×1000) × (6×3.5) = **35700 m^3**

6. Conclusions

The following are the primary conclusions that can be drawn from this research: -

1- There was good agreement between the field and predicted value of CBR.
2- The regression analysis indicates a good relationship in predicting CBR value from MDD % and OMC %.
3- The results reveal that in several types of investigated soils, there was a strong positive link between California bearing ratio (CBR%) value and (MDD %), whereas CBR value correlated negatively with OMC %. Wile, PI was adversely correlated with CBR value (to a lesser extent).
4- The comparison of field and predicted CBR values revealed a slight difference in A-1a, A-1-b, and A-3 types of soil, but a considerable disparity between the two values in A-2-4 and A-2-6 types of soil.
5- There was a relationship between CBR value and soil parameters such (MDD) and (OMD).
6- Using the predicted value will improve the (K) for soil and then the thickness of slab will decreases by

7- 1.24 to 1.7 %.
8- The effect of increasing sub-grade reaction deceases the slab depth and hence it can help governments to save money spent on infrastructure projects.

Abbreviations List

PI : Plasticity Index.
CBR : California Bearing Ratio.
MDD : Maximum Dry Density.
R^2 : Coefficient of Determination.
OMC : Optimum Moisture Content.
MLRA : Multiple Linear Regression Analysis.
W18: Predicted number of 80 KN. ESALs which calculate by cumulative number of ESAL.
Z_R : Normal Deviation Standard.
SLRA : Simple Linear Regression Analysis.
S0 : Overall Standard deviation of design.
D : Slab Depth (inch)
P_t : Index of Terminal Serviceability.
DPSI : Design Serviceability Loss.
S_C: Modulus of Rupture (psi) of PCC (Flexural Strength)
C_d = Coefficient of Drainage.
k = Sub-grade Reaction Modulus (pci).
J = Coefficient of Load Transfer.
E_c = Elastic Modulus of Concrete (psi).

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Conflict of interest

The corresponding author declares that there is no conflict of interest on behalf of all authors.

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