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Prediction of CBR Value from Index Properties of Cohesive Soils

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Abstract: The aim of this paper is to develop empirical relationship between CBR values and soil index properties of cohesive soils as road subgrade. However; it is always difficult for highway engineers to obtain representative CBR values for design of pavement. Over the years, many correlations had been proposed by various researchers in which the soil index properties were used to develop these correlations. The CBR value is affected by the initial state parameters of soil as described by the water content and dry density and the testing conditions. Silty clay soil samples were compacted at different water contents and dry densities to measure the strength by CBR tests in soaking and unsoaking conditions. The results show that the CBR values of these soils are greatly influenced by the water content and dry density (i.e. the initial state parameters) of the soil as well as the testing conditions. Analysis of the experimental data indicated that it is possible to combine these initial state parameters in a way reflecting the influence of each of them on the CBR. Therefore a new concept has been developed; this is called the initial state factor. This factor is also developed for the soaking or saturated condition and is called the soaking state factor. On basis of this concept, a reliable strong correlation has been established between CBR values and soil state factors and plasticity index. Comparison between the measured soaked or unsoaked CBR values and the calculated results using the developed equations clearly indicates the reliability of these equations.

1. INTRODUCTION

The design of pavements is much dependent on the CBR value of subgrade. CBR values can be measured directly in the laboratory test in accordance with BS1377:1990, ASTM D4429 and AASHTO T193. A laboratory test takes at least four 4 days to measure the CBR value for each soil sample. The soil sample will be compacted as required in a standard mould and then a plunger is made to penetrate the soil at a specified penetration rate. Load versus penetration curve will be plotted from the result of the penetration and will be compared with the bearing resistance of standard crush rock. Civil engineers always encounter difficulties in obtaining representative CBR values for design of pavement. A CBR value is affected by the type of soil and different soil properties. An attempt has been made to correlate the CBR with soil properties. It can be the alternate method for the time consuming tests. These tests are much economical and rapid than CBR test. This paper aims to develop a correlation between CBR values with the state factors developed from easy measured soil index properties such as water content, dry density, void ratio and plasticity index that can be used for prediction of CBR values of silt-clay soils.

2. LITERATURE REVIEW

It is reasonable to assume that California Bearing Ratio (CBR) values are related to soil index properties in some ways. Many researches had been carried out to show the effect of soil types and characteristics on CBR values by as Black (1962), de Graft-Johnson & Bhatia (1969), Agarwal & Ghanekar (1970) and NCHRP (2001).

A number of attempts have been made to correlate California Bearing Ratio (CBR) with soil grain distribution and plasticity. Among them, Black (1962) had developed a method of estimating the CBR value for cohesive soils. He had obtained the correlations between CBR and plasticity index for various values of liquidity index which is shown in Figure 2.1. Note that the values given in Figure 2.1 are only referred to saturated soils only. For unsaturated soils, the CBR values obtained can be corrected by applying the correction factor as shown in Figure 2.2.

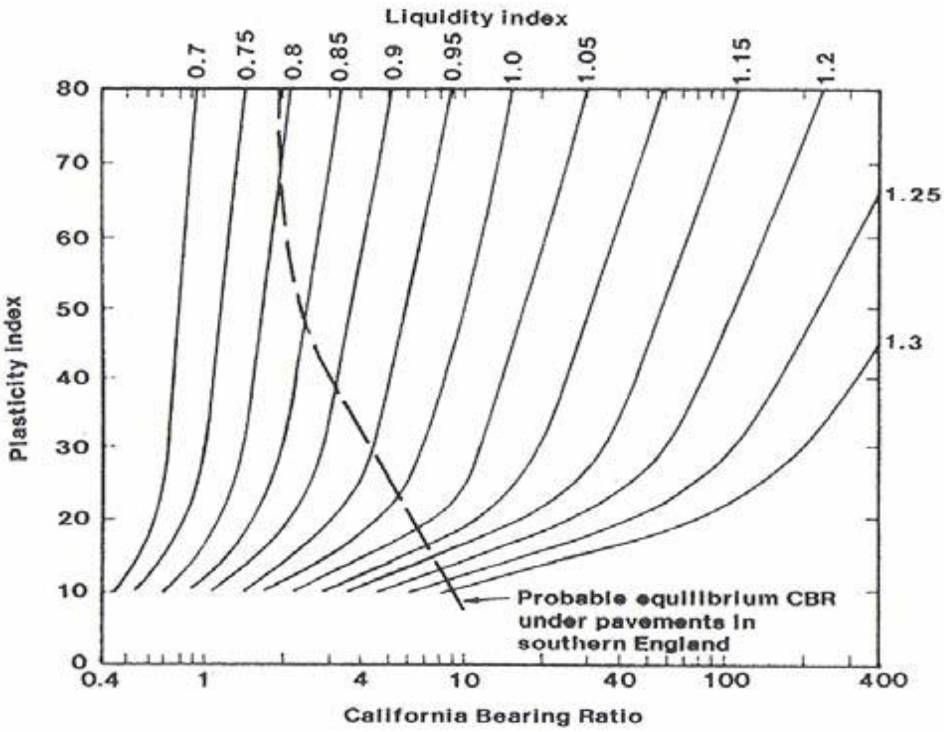

Figure (2.1). Relationship between CBR and plasticity index at various liquidity index values

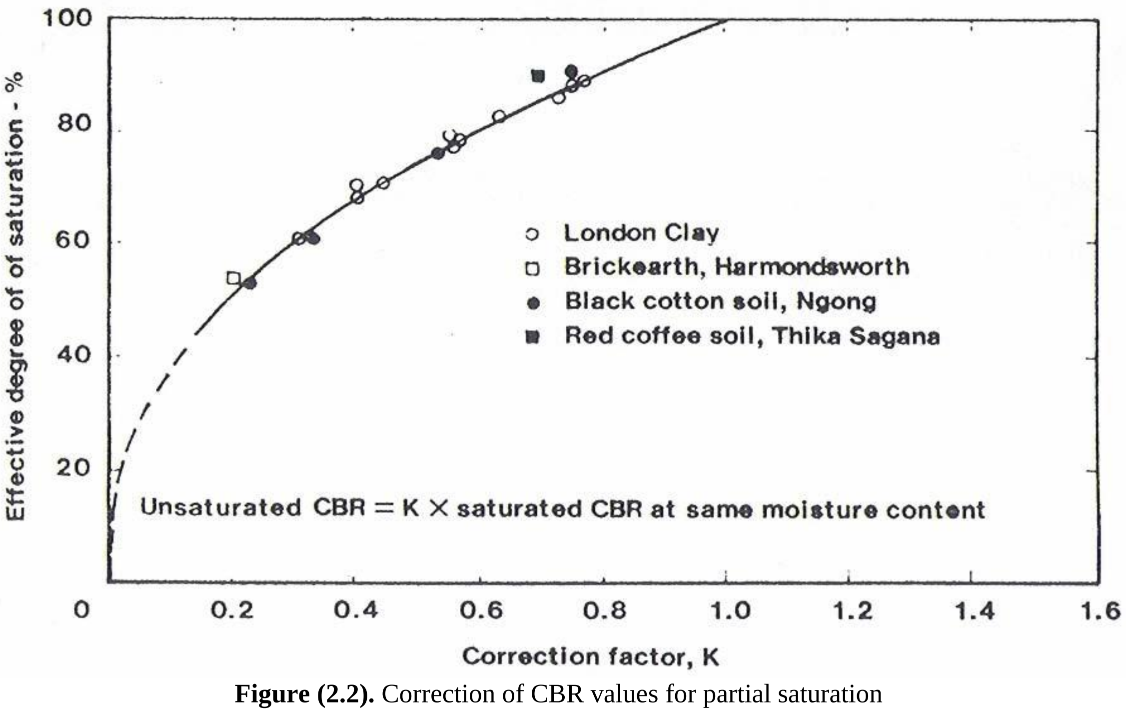

Figure (2.2). Correction of CBR values for partial saturation

Agarwal and Ghanekar (1970) had tried to develop a correlation between CBR values and either liquid limit, plastic limit or plasticity index. However, they failed to found any significant correlation between them. Instead, they did found an improved correlation when they included the optimum moisture content and liquid limit. The correlation is defined as below.

$$CBR = 2 - 16\log(OMC) + 0.07LL \quad 2.1$$

Where; OMC = Optimum Moisture Content
LL = Liquid Limit

The 48 soil samples tested by them had CBR values of not more than 9% and the standard deviation obtained was 1.8. Hence, they suggested that the correlation is only of sufficient accuracy for preliminary identification of material.

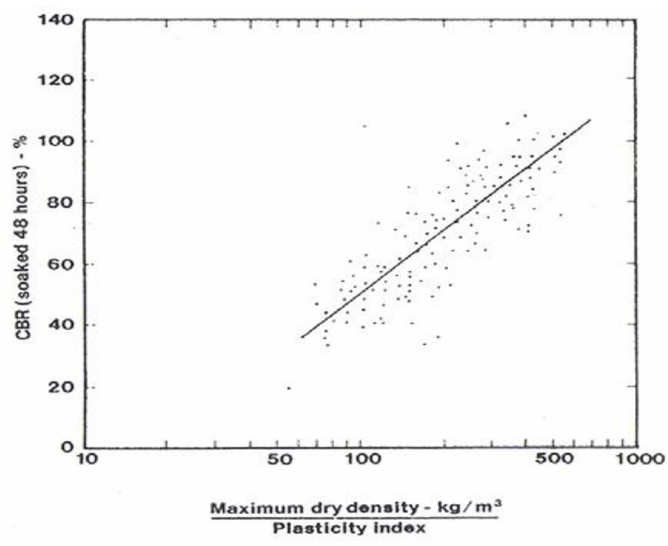

Figure 2.3: Relationship between the ratio of maximum dry density to plasticity index and CBR for laterite-quartz gravels

The National Cooperative Highway Research Program (2001) of United States of America through the "Guide for Mechanical-Empirical Design of New and Rehabilitated Pavement Structures" had developed some correlations that describe the relationship between soil index properties and CBR values. An equation was established for soils which contain 12% fines and exhibit some plasticity. For plastic, fine-grained soils, the soil index properties chosen to correlate CBR are the percentage passing No.200 U.S. sieve or 0.075mm size sieve and plasticity index. The suggested equation by NCHRP is shown below.

$$CBR = \frac{75}{1 + 0.728(wPI)} \quad 2.2$$

Where; w = Percentage passing No.200 U.S. sieve (in decimal) ,
PI = Plasticity Index

3. EXPERIMENTAL WORK

The primary objective of this paper is to predict the CBR values (soaked and unsoaked) of clayey soils using soil index properties such as water content, dry density, void ratio and plasticity index. To achieve this objective an experimental testing program was conducted on soil samples collected from three different locations of clayey soils. The selected soil samples are tested for CBR, water content, dry density, plastic limit, liquid limit and specific gravity. The Soil samples were prepared with different water contents and compacted into a standard CBR mould to different dry densities and subjected to CBR testing conditions. Some of the soil samples were tested to measure unsoaked CBR values and others to measure soaked CBR values. These tests were performed according BS 1377.

4. ANALYSIS AND RESULTS

The results of the laboratory tests are summarized and presented as given in Tables (4.1) and (4.2). These tests results were analysed and used to verify the linear relationship between the State Factor and the measured CBR value.

4.1 Soil State Factor

The soil state factor of compacted soil was first developed by Mohamed (1986) and then modified by Zumrawi (2000). This factor is defined as a combination of the soil initial state parameters such as dry density, water content and void ratio and can be expressed thus:

$$F_i = \frac{\rho_d}{\rho_\omega} \cdot \frac{1}{\omega \cdot e} \quad 4.1$$

Where:
F_i is the initial state factor
ρ_d is the initial dry density of soil
ρ_ω is the density of water
ω is the initial water content of soil
e is the initial void ratio of soil.

$$e = \frac{G_s}{\rho_d} - 1 \quad 4.2$$

Where: G_s is the specific gravity of soil.

When the soil is subjected to soaking, the factor is called the soaking state factor and is expressed as:

$$F_s = \frac{\rho_{ds}}{\rho_\omega} \cdot \frac{1}{\omega_s . e} \quad 4.3$$

Where:
ρ_{ds} is the dry density for the soaked soil
ω_s is the saturated water content for the soaked soil

For the soaked soil, the dry density (ρ_{ds}) and the water content (ω_s) can be calculated using the following equations:

$$\rho_{ds} = \frac{\rho_d}{1+S} \qquad 4.4$$

$$\omega_s = \frac{\omega}{S_r} \qquad 4.5$$

Where: S_r is the degree of saturation

S is the amount of swelling due to soaking.

4.2 The state factors and CBR relationships

To investigate the relationship between the state factors (F_i & F_s) and the CBR values, the tests results obtained in this study were analysed as given in Tables (4.1) & (4.2). The relationships of the analysed data are shown in Figures (4.1) & (4.2). The plots in these figures and the values of the correlation coefficient (R) as listed in Table (4.3) have clearly demonstrated that a direct linear relationship exists between the CBR values and the state factors for all the data analysed. The straight lines shown in the plots of Figures (4.1) & (4.2) can be expressed as:

$$Unsoaked\ CBR = M_i * (F_i - F_{i0}) \qquad 4.6$$

$$Soaked\ CBR = M_s * (F_s - F_{s0}) \qquad 4.7$$

Where:

F_{i0}, F_{s0} is the value of F_i , F_s at zero CBR value.

M_i, M_s is the gradient of the straight lines.

Table (4.2). The soaked CBR values (measured and calculated) and initial state data analysed of the three soils (1to3)

ω (%)	ρ_d (g/cm^3)	e	S (%)	ω_s (%)	ρ_{ds} (g/cm^3)	F_s	S. CBR$_m$ (%)	S. CBR$_c$ (%)	R
5.9	1.701	0.60	3.5	22.02	1.643	12.5	0.63	0.78	1.24
9.5	1.695	0.60	2.1	22.23	1.660	12.3	0.61	0.78	1.27
10.7	1.814	0.50	2.3	18.36	1.774	19.3	0.94	1.09	1.15
14.2	1.893	0.44	2.0	16.06	1.856	26.4	1.11	1.40	1.26
15.1	1.862	0.46	2.0	16.94	1.826	23.4	1.03	1.26	1.23
17.7	1.766	0.54	1.3	19.86	1.744	16.3	0.81	0.95	1.17
17.9	1.835	0.48	1.2	17.73	1.814	21.2	0.88	1.17	1.33
19. 8	1.804	0.51	1.1	18.67	1.784	18.8	0.90	1.06	1.18
24.3	1.699	0.60	0.6	22.09	1.689	12.7	0.68	0.79	1.17
25.0	1.648	0.65	0.5	23.91	1.640	10.5	0.60	0.70	1.16
27.1	1.592	0.71	0.5	26.05	1.585	8.6	0.52	0.61	1.18
29.7	1.510	0.80	0.4	29.46	1.504	6.4	0.33	0.51	1.56
13.2	1.453	0.86	8.9	31.79	1.334	4.9	0.6	0.7	1.17
14.6	1.470	0.84	7.8	30.99	1.364	5.3	0.9	0.9	0.96
16.0	1.496	0.80	7.2	29.81	1.396	5.8	1.2	1.1	0.91
20.2	1.540	0.75	5.8	27.90	1.456	6.9	1.6	1.6	0.98
23.5	1.508	0.79	3.5	29.28	1.457	6.3	1.0	1.3	1.30
25.5	1.470	0.84	1.8	30.99	1.444	5.6	0.8	1.0	1.24
8	1.664	0.59	3.0	22.4	1.616	12.2	3.0	3.9	1.29
10	1.696	0.56	2.2	21.2	1.659	13.9	5.0	5.0	0.99
14	1.792	0.48	1.0	18.1	1.774	20.5	9.5	9.2	0.96
16	1.824	0.45	0.2	17.1	1.820	23.5	10.6	11.1	1.05
18	1.76	0.51	0.1	19.1	1.758	18.2	7.0	7.7	1.10
22	1.632	0.62	0.0	23.5	1.632	11.1	3.5	3.2	0.91

Note:

- U. CBR$_m$ is the measured value of unsoaked CBR
- U. CBR$_c$ is the calculated value of unsoaked CBR
- R is the ratio between the calculated and the measured unsoaked CBR values

Table (4.3). The tests results of the soils index properties and the analysis results

Soil	LL (%)	PL (%)	PI (%)	G_s	F_{i0} or F_{s0}	M_i or M_s	R
Soil A	70	28	42	2.75	0.66	1.81	0.978
Soil B	65	40	25	2.74	2.79	4.56	0.972
Soil C	59	26	33	2.72	5.93	3.00	0.989
Soil D	59	25	34	2.70	0.66	1.85	0.987
Soil 1	59	27	32	2.72	-5.10	0.04	0.980
Soil 2	54	30	24	2.70	3.40	0.43	0.894
Soil 3	43	24	19	2.65	6.27	0.63	0.986

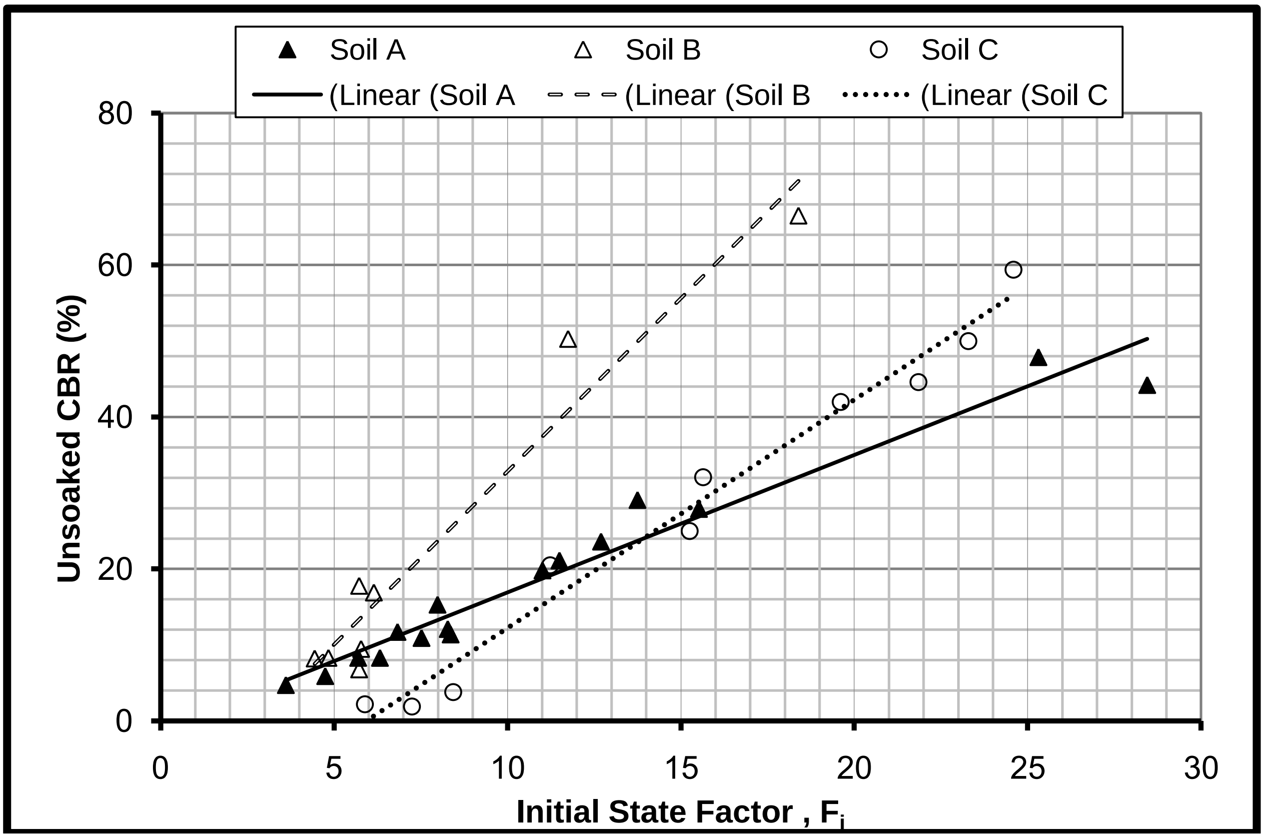

Figure (4.1). The Linear Relationship between Unsoaked CBR and Initial State Factor (F_i) for the data analysed of the three soils (A, B& C).

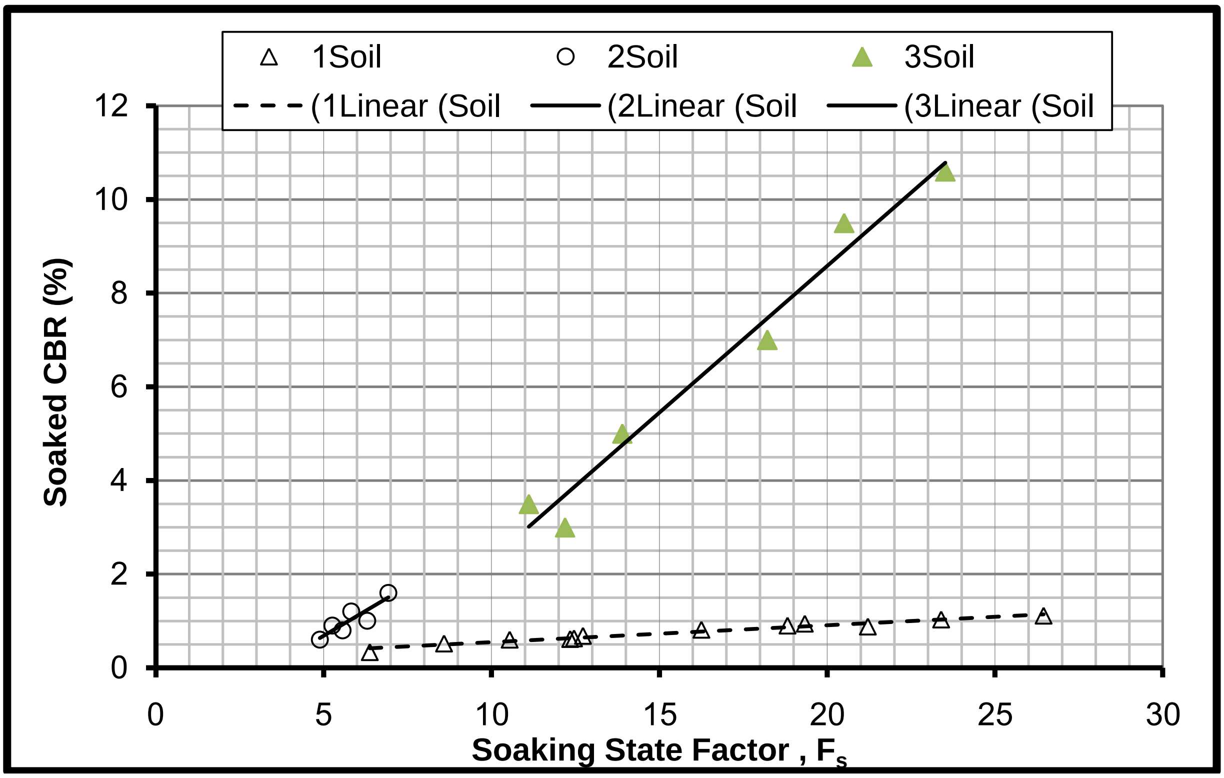

Figure (4.2). The Linear Relationship between Soaked CBR and Soaking State Factor (F_s) for the data analysed of the three soils (1, 2& 3).

The relationship of F_{io}, F_{so} and M_i, M_s with plasticity index was plotted in Figures (4.3 & 4.4). It can be noted that in these figures, increasing in plasticity index will decrease M and F_o values. The equations of the best fit curves and lines are expressed thus:

$$F_{io} = -488\,(PI)^2 + 314\,PI - 45 \quad 4.8$$

$$F_{so} = -264\,(PI)^2 + 56\,PI + 5 \quad 4.9$$

$$M_i = -16.1\,PI + 8.44 \quad 4.10$$

$$M_s = -4.23\,PI + 1.44 \quad 4.11$$

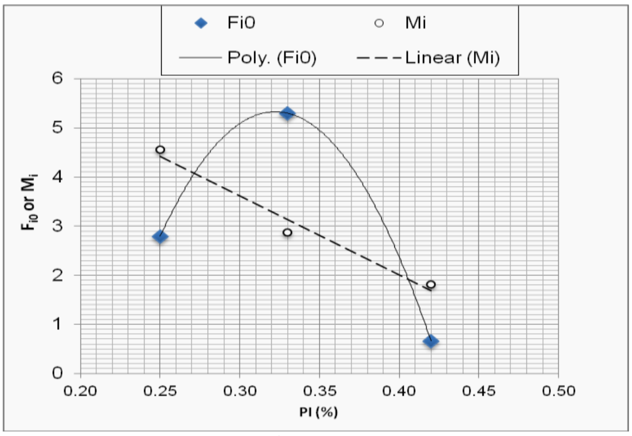

Figure (4.3). Variation of F_{i0} and M_i with plasticity index for the unsoaked CBR data

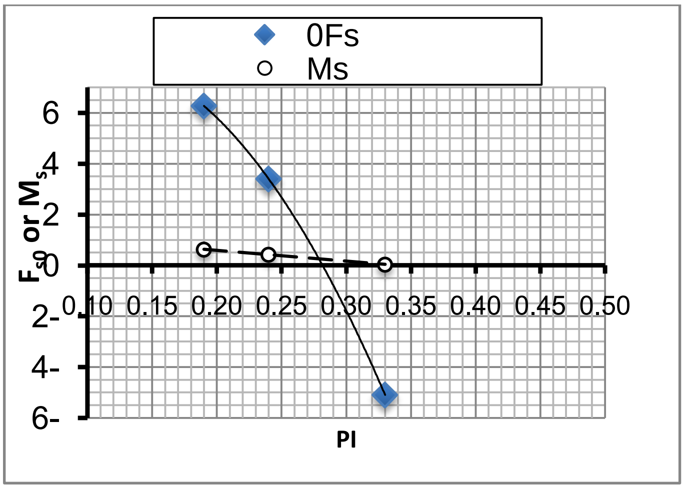

Figure (4.4). Variation of F_{s0} and M_s with plasticity index for the soaked CBR data

By substituting the above equations 4.8 to 4.11 in the general two equations 4.6 and 4.7 and rearranged to express unsoaked and soaked CBR as:

$$unsoaked\ \ CBR = (8.44 - 16.1 PI)\left[F_i + 488(PI)^2 - 314 PI + 45\right] \quad 4.12$$

$$soaked\ \ CBR = (1.44 - 4.23 PI)\left[F_s + 264(PI)^2 - 56 PI - 5\right] \quad 4.13$$

Where:

F_i is the initial state factor

PI is the plasticity index (%).

The analysis results when using the above two equations (4.12 & 4.13) to calculate CBR soak and unsoak condition are presented in Tables (4.1 & 4.2). As seen in these tables the calculated CBR values using the equations (4.12 & 4.13) and measured CBR (0.80 ~ 1.30) for all the data analysed proved the validity of the developed equations. This result shows that CBR (soaked or unsoaked) could be defined as a function of soil states factors (initial and soaking) and the plasticity index.

5. CONCLUSIONS

- Experimental work has been carried out to study the CBR of cohesive soils. Several tests to measure the CBR and index properties were performed on samples compacted to different water contents and dry densities.

- Initial water content, dry density and void ratio were combined in a way reflecting the influence of each of them on CBR value. This combination was termed the initial state Factor (F_i). On the other hand the combination of the soaked or saturated water content, dry density and amount of swelling was termed the soaking state Factor (F_s).

- Analysis of the experimental results demonstrates very clearly that a direct linear relationship exists between unsoaked CBR and the initial state Factor (Fi). Similarly the relationship between soaked CBR and the soaking state Factor (Fs) is linear as well. The coefficients of this linear relationship (i.e. constant and slope) were found to depend on plasticity index of soil.

- It has been proved that a direct linear relationship exists between unsoaked CBR and the initial state Factor (F_i). Similarly the relationship between soaked CBR and the soaking state Factor (F_s) was verified to be linear relationship as well. Based on this relationship, a reliable strong correlation has been established between CBR values and soil state factors and plasticity index. Comparison between the measured soaked or unsoaked CBR values and the calculated results using the developed equations clearly indicated the reliability of these equations. These equations can be used to predict the subgrade strength for the pavement design purposes.

- It is recommended for future researches to establish CBR correlations using cohesionless soils as base or subbase materials.

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