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Prediction of CBR Values Under Covered Areas

by

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1 INTRODUCTION

One of the main factors governing the design of flexible pavements is the shear strength of the subgrade. Among the many parameters affecting this strength, one of the more importance is the moisture content of the soil. Thus, it is a mandatory condition to predict in each case the moisture distribution in the subgrade. Since moisture redistribution occurs after construction of a pavement, it is more relevant to consider the distribution associated with the conditions of moisture equilibrium.

The CBR tests as carried out by the U.S. Corps of Engineers account for the moisture conditions to be expected in the subgrade by simply soaking the samples for four days in water before shearing. The validity of the 4-day saturation has been raised in connection with the Canadian procedure. McLeod (Ref. 1) has shown that in situ CBR performed under existing pavements can be as high as 3 to 4 times the corresponding 4 day soaked laboratory CBR. Consequently, the Canadian Transportation Dept. does not base its pavement design of values of CBR obtained after soaking but rather on unsoaked values. It seems to be that the U.S. Corps of Engineers procedure may lead sometimes to over-design, while the Canadian Transportation Dept. procedure may lead to under-design. Contrary to the above mentioned procedures, the Road Research Laboratory's one (Ref. 2) states that the subgrade material should be compacted in the laboratory at the equilibrium moisture content expected below the pavement and sheared without saturation.

Until physical theories and applications will be developed, a reliable prediction of equilibrium moisture content of covered subgrades must be based on sound correlations between laboratory tests and actual field performance. A recent extensive work has been made in order to evaluate five existing runways in Israel after 10 to 15 years of service. Several recent research projects were also performed to determine the physical and mechanical properties of local expansive clays. Selected data were extracted from these works and are given in this paper. The purpose of the paper is to deal with the correlation of index properties of local expansive clays with other characteristics which govern the behaviour of the material as a subgrade for road and airfield pavements under specific moisture conditions. The correlations involved, relate the consistency limits to:

- (a) Moisture equilibrium conditions in the subgrade
- (b) Moisture-suction relationships
- (c) CBR value at various conditions.

These correlations, with the aid of simple index tests, allow for the evaluation of the

factors governing the design of pavements and selection of design values for small projects in expansive clays and the corresponding factors and values for the preliminary design of large projects. Although these correlations apply primarily to expansive clays in Israel, they may serve as an indication for similar correlations in other part of the world.

2 MOISTURE CONTENT AT EQUILIBRIUM CONDITIONS

Water is held in porous materials by surface tension and adsorption forces. In granular soils, such as sand, the water is held by surface tension forces only. In clay soils, which contain particles whose surfaces are negatively charged, forces of adsorption exist in addition to surface tension, and these are affected by the salts in the soil.

The total potential of soil moisture, ψ , is fundamentally a thermodynamic variable. For practical purposes considered in the treatment of suction for road pavements:

$$\psi = z - s = z - h_m - h_s \quad (1)$$

where, z is the gravitational potential, s is the total suction, h_m is the matrix suction, and h_s is the solute suction or osmotic head due to dissolved salts.

Suction changes in the soil lead to movement of moisture from region of low suction to those of high suction. As a result, moisture is redistributed until a state of equilibrium, involving non-uniform moisture distribution, is established. The estimation of the final moisture content is of a great importance, since this condition will govern the behaviour of the pavement from the point of view of movement and bearing capacity. Extensive and basic work on this subject has been done by the Road Research Laboratory, England (Ref. 3). A summary of the methods they developed for estimating moisture condition after covering is given by Kassiff *et.al* (Ref. 4).

Usually the soil conditions are divided into three categories:

- (a) A covered area with ground water level closed to ground level.
- (b) A covered area with deep ground water level and a yearly rainfall of over 250 mm.
- (c) A covered area with arid climatic conditions and a yearly rainfall of less than 250 mm.

Category (b) is the most representative of conditions in semi-arid countries. Estimation of moisture conditions in this case is based on the assumption that suction equilibrium will tend towards the suction below the active zone

(see Fig. 1). This can be expressed in the following equation:

$$h_z = h_{z_0} + (z_0 - z) \quad (2)$$

where, h_z is the equilibrium suction beneath covered area at depth z , and h_{z_0} is the suction at a depth z_0 which is below the depth of seasonal moisture variation (active zone).

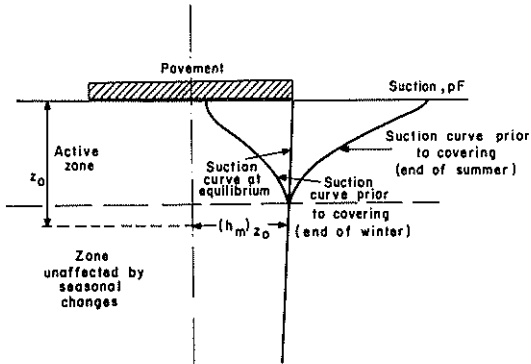


Fig. 1 Idealized distribution of suction below the center of a covered area with deep water table.

Eq. (2) is based on several approximate assumptions which have been verified both theoretically and experimentally at a practical level [Richards, (Ref. 5)]. It has physical significance since it defines the suction profile with no upward flux of water through the soil profile. In general, this approach tends to be conservative, but much more accurate than empirical procedures now in use. With shallow water tables it is accurate [Croney, (Ref. 6), Russam, (Ref. 7)], but in other cases (category "b" and "c") it must only be considered as a good approximation.

The case under discussion is that of category (b). The use of Eq. (2) for this category requires measurement of suction on the site and in the laboratory for each specific location. To overcome this tedious and time-consuming procedure, the evaluation of the equilibrium moisture content will be made by correlation with index properties of the soil (as stated in the introduction of the paper). According to Road Research Laboratory (Ref. 3) such evaluation can be made by the ratio of in-situ moisture content to plastic limit (w/PL).

A recent extensive work has been made in order to evaluate 5 existing runways after 10 to 15 years of service. The values of the ratio of in-situ moisture content to plastic limit in borings under the above mentioned runways are given in Fig. 2. From this figure it can be seen that despite the scatter of the data, some tendency exists to get higher values of w/PL with higher values of the plastic limit. The regression line for the above tendency is:

$$\frac{w}{PL} = 0.86 + 0.14 PL \quad (3)$$

where w/PL ranges between 0.9 to 1.5.

It should be noted that the scatter in the values of w/PL as a function of PL is due to several reasons which must be taken into account for any prediction of the in-situ moisture content at equilibrium. For example, when the in-situ

moisture content of the uncovered soil is above the equilibrium value, the tendency of the values of the w/PL ratio is to be in the lower part of the region (as defined by the two solids lines in Fig. 2). However, when the process is generally reversed the w/PL value is to be expected in the upper part of that region. It should be also recognized that local fluctuations in the water table influence the values of w/PL . Therefore for prediction purposes, use of Eq. (3) can be made by taking into account that the range of that calculated ratio is about +0.1 and -0.2 as expressed by the solid boundaries in Fig. 2 which are parallel to the regression line.

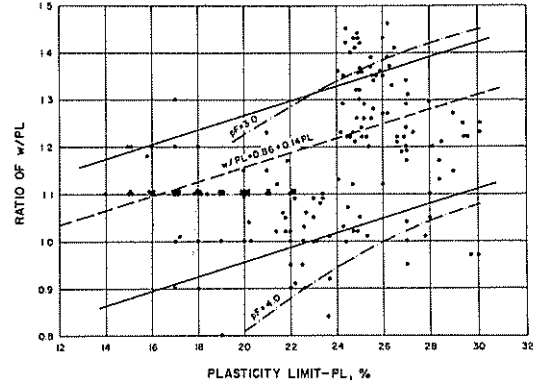


Fig. 2 Relationship between plastic limit and the ratio w/PL as measured in boring under five runways.

It should be also noted that the above relationships can modify the commonly accepted rule that under covered areas, the ratio of w/PL is in the order of or less than unity (Ref. 8), since higher values of PL tend to produce higher values of w/PL .

3 SUCTION - MOISTURE RELATIONSHIPS

As well as being a measure of the potential of the water in soils, suction is also an important factor controlling the effective stress in the soil. Croney *et al.* (Ref. 9), Black (Ref. 10) and Richards (Ref. 11) have found clear relationships between the suction and other soil properties such as CBR. The next step is therefore aimed to describe the method by which the suction of a given clay can be estimated.

Livneh *et al.* (Ref. 12) have found that for local clays the moisture content, w , in percent, corresponding to various values of suction, is related to the plastic limit, PL , as following (see solid lines in Fig. 3):

$$w = -13.5 + 1.9 PL \quad (4)$$

for a suction of pF equals 3 (1.0 kg/cm^2), and

$$w = -16.2 + 1.6 PL \quad (5)$$

for a suction of pF equals 4 (10.0 kg/cm^2).

It should be pointed out, however, that the above results have been obtained on remoulded samples using the pressure membrane and pressure plate method (ASTM, D-2325). These remoulded samples have been prepared as following: Approximately 25 g of air-dried soil (passing a 2 mm sieve) were introduced into a rubber ring ($h = 10 \text{ mm}$ and $\phi = 65 \text{ mm}$), placed on the membrane

and compressed at a pressure of 10-15 g/cm². Then the soil samples were soaked with water until saturation was reached. The apparatus was then closed and pressure was applied. In using this simple procedure, it has been assumed that the initial conditions, such as density, moisture content etc., do not influence the values of the suction. This assumption seems to be logical for those values of suction which are not influenced by the macrostructure (initial conditions) but depends only upon the microstructure.

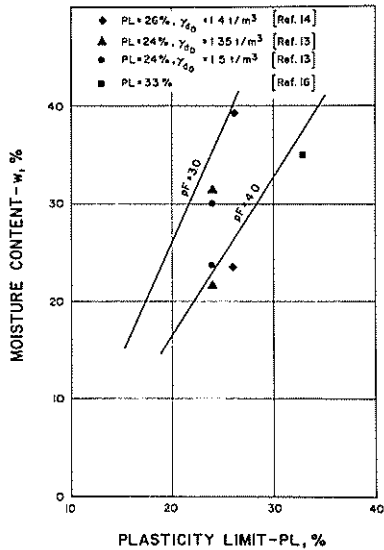


Fig. 3 Relationship between plastic limit and moisture content for constant suction values in expansive clays.

Recent data enable verifying whether suction's values greater than 1.0 kg/cm² are compatible with the above assumption, i.e. with Eq. (4) and (5). Data taken from Kassiff and Ben Shalom (Ref. 13) and Smucha (Ref. 14) are shown in Fig. 4. This figure represents the suction - moisture relationships for remoulded samples of expansive clays with the following initial conditions: density of 1.35 g/cm³, 1.5 g/cm³ (Kassiff) and 1.4 g/cm³ (Smucha) and moisture content of 21%, 23%, 27% (Kassiff) and 20% (Smucha). Kassiff's results were obtained by using a conventional consolidometer with a modified cell to allow the application of the osmotic system to control moisture intake. By this method the amount of swell and moisture content can be measured for any designed suction value applying the principle shown by Zur (Ref. 15) in which the soil water suction is brought to equilibrium with the osmotic pressure of a salt solution, through a semi-permeable membrane. Smucha's results were obtained in a similar method using a hollow cylinder specimen in a triaxial cell, and applying an all-round pressure.

The moisture contents for suctions of 1.0 kg/cm² and 10.0 kg/cm² taken from Fig. 4 and from Richards et al (Ref. 16), are plotted in Fig. 3. The agreement between these data and the regression lines representing Eqs. (4) and (5), supports the application of the equations for predicting the suction's values regardless the initial condition of the clay under consideration, provided that the suction is between 1.0 to 10.0 kg/cm². The practicality of this range of suction

can be easily verified. If the curves representing Equations (4) and (5) are plotted on Fig. 2, it can be seen that about 90% of the measurements represent suction values between 1.0 and 10.0 kg/cm². However, due to the limited suction test data, the full lines in Fig. 3 are not to be used for suction prediction purposes, but they should be considered as reference lines within an intermediate step for predicting the CBR (as will be shown in the succeeding sections of this paper).

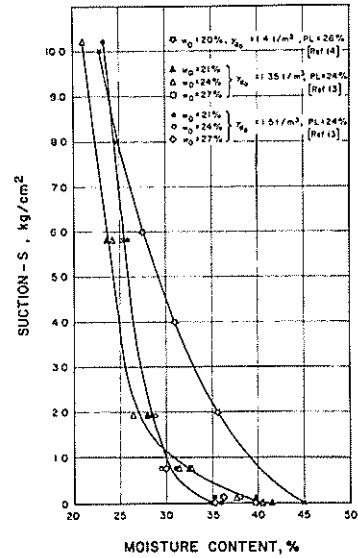


Fig. 4 Relationship between moisture content and suction for remoulded samples of expansive clays.

4 CBR - SUCTION RELATIONSHIP

Various theories relate the ultimate bearing capacity of circular footings to the shear strength of clays. Since the bearing capacity of soil is a direct measure of the resistance of the soil to lateral displacement, and since the CBR test was designed to measure this property, some degree of correlation would be expected between the CBR and bearing capacity and between CBR and shear strength of clays.

Wiseman and Zeitlen (Ref. 17) have found highly correlated linear relationship between CBR and the in-situ shear strength (cohesion), C, of the subgrade at three airfields in Israel. This was expressed as follows:

$$CBR = k C \quad (6)$$

where k ranges between 4-6, depending on the rate of shear.

Along similar lines of thoughts Black (Ref. 10) suggested to estimate the CBR values from plasticity and consistency indices. This estimation was based on the assumption that at 0.1 inch penetration the soil is closed to failure and that the CBR in fully saturated clays can be expressed by the following equation:

$$CBR = S \frac{N_q}{10} \quad (7)$$

where S is the saturated suction and N_q is Terzaghi's bearing capacity factor.

For unsaturated soils a correction factor for Eq. (7) is given, using the value of degree of saturation, S_r .

With the above background in mind, an attempt was made to find the relationship between the effective suction and the in-situ CBR values using the data obtained from the borings beneath the 5 existing runways described in the preceding sections.

The CBR values used for this correlation were measured directly on site. The suction values were determined from Fig. 3 with the aid of the measured values of plasticity limits and in-situ moisture contents. An adjustment for partial saturation was made by relating the effective suction, \bar{S} , to the degree of saturation, S_r , as measured on site:

$$\bar{S} = S S_r^2 \quad (8)$$

where S is the suction for the saturated soil as obtained from Fig. 3.

Figure 5 represents the above relationship between the measured CBR and the estimated effective suction, with the plasticity limit as a parameter. Regression analyses on groups of data showed good linear correlations between the CBR and the effective suction (correlation coefficients of 0.74 and 0.94 for groups of data representing $PL \leq 22$ and $22 < PL < 26$, respectively). Therefore after adjusting the regression lines to pass through the origin Fig. 5 can be used as a tool for estimating in-situ CBR values under a given condition of water content and degree of saturation.

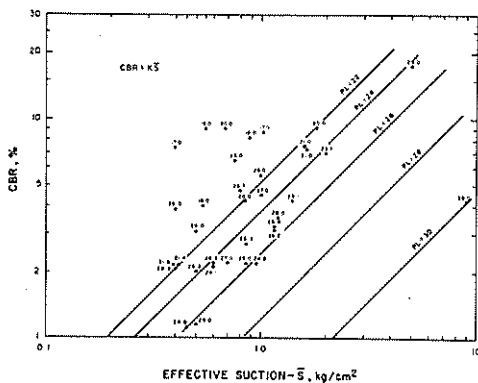


Fig. 5 Relationship between measured CBR and estimated effective suction.

The procedure for estimating the CBR values can be illustrated by a simple example: The following values were measured: $PL = 26\%$, $w = 31\%$ and $S_r = 0.9$. From Fig. 3 a value of $S = 4.0 \text{ kg/cm}^2$ can be estimated. Substitution in Eq. 8 leads: $\bar{S} = 0.9^2 \times 4.0 = 3.2 \text{ kg/cm}^2$; and from Fig. 5 a value of $CBR = 8\%$ can be estimated.

The validity and closeness of the above procedure can be checked by comparing different methods for estimating CBR values of clays. Table I represents shearing tests results which obtained by Smucha (Ref. 14) together with results of three methods for estimating CBR values. They are: (a) The method presented in this paper, (b) a method reported by Wiseman and Zeitlen (Ref. 17) using of Eq. (6) and (c) a method reported by Black (Ref. 10) using of Eq. (7).

TABLE I

COMPARISON OF CBR VALUES OF CLAYS AS ESTIMATED BY THREE METHODS

Test Data (Ref. 14)				Estimated CBR, %		
Moisture Content -w, %	Degree of Saturation - S_r	Measured Suction - S, kg/cm ²	Measured Shear Strength - C, kg/cm ²	Method Presented In This Paper	Weisman & Zeitlen's Method (Ref.17)	Black's Method (Ref.10)
45.0	0.98	0	0.125	0	0.75	0
35.6	0.81	2	0.30	3.2	1.8	0.9
31.0	0.726	4	0.55	5.1	3.3	1.7
27.5	0.66	6	0.83	6.4	5.0	2.5
24.8	0.61	8	1.25	7.4	7.5	3.8
23.0	0.57	10	1.55	8.1	9.3	4.6

It can be seen from Table I that fairly close agreement exists between CBR values estimated by methods (a) and (b). On the other hand CBR values estimated by Black's method (c) are somewhat lower. It must be pointed out that both methods (a) and (b) are based on results obtained from similar clays; namely expansive clays typical to Israel. On the contrary, the British clays investigated by Black are known to be non-expansive. This may explain the deviation shown in Table I. However, the agreement between methods (a) and (b) can indicate the practicality of the procedure suggested here. It must be pointed out that the method reported here requires only indicative tests results without any strength evaluation.

5 ESTIMATION AND PREDICTION OF CBR VALUES

The data and analysis presented so far enable us to estimate the in-situ CBR values of expansive clays under present moisture conditions. This estimation needs only the measurement of three single parameters: plastic limit, PL , moisture content, w , and degree of saturation, S_r . The procedure for estimating the present CBR values is summarized in Fig. 6.

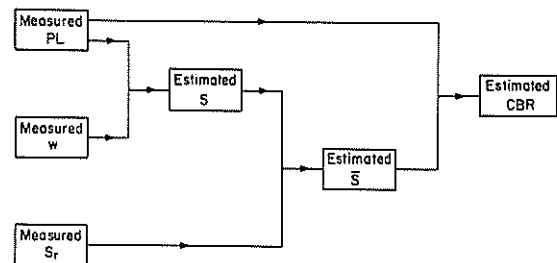


Fig. 6 Suggested procedure for estimating CBR values of expansive clays.

Furthermore, it is also possible to predict the CBR values when equilibrium moisture conditions will occur under the covered subgrade. This can be done if the degree of saturation, S_r , at equilibrium moisture content could be predicted.

The relationship between moisture content, w , and degree of saturating, S_r , of expansive clays at variable moisture conditions, can be physically expressed by the following equation:

$$S_r = \frac{w}{\frac{\gamma_w}{\gamma_{d_o}} (1+\epsilon) - \frac{1}{G}} \quad (9)$$

where ϵ expresses the swell of the clay and γ_{d_o} is the initial dry density.

The prediction of S_r from this equation will require additional laboratory swell testing for determining γ_d as a function of w , and in-site determination of the present ϵ . However, analysis of the relationship between S_r and w from existing data can produce practical correlations for predicting the degree of saturation at any given moisture conditions without further testing.

Fig. 7 shows relationship between degree of saturation, S_r , and moisture content, w , as obtained from data measured on expansive clays (Ref. 13 & 14). It can be seen that linear relationship exists, and despite the variability in the initial conditions a practical common trend exists by a set of parallel lines at the range of w between 20% and 45%. This set of lines can be expressed by the following equation

$$S_r = 2.055 w + b \quad (10)$$

where b is a parameter which depends on the initial conditions and w ranges between 20% and 45%.

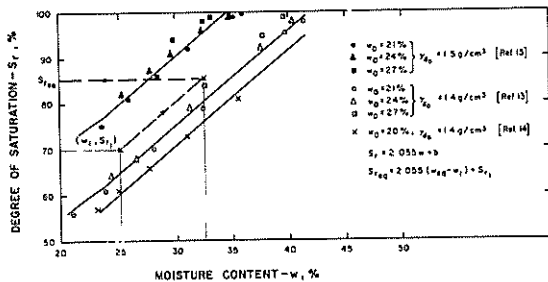


Fig. 7 Relationship between degree of saturation and moisture content for local expansive clays.

Following these trends, the degree of saturation of a clay under a given equilibrium moisture content, w_{eq} , can be predicted by measuring its present moisture content and degree of saturation (w_1 and S_{r1} , respectively), as expressed by the following equation

$$S_{r_{eq}} = 2.055 (w_{eq} - w_1) + S_{r1} \quad (11)$$

The procedure for predicting S_{req} can be illustrated as follows: Values of $w = 25\%$, $S_r = 70\%$ and $PL = 26$ were measured on the clay to be covered. From Fig. 2 a ratio of $w_{eq}/PL \approx 1.25$ can be predicted. Therefore $w_{eq} \approx 1.25 \times 26 = 32.5\%$, and as illustrated in Fig. 7, a value of $S_{req} \approx 85.5\%$ can be predicted.

Therefore, by simple measurement of the present w , PL and S_r , the equilibrium moisture content can be predicted from Fig. 2 and the degree of saturation can be predicted from Fig. 7 (or Eq. 11). This permits the prediction of the CBR value to be expected in the subgrade under equilibrium moisture conditions. The procedure for predicting this CBR value is summarized in Fig. 8.

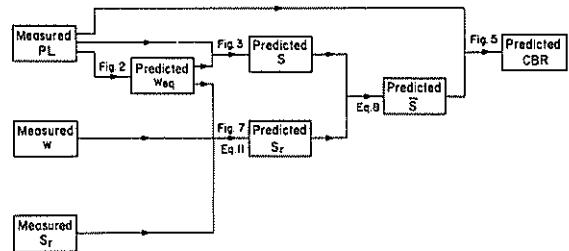


Fig. 8 Suggested procedure for predicting CBR values of expansive clays.

6 SUMMARY

The purpose of this investigation was to deal with the correlation of index properties of local expansive clays with other characteristics which govern the behavior of the material as a subgrade for road and airfield pavement under specific moisture conditions. The correlation involved, relates the measured consistency limits and moisture conditions to; a) Moisture equilibrium condition in the subgrade, b) Moisture - Suction relationships and c) CBR values at various moisture conditions.

Procedures, charts and equations were developed in order to:

- (1) estimate the CBR values of expansive clays under present moisture conditions,
- (2) predict the CBR values of expansive clays at equilibrium moisture condition to be expected under covered areas.

Although these correlations apply primarily to expansive clays in Israel (based on data taken from boring under 5 existing runways), they may serve as an indication for similar correlations in other parts of the world.

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