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Prediction of CBR Using Dynamic Cone Penetrometer

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Abstract. California Bearing Ratio (CBR) value is very popular among highway engineers as a soil support value for pavement design. However, since CBR cannot be easily determined in the field, prediction of CBR values from other soil support tests such as Dynamic Cone Penetrometer (DCP) is a valuable alternative. In this study penetration depth (D) of the dynamic cone penetrometer from the laboratory prepared samples were correlated with laboratory CBR's for a number of different soil types ranging from clay to gravely sand. Unique models were found for each type of soil with good coefficient of determination (R^2) and low standard error of estimate. The combined data gave also a correlation between CBR and D which compare very well with those obtained from other studies.

Introduction

The dynamic cone penetrometer (DCP), since being introduced by Scala in 1956 [1], has been successfully ultilized for estimating the strength of soils. The DCP was studied mainly in relation to application in pavement structures and was primarily correlated with California Bearing Ratio (CBR) [1-3] . Since in situ CBR testing is expensive, relatively slow to conduct, and generally not favoured by highway engineers, DCP, being light and portable, offers an attractive means for determining in situ CBR at a comparative speed and ease of operation. The repeatability of DCP is considerably higher than that of CBR. Smith and Pratt [4] indicated that the coefficient of variation in CBR for a particular soil at one test location could be of the order of 60% whilst that of the DCP could be of the order of 40%.

Several correlations have been reported between the DCP and CBR. Livneh [3] compared 21 correlations that were published in the world technical literature. However, many researchers have already pointed out the importance of local soil characteristics on the obtained correlation between DCP and CBR.

Livneh [5] emphasized that differences in geographic areas throughout the world lead to changes in the empirical values obtained. According to McNaughton [6] various correlations exist in accordance with the tested soil's character.

The objective of this laboratory study is to establish some definitive relationships between California Bearing Ratio (CBR) and penetration depth (D) of the dynamic cone penetrometer for different types of local soil.

Experimental Work

1. The dynamic cone penetrometer (DCP)

The DCP used in this study was based on South African Standards and previously studied by different investigators [7,8]. The DCP used consists of 16mm steel rod, to which a tempered steel cone with a 20mm base diameter and a 60 point angle is attached. The DCP is driven into the soil by a 8kg hammer with a dropping height of 575mm. Figure 1 shows the dimensions of the DCP used. The DCP index or reading is defined as the penetration depth (D) in mm per a single drop of the hammer.

2. Soil properties

To evaluate the potential usefulness of the dynamic cone penetrometer for determining the CBR,an experimental program was designed using six natural soils the characteristics of which are given in Table 1. These soils were chosen for their range of properties and

Table 1. Index properties and compaction data of tested soils

Sample No.	Unified soil classification system	G_s	LL (%)	PI (%)	OMC (%)	MDD	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
S-2	SP (poorly graded sand with gravel)	2.72	-	NP	10	1.864	15	81	(4)	
S-5	SP-SM (poorly graded sand with silt and gravel)	2.70	14.7	NP	7	2.168	15	75	6	4
S-4	SM (silty sand with gravel)	2.72	21.2	2.4	10	2.025	16	52	15	17
S-7	SM (silty sand)	2.71	15.7	NP	12	1.960	1	57	33	9
S-3	ML (sandy silt)	2.72	21.4	2.5	12	1.905	1	36	46	17
S-9	CL (clean clay with sand)	2.77	32.5	9.5	15.5	1.840	2	15	58	25

Note: Gs = Specific gravity (ASTM D854-91, C127-84); LL = liquid limit; PI = plasticity index; OMC = optimum moisture content (ASTM D698-91); MDD = maximum dry density; USCS = unified soil classification system; percentage of clay is the 2 μm fraction, and all other particle sizes are based on USCS definitions significance as locally encountered materials. The tested soils ranged from poorly graded sand with gravel to clay with sand. All samples were obtained from the Riyadh Area.

3. Test procedure

Samples were prepared by mixing air-dry soil and water to the required water content and then compacting it into a CBR mold. Five layers of apporximately equal thickness were used. Each layer was subjected to impact of a 4.54 kg hammer falling 457 mm, and the number of blows per layer was kept constant for each layer of a particular sample. The number of blows for each layer ranged from 10 to 56. To relate CBR and DCP results at the same moisture content and density a pair of identical samples were prepared. The first sample

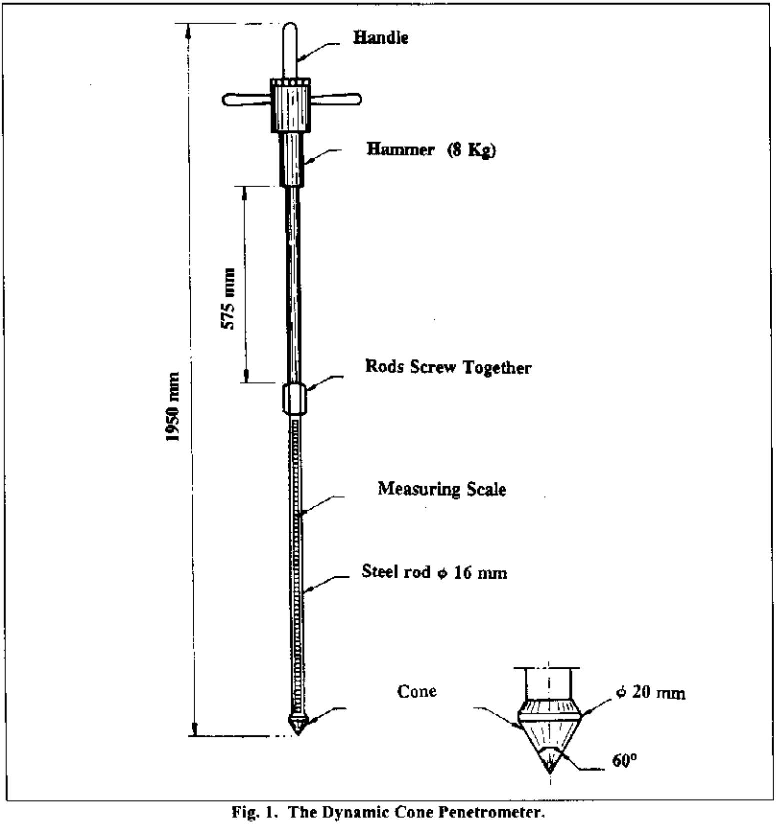

Fig. 1. The Dynamic Cone Penetrometer.

was used for CBR test according to ASTM D1883 method and the second for the DCP test. As the shape of the load- penetration curve measured in the CBR test is sensitive to bedding errors, efforts were made to reduce these by careful preparation of the sample's surface.

DCP tests were carried out on the surface of the samples confined by the conventional CBR mold under the same surcharge load used in CBR tests.

The DCP was directly placed at the surface in the center of the sample. The DCP test was then started by sliding the hammer while measuring the soil resistance to penetration in terms of mm/blow. It must be pointed out that the penetration for the first blow should be discounted due to the fact that the imprint area of the cone tip for the first blow is smaller than that of subsequent blows. The number of blows to drive the DCP 50mm into the sample was averaged and taken as the reading of DCP. A 50mm depth was selected because CBR values are reflected by soil's shear strength mobilized in that zone.

Test Results and Discussions

Before identifying a general DCP-CBR relationship, it is important to examine if a unique relationship between DCP and CBR can be found for each soil regardless of soil density or moisture conditions.

Figures 2, 3 and 4 show the relationships of moisture content and dry density with CBR and penetration depth (D) for poorly graded sand, silty sand and clay, respectively. These plots show that CBR and D responded in a similar manner to changing moulding moisture content and dry density.

Similar observations have been noticed by Harison [8]. To bolster the validity of CBR-DCP relation, a large number of CBR and DCP tests were conducted on identical specimens over a wide range of moisture and density conditions. Natural moisture content and field dry density for the six samples are presented in Table 2. The ranges of moisture content and dry density used in preparing compacted soil samples are shown in Table 2.

The relationship between the penetration depth (D), in mm/blow and CBR (%) for all tested soils under different density and moisture content conditions is shown in Fig. 5. It is clear from this Fig. that a unique relationship between penetration depth (D) and CBR exists for all tested soils regardless of density and moisture content conditions.

Regression analysis on DCP - CBR data was conducted using SPSS computer program [9] for each type of soil and for combined results.

A variety of regression models was attempted. The highest correlation coefficients were achieved with log-log model. Regression lines are shown in Fig. 5 whereas regression

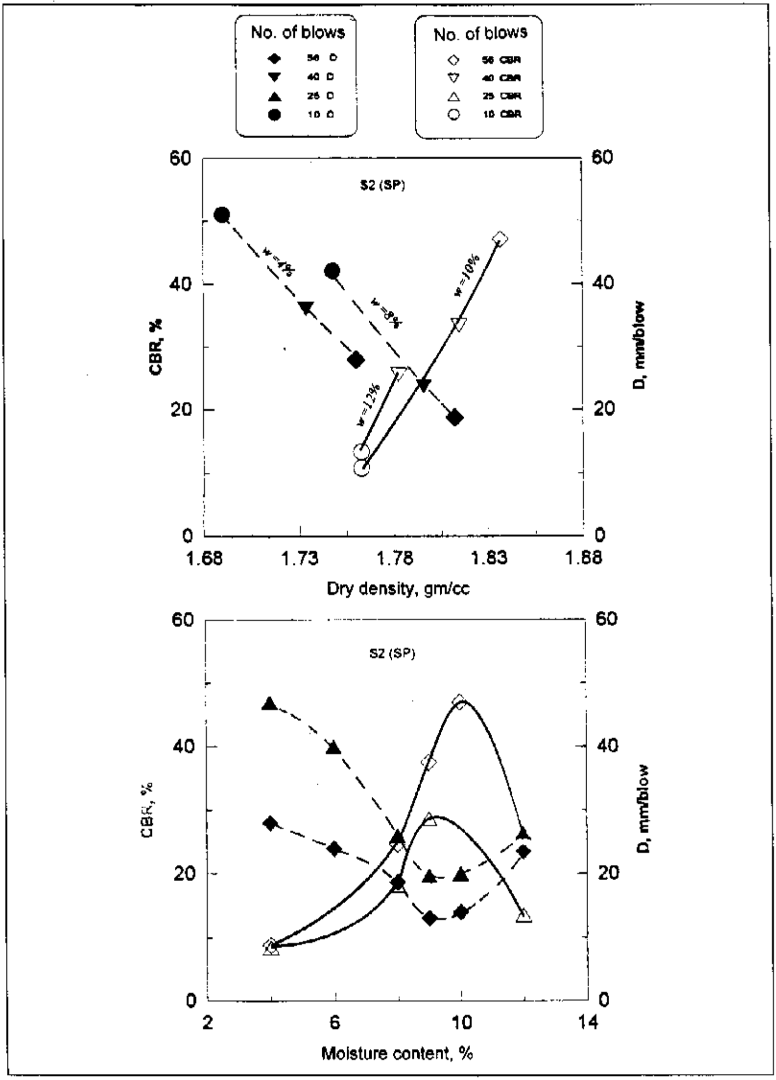

Fig.2. CBR and D versus dry density and moisture content for sand.

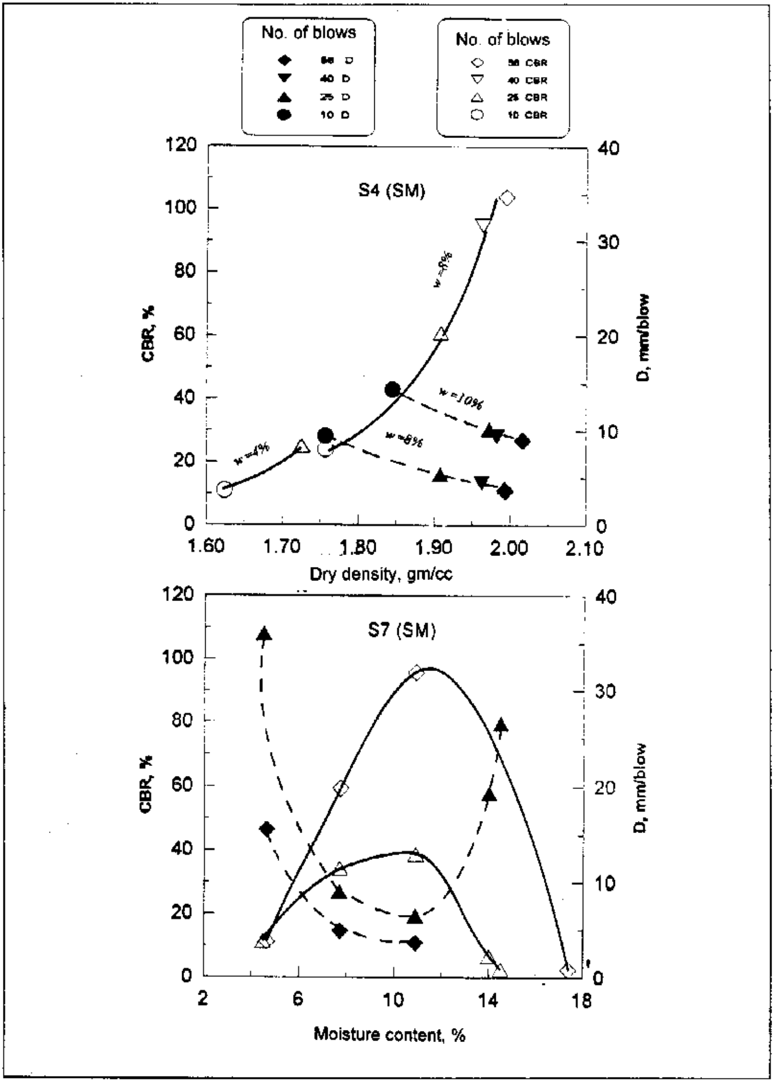

Fig.3. CBR and D versus dry density and moisture content for silty sand.

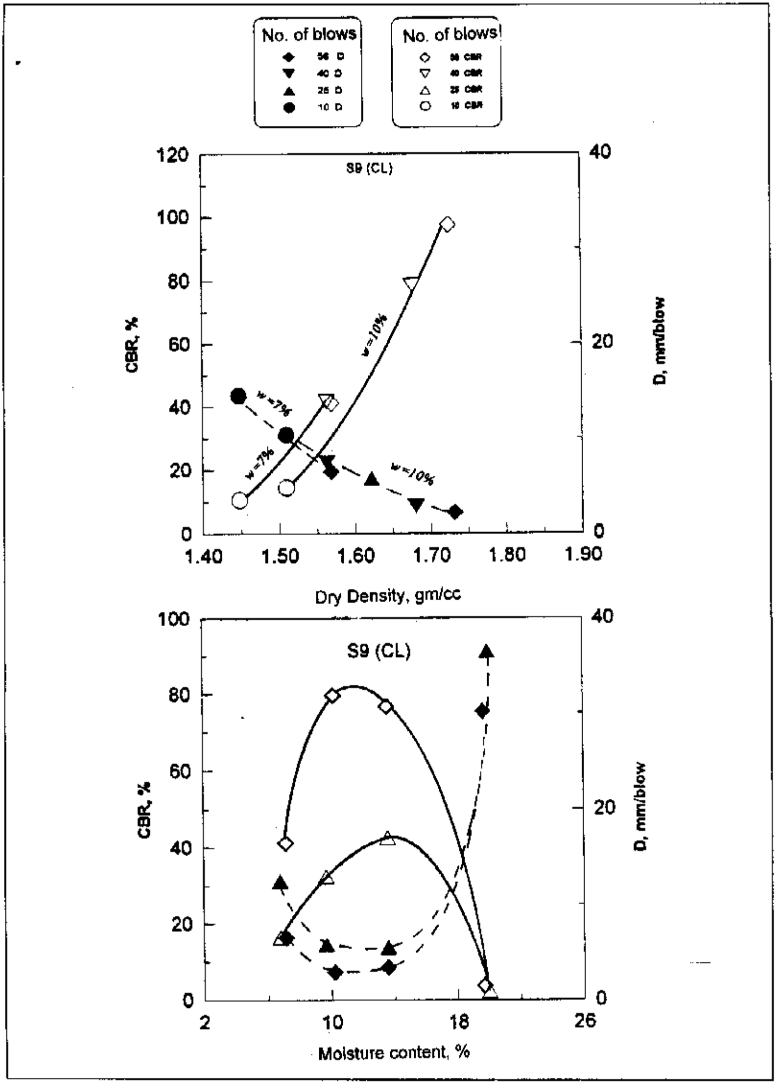

Fig.4. CBR and D versus dry density and moisture content for clay.

Table 2. Field and laboratory conditions of tested soils

Sample	Field		Laboratory	
	Moisture content (%)	Dry density (gr/cc)	Moisture content (%)	Dry density
S2	5.4	1.63	4 - 12	1.69 - 1.84
S5	0.70	2	2 - 10	1.71 - 2.09
S4	8.90	1.68	3 - 14	1.62 - 2.02
S7	3	1.58	2- 14.5	1.53 - 1.96
S3	8.84	1.69	5 - 14	1.50 - 1.90
S9	5.50	1.48	5.6 - 20	1.45 - 1.77

models, coefficient of determination (R^2) and standard error of estimate (SEE) are listed in Table 3.

When dealing with such complex materials as natural soils we always have to anticipate unexpected behavior. Amazingly enough, however, the relationship between penetration depth (D) and CBR of the tested soils is very good with a relatively high coefficient of determination (R^2) for which its value is higher than 0.81 for all six soil groups. The coefficient of determination (R^2) for the CBR-D relationship for CL, ML and SM soils is relatively high as compared to that for SP and SP-SM soils. Gravel particles influence the obtained results, where relatively low coefficient of determination for soil samples with appreciable amount of gravel (15%) is obtained due to unavoidable variability in density between CBR and penetration tests during the testing program which may have been responsible for some of the scatter in data.

In the practical application of the dynamic cone penetration approach for assessing CBR at a test site, and when the tested soil cannot be affiliated in advance with any one of the five soil types used in the study, one must use a regression function for data obtained for various conditions of soil type, moisture and density.

In the light of that, all data were pooled to give a regression model for all tested soils as shown in Fig. 6 and Table 4 , also Table 4 shows the regression analysis results in a form of ANOVA Table. It is well known that a wide range of soil types are encountured in various regions of the kingdom [10]. However, a recent study [11] shows that some classes of soil are more dominant than others, especially along the major highways investigated (represent about 6640 Km) in the kingdom.The classes of soil studied herein, represent about 90% of those encountered in the above study[11].

In order to examine the generality of the local correlation obtained in this study, two of the best-fit regression equations relating the CBR to the penetration of DCP from previous studies were compared with the correlation suggested in this study as shown in Fig. 7. Harison [8] performed the DCP tests using the same DCP on soil samples (clay, sand, and gravel; soaked and unsoaked samples) in the standard CBR molds. Livneh and

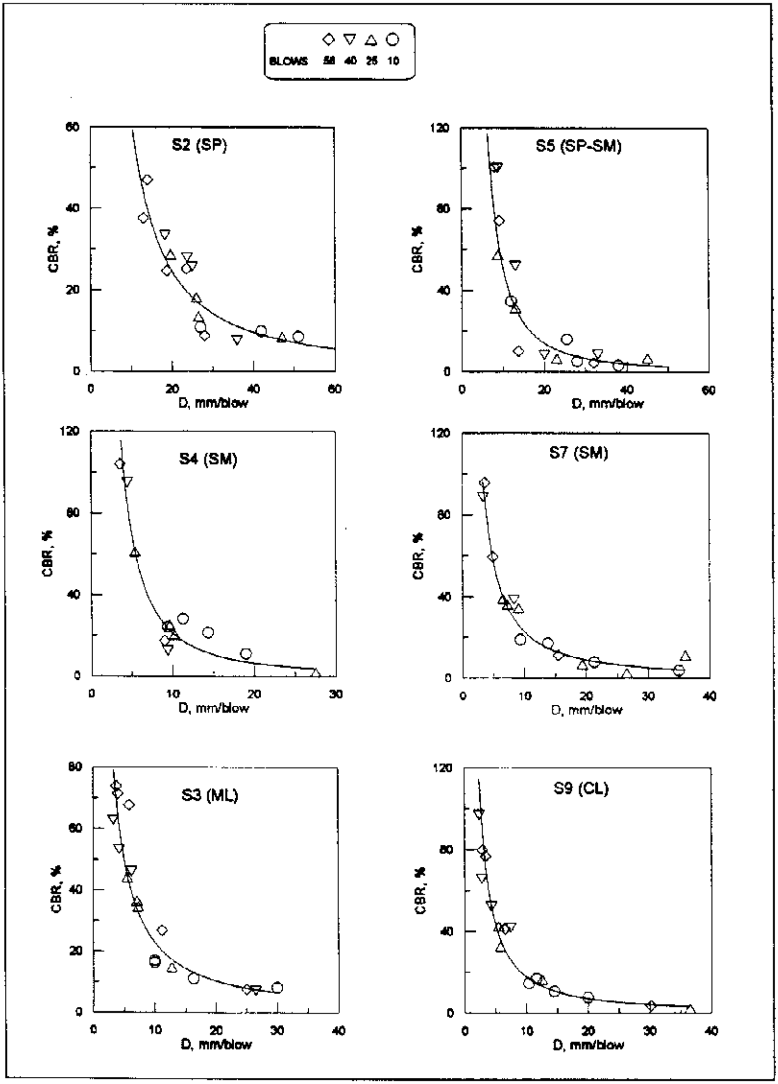

Fig.5. Correlation between CBR and cone penetration for individual sample.

Table 3. Regression analysis results

Sample	USCS	Model	R^2	SEE
S2	SP	log CBR = 3.16 - 1.36 log D	0.81	0.275
S5	SP-SM	log CBR = 3.57 - 1.86 log D	0.83	0.509
S2 + S5		log CBR = 3.24 - 1.50 log D	0.71	0.503
S4	SM	log CBR = 3.05 - 1.73 log D	0.85	0.442
S7	SM	log CBR = 2.70 - 1.35 log D	0.87	0.410
S4 + S7		log CBR = 2.80 - 1.46 log D	0.85	0.426
S3	ML	log CBR = 2.51 - 1.15 log D	0.93	0.226
S9	CL	log CBR = 2.55 - 1.31 log D	0.96	0.233
S3 + S9		log CBR = 2.54 - 1.23 log D	0.93	0.261

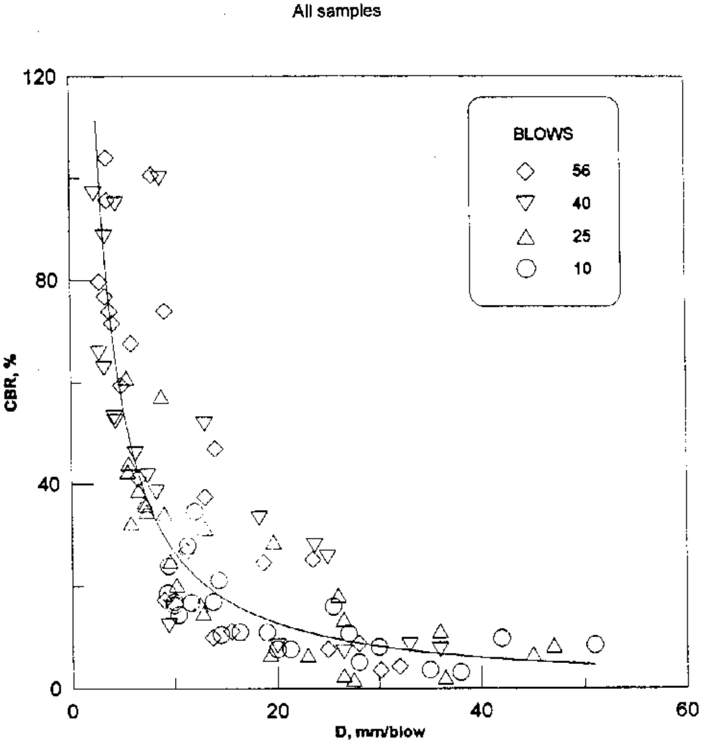

Fig.6. Correlation between CBR and cone penetration for all samples.

Table 4. Regression analysis results for all samples

Multiple R	.83242				
R Square	.69292				
Adjusted R square	.68959				
Standard error	.54782				

Analysis of variance

	DR	Sum of square	Mean square
Regression	1	62.302825	62.302825
Residuals	92	27.610134	
F =	207.59986	Signif F = .0000	

Variables in the equation

Variable	B	SE B	Beta	T	Sig T
D	-1.067203	.074068	-.83242	-14.408	.0000
(constant)	312.013186	60.785245			.0000

Model: Log CBR = 2.50 - 1.07 log D

Ishai [12] related CBR to the DCP values -using the same DCP but with 30° cone - from data obtained in the laboratory and in the field for a wide range of pavement and subgrade materials. As can be seen, there is a good agreement between the suggested correlation and those of Harison [8] and Livneh and Ishai [12].

California Bearing Ratio tests can be carried in laboratory on undisturbed or remoulded samples or in the field. It is well known that CBR specimens tested in the laboratory, after being prepared at field moisture content and density, tend to give CBR values higher than those obtained in the field especially for granular soils [13]. The difference is attributed to the confining effect of the rigid mold in laboratory tests. Thus for granular material, laboratory testing should be discouraged and field testing performed. However, it must be remembered that even small stone or pebbles will lead to erroneous field-CBR results if the piston tip rests on a stone particle.

It is believed that the obtained model can be used to predict CBR in Laboratory as well as in the field. Laboratory CBR's can be predicted from Laboratory DCP's values while field CBR's can be predicted from field DCP's values.

It is therefore proposed that field testing should consist of a considerable number of cone penetrometer tests rather than a few field-CBR tests. DCP tests when properly executed and interpreted can provide invaluable information which can be converted to CBR.

Conclusions

Based on the results obtained in this study the following conclusions can be drawn:

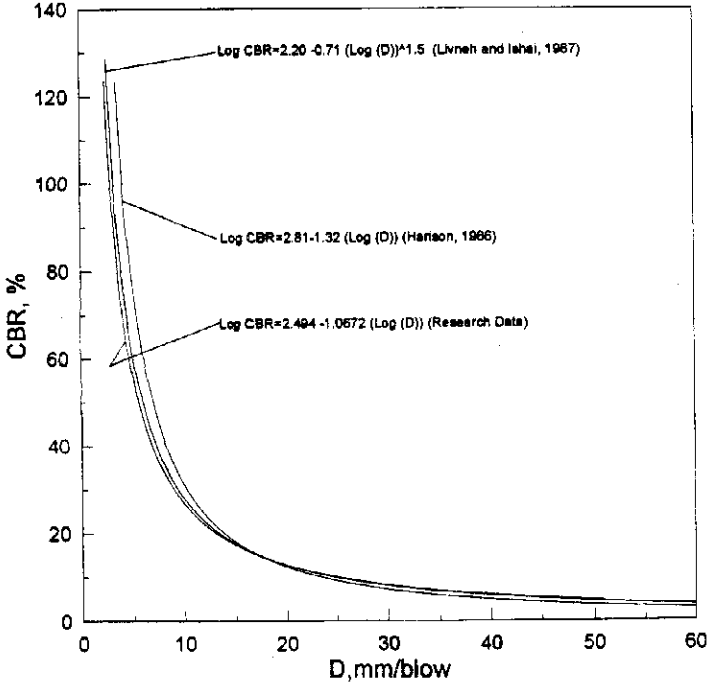

Fig.7. Comparison of CBR - D correlations.

1. Results of correlation study between the cone penetrometer laboratory tests and CBR laboratory tests indicate a consistent and definable relationship. DCP penetration can be used to predict CBR values with relatively high accuracy for soils ranging from sand with gravel to clay.
2. A very good relationship between DCP penetration and CBR were obtained for each type of soil tested. The coefficient of determination (R^2) ranges between 0.81 and 0.96 and the standard error of estimate (SEE) was relatively low.
3. For a given type of soil, the variability in data, as indicated by SEE values and the scatter of data points in CBR-D plots, is affected by the type of soil and increases as the soil changes from fine grained to granular.

4. When all soils data were pooled together, a relatively good relationship was obtained between CBR and D values. R^2 and SEE were 0.69 and 0.548 respectively.
5. A good agreement was found between the model developed in this study and two other models reported in literature.

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التنبؤ بنسبة تحمّل كالفورنيا باستخدام جهاز الاختراق الهرمي المتحرك

طلال عبيد الرفيعي و عبد الرحمن صالح السحيباني

قسم الهندسة المدنية ، كلية الهندسة ، جامعة الملك سعود ، ص.ب. ٨٠٠ ،

الرياض ١١٤٢١ ، المملكة العربية السعودية

(استلم في ٢٢/١/١٩٩٦م ؛ وقبل للنشر في ١١/١١/١٩٩٦م)

ملخص البحث . تعتبر نسبة تحمّل كالفورنيا (CBR) من أشهر الطرق المستخدمة لقياس تحمّل التربة لغرض تصميم الرصف لدى مهندسي الطرق . وحيث إنّه لا يمكن قياس نسبة تحمّل كالفورنيا حقليًا بسهولة فإنّ التنبؤ بقيمها من اختبارات التحمّل الأخرى مثل جهاز الاختراق الهرمي المتحرك (الحركي) (DYNAMIC CONE PENETROMETER DCP) يمثّل بديلاً جيدًا . تمّ في هذه الدراسة ربط (رياضيًا) عمق الاختراق (D) لجهاز الاختراق الهرمي المتحرك والمقاس في المختبر لعيّنات تربة مختلفة تتراوح من طين إلى رمل مع حصى بنسبة تحمّل كالفورنيا والمقاسة أيضًا في المختبر . تمّ الحصول على نماذج رياضيّة فريدة ذات معاملات تعيين (R^2) جيّدة ومقادير معيّاريّة منخفضة وذلك لكل نوع من أنواع التربة المستخدمة . كذلك ، عند جمع البيانات لكل أنواع التربة مع بعضها ، وجدنا أنّ هناك علاقة ربط رياضيّة جيّدة بين نسبة تحمّل كالفورنيا وعمق الاختراق وهذه العلاقة مماثلة لعلاقات تمّ الحصول عليها في دراسات أخرى .