PREDICTION OF CBR AND MR OF FINE GRAINED SOIL USING DCPI

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ABSTRACT

Determining the in-situ engineering properties such as Modulus of Resilient (Mr), California Bearing Ratio (CBR) and for some subgrade materials in road construction has always been an economic challenge for geotechnical engineers. Therefore, a number of in-situ tests have been developed to overcome this challenge. One of the most adaptable techniques that can be used to predict geotechnical properties of soils economically is Dynamic Cone Penetration Index test (DCPI). It is accomplished by dropping 8-kg hammer over a height of 575mm and assessing the penetration depth of a 60° cone tip with 20 mm base diameter into the ground per blow for each tested depth. In this paper, the empirical equations to predict CBR and Mr of fine-grained soil using DCPI were reviewed and revised based on data obtained from the literature review. Based on the statistical analysis, two empirical equations were proposed to predict CBR and Mr. The obtained results verify the reliability of the modified equations. Also, the correlation between DCPI and dry density of fine-grained soils was studied.

Keywords: DCPI, CBR, Resilient Modulus, Dry Unit Weight, Water Content, Cohesive Soil.

1. INTRODUCTION

CBR and Mr of subgrade materials are crucially required to design subbase and base of road constructions. Usually, the values of these parameters are determined from the laboratory tests. However, laboratory tests demand a significant effort as well as time consuming. The simple alternative method is to use the Dynamic Cone Penetration Index (DCPI). A comprehensive undisturbed sample can be defined as a soil with an in-place structure that is absolutely unchanged. Such samples are vital for the laboratory tests that examine the structures of the soil. Yet, several issues make it practically incredible to obtain a justly undisturbed sample. In concern to those issues, various techniques have been developed to conduct in-situ tests such as dynamic cone penetrometer device (DCP), which is initially developed by Scala [1].
DCPI has been used to characterize sites of pavement layers and subgrades. The degree of compaction, water content, California bearing ratio and resilient modulus (Mr) are the major technical keys that significantly affect the for subgrade's resistance to deformation[2,3,4]. DCP device is well-known for its easiness to operate with low costs, superiority to provide consistent results, and rapid assessment of soil properties. It is significantly cheaper and faster than digging bore holes, mainly when the depth of examination is low and the soils being explored are not gravel materials [5, 6]. Nevertheless, sometimes false values are obtained in the field when piston tip rests on a small stone unit or pebble. Furthermore, it should always be kept in mind that DCP measured parameters are gained at natural water content. when relating these values back to those determined in the laboratory, the mentioned circumstances must be taken into consideration.

2. CBR PREDICTION FROM DCP

CBR is measured by converting pavement unbound material strength values which result from cone penetration resistance [7]. In 1969, the results of DCPI were correlated with CBR values by Van Vuuren [7]. The United States Army Corps of Engineers (USACE) [8] found a relationship between CBR) and DCPI* that was generally used by geotechnical engineers.

$$CBR = 292/(DCPI)^{1.12} \quad (1)$$

Webster et al. [8] as reported by Mejías-Santiago et al. [7] developed the following Equations (2 and 3) to take into account the plasticity of soils as high plasticity (CH) clays and low plasticity clays (CL) of CBR values smaller than 10%:

$$CBR = 1/ (0.017019 \times DCPI)^2 \quad \text{for CL soils CBR<10} \quad (2)$$

$$CBR = 1/ (0.002871 \times DCPI) \quad \text{for CH soils} \quad (3)$$

These empirical equations are accepted by many agencies and experts. These equations are used in ASTM D6951 for predicting CBR using DCPI. Similar relationships are found in literature based on both laboratory and field measurements of CBR. Table 1 presents the empirical equations to estimate CBR from DCPI value.

TABLE 1.
DCP and CBR relationships obtained from literature [7]

References	Correlation (DCPI in mm/blow)	Type of study
Livneh [9]	$\log CBR = 2.20 - 0.71 (\log DCPI)^{1.5}$	Lab
Harison [10]	$\log CBR = 2.81 - 1.32 \log DCPI$	Lab
Gabr et al. [11]	$\log CBR = 1.4 - 0.55 \log DCPI$	Both
Abu-Farsakh et al [12]	$CBR = 1,161.1/(DCPI)^{1.52}$	Both
George et al. [13]	$\log CBR = 1.68 - 0.78 \log DCPI$	Field
Patel and Patel [14]	$CBR = 24.903/(DCPI)^{1.331}$	Lab

*Some references use the abbreviation (PR) instead of (DCPI).

3. PREDICTION OF Mr FROM DCPI

Determining resilient modulus from laboratory tests is time consuming, expensive and involves high-quality undisturbed samples. As an alternative, the DCPI is a suitable method to estimate the modulus value in the field because of its simplicity and portability. Literature found many empirical correlations that connect the value of CBR to value of DCPI. Heukelom and Klomp [15] proposed the linear equation as given by Equation 4 for cohesive soils having a CBR value of less than or equal to 10. Powell et al. [16] suggested Equation 5 as an alternative one between CBR and resilient modulus which is suitable for CBR values of 2 to 12. Various relationships were found by researchers are presented in Table 2.

$$M_r \text{ (MPa)} = 10.34 \text{ CBR} \quad (4)$$

$$M_r \text{ (MPa)} = 17.58 \text{ CBR}^{0.64} \quad (5)$$

TABLE 2.

DCP and Mr relationships obtained from literature [7]

Reference	Correlation DCPI in mm/blow and Mr in MPa	Type of study
Chen et al. [17]	$M_r = 338/DCPI^{0.39}$	Field
Chen et al. [18]	$M_r = 537.76/DCPI^{0.66}$	Field
Abu-Farsakh et al. [12]	$\ln(M_r) = 2.35+(5.21/\ln(DCPI))$	Field
Herath et al. [19]	$M_r = 16.28+(928.24/DCPI)$	Both
Nazzal et al. [20]	$M_r = 5{,}301.54/(DCPI^{1.44}+8.31)$	Field
Mohammad et al. [21]	$M_r = 151.80/DCPI^{1.10}$	Both
George et al . [13]	$M_r = 600.61/DCPI^{1.31}$	Field

4. METHODOLOGY

Data collected from the literature review was subjected to a statistical analysis so as to develop new empirical equations to estimate values of CBR and Mr of subgrade and base materials using DCPI. The study focused on CBR and Mr data. In addition, moisture content and dry unit weight corresponding to DCPI was studied. This process was made possible by using data from earlier studies and then graphing them to understand how each parameter impacted on the results obtained by other authors. Data from different references through (2005 and 2017) is presented in Table 3.

5. DYNAMIC CONE PENETRATION TEST (DCPI)

5.1 DCP INSTRUMENT

Figure 1 shows the DCP equipment that was adopted by ASTM under the fixed term D6951/D6951M. It comprises of two 16-mm (5/8-inch) diameter shafts coupled at a near midpoint, and a handle which is located at the upper part of the device. The mass of the hammer is 8-Kg that can be dropped freely from a height of 575 mm to transfer energy through the lower shaft to the tip of cone. The lower shaft contains an anvil and a pointed tip sloped at 60 degrees. The tip is driven into the soil by dropping the hammer into the anvil which serves as the lower stopping mechanism for the hammer. By measuring the penetration of lower shaft into the soil after each hammer drop the underlying soil strength is determined. This value is recorded in millimeters per blow and is known as dynamic cone penetration index (DCPI) (ASTM). By plotting the DCPI versus depth, thickness and strength of different soil layers can be obtained.

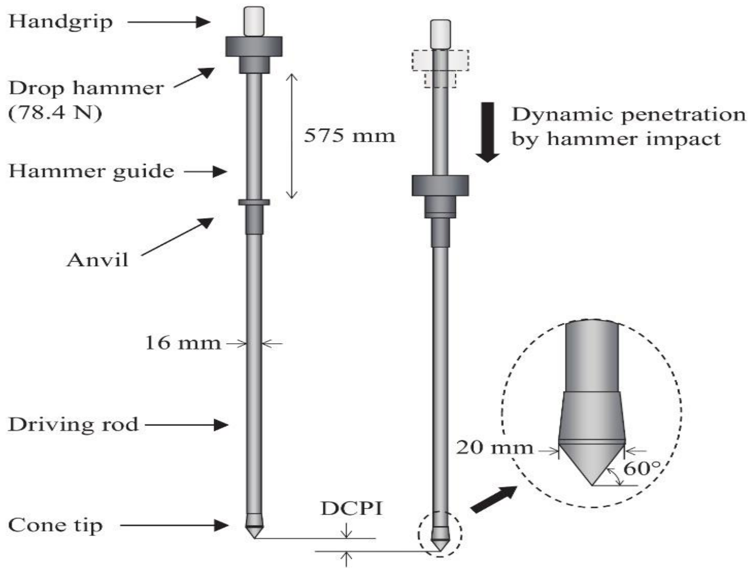

FIGURE 1. The dynamic cone penetrometer device [22]

5.2 SUMMERY OF DCP TEST

The DCP tip can be pushed into soil under consideration by bracing the sliding hammer to the handle then releasing it.Figure 2 shows the test setup. The net penetration for a given number of blows can be measured in mm/blow and named as DCPI. This value can be correlated with geotechnical properties such in situ CBR, shear strength, dry unit weight and Mr [23].

FIGURE 2. DCP test operation [24]

TABLE 3.

Literature review on DCP data corresponding to different parameters

Reference	Soil type	DCPI (mm/ blow)	CBR %	Mr MPa	W%	γdry (KN/m^3)	Remarks
Abu-Farsakh et al., [12]	CM and MC	6.52 - 11.83	24.22 - 62.5	--	--	--	The results showed a good correlation between the DCP-PR and the CBR value with R^2 of 0.84
Mohammad et al., [26]	Clay and Clayey Silt	9 - 65.2	---	7.5 - 91.7	12 - 36.7		A good agreement was obtained between the M_r predicted using DCPI
George et al.,[13]	SM and SC	1 - 18.3	3.9 - 50	---	5.8 - 19	8.23 - 22.68	The best fit curve obtained followed a logarithmic model
Sahoo and Reddy, [25]	ML and CL	6.82 - 105	1 - 46.18	---	7.2 - 11.4	19.2 - 20.8	logarithmic relationships have been developed correlating the Laboratory DCP values with the corresponding CBR values
Patel et al.,[14]	Sandy Soils, Sandy-Clay soils and Clayey soils	16.6 - 29.4	9.5 - 3.5	---	8 - 10.2	19 - 20.5	Good relationship observed between DCPI and CBR with R^2 greater than 0.8

TABLE 3.

(continued)

Reference	Soil type	DCPI (mm/blow)	CBR %	Mr MPa	W%	γdry (KN/m³)	Remarks
Herath et al.,[19]	CL, CL-ML and CH	*6.54 - 63.7	38.8 - 106	--	8.5 - 32.8	13.1 - 18.9	A good correlation was obtained between the predicted and measured Mr using DCPI.
Mohammad et al.,[21]	Silt and Clay	9 - 65.2	--	7.6 - 87.4	5 - 60	--	A Good relationship was found to predict Mr using DCPI
Singh et al., [27]	CL, ML-CL and SM	12 - 21.33	3 - 9.07	---	4.9 - 14.6	---	Increase in PI of soil adversely affect the performance of the subgrade
Sisodia and Amin, [28]	Clayey, Silt and Sandy Soils	9.8 - 32.52	3.4 - 8.2	---	9.8 - 13.6	18 - 20.3	Logarithmic relationship was observed among DCPI and CBR with an R^2 of 0.88
Current study	Fine grained soil	1 - 105	1 - 48.14	7.5 – 91.4	4.9 – 14.6	17.9 – 20.9	Power relation was observed between DCPI and both CBR and Mr,
Remarks	Different types of fine grained soils were investigated	DCPI data varies from 1 to 105 mm/blow	CBR varies from 1 to 106 percent	Mr varies from 7.5 to 91.7 MPa	W% ranged from 4.9 to 60 percent	Dry unit weight varies from 8.23 to 22.68	CBR, Mr, W% and dry unit weight have been studied

6. RESULTS AND DISCUSSION

Geotechnical properties (CBR and Mr) of fine grained soil were the main aim in this research. A data of 132 data was collected from literature where DCPI and in situ CBR values were conducted. A data of 146 was collected from literature in which DCPI and lab data were analyzed. Furthermore, collected data points for DCPI corresponding to moisture content and dry unit weight were (55 and 44) points, respectively, are presented in Table 4. In the statistical analysis, the simple regression analysis was utilized and the coefficient of correlation (R) is used to determine the suitability of the fit. It describes the relative correlation between the predicted and actual results. The guide proposed by Smith (1993) was adopted as follows: (a) a robust correlation exists between two sets of variables if R=>0:8; (b) correlation exists between two sets of variables if 0:2 < R=< 0:8; (c) a weak correlation occurs between two sets of variables. If R=< 0:2.

TABLE 4.
Data collected in this research

Parameter	No. of collected data	References
CBR	132	Wu and Sargand, [7] ; George et al., [13] ; Patel et al., [14]; Singh et al., [27]; Sisodia and Amin, [28]
Mr	146	Mohammad et al., [21] ; Mohammad et al., [26]; Herath et al., [19]
W%	55	Patel et al., [14]; Singh et al., [27]; Sisodia et al., [28]
Dry unit weight	44	Patel et al., [14]; Sisodia et al., [28]

After analyzing the collected data, the relationships between each of CBR, Mr, W%, and dry unit weight with DCPI were obtained. On one hand, a power relationship was found between DCPI and each of CBR, Mr, and dry unit weight. However, the value of the R^2 varied in the developed relationships. The values of R^2 were 0.64, 0.77 and 0.58 for CBR, Mr, and dry unit weight, respectively, as shown in Figures (3, 4, and 5). On the other hand, the DCPI has a logarithmic relationship with W% with an R^2 of 0.36 (see, Figure.6).

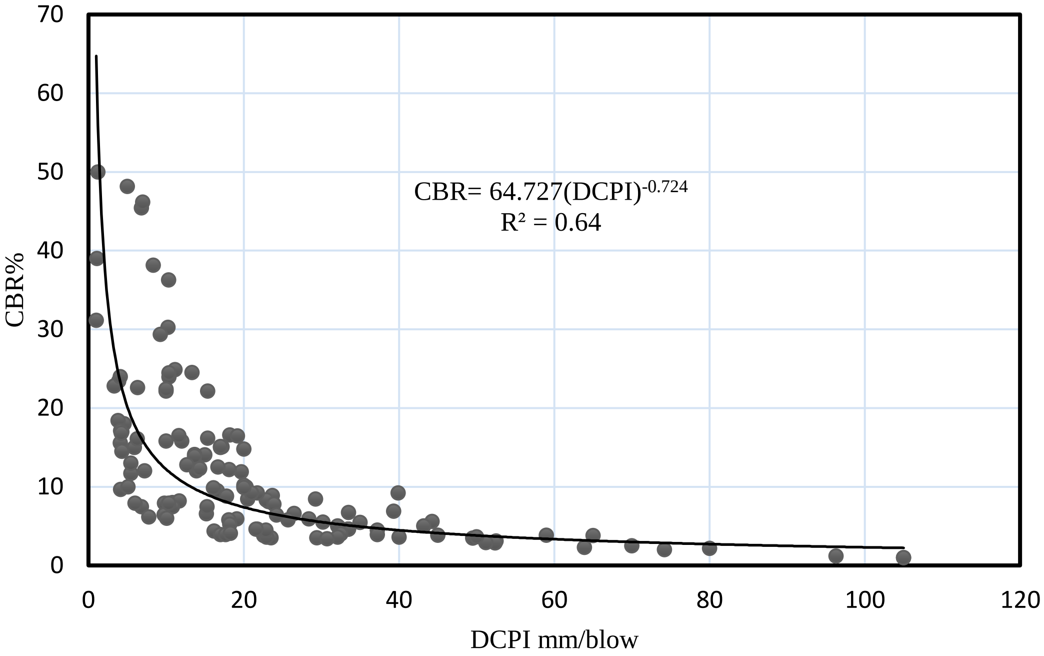

FIGURE 3. Relationship between DCPI and CBR

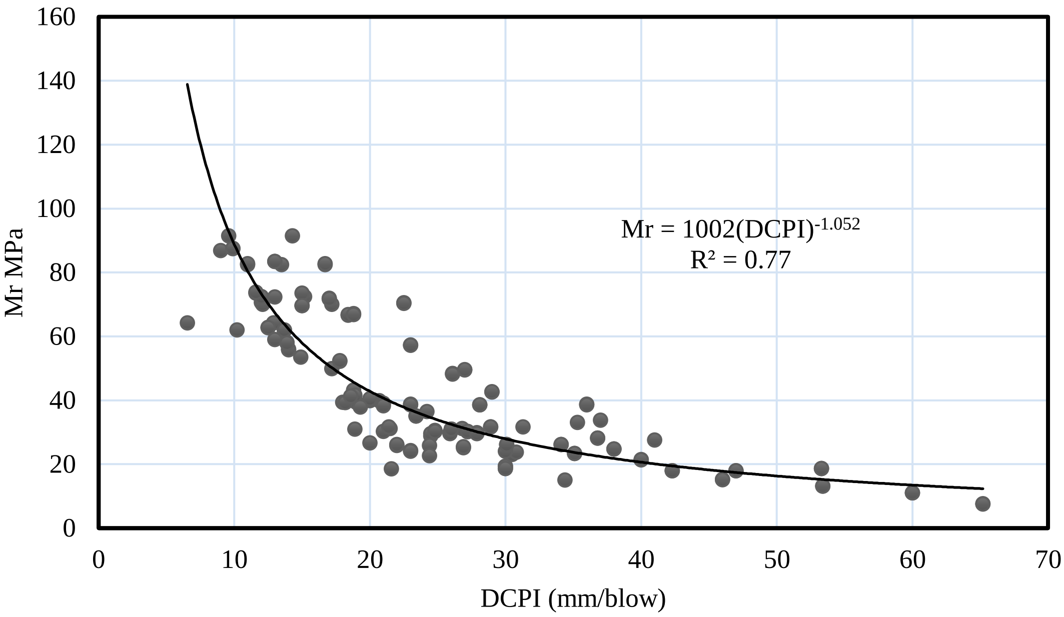

FIGURE 4. Relationship between DCPI and Mr

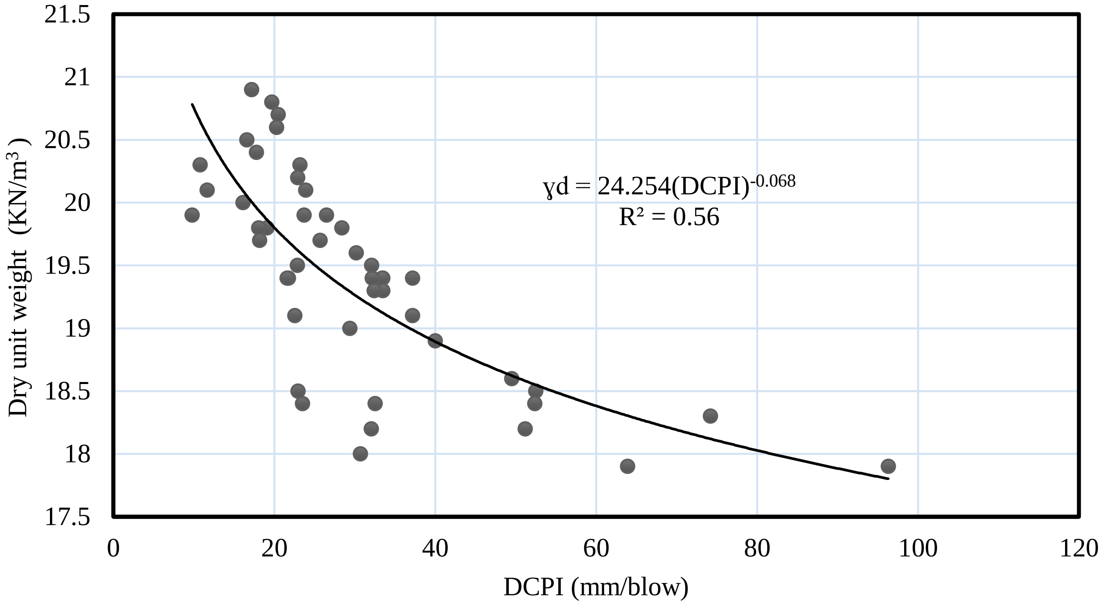

FIGURE 5. Relationship between DCPI and dry unit weight

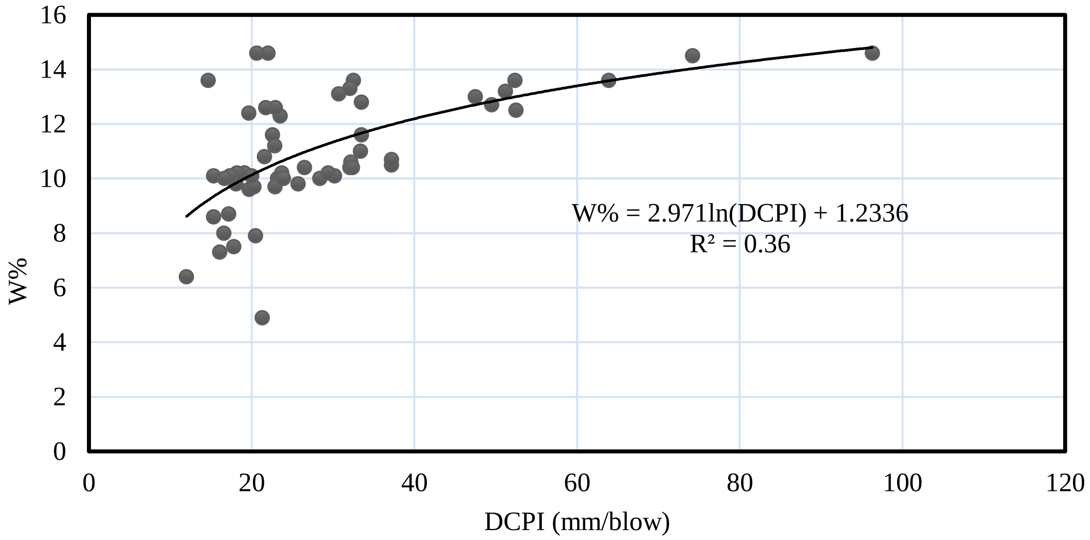

FIGURE 6. Relation between DCPI and W %.

From the analysis, the following empirical equations are proposed to estimate CBR, Mr, γdry, w% from DCPI value:

$$CBR = 64.727*(DCPI)^{-0.724} \quad (R^2 = 0.64) \quad (6)$$

$$Mr = 1002*(DCPI)^{-1.052} \quad (R^2 = 0.77) \quad (7)$$

$$\gamma dry = 24.254(DCPI)^{-0.068} \quad (R^2 = 0.56) \quad (8)$$

$$W\% = 2.971*\ln(DCPI) + 1.2336 \quad (R^2 = 0.36) \quad (9)$$

It would be interesting to study the reliability of the empirical equation developed in the literature and in this study using extensive statistical analysis.

8. CONCLUSIONS

In this study the empirical equations to predict CBR and Mr values using DCPI were modified using data obtained from literature, the study focused on fine grained soil. According the statistical analysis of the collected data, the following conclusions are made:

1. A power relationship was found between Mr and DCPI with coefficient of determination(R^2) of 0.77
2. A power relationship was found between CBR and DCPI with coefficient of determination (R^2) of 0.64.
3. A poor correlation was found between dry unit weight and DCPI with R^2 of 0.56 whereas a very poor correlation was found between water content and DCPI value ($R^2 = 0.36$).
4. Resilient modulus and CBR values are influenced by the moisture content and dry unit weight, Theses values decreased with an increase of moisture content and increased with an increase of dry unit weight.
5. Dynamic cone penetrometer test (DCP) can be recommended devise to predict the geotechnical properties of soils.

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