Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 104 (2013) 245 – 254

Procedia
Social and Behavioral Sciences

2nd Conference of Transportation Research Group of India (2nd CTRG)

Prediction of Subgrade Strength Parameters from Dynamic Cone Penetrometer Index, Modified Liquid Limit and Moisture Content

Mukesh A. Patel[a], H.S. Patel[b], Gautam Dadhich[c]*

[a]*Reaearch scholer, Ganpat University, Mehsana-382 711, Gujarat, India*
[b]*Associate Professor Department of Applied Mechanics, L. D. College of Engineering Ahmedabad-380 015, Gujarat, India*
[c]*UG Student, Pandit Deendayal Petroleum University, Gandhinagar-382 007, Gujarat, India*

Abstract

Subgrade soil is an essential component for design of both flexible and rigid pavement structures. Laboratory investigation of subgrade strength parameter as California Bearing Ratio beneficial for design of flexible pavement, Coefficient of subgrade reaction K-Value required for design of rigid pavement, raft footing and unconfined compressive strength (UCS) is useful for determination of shear strength parameter of subgrade. These tests are time consuming and demand significant effort but mandatory. This study considers the use of multiple variable regression analysis (MLR) to predict the California Bearing Ratio (CBR), Coefficient of subgrade reaction K-Value, unconfined compressive strength (UCS), Field dry density from Dynamic Cone Penetrometer (DCP), modified liquid limit and moisture content of subgrade. This paper presents the empirical correlations developed from multiple variable regression analysis from test results obtained from experimental investigation of soil sample taken from different locations of Gujarat region in India. The formulations are validated using other sets of tests data. The developed empirical correlations may be useful in quick determination of strength parameters of subgrade from physical properties of subgrade and Dynamic Cone penetrometer. Results obtained from validation of these developed empirical correlation proves their reliably and accuracy to perform subgrade strength evaluation for both rigid and flexible pavement.

Keywords: Modified liquid limt; DCP; CBR; UCS; K_{PBT}

* Corresponding author. Tel.:+91-9825365952; fax: 91-79-32428856
E-mail address: map_technical@yahoo.co.in

doi:10.1016/j.sbspro.2013.11.117

Nomenclature

Abbreviations

C	Fraction of soil coarser than 425 micron (%)
CBR	California Bearing Ratio
DCP	Dynamic cone Penetrometer Index
IS	Indian Standards
K_{PBT}	Coefficient of Subgrade reaction
LL	Liquid Limit
M.C.	Moisture content
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PBT	Plate Bearing Test
PI	Plasticity Index
PL	Plastic Limit
QA/QC	Quality Assessment/Quality Control
SPG	Specific Gravity
UCS	Unconfined Compressive Strength
W_L	Liquid Limit (%)
W_{LM}	Modified Liquid Limit (%)

1. Introduction

Subgrade layer plays a vital role in conveying structural strength to the pavement structure as it receives loads enacted upon it by road traffic. Traffic loads need to be transmitted in a manner that the subgrade-deformation is within elastic limits, and the shear forces developed are within safe limits under adverse climatic and loading conditions. The subgrade comprises unbound earth materials such as gravel, sand, silt and, clay that influence the design and construction of roads. The assessment of properties of soil subgrades, in terms of density, soil stiffness, strength, and other in-situ parameters is vital in the design of roads, and their performance. There are various tests including CBR or K-Value is mandatory parameters for subgrade strength evaluation. The laboratory determination of CBR and K-value tests requiring considerable effort and time in strength of subgrade determination. The CBR is a measure of shearing resistance of material under controlled density & moisture condition. it is a ratio of the force per unit area required to penetrate a soil mass with a standard circular piston of 50 mm diameter at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material. The CBR value obtained is an integral part of several flexible pavement design method, as per the test method standard one CBR test will need minimum 7 days. The Plate Bearing Test (PBT) is one of the most important tests to determine the stiffness of road subgrade. The PBT test measures deformation under rigid plate for various loading conditions. The test is expensive and long duration. The PBT test is used to determine modulus of subgrade reaction (K-value) of subgrade which is important parameter to design rigid pavement and

raft footing. The unconfined compression strength of subgrade soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in simple compression test. This Test is lengthy and precise and need experienced engineer to conduct. UCS test gives the shear strength of the soil that is useful parameters for computing safe bearing capacity of soil as well as strength of soil.

The primary objective of this research work is to develop common unified in-situ approach by developing multivariate linear parametric regression models for estimating the strength parameters of subgrade soil to accelerate the decision process of pavement design and to simplify the QA/QC assessment of pavement system. It becomes easier to evaluate the strength parameters by correlating the results of PBT, CBR, UCS with DCP and index properties. In view of present pavement design procedures this paper is aims to develop multiple variable linear correlations between Dynamic Cone Penetrometer Index, Modified Liquid Limit and Moisture Content with other subgrade soil parameters such as CBR, UCS, KPBT in soaked condition for direct determination of these parameters from simple empirical formulas.

2. Scope of Research work

The scope of the proposed research work is as follows

- Identification of critical locations of soil samples is Gujarat state as per IS classification. Total 29 soil samples were selected with diverse characteristics from different locations of Gujarat region.
- Selected soils samples are classified as of Sandy soils (SM & SM-SC), Sand-clay soils (CL, CL-ML, SC & MI) and Clayey soils (CH & CI).
- Detailed laboratory investigations for natural in soaked conditions were performed in laboratory.
- Multivariate linear parametric regression models are also developed for estimating the strength parameters such as CBR value, UCS value and KPBT value with maximum dry density, optimum moisture content , modified liquid limit, DCP values in soaked conditions for natural soils.

3. Laboratory Investigation

Laboratory investigations have been performed for the samples collected from the trial pit by following IS 4453-1980. The laboratory investigations were performed for all soil samples in different moisture contents and compaction characteristics. Various soil Samples are collected from selected locations of Gujarat state of India, The index properties of the selected soils samples were determined as shown in Table 1. Wet sieve analysis is conducted to determine the percentage by weight coarser than 425 micron (C) One kilogram of oven dried soil sample is taken in a 425 micron I.S. sieve and washed under a jet of water until the wash water became clear. The material retained on the sieve is collected and dried in oven for 24 h. The dried soil sample is weighted accurately and the value of C is determined (Table 2) (IS-2720-P-4: 1985)

Based on the experimental study, Regression analysis is carried out to develop the correlation for CBR, KPBT and UCS with DCP, Moisture content and modified liquid limit. The generalization for natural soils can be made by accounting for the presence of coarser fraction and modifying the liquid limit as

$$W_{LM} = W_L (1- C/100) \qquad \ldots\ldots\ldots eq.\ 1$$

Where, W_{LM} = Modified Liquid limit (%),
W_L= Liquid Limit (%)

C = Fraction of soil coarser than 425 micron (%)

In the present study, Modified liquid limit has been used as the characteristic property of the soil and presented in Table 1.

It was planned to perform the CBR, PBT, and UCS as well as DCP tests for soaked and unsoaked remolded soil samples for Maxi-mum Dry Density by using Modified Proctor Compaction test(IS-2720-P-8: 1983), CBR, PBT, UCS and DCP test were conducted three times for each sample and average of three results was considered and tabulated in Table 2.

3.1. Test Set Up For Investigation Using Plate Bearing Test (PBT)

The investigation was carried out on prototype cylindrical mould of 490 mm diameter and 490 mm height made of 10 mm thick steel plate. The mould was stiffened by 12 mm thick and 40 mm wide steel ring at bottom and top. The photograph of mould and reaction frame is shown in Figure 1.

Fig. 1. The photograph of mould and Reaction frame

Table 1. Test results of selected soil samples

Location	Gradation					LL	PL	PI	Modified LL	Soil classification	SPG
	Gravel	Coarse	Med.	Fine	Silt + Clay						
Netrang Rajpipla	4.00	0.00	0.00	76.00	20.00	23.00	NP	NP	21.62	SM	2.63
Netrang Rajpipla	3.00	4.00	6.00	40.00	47.00	28.00	21.00	7.00	25.76	SM-SC	2.62
Rapar, Kutch	5.00	4.00	4.00	65.00	22.00	25.00	NP	NP	24.36	SM	2.62
Bhachau, Kutch	6.00	2.00	2.00	63.00	27.00	26.00	NP	NP	24.90	SM	2.63
Jamnagar	1.00	2.00	6.00	12.00	79.00	54.00	24.00	30.00	49.14	CH	2.60
Akleshwar Road	0.00	1.00	0.00	40.00	59.00	47.00	23.00	24.00	46.53	CI	2.58
Akleshwar Road	2.00	3.00	12.00	16.00	67.00	36.00	23.00	13.00	35.28	CI	2.59
Akleshwar Road	0.00	0.00	2.00	16.00	82.00	49.00	24.00	25.00	49.00	CI	2.59
Akleshwar Road	0.00	2.00	16.00	10.00	72.00	42.00	22.00	20.00	34.44	CI	2.57
Ahmedabad Viramgam Maliya	4.00	13.00	12.00	15.00	56.00	42.00	22.00	20.00	35.70	CI	2.62

Ahmedabad Viramgam Maliya	6.00	11.00	15.00	10.00	58.00	44.00	22.00	22.00	35.20	CI	2.62
Ahmedabad Viramgam Maliya	4.00	6.00	11.00	20.00	59.00	36.00	22.00	14.00	32.04	CI	2.61
Jambusar	0.00	3.00	10.00	17.00	70.00	38.00	23.00	15.00	38.00	CI	2.60
Ankleshwar	1.00	4.00	7.00	7.00	81.00	46.00	22.00	24.00	40.48	CI	2.60
Kheda	0.00	5.00	8.00	11.00	76.00	48.00	24.00	24.00	41.76	CI	2.60
Dhandhuka	1.00	1.00	1.00	9.00	88.00	36.00	22.00	14.00	34.92	CI	2.61
Radhanpur	3.00	2.00	9.00	17.00	69.00	52.00	24.00	28.00	44.72	CH	2.60
Rajula	4.00	1.00	8.00	20.00	67.00	58.00	24.00	34.00	50.46	CH	2.60
Ahmedabad Viramgam Maliya	4.00	7.00	14.00	19.00	56.00	33.00	21.00	12.00	23.40	CL	2.61
Ahmedabad Viramgam Maliya	2.00	3.00	20.00	23.00	52.00	35.00	21.00	14.00	29.10	CL	2.61
Modasa	0.00	24.00	15.00	6.00	55.00	32.00	21.00	11.00	27.20	CL	2.61
Piludra -Kareli	0.00	8.00	8.00	26.00	58.00	32.00	25.00	7.00	31.40	CL-ML	2.60
Piludra -Kareli	5.00	6.00	8.00	26.00	55.00	33.00	26.00	7.00	31.00	CL-ML	2.58
Piludra -Kareli	2.00	3.00	7.00	46.00	42.00	28.00	21.00	7.00	26.00	SC	2.60
Vadodara Bharuch	4.00	11.00	11.00	49.00	25.00	38.00	21.00	17.00	32.70	SC	2.61
Vadodara Bharuch	3.00	8.00	20.00	21.00	48.00	48.00	21.00	27.00	39.40	SC	2.61
Ahmedabad Viramgam Maliya	4.00	2.00	26.00	27.00	41.00	31.00	21.00	10.00	14.90	SC	2.62
Ahmedabad Viramgam Maliya	6.00	9.00	11.00	26.00	48.00	32.00	21.00	11.00	17.90	SC	2.62
Ahmedabad Viramgam Maliya	6.00	5.00	20.00	21.00	48.00	34.00	21.00	13.00	25.80	SC	2.62
Ahmedabad	0.00	2.00	27.00	32.00	39.00	29.00	21.00	8.00	20.60	SC	2.62
Sudhi Samni Road	0.00	5.00	10.00	22.00	63.00	32.00	21.00	11.00	32.00	CL	2.60
Jambusar	0.00	0.00	2.00	27.00	71.00	40.00	25.00	15.00	40.00	MI	2.60

A base plate of 25 mm thickness was prepared to fix the cylindrical mould. It is stiffened by 4 mm wide and 2 mm thick steel plate. At the bottom of the base plate for soaking of the sample, 6 mm diameter holes were drilled at uniform spacing. During soaking top soil surface was closed by perforated steel plate, which is properly clamped with mould to prevent swelling or particles displacement of soil. It was placed in steel water tank of larger size by means of crane so that sample in mould got saturated uniformly during soaking are as shown in Figure 2.

Fig. 2. Mould with saturation tank

The diameter of the test mould for the sample satisfies the recommendation for the experimental set up and the test procedure as per the Indian standard that is the diameter of the loading plate should be approximately one fifth of the diameter of the sample specimen mould in order to overcome the effect due to the confining of the boundary. (IS-1498:1997, IS-1888: 1982 & IS-9214: 1979). PBT was conducted on samples prepared in the test mould. Weight of sample required filling the mould of an inner diameter of 490 mm and a sample depth of 400 mm was determined. Total soil was filled in five equal layers by static efforts using compression testing machine specially developed as shown in Figure 3.

Fig. 3. Compression testing machine for static compression of sample in mould

The load was applied on the circular plate of diameter 10.5 cm and thickness of 15 mm by manually operated jack fitted on reaction frame .The load was applied without impact, fluctuation or eccentricity. Initially a seating stress of 0.007 MPa was applied and released before the actual test was started. The loads were applied in convenient increment and measured by proving ring of capacity 50 kN or more and settlement of Plate for each increment were measured by two nos. of dial gauge (0.01 mm accuracy) placed at diametrically opposite ends of the plate. The settlements were measured until the rate of settlement becomes less than 0.025 mm per minute. This procedure was continued up to the total settlement became 1.75 mm or more three tests were performed and average of three results are presented in Table 2 Similar tests were performed for the each type of soil for MDD in soaked and unsoaked condition. The results of the test are used in calculation of K-value (Coefficient of subgrade reaction) and presented in the Table 2.

3.2. Test Set Up For Investigation Using Dynamic Cone Penetrometer (DCP)

DCP tests were performed using cylindrical mould at the same densities and moisture content in soaked and unsoaked condition as were done in the case of test using PBT. Figure 4 shows test set up for DCP specially developed with digital facilities for blows count and penetration measurement and also mechanical arrangement for hammer falling. In the DCP test the 8 kg hammer was dropped through the height of 575 mm on the anvil hammer was dropped by mechanical pulling arrangement, the anvil was connected with rod attached by 60 degree cone of 20 mm diameter was kept on the top of the soil surface. In the DCP test, observation were made of number of blows corresponding to penetration of cone through digital display The penetration test using DCP was performed up to 300 mm depth; the penetration resistance was obtained that was the ratio of the total penetration to the corresponding number of blows. Similar tests were performed for MDD for each type of soil in soaked and unsoaked condition. The results of the test were observed and are noted in the Table 2.

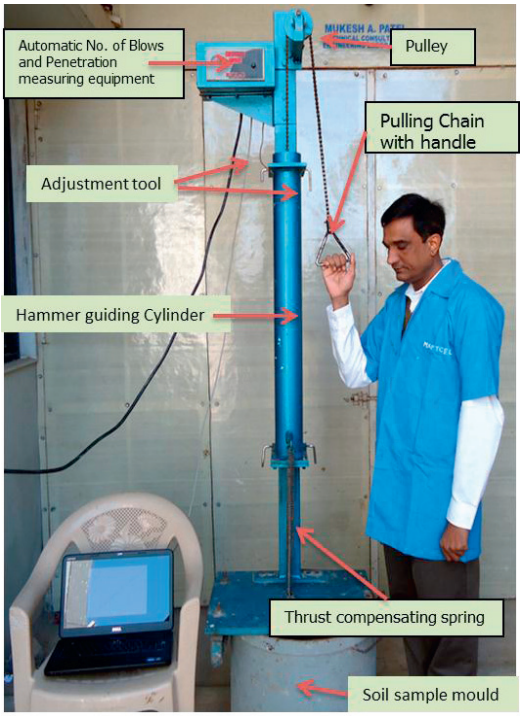

Fig. 4. Digital Dynamic Cone Penetrometer

3.3. California Bearing Ratio Test (CBR)

CBR tests were performed on soaked soil samples as per the test procedure stipulated in Indian standard.(IS-2720-P-16: 1987) In the CBR test, load and penetration reading of 50 mm plunger were observed at a rate of 1.25 mm/minute, the load for 2.5 mm and 5 mm were observed, the load was expressed as a percentage of standard load value at a respective deformation level. CBR test were conducted at the similar densities and moisture contents for soaked condition as were performed using PBT and DCP. Test results of CBR are tabulated in Table 2.

Table 2. Results of experimental investigation

Location	Dry density kN/m^3	Moisture content %	CBR %	UCS Kg/cm^2	KPBT $N/mm^2/mm$	DCP cm/blow
Netrang Rajpipla	20.50	8.00	9.50	-	0.08	1.66
Netrang Rajpipla	20.40	7.50	8.80	-	0.07	1.78
Rapar, Kutch	20.70	7.90	8.45	-	0.07	2.05
Bhachau, Kutch	20.00	7.30	9.86	-	0.08	1.61
Jamnagar	17.90	13.60	2.28	0.24	0.04	6.39
Akleshwar Road	18.30	14.50	2.00	0.20	0.03	7.42
Akleshwar Road	19.40	10.50	4.50	0.54	0.06	3.72

Akleshwar Road	17.90	14.60	1.20	0.11	0.03	9.63
Akleshwar Road	19.40	12.80	4.60	0.55	0.06	3.35
Ahmedabad Viramgam Maliya	19.40	11.00	4.60	0.55	0.06	3.34
Ahmedabad Viramgam Maliya	19.30	11.60	4.60	0.55	0.06	3.35
Ahmedabad Viramgam Maliya	19.40	10.60	4.90	0.60	0.06	3.22
Jambusar GIDC	19.10	10.70	3.90	0.45	0.05	3.72
Ankleshwar	18.50	12.50	3.10	0.34	0.05	5.25
Kheda	18.60	12.70	3.47	0.39	0.05	4.95
Dhandhuka	18.90	13.00	3.59	0.41	0.05	4.00
Radhanpur	18.40	13.60	2.84	0.31	0.04	5.24
Rajula	18.20	13.20	2.90	0.32	0.04	5.12
Ahmedabad Viramgam Maliya	20.30	10.00	8.10	1.22	0.07	2.32
Ahmedabad Viramgam Maliya	19.90	10.40	6.60	0.92	0.07	2.65
Modasa	19.90	10.20	8.90	1.42	0.07	2.37
Piludra -Kareli	19.70	9.80	5.80	0.64	0.06	2.57
Piludra -Kareli	19.80	10.00	5.90	0.71	0.06	2.84
Piludra -Kareli	20.20	9.70	8.30	1.33	0.07	2.29
Vadodara Bharuch	19.50	10.40	5.00	0.65	0.06	3.21
Vadodara Bharuch	19.30	10.40	4.20	0.50	0.05	3.24
Ahmedabad Viramgam Maliya	20.80	9.60	11.90	1.79	0.08	1.97
Ahmedabad Viramgam Maliya	20.60	9.70	10.00	1.50	0.08	2.03
Ahmedabad Viramgam Maliya	20.10	10.00	7.80	1.01	0.07	2.39
Ahmedabad	20.90	8.70	15.05	2.86	0.09	1.72
Sudhi Samni Road	19.60	10.10	5.50	0.61	0.06	3.02
Jambusar GIDC	19.00	10.20	3.50	0.42	0.05	2.94

3.4. Unconfined Compressive Strength (UCS)

UCS tests were performed on soaked soil samples as per the test procedure stipulated in Indian standard. (IS-2720-P-10: 1991) The maximum load that can be transmitted to the sub soil depends upon the resistance of the underlying soil. To measure the resistance of the soil by compressibility or shearing deformation, unconfined compression test is the load required per unit area to fail the unconfined soil specimen by application of compressive pressure. UCS test were conducted at the same densities and moisture contents as were performed using PBT, CBR and DCP. Test results of UCS are tabulated in Table 2.

4. Results And Discussion

Assessment of soil is focused on results obtained by CBR, PBT, UCS, and DCP tests in soaked condition. Here attempt has been made to develop correlation between various strength parameters. These relationships help civil engineers to estimate various parameters of soil. The multiple variable regression analysis have been

adapted to evaluated relation between strength parameters and other parameters. Development of correlation between results of various tests in soaked condition is done in following way.

4.1. Prediction of CBR from DCP, Modified Liquid Limit and Moisture Content

A relation between CBR of subgrade, DCP, Modified Liquid Limit and Moisture Content is determined from regression analysis of results obtained from Experimental Investigation is expressed by Equation No. – 2

$$CBR = 0.26235 * DCP - 0.29716 * W_{LM} - 0.34399 * M.C. + 18.59709 \quad (R^2 = 0.83) \dots\dots\dots eq.2$$

A plot between actual and predicted value of CBR is shown in Figure 5

4.2. *Prediction of UCS from DCP, Modified Liquid Limit and Moisture Content*

A relation between UCS of subgrade, DCP, Modified Liquid Limit and Moisture Content is determined from regression analysis of results obtained from Experimental Investigation is expressed by Equation No. – 3

$$UCS = 0.07904 * DCP - 0.05686 * W_{LM} - 0.07359 * M.C. + 3.223091 \quad (R^2 = 0.70) \dots\dots\dots eq.3$$

A plot between actual and predicted value of UCS is shown in fig. 6

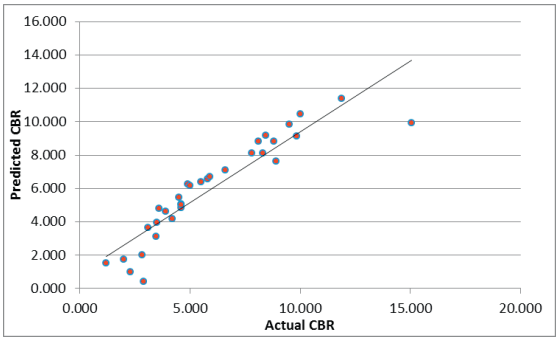

Fig. 5. Predicted and actual CBR

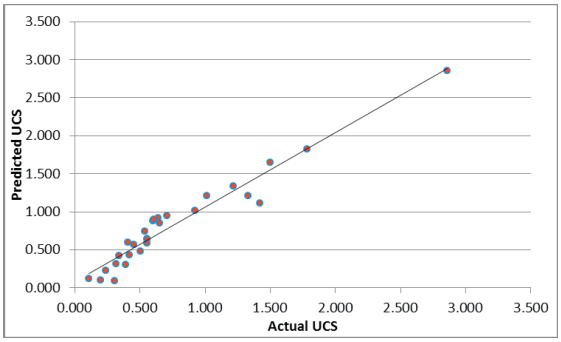

Fig. 6. Predicted and actual UCS

4.3. Prediction of KPBT from DCP, Modified Liquid Limit and Moisture Content

A relation between KPBT of subgrade, DCP, Modified Liquid Limit and Moisture Content is determined from regression analysis of results obtained from Experimental Investigation is expressed by Equation No. – 3

$$K_{PBT} = 0.00271 * DCP - 0.001 * W_{LM} - 0.00057 * M.C. + 0.10859 \quad (R^2 = 0.96) \dots\dots\dots eq.4$$

A plot between actual and predicted value of KPBT is shown in fig. 7

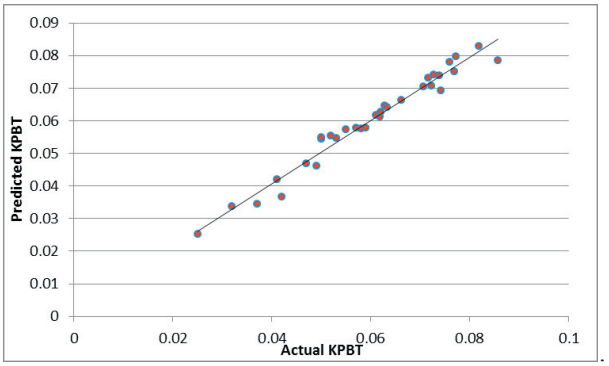

Fig. 7. Predicted and actual K_{PBT}

5. Conclusion

The above experimental analysis was done to develop the co relations between various tests results like KPBT.UCS, CBR and DCP of soil in soaked condition. The correlations developed are very useful to the civil engineer in estimating strength parameters of various soils. These correlations will helpful for quick determination of strength parameter for subgrade. The results of the statistical analysis show that good correlation do exist between the devices under evaluation (DCP) and the standard tests (CBR, UCS and PBT). The relations obtained from statistical analysis, were linear for model developed. All regression models had an adjusted R^2, and a significance level greater than 0.8. The result of this study suggests that modified DCP can be reliably used to predict the soaked CBR, UCS and PBT based on given Index properties.

References

[1]. Harison, J. A. "Technical Note. Correlation Between California Bearing Ratio And Dynamic Cone Penetrom Eter Strength Measurement Of Soils. Technical Note 463." *ICE Proceedings*. Vol. 83. No. 4. Thomas Telford, 1987.

[2]. Patel, Mukesh A., and H. S. Patel. "Experimental Study to Correlate the Test Results of PBT, UCS, and CBR with DCP on Various soils in soaked condition." *International Journal of Engineering (IJE)* 6.5 (2012): 244.

[3]. IS: 2720 (Part-3, Section-1)-1980, Methods of Test For soils: Part-3 Determination of Specific Gravity, Section 1 Fine Grained Soils.

[4]. IS: 1498 -1970, Classification and Identification of Soils for General Engineering Purposes.

[5]. IS: 1888-1982, Method of Load Test on Soils.

[6]. IS:2720 (Part-4)-1985, Methods of Test for Soils: Part -4 Grain Size Analysis.

[7]. IS:2720 (Part-5)-1985, "Methods of Test for Soils: Determination of Atterberg's limits."

[8]. IS: 2720 (Part-10) – 1973, Method Test for Soil: Part-10 Determination of Unconfined Compressive Strength.

[9]. IS: 2720 (Part-16) -1983, Indian Standard Method of Test for Soils, Laboratory Determination of "CBR".

[10]. IS: 2720 (Part-8), Method of test of Soils: Part -8 Determination of Water Content-Dry Density Relation using Heavy Compaction.

[11]. IS: 9214- 1974, Method of Determination of Modules of Subgrade Reaction (K-Value) of Soils in Field.