Experimental Study to Correlate the Test Results of PBT, UCS, and CBR with DCP on Various soils in soaked condition

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Abstract

The development of new roads, enhancement of existing roads and new runways are part of infrastructure boom in India as well as in Gujarat. Need of strength parameters of subgrade soils is very important in monitoring and evaluation of roads and runways subgrade quality. Laboratory determination of California Bearing Ratio useful for flexible pavement design, Coefficient of subgrade reaction K-Value needed for rigid pavement, raft footing and unconfined compressive strength (UCS) is required for determination of shear strength parameter of subgrade are time consuming and demand significant effort but mandatory. Dynamic Cone Penetration test can be a faster and easier way to evaluate subgrade strength.

In present study an investigation has been carried out on strength parameters for the soil from various locations of Gujarat, In-situ condition has been created in laboratory using bigger testing mould and various tests like Liquid Limit, Plastic limit as well as CBR, PBT, UCS and DCP were carried out on repetitive samples of Maximum Dry Densities achieved through modified proctor effect in soaked condition.The empirical correlations have been established among test results using linear regression procedure. The formulations are validated using other sets of tests data. The developed empirical correlations may be useful to estimate time consuming strength parameters as well as physical properties at numerous locations within area under consideration using simple and rapid DCP test.

Keywords: Subgrade, CBR, DCP, UCS, PBT.

1. INTRODUCTION

The quality of the road or runways depends to a large extent on the strength and shear characteristics of subgrade material. To per-form optimistic Pavement design, an accurate and representative material characterization technique is essential; such technique would be more acceptable if it is simple, rapid and economic. The evaluation of subgrade strength is an important for the road pavement during design, construction and service stages.

The use of CBR or K-Value is mandatory parameters for pavement design, to estimate the CBR or K-value for the subgrade soil. The laboratory determination of CBR and K-value tests demand significant effort, In strength of subgrade determination, initially the California Bearing Ratio (CBR) test was developed by the California Division of Highway. 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 take minimum 7 days.

The Plate Bearing Test (PBT) is one of the most important tests to determine the stiffness of road subgrade. The PBT teat 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 sub grade soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in simple compression test, 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.
In view of present pavement design procedures, it reflect that there is a need of performing direct monitoring of stiffness of subgrade to design, construction and operation period which demands rapid & easy way to verify subgrade strength parameters, It become easier to evaluate the strength parameters by correlating the results of PBT, CBR, UCS & DCP in soaked as well as Unsoaked condition.

This paper is aims to develop linear correlations between DCP and other subgrade soil parameter such as CBR, UCS, K_{PBT} etc. in both soaked and unsoaked condition for direct determination of these parameters from DCP results. The Dynamic Cone Penetrometer Test is a Portable Equipment that measures Penetration resistance by cone penetration with blows count of hammer; it is designed for the rapid insitu measurement of subgrade. So the use of Dynamic cone penetrometer is the faster and the easier way to estimate the strength parameters. (Harison, J.R., 1983 – 1987, Kleyn, E.G., 1975, Livneh, M. 1987, Rodrigo Sal-gadi, Sungmin Yoon, 2003, Talal Ao-Referal & Al Suhaibani, 1996).

2. EXPERIMENTAL SETUP

As a test samples, various soils belongs to different locations of Gujarat were collected ,The index properties of the selected soils samples were determined as shown in Table -1 and Grain Size analysis results were depicted in FIGURE 1. (IS-2720-P-4, IS-2720-P-5, IS-1498, IS-2720-P-3). 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).

Based on the experimental study, analysis is done to develop the correlation for CBR, KPBT and UCS with plasticity/gradation characteristics. The generalization for natural soils can be made by accounting for the presence of coarser fraction and modifying the liquid limit as

$W_{LM} = W_L\ (1- C/100)$ ------------------- (1)

Where, WLM = Modified Liquid limit (%),
WL= 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.

Sample No.	Gravel	Coarse Sand	Fine Sand	Silt + Clay content	Group of Soil	W_L	modified LL(W_{LM})	PL	PI
S1	0	15	30	55	CL	32	19.52	21	11
S2	0	29	32	39	SC	29	20.59	21	8
S3	4	48	7	41	SC	31	21.08	21	10
S4	4	2	74	20	SM	23	22.08	NP	NP
S5	6	38	8	48	SC	32	22.08	21	11
S6	3	5	45	47	SM-SC	28	24.36	21	7
S7	2	5	51	42	SC	28	24.64	21	7
S8	4	25	15	56	CL	33	24.75	21	12
S9	6	18	28	48	SC	34	25.16	21	13
S10	2	15	31	52	CL	35	26.25	21	14
S11	7	13	17	63	CI	38	26.64	23	15
S12	1	5	9	85	CL-ML	33	26.73	26	7
S13	0	2	9	89	CL-ML	32	26.88	25	7
S14	0	0	37	63	CL	32	27.2	21	11
S15	4	10	61	25	SC	38	28.12	21	17
S16	4	7	30	59	CI	36	28.44	22	14
S17	0	18	10	72	CI	42	29.82	22	20
S18	3	12	19	66	CI	42	29.82	22	20
S19	2	0	31	67	CI	36	29.88	23	13
S20	5	15	5	75	CI	44	29.92	22	22
S21	0	0	20	80	CI	38	33.06	23	15
S22	0	18	34	48	SC	48	33.12	21	27
S23	1	2	9	88	CI	36	34.92	22	14
S24	1	11	7	81	CI	46	40.48	22	24
S25	0	13	11	76	CI	48	41.76	24	24
S26	0	0	19	81	MI	40	42.14	25	15
S27	1	8	12	79	CH	54	49.14	24	30
S28	0	1	40	59	CI	47	51.3	23	24
S29	0	0	18	82	CI	49	58.9	24	25

TABLE 1: Index Properties

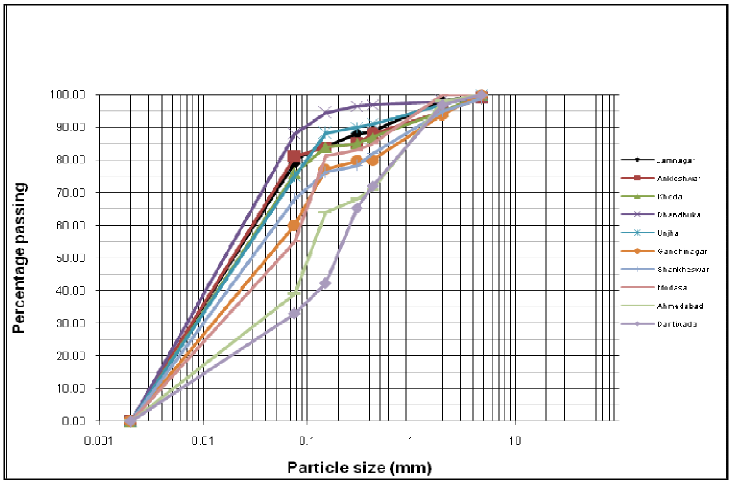

FIGURE 1: Grain Size analysis

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), 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.

2.1 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 are shown in FIGURE 2.

FIGURE 2: The photograph of mould and Reaction frame

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 3.

FIGURE 3: 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, IS-1888, IS-9214).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 4.

FIGURE 4: 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 load 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-2A & 2B Similar tests were performed for the each type of soil for M.D.D. 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-2A & 2B.

2.2 Test Set Up For Investigation Using Dynamic Cone Penetrometer (DCP)
DCP test 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 5 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 DCP test the 8 kg hammer were dropped through the height of 575 mm on the anvil hammer was dropped by mechanical pulling arrangement, 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 M.D.D. for each type of soil in soaked and unsoaked condition. The results of the test were observed and are noted in the Table-2A & 2B.

FIGURE 5: Dynamic Cone Penetrometer

2.3 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) 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 same densities and moisture contents for soaked and unsoaked sample as were performed using PBT and DCP. Test results of CBR are tabulated in Table-2A & 2B.

2.4 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) 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-2A & 2B.

Sample no.	MDD (KN/m^3)	OMC	Wet Density	SPG	Soaked CBR	Soaked K_{PBT} (N/mm2/ mm)	Soaked UCS (N/mm^2)	Soaked DCP (mm/blows)
S1	19.9	10.2	2.19	2.61	8.9	0.205	1.72	2.18
S2	20.9	8.7	2.27	2.62	15.05	0.828	2.48	1.72
S3	20.8	9.6	2.28	2.62	11.9	0.569	2.06	1.97
S4	20.6	8	2.21	2.63	9.5	0.359	1.7	2.08
S5	20.5	9.7	2.26	2.62	10	0.458	1.78	2.03
S6	20.4	7.5	2.19	2.62	8.5	0.195	1.56	2.22
S7	20.2	9.7	2.22	2.60	8.3	0.181	1.53	2.29
S8	20.3	10	2.23	2.61	8.1	0.179	1.5	2.32
S9	20.1	10	2.21	2.62	7.8	0.168	1.46	2.39
S10	19.9	10.4	2.20	2.61	6.6	0.102	1.28	2.65
S11	19.9	12.5	2.24	2.62	6.5	0.093	1.27	2.68
S12	19.8	10	2.18	2.58	5.9	0.088	1.2	2.84
S13	19.7	9.8	2.16	2.60	5.8	0.081	1.18	2.93
S14	19.6	10.1	2.16	2.60	5.5	0.08	1.14	3.02
S15	19.5	10.4	2.15	2.61	5	0.075	1.08	3.21
S16	19.4	10.6	2.15	2.61	4.9	0.069	1.06	3.22
S17	19.4	12.8	2.19	2.57	4.6	0.062	1.01	3.35
S18	19.4	11	2.15	2.62	4.6	0.062	1.02	3.34

S19	19.4	10.5	2.14	2.59	4.5	0.058	0.98	3.72
S20	19.3	11.6	2.15	2.62	4.6	0.066	1.03	3.35
S21	19.1	10.7	2.11	2.60	3.9	0.054	0.91	3.72
S22	19.3	10.4	2.13	2.61	4.2	0.056	0.96	3.55
S23	18.9	13	2.14	2.61	3.59	0.052	0.93	4.00
S24	18.5	12.5	2.08	2.60	3.1	0.047	0.75	5.25
S25	18.6	12.7	2.10	2.60	3.47	0.048	0.81	4.95
S26	19	10.2	2.09	2.60	3.5	0.049	0.86	3.98
S27	17.9	13.6	2.03	2.60	2.28	0.013	0.62	6.39
S28	18.3	14.5	2.10	2.58	2	0.008	0.64	7.42
S29	17.9	14.6	2.05	2.59	1.2	0.004	0.52	9.63

TABLE 2B: Results of CBR, K_{PBT}, UCS & DCP (soaked)

3. RESULTS AND DISCUSSION

Assessment of soil focused on observations 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 linear and multiple variable regression analysis has been adopted to evaluated relation between strength parameters. development of correlation between results of various tests in soaked condition is done in following way.

3.1 LINEAR REGRESSION ANALYSIS

3.1.1 Relation between MDD and DCP observations.

A relation between MDD and penetration index determined from DCP results is represented by equation as shown by Equation No.-2 a plot of MDD verses DCP results are presented in FIGURE 6.

$$\textbf{MDD = 21.908DCP-0.099} \qquad \text{----- (2)}$$

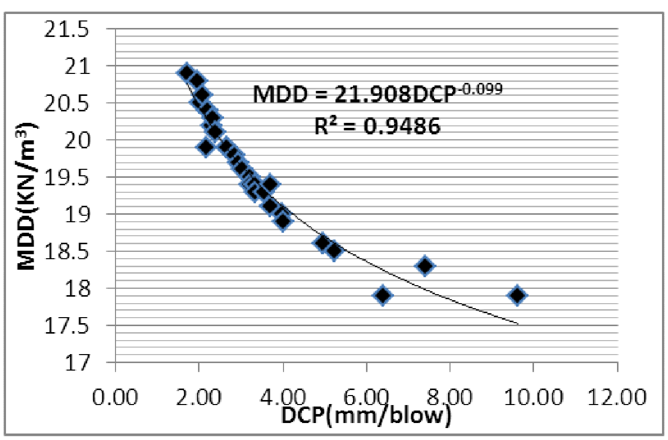

FIGURE 6: Correlation between MDD and DCP Results

3.1.2 Relation between CBR and DCP observations

A relation between CBR and penetration index determined from DCP observations is formulated as shown in Equation No.- 3.

$$\mathbf{CBR = 24.903DCP^{-1.331}} \qquad \text{------- (3)}$$

A graph presented in FIGURE 7 of CBR verses DCP results

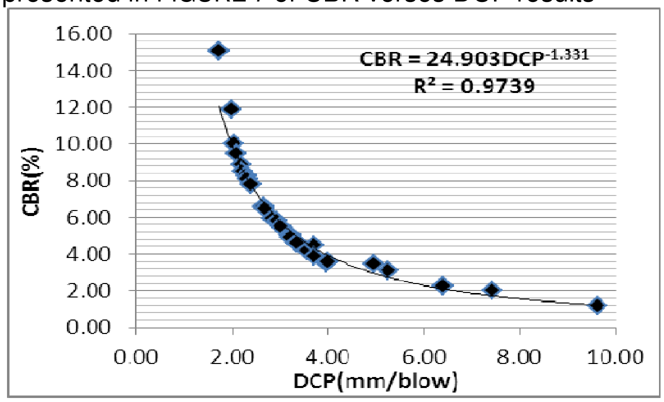

FIGURE 7: Correlation between CBR and DCP Results

3.1.3 Relation between K_{PBT} and DCP observations

A relation between KPBT and penetration resistance computed from DCP observations is formulated as shown in Equation No. - 4.

$$\mathbf{K_{PBT} = 2.0173DCP^{-2.721}} \qquad \text{------- (4)}$$

A Plot of K_{PBT} and DCP results are as shown in FIGURE 8.

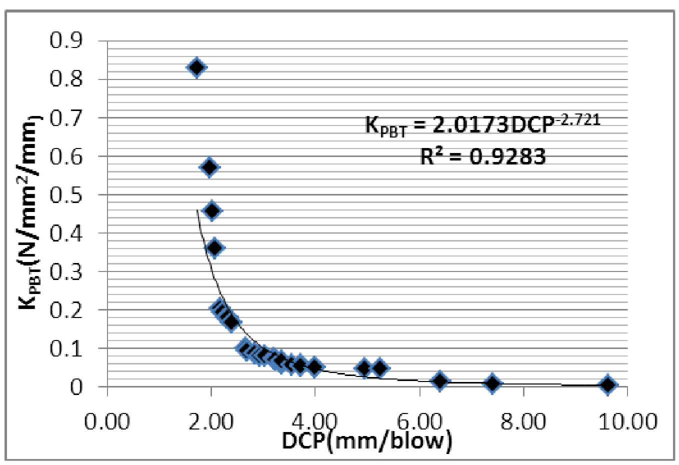

FIGURE 8: Correlation between KPBT and DCP Results

3.1.4 Relation between UCS and DCP observations

A relation between UCS and penetration resistance computed from DCP observations is formulated as shown in Equation No. – 5.

A Plot of UCS and DCP results are as shown in FIGURE 9.

$$\mathbf{UCS = 3.1237DCP^{-0.865}} \qquad \text{------- (5)}$$

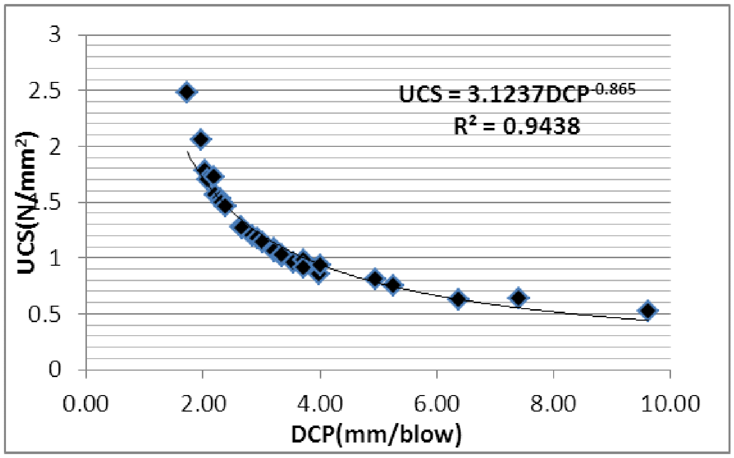

FIGURE 9: Correlation between UCS and DCP Results

3.1.5 Relation between MDD and W_{LM} observations

A relation between MDD and Modified Liquid limit W_{LM} results is provided by equation as shown by Equation No.-6

$$\mathbf{MDD = 31.722W_{LM}^{-0.143}} \quad \text{----- (6)}$$

A plot of MDD verses W_{LM} results are presented in FIGURE 10.

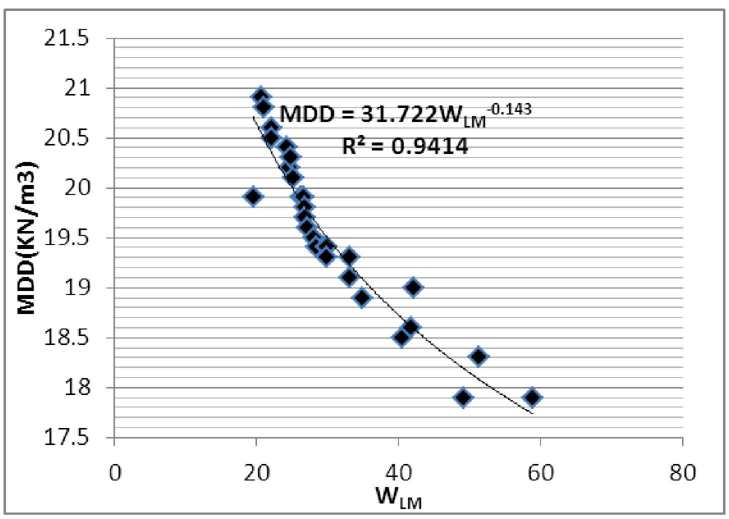

FIGURE 10: Correlation between MDD and WLM Results

3.1.6 Relation between CBR and W_{LM} observations

A relation between CBR and Modified Liquid limit WLM observations is formulated as shown in Equation No. - 7.

$$\mathbf{CBR = 3246.4W_{LM}^{-1.895}} \quad \text{------- (7)}$$

A graph presented in FIGURE 11 of CBR verses W_{LM} results

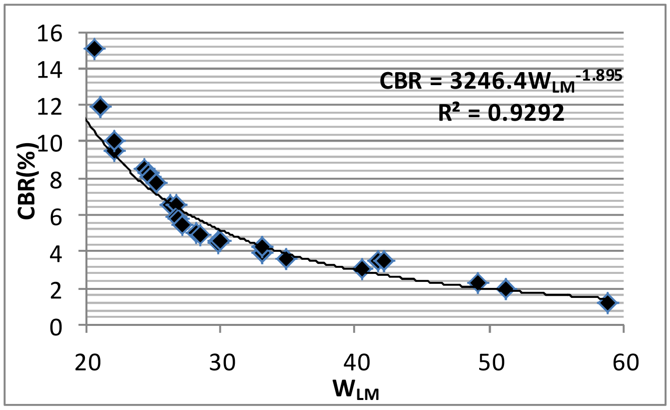

FIGURE 11: Correlation between CBR and W_{LM} Results

3.1.7 Relation between K_{PBT} and W_{LM} observations

A relation between K_{PBT} and Modified Liquid limit W_{LM} observations is formulated as shown in Equation No. - 8.

$$K_{PBT} = 35756W_{LM}^{-3.822} \quad \text{------- (8)}$$

A Plot of K_{PBT} and W_{LM} results is as shown in FIGURE 12.

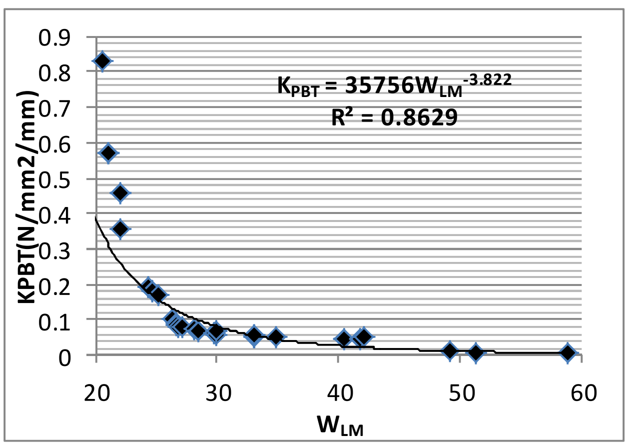

FIGURE 12: Correlation between K_{PBT} and WLM Results

3.1.8 Relation between UCS and W_{LM} observations

A relation between UCS and Modified Liquid limit WLM observations is formulated as shown in Equation No. - 9

$$UCS = 75.791W_{LM}^{-1.239} \quad \text{------- (9)}$$

A Plot of UCS and W_{LM} results are as shown in FIGURE 13.

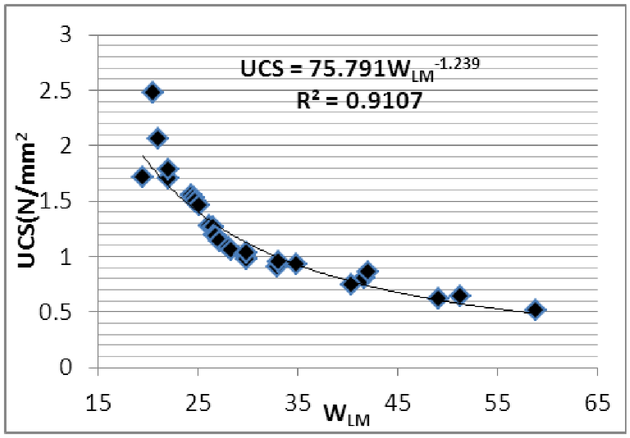

FIGURE 13: Correlation between UCS and W_{LM} Results

3.1.9 Relation between DCP and W_{LM} observations

A relation between DCP and Modified Liquid limit W_{LM} observations is formulated as shown in Equation No. – 10

$$DCP = 0.0259 W_{LM}^{1.4214} \qquad \text{------- (10)}$$

A Plot of DCP and W_{LM} results are as shown in FIGURE 14.

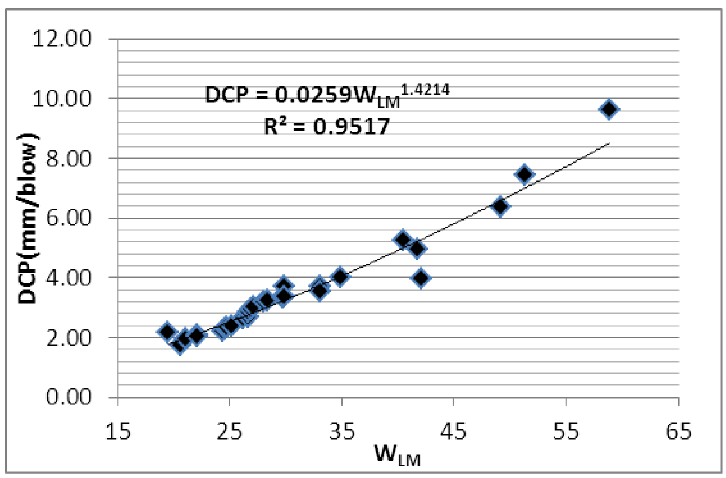

FIGURE 14: Correlation between DCP and W_{LM} Results

3.2 MULTIVARIABLE REGRESSION ANALYSIS

3.2.1 Prediction of UCS Using Maximum Dry Density, Optimum Moisture Content And Modified Liquid Limit

A relation of MDD, OMC and modified liquid limit with UCS is represented by equation as shown by Equation No.-11

A plot of Comparison of Predicted UCS and actual UCS is presented in FIGURE 15.

$$UCS = 4.287255904 \cdot 10^{-1}\, MDD - 2.581485936 \cdot 10^{-2}\, OMC + 1.039471265 \cdot 10^{-2}\, W_{LM} - 7.165088134 \qquad \text{------ (11)}$$

Residual Sum of Squares: rss = 1.429119183

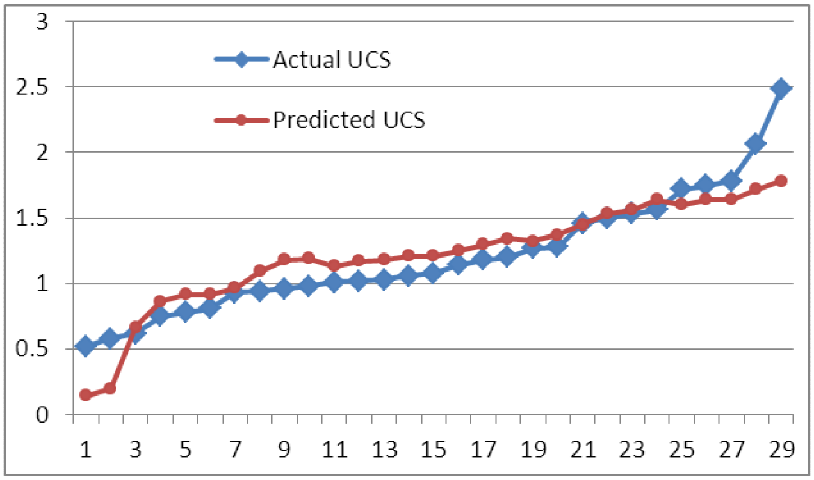

FIGURE 15: Comparison of Predicted UCS and actual UCS

3.2.2 Prediction of K-Value Using Maximum Dry Density, Optimum Moisture Content And Modified Liquid Limit

A relation of MDD, OMC and modified liquid limit with K-Value is represented by equation as shown by Equation No.-12

A plot of Comparison of Predicted K-value and actual K-Value is presented in FIGURE 16.

K-Value = 2.841852052·10-1 MDD - 6.666796321·10-3 OMC + 2.006130462·10-2 W_{LM} - 5.922789562 ------- (12)

Residual Sum of Squares: rss = 4.882056826*10-1

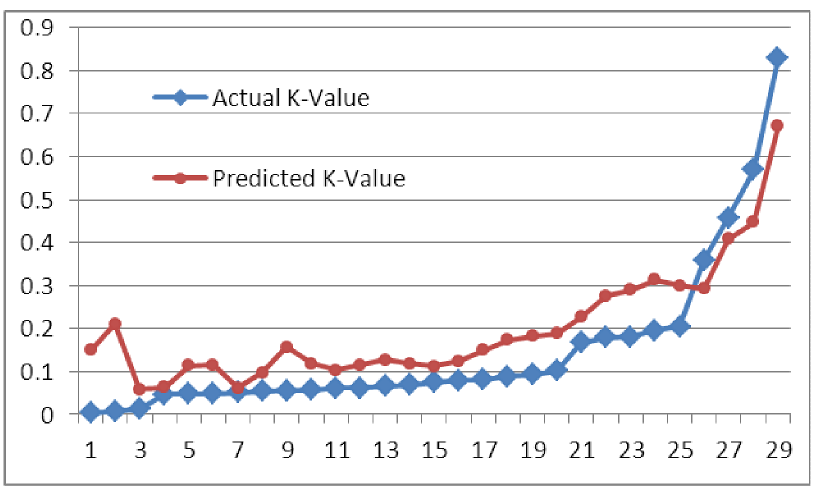

FIGURE 16: Comparison of Predicted K-value and actual K-Value

3.2.3 Prediction of CBR Using Maximum Dry Density, Optimum Moisture Content And Modified Liquid Limit

A relation of MDD, OMC and modified liquid limit with CBR is represented by equation as shown by Equation No.-13

A plot of Comparison of Predicted CBR and actual CBR is presented in FIGURE 17.

CBR = 3.753294993 MDD - 1.366922172·10-1 OMC + 1.519309837·10-1 WLM - 70.10518931 ------ (13)

Residual Sum of Squares: rss = 75.9823576

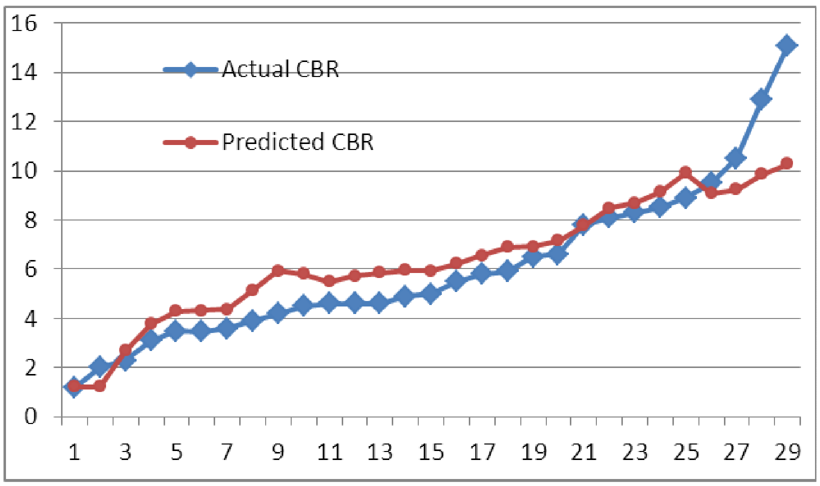

FIGURE 17: Comparison of Predicted CBR and actual CBR

3.2.4 Prediction of DCP Using Maximum Dry Density, Optimum Moisture Content And Modified Liquid Limit

A relation of MDD, OMC and modified liquid limit with DCP is represented by equation as shown by Equation No.-14

A plot of Comparison of Predicted DCP and actual DCP is presented in FIGURE 18.

DCP = -8.727239902·10-1 MDD - 4.783120596·10-2 OMC + 9.150404595·10-2 W_{LM} + 18.17841692 **------- (14)**

Residual Sum of Squares: rss = 3.895738853

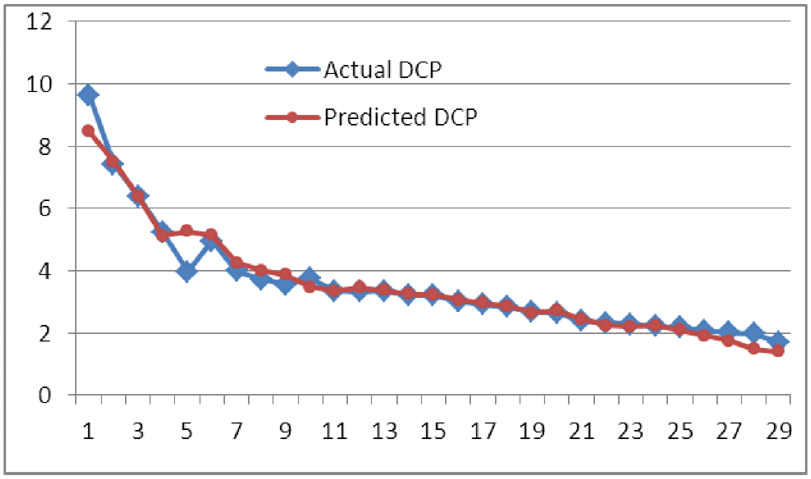

FIGURE 18: Comparison of Predicted DCP and actual DCP

3.2.5 Prediction of CBR Using MDD, OMC, Modified Liquid Limit and DCP

A relation of MDD, OMC, modified liquid limit and DCP with CBR is represented by equation as shown by Equation No.-15

A plot of Comparison of Predicted CBR and actual CBR is presented in FIGURE 19.

CBR = 5.61152798 MDD - 3.484842045·10-2 OMC - 4.290247861·10-2 MLL + 2.129233306 DCP - 108.8112801 --------------- (15)

Residual Sum of Squares: rss = 58.32050164

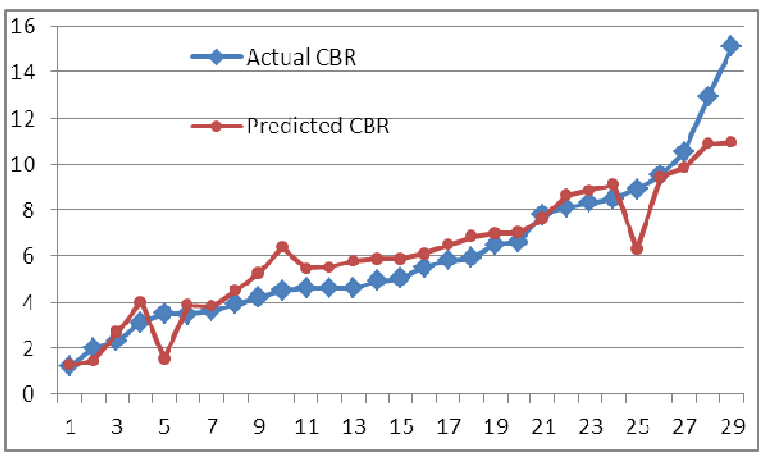

FIGURE 19: Comparison of Predicted CBR and actual CBR

3.2.6 Prediction of K-Value Using MDD, OMC, Modified Liquid Limit and DCP

A relation of MDD, OMC, modified liquid limit and DCP with K-Value is represented by equation as shown by Equation No.-16

A plot of Comparison of Predicted K-value and actual K-Value in FIGURE 20

K-Value = 4.209888602·10-1 MDD + 8.30973734·10-4 OMC + 5.717608247·10-3 MLL + 1.567547777·10-1 DCP - 8.772343264 ------------- (16)

Residual Sum of Squares: rss = $3.924793526 * 10^{-1}$

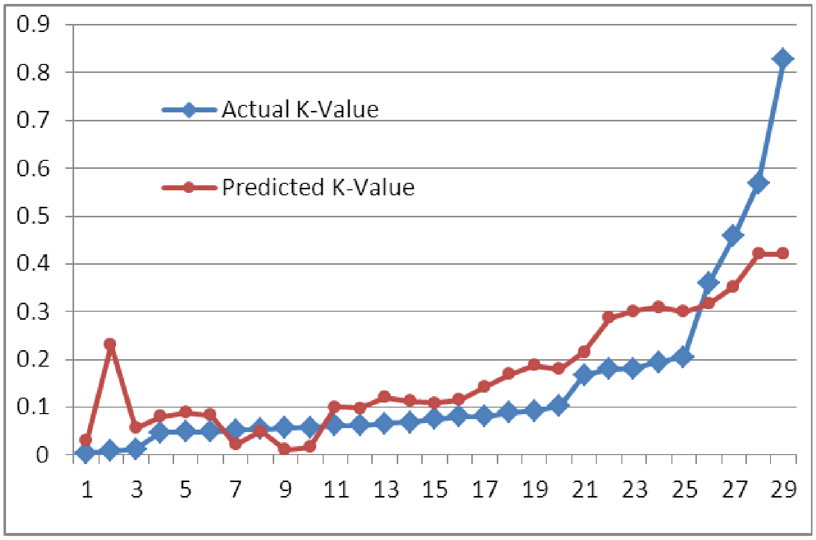

FIGURE 20: Comparison of Predicted K-value and actual K-Value

3.2.7 Prediction of UCS USING, OMC, Modified Liquid Limit and DCP

A relation of MDD, OMC, modified liquid limit and DCP with UCS is represented by equation as shown by Equation No.-17

A plot of Comparison of Predicted UCS and actual UCS in FIGURE 21.

UCS = 6.904701568·10-1 MDD - 1.146947823·10-2 OMC - 1.704888589·10-2 MLL + 0.299916777 DCP - 12.61710035 --------------- (17)

Residual Sum of Squares: rss = 1.078697188

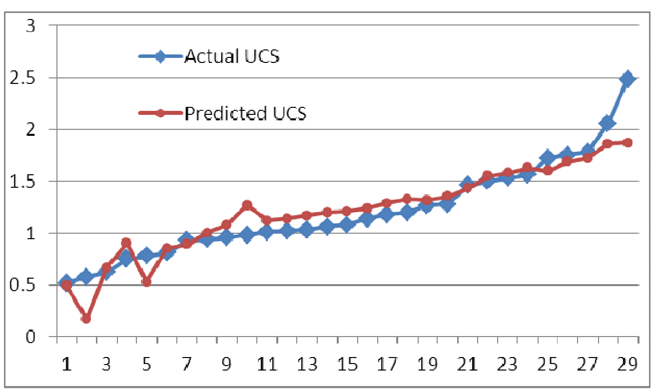

FIGURE 21: Comparison of Predicted UCS and actual UCS

4. CONCLUSION

The above experimental analysis was carried out to develop the co relations between various tests like MDD, K_{PBT}.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 from the results of very fast and easier DCP test. Based on experimental results the following conclusions are drawn. In short we can say that the relations between MDD, K_{PBT},UCS, CBR with DCP results are in form of $y = ax^b$, where y denote the values of MDD, K_{PBT}, UCS and CBR and x represent the DCP results, a & b are constant.

a) With increase in Maximum Dry Density of soil, Penetration resistance observations from DCP decrease.
b) California Bearing Ratio Test results and Penetration resistance observations from DCP test shows that CBR-value increase with decrease in DCP values.
c) Results of Coefficient of sugrade reaction K-value from Plate bearing Test and Penetration resistance observations from DCP test shows that K-value increase with decrease in DCP values.
d) Results of Unconfined Compression Test and Penetration resistance observations from DCP test shows that UCS increases with decrease in DCP values.
e) Results of DCP decreases as modified liquid limit increases.

5. REFERENCES

[1] Harison, J.R. (1983). “Correlation between CBR and DCP strength Measurements of Soils,” Proc. Institution of Civil Engineers London, Part-2.

[2] Harison, J.R. (1987). “Correlation between California Bearing Ratio and Dynamic Cone Penetrometer Strength Measurement of Soils,” Proc. Institution of CivilEngineers, London, Part-2, pp. 83-87.

[3] IS: 2720 (Part-3, Section-1)-1980, Methods of Test ForSoils: 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.

[12] Kleyn, E.G., (1975),” The Use of the Dynamic Cone Penetrometer (DCP),” Rep. No.-2/74. Transval Roads Department, South Africa.

[13] Kleyn, E.G., and Savage, P.E.(1982). “The Application of the Pavement DCP to Determine the Bearing Properties and Performance of the Road Pavements,” International Symposium on Bearing Capacity of Roads and Airfields, Trodheim, Norway.

[14] Livneh, M. (1987). “Validation of Correlation between a Number of Penetration Test and In situ California Bearing Ratio Tests, “Transp. Res. Rec. 1219. Transportation Research Board, Washington, D.C., pp. 56-67.

[15] Livneh, M. (200). “Friction Correction Equation for the Dynamic Cone Pentrometer in Subsoil Strength Testing” Paper Presented at the 79th Transportation Research Board Annual Meeting, Washington, D.C.

[16] Livneh, M., and Ishai, I. (1988). “The Relationship between In situ CBR Test and the Various Penetration Tests.” Proc. First Int. Conf. On Penetration Testing, Orlando, Fl, pp.445-452.

[17] Livneh, M., and Livneh, N.A. (1994). “Subgrade Strength Evaluation with the Extended Dynamic Cone Penetrometer,” Proc. 7th Int. IAEG Congress.

[18] P. Vinod and Reena Cletus, “Prediction of CBR value of lateritic soils using liquid limit and gradation characteristics data”

[19] Rodrigo Salgadi., Sungmin Yoon., (2003). “Final Report on Dynamic Cone Penetration test (DCPT) for Subgrade assessment.

[20] TalalAo-Referal., & Al Suhaibani., (1996). “Predication of CBR using Dynamic Cone Penetrometer”.

[21] Varghese George, Ch. Nageshwar Rao, and R. Shivashankar.(2009) “A laboratory investigation on evaluation of lateritic subgrade using PFWD, and CBR, and their correlations”