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PREDICTION OF CBR USING DCP FOR LOCAL SUBGRADE MATERIALS

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DCPI	Dynamic Cone Penetrometer Index
DSCBR	Disturbed Soaked CBR
DUCBR	Disturbed Unsoaked CBR
FDD	Field Dry Density
IDOT	Illinois Department of Transportation
LL	Liquid Limit
Log	Logarithm base 10
MDD	Maximum Dry Density
NMC	Natural Moisture Content
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
R^2	Coefficient of determination
SCBR	Soaked CBR
TRL	Transport Research Laboratory
UCBR	Unsoaked CBR
UUCBR	Undisturbed Unsoaked CBR

Contents

ABSTRACT

There is lack of correlation between Dynamic Cone Penetrometer (DCP) and Soaked California Bearing Ratio (CBR) for local subgrade materials. The aim of this study is to develop relationships between DCP and soaked CBR, DCP and unsoaked CBR, soaked CBR and unsoaked CBR for fine and coarse grained soils.

This paper presents relationships between DCP and CBR for local Subgrade materials. The relationship developed in this research considers subgrade material's behavior and largely saves time and cost of preliminary and detailed engineering works of road projects. A series of DCP tests in the field, soaked CBR at OMC, and unsoaked CBR at field conditions in the laboratory are conducted. Based on the field and laboratory test results relationships between soaked CBR and DCP, unsoaked CBR and DCP, and soaked CBR and unsoaked CBR are established for fine and coarse grained soils.

The relationship developed between DCP and CBR value for fine grained soil shows better than that of for coarse grained soil.

Keywords: Dynamic Cone Penetrometer, Soaked CBR, Unsoaked CBR

1. INTRODUCTION

In civil engineering the investigation of subgrade materials for pavement design works become necessary to optimize structural safety and economy aspects of the road infrastructures. One of the activities during the site investigation is determination of subgrade material strength with different in-situ and laboratory tests such as the Dynamic Cone Penetrometer (DCP) test and the California Bearing Ratio (CBR) test.

California Bearing Ratio (CBR) is a parameter that measures the strength of road soils and used asan integral part of pavement design. This test involves sampling, transporting, preparing, compacting, soaking, and penetrating with a plunger of CBR machine to measure the soil resistance. As it needs much time to have the end result and it cannot be easily determined in the field, civil engineers always encounter difficulties in obtaining representative CBR values for design of pavements.Whereas conducting DCP test including its analysis and interpretation takes a very short time. DCP is also multi-advantageous equipment used to evaluate the in-situ strength of subgrade soil materials for road pavement works at shallow depths [1, 2, 3, 4, 5].

Therefore,predicting CBR value from DCP test and exploiting itduring performance evaluation ofpavement layers makesbetteroptionthan usingcostly and time intensive procedures. The intention of this research is to establish a relationshipbetween CBR and DCPwhich helps to predict CBR value from DCP test result that suits for the localsubgrade materials.

The aim of this research is to develop relationships between DCP and laboratory determined CBR for local subgrade materials.

- To develop relationshipsthat predictsCBR value from DCPI for localsubgrade materials both in a soaked and in an unsoaked condition.
- To compare relationships of DCP and CBR developed for coarse grained soils and fine grained soils separately.
- To enhancethe level of confidence of the DCP usage for locally used subgrade CBR determination.

2. LITERATURE REVIEW

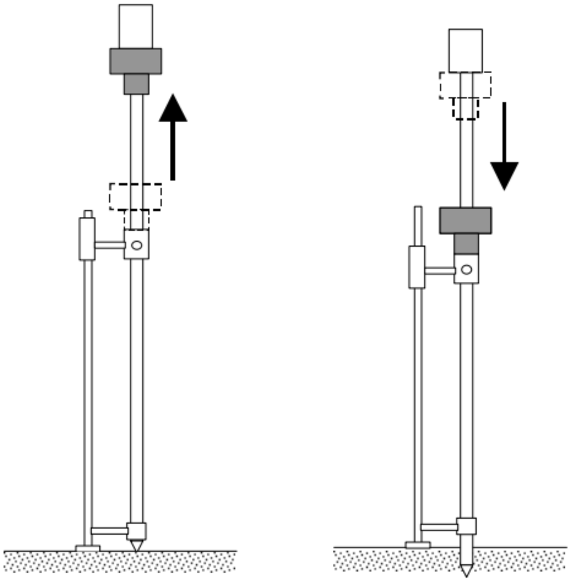
2.1. Description of Dynamic Cone Penetrometer

The Dynamic Cone Penetrometer (DCP) which is also known as the Scala penetrometer with a 9kg hammer, 508mm fall distance and 30° cone was first introduced in Australia by Scala in 1956 to assess the strength of subgrade and then during the early 1970's DCP with a 8kg hammer, 575mm fall distance and 60° cone was standardized again by Scala in South Africa [6, 7]

DCP test results consist of number of blow counts versus penetration depth. Since the recorded blow counts are cumulative values, results of DCP test in general are given as incremental values defined as follows [8],

$$DCPI = \frac{\Delta D_P}{\Delta BC} \quad \text{.......... Equation 1}$$

WhereDCPI = Dynamic Cone Petrometer Index in units of length divided by blow count; ΔD_p = penetration depth; ΔBC = Blow Counts corresponding to penetration depth ΔDp.



(a) Before hammer dropping (b) After hammer dropping

Figure 2-1 Dynamic Cone Penetrometer Test [2, 8]

2.2. California Bearing Ratio (CBR)

The California Bearing Ratio test (CBR), whichwas first developed during the early 1930's, is a penetration test,wherein a standard piston, having an area of 1935mm^2, is used to penetrate the soil at a standard rate of 1.27mmper minute. The pressure at each 2.54mmpenetration up to 5.08mmis recorded and its ratio to the bearing value of a standard crushed rock is termed as the CBR. The standard values of a high-quality crushed rock are as follows:

Table 2-1 Penetration versus standard load values [2, 10]

Penetration, mm	Pressure, MPa
2.54	6.9
5.08	10.4

The CBR is defined as

$$\text{CBR}(\%) = \frac{\text{Test Unit Load}}{\text{Standard Unit Load}} \times 100 \qquad \text{Equation 2}$$

Figure 2-2CBR testing Machine

2.3. Relationships between DCP Index and CBR Value

Salgado [8]has mentioned that the power model (or log-log equation) has been used by different authors for the relationship between the DCPI and CBR andHarison [11] hasconcluded that the log-log equation produces reliable results.

Farshad [4], Ferede [12], and Ehsan [13] also mentioned that most of the relationships developed between DCP and CBRare based on the best fit log-log equation having the form:

$$\log(CBR) = A + B\log(DCPI) \qquad \text{Equation 3}$$

Where

CBR = California Bearing Ratio in percent

DCPI = DCP penetration resistance or penetration index in units of mm per blow

A and B are regressionconstantsfor therelationship

Table 2-2Relationships developedbetween CBR and DCPI by different authors [2, 4, 8, 12]

Correlation Equation	Soil type	Reference
$\log(CBR) = 2.81-1.32\log(DCPI)$	all	Harison (1989)
$\log(CBR) = 2.20-0.71(\log DCPI)^{1.5}$	all	Livneh (1987)
$\log CBR = 2.465-1.12\log(DCPI)$ or $CBR = 292/ DCPI^{1.12}$	all	U.S. Army Corps of Engineers (1992)
$\log(CBR) = 2.48-1.057\log(DCPI)$	all	TRL
$\log(CBR) = 2.954-1.496\log(DCPI)$ $(R2 = 0.943)$	Clay unsoaked	Yitagesu(2012)
$\log(CBR) = 2.222-0.576\log(DCPI)$	cohesive	TRL 1986
$\log(CBR) = 0.84-1.26\log(DCPI)$	all	IDOT 1997

Karunaprema and Edirisinghe [14, 15] have made investigation on the different conditions of CBR as show in *table2-3* and made discussions on the different models usedfor the statistical analysis of their research data and on the values of R^2 which is explained as the coefficient of determination that measures the goodness of fit. It ranges from 0 to 1. If R^2 is greater than 0.5, the determination is considered as acceptable. Moreover Mendenhall, Beaver and Beaver [16] strengthen that regression analyses result with a coefficient of determination $R^2 = 0.705$, or 70.5%, is substantial. The regression model is working very well.

Table 2-3 Summary of statistical analysis [14]

Correlation	Model	Equation	MSE	R^2
DCP/ DUCBR	Linear	CBR= -0.394DCP+21.81	20.200	0.55
	Logarithmic	CBR = -10.249Ln(DCP)+43.514	14..900	0.67
	Exponential	$CBR = 24.882e^{-0.0352DCP}$	0.127	0.61
	Power	Log CBR = 2.182-0.872LogDCP	0.020	0.68
DCP/ UUCBR	Linear	CBR = -0.046DCP+6.245	0.970	0.48
	Logarithmic	CBR = -1.641Ln(DCP)+10.18	0.695	0.63
	Exponential	$CBR = 6.317e^{-0.0098DCP}$	0.402	0.50
	Power	Log CBR = 1.145 - 0.336LogDCP	0.055	0.61
DCP/ DSCBR	Linear	CBR = -0.132 DCP12.17	3.890	0.39
	Logarithmic	CBR = -4.983Ln(DCP) + 24.18	7.500	0.61
	Exponential	$CBR = 12.014e^{-0.0162DCP}$	0.139	0.45
	Power	Log CBR = 1.671-0.557LogDCP	0.018	0.62

2.4. Relative Advantages and Disadvantages of DCP and CBR Tests

Table 2-4 Relative advantages and disadvantages of DCP and CBR tests [4, 13, 14]

CBR Test		DCP test	
Advantages	Disadvantages	Advantages	Disadvantages
• Wide acceptance as a	• Laborious • Slow • Expensive	• Portable, light weight, durable,easy to use • Relatively inexpensive, fast,	• Nomethod to measure soaked DCP

CBR Test		DCP test	
Advantages	Disadvantages	Advantages	Disadvantages
measure of strength • Many Pavement design and analysis procedures are based on CBR value • Soaked condition can be measured	• Layer differentiation is not possible • Nota fundamental soil property • Limitation on maximum aggregate size • Needs annual calibration • Conservative factor of safety	• Non-destructive test • Possible to obtain thickness • Widerange of material types • Characterizes the in-situ strength with depth • Verifies uniformity of compaction • Maintenance is simple • Does not need annual calibration • Not nuclear and not rocket science • Does not need electricity	• Nota fundamental soil property • Questionable for larger than 50mm diameter • Affected by skin friction • Extraction problem after deep test • Manual reading causes some errors

3. RESEARCH METHODOLOGY

3.1. Testing Program&Data Source

This research consists of field, laboratory testing, and analysis of the results. Thus, it is important to have a clear program of testingand the sequence of activities, input factors these influence outputs as in *figure 3-1*. At the selected test pits, both the DCP and in-situ test were performed.Soil samples from the selected test pits were also obtained for the laboratory testing.

The data used throughout this study is primary data which is collected from primary source and that is the investigator itself collects the data. This primary data is obtained by conducting field and laboratory experiments following standard test methods.

3.2. Location of study& Excavation

The site of research is located at Mekelle, Tigray, Ethiopia in between the stretch Elala River to Kelamino secondary school, 0+000 to 16+700 km, along the stretch of Mekelle-Dengolat-Samre-Finarwa route.

The excavation was done for a depth of 0.8 to 1.5 m for all soils as per their existing level of natural soil. As the research site is located in a town section there was great depth of soil deposits which does not represent the local subgrade material.

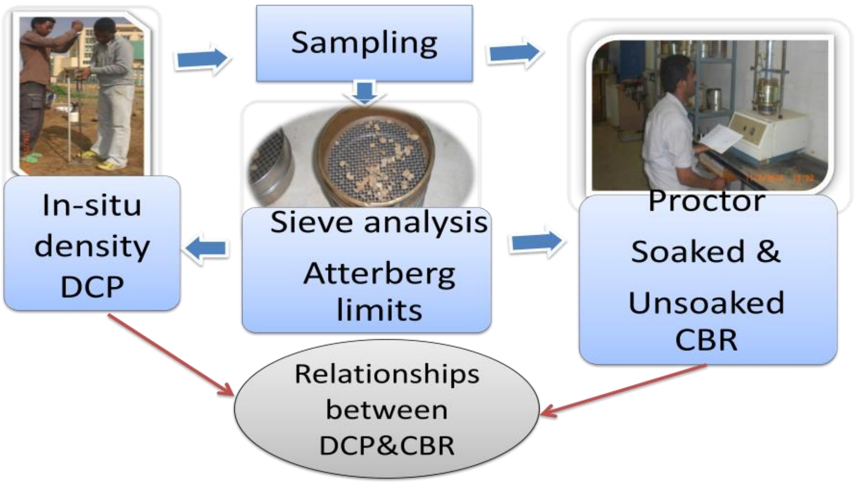


Figure 3-1Testing program

4. TESTRESULTS, ANALYSIS AND DISCUSSION

Here, only results of tests conducted during the wet season are presented due to limitation of paper size even though the research has been conducted for both the wet and dry season.

4.1. Field Density

The dry density and the natural moisture content of the soil are conducted at field.The results of these tests were used as input parameters to prepare the specimen of unsoaked CBR test to simulate the field conditions in the laboratory.

Table 4-1 Field density test results

Code	FG15	CG4
NMC, %	19.05	11.07
FDD), g/cm^3	1.731	2.209

Table 4-1 presents outputs of the field dry density and natural moisture content of soils. The results show that the moisture content of fine grained soils is greater than the coarse grained soils. This may be because of the more moisture holding capacity of finegrained than coarse grained soils.

Thus, it can be generalized that moisture contents of fine grained is greater than moisture contents of coarse grained soils where as their density is the reverse. Hence the relationship of natural moisture content and field dry density is inversely proportional. For instance the sample with higher moisture content has less dry density and vice versa.

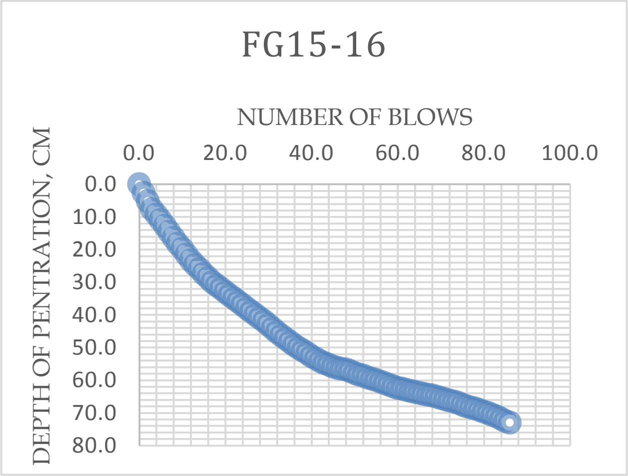
a. Excavate a test hole

b. Pour the sand to the hole

Figure 4-1Field density test

4.2. Dynamic Cone Penetrometer

Dynamic Cone Penetrometeris one of the field tests conducted at in-situ to measure the strength of the soil. During conducting this test the penetration depth versus corresponding number of blow were collected, recorded and analyzed. The ratio of these two values gives the rate of resistance in mm per blow. Corrections against operators, moisture content, and grain size and over burden pressure in conducting DCP have not been applied. The DCPI obtained from thisstudy is used to develop a relationship with CBR value.



Slope	x	y	mm/blow
	44.00	580.00	13.2

Figure 4-2Chart of DCPI for FG15-16

The graph drawn for FG15-16 shows two layers. The slope of the first layer is considered as the DCPI value as it is the location from where the sample for CBR test is taken. Accordingly the DCPI value computed for the layer considered is 13.2mm/blow.

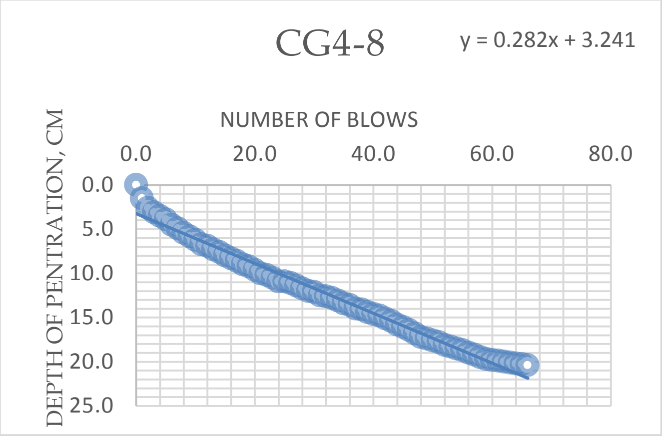


Figure 4-3Chart of DCPI CG4-8

The slope of the data is the DCPI in mm per blow. The value computed for CG4-8 is 2.82mm/blow.

It can be concluded that coarse grained soils have more resistance than fine grained soils as 13.2mm/blow is greater than 2.82mm/blow.

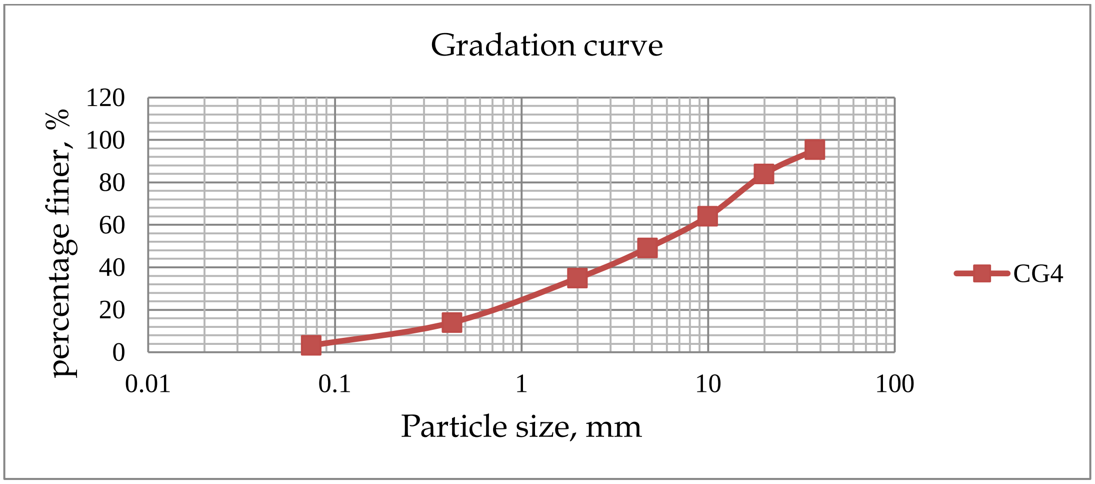
Figure 4-4DCP test

4.3. Particle Size Distribution

The objective of particle size distribution is to determine the percentage of soils passing different sieve opening sizes. In this study, this determination is used for classification purpose and for overall engineering characteristics indication. Two kinds of tests were conducted in this research. These are wet sieve and dry sieve.Wet sieve was conducted for cohesive soils to disintegrate sticky soil particles into their original particle size by soaking and washing in water and sieving the retained portion mechanically,whereas dry sieve was carried out for non-cohesive soils using a mechanical sieve. The test is conducted as per AASHTO T88.

Table 4-2Results of sieve analysis

Sieve size, mm		37.5	20	10	4.75	2.00	0.425	0.075	Method of sieve
% passing	FG15				92.0	88.8	82.5	76.0	Wet
	CG4	92.3	67.7	48.7	37.3	28.1	11.3	1.4	Dry



Percent passing No.200 (75µm)for soil FG15 is greater than 35% as shown in *table 4-2* which in turn imply that this soilis categorized as fine grained soil (Silt-Clay material) according to AASHTO M145. However; Percent passing No.200 (75µm) for soils CG4 is less than 35% which in turn imply that this soilis categorized as coarse grained soil (granular material) according to AASHTO M145.The percent passing of each test is not only used to categorize soil as coarse and fine grained but it also helps to determine the soil class together with the Atterberg limits.

a. Sample collection b. Set of sieves

Figure 4-5 Sample collection and sieve analysis test

4.4. Atterberg Limits

The purpose of conducting Atterberg limit test is to know the plasticity property of a soil passing the No. 40 (425 μm) sieve with varying degrees of moisture content. In this study, it is found important to carry out Atterberg limits as these are helpful as input index parameters to make the soil classification together with the particle size distribution results as applied in *table 4-4.*The basic limits needed for this research are the liquid limit and the plastic limit.

In this research, two kinds of methods were used to carry out liquid limit. These are casagrande method and cone penetrometermethod. The former one is a method which uses the casagrande device with a grooving tool that is adopted for cohesive soils having clayey nature whereas the later one is a method which has penetrating cone and cup that is generally adopted for less cohesive or non-cohesivegranular materials. The liquid limit test is conducted as per AASHTO T 89 whereas the plastic limit test is conducted as per AASHTO T 90.

Table 4-3Atterberg limit test results and corresponding flow curves

Code	FG15	CG4
LL, %	42.8	28.5
PL, %	25	NP
PI, %	17.8	NP

The result indicate that coarse grained soil has less liquid limit and less plasticity index than fine grained soil. Moreover it is observed that the coarse grained soil has no plastic limit.

a. mixing the sample paste

b. Grooving paste into two portion

c. Cone penetrometer

d. Rolling a soil thread for plastic limit

Figure 4-6 Atterberg limit test

4.5. Soil Classification

According to AASHTO Standard M145, the classification of the soil samples is carried out as shown in*table 4-4*. This classification process result tells the researcher or reader:

1. Whether the soil under consideration is categorized as coarse grained or fine grained soil by seeing on the percent passing.
2. The degree of plasticity of the soil, as it is one basic index property of the soil.
3. The type of the soil class, as each soil class has unique engineering property and applicability.

Table 4-4 Soil classification according to AASHTO M 145

Code	% passing	% passing	% passing No.	LL,	PI,	Soil

	No. 10 sieve	No. 40 sieve	200 sieve	%	%	Class
CG4	28.1	11.3	1.4	28.5	NP	A-1-a
FG15	88.8	82.5	76	42.8	17.8	A-7-6

The soil classification result performed in table 4-4explains that A-1-a is coarse grained soil whereas A-7-6 is fine grained soil. Such kind of classification helps to provide information in which group symbol the soil lies. Besides this, these group symbols inform the quality of the soil which and where to use as a highway material.

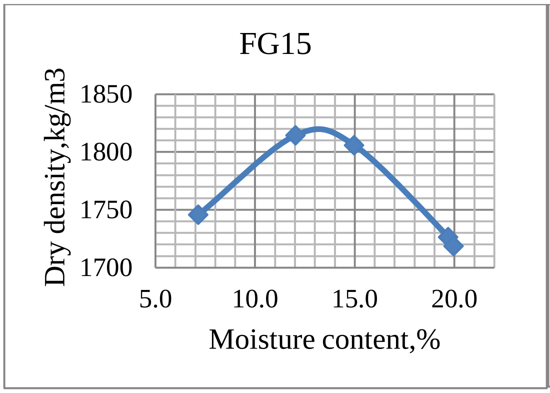
4.6. Modified ProctorTest

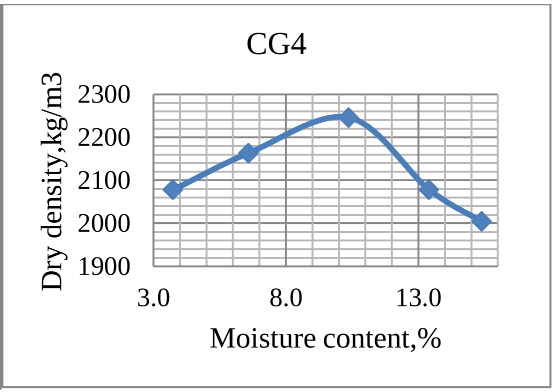
Modified proctor test were conducted for the soils under consideration to determine the maximum dry density and optimum moisture content of the soils. The optimum moisture content is the moisture content corresponding to the maximum dry density of soils obtained from the compaction curve. The optimum moisture content obtained from this compaction test is used as input datato prepare the CBR specimen to be tested for the soaked condition CBR determination.

Table 4-5 Modified proctor test results

Code	FG15	CG4
MDD,kg/m^3	1820	2250
OMC, %	13	10

Here from *table 4-5*, it can be generalized that the coarse gained soil has higher MDD and lower OMC than the finegrained soil sample.The purpose of drawing the compaction curves shown below is to show the peak of the curve of moisure-density relationship and to extract MDD and OMC values from it.





4.7. California Bearing Ratio

The CBR data is important variable to make relationship with the DCP data.

From CBR data analysis, it has been observed that the ranges of CBR values for fine grained soils is from 4% to 11% and for coarse grained from 11% to 66%. Thus, it can be generalized that better resistance strength is expected from coarse grained soils than fine grained soils for both soaked and unsoaked conditions.

One thing is observed and found from the soaked CBR results is that the CBR values for FG15-16 is by far lower in the bottom penetration than in the top penetration which is not usually and logically expected. This phenomenon has happened only during the soaked condition due to the swelling nature of the soil. Such soils have the property to swellwhen soaked in water and push the surcharge up which bears an increment about 6-12mm or 5-10 % in height of the soil specimen. This increased extra height is not confined and does not resist during compression and in turn it has an impact and contributes a reduction in CBR value on the bottom penetration when tested upside down.

a. CBR Molds

b. CBR Molds

c. Surcharge loads and spacer

d. Surcharge loads and spacer

Figure 4-7 CBR test apparatuses and procedures

4.8. Summary of Test Results

Table 4-6Summaryfor SCBR, UCBR and DCPI

Fine grained				Coarse grained			
Code	SCBR %	UCBR %	DCPI mm/blow	Code	SCBR %	UCBR %	DCPI mm/blow
FG15-1	10.0	4.7	13.19	CG4-1	76.8	32.2	2.55
FG15-2	12.8	5.7	10.29	CG4-2	47.3	14.8	3.96
FG15-3	12.0	6.3	10.48	CG4-3	58.1	25.0	3.29
FG15-4	9.1	4.2	14.23	CG4-4	88.0	37.2	2.33
FG15-5	11.1	4.9	12.22	CG4-5	50.1	24.5	3.50
FG15-6	11.0	5.1	11.68	CG4-6	38.4	14.0	4.44
FG15-7	8.5	4.1	15	CG4-7	81.2	32.0	2.36
FG15-8	8.4	3.8	15.2	CG4-8	65.6	30.0	2.82

FG15-9	10.6	4.8	13.55	CG4-9	88.9	36.2	2.35
FG15-10	11.1	5.2	11.2	CG4-10	69.3	25.2	2.71
FG15-11	13.7	5.6	9.25	CG4-11	90.5	32.9	2.26
FG15-12	11.5	5.8	10.43	CG4-12	82.7	33.3	2.47
FG15-13	13.8	6.7	9.15	CG4-13	43.7	16.0	4.21
FG15-14	15.4	6.4	8.87	CG4-14	99.1	64.4	1.36
FG15-15	16.0	6.7	8.1	CG4-15	76.7	34.6	1.8
FG15-16	11.2	4.7	13.18	CG4-16	52.8	23.0	3.45
FG15-17	13.9	6.7	9.14				
FG15-18	13.6	7.0	8.86				

Based on the results found in *tables 4-6* above, it can be discussed the following basic findings. These findings are observed from the summary results of Soaked CBR, Unsoaked CBR and DCPI for all types of soils separately and/or in combination.

From resultspresented in *table 4-6*, it can be concluded that the CBR values, in percent, of the soaked condition are greater than that of the unsoaked condition in both fine and coarse grained cases. This greatness is attained because of the greater density (MDD) and optimum moisture content (OMC) despite the simulation of the worst condition. Regarding the DCPI, it can be concluded that the DCPI, in mm per blow, of each sample of fine grained soils is greater in magnitude than that of coarse grained soils. This in turn implies that the coarse grained soils are more resistant than fine grained soils due to their unit weight and availability of water voids.

Thus, it can be concluded that the type of sampling, method of sampling, the soil grain particles, density, moisture content and of course in general type of soil matters to get the intended result because these factorscan affect the level of consistency of test results to make conclusion.

4.9. Regression Analysis and Discussion

The regression analysis tool performs linear regression analysis as it is a statistical technique for modeling and exploring relationships between two or more variables. The linear regression has a best-fitting line for the bivariate observations in the form of:

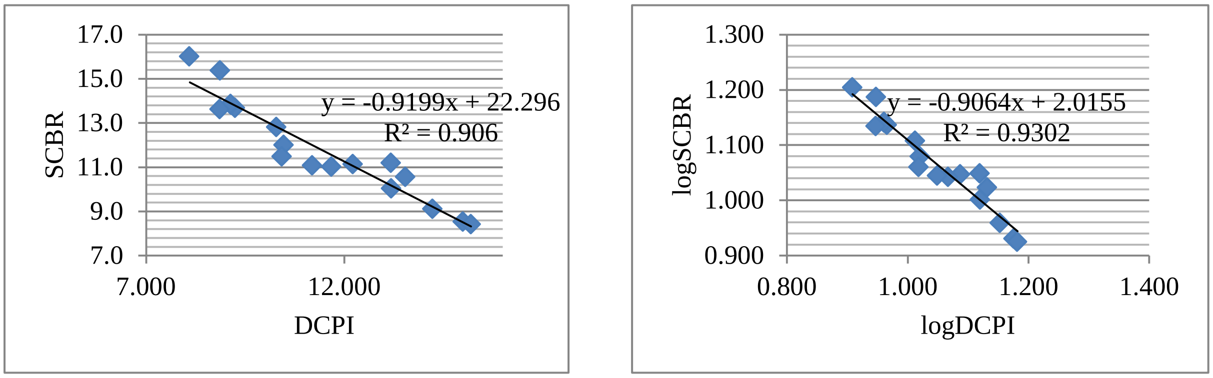
$$y = a + bx$$ ……..……………………………..Equation 4

Where y= the response variable, x= the predictor variable, a, and b are coefficient letters, a stands for the y-intercept and b stands for the slope.

The regression analyses carried out in tables below under subsection *4.9.1* are done using a customized excel analysis toolpak. This excel analysis toolpak is very helpful to find the regression coefficient values and corresponding coefficient of determination (R^2). Results of regression analysis for each case are displayed and summarized as shown in following scatter plots and summary tables. Coefficient of determinations of the log-log (power) model in *table 4-7*show better relationship strength than linear model in same model as R^2=0.9302 in plot b is greater than R^2=0.906 in plot a, R^2=0.9017 in plot d is greater than R^2=0.8974 in plot c, R^2=0.847 in plot f is greater than R^2=0.8038 in plot e.Thisagrees with literature reviewed under *section 2.3*.

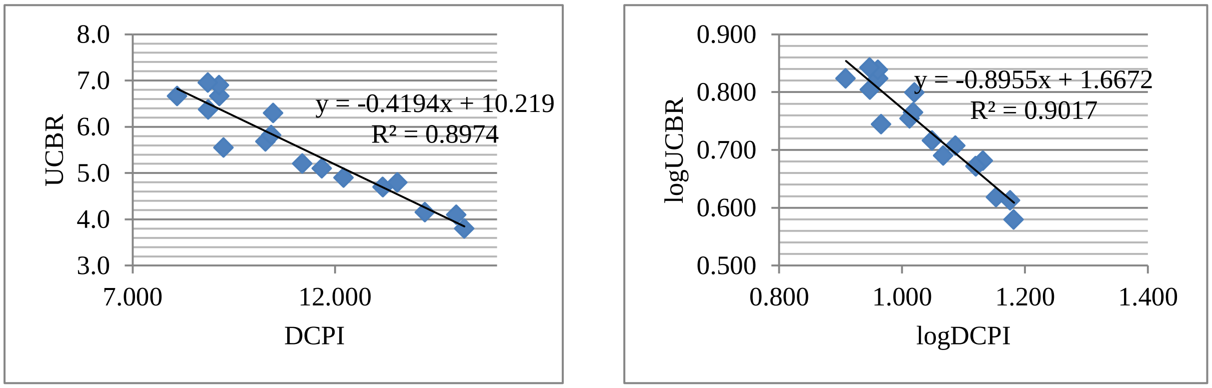
Summary outputs of the regression analysis comprise the regression statistic and ANOVA results. In the regression statistic the R-square and adjusted R-square are important to conclude the strength of relationship between two variables. In addition to this the ANOVA displays the regression coefficient values which are the major outputs of this study and the p-value which checks the normality distribution and significance of data used in the analysis. Here for any p-value less than significance level α = 0.05 implies data under usage is statistically significant and normally distributed.

Table 4-7Regression analysis for fine grained soils



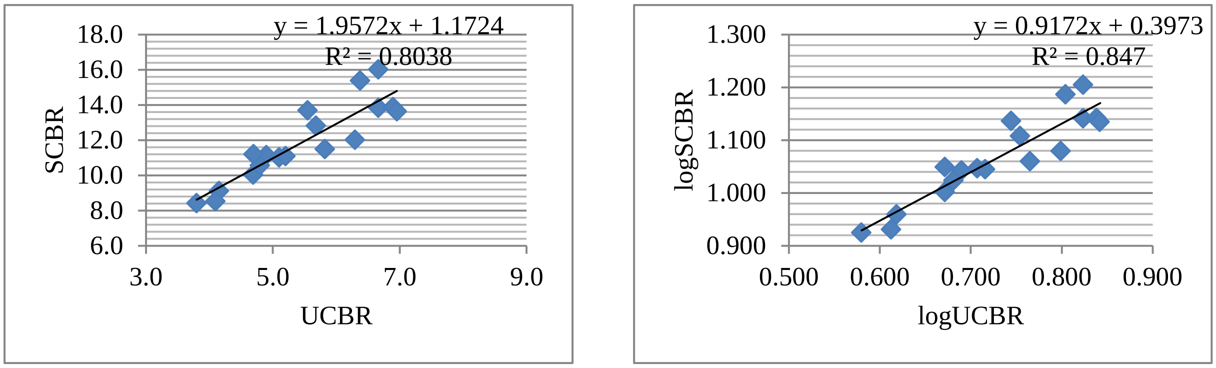
a. SCBR versus DCPI

b. logSCBR versus logDCPI



c. UCBR versus DCPI

d. logUCBR versus logDCPI



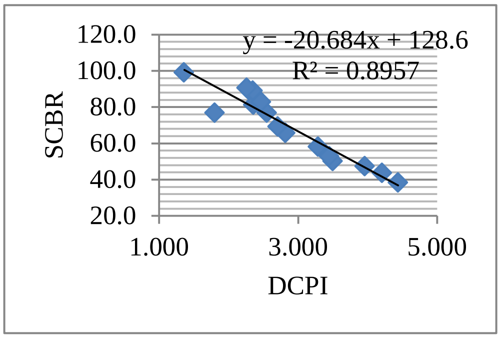
e. SCBR versus UCBR

f. logSCBR versus logUCBR

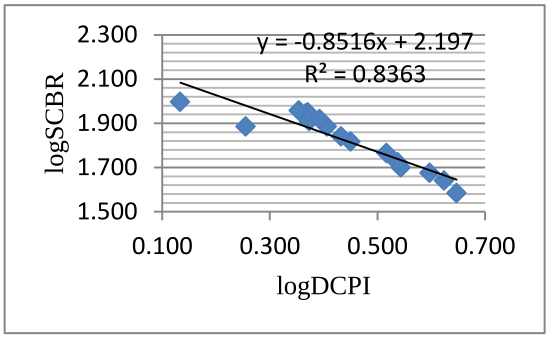
Table 4-8 Summaryregression analysis for fine grained soils

Correspondent functions	R-square	observations	Coefficient intercept(a)	Coefficient X variable 1 (b)	P-value
logSCBR versus logDCPI	0.930	18	2.015	-0.906	1.1E-10
logUCBR versus logDCPI	0.902	18	1.667	-0.895	1.8E-09
logSCBR versus logUCBR	0.847	18	0.397	0.917	6.3E-08

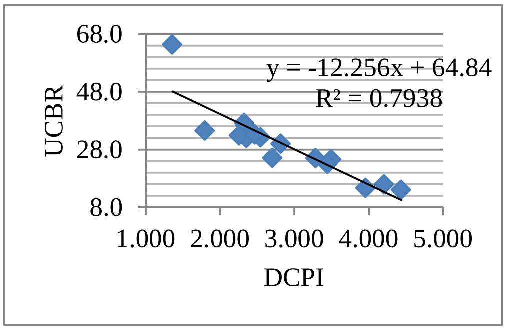
Table 4-9 Regression analysis for coarse grained soils



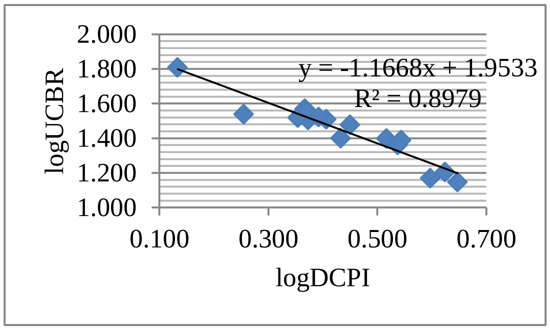
a. SCBR versus DCPI



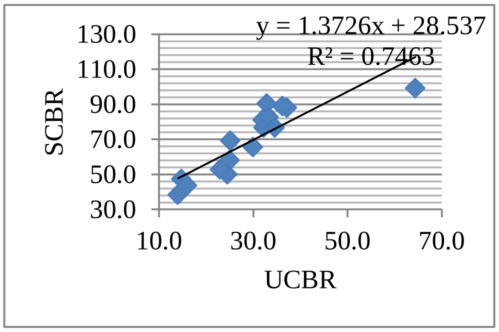
b. logSCBR versus logDCPI



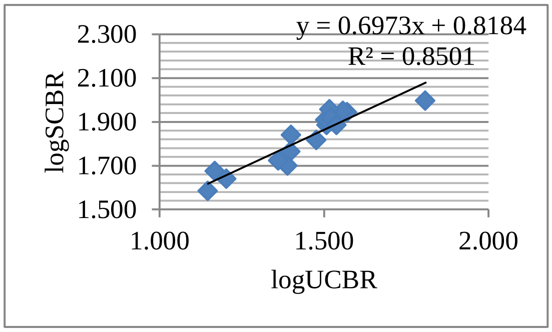
c. UCBR versus DCPI



d. logUCBR versus logDCPI



e. SCBR versus UCBR



f. logSCBR versus logDCPI

Table 4-10Summary regression analysis for coarse grained soils

Correspondent functions	R-square	observations	Coefficient intercept (a)	Coefficient X variable 1 (b)	P-value
logSCBR versus logDCPI	0.836	16	2.197	-0.852	7.1E-07
logUCBR versus logDCPI	0.898	16	1.953	-1.167	2.5E-08
logSCBR versus logUCBR	0.850	16	0.818	0.697	3.8E-07

In the tables under *tables 4-7*and *4-9*the coefficients of determinations (R^2) of the log-log form of analysis show that better relationship than the nonlog-log form. The summaries of the regression analysis in *tables 4-8* and *4-10*show that there is strong relationship between the correspondent functions as far as R^2 is greater than 0.5.

Table 4-11 Summaries of relationships

S.No.	Equation	R^2	Remark
	Fine grained soils (FG)		
1	$\log_{10}SCBR=2.015-0.906\log_{10}DCPI$	0.930	Strong relationship
2	$\log_{10}UCBR=1.6677-0.895\log_{10}DCPI$	0.902	Strong relationship
3	$\log_{10}SCBR=0.397+0.917\log_{10}UCBR$	0.847	Strong relationship
	Coarse grained soils (CG)		
4	$\log_{10}SCBR=2.197-0.852\log_{10}DCPI$	0.836	Strong relationship
5	$\log_{10}UCBR=1.953-1.167\log_{10}DCPI$	0.898	Strong relationship
6	$\log_{10}SCBR=0.818+0.697\log_{10}UCBR$	0.850	Strong relationship

From the above six relationships in *table4-11*, it can be concluded that the fine grained soils have stronger correlations than the coarse grained soils. This is because of that fine grained soils are less sensitive while exerting load up on them than coarse grained soils. In addition fine grained soils have closer moisture contents and densities as it is seen from the previous test results under section *4.1*.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From this study, following conclusions can be drawn:

- CBR test can be replaced by DCP test by developing such empirical formula which predicts CBR value from DCP test. Hence, it can be noted also that it is possible to predict CBR value which is used for road pavement design purpose from DCP test.
- The relationship developed between DCP and CBR value for fine grained soil shows better relationship than that of for coarse grained soil.
- Looking at the DCPI results and the R^2 of the developed relationships,DCPis more reliable for testing fine grained soils than coarse grained soils as the results indicate. Moreover, looking the overall working conditions DCP test is more effective and efficient than CBR test.That is DCP test is an easy, a low cost solution and time savingkind of test for road subgrade evaluation during soil investigation. DCP takes about ten minutes whereas CBR test needs more than ten thousand minutes.
- Finally, the subgrade CBR value determined from DCP using the above established relationships can be used for local soils since the result obtained from local soils shows substantial and strong relationships between CBR and DCP.

5.2. Recommendations

From this study, following recommendations can be drawn:

- In this study fine grained and coarse grained soils were considered, thus it will be better if future related research works are focused specifically on different kinds of soils such as sand soils, silty soils, clayey soils and expansive soils.
- It is possible to predict CBR from DCP by developing a relationship between them. And then DCP can be used to investigate soil strength of subgrade layer for our local materials.
- Thus, from practical point of view it is easierand feasible to use DCP to evaluate the subgrade strength characterization for road design purpose within short time and less cost than the CBR test.

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