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EVALUATION OF SUBGRADE CAPACITY OF JIMMA SOILS USING DCP TEST: A CORRELATION OF CBR AND DCPI

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Abstract: Subgrade strength of soils is usually evaluated using California Bearing Ratio (CBR) values. As the cost and time required to conduct CBR test are high, dynamic cone penetrometer (DCP) would be recommended and CBR value can be estimated later from DCP result using a correlation formula. In this paper, laboratory CBR of Jimma fine-grained soils has been correlated with field DCP values referring to the physical properties such as natural moisture content and field density; as these factors significantly influence the behaviour of subgrade soils. Different techniques were used to demonstrate relations that best suit to find values of CBR from DCP test. Equations were developed between CBR and dynamic cone penetrometer index (DCPI) for the total of 36 sample points and adjusted coefficient of determination becomes 0.84. A validation was also done to test the applicability of the developed correlation formula for the local soils with the given physical conditions. The correlation gave a promising relationship between CBR and DCP and can be applicable for preliminary design purpose with the due consideration of the locality circumstances.

Keywords: *Subgrade capacity, CBR, DCPI, correlation, moisture content, density*.

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1.0 Introduction

Before starting the construction of roads, a proper site investigation is mandatory as an input for the subsequent designs such as geometric design, pavement design and structural design. Hence, preliminary investigations are carried out at the design stage. This will lead to the need for another subgrade investigation during the final road construction phase. However, in doing so, geotechnical engineers find out that a high amount of money is invested through these stages. So that, they proposed to conduct simple and economical tests and find the remaining values from correlation equations. Among the tests, DCP can easily be correlated to different kinds of soil parameters. Dynamic cone penetrometer (DCP) has been used for determination of the soil strength parameters including, but not limited to, California bearing ratio (CBR), unconfined compressive strength (UCS) and plate loading test (Wang, 2001). The DCP is mainly studied and correlated for the application of pavement analysis and hence mainly correlated to CBR (Sahoo, 2009). Since the testing of CBR is relatively expensive and time taking, replacing this test with DCP will be ideal and cost effective. Furthermore, the repeatability of DCP is more than CBR hence more accurate result can be achieved. The DCP serves as an excellent tool for construction inspection; it has the ability to verify both the level and uniformity of compaction (Luo, 1998). DCP test can also be carried out for rehabilitation design of asphalt surfaced roads. To evaluate its viability, comparisons with various rehabilitation methods including the Asphalt Institute method, Mechanistic methods and standard references have been done. Thus, a low cost DCP survey can provide sufficient information to design appropriate overlays (Paige- Green, 2009).

For the reason that predictions using the DCP tests are subjected to considerable uncertainty. DCP tests need to be performed for compaction control in combination with other conventional test methods. These can be used to calibrate the DCP correlation for specific sites, reducing the uncertainty in the predictions. Site-specific correlations do appear to be of better quality (Saldrigo and Yoon, 2003). Al-Refeai and Al-Suhaibani (1997) mentioned that variability in DCPI on CBR data changes as the soil changes from fine-grained to granular. Livneh (2000) developed a method to accommodate the effect of uncertainty from skin friction forces on the DCP rod during testing in cohesive materials. Swenson *et al*. (2006) also found out that both moisture and density had a measurable effect on the modulus of fine-grained soils (Ehsan, 2011). The study was conducted in Jimma. It is located in South-West Ethiopia and the climatic condition is classified as warm to cold (sub-tropical) or locally called as “Weyna Dega” with high degree of humidity. The topography is predominantly flat and rolling terrain. It is mainly covered with black, gray and red colored plastic clay soils (Jemal, 2014).

The primary aim of this study is to evaluate subgrade strength of roads using DCP test and to develop a correlation between California Bearing Ratio (CBR) and Dynamic Cone Penetrometer Index (DCPI) values under consideration of locality field conditions.

1.1 Existing DCP-CBR Correlations:

Several authors have investigated relationships between the dynamic cone penetration index (DCPI) which is the amount of penetration depth per blow and CBR. Among them which were developed for fine-grained soils by different authors and institutions are presented as in Table 1.

Table 1: Existing Correlation between CBR and DCP

Existing Correlation	*Author*
$\log_{10}(CBR) = 2.63 – 1.28 \log_{10}(DCPI)$	Kleyn (1982), TRL(1992), ERA(2013)
$CBR = 1 / (0.002871 \times DCPI)$	Webster (1994)
$CBR = 247DCP^{-0.98}$	Zohrabi (2003)
$CBR = 24.903DCP^{-1.331}$	Patel (2012)

However, as these formulae are developed for the soils conducted in other countries, considering the erratic behavior of soils and other specific conditions. Hence, it would be inappropriate to use one formula for every other type of soils without modifications. Hence, due to these conditions, this study discusses the correlation of DCP with CBR and other factors which can affect their relation; thereby it would derive empirical equation for the particular case of Jimma fine-grained soils.

2.0 Field and Laboratory Tests Design

In the field, DCP field tests were conducted at different locations from the study area. The natural moisture contents and field densities were also measured in the lab to simulate the physical properties of the soils in their natural state. These factors affect the value of field DCP (Kleyn, 1982). Forty samples were systematically collected from fourteen sample pits at 1m and 2m depths according to ERA (2013) suggestion. The locations of sample pits which represent fine-grained soils of Jimma town are shown in Figure 1.

Sample locations were predominantly covered with red, black and grayish colour clay soils. The samples were then transported to the Geotechnical laboratory to conduct proctor compaction, lab DCP and lab CBR tests. Lab DCP was conducted on samples compacted with optimum moisture content (OMC). The study was done on fine-grained soils of the study section as DCP is highly recommended for fine-grained soils including sand soils than for gravel soils as it was suggested by Sahoo (2009), ERA (2013), Gebremariam (2016), Wilches (2018). For these recovered soil samples, one-point CBR test was carried out, on samples remoulded with OMC, 56 blows of standard proctor compaction and soaked for four days (AASHTO, 2004).

3.0 Test Results and Correlation Analysis

3.1 Test Results

The soils of Jimma town are classified as clay and silt having high degree of plasticity. The clay soils range from red to black color. Some soils are categorized as fair strength for subgrade of roads while the others are poor as per AASHTO criteria. Expansive and latertitic soils are also found to exist in this area (Jemal, 2014).

The DCP equipment used in this study has a hammer weight of 8kg and 576 mm falling height. The cone of the rod tip used was based on the 60° inclined angle. The studied soils are fine-grained clay soils, so that readings were taken after each number of blows as significant amount of penetrations was measured in each blow. Field and laboratory test results for this study are presented as in Table 2.

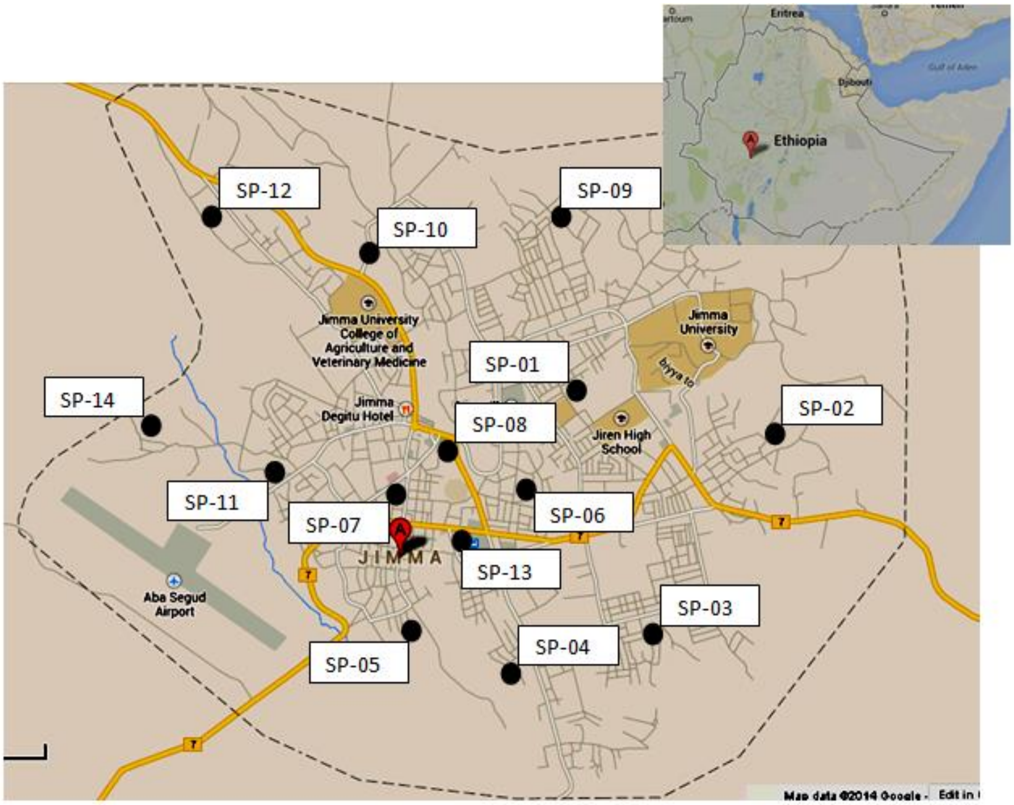

Figure 1: Map of sample pit (SP) locations of Jimma (Source of Map: Google @2014)

Table 2: Summary of test results of soils for N = 36 samples

Test type	*Range of values*
Field DCPI -mm/blow	28 – 92
Natural moisture content (NMC)- %	30 – 62
Field density – gm/cc	1.54 -1.86
Maximum dry density – gm/cc	1.23 – 1.58
Optimum moisture content (OMC)-%	30 – 38
Lab DCPI at OMC – mm/blow	27 – 61
Lab CBR -%	0.7 – 9.4
Classification as per Ethiopian Roads Authority (ERA-2013)	Very poor to fair strength

3.2 Statistical Analysis

3.2.1 Scatter plot

While developing correlations, the first step is creating a scatter plot of the data, to visually assess the strength and form of the relationship between dependent and independent variables. The graphs are plotted as shown in Figure 2, Figure 3, Figure 4 and Figure 5.

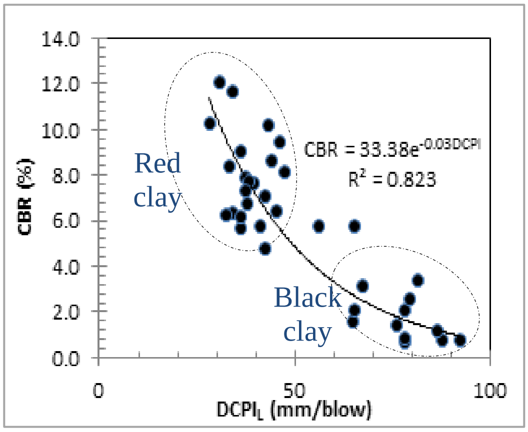

Figure 2: A plot of CBR vs. laboratory DCPI$_L$

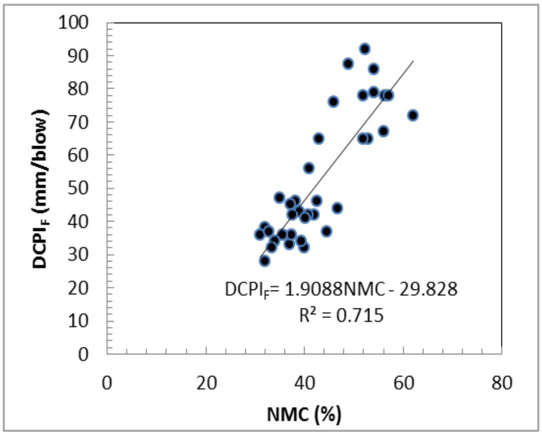

Figure 3: A plot of field DCPI$_F$ vs. natural moisture content (NMC)

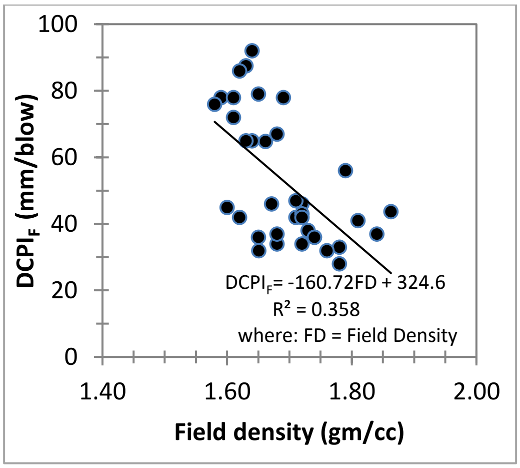

Figure 4: A plot of DCPI$_F$ vs. Field dry density

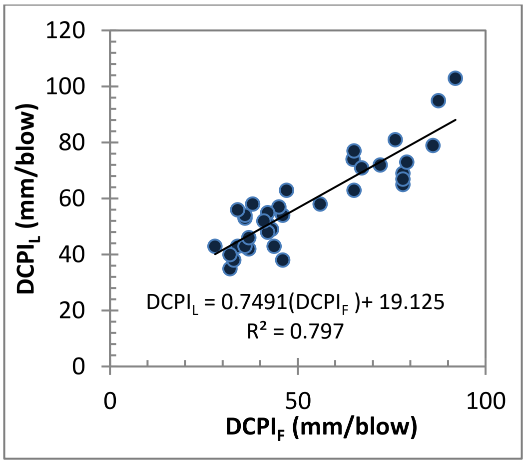

Figure 5: A plot of lab DCPIL vs. field DCPF

3.2.2 Matrix of Scatter Plot

The relationship between variables can be portrayed visually by using a scatter plot of SPSS statistical software. The plot shall include drawing a matrix of scatter plots of every independent variable against the dependent variables. The matrix scatter plot is presented as in Figure 6.

From the plot, one can see that different relationships are found between two variables. Between CBR versus lab DCPI, field DCPI versus NMC, field DCP versus field density; the plot shows that these parameters are fairly correlating one another in a non-linear relationship while CBR on NMC, CBR on OMC and DCP on OMC are poorly correlated. Before starting our multiple regression analysis, it is important to compute the correlation matrix. However, here the scatter plot matrix is used to check the correlation trends among different variables. It is only for the sake of convenience and presentation of the relations among variable parameters.

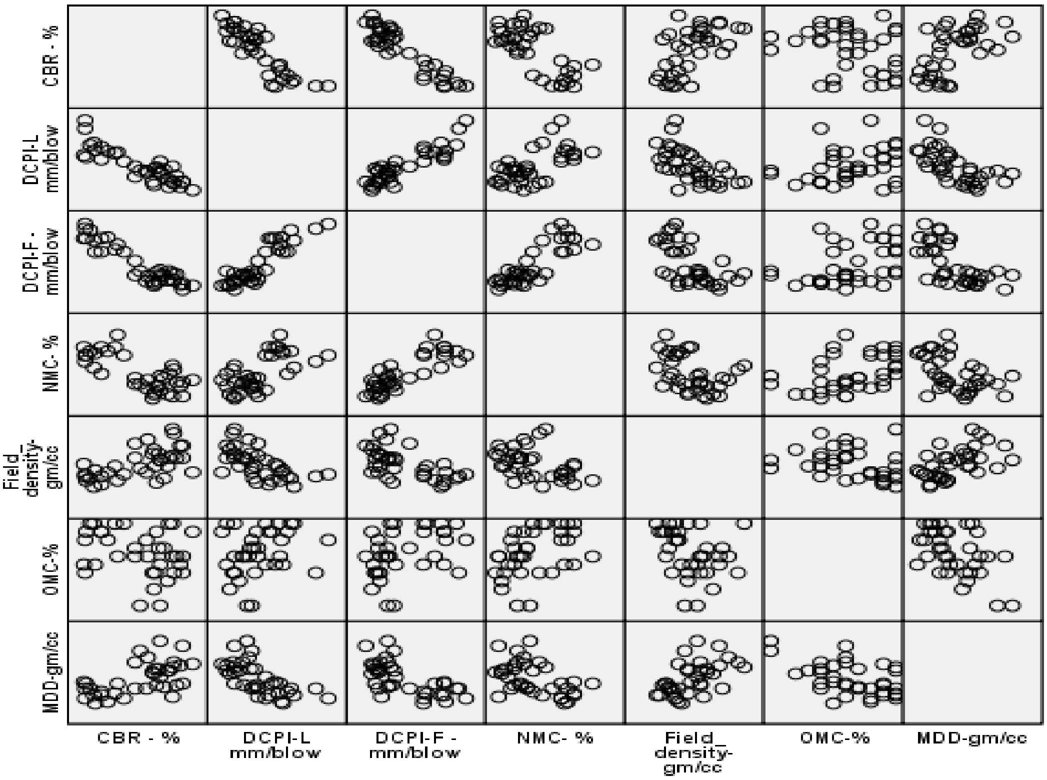

Figure 6: A Matrix of scatter plots for different input variables

3.3 Regression Analysis

3.3.1 Ordinary Regression

In this research work, an attempt is made to apply linear and non-linear regression model to find CBR from a lab DCPI values and other soil parameters using a statistical approach. Correlations are developed by emphasizing based on independent variables which have a direct influence on the dependent variables. These correlations are CBR with the lab DCPI, field DCPI with NMC, field DCPI with the field density and field DCPI with a lab DCPI. However, variables like natural moisture content and bulk density have great influence on DCPI of the field even though they don't have on CBR directly. In this scenario it is possible to incorporate the variables such as bulk density and natural moisture content on the field DCPI. Moreover, in this particular study, as NMC has more influence on DCP than field density (Eqn. 3) and (Eqn. 4). Hence, it can more logical and practical to consider the natural moisture content than field bulk density value as NMC significantly influence field DCPI.

The correlation formulas that are obtained from this study are presented as follows. The formulas are presented with their total number of sample size (N) used used in the regression, R-suared value (R^2) and significance level (sig.) in which how strong the dependent and the independent variables are statistically correlated.

- Correlation of CBR with laboratory DCPI is:

$$CBR=33.65*EXP^{(-0.038*DCPI\text{-}L)},\ N= 36,\ R^2 = 0.82,\ sig.< 0.05 \qquad (1)$$

- Correlation of field DCPI with natural moisture content (NMC) and field density (FD):

$$DCPI_F = 1.91NMC- 29.83,\ N = 36,\ R^2 = 0.72,\ sig. < 0.005 \qquad (2)$$

$$DCPI_F=-160.72FD + 324.56,\ N = 36,\ R^2 = 0.34,\ sig < 0.005 \qquad (3)$$

3.3.2 Two Stages Least Square Method

Two stages least square method provides consistent estimates for linear regression models with some explanatory variables correlated with instrumental variables. The name two stages least square method comes from the two regressions in the estimation process. In the first stage, an ordinary least square prediction of the explanatory term is obtained from regressing it on the instrumental variable. In stage two, the coefficient of interest are estimated using ordinary least square after substituting the instrumental variable by its prediction/or inclusion of residual from stage one (Douglas, 2003).

As the CBR tests were conducted in the laboratory one can correlate CBR with the field DCPI indirectly. This can be done first by correlating field DCPI with the laboratory DCPI, and eventually field DCPI can be correlated with the CBR as in (Eqn. 4) using two stage least square method (2SLS).

$$CBR = -0.139DCPI_F + 12.462, N= 36, R^2 = 0.84, sig. < 0.05 \quad (4)$$

It is also important to consider the effect of field conditions such as natural moisture content and field density to estimate the field DCPI. Becouse the field DCPI is ultimately influences the value of CBR. This is also done by employing two stages least square method as in (Eqn. 5).

$$CBR = -0.128DCPI_F + 11.87, N= 36, R^2 = 0.81, sig. < 0.05 \quad (5)$$

where, $DCPI_F = 1.63NMC – 78.25FD + 11.48$; $N= 36$, $R^2 = 0.76$, sig. < 0.05

In the ordinary least square method, since the effect of natural moisture content and bulk density do not significantly affect CBR values directly, both parameters were overlooked during the development of (Eqn. 4). However, since both parameters have a significant influence on DCPI-F values, a two stage regression, with the predictor substituted, was carried out. The result shows that CBR has a fair correlation with the predicted DCPI, natural moisture content (NMC) and field density (FD) by achieving adjusted coefficient of determination of 0.76 as in (Eqn.5).

4.0 Validation of CBR-DCPI Correlation and Discussion

Validation describes how good the newly developed correlation is able to predict CBR values from DCPI test results. In practical sense, it is usually aimed at contributing to the issue of the applicability of the Dynamic Cone penetration tests to evaluate subgrade and pavement performance in a number of important site investigations and pavement condition surveys (Livneh, 1987).

Hence, to validate the correlation equation developed, four additional samples were taken from the nearby sites in the study area. Field tests and laboratory tests were performed on these four extra samples for validation test. These values are not included while developing the correlation between CBR and DCPI. With these data in hand, the CBR obtained from the equation developed and the CBR values from the laboratory were compared as presented in Table 3. The results show that there is a good relationship between CBR and the field DCPI for these fine-grained clay. Here, one need to well understand that the soils considered for the correlation of CBR and DCPI are both red and black clay highly plastic soils. The reason is that it is to properly represent a wide range of clay soils found in the study area.

The predicted CBR values from the developed correlation formula are very closer to the lab CBR values as shown in Figure 7. The dot points in the figure fairly converge to the normality line (line of equality), which is drawn from expected and observed commulative probability of CBR values. The predicted CBR value slightly deviates from the lab CBR value with nearly 20 percent. This can be taken as a very good correlation to estimate CBR value from DCP test.

Table 3: Validation of the correlation (N = 4 samples)

No. (1)	*Field DCPI (mm/below)* (2)	*Lab-CBR (%)* (3)	*Pred-CBR (%)* (4)	*CBR Variation (%)* (|4-3|)
1	58	3.4	4.4	22.7
2	73	1.5	2.3	35.2
3	41	6.5	6.8	3.9
4	39	5.2	7.0	26.1
			Average	22.0

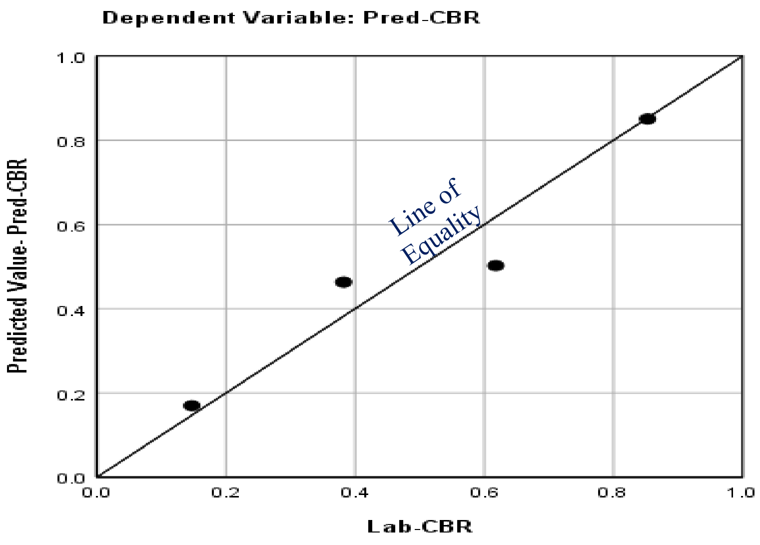

Figure 7: A normal P-P plot for predicted CBR and laboratory CBR

5.0 Conclusions and Recommendations

The major objective of this paper was to introduce DCP to replace CBR test at the preliminary design stage since DCP is cheap, portable and very easy to operate it. As well, it is easy to conduct as many test as possible in a single spot to achieve a better result. In the study the following conclusions can be drawn.

- Results of single regression analysis shows that the relationship developed between DCPI, bulk density and natural moisture content have a good determination of coefficient (R^2). In addition, the exponential regression analysis shows that CBR has a good relationship with DCPI.
- DCPI is also significantly influenced by moisture content and bulk density. Thus, alternatively, the influence of natural moisture content and field density is involved in the correlation equation.
- CBR can be fairly estimated from DCP; hence, CBR test can be replaced by DCP for preliminary design purposes in roads construction to assess the relative strength of road subgrade.

The authors suggest that DCP values must be accompanied by engineering judgments to get the best estimate of the behavior of soils; otherwise, blindly using the DCP values to "plug into an equation" may lead someone to wrong results and conclusions.

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