Prediction of California Bearing Ratio (CBR) using Dynamic Cone Penetrometer (DCP) for Soils from Second District in the Province of Sorsogon

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Abstract— California Bearing Ratio (CBR) is one important parameters considered in design and construction of pavement. However, since CBR cannot be easily determined in the field or in laboratory, CBR can be related to other in situ test such as Dynamic Cone Penetrometer (DCP). In this study, laboratory soaked CBR value and field DCP test were correlated for soils from second District in the Province of Sorsogon allowing to expediently determine the subgrade strength for pavement design. Fifteen soil samples from proposed road construction in the Sorsogon second district were taken for laboratory soaked CBR test. DCP test have been performed in the field on different pits 0.5 m depth from Natural Ground Line to record the penetration value. On the same pits, soil samples is extracted directly where the DCP test performed and bring to laboratory for CBR test and some soil index properties determination. To analyze if a relationship exists between CBR and DCP, Pearson Product Moment Coefficient are utilized setting CBR as independent variables. Then, simple regression analysis has been performed to determine relationship of CBR value with DCP penetration. Regression analysis results showed that soaked CBR value have strong relation with DCP index having coefficient of determination (R^2) of 0.76. Comparison between the developed equation and previous study shows conservatively similar regression curve and result suggesting validity of the developed equation.

Keywords— California Bearing Ratio, Classification, Correlation, Dynamic Cone Penetrometer, Index Properties.

I. INTRODUCTION

The California Bearing Ratio (CBR) test is used in evaluating subgrade, subbase and base materials as an aid to the design of pavements (ASTM D1883, 2014). The test was developed by the California Division of Highways as means of classifying the suitability of a soil for use as a subgrade or base course material in highway construction (Bowles, 1986). This laboratory test uses a circular piston to penetrate material compacted in a mold at a constant rate of penetration. The CBR is expressed as a ratio of the unit load on the piston required to penetrate 0.1 inch and 0.2 inch of the test material to the unit load required to penetrate a standard material of a well –graded crushed stone (ASTM D1883, 2014). CBR is one important parameter considered in the design of pavement, however laboratory soaked CBR testing is time consuming, relatively slow to conduct and uneasy to conduct for civil engineers and technicians. Due to this, highway civil engineers faces challenges in obtaining fast CBR results to be used in designing a pavement.

On the other hand, the Dynamic Cone Penetrometer (DCP) test is used to assess in situ strength of undisturbed soil and /or compacted materials (ASTM D6951, 2015). The DCP as cited by Wilches et. al., was developed in South Africa in the 1960s by Dr. D.J. Van Vauren to simply estimate in-situ support capacity of subgrade materials and layers making up pavement (Wilches et.al., 2018). The test provides a measure of a material’s in-situ resistance to penetration. The test is performed by driving a metal cone into the ground by repeated striking it with an 8kg weight dropped from a distance of 575mm. The penetration of the cone is measured after each blow and is recorded to provide a continuous measure of shearing resistance up to 5 feet below the ground surface (DGCS, 2015). The DCP provides simple test method in evaluating the subgrade strength due to its being portable, fast and ease of operation. The DCP is lightweight, simply to operate and superior in providing quick result of the test.

Several studies and correlations have been conducted for the use of DCP. Abdela & Chemada, (2019) and Ampadu, (2006) correlates DCP Index with the bearing capacity while Wilches et al., (2018), Rajasekhar et al., (2016) and Al-Refeai & Al-Suhaibani (1996) correlates DCP index with the California Bearing Ratio (CBR). In their study, both Wilches and Al-Refeai proposed a model to predict CBR values using DCP considering their local soils characteristics. Livneh as cited by Al-Refeai (1996) emphasized that difference in geographic areas throughout the world lead to changes in the empirical values obtained. According to Wilches (2018), it is convenient to establish an equation that correlates CBR values with greater precision for each soil, depending on the geotechnical characteristics of each region based on the in situ DCP test. Therefore, it is necessary to provide an easy method to estimate CBR value considering the local condition of the soil from Sorsogon Second District by correlating with DCP test data. .

II. OBJECTIVE OF THE STUDY

This study correlates the relationship between laboratory soaked CBR and DCP index for soils from second district in the Province of Sorsogon. It specifically aims to established correlation equation that predicts CBR value from DCP index for soil from Sorsogon second district; to provide fast, easy and affordable method in estimating CBR values of subgrade soil for pavement design; and to characterize the subgrade soil being tested.

III. MATERIALS AND METHODS

Soil samples and field DCP test were carried out in the nine municipality of Sorsogon Second District on test pit locations (Figure 1). Fifteen (15) samples points where selected from the proposed road construction in 2021-2022 of the Department of Public Works and Highways (DPWH) Sorsogon Second District Engineering Office (DEO) representing at least one sample for each municipality. The depth of sampling is 0.5 meter below the Natural Ground Line (NGL) to exclude the effects of surface moisture and to attain the in situ DCP Index values. The soil sample is extracted directly from where the DCP test is conducted. Then the disturbed soil sample is brought to laboratory for soaked CBR test and index property test.

At the DPWH Sorsogon second DEO Laboratory, the index property test for the soil sample is conducted. All the test was conducted following the agency testing procedure manuals and ASTM Standards. The soaked CBR value was obtained for each sample employing 65 blows compaction and soaking for 4 days. Also, with the obtain index property of the soil, the sample is classified based on AASHTO classification system.

The DCP test was performed in the test pit after excavation of 0.5-meter depth. The test device used in this study is shown in Figure 2. It is consisting of 16 mm diameter drive rod to which a disposable tip cone with 20mm base diameter and a 60-degree point angle is attached. The DCP is driven into the soil by an 8kg hammer dropping a height of 575 mm. The operator drives the DCP tip into soil by lifting the sliding hammer to the handle then releasing it. The penetration achieved by each blow was measure and recorded to obtain the dynamic cone penetration index.

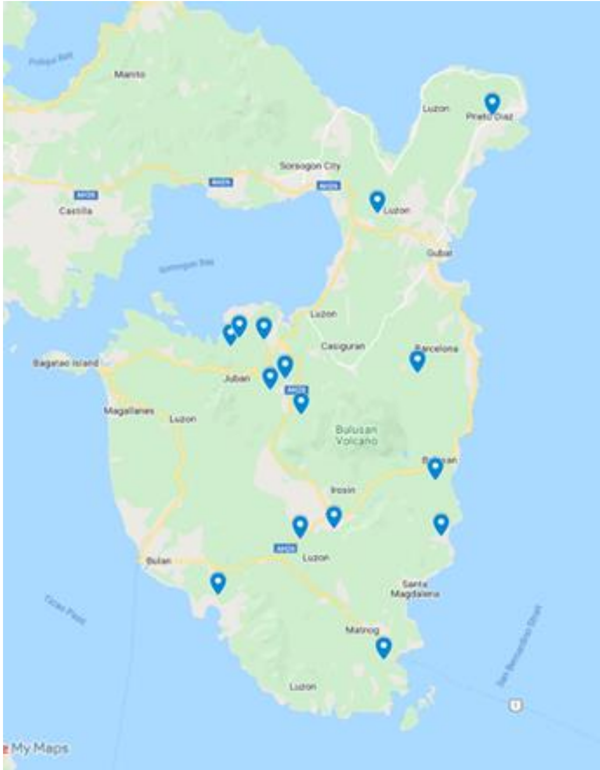

Figure 1: *Location Map of Study Area and Test pits location (google map).*

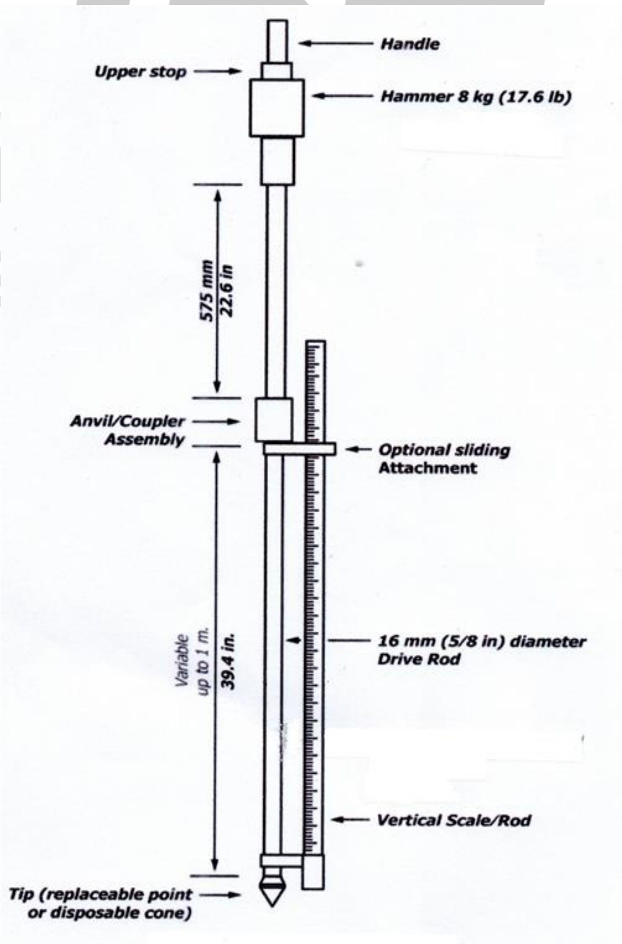

Figure 2: *Sketch of Dynamic Cone Penetrometer Device (ASTM D 6951-15)*

Table 1: *Index Properties of Soils used in the study*

Sample		NMC%	Liquid Limit %	Plastic Limit %	Plasticity Index %	AASHTO Classification
Pit	Location					
1	Carriedo, Irosin	36.22	36.69	23.83	12.86	A-6(3)
2	Salvacion, Irosin	33.73	Non Plastic			A-1-b
3	Binanuahan, Juban	48.16	Non Plastic			A-4
4	Caruhayon, Juban	25.42	Non Plastic			A-2-4
5	Caruhayon, Juban	41.61	49.09	31.62	17.47	A-7-5(15)
6	Puting Sapa, Juban	47.86	Non Plastic			A-4
7	Sipaya, Juban	55.73	61.79	18.17	43.62	A-7-5(12)
8	Calateo, Juban	49.84	Non Plastic			A-4
9	Butag, Bulan	28.92	36.78	23.06	13.72	A-4
10	Tinampo, Bulusan	29.54	61.72	50.77	10.95	A-7-5(9)
11	San Bartolome, Sta. Magdalena	30.59	37.47	19.40	18.07	A-2-6
12	Sinebaran, Matnog	35.96	54.25	37.67	16.58	A-7-5(13)
13	Fabrica, Barcelona	42.53	Non Plastic			A-4
14	Cabiguhan, Gubat	29.47	50.28	36.62	13.66	A-7-5(16)
15	San Isidro, Prieto. Diaz	29.01	41.47	24.72	16.75	A-7-6(13)

For determining the index relationship between the DCP and CBR value, Pearson Product Moment Coefficient correlation (r) was utilized assigning CBR value as dependent variables. To determine the correlation equation, DCP result were plotted on the abscissa axis and CBR results on the ordinate axis to find a scatter plot. Using Microsoft Excel software, the dispersion plots and best fit curve were generated together with the correlation equation.

IV. RESULTS AND DISCUSSION

4.1. Characteristics of the Soil Samples

The index properties of the fifteen samples taken from different location in Sorsogon second district and tested in the laboratory are summarized in Table 1. According to AASHTO classification system, two types of soil is predominant, Non Plastic (NP) usually fine sand and A-7 group indicates clay soils. Both soils may be describing as sandy to silty clay and have a Natural Moisture Content (NMC) range of 25 – 56%.

The NMC of the soil tested was found to be relatively higher indicating the soil under investigation possess water adsorption. The large values of water content usually associated with fine grain, loosely deposited clay. (Cernica, 1996). The liquid limit (LL) and plastic limit (PL) range from 36 – 62 % and 18 -51% respectively with six samples of non-plastic materials, NP. The plasticity index range from 10 – 44%. Most of the soil of the study area fall with high plasticity type except test pit 2, 3, 4, 6, 8 and 13 which is non-plastic materials. NP soils generally rate as good subgrade materials while high plasticity clayey soil rated as poor subgrade materials.

4.2. Correlation between DCP and CBR value

To determine the potential relationship between DCP and CBR, the data is analyzed employing Pearson statistics (r). The result (r = - 0.75) indicates that there is a negative high correlation (Del Rosario AC, 2006). Also, to determine whether there is a significant negative relationship, the data were tested at 0.05 level of significance with 13 degrees of freedom, and confirmed (r 0.05 = -0.553) that there is a significant negative relationship between the DCP and CBR value. It implies that the high DCP index value in mm/blow there is a low CBR value in percent.

To determine the correlation equation, a simple regression analysis between the DCP index and CBR values as dependent variables is carried out. In table 2 column 4 and 5 shows result obtained in the field DCP test and laboratory soaked CBR test on disturbed samples, respectively.

Figure 3 shows the scatter plot and correlation curve between CBR and DCP found using Microsoft Excel software. As observed, the curve shown have a good fit estimation as indicated by the coefficient of determination (R^2) of 0.76. The moderately strong correlation between laboratory soaked CBR and field DCP indicates the potential.

Table 2: DCP field test result, laboratory CBR test result and comparison of predicted CBR value

Sample		Depth (m)	DCP mm/blow	CBR %	Predicted CBR %	Variation %
Pit	Location			A	a	(A-a)*100/A
1	Carriedo, Irosin	0.5	140	1.08	1.08	0.00
2	Salvacion, Irosin	0.5	14	8.67	9.15	-0.48
3	Binanuahan, Juban	0.5	50	2	2.81	-0.81
4	Caruhayon, Juban	0.5	7	15.07	17.40	-2.33
5	Caruhayon, Juban	0.5	76	2.32	1.90	0.42
6	Puting Sapa, Juban	0.5	98	0.54	1.50	-0.96
7	Sipaya, Juban	0.5	53	2.73	2.66	0.07
8	Calateo, Juban	0.5	114	1.53	1.31	0.22
9	Butag, Bulan	0.5	81	1.23	1.79	-0.56
10	Tinampo, Bulusan	0.5	56	2.23	2.53	-0.30
11	San Bartolome, Sta. Magdalena	0.5	26	9.6	5.15	4.45
12	Sinebaran, Matnog	0.5	84	2.87	1.73	1.14
13	Fabrica, Barcelona	0.5	25	4.08	5.34	-1.26
14	Cabiguhan, Gubat	0.5	86	3.2	1.70	1.50
15	San Isidro, Prieto. Diaz	0.5	36	4.63	3.81	0.82
Average						± 1.02

DCP test in estimating the CBR value for pavement design. To obtain conservative values when estimating the CBR as a function of DCP, the correlation model resulted from the dispersion curve plot from Figure 2 is shown below.

$$\mathbf{CBR} = \frac{\mathbf{105.88}}{(\boldsymbol{DCP})^{\mathbf{0.928}}}$$

Evaluation and validation of the developed equation

The validity of the developed correlation equation model has been examined by calculating the CBR value using the developed empirical equation and comparing it with the actual value using soaked CBR testing method and also with previous works.

As indicated in Table 2 column 7, the average variation of the predicted CBR value from actual soaked CBR value is about ± 1.02%.

It indicates that the laboratory soaked CBR value in Sorsogon second District can be reliably predicted from the field DCP test.

The result of this study is compared with the work of Wilches et. al., (2018) for the correlation between CBR and DCP value (Figure 4). The DCP device used by Wilches are similar with the present work while the soil type varies from NP to high plastic soil but same fine grained soil. It must be noted however that, the test condition of CBR are different.

Although, both DCP test are conducted in situ condition, in the present case the CBR are tested on disturbed samples while Wilches tested on unaltered condition. Hence the computed CBR value are relatively lower in the present study.

However, it can be noted that regardless of the testing conditions, the correlation curve have comparable gradients and the resulted model equation are relatively similar.

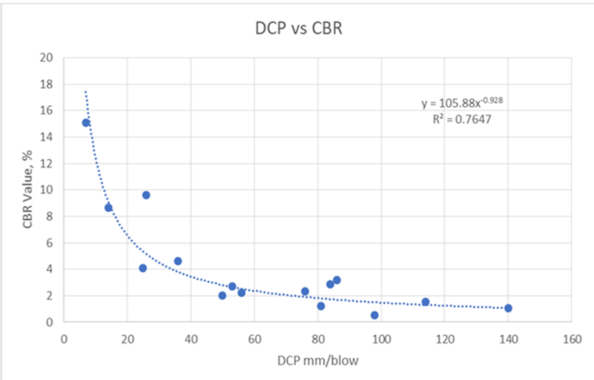

***Figure 3:** Scatter Plot and Correlation curve between DCP and CBR*

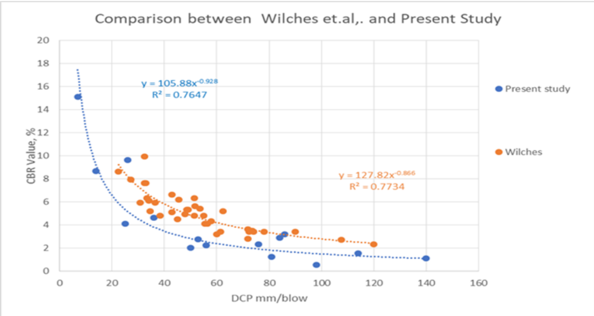

Figure 4: *Comparison of the developed empirical correlation between DCP reading and CBR value with the work of Wilches et. al, (2018).*

V. CONCLUSION

Based on the result of this study, it can be concluding that the obtained correlation equation can be considered as a reliable alternative for determination of CBR based on DCP test particularly for soil from Sorsogon Second district. Therefore, it can be considered as an affordable, fast and easy alternative for determination of CBR value for use in the design of pavement. However, the user of the model must exercise caution in obtaining data from this developed correlation equation particularly for soil outside the study area. Additional works need to be done by increasing the sample number so as to validate the established correlation.

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