CBR Value Estimation Using Dynamic Cone Penetrometer—A Case Study of Brazil's Midwest Federal Highway

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ABSTRACT

For the design of a road pavement, the knowledge of the soil that will serve as the future structure to be built is indispensable. The foundation soil requires special attention, through geotechnical studies that enable the recognition, identification and quantification of their physical and mechanical characteristics as well as obtaining the necessary geotechnical parameters for the design of the structure. The field verification of the conditions and the soil used is one of the different stages of a construction site. Among these verifications, there is the evaluation of the degree of soil compaction by sand cone method. The dynamic cone penetrometer is an instrument that can be studied in order to obtain a correlation between the penetration resistance of the insitu soil with the California bearing ratio. This paper studies the variation of the values of dynamic penetrometer cone index, obtained in the field, with values California bearing ratio index, obtained in the laboratory. The results showed a good consistency, a correlation equation that can point the California bearing ratio index of soil on field by its cone penetration resistance.

KEYWORDS: California Bearing Ratio; Dynamic Cone Penetrometer; Soil; Correlation.

INTRODUCTION

The strength of a soil that is used as a sub-grade in pavement is assessed from its California bearing ratio (CBR) value. If the CBR value of soil is low, the thickness of pavement will be increased, which will result in high cost of construction (SABAT, 2013). The design of new flexible pavements and rehabilitation of existing pavements needs an accurate estimation of CBR value. In the design of overlays, generally, Benkelman’s beam method and Falling Weight Deflectometer (FWD) are used but these methods are sophisticated and time consuming. The dynamic cone penetrometer (DCP) has showed satisfactory results on estimating the strength of soil. Some of the work regarding correlation between DCP and CBR has been reported in literature as Kleyn e Savage (1982), Harison (1987) e Ponce *et al.* (1991). Heyn (1986), Vertamati e Oliveira (1997) e Trichês e Cardoso (1998). The DCP test values can be used to estimate the CBR values provided a suitable relationship exists between the CBR and the DCP value. Development of any such relationship may become very effective tool for highway engineers.

CBR-DCP Correlations

The correlations between CBR and DCP are obtained through several tests conducted on both field and laboratory. The soils that were studied on those tests, present some differences: soil type, weather conditions and degree of compaction. Table 1 presents the correlations found in literature and Figure 1 shows those correlations in a CBR-DCP chart.

Table 1: CBR-DCP Correlations

Soil Type	Correlation	R^2	Sources
Not provided Location: South Africa	Log (CBR) = 2,63 -1,28 Log (DCP)	-	KLEYN E SAVAGE (1982)
Clays	Log (CBR) = 2,56 -1,16 Log (DCP)	0,97	HARISON (1987) *apud* ALVES (2002)
Sands	Log (CBR) = 3,03 -1,51 Log (DCP)	0,92	
Gravel	Log (CBR) = 2,55 -0,96 Log (DCP)	0,96	
All types of soils	Log (CBR) = 2,81 -1,32 Log (DCP)	0,98	
Fine Grained Soils / Location: Chile	Log (CBR) = 2,89 -1,46 Log (DCP)	0,95	PONCE H. *et al.* (1991), *apud* ALVES (2002)
Not provided Location: Paraná - Brazil	$CBR = 443,45 (DCP)^{-1.30}$	-	HEYN (1986), *apud* FONTES (2001)
Oxisols Location: Brazil	Log (CBR) = 2,490 -1,057 Log (DCP)	-	VERTAMATI E OLIVEIRA (1997)
Not provided Location: Santa Catarina - Brazil	$CBR = 512,64 (DCP)^{-1,25}$ *in situ*	-	TRICHÊS E CARDOSO (1998), *apud* FONTES (2001)
	$CBR = 151,58 (DCP)^{-1,03}$	-	

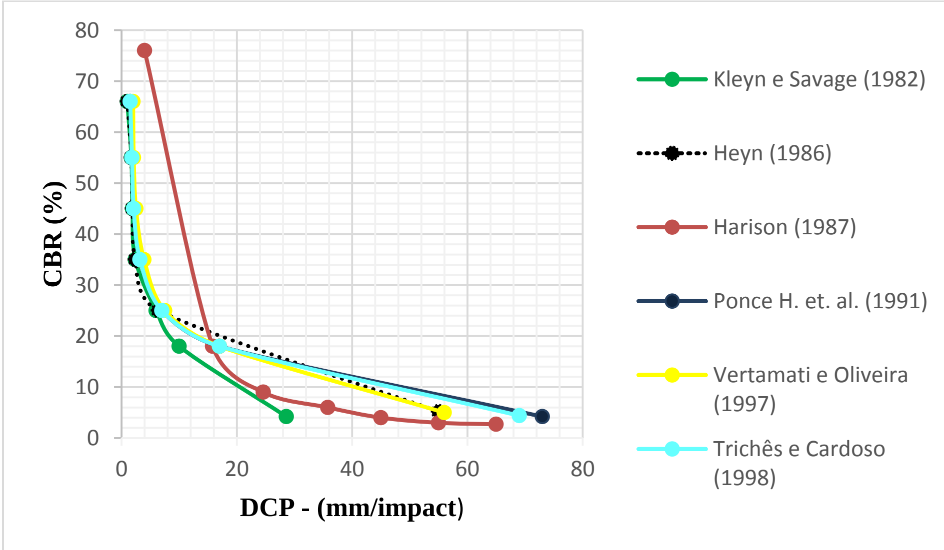

Figure 1: CBR-DCP Correlations in literature

CASE STUDY

In the present study, DCP tests were conducted along the 87 km long stretch of the federal highway BR 158/MT, located in Brazil's Midwest. A total of 247 DCP tests were performed on the red sections marked on Figure 2, the yellow section represents the BR 158/MT federal highway construction project. Soil characterization testing and degree of compaction verification were performed on all pavement layers. The present study describes a series of DCP tests conducted at insitu conditions. In addition to the above field test, laboratory soaked CBR tests moulded at insitu density were also carried out. The soils were classified according to TRB (Transportation Research Board). Table 2 presents the number of tests conducted in each pavement layer and the soil composition of that layer.

Table 2: Soil types and tests performed in each layer

Layer	Soil Type	Tests performed
Subgrade	A-6	32
	A-2-4	27
	A-2-6	10
Subbase 1° Layer	A-2-4	8
	A-2-6	30
Subbase 2° Layer	A-1-B	2
	A-2-4	30
	A-2-6	21
Base	A-2-4	72
	A-2-6	15

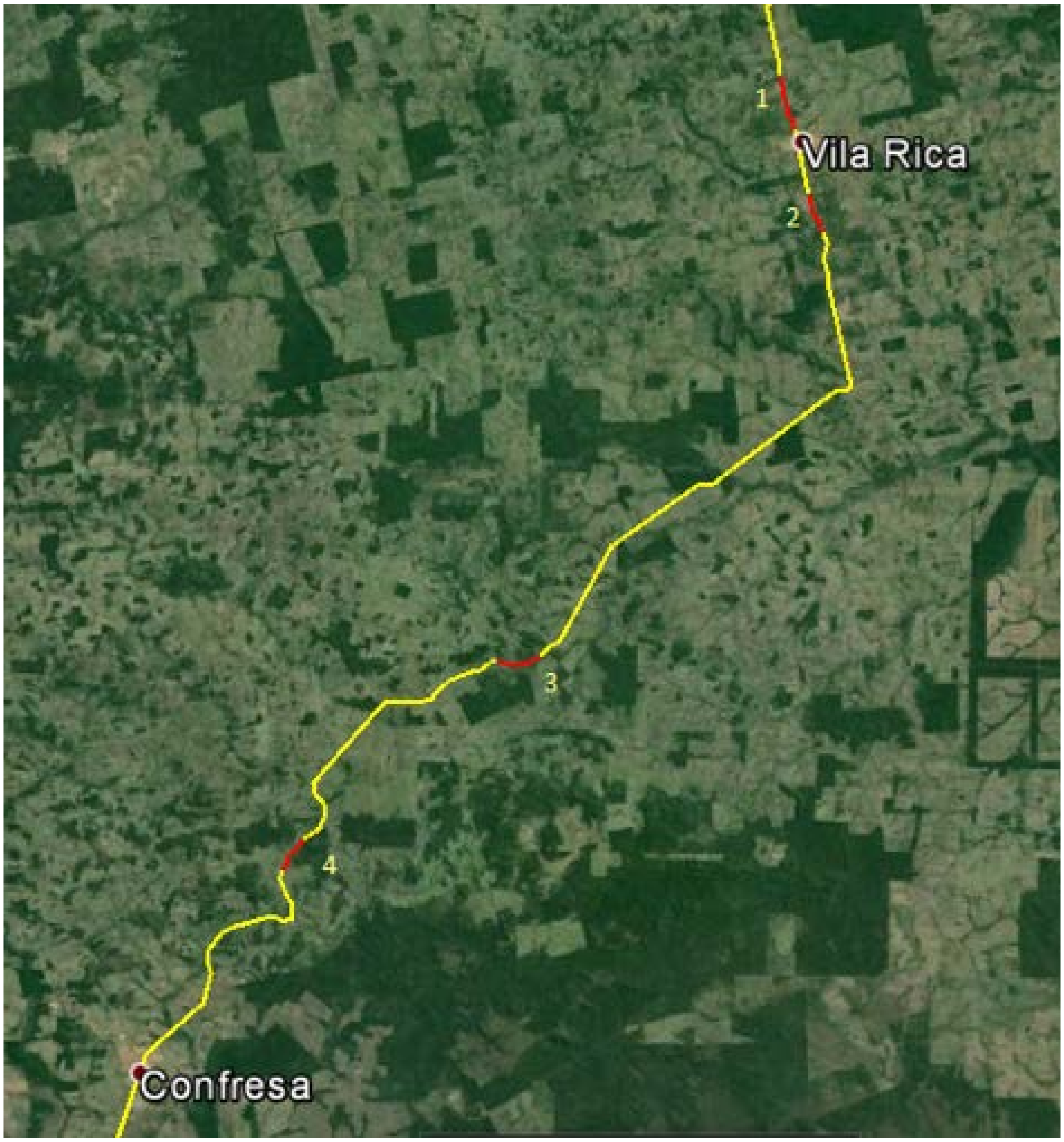

Figure 2: BR 158/MT federal highway construction project

RESULTS AND DISCUSSIONS

Due to the great number of tests performed, average values for the results of CBR and DCP tests were assigned for the soils on this study. Table 3 presents the CBR and DCP tests results for the soils used in the construction of the BR 158/MT federal highway sections.

Table 3: CBR and DCP Tests Results

A-2-4 Soil		A-2-6 Soil		A-6 Soil		A-1-B Soil	
CBR(%)	DCP (mm/impact)	CBR(%)	DCP (mm/impact)	CBR(%)	DCP (mm/impact)	CBR(%)	DCP (mm/impact)
97.40	1.60	85.2	1.49	23.9	3.46	32.1	4.46
91.90	1.50	82.20	1.98	21.5	4.24	28.27	6.14
87.20	1.35	81.80	2.34	21	4.49	-	-
82.00	2.70	80.70	2.16	19.1	4.53	-	-
79.90	2.22	51.20	4.19	18.9	4.09	-	-
77.90	1.30	49.00	4.32	18.2	3.94	-	-
51.80	5.21	45.50	3.65	17.5	5.10	-	-
51.60	4.46	42.50	3.42	16.3	6.18	-	-
47.50	4.31	41.80	4.36	16.1	6.29	-	-
38.80	3.93	40.50	3.62	-	-	-	-
28.80	4.60	39.70	4.27	-	-	-	-
27.70	5.75	35.80	3.46	-	-	-	-
20.50	12.70	21.90	8.16	-	-	-	-
18.90	11.70	19.50	8.91	-	-	-	-

The results on Table 3 provide the data to establish the correlation between the DCP and CBR tests results. It is noticed that the ISC and DCP values present a satisfactory relationship of proportionality, despite the occurrence of some points that did not fit the correlation proposed as shown in Figure 3.

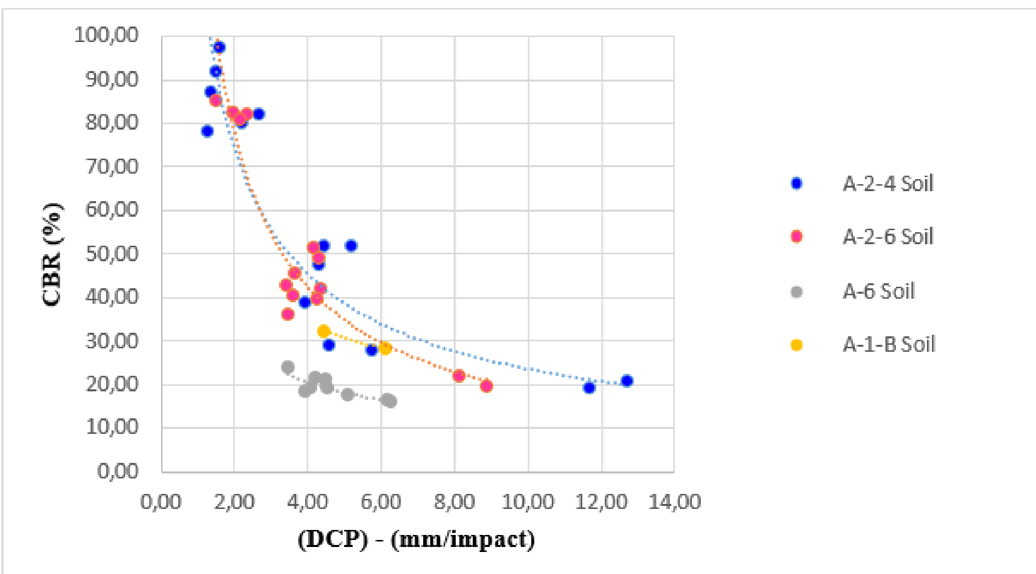

Figure 3: CBR-DCP Correlations Adjustments

An analysis of several mathematical models were proposed, in order to find a relationship between CBR and DCP values. It was found that the model "power" (a power trend line is a curved line that is best used with data sets that compare measurements that increase at a specific rate) showed a better fit to the values obtained from the tests. Table 4 displays the equations corresponding to the adjustments that best represented the behavior of the relationship between CBR and DCP values, as seen in Figure 3.

Table 4: Proposed DCP – CBR Correlations

Soil Type	Correlation	R^2
A-2-4 Soil	CBR = 121,64 (DCP) $^{-0,713}$	0,86
A-2-6 Soil	CBR = 143,13 (DCP) $^{-0,879}$	0,89
A-6 Soil	CBR = 43.91 (DCP) $^{-0,547}$	0,71
A-1-B Soil	CBR = 58,154 (DCP) $^{-0,397}$	1

From the equations presented in Table 4, it is possible to identify a trend existence, it is apparent that lower the magnitude of DCP, the higher the CBR. In Figure 4, it is noteworthy that some points do not behave according to the trend, which undermines a better fit of the equation, directly influencing the coefficient of determination (R^2). The equation is fit to the soil type A-2-6, which showed the best determination coefficient. The equation can satisfactorily represent the correlation between the results of CBR and DCP. Although the A-2-4 soil has a smaller determination coefficient, we note that both soils exhibit similar behavior to the soils studied in Kleyn and Savage (1982), Heyn (1986), Vertamati and Oliveira (1997) and Triches and Cardoso (1988). Due to small amount of tests on the A-1-B soil, it was not possible to determine an appropriate trend that can represent the soil behavior, indicating the need for more tests. The A-6 soil presented a trend that does not match a similar behavior to the soils studied in the research.

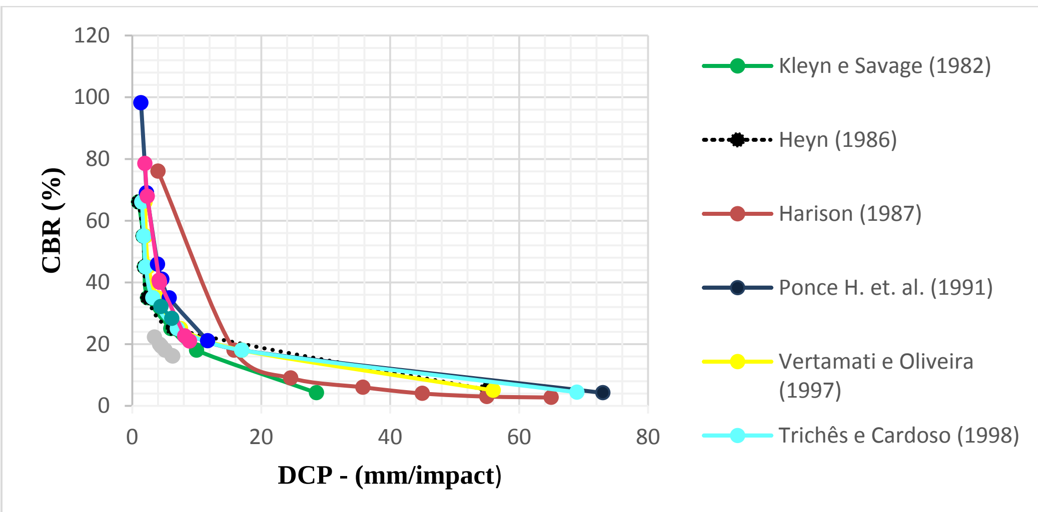

Figure 4: Proposed Equations Fitting

CONCLUSIONS

(1) The research has shown that the DCP equipment constitutes a technological tool that can evaluate pavements load capacity with DCP-CBR correlations.

(2) For CBR values ranging between 20% and 70% it was noted concordant values with the methods presented in the literature and those obtained in this work, therefore, it can be interpreted that the correlations proposed by the work are satisfactory

(3) In the CBR values range of 70% to 100%, the behavior of the correlation between DCP and CBR remained as expected, because as the CBR increased, the DCP index decreased.

(4) Due to small amount of tests on the A-1-B soil, it was not possible to determine an appropriate trend that can represent the soil behavior, indicating the need for more tests

(5) The A-6 soil presented a trend that does not match a similar behavior to the soils studied in the research.

(6) From the results of the study, it can be concluded that for A-2-4 and A-2-6 soils, the CBR – DCP correlation showed great conformity. Soils exhibited similar behavior to the soils studied in Kleyn and Savage (1982), Heyn (1986), Vertamati and Oliveira (1998) and Triches and Cardoso (1998).

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