Article

Not peer-reviewed version

Recalibration and Recommendation for the Prediction of the California Bearing Ratio (CBR) from Dynamic Cone Penetrometer (DCP)

Jirawat Chokkerd , Artit Udomchai , Sivarit Sultornsanee , Nopanom Kaewhanam *

Posted Date: 5 April 2024

doi: 10.20944/preprints202404.0404.v1

Keywords: California Bearing Ratio; CBR; Dynamic Cone Penetrometer; DCP; Estimation, Prediction; Forecasting; Subgrade; Sand; Soil

Article

Recalibration and Recommendation for the Prediction of the California Bearing Ratio (CBR) from Dynamic Cone Penetrometer (DCP)

Jirawat Chokkerd [1], Artit Udomchai [2], Sivarit Sultornsanee [3] and Nopanom Kaewhanam [1,*]

[1] Department of Civil Engineering, Faculty of Engineering, Mahasarakham University, Maha Sarakham 44150, Thailand; jirawat.c@msu.ac.th

[2] School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand; artit.u@g.sut.ac.th

[3] College of Engineering, Northeastern University, Boston, Massachusetts, USA; s.sultornsanee@northeastern.edu

* Correspondence: nopanom.k@msu.ac.th

Abstract: The high reliable correlations between CBR and DCP in general proposed are presented in this paper. We analyzed the test data and correlations from many researchers to find the best equation for prediction the CBR from DCP test. The findings show that all correlations from existing paper are based on local material and cannot apply to soil in a different location in general purpose. New correlations between CBR and DCP were proposed and validated in this paper for general uses. The validation confirmed that these new correlations can predict well with higher R^2.

Keywords: California Bearing Ratio; CBR; Dynamic Cone Penetrometer; DCP; estimation; prediction; forecasting; subgrade; sand; soil

1. Introduction

The California Bearing Ratio (CBR) is one of the most important characteristics representing the strength of subgrade or base material in pavement structure. In order to conduct the CBR test, samples must be transported, prepared, compacted, soaked, then penetrated with a CBR equipment in the laboratory. Consequently, realistic CBR is difficult to obtain because it takes a long time and is not readily determined in the field. In addition, civil engineers often faced with the urgent need of the CBR of soil in a short amount of time, a survey of large amount of material resources for road construction is a good example. Therefore, in the literature, a number of correlations between CBR and other strength properties of soil were established [1–12]. One of the tests that can provides a high reliable correlation with the CBR is the Dynamic Cone Penetration (DCP) test [3,4,13–20]. Notably, the DCP equipment is considered as the compact and lightweight equipment as demonstrated in Figure 1.

The correlations between CBR and DCP for local material proposed by many researchers are usually in the form of log-log or exponential equation as shown in Table 1. Although all equations in Table 1 have the same trend, The big errors were found among these equations. Feleke and Araya (2016) [14] proposed equation for material having low DCP ranging from 1 to 15 mm/blow. Surprisingly, the equation proposed by Fernando et al. (2018) [16] for material having high DCP ranging from 20 to 60 mm/blow was well consistent with Feleke and Araya (2016) [14]. However, these two equations provide much lower value than the test results conducted by Al-Refeai and Al-Suhaibani (1996). This implies that the correlation from local material can be problematic for other material in general engineering practice. Therefore, existing equations are need to be recalibrated and the proper correlations for CBR and DCP for general material are required.

In this paper, the study composed of two steps: (1) evaluation of the existing correlations between CBR and DCP in the literature by four test results from distinct researchers (three existing data from Al-Refeai and Al-Suhaibani (1996), Felek and Araya (2016) and Fernando et al. (2018) and one additional data set from the authors); and (2) derivation of the proper correlations for CBR and DCP that can be used in general material rather than the local material.

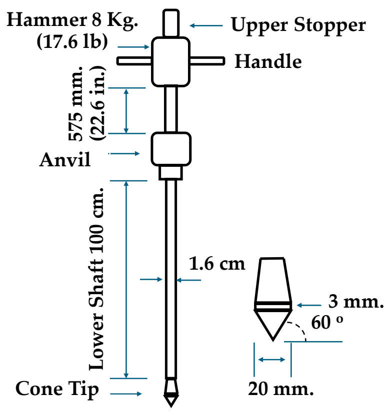

Figure 1. The Dynamic Cone Penetrometer (DCP).

Table 1. Existing correlation between CBR and DCP.

Equation No.	Correlation CBR = California Bearing Ratio (%) DCP = Dynamic penetration resistance (mm/blow)	Researchers
1	$Log(CBR) = 2.494 - 1.0672Log(DCP)$	Al-Refeai, Al-Suhaibani (1996)
2	$Log(CBR) = 2.015 - 0.906Log(DCP)$	G. Feleke, A. Araya (2016)
3	$Log(CBR) = \frac{112.03}{DCP^{0.808}}$	Fernando Jove Wilches et al. (2018)
4	$Log(CBR) = 2.81 - 1.32Log(DCP)$	Harrison J.A. (1986)
5	$Log(CBR) = 2.20 - 0.71Log(DCP)^{1.5}$	Livneh (1987)
6	$Log(CBR) = 2.465 - 1.12Log(DCP)$	U.S. Army Corps of Engineers (1992)
7	$Log(CBR) = 2.48 - 1.057Log(DCP)$	TRL
8	$Log(CBR) = 2.954 - 1.496Log(DCP)$	Yitagesu (2012)
9	$Log(CBR) = 0.84 - 1.26Log(DCP)$	IDOT (1997)

[1] TRL denotes Transport Research Laboratory, Huntingdon, UK. [2] IDOT denotes Illinois Department of Transportation, US.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2024 doi:10.20944/preprints202404.0404.v1

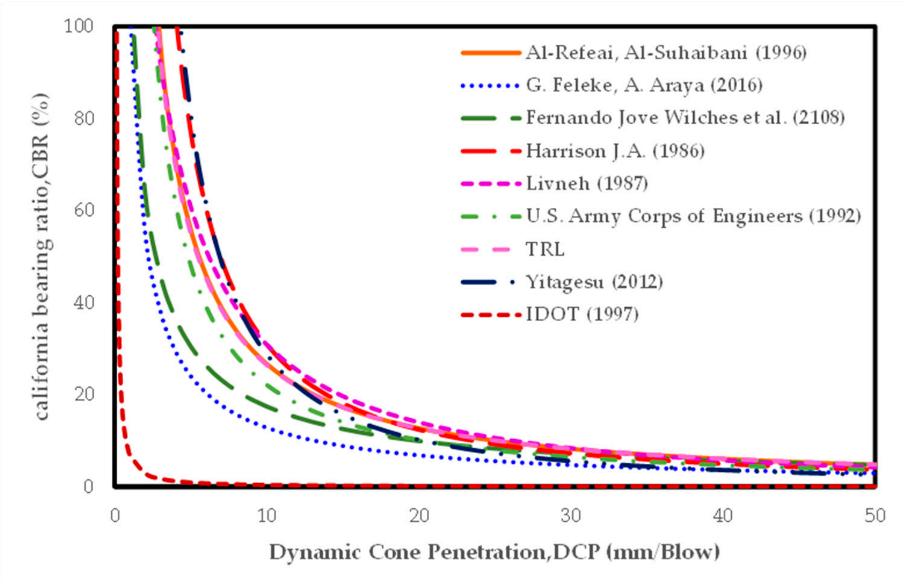

Figure 2. Graphs of the existing correlation between California Bearing Ratio (CBR) and Dynamic Cone Penetration Test.

2. Evaluation of the Existing Equations

The existing equations in Table 1 were investigated by four set of different data set. The results were expressed by the coefficient of determination (R^2).

From Table 2, It is obvious that the existing correlations are not able to predict the CBR from DCP test for all material in all locations. Therefore, the new correlations are required.

Table 2. Existing correlation between CBR and DCP.

Researcher	Correlation	Tala	Felek	Fernando	This Study
Tala	log(CBR) = 2.494-1.0672log(DCP)	0.82	0.45	0.96	0.97
Felek	log(CBR) = 2.015-0.906log(DCP)	0.59	0.85	0.83	0.77
Fernando	CBR =112.03/DCP$^{0.808}$	0.78	0.92	0.97	0.91
harrison	log(CBR)= 2.81 -1.32log(DCP)	0.43	-	0.92	0.93
Livneh	log(CBR)= 2.20 -0.71log(DCP)1.5	0.85	0.74	0.93	0.92
U.S. ACE	log(CBR)= 2.465 -1.12log(DCP)	0.82	0.67	0.92	0.97
	CBR = 292/DCP$^{1.12}$	0.82	0.67	0.93	0.97
TRL	log(CBR)= 2.48 -1.057log(DCP)	0.83	0.51	0.96	0.97
Yitagesu	log(CBR)= 2.954 -1.496log(DCP)	0.09	-	0.81	0.95
IDOT(1997)	log(CBR)= 0.84 -1.26log(DCP)	0.03	0.06	0.02	0.03

[1] TRL denotes Transport Research Laboratory, Huntingdon, UK. [2] IDOT denotes Illinois Department of Transportation, US.

3. Proposed correlation between CBR and DCP

After we analyzed the data between existing relationships from various studies including experimental results data. We then derived new two correlations for a general proposed as shown in Figure 3 and Equations (1) and (2).

 doi:10.20944/preprints202404.0404.v1

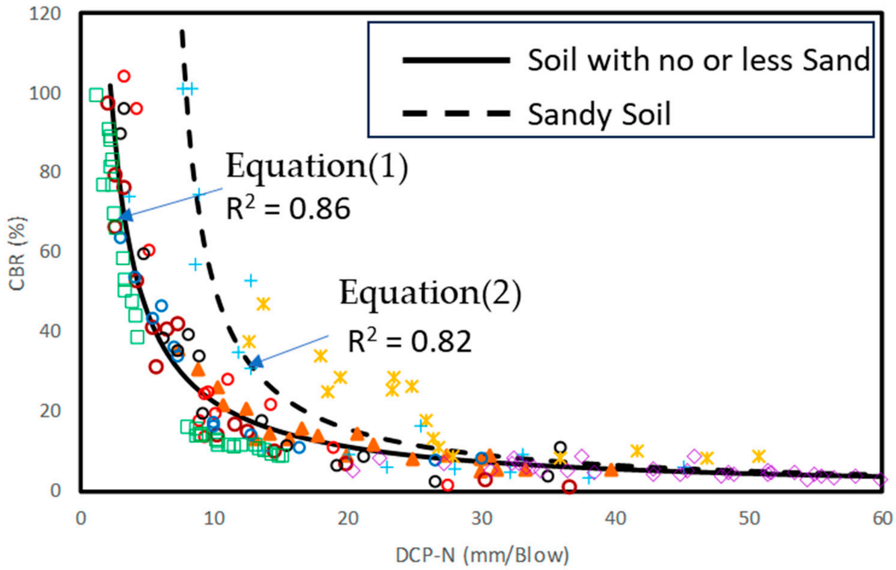

Figure 3. New correlations proposed in this paper (for soil and sandy soil).

In Figure 3, two new correlations are proposed to gain higher R^2. The obtained equation for soil with no or less sand and equation for sandy soil are expressed as shown in Equations (1) and (2), respectively.

$$CBR = 190/(DCP) + 0.53704 \quad \text{(Soil win no or less Sand)} \tag{1}$$

$$CBR = 235/(DCP-5.9) + 1.15 \quad \text{(Sandy Soil)} \tag{2}$$

Equation (1) was validated by the test results of soil from 5 provinces in Thailand (Maha-Sarakham, Khon Kaen, Chaiyaphum, Roi-Et and Kalasin)- the orange triangle symbols. It was found that Equation (1) provides a high value of R^2 to the test results of soil in Thailand up to 0.904.

4. Conclusions and Discussion

The California Bearing Ratio (CBR) representing the strength of soil subgrade in highway engineering. A high performance to gain the reliable value of CBR still required in the design and the construction processes. However, in some process such as the material surveying of the large amount of subgrade borrow pits is different. The test of the reliable value of CBR can be replaced by the estimation with less time-consuming in this case. The objective becomes the simple test with high predictive capability in correlation. The Dynamic Cone Penetration Test (DCP) is one of the tests that can provide the high R^2 to CBR when compared to other tests for soil strength. Therefore, in this study we focus on determination of correlations that can predict the CBR from the DCP test. In this study, the evaluation of a number of existing CBR-DCP correlations was performed in first stage. The findings show that no existing correlation provide a high value of R^2 to all of the published test results. A recalibrated for existing equations was required. After investigation of all test data, two new correlations were proposed in this paper i.e., equation for soil which has no sand of less sand and equation for sandy soil and the R^2 for these two cases are 0.86 and 0.82, respectively. In addition, equation for soil with less sand was validated by soil from 5 provinces in Thailand and the obtained R^2 was up to 0.904. This confirmed that calibrated equation can be improve the prediction. It was recommended that a simple visual inspection of engineer is enough in the distinguishing between soil has less sand and sandy soil.

Funding: This research was funded by Mahasarakham University, grant number 6717022/2567.

 doi:10.20944/preprints202404.0404.v1

Data Availability Statement: The data presented in this study are available on request.

Acknowledgments: This research was supported by Mahasarakham University. The support is gratefully acknowledged.

Conflicts of Interest: The authors confirm that they are no conflict of interest with respect to the publication of this paper.

References

1. Scott Lines, A.B.; David J. Williams, C.D.; Sergio A Galindo-Torres, E.F.; H.A. Danyaya, G.H. Determination of Thermal Conductivity of Soil Using Standard Cone Penetration Test. 2nd International Conference on Advances on Clean Energy Research., Berlin, Germany,7-9 April 2017.
2. Mukesh A. Patel, A.B.; H.S. Patel, C.D.; Gautam Dadhich, E.F. Prediction of Subgrade Strength Parameters from Dynamic Cone Penetrometer Index, Modified Liquid Limit and Moisture Content. 2nd Conference of Transportation Research Group of India, Agra, India,12-15 December 2013.
3. Mukesh A. Patel, A.B.; Dr. H. S. Patel, C.D. Experimental Study to Correlate the Test Results of PBT, UCS, and CBR with DCP on Various soils in soaked condition. IJE. **2012**, 6,
4. Mukesh A. patel, A.B.; HS Patel, C.D. Laboratory Assessment to Correlate Strength Parameter from Physical properties of Subgrade. Non-Circuit Branches of the 3rd Nirma University International Conference on Engineering, Ahmedabad, India, 6-8 Dec. 2012.
5. Joel Fabrice Nyemb Bayamack, A.B.; Vincent Laurent Onana, C.D,Aloys Thierry Ndzié Mvindi.E.F, Arnaud Ngo'o Ze, G.H, Hervé Nyassa Ohandja,I.J, Robert Medjo Eko,K.L.Assessment of the determination of Californian Bearing Ratio of laterites with contrasted geotechnical properties from simple physical parameters. Transportation Geotechnics .**2012**, 19,84-95.
6. Sanjeev Kumar, A.B.; Davinder Singh, C.D. Prediction of UCS and CBR behavior of fiber-reinforced municipal solid waste incinerator bottom ash composites using experimental and machine learning methods. Construction and Building Materials. **2023**, 367,
7. Kareem Othman, A.B.; Hassan Abdelwahab, C.D. The application of deep neural networks for the prediction of California Bearing Ratio of road subgrade soil. Ain Shams Engineering Journal. **2023**, 14,
8. Kareem Othman, A.B.; Hassan Abdelwahab, C.D. Influence of clay mineralogy on the relationship of CBR of fine-grained soils with their index and engineering properties. Transportation Geotechnics. **2018**, 15,29-38.
9. Z. U. Rehman, A.B.; U. Khalid, C.D.; K. Farooq, C.D.; H. Mujtaba, C.D. Prediction of CBR Value from Index Properties of different Soils. UET.**2017**, 22
10. B. Yildirim, A.B.; O. Gunaydin, C.D. Estimation of California bearing ratio by using soft computing systems. Expert Systems with Applications. **2011**, 30, 6381–6391.
11. Naveen B Shirur, A.B.; Santosh G Hiremath, C.D. Establishing Relationship between Cbr Value and Physical Properties of Soil. IOSR-JMCE. 2014, 11, 26-30
12. Gouri Priya, A.B.; Arya KS, C.D.; Eldhose M Manjummekudiyil, E.F.; Unni A, G.H.; Vinayak S Menon, C.D. PREDICTION OF CBR VALUE FROM INDEX PROPERTIES OF SOIL. IRJET. 2019, 6, 4029-4033
13. Talal AI-Refeai, A.B.; A. Al-Suhaibani, C.D. Prediction of CBR Using Dynamic Cone Penetrometer. King Saud Univ. 1997, 9, 191 - 204.
14. Gebremariam G. Feleke, A.B.; Alemgena A. Araya, C.D. PREDICTION OF CBR USING DCP FOR LOCAL SUBGRADE MATERIALS. the1stInternational Conference on Transportation and Road Research, Mombasa,Kenya,15-17 March 2016.
15. Fernando Jove Wilches, A.B.; Jorge Luis Argoty Burbano, C.D. Edilberto Elías Contreras Sierra, C.D. Subgrade soils charac-terization data, for correlation of geotechnical variables on urban roads in northern Colombia. Data in Brief. **2020**, 32,
16. Fernando Jove Wilches, A.B.; Jhon Jairo Feria Díaz, C.D .; José Rodrigo Hernandez Ávila, C.D. Correlation between California Bearing Ratio (CBR) and Dynamic Cone Penetrometer (DCP) for soil from Sincelejo city in Colombia. International Journal of Applied Engineering Research ISSN 0973-4562.**2018**,13,2068-2071
17. Jong-Sub Lee, A.B.; Sang Yeob Kim, C.D.; Won-Taek Hong, C.D.; Yong-Hoon Byun, C.D. Assessing subgrade strength using an instrumented dynamic cone penetrometer. *Soils and Foundations*. **2019**, 59, 930–941
18. A.A. Amadi, A.B.; S. Sadiku, C.D.; M. Abdullahi, C.D.; Danyaya, C.D. Case study of construction quality control monitoring and strength evaluation of a lateritic pavement using the dynamic cone penetrometer. *International Journal of Pavement Research and Technology*. **2018**, 11, 530–539.

doi:10.20944/preprints202404.0404.v1

19. Rodrigo Salgado, A.B.; Sungmin Yoon, C.D .; José Rodrigo Hernandez Ávila, C.D. Dynamic Cone Penetration Test (DCPT) for Subgrade Assessment .*INDOT Research*. **2003**
20. Nopanom Kaewhanam, A.B.; Prasat Juntasan, C.D.; Somkiat Narong, E.F. Evaluation of Highway Subgrade Compaction by Dynamic Cone Penetrometer. The Fifth International Conference on Science, Technology and Innovation for SustainableWell-Being, Luang Prabang, Lao PDR, 4-6 September 2013.