To Develop Correlation between California Bearing Ratio (CBR) and Dynamic Cone Penetrometer (DCP) value for subgrade soil of selected stretches of Suredranagar District

[1]Dilip D Parmar, [2]Ashraf Mathakiya,
[1]PG Student, [2]Assistant Professor,
Civil Engineering Department
Atmiya Institute of Technology & Science, Rajkot, India

Abstract: There is lack of correlation between dynamic cone penetrometer (DCP) and California bearing ratio (CBR) for subgrade materials. This reasearch aims at determining a correlation equation between California bearing ratio (CBR) and dynamic cone penetrometer (DCP) for subgrade soils of surendranagar city in Gujarat allowing to economically and appropriety determine bearing capacity of subgrade soils in pavements design. The relationship developed in this reasearch considers subgrade materials behavior and largely saves time and cost of preliminary and detailed engineering works of road projects. Total 52 pits locations of surendranagar region of Gujarat state, where tests were conducted on in-service flexible pavement and also samples were collected for laboratory test. A series of DCP tests in field and CBR, proctor, Atterberg's limit and grain size analysis tests in the laboratory has been conducted. Based on the field and laboratory test results relationship between DCP and CBR has been established. Power regression models were found to the best fit, which connecting soaked CBR with DPI shows strong correlation of a coefficient of determination (R2) of 0.876.

Keywords – *dynamic cone penetrometer, california bearing ratio soaked, geotechnical parameters*

I. INTRODUCTION

Subgrade comprises of unbound earth materials such as gravel, sand, silt and, clay that influence on the structural capacity of the pavement system. The quality of the Pavement depends largely on the strength and shear characteristics of subgrade material. The assessment of physical and strength properties of soil subgrade are vital in design, construction, and maintenance phases of the pavement structure. Therefore, to perform optimistic Pavement design, an accurate and representative material characterization technique is essential; such technique would be more acceptable in developing countries like India if it is simple, rapid and economic. 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 as an 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.One of most versatile frugal innovative equipment for In-situ subgrade strength assessment is Dynamic Cone Penetrometer (DCP). Primarily, this equipment is developed for the determination of in-situ CBR based on the penetration resistance in terms of mm/blow. DCP is also multi-advantageous equipment used to evaluate the in-situ strength of subgrade soil materials for road pavement works at shallow depths. DCP has a wide variety of applications such as Quality control/Quality assurance tool during construction phase and also provides primary design input for the flexible pavement.Therefore, predicting CBR value from DCP test and exploiting it during performance evaluation of pavement layers makes better option than using costly and time intensive procedures. The intention of this research is to establish a relationship between CBR and DCP which helps to predict CBR value from DCP test result that suits for the subgrade of soil. The aim of this research is to develop relationships between DCP and laboratory determined CBR for subgrade. To enhance the level of confidence of the DCP usage for used subgrade CBR determination. In this present study, region of surendranagar district of gujarat state was selected for in-situ testing on in- service flexible pavement. The site visit was carried out before testing and a finalized 48 km of length stretch. Intact length stretch is passing through plain terrain, has sufficient drainage condition and also observed rain cuts at some places on the embankment beyond the paved shoulder. Surendranagar district is located at the Western Coast of India in Gujarat city.

II. LITERATUREREVIEW

The importance of evaluation a sub-grade and CBR for structural design of pavement. Conventional methods are laborious and time consuming as studied Erlingsson (2007). Therefore, researchers try to robustly correlate the CBR with DCP obtained DPI for convenience of pavement engineers for rapid and economical design. Early interrelation model equations developed by various organizations and researchers are present in Table 1

Table 1 Interrelation model equations

Model Equation	Organization /Researcher
[1]. log CBR=2.456-1.12 log (DPI)	U.S Army corps of Engineers (USAGE), Webster et al (1992) Konrad and Lachance (2001), Siekmeier (2000), Chen et al. (2001) and Indian Roads Congress (IRC):37-2012
[2] log CBR = 1.4 -0.55 log (DPI)	Gabr et al. (2000)
[3] log CBR = 1.675 -0.7852 log (DPI)	George et al. (2009)
[4] log CBR = 2.51 – 1.074 log (DCPI)	A.A. Amadi, et. al. (2018)
[5] CBR = 64.727*$(DCPI)^{-0.724}$	Alle A. Hussein and Younis M. Alshkane (2018)
[6] log (CBR) = 0.441-0.296 log (DCPI)	Deepika.Chukka and Chakravarthi.V.K (2012)

Note: CBR in percentage and DPI in mm/blow.

The DCP and CBR, both are penetration tests and have significant interrelation. In this section, it is briefly reviewed, researchers, Smith and pratt(1983), Kleyn et al.(1982), Harison (1986), Livneh and ishai (1987), Chua (1988), Livneh et al.(1992), Livneh and Livneh (1994), Ese et al.(1994), Coonse (1999), Edil et al. (2005), Sawangsuriya et al. (2005) and Rao et al. (2008) described a usefulness and potentiality of the DCP to finding reliable and significant CBR values. Equation [1] is extensively used worldwide and was established by Webster et al (1992), earlier was developed by U.S. army corps of engineers (USAGE) for cohesive and granular material of sub grade. Livneh (1989), Konrad and Lachance (2001), Siekmeier (2000), Chen et al. (2001) and IRC: 37-2012 have also used it. Gabr et al. (2000) use the DCP for investigation of pavement distress condition using penetration rate for sub-base, sub-grade and developed an Equation [2]. George et al. (2009) develop equation [3] with the coefficient of determination (R^2) of 0.82 and penetration rate and CBR ranges from 1 to 18.3 mm per blow and 3.9 to 50 percentages respectively. A.A. Amadi, et. al. (2018) develop equation [4] The best correlation between the average DCP penetration rates and laboratory CBR in the present study for the top 500 mm (i.e., subgrade and sub-base layers) disregarding DCPI values of 2 mm/blow. Alle A. Hussein and Younis M. Alshkane (2018) A power relationship [5] was found between CBR and DCPI with coefficient of determination ($\boldsymbol{R^2}$) of 0.64.

III. METHODOLOGY FOR DATA COLLECTION

In this research work, Total 52 test pits of a uniform one metres by one metre square size was dug for perform tests on sub-grade. Test pit locations were selected uniformly at 800 metre interval on the outer wheel path, which covered 48 km of length stretch. The DCP test was conducted in accordance with ASTM D6951/D6951M – 09. The DCP test was conducted at the same test location for maintain undisturbed condition of sub-grade. The LWD test induces vibration but not affects the natural condition of sub-grade, while the DCP test does. 20 mm size penetration cone was set to ensure a proper contact between a tip of cone and top of sub-grade, then after a test commencement with considering first drop as seating drop, in which eight kg hammer was falling from 575 mm height for accurate measurements. Moreover, 300 mm penetration was attained and a corresponding number of drops recorded, DPI in mm per blow is calculated. Field dry density is also determined at same test location using the core cutter method for sub-grade as describe in IS: 2720- Part 29 (1975), test was conducted with a diameter of core 10 cm and height of core 12.8 cm.

Samples were collected from each pit location for laboratory testing to determine CBR, Atterberg's limit, grain size analysis and Proctor test. The 4 day soaked CBR tests at maximum dry density were conducted accordance with IS: 2720-Part 16 (1979), the standard CBR mould of 150 mm diameter and 125mm height was used. The CBR mould was filled by compacting soil in three equal layers. A steel hammer of 5kg weight was used to compact each layer of soil to the essential thickness. Three tests were conducted on the soil sample obtained from each pit location, and the average of the three was considered as the CBR value. Atterberg's, limit grain size analysis and Proctor test were determined as describe in IS: 2720-Part 5 (1985), (is 2720 - part 4) and IS: 2720-Part 2 (1973) respectively.

IV. RESULTS AND DISCUSSION

In this section, details of measured results of the in- situ DCP test conducted on in-service flexible pavement and laboratory determined, CBR, atterberg's limit grain size analysis and proctor test were discussed. Total 52 test point, location's wise experiment conducted of liquid limit(LI),plastic limit(PL),plasticity index (PI), water content (W), maximum dry density (MDD), CBR, DPI. The excel tool was used for complex regression analysis

V. DEVELOPMENT OF RELATION BETWEEN CBR AND DPI

To develop a relation between CBR and DPI, the origin tool was used. Various curve fitting methods were analyzed and found power and logarithm models are the best fitted model. The CBR and DCP obtained DPI are considered as an input variable, where a CBR is dependent and DPI is independent variable. For power model, model equation [7] with the observed coefficients of determination (R2) is 0.876, adjusted R2 is 0.873 and standard error of the estimated is 0.124. The regression equation is a significant (F= 352.042, p <0.001) and coefficients of the independent variable had a significant standardized regression weight of DPI (Beta= -0.936, t = -18.763, p <0.001). For logarithm models, model equation [8] with observed coefficient of determination (R2) is 0.784, adjusted (R2) is 0.780 and standard error of the estimated is 1.034. The regression equation is a significant (F= 181.869, p <0.001) and coefficients of the independent variable had a significant standardized regression weight of DPI (Beta= -0.866, t = -13.486, p <0.001. Power regression model results showed well significant of the correlation as compared to logarithm model. Therefore, only performance of a power model was analyzed. Herein, the CBR value varies in range from 2.5 (%) to 15 (%) and DPI 4 to 45 mm per blow. Scatter plots of a power and logarithmic regression models of DPI verse's sub-grade modulus is shown in Fig. 3.a.

$$CBR\ (\%) = 20.268\ (DPI)\ -0.505 \text{ or } \log(CBR) = 1.3068 - 0.505 \log(DPI),\ R^2 = 0.87 \qquad \text{Equation [7]}$$

$$CBR\ (\%) = 13.732 - 3.028 \ln(DPI),\ R^2 = 0.784 \qquad \text{Equation [8]}$$

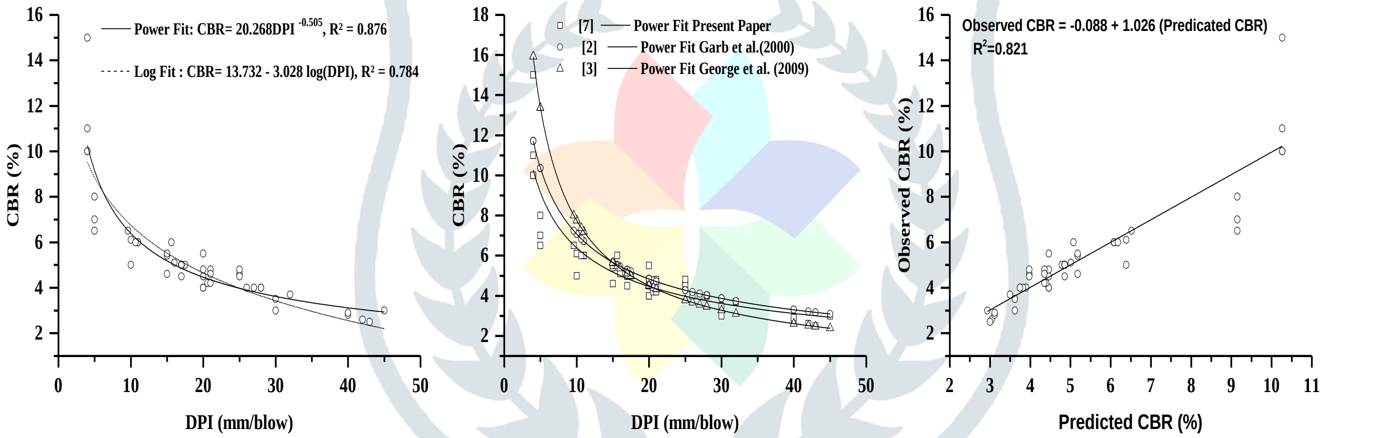

Figure 3.a: DPI vs CBR Figure 3.b: DPI vs CBR Figure 3 Predicted vs observed CBR

To check the trustworthiness of a present work power regression model, it is compared with various models as shown in Fig. 3.b. Mean absolute percent error (MAPE) was used to measure error between various models, which were expressed in Table.1. It was observed, equation [1], [2] and [3] follow a same trend line path with MAPE of 176.463 %, 9.372% and 15.231% respectively. Here, high value of error was due to models equations [1], [2] and [3] used unsoaked CBR. The scatter plot and best-fit curve connecting observed CBR values and predicted CBR values are shown in Fig.3 for equation [7] here, observed coefficient of determination (R2) is 0.821, adjusted R2 is 0.817 and standard error of the estimated is 0.942. The regression equation is a significant (F= 229.129, p <0.001).

VI. CONCLUSION

- Two equations are developed for connecting CBR with DPI; power model shows strong correlation of R^2 of 0.876 for Equation [7] as compared to logarithm model. It also follows a same trend line path with various early developed model and observed 9.372% and 15.231% MAPE for Equation [2] and [3] respectively and also observed strong correlation between predicted CBR and observed CBR with R2 of 0.821, which validate results.

REFERENCE

1. American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures (1993)
2. A.A. Amadi, et. Al. (2018). Case study of construction quality control monitoring and strength of a lateritic pavement using the dynamic cone penetrometer. Science Direct

3. Alle A. Hussein and Younis M. Alshkane (2018). Prediction of CBR and MR of fine grained soil using DCPI. Research gate (Conference paper)
4. American Society for Testing and Materials (ASTM), ASTM D6951/D6951M – 09 Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications.
5. Burnham, T. (1996). Application of Dynamic Cone Penetrometer to Mn-Dot Pavement Assessment Procedures. Revised Draft Report. Office of Minnesota Road Research.
6. Chen, D. H., Lin, D. F., Liau, P. H., & Bilyeu, J. (2005). A correlation between dynamic cone penetrometer values and pavement layer moduli. Geotechnical Testing Journal, 28(1), 42-49.
7. Chen, D. H., Wang, J. N., & Bilyeu, J. (2001). Application of dynamic cone penetrometer in evaluation of base and subgrade layers. Transportation Research Record: Journal of the Transportation Research Board, (1764), 1-10.
8. Chen, J., Hossain, M., & Latorella, T. (1999). Use of falling weight deflectometer and dynamic cone penetrometer in pavement evaluation. Transportation Research Record: Journal of the Transportation Research Board, (1655), 145-151.
9. Chua, K. M. (1988). Determination of CBR and elastic modulus of soils using a portable pavement dynamic cone penetrometer. In Penetration testing (pp. 407-414).
10. Chua, K. M., & Lytton, R. L. (1981). Dynamic analysis using the portable dynamic cone penetrometer. Transportation Research Record, 1192, 702-708
11. Coonse, J. W. (1999). Estimating California bearing ration of cohesive Piedmont residual soil using the Scala dynamic cone penetrometer.
12. Deepika.Chukka and Chakravarthi.V.K (2012). Evaluation of Properties of Soil Subgrade Using Dynamic Cone Penetration Index – A Case Study. International Journal of Engineering Research and Development
13. Edil, T. B., & Sawangsuriya, A. (2005). Investigation of the DCP and the SSG as Alternative Methods to Determine Subgrade Stability (No. 0092-01-05).
14. Erlingsson, S. (2007). On forecasting the resilient modulus from the CBR value of granular bases. Road Materials and Pavement Design, 8(4), 783-797.
15. Ese, D., Myre, J., Noss, P., & Vaernes, E. (1994). The use of dynamic cone penetrometer (DCP) for road strengthening design in Norway. In 4th International Conference, Bearing Capacity of Roads and Airfields (Vol. 1).
16. Gabr, M. A., Hopkins, K., Coonse, J., & Hearne, T. (2000). DCP criteria for performance evaluation of pavement layers. Journal of performance of constructed facilities, 14(4), 141-148.
17. George, V., Rao, N. C., & Shivashankar, R. (2009). PFWD, DCP and CBR correlations for evaluation of lateritic subgrades. International Journal of Pavement Engineering, 10(3), 189-199.
18. Harison, J. A. (1986). Correlation of CBR and dynamic cone penetrometer strength measurement of soils. Australian Road Research, 16(2).
19. Indian Road Congress (IRC), IRC: 37-2012 Guidelines for the Design of Flexible Pavements (Third Revision).
20. Indian Standard 2720 Part- 2 (1973 Methods of Test for Soils Part II Determination of Water Content (Second Revision)
21. Indian Standard 2720: Part 16 (1987) "Methods of Test for Soil Part 16 Laboratory Determination of CBR" (Second Revision)
22. Indian Standard 2720: Part 5 (1985) "Method of Test for Soils Part 5 Determination of Liquid and Plastic limit (Second Revision)
23. Kleyn, E. G., Maree, J. H., & Savage, P. F. (1982). Application of a portable pavement dynamic cone penetrometer to determine in situ bearing properties of road pavement layers and subgrades in South Africa.
24. Konrad, J. M., & Lachance, D. (2001). Use of in situ penetration tests in pavement evaluation. Canadian geotechnical journal, 38(5), 924-935.
25. Lin, D. F., Liau, C. C., & Lin, J. D. (2006). Factors affecting portable falling weight deflectometer measurements. Journal of geotechnical and geo-environmental engineering, 132(6), 804-808.
26. Livneh, M. (1989). Validation of correlations between a number of penetration tests and in situ California bearing ratio tests. Transportation Research Record, (1219).
27. Livneh, M., & Ishai, I. (1987). The Relationship between In-situ CBR Test and Various Penetration Tests. Technion-IIT, Transportation Research Institute.
28. Livneh, M., & Livneh, N. A. (1994). Subgrade strength evaluation with the extended dynamic cone penetrometer. In Proc. 7th Int. IAEG Congress.
29. Livneh, M., Ishai, I., & Livneh, N. A. (1992). Automated DCP device versus manual DCP device. Road and Transport Research, 1(4).
30. Rao, C. N., George, V., & Shivashankar, R. (2008, October). PFWD, CBR and DCP evaluation of lateritic subgrades of Dakshina Kannada, India. In The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics. Goa: Indian Institute of Technology.
31. Scala, A. J. (1956). Simple methods of flexible pavement design using cone penetrometers. New Zealand Engineering, 11(2), 34.

32. Smith, R. B., & Pratt, D. N. (1983). A field study of in situ California bearing ratio and dynamic cone penetrometer testing for road subgrade investigations. Australian Road Research, 13(4).
33. Webster, S. L., Grau, R. H., & Williams, T. P. (1992). Description and application of dual mass dynamic cone penetrometer (No. WES/IR/GL-92-3). Army Engineer Waterways Experiment Station Vicksburg Ms Geotechnical Lab.