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Prediction of California Bearing Ratio from Physical Properties of Fine-Grained Soils

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***Abstract*—**The California Bearing Ratio (CBR) has been acknowledged as an important parameter to characterize the bearing capacity of earth structures, such as earth dams, road embankments, airport runways, bridge abutments and pavements. Technically, the CBR test can be carried out in the laboratory or in the field. The CBR test is time-consuming and is infrequently performed due to the equipment needed and the fact that the field moisture content keeps changing over time. Over the years, many correlations have been developed for the prediction of CBR by various researchers, including the dynamic cone penetrometer, undrained shear strength and Clegg impact hammer. This paper reports and discusses some of the results from a study on the prediction of CBR. In the current study, the CBR test was performed in the laboratory on some fine-grained subgrade soils collected from various locations in Victoria. Based on the test results, a satisfactory empirical correlation was found between the CBR and the physical properties of the experimental soils.

***Keywords*—**California bearing ratio, fine-grained soils, pavement, soil physical properties.

I. Introduction

During the early 1920s, the California Bearing Ratio (CBR) test was developed by O. J. Porter for the California Highway Department to evaluate the bearing capacity of pavement materials in laboratory conditions [1]. Since then, several countries have developed or adopted pavement design methods based on the CBR value of the materials. The CBR is the most widely used strength parameter for fine-grained subgrade soils in flexible pavement design, while research into the use of the resilient modulus in pavement design continues [2].

In the CBR test, a standard plunger is used to penetrate the material at a standard rate (1mm/min). The CBR value is defined as the ratio between the applied load and the standard load of standard crushed rock shown in Table I for the plunger to reach the same depth [3].

$$\text{CBR} = \frac{\text{Applied load}}{\text{Standard load}} \times 100 \qquad (1)$$

The standard CBR test can be carried out in the laboratory or on site [5]-[8]. In the laboratory, the CBR test is typically performed on compacted soil samples, while, in the field, the CBR test would be performed on the ground surface, or on a level surface excavated in a test pit, trench, or bulldozer cut [9].

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TABLE I
LOAD-PENETRATION DATA FOR COMPACTED CRUSHED ROCK WITH CBR = 100 [4]

Penetration depth (mm)	Load (kN)
2	11.5
2.5	13.24
4	17.6
5	19.96
6	22.2
8	26.3
10	30.3
12	33.5

The CBR test method is most appropriate and gives the most reliable results for fine-grained soils. It can also be used to characterize the strength of pavement materials. In cohesionless soils, especially those that include large particles, the reproducibility of the test is poor [10]. In the laboratory test procedure, the test samples are prepared with soils of aggregate particle size of less than 19 mm. In the case of soils where particle sizes greater than 19 mm exist, the large particles are removed from the sample and replaced with an equal mass of material that falls between the 19 mm and 4.75 mm sieve size. In the field CBR test procedure, removal of larger particles that may adversely affect the test results is not possible, and, therefore, these types of soil are likely to produce unreliable results.

A. CBR Prediction

Field CBR testing is a time-consuming operation requiring a skilled operator, and can be hazardous for the evaluation teams in hostile environments. Limited amounts of published CBR data are available. Engineers always experience difficulties in obtaining representative CBR values for design. Due to limited budgets and poor planning conditions, insufficient soil investigation data are obtained in many cases. On the other hand, the laboratory CBR test is not only laborious and time consuming, but, sometimes, the results are not accurate due to the sample disturbance and poor quality of the laboratory testing conditions. Therefore, the development of prediction models might be useful and become a base for the judgment of the validity of the CBR values. Over the years, many correlations have been developed for the prediction of CBR by various researchers, including the dynamic cone penetrometer (DCP), undrained shear strength and Clegg impact hammer [11]-[19]. In addition, there have been several attempts to predict CBR values based on the

USCS soil classification. Table II shows the summary of some predictions reported in previous research.

TABLE II
PREDICTION OF CBR FROM USCS SYMBOL

References	USCS Symbol						
	CH	CL	MH	ML	OH	OL	SC
Army Corps of Engineers (1960) [20]	15 or less	15 or less	10 or less	15 or less	5 or less	5 or less	5-20
Yoder and Witczak (1975) [1]	3-5	5-15	4-8	5-15	3-5	4-8	10-20
National Cooperative Highway Research Program (2004) [21]	1-5	5-15	2-8	8-16	-	-	10-20
Austroads (2012) [2]	5	5-6	-	4	-	-	5-6
Austroads (2012) [2]	2-3	3-4	-	2	-	-	3-4

Semen [22] discussed several site-specific or specialized prediction models, in which soils from a specific location or region were sampled and tested to determine the CBR relationships specific to those soils. The equations developed include among others terms for the field dry density, moisture content, plasticity index, and liquid limit. These approaches, although developed to work in specific locations, may also be applied in a global database and prediction model.

Moreover, there have been attempts to develop prediction models based on the fact that there is some form of relationship between the CBR of soils and the soil index properties. However, most of these previous models were essentially statistical correlations between the CBR and classification data and/or index properties of the soil. Many researchers have conducted studies to show the effect of soil type and characteristics on the CBR values [23]-[25] and [21]. Some efforts have been devoted to correlate the CBR with the soil grain distribution and plasticity. Among them, [23] developed a correlation between the CBR and the plasticity index (PI) for cohesive soils. Using the concept of a suitable index, which varies according to the plasticity and grading characteristics, a correlation for CBR was suggested by [24]. The suitability index is:

$$\mathrm{CBR} = \frac{(\#2.4\mathrm{mm})}{\mathrm{Log(PI)} \times \mathrm{(LL)}} \quad (2)$$

where #2.4mm is percentage passing 2.4 mm BS sieve; LL is liquid limit; PI is plasticity index.

Agarwal and Ghanekar [25] tried to develop a correlation equation between the CBR and the liquid limit, plastic limit (PL) or plasticity index. However, they were not able to find any significant correlation among these parameters. Instead, they found an improved correlation when optimum moisture content (OMC) and liquid limit were included. Hence, they suggested a correlation that was only of sufficient accuracy for the preliminary identification of material. This correlation is:

$$\mathrm{CBR} = 2 - 16 \times \mathrm{Log(OMC)} + 0.07 \times \mathrm{(LL)} \quad (3)$$

In [26], it was also concluded that the CBR is most dependent on the maximum dry density (MDD) and is least dependent on OMC. Using MDD and OMC as independent variables, several equations for CBR have been presented. Stephens [27] carried out an investigation in which archival data were used to evaluate the performance of existing models for some selected Natal soils. He described the relationships between the CBR and various classification parameters (in both simple and multivariate forms); however, further examination of these models found them to be generally unsatisfactory. In this study, the lack of any suitable correlations for universal use was discussed and a good relationship between the CBR and maximum swell was examined. The influence of the clay fraction on the CBR was reported and the interim use of the shrinkage and grading moduli to obtain minimum CBR values for shrinking and non-shrinking soils respectively was proposed. Another method for the estimation of the CBR, which was presented by [28], made use of the plasticity index for British soils compacted at natural moisture content for which the correlations were given in the format of a table.

The National Cooperative Highways Research Programme through the "Guide for mechanical-empirical design of new and rehabilitated pavement structures" [29] suggested some correlations that describe the relationship between the soil index properties and the CBR. For plastic fine-grained soils, the chosen soil index properties to correlate with the CBR are the percentage passing No. 200 US sieve or 0.075 mm size sieve and the plasticity index. The suggested equation is:

$$\mathrm{CBR} = \frac{7}{1 + 0.728 \times (\#200) \times (\mathrm{PI})} \quad (4)$$

where #200 is passing No. 200 US sieve (%); PI is plasticity index.

Moreover, [30] also developed a new lightweight dynamic cone penetrometer to predict the CBR values for fine-grained subgrade soils. The findings showed a strong correlation between the CBR and lightweight dynamic cone penetration index [31]-[33].

II. MATERIALS AND METHODS

A. Experimental Materials

In the testing programme, a total of eight different fine-grained soils obtained from different suburbs in Melbourne, Victoria, were used. The physical properties of the soil samples were determined according to the Australian Standards [34]-[36]. The summary of the physical properties of these experimental soils is shown in the following table:

TABLE III
PHYSICAL PROPERTIES OF EXPERIMENTAL SOIL SAMPLES

Sample	Sample location	USCS Symbol	OMC (%)	MDD (T/m^3)	PI (%)
S1	Featherbrooke Estate, Point Cook	CL	26.8	1.41	15
S2	Deer Park Bypass, Deer Park	CL	19.5	1.49	7
S3	Waverley Park Estate, Mulgrave	CL	20.1	1.57	10
S4	Garnet Street, Ferntree Gully	CH	22.9	1.67	33
S5	Kingsley Avenue, Point Cook	CL	19.6	1.52	11
S6	Processed quarry by-product	SC	17.0	1.81	10
S7	Processed product	SC	14.0	1.84	8
S8	Processed product	SC	15.0	1.82	8

B. CBR Test

The apparatus used for the CBR test comprised a standard CBR apparatus with a computer interface. Fig. 1 is a photograph of the CBR set up with a specimen. The penetration was measured using a 25 mm strain transducer mounted on the CBR plunger. The load was measured using a 50.0 kN S-type load cell.

TABLE IV
CBR VALUES FOR THE EXPERIMENTAL SOILS AT DIFFERENT MOISTURE CONTENTS

Sample	Moisture content (%)	Comments
S-1-O	26.8	OMC
S-1-W	30.0	Wet of OMC
S-1-D	24.0	Dry of OMC
S-1-S	37.0	Soaked condition
S-2-O	19.5	OMC
S-2-W	23.0	Wet of OMC
S-2-D	17.0	Dry of OMC
S-2-S	29.0	Soaked condition
S-3-O	20.1	OMC
S-3-W	23.0	Wet of OMC
S-3-D	17.0	Dry of OMC
S-3-S	27.0	Soaked condition
S-4-O	20.4	OMC
S-4-W	23.0	Wet of OMC
S-4-D	18.0	Dry of OMC
S-4-S	27.0	Soaked condition
S-5-O	17.5	OMC
S-5-W	20.0	Wet of OMC
S-5-D	15.0	Dry of OMC
S-5-S	24.0	Soaked condition
S-6-O	17.0	OMC
S-6-W	19.0	Wet of OMC
S-6-D	14.5	Dry of OMC
S-6-S	19.5	Soaked condition
S-7-O	14.0	OMC
S-7-W	16.5	Wet of OMC
S-7-D	11.5	Dry of OMC
S-7-S	18.9	Soaked condition
S-8-O	15.0	OMC
S-8-W	17.5	Wet of OMC
S-8-D	12.5	Dry of OMC
S-8-S	19.6	Soaked condition

Fig. 1 CBR testing apparatus

The samples were prepared at different moisture contents, including optimum moisture content (OMC), wet of OMC, dry of OMC and soaked conditions. After each soil specimen was prepared, the CBR tests were carried out according to the Australian standard [5].

III. RESULTS AND DISCUSSION

As mentioned earlier, the CBR tests were carried out for four different moisture levels for each experimental soil. These were dry of OMC (-2.5%), OMC, wet of OMC (+2.5%) and soaked condition. The testing results are presented in Figs. 2 (a)-(h).

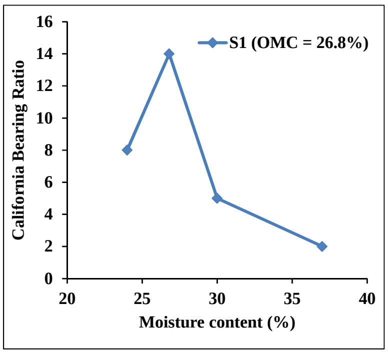

Fig. 2 (a) The CBR versus the moisture content for soil sample S1

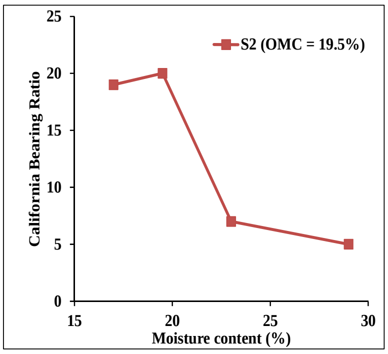

Fig. 2 (b) The CBR versus the moisture content for soil sample S2

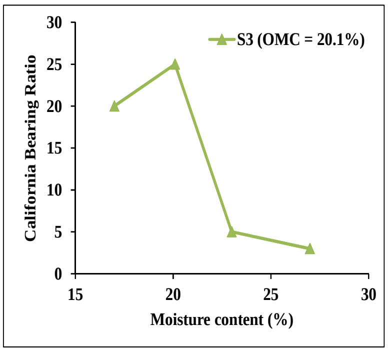

Fig. 2 (c) The CBR versus the moisture content for soil sample S3

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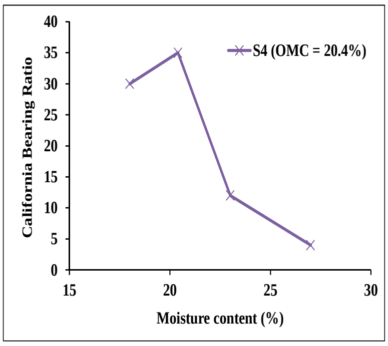

Fig. 2 (d) The CBR versus the moisture content for soil sample S4

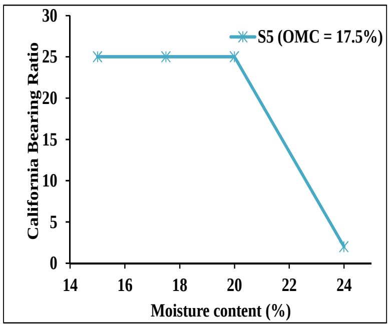

Fig. 2 (e) The CBR versus the moisture content for soil sample S5

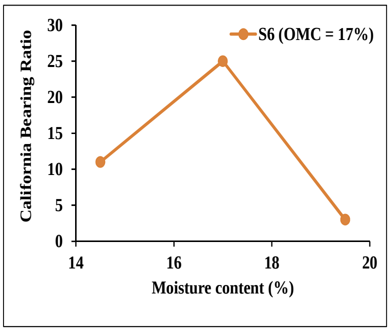

Fig. 2 (f) The CBR versus the moisture content for soil sample S6

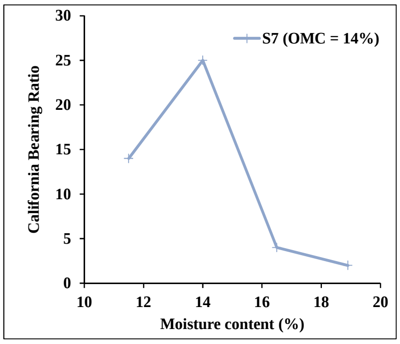

Fig. 2 (g) The CBR versus the moisture content for soil sample S7

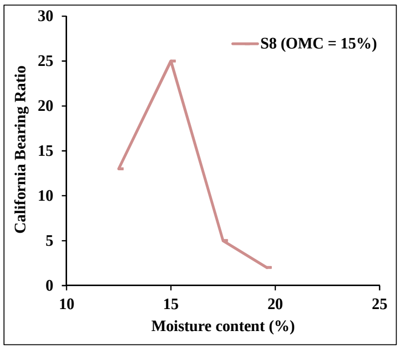

Fig. 2 (h) The CBR versus the moisture content for soil sample S8

Figs. 2 (a)-(h) show, as expected, that, as the moisture content changes, the CBR value changes accordingly. For example, at the wet side of OMC, when the moisture content of the soil sample increases, the CBR value decreases due to the reduction of the shear strength and the density of the experimental fine-grained soils. Moreover, the maximum CBR values occur at the OMC. This observation is in good agreement with the reports from previous research work.

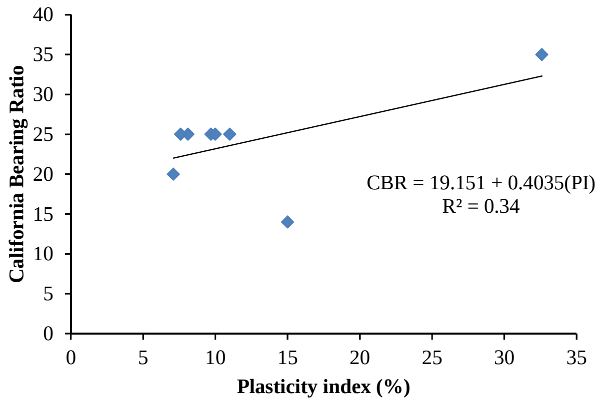

Fig. 3 Plasticity index versus CBR for the experimental soil samples at OMC

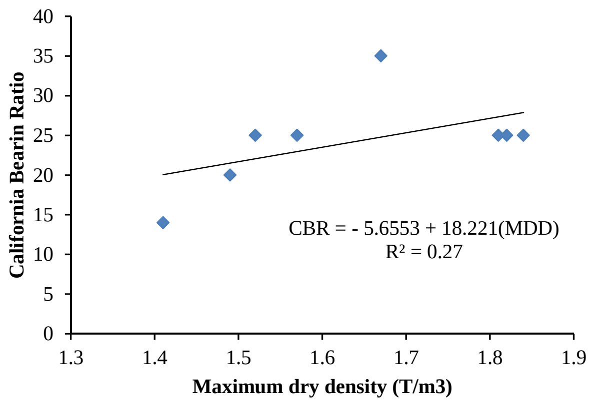

Fig. 4 Maximum dry density versus CBR for all experimental soil samples at OMC

To investigate the effect of other soil physical properties, such as the plasticity index and maximum dry density on CBR, these values are plotted against the CBR, as illustrated in Figs. 3 and 4.

It can be seen from Figs. 3 and 4, that, overall, the plasticity index and maximum dry density have an effect on CBR. For example, for soil S2 and S4, the CBR increases as the plasticity index increases. Moreover, for soil S1, S2, S3, S4 and S5, the CBR values increase as the maximum dry density increases. Based on the experimental results, the correlations between the CBR and moisture content, plasticity index and maximum dry density for each experimental soil sample were analysed and are presented in Table V.

TABLE V
CORRELATION OF CBR AND MOISTURE CONTENT (MC), PLASTICITY INDEX (PI) AND MAXIMUM DRY DENSITY (MDD) FOR EACH EXPERIMENTAL SOIL SAMPLE

Sample	Equation	R^2
S1	$\text{Log(CBR)} = 3.5 + 1.179(\text{MC}) + 0.255(\text{PI}) - 5(\text{MDD})$	0.38
S2	$\text{Log(CBR)} = 4 + 1.260(\text{MC}) - 0.125(\text{PI}) + 0(\text{MDD})$	0.28
S3	$\text{Log(CBR)} = 16 + 0.397(\text{MC}) + 4.625(\text{PI}) - 24(\text{MDD})$	0.61
S4	$\text{Log(CBR)} = 16 + 0.915(\text{MC}) + 0.554(\text{PI}) - 18(\text{MDD})$	0.56
S5	$\text{Log(CBR)} = 2 + 0.692(\text{MC}) + 0.344(\text{PI}) - 1(\text{MDD})$	0.90
S6	$\text{Log(CBR)} = 4 + 1.491(\text{MC}) - 0.063(\text{PI}) + 0(\text{MDD})$	0.61
S7	$\text{Log(CBR)} = 1 - 0.823(\text{MC}) + 0(\text{PI}) + 2(\text{MDD})$	0.75
S8	$\text{Log(CBR)} = 32 + 1.466(\text{MC}) - 3(\text{PI}) - 4(\text{MDD})$	0.69

From Table V, it can be seen that the R^2 values vary significantly from 0.28 to 0.9 for the experimental soils used in this study. By taking into account all the soil samples, regression (5) was found for the CBR as a function of the moisture content, plasticity index and maximum dry density.

$$\text{Log(CBR)} = 5.549 - 0.082(\text{MC}) + 0.021(\text{PI}) - 1.940(\text{MDD}) \quad (R^2 = 0.66) \tag{5}$$

It should be noted that in the field, the subgrade soil is recommended to be compacted at the OMC initially in order to achieve the MDD. Over the service life of the infrastructure, under the changes of the seasonal climate and the drainage conditions, the moisture content of the subgrade soils underneath the infrastructure eventually changes to the wet side of the OMC. For instance, [37] found that the subgrade soils showed an increase in moisture content of about 30% higher than the plastic limit of the soil during the first 5 years of pavement service life. Moreover, it was also reported that the moisture content of the subgrade soils would change until reaching the equilibrium moisture content [38], [39]. Therefore, in order to eliminate that effect and characterise the typical change in the moisture content, it is recommended to consider only the wet side of the OMC in the relationship. In addition, including the results from OMC and only wet side of OMC in the regression analysis, regression (6) was found to have the significantly higher R^2 value of 0.75.

$$\text{Log(CBR)} = 4.767 + 0.843(\text{MC}) + 0.020(\text{PI}) - 1.522(\text{MDD}) \quad (R^2 = 0.75) \tag{6}$$

In order to examine and illustrate the above correlation, the experimental CBR results have been plotted against the predicted CBR values from (6) in Fig. 5 for all the experimental soil samples.

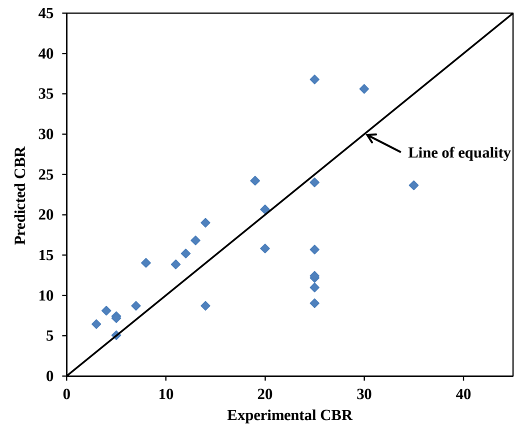

Fig. 5 The experimental CBR versus predicted CBR for all tested soil samples

Fig. 5 shows the predicted CBR values against the actual CBR results for the experimental soils at different moisture contents of OMC, wet side of OMC and soaked conditions. As mentioned before, it can be seen from the above figure that the variations predicted and measured CBR values for some of the soil samples are high while for most of the samples the variations are not significant.

IV. CONCLUSION

In the current study, the effect of soil physical properties, including moisture content, plasticity index and maximum dry density, on the California Bearing Ratio (CBR) values for fine-grained soils was investigated. Eight different fine-grained soils were collected from various locations in Melbourne, Australia. For each soil sample, the CBR tests were carried out at four different moisture contents, including the dry of optimum moisture content (OMC), OMC, wet of OMC and soaked condition. Based on the testing results, the following conclusions are drawn:

The effect of moisture content on CBR value is significant. For example, on the wet side of OMC, as moisture content increases, the CBR decreases significantly.

The maximum CBR is observed at the OMC because at this moisture level, the maximum dry density and the highest strength are achieved.

The influence of the plasticity index on the CBR is not clear. However, the effect of the maximum dry density on the CBR is clearly observed with the proportional relationship. The CBR increases as the maximum dry density increases.

From the experimental results, the correlation of CBR and the moisture content (MC), plasticity index (PI) and maximum dry density (MDD) was found to be strong for the samples tested at OMC, wet side of OMC and soaked conditions.

$$\text{Log (CBR)} = 4.767 + 0.843(\text{MC}) + 0.020(\text{PI}) - 1.522(\text{MDD}) \quad (R^2 = 0.75)$$

It should be noted that the above relationship is for the experimental soil samples. Therefore, further investigation with more different fine-grained soil samples and testing conditions is recommended.

Notation

CBR California bearing ratio
PI plasticity index (%)
MC moisture content (%)
MDD maximum dry density (t/m3)
OMC optimum moisture content (%)
USCS unified soil classification system

References

[1] E. J. Yoder and M. W. Witczak, “Principles of pavement design” 2nd Ed. New York: John Wiley & Sons, 1975.
[2] Austroads, “A guide to the structural design of road pavements” Austroads, 2012.
[3] M. Aytekin, “Soil mechanics” Academy Publishing house, Trabzon, Turkey, 2000.
[4] BS 1377-4, “Methods of test for soils for civil engineering purposes. Compaction-related tests“ British Standard, UK, 1990.
[5] AS 1289.6.1.1, “Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the California Bearing Ratio of a soil - Standard laboratory method for a remoulded specimen” Australian Standard, Australia, 1998.
[6] AS 1289.6.1.3, “Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the California Bearing Ratio of a soil - Standard field-in-place method” Australian Standard, Australia, 1998.
[7] American Society for Testing and Materials, “D 1883-05, Standard test method for CBR (California bearing ratio) of laboratory-compacted soils” Annual Book of ASTM Standards, Vol. 04.08. West Conshohocken, PA: ASTM, 2005.
[8] American Society for Testing and Materials, “D 4429-04, Standard test method for CBR (California bearing ratio) of soils in place” Annual Book of ASTM Standards, Vol. 04.08. West Conshohocken, PA: ASTM, 2004
[9] W. R. Day, “Soil testing manual: procedures, classification data, and sampling practices” USA, 2001.
[10] M. P. Rollings and R. S. Rollings, “Geotechnical materials in construction” McGraw-Hill, New York, 1996.
[11] E. G. Kleyn, “The use of the dynamic cone penetrometer” Rep. No. 2/74, Transvaal Roads Department, Pretoria, South Africa, 1975.
[12] M. Livneh, “The use of dynamic cone Penetrometer in determining the strength of existing pavements and subgrades” Proceedings of Southeast Asian Geotechnical Conference, Bangkok, Thailand, 1987.
[13] J. A. Harison, “In situ California bearing ratio determination by dynamic cone penetrometer testing using a laboratory based correlation” Australian Road Research, Vol. 19 No. 4, pp. 313-317, 1989.
[14] M. Livneh, I. Ishai and N. A. Livneh, “Effects of vertical confinement on dynamic cone penetrometer strength values in pavement and subgrade evaluations” Transport Research Record 1473, Transportation Research Board, Washington, DC, 1992.
[15] D. Ese, J. Myre, P. Noss and E. Vxrnes, “ The use of dynamic cone Penetrometer for road strengthening design in Norway” Proceedings of the 4th International Conference on the Bearing Capacity of Roads and Airfields, pp. 343-357, 1994.
[16] J. Coonse, “Estimating California bearing ratio of cohesive piedmont residual soil using the Scala dynamic cone penetrometer” Thesis (Master), North Carolina State University, Raleigh, N.C, 1999.
[17] M. A. Gabr, K. Hopkins, J. Coonse and T. Hearne, “DCP criteria for performance evaluation of pavement layers” Journal of Performance and Constructed Facilities, Vol. 14, pp. 141-148, 2000.
[18] O. Al-Amoudi, I. Asi, H. Wahhab and Z. Khan, “Clegg hammer – California Bearing Ratio correlations” Journal of Materials in Civil Engineering, Vol. 14, pp. 512–523, 2002.
[19] G. H. Gregory, “Correlation of California Bearing Ratio with shear strength parameters” Transportation Research Record: Journal of the Transportation Research Board, Vol. 1989, pp. 148-153, 2007.
[20] U.S. Army Corps of Engineers, “Validation of soil strength criteria for aircraft operation on unprepared landing strips: Vicksburg, Mississippi” Waterways Experiment Station, technical report 3-554, 1960.
[21] National Cooperative Highway Research Program, “Guide for mechanistic-empirical design of new and rehabilitated pavement structures” Final Report for Project 1-37A, Appendix CC-1: Correlation of CBR Values with Soil Index Properties. Washington, DC: NCHRP, Transportation Research Board, National Research Council, 2004.
[22] P. M. Semen, “A generalized approach to soil strength prediction with machine learning methods” Technical Report ERDC/CRREL TR-06-15. Hanover, NH: Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, 2006.
[23] W. P. M. Black, “A method of estimating the CBR of cohesive soils from plasticity data” Geotechnique, Vol. 12, pp. 271–272, 1962.
[24] J. W. S. De Graft-Johnson and H. S. Bhatia, “The engineering characteristics of the lateritic gravels of Ghana” Proceedings of 7th international conference on soil mechanics and foundation engineering, Vol. 2, Mexico, pp. 13–43, 1969.
[25] K. B. Agarwal and K. D. Ghanekar, “Prediction of CBR from plasticity characteristics of soil” Proceeding of 2nd south-east Asian conference on soil engineering, Singapore, pp. 571–6, 1970.
[26] S. N. Doshi, M. S. Mesdary and H. R. Guirguis, “Statistical study of laboratory CBR for Kuwaiti soils” The fourth conference of the road engineering association of Asia and Australasia, Vol. 2, Jakarta, pp. 43–51, 1983.
[27] D. J. Stephens, “Prediction of the California bearing ratio” The Journal of the South African Institution of Civil Engineering, Vol. 32 No.12, pp. 523–527, 1990.
[28] British Highway Agency, “Design manual for roads and bridges” Vol. 7. London: Stationery Ltd., Section 2, Part 2 HD 25/94, 1994.
[29] National Cooperative Highway Research Program, “Guide for mechanistic and empirical – design for new and rehabilitated pavement structures, final document” Appendix CC-1: correlation of CBR values with soil ındex properties, West University Avenue Champaign, Illinois: Ara, Inc, 2001.
[30] B. T. Nguyen and A. Mohajerani, “Development of a new dynamic lightweight penetrometer for the determination of mechanical properties of fine-grained soils” Journal of Civil Engineering and Architecture, Vol. 6 No.10, pp. 1417-1422, 2012.
[31] B. T. Nguyen and A. Mohajerani, “A new lightweight dynamic cone penetrometer for laboratory and field application” Journal and News of the Australian Geomechanics Society, Vol. 47 No.2, pp. 41-50, 2012.
[32] B. T. Nguyen and A. Mohajerani, “Determination of CBR for fine-grained soils using a dynamic lightweight cone penetrometer” International Journal of Pavement Engineering, 2014.
[33] B. T. Nguyen and A. Mohajerani, “A new dynamic cone penetrometer to predict CBR for fine-grained subgrade soils in the laboratory and field conditions” 11th Australia-New Zealand Conference on Geomechanics: Ground Engineering in a Changing World, Melbourne, Australia, 2012.
[34] AS 1289.5.1.1, “Methods of testing soils for engineering purposes - Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using standard compactive effort” Australian Standard, Australia, 2003.
[35] AS 1289.3.1.1, “Methods of testing soils for engineering purposes - Soil classification tests - Determination of the liquid limit of a soil - Four point Casagrande method” Australian Standard, Australia, 2009.
[36] AS 1289.3.2.1, “ Methods of testing soils for engineering purposes - Soil classification tests - Determination of the plastic limit of a soil - Standard method” Australian Standard, Australia, 2009.
[37] J. Uzan, “Characterization of clayey subgrade materials for mechanistic design of flexible pavements” Transportation Research Record. 1629, Transportation Research Board, Washington, D.C., pp. 188–196, 1998.
[38] M. K. Elfino and J. L. Davidson, “Modeling field moisture in resilient modulus testing” Geotechnical Special Publication 24, ASCE, pp. 31–51, 1989.
[39] G. B. Thadkamalla and K. P. George, “Characterization of subgrade soils at simulated field moisture” Transportation Research Record. 1481, Transportation Research Board, Washington, D.C., pp. 21–27, 1995.