A NEW DYNAMIC CONE PENETROMETER TO PREDICT CBR FOR FINE-GRAINED SUBGRADE SOILS IN LABORATORY AND FIELD CONDITIONS

Bao Thach Nguyen[1] and Abbas Mohajerani[2]

[1]School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia; PH (61) 03-9925-3847; FAX (61) 03-9925-3921; email: baothach.nguyen@rmit.edu.au
[2]School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia; PH (61) 03-9925-3082; FAX (61) 03-9925-3921; email: dr.abbas@rmit.edu.au

ABSTRACT

Since originally developed in 1959 by Scala in Australia, the Dynamic Cone Penetrometer (DCP) has been extensively used to characterise the strength of pavement materials. The literature review reveals that DCP is mainly used as an in situ device and laboratory application of DCP, in a mould, was rarely reported, due to the confining effect. In this study a lightweight DCP that can be used in a CBR mould in the laboratory as well as in the field with similar results was developed and the results show that the influence of the confinement on the DCP can be eliminated when the hammer mass is 2.25 kg. And a strong correlation was found between CBR and the new light dynamic penetrometer index for six fine-grained soil samples, with different moisture contents, used in this study.

Keywords: dynamic cone penetrometer, California Bearing Ratio.

1. INTRODUCTION

The early development of the DCP was reported by Scala in 1959. It was originally developed as an in situ device to assess and monitor the characteristics of pavement materials. The standard DCP described in the AS 1289.6.3.2-1997 consists of a 16 mm steel rod, to which a steel cone with a 20 mm base diameter and 60° cone tip is attached. The DCP is driven into the soil by a 9 kg hammer with a falling height of 510 mm. In testing, the DCP is held vertically to the surface of the soil to be tested and two operators are required. One person is to hold the device, lift the hammer to the stop and drop the hammer freely onto the anvil to drive the DCP into the soil and another one is to record the readings. The accumulative number of blows and penetration depth is recorded during the operation. The slope of the curve defining the relationship between the penetration depth and number of blows is described as the dynamic cone penetration index (DCPI) in mm/blow.

Generally speaking, the DCP is an inexpensive, portable and easy to operate instrument. However, performing the DCP experiment can be labour intensive due to the heavy hammer. Parker and Hammons (1998) proposed an idea for an Automated Dynamic Cone Penetrometer. Basically, the set up consists of a vertical frame with wheels for lifting and dropping the hammer. The results are collected automatically by a data logger. In a similar attempt, Webster et al. (1992) at the US Army Corps of Engineers proposed the dual mass dynamic cone penetrometer, a modified version of the DCP with 8 kg hammer (ASTM D6951, 2003). In the dual mass dynamic cone penetration device, the hammer weight decreased to 4.6 kg. This mass for the hammer reduces the DCPI by half of that of the original DCP with a mass of 8 kg. With the same objective, Fumio et al. (2004) also developed an automated data collection system for portable DCP with a hammer mass of 3 kg. However, the use was limited to field surveys and no information was mentioned about the laboratory application.

As mentioned earlier, the DCP was mainly designed for field conditions. The application of DCP in the laboratory has rarely been reported, due to the effect of the lateral confinement. When performing the DCP in laboratory conditions inside a compaction mould or a CBR mould, the confining effect will become very significant and the results will not be comparable with those obtained in the field. The objective of this investigation was to study the effect of the confinement of a CBR mould on the DCP test results and develop a light DCP that can be used in the laboratory, in the CBR mould, as well as in the field for the determination of CBR, and other soil parameters, for fine-grained subgrade soils.

2. MATERIALS AND METHODS

2.1 Physical properties of experimental soils

The experimental fine-grained soils were collected from different suburbs in Melbourne, Victoria. The physical properties of the soils were determined according to the Australian Standards. A summary of the soils properties measured is presented in Table 1.

Table 1: Physical properties and compaction results of soil samples used in this study

Sample No.	Sample location	USCS Symbol	OMC (%)	MDD (t/m^3)	LL (%)	PL (%)	PI (%)
S-1	Deer Park Bypass, Deer Park	CL	19.5	1.49	25.3	18.2	7.1
S-2	Featherbrooke Estate, Point Cook	CL	26.8	1.41	39.1	24.1	15.0
S-3	Waverley Park Estate, Mulgrave	CL	20.1	1.57	31.8	22.1	9.7
S-4	Garnet Street, Ferntree Gully	CH	22.9	1.67	56.0	23.4	22.6
S-5	Kingsley Avenue, Point Cook	CL	19.6	1.52	25.4	13.7	11.7
S-6	Processed quarry by-product	SC	17.0	1.81	31.0	21.0	10.0

2.2 Laboratory test procedure

The testing program consisted of two stages. The first stage was the development of the new lightweight DCP that can be used in the laboratory and in the field. The second stage was the investigation of the relationship of CBR and the new lightweight DCP index (DLP).

In the first stage, two sets of DCP tests were performed on compacted soil (S1) in mould 1 (M1) and mould 2 (M2), as shown in Figure 1. The soil was compacted, in both moulds, with OMC (19.5%) and the same density was produced in order to achieve comparable data.

Figure 1: DCP test in the CBR mould (M1) and in the 700 mm x 700 mm x 700 mm mould (M2)

The main purpose for using the large mould was to simulate the field conditions by eliminating the confining effect of the wall of the mould on penetration results. The fundamental background to simulate the field condition comes from the conclusion of Abu Farsakh *et al.* (2004) and Mohammadi *et al.* (2008). In their investigation of the effect of the mould sidewalls on the DCP test results, they proposed that the minimum distance between the cone tip and the edge of the testing mould should be 250 mm in order to completely eliminate the mould size effect.

Technically speaking, the hammer mass has a significant impact on the value of DCP index. Therefore, a wide range of hammers, including 2.5, 3.5, 4.6, 6.0, 8.0 and 9.0 kg was selected and used in the current work. The range of hammers was selected based on the literature review and after some trial experiments. For example, the selection of 9 and 8 kg hammers are from the AS 1289.6.3.2 (1997) and ASTM D6951 (2003), respectively. Moreover, the 4.6 kg hammer is from Webster (1992) at the US Army Corps of Engineers. In this stage, all penetration tests were conducted with the Australian dynamic cone penetrometer with different hammer masses (AS 1289.6.3.2-1997; steel cone-30 degrees angle; 20 mm diameter rod; 510 mm drop height).

In the second stage, CBR tests and penetration tests using the newly developed lightweight DCP were carried out on all compacted soil samples in a CBR mould. For the CBR and penetrometer tests, different moisture contents were used as shown in Table 3. The compaction effort was kept constant throughout testing. Each specimen was tested only once at each varying moisture content due to time constraints. A total of 24 CBR tests and 24 lightweight DCP tests were performed.

3. RESULTS AND DISCUSSION

The results of the DCP tests in mould M1 and M2 are summarised in Table 2 and illustrated in Figure 2.

Table 2: DCPI for mould M1 and mould M2

Hammer mass (kg)	DCPI in mould M1 (mm/blow)	DCPI in mould M2 (mm/blow)	The difference of DCPI, in Mould 1 and Mould 2 (mm/blow)
9.0	14.3	25.5	11.2
8.0	10.6	17.3	6.7
6.0	6.9	11.7	4.8
4.6	5.2	8.6	3.4
3.5	3.7	4. 7	1.0
2.5	2.3	2.4	0.1

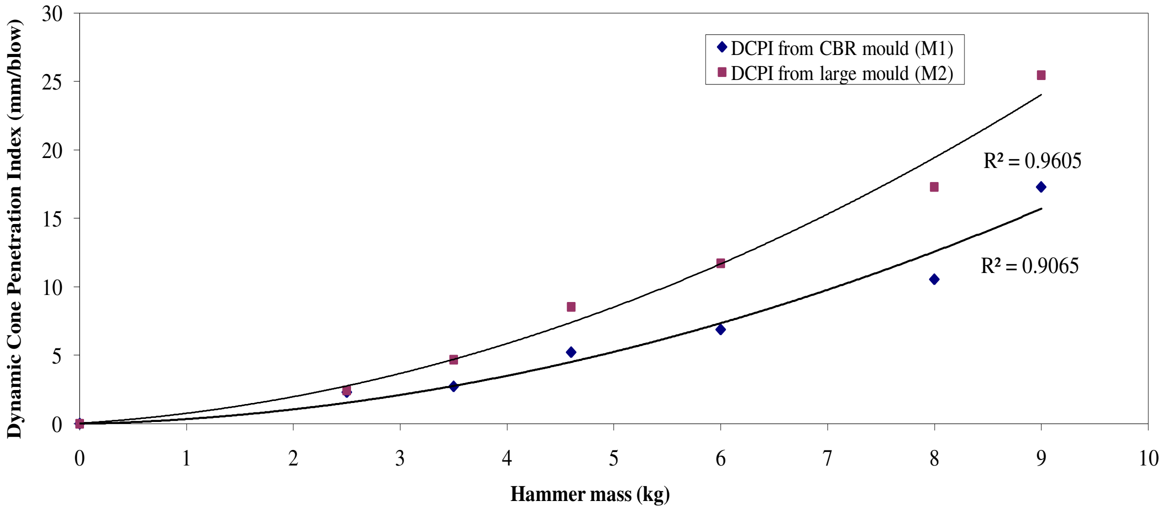

Figure 2: DCPI vs. hammer mass for mould M1 and M2 for soil S-1 used in this study

The results show that DCPI values are significantly higher for the larger hammer masses and the difference in DCPI values from the small and large moulds increases with the increase in the hammer mass. The differences clearly show the confining effect of the CBR mould (M1) on the DCP test results with different hammer masses.

Furthermore, the difference in value of DCPI reduces to an insignificant value for a hammer mass of less than 2.5 kg, for the experimental soil, and number of tests carried out in this study. It means that the results of a DCP test in a CBR mould in the laboratory will be almost similar to the results from a DCP test in the field using the same hammer for the same soil conditions. Based on these findings, the optimised mass for the hammer of the new lightweight DCP can be selected as 2.25 kg, which can eliminate the influence of the confining pressure from the sidewall in a CBR mould.

In the second stage, DCP and CBR experiments were performed with different soil samples at different moisture contents. The summary of dynamic light penetrometer (DLP) and CBR results are presented in the Table 3.

Table 3: DLP and CBR values for soil sample S-1, S-2, S-3, S-4, S-5 and S-6

Sample No.	Moisture Content (%)	DLP (mm/blow)	CBR (%)	Comments
S-1	19.5	2	20	OMC
S-1	23.0	3	7	Wet of OMC
S-1	17.0	2	19	Dry of OMC
S-1	29.0	10	5	Soaked condition
S-2	26.8	3	14	OMC
S-2	30.0	6	5	Wet of OMC
S-2	24.0	5	8	Dry of OMC
S-2	37.0	11	2	Soaked condition
S-3	20.1	2	26	OMC
S-3	23.0	5	5	Wet of OMC
S-3	17.0	2	21	Dry of OMC
S-3	27.0	11	3	Soaked condition
S-4	20.4	1	35	OMC
S-4	23.0	6	12	Wet of OMC
S-4	18.0	2	31	Dry of OMC
S-4	27.0	8	4	Soaked condition
S-5	17.5	2	27	OMC
S-5	20.0	3	25	Wet of OMC
S-5	15.0	3	24	Dry of OMC
S-5	24.0	26	2	Soaked condition
S-6	17.0	2	27	OMC
S-6	19.0	10	3	Wet of OMC
S-6	14.5	5	11	Dry of OMC
S-6	19.5	12	3	Soaked condition

Based on the literature review, the most widely accepted model for representing the correlation between CBR and the field DCP index is in the format of a log-log relationship. In this study, a variety of correlations such as linear, power, exponential were examined and the log-log regression relationship gave the highest value for the coefficient of determination (R^2).

$$\text{Log[CBR]} = 1.647 - 1.06 \times \text{Log[DLP]} \qquad R^2 = 0.87 \qquad (1)$$

Where: CBR = California bearing ratio (%)
DLP = new lightweight dynamic cone penetration index (mm/blow)

Figure 3 shows this relationship for all experimental soil samples used in this study.

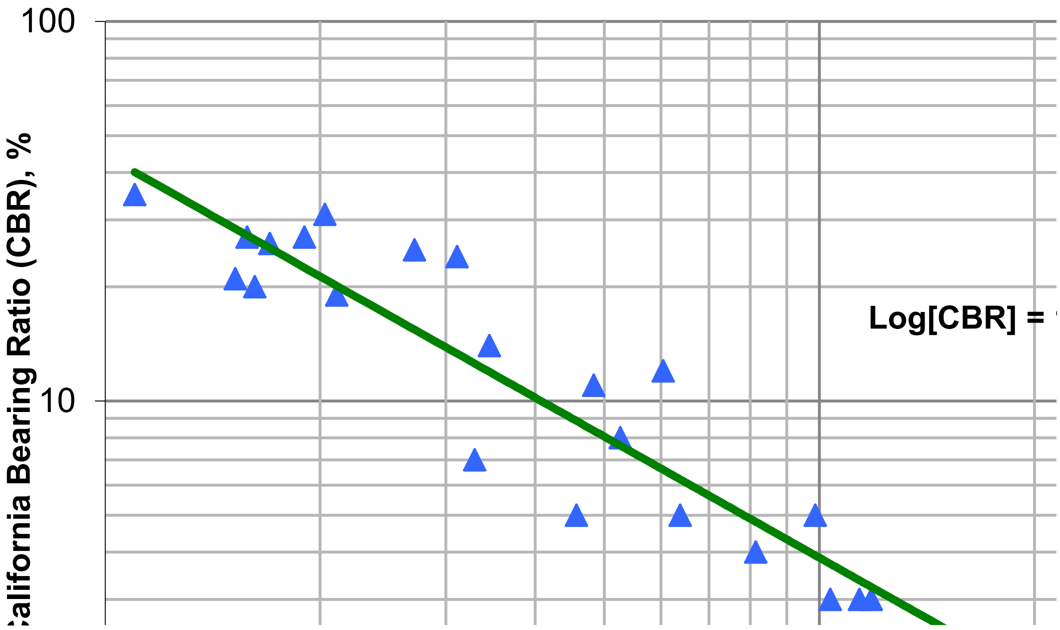

Figure 3: Log[CBR] versus Log[DLP] for soil sample S-1, S-2, S-3, S-4, S-5 and S-6

It can be seen from figure 3 and equation 1 that there is a strong correlation between DLP and CBR for the soils used in this study at different moisture contents. The major advantage of using the new lightweight penetrometer is that the relationship shown in figure 3 can be used in the laboratory as well as in the field for the evaluation of CBR of a soil with similar results. All the correlations reported in the literature can only be used with the DCP in the field.

4. CONCLUSION

The objectives of this study were to develop a lightweight DCP that can be used in a CBR mould in the laboratory as well as in the field with similar results for the same fine-grained subgrade soil and to investigate the relationship of CBR and the new light dynamic penetrometer. The experimental program consisted of two stages. In the first stage, two sets of DCP tests were performed on a compacted soil, one in a standard CBR mould and the other in a large cubic mould (700 mm x 700 mm x 700 mm). The soil was compacted at the same moisture content and the same density in the small and large moulds to achieve comparable results for DCP testing. A wide range of hammer masses, including 2.5, 3.5, 4.6, 6.0, 8.0 and 9.0 kg was used in the study, with the Australian standard dynamic cone penetrometer. In the second stage, the CBR and new lightweight DCP testings were carried out for all six soil samples at different moisture contents.

The results show that DCPI values are significantly higher for the larger hammer masses and the difference in DCPI values from the small and large moulds increases with the increase in the hammer mass. The differences clearly show the confining effect of the CBR mould on the DCP test results. Therefore, a new lightweight penetrometer with 2.25 kg hammer that can be used in a CBR mould in the laboratory as well as in the field with similar results for the same soil was proposed. And a strong correlation (R^2 = 0.87) was found between CBR and the new lightweight DCP index. More experimental works will be conducted to confirm the findings in this study.

NOTATION

CBR	California bearing ratio (%)
DCP	dynamic cone penetrometer
DCPI	dynamic cone penetrometer index (mm/blow)

DLP	new lightweight dynamic cone penetration index (mm/blow)
HM	hammer mass (kg)
LL	liquid Limit (%)
M1	CBR mould
M2	large mould 700 mm x 700 mm x 700 mm
MDD	maximum dry density (t/m^3)
OMC	optimum moisture Content (%)
PI	plasticity index (%)
PL	plastic limit (%)
USCS	unified soil classification system

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