

Effect of Boundary Conditions on Dynamic Cone Penetrometer Test

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Abstract - This paper investigates the effect of boundary conditions on the Dynamic Cone Penetrometer (DCP) test. Two soil types e.g. sand and lateritic soil samples collected from a highway construction site were compacted in the metal molds having diameters of 150, 200, and 300 mm. These samples were prepared near the optimum moisture content using a modified compaction effort. Results indicated that the DCP penetration index (DPI) values obtained in varied mold diameters divided by the DPI values obtained in a 150-mm diameter mold increased as the ratio of mold-to-cone diameter increased for both sand and lateritic soil samples. This finding was also in good agreement with other study for a similar soil type. Caution must be exercised when testing the DCP in the metal mold due to the presence of boundary condition effect. The effect of boundary conditions on the DCP test on two soil types could be negligible.

Keywords: Dynamic Cone Penetrometer, Boundary Condition, Sand, Lateritic Soil.

1. Introduction

Scala [1] developed the Scala penetrometer for assessing in situ California Bearing Ratio (CBR) of cohesive soils for over decades. The Scala penetrometer evolved into the Dynamic Cone Penetrometer (DCP) test for determining in situ CBR and modulus. The DCP is being used extensively in South Africa, the United Kingdom, the United States, Australia, and many other countries because it is simple, rugged, convenient and economical. The DCP has been successfully utilized to measure the instantaneous in-place strength index of various compacted earthen materials as well as exhibit potential for adaptation to earthwork quality control. A number of past studies [2]-[8] suggested that the DCP can be effectively used in companion with traditional moisture-density measurements in order to enhance the quality control during earthwork construction. The ultimate goals of utilizing the DCP with an independent moisture-density measurement are to achieve more uniform structural properties as well as to meet typical earthwork compaction acceptance criteria.

Although the DCP test can be conducted in laboratory and field, the results from the laboratory and the field can be different due to their boundary conditions and mold effects [9]-[13]. This study investigates the effect of boundary conditions on the DCP test. A series of DCP test were performed on two soil types (e.g. sand and lateritic soil) in the metal mold having diameters of 150, 200, and 300 mm. All samples were compacted near the optimum moisture content using a modified compaction effort. The effect of mold size on DCP test data for both sand and lateritic soil samples were investigated and compared with other study for a similar soil type.

2. Materials and Method

Disturbed samples were collected from a highway construction site in the western part of Thailand. Details were described in Sawangsuriya et al. [14]. Their basic properties, classification, and compaction characteristics are summarized in Table 1. The samples were compacted in the 175-mm high metal molds having diameters of 150, 200, and 300 mm. Each sample was compacted in five layers near the optimum moisture content using a modified compaction effort. The total number of blows, e.g. 25, 45, and 100 blows per layer were respectively applied for the 150-, 200-, and 300-mm diameter molds.

The DCP (ASTM D6951 [15]) was used for measuring the material resistance to penetration in terms of millimetres per blow while the cone of the device is being driven into the soil sample compacted in the molds. It consists of an 8-kg

hammer that drops over a height of 575 mm, strikes an anvil, and drives a 60-degree 20-mm-base diameter cone tip vertically into the soil. The steel rod to which the cone is attached has a smaller diameter than the cone (16 mm) to reduce skin friction. The number of blows during operation was recorded with depth of penetration. The slope of the relationship between cumulative number of blows and penetration at a given linear depth segment was recorded as DCP Penetration Index (DPI) (in millimeters per blow). In this study, the penetration was recorded for each blow until the cone penetrated the full depth of the sample in the mold. The moisture content measurements were taken from the top, middle, and bottom of the sample in the mold. The average value was used as the representative moisture content of the sample. The DPIs determined near the optimum moisture content were reported as DPI_{opt} .

Table 1: Properties of test materials.

Properties	Sand	Lateritic Soil
USCS	SP	GP
AASHTO	A-3	A-2-4
25 mm (1 in.)	100	100
19 mm (3/4 in.)	100	100
9.5 mm (3/8 in.)	97.8	88.3
No.4	92.3	44.6
No.10	71.1	8.8
No.40	25.7	3.7
No.200	1.7	1.5
D_{10} (mm)	0.2	2.2
D_{30} (mm)	0.5	3.5
D_{60} (mm)	1.4	6.0
LL	NP	19.2
PI	NP	9.1
w_{opt} (%)	9.3	6.5
$\gamma_{d, max}$ (kN/m ³)	20.7	22.4

3. Results and Discussion

To investigate the effect of boundary conditions on the DCP test, the ratio between the diameter of the metal mold (e.g. 150, 200, 300 mm) and the base diameter of the DCP cone tip (e.g. 20 mm) was used and expressed as the ratio of mold-to-cone diameter) herein. As illustrated in Fig. 1, the DPI_{opt} values increased as the ratio of mold-to-cone diameter increased from 7.5 to 15 for both sand and lateritic soil samples used in this study. Sand sample exhibited larger DPI_{opt} values than lateritic soil sample for a given ratio of mold-to-cone diameter. A slope of the relationship between DPI_{opt} and mold-to-cone diameter ratio for sand sample was also steeper than that for lateritic soil sample. These results were compared with [13], which utilized similar lateritic soil sample having a LL of 52, a PI of 34 with a fine content of 45.8%, a gravel content of 13.8%, a w_{opt} of 15.7%, and a $\gamma_{d, max}$ of 18.5 kN/m³ but prepared at compaction levels of 80%, 90%, and 100% of the modified Proctor maximum dry density and at moisture content near the optimum.

The DPI_{opt} values in Fig. 1 were normalized by the DPI_{opt} value obtained in a 150-mm diameter metal mold (i.e. conventional CBR mold). The normalized values were plotted against the ratio of mold-to-cone diameters as presented in Fig. 2. It was found that the normalized DPI_{opt} increased as mold-to-cone diameter increased. The normalized curves for both lateritic soil samples tested in this study and those in [13] were remarkably close to each other for the ratio of mold-to-cone diameter ranging from 7.5 to 15. The normalized DPI_{opt} became almost constant (~ 2.00) as the ratio of mold-to-cone diameter increased to 25. A slight difference in normalized curve was observed between sand and lateritic soil samples. Results suggested that the effect of soil type on the normalized DPI_{opt} -ratio of mold-to-cone diameter could be less significant, which was similar to that of compaction level observed in [13].

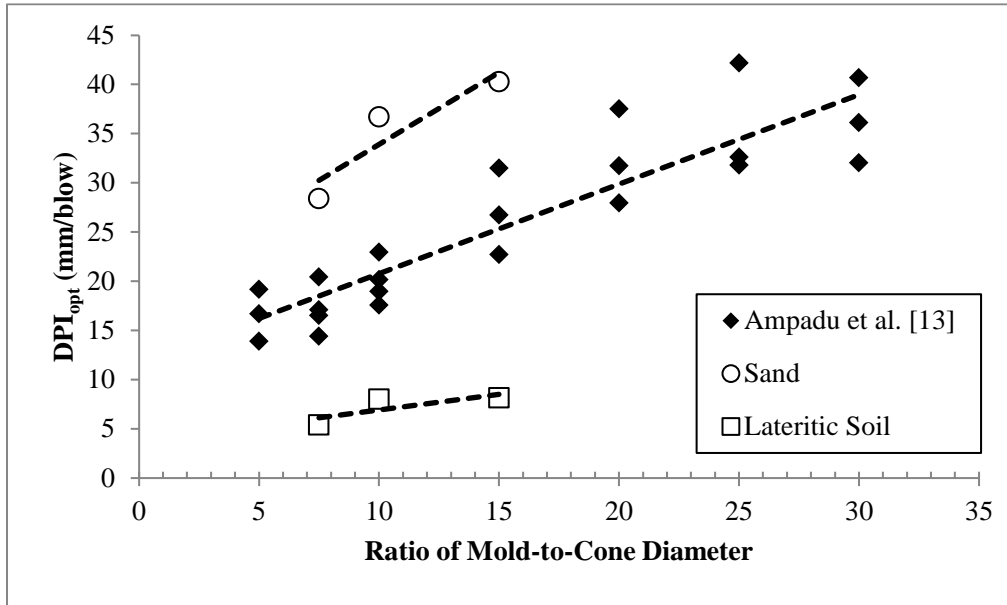


Fig. 1: DPI_{opt} vs. ratio of mold-to-cone diameter.

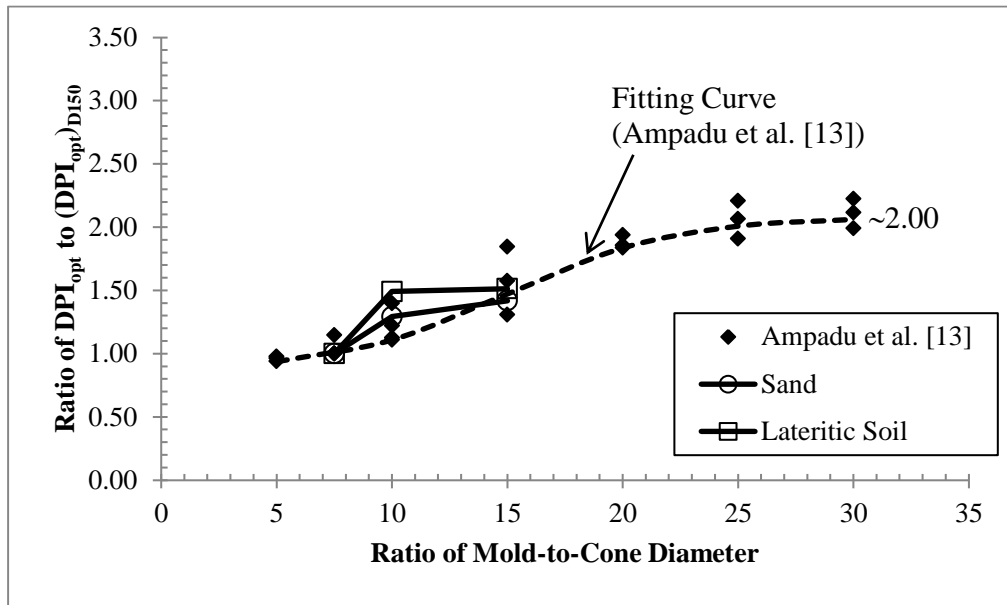


Fig. 2: Normalized DPI_{opt} vs. ratio of mold-to-cone diameter.

4. Conclusions and Recommendations

The effect of boundary conditions (e.g. mold diameter) on the DCP test on sand and lateritic soil samples compacted near the optimum moisture content using a modified compaction effort was investigated in this study. The metal molds having diameters of 150, 200, and 300 mm were used in preparing samples for this purpose. Studies suggested that the DPI_{opt} increased with the ratio of mold-to-cone diameter for both sand and lateritic soil samples. There existed slightly difference in increasing trends between sand and lateritic soil. Results obtained in this study were compared with [13], which also used the similar lateritic soil. For the case of the lateritic soil sample, the DPI_{opt} values obtained in varied mold diameters divided by the DPI_{opt} obtained in a 150-mm diameter metal mold (i.e. conventional CBR mold) increased as the

ratio of mold-to-cone diameter increased, which was in good agreement with [13]. This study also confirmed the implication of the boundary condition effect on the DCP test and that the relationship between the normalized DPI_{opt} the ratio of mold-to-cone diameter gradually became almost constant (~ 2.00) at the ratio of mold-to-cone diameter exceeding about 25. Such implication could be applied for the other soil types. Further studies are necessary to study.

References

- [1] A. J. Scala, "Simple methods of flexible pavement design using cone penetrometers," *New Zealand Engineering*, vol. 11, no. 2, pp. 34-44, 1956.
- [2] T. B. Edil and A. Sawangsuriya, *Investigation of the DCP and SSG as alternative methods to determine subgrade stability*. Report No. 0092-01-05, Wisconsin Department of Transportation, Madison, WI, 2005.
- [3] A. Sawangsuriya and T. B. Edil, "Evaluating stiffness and strength of pavement materials," *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering*, vol. 158, no. 4, pp. 217-230, 2005.
- [4] T. B. Edil and A. Sawangsuriya, "Use of stiffness and strength for earthwork quality evaluation," *GeoShanghai Conference, Site and Geomaterial Characterization*, ASCE, Geotechnical Special Publication, China, no. 149, pp. 80-87, 2006.
- [5] Y. Taesiri, A. Sawangsuriya, S. Wachiraporn, and W. Sramoon, "Assessment of in-situ tests for stiffness and strength characteristic of pavement materials," *13th REAAA Conf. Korea 2009*, South Korea, 2009.
- [6] S. Wachiraporn, A. Sawangsuriya, J. Sunitsakul, and W. Sramoon, "Stiffness and strength based in-place evaluation of compacted unbound materials," *Proc. of Sessions of GeoShanghai 2010*, Geotechnical Special Publication no. 203, Shanghai, China, pp. 347-354, 2010.
- [7] A. Sawangsuriya and T. B. Edil, "Evaluation of soil stiffness and strength for quality control of compacted earthwork," *Int. J. Envi., Chem., Ecol., Geol. and Geophysical Engr., WASET*, France, vol. 10, no. 2, pp. 95-99, 2016.
- [8] A. Sawangsuriya, Wachiraporn, S., Sirisak, S., and Lawanwisut, W., "Proposed performance criteria for earthwork construction quality control," *Proceedings of the 5th Int. Conf. on Geotech. and Geophysic. Site Characterisation (ISSMGE TC-102 - ISC'5)*, Australia, pp. 717-722, 2016.
- [9] E. G. Kleyn, *The use of the dynamic cone penetrometer (DCP)*. Report No.2/74, Transvaal Roads Department, South Africa, 1975.
- [10] M. A. Gabr, J. Coonse, and P. C. Lambe, "A potential model for compaction evaluation of piedmont soils using dynamic cone penetrometer (DCP)," *Geotech. Test. J.*, vol. 24, no. 3, pp. 301-313, 2001.
- [11] B. T. Nguyen and A. Mohajerani, "A new lightweight dynamic cone penetrometer for laboratory and field applications," *Aust. Geomech. J.*, vol. 47, pp. 41-50, 2012.
- [12] B. T. Nguyen and A. Mohajerani, "Determination of CBR for fine-grained soils using a dynamic lightweight cone penetrometer," *Int. J Pavement Engineering*, vol. 16, no. 2, pp. 180-189, 2015.
- [13] S. I. K. Ampadu, P. Ackah, F. O. Nimo, F. Boadu, "A laboratory study of horizontal confinement effect on the dynamic cone penetration index of a lateritic soil," *Transportation Geotechnics*, vol. 10, pp. 47-61, 2017.
- [14] A. Sawangsuriya, U. Krabuanrat, J. Sunitsakul, and W. Sramoon, "Effect of lateral confinement on California Bearing Ratio (CBR) test," *Proc. of the 18th Southeast Asian Geotechnical Conf.*, Singapore, 2013.
- [15] ASTM D6951, Standard test method for use of the dynamic cone penetrometer in shallow pavement applications, West Conshohocken, PA, ASTM International, 2003.