

Evaluation of Highway Subgrade Compaction by Dynamic Cone Penetrometer

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Abstract. *This study established correlations between the number of blows from Dynamic Cone Penetrometer (DCP) tests and the compaction of the material that complied with the standard for soil subgrade set by Department of Highways, Thailand.*

Soil samples from 12 construction sites were compacted to achieve various densities in the laboratory. The DCP tests were conducted at the center of the pits. A series of tests were then performed to determine soil classification and measure the trial compaction. The relationships between the number of DCP blows and compaction can be modeled as $y = a \ln(x)+b$, where y is the compaction and x is the number of DCP blows. The model parameters were derived for four types of soil: A-2-4, A-3, A-4 and A-7-5.

The model was validated by comparing the predicted compaction with the measurements at three actual sites using a traditional sand cone method. The study sites were compacted by heavy machines. The predicted values agreed with the actual field measurements with the difference less than 5% and were obtained faster than using a typical current method.

Keywords:

Highway, subgrade, dynamic cone penetrometer, compaction

1.Introduction

The sand cone test is widely used to determine the soil density in the field, in particular to evaluate the level of compaction of road layered materials. Compaction evaluation is required in control of construction of the compacted layers of roads, especially for the soil subgrade which acts as the foundation in all highways [1]. Practically, the degree of compaction is typically expressed as a percentage and computed as: [2]

$$\text{Percent compaction} = \frac{\gamma_{d(\text{field})}}{\gamma_{d-\text{max}(\text{lab})}} \times 100 \quad (1)$$

where $\gamma_{d(\text{field})}$ is the dry density of compacted soil in the field and $\gamma_{d-\text{max}(\text{lab})}$ is the maximum dry density of the remolded soil measured under laboratory conditions.

The Proctor test is generally used to investigate the moisture-density relation in laboratory test in compliance with standards ASTM D698-12/ AASHTO T99-10 [3-4] for the standard Proctor test or ASTM D1557-12/ AASHTO T180-10 [5-6] for the modified Proctor test. Maximum density can be determined from the peak of the curve. Soil density and moisture content can be determined in the field with tests described in standards ASTM D1556-07/ AASHTO T191-02 [7-8]. The dry densities in equation (1) cannot be measured directly from either laboratory or field tests. However, it can be calculated as: [9]

$$\gamma_d = \frac{\gamma_t}{1 - m} \quad (2)$$

where γ_t is the soil density and m is the moisture content.

Although the laboratory work can be carried out prior to the field work, the degree of compaction cannot be measured immediately in the field, because soil samples need to be dried for at least 24 hours to comply with the test standard and obtain the moisture content from equation (2). This time is a drawback of the conventional test. Therefore, development or improvement of the test to shorten the test time is still desirable.

A dynamic cone penetrometer (DCP) is a device frequently used to determine in-situ engineering properties. Harison established the correlations between DCP and California bearing ratio (CBR) [10]. Beer also used a dynamic cone penetrometer for the design of road structures [11]. Mohammadi et al. [12] determined the in-situ properties of sandy soil with a DCP. However, the relation between DCP data and degree of compaction for highway subgrade material has not been reported.

This paper studies the degree of compaction of material complying with the Department of Highways standard for subgrade with various energy inputs. We determined the correlations suitable for estimating the compaction by a DCP test in the field and validated them with the data from actual construction sites.

2. Experimental Program

2.1 Raw Material

Raw material was taken from twelve highway construction sites in Northeast Thailand. Approximate locations and detailed information of the sites are shown in Fig. 1 and Table 1, respectively.



Fig. 1 Approximate locations of sample sites.

All soil samples were assessed to ensure that they met the criteria for the highway subgrade set by the Department of Highways, Thailand (Standard No. DH-S 102/2532) [13]. According to the standard: the soil subgrade is neither the top soil nor inorganic soil; the minimum dry density is not less than 1,140 kg/m³; the chunks of soil which size greater than 50 mm must be broken or eliminated; the minimum CBR is that specified on the drawing, and the value of swelling from the CBR test is not greater than 4%.

2.2 Sample Preparation

Soil samples were compacted using a small manual compactor in a circular concrete pit approximately 0.5m in diameter and 0.3m in height - see Fig. 2. The trial density of samples was controlled in the range of 1.6-2.0 t/m³.



Fig. 2 Concrete pit used for soil compaction in the laboratory.

No.	Location	Highway Route Number	Area
1	KM. 117+000	23	Muang, Roi Et
2	KM. 8+000	202	Yasothon
3	KM. 210+000	23	Kamkuenkaew, Yasothon
4	KM. 251+000	23	Kung-nai, Ubon Ratchathani
5	KM. 237+000	24	Prai-bueng, Si Sa Ket
6	KM. 11+000	226	Muang, Surin
7	KM. 27+000	2046	Phontong, Roi Et
8	KM. 4+000	226	Muang, Buri Ram
9	KM. 4+000	2262	Phoe-sri-suwan, Si Sa Ket
10	KM. 86+000	219	Phayakkaphumpisai, Maha arakham
11	KM. 20+000	24	Varin chamrap, Ubon Ratchathani
12	KM. 3+000	2076	Tha-toom, Surin

Table 1 Information of sample sites

2.3 Dynamic Cone Penetrometer (DCP)

The DCP configuration followed the specifications of ASTM D-7380-08 [14] - see Figs. 2-3. The test procedure of DCP is as follow: 1) the cone is located at the testing point and testing rod was set vertically; 2) a 5-lb drop hammer is used to penetrate the driving rod in to the soil until the lower mark leveled at the soil surface, and 3) a freely fall by gravity of drop hammer from the upper stop plate to the anvil is conducted repeatedly until the upper mark on driving rod reached the soil surface. The number of drops in step 3) is then recorded as DCP blow count. The testing time spent for all steps of DCP test is 20-30 minutes approximately.

2.4 Testing

Atterberg's limit tests and grain size distribution analysis were used to classify the soil based on the AASHTO system. Once the soil sample was compacted to the desired density, several tests were conducted. The DCP test was first applied at the center of the pit and then the sand cone, moisture content and standard compaction tests were done to achieve the target compaction of compacted soil. The same procedure was repeated at a different density

to obtain enough number of data points for the reliable relations. More than 60 tests were made in this study.

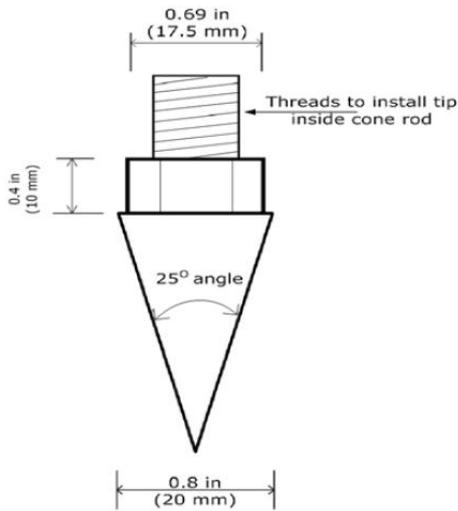


Fig. 3 Cone at the end of the driving rod of the DCP: taken from ASTM D-7380-08[10].

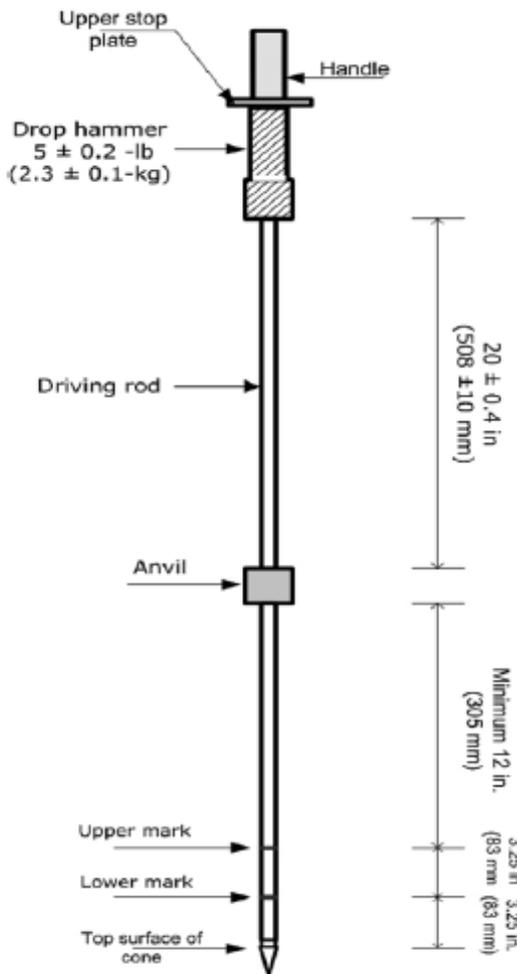


Fig. 4 Cone at the end of the driving rod of the DCP: taken from ASTM D-7380-08[10].

3. Results and Discussions

This study covered soil types A-2-4, A-3, A-4 and A-7-5 (AASHTO soil classification system). In each case, the function that gave the best fit to the data for all lines can be written as

$$y = a \cdot \ln(x) + b \quad (3)$$

where x denotes the DCP blow count and y denotes the soil percent compaction. The coefficients for equation (3) were determined as shown in Table 2. The values of coefficient of determination, r^2 , were all greater than 0.96. Results for each soil group are presented in Figs. 5-8.

For soil A-2-4 in Fig. 5, the graph shows an upward trend for 4 soils having different dry densities. The degree of compaction increased with the number of DCP blows. For all cases at the same number of DCP blows, the percent compaction increased with the density. Soil with higher density requires less effort to compact. In the other words, for the same degree of compaction, lower density soils required more DCP blows.

For soil A-3 in Fig. 6, the pattern is similar to A-2-4. It should be noted that both A-2-4 and A-3 soils are classified in the same zone of granular material in the AASHTO standard.

For A-4 soil (Fig. 7), the curves had a similar functional shape. However, in contrast to the granular materials (A-2-4 and A-3), at the same degree of compaction, fewer DCP blows were required for a lower density. This is probably caused by cohesion in this type of soil:

A-4 is a silt-clay material in the AASHTO standard.

Only a few samples were A-7-5 soil, so we were only able to obtain the single curve in Fig. 8. Therefore the parameters for A-7-5 must be regarded as less reliable than the values for A-2-4 and A-4 for which we had many samples. Similarly the results for A-3 soil are slightly less reliable than A-2-4. This is because most borrow pits in the Northeast Thailand had A-2-4 and A-4 soil.

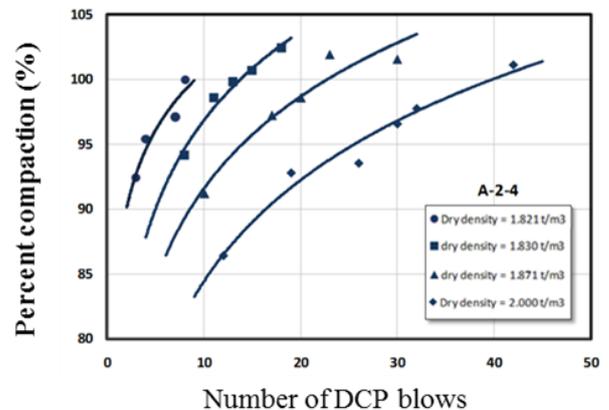


Fig.5 A-2-4 soil: percent compaction vs number of DCP blows.

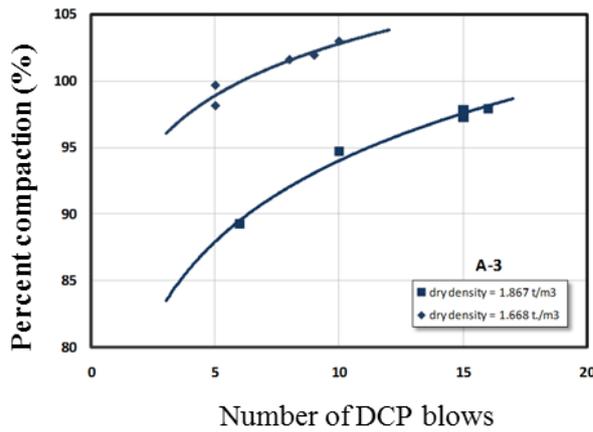


Fig. 6 A-3 soil: percent compaction vs number of DCP blows.

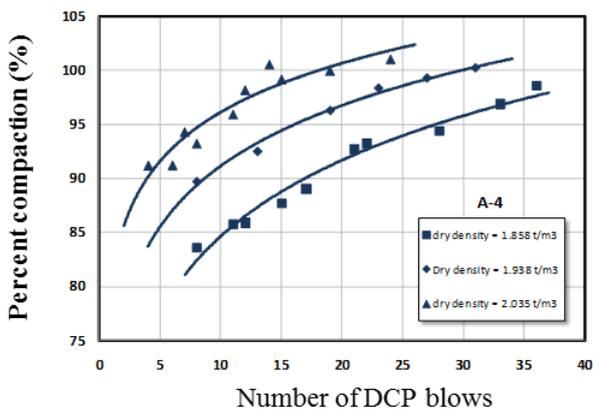


Fig. 7 A-4 soil: percent compaction vs number of DCP blows.

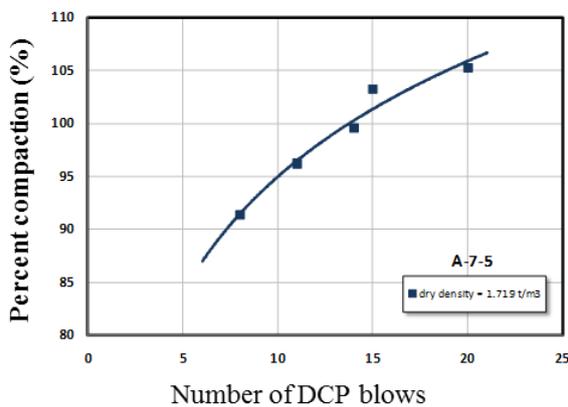


Fig. 8 A-7-5 soil: percent compaction vs number of DCP blows.

Soil Type	Dry density, γ_d (t/m ³)	Parameter	
		a	b
A-2-4	1.82	5.785	86.654
	1.83	9.868	75.158
	1.87	10.184	68.215
	2.00	11.263	58.478
A-3	1.67	5.602	89.878
	1.87	8.751	73.902
A-4	1.86	10.114	61.403
	1.94	7.373	74.713
	2.04	5.935	82.513
A-7-5	1.72	15.590	58.891

Table 2 Parameters a and b for models for each soil type and density

4. Validation

The correlations obtained from the analyses were compared to the tests by the traditional sand cone method on actual construction sites which employed heavy equipment.

We validated our models by comparing the correlations between DCP blow counts and the compaction from our models to the field test values. An example of the A-3 soil with the dry density of 1.87t/m³ was shown in Fig. 9. Clearly there is good agreement between the models and field results. Therefore, these models can be used with the DCP test to predict compaction of highway subgrade more quickly than using conventional tests.

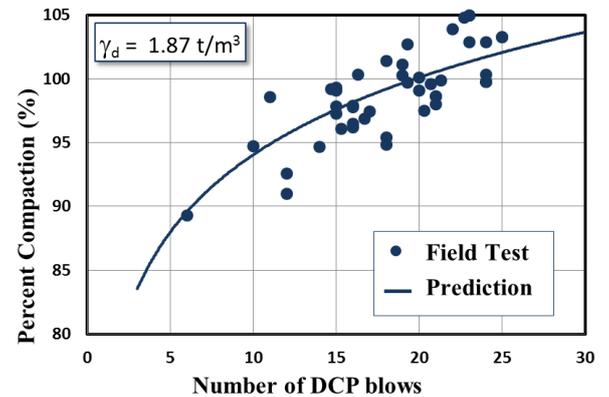


Fig. 9 Predicted compaction from our model and values from field tests.

5. Conclusion

We studied the relations between the number of blows from Dynamic Cone Penetrometer (DCP) tests and the compaction of soil subgrade. Our results can be summarized as follows:

1) We derived mathematical models for the relations between DCP blows and compaction.

2) Soil types A-2-4, A-3, A-4 and A-7-5 were evaluated.

3) The proposed model shows good agreement with experiment for each soil group.

4) Validation against field tests confirmed that our models predict compaction well.

5) The DCP test takes only about 30 minutes compared to at least 24 hours for the conventional method.

6) The proposed model can be used for construction control for highway subgrade - reducing testing time without sacrificing accuracy.

Acknowledgement

We thank the Faculty of Engineering, Mahasarakham University for financial support and laboratory facilities. Special thanks to colleagues in the Faculty for advice on English expression.

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Biography

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