Innovative Tools for Highway Construction Quality Control

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Abstract

Conventional sand cone test for density measurement is time consuming and cumbersome. The practical use of nuclear moisture-density gauge becomes increasingly problematic. Such nuclear method is considered a safety issue and is subjected to strict environmental regulations. It also requires certified operator with specialized training. Currently, several innovative tools have been developed and introduced to the market. They are portable, non-nuclear, and capable of rapidly measuring in-place stiffness, strength, density, and moisture content of compacted pavement materials. The implementation of innovative tools, e.g. the Soil Stiffness Gauge, the Dynamic Cone Penetrometer, the Soil Density Gauge etc., for construction quality control of highway earthwork in Thailand is anticipated to (1) increase test coverage, (2) improve statistical evaluation, and (3) reduce compaction variability, thus ensure structural uniformity during construction.

1. Introduction

The long-term structural performance of the highway pavement depends on the structural properties of the pavement materials and subgrade stability. Quality control monitoring and structural evaluation during highway construction play an important role to assure the suitability and compaction of the materials used. Typical earthwork compaction acceptance criteria is currently based on the specified target dry density of the placed earthen materials achieved through appropriate moisture content (i.e., 95% of maximum dry density near the optimum moisture content according to Thailand Department of Highways construction specification). Conventional compaction control practice in Thailand is based on in-place density measurement using the sand cone method (ASTM D1556).

Monitoring compaction quality through sand cone density test is relatively simple and has been adopted for a statistical evaluation of compaction quality by Thailand Department of Highways (DOH) for decades. However, such density test is generally time consuming, labor intensive, less cost-effective and destructive. Recently, the nuclear moisture-density gauge has been experimented in Thailand DOH construction. Unfortunately, it was not successfully accepted because (1) it contains radioactive source, which requires certified operator to run the gauge, (2) it is an intrusive method for soil test, and (3) it takes

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time for preparing a test area (i.e., driving a pin to a desired depth) prior to the measurement. A simple, rapid, and direct structural property testing in conjunction with moisture-density testing which can be conducted independently and safely by the inspector without interference with the construction process is anticipated to increase test coverage, to improve statistical basis of evaluation, and to reduce variability.

Due to the advancement in science and technology, a number of innovative tools have been widely developed and become currently available in the geotechnical and pavement engineering communities for in-situ assessment of structural properties and quantitative evaluations of construction practices and materials. These tools are portable, operator friendly, and also provide rapid and instantaneous measurement with reasonable accuracy during construction. As a consequent, construction quality control of the entire earthwork can be enhanced substantially. Examples of innovative tools including the Light Weight Deflectometer (LWD), the Portable Falling Weight Deflectometer (PFWD), the Soil Stiffness Gauge (SSG), the Briaud Compaction Device (BCD), the Dynamic Cone Penetrometer (DCP), the Soil Density Gauge (SDG) and others can provide either direct or indirect measurement of in-situ stiffness, strength, density, and moisture assessment of pavement materials and are therefore considered as alternative means for Thailand highway construction quality control in the near future.

2. Innovative Tools

Given the importance of quality control during construction, methods for in-situ property assessment of compacted materials must be reliable, reasonably accurate, rapid and instantaneous so as to increase test coverage. Such methods shall provide an effective assessment of structural uniformity with acceptable range for compacted pavement layer materials and natural subgrade in order to ensure the load support capacity and structural performance over both as-compacted and post-compaction stages. This paper presents some potential innovative tools for future highway construction quality control in Thailand. These tools are portable, simple to use, absolutely safe for operator, and provide rapid measurement without interference with construction process.

2.1 Soil Stiffness Gauge (SSG)

The Soil Stiffness Gauge (SSG), which is currently marketed as the Humboldt GeoGauge™ (Figure 1), is a portable, non-nuclear testing device that provides simple and non-destructive means of directly and rapidly measuring in-situ soil stiffness. The SSG weighs about 11.4 kg, is 28 cm in diameter, 25.4 cm height, and rests on the soil surface via a ring-shaped foot. The SSG measures near-surface stiffness by imparting small dynamic force to the soil though a ring-shaped foot at 25 steady state frequencies between 100 and 196 Hz. Based upon the force and displacement-time history, stiffness is calculated internally as the average force per unit displacement over the measured frequencies and reported. A measurement takes only about 1.5 minutes. The measured soil stiffness from the SSG can be used to calculate the elastic modulus of the materials at near surface [1-3].

2.2 Dynamic Cone Penetrometer (DCP)

The Dynamic Cone Penetrometer (DCP) (Figure 2) is simple, rugged, economical, and able to provide a rapid in-situ index of strength of pavement structure. The DCP is used for measuring the material resistance to penetration while the cone of the device is being driven into the pavement structure. The number of blows during operation is recorded with depth of penetration. The slope of the relationship between number of blows and depth of penetration (in millimeters per blow) at a given linear depth segment is recorded as DCP penetration index (DPI), which can be correlated with California bearing ratio or CBR [1-3].

Figure 1 Soil Stiffness Gauge (Humboldt GeoGauge^{TM})

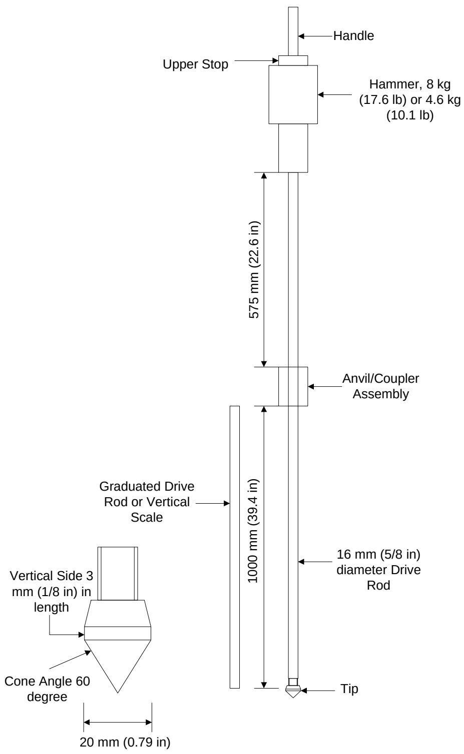


Figure 2 Dynamic Cone Penetrometer (DCP)

2.3 Soil Density Gauge (SDG)

The Soil Density Gauge (SDG) (Figure 3) is portable and non-destructive testing device for determining the in-place density, and moisture content of unbound pavement materials. The SDG produces an electromagnetic field using a transmitter and receiver. The operating frequency falls within radio frequency range. The density and moisture content are determined by the electrical impedance spectroscopy measurement. The entire measurement takes less than one minute. Unlike the nuclear gauge, the SDG is absolutely safe for the operator and there is no need for certified operator to perform the test. Therefore, the SDG might be considered as an alternative tool for highway construction quality control in Thailand.

Figure 3 Soil Density Gauge (SDG)

3. Field Testing Program

The field tests (Figure 4) conducted at one highway construction site, HWY No. 351, in Bangkok, Thailand. The SSG, DCP, nuclear gauge, and SDG were performed on three types of pavement materials: (1) sand embankment, (2) soil-aggregate subbase, and (3) crushed aggregate base. There were five test locations for each material type. Five measurements of the SSG were made first, followed by five measurements of the SDG, then two measurements of the nuclear gauge and a single measurement of the DCP, respectively per one test location. Every measurement was made at the adjacent location. Besides the four methods, the sand cone tests were performed on 2-3 locations for each material type. It is also noted that two SDGs (SDG Beta 6 and SDG Beta 15) were evaluated in this study.

(a) SSG test

(b) DCP test

(c) SDG test

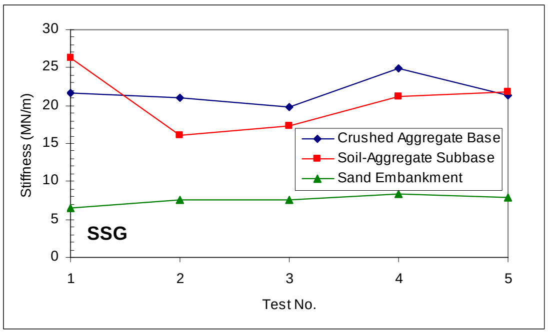
(d) Nuclear gauge test

(e) Sand cone test

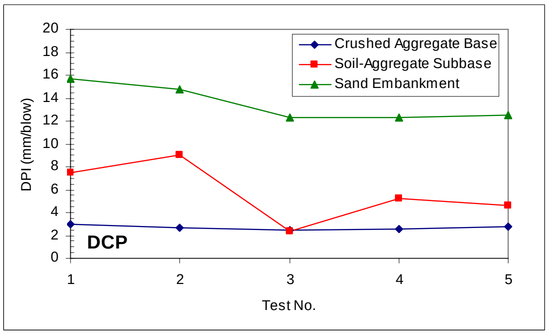
Figure 4 SSG, DCP, SDG, nuclear gauge and sand cone tests

4. Field Testing Results and Discussion

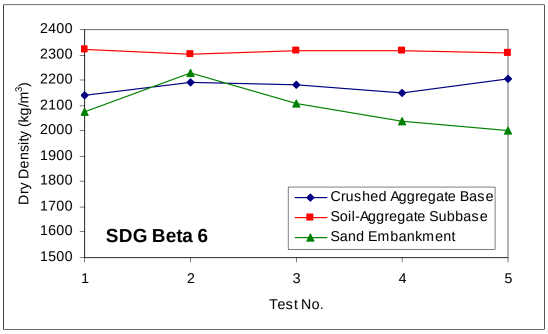
Results from field testing on three pavement materials are shown in Figures 5 and 6. Their average stiffness and strength values are also summarized in Table 1. The SSG, DCP, and SDG show good potential for future use in the pavement and subgrade property evaluation during construction phase. The in-situ stiffness and strength properties of three pavement materials can be rapidly and directly monitored in companion with the moisture-density control tests (i.e., the sand cone test and the nuclear gauge) during earthwork construction. Due to their rapid and instantaneous measurement, the inspector can increase test coverage, improve statistical evaluation, and reduce compaction variability, thus ensure structural uniformity during construction.



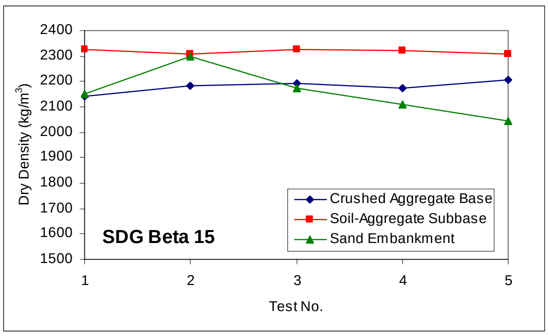
(a) Stiffness with test location number



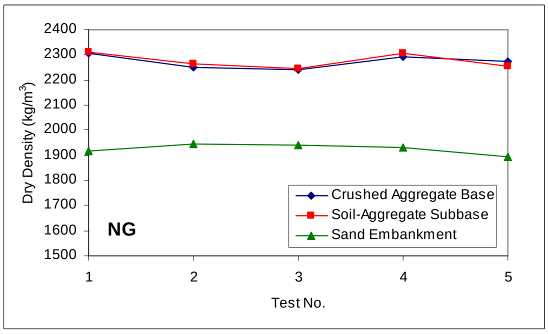
(b) DPI with test location number



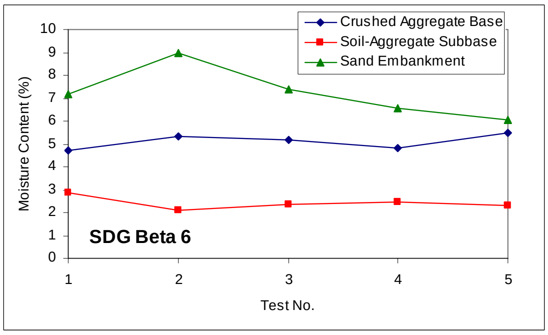
(c) Dry density (SDG Beta 6) with test location number



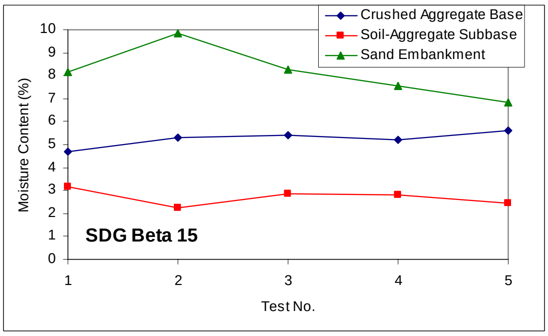
(d) Dry density (SDG Beta 15) with test number



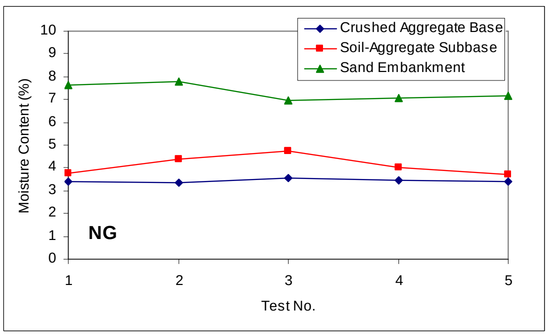
(e) Nuclear dry density with test location number



(f) Moisture content (SDG Beta 6) with test location number



(g) Moisture content (SDG Beta15) with test location number



(h) Nuclear moisture content with test location number

Figure 5 Stiffness, DPI, dry density and moisture content of three pavement materials

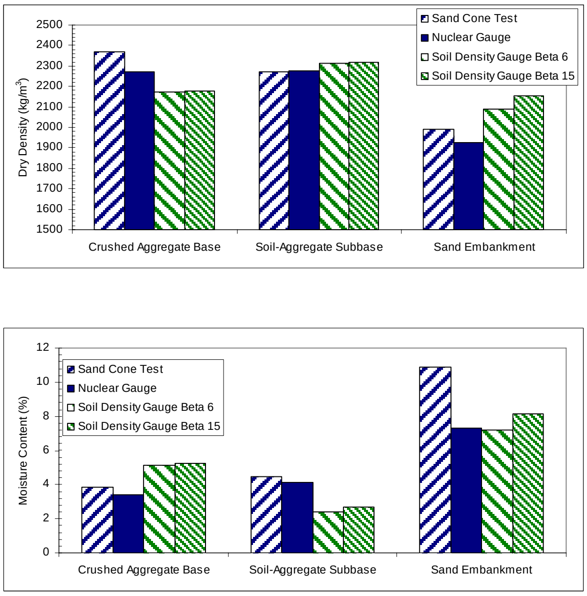


Figure 6 Comparison of dry density and moisture content obtained from the sand cone test, nuclear gauge, and SDG

Table 1 Average stiffness and strength of three pavement materials

Pavement Material	K (MN/m)	E (MPa)	DPI (mm/blow)	CBR (%)
Sand Embankment	7.6	68	13.5	16
Soil-Aggregate Subbase	20.5	184	5.7	54
Crushed Aggregate Base	21.8	196	2.7	96

Note: K = stiffness, E = elastic modulus

As shown in Figures 5a and 5b, both stiffness and DPI as measured by the SSG and the DCP, respectively indicated that both crushed aggregate base and sand embankment had good structural uniformity, i.e., smaller standard deviation (S.D. is ranged from 0.2 to 1.9). The soil-aggregate subbase, however, had poor structural uniformity, i.e., larger S.D. of 2.6 and 4.0. The elastic modulus (E) and the CBR of three pavement materials (see Table 1) fall within the reasonable range as suggested in Sawangsuriya et al. [3]. Moreover, their measured CBR values are much larger than the design CBR values (i.e, CBR of crushed aggregate base ≥ 80%, CBR of soil-aggregate subbase ≥ 25%, and CBR of sand embankment ≥ 10%). Results from stiffness and strength assessment can ensure the structural uniformity and the load support capacity of compacted sand embankment and crushed aggregate base. Although the compacted soil-aggregate subbase had high CBR, it exhibited non-uniformity of stiffness and strength.

The comparison of dry density obtained from the sand cone test, nuclear gauge and SDG indicated that these tests agreed fairly well. The SDG tended to give lower dry density for the crushed aggregate base (~ 8 % difference) but higher for the sand embankment (~ 5-8% difference). The comparison of moisture content obtained from the sand cone test, nuclear gauge and SDG indicated that the SDG moisture content showed consistently large difference from the sand cone and nuclear moisture content (~ 25-46 % difference) with an exception for the nuclear moisture content of sand embankment. A high sand cone moisture content of sand embankment was however suspicious.

It is important to note that the dry density or relative compaction alone is not a reliable indicator of the soil mechanical property (i.e., stiffness and strength) [4]. The soil density is only a quality index used to judge compaction acceptability and is not the most relevant property for engineering purposes. For compacted pavement materials and subgrade, the ultimate engineering parameters of interest are often the soil stiffness and strength, which are direct structural properties for determining load support capacity and deformation characteristic in engineering design. Stiffness and strength of compacted soils depend on density and moisture but also on soil structure which varies along the roadway route. The conventional approach of moisture-density control, however, does not reflect the variability of the soil structure and fabric and hence its stiffness and strength. Even if the soil layers satisfy a compaction quality control requirement based on density testing, a large variability in soil stiffness and strength can still be observed as well. Since the non-uniformity of stiffness and strength is directly related to progressive failures and life-cycle cost, a simple, rapid, and direct stiffness-strength testing which can be conducted independently and in conjunction with conventional moisture-density testing without interference with the construction process is anticipated to increase test coverage, to improve statistical evaluation, and to reduce variability, thus substantially enhance construction quality control of the entire earthwork.

5. Future Benefits

Assessment of in-situ density, moisture content, stiffness, and strength of compacted pavement materials during construction requires portable, simple-to-use, non-nuclear, and rapid tools without interference with construction process in order to effectively enhance construction quality control of the entire earthwork. This study presents the implementation of innovative tools, e.g. the Soil Stiffness Gauge, the Dynamic Cone Penetrometer, the Soil Density Gauge etc., for construction quality control of highway earthwork in Thailand. There are several benefits of using these tools: (1) enhances highway construction quality control, (2) ensures long-term pavement performance as well as during-construction working platform support and stability, (3) achieves more uniform structural property, (4) develops the role of inspector during construction, and (5) increases operator safety during construction.

6. Acknowledgement

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