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Field Validation of Intelligent Compaction Monitoring Technology for Unbound Materials

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INTRODUCTION

This document summarizes test results from a field study conducted on TH14 in Janesville, Minnesota, using Ammann AC110 vibratory smooth drum roller equipped with roller-integrated stiffness (k_s) measurement value with automatic feedback control (AFC). Some highlights of this project are presented in this document. Full details of this project and results are presented in White et al. (2007) and Thompson et al. (2008). The study focused on: (1) relationships between k_s and various in-situ point measurement values (point-MVs), (2) performance of AFC of amplitude and frequency, and (3) comparison of k_s with rut depth from test rolling. Point-MVs used in this study included dry unit weight, moisture content, dynamic cone penetration index (DCP index), light weight deflectometer (LWD) modulus, Clegg impact value, and state plate load test modulus.

AMMANN RICM SYSTEM

The Ammann RICM system is called the Amman Compaction Expert (ACE) system. It provides a continuous measurement and display of roller-integrated k_s measurement value, which is based on drum vibration amplitude and applied force, and also on-the-fly AFC of vibration amplitude and frequency. The AFC works in parallel with k_s measurement using a closed-loop feedback control algorithm, which increases the vibration amplitude and reduces the vibration frequency when operated on soft material, or vice-versa when operated on stiff material. The anticipated benefits of operating the roller in AFC mode include (1) more efficient soil compaction, (2) improved uniformity of compacted materials, (3) prevention of over-compaction, and (4) reduced vibration amplitudes in the vicinity of sensitive structures (Anderegg and Kaufmann 2004).

MATERIALS

Soils tested in this study included a subgrade soil classified as sandy lean clay (CL; A-6), and a base material classified as poorly graded sand with silt and gravel (SP-SM ; A-1-b).

COMPARISON BETWEEN k_s AND IN-SITU MEASUREMENTS

An example subgrade test strip, shown in Figure 1, was constructed perpendicular to the highway alignment through the soft median to capture a wide range in soil stiffness conditions. The roller was operated in AFC mode. Following roller passes, point-MVs were obtained from 7 to 30 test locations. k_s and point-MVs obtained along this test strip are shown in Figure 2. Mean (μ and coefficients of variation (CV) values are also provided in Figure 2 for all point-MVs. Along the test strip, all point-MVs follow closely the k_s. Furthest deviation from k_s was observed in the median with Clegg impact and DCP index values.

To better identify the relationships between k_s and in-situ point-MVs, the compaction measurements are plotted against spatially-nearest k_s values in Figure 3. Linear relationships were observed for all measurements except for DCP index, which was highly influenced by a single observation. Measurements were collected over a range of soil characteristics (i.e., roadbed versus median), and correlation R^2 values ranged from 0.30 to 0.80. As expected, highest correlation was seen with static plate load test modulus (shown as E_{V1}). k_s was also highly correlated with moisture content, which demonstrates the sensitivity of soil stability to moisture content.

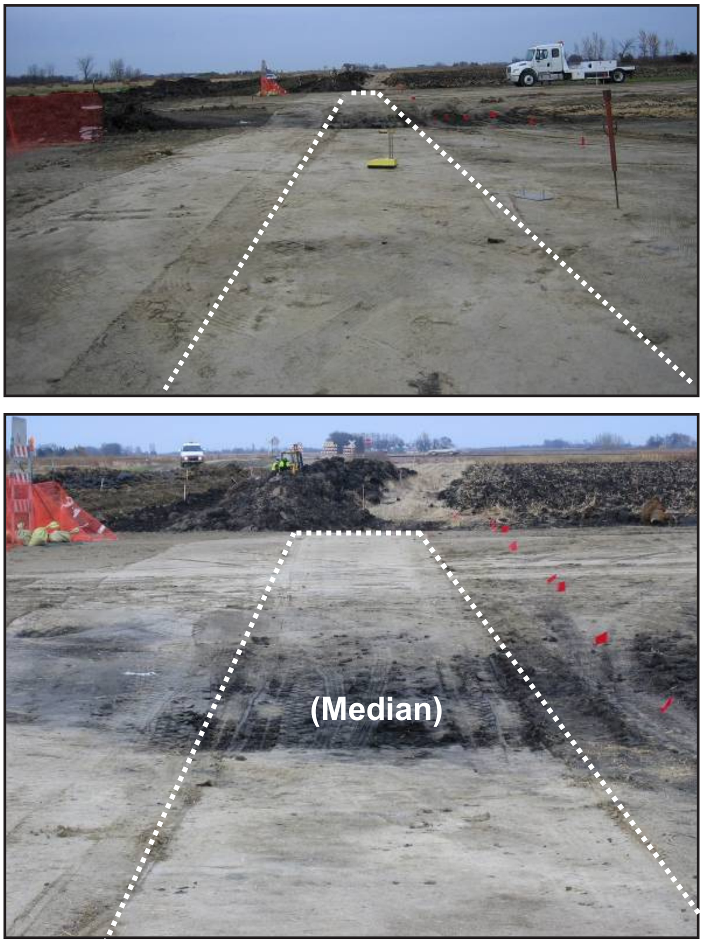

Figure 1. Test strip (outlined with dashed lines) comprised of subgrade material with testing locations spaced at 1.5-m intervals (from Thompson et al. 2008)

Similar comparison measurements were obtained on a base material test strip with relatively uniform conditions, which did not show any statistically significant relationship between k_s and point-MVs due to narrow measurement range (Figure 4). Additional details are provided in Thompson et al. (2008).

EVALUATION OF AFC

The benefits of AFC have not been thoroughly investigated and supported with quantitative compaction data. In this study, the ability of AFC systems to produce compacted material with higher uniformity than material compacted with constant amplitude and frequency was investigated.

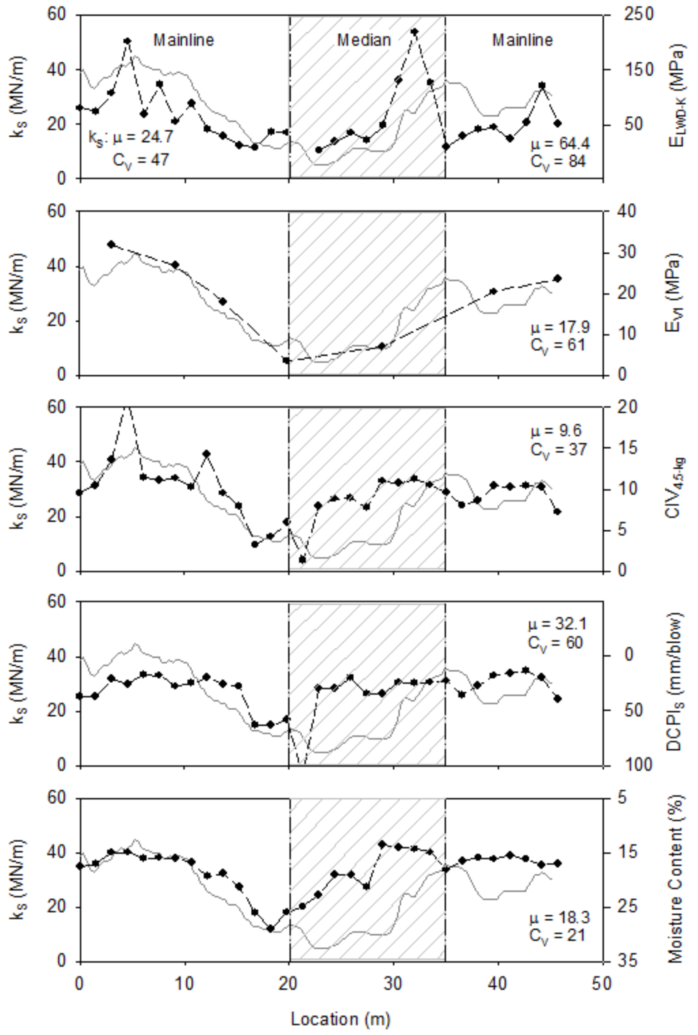

Figure 2. Comparison of k_s (solid line) and in-situ compaction measurements on a test strip comprised of subgrade material (from Thompson et al. 2008)

A 90-m long test strip with granular base material placed by the contractor, solely as subgrade cover for the winter months, was selected for compaction. The test strip was compacted using three roller passes in AFC mode at the high force setting. Even though the roller used in this study did not output vibration amplitude and frequency with k_s, changing operational parameters through the AFC algorithm was apparent during roller operation.

Figure 5 provides the k_s histograms and summary statistics for the three compaction passes. Average soil stiffness decreased slightly from the first to the second roller pass. Further, CVs for the first, second, and third roller passes were 5, 7, and 9%, respectively. Therefore, these admittedly limited compaction data do not support AFC systems as capable of improving the uniformity of compacted materials. It is also worth noting that the base material was initially placed with relatively uniform conditions. Increasing compaction was unlikely to produce more uniform soil. The performance of AFC must be further investigated, quantified, and documented in future studies.

COMPARISON WITH TEST ROLLING

A two-dimensional test area was established as four adjacent test strips, each 60 m in length and the width of the roller drum. The subgrade material was compacted with three roller passes. For the first and second lanes, the roller was operated in the manual mode with amplitude set to 80% of maximum. The roller was operated in the third and fourth lanes in the variable feedback control mode at the high force setting. k_s data for the first and third roller passes are shown in Figure 6. The comparatively soft areas (e.g., first and second lanes from 35 to 45 m) and stiff areas (e.g. third and fourth lanes from 25 to 50 m) are observed for both passes to demonstrate measurement repeatability.

Test rolling per Minnesota DOT specifications was performed using a pneumatic-tired roller with gross mass of 27.2 metric tons and tire pressure of 650 kPa towed by tractive equipment (see Figure 7). Two passes were made over each test area. The roadbed was considered to be suitable if, under the operation of the roller, the surface shows yield or rutting of less than 50 mm measured from the top of the constructed grade to the rut bottom. As the subgrade material was placed without compaction by the contractor at the location of the two-dimensional test area (by request of the investigators), considerable rutting was observed (see Figure 7).

Figure 8 shows k_s comparison to rut depth measurements, which indicates that the rut depth measurements track well with roller k_s data. The principal advantages of using RICM technology over testing rolling include (1) more efficient construction process control and QC/QA practice, (2) documentation of subgrade stability, and (3) ability to map 100% of the test area.

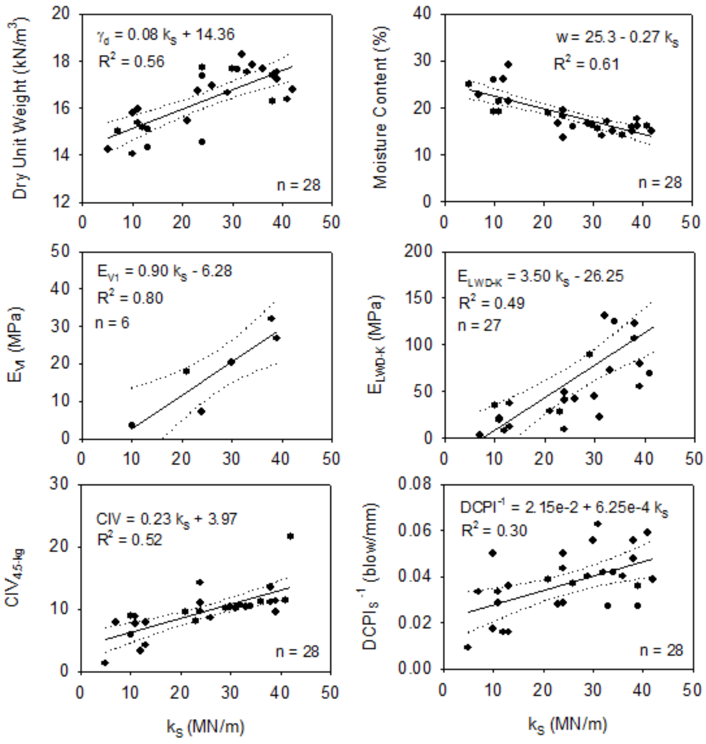

Figure 3. Relationships between k_s and in-situ compaction measurements for a test strip comprised of subgrade material (from Thompson et al. 2008)

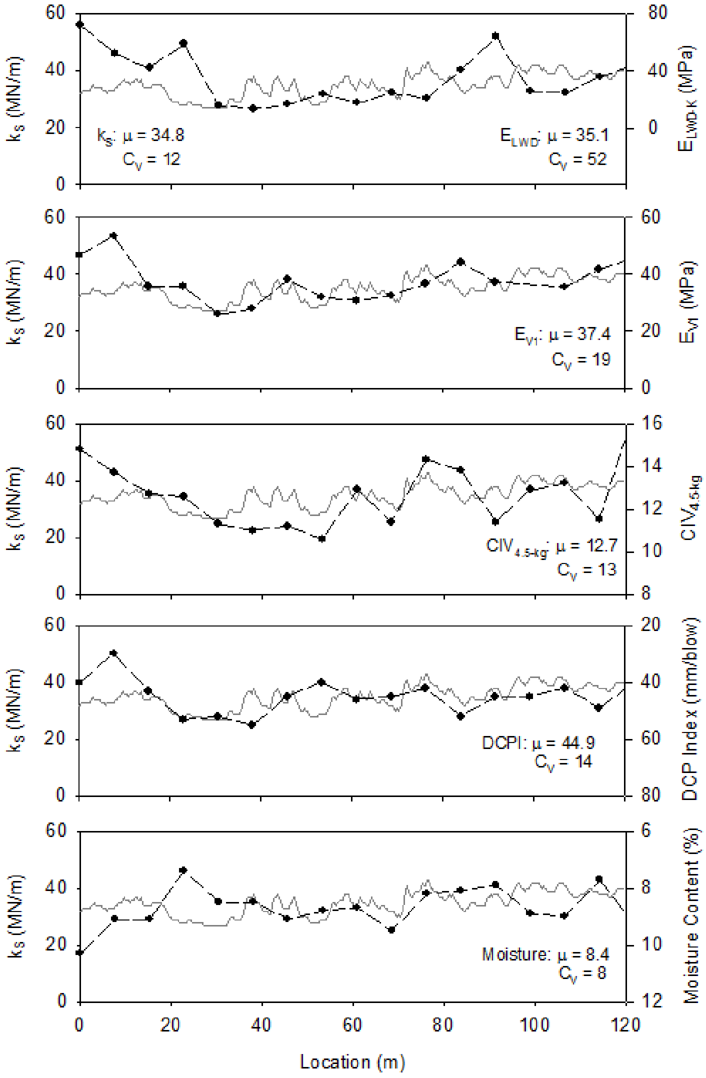

Figure 4. Comparison of k_s (solid line) and in-situ compaction measurements on a test strip comprised of granular material (from Thompson et al. 2008)

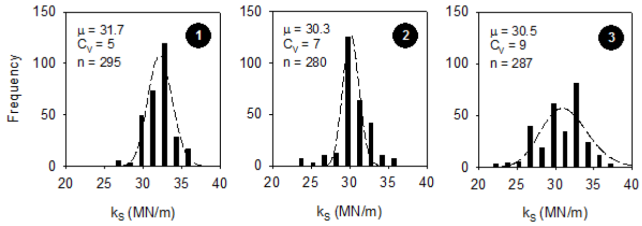

Figure 5. Distribution of k_s for three consecutive roller passes on Class 5 using variable feedback control operation (from Thompson et al. 2008)

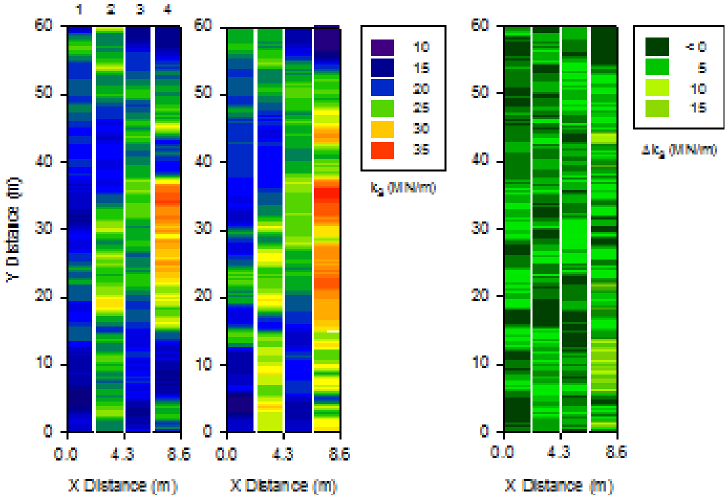

Figure 6. Ammann k_s (MN/m) for Pass 1 (left) and Pass 3 (middle), change in k_s (right) on test strip of subgrade material (from Thompson et al. 2008)

Figure 7. Test roller and subgrade rutting observed following test rolling (from Thompson et al. 2008)

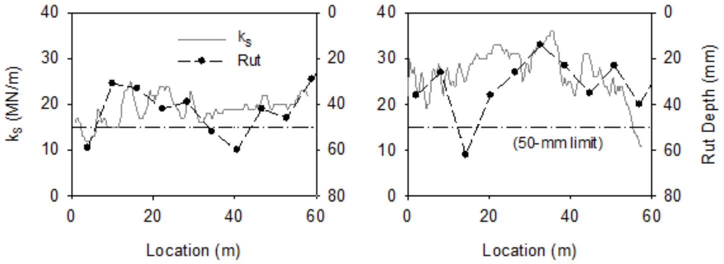

Figure 8. Comparison of k_s and rut depth along adjacent test strips of subgrade material (from Thompson et al. 2008)

KEY FINDINGS

- Subgrade stability measurements from in-situ testing devices follow closely roller-measured stiffness.
- Roller-measured stiffness is highly correlated with moisture content, which clearly shows that interpretation of k_s must consider soil moisture conditions.
- Ammann k_s is empirically related to in-situ compaction measurements through linear relationships with R^2 values ranging from 0.49 to 0.80 (for this study). The relationships are heavily influenced by the range of values over which the measurements are taken.
- The RICM measurements collected in AFC mode during this study alone did not support the process being capable of improving the uniformity of compacted materials. Future studies should more thoroughly investigate these systems to verify the intended benefits of the technology.
- The RICM system used in this study effectively identified areas of unstable subgrade material similar to test rolling.

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