INTELLIGENT COMPACTION BRIEF February 2012

Iowa I-29—Pavement Foundation Layer Construction—Summer 2009

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RESEARCH PROJECT TITLE
Iowa DOT Intelligent Compaction Research and Implementation – Phase I

SPONSOR
Iowa Department of Transportation

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MORE INFORMATION
http://www.iowadot.gov/research/pdf/newsnovember2010.pdf

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Objectives

The objective of this field demonstration project was to evaluate the compaction meter value (CMV) roller integrated compaction monitoring (RICM) system on the Volvo SD116DX smooth drum vibratory roller for use in quality control (QC) and quality assurance (QA) during construciton of pavement foundation layers.

The following research tasks were established for the study:

- Develop correlations between CMV and various conventionally used in situ point measurement values (point-MVs) in earthwork QC/QA practice.
- Evaluate the advantages of using the technology for production compaction operations.
- Obtain data to evaluate future RICM specifications.
- Develop content for future educational and training materials for Iowa DOT and contractor personnel.

Project Description

This demonstration project was one of three projects conducted as part of this research (White et al. 2010) and was located on I-29 in Monona County, Iowa. The project involved reconstructing the pavement foundation layers (base, subbase, and subgrade) of the existing Interstate highway on the northbound and southbound lanes on I-29 in Harrison and Monona Counties from just south of county road F-20 to just north of I-75. The existing subgrade layer was undercut to about 0.30 to 0.60 m below the existing grade. The exposed subgrade in the excavation was scarified and recompacted. The excavation was then replaced with a 0.30 to 0.45 m thick recycled asphalt ("special backfill subgrade treatment") subbase layer and a 0.15 m thick recycled portland cement concrete (RPCC) base layer. Crushed limestone material was also used for the subbase layer in some areas.

The Volvo SD116DX smooth drum vibratory roller used on this project was equipped with a compaction meter value (CMV) system and global positioning system (GPS) outfitted by Trimble, Inc.

The onboard display unit on the machine consisted of a Trimble® CB430 unit for real-time display of RICM measurements (Figure 1). A total of 11 test beds were constructed and tested as part of this project. Compaction on the test beds was achieved using the Volvo IC roller. Three in situ testing methods (Figure 2) were used in this project to evaluate the in situ soil compaction properties and obtain correlations with CMV: (a) Humboldt nuclear gauge (NG) to measure soil dry unit weight (γ_d) and moisture content, (b) Zorn light weight deflectometer (LWD) setup with 300 mm plate diameter to measure elastic modulus ($E_{LWD\text{-}Z3}$), and (c) dynamic cone penetrometer (DCP) to determine California bearing ratio (CBR).

Figure 1. Volvo SD116DX smooth drum vibratory roller (top), and the on-board Trimble CB430 display (bottom) (from White et al. 2010)

Figure 2. Nuclear gage (top left), dynamic cone penetrometer (top right), light weight deflectometer (bottom) (from White et al. 2010)

The Volvo machine consisted of low amplitude and high amplitude settings. In low amplitude setting the theoretical amplitude was $a = 1.50$ mm at frequency $f = 34$ Hz. In high amplitude setting the theoretical amplitude was $a = 1.85$ mm at frequency $f = 30$ Hz. the actual amplitude was measured and reported in the output. The data output contained the following information: (a) GPS position (i.e., northing/easting/ elevation), (b) machine speed, (c) CMV, (d) resonant meter value (RMV), (e) frequency and amplitude, (f) machine gear (forward/reverse), and (g) vibration setting (on/off).

Test Results and Analysis

Calibration Test Beds

One calibration test bed each for each material (subgrade, subbase, and base) was constructed as part of this project (Figure 3). CMV and in situ point-MVs obtained from multiple roller passes on subgrade, recycled asphalt subbase, and RPCC base layer test beds were used to develop compaction curves, as shown in Figure 4. Results indicated that the CMV, $E_{LWD\text{-}Z3}$, CBR, and γ_d measurements on the subbase layer are higher than on the subgrade layer.

Figure 3. Preparation of calibration test beds (from White et al. 2010)

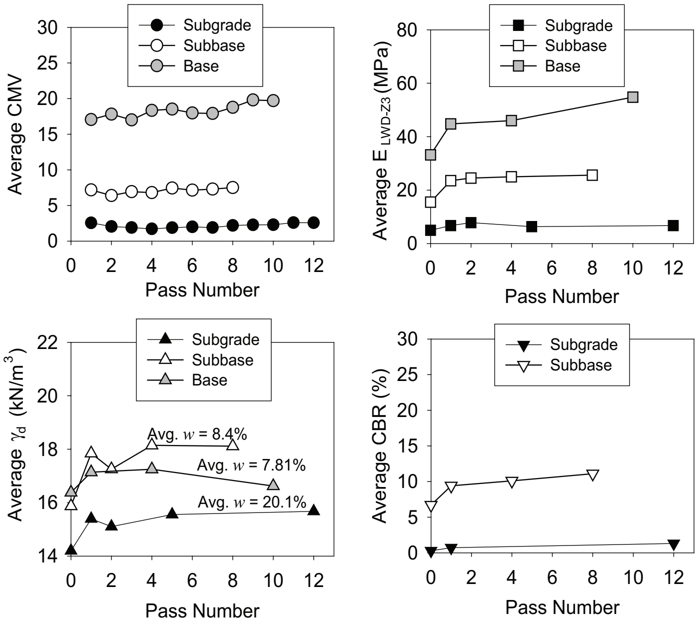

Figure 4. Average (per pass) CMV, $E_{LWD\text{-}Z3}$, γ_d, and CBR compaction curves for subgrade, subbase, and base layers (from White et al. 2010)

The CMV and $E_{LWD\text{-}Z3}$ values on the base layer were higher than on the subbase layer. The γ_d measurements were slightly lower on the base layer than on the subbase layer. The average CMV did not change considerably with increasing pass number on the three layers. The average $E_{LWD\text{-}Z3}$ values on the subgrade and subbase layers increased up to pass 2 and then remained constant up to the final compaction pass. The average $E_{LWD\text{-}Z3}$ on the base layer increased from pass 0 to 1, remained constant up to pass 4, and then increased up to pass 10. The average γ_d on all three layers increased from pass 0 to 1 and then generally remained at the same level up to the final pass. Correlations from these calibration test beds yielded correlations with $R^2 < 0.5$ due to the narrow range of the measurements. The correlations calculated by combining results from multiple test beds are presented below.

Production Test Beds

A total of seven production area test beds were constructed and tested as part of this study. Production area maps were obtained by creating two to three roller maps (Figure 5) at different amplitude settings (i.e., low and high amplitude). The in situ point-MV locations were selected based on the roller map, i.e., at locations with relatively high, medium, and low CMV. Figure 6 shows an example of production test bed data (CMV in low and high amplitude settings) from subgrade and overlying special backfill subbase layers with DCP-CBR profiles at three selected locations.

Results indicate that the CMV measurements are influenced by vibration amplitude. CMV measurements on the subgrade were on average about 1.1 to 1.3 times greater at high-amplitude setting (i.e., a = 2.00 mm) than at low-amplitude setting (i.e., a = 1.50 mm). Similarly, CMV measurements of the subbase and base layers were on average about 1.2 to 1.5 times greater at high-amplitude setting than at low-amplitude setting. This is likely due to potential differences in the magnitude of stresses applied to the materials by the roller drum under different amplitude settings. Figure 7 shows a CMV map on an on-board display highlighting a box culvert location with a high CMV.

Regression Analysis Results

Based on data obtained from multiple test beds on this project, regression relationships between CMV (in low- and high-amplitude settings) and point-MVs were developed, as shown in Figure 8. Nonlinear exponential relationships showed the best fit for CMV vs $E_{LWD\text{-}Z3}$ MVs with R^2 = 0.66 to 86. Relatively weak regression relationships with R^2 = 0.12 to 0.18 was observed for CMV vs CBR. No statistically significant relationship was found for CMV vs. γ_d.

Figure 5. Mapping operations on a production base layer test production test bed (from White et al. 2010)

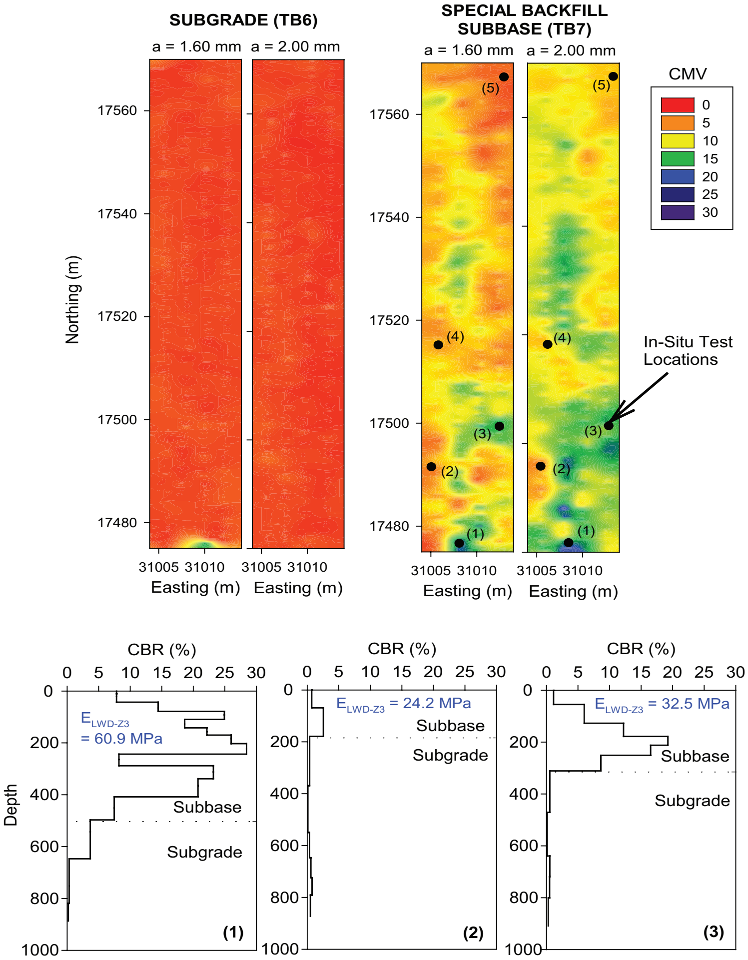

Figure 6. Spatial comparison of a subgrade layer CMV map overlain by a special backfill subbase layer CMV map and DCP-CBR profiles at three selected locations (from White et al. 2010)

Figure 7. CMV map on an on-board display highlighting a box culvert location with a high CMV (from White et al. 2010)

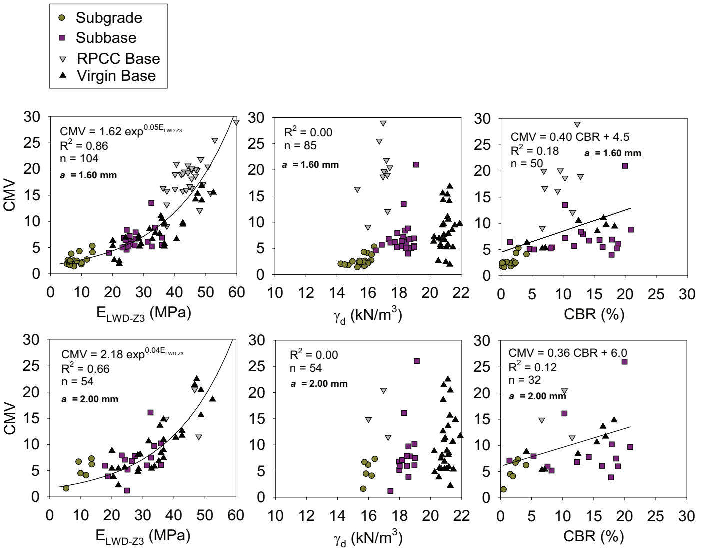

Figure 8. Empirical correlations between CMV and in situ point-MVs (from White et al. 2010)

Repeatability Analysis Results

The error associated with the repeatability of IC is believed to be one source of scatter in relationships with in situ point-MVs. One challenge for evaluating the repeatability of IC measurements is that the data points obtained from different passes are not collected at the exact same location. To overcome this problem on this project, the data were processed in such a way that an average data point was assigned to a preset grid point along the roller path. The grid point was set at 0.3 m along the roller path, which represented an average of IC-MVs that falls within a window of size 0.15 m in the forward and backward directions (the actual data were reported every 0.15 to 0.3 m). Repeatability analysis was performed on measurements obtained from compaction passes on subgrade, subbase, and base layer calibration beds (Figure 9) under identical operating conditions (i.e., same amplitude, nominal speed, and direction). The CMV measurement error was quantified by taking pass count and measurement location into account as random effects in a two-way analysis of variance (ANOVA). For this data set, the CMV measurement error was about ≤ 1.1 for low-amplitude settings at a nominal operation speed of about 4 km/h.

Summary of Key Findings

- Data from calibration strips indicated that the CMV, E_{LWD-Z3}, CBR, and γ_d measurements on the recycled asphalt subbase layer were relatively higher than on the subgrade layer. The CMV and E_{LWD-Z3} values on the RPCC base layer were higher than on the subbase layer. The γ_d measurements were slightly lower on the RPCC base layer than on the recycled HMA subbase layer.
- Correlations developed from this project yielded nonlinear exponential relationships between CMV and E_{LWD-Z3}, with R^2 = 0.66 and 0.86 for low- and high-amplitude settings, respectively. Relatively weak regression relationships with $R^2 < 0.2$ were observed between CMV and CBR. No statistically significant relationship was found between CMV and γ_d.

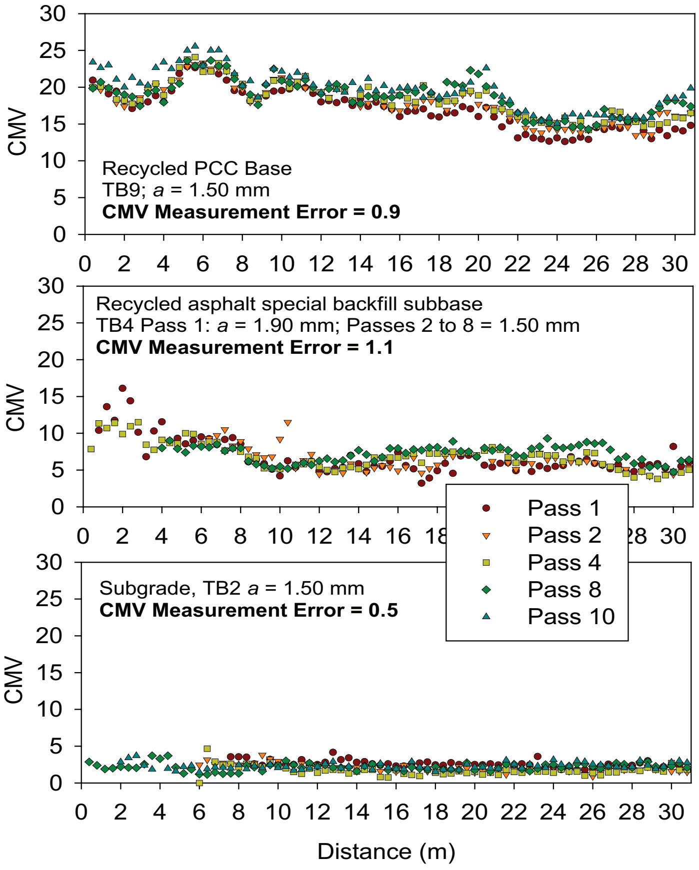

Figure 9. CMV measurements from multiple passes on subgrade, subbase, and base layers (from White et al. 2010)

- CMV maps obtained on the subbase and the overlaid RPCC base layers indicate that "soft" and "stiff" zones in the subbase layer maps are reflected on the RPCC base layer maps.
- CMV maps were able to effectively delineate "soft" and "stiff" zones effectively.
- CMV measurements were on average about 1.1 to 1.5 times greater at high-amplitude setting than at low-amplitude setting. This is likely due to potential differences in the magnitude of stresses applied on the materials by the roller drum under different amplitude settings.
- The CMV measurement error was about ≤ 1.1 for low-amplitude settings at a nominal machine speed of about 4 km/h.

Reference

White, D.J., Vennapusa, P., and Gieselman, H. (2010). *Iowa DOT Intelligent Compaction Research and Implementation—Phase I.* Final Repoart ER10-06, Iowa State University, Ames, Iowa.