DRAFT
April 2013

INTELLIGENT COMPACTION BRIEF

New York US 219 – Granular Embankment Subgrade and Subbase – May 2009

PROJECT DATE/DURATION
May 17 to 21, 2009

RESEARCH PROJECT TITLE
Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials (FHWA DTFH61-07-C-R0032)

SPONSOR
Federal Highway Administration

PRINCIPAL INVESTIGATOR
George Chang, PhD, PE
Project Manager
The Transtec Group, Inc.
512-451-6233

RESEARCH TEAM
David J. White, PhD
Pavana K. R. Vennapusa, PhD
Heath Gieselman, MS
Luke Johanson
Rachel Goldsmith
Bradley Fleming
Caleb Douglas, PE

AUTHORS
David J. White, PhD
Pavana K. R. Vennapusa, PhD
Center for Earthworks
Engineering Research, Department of Civil, Construction, and Environmental Engineering
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664

MORE INFORMATION
http://www.ceer.iastate.edu/research/project/project.cfm?projectID=-373342403

This document was developed as part of the Federal Highway Administration (FHWA) transportation pooled fund study TPF-5(233) – Technology Transfer for Intelligent Compaction Consortium (TTICC).

CENTER FOR
CEER
EARTHWORKS ENGINEERING
RESEARCH

IOWA STATE UNIVERSITY
Institute for Transportation

Introduction

This demonstration was conducted on US Highway 219 near Springville, New York. The machine configurations and roller-integrated compaction measurement (RICM) systems used on this project included (as shown in Figure 1) a Caterpillar CS683 smooth drum roller equipped with machine drive power (MDP) and compaction meter value (CMV) measurement systems and a Bomag BW213-DH smooth drum roller equipped with a vibratory modulus (E_{VIB}) measurement system along with automatic feedback control (AFC). Both machines were equipped with real-time kinematic global positioning systems and on-board display and documentation systems.

The project involved constructing and testing calibration and production areas with granular embankment subgrade and subbase materials. The RICM systems were evaluated by conducting field testing in conjunction with a variety of in situ testing devices measuring the following: dry unit weight (γd) and moisture content (w) using Humboldt and Troxler nuclear gauge devices and a non-nuclear gauge (soil density gauge); California bearing ratio (CBR) from dynamic cone penetrometer; dynamic elastic modulus using a 200 mm plate and a 300 mm plate light weight deflectometer (E_{LWD-Z2} and E_{LWD-Z3}) and a 300 mm plate falling weight deflectometer (E_{FWD-D3}), small strain modulus using Briaud Compaction Device (E_{BCD}); and initial (E_{V1}) and re-load modulus (E_{V2}) using a static plate load test with a 300 mm diameter plate.

The goals of this field study were as follows:

1. Document the impact of AFC operations on compaction uniformity
2. Document machine vibration amplitude influence on compaction efficiency
3. Evaluate impact of lift thickness on RICM measurement values and compaction efficiency
4. Develop correlations between RICM values and traditional in situ test measurements
5. Study RICM roller measurement influence depth
6. Compare RICM results to traditional compaction operations
7. Study RICM measurement values in production compaction operations
8. Evaluate RICM measurement values in terms of alternative specification options

This tech brief presents results from AFC mode in comparison with manual mode mapping operations, site-wide correlations between the three RICM measurement systems and in situ point measurements, and a summary of key findings/observations from a production area compaction by the contractor.

Figure 1. Caterpillar CS683 (left) and Bomag BW213-H (right) vibratory smooth drum rollers

RICM Systems Overview

The Caterpillar CS683 roller was equipped with CMV and MDP measurement systems. CMV is an index parameter (measure of non-linearity) computed as the ratio of drum acceleration amplitude of the first harmonic divided by the acceleration amplitude at the fundamental (eccentric excitation) frequency. This value requires only the measurement of vertical drum acceleration. MDP relates to the soil properties controlling drum sinkage and uses the concepts of rolling resistance and sinkage to determine the stresses acting on the drum and the energy necessary to overcome the resistance to motion. MDP values can be obtained in both vibratory and static compaction operation modes. The MDP values reported on this project are shown as MDP_{40}.

The Bomag BW213-DH roller was equipped with the E_{VIB} measurement system with AFC. E_{VIB} values are derived by determining drum displacement, estimating the soil force, and using a dynamic model to extract stiffness. Soil stiffness is determined as the ratio of soil force to maximum drum displacement. To determine an elastic modulus of the soil, a continuum contact model of the drum/soil is required and a relationship between a cylinder oscillating on an elastic half space is used.

The AFC system on the Bomag roller uses a concept of counter-rotating eccentric mass assembly that is vectored directionally to vary the vertical excitation force on the soil. If the counter-rotating masses are opposite each other in their rotation cycles, the eccentric force is zero. On the other hand, when the counter-rotating masses pass each other, the eccentric force is at maximum. The AFC system adjusts the amplitude automatically (by adjusting the vectors) depending on the pre-selected settings or the drum behavior. Two different AFC settings are available on the roller:

1. Pre-selected target E_{VIB} and a maximum amplitude amax value: In this setting, the vibration amplitude is reduced below the a_{max} value when $E_{VIB} \geq$ target E_{VIB} and the amplitude is at the a_{max} value when $E_{VIB} <$ target E_{VIB}.
2. Pre-selected amax value: In this setting, the vibration amplitude is controlled based on the drum double jump behavior as measured by the jump value. When the jump value increases above 0, the amplitude is lowered to 0.6 mm.

More information about these measurement systems is provided in White et al. (2010).

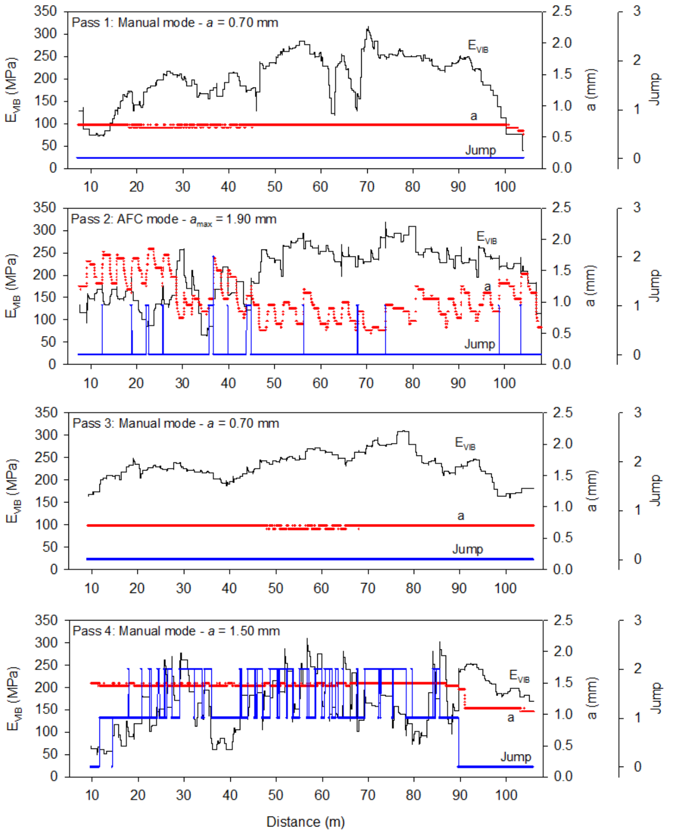

Figure 2. E_{VIB} and jump measurements from each pass TB3 embankment material

Test Beds and Materials

Ten test beds (TBs) consisting of granular embankment subgrade and subbase materials were constructed and tested in this field study. The granular embankment material was classified as SM or A-1-b and the granular subbase material was classified as GW or A-1-a.

Influence of Compaction Mode (AFC or Manual) and Amplitude on RICM

The Test Bed 3 (TB3) area consisting of compacted granular embankment subgrade material was mapped using the Bomag roller for four passes with the following settings:

- Pass 1: Manual low amplitude – a = 0.70 mm, f = 28 Hz
- Pass 2: AFC mode setting (2) – a_{max} = 1.90 mm, f = 28 Hz
- Pass 3: Manual low amplitude – a = 0.70 mm, f = 28 Hz
- Pass 4: Manual medium amplitude – a = 1.50 mm, f = 28 Hz

E_{VIB}, jump, and amplitude measurements are presented for passes 1 through 4 in Figure 2. For pass 2 performed in AFC mode, the amplitude values varied from 1.3 to 1.9 mm for E_{VIB} > 160 MPa and the amplitude values varied from 0.6 to 1.3 mm for E_{VIB} < 160 MPa. Roller jumping was observed (as shown with Jump > 0) at several short intervals along the length of the test bed for pass 2. No roller jumping was observed for passes 1 and 3 performed in manual a = 0.70 mm mode. Roller jumping was observed for pass 4 performed in manual a = 1.50 mm mode at many locations along the lane. Drum jumping behavior is linked to ground stiffness and vibration amplitude, which affects the E_{VIB} measurement values (White et al. 2010). In this study, roller jumping (Jump > 0) reduced the E_{VIB} values, for example between the 70 to 80 m marks on the test bed the jumping E_{VIB} values are generally < 150 MPa whereas with no jumping, E_{VIB} values are > 220 MPa. Considering the drum jumping behavior observed for pass 4 with a = 1.50 mm, it appears that pass 2 performed in AFC mode with amax = 1.90 mm effectively controlled the roller jumping by reducing the amplitude at many locations along the lane. In some segments though, jumping was still observed even in AFC mode.

The TB10 area was constructed using 1 m wide x 0.3 m deep and 2.0 m wide x 1.0 m deep loose fill layer trenches within the compacted embankment subgrade to evaluate the effectiveness of AFC mode compaction over manual mode compaction. Detailed results and analysis from this TB area are presented in White et al. (2010). In brief, analysis of DCP-CBR profiles within the 2.0 m wide x 1.0 m deep trench after multiple passes did not show considerable differences between AFC mode and manual mode compaction.

Correlations between RICM Values and In Situ Test Measurements

Comparison between E_{VIB} and in situ test measurements, and MDP_{40} and in situ test measurements from TB3, over a 120 m long strip is presented in Figures 3 and 4, respectively.

Data obtained from individual test beds on this project were captured over a wide measurement range of in situ test measurements and RICM values. This data was combined to develop site-wide correlation results. Many test bed results represented only a narrow range of measurement values. Combining results should provide a perspective on more general trends and associated variability.

Relationships between MDP_{40} obtained in the low amplitude setting (a = 0.90 mm, f = 30 Hz) and various in situ test measurements are presented in Figure 5. Non-linear logarithmic relationships showed the best fit for all in situ test measurements. Relationships with $E_{LWD\text{-}Z2}$, $E_{LWD\text{-}Z3}$, $E_{FWD\text{-}K3}$, and CBR showed good correlations with R^2 values > 0.60. Correlation with E_{BCD} showed relatively low R^2 value (0.10). Similar non-linear logarithmic relationships were observed between MDP_{40} obtained in static mode and $E_{LWD\text{-}Z3}$ and $E_{FWD\text{-}K3}$ measurements. These relationships also yielded good correlations with R^2 values > 0.70.

Non-linear power relationships between CMV obtained in the low amplitude setting (a = 0.90 mm, f = 30 Hz) and $E_{LWD\text{-}Z2}$ and CBR measurements are presented in Figure 6. Due to limited measurements and the narrow measurement range, these relationships yielded relatively weak correlations with R^2 values < 0.40.

Simple linear relationships between E_{VIB} obtained in the low amplitude setting (a = 0.70 mm, f = 28 Hz) and $E_{LWD\text{-}Z3}$ and $E_{FWD\text{-}K3}$ measurements are presented in Figure 7. These relationships produced correlations with R^2 values > 0.7.

Production Area Compaction Operations by Contractor

TB9 consisted of granular subbase material placed over the geosynthetic separation layer and compacted embankment layer.

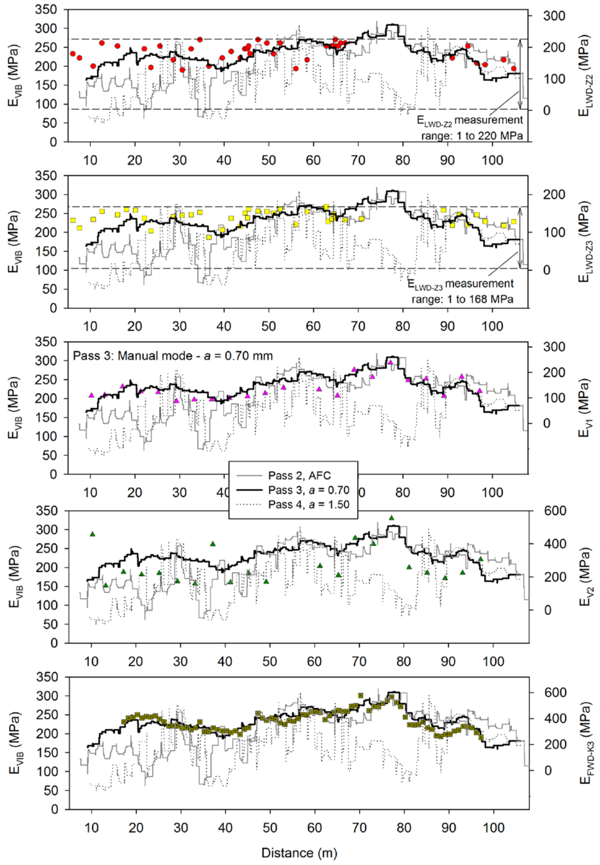

Figure 3. Comparison between E_{VIB} and in situ test measurements from TB3 embankment material

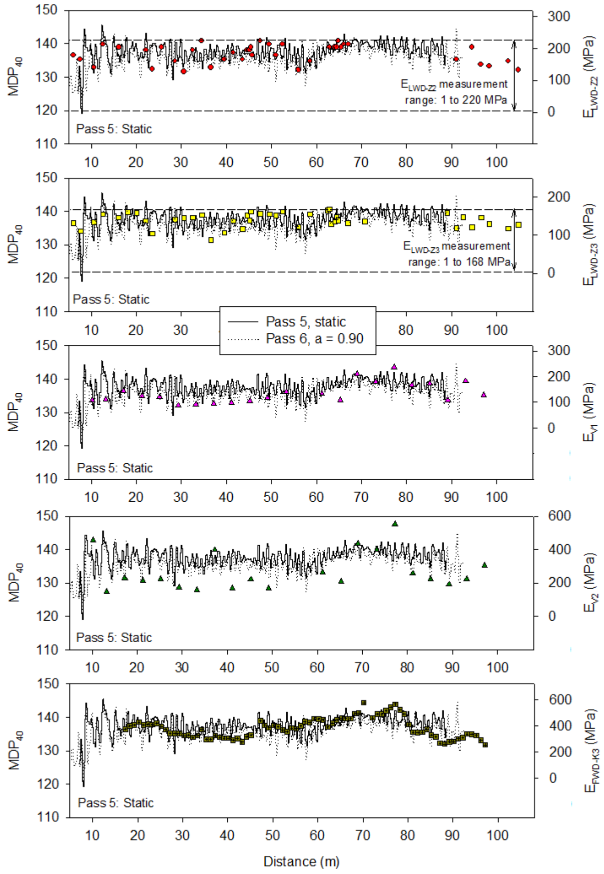

Figure 4. Comparison between MDP_{40} and in situ test measurements from TB3 embankment material

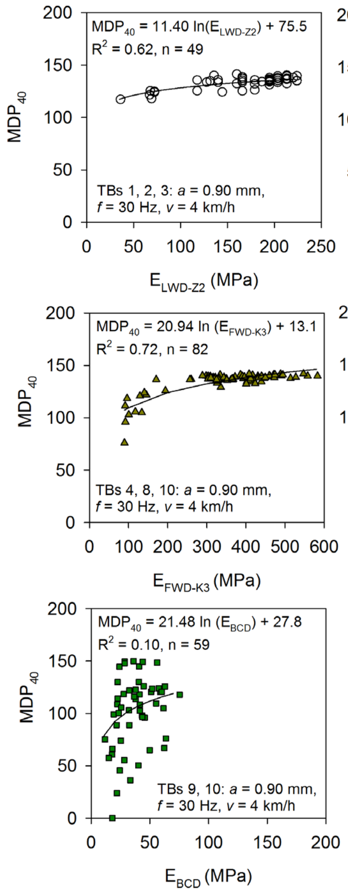

Figure 5. Regression analysis between MDP_{40} (a = 0.90 mm, f = 30 Hz, and v = 4 km/h) and Point-MVs combining data from different test beds

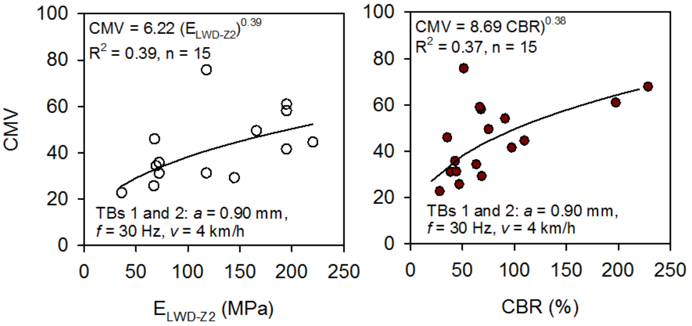

Figure 6. Regression analysis between CMV (a = 0.90 mm, f = 30 Hz, and v = 4 km/h) and Point-MVs combining data from different test beds

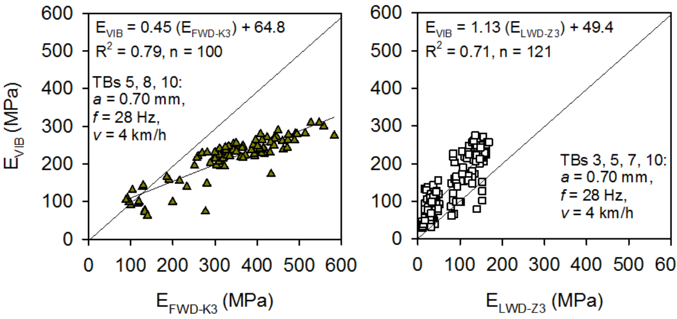

Figure 7. Regression analysis between E_{VIB} (a = 0.70 mm, f = 28 Hz, and v = 4 km/h) and Point-MVs combining data from different test beds

The area was compacted using the Caterpillar CS683 roller using the low amplitude settings (a = 0.90 mm, f = 30 Hz). Compaction operations on the test bed were performed by the contractor. The roller operator was trained on-site to make use of the on-board display unit and was reportedly instructed to perform two passes (one pass in the forward direction and one pass in the reverse direction) using the low amplitude setting.

MDP_{40}, CMV, and pass coverage maps after the final pass are shown in Figure 8 for a portion of the TB9 area. The pass coverage map indicates that the operator made a minimum of two roller passes as instructed over the test area and the resulting roller coverage was very uniform.

Field observations on this test bed indicated that the dump trucks placing the fill followed a process of backing up in to the test bed area, dumping the fill, and returning. A dozer was used to spread the material and then it was compacted using the roller. The area that was used to dump the subbase fill material, highlighted on Figure 8, produced somewhat higher CMV measurement values suggesting construction traffic contributed to additional compaction.

Reference

White, D. J., P. Vennapusa, H. Gieselman, J. Zhang, R. Goldsmith, L. Johanson, and S. Quist. 2010. *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials.* FHWA TPF-5(128) – New York IC Demonstration Field Project. Report submitted to The Transtec Group.

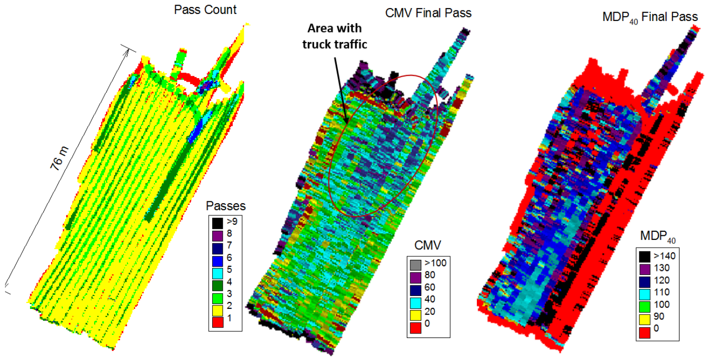

Figure 8. CMV and MDP_{40} spatial maps after final pass – TB9b gravel subbase material production compaction (highlighted area subjected to truck traffic carrying/dumping the base material)