

# Minnesota TH 60 – Non-Granular Embankment Subgrade Fill – August-October 2007

## PROJECT DATE

August to October 2007

## RESEARCH PROJECT TITLE

Implementation of Intelligent Compaction Performance Based Specifications in Minnesota

## SPONSORS

Federal Highway Administration  
Minnesota Department of Transportation (MnDOT)

## PRINCIPAL INVESTIGATOR

David J. White, PhD, PE, Iowa State University, djwhite@iastate.edu, 515-294-1463

## RESEARCH TEAM

David J. White, PhD, PE; Pavana K. R. Vennapusa, PhD, PE; Jiake Zhang, Heath Gieselmann, MS; Max Morris, PhD

## AUTHORS

David J. White, PhD, PE; Pavana K. R. Vennapusa, PhD, PE; Center for Earthworks Engineering Research, Institute for Transportation, 2711 South Loop Drive, Suite 4700, Ames, IA 50010-8664

## MORE INFORMATION

<http://www.ceer.iastate.edu/research/project/project.cfm?projectID=1995638463>

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).

The sponsors of this research are not responsible for the accuracy of the information presented herein. The conclusions expressed in this publication are not necessarily those of the sponsors.

CENTER FOR

# CEER

EARTHWORKS ENGINEERING  
RESEARCH

IOWA STATE UNIVERSITY

Institute for Transportation



Figure 1. Caterpillar CP563 padfoot roller with MDP\* measurement system on TH 60 project (from White et al. 2009)

## Project Overview

This project involved construction of the new four-lane Trunk Highway (TH) 60 bypass around Bigelow, Minnesota. The highway construction extended from just north of 120th Street in Iowa to about 1.6 km north of Nobles County Road (CR) 4 in Minnesota for a total length of about 8 km. Construction involved embankment fill sections varying from 1 m to 10 m in height. The embankment fill material on the project mostly consisted of non-granular materials derived from glacial deposits (lean clay to sandy lean clays).

The project implemented the MnDOT intelligent compaction (IC) pilot specification titled *2106 – Excavation and Embankment – (QA/QC) IC Quality Compaction (Pilot Specification) for Granular and Non-Granular embankment grading materials*. Some key elements of the specification are discussed below.

CP563 (Figure 1) and CP663 padfoot

rollers equipped with machine drive power (MDP) measurement technology (measurements reported as MDP\* and see White et al. 2009 for description), real-time kinematic global positioning system (GPS), and AccuGrade compaction mapping system were used on this project.

Three test areas were constructed and tested as part of a field study on this project by Iowa State University (ISU) researchers. One test area consisted of a production area and two test areas consisted of calibration test strips. Results from these test areas are presented in this Tech Brief along with MnDOT quality assurance (QA) test results.

## Materials

The embankment fill material in the test areas was classified as lean clay (CL or A-6(6), A-7-6(14), and A-6(11)) soil. The liquid limit of the material varied from about 30 to 43 and the plasticity index varied from about 14 to 19.

## Overview of Project Specifications

The key attributes of the MnDOT 2106 pilot specification included the following: Equipment Specifications, Compaction Process and Acceptance Specifications, Location Specifications (including size, depth, and track overlap) for Production and Calibration Areas for Testing, and Documentation and Reporting Requirements.

As part of the compaction process and acceptance guidelines, the contractor was required to construct a control strip to develop a quality control (QC) procedure including proper IC equipment and procedures, collecting and reporting IC compaction results, ensuring uniformity, confirming acceptable moisture limits and compaction pattern and speed of roller passes, etc. The contractor was required to construct one control strip for each different type/source of grading material used on the construction site to determine the Intelligent Compaction – Target Value (IC-TV) and Light Weight Deflectometer Target Value (LWD-TV). IC-TV was defined as the optimum compaction value determined by the Engineer when optimum compaction was reached (i.e., when additional compaction passes do not result in a significant increase in stiffness).

Three LWD tests were performed by the Engineer on each layer of control strip to determine the average and use as LWD-TV. Moisture was controlled to be within 65% to 95% of standard Proctor optimum moisture content. To determine the moisture sensitivity correction for IC-TV and LWD-TV, the control strip was constructed at or near each extreme of 65% and 95% of optimum moisture content and the data were utilized to produce a correction trend line using a linear relationship. As part of QC, the contractor was required to perform moisture content tests at a minimum of 1 per 3,000 cubic meter for compliance.

QA was accomplished by constructing proof layers in production areas. All segments of proof layers were required to be compacted so that at least 90% of the IC measurements were at least 90% of the IC-TV prior to placing the next lift. In areas < 80% of IC-TV, the contractor was required to bring the areas to at least 90% of IC-TV prior to placing the next lift. If a significant portion of the grade was more than 20% in excess of the IC-TV, the Engineer re-evaluated the IC-TV. QA tests were required with one LWD and moisture test per proof layer per 300 m in length for the entire width of the embankment. The LWD value must be at least 90% but not more than 120% of the corrected LWD-TV. Areas that did not meet these requirements were required to be re-compacted (and dried or added moisture as needed).

MnDOT performed moisture tests using “speedy” moisture tester and LWD tests using a Zorn LWD setup with a 200 mm diameter plate.

## Selection of Target Values and QA Test Results

Field observations indicated that the embankment material from the borrow areas was generally wet due to prolonged rain events at the time of ISU field testing. Compaction of fill materials was achieved using the padfoot roller and also by scraper traffic. The research team interviewed both MnDOT and contractor personnel to gain insights on challenges with respect to understanding the technology and implementing IC-TVs and LWD-TVs. Some of the findings are summarized below. Further, LWD, moisture content, and average IC values obtained from QA testing are provided.

### Selection of IC-TVs

Prior to the beginning of the project, MnDOT field personnel and the contractor/roller operator had limited experience with the MDP\* technology. For this project, minimum threshold values as opposed to target values were agreed to by the inspectors and the contractor. In general, the inspectors and contractors displayed a sense of goodwill toward developing the IC threshold values. This provided the flexibility required to develop acceptance values for the IC rollers on the fly to supplement information gathered from control strips. At the time of ISU field testing, a minimum threshold value of MDP\* = 138 was being used at the project site.

### Selection of LWD-TVs

MnDOT personnel indicated that similar to IC-TVs, there was limited information on what are reasonable target values for LWD measurements. Therefore, for this project, some common sense and practicality contributed to developing LWD-TVs. Observing pad foot indentations and roller walkout was one of the elements used in developing LWD-TVs. Materials difficult to trim with a motor grader produced LWD moduli ( $E_{LWD}$ ) values = 60 to 70

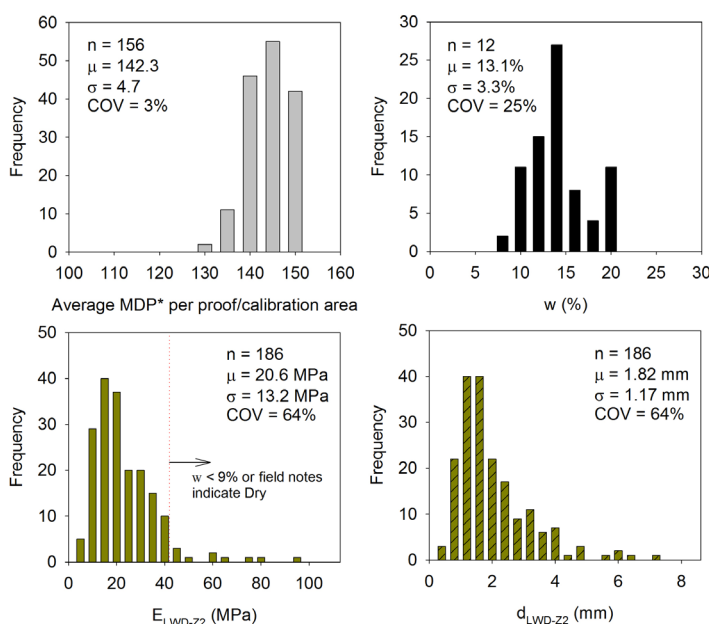


Figure 2. Histogram plots of moisture content, LWD, and MDP\* measurements (from White et al. 2009)

MPa, and materials with moisture contents that complied with the specifications produced  $E_{LWD} = 20$  to 30 MPa. For relatively wet soils,  $E_{LWD} < 15$  MPa was observed. When the inspectors released the drop-weight, they also looked for “hard recoil” as an indicator of compaction quality. At the time of ISU field testing, a minimum acceptable threshold value of  $E_{LWD} = 18$  MPa was used for acceptance. When the moduli values were less than the threshold value, the field inspectors generally found that the in-place moisture content was relatively high. When the measurements were equal to or greater than the minimum threshold value, but the embankment layers appeared to show pumping under construction traffic or roller, an additional LWD reading was taken at a depth of about 100 to 150 mm below the surface. When additional compaction effort did not improve the LWD values, the embankment was disked, aerated, and re-compacted.

*QA Test Results by MnDOT*

The QA test results of moisture content ( $w$ ),  $E_{LWD}$ , LWD deflection values ( $d_{LWD}$ ), and MDP\* values are summarized as histograms in Figure 2. Simple linear regression analysis was performed between these measurements to assess the influence of moisture content on  $E_{LWD}$  and MDP\*, and the relationship between MDP\* and  $E_{LWD}$ . The results are summarized in White et al. 2009, which indicated that the LWD and MDP\* values were influenced by changes in moisture content (increasing moisture decreases  $E_{LWD}$  and MDP\*), MDP\* values are empirically correlated with  $E_{LWD}$  measurements, and  $E_{LWD}$  values are affected by wet/soft layers below the testing surface. Significant scatter was observed in those relationships with  $R^2$  values ranging from 0.1 to 0.2. Regression relationships between these parameter values are further explored through controlled test strip construction and testing and the results are summarized below.

**Results from Research Test Strips**

Test strips 2 and 3 involved calibration test areas. Test strip 2 consisted of a 36 m long one-dimensional test strip. Motor scrapers were used to place the fill material and a bulldozer was used to level the material in the test strip area (Figure 3). The uncompacted lift thickness of the fill was in the range of 0.3 to 0.5 m. The test strip was compacted with 15 roller passes with two nominal vibration amplitude ( $a$ ) settings: Pass 1 through 8 at  $a = 1.87$  mm and Pass 9 through 15 at  $a = 0.85$  mm. In situ point measurements were obtained using nuclear gauge (NG), dynamic cone penetrometer (DCP), and Zorn LWD test devices at 0, 4, 8, and 15 roller passes. DCP test results are reported as dynamic penetration index values for top 300 mm ( $DPI_{300}$ ).

Figure 4 presents MDP\* data plots along test strip 2 and corresponding point measurement values after 1, 4, 8, and 15 roller passes. Point measurements showed variations that generally coincided well with variations in MDP\* along the test strip. The target minimum  $E_{LWD}$  and MDP\* values used for QA are also shown in Figure 4, for reference.

To assess influence of vibration amplitude on MDP\* values, tests strip 3 was evaluated with three 45 m long lanes compacted using different amplitude settings as follows: (3a) static, (3b)  $a = 0.85$

mm, and (3c)  $a = 1.87$  mm. LWD tests were conducted after 1, 2, 4, 8, and 12 roller passes, and NG tests were conducted after 12 passes at five test locations across each lane. MDP\* compaction growth curves for each lane are presented in Figure 5.

The compaction curves for all lanes followed the same path of increasing average MDP\* from pass 1 through 7, some decrease in MDP\* after passes 8 and 9, and then a slight increase in MDP\* and/or relatively constant MDP\* after pass 10. Low MDP\* values were recorded for pass 9 on lane 3b, which is a result of a low throttle setting during roller operation. The results did not show any evidence of the influence of vibration amplitude on MDP\* on this test strip. However, the material was generally wet of optimum moisture content and variable on this test strip.



**Figure 3. Test strip 2 construction and testing (from White et al. 2009)**

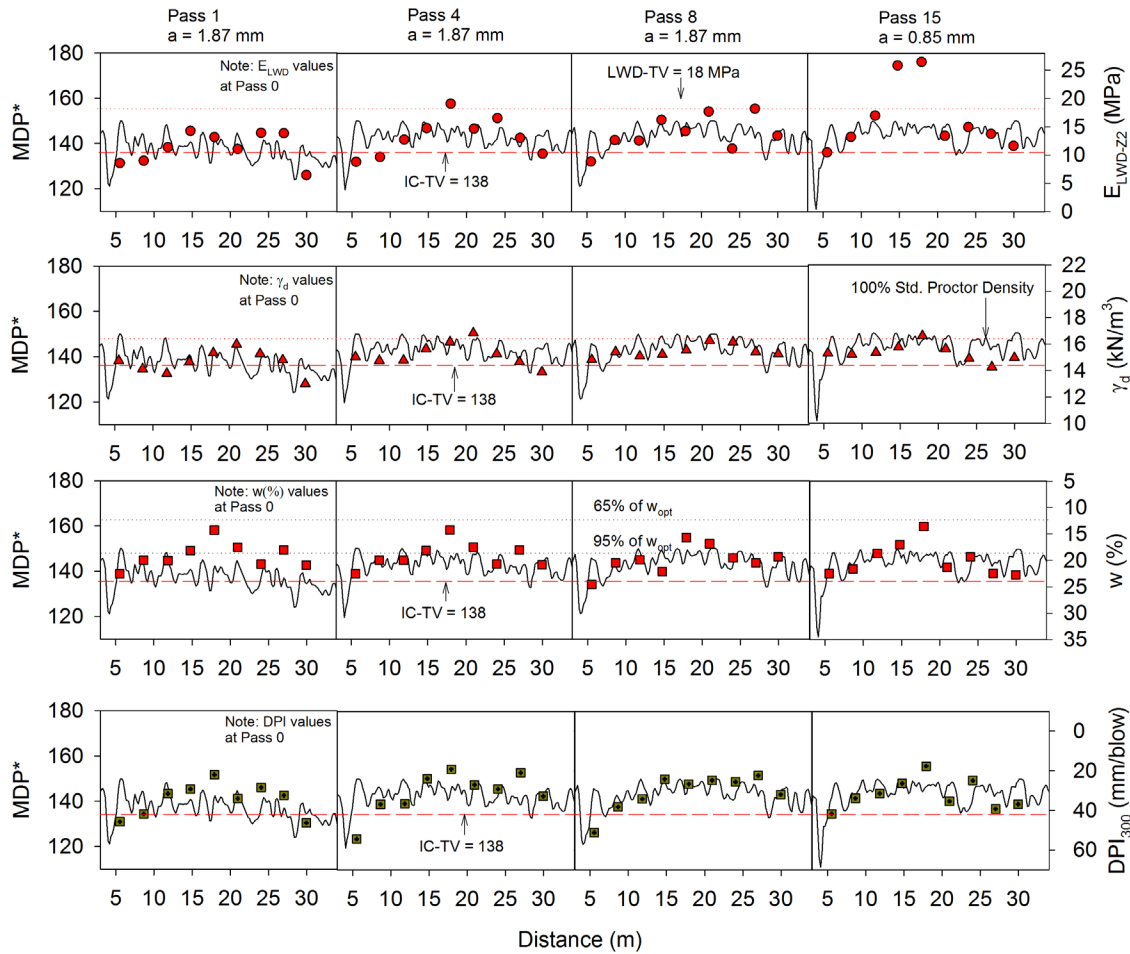


Figure 4. MDP\* versus in situ point measurement values after several passes along test strip 2 (from White et al. 2009)

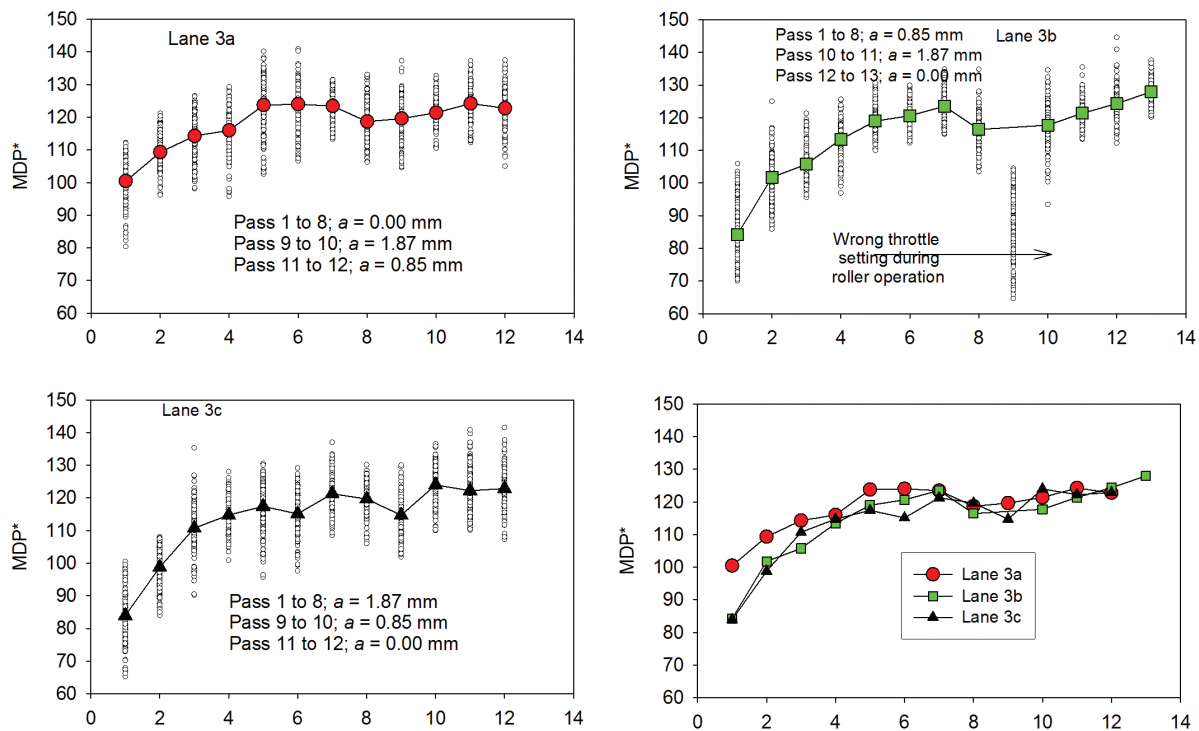


Figure 5. Influence of amplitude on MDP\* compaction curves on test strip 3 lanes 3a, 3b, and 3c (from White et al. 2009)

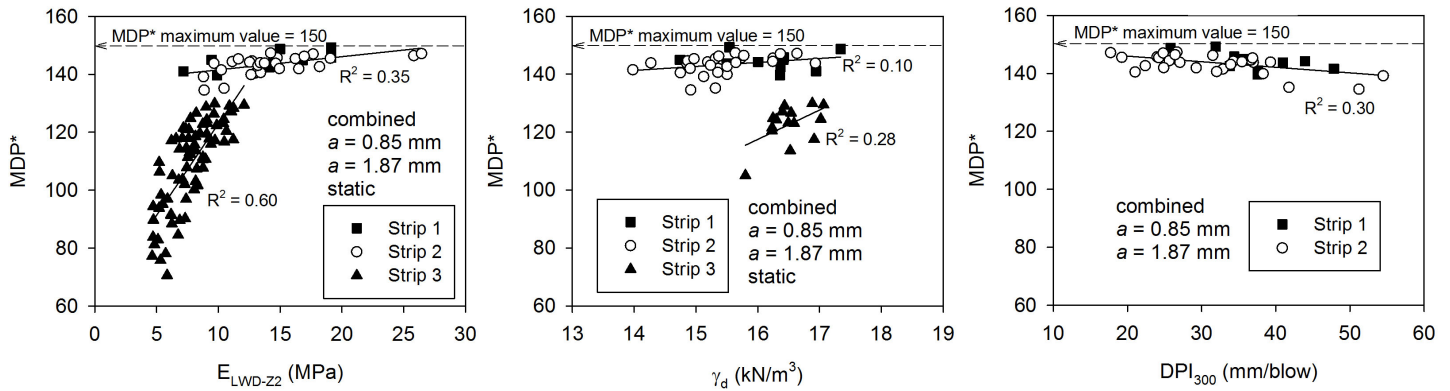


Figure 6. Linear regression relationships between  $MDP^*$  and LWD, nuclear gauge, and DCP test measurements from test strips 1, 2, and 3 (from White et al. 2009)

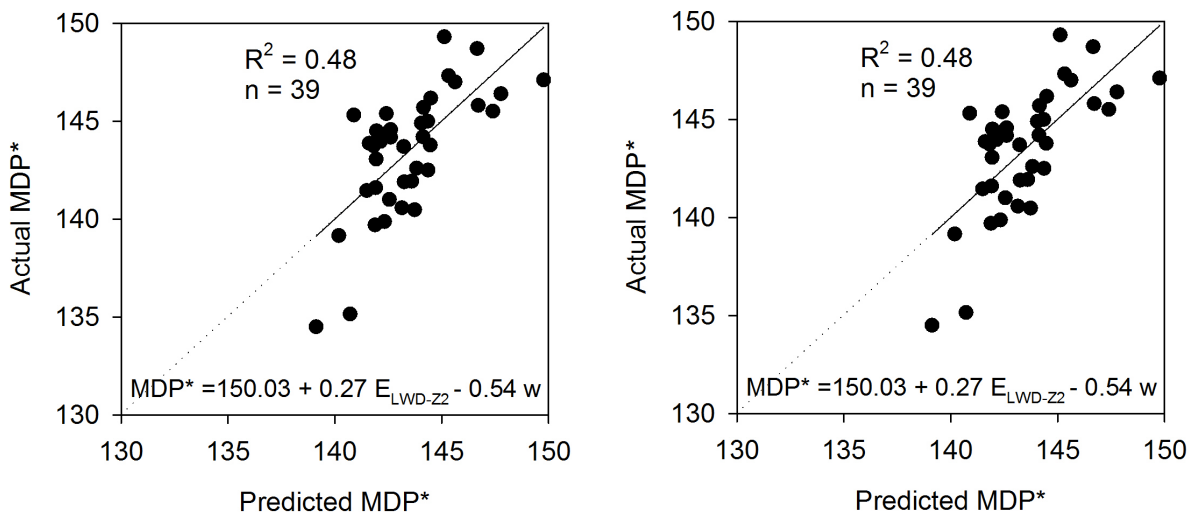


Figure 7. Multiple linear regression relationships incorporating moisture content in predicting  $MDP^*$  values from DCP and LWD test results (from White et al. 2009)

Regression relationships based on data obtained from research test areas are summarized in Figure 6.  $MDP^*$  data obtained from test strips 1 and 2 and test strip 3 showed different trends in the relationships with LWD measurement values.  $MDP^*$  values tended to reach an asymptotic value of 150. The  $MDP^*$  versus  $E_{LWD}$  relationships showed improved correlations for the trends observed with  $MDP^*$  values less than 138 ( $R^2 > 0.4$ ) and greater than 138 ( $R^2 < 0.3$ ).

$MDP^*$  and dry density ( $\gamma_d$ ) relationships showed poor correlations with  $R^2$  values between 0.0 and 0.3.

Similar to correlations between  $MDP^*$  and  $E_{LWD}$  measurements, at  $MDP^*$  values greater than 138,  $MDP^*$  and  $DPI_{300}$  relationships showed relatively poor correlations with  $R^2$  of about 0.3.

Multiple regression analysis was performed on the data to assess the influence of moisture content and amplitude on relationships between  $MDP^*$  and  $E_{LWD}$ ,  $MDP$  and  $\gamma_d$ , and  $MDP$ - $DPI_{300}$ . The analysis indicated that vibration amplitude was not statistically significant. Moisture content was statistically significant in

predicting  $MDP^*$  from  $E_{LWD}$  and  $DPI_{300}$  measurements and improved the  $R^2$  values from 0.37 to 0.48 and 0.30 to 0.45, respectively (Figure 7). Moisture content was not statistically significant in predicting  $MDP^*$  from  $\gamma_d$  measurements for this dataset.

### Summary of Key Findings

- $MDP^*$  measurements showed positive correlations with surface  $E_{LWD}$  and compaction layer DPI measurements. The regression relationships, however, showed varying degrees of uncertainty with  $R^2$  values varying from about 0.3 to 0.8. Relationships between  $MDP^*$  and  $\gamma_d$  generally showed poor correlations ( $R^2 < 0.3$ ). Soft or uncompacted zones at depths below about 0.25 m on tests strips 1 and 2 did not affect the  $MDP^*$  measurements.
- Regression relationships improve in predicting  $MDP^*$  from  $E_{LWD}$  and DPI when moisture content is included in the regression analysis. This illustrates the sensitivity of soil moisture content in interpreting  $MDP^*$  values.

- Separate trends were observed in MDP\* correlations with  $E_{LWD}$ , which present a challenge in implementing the QA requirement of a production area meeting 90% to 120% of IC-TV as the limits are applicable only with one linear trend in the data with increasing compaction.
- The wrong throttle and gear settings used during roller operations invalidated IC measurement values for some sections. The roller manufacturer recommendation is that the roller should be operated at a high throttle and low gear setting during compaction operations.
- No evidence of influence in vibration amplitude on MDP\* was found for the material tested on tests strips 2 and 3. On test strip 3, the average MDP\* achieved on all lanes was almost the same as on pass 8. The material in the test strips was either close to or wet and of optimum moisture content.

## Reference

White, D. J., Vennapusa, P., Zhang, J., Gieselman, H., and Morris, M. 2009. *Implementation of Intelligent Compaction Performance Based Specifications in Minnesota*, Final Report, MN/RC 2009-14, Minnesota Department of Transportation, St. Paul, MN.