RESEARCH news
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BUREAU OF RESEARCH AND TECHNOLOGY
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Iowa's intelligent compaction research and implementation

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Intelligent compaction (IC) technology integrated with a global positioning system (GPS) provides 100 percent coverage for compacted earth materials and hot-mix asphalt (HMA) conditions. Using IC shows significant potential for enhancing the abilities of governmental agencies and contractors to construct better, safer and less expensive transportation infrastructure projects.

The Iowa Department of Transportation (DOT) and Earthworks Engineering Research Center (EERC) at Iowa State University (ISU) organized three national annual workshops (2008-2010) to provide a collaborative exchange of ideas and experiences; share research results; and develop research, education and implementation initiatives for IC.

Recently, the Iowa DOT started the Intelligent Compaction Research and Implementation – Phase I initiative in collaboration with the EERC. Three demonstration projects involving HMA overlay and pavement foundation layer earthwork construction were conducted in Iowa in 2009. New IC specifications have been developed and incorporated into 2010 HMA and embankment construction projects in Iowa.

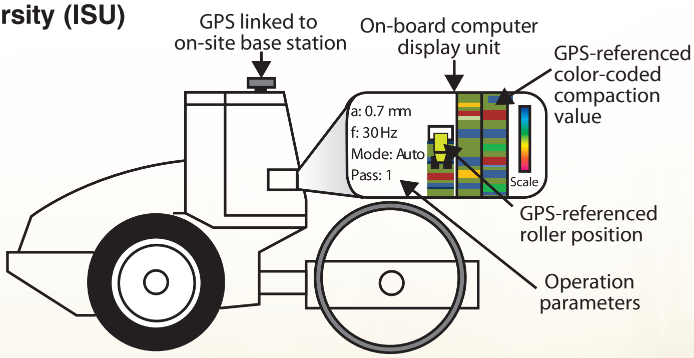
This article provides background information about IC, an overview of the 2010 IC workshop, results from the 2009 demonstration projects, and a summary of the new IC special provision specifications.

What is IC?

IC technologies consist of machine-integrated sensors and control systems that provide a record of machine-ground interaction on an onboard display unit in real time **(Figure 1)**.

With feedback control and adjustment of vibration amplitude and/or frequency and/or speed during the compaction process, the technology is referred to as "intelligent" compaction. Without the vibration feedback control system, the technology is commonly referred to as continuous compaction control (CCC).

The machine-ground interaction measurements provide an indication of ground stiffness/strength and, to some extent, degree of compaction. Most of the IC/CCC technologies are vibratory-based systems applied to single-drum, self-propelled smooth-drum rollers.



Machine-integrated sensors to measure drum/machine response to soil behavior

Figure 1 – *IC/ICCC compaction monitoring systems*

IC/CCC technologies have also been applied to vibratory, double-drum asphalt compactors and self-propelled padfoot compactors. CCC vibratory roller systems have been used in Europe for more than 20 years.

Most of the research documented in the literature deals with CCC applications for granular materials on smooth-drum vibratory rollers. A static-based measurement technology based on machine-drive power (MDP) has recently developed for padfoot and smooth-drum rollers.

More recently, an artificial neural network (ANN)-based measurement system has been developed for use on asphalt rollers. Over the years, the technologies evolved to integrate roller measurements with GPS measurements for real-time, onboard mapping and visualization capabilities. These technologies are expected to continue to improve and find applications to a wider range of earth materials and field conditions.

Currently, there are at least eight IC/CCC systems/parameters: compaction meter value (CMV), oscillometer value (OMV), compaction control value (CCV), roller-integrated stiffness (k_s), omega value (ω), vibratory modulus (E_{vib}), machine-drive power (MDP), and intelligent asphalt compaction analyzer (IACA).

The CMV, OMV, CCV, k_s, ω, and E_{vib} measurement systems are accelerometer-based technologies. The CMV, OMV and CCV systems follow the approach of calculating the ratio of selected frequency harmonics for a set time interval. The k_s, ω and E_{vib} measurement systems follow the approach of calculating ground stiffness or elastic modulus based on a drum-ground interaction model and some assumptions. The MDP measurement system is based on principles of machine rolling resistance. The IACA relates machine harmonics to asphalt stiffness through a trained ANN model.

Implementation challenges

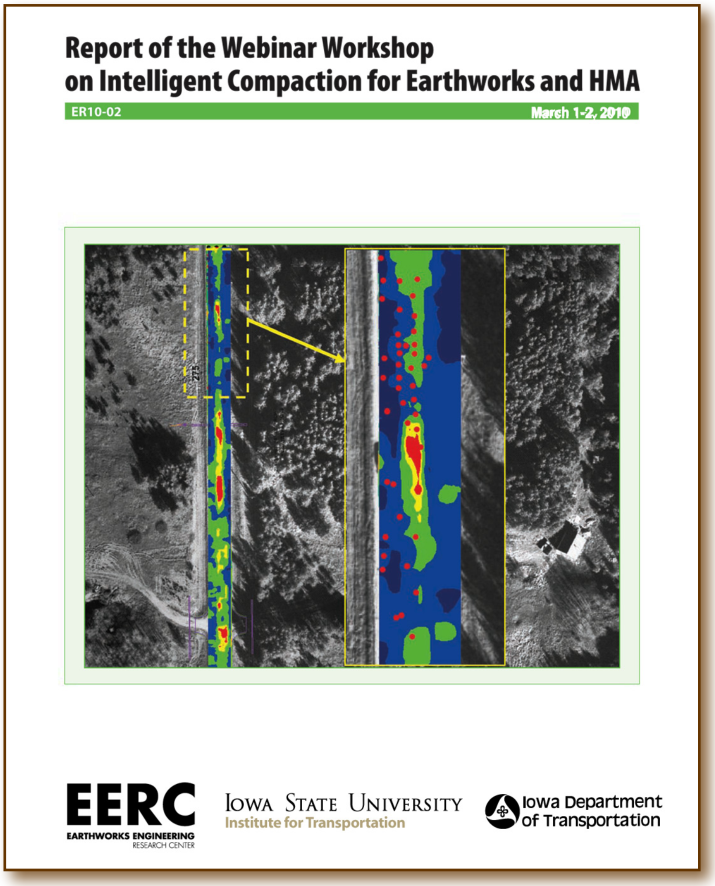
There is growing interest among transportation agencies and contractors to incorporate IC/CCC technologies into earthwork and HMA pavement construction practice. Expectations are that the IC/CCC systems will: 1) improve construction efficiency; 2) streamline quality management programs of earthwork and asphalt projects; 3) provide a link between quality acceptance parameters and pavement design parameters; and 4) improve the performance of compacted materials.

These expectations cannot be met without addressing the following key implementation challenges.

- Lack of adequate knowledge about technical aspects
- No widely accepted specifications or standards
- Limited number of well-documented case histories demonstrating the benefits of IC/CCC
- Inadequate education/training materials

Intelligent compaction workshops

Since 2008, the Iowa DOT and EERC have organized three national annual workshops. The 2008 and 2009 workshops were face-to-face meetings, while the 2010 workshop was organized as a Webinar. Proceedings for workshop sessions that summarize workshop events and outcomes are available online at: www.eerc.iastate.edu/publications.cfm **(Figure 2)**.



Report of the Webinar Workshop on Intelligent Compaction for Earthworks and HMA

ER10-02

March 1-2, 2010

EERC
EARTHWORKS ENGINEERING RESEARCH CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Iowa Department of Transportation

Figure 2 – *2010 workshop report cover*

The 2008 and 2009 workshops were attended by about 100 participants, with representatives from several state DOTs, Federal Highway Administration, industry/manufacturers, contractors, and universities. The workshops featured several technical presentations, breakout sessions, panel discussions, and group exercises to identify and prioritize implementation strategies.

The 2010 Webinar had about 165 participants with representatives from state DOTs, Federal Highway Administration, the National Highway Research Program, trade organizations, contractors, equipment manufacturers, and universities. The Webinar's objective was to generate a focused discussion to identify the research, education and implementation goals necessary for advancing IC for earthwork and HMA. Technical presentations were made by EERC researchers and representatives from state DOTs and manufacturers. Webinar participants were surveyed to update the IC Road Map, a list of key research, implementation and training areas developed from the 2008 and 2009 workshops.

Participants were given the 2009 IC Road Map and asked to rank the items and provide comments regarding topics that should be removed, adjusted or added. The 2010 IC Road Map is based on participant voting **(Figure 3)**.

Prioritized IC/CCC Technology Research/Implementation Needs

Workshop topic to be adjusted, added or removed	Votes
Intelligent compaction and in situ correlations	**91**
Intelligent compaction specifications/guidance	**46**
In situ testing advancements and new mechanistic based quality control and quality assurance	**43**
Intelligent compaction technology advancements and innovations	**21**
Project scale demonstration and case histories	**19**
Understanding impact of nonuniformity of performance	**18**
Data management and analysis	**17**
Standardization of roller output and output format files*	**13**
Understanding roller measurement influence depth	**11**
Education program/certification program	**6**
Intelligent compaction research database	**6**
Standardization of roller Sensor Calibration Protocols*	**4**

Figure 3 – ** denotes the new elements added in 2010*

Similar to previous year workshop results, the top two needs remain 1) developing and providing evidence of correlations between IC/CCC measurements and in situ test measurements, and 2) developing IC/CCC specifications/guidance.

Important outcomes from the 2010 workshop included providing a forum that facilitated information exchange and collaboration, updating and prioritizing the IC/CCC road map, connecting people interested in implementing IC/CCC into earthwork and HMA construction practice, and developing plans for further workshops and other activities. Based on the information derived from the Webinar, an action plan for advancing IC/CCC technologies was developed **(Figure 4)**.

Item one of the action plan was a technology transfer intelligent compaction consortium (TTICC) pooled-fund initiative, proposed at the 2010 workshop by circulating a draft TTICC problem statement to participants. The pooled-fund initiative is now solicited under the Transportation Pooled Fund Program (**www.pooledfund.org/projectdetails.asp?id=1262&status=1**).

Iowa demonstration projects

Three demonstration projects were conducted in Iowa in 2009. These included: (1) a cohesive subgrade construction project on U.S. 30 near Colo; (2) a subgrade, subbase, and base construction project on Interstate 29 in Monona County; and (3) a HMA overlay construction project on U.S 218 near Coralville.

Action Plan for Advancing IC/ICCC Technologies into Earthwork and HMA

1. Establish a Technology Transfer Intelligent Compaction Consortium (TTICC) to identify research gaps and implementation needs, develop problem statements for needed research, identify key partners and form a national-level Specifications Technical Working Group to coordinate efforts.
2. Explore the possibility of conducting a National Highway Institute course or a one-day training course at conferences on IC/CCC technologies.
3. Develop several case histories (technical briefs) to demonstrate the technical aspects and benefits of the technologies.
4. Plan future Webinars to facilitate technology transfer.

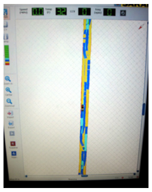
Figure 4 – *Action plan for advancing IC technologies into earthwork and HMA practices – 2010 workshop*

Compaction monitoring technologies

The Caterpillar CP56 padfoot roller, equipped with Caterpillar's MDP measurement system, was used on the U.S. 30 project. A Volvo SD116DX vibratory smooth-drum roller equipped with Trimble's CMV measurement system was used on the Interstate 29 project. A Sakai SW880 dual-drum, vibratory, smooth-drum asphalt roller equipped with a CCV measurement system was used for break-down rolling on the U.S. 218 project.

A digital display unit employing proprietary software can be mounted in the roller cabin for onboard visualization of roller position, IC-MVs, coverage information, amplitude/frequency settings, speed, etc. Several key features of the rollers are summarized below **(Figure 5)**. In situ testing methods are highlighted on the next page **(Figure 6)**.

Figure 5 – *Key features of the IC rollers used in the demonstration projects*

IC Roller	Drum Type	Frequency (f) in Hz	Amplitude (a) settings	IC-MV	Display Software	Output Documentation	Output Export File	Automatic Feedback Control
Caterpillar CP56 	Padfoot	30	Static, 0.90 mm (low), and 1.80 mm (high)	MDP40 (shown as CCV in the output)	AccuGrade® 	Date/time, location (northing/easting/ elevation), speed, CCV(MDP40), frequency, amplitude, direction (forward/ backward), vibration (On/Off)	*.csv	NO
Sakai SW880 	Dual, smooth-drum	42, 50, and 67	0.30 mm (low), 0.60 mm (high)	CCV	Aithon MT-R® 	Date/time, location (northing/easting/ elevation), CCV, temperature, frequency, direction (forward/ backward), vibration (on/off), GPS quality	*.txt	NO
Volvo SD116DX 	Smooth-drum	34 (low amp) 30 (high amp)	1.45 mm (low), 1.85 mm (high)	CMV, RMV	Trimble CB430 	Date/time, location (northing/easting/ elevation), speed, CMV, RMV, frequency, amplitude, direction (forward/ backward), vibration (on/off)	*.csv	NO

In situ testing methods

Five different in situ testing methods were employed to evaluate the in situ soil/asphalt engineering properties.

- Calibrated Humboldt nuclear gauge (NG) to measure moisture content and dry unit weight of soil, and dry unit weight of asphalt
- Dynamic cone penetrometer (DCP) to measure the penetration index per blow
- Zorn lightweight deflectometer (LWD) setup with 300-mm plate diameter to measure In situ elastic modulus (ELWD-Z3)
- 300-mm diameter four-segmented plate KUAB falling weight deflectometer (FWD) to measure in situ elastic modulus (ELWD-k3)
- FLIR thermal camera to measure temperature of the asphalt layer

Figure 6 – *Different in situ testing methods employed on the demonstration projects – (from top left to bottom right) nuclear density gauge, dynamic cone penetrometer, lightweight deflectometer, falling weight deflectometer and thermal camera*

U.S. 30 Colo – Iowa cohesive subgrade construction

Located on U.S. 30 east of Colo, Iowa, this project involved new construction of two lanes of traffic and focused on embankment construction using approved fill materials on site. Onsite soil conditions were tested **(Figure 7)**. The subgrade soils on site are classified as clayey sand (SC) according to the Unified Soil Classification System (USCS) and A-4 according to the AASHTO classification system, with liquid limit equal to 22, and plasticity index equal to 10.

The EERC research team was present on site during the demonstration and constructed test beds where in situ moisture and density measurements from various test beds on site were collected and compared with laboratory Proctor curve **(Figure 8)**.

Frequent rain events during the field-testing phase of the project resulted in challenges to construction.

Figure 7 – *Soil conditions on site*

In situ moisture and density measurements obtained from various test beds on site in comparison with laboratory Proctor curve were collected **(Figure 9)**. The results indicate that the soils are generally on the wet side of the materials' optimum moisture content.

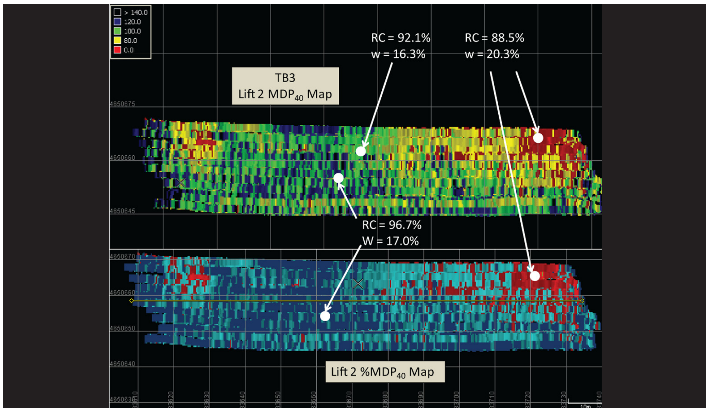


Figure 8 – *MDP40 and percent of target MDP40 maps (final pass) on lift 2, and in situ NG test measurements at three selected locations – TB3 (target MDP40 = 140)*

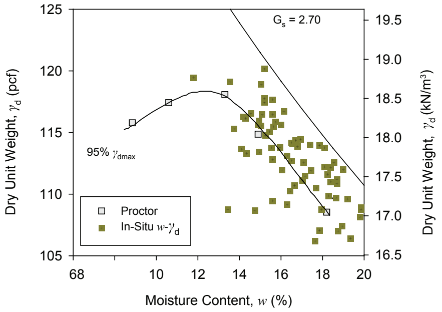


Figure 9 – *In situ moisture-density measurements in comparison with laboratory standard Proctor test data*

Interstate 29 in Monona County, Iowa – cohesive subgrade, granular special backfill and granular-base construction

This demonstration project was located on I-29 in Monona County, Iowa, and involved reconstruction of the existing interstate highway section. The old Portland Cement Concrete (PCC) surface layer and foundation layers were removed, and new subgrade, subbase, base, and PCC surface layers were constructed **(Figure 10)**. The existing subgrade layer was undercut to about 0.3 - 0.6 m below the existing grade. The exposed subgrade in the excavation was scarified and recompacted. The excavation was replaced with recycled asphalt ("special backfill") subbase layer and base material, which was mostly recycled PCC (RPCC).

The subgrade soil is classified as lean clay (CL) according to the USCS and A-7-6 (19) of the AASHTO classification system, with liquid limit equal to 41, and plasticity index equal to 21. The special backfill and aggregate base materials are classified as well-graded gravel (GW) according to the USCS and A-1-a according to the AASHTO classification system.

In situ point-test measurements were obtained in conjunction with roller measurements. Results from roller CMV measurements taken during multiple roller passes from a subgrade, a special backfill subbase and a RPCC base-layer test bed indicate roller CMV measurement values are repeatable **(Figure 11)**. The CMV measurements for the RPCC layer were in the range of 15-25, for the subbase layer in the range of 5-12, and for the subgrade layer less than five.

Figure 10 – *On-site conditions and construction operations*

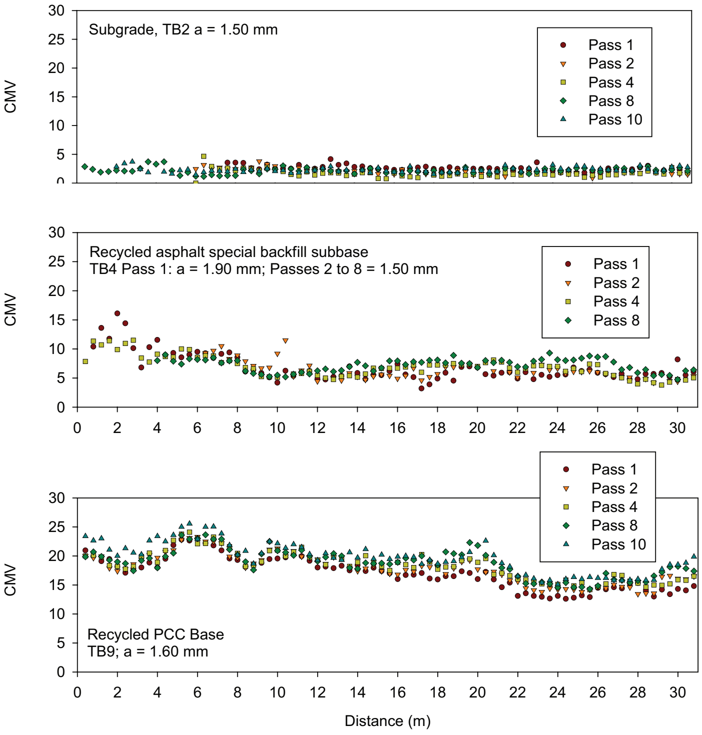


Figure 11 – *Roller-integrated CMV measurements from multiple roller passes on subgrade, special backfill subbase and RPCC base layers*

Interstate 29 continued on page 6

Interstate 29 continued from page 5

Data for compaction growth curves of roller CMV measurements and in situ ($E_{LWD\text{-}Z3}$) and dry density measurements with increasing pass on subgrade, subbase and base layers were collected **(Figure 12)**. Correlations obtained from various test beds between roller CMV and $E_{LWD\text{-}Z3}$ and γ_d in situ test measurements were developed **(Figure 13)**. Correlation between CMV and $E_{LWD\text{-}Z3}$ showed an exponential relationship with $R^2 = 0.81$. No statistically significant relationship was present between γd and CMV. Spatial comparison of CMV maps obtained in low- and high-amplitude settings on a subgrade layer and an overlying subbase layer was developed for a test bed along with DCP-CBR profiles at three select locations with low, medium and high CMV measurement values **(Figure 14)**. The CBR profiles, $E_{LWD\text{-}Z3}$ measurements at the DCP test locations correspond well with variations in CMV at these test locations.

CMV spatial maps were developed in low-and high-amplitude settings on a RPCC base layer **(Figure 15)**. The test bed consisted of a buried box culvert beneath the base layer that was clearly identified with high CMV measurement values.

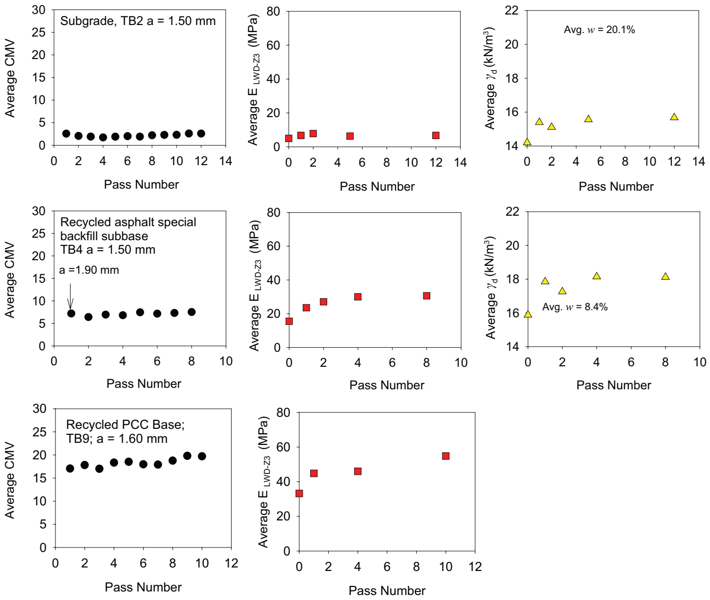


Figure 12 – *Comparison of CMV, ELWD-Z3, and γd growth curves with increasing pass on subgrade, special backfill subbase, and RPCC base layer*

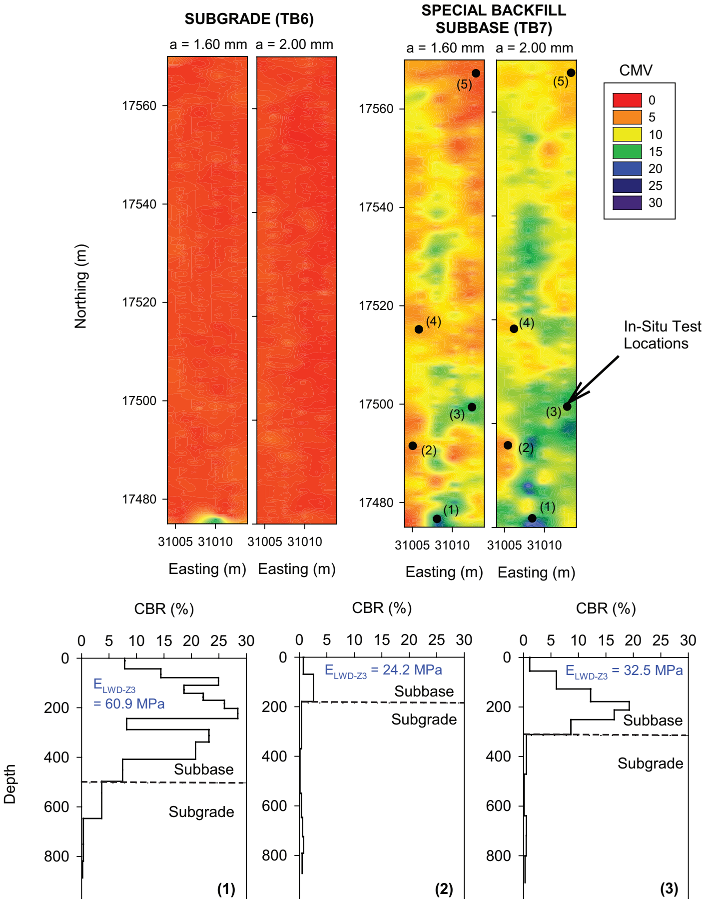


Figure 14 – *Spatial comparison of a subgrade layer CMV map overlain by a special backfill subbase layer CMV map and DCP-CBR profiles at three selected locations*

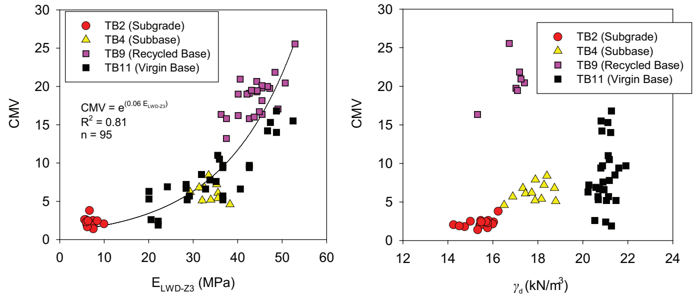


Figure 13 – *Correlations between roller-integrated CMV and in situ point measurements ($E_{LWD\text{-}Z3}$ and γ_d) from subgrade, special backfill subbase and aggregate base layers*

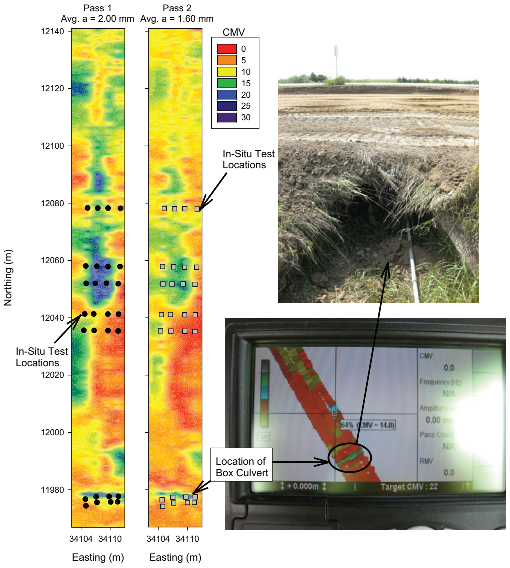


Figure 15 – *(left) Spatial comparison of CMV maps obtained on a test bed with RPCC base layer using low-and high-amplitude settings*

U.S. 218 Coralville, Iowa – HMA overlay construction

This demonstration project was located on U.S. 218 south of I-80 in Coralville, Iowa. The project involved construction of HMA over the existing PCC surface. The HMA-base course layer was compacted using two Sakai dual-drum rollers in the breakdown position. Of the two rollers, one Sakai roller was equipped with an IC-monitoring system. The compaction monitoring system monited roller coverage (i.e., number of passes) and IC measurement values (Sakai CCV), and displayed data in real time on the onboard display monitor located in front of the roller operator.

A temperature sensor was present on the roller and linked to GPS measurements to provide a continuous record of the temperature of the asphalt surface. The ISU research team was present onsite periodically during paving operations from Aug. 31, 2009, through Sept. 2, 2009 (**Figure 16**).

Day 1: The compaction monitoring system on the roller was switched on, but the onboard display monitor was closed for viewing by the operator.

Days 2 and 3: The roller operator was allowed to use the onboard display to aid uniform roller-pass coverage. Then they were asked to perform four passes (two forward and two reverse). The two Sakai rollers on the project generally followed each other, resulting in a total of eight roller passes (compaction monitoring was available on only one roller).

Day 3: In situ relative compaction was obtained using a nuclear density gauge, modulus testing using KUAB FWD, and asphalt mat temperature measurements using a thermal imaging camera provided by the Iowa DOT and infrared camera mounted on the FWD trailer. Measurements were obtained on mainline and paving over the existing shoulder lane. Correlations between roller CCV measurements and in situ relative compaction and FWD modulus (E_{FWD-K3}) values have been developed. FLIR thermal images showing spatial variation in the asphalt surface temperatures were taken (**Figure 17**) and roller-pass coverage maps from day one and two were created.

Figure 16 – *Paving operations*

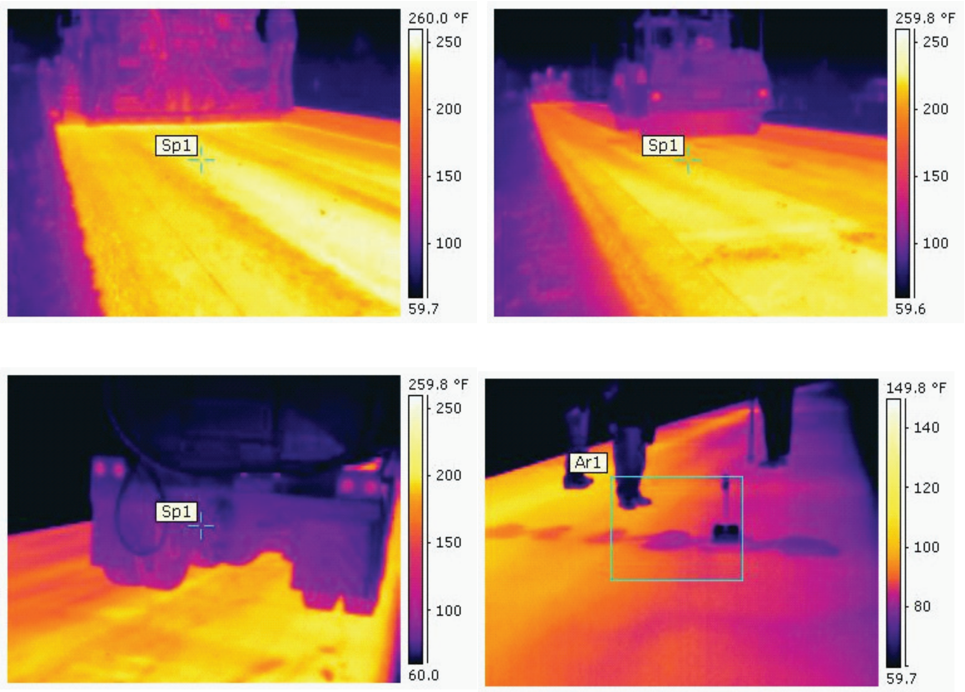


Figure 17 – F_{LIR} *thermal images: in front of paver (top left), in front of breakdown roller (top right), behind water truck during finish rolling (bottom left), and nuclear gauge testing on the final compacted surface (bottom right)*

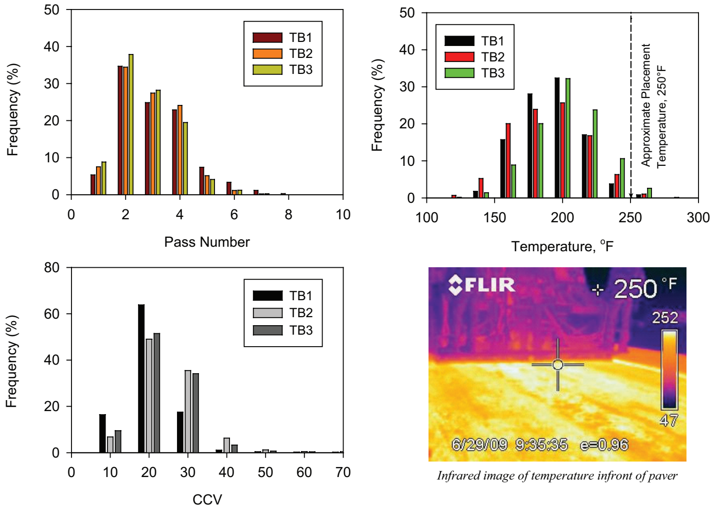
U.S. 218 continued on page 8

U.S. 218 continued from page 7

Histogram plots of roller-pass coverage data, temperature and CCV data obtained from days one, two and three were developed (**Figure 18**).

The histogram plots did not reveal any significant differences in the number of roller passes, temperatures, and CCVs between days one and three. To further analyze any differences in the uniformity of pass coverage, geostatistical semivariograms of the number of roller passes were developed (**Figure 19**). The semivariograms indicate improved uniformity in pass coverage on day three compared to day one. This is a significant finding that provides quantitative evidence of improvement in compaction operations by viewing the data in real time.

FLIR temperature (T_{FLIR}) and relative compaction measurements were obtained at two locations with several measurements across the pavement width (including mainline and shoulder) at each location (**Figure 20**).



Infrared image of temperature infront of paver

Figure 18 – *Histogram plots of number of passes, measured temperature and CCV measurements from the IC rollers from TBs 1, 2 and 3*

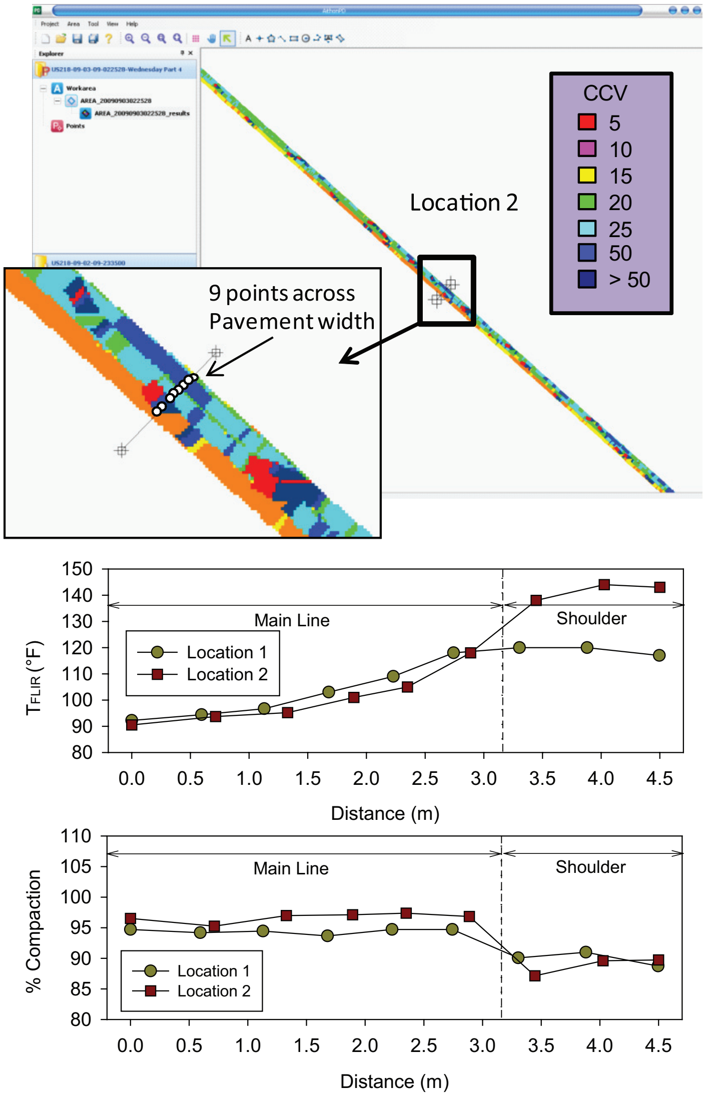


Figure 20 – *Comparison of semivariogram of number of roller passes: Day 1 (TB1 – blind study) and day 3 (TB3 – with aid of onboard monitor) assessing uniformity in pass coverage*

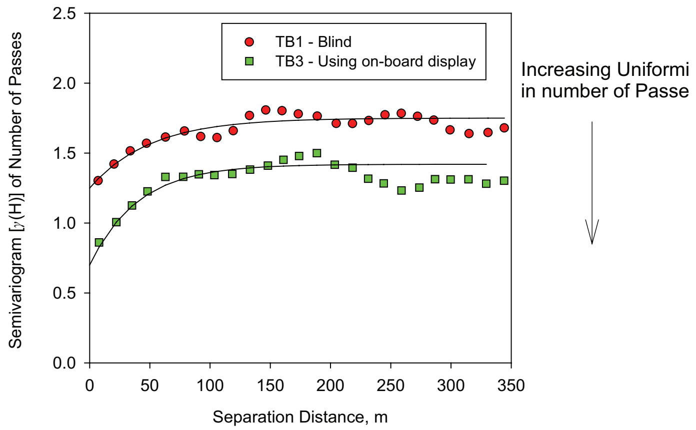


Figure 19 – *Comparison of semivariogram of number of roller passes from day 1 (TB1 – blind study) and day 3 (TB3 – with aid of onboard monitor) assessing uniformity in pass coverage*

EERC equipment and facilities

The main focus of ISU's EERC is to solve infrastructure geotechnical engineering and earthwork construction problems. New technologies and interdisciplinary approaches are emphasized in research and through a new academic program at ISU. The EERC works with partners to define, prioritize and conduct a strategic program of research.

The EERC has a unique geotechnical mobile lab with many laboratory and In situ testing devices that provides research and learning opportunities.

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Relative compaction, $E_{FWD\text{-}K3}$, and T_{FLIR} in situ test measurements **(Figure 21)** were obtained at several locations along a stretch of about 1.3 km on the mainline and shoulder and compared with roller CCV measurements.

Results presented in figures 20 and 21 indicate that the density, modulus and roller-measured CCV were all lower on the shoulder compared to the mainline. This is likely because of comparatively weak support conditions under the shoulder compared to the mainline.

Correlations between CCV, relative compaction and $E_{FWD\text{-}K3}$ were developed **(Figure 22)**. Correlation between CCV and $E_{FWD\text{-}K3}$ showed strong linear regression relationship (with R^2 equal to 0.8) compared to correlation between CCV and relative compaction (with R^2 equal to 0.4).

This is expected as CCV is a result of drum response under vibratory loading that is a measure of the stiffness and not necessarily related to the density of the material.

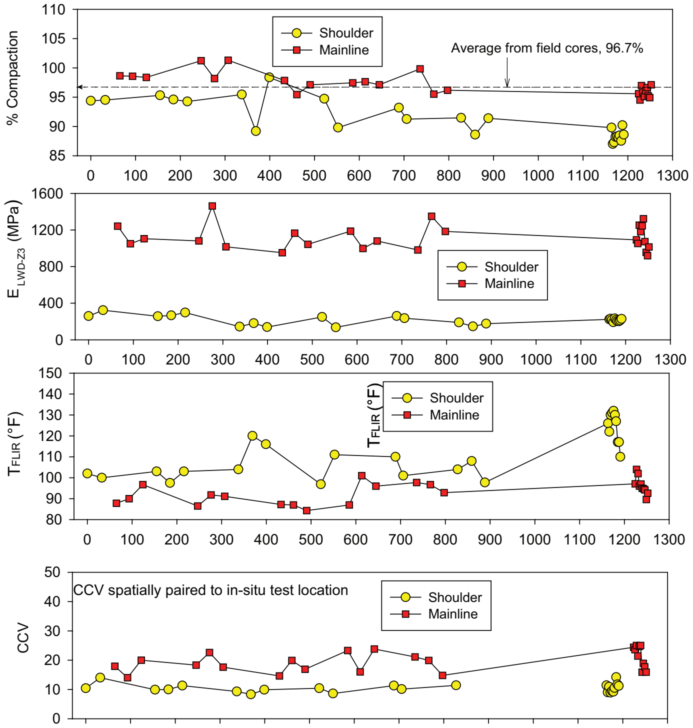

Figure 21 – *Comparison of CCV, percent compaction, $E_{FWD\text{-}K3}$, and T_{FLIR} along shoulder and mainline*

In addition, various other factors influence both roller and in situ test measurements, including: a) differences in underlying support conditions; b) differences in measurement influence depths of each device; c) temperature at the time of the measurement; and d) direction of roller travel.

The influence of differences in underlying support conditions is clearly reflected with data groupings in correlations shown in Tables 1 and 2 on the next page.

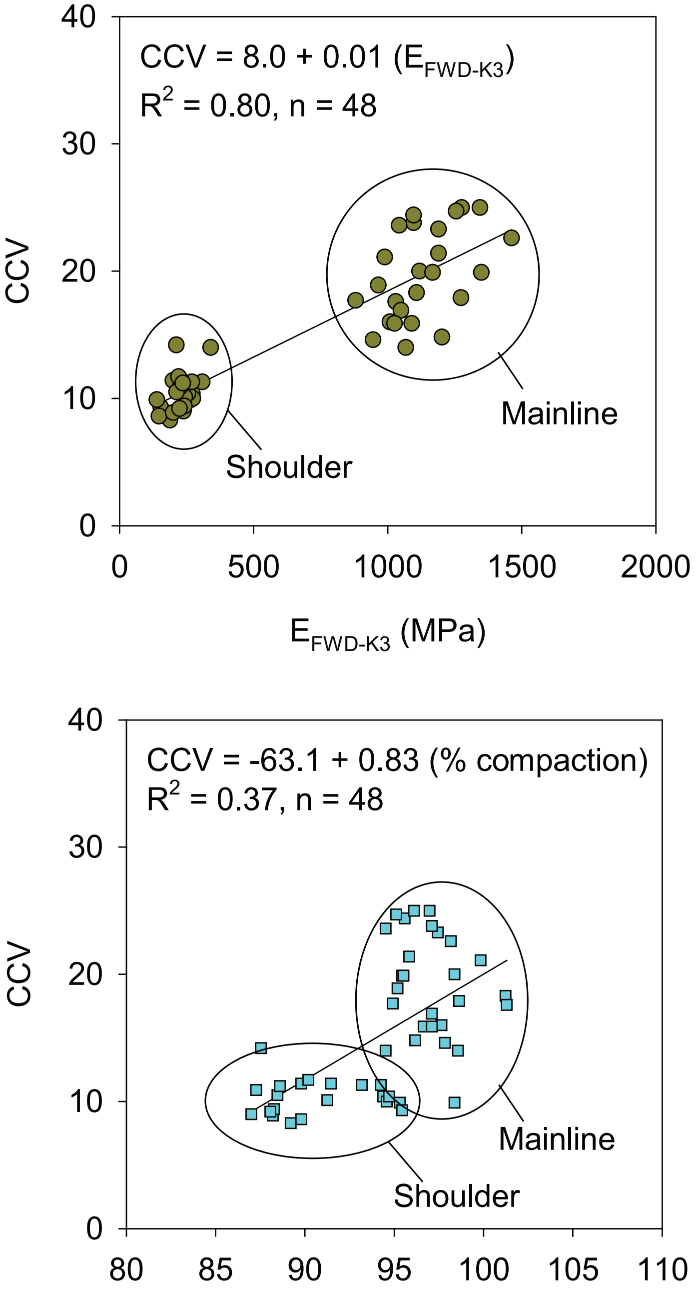

Figure 22 – *Correlations between CCV, $E_{FWD\text{-}K3}$ and percent compaction*

Overview of Iowa DOT IC specifications

Special provisions have been developed for incorporating IC into existing specifications on three HMA projects and one embankment construction project in Iowa.

Specification 1

- Iowa DOT Special Provisions for Intelligent Compaction – HMA, Harrison County, NHSN-030-1(127)—2R-43 (Effective Jan. 20, 2010) [SP-090048]

Specification 2

- Iowa DOT Special Provisions for Intelligent Compaction – HMA, Ida County, NHSN-020-2(70)—2R-47 (Effective Feb. 16, 2010) [SP-090057a]

Specification 3

- Iowa DOT Special Provisions for Intelligent Compaction – HMA Roller-Pass Mapping, Kossuth County, STPN-009-4(44)—2J-55 (Effective Feb. 16, 2010) [SP-090058]

Specification 4

- Iowa DOT Special Provisions for Intelligent Compaction – Embankment, Sac County, NHSX-020-2(89)—3H-81 (Effective April 20, 2010) [SP-090063]

Feature specification attribute	Specification			
	1	2	3	4
Description	x	x	x	x
Equipment and materials				
Rollers	x	x	x	x
Data collection, export, and onboard display	x	x	x	x
Local GPS base station	x	x	x	x
Training	x	x	x	x
Geotechnical mobile lab parking	x	x	x	x
Test strips				x
Proof-area mapping				x
Construction				
Roller verification/repeatability	x			
Roller operations	x	x	x	x
Equipment breakdowns	x	x	x	x
Data submittal	x	x	x	x
Method of measurement	x	x	x	x
Basis of payment	x	x	x	x
Equipment availability*	Y	Y	Y	N

Table 1 – *Overview of specifications*

****Notes:*** *Y = Yes, N = No (not available at the time of bidding*

These special provisions describe the contractor's responsibilities for furnishing IC-equipped rollers, data acquisition and the attributes listed in **Table 1**.

The specification attributes differ slightly from each specification. For example, specification 1 requires repeatability testing of roller measurement values, while specifications 2, 3 and 4 do not.

The data collection, export and onboard display attributes also differ between the specifications as highlighted in **Table 2**.

The Harrison, Ida and Kossuth counties HMA projects are underway. The Sac County embankment project specification could not be implemented due to IC rollers not being available for cohesive soil compaction during the construction period.

Results from the projects constructed with IC this year do not require changes in the acceptance process. Results collected this year will be used to assess if and how IC values can be incorporated in the quality control, and possibly quality assurance, processes.

Data collection	Specification			
	1	2	3	4
Machine model, type, and serial/machine number	x	x	x	x
Roller drum dimensions	x	x	x	x
Roller and drum weights	x	x	x	x
File name	x	x	x	x
Date stamp	x	x	x	x
Time stamp	x	x	x	x
RTK-based GPS measurements (northing, easting, and elevation)	x	x	x	x
Roller travel direction (forward or reverse)	x	x	x	x
Roller speed	x	x	x	x
Vibration setting (on or off)	x	x		x
Vibration amplitude	x	x		x
Vibration frequency	x	x		x
Surface temperature	x	x		
Compaction measurement value	x			x
Roller pass count			x	x

Table 2 – *Differences in data collection requirements*

About the Authors

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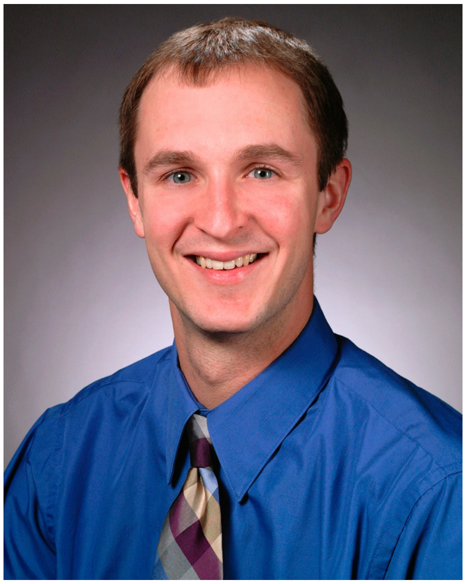
Dr. Pavana Vennapusa is a research assistant professor at ISU's department of civil, construction and environmental engineering.



Mr. Heath Gieselman is a research scientist at the EERC, and manages laboratory and field testing and the ISU's geotechnical mobile laboratory.

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Some recent IC-related publications from EERC

More than 50 technical articles were published on IC-related research from EERC. Some selected recent publications are listed below.

White, D.J., Vennapusa, P. (2010) Report of the Webinar Workshop on Intelligent Compaction for Earthworks and HMA, EERC Publication ER10-02, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa.

Mooney, M., Rinehart, R., White, D.J., Vennapusa, P., Facas, N., (2010). Intelligent Soil Compaction Systems, NCHRP 21-09 Final Report, National Cooperative Highway Research Program, Washington, D.C. (in print).

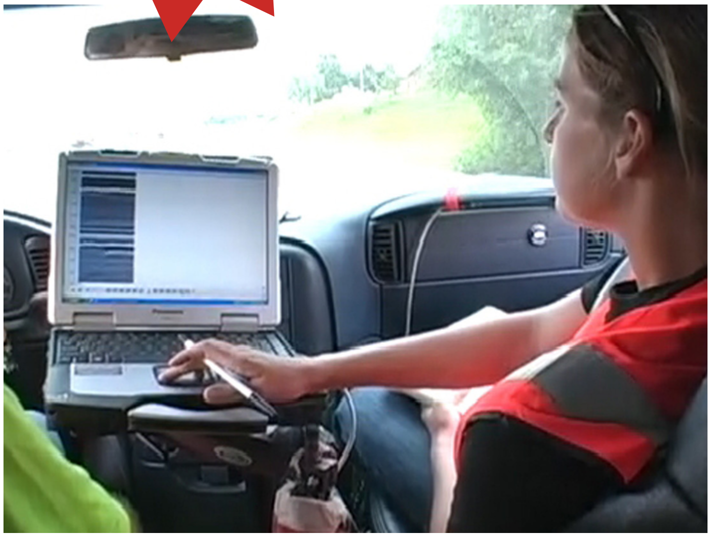
Vennapusa, P., White, D.J., Morris, M. (2010). "Geostatistical analysis for spatially referenced roller-integrated compaction measurements." Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 136(6), 813-822.

White, D.J., Vennapusa, P., Zhang, J., Gieselman, H., Morris, M. (2009). Implementation of Intelligent Compaction Performance Based Specifications in Minnesota, EERC Publication ER09-03, MN/RC 2009-14, Minnesota Department of Transportation, St. Paul, Minn.

NEW VIDEOS ONLINE!

Iowa DOT Research and Technology Bureau releases two new project videos.

All videos can be viewed at **www.iowadot.gov/research/video/videogallery.html**.
New videos are also posted at **www.iowadot.gov/research/index.htm.**



Nondestructive bridge deck evaluation

This video presents collaborative efforts between Iowa DOT and Rutgers University to investigate non-destructive bridge testing methods and technologies that save valuable resources, time and project funds.

Intelligent compaction (IC) techniques for quality permanent foundations

This short video highlights recent evaluations of IC systems research to develop better construction methods, improve pavement performance over time and extend pavement life.

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