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**“Moving Advancements into Practice”**

**MAP Brief 5-2:**

Describing promising technologies that can be used now to enhance concrete paving practices

# Intelligent Compaction for Concrete Pavement Bases and Subbases

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**ROAD MAP TRACK 5**
**Concrete Pavement Equipment Automation and Advancements**

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## Introduction

Unfortunately, many concrete pavement failures in the United States are related to inadequate foundation layers—the soils and aggregates in the natural subgrade and in the subbase. One factor in foundation-related pavement failures is poor compaction practices. The use of conventional compaction machines, even when skillfully operated, cannot ensure uniform pavement foundation layer support conditions.

A relatively new “smart” technology—intelligent compaction (IC)—has the potential to significantly improve compaction processes with a near continuous record of compaction data that can aid in controlling uniformity of support conditions.

This MAP Brief provides a brief overview of IC technology, research, and implementation issues.

## What is IC?

Intelligent compaction (IC) technologies consist of machine-integrated sensors and control systems that provide a record of machine-ground interaction on an on-board display unit in real-time using global positioning systems (GPS). With feedback control and automatic adjustment of vibration amplitude, 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).

## Benefits of IC

The major potential benefits of IC can be categorized as follows:

- Improved uniformity through optimized compaction control
- Increased productivity (each pass is optimized; unnecessary passes are eliminated)
- Identification of non-compactable and unstable areas
- Continuous record of material-related stiffness parameter values
- Ultimately, reduced pavement failure and repair costs

**Figure 1. Smooth-drum roller equipped with onboard display unit**

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. MAP Brief 5-2 provides information relevant to Track 5 of the CP Road Map, Concrete Pavement Equipment Automation and Advancements.

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by TPF-5(185).

MAP Brief 5-2 is available at: http://www.cproadmap.org/publications/ MAPbrief5-2.pdf

### Improved uniformity through optimized compaction activities

Using on-board color-coded compaction data that is available in real-time, the roller operator can optimize compaction efforts, leading to improved uniformity. Optimization algorithms are being researched and should add value to this process in the near future through additional "intelligence" and increased automation for the process.

### Increased productivity

Because IC systems are designed to rapidly determine compaction quality, compaction can be more efficient. The contributions to compaction from other equipment on the projects can be easily documented. For some projects, it is expected that equivalent or better levels of density can be achieved in less time and with fewer passes.

### Identification of non-compactable areas

By comparing the results of subsequent passes, IC systems identify areas that are not compacting as desired. The non-subjective capability to detect projects or portions of projects that will not provide sufficient support allows personnel to address the problem by removing and replacing underlying materials, stabilizing and re-compacting the underlying materials, drying wet soils, or modifying the compaction requirements.

### Continuous record of material-related stiffness values

The ability to continuously monitor material-related stiffness parameters values, both as an aid to "on the fly" compaction adjustments and as a partial acceptance tool for in-place material, is an exciting development in highway engineering.

In addition, accumulated records could support identification of optimum pavement modulus values or other values for use in design or performance specifications. Ongoing research is focused on better understanding how IC values can be linked to pavement design/performance values for foundation layers.

### Reduced costs

Improvements in the efficiency of compaction operations when IC is used may result in lower construction and maintenance/repair costs for the paving contractor and, ultimately, State DOTs and the traveling public.

## How IC works

### Instrumentation

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 (figure 1). IC/CCC technologies have also been applied to vibratory double-drum compactors and self-propelled padfoot compactors. Currently, there are at least seven IC/CCC systems/parameters:

- compaction meter value (CMV)
- oscillometer value (OMV)
- compaction control value (CCV)
- roller-integrated stiffness (ks)
- omega value (ω)
- vibratory modulus (Evib)
- machine drive power (MDP)

The CMV, OMV, CCV, ks, ω, and Evib measurement systems are accelerometer-based technologies. The CMV, OMV, and CCV systems calculate the ratio of selected frequency harmonics for a set time interval. The ks, ω, and Evib measurement systems calculate ground stiffness or elastic modulus based on a drum-ground interaction model and some assumptions.

The MDP measurement system is based on the principle of machine rolling resistance and works in both vibratory and non-vibratory mode of operation.

The type of technology used by each roller manufacturer and the way their system captures compaction results may be different, but they all provide information to the roller operator in real-time by integrating compaction measurements with GPS data and a computer display for the operators.

### Documentation

On-board software collects a continuous record of data—roller location (i.e., northing, easting, and elevation); roller speed; number of passes; compaction measurements, etc.—that are mapped with a color-coded system and displayed on an on-board monitor.

## Research and information on IC

### National Pooled Fund Study TPF-5(954)

As part of a national pooled-fund study, researchers in several States are field testing existing and emerging IC technologies, with the goal of accelerating the development of IC quality control and quality assurance specifications for subgrades and bases. Researchers are focusing on the following:

- Providing a reliable method to capture the maximum potential value added from current IC technology and currently used/available QC/QA field-testing equipment (dynamic cone, FWD, plate load tests, nuclear density, Moisture, temperature, cores, etc.)

- Developing an experienced and knowledgeable IC expertise base within the participating State Departments of Transportation (DOTs)
- Identifying and prioritizing needed research to improve IC equipment and QC/QA field-testing equipment. Prioritization will be based on simplifying IC usage, achieving greater IC value (cost-benefit), and improving accuracy

The study involves 12 State DOTs (Georgia, Indiana, Kansas, Maryland, Minnesota, Mississippi, North Dakota, New York, Pennsylvania, Texas, Virginia, and Wisconsin), FHWA, and programs at several universities. Demonstration projects have been conducted in all 12 participating States and California.

For more information on the pooled fund study, visit www.intelligentcompaction.com.

### NCHRP Project 21-09

Under National Highway Cooperative Research Program (NCHRP) Project 21-09, the Colorado School of Mines and Iowa State University conducted research to determine the reliability of intelligent compaction systems and to develop recommended construction specifications for the application of intelligent compaction systems in soils and aggregate base materials.

The researchers collected and analyzed intelligent and traditional compaction data. Their analysis of the data confirmed the importance of determining moisture, layer depth, and the foundation layer with the accuracy of intelligent compaction data. The report includes target values for the modulus of different soil types as well as preliminary recommended construction specifications for intelligent compaction systems.

View the report online at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_676.pdf.

## Iowa State University field demonstration project

### Objectives

The objective of this field demonstration project was to evaluate the compaction meter value (CMV) system—an intelligent compaction (IC) technology on the Volvo SD116DX smooth drum vibratory roller—for use in quality control (QC) and quality assurance (QA) during reconstruction of pavement foundation layers (e.g., subgrade, subbase, and base layers). The following research tasks were established for the study:

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

### Project description

This demonstration project 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. 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 concrete 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 (figure 2) was equipped with a compaction meter value (CMV) system and global positioning system (GPS) outfitted by Trimble, Inc. (figure 3). A total of 11 test sections

Figure 2. Volvo SD116DX roller with onboard Trimble CB430 display unit used on I29 project in Monona County, Iowa

Figure 3. Onboard Trimble CB430 display unit

were constructed and tested by the ISU research team. Three in situ testing methods were used to evaluate the in situ soil compaction properties and obtain correlations with CMV: (1) Humboldt nuclear gauge (NG) to measure soil dry unit weight (ϒd) and moisture content, (2) Zorn light weight deflectometer (LWD) setup with 300 mm plate diameter to measure elastic modulus and (3) dynamic cone penetrometer (DCP) to determine California bearing ratio (CBR).

### Summary of key findings

- Data from calibration strips indicated that CMV measurements and all the point measurements on the recycled asphalt subbase layer were higher than on the underlying subgrade layer. Similarly, values on the recycled concrete base layer were higher than on the subbase layer.
- Correlations developed from this project yielded statistically significant correlations between CMV and LWD modulus point measurements. No statistically significant relationships were found between CMV and NG density measurements.
- CMV maps obtained on the subbase and the overlaid recycled concrete base layers (figure 4) indicate that "soft" and "stiff" zones in the subbase layer maps are reflected on the recycled concrete base layer maps, emphasizing the importance of preparing a uniform subgrade support layer.
- CMV maps were able to effectively delineate "soft" and "stiff" zones.
- Repeatability of CMV measurements was evaluated in this study. Results indicated that the the CMV measurement error was about ≤ 1.1 for low-amplitude settings at a nominal machine speed of about 4 km/h.

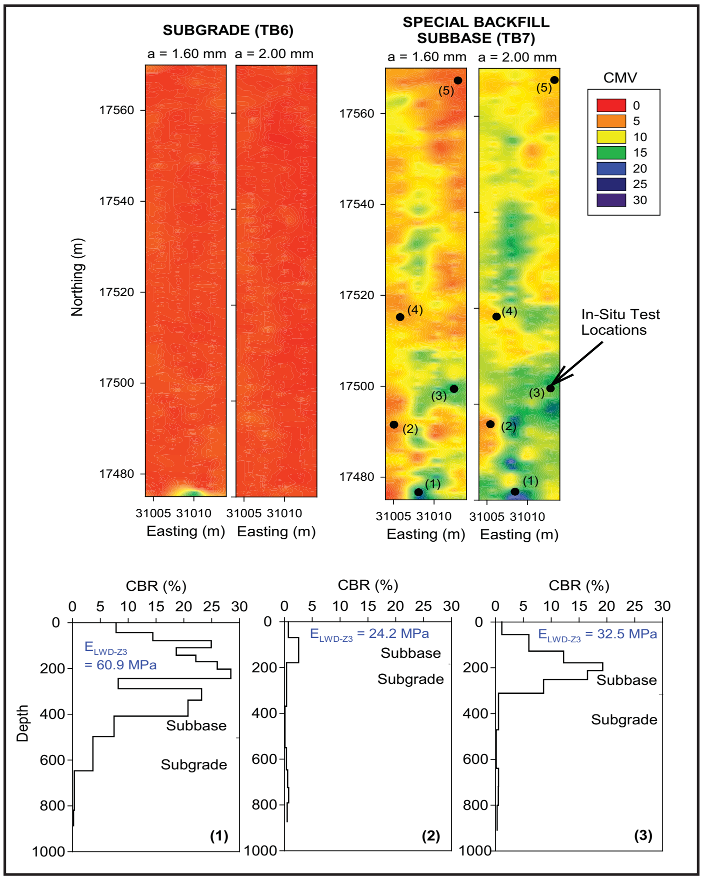


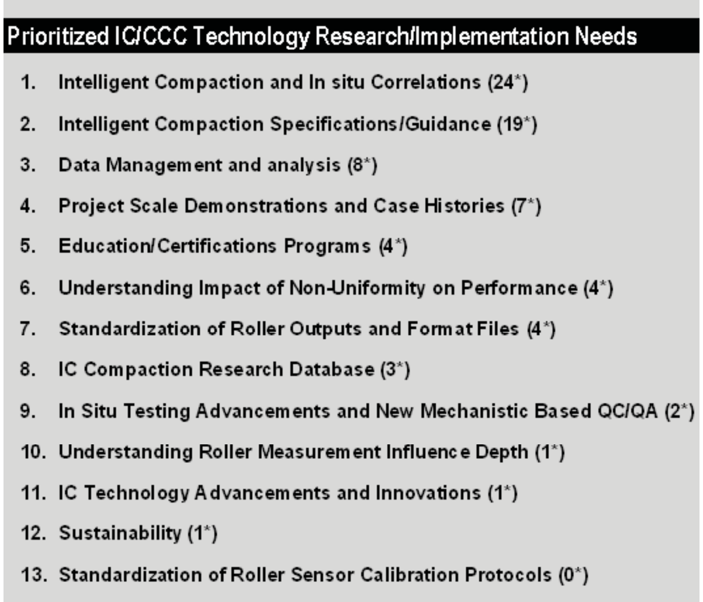
Figure 4. Spatial comparison of a subgrade layer CMV map overlain by a special backfill subbase layer CMV map and DCP-CBR profiles at three selected locations

# IC implementation issues

Realizing that a national forum is needed to provide broad leadership that can rapidly address the needs and challenges facing DOTs with the adoption of IC technologies, the Iowa DOT initiated the Technology Transfer Intelligent Compaction Consortium (TTICC) project under pooled fund study TPF-5(233).

The purpose of this pooled fund project is to identify, support, facilitate, and fund IC research and technology transfer initiatives. At this time, the following 11 State highway agencies are part of this pooled fund study: California DOT, Georgia DOT, Iowa DOT, Kentucky DOT, Missouri DOT, Mississippi DOT, Ohio DOT, Pennsylvania DOT, Utah DOT, Virginia DOT, and Wisconsin DOT.

As part of this project, a workshop was held on December 14-15, 2010, to identify and prioritize a list of IC implementation/research needs (table 1). Developing IC specifications and correlations between IC measurements and in-situ point measurements were rated as the top two research/implementation needs.



**Prioritized IC/CCC Technology Research/Implementation Needs**

1. Intelligent Compaction and In situ Correlations (24*)
2. Intelligent Compaction Specifications/Guidance (19*)
3. Data Management and analysis (8*)
4. Project Scale Demonstrations and Case Histories (7*)
5. Education/Certifications Programs (4*)
6. Understanding Impact of Non-Uniformity on Performance (4*)
7. Standardization of Roller Outputs and Format Files (4*)
8. IC Compaction Research Database (3*)
9. In Situ Testing Advancements and New Mechanistic Based QC/QA (2*)
10. Understanding Roller Measurement Influence Depth (1*)
11. IC Technology Advancements and Innovations (1*)
12. Sustainability (1*)
13. Standardization of Roller Sensor Calibration Protocols (0*)

Table 1. Prioritized IC technology research/implementation needs from the 2010 TTICC workshop