TECHBRIEF

U.S. Department of Transportation
Federal Highway Administration

Intelligent Compaction

CASE STUDY • SPRING 2014

SUMMARY OF INTELLIGENT COMPACTION ON FOR HMA/WMA PAVING

INTRODUCTION

Intelligent compaction (IC) is an innovative pavement construction technology that equips conventional rollers with instrumentation that is used to monitor and control the material compaction process. The technology, which is applicable to both soil/subbase and to hot-mix asphalt/warm-mix asphalt (HMA/WMA) pavement compaction, provides graphical information that roller operators can use to better manage their operations. This, in turn, ensures that the target properties of the layer are more uniform and are more efficiently achieved.

Europeans originally developed IC technology in the 1980s for soil/sub-base compaction and then adapted it in the 1990s for paving bituminous mixtures. Since then, IC has proved to be an effective construction practice in many European countries. IC arrived in the United States roughly 10 years ago and, despite its verified successes and demonstrated benefits, U.S. highway officials are only slowly adopting the technology.

ABSTRACT

This tech brief presents information about intelligent compaction (IC) technology and helps to promote its use throughout the United States. A companion tech brief provides an executive summary containing background information, a detailed description of IC technology, and advantages and implementation considerations. It is applicable to IC for both soil/subbase and hot-mix asphalt/warm-mix asphalt (HMA/WMA) construction. Using the findings of recent demonstration projects, this tech brief provides information that exhibits the field application of this technology for HMA/WMA paving.

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DESCRIPTION OF IC HMA/WMA

Double drum vibratory steel wheel roller equipped with IC technology

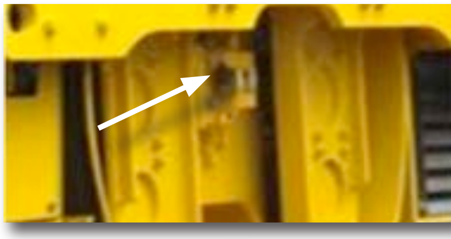
OVERVIEW: When conventional roller compaction equipment and techniques are used for pavement construction, roller operators receive very little feedback as to what is happening to the materials being compacted, especially after the first roller pass. To achieve adequate compaction, the operators must rely heavily on the application of pre-established roller patterns and the use of portable gauges that measure density at spot locations. In contrast, the continuous graphical and numeric information produced by IC-equipped rollers create a window into the layer compaction process.

INSTRUMENTATION: The vibratory steel wheel rollers used for IC on HMA/WMA materials are the same as the vibratory steel wheel rollers used for conventional rolling operations. The primary difference is the instrumentation system that is attached to measure, display, and record the compaction effects. (At this time, no pneumatic-tired rollers have been equipped with IC technology). The key components of the instrumentation system are:

- **GPS** – Global positioning systems (GPS) are used to accurately locate the roller on the project. A real-time kinematic (RTK) GPS capable of providing the highest level of precision location (within 1 to 3 cm) is required for IC operations. This level of precision is achieved through the use of single or multiple RTK on-site GPS base stations or virtual reference stations, depending on the terrain. If the line of sight is unobstructed, the effective range of a GPS station on the project is approximately 2 miles. On IC rollers, the GPS antenna is mounted on the top of the cab.

RTK using a handheld rover/ receiver with a reference network

- **Accelerometer** – A key component of the IC system is a small device that is mounted on the roller frame near the vibratory drum. Double vibratory drum rollers may have two accelerometers, one mounted near both vibratory drums. The accelerometers (also known as acceleration transducers) measure the vertical acceleration of the roller frame as the roller moves down the project.



Accelerometer

- **Infrared Temperature Sensor** – The ability to compact an HMA or WMA layer is highly dependent upon the temperature of the mix. Mixes are best compacted within certain temperature ranges and avoiding "tender zones." Accordingly, infrared temperature sensors, which are mounted on the front and rear of the roller, allow the operator to monitor the mix surface temperature and create a surface temperature record.

Infrared temperature sensor

- **Processing** – The software for processing the IC data is proprietary and manufacturer dependent. Each type of software, however, is capable of conducting a real-time analysis in which the measured vertical acceleration is converted to downward displacement and then combined with other roller information (such as amplitude, frequency, and speed). It produces a continuous profile of the level of compaction in the HMA/WMA layer. The software also uses information from the accelerometers to indicate drum bouncing or soft spots in the underlying layers.
- **Visual Display** – A monitor located in the cab displays real-time compaction information in both numerical and graphical format so that roller operators can make appropriate corrections or adjustments to the operation. The displayed information includes roller amplitude, frequency, GPS location, and speed. The effects of a roller pass are displayed in varying colors (or shades of color) so that the operator can track his location along the project, monitor the increase in layer stiffness, and ensure uniform coverage.

Caterpillar on-board display unit with AcuGrade® software.

- **Data storage** – The system produces a complete digital record of the compaction process. Operators can download stored data at any time for analysis and documentation.

Each of these components is part of the overall IC system. The system does require routine inspection and calibration checks; however, the IC technology is relatively reliable and robust considering the construction conditions under which it must operate.

EQUIPMENT MANUFACTURERS: Amman/Case, Bomag, Caterpillar, Dynapac, HAMM (Wirtgen), and Sakai are the primary manufacturers of IC rollers. However, only Bomag, Caterpillar, HAMM, and Sakai produce the IC rollers for HMA/WMA paving that are commercially available in the United States. The primary vendors for GPS equipment (e.g., base stations and virtual reference stations) are Trimble, TopCon, and Leica. Trimble also offers equipment and software for retrofitting IC on an existing roller.

INTELLIGENT COMPACTION MEASUREMENT VALUE: The industry has not agreed upon a standard measure for reporting the compaction results of IC rollers for HMA/WMA paving. Accordingly, each IC equipment manufacturer has developed its own unique method for characterizing the level of HMA/WMA layer compaction (which in turn is incorporated into its own proprietary software for data processing and display). Because no standard exists, the term intelligent compaction measurement value (ICMV) is used to represent (collectively) the compaction results for all the equipment. ICMV can be determined using the following measures:

- Compaction Meter Value (CMV) was the first ICMV. It was established in 1976 by Geodynamic (a Swiss company) in cooperation with the Dynapac Research Department. CMV is an indicator of the layer's stiffness/modulus and is dimensionless. Dynapac, Caterpillar, and Trimble report CMV.
- Compaction Control Value (CCV) is a measure of Sakai IC asphalt rollers' compacted layer stiffness. Like CMV, CCV is dimensionless.

KEY FINDINGS OF THE FHWA/TPF DEMONSTRATION PROJECTS FOR HMA/WMA INTELLIGENT COMPACTION

PROJECT OVERVIEW: Between 2008 and 2010, 13 states participated in an FHWA-sponsored, Transportation Pooled Fund (TPF) study entitled Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials. The primary purpose of the study was to demonstrate and evaluate IC technologies through multiple field projects. Of the 13 states, 10 participated in the HMA field demonstration projects (or case studies). These included Georgia, Indiana, Maryland, Minnesota, Mississippi, New York, Pennsylvania, Texas, Virginia, and Wisconsin. Following is summary of construction information on each demonstration project.

DEMONSTRATION PROJECTS FOR HMA/WMA INTELLIGENT COMPACTION

Location and Year	Thorough-fare	Construction Summary	Machine(s)	In-situ Tests
Clayton, GA (2009)	Park and Ride Lot	Place HMA intermediate and surface layers on graded aggregate base	Sakai	FWD, LWD, Core
Lafayette, IN (2009-10)	US 52	Mill 2 in. of existing 6-in. HMA (on PCC pavement) and place 2.5-in. intermediate HMA and 1.5-in. HMA surface	Sakai and Bomag	NG, NNG, Core
Frederick Co., MD (2009)	US 340	Mill existing HMA and place SMA overlay	Sakai and Bomag	LWD, DCP, NG, FWD, PLT
Renville Co., Kandiyohi Co., Kandiyohi Co., MN (2008)	TH 71 Route 4 Route 40	Place HMA overlay Place HMA overlay Place HMA base course and wearing course	Sakai	LWD, NG, Core
Wayne Co., MS (2009)	US 84	Place HMA base	Sakai	FWD, NG
Springville, NY (2009)	US 219	Place HMA permeable base (in two lifts) followed by HMA binder course	Sakai	NG
Summerhill, PA (2010)	SR 53 @ SR 219	Remove entire existing HMA (down to PCC pavement) and place HMA binder layer and wearing course	Sakai, Volvo	LWD, NG
El Paso, TX (2010)	SR 53 @ SR 219	Milled existing 4-in. HMA surface, stabilized to 4-in. of granular base (4% cement) and then placed a 2-in. HMA	Sakai	FWD, LWD, NNG
Markham, VA (2010)	FM 1281	HMA surface	Sakai, Volvo	LWD, NG
Mosinee, WI (2010)	I-39	Crack & seated existing PCC pavement, compacted aggregate base, & placed/ compacted new HMA pavement layers	Sakai	FWD, LWD, NG

FWD-Falling Weight Deflectometer, LWD-Light Weight Deflectometer, NG-Nuclear Density Gauge, NNG-Non-nuclear Density Gauge, PLT - Plate Load Test, PCC - Portland Cement Concrete

SUMMARY OF KEY FINDINGS: The use of IC was demonstrated to be a success in all 10 States. One finding, consistent in all States, was that IC mapping of the base does help identify soft/weak spots as well as stiff areas prior to HMA placement. The following table provides a summary of other significant findings reported from the State demonstration projects.

State										Significant Findings from State Demonstration Projects
GA	IN	MD	MN	MS	NY	PA	TX	VA	WI	
X	X	X	X			X	X	X	X	Roller operator was able to track roller passes and asphalt surface temperatures (and make appropriate adjustments to compaction process).
			X	X		X				Roller operator was able to identify changes in mix based on IC display results.
X	X	X		X	X	X				Temperature played an important role in determining ICMV of the HMA.
					X	X			X	Compaction uniformity appears to increase from the "ground up" for HMA paving materials.
				X						The FWD-based moduli correlated well with the ICMVs of subbase and HMA base course.
							X			PSPA results correlated well with ICMV when performed at the same mix temperature.
		X							X	IC technology was satisfactory for night paving.
X										Moisture in base can significantly affect the compaction of the HMA.
	X									Low vibration amplitude setting worked better on HMA shoulders due to shallower influence depth.
	X									IC rollers can be used to map a milled HMA surface prior to paving.
									X	IC rollers can be used to map a rubblized and crack-and-seat PCC surface prior to HMA overlay.
FWD-Falling Weight Deflectometer, PCC - Portland Cement Concrete, PSPA - Portable Seismic Property Analyzer										

Additional findings from the FHWA/TPF demonstration projects fall under four categories:

- **Rolling patterns and mapping** – Rolling patterns are established at the beginning of an HMA/WMA paving project to determine the type, sequence, and timing of roller applications that compact the HMA/WMA layer in a manner that provides for both proper compaction and productivity. Mapping creates a color-coded, two-dimensional image of the level of compaction achieved during rolling operations.
- **Compaction curves** – This category refers to the two-dimensional graphs of a layer's level of compaction versus the number of roller passes. They are typically used to determine number (and tming) of roller passes that are required to achieve the target level of compaction.
- **Compaction uniformity** – This category is important because of its impact on pavement performance. If the layers of the pavement structure are not compacted uniformly, the pavement is more likely to perform poorly because weak spots are vulnerable to wear.
- **Correlation studies** – These studies develop meaningful relationships between ICMVs and other in-situ measurements, such as moduli, density, and California bearing ratio.

Key Findings for Rolling Patterns and Mapping

- IC technologies are useful in establishing improved roller patterns.
- IC rollers can be used successfully to map the underlying materials prior to paving for just-in-time corrective actions. The demonstration projects proved that mapping can identify weak areas and soft spots on milled surfaces, Portland Cement Concrete pavements, and both stabilized bases and untreated bases.
- IC mapping can be used to monitor the strength gain of a stabilized base layer.
- IC technologies can be used to improve construction quality during night paving.

Key Findings for Compaction Curves

- For a paving project with relatively uniform support, the optimum number of roller passes can be established using IC rollers and a test strip.
- IC-equipped rollers can be used satisfactorily to identify mix tender zones and sensitive periods when roller passes are not effective at achieving compaction.

Key Findings for Compaction Uniformity

- Compaction uniformity generally increases based on the compaction of the lowest foundation layer. Thus, if the sub grade achieved a high level of uniformity in compaction, each subsequent layer, including the HMA/WMA layer(s), will be much more likely to achieve high levels of compaction uniformity during construction.

Key Findings from Correlation Studies

- The quality of the correlations between ICMV and HMA density (determined from both nuclear and non-nuclear gauges) ranged from poor to good. In a large majority of the cases, ICMV increased with increasing density (as expected); however, the scatter in the data was generally high.
- Correlations between ICMV and HMA density (from cores) were inconsistent. The results showed that ICMV can increase or decrease with increasing density.
- Correlations between ICMV and light-weight deflectometer (LWD) base layer modulus were generally fair. ICMV did increase layer modulus (as expected); however, the sensitivity was low and there was significant scatter. [Note: There were not enough correlation results between ICMV- and FWD-based layer moduli to assess the validity of those relationships].

CONCLUSIONS

1. The primary conclusion that can be drawn from the FHWA/TPR study is that IC is very effective for achieving the target level of HMA compaction while at the same time increasing the uniformity of the material.
2. The IC roller demonstrations provided proof that IC rollers could track roller passes, monitor HMA surface temperature, and report an ICMV that the operator could use to better control the compaction process.
3. The results show that a key factor in achieving uniform compaction in the final HMA surface layer is to achieve better compaction uniformity in the underlying layers. This was referred to as the "ground up" approach.
4. IC rollers proved to be an effective tool in mapping the surface prior to HMA placement so that appropriate corrective measures could be taken to address any soft spots or weak areas.
5. IC equipment can be used effectively to develop compaction curves and to determine the optimum number of roller passes.
6. The correlation studies show correlation between the ICMVs and in-situ measurements, including HMA density (from nuclear and non-nuclear density gauges) and certain deflection-based parameters i.e., normalized maximum deflection and layer modulus. However, there is considerable variability in the correlations.

AVAILABLE RESOURCES

The best source of information currently available on IC is located at www.intelligentcompaction.com. In addition to providing valuable up-to-date information on most IC topics, it also identifies sources of information from previous and currently ongoing research efforts and case studies and provides links to other useful websites.

Following are several recent reports that address IC for HMA/WMA materials:

Chang, G., Xu, Q., Rutledge, J., Horan, R., Michael, L., White, D., Vennapusa, P., "Accelerated Implementation of Intelligent Compaction Technology for Embankment Sub grade Soils, Aggregate Base, and Asphalt Pavement Materials," FHWA-IF-12-002, Federal Highway Administration, Washington DC 2011

Gallivan, V., Horan, R., D'Angelo, J. "Intelligent Compaction – Improved Construction Technologies for Hot Mix Asphalt That Benefits Agencies and Contractors," International Society of Asphalt Pavements (ISAP) 11th International Conference on Asphalt Pavements, Nagoya, Japan, 2010.

Gallivan, V.L., Chang, G.K., Horan, R.D., Practical Implementation of Intelligent Compaction Technology in Hot Mix Asphalt Pavements. Journal of the Association of Asphalt Paving Technologies, Vol. 80, Tampa, FL, 2011.

Gallivan, V., Horan, R., Chang G., Xu C., "Validation of Intelligent Compaction Measurement Systems for Practical Implementation," Transportation Research Board 90th Annual Meeting, Washington DC, 2011.

Xu Q., Chang G., Gallivan V., Horan R., "Data Analysis for Hot Mix Asphalt Intelligent Compaction", Transportation Research Board 90th Annual Meeting, Washington DC, 2011.

Xu, Q., Chang, G.K., Gallivan, V.L., Horan, R.D. "Influence of Intelligent Compaction Uniformity on Pavement Performances of Hot Mix Asphalt," Construction and Building Materials, Elsevier, Vol 30, May 2012, pages 746-752.

Horan, R., Chang, G., Xu, Q., Gallivan, V. "Improving Quality Control of Hot Mix Asphalt Paving Using Intelligent Compaction Technology," Transportation Research Record, Journal of the Transportation Research Board (in press), 2012.

Xu, Q., Chang, G., Gallivan, V., "Development of A Systematic Method For Intelligent Compaction Data Analysis And Managements," Construction and Building Materials, Elsevier,Vol 37, December 2012, pages 470-480.

Xu, Q., Chang, G.K., Evaluation of Intelligent Compaction for Asphalt Materials, Automation in Construction, Elsevier, 2013, Vol 30, pages 104-112.

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