



U.S. Department  
of Transportation

**Federal Highway  
Administration**

Transportation Pooled Fund Program

# Intelligent Compaction for Asphalt Materials

## Introduction

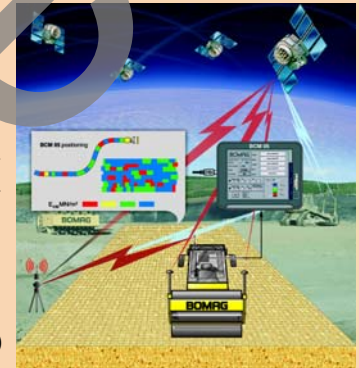
Intelligent compaction (IC) is a construction method relatively new to the USA that uses modern vibratory rollers equipped IC components and technologies.

Though used for decades in the rest of the world, the IC technology is less mature for its application in the asphalt compaction than its counter part for the soils and subbase compaction. Under the on-going FHWA/TPF IC studies, tremendous amount of knowledge has been gained on HMA IC.

Components of asphalt IC include: double-drum IC rollers, roller measurement system, global position system (GPS) radio/receiver/base station, infrared temperature sensors, and integrated reporting system.

Therefore, an asphalt IC roller can "adapt its behavior in response to varying situations and requirements" - being "intelligent"!

There are many benefits using asphalt IC rollers. To name a few: proof rolling (mapping) to identify soft spots, achieve consistent roller patterns, monitor asphalt surface temperature (to keep up with the paver) and levels of compaction for 100% coverage area, and many more.



IC System (courtesy of Bomag)

### Top Three Factors for Asphalt Compaction:

Temperature! Temperature! and... Temperature!

## Asphalt IC Rollers in the US

There are at least 6 vendors around the world have been developing HMA IC rollers. Currently, there are two type of HMA IC rollers available in the US that meet the above IC roller requirements: Sakai America and Bomag USA.

It is anticipated more HMA IC rollers from other vendors (such as Caterpillar, Case/Ammann, Dynapac, and Volvo) will be available in the US during the next few years.



Sakai asphalt IC roller



Bomag asphalt IC roller

## TechBrief

*The Transportation Pooled Fund (TPF) study, "Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base and Asphalt Pavement Material" is being conducted under TPF-5 (128). It is a three year study beginning September 2007 and ending September 2010.*

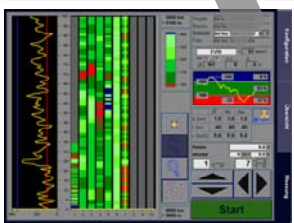
*Visit the IC project website for further details on IC technologies:*

[IntelligentCompaction.com](http://IntelligentCompaction.com)

Sakai IC system



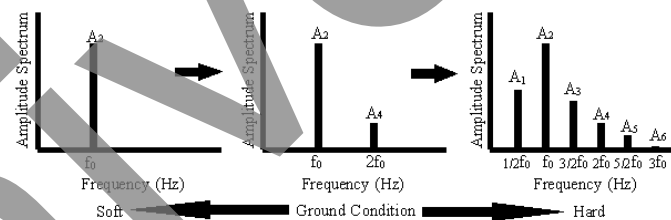
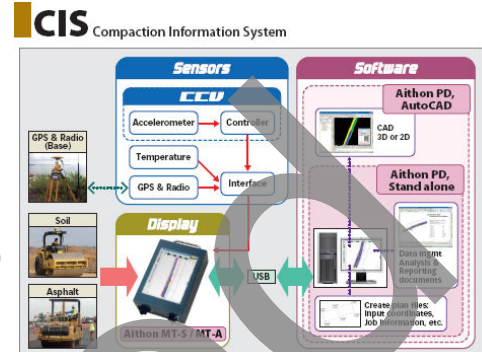
Bomag BCM05 System



## Sakai Asphalt IC System

The basis of the Sakai IC system is the IC roller (equipped with CCV measurement system, temperature sensors, and GPS radio/receiver) and a GPS with radio base station. All measurements are consolidated to the CIS display. IC data can then be transferred to PCs via USB ports for further reporting/documentation and integration with CAD systems.

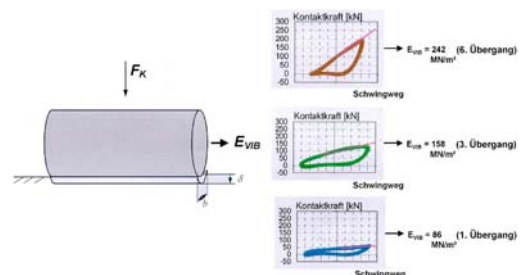
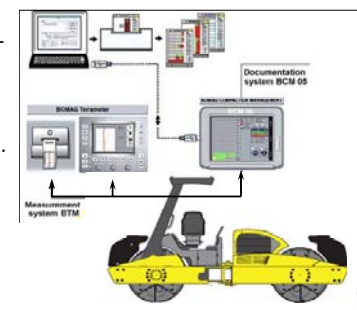
The Sakai Compaction control value (CCV) is a unitless vibratory-based technology which makes use of an accelerometer mounted to the roller drum to create a record of machine-ground interaction. Its value represents the stiffness of the compacted pavement layers underneath. The concept behind the CCV is that as the ground stiffness increases, the roller drum starts to enter into a "jumping" motion which results in vibration accelerations at various frequency components. The current Sakai IC system does not yet consist of auto-feedback.



## Bomag Asphalt IC System

The Bomag IC system is called VarioControl IC system. The Bomag IC roller is equipped with two acceleration transducers, processor/control unit, distance measurement, GPS radio/antenna, Bomag Operation Panel (BOP), and onboard BCM 05 documentation system (BCM 05-Tablet-PC, BCM 05 mobile software). This system is capable of measuring compaction values that can be transferred to another computer using USB memory sticks for further analysis and reporting using the BCM05 office software.

The Bomag IC measurement value is called  $E_{vib}$  [MN/m<sup>2</sup>] or vibration modulus (more strictly, stiffness). The  $E_{vib}$  values are computed based on the compression paths of contact forces vs. drum displacement curves. The  $E_{vib}$  values increase with increasing pass number.  $E_{vib}$  also responds to changes of material density and asphalt mixture temperature (with dropping compaction temperature,  $E_{vib}$  of asphalt mixtures becomes greater). The Bomag  $E_{vib}$  values correlate well with load bearing capacities ( $E_{v1}/E_{v2}$ ) from the plate loading tests. The feedback control in the Bomag IC system is called VarioControl that enables the automatic adaption of the amplitude during the compaction process.

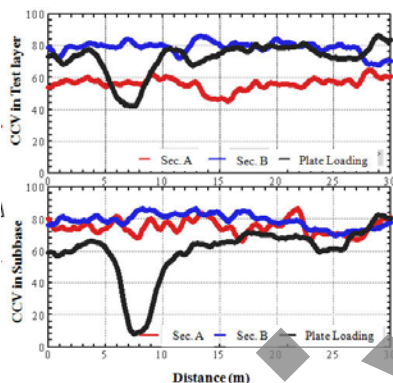


## Mapping of Existing Support Layers

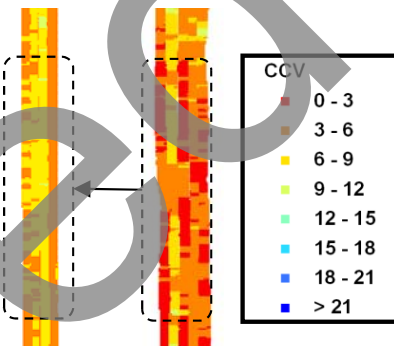
More and more evidences show significant influence of support layers on the top layer compaction. Therefore, it is strongly recommended to “map” the existing support layers prior to asphalt paving using a doubled-drum IC roller in order to identify any soft spots. Thus, corrective actions can be made at those soft spots prior to asphalt construction.

Mapping can be done on existing soils, granular, subbase, stabilized base, and even asphalt pavement for overlay construction. However, the roller settings (vibration frequency and amplitude) need to be carefully selected to maximize the benefits of mapping and avoid damages of support layers or the roller machines (e.g. jumping).

It is anticipated that the IC team will recommend machine settings for IC mapping support materials based compiled knowledge from various TPF IC demonstration projects.



Reflection of soft spots on the HMA layer



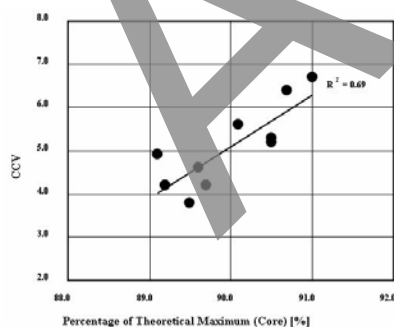
GPS is an essential part of the IC system for accurate and consistent data collection. Recommended requirements are as follows:

- RTK-GPS (Real Time Kinematic-GPS) system (radio and receiver) on IC rollers.
- System reports and records values in Northing and Easting and vertical position in meters in UTM coordinates for the project site.
- If an offset is necessary between GPS antenna and center of drum, the IC system settings and GPS measurements have to be validated onsite.

Current RTK-GPS system for IC may require a GPS base station, though stand-alone systems are evolving to obtain desirable accuracy.



## In-situ Point Tests

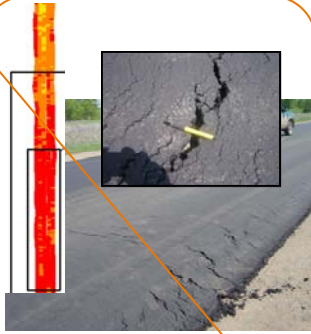


In-situ point tests are needed in order to meet current (mostly density-based acceptance) specifications. The density measurements, by nuclear density gauges or non-nuclear density gauges, are often used to correlate the IC measurements to establish rolling patterns. Note that the correlation is materials-dependent, and site-specific (e.g. support condition) and influenced by many other constructional/operational factors.

The IC team has been experimenting with other in-situ point devices for asphalt: e.g., Portable Seismic Pavement Analyzer (PSPA), and LWD-a (lightweight deflectometer).







Premature failure due to weak support identified by IC mapping

## MN IC Demonstration

This project successfully demonstrated the ability of the IC roller to map the compaction of the subbase, asphalt base course, and asphalt wearing course. The important findings of this project included:

The Sakai Compaction Control Value (CCV) displayed on the screen allowed the operator to see in real time the relatively softer and stiffer areas of the entire roadway during compaction.

The roller operator was able to identify changes (stiffness, temperature, and roller pass) in the asphalt mixture when

noticing changes in the values shown on the display.

CCV measurements obtained on the subbase layer at the 0.6 mm (0.024 in.) amplitude setting better distinguished the hard/soft spots compared to CCV measurements obtained at 0.3 mm (0.012 in.) amplitude setting.

The surface temperature measurements from the roller dot sensor and thermal camera are consistent.

A pavement section with premature failure of the asphalt base course was verified to

be within a weak spot identified during mapping of the subbase using lower frequency (2,500 vpm) and higher amplitude (0.6 mm). This area is located within the area where the subgrade layer reportedly "failed" under the test rolling in summer 2007, and is an area identified on NRCS soil survey maps consisting of peat/muck soils.

The lower frequency and higher amplitude settings for mapping the existing base were found to be highly correlated (reflected) to the asphalt mapping on top of the asphalt base course layer.

3-D CCV maps of HMA base course



## NY Mini IC Demonstration

The Sakai CCV displayed on the screen allowed the roller operator to observe real time information that identify relatively softer and stiffer areas of the roadway during compaction.

The roller measurement values (RMV) can be used to identify the weak or stiff areas of the pavement layers and the underneath support.

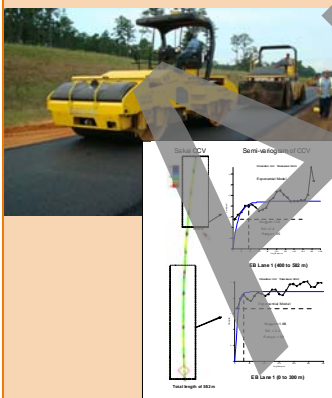
The RMVs are affected by the vibration frequency, roller

pass, amplitude, and material temperatures.

The measurement values between different pavement layers correlated well, which indicates that a stiff or soft layer underneath could significantly affect the compaction results for the upper layers and reflected by the RMV values.

The RMVs and nuclear/Non-clear gauge test results of asphalt density have inconsis-

tent trends. It may be interpreted with multiple reasons including the effective temperature variation, (RMV has a deeper influence depth than the density that measures a single layer), roller passes, vibration amplitude and frequency, and etc. Note that the factors affecting (achieving) HMA density may also include the mixture properties, construction machines, and etc. in addition to compaction.



Semivariogram to assess uniformity of compacted materials

## MS Mini IC Demonstration

The Sakai IC double drum roller was used to successfully map the existing, tack-coated cement-stabilized subbase at different cured stages. Relatively soft spots were easily identified with the IC maps. The strength gains of cement-stabilized subbase was reflected on the IC maps after the compaction was performed.

The FWD measured deflection

and modulus of subbase correlate well with the RMVs of HMA base course, indicating the reflecting effect of underneath layer on the stiffness of the upper layer.

The RMVs and nuclear gauge test results of asphalt density seem to have linear relationships while with relatively low correlation.

The Geostatistics of semi-

variogram analysis indicates that the HMA base course has higher compaction uniformity than that of the subbase layer, which sounds reasonable since the compaction was improved from the lower subbase course to the upper HMA base course in order to achieve a more uniform compaction. Semi-variogram is anticipated to be included in the standard IC reports to assess uniformity.

## MD IC Demonstration

Using IC rollers for such a challenging night paving projects turned out to be very successful. The IC technologies such as tracking roller passes and coverage were exceptionally useful under low visibility. This demonstrates significant benefits for both agencies and contractors to maintain consistent rolling patterns for night-time paving.

The Sakai double-drum IC roller and Bomag double-drum IC roller were used successfully to map the existing HMA surface prior to the SMA overlay. Both the Sakai and

Bomag IC mappings of the existing HMA pavements have indicated relatively lower roller measurement values (RMVs) on the shoulder than those of the pavement lane. RMVs from both IC machines also identify soft or stiff support consistently

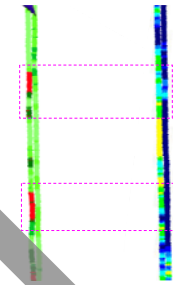
The Sakai Compaction control values (CCV) on the existing HMA pavements correlate satisfactorily with the FWD deflections and back-calculated layer moduli of the existing HMA pavements;

The Sakai CCVs on the fresh SMA overlay do not appear

to correlate well with the nuclear density gauges readings;

The compaction uniformity – indicated by the RMV semi-variogram – has significantly improved from the existing HMA pavements to the fresh SMA overlay.

The HMA modulus values measured by the Portable Seismic Property Analyzer (PSPA) did not appear to have linear relationship with the FWD measured deflection/back-calculated layer moduli or the Sakai CCVs for the existing pavement.



Mapping existing asphalt pavements with Bomag Evib (left) and Sakai CCV (right)

## GA IC Demonstration

Low Sakai compaction control values (CCVs) on the graded aggregate base (GAB) reflect on low CCVs on the HMA layer.

The moisture of GAB significantly affects the CCVs based on the mapping data. Therefore, it is recommended to pave the HMA layer when the GAB is in “drier” condition.

The mapping of subbase using the Sakai double drum IC roller can be correlated to

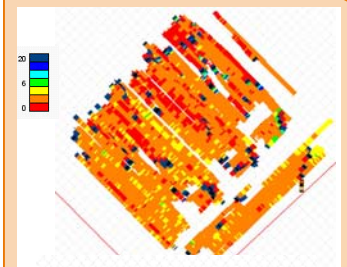
conventional in-situ nuclear density measurements.

The FWD deflections and back-calculated moduli of the GAB layer are correlated to CCVs at some test beds but not at others. Further investigation is warranted.

The densities of HMA core samples are correlated to CCVs on the HMA layer, but in a reversed trend. However, it should be noted that only limited (5 in this case)

core samples are available while more samples may be required to reach a solid conclusion.

The measured LWD (a Zorn version for HMA testing) deflections and derived CBR values are not correlated well to CCVs on the HMA layer based on the available and yet limited data.



Sakai CCV map of the HMA base course

## IN IC Demonstration

Roller patterns were drastically improved!

Double-drum IC rollers can be used to map the milled asphalt pavements prior to the paving of HMA overlay.

From the Bomag IC mapping of the existing asphalt shoulders, lower vibration amplitude setting results in higher vibration modulus values (Evib) due to its shallower influence depth that concentrating on the asphalt layers;

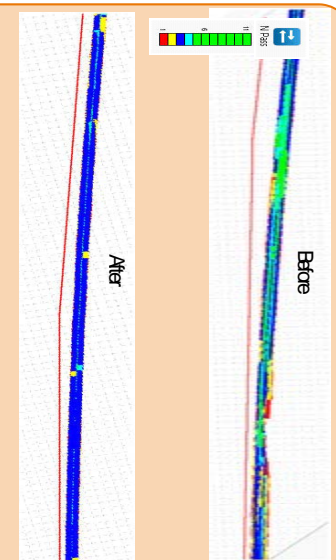
The Bomag Evib values on the milled HMA surface is higher than that of the HMA shoulder, indicating the former a stronger pavement structure;

For both Bomag and Sakai IC compaction, the non-nuclear density gauge measurements increase with increasing roller pass numbers with the change rate reducing with roller pass numbers.

The FWD deflections at HMA surfaces corresponding to the

underlying concrete slab joints is higher than those at HMA surfaces corresponding to slab centers due to the weaker support at the concrete slab joints, and the FWD deflections at the milled HMA are higher than those at the HMA surface overlay due to the improved structure and material strength.

The non-nuclear density gauge measurements of HMA overlay do not correlate well with the Sakai CCV.



Improvement of rolling patterns using IC

## Recommendations

- Validation of the IC Global Positioning System (GPS) setup prior to the compaction operation using a survey grade GPS hand-held unit is crucial to providing precise and correct measurements.
- To correlate in-situ tests with IC data properly, in-situ test locations must be established using a hand-held GPS "rover" unit that is tied into the project base station and offers survey grade accuracy.
- It is highly recommended to perform IC measurements (mapping) of the underlying layers prior to the paving of upper layers in order to identify possible weak spots.
- Standardization is strongly recommended to accelerate the implementation IC for State agencies: a standard IC data storage format, an independent viewing/analysis software tool, and detailed data collection plan

## Benefits of Intelligent Compaction

- \* **Improve Density...**  
better performance
- \* **Improve Efficiency...**  
cost savings
- \* **Increase Information...**  
better QC/QA



Contact — Victor (Lee) Gallivan, P.E. — [victor.gallivan@dot.gov](mailto:victor.gallivan@dot.gov)  
FHWA Office of Pavement Technology, 575 N. Pennsylvania St., Indianapolis, Indiana 46204. (317) 226-7493

George Chang, Ph.D., P.E. — [gkchang@thetranstecgroup.com](mailto:gkchang@thetranstecgroup.com)  
The Transtec Group, 6111 Balcones Drive, Austin TX 78731. (512) 451-6233

Research — This TechBrief was developed by Dr. George Chang, and Qinwu Xu from the Transtec Group. The project team also includes: Dr. Robert Otto Rasmussen and David Merritt of the Transtec Group, Larry Michael of LLM Asphalt Consulting, Dr. David White of Iowa State University, and Bob Horan of the Asphalt Institute.

Distribution — This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to FHWA's field offices.

Availability — This technical brief is freely available from the FHWA DTFH61-07-C-R0032 research project team "Accelerated Implementation of Intelligent Compaction technology for Embankment Soils, Aggregate Base, and Asphalt Pavement Materials". The goal of this technical brief is to better inform the public about this study.

Key Words — compaction, intelligent compaction, roller, soils, subgrade, aggregate, embankment, stabilized base, asphalt, HMA, pavement performance, quality control, quality assurance.

Notice — This TechBrief is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The TechBrief does not establish policies or regulations, nor does it imply Federal Highway Administration (FHWA) endorsement of any products or the conclusions or recommendations presented here. The U.S. Government assumes no liability for the contents or their use.

Quality Assurance Statement — FHWA provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.