Appendix G-2

Intelligent Compaction Technology for Hot Mix Asphalt Applications

DESCRIPTION

This work shall consist of the compaction of Hot Mix Asphalt (HMA) pavement mixtures utilizing Intelligent Compaction (IC) rollers within the limits of the work as described in the plans. IC is defined as a process that uses vibratory rollers equipped with a measurement/ documentation system that automatically records various critical compaction parameters correlated to MassDOT standard testing protocols in real time during the compaction process. IC uses roller vibration measurements to assess the mechanistic properties of the underlying compacted materials to ensure optimum compaction is achieved through continuous monitoring of the operations.

The Contractor shall supply sufficient numbers of rollers and other associated equipment necessary to complete the compaction requirements for the specific materials. The Contractor will determine the number of IC rollers to use depending on the scope of the project. The primary position for the IC roller is in the initial phase (breakdown) in the HMA compaction sequence. IC rollers can also be used in the intermediate phase as long as the mat temperatures are sufficient for compaction. The use of IC rollers in the finish phase is not recommended.

EQUIPMENT

IC Roller - The IC roller(s) shall meet the following specific requirements:

1. IC rollers shall be self-propelled double-drum vibratory rollers equipped with accelerometers mounted in or about the drum to measure the interactions between the rollers and compacted materials in order to evaluate the applied compaction effort. IC rollers shall also be equipped with non-contact temperature sensors for measuring pavement surface temperatures.

2. The output from the roller is designated as the Intelligent Compaction Measurement Value (IC-MV) which represents the stiffness of the materials based on the vibration of the roller drums and the resulting response from the underlying materials.

3. GPS radio and receiver units shall be mounted on each IC roller to monitor the drum locations and track the number of passes of the rollers.

4. The IC rollers shall include an integrated on-board documentation system that is capable of displaying real-time color-coded maps of IC measurement values including the stiffness response values, location of the roller, number of roller passes, pavement surface temperatures, roller speeds, vibration frequencies and amplitudes of roller drums.

5. The display unit shall be capable of transferring the data by means of a USB port.

6. An on-board printer capable of printing the identity of the roller, the date of measurements, construction area being mapped, percentage of the construction area mapped, target IC-MV, and areas not meeting the IC-MV target values *(Printer option shall be selected by MassDOT)*.

Vendor	Bomag	Sakai	Wirtgen/Hamm
Model	Asphalt Manager	CIS	HCQ
Model No.	BW190AD-4AM	SW880/SW890	HD+ 90 / HD+ 110 HD+ 120 / HD+ 140
IC-MV	Evib	CCV	HMV
IC-MV Units	MN/m^2	Unitless	Unitless
Documentation	BCM 05 Office	AithonMT-A	HMV
Company Address	Bomag Americas, Inc. 200 Kentville Road Kewanee, Il. 61443	Sakai America, Inc. 90 International Parkway Adairsville, Ga. 30103	Wirtgen America, Inc. 6030 Dana Way Antioch, TN 37013
Contact Information	Chris Connolly (301) 262-5447 Chris.Connolly@bomag.com	Brandon Crockett (800)-323-0535 B-crockett@sakaiamerica.com	Tim Kowalski (615) 501-0600 tkowalski@Wirtgenamerica.com

Notes:

- Evib: Vibration modulus
- HMV: HAMM Measurement Value
- HCQ: HAMM Compaction Quality
- CCV: Compaction Control Value
- CIS: Sakai Compaction Information System

Global Positioning System (GPS). The Contractor shall provide a GPS system that meets the following requirements. The goal of GPS requirements is to achieve accurate and consistent GPS measurements among all GPS devices on the same project. Conversions of GPS data need to be minimized to avoid errors introduced during the process.

GPS-Related Definitions -

- GPS: A space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth to determine the location in geodetic coordinates. In this specification, GPS refers to all GPS-related signals including US GPS, and other Global Navigation Satellite Systems (GNSS).

- Hand-Held GPS rover: A portable GPS radio/receiver for in-situ point measurements.

- GPS Base Station: A single ground-based system that consists of a GPS receiver, GPS antenna, radio and radio antenna to provide L1/L2 differential GPS correction signals to other GPS receivers within a range limited by radio, typically 3 miles (4.8 Km) in radius without repeaters.

- Network RTK: Network RTK is a system that uses multiple bases in real-time to provide high-accuracy GPS positioning within the coverage area that is generally larger than that covered by a ground-based GPS base station; e.g.., VRS™.

- GPS Correction Service Subscription: A service that can be subscribed to receive VRS signals in order to achieve higher accuracy GPS positioning normally via cellular wireless data services; i.e., without the need for a ground-based base station. Examples of GPS Correction Service subscriptions are: Trimble VRS™, Trimble VRS NOW™, OmniSTAR, etc.

- RTK-GPS: Real Time Kinematic Global Positioning Systems based on the use of carrier phase measurements of the available GPS signals where a single reference station or a reference station network provides the real-time corrections in order to achieve centimeter-level accuracy.

- UTM Coordinates: Universal Transverse Mercator (UTM) is a 2-dimentional Cartesian coordinates system that divides the surface of Earth between 80°S and 84°N latitude into 60 zones, each 6° of longitude in width and centered over a meridian of longitude. Zone 1 is bounded by longitude 180° to 174° W and is centered on the 177th West meridian. The UTM system uses projection techniques to transform an ellipsoidal surface to a flat map the can be printed on paper or displayed on a computer screen. Note that UTM is metric-based.

- Geodetic Coordinates: A non-earth-centric coordinate system to describe a position in longitude, latitude, and altitude above the imaginary ellipsoid surface based on a specific geodetic datum. WGS-84 and NAD83 datum are required for use with UTM and State Plans, respectively.

- ECEF XYZ: Earth-Centered, Earth-Fixed Cartesian X, Y, Z coordinates.

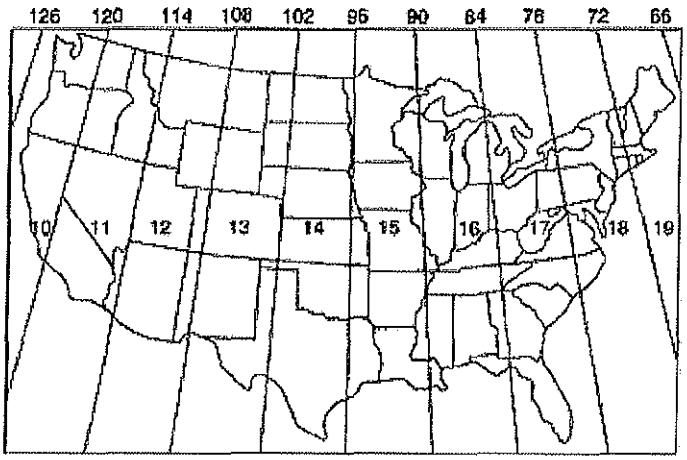
- Grid: Referred to ECEF XYZ in this specification.

- GUI Display: Graphical User Interface Display

- State Plane Coordinate: A set of 124 geographic zones or coordinate systems designed for specific regions of the United States. Each state contains one or more state plane zones, the boundaries of which usually follow county lines. The current State Plane coordinate is based on NAD83. Issues may arise when a project crosses state plane boundaries.

- UTC: Coordinated Universal Time (UTC) is commonly referred to as Greenwich Mean Time (GMT) and is based on a 24 hours' time scale from the mean solar time at the Earth's prime meridian (zero degrees longitude) located near Greenwich, England.

All GPS devices for this project shall be set to the same consistent coordinate datum/system no matter whether GPS or Grid data are originally recorded. UTM is the preference and shall be set to zone no. 19 for this project. Zones outside of the continental United States can be acquired on the web at www.dmap.co.uk/utmworld.htm. The records shall be in feet and meters. Use of UTM will facilitate GPS data checks onsite.



The State Plane Coordinate system can be used and set as North American Datum of 1983 (NAD83) for this project. Ad-hoc local coordinate systems will not be allowed.

Construction Requirements. Contractor shall provide the GPS system (including GPS receivers on IC rollers and hand-held GPS receivers (Rovers)) that makes use of the same reference system that can be a ground-based base station or network-RTK, to achieve RTK-GPS accuracy. Examples of combinations are:

1. GPS receivers on IC rollers and hand-held GPS rovers referenced to the same on-ground base station.

2. GPS receiver on IC rollers and hand-held GPS receivers referenced to the same network RTK.

GPS Data Records and Formats. The recorded GPS data, whether from the IC rollers or hand-held GPS rovers, shall be in the following formats:

1. Time: The time stamp shall be in military format, hhmmss.ss in either UTC or local time zone. 0.01 second is required to differentiate sequence of IC data points during post process.

2. GPS: Latitudes and longitude shall be in ddmm.mmmmmmmm or decimal degrees, dd.ddddddddd. . Longitudes are negative values when measuring westward from the Prime Meridian.

3. Grid: Coordinates shall be in meters with at least 3 digits of significance (0.001 m or 1 mm).

When importing IC-MV data into the data analysis management program, the GPS data and associated IC measurements shall be stored with minimum data conversions and minimum loss of precisions. Users can then select unit of preference to allow real time unit conversion for the GUI display.

Post-Process GPS Check. Follow the vendor-specific instructions to export IC-MV data to Veda-compatible formats. The Contractor shall import the IC roller data in to Veda and enter GPS point measurements from the rover and visually inspect the IC map and point measurements on the Veda display screen for consistency.

Data Analysis Software. Standardized data analysis software (Veda) is available on the website www.intelligentcompaction.com or will be provided by MassDOT. The software program will utilize the IC-MV data from the IC roller for analysis of coverage, uniformity, and stiffness values during construction operations. As a minimum, the following Essential IC Data Information and IC Data Elements shall be collected for each roller and shall be available for post processing.

- Essential IC Data Header Information for Each Data File or Section:

Item No.	Description
1	Section Title
2	Machine Manufacturer
3	Machine Type
4	Machine Model
5	Drum Width (m)
6	Drum Diameter (m)
7	Machine Weight (metric ton)
8	Name index of intelligent compaction measurement values (IC-MV)
9	Unit index for IC-MV
10	Reporting resolution for independent IC-MVs – 90 degrees to the roller moving direction (mm)
11	Reporting resolution for independent IC-MVs – in the roller moving direction (mm)
12	UTM Zone
13	Offset to UTC (hrs)
14	Number of IC data points

- Essential IC Data Elements for Each Data Point:

Item No.	Date Field Name	Example of Data
1	Date Stamp (YYYYMMDD)	e.g. 20080701
2	Time Stamp (HHMMSS.SS -military format)	e.g. 090504.00 (9 hr 5 min. 4.00 s.)
3	Longitude (decimal degrees)	e.g. 94.85920403
4	Latitude (decimal degrees)	e.g. 45.22777335
5	Easting (m)	e.g. 354048.300
6	Northing (m)	e.g. 5009934.900
7	Height (m)	e.g. 339.9450
8	Roller pass number	e.g. 2
9	Direction index	e.g., 1 forward, 2 reverse
10	Roller speed (kph)	e.g. 4.0
11	Vibration on	e.g., 1 for yes, 2 for no
12	Frequency (vpm)	e.g. 3500.0
13	Amplitude (mm)	e.g. 0.6
14	Surface temperature (°C) - HMA	e.g. 120
15	Intelligent Compaction Measurement Values	e.g. 20.0

Items 3 and 4 can be exclusive with items 5 and 6, and vice versa. Item 14 is only required for HMA application. The size of data mesh after post-processing shall be less than 18 inches (450 mm) by 18 inches (450 mm) in the X and Y directions.

QUALITY CONTROL PLAN

The Contractor shall prepare and submit a written Quality Control Plan (QC Plan) for HMA Pavement. The QC Plan shall comply with the requirements contained in Section 2.6 of the RFP/Contract Volume II – Technical Provisions. The QC Plan will fully describe the IC system to be used and will also address Quality Control procedures utilizing Intelligent Compaction as indicated below.

References.

1. **AASHTO Standards.**

   (See MassDOT Specification Section 450.65 for applicable Standards)

2. **ASTM Standards.**

   (See MassDOT Specification Section 450.65 for applicable Standards)

Field Quality Control Technician (QCT). The Field QCT shall be responsible for the following minimum functions:

1. Daily GPS check testing for the IC roller(s) and rover(s).

2. Monitoring Control Strip construction to establish target compaction pass counts and target values for the in-place density of the materials using the standard testing devices; i.e., Nondestructive density gauges, pavement cores, and IC roller(s).

3. Monitoring of the construction operations and the IC roller(s) during production and final evaluation operations.

4. Quality Control inspection to monitor the pavement temperature and the required level of compaction.

5. Daily download and analysis of the IC data from the roller(s), including review, comparison, and correlation of IC-data with the Quality Control test results.

6. Daily set-up, take down and secure storage of GPS and IC roller components

QC Inspection, Sampling and Testing. The procedures for Quality Control inspection, sampling and testing of the HMA pavement shall be in accordance with the requirements of MassDOT Section 450. In addition, QC procedures for the Intelligent Compaction operations shall be identified and include as a minimum the following:

1. Temperature. The procedure for inspecting the temperature of the materials during production, transportation, laydown and compaction operations. A minimum frequency shall be one inspection measurement for two (2) hours of HMA placement and shall include all steps in the process.

2. In-Place Density. Identification of the standard testing device(s) and frequency for measuring the in-place density of the HMA mixture. The minimum frequency of tests shall be one random test for each 150 tons of HMA mixture placed.

3. IC Roller Data. The procedure for obtaining the IC roller data. The minimum frequency of obtaining the data from the roller shall be two (2) times per day of HMA compaction operations, but not less than at the completion of each compacted lift. The data is date/time stamped which permits for external evaluation at a later time. Data from the on-board printer shall be given to MassDOT when requested. The IC roller raw data and results from the analysis software shall be made available to MassDOT within 24 hours of obtaining the roller data and test results.

GPS Check Testing. Prior to the start of production, the Contractor and representatives of the GPS and IC roller manufacturer shall conduct the following to check the proper setup of the GPS, IC roller(s) and the rover(s) using the same datum:

1. On a location nearby or within the project limits, the GPS base station (if required by the GPS) shall be established and the IC roller and the GPS rover tied into the same base station.

2. Verification that the roller and rover are working properly and that there is a connection with the base station.

3. There are two options for comparing the roller and rover coordinates. Production shall not begin until proper GPS verification has been obtained. IC vendors' recommended verification process can be used to augment either of the following options:

    a. GPS measurement shall be conducted while the IC roller is stationary. The GPS coordinated from the roller on-board display shall be recorded ensuring that the distance offsets are applied correctly to the center of the front drum (e.g., the measurement is at the roller GPS receiver position). Place the hand-held GPS receiver on top of the GPS receiver mounted on the IC roller and record the coordinates from the hand-held receiver display. The differences of the coordinates between the IC roller GPS receiver and hand-held GPS receiver shall be within 2 inches (50 mm) in both the horizontal axes (X and Y). The check for the vertical axis is not required.

    b. A location shall be marked on the ground. Move the IC roller so that the center of the front drum is on top of the marked location. Record the GPS measurements from the IC roller ensuring the distance offsets are applied so that the GPS coordinate is at the center of the front drum. Move the IC roller from the marked location and use a hand- held rover to measure at the marked location. The differences of the coordinates in grid shall be within 6 inches (150 mm) in both the horizontal axes (X and Y). On some IC systems, distance offsets are applied to the roller GPS measurements from the on-board display and the coordinates may be on the left or right side of the drum. In those cases move the IC roller so that the left or right side of the front drum axle is flush with the marked location. Place the hand-held rover right on the marked location and check the difference of both coordinate records. The final GPS coordinate for each IC data point recorded in data files need to be at the center of the front drum.

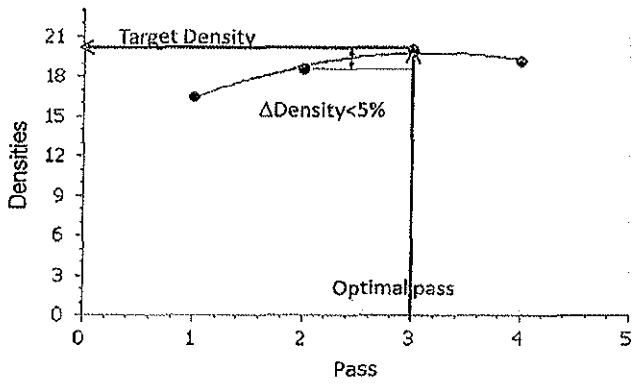
4. The project plan file provided by the Contractor or MassDOT shall be uploaded into the IC Data analysis software and depending on the roller manufacturer, the on-board IC computer.

5. GPS check testing shall be conducted daily during production operations to ensure consistency and accuracy of GPS measurements for all GPS devices prior to the paving and compaction operations.

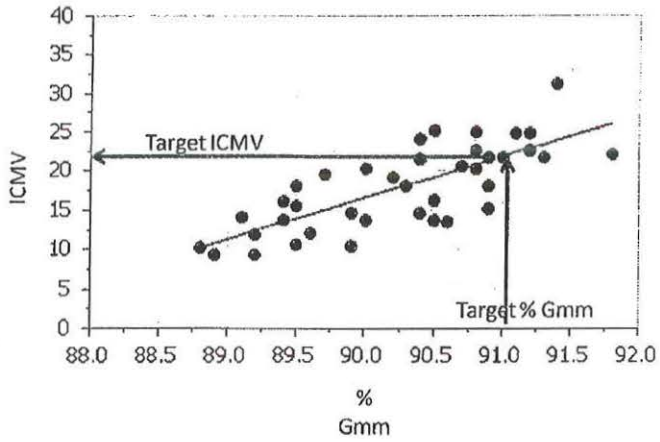
Control Strips. Control Strip evaluations are intended to verify the volumetrics of HMA mixtures and determine a compaction curve of the HMA mixtures in relationship to the number of roller passes and to the stiffness of HMA mixture while meeting the MassDOT in-place density requirements. Each Control Strip Lot shall be constructed and evaluated in accordance with MassDOT Section 450.66 and the IC requirements below.

The IC roller in the initial phase shall use low vibration amplitude and the same settings (speed, frequency) throughout the section. After each roller pass, a nondestructive density device shall be used to estimate the density of the HMA mixture at five (5) locations uniformly spaced throughout the Control Strip. The density readings and the number of roller passes that it takes to achieve the target in-place density will be recorded.

The estimated target density will be the peak of the nondestructive readings within the desired compaction temperature range for the mixture. The IC roller data using the IC data analysis software will create an IC compaction curve for the HMA mixture. The target IC-MV is the point when the increase in the IC-MV of the material between passes is less than 5 percent on the compaction curve. The IC compaction curve is defined as the relationship between the IC-MV and the roller passes. A compaction curve example is as follows:



Linear regression relationships between the point test results and the IC-MV results will be used to establish the production target IC-MV as the target density (% G_{mm}) meets the MassDOT in-place compaction requirements. A linear regression curve example is as follows.



Mapping. The Contractor's procedures for mapping should be included in the QC Plan for HMA Pavement. Pre-paving mapping with an IC roller of the underlying materials is recommended to be completed prior to tacking operations to identify weak areas and may be part of the Control Strip evaluations on the project or independently run. Pre- construction mapping should be approximately 500 ft (150 m) in length. Underlying materials includes treated or non-treated subgrades, treated or non-treated aggregate bases, or on milled or non-milled HMA pavements. Mapping operations are intended to provide the Contractor an understanding of the stiffness of the existing roadway being paved. Subsequent mapping may be conducted at any time to understand the changes in the roadway that affect the target IC-MV or the density verification testing. The stiffness of the underlying materials should increase with subsequent lifts of HMA mixtures.

Response to QC Inspection and Test Results. The response to Quality Control inspection and tests for the Control Strips and during production compaction shall include as a minimum the following:

1. Temperature. The procedure for corrective action when the QC inspection or IC temperature readings are not within the recommended laydown values for the mixtures.

2. In-Place Density. The procedure for corrective action when the in-place density (%G_{mm}) results fall below the MassDOT Lower Engineering Limit (LEL) of 92.0%.

3. IC Coverage Area and Uniformity Criteria. The procedures to be taken when the IC criteria for coverage area or the minimum IC-MV target criteria are not being met.

Documentation. The documentation shall include the following.

1. Quality Control Inspection and Test Results. The results from the temperature inspection and in-place density testing. All Quality Control test results shall be signed by the Field QCT and submitted to MassDOT in electronic form and hardcopy within 24 hours of testing.

2. Equipment. Documentation of the manufacturer, model, type of paver, roller weight (xx tons), and type of rollers used each day of HMA materials operations (this information shall be included in the QC Plan and provided with the daily QC test results). The positioning of the IC roller(s) in the paving operations shall be noted.

3. IC Roller Data. At a minimum, the electronic data from IC roller(s) and the data analysis software shall be provided to MassDOT upon the completion of the Control Strip, Mapping and individual IC Construction Area operations.

4. IC-MV Analysis. The Contractor will analyze the IC-MV data for conformance to the requirements for coverage area and uniformity and will submit the results to the Engineer at the completion of the individual IC Construction Area operations.

   IC data shall be exported from the vendor's software in both all passes data and proofing data files. All passes data includes the data from all of the passes and proofing data is the data from just the last pass within a given area.

5. IC Construction Area. The limits of and total tons of the HMA mixtures within each IC Construction Area.

IC CONSTRUCTION

Construction Quality Meetings. Prior to the start of any work activity associated with the HMA pavement construction, a Construction Quality Meeting shall be held with MassDOT to review the Contractor's Quality Control and Intelligent Compaction system. At each meeting, the Contractor shall present and discuss with the Engineer the specific Quality Control information and activities contained in each section of the Quality Control Plan for the applicable work category. Each meeting is intended to ensure that the Contractor has an adequate Quality Control system in place and that the Contractor's personnel are fully knowledgeable of the roles and activities for which they are responsible to achieve the specified level of quality. Contractor personnel required to attend the Construction Quality Meetings include; the Construction QC Manager, all other Construction QC personnel (production facility and field operations), Superintendent(s), and the Foremen for field operations. The Contractor shall provide a copy of the relevant approved Quality Control Plan(s) to each Contractor and Department attendee of the meeting.

Technical Assistance. The Contractor shall coordinate for on-site technical assistance from the IC roller representatives during the initial seven (7) days of production and then as needed during the remaining operations. As a minimum, the roller representative shall be present during the initial setup and verification testing of the IC roller(s). The roller representative shall also assist the Contractor with data management using the data analysis software including IC data input and processing.

On-Site Training. The Contractor shall coordinate for on-site training for Contractors and MassDOT project personnel related to operation of the IC technology. Contractor's personnel shall include the paving superintendent, Construction QC Manager, Field QC Technician(s), and roller operator(s). MassDOT's personnel shall include the MassDOT Resident Engineer, District Quality Engineer, District Materials Engineer, and Inspectors/Technicians. Arrangements shall be provided that includes an enclosed facility with electrical availability and a projector for visual presentations and should be 4-8 hours in duration.

Minimum training topics shall include:

1. Background information for the specific IC system(s) to be used
2. Setup and checks for IC system(s), GPS receiver, base-station and hand held rovers
3. Operation of the IC system(s) on the roller; i.e., setup data collection, start/stop of data recording, and on-board display options
4. Transferring raw IC data from the rollers(s); i.e., via USB connections
5. Operation of vendor's software to open and view raw IC data files and exporting all-passes and proofing data files in Veda-compatible format
6. Operation of Veda software to import the above exported all-passes and proofing data files, inspection of IC maps, input point test data, perform statistics analysis, and produce reports for project requirements
7. Coverage and uniformity requirements

IC Construction Areas. IC Construction Areas are defined as subsections of the project being worked continuously by the Contractor. Each IC Construction Area must be within the same HMA Lot. The procedure for determining and documenting the limits of each IC Construction Area shall be provided to MassDOT. The size of the IC Construction Areas may vary with production but they need to be at least 1,200 tons (two Sublots) for evaluation. Partial IC Construction Areas of 600 tons or less will be included in the previous area evaluation. Partial IC Construction Areas of greater than 600 tons will constitute a full area to close out the Lot. IC Construction Areas may extend over multiple days depending on the operations.

IC Construction Operations Criteria. A minimum coverage of 90% of the individual IC Construction Area shall meet the optimal number of roller passes and 70% of the target IC-MV determined from the Control Strips. I C Construction Areas not meeting the IC criteria shall be evaluated prior to continuing with the operations in that area. The IC Quality Control data shall be used by the Contractor to control their compaction Construction Operations. The Contractor shall not rely on MassDOT's Acceptance testing data for QC purposes.