Test Protocol for the Rolling Density Meter

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Prepared by:

Ryan Conway
Kyle Hoegh
Lev Khazanovich

Contents

Definitions

°F	degrees Fahrenheit
ft	feet/foot
GPR	ground penetrating radar
GPS	global positioning system
HMA	hot mix asphalt
ID	identification
RDM	rolling density meter
UTC	Coordinated Universal Time

1.0 Introduction

The rolling density meter (RDM) is developed by Geophysical Survey Systems, Inc. for asphalt paving construction quality assurance/quality control. A manually-propelled cart is used to collect the measurements. Front and side views of the RDM are shown in Figure 1 and Figure 2, respectively. The cart is lightweight and can be easily propelled by a single operator. The RDM system uses specially-designed ground penetrating radar (GPR) sensors to determine the dielectric constant of asphalt. GPR data is collected by the sensors and processed using a concentrator box. The survey data is then stored internally and can be exported in .csv files. Global positioning system (GPS) data is recorded in conjunction with GPR data. The cart is outfitted with a Toughpad tablet for easy system operation and data visualization. Assembly may differ based on the use of additional equipment, including GPS sensor.

Typically, data can be collected using the RDM system at a similar rate to the advancement of a paving operation, enabling an operator to provide real-time feedback of general trends in compaction. This document provides a testing protocol for collecting data using the RDM equipment.

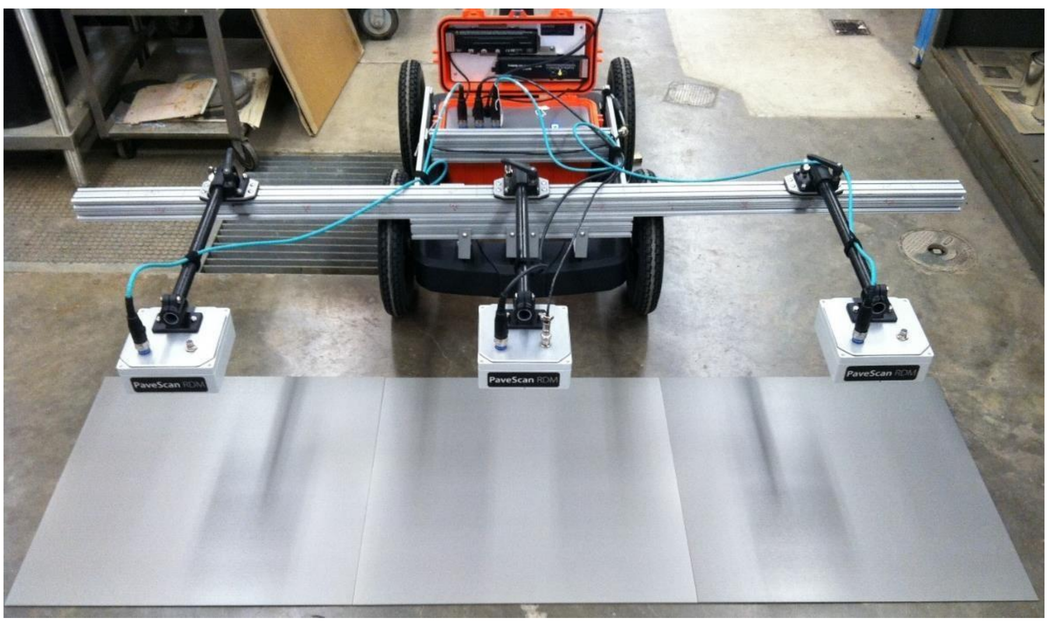


Figure 1. Front View of Rolling Density Meter Cart under Calibration in Laboratory

Figure 2. Side View of Rolling Density Meter Cart

2.0 Preparation and Equipment Start-Up Before Testing

The protocol outlined in this manual is designed for testing of newly placed hot mix asphalt (HMA) lifts. The survey should be implemented as soon after final compaction as possible. The survey should be conducted on both wear and non-wear lifts and in all lanes if multiple lanes are being paved. An RDM survey should be completed by a minimum of a two-person crew. The first person (operator) operates the RDM cart, while the second person (recorder) records data and clears obstacles for the cart.

2.1 Selecting a Site for the Rolling Density Meter Test

2.1.1 Timing of Testing Relative to Construction

The RDM survey should be conducted after the final compaction of the lift, but before trafficking (construction traffic and debris on the surface will negatively affect the readings and traffic control). The survey can be conducted on both wear and non-wear lifts.

2.1.2 Ongoing Construction and Rolling Density Meter Testing

The RDM survey should be conducted where a limited amount of construction traffic is expected. The survey team should have access to the full lane and, preferably, two lanes constructed on the same day to test the longitudinal joint. The testing should be conducted fully independent and without disturbing the paving crew.

The procedure described in this manual can cover approximately 0.5 to 1 mile of pavement length per hour. For a paving operation consisting of milling and compaction using four to five roller passes, RDM data can be collected at the same rate as, or faster than, paving. Therefore, RDM surveying should be started some distance behind the paving crew to avoid interfering with paving. The RDM survey should be conducted in the same direction as paving. Battery charge typically limits RDM surveys to 6 to 8 hours, where the limiting battery is the battery contained in the tablet. If total survey time is expected to exceed 6 hours, ensure a charging station is available on site.

2.1.3 Total Coverage of Testing

Testing in 500-feet (ft) long segments is recommended. This segment length was suggested for several reasons. First, testing in smaller segments limits data loss because of file corruption or user error. Also, smaller survey lengths require less walking distance when collecting cores. Finally, a 500-ft survey length allows RDM crew to remain close to paving crew during operations with moving closures where the total closure length is limited. Longer testing lengths can be used if a faster survey time is required. If survey lengths other than 500 ft are used, the testing protocol must be modified accordingly.

2.1.4 Possible Factors to Exclude Sites from Testing

Site conditions that add uncertainty or affect the operation of the RDM system and should be avoided include:

- HMA overlays thinner than 1 inch or thicker than 3.5 inches
- Stone mastic asphalt
- Permeable friction courses
- Temperatures less than 40 degrees Fahrenheit (°F)
- Rainfall or other conditions that will lead to wet pavement

2.2 Rolling Density Meter Equipment Start Up

After assembly, the RDM system is activated by powering on the concentrator box, the tablet, and the GPS. No particular order of equipment power-up is necessary. The RDM program should start up immediately when the tablet powers on. If it does not, select the RDM shortcut icon on the desktop. The program opens using a Google Chrome interface. A full description of the RDM equipment start-up procedure can be found in the manufacturer's guide to the RDM.

2.3 Global Positioning System Testing

If GPS data is collected during the survey, the functionality of the GPS system must be checked before data collection. Once system startup has been achieved, check the GPS settings by navigating to the "GPS Settings" found by navigating from the "System Settings" page to the "Project Properties" page. The COM port field and BAUD rate should match the specifications of the associated GPS. If not, overwrite with correct input. The GPS Latitude, GPS Longitude, and GPS Coordinated Universal Time should read non-zero values. Move the cart back and forth 5 to 10 ft. If the Longitude and Latitude do not change, clear and reenter the correct inputs and select "Test Settings". The GPS Latitude, GPS Longitude, and GPS Coordinated Universal Time (UTC) should update. A full description of the GPS testing procedure can be found in in the manufacturer's guide to the RDM.

The GPS Latitude, GPS Longitude, and GPS UTC should update. A full description of the GPS testing procedure can be found in the manufacturer's guide to the RDM. If the GPS does not update, restart the GPS and repeat process. If GPS cannot be initialized, special care must be taken to record survey starting and ending locations.

2.4 Data File Initialization

If the system is running and GPS settings have been validated, the data collection file can be created.

2.4.1 New Project Settings

At the beginning of a new project, new project settings must be defined. If continuing an existing project, the current project settings are saved and applied to all surveys taken within the project. Within the software, new project settings are entered by pressing the "New Project" button on the Project Settings window (Figure 3). For the testing protocol outlined in this document, the "Lateral Offset Reference" is specified as the longitudinal joint (cold joint) within the project settings for all data collected and the Lateral Offset Reference side is always specified as the Left. All other inputs vary from project to project. The inputs of "Project Settings" are discussed herein. All inputs listed should also be entered into the "RDM Project Title Page" form by the recorder (see Appendix A1).

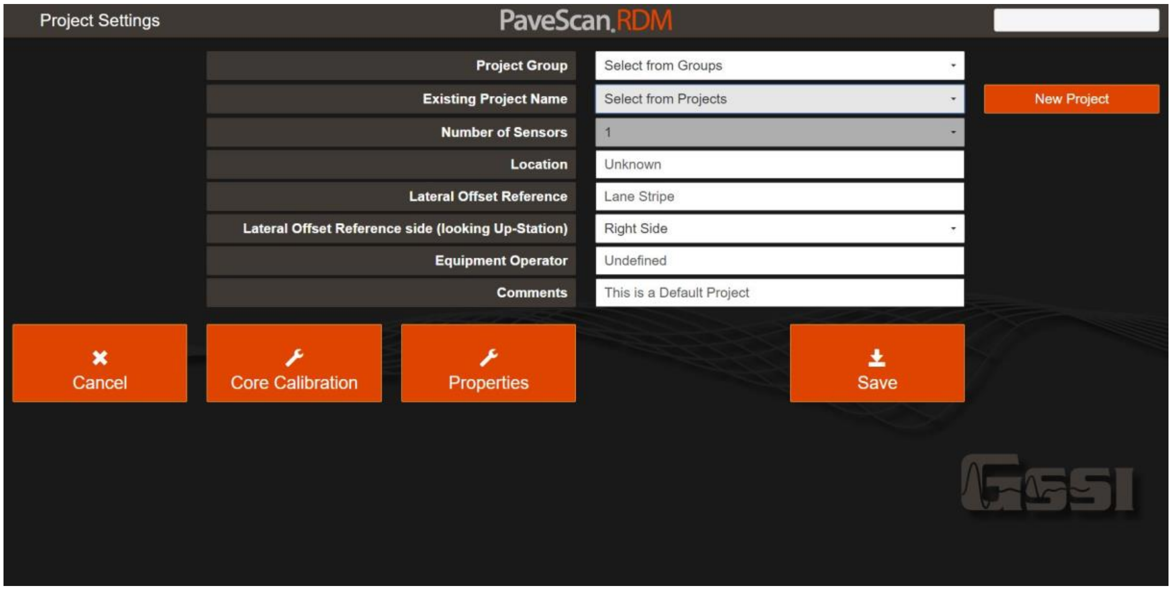


Figure 3: New Project Settings Window

Project Group: Specify the group the file belongs to. Suggestions for Group Names range from highway or road names to years and months. New Project Groups can be added when New Projects are created.

Project Name: The name associated with the project. Project names must be unique. The agency identification (ID) for the project is recommended as the project name.

Number of Sensors: Number of sensors attached (1 to 3). Most systems should have 3 sensors.

Location: Optional entry for specifying information related to where the data are being obtained. This information is exported with the data.

Lateral Offset Reference: Optional entry for specifying the reference used when Y-coordinates (transverse location) are assigned to a file. The longitudinal joint between the lanes is recommended and should be entered as “longitudinal joint”.

Lateral Offset Reference side (looking Up-Station): When facing in the up-station direction, the side of the cart that the Y-Reference is located. For the protocol outlined in this document, “left” should always be selected except for the inner lane.

Equipment Operator: Optional entry for specifying who is operating the equipment.

This will be included in the exported data.

Comments: Project-specific comments that will be included in the exported data.

2.4.2 Sensor Detection and Configuration

After initializing and saving the project, the “Sensor Configuration” window will open (see Figure 4). The software will then detect the sensors. This may take 15 to 60 seconds. If the sensors are not detected or detection takes longer than 2 minutes, check all the connections and restart the system.

Once the sensors are detected, they will appear as shown in the image provided as Figure 4. You must specify their relative location on the cart. First, use the dropdown list to associate the sensor serial number with the sensor that most closely matches its position on the cart. The sensor number is the serial number that can be seen on the side of the sensor when it is mounted on the cart. For example, if sensor serial number 12 is located on the left side of the cart (Figure 5), it should be positioned on the left side of the window, as shown on Figure 3.

Once the sensors serial numbers are specified in the proper locations, set the correct inline and crossline positions of the sensors (Figure 4). The crossline position reference is in relation to the center of the cart. It is a good strategy to always place the same sensor in the same relative location: left, center, or right. In the testing protocol developed, the two side sensors should be offset 2 ft from the center.

If the status changes to “Sensor Not Found” (which may happen occasionally), turn off the sensors by pressing the button on the front panel of the orange box, close the application navigating to Main Menu -> Exit. Then restart the application from the desktop shortcut.

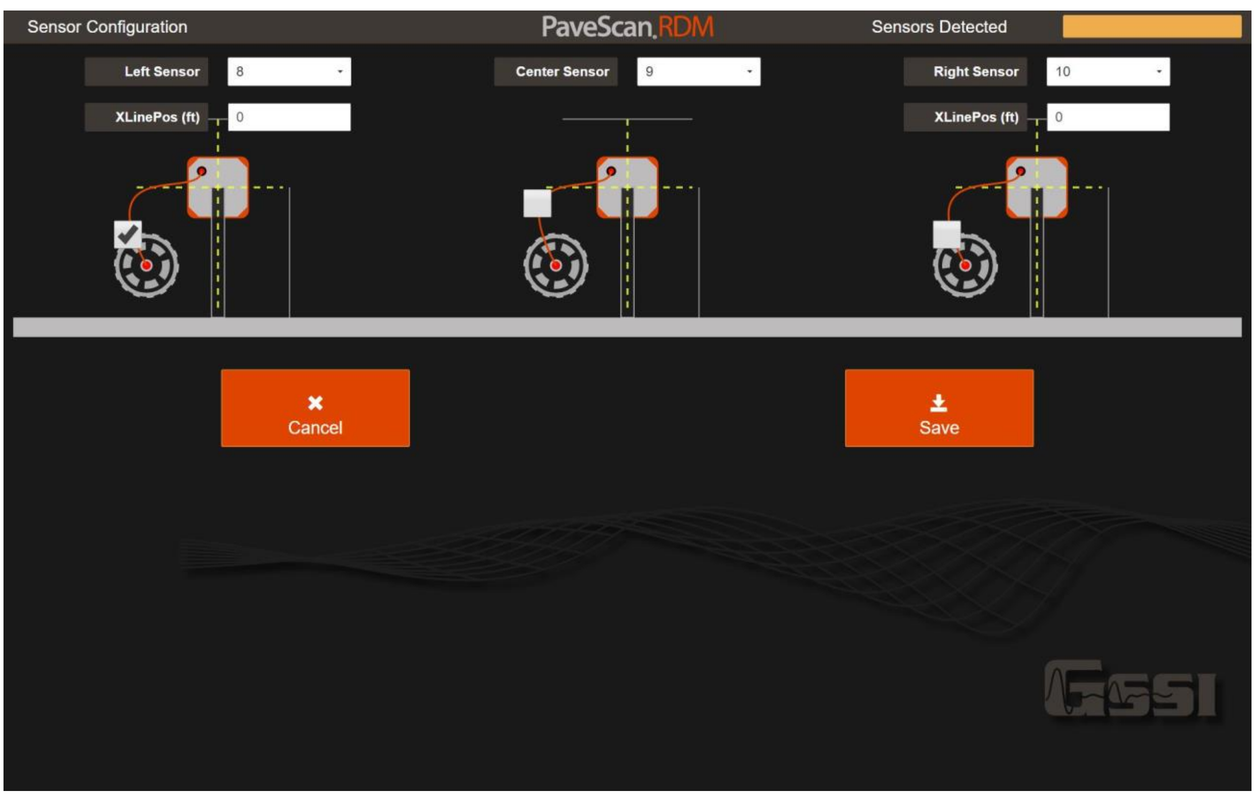


Figure 4: Sensor Configuration Input

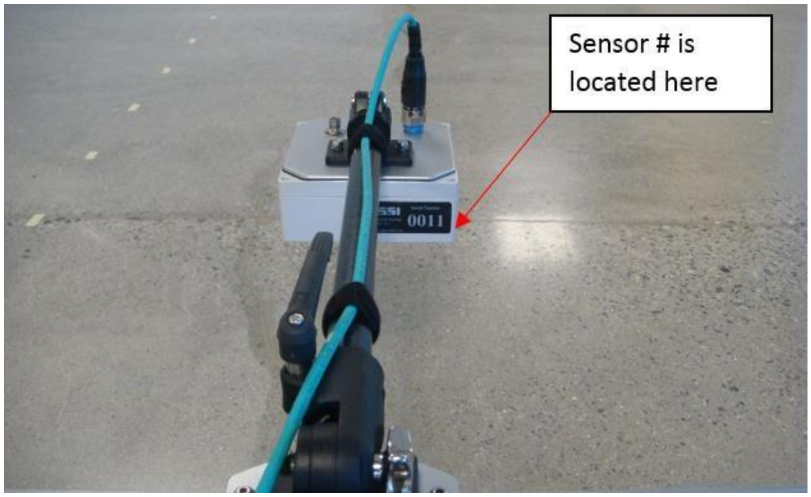


Figure 5: Sensor Serial Number Location

2.4.3 File Information

Each project will contain several, sometimes hundreds, of individual data files. Each individual data file is tied to a single segment survey. For the protocol outlined in this document, each segment survey is 500-ft long. Key spatial and other information is specified for each data file in the "File Information" window (Figure 6).

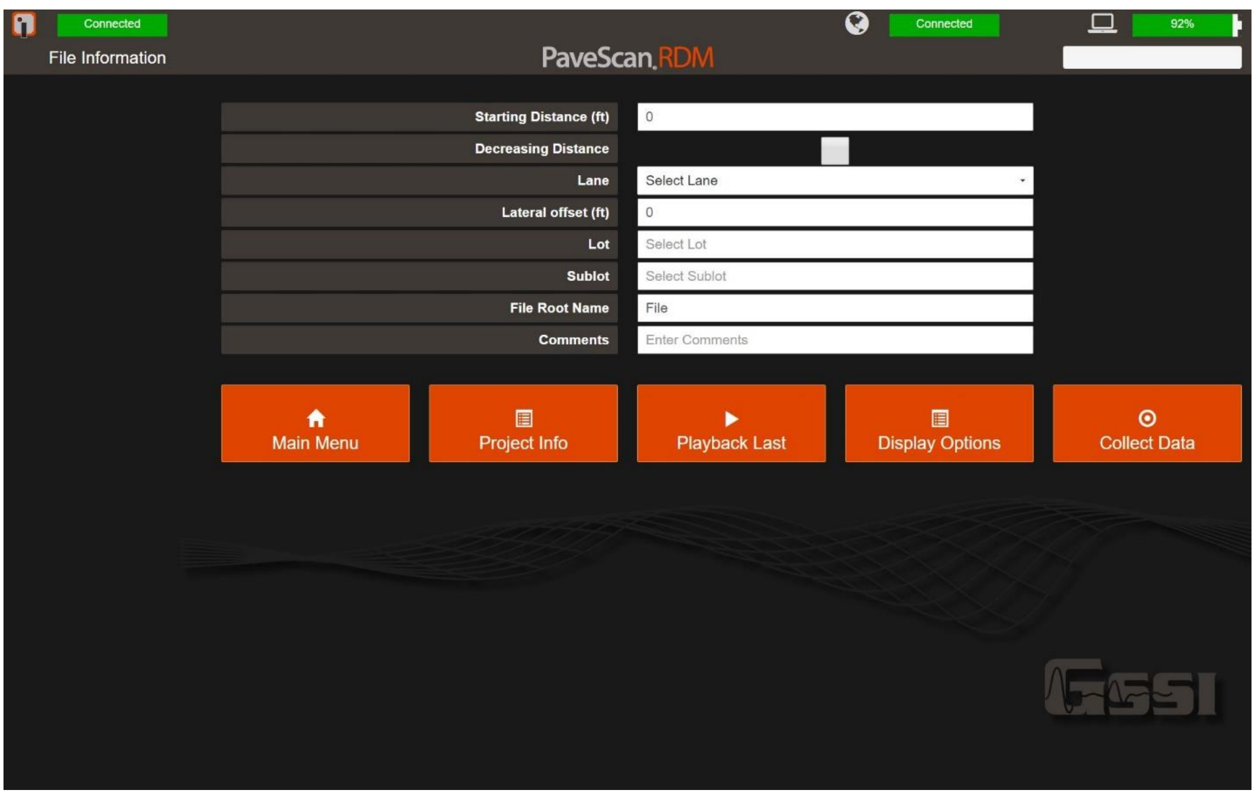


Figure 6. File Information Window

For the testing protocol outlined within this document, the following file input methodology is recommended:

Starting Station: This is the starting station of the file. If stationing is not used, enter 0. If stationing is used, only enter digits above the hundreds place. For example, if at 233+16, enter 233. The 16 will be entered in the starting distance field.

Starting Distance (ft): This is starting distance of the file. If stationing is being used, this value is 0-99.9. For example, if at 233+16, the 16 will be entered in the starting distance field. If distance is used instead of stationing, enter the full distance in this field. For example, if at 233+16, enter 0 in stationing and 23316 in the distance field.

Decreasing Distance: Check this box if the survey is being taken in the direction of decreasing stationing (for example, starting at 905+00 ft, ending at 900+00 ft).

Lane: The lane in which the data are obtained. Select the lane from a dropdown list of available names. For the protocol described in this document, only the inner, outer and middle lane are surveyed. The inner lane is defined as the left most lane in the direction of vehicle travel, the outer lane is described as the right most lane in the direction of vehicle travel, and the middle lane is any lane between the right and left lane (Figure 9).

Lateral Offset (ft): The Lateral Offset is defined as the distance between the center of the cart and the Lateral Reference (the longitudinal joint for the testing protocol outlined in this document). The Lateral Offset changes based on survey type and the lane number (see Section 2.5) in which it is conducted.

Lot: Optional entry. This is one of the filter options in the Playback Range menu.

Sublot: Optional entry. This is one of the filter options in the Playback Range menu.

File Root Name: The files will be named to reflect key survey parameters. Maintaining a consistent naming convention is crucial because a large number of survey files can be generated within a project and data organization is crucial. Additionally, naming the files in a consistent format allows for automated data processing. Table 1 provides the filename conventions adopted in the developed test protocol; Figure 7 provides an example of a filename. Lift and lane inputs may be modified according to agency-specific terminology.

Table 1. Suggested File Naming Legend

Filename Legend	
Format	AAABCDEF_H_GG
Note	If no provided option fits the project, put a "Z" in the corresponding field location and make a note in comments.
AAA	Route number (use 00# or 0## if <3 digits)
B	Direction (E, W, N, S)
C	Lift (W = Wear, N = Non-wear)
D	Lane (O = outer, I = inner, M = middle, 1 = one lane)
E	Left Joint Condition (C = Confined or U = Unconfined, see Figure 8)
F	Right Joint Condition (C = Confined or U = Unconfined, see Figure 8)
_	Field separator
H	Pass type (L = Lane, J = joint, S = shoulder, C = swerve calibration survey)
_	Field separator
GG	Section Index (first 500-ft section = 01, second section = 02, etc.) (use 0# if single digits)

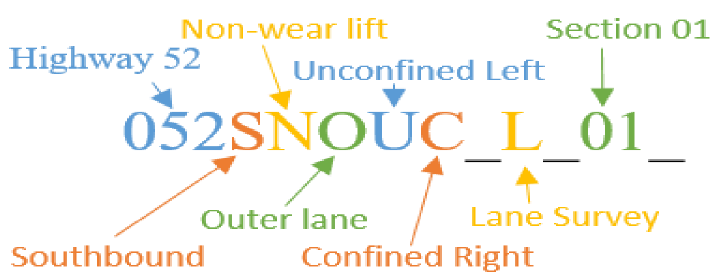


Figure 7: Example File Root Name

Figure 8. Definition of "Confined" and "Unconfined" Joints

2.5 Defining Offsets for Surveys

Properly defining the offset of a survey is important as it allows the surveyer to be more confident, spatially, related to a location within the lane than would be possible with GPS alone. Within the software, offset is defined by "Lateral Offset". The "Lateral Offset" is defined as the distance from the center of the cart to the Y-Reference point (longitudinal joint) entered in the New Project Settings page. Offsets to the left are positive, while offsets to the right are negative.

Offset sides (left versus right) are determined looking in the direction of increasing stationing. The lateral offset distance varies based on survey type and lane number. Lane number is defined as the number of the lane, increasing from left to right, if looking in the direction of the increase (Figure 9). Lane number is independent of the direction of vehicle travel. Lane number is NOT lane type.

Lane type is defined by the direction of vehicle traffic. In the procedure outlined in this protocol, only main line lanes are of interest and are defined as follows: In the direction of vehicle travel, the left most lane is defined as the inner lane (denoted *I*), the right most lane is defined as the outer lane (denoted *O* in the corresponding location in the filename), and the center lane is defined as the middle lane (denoted *M*) (Figure 9). One-lane roads (denoted *1*) can also be surveyed.

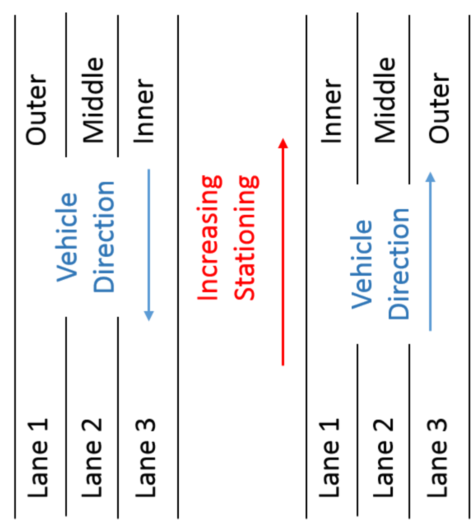


Figure 9. Lane Type and Lane Number Definitions

2.6 Other Testing Concerns (Material Needs)

Before RDM testing, ensure all batteries are fully charged: two batteries for the concentration box, a battery for the GPS sensor, and a battery for the Toughpad. Testing may also require the following materials:

1. Safety equipment (personal protective equipment, sunblock, insect repellent, and cones)
2. System (RDM, Batteries, GPS, and Toughpad)
3. Charging equipment
4. Measuring wheel
5. Marking paint
6. Chalk
7. Calculator

8. Clip board for the recorder
9. At least five copies of the RDM Project Title Page, a formatted example of which is provided in Appendix A1
10. At least 100 copies of the RDM Survey Log (100), a formatted example of which is provided in Appendix A2
11. Binders, pens, clips for windy days

2.7 Core Selection Sites

Cores are not selected before testing and instead selected in the course of surveying the pavement using one of the described survey methods section.

3.0 Calibration of Rolling Density Meter Equipment Prior to Testing

Before data collection, several calibration steps must be performed. The recommended calibration intervals vary between calibration types. There are four calibrations associated with the protocol outlined in this document: airwave calibration, metal plate calibration, survey wheel calibration, and the swerve pass calibration. If an airwave and metal plate calibration are required, the software will automatically direct the user to the calibration window. The survey wheel calibration and the swerve calibration survey should be performed whenever starting a new project. The survey wheel calibration is crucial for proper location of coring sites and the relation of RDM survey data to construction practices. In general, it is more important that the survey wheel be calibrated to be consistent with contractor stationing rather than “true” stationing. A survey wheel which is calibrated with the “true” station but does not agree contractor stationing will not be useful in comparing RDM data to construction practices.

3.1 Survey Wheel Calibration

If conducting a new project, the survey wheel calibration check should be performed. From the Main Menu, select “Collect – New Project.” The survey wheel calibration is checked as follows:

1. Create a “dummy” project by entering random inputs. This project will not be saved, so inputs do not matter. Select “Save”.
2. Create a “dummy” survey file. Set the starting station and distance to 0. Do not check decrementing. The rest of the inputs do not matter.
3. Select “Collect Data”. You may be directed to perform the metal plate and airwave calibrations if not already performed. Complete the calibrations.

4. Mark a starting location that provides a 500-ft length of flat straight pavement.
5. Record a 500-ft length of pavement using a measuring wheel or similar device. If possible, use the same device, which was used by the contractor. If station posts are available, they can be used as measurement marks.
6. Mark the start and end of the 500-ft segment.
7. Align the center of the sensors on the cart with the start line. Select “Collect Dist” and begin to walk the 500-ft segment.
8. During the survey, the distance will be reported in the top of the survey window.
9. If at the end of the 500-ft segment, if the distance reported in the RDM survey window is NOT within 1 ft of the 500-ft measured, the survey wheel should be recalibrated. If the measurements are within 1 ft, the current calibration is sufficient and no further action needs to be taken.
10. If the measurements are not within 1 ft, calibration is required.
11. Turn the cart around and realign on the end of the 500-ft segment.
12. Navigate to the survey wheel calibration (Main Menu -> System Settings -> Survey Wheel Calibration) (Figure 10).
13. Enter 500 into the “Calibration Length (ft)” field.
14. Select “Start” and walk the distance back to the 500-ft segment start.
15. When the cart is aligned on the segment start, select “Stop” and then “Save”. The survey wheel calibration is complete.
16. The survey wheel calibration can be verified by creating a new “dummy survey” file and measuring back to the end of the 500-ft segment.

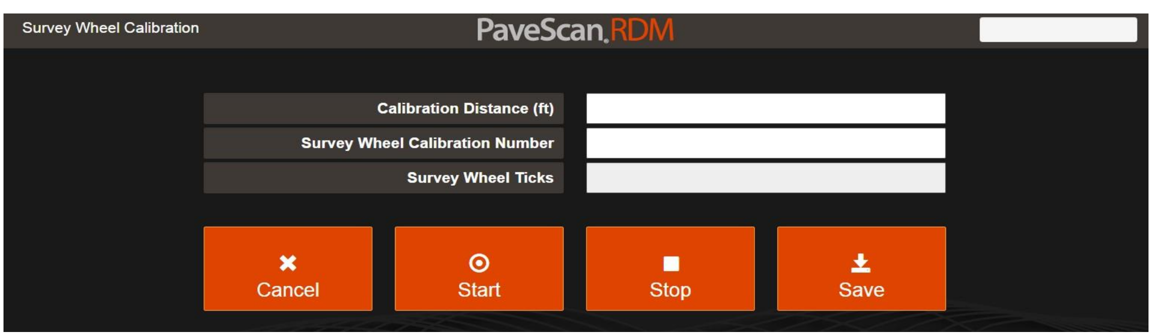


Figure 10. Survey Wheel Calibration Window

3.2 Airwave Calibration

When beginning a new project or the system has been powered down, an airwave calibration must be performed. This process involves rotating the sensors or pivoting the cart in a manner that lifts the sensors a minimum of 2 ft off the ground. If the airwave calibration is required, the software will automatically initiate the calibration window. The airwave calibration methodology is as follows:

1. If airwave and metal plate calibration are required, the software will notify the user and automatically initiate the process when the "Collet Data" is selected from the survey file window.
2. The sensor warm-up will begin. The warm up process takes approximately 10 minutes. The warm-up progress is shown in the progress bar. If the system has been used to collect files within the past 20 minutes, the warm-up time will be less than 10 minutes.
3. When the sensors are ready for calibration, the "Air" button will turn green (Figure 11). The air measurement requires that all the sensors be lifted at least 2 ft off the ground. To accomplish this lift, untighten the large metal thumb screw and lift the sensor arm up to about a 45-degree angle, then retighten. (Figure 12).

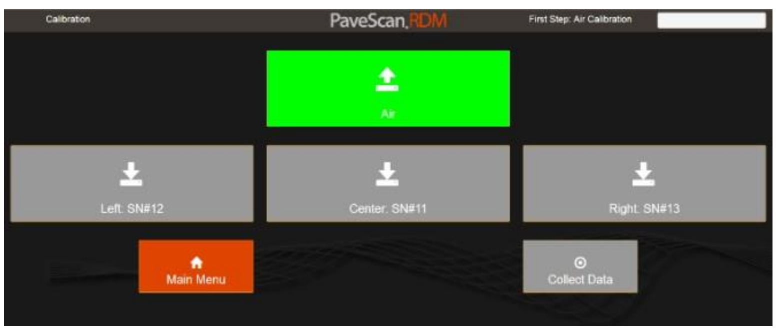


Figure 11. Calibration Window: Airwave Calibration

Figure 12. Airwave Calibration Method

4. When the "Air" button is pressed, it turns orange while the calibration measurement is being performed. The air calibration will take 5 to 10 seconds per sensor. For a 3-sensor setup, the total measurement time will then be about 15 to 30 seconds. All sensors must be in the air during air calibration.

3.3 Metal Plate Calibration

A metal plate calibration must be performed in conjunction with an airwave calibration. The metal plate calibration involves activating the sensors one at a time over a metal plate. The following is a full description of the metal plate calibration procedure:

1. Once the air calibration is completed, the metal plate calibration step can be initiated. Remove the metal plate from the cart by loosening the lock screw. Place the plate on flat pavement. Take care not to scratch the plate. One side of the metal plate should be marked with a sticker. This side should always be up when performing calibration. One side of the metal plate should always face the cart, as indicated on the sticker. Always positioning the same side on the pavement will prevent the surface of the plate from getting scratched.

2. One of the three sensor buttons will turn green (Figure 13). If the first sensor specified for metal plate calibration is the center sensor, an error has occurred and the program must be closed and restarted.

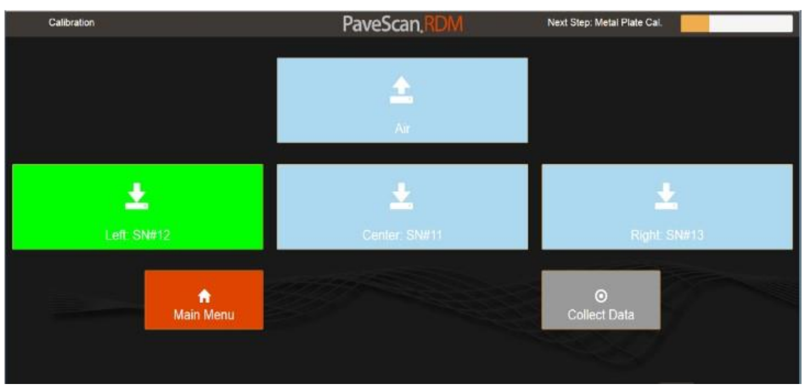


Figure 13. Calibration Window: Metal Plate

3. Center the specified antennae over the plate by maneuvering the cart (Figure 14) or adjusting the plate. Have the recorder center the sensor in the transverse and then longitudinal direction (Figure 15). The metal plate needs to be centered under the sensor to within ± 1 inch. Once the sensor is centered, select the specified sensor on the window. This will initiate calibration, which may take 5 to 10 seconds. This process will be repeated for the remaining sensors. The order in which the sensors turn green is not important and may vary. Once all sensors have been calibrated, the "Collect Data" button will turn green.

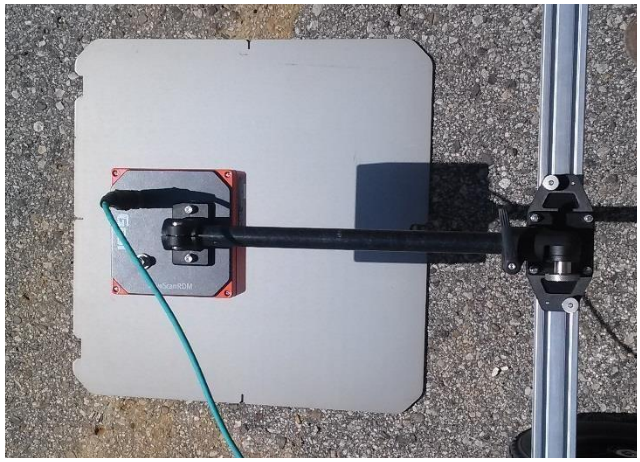


Figure 14. Correctly Centered Sensor for Metal Plate Calibration

Figure 15. Transverse and Longitudinal Alignment

3.4 Additional calibration

The test protocol includes a swerve calibration, conducted along with regular data collection. This survey is taken to collect a random data set for sensor bias correction. The swerve calibration methods are discussed along with the survey methods in Section 4.

4.0 Testing at the Pavement Site Using Rolling Density Meter

Three survey types for data collection are recommended. First, a lane survey to collect data in the middle of a lane; second, a joint survey to collect data along the longitudinal joint; and finally, a shoulder survey is used to collect data near the shoulder or on the opposite lane of the joint survey if surveying a multi-lane roadway. All three surveys should be performed in all lanes made available for data collection. In addition, a swerve calibration is performed to ensure the repeatability and validity of data collected in the survey passes.

Once sensors and survey wheel calibration are complete and GPS settings have been confirmed, data collection can begin.

4.1 General Considerations and Best Practice Recommendations

The exact timing and order of lane and joint surveys is not specified and will vary based on project-specific factors. It is recommended that lane, joint, and shoulder surveys are conducted on each asphalt lift and in all lanes if possible. A lane survey should be conducted on each lane.

Joint and shoulder surveys should be conducted on all longitudinal joints and shoulders. Generally, an entire lane and lift will be surveyed before moving on to another lane and lift because of standard paving practice. An example survey pattern is presented in Figure 16. In this pattern, first a lane survey is conducted in the middle lane, then a joint survey is conducted along the longitudinal joint, and final a shoulder survey is conducted.

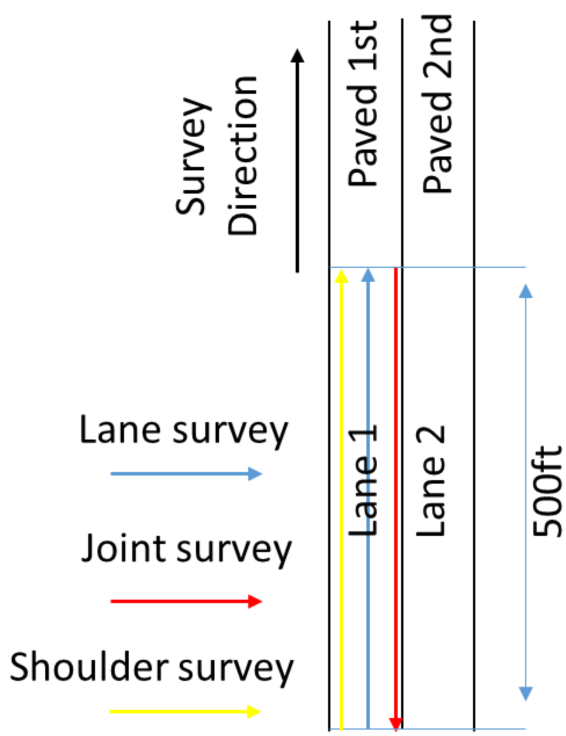


Figure 16: Example Survey of Two-lane Project

Factors that should be considered when beginning the survey:

- Surveys should be conducted as soon after paving as possible.
- Survey parameters should account for paving speed and available closure length. For projects with full closure, longer surveys with multiple passes and many cores will be possible. However, faster projects with moving closures may only allow for single passes.

- Battery charge typically limits RDM surveys to 6 hours. The battery in the tablet is usually the limiting battery. Ensure field charging is available.
- Conducting a joint or shoulder survey requires about 9 inches of pavement on the other side of the joint. Coordinate traffic barrel placement and removal accordingly.
- A joint survey may require being close to traffic. If conducting a joint survey next to traffic, plan joint survey so that it is conducted against the direction of traffic. This allows users to see possible troublesome vehicles before they arrive.
- A minimum of a two-person crew is recommend; one person to operate the RDM and one person to record data. If the agency is also responsible for coring, additional personal should be provided.
- If cores are collected, collect them when conducting return survey rather than going back at each segment to mark locations.

4.2 General Survey Method

The following steps indicate the general procedure to be followed when operating the RDM to survey a pavement.

Step One: To begin a survey, create a chalk line at the desired starting location. For ease of recording, even 500 ft stationing is recommended (for example, 15+00, 2505+00, 910+00). Label the stationing of the start location in chalk (Figure 17). The station markings should correspond with stations marked by the construction crew. If the construction crew marked stations at STA +15 ft increments, the RDM survey crew should do the same. All surveys are recommended to be taken in 500-ft increments. Larger increments may be used to increase survey speed.

Generally, contractors will mark stationing points along the survey for their own purposes. When contractor stationing points are encountered, make note of any difference between RDM survey stationing and contractor stationing and correct to the contractor stationing at the start of the next survey. This allows better comparison of mix or design changes.

Figure 17. Survey start/end marking

<u>Step Two</u>: Maneuver the cart into the correct transverse position specified by the survey type being performed. The four survey types (lane, joint, shoulder, and swerve calibration) are outlined herein. If starting a new project or the system was shut down or has not been used for more than 1 hour, a swerve calibration survey (detailed in Section 4.4) must be performed before data collection. A swerve calibration survey should also be performed as the final survey at the end of data collection for the day or for a project.


Figure 18. Transverse and Longitudinal Alignment

<u>Step Three</u>: Center the sensors over the starting line. Use recorder to confirm offset and data input (Figure 18) into the RDM software as well on the entries on the field sheet.

<u>Step Four</u>: The recorder should fill out all the corresponding fields on the RDM Survey Log (see Appendix A2).

<u>Step Five</u>: Select "Collect Data". This opens up the "Collect File" window, shown in Figure 19. No data collection starts until either the "Collect Dist" or "Collect Time" buttons are pressed:

- "Collect Dist" begins a distance specified survey and is the primary survey type performed.

- “Collect Time” initiates collection of a continuous file at a rate of about 60 scans per second and is only used for static (nonmoving) survey.

As this test protocol uses “Collect Dist,” select the “Collect Dist” survey type. Wait for the file name to appear at the top left of the window before moving the cart (Figure 19). If the filename does not appear after five seconds, press the “Cancel File” button and then press

“Collect Data” from the File Information page.

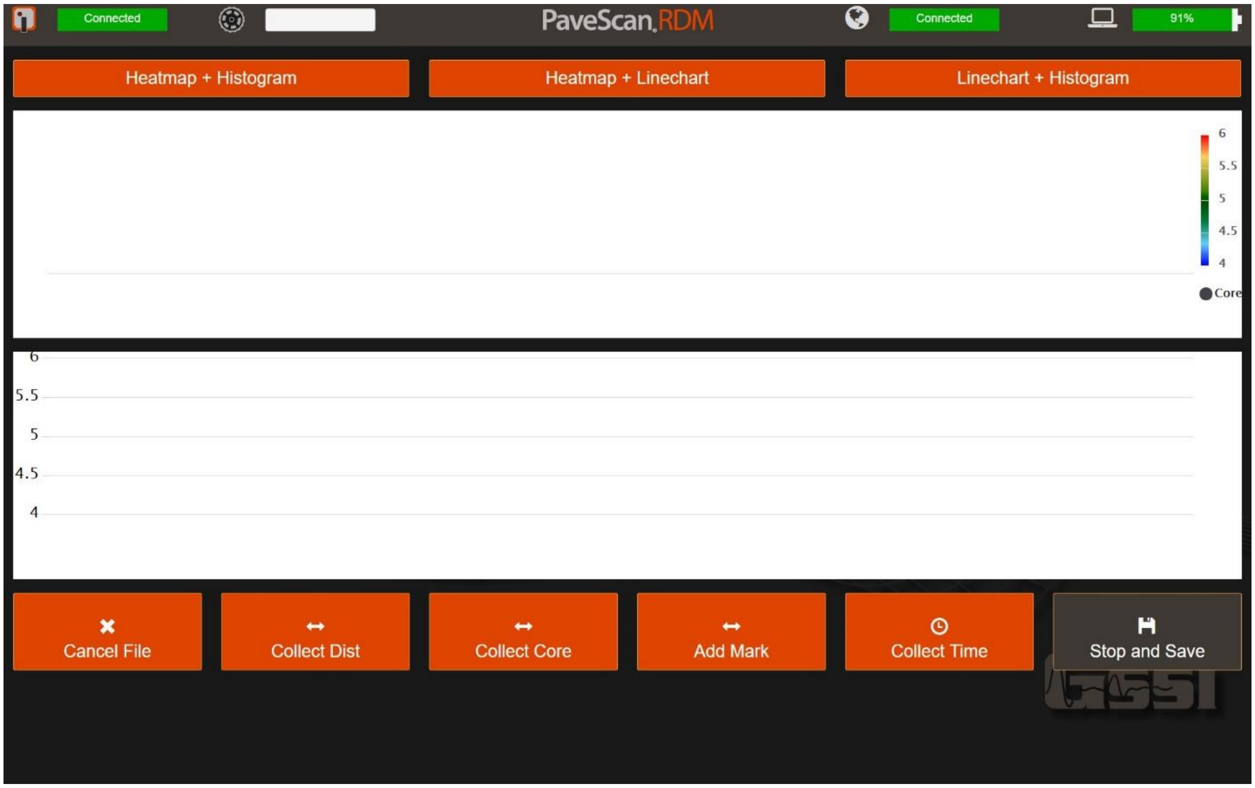


Figure 19. Collect File Initialization

<u>**Step Six**</u>**:** Begin the survey. For lane, joint, and shoulder surveys, the transverse position specified for the survey should be maintained as straight as possible. See swerve survey description for swerve survey methodology. A walking speed of approximately 3 ft per second (2 miles per hour) should be maintained. This speed corresponds to an average walking pace. During the survey, the following precautions should be taken:

- The recorder should look ahead of the operator and move any obstructions, monitor operator alignment, and record the exact location of any changes (for example, pavement appearance and wet pavement).
- The record should monitor traffic and watch for troublesome vehicles.
- The recorder should provide feedback to the operator to ensure that the cart maintains the correct offset.

During the survey, the dielectrics of each sensor are plotted together on a heat map and line chart. The dielectrics at a specific location can be displayed by placing the mouse at the desired location on the chart.

<u>Step Seven</u>: Once the 500-ft end point has been reached, hold the RDM still and allow the recorder to mark the location with a chalk line and write the stationing in chalk (Figure 18). Save the data file. Reposition the cart if performing further surveys in the segment and repeat Steps 1 through 6 for the next survey type. If the segment is completed, reposition the cart to start data collection on the next segment and repeat Steps 1 through 6.

4.3 Lane Pass Survey

A lane pass survey is taken in the middle of a lane. The center sensor is offset 6 ft from longitudinal joint. This corresponds to the approximate center of typical 12-ft lane. The distance from the Y-reference axis is based on the lane number in which the survey is conducted, as shown in Figure 20:

- If the lane number is 2 or 3, the lateral offset distance (distance from the Y-reference axis in the figure) is -6 feet.
- If the lane number is 1, the distance from the lateral reference is 6 ft.

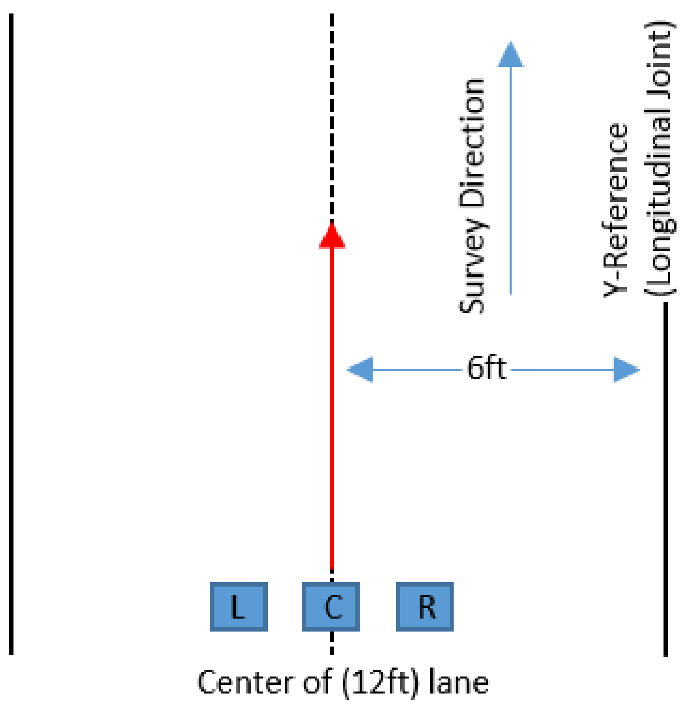


Figure 20. Lane Survey

4.4 Longitudinal Joint Pass Survey

The longitudinal joint pass survey is taken on longitudinal Joint (Figure 21). Depending on lane number and direction, either left or right sensor is offset 3 to 6 inches from the longitudinal joint. It is important that the sensor near the joint does not pass directly over the joint. The distance from the lateral reference (which is the Y-reference axis in Figure 21) is based on the lane number the survey is performed in, as indicated in Figure 21:

- If the lane number is 2 or 3, the distance from the longitudinal joint (which is the lateral offset reference) is -2.5 ft.
- If the lane number is 1, the lateral offset distance is 2.5 ft.

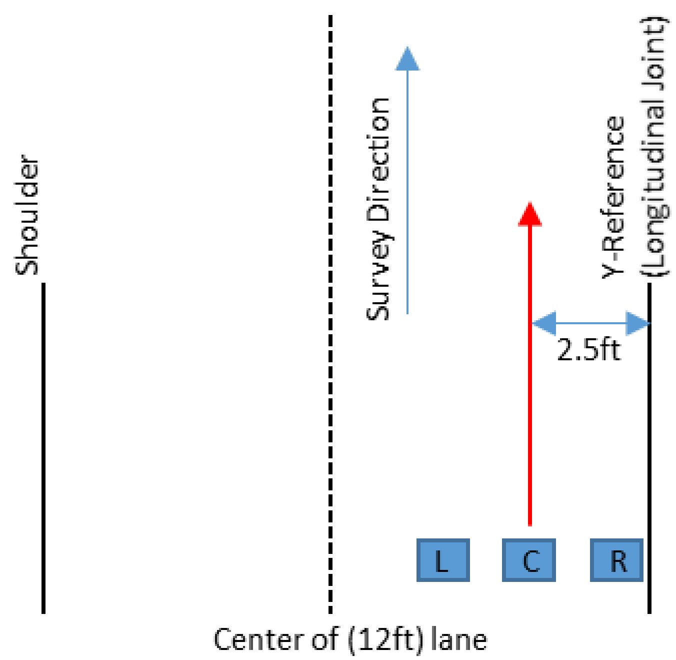


Figure 21. Joint Survey

4.5 Shoulder Pass Survey

The shoulder pass survey is taken on the shoulder (Figure 22). Depending on lane number and direction, either left or right sensor is offset 3 to 6 inches from the shoulder joint. It is important that the sensor near the joint does not pass directly over the joint. The distance from the lateral offset reference (the lateral offset reference is the Y-reference axis) is based on the lane number the survey is performed in, as indicated in Figure 22:

- If the lane number is 2 or 3, the distance from the Y-reference axis is -9.5 ft.

- If the lane number is 1, the distance from Y-reference axis is -9.5 ft.

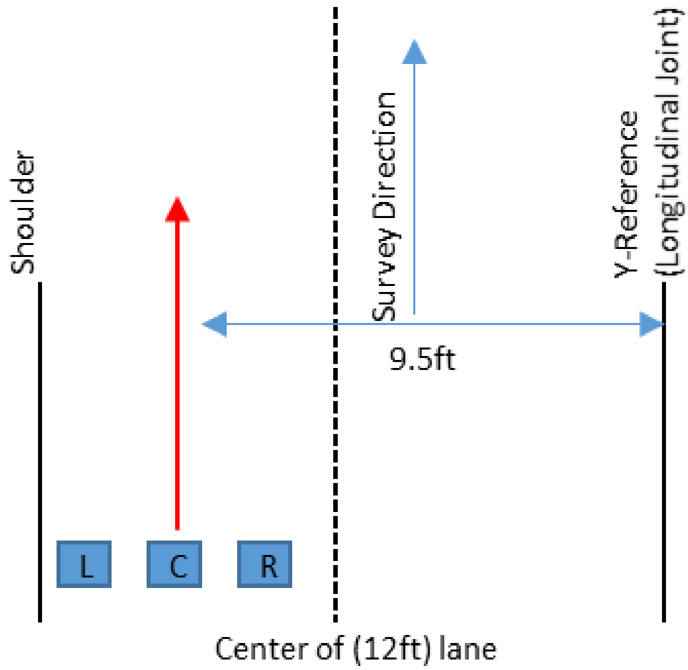


Figure 22: Shoulder Survey

4.6 Swerve Calibration Survey

The swerve calibration survey is taken to collect a random data set for sensor bias detection. Unlike lane and joint surveys, the swerve calibration survey is not used to collect data; therefore, performing a swerve calibration survey over a segment of pavement does not constitute data collection. The swerve calibration survey can be performed over a segment that has already been surveyed. If performed on a new segment, a data collection survey (lane or joint survey) should be performed after the swerve calibration survey.

As in the lane and joint surveys, the swerve calibration survey takes place over a 500-ft segment. The cart should be maneuvered such that the left and right sensors spend approximately one second in the center of the lane before the cart is swerved to move the opposite sensor into the center (Figure 23). Though the exact starting position of the swerve survey is not important, the center sensor should start in approximately the center of the lane because of the swerving path. The distance reported in the collect window does not accurately reflect the change in stationing. However, the exact length of the swerve survey is not important. Stop the survey when the collect window reports 500 ft.

At the conclusion of the swerve calibration, check the average sensor values by selecting "playback last -> statistics". The mean dielectric for each sensor should be within 0.2. If all the means values are within tolerance, no further action is required. If any mean differs by more than 0.2, the swerve calibration survey should be performed returning back to the segment start and the means should be checked again. If the same sensor reports the same bias, the issue is likely internal and needs to be recorded and the airwave and metal plate calibration must be re-performed. If the bias has moved to a different sensor, the bias likely results from highly variable asphalt dielectric and does not need to be noted. It at any point during surveying, a sensor is consistently reporting an anomalously high or low value, the swerve calibration should be performed.

The software inputs for the distance from the lateral offset reference for the swerve calibration survey are as follows:

- If the lane number is 2 or 3, the distance from the Y-reference axis is -6 ft.
- If the lane number is 1, the distance from Y-reference axis is 6 ft.

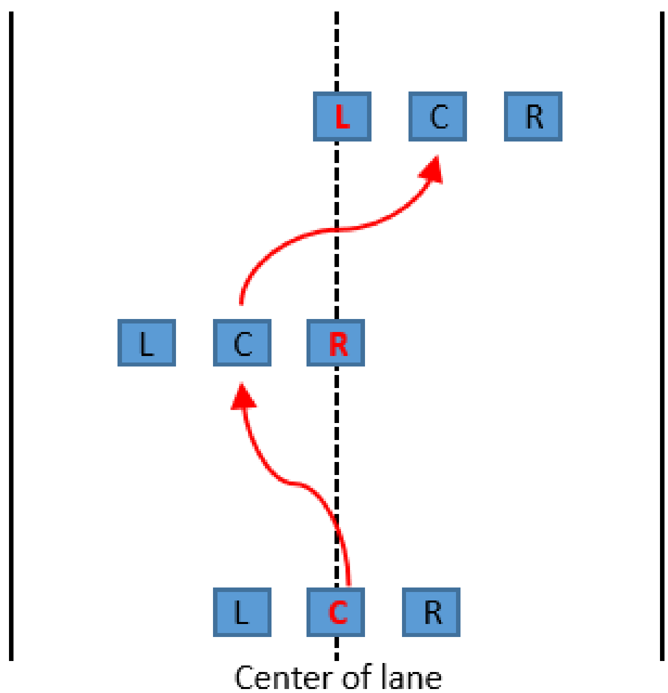


Figure 23. Swerve Calibration Survey

4.7 Core Location Selection Using File Playback

There are two main methods for core collection. The first involves the use of the "Core Locations" feature within the file playback window. This method tends to be better at identifying extreme high and low dielectric values better than the real-time collection method. However, the real-time collection method tends to be significantly faster. File playback allows for in-field selection of core locations and viewing of data files (Figure 24).

Figure 24. Playback File Window

The playback window provides many options. For this procedure, only the core locations option is of interest. The "Core Locations" feature locates high, middle, and low dielectric areas in the current file that are suitable for obtaining cores used to generate a dielectric-percent air void calibration curve generated during later analysis.

The relationship between dielectric response and % void is highly dependent on asphalt material properties. Therefore, any change in asphalt mix requires a unique calibration curve. To produce good calibration results, a minimum of 10 cores is recommended. The core collections procedure varies based on the distance over which a particular mix is applied (the mix length, L_{mix}). The coring protocol for different mix lengths is as follows:

L_{mix} < 2,500 ft	Collect two high, two low, and one medium core in both the first and last 500-ft segment of the mix length. This results in 10 cores.
2,500 ft < L_{mix} < 10,000 ft	Collect one high AND one low in each 500-ft segment. This results in 10 to 40 cores.
L_{mix} > 10,000 ft	Collect one core, alternating high and low, in each 500-ft segment. This produces a minimum of 10 cores.

High cores should be taken at the locations of the highest dielectric and low cores should be taken at the location of the lowest dielectric. If multiple high or low cores are required, highest and lowest available cores should be taken. For example, if two low cores are required, the two lowest locations should be cored. In general, the lane pass survey produces higher dielectric values; therefore, high dielectric cores should be collected from lane pass surveys. Joint surveys generally produce lower dielectric values and low dielectric cores should be collected in joint surveys.

If cores are collected after the survey select "Core Location" within the file playback window (Figure 25). Record all the locations, offsets (from sensor positions), and dielectrics of the desired core locations on the RDM Survey Sheet (see Appendix A2, RDM Survey Log for Field Data Collection). Offset is determined based on distance from the lateral offset reference and distance between sensors. For example, if the first core location in Figure 25 is selected and the survey is a lane survey with a 6 ft offset, and the lateral offset reference is on the left side, the offset of the core location reported at the center sensor would be -6 ft. The left and right sensor offsets would be -4 ft or -8 ft depending on cart position. An example is presented in Appendix A2.

Once all the desired core locations have been recorded, create a "dummy" survey file. The stationing/distance and decrementing distance must be entered correctly, but the other inputs do not matter. Turn the cart around to survey back in the direction where the cores are to be collected, making sure that the cart is in the same offset as when the data was collected. Start the dummy survey file by selecting "Collect Dist." Begin pushing the cart back toward the core locations. When the first core location has been reached, slow down and look for the high, low, or medium dielectric value reported. It is unlikely that you will encounter the exact value again, this is not a problem. If looking for a low value, stop at the lowest value encountered. If looking for a high value, stop at the highest value encountered. Mark the location of the value found. The value does not need to be under the same sensor as was originally reported.

Relative Dielectric	Sensor Position	Distance (ft)	Dielectric	1 ft Average	2 ft Average
High	Center	1155+99.02	5.68	0.08	0.11
High	Center	1158+94.65	5.67	0.09	0.14
High	Center	1155+57.22	5.67	0.06	0.10
High	Center	1159+72.34	5.66	0.10	0.13
High	Center	1155+50.85	5.65	0.10	0.14
Low	Left	1155+23.95	4.79	0.08	0.12
Low	Left	1155+10.79	4.79	0.07	0.07
Low	Left	1155+1.35	4.80	0.07	0.13

Figure 25: Core Location Window

4.8 Core Location Selection Using Real-time Survey Results

Another method for core data is using real-time survey results to select core locations. This method tends to be faster than using the file playback mode, but does not guarantee that the highest and lowest dielectric values will be selected. This method involves watching the survey dielectrics in real time during the survey and can be done during any survey type. When a location is encountered that is desirable for coring (extreme high, extreme low, or medium dielectric value), the cart is stopped and approximate location of the reading is marked under the sensor and the initial offset, stationing, and dielectric are recorded on the survey sheet. The survey is then completed. When all survey passes within the segment are completed, return to the marked core locations for core data collection.

4.9 Core Data Collection

Accurate measurement of the dielectric at the core location is crucial to development of a good calibration model. Three methods of core data collection are presented.

4.9.1 Distance Survey Pass over the Core Location

Once the RDM is at the core location, reposition the RDM such that the one of the sensors will exactly pass over the marked core location and back the RDM up a few feet. Then, initiate a dummy survey file (inputs do not matter) and slowly roll the cart over the location to be cored. When the sensor is exactly over the core location, record the reported dielectric. Repeat for the remaining cores.

4.9.2 Static Time Survey over the Core Location

Once the RDM is at the core location, reposition the RDM such that one of the sensors is exactly over the core locations. Use the recorder to verify the sensor alignment. Be sure to record which sensor is over the core on the RDM survey sheet. Initiate a survey file, with name of the survey, the name of the current file appended with the number of the core or some other signifying ending (Figure 26). Begin the survey as TIME survey. Allow the sensor to record for about 5 seconds while holding it still over the core location. Stop and save the survey file. Repeat for the remaining cores.

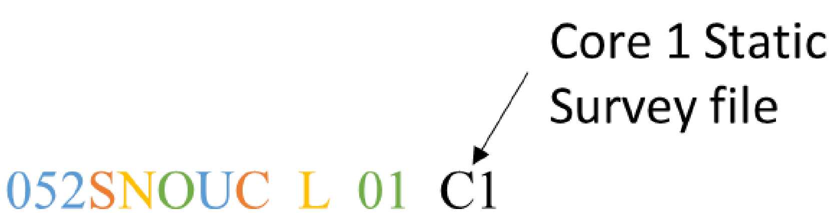


Figure 26: Static Core Data File Naming

4.9.3 Dynamic Time Survey over the Core Location

A dynamic time survey of the core location is recommended to be performed in conjunction with a static time survey. Once the RDM is at the core location, reposition the RDM such that one of the sensors is just behind the core location, with the front edge of the sensor adjacent to the core mark (Figure 27). Use the recorder to verify the sensor alignment. Initiate a survey file, with name of the survey, the name of the current file appended with the number of the core, or some other signifying ending (Figure 28). Be sure that the file can be distinguished from the static time survey file. Begin the survey as TIME survey. Over the course of about 5 to 10 seconds, push the cart of the core location and stop when the back edge of the sensor is adjacent with the core location (approximately 6 in total survey) (Figure 28). Stop and save the survey. Repeat for the remaining cores.

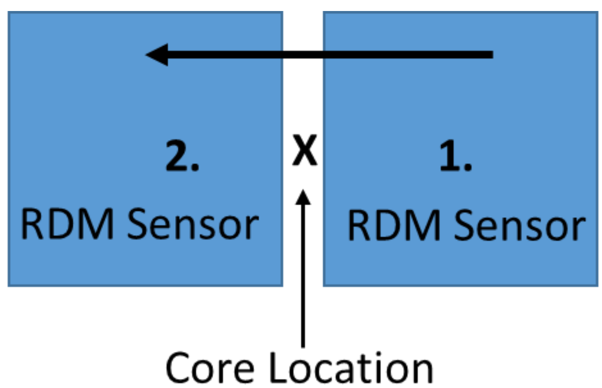


Figure 27: Dynamic Core Location Survey

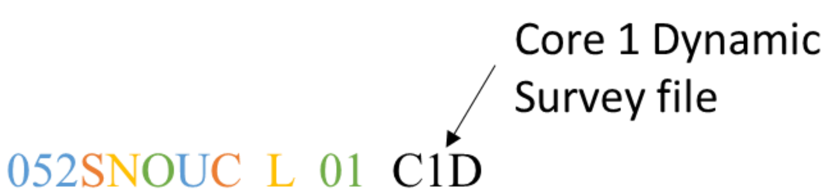


Figure 28: Dynamic Core Data File Naming

Like the survey data files, it is good practice to name cores reflecting the information about the cores. This limits confusion and help relate cores and survey files. A naming convention for a core is outlined in Table 2.

Table 2: Core Identification Legend

Format	AB_CC_DE
A	Lift (W = Wear, N = Non-wear)
B	Lane (O = Outer, I = Inner, M = Middle, 1 = one lane)
CC	Segment Index (use 0# if single digits)

D	L = Low, M = Medium, or H = High dielectric constant
E	# denoting which high or low core (1 for first L location, 2 for second H location, etc.)

For example, using the file ID given in Figure 7, a core collection on the non-wear lift ("N") in the outer lane ("O"), which is the first ("1") of two high dielectric cores ("H") taken from Pavement Segment 26 ("26") should be labeled as "NO_26_H1".

Once core locations have been determined, marked, and labeled, they should be entered on the survey sheet. Arrangements should be made for labeled and marked cores to be collected.

5.0 Analysis of Rolling Density Meter Data

While this document is focused on the developed test protocol, the protocol should be conducted with analysis of data in mind. After the completion of the test procedure previously detailed, data files can be exported for visualization and analysis. For full description of data file exporting, see the manufacturer's guide to the RDM. The following section briefly summarizes the creation of the air void versus dielectric curve and viewing of air voids within the RDM software.

5.1 Creation of Air Void Content versus Dielectric Calibration Curve Using Cores

Cores of known dielectric taken during the survey are analyzed for air void content and used to create a site-specific calibration curve for the survey. Figure 30 shows an example calibration curve. The curve can be created in Microsoft Excel (Figure 31) or directly within the RDM software or with other statistical software. It is important to note that percent air voids should not be listed as decimal values in the calibration. For example, 5-percent air voids should be entered as 5, not 0.05. Calculating the relationship directly within the RDM software is recommended. If core location survey files were not created, the dielectric value recorded at the core location during the survey is used directly. If static core location surveys were performed, the dielectric data in the core location survey files can be averaged and the average applied to the calibration curve. The same can be done for the dynamic core location survey data, if available. Ensure the data from the sensors positioned over the core locations is used. If both dynamic and static core surveys were conducted, the results can be averaged or one or the other may be used.

It is recommended that the air void versus dielectric relationship fits directly within the program rather than within Excel. This can be performed by navigating to Main Menu -> Collect- -> Core Calibration -> Calc from Cores or Main Menu -> Playback -> Project Info -> Core Calibration -> Calc from Cores. Either of these two paths will open up a window which allows the user to enter dielectric and air void values (Figure 29). The coefficients can then be automatically computed by selecting Calc A & B. The fit coefficients are then applied to the project.

Figure 29: Calculate Coefficients from Cores

To create the curve in Microsoft Excel, create a plot with the air voids on the Y-axis and dielectric values on the X-axis. An exponential trend line is then fit to the data and the "display equation on chart" option in Excel is selected. The fit coefficients A and B can be entered into the program (Figure 31). The coefficients are entered in Main Menu -> Collect -> Core Calibration or, Main Menu -> Playback -> Project Info -> Core Calibration and enter the A and B value determined in the regression.

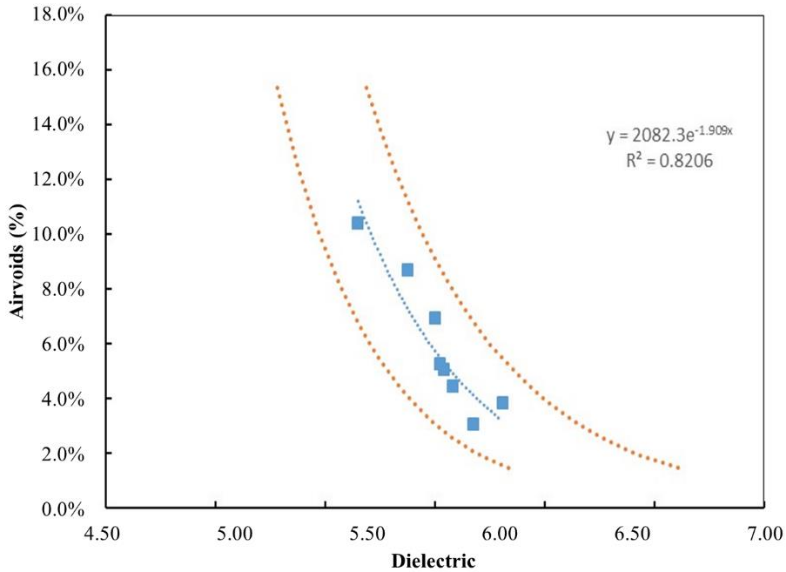


Figure 30: Air Void versus Dielectric Calibration

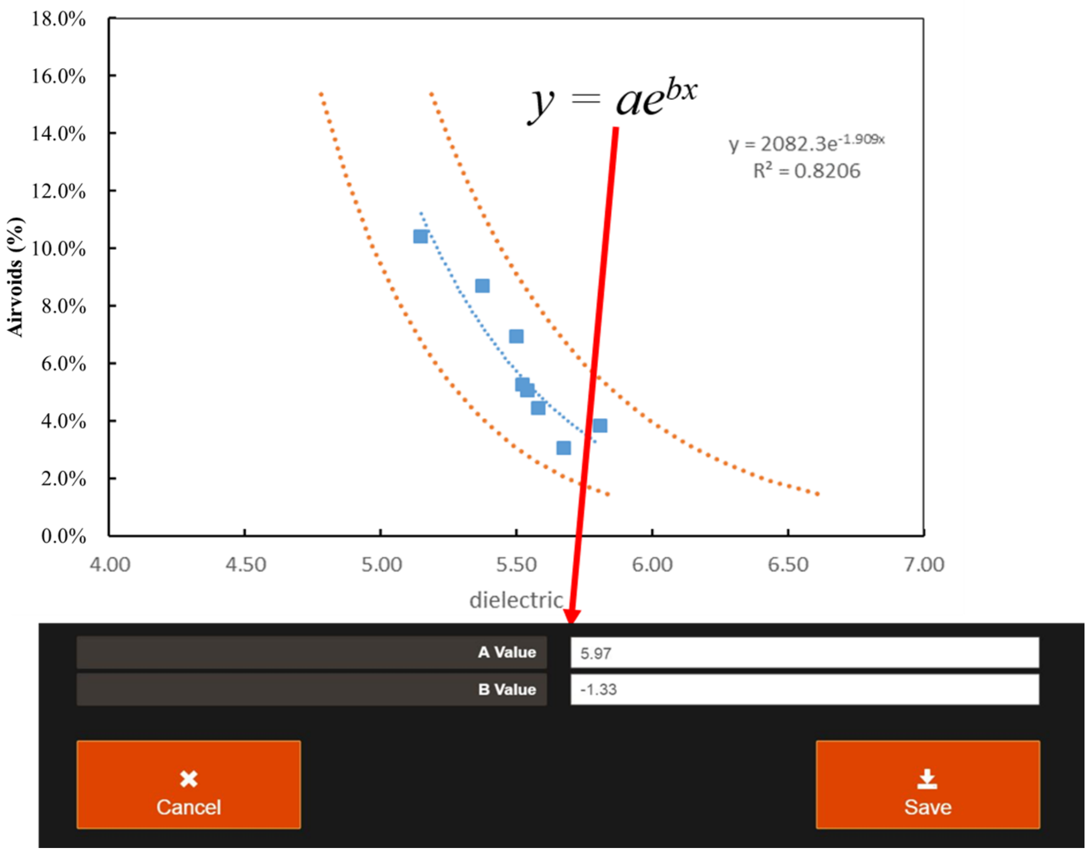


Figure 31: Air Voids versus Dielectric in Excel

5.2 Conversion of Dielectric Data to Air Void Estimates

Once the coefficients have been determined either in the RDM software or within Excel and entered into the program, files can then be viewed in either dielectric or in air void content

Figure 32: File Playback Using Air Voids

Appendix A1. RDM Project Title Page Guide

1. Test Date: The date on which the survey project is conducted.
2. Construction Type: The construction type that is being surveyed (ex. Mill and 1.5-inch lift).
3. Route: The roadway on which the project is performed (ex. HWY 52).
4. Route Direction: The direction which is being surveyed (N, S, E, W).
5. Lanes in Direction: The number of lanes in the survey direction.
6. Lift: The lift which is being surveyed (ex. Wear and non-wear).
7. RDM Survey Starting Station: The station at which the project is begun. For example, if the first section begins at STA 90+00, then 90+00 would be the stating station.
8. Project Name: The name assigned to project. Recommended to be the agency project ID.
9. Number of Sensor: The number of radar sensors attached to the cart. Generally, is 3.
10. Location: The location at which the project is performed (ex. HWY 52 S near Zumbrota at Exit 61).
11. Collected By: Operator and data recorder names.
12. Y Reference: The Y-reference used to assign offset measurements. Usually taken to be the longitudinal joint.
13. Lateral Offset Reference Side: The side of the cart that Lateral Offset reference is on. Specified as left for lanes 2 and 3 and right for lane 1.
14. Comments: Project specific comments.
15. Log GPS: Select if GPS is being logged.
16. Survey Wheel Calibration: Select if survey wheel calibration was checked or performed.
17. Swerve Calibration: Check if swerve calibration was performed.
18. Left Serial #: The serial number associated with the left sensor.
19. Middle Serial #: The serial number associated with the middle sensor.
20. Right Serial #: The serial number associated with the right sensor.
21. Left Offset: The offset of the left sensor from center of the cart. Always a positive number.
22. Center Offset: The offset of the center sensor from center of the cart. Always zero for 1 and 3 antenna setups.

23. Left Inline, ft: Always 0.

24. Middle Inline, ft: Always 0.

25. Right Inline, ft: Always 0

Rolling Density Meter Project Title Page EXAMPLE

Test Date	7/21/16				
Construction Type	1.5 in mill and overlay				
Route	52	**Route Direction**	S	**Lanes in Section Direction**	2
Lift	Wear and Non-wear	**RDM Survey Starting Station**			900+00

Program Project Inputs (Use these in PaveScan RDM inputs)			
Project Name	11764 (MnDOT Project ID)	**#of Sensors**	3
Location	Hwy 52 near Zumbrota (exit 61)	**Collected By**	Ryan Conway and Erik Hill
Lateral Offset Reference	Longitudinal Joint		
Lateral Offset Reference Side	Left		
Comments	Project also includes nuclear testing and intelligent compaction. Lots of rain in past few days		

Log GPS: [X] (Mark if collection GPS)
Survey Wheel Calibration: [X] (Mark if preformed survey wheel calibration)
Swerve Calibration: [X] (Mark if preformed swerve calibration)

Program Sensor Inputs (Use these in PaveScan RDM inputs)					
Left Serial #	26	**Middle Serial #**	27	**Right Serial #**	28
Left Offset	2	**Middle Offset**	0	**Right Offset**	-2
Inline, ft	0	**Inline, ft**	0	**Inline, ft**	0

Appendix A2. Rolling Density Meter Survey Sheet Guide

1. Operator: The person operating or “driving” the RDM cart.
2. Recorder: The person filling out forms and perform the role of data recorder.
3. Date: The date the data is being collect.
4. Section: The section number. The first 500 ft section is Section 01, the second 500-ft section is Section 02, and so on.
5. Weather: The current weather conditions when conducing the survey.
6. Select Lane Type: The lane type being surveyed.
7. Select Lane Number: The lane number is defined as the number of lane increasing from left to right if looking up station. See quick survey reference guide for more information and examples.
8. Check If Same as Previous: If information for the current survey is the same as for the previous survey, check this box and leave fields which did not change, blank. For example, if the only thing that changed since the previous section is the section number, record the new section number and leave all other entries blank and check this box.
9. Start Station: The starting station for the current pass being conducted.
10. End Station: The ending station for the current pass being conducted.
11. RDM Survey type (L, J, S): The type of RDM survey being performed. Either a lane survey (L), joint survey (J), a swerve survey (S), or some other type of special user-specified survey.
12. I or D: Record I if the survey is being conducted in the direction of increasing stationing and D if the survey is being conducted in the direction of decreasing stationing.
13. Distance from Lateral Offset reference (ft): The distance from the center of the cart to the Y-reference (usually specified as the longitudinal joint). This change is based on survey type and lane number. Generally, -6 ft for lane or joint survey and -2.5 ft joint survey when the lateral offset reference side is the left side. See quick survey guide for more information.
14. Comments: Record any observations which may influence data including pavement damage, and standing water.
15. Left and Right Confined Joint: Mark Y in the left joint location if the left joint is confined or N if the joint is unconfined. Mark Y in the right joint location if the right joint is confined or N if the joint is unconfined.

16. H/M/L: Indicates if the core is a high (H), medium (M), or low value (L).

17. Core station:

    Reported: The stationing of the core reported in the RDM core location software (NOTE: “reported” only applies if using file play back method for core selection for all entries).

    Collected: The actual stationing at which the core was marked when conducting the return survey for core location marking.

18. Core Sensor:

    Reported: The sensor reported in the RDM core location software.

    Collected: The actual sensor at which the core was marked when conducting the return survey for core location marking.

19. Core Offset:

    Reported: The offset of the core location reported in the RDM core location software as determined based on the sensor at which the core location was detected. For example, if conducting a joint survey in which the left sensor is closest to the joint and RDM software reports a core location at the right sensor, the offset would be the offset of the center sensor - spacing between center and right sensor (ex. Offset = -2.5-2 = -4.5).

    Collected: The actual offset from the lateral reference at which the core location was marked when conducting the return survey for core location marking. Measured in the same manner as previously described for the reported core offset.

20. Core Dielectric:

    Reported: The dielectric of the core reported in the RDM core location software.

    Collected: The actual dielectric of the core location that was marked when conducting the return survey for core location marking.

21. Core ID: The standardized core ID input. The format of the core ID is as follows: AB_CC_DE, where A is the lane (I = inner, O = outer, P = passing), B is the lift (W = wear, N = non-wear), CC is the section number (01, 02, 28, etc.), D indicates if the core is a high (H), medium (M), or low value (L) and E is the number of the high, medium or low value. For example, for the second high core collected in a single 500 section (ex. E would be 2, for the third, E would be 3).

22. Data File Name

    The extension appended onto the current survey file name for the core survey file. It is recommended that the _C1 be used for the first core marked, _C2 be used for the second core marked, etc. If static and dynamic cores measurements are collected, the survey name files should be denoted accordingly. For example, _C1S for the static core measurement and _C1D for the dynamic measurement.

SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

RDM Survey Log EXAMPLE

Who is "Driving"

Who is recording data

Operator:	Ryan Conway	**Recorder:**	Dan Seeds	**Date:**	7/21/16
Section:	01	**Weather:**	Sunny, hot very humid		

The # of the section (first 500 ft section = 01, second 500 ft section = 02, etc.)

Select Lane Type: [X]Inner [ ]Travel [ ]Passing [ ]Outer [ ]Shoulder [ ]Middle
Select Lane Number: [X]1 [ ]2 [ ]3 [ ]Other
Check if same as previous survey log: [ ]

If this survey has same header information (above) as previous, check instead of filling out above info

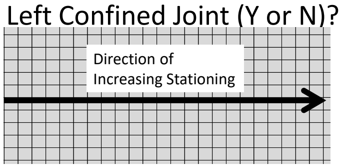
	Start Station	**End Station**	**RDM Survey Type (L,J,S)**	**I or D**	**Dist. from Y-reference (ft)**	**Comments**
1	90+00	95+00	L	I	6	Wet spot at 91+228 at 6 ft offset
2	90+00	95+00	J	I	2.5	
3						
4						
5						

Survey conducted in the direction of increasing (I) or decreasing (D) stationing

Distance from CENTER of cart to longitudinal joint. 6 ft for lane or swerve survey, 2.5 ft for joint

L = Lane survey, J = Longitudinal Joint survey, S = Swerve Calibration survey

Left Confined Joint (Y or N)? __Y__



Right Confined Joint (Y or N)? __N__

See core naming reference

H/L/M[16]	Core Station[17] Reported	Core Station[17] Collected	Core Sensor[18] Rep. (L,C,R)	Core Sensor[18] Coll. (L,C,R)	Core Offset[19] Rep.	Core Offset[19] Coll.	Core Dielectric[20] Rep.	Core Dielectric[20] Coll.	Core ID[21]	Data file name[22]
H	91+26	91+27	C	C	6	6	5.92	5.94	IW_01_H1	_C3S, _C3D
H	92+22	92+20	C	R	6	4	5.99	5.96	IW_01_H2	_C2S, _C2D
M	93+02	93+06	R	L	8	8	5.51	5.55	IW_01_M1	_C1S, _C1D
L	94+19	94+19	R	L	0.5	0.5	4.55	4.39	IW_01_L1	_C4S, _C4D
L	90+77	90+78	R	L	0.5	0.5	4.45	4.45	IW_01_L2	_C5S, _C5D

Is the core high (H), low (L), or medium (M)

Information reported in RDM core lookup

Actual collection location information

Ending of core survey file name with "S" for static survey and "D" for dynamic (if performed)