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16. Abstract The first phase of Texas Department of Transportation (TxDOT) research project 0-4577, "Further Development of NDT Devices to Identify Segregation in HMAC," focused on evaluating non-nuclear density gauges for measuring hot-mix asphalt (HMA) density on paving projects and is documented in Report 0-4577-1. This report documents the second phase of that project. In this phase, researchers refined infrared methods for detecting segregation on paving projects, verified previously recommended limits on surface dielectric variations for different TxDOT paving mixtures, and developed new ground-penetrating radar (GPR) tools to more rapidly investigate the uniformity of a new overlay. To refine infrared methodology, the research team created an infrared sensor bar that gets pushed behind the paver. Data collection and processing software allow personnel to inspect and identify suspected segregated areas in real time. To verify the previously recommended limits on surface dielectric variations, the research team used GPR to inspect completed overlays for segregation on six TxDOT paving projects. Results matched well with the previously recommended guidelines. On projects using coarse-graded mixes, locations with surface dielectrics that are not within ± 0.8 of the mean dielectric value should be investigated for segregation. On projects using dense-graded mixes, locations with surface dielectrics that are not within ± 0.4 of the mean dielectric value should be investigated for segregation. A new software package, RadSeg, allows personnel to more rapidly analyze GPR data for segregation. A newly developed three-channel GPR system allows personnel to collect data over both wheel paths and the centerline in one pass for rapid assessment of the uniformity of a project.					
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NEW INFRARED AND RADAR SYSTEMS FOR DETECTING SEGREGATION IN HOT-MIX ASPHALT CONSTRUCTION

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EXECUTIVE SUMMARY

This report is the second of two reports documenting Texas Department of Transportation (TxDOT) project 0-4577, “Further Development of NDT Devices to Identify Segregation in HMA.” TxDOT initiated this project to continue development of technologies identified in Project 0-4126. Project 0-4126 demonstrated the utility of infrared imaging and ground-penetrating radar (GPR) for detecting thermal segregation in hot-mix asphalt (HMA) construction. Under this project (0-4577), the Texas Transportation Institute (TTI) research team refined and developed new infrared and GPR systems for use in detecting segregation. Additionally, the TTI team evaluated the Pavement Quality Indicator and Pavetracker non-nuclear density gauges. Report 0-4577-1 documents the findings from testing the non-nuclear density gauges.

This report focuses on the development of infrared and GPR systems for detecting segregation. Based upon previous experience with using infrared cameras for evaluating paving operations, the research team recommended development of an infrared temperature bar to overcome limitations of the infrared camera. Primarily, use of a temperature bar allows for more accurate location of anomalous areas for follow up testing, and the temperature bar allows for collection of sufficient data to develop a quantitative assessment of temperature uniformity on a project. The system developed by TTI, called *Pave-IR*, uses a series of infrared temperature sensors mounted on a bar, which is suspended transversely across the new HMA mat. A computer-controlled data acquisition and processing system, in conjunction with a distance measurement device, allows for the acquisition of a transverse temperature scan across the pavement mat at user-defined longitudinal intervals. In real time, the system displays a color plot of the data on a computer screen. The TTI team built two prototype systems; one currently is in use within TxDOT; the other system remains at TTI. [Chapter 1](#) documents development of the *Pave-IR* system, and [Appendix A](#) presents procedures for detecting segregation with this device. Based upon promising results with using the *Pave-IR* system, TxDOT initiated an implementation project (455775) under which TTI will produce additional *Pave-IR* systems for TxDOT.

In addition to the infrared system, this project also refined the use of GPR for detecting segregation. In addition to data collection and processing procedures, a new three-channel GPR system was constructed. This new system can collect enough data to locate segregation and quantify the uniformity of an HMA paving operation with one vehicle pass. [Chapter 2](#) documents the processes completed to refine the use of GPR for detecting segregation. [Appendix B](#) presents user’s instructions for the *RadSeg* software developed, and [Appendix C](#) presents procedures for detecting segregation with GPR. Based upon the promising results of both the infrared and GPR systems, the project team recommends continued efforts focusing on the use of these systems for paving quality control/quality assurance (QC/QA) operations.

CHAPTER 1

DEVELOPMENT OF PAVE-IR SYSTEM

SUMMARY

Project 0-4126 (1), along with several studies performed by other agencies (2-4), lent strong support to the notion that infrared imaging could serve a useful purpose for inspecting paving operations for uniformity and segregation. All the previous studies used infrared cameras for the inspection tool. Because of deficiencies with this technique, TTI researchers undertook development of an infrared sensor bar to use in place of the camera. This chapter describes the development of two prototype sensor bars and the accompanying software. The completed system, termed PAVE-IR, enables personnel to efficiently collect and summarize infrared temperature data from a paving project to evaluate the project for uniformity and segregation.

DESIRED FEATURES OF INFRARED SYSTEM

Figure 1.1 shows the basic design idea for the infrared sensor bar. The TTI team set forth several key features to incorporate into the infrared sensor bar system. Some features are specific to the hardware, while some are handled by software features. The primary functions the research team desired in the system include:

- Hardware Features:
 - Rapid setup time
 - Flexibility to survey projects of varying paving widths
 - Ability to include a distance encoder
 - Ability to adjust height of infrared sensors
 - Robust
- Software Features:
 - Ability to collect data in a distance mode
 - Real-time color display of data
 - Ability to quickly identify when temperatures in a transverse scan stray from acceptable limits
 - Ability to quickly evaluate the overall uniformity of a project as data are collected
 - Ability to quickly summarize results from an entire project

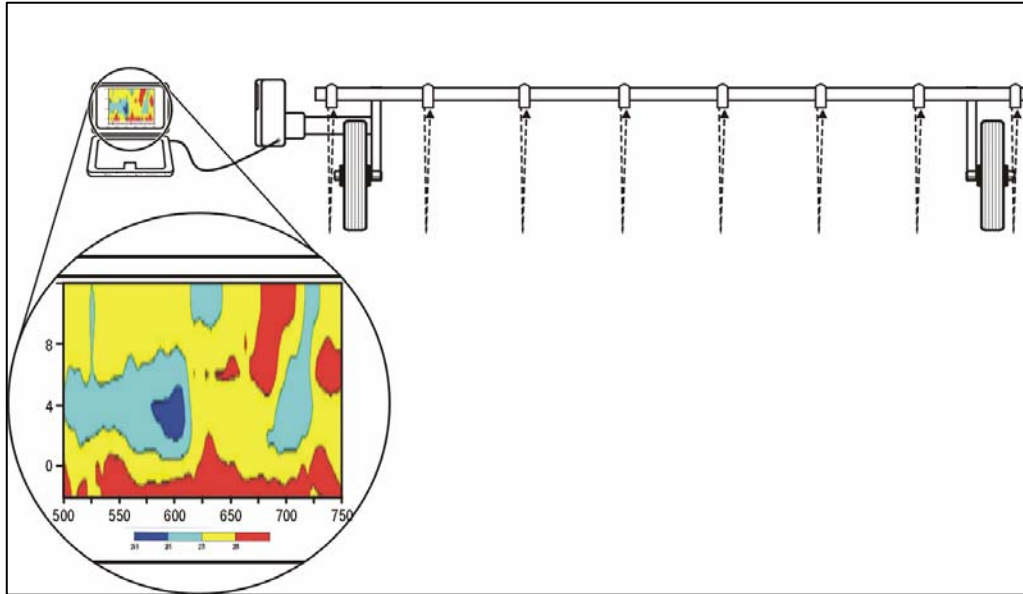


Figure 1.1. Design Idea for Infrared Sensor Bar (I).

Before building a prototype, the research team decided upon some basic specifications for the infrared bar. For the basic design, the team estimated the bar would operate at a distance of approximately 1 to 3 feet above the mat. The minimum spot size of practical importance then needed to be determined so appropriate sensors could be selected. The research team concluded 1 foot represented a reasonable value for this parameter. Therefore, the team selected to use 10 infrared sensors with a distance:spot ratio of 2:1. The team planned to place the outer sensors 1 foot in from the edge of the mat, so on a typical 12 foot wide paving project the sensors would be approximately 13 inches center to center. If the sensors get placed 2 feet above the mat, and with their 2:1 distance:spot ratio, only approximately 1 inch between sensors would not get measured. Therefore, the sensor selection and layout design provides near 100 percent coverage and will detect anomalous locations as small as 1 foot in diameter.

In addition to sensor placement and distance:spot ratio, other sensor specifications needed definition. The sensor measurement range, spectral response, and operating ambient temperature needed to be appropriate. After examining numerous options, the research team selected sensors with a temperature measurement range of -40 to 1112 °F, a spectral response of 8 to 14 μm , and an operating ambient temperature of 32 to 185 °F. The temperature range clearly encompasses expected temperatures on an asphalt paving mat. The spectral response is in a range appropriate for relatively low temperature applications and where atmospheric transmission is near 100 percent. The operating ambient temperature range is suitable for temperatures encountered a few feet above a freshly placed HMA overlay. With 10 of these sensors on hand and basic design criteria outlined, the research team built the first generation infrared sensor bar, described next.

GENERATION 1 INFRARED TEMPERATURE BAR

Figure 1.2 shows the first generation infrared temperature bar. Operators assemble the transverse bar by coupling together pieces of aluminum stock of varying lengths to achieve the appropriate span length relative to the width of the mat the contractor paved. Operators select the transverse offset of the 10 sensors to evenly space the sensors across the mat width. The first generation bar also included a distance-measuring instrument and use of all-thread rods to raise or lower the height of the transverse bar. On the downside, this prototype required approximately 20 minutes for set up and contained numerous loose wires. Additionally, the bicycle control cart and unicycle end support did not yield a very stable design. TTI personnel tested this device on three projects:

- Type D mix at the mobile load simulator (MLS) test site in Austin, TX, in October 2003
- ¾ inch SFA on SH 114 near Rhome, TX, in the Fort Worth District, in December 2003
- 1 inch Superpave on IH 20 in the Odessa District in May 2004

Figures 1.3 through 1.10 show the placement operation and sample data from each of the projects.



Figure 1.2. First Generation Infrared Temperature Bar.



Figure 1.3. Placement Operation at MLS Test Site.

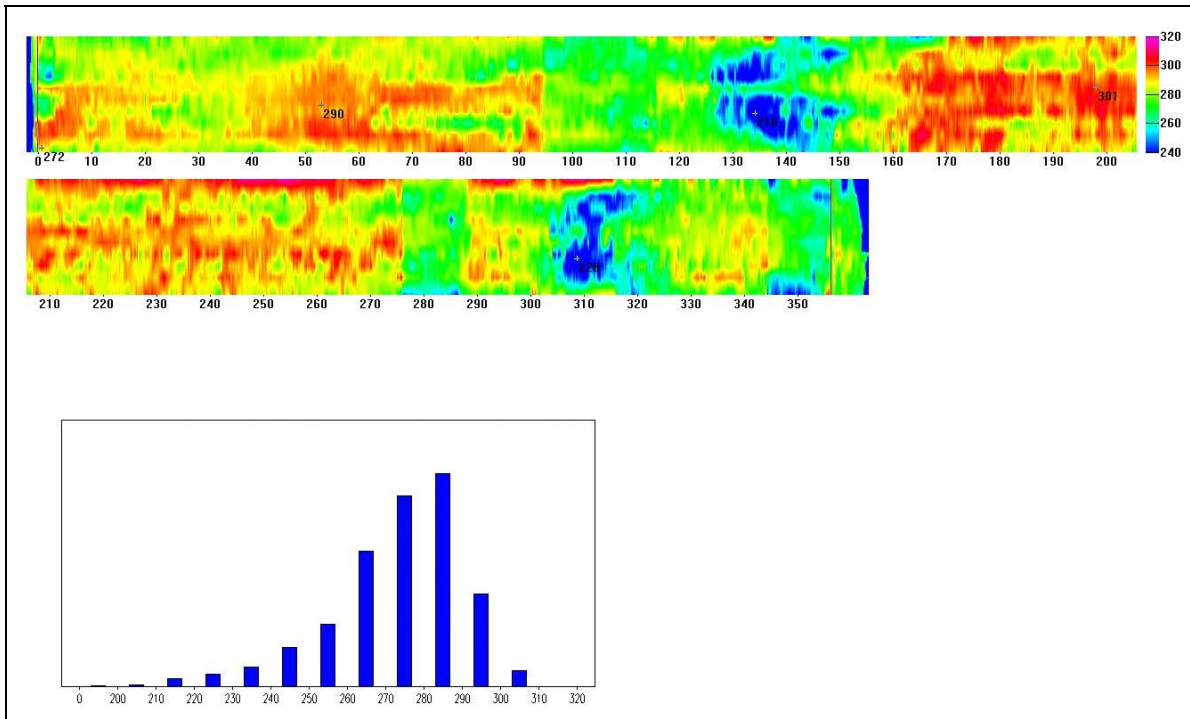


Figure 1.4. Example Infrared Data from MLS Test Site.



Figure 1.5. SH 114 ¾ inch SFA Placement Operation, Day 1.

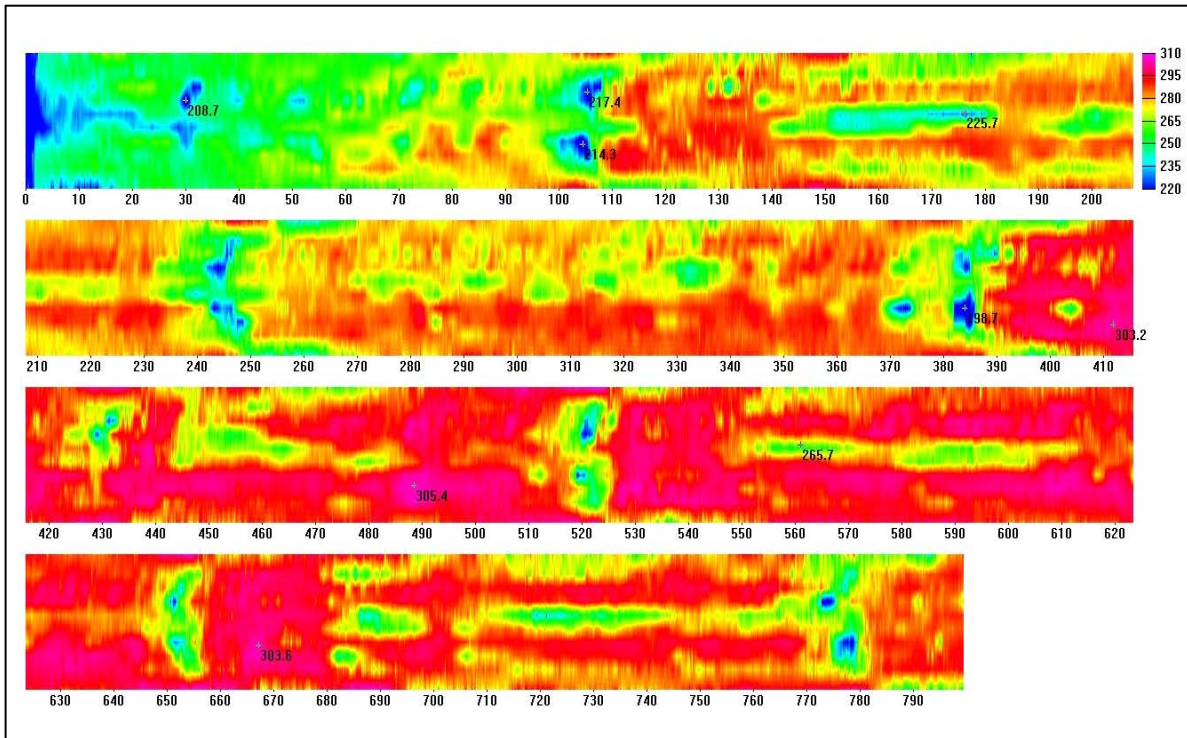


Figure 1.6. Sample Infrared Data from SH 114 ¾ inch SFA, Day 1.



Figure 1.7. SH 114 ¾ inch SFA Placement Operation, Day 2.

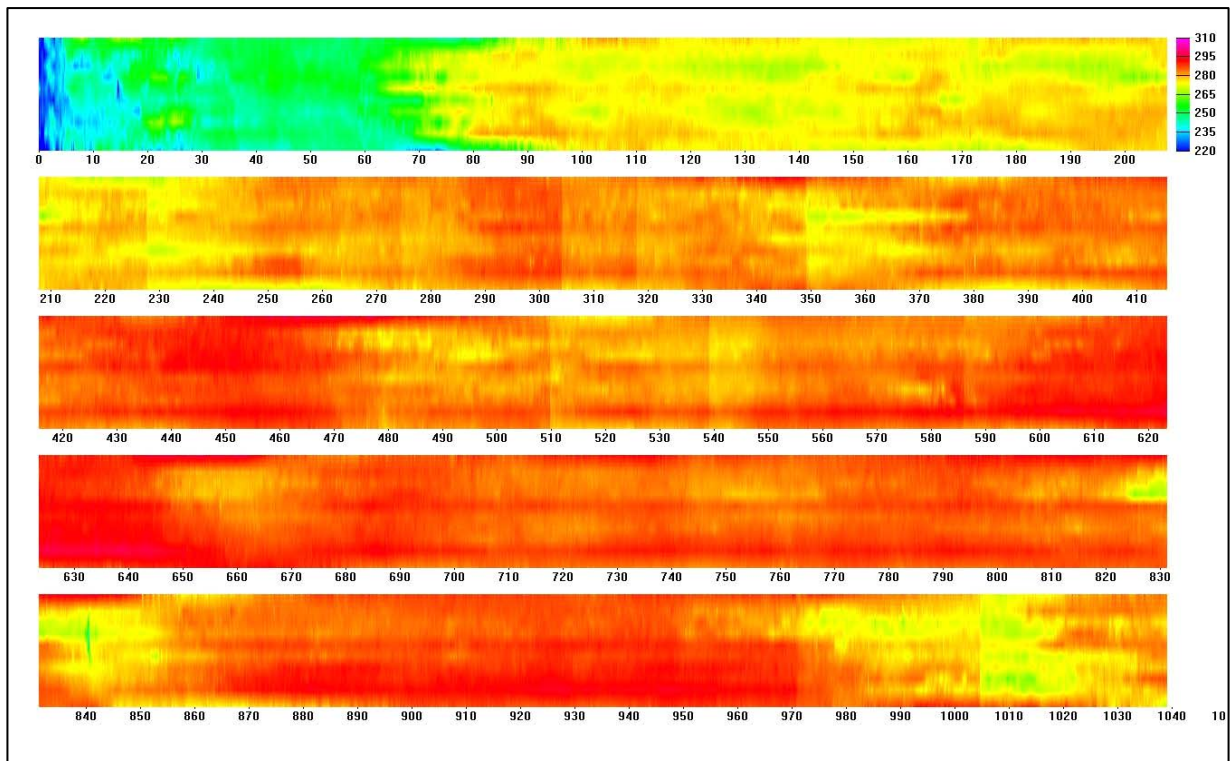


Figure 1.8. SH 114 ¾ inch SFA Sample Infrared Data, Day 2.



Figure 1.9. Placement Operation on IH 20 1 inch Superpave.

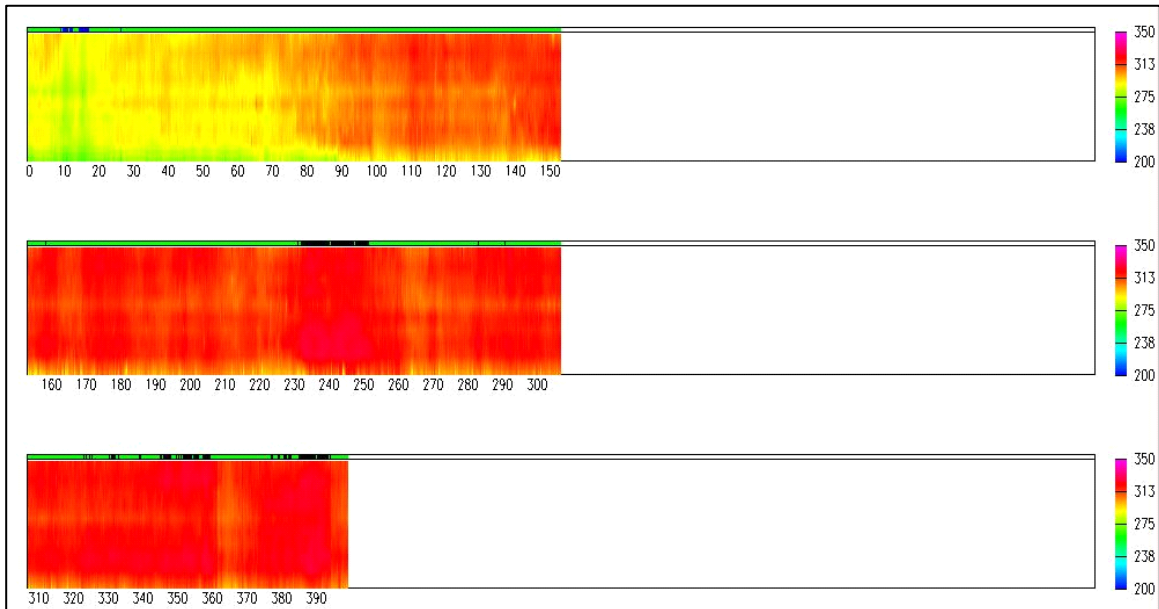


Figure 1.10. Sample Infrared Data from IH 20 1 inch Superpave Project.

GENERATION 2 INFRARED TEMPERATURE BAR

After using the first generation temperature bar on several projects, the research team built a second generation device incorporating design changes deemed necessary. Specifically, the team sought improvements in setup time and device stability. To improve setup time, all the infrared sensors were wired into one connection and a master control box (shown in [Figure 1.11](#)) that includes the required power supply, signal conditioners, and necessary connections to connect to the data acquisition card in the computer. To further improve setup time, the 10 infrared sensors were permanently installed into a three-piece hinged beam, and the sensors were spaced at intervals appropriate for a 12 foot wide mat. To improve stability, the bicycle/unicycle carts were replaced with a tricycle design. [Figure 1.12](#) shows the second generation device on a paving project.



Figure 1.11. Master Control Box for Second Generation Infrared Sensor Bar.



Figure 1.12. Second Generation Infrared Sensor Bar on Paving Project.

Several unique advantages were realized with the second generation infrared bar. The changes in the hardware assembly procedures reduced setup time to approximately 5 minutes, and the tricycle cart designs produced an extremely stable device. On the downside, the components were substantially heavier than their first generation counterparts, and the fixed sensor position in the transverse bar proved to be a detriment to the device. On numerous paving projects, the outer two sensors were not even over the mat being placed. Additionally, the fixed bar length and the tricycle carts resulted in clearance problems on projects with tight space requirements. The research team tested the following projects in TxDOT's Houston District with the second generation infrared sensor bar:

- Permeable friction course (PFC) on US 90 in Brookshire, Texas, in May 2004
- Superpave D on Business 290 near Hempstead, Texas, in August 2004
- Type D on Business 290 near Hempstead, Texas, in August 2004

Figures 1.13 through 1.18 show the placement operation and sample infrared data from each of these projects.



Figure 1.13. Placement Operation on US 90 in Brookshire, Texas.

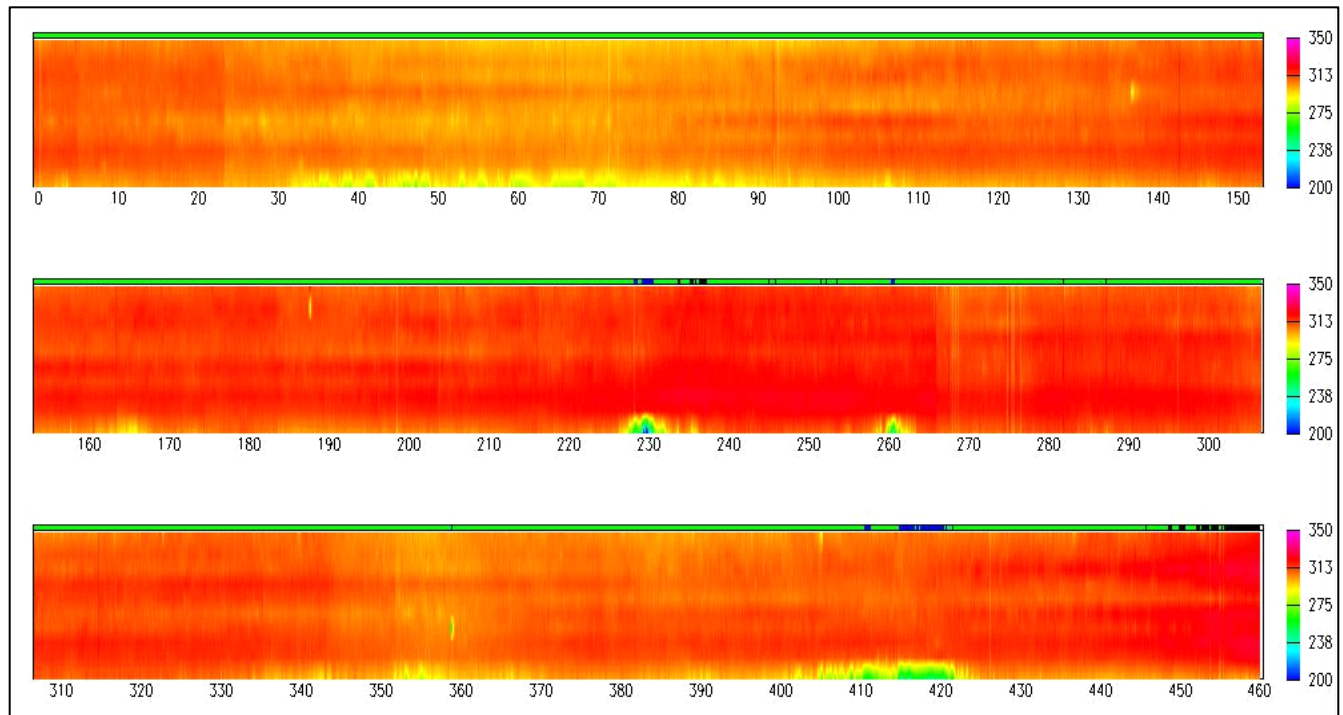


Figure 1.14. Example Infrared Data from US 90 PFC.



Figure 1.15. Placement Operation of Superpave D on Business 290.

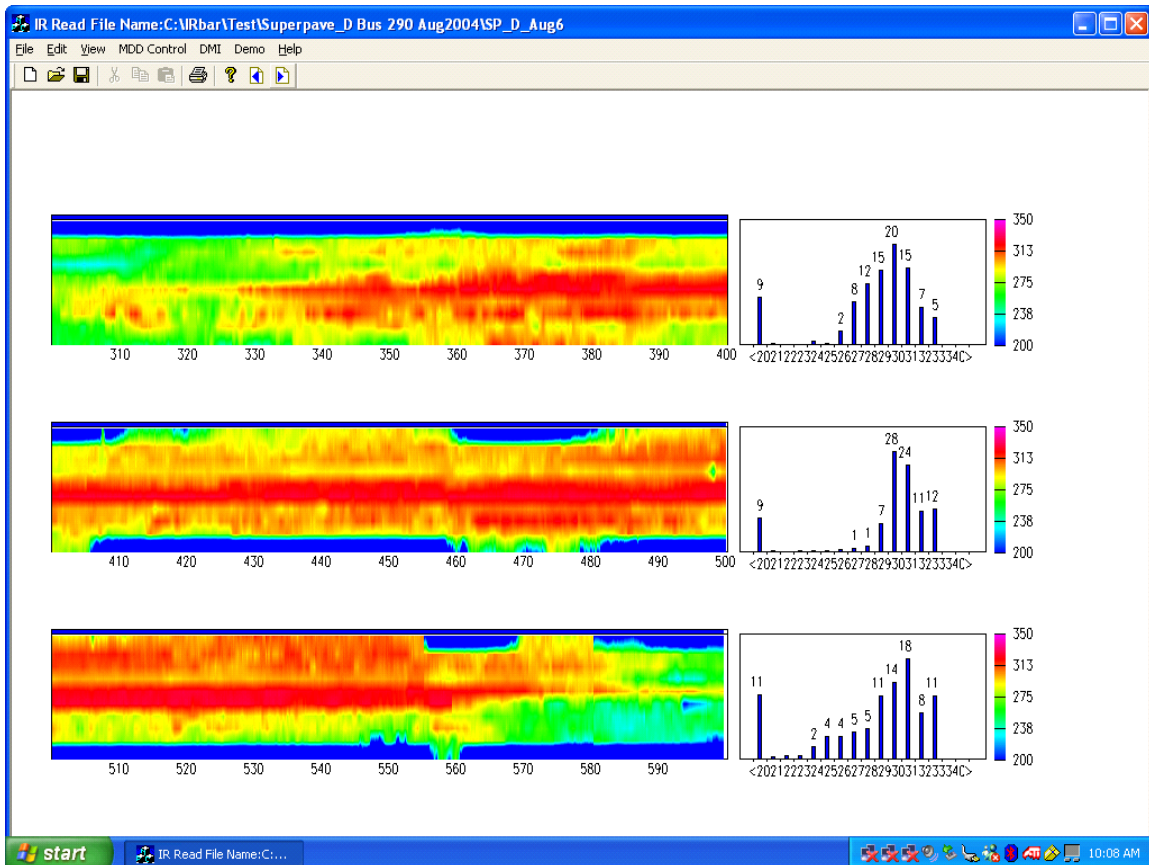


Figure 1.16. Example Infrared Data from Superpave D Project.



Figure 1.17. Placement Operation of Type D Mix on Business 290.

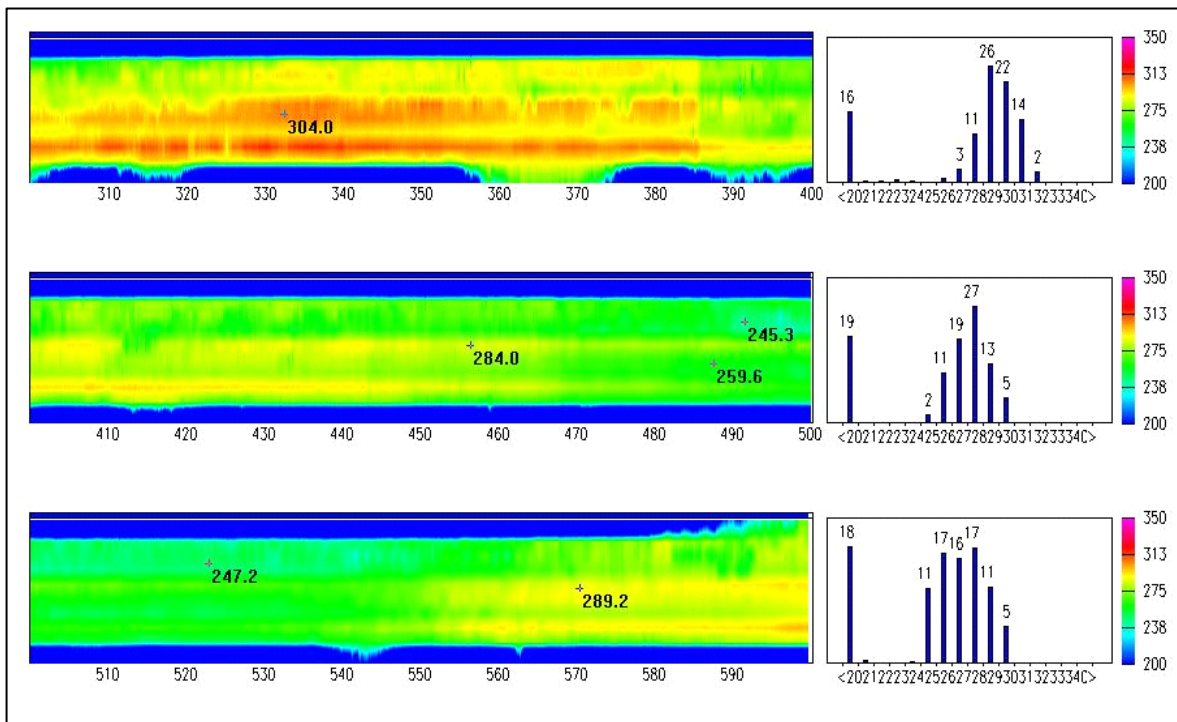


Figure 1.18. Example Infrared Data from Business 290 Type D Paving Project.

Note: Outer two infrared sensors were off the mat.

RECOMMENDED DESIGN OF GENERATION 3 INFRARED TEMPERATURE BAR

Based upon experiences with the first two generation infrared sensor bars, the research team believes the next system should incorporate the best aspects of both previous generations. These features need to be retained:

- Master control box with single connection to all 10 sensors
- Adjustable span length of transverse bar
- Operator-defined transverse offsets for the sensors

Additionally, the research team recommends pursuit of a system that attaches directly to the paver. Such a system would reduce labor requirements, provide better operator safety, and allow the contractor to more easily and rapidly see the uniformity of the mat being placed.

COMPLETING THE PAVE-IR SYSTEM: SOFTWARE DEVELOPMENT

The data generated from the infrared sensor bar is of little use unless project personnel can quickly view and evaluate the data. Thus, appropriate software needed development for use with the bar. TTI's collection and processing software, PAVE-IR, enables the user to:

- View data in real time
- Determine in real time when the temperatures in a scan are outside the limits set by the operator
- View a histogram of measured temperatures every 100 feet, as data are collected
- View the distribution of measured temperatures for the entire data set in post-processing

Figure 1.19 shows the control screen in PAVE-IR. In this screen, the user inputs parameters such as file name, any comments, target temperature with upper and lower temperature limits, and graphing parameters. With these parameters set, the user can proceed to collect data. Figure 1.20 shows an example display of data as displayed in real time. Along with the temperature data, Figure 1.20 shows a small analysis bar at the top of the temperature display. This bar is color-coded according to whether the temperature differentials in a scan are within the operator-defined temperature limits previously set in the control screen. If temperatures exist in the scan below the limit, the bar turns blue. The bar changes to green if temperatures are within the limits. If temperatures exceed the maximum defined value, the bar turns black. This function allows the operator to quickly assess the data during collection. Additionally, Figure 1.20 illustrates the capability of the software to display a histogram of measured temperatures for each 100 feet. After closing a data collection file, a histogram of the entire project can be viewed. Figure 1.21 illustrates a temperature distribution from an entire project in post-processing. Appendix A details procedures for detecting segregation with the PAVE-IR system.

Collect Mode LWT ✖

Data output name:

Comment

No. of Channels Conversion Factor (°C/volt)

Samples rate (in/Point)

Data Length (ft)

Collect Mode
Distance

Channel...1	100
Channel...2	100
Channel...3	100
Channel...4	100
Channel...5	100
Channel...6	100
Channel...7	100
Channel...8	100
Channel...9	100
Channel...10	100

Target

+	<input type="text" value="25.0"/>	<input type="text" value="300.0"/>
	<input type="text" value="Target 275"/>	
-	<input type="text" value="25.0"/>	<input type="text" value="250.0"/>

Y axis Scale

Minimum	<input type="text" value="200"/>
Maximum	<input type="text" value="350"/>

Prompt

Ask file name

Ask comment

Figure 1.19. PAVE-IR Control Screen.

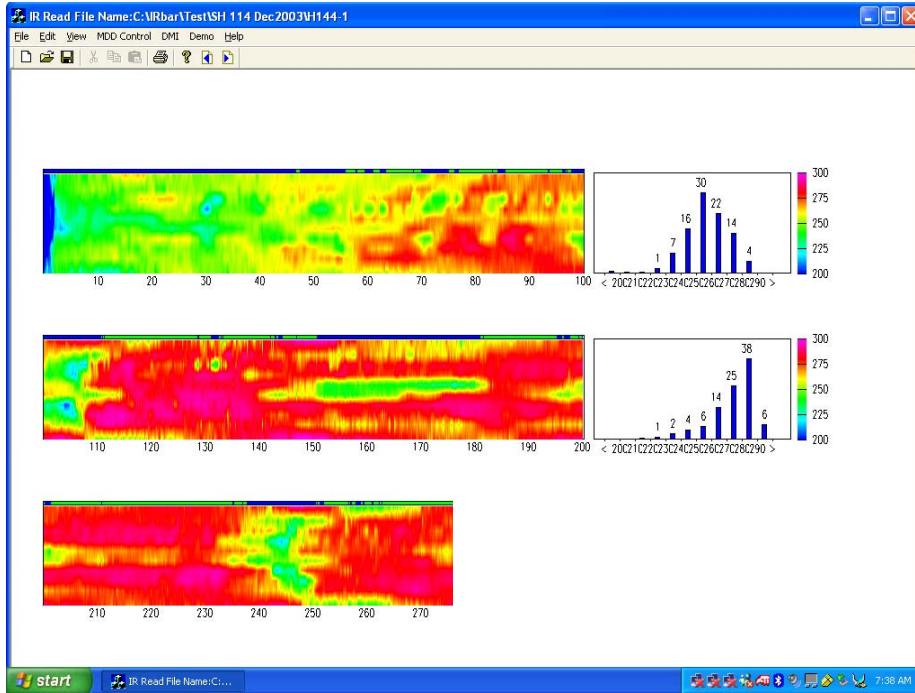


Figure 1.20. Infrared Data Display in Real Time.

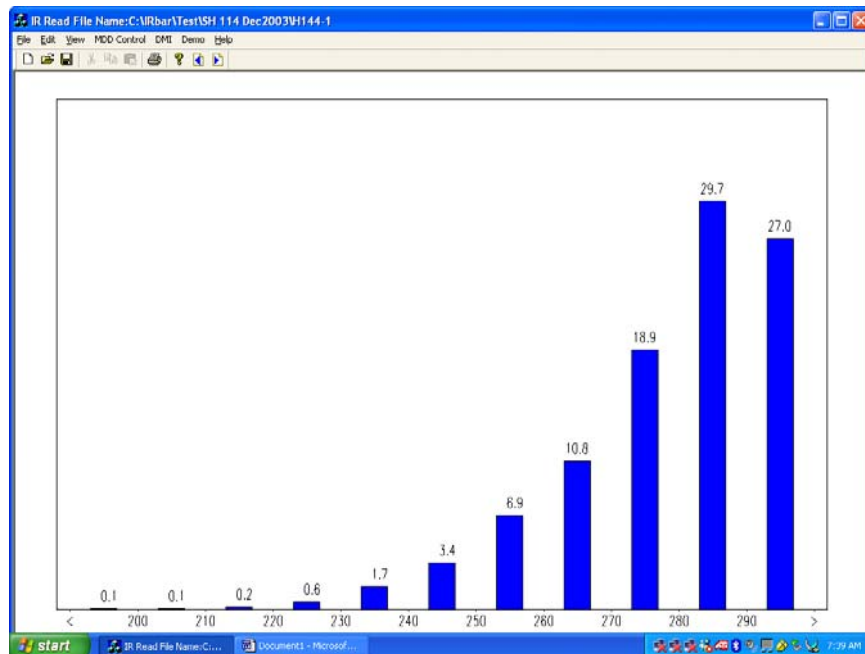


Figure 1.21. Distribution of Temperatures for Entire Paving Project.

CHAPTER 2

REFINEMENT OF GPR FOR DETECTING SEGREGATION

SUMMARY

Project 0-4126 showed the utility of using GPR for detecting segregation, where changes in the surface dielectric correlated to changes in important properties of the HMA. Additionally, that project outlined procedures for making a two-dimensional surface plot of the in-place air voids on an HMA project by performing multiple GPR passes over the project at different transverse offsets. This procedure uses a calibration between the surface dielectric and in-place air voids based upon findings first presented by Saarenketo and Roimela (5). During the previous project, TTI researchers utilized manual-processing techniques with various software packages to produce the color plot. Thus, one priority during this project included efforts to make detecting segregation with GPR more user-friendly and easier for implementation. Similar to the refinement of the infrared system, these efforts focused both on hardware and software. Hardware that could reduce the required number of passes was needed to make field data collection more rapid and software that could simplify data-processing requirements similarly needed development. Thus, TTI developed a three-channel GPR system to collect GPR traces from both wheel paths and the centerline in a single pass. Furthermore, TTI developed a software package, RadSeg, that uses a file generated from Colormap's thickness-computing function to enable the user to quickly examine the GPR data for locating potentially segregated areas. Additionally, the research team collected GPR data on several projects with TTI's existing single-channel GPR system to evaluate if the recommendations on GPR from the previous 0-4126 project were reasonable.

VERIFICATION OF 0-4126 UNIFORMITY RECOMMENDATIONS FOR GPR

One of the original concepts of using GPR for locating segregation involved examining the data in the field to flag potential problem areas. Locations with significantly different surface dielectrics (particularly abnormally low dielectric values) as compared to the rest of the mat could potentially be problematic. Therefore, project 0-4126 studied the relationship between changes in surface dielectrics and changes in HMA properties (such as air voids, asphalt content, and gradation) from several projects. Based upon those results, project 0-4126 recommended flagging areas based upon mix type and mean dielectric value as follows (1):

- Coarse-graded mixes: locations not within ± 0.8 of the mean dielectric value should be flagged
- Dense-graded mixes: locations not within ± 0.4 of the mean dielectric value should be flagged

In this project, the TTI team collected data on several additional HMA paving projects to verify the 0-4126 recommendations. Using procedures developed previously (1), the research team collected GPR data on the projects, selected core locations, collected GPR readings over

the core locations, and then in the laboratory tested the cores for density, air voids, asphalt content, and gradation. The team then examined the data for relationships between changes in surface dielectric constant and changes in important HMA properties. The projects tested included:

- ¾ inch SFA near on IH 20 near Cisco, Texas, in October 2002
- Type C mix on FM 158 in Bryan, Texas, in May 2003
- Type D mix at the MLS test pad in Austin, Texas, in October 2003
- ¾ inch SFA on SH 114 near Rhome, Texas, in December 2003
- 1 inch Superpave on IH 20 in the Odessa District in May 2004
- Type D mix on Business 290 near Hempstead, Texas, in August 2004

On all but one project, the changes in the surface dielectric most related to changes in density. On the SH 114 project, changes in dielectric corresponded most to changes in the individual percent retained on the ½ inch sieve. Figures 2.1 through 2.6 show the most significant observed relationships between the dielectric changes and changes in the mix properties for these paving projects.

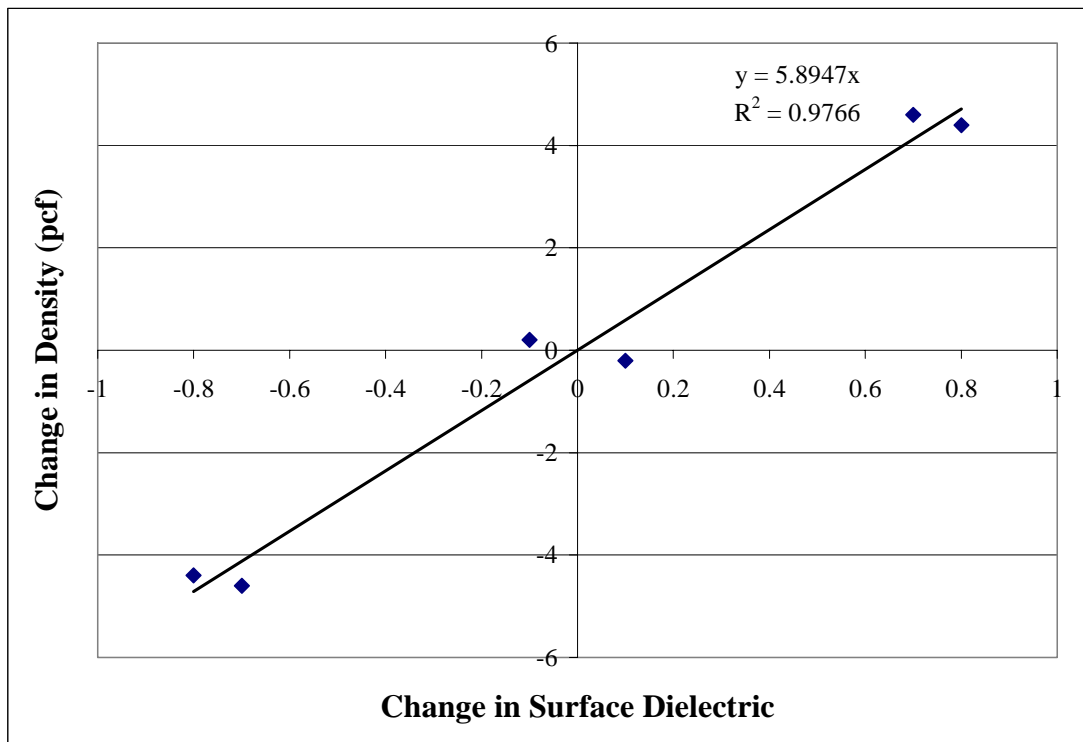


Figure 2.1. Change in Density versus Change in Dielectric for ¾ inch SFA on IH 20.

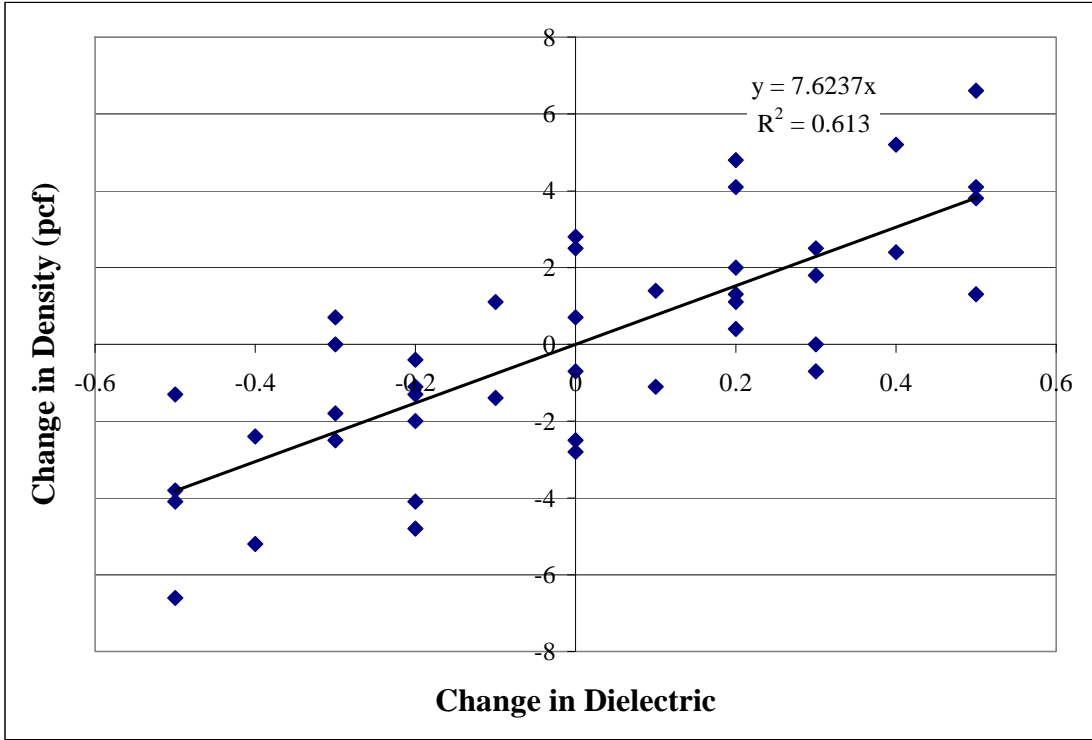


Figure 2.2. Change in Density versus Change in Dielectric for Type C on FM 158.

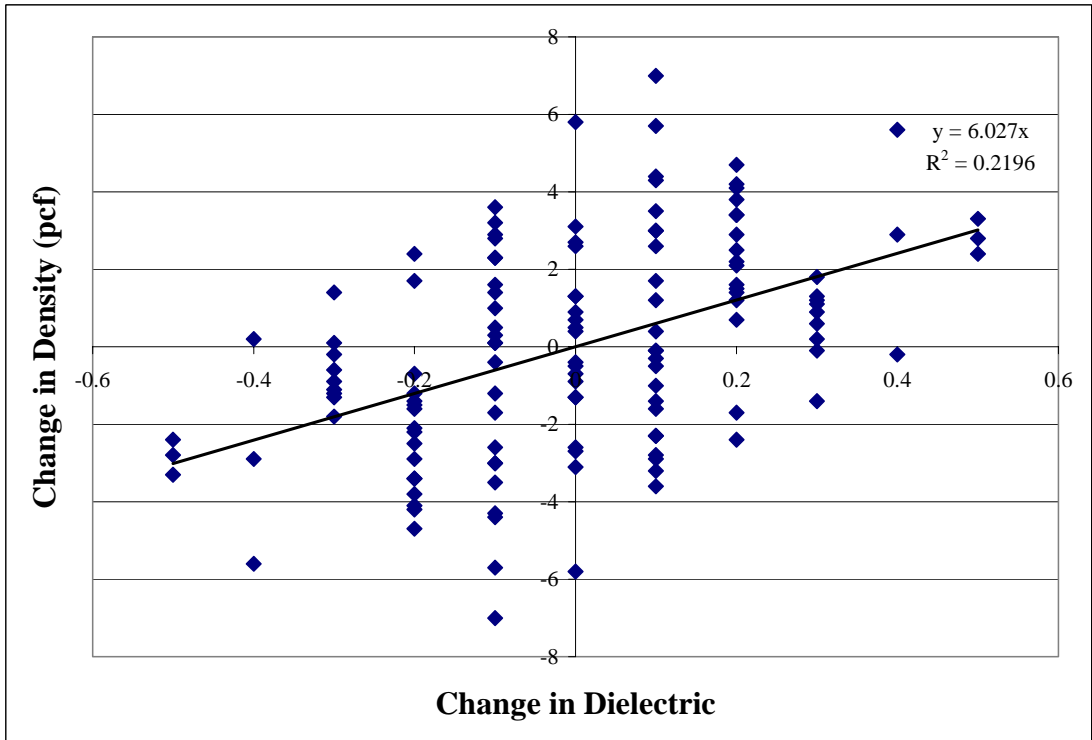


Figure 2.3. Change in Density versus Change in Dielectric from MLS Test Pad.

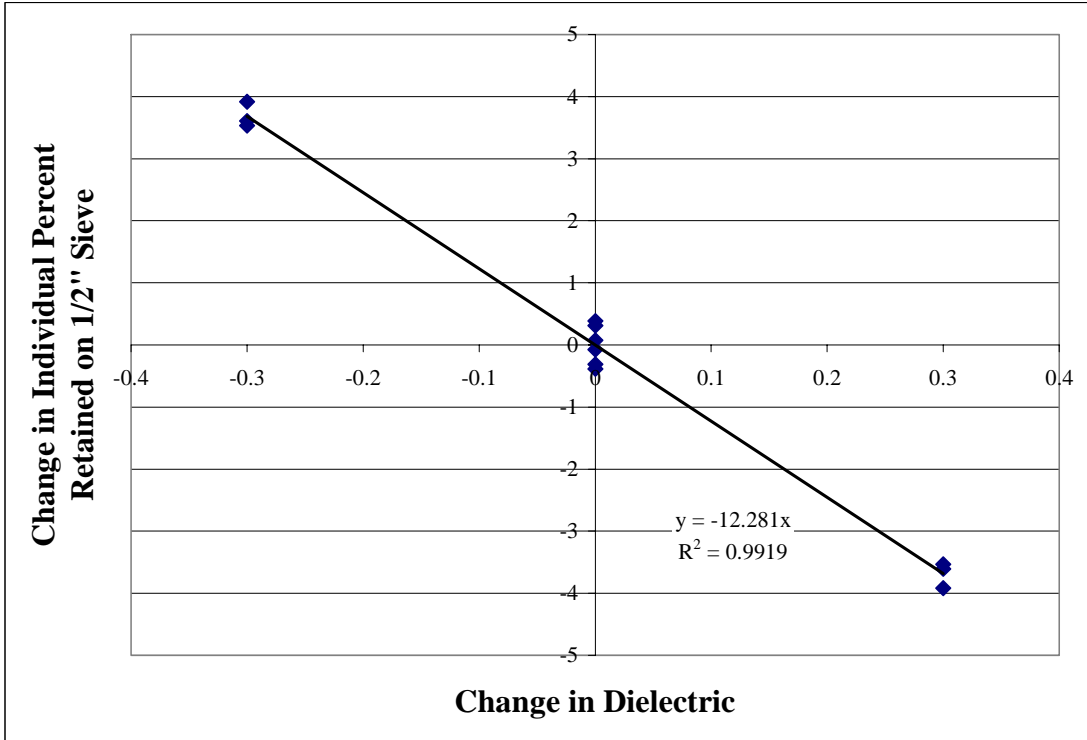


Figure 2.4. Change in Individual Percent Retained on 1/2 inch Sieve versus Change in Dielectric for 3/4 inch SFA on SH 114 Project.

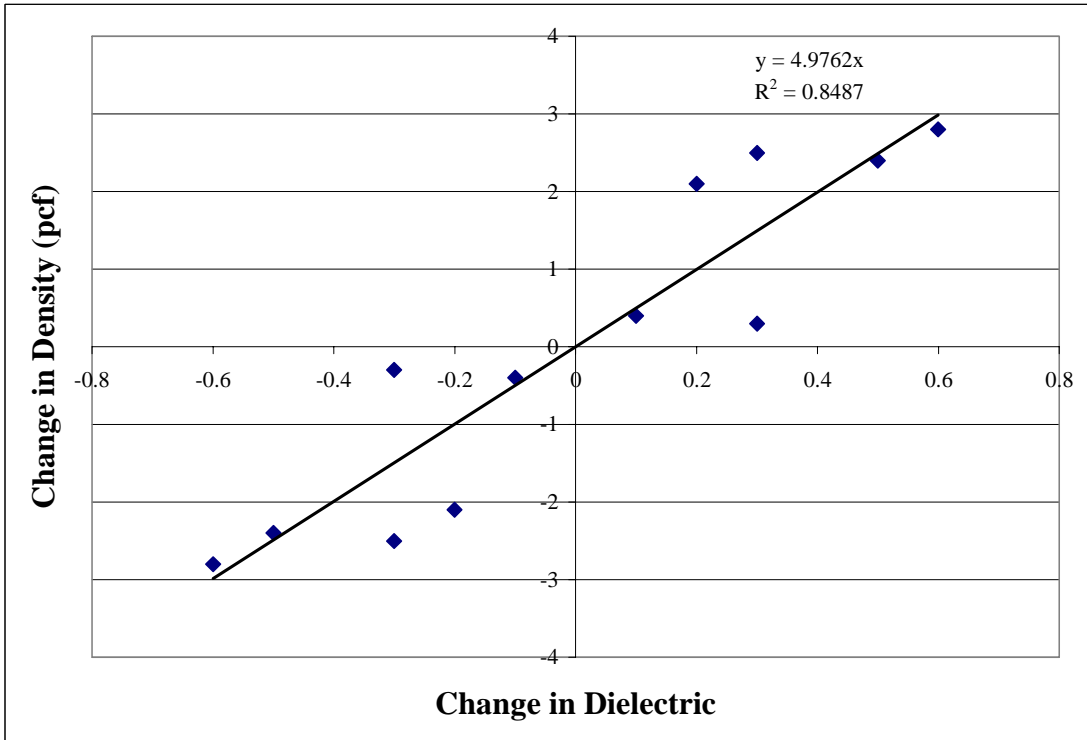


Figure 2.5. Change in Density versus Change in Dielectric for 1 inch Superpave on IH 20.

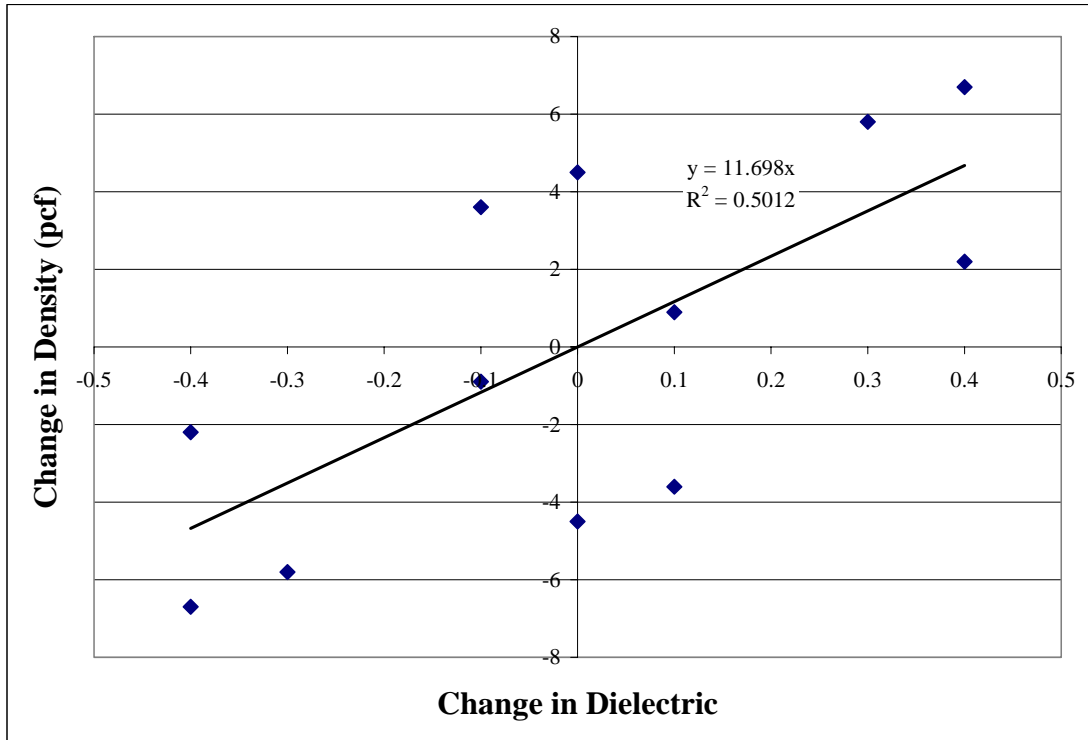


Figure 2.6. Change in Density versus Change in Dielectric for Type D on Business 290.

Based upon these observed relationships and TxDOT specifications, the research team identified the maximum recommended change in surface dielectric for each project. If the dielectric constant changes by more than this recommended limit, the location may be problematic. For example, on the 1 inch Superpave project, [Figure 2.5](#) shows that one would expect a 5 pcf drop in density for every 1 unit drop in the surface dielectric constant. For this mix type, TxDOT density profile specifications require the minimum density to be within 5 pcf of the average. Therefore, since a 1 unit drop in surface dielectric should correspond to a 5 pcf drop in density, the minimum dielectric constant should be within 1 unit of the average dielectric.

Using the same development process as illustrated for the 1 inch Superpave project, the research team determined the recommended limits on changes in surface dielectric for the remaining projects. [Table 2.1](#) presents these limits. For the coarse-graded mixes, the average tolerance before flagging an area as potentially problematic was ± 0.73 from the mean. For dense-graded mixes, this average tolerance was ± 0.42 from the mean. These values closely match with the recommendations from the 0-4126 project. The research team, therefore, does not believe the recommendation should be modified. Therefore,

- On projects using coarse-graded mixes, locations with surface dielectrics that are not within ± 0.8 of the mean dielectric value should be investigated for segregation.
- On projects using dense-graded mixes, locations with surface dielectrics that are not within ± 0.4 of the mean dielectric value should be investigated for segregation.

Table 2.1. Recommended Tolerance on Surface Dielectric from HMA Verification Projects.

Project	Mix Type	Recommended Dielectric Tolerance
IH 20	¾ inch SFA	± 0.8
SH 114	¾ inch SFA	± 0.4
IH 20	1 inch Superpave	± 1.0
FM 158	Type C	± 0.4
MLS	Type D	± 0.6
Business 290	Type D	± 0.25

DEVELOPMENT OF SOFTWARE TO ANALYZE GPR DATA FOR SEGREGATION

One major drawback of the previous work using GPR to investigate segregation and pavement uniformity was the necessity of utilizing multiple software packages and manual data-processing procedures. TTI researchers developed a software package, RadSeg, that enables personnel to use an output file from Colormap and the calibration data between the surface dielectric and density to quickly evaluate the data. RadSeg enables the user to not only view distributions of parameters such as surface dielectrics or predicted surface air voids, but also provides the user with automated functions to mark out section limits of anomalous areas. The primary procedures for using RadSeg to investigate a paving project are:

- Collect GPR data over the project.
- Collect stationary GPR readings over core locations. Collect cores and measure their density in the lab.
- Use Colormap (6) to create a text output file containing layer dielectric values and layer thickness values.
- In RadSeg, open the output file created in Colormap.
- Use the “HMA Constants” function in RadSeg to create a calibration between dielectric and air voids.
- Analyze the data with RadSeg’s graphical, histogram/cumulative distribution, finding problem areas, and segmentation functions.

[Appendix B](#) presents a detailed user’s guide for using RadSeg for analysis of GPR data.

DEVELOPMENT OF THREE-CHANNEL GPR SYSTEM

With reasonable tolerances on surface dielectrics to use for screening a paving project for segregation, and with the ability to convert measurements of surface dielectrics into a color plot of predicted in-place air voids for a paving project, the TTI team turned their attention to developing faster methods to collect and interpret the data. To accomplish these objectives, a three-channel GPR system was developed. This system can collect data over both wheel paths and the centerline in one pass. The 1 GHz systems meet the same specifications as existing TxDOT 1 GHz systems. [Figure 2.7](#) shows the system mounted on a vehicle for data collection. Unfortunately, the research team did not have the opportunity to test this system on a paving project during the course of this research project. However, testing was conducted at the Texas

A&M Riverside Campus to verify proper operation of the system and software. Over one mile of data was collected. [Figure 2.8](#) shows the data collection screen, which in real time displays the trace and Colormap plot from each antenna. [Figure 2.9](#) shows an excerpt of the processed data from the section tested. It was found that the data from the three antennas track well with each other, and the system can collect data on all three channels at 1 foot per trace while traveling at 30 mph. This test rate should satisfy most test situations. Increasing the distance traveled between collected traces would allow data collection at even higher travel speeds.



Figure 2.7. Three-Channel GPR System Mounted on Vehicle.

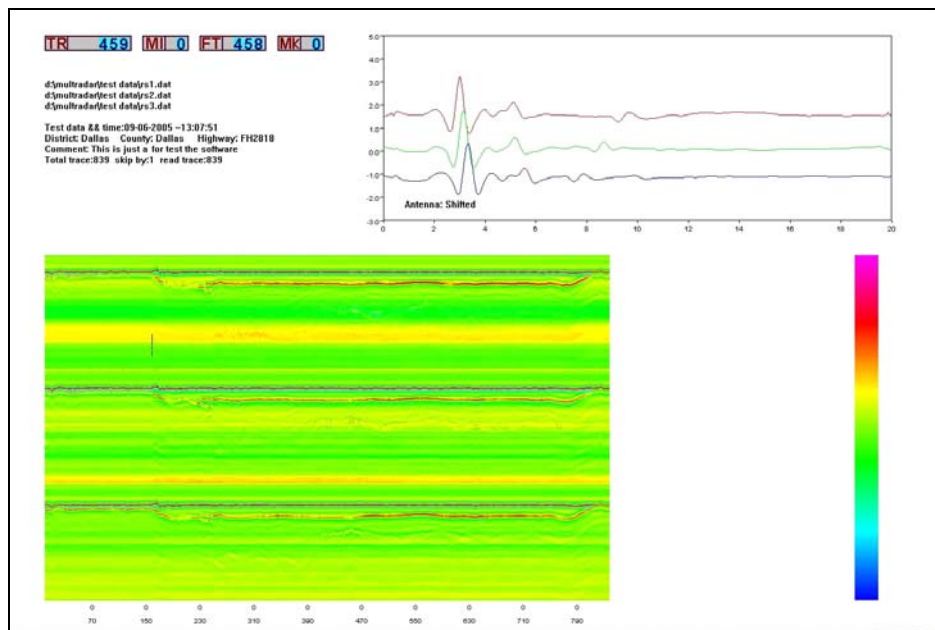


Figure 2.8. Multi-Channel GPR Data Collection Screen.

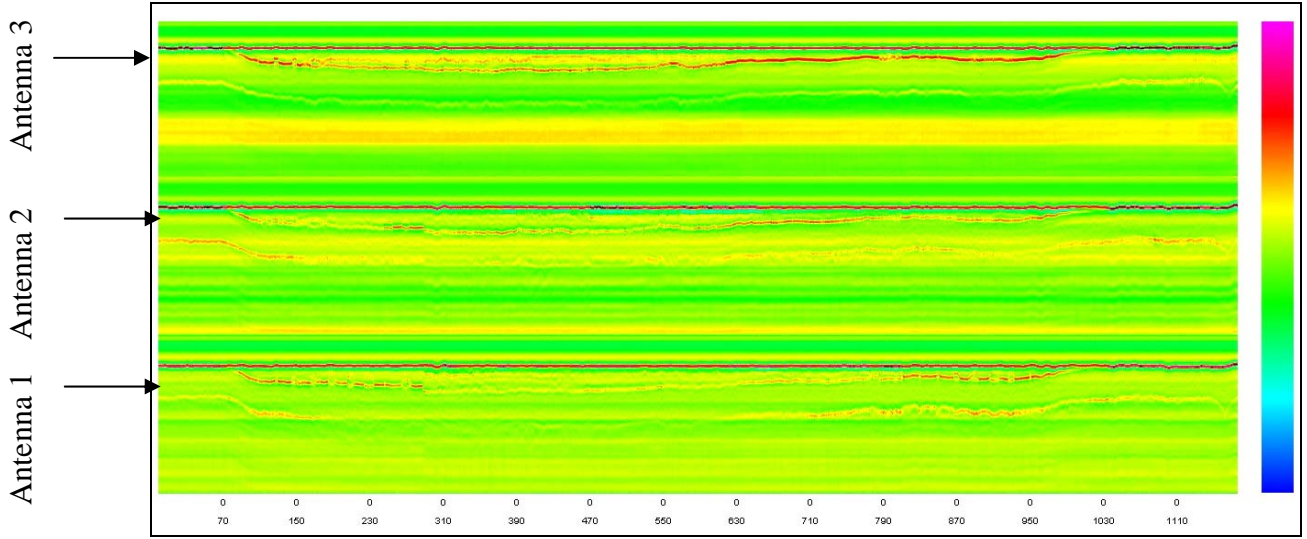


Figure 2.9. Excerpt of Processed Data from GPR Test at Riverside Campus.

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

TTI researchers refined infrared methods for detecting segregation on paving projects by developing an infrared sensor bar and data collection/analysis software. Field trials of this device verified the utility of the new device, and the experiences gained through use of first- and second-generation sensor bars will serve as the basis for refinement of the system for future use. Additionally, GPR data collected on several projects verified the reasonableness of uniformity recommendations made previously in project 0-4126. To provide for rapid collection of GPR data over both wheel paths and the centerline, a three channel GPR system was developed. Additionally, a software package called RadSeg allows for more rapid evaluation of GPR data for detecting segregation. Both the infrared and GPR technologies proved useful for investigation of HMA paving operations. These technologies assist with the evaluation of segregation on a project, project uniformity, and overall project quality. Both technologies can provide near 100 percent coverage of a paving project. Based upon work completed, the guidelines given below should serve to flag potentially segregated areas with thermal imaging and GPR. Additionally, a proposed system to implement thermal imaging for controlling segregation is provided. The ideal system would use an infrared sensor bar mounted directly to the paver. In order to gain a substantially improved picture of the quality of a paving project, TxDOT should consider use of certifying a paving operation through thermal imaging, then verifying the final overall quality through use of GPR.

GUIDELINES FOR DETECTING SEGREGATION WITH INFRARED AND GPR

Based upon previous work by other agencies, previous findings from TxDOT project 0-4126, and validation findings conducted under this project, the following guidelines apply for using thermal imaging and GPR to identify potential segregation:

- With thermal imaging, locations with temperature differentials greater than 25 °F should be inspected for segregation.
- With GPR, recommendations differ according to mix type:
 - Coarse-graded mixes: locations not within ± 0.8 of the mean dielectric value should be inspected for segregation.
 - Dense-graded mixes: locations not within ± 0.4 of the mean dielectric value should be inspected for segregation.

[Appendix A](#) provides a test protocol to detect segregation with infrared imaging. [Appendix B](#) provides instructions for using RadSeg to investigate segregation using GPR data, and [Appendix C](#) presents a test protocol for using GPR to detect segregation.

RECOMMENDATIONS FOR IMPLEMENTATION OF TEMPERATURE FOR CONTROLLING SEGREGATION

Thermal imaging of HMA projects is best accomplished with a sensor bar similar to the type developed in this project. An ideal use of infrared imaging for controlling segregation would be to perform testing in order to certify the paving operation. The following procedures could be used:

- Collect thermal imaging data over at least 1000 feet of paving.
- Review the thermal imaging data, and evaluate which of the following categories best describes the thermal plot:
 - Uniform: little thermal variation, with at least 90 percent of measured temperatures falling into a 25 °F range. Such a project would appear similar to [Figure 1.14](#).
 - Uniform within truckload(s), with occasional instances of varying mean placement temperature. In this scenario, the operation typically results in uniform placement temperature within truckloads, but from time to time the mean placement temperature decreases or increases. These cases typically are the result of a difference in the temperature of the mix leaving the plant. [Figures 1.16 and 1.18](#) illustrate thermal plots representative of this scenario.
 - Truck-end cold spots: somewhat uniform within truckloads, but with significant cold spots between trucks. This case typically results from truck-end segregation. [Figure 1.6](#) shows the thermal plot from a project exhibiting this pattern.
 - Seemingly random temperature variations: these projects typically require the most corrective action because numerous factors likely account for the temperature variations. Factors including poor control of temperature at the plant, truck-end segregation, lack of a remixing material transfer vehicle, and poor control over heaters on the paver can all contribute to this type of thermal plot.

The ideal mode of implementation of infrared imaging for controlling segregation would be to mount the sensor bar directly onto the paver, as illustrated in [Figure 3.1](#). This setup would improve the safety of the operation, ensure a constant distance is maintained between the screed and the sensor bar, and potentially reduce the labor requirement for collecting the thermal plot. With systems mounted on pavers, contractors would likely provide the test equipment and conduct the testing. The contractor then would provide the data to TxDOT for acceptance of the operation. If the thermal plot shows the operation produces mix placed at uniform temperatures, TxDOT would certify the operation. The contractor would then continue work using the same placement process. The contractor could be required to provide an additional thermal plot as directed by the Engineer if at any time the Engineer felt changes made in the placement process necessitate re-verification.



Figure 3.1. Concept Infrared Sensor Bar Mounted to Paver for Implementation.

RECOMMENDATIONS

From prior experiences and work conducted in this project, both thermal imaging and GPR can assist with detecting segregation in hot-mix asphalt overlays, and both technologies can provide data to evaluate the uniformity and overall quality of a paving project.

- Use thermal imaging, with the infrared sensor bar mounted directly to the paver, to certify a placement operation. Such testing should be conducted early in the placement process, such as during the first lot, to provide opportunity for corrective action before substantial amounts of HMA are placed.
- Use GPR for a final quality assurance check on the previously certified placement operation. Conduct the GPR survey after completion of all rolling. The GPR survey provides for a uniformity check of the final product, and this survey allows for more extensive analysis of the distribution of air voids throughout the project. Research report 4126-1 illustrated the methodology for such analysis.

REFERENCES

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4. Willoughby, K., S.A. Read, J.P. Mahoney, S.T. Muench, L.M. Pierce, T.R. Thompson, J.S. Uhlmeier, R. Moore, and K.W. Anderson. *Construction-Related Asphalt Concrete Pavement Temperature Differentials and the Corresponding Density Differentials*. Report WA-RD 476.1. Washington Department of Transportation, July 2001.
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6. Scullion, T., and Y. Chen. Colormap Version 2 User's Guide with Help Menus, Report 1702-4, Texas Transportation Institute, November 1999.

APPENDIX A

**TEST PROTOCOL TO DETECT THERMAL SEGREGATION WITH
THE PAVE-IR SYSTEM**

DETECTING SEGREGATION WITH PAVE-IR

Section 1. Overview

This method uses the Pave-IR thermal imaging system to detect potentially segregated areas on a newly placed, uncompacted, hot-mix asphalt overlay. The thermal profile is acquired with an infrared temperature bar controlled by a laptop computer with appropriate software. This method requires the user possess a working knowledge of the Pave-IR data collection equipment and Pave-IR operating software.

Section 2. Definitions

Thermal segregation is defined as an area with temperature differentials greater than 25 °F.

Section 3. Apparatus

- Infrared temperature bar capable of imaging at least a 12 foot wide mat and including a minimum of 10 sensors, each with a distance:spot ratio of 2:1, a spectral response of 8 to 14 μm , a measurement temperature range that includes -40 to 1112 °F, and capable of operating in ambient temperatures ranging from 32 to 185 °F.
- Laptop computer with Pave-IR operating software.

Section 4. Procedure

Locating Potential Segregation with Pave-IR	
Step	Action
1	At the project site, set up the Pave-IR system and verify system operation according to the unit instructions. Set the outer infrared sensors no closer than 1 foot, and no further than 2 feet, from the outer HMA edge.
2	Document the mix type, contractor, haul distance, target placement temperature, and brief description of placement operation.
3	Collect a thermal survey over a distance of 150 feet, or the distance of two truckloads, whichever is greater. Record the limits of the survey by stationing and/or GPS. Observe the following guidelines for collecting data: <ul style="list-style-type: none">• Set Pave-IR to collect a transverse scan every 2 inches.• The infrared temperature bar should be no more than 8 feet behind the screed.• Document the location of any paver stops for reference.
4	View the collected thermal profile with the Pave-IR software. Display the analysis bar along with the thermal profile according to the following guidelines: <ul style="list-style-type: none">• Set the target mat placement temperature as the target temperature in Pave-IR.• Set the target range in Pave-IR at ± 25 °F from the target temperature.

5	Locate and annotate the areas of hottest temperatures on the thermal profile by pressing <CTRL> concurrently with the left mouse button.
6	Locate and annotate the areas of the coldest temperatures on the thermal profile. Specifically, locate and annotate areas that are 25 °F or more cooler than the hottest measured temperature.
7	Annotate the location of any paver stops on the thermal profile.
8	Create the histogram of temperature distributions within the survey limits using the Pave-IR bar chart function.

Section 5. Reporting

Report the following information from the thermal imaging survey:

- Project description, including mix type, contractor, haul distance, target placement temperature, and brief description of placement operation.
- Station or GPS limits of the survey.
- Thermal plot produced by the survey, including Analysis Bar, annotated locations of the hottest and coldest locations, and annotated locations of any paver stops.
- Histogram of temperatures from the survey.

APPENDIX B

RADSEG USERS MANUAL: A GROUND PENETRATING RADAR ANALYSIS SYSTEM FOR DETECTING SEGREGATION IN NEW ASPHALT OVERLAYS

INTRODUCTION

The RadSeg program has been developed to provide TxDOT engineers with advanced capabilities for analyzing ground penetrating radar data and converting the computed layer dielectrics into important engineering properties. The program inputs text (.TXT) files from the COLORMAP system. The main purpose of RadSeg is to locate areas in new asphalt layers that contain segregation. Research conducted in project 0-4126 ([Sebesta and Scullion, 2002](#)) determined that periodic drops in surface dielectric are associated with low-density areas in the material. For dense-graded mixes, decreases in surface dielectric of greater than 0.4 from the mean are potential low-density problem areas. The program will identify the location of these areas so that engineers can consider corrective action.

This user-friendly RadSeg software inputs the following properties from the COLORMAP TXT file:

- E1 — Layer 1 Dielectric
- E2 — Layer 2 Dielectric
- E3 — Layer 3 Dielectric
- T1 — Layer 1 Thickness
- T2 — Layer 2 Thickness
- T3 — Layer 3 Thickness

The program provides the capability of converting layer dielectrics into engineering properties. This requires the use of calibration cores and laboratory testing to convert surface dielectric into air void content and base dielectric into base moisture content. The methodology used for air void determination was proposed by [Saarenketo and Roimela \(1998\)](#).

RadSeg can present the data as either a histogram or cumulative frequency plot. It can also identify problem areas based on user input criteria. For example, it can find all locations where the surface air voids are greater than 10 percent, or all locations where the surface thickness is less than 3 inches. For long data sets, the program can automatically or manually segment the data, based on significant changes in the mean parameter.

SETUP

System Requirements

The minimum system requirements to run the program are:

- operation systems: Windows 95/98/ME/NT 4.0/2000/XP®,
- CPU: Pentium-133 MHz or higher,
- 16 MB RAM or higher,
- 20 MB free hard drive space,
- SVGA - True Color video mode,
- the recommended screen resolution is 1024×768 pixels,
- the print outs are directed to the default printer, and
- a CD-ROM drive.

Installing the Software

Before installation, make sure that your computer meets the minimum requirements. It is strongly recommended that before proceeding you ensure that no other Windows programs are running.

Run RadSegsetup.exe from the installation CD. As shown in [Figure B-1](#), the setup program then asks a few simple questions relating to the location on the computer where you wish to install the files.

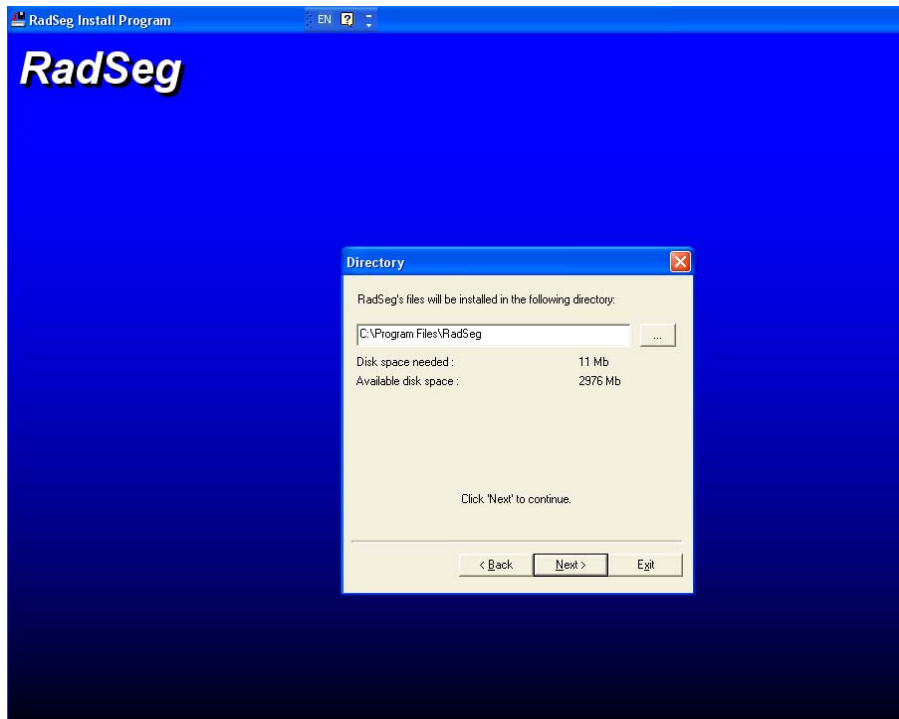


Figure B-1. Setup Screen for RadSeg Installation.

Follow the setup instructions on the screen. The user can change the default installation directory C:\Program Files\RadSeg. Once the setup procedure is complete, the user can run the RadSeg program by using the desktop shortcut or the start button on the task bar in Windows.

The setup program will install several sample data files in your computer along with the RadSeg program.

GETTING STARTED WITH RADSEG

Generate a Data File from COLORMAP

The RadSeg program inputs the text file created using the Thickness Computing function with the COLORMAP system. For details of this operation, refer to the COLORMAP manual ([Scullion and Chen, 1999](#)).

Running the Software

Launch RadSeg software from the desktop shortcut. The main menu screen shown in [Figure B-2](#) will appear.

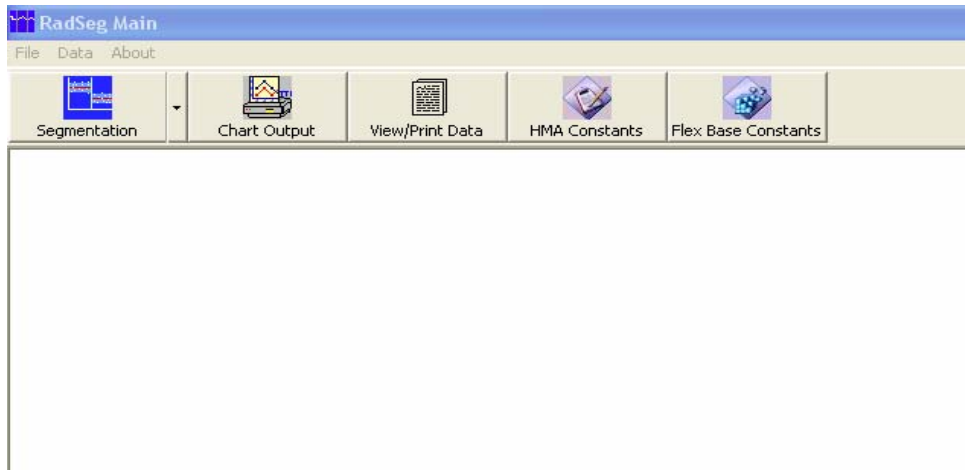


Figure B-2. Main Menu Screen in RadSeg.

Open a Data File

Opening a data file is the first thing you need to do when you run RadSeg. Make sure that you select a correct .TXT file that was previously generated by COLORMAP. NOTE: If you open this text file in an editor and re-save it, the format of the data file may be changed and it will cause a reading data failure in RadSeg.

Click “Open a Data file” under the “File” in the menu as shown in [Figure B-3](#).

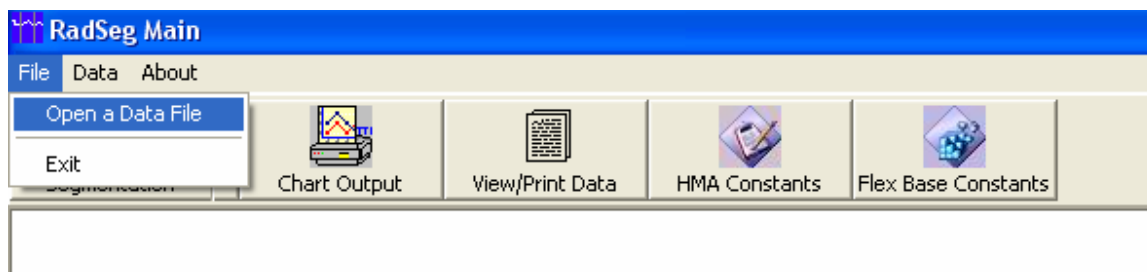


Figure B-3. Opening a Date File in RadSeg.

After you select a data file, the program will check whether the data file format is correct. If correct, the program will read data from the file and display the data as illustrated in [Figure B-4](#); otherwise, the program gives an error message.

Dist. (miles)	Thick1	Thick2	Thick3	E1	E2	E3	BulkD	Air Voids	Base Moist	Cont
0.0119	4.2	3.3	0	6	7.5	10.3	0	0	0	0
0.0121	4.3	3.1	0	5.9	7.6	10.9	0	0	0	0
0.0123	4.4	3.1	0	5.9	7.6	10.7	0	0	0	0
0.0125	4.6	2.9	0	5.8	7.4	9.4	0	0	0	0
0.0127	4.7	2.8	0	6	7.9	10.9	0	0	0	0
0.0129	4.9	2.5	0	5.9	7.6	9.9	0	0	0	0
0.0131	5	2.4	0	6	7.3	9.9	0	0	0	0
0.0133	5.1	2.3	0	5.9	7.3	10	0	0	0	0
0.0134	5.1	2.3	0	6	7.8	10.3	0	0	0	0
0.0136	5.2	2.6	0	5.8	7.4	10.2	0	0	0	0
0.0138	5.2	2.5	0	5.9	7.6	10.5	0	0	0	0
0.014	5.2	2.4	0	5.8	7.2	9.4	0	0	0	0
0.0142	5.1	2.5	0	5.8	7.3	9.6	0	0	0	0
0.0144	5.1	2.5	0	5.8	7.7	10.2	0	0	0	0
0.0146	4.8	3	0	5.8	7.5	10.5	0	0	0	0
0.0148	4.8	2.9	0	5.9	7.4	10	0	0	0	0
0.015	5	2.8	0	5.8	7.3	10.1	0	0	0	0
0.0152	5.2	2.7	0	5.9	7.5	10.4	0	0	0	0
0.0153	5.2	2.6	0	5.9	7.5	10.2	0	0	0	0
0.0155	5.4	2.5	0	5.7	7.5	10.2	0	0	0	0
0.0157	5.3	2.5	0	5.9	7.5	9.8	0	0	0	0
0.0159	5.4	2.3	0	5.8	7.3	9.4	0	0	0	0
0.0161	5.3	2.5	0	5.8	8.1	9.5	0	0	0	0
0.0163	5.4	2.5	0	5.8	10.7	11.5	0	0	0	0
0.0165	5.1	2.7	0	5.8	9.5	10	0	0	0	0
0.0167	4.8	2.8	0	5.9	9.2	9.8	0	0	0	0
0.0169	4.9	3.1	0	5.7	8.5	8.9	0	0	0	0
- - -	- -	- -	-	- -	- -	- -	-	-	-	-

Figure B-4. Raw Input Data from the COLORMAP Text File.

Note at this stage the columns for Bulk Density, Air Voids, and Base Moisture Content are all zero since these data are computed within RadSeg. To do the analysis for these properties, click “HMA Constants” and “Flex Base Constants,” and new screens will pop up to guide you to calculate these values. See the following sections for more detailed information.

How to Calculate Bulk Density and Air Voids

In this section RadSeg will compute regression factors to relate surface dielectric to surface air void content. The surface dielectric value computed from the amplitude of GPR reflection is influenced by the density of the top 2 inches of the HMA surface. To perform this analysis, it is required that 6-inch cores be taken from field locations of known surface dielectric. The surface dielectric is computed from GPR signals captured at known test locations. A core is taken from these locations and returned to the laboratory for bulk density and air void determination. This calculation requires a minimum of two cores, but it is recommended that three cores be used. [Figure B-5](#) shows an example of field dielectrics and laboratory properties. As an alternative, if the maximum specific gravity of the mix is known from the mix design, it is possible to simply measure in-place bulk density at the location where the surface dielectrics are measured. A nuclear density gauge, or similar device, can be used for this purpose. This will

eliminate the need for field coring. Caution should be exercised with this method, as the nuclear gauge is not as reliable a measurement as coring and laboratory analysis.

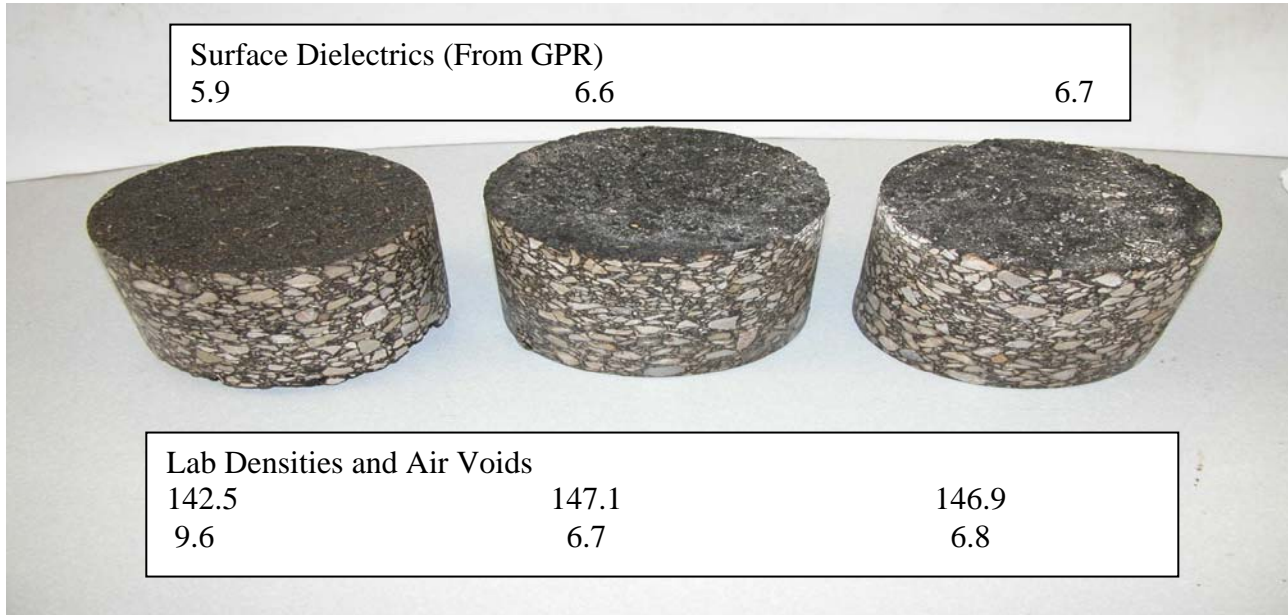


Figure B-5. Calibration Cores for a Typical Job.

To input the core information into RadSeg, as shown in [Figure B-6](#), click either the “HMA Constants” menu button or “HMA Constants” under “Data” in the menu. This opens the input screen shown in [Figure B-7](#) (Determination Constant for Air Voids/Bulk Density).

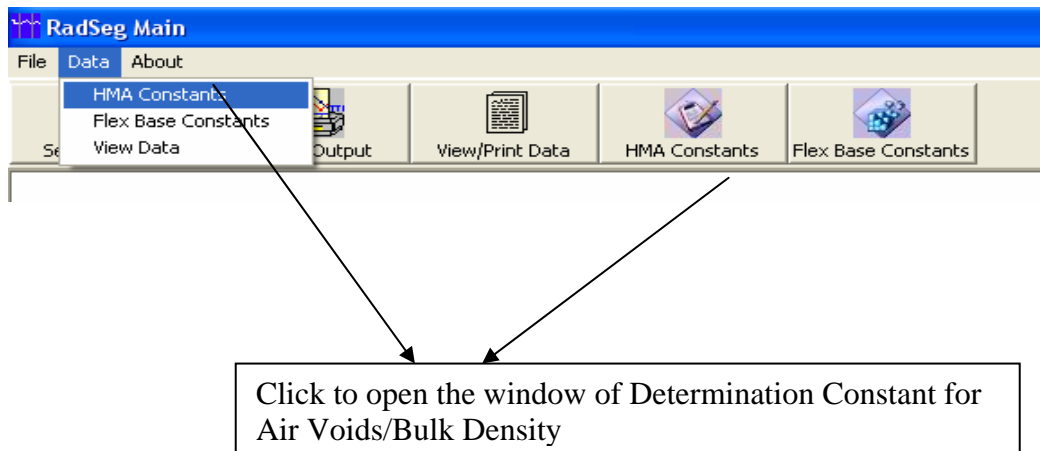


Figure B-6. Activating the Routine to Develop Conversion Factors.

Determination Constant for Air Voids/Bulk Density

$\% \text{Air Voids} = A * \text{Exp}(B * E)$ Default A: 85.713 Default B: -0.3435	$\text{Bulk Density} = C * \text{Exp}(D * E)$ Default C: 107.61 Default D: 0.0373
--	---

Please enter at least two groups of E, %V and/or Bulk Density from field:

<i>E</i>	Bulk Density	Air Voids	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	

Get A, B

<i>A</i>	<i>B</i>
<input type="text"/>	<input type="text"/>

Get C, D

<i>C</i>	<i>D</i>
<input type="text"/>	<input type="text"/>

Calculate Air Voids

Calculate Bulk Density

Close

If want to calculate Air Voids based on Bulk Density you enter, please enter Max. Density.

Max. Density(lbs/cf):

Get Air Void

Figure B-7. Computing Relationship between Field Dielectrics and Lab Densities.

The screen displays the formulas to be used in the program to calculate percent Air Voids and Bulk Density. Default constant values are provided here for your reference. The program allows you to enter 2-10 groups of E, %V, and/or Bulk Density field data and calculate A, B or C, D constants through linear regression.

There are three ways to calculate percent Air Voids:

1. Directly enter valid constant A and B; then click the “Calculate Air Voids” button.
2. Enter 2-10 groups of E2 and %V and click the “Get A, B” button. A and B are calculated and shown in the text boxes. Then click the “Calculate Air Voids” button.
3. Enter 2-10 groups of E2 and Bulk Density. Enter the Maximum Density (Rice density); then click the “Get Air Void” button. The corresponding number of %V will be displayed. “Air Voids=100*(1-Bulk Density/Max Density)” is the formula used in the calculation.

There are two ways to calculate Bulk Density:

1. Directly enter valid constant C and D; then click the “Calculate Bulk Density” button.
2. Enter 2-10 groups of E and Bulk Density; then click the “Get C, D” button. C and D are calculated and shown in the text boxes. Then click the “Calculate Bulk Density” button.

After completion, close the window. The data displayed in the main screen will be refreshed. Calculated values for the Air Void and/or Bulk Density will be displayed.

How to Calculate Base Moisture Content

Click the “Flex Base Constants” menu button or “Flex Base Constants” under “Data” in the menu. Open the window Determination of Base Moisture Content, as illustrated in [Figure B-8](#).

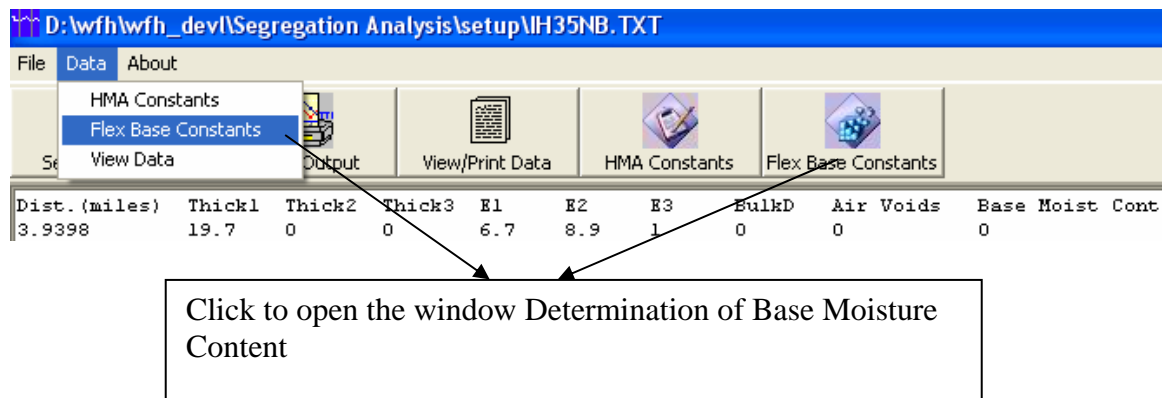


Figure B-8. Activating Routine to Calculate Parameters for Moisture Content Determination.

There are two methods for developing the inputs required for Figure B-9. First, use the GPR unit to calculate the base dielectric (ϵ_2) at static locations in the field. Then obtain a base sample from this location. The sample can be taken by either dry auguring or careful drilling with a diamond core bit. Care must be exercised to ensure that little or none of the drilling water enters the base. Samples of the bases are returned to the laboratory for moisture content determination. It is recommended to sample at least three locations for any base material. A second method for determining the inputs is to develop both dielectric and moisture content in the laboratory. This testing could be performed during the standard optimum moisture content sequence, where the surface dielectric is measured with a surface dielectric probe.

Determination of Base Moisture Content

% Moisture = $E * \exp(F * e_2)$

Default E: 3.370

Default F: 0.0558

Please enter at least two groups of E2, % Moist from field:

<i>E2</i>	<i>% Moist</i>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>

Get E, F

<input type="text"/>	<input type="text"/>
----------------------	----------------------

Calculate Base Moisture

Close

Figure B-9. Generating Regression Parameters for Flexible Base Materials.

As with the Air Void/Bulk Density screen, the formulas used to calculate Base Moisture are displayed, and the default value for the regression parameters E and F constants are provided for your reference. You must enter at least two groups of E2 dielectric values and their corresponding base moisture field data to acquire the constants E and F.

There are two ways to calculate Base Moisture Content:

1. Directly enter valid E and F constants; then click the “Calculate Base Moisture” button.
2. Enter 2-10 groups of E2 and Base Moisture; then click the “Get E, F” button. E and F are calculated and shown in the text boxes. Then click the “Calculate Base Moisture” button.

After completing this operation, close the Base Moisture window. The Base Moisture Content data should be shown on the main screen.

DATA ANALYSIS WITH RADSEG

RadSeg offers many advanced functions for COLORMAP users. These advanced features are described in the various sections below:

- ❑ Graphically Displaying Data
- ❑ Histogram/ Cumulative Distribution Plot
- ❑ Histogram/Cumulative Distribution Comparison
- ❑ Finding Problem Areas and Grouping Data
- ❑ Automatic/Manual Segmentation

Graphically Displaying Data

After the data are ready, you can start the analysis by selecting a test field from the Segmentation button (down arrow) in the tool bar. [Figure B-10](#) shows this button’s menu and a data set where all the columns contain data.

	Thick1	Thick2	Thick3	E1	E2	E3	BulkD	Air Voids	Base M	
E1	0	27.4	6.4	7	7	135.6	9.6	5		
E2	0	27.4	6.4	7.1	7.1	135.6	9.6	5		
E3	0	27.3	6.5	7.1	7.1	136.1	9.3	5		
Bulk Density	0	27.5	6.7	7	7	137.1	8.7	5		
Air Voids	0	27.6	6.5	7	7	136.1	9.3	5		
Base Moist Cont	0	27.3	6.6	7.2	7.2	136.6	9	5		
Thickness 1	0	27	6.7	7.3	7.3	137.1	8.7	5.1		
Thickness 2	0	27.1	6.6	7.4	7.4	136.6	9	5.1		
Thickness 3	0	26.7	6.6	7.8	7.8	136.6	9	5.2		
	0	26.9	6.5	7.7	7.7	136.1	9.3	5.2		
1.3006	5.8	0	27.3	6.4	7.5	7.5	135.6	9.6	5.1	
1.3009	5.9	0	27.2	6.4	7.5	7.5	135.6	9.6	5.1	
1.3015	5.6	0	27.7	6.4	7.4	7.4	135.6	9.6	5.1	
1.3017	5.5	0	27.7	6.4	7.5	7.5	135.6	9.6	5.1	
1.3021	5.8	0	27.3	6.3	7.5	7.5	135.1	10	5.1	
1.3027	5.9	0	27.3	6.3	7.4	7.4	135.1	10	5.1	
1.3028	6	0	27.1	6.4	7.5	7.5	135.6	9.6	5.1	

Figure B-10. Selecting the Variable to be Analyzed.

Before the analysis, the program will check the data of the field selected. The data checking includes the following two aspects:

- Due to problems in the COLORMAP analysis, particularly when the start and end locations are defined, some of the computed fields at the start of the TXT file may contain zero values. If more than 10 starting locations have zero data values, this field's data are not accepted by the program for further analysis. The program will report the information to users. At this stage, the user should re-run the COLORMAP analysis. If less than 10 starting locations' data are zero, the program will discard these data, and the analysis will start from the location that has non-zero data.
- The program also checks whether each data item exceeds the pre-defined maximum allowable value. If at any location the computed data item is greater than the maximum allowable, the program will ask users if they want to discard these location data or replace these location data with the maximum possible. The following is the list of maximum allowable values used in the program.

E1—10, E2—30, E3—30, Layer 1 Thickness —20, Layer 2 Thickness —30, Layer 3 Thickness —30, Bulk Density — 160 lb/cf, Air Voids — 30%, Moisture content —20%

If the selected data are within the normal ranges, the program will run the “Segmentation” program to graphically display the stored data and open the segmentation analysis window. The default number of segments is 1, so that the first time through the program the graph displays data for the entire file. The user can either run the statistical analysis on the complete data set or run the segmentation routine to break the data file. The manual and automatic segmentation routines will be described later.

Graphical Display

Figure B-11 shows the segmentation window.

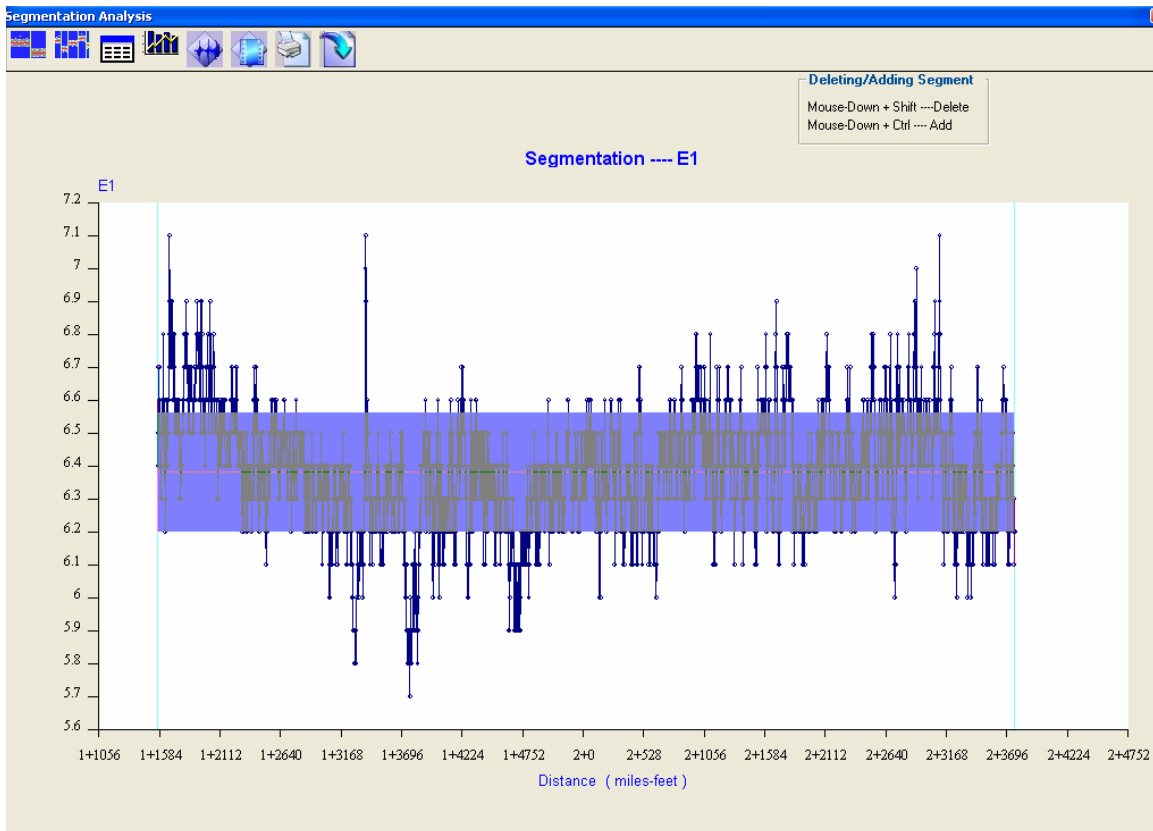


Figure B-11. Graphical Display of Surface Dielectric.

Figure B-11 shows the plot of surface dielectric (ϵ_1) for the complete data set. The red line at the center of the graph is the mean value, and the blue band shows the computed standard deviation for the data set.

As shown below, the user can now use the other menus in the segmentation menu bar to develop several statistical summaries of the data.

Histogram/Cumulative Distribution Plot

The user can view the histogram and cumulative distribution plot for the entire file or each segment within the file by clicking the button “Histogram/Distribution,” as shown in Figure B-12.

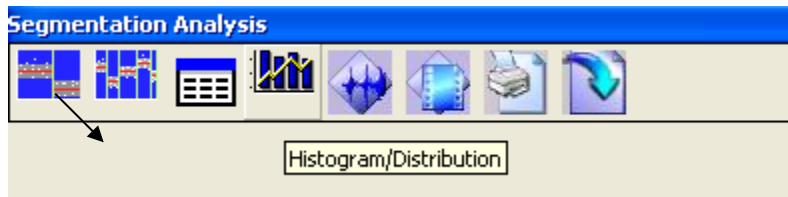


Figure B-12. Segmentation Menu Bar.

The purpose of a histogram is to graphically summarize the distribution of the selected data field. The histogram in the program shows both the actual frequencies at each interval and the percentage of the data at each interval. The user can select an interval value from the drop-down list. However, there currently is only one interval (0.2) that can be selected. If the data have been segmented using the routine described later, the user can choose the segment from the box, as shown in Figure B-13. After selecting a segment, the histogram of the selected segment will be displayed. If the data file has not been segmented, the analysis will be performed for all the data. The default is the histogram of the first segment.

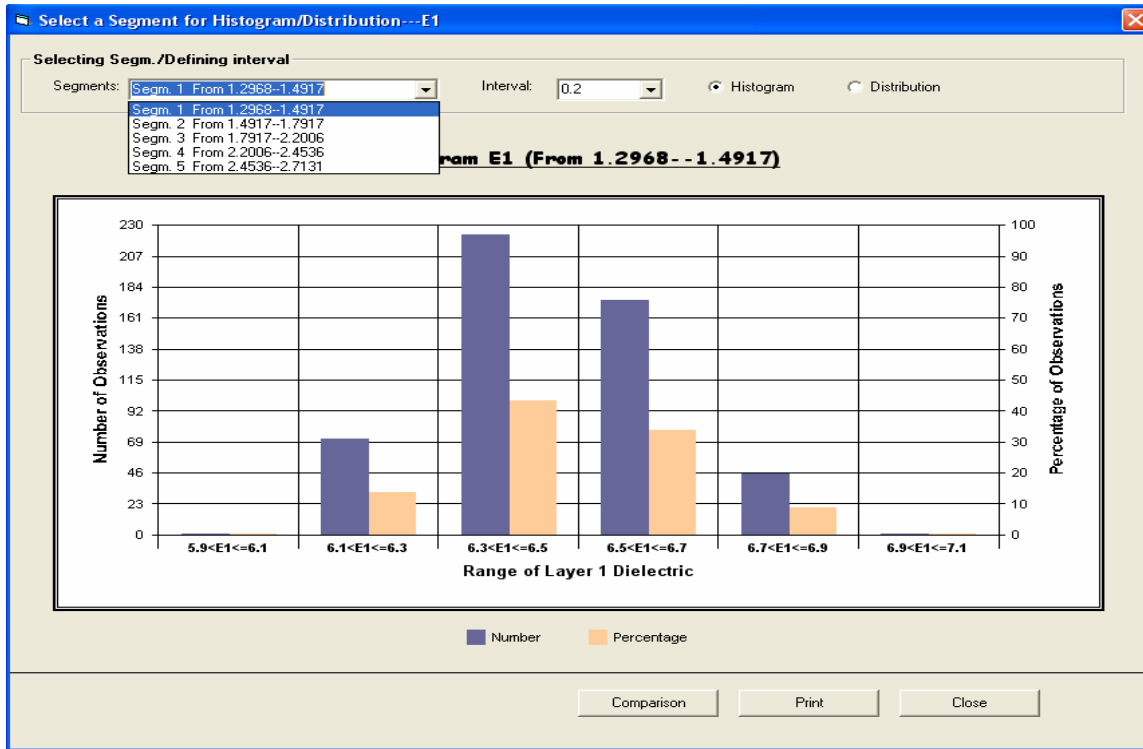


Figure B-13. Histogram of Selected Variable (Surface Dielectric).

A cumulative frequency distribution plot displays the percentage of the number of observations falling in or below an interval. The user can view the distribution plot by clicking the button “Distribution.” [Figure B-14](#) shows an example distribution plot. The user can print the plot by clicking the “Print” button on the screen.

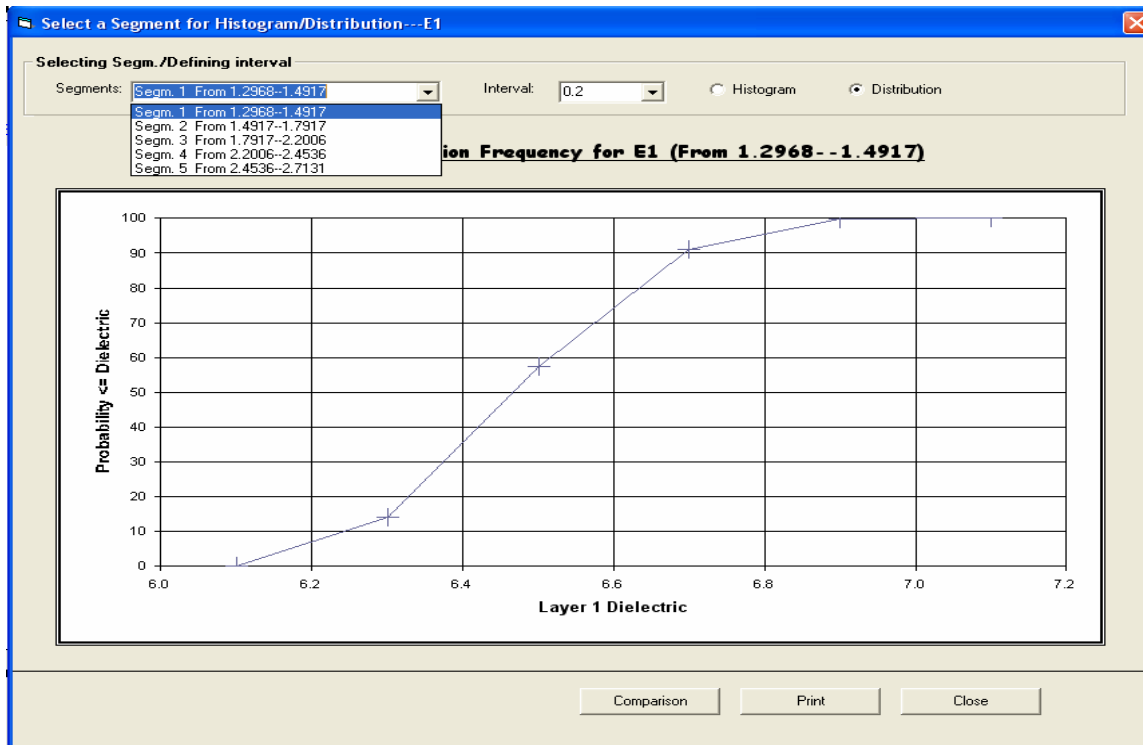


Figure B-14. Cumulative Frequency Plot of Selected Variable.

Histogram Comparison/Distribution Comparison

Another feature of RadSeg is that it provides the histogram/distribution plot which compares the surface dielectric data from the current file with that obtained previously on sections that were ranked as good and bad in terms of surface segregation. The good and bad distribution data are based on the Layer 1 dielectric. [Table B-1](#) shows the good/bad distribution data used in these plots. The user can view the histogram/distribution comparison plot by clicking the “Comparison” button on the histogram screen/distribution plot screen. [Figures B-15](#) and [B-16](#) show example comparison plots.

Table B-1. Surface Dielectric Distributions for Both Good and Bad Projects.

Histogram										
Interval	-1.0	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8
Good	0	0	0	1	13	56	28	2	0	0
Bad	1	2	3	5	15	34	30	8	2	0
Distribution										
Good	0	0	0%	1%	14%	70%	98%	100%	100%	100%
Bad	1%	3%	6%	11%	26%	60%	90%	98%	100%	100%

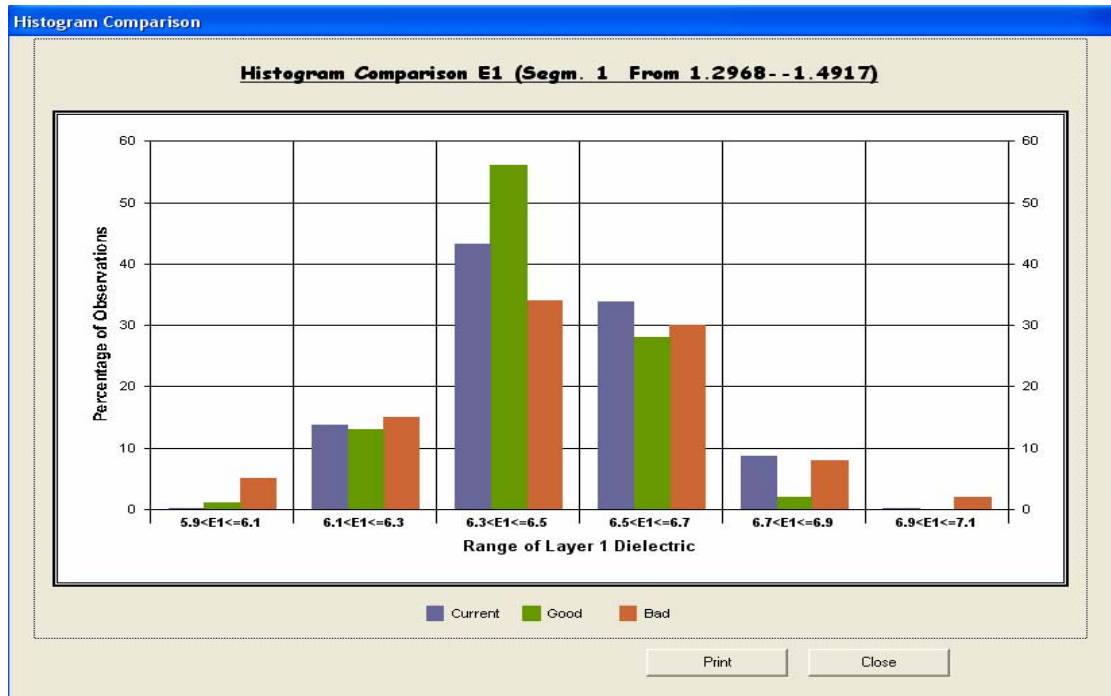


Figure B-15. Comparing Project Histogram with Those from Good/Bad Projects.

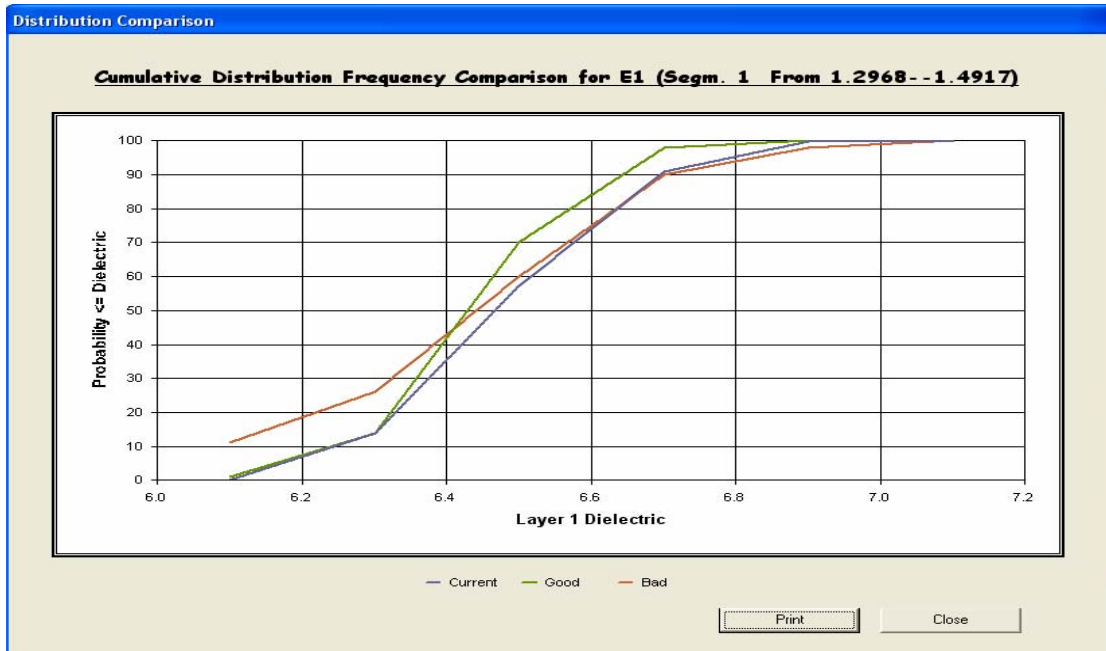


Figure B-16. Comparing Project Cumulative Distributions with Those from Good/Bad Projects.

Finding Problem Areas and Grouping Data

Finding Problem Areas

The user is able to locate problem areas in the project by clicking the “Find Problem Area” button on the tool bar, illustrated in [Figure B-17](#).

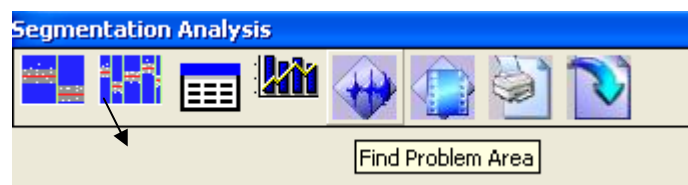


Figure B-17. Options in the Segmentation Menu Bar.

The program identifies a problem area based on the computed mean value of the test parameter and the user-defined maximum allowable change in variable. The range of maximum allowable change is from +5 to -5; the interval is 0.2. If the maximum allowable change is negative, the problem area will be those values below the mean value minus allowable change;

otherwise, those values above the mean value plus allowable change will be identified as the problem area. This function can be applied to any of the selected data fields. RadSeg displays problem areas in both graphical and tabular form. The table below the graph provides very detailed location information of each problem area. The information includes the problem area's start location, stop location, number of spots, and maximum or minimum value. If the data file has been segmented, the user can view the problem area of any specified segment by choosing a segment from the segment drop-down list. Figure B-18 illustrates the feature of finding problem areas.

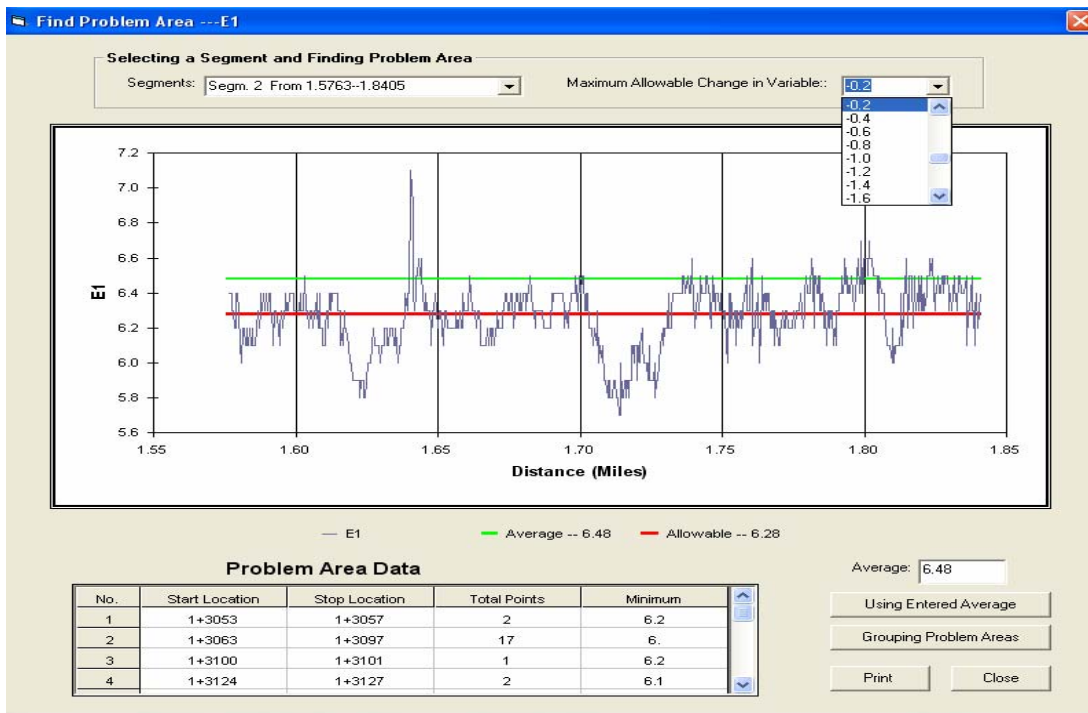


Figure B-18. Locating Potential Problems, Locations with Dielectric Values below a User Defined Limit.

The user can also overwrite the computed mean value to re-define the problem area. To do this, change the value in the text box of average value, and then click the button "Using Entered Average." The user can print the problem area data table by clicking the "Print" button.

Grouping Problem Areas

RadSeg allows the user to group some problem areas that are close together by clicking the button “Grouping Problem Areas” in the screen shown in [Figure B-18](#). The problem area data table is displayed in a new screen. By holding down the left mouse button, the user can select any number of continuous problem areas in the table and then right click the mouse. There will be a popup menu shown on the table. Click “Group” in the menu to group the selected problem areas. [Figure B-19](#) shows the problem area grouping screen. After finishing grouping, the user can print out the new problem area data table by clicking “Print.”

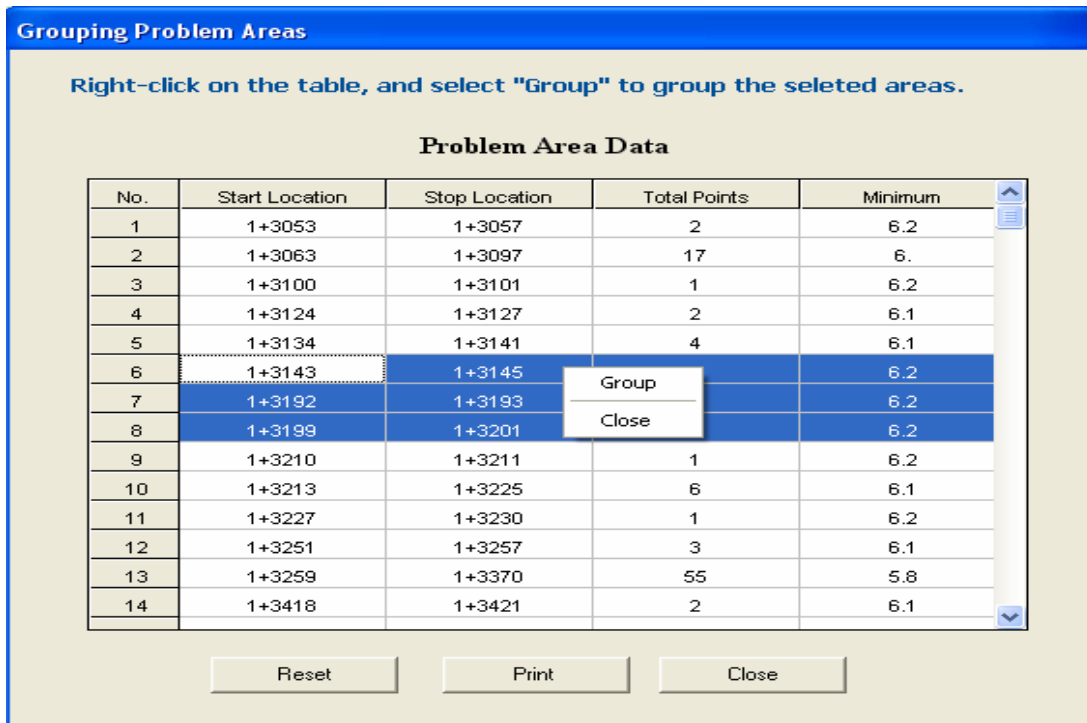


Figure B-19. Grouping Problem Areas.

SEGMENTATION ROUTINES

With long GPR data sets, it may be necessary to break the data sets into several different segments. These could be different days' production or different jobs. RadSeg provides two options for subdividing long data sets.

Segmenting Automatically

The user can do segmentation automatically by clicking the button shown below in [Figure B-20](#).

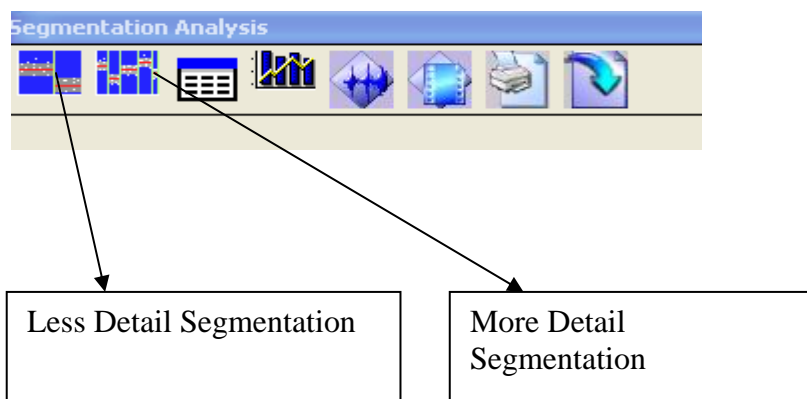


Figure B-20. Activating the Automatic Segmentation Routine.

Segmenting Manually

It is also easy to do segmentation manually. Using the mouse, point to the location where you want to add the segmentation line. Press CTRL and click the mouse at the same time. If you want to change the location of the segmentation line, point on the line with the mouse, and then drag the line. [Figure B-21](#) shows the details.

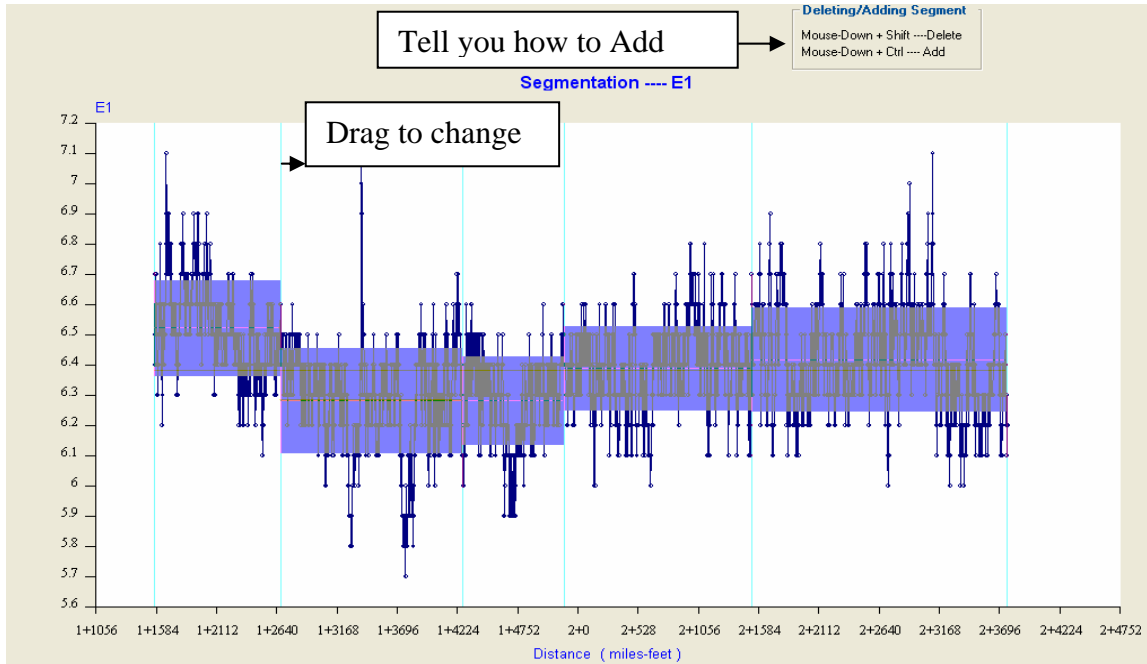


Figure B-21. Activating the Manual Segmentation Routine.

Viewing Segmentation Data

The segmentation data table provides the user with detailed information about each segment. Figure B-22 shows which button in the tool bar you should click and what the table looks like. From the table, the user can see the start location (miles + feet) and stop location (miles + feet) for each segment.

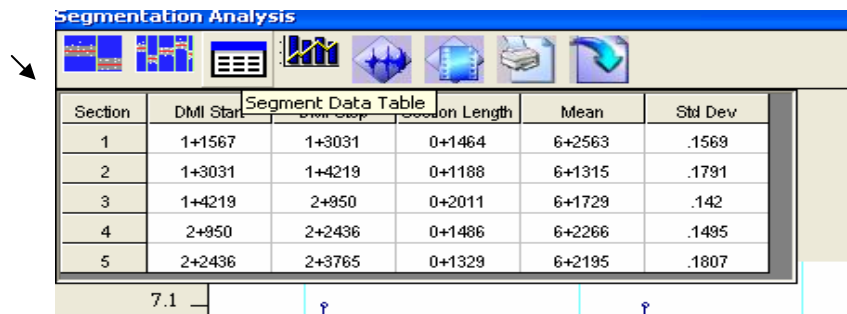


Figure B-22. Viewing the Limits of the Selected Segments.

Save and Print Segmentation Data

The user can save the segmentation table data into a file by clicking the “Save to a File” button on the tool bar, and print the segmentation plot and table data by clicking the “Print” button. [Figure B-23](#) shows these tool bar buttons.

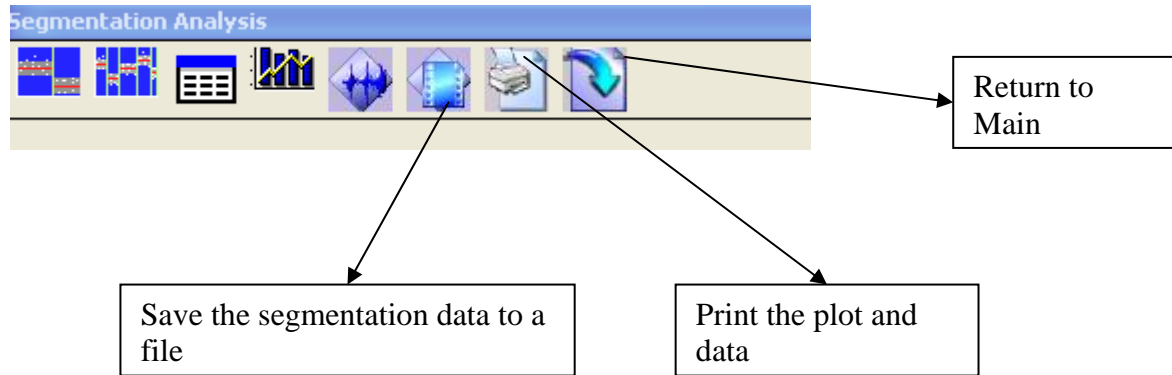


Figure B-23. Other Options in the Segmentation Tool Bar.

OTHER GENERAL FEATURES

“Chart Output” and “View/Print Data” are two additional features in RadSeg. These features provide convenient tools for users to view the test data. [Figure B-24](#) shows how to use these features.

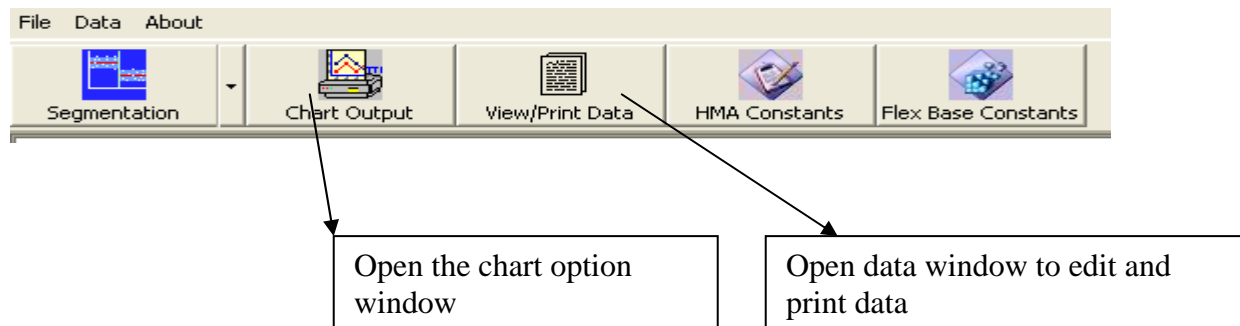


Figure B-24. Additional Options in the Main Menu Tool Bar.

Chart Output

The chart option window allows users to select the charts they want to plot. These charts are based on the raw data. After selecting the chart type, click the “View and Print” button.

Figure B-25 shows the chart option screen. Figure B-26 shows an example chart. The user can click the “Print” button on the window to print the chart.

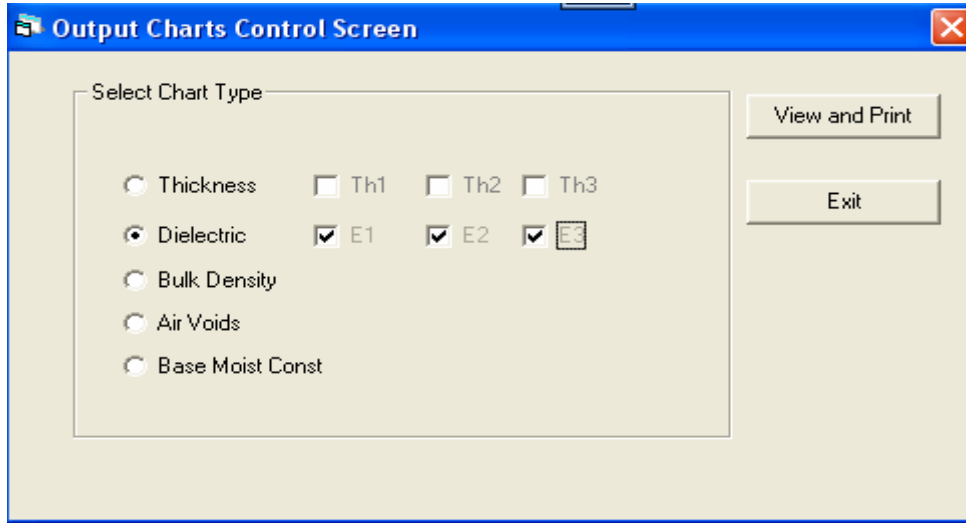


Figure B-25. Selecting Parameters to be Graphed.

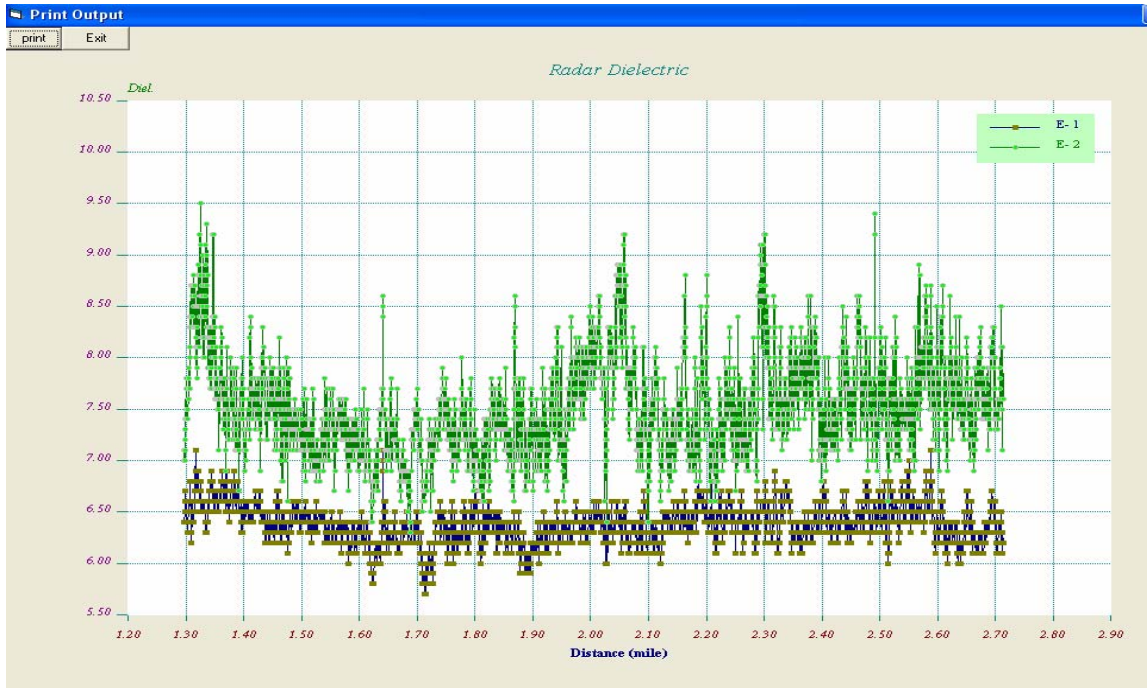


Figure B-26. Graph of Selected Variables.

View and Print Data

Data are displayed in the main window for viewing after you open a data file. However, if you want to print the data, edit the data, and save the current data as a new file, you need go to the data viewing window, as illustrated in [Figure B-27](#).

Dist. (miles)	Thick1	Thick2	Thick3	E1	E2	E3	BulkD	Air	Voids	Base	Moist	Cont
1.2968	5.5	0	27.4	6.4	7	7	135.8	9.5	5			
1.2972	5.7	0	27.4	6.4	7.1	7.1	135.8	9.5	5			
1.2977	5.4	0	27.3	6.5	7.1	7.1	136.4	9.2	5			
1.2979	4.9	0	27.5	6.7	7	7	137.4	8.6	5			
1.2983	5.5	0	27.6	6.5	7	7	136.4	9.2	5			
1.2989	5.8	0	27.3	6.6	7.2	7.2	136.9	8.9	5			
1.2991	6.2	0	27	6.7	7.3	7.3	137.4	8.6	5.1			
1.2994	6	0	27.1	6.6	7.4	7.4	136.9	8.9	5.1			
1.3	5.8	0	26.7	6.6	7.8	7.8	136.9	8.9	5.2			
1.3004	5.9	0	26.9	6.5	7.7	7.7	136.4	9.2	5.2			
1.3006	5.8	0	27.3	6.4	7.5	7.5	135.8	9.5	5.1			
1.3009	5.9	0	27.2	6.4	7.5	7.5	135.8	9.5	5.1			
1.3015	5.6	0	27.7	6.4	7.4	7.4	135.8	9.5	5.1			
1.3017	5.5	0	27.7	6.4	7.5	7.5	135.8	9.5	5.1			
1.3021	5.8	0	27.3	6.3	7.5	7.5	135.3	9.8	5.1			
1.3027	5.9	0	27.3	6.3	7.4	7.4	135.3	9.8	5.1			
1.3028	6	0	27.1	6.4	7.5	7.5	135.8	9.5	5.1			
1.3032	5.8	0	27.1	6.4	7.5	7.5	135.8	9.5	5.1			
1.3038	5.7	0	26.9	6.5	7.6	7.6	136.4	9.2	5.1			
1.304	5.8	0	26.8	6.5	7.6	7.6	136.4	9.2	5.1			
1.3044	5.9	0	26.5	6.5	7.7	7.7	136.4	9.2	5.2			
1.3049	5.8	0	26.5	6.5	7.8	7.8	136.4	9.2	5.2			
1.3051	5.7	0	26.5	6.6	7.8	7.8	136.9	8.9	5.2			
1.3055	5.6	0	26.5	6.5	7.9	7.9	136.4	9.2	5.2			
1.3061	5.7	0	26.6	6.6	7.7	7.7	136.9	8.9	5.2			
1.3062	5.6	0	26.1	6.8	8	8	137.9	8.3	5.3			
1.3066	5.4	0	26.5	6.6	7.7	7.7	136.9	8.9	5.2			
1.3072	5.3	0	26.3	6.6	8.1	8.1	136.9	8.9	5.3			
1.3074	5.2	0	25.8	6.6	8.3	8.3	136.9	8.9	5.4			
1.3078	5.1	0	25.6	6.6	8.4	8.4	136.9	8.9	5.4			
1.3081	5	0	25.3	6.6	8.7	8.7	136.9	8.9	5.5			
1.3087	4.8	0	25.1	6.5	8.7	8.7	136.4	9.2	5.5			
1.3089	4.8	0	25	6.5	8.7	8.7	136.4	9.2	5.5			
1.3093	4.9	0	25.6	6.2	8.3	8.3	134.8	10.2	5.4			
1.3098	5	0	25.7	6.3	8.4	8.4	135.3	9.8	5.4			
1.31	5	0	25	6.4	8.7	8.7	135.8	9.5	5.5			
1.3104	5	0	25	6.5	8.7	8.7	136.4	9.2	5.5			

Figure B-27. Printing the Variables in the Data File.

REFERENCES

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Sebesta, S., and T. Scullion. "Using Infrared Imaging and Ground Penetrating Radar to Detect Segregation in HMA Surfacing," Texas Transportation Institute, Report 4126-1, College Station, Texas, May 2002.

Scullion, T., and Y. Chen. "COLORMAP Version 2, User's Manual with Help Menus," Texas Transportation Institute, Report 1702-5, September 1999.

APPENDIX C

TEST PROTOCOL TO DETECT SEGREGATION WITH GPR

IDENTIFYING SEGREGATION WITH GROUND-PENETRATING RADAR

Section 1. Overview

This method details procedures for using ground-penetrating radar for detection of potentially segregated areas on a newly placed hot-mix asphalt overlay. This method requires the user to possess a working knowledge of the GPR data collection equipment, radar data collection software, Colormap processing software, and RadSeg software. This method uses variations in the surface dielectric constant to examine the project for segregation. Additionally, optional steps in this procedure allow for analysis of the in-place air void content of the overlay through use of a project-specific calibration between the surface dielectric constant and the air void content.

Section 2. Apparatus

- Air-launched GPR system operating at 1 GHz, capable of collecting signals both in distance and time modes, and capable of collecting a signal at least every foot.
- Field coring equipment
- Colormap GPR data processing software
- RadSeg GPR analysis program

Section 3. Procedure

Locating Potential Segregation with GPR	
Step	Action
1	At the project site, set up the GPR data collection equipment and allow the antenna to warm up.
2	After placement and final rolling of the overlay at the project site, determine and document the limits where GPR data will be collected.
3	After placement and final rolling of the overlay, collect GPR data in a longitudinal pass covering the desired section limits. Collect this pass over the outside wheel path. NOTE: Data should be collected in distance mode with one trace recorded every foot. NOTE: If a more complete analysis of the project is desired, collect additional passes over the centerline and the inside wheel path with the GPR system.
4	After collecting the desired longitudinal GPR passes, collect the metal plate file.
4a (OPTIONAL)	In the field, use Colormap to examine the collected data and locate areas of high, low, and normal surface dielectric. Return to each of these locations and collect a stationary GPR reading over each location. Collect these data by positioning the antenna directly over the desired location, setting the GPR vehicle in Park, and using the time data collection mode in Radar. Document

	<p>each location with a unique label for future reference. Before moving to the next location, paint a circle approximately 12 inches in diameter directly underneath the antenna.</p> <p>NOTE: This step is necessary if an analysis of the in-place air voids over the section is desired</p>
4b (REQUIRED IF 4a PERFORMED)	At each of the previously marked locations from 4a, determine the bulk density, percent compaction, and percent air voids of the hot-mix asphalt through an approved method. Currently, cores should be taken from within each marked circle, returned to the lab, and tested with the appropriate part from Test Method Tex-207-F.
5	Using Colormap's Thickness Computing function, create a text output file from each GPR pass that contains, as a minimum, the surface dielectric (E1) value.
6	<p>For a basic analysis, open the text file with Excel and determine the mean surface dielectric value of the tested section. Graph the surface dielectric value with distance. From this graph, determine if any areas of the project need investigation according to the following criteria:</p> <ul style="list-style-type: none"> • Coarse-graded mixes: locations not within ± 0.8 of the mean dielectric value should be inspected for segregation. • Dense-graded mixes: locations not within ± 0.4 of the mean dielectric value should be inspected for segregation.
7	For a more advanced analysis, use RadSeg to investigate the project for problem areas, discernable project segments and, if stationary GPR traces and accompanying cores were collected, in-place air void content.
8	Based upon the results of the analysis, determine what, if any, corrective action should be taken.

Section 5. Reporting

Report the following information from the GPR survey:

- Project description, including mix type, contractor, and brief description of placement operation.
- Limits of the GPR survey.
- Graph of surface dielectric with distance.
- Mean, minimum, and maximum observed surface dielectric.
- Limits of potentially segregated areas.
- Results from core analysis and analysis of in-place air voids, if conducted.
- Recommended corrective action.