



TRC0102

# **Use of Ground Penetrating Radar in a Pavement Management System**

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Final Report

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## **TRC-0102 USE OF GROUND PENETRATING RADAR IN A PAVEMENT MANAGEMENT SYSTEM**

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## **ABSTRACT**

The Arkansas State Highway and Transportation Department (AHTD) contracted with Infrasense, Inc. of Arlington, Massachusetts to provide pavement layer thickness data utilizing Ground Penetrating Radar (GPR) technology. The focus of the research was to determine if GPR could provide relatively fast and reliable thickness data on a network level survey for use in a Pavement Management System (PMS) without the benefit of calibration cores. Secondary data was also provided to determine if GPR could be used to locate voids in certain pavement structures, excessive moisture levels in the base and subgrade, and to determine if GPR could provide accurate characteristic information on bridge decks. Analysis of the secondary data was outside of the scope of this report and findings will not be discussed.

Data collection took place on May 8 - 9, 2001 utilizing personnel and equipment from Infrasense, Inc. and Wave Tech, Inc. of Baton Rouge, Louisiana. The project was composed of eight test sites in central Arkansas with varying cross-sections and surface type. The sites varied in length with a total project length of about fifty miles.

The main goal of determining pavement thickness for a PMS is to allow analysis of homogenous pavement sections. The results of the data analysis indicate that on asphalt pavements GPR can provide reliable thickness data for use at the network level. Concrete pavements did not provide the same results. Known differences in pavement thickness were evident but GPR measured thickness did not compare well to measures of core samples taken from the pavements. However, based on previous research studies by other agencies this was not unexpected.

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## **1.0 Introduction**

To maintain a comprehensive Pavement Management System (PMS), a highway agency must collect, process, maintain, and analyze vast amounts of pavement performance and attribute data. Because of the size of the typical highway agency's pavement network, the current trend of government to reduce agency staffing, and the costs in time and money to the agency and its' users, the ability to collect accurate data efficiently is of paramount importance.

Pavement attribute data is required to allow a functioning PMS to properly analyze or compare the performance of various pavements. One of the most basic and important of these attributes is the thickness of the layers comprising the existing pavement structure.(5) The thickness of a pavement is an important factor in determining its service life. In fact, research in the area of pavement performance models has shown that a half-inch deficiency in a pavement with a design thickness of 3.6 inches can result in a 40 % decrease in service life.(3) Despite its importance, the inability to obtain reliable system wide thickness data in an affordable manner is one reason it is lacking in many systems. The most commonly used method of determining the layer structure of a pavement is coring.(8) This requires cutting a core from the pavement and inspecting it to determine the thickness and composition of the individual pavement layers. Ground Penetrating Radar (GPR) technology provides a non-destructive way to evaluate the existing pavement structure at normal highway speed.(4)

A PMS utilizes pavement layer data as one criterion to establish and compare homogenous pavement sections. An ideal PMS would include pavement layer data for its entire pavement network. However, accurate data is not always available. Roadway

construction plans provide typical sections of pavement systems but these do not always reflect the as-built pavement cross section.(1) Pavement coring is not an economical option for determining pavement layer thickness on a network level. Coring is time and labor intensive and also requires traffic control and lane closures, which are not typically practical on many high volume roadways. Most highway agencies cannot justify the costs in money, manpower, and equipment needed to provide adequate sampling for the provision of network level layer thickness data.(8)

GPR has several benefits over other existing means of obtaining thickness data. GPR can provide almost continuous, non-destructive thickness data for a pavement structure at or near normal highway speeds.(9) It limits interruptions to the traffic flow by eliminating lane closures; this is a cost benefit to users due to less traffic delay and to highway agencies in maintenance of lane closures.(6) This also provides an increase in safety to highway workers by minimizing their exposure to traffic and protects the motoring public from the safety risks of lane closures.(15) The need for a fast, accurate, and non-destructive sampling device is required. The goal of this research is to determine the ability of GPR to fulfill these requirements on a network level.

## **2.0 Purpose and Scope**

The main focus of this study was to evaluate the use of GPR for collecting accurate network level pavement layer or thickness data to be used in the AHTD's PMS. Specifically, the study is to determine the ability of a GPR system to provide accurate, non-destructive network level pavement layer or thickness data on various pavement cross-sections in a timely manner without the aid of calibration cores.

A 1.0 GHz dual horn antenna GPR system manufactured by Geophysical Survey Systems, Inc. (GSSI) of North Salem, New Hampshire was used to collect the data on approximately fifty miles of pavements in the central Arkansas area. Eight pavement sections of varying lengths and cross-sections were chosen for the analysis of pavement layer thickness.

### **3.0 Background**

GPR technology has been in use for several years in the highway and transportation industry. There are two main types of antennas in use for transportation related GPR investigations, ground-coupled and air-coupled. The penetration depth and resolution required determine the antenna type used for a particular application. Antennas that operate at lower frequencies can penetrate to greater depths at a lower resolution and higher frequency antennas penetrate to shallower depths with higher resolutions.

Ground-coupled antennas operate at the pavement surface. Since the antenna is in contact with the pavement surface the data collection speed is limited, but the antenna's effective penetration depth can be much greater. In fact, depending on the antenna's frequency and ground material, penetration depths up to 200 feet are possible. This makes the ground-coupled antenna ideal for locating deeper underground structures, larger buried objects, and subsurface anomalies.

Air-launched antennas typically operate above the pavement surface, typically at a height close to 10 inches. Since the antenna is not in contact with the pavement surface, data collection can take place at typical highway speeds. Depending on

frequency, optimal penetration depths of about two feet are obtainable with high resolution, making it ideal for determining thickness of pavement layers.(12)

The principles behind GPR technology rely on the dielectric discontinuities of different materials. GPR operates by sending short pulses of electromagnetic energy from an antenna to the pavement structure and measuring the time it takes for the reflected energy to return to the antenna. Primarily, the density and moisture content of each layer determine how much energy is reflected.(14)

The dielectric discontinuities between different layer interfaces produce waveforms that can be used to differentiate between the layers. The dielectric discontinuity of the materials in adjacent layers must vary enough to allow them to be measured. The following table shows the dielectric properties of typical materials used or found in pavement structures.

Material	Dielectric Constant
Air	1
Fresh Water	81
Sea Water	80
Dry Sand	3 – 5
Saturated Sand	20 – 30
Silts	5 – 30
Clays	5 – 40
Limestone	4 – 8
Granite	4 – 6
Bituminous Concrete	3 – 6
Concrete (cured)	6 – 11

(12)

Past research has shown that GPR is the most established non-destructive method of determining thickness in asphalt pavements; however, the situation is different with concrete pavements. The dielectric contrast between the concrete surface and typical base materials is not as distinct as that between asphalt and base materials. This can



cause the reflection at the bottom of the concrete layer to be greatly diminished or, in some cases, non-existent.(10) The accuracy of GPR has typically been tied to the use of calibration cores to aid in the analysis software's ability to produce more accurate thickness results.(2, 7, 13) Because pavement thickness can vary as much as an inch or more over very short distances on a typical pavement, an average thickness for a given distance would have to be used.(8)

The AHTD is not unlike many state transportation agencies in that pavement layer data is not readily available on much of its network. Pavement job history data is available along with construction documents and engineer diaries to build a pavement profile; however, most of the data is in paper form in filing cabinets. Building a network level database is impractical with existing staff. Also, many routes have been ceded to the Department from local jurisdictions without any accompanying historical pavement history.(8) The need to have a comprehensive pavement layer thickness database for pavement management is essential to allow analysis of pavements with similar cross sections.

If GPR technology can provide accurate network level data in a relatively short period of time without the need of calibration cores for each pavement section, it will benefit Pavement Management and the Department. Pavements can be compared to establish performance curves for each class of pavement cross-section in the network.

## **4.0 Equipment and Methods**

### **4.1 Equipment**

Infrasense, Inc. and WaveTech, Inc. of Baton Rouge, Louisiana provided the equipment and operator used in the project. The GPR equipment (Figure 1) utilized was

a GSSI 1.0 GHz dual horn antenna system that was mounted to the rear bumper receiver hitch of a Dodge van. The vehicle was equipped with an electronic survey wheel, or distance-measuring instrument (DMI), also mounted to the rear bumper. The DMI controlled the data collection interval used by the equipment.



Figure 1.

The equipment used to verify the pavement thickness results of the GPR were two coring units operated by AHTD Planning and Research Division and Materials Division personnel. A small coring unit operated by Planning and Research Division personnel provided cores on pavements with surfaces of total thickness less than 16 inches. A larger coring unit operated by Materials Division personnel provided cores on thicker pavements.

#### **4.2 Methods**

Data collection for each of the pavement test sections was made in the right or outermost lane. Data was acquired in both wheel paths at a rate of one scan per two-foot

interval. The data collection was accomplished at normal highway speeds between 45 mph and 55 mph. This allowed data collection to be performed with no lane closures.

All of the GPR equipment was operated from inside the vehicle, providing a safe operating environment for the data collection personnel. The data was digitized and stored on hard disks inside the vehicle. The DMI provided an offset distance from the starting value corresponding to each subsequent GPR data record. The highway test sections were collected from a known beginning point to a known ending point with data averaged over 50-foot intervals. Location reference markers were noted in the file to provide secondary location data.(11)

The field verification process for the highway test sections involved inspecting the pavement thickness reports and establishing locations to obtain cores for comparison to GPR reported pavement thickness. The GPR thickness data was averaged over 50 foot sample lengths and reported in a Microsoft Excel™ spreadsheet. The thickness values were displayed in a bar chart to provide a longitudinal “picture” of the pavement thickness profile. The profiles were examined for minimum 150-foot sections with reported thickness within one-tenth of an inch variance. These sites were selected as targets for collecting verification cores. Each highway section had between three and six core locations selected per test section. The midpoint of each site was located and marked. Also, one point 25 feet behind and one point 25 feet ahead of the midpoint were marked. One core was taken from the right wheel path at each of the marked locations and measured to determine the pavement thickness. The three core thickness values were then averaged to provide a pavement thickness value for the site. Only one site had cores

taken from both the left and right wheel paths. This was due to the known variance in the pavement cross-section at the site.

## **5.0 Presentation of Results**

The evaluation sites were selected based on known pavement attributes, such as surface type and basic layer information. A variety of pavements were chosen to determine the ability of the GPR to provide thickness data on multiple pavement cross-sections. The following is a list of the sites along with a basic description of the pavement type.

Site A. Interstate 30 – University Avenue to Interstate 430 – 2.4 miles – West bound

- Pavement Type – Asphalt over concrete

Site B. Interstate 30 – Highway 70 to Old Military Road – 4.1 miles – West bound

- Pavement Type – Concrete

Site C. Interstate 40 – Interstate 430 to Highway 365 – 4.3 miles – West bound

- Pavement Type – Asphalt over rubblized concrete

Site D. Interstate 530 – Pulaski County Line to Highway 46 – 3.7 miles – South bound

- Pavement Type – Asphalt over rubblized concrete

Site E. Interstate 530 Frontage Road in Pine Bluff – 0.75 miles – East bound

- Pavement Type – Asphalt and Concrete

Site F. State Highway 161 – Interstate 440 to Trickey Lane – 2.9 miles – North bound

- Pavement Type – Asphalt over old 18 foot wide concrete pavement

Site G. State Highway 46 – Hurricane Creek Bridge East – 5.0 miles – East bound

- Pavement Type – Asphalt

Site H. State Highway 270 – East end of Hot Springs Bypass – 1.7 miles – West bound

- Pavement Type – Asphalt

Data was collected in both wheel paths at all sites; however, the vendor reported that left and right wheel path results were identical so only the right wheel path thickness values were used. The exception to this was Site F, State Highway 161, which was a

widening and overlay of an old 18-foot wide concrete pavement to a 22-foot wide asphalt surface pavement. The asphalt thickness of the outside wheel path was considerably more than the inside wheel path thickness. Both wheel paths were reported for this site.

Two of the sites, Site A and Site E, were not cored and were not included in the evaluation. Site A was located on a section of heavily traveled Interstate 30 in metropolitan Little Rock and it was determined that closing a lane of traffic to provide cores was not acceptable. Site E was located on a very low volume frontage road of Interstate 530 in Pine Bluff. There are two Strategic Highway Research Program (SHRP) test sections located on the frontage road that cannot be disturbed. Due to the short length of the frontage road, there was not enough remaining pavement length to provide an adequate core sample for comparison.

The data for each site is presented in the following tables with an accompanying description of the site and any anomalies pertaining to the site. The table indicates the distance to the beginning and ending of each core site. Each location is provided an identifier, for example, B1 would be the first core site on the Site B pavement section. B1 would have thickness values for three cores associated with it. The cores were taken 25 feet before the site midpoint, at the midpoint, and 25 feet beyond the site midpoint. The average thickness of the three cores and the average thickness of the GPR values for the site are provided as well as the reported GPR thickness at the midpoint of the site. Also provided is the difference between the midpoint core thickness and the reported GPR midpoint thickness and the difference between the average core thickness and the average of the reported GPR thickness for the site.

**Site B** is a 4.1-mile section of jointed concrete pavement located on Interstate 30 southwest of Little Rock between the junctions of Highway 70 and Old Military Road. The original design thickness of the concrete pavement was 12 inches. A change order incorporated a 2.6-mile SHRP section into the job. The section contains twelve separate 500-foot long SHRP test sites with varying length transition areas between them. Six of the test sites have an eight-inch thick jointed concrete surface and six have an eleven-inch thick jointed concrete surface, each with a different strength concrete or combination of base materials and thickness.

Four core locations were chosen that did not interfere with the SHRP sites, three sites, B1, B2, and B3, were sandwiched in the transition areas between SHRP sites and one, B4, was located within the limits of the original design cross-section area. Figure 2 shows the results of the GPR report and the coring thickness data for the sites.

An overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows the range is from a minimum of 0.2 inches to a maximum of 1.03 inches, or 0.83 inches. The mean of the midpoint differences of the four core sites is 0.561 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.659 inches. The average difference of the four core sites is 0.621 inches.

Core site B1 was located within a transition section between two eleven-inch SHRP pavements. The average core thickness is 10.917 inches while the average reported GPR thickness is 10.5 inches, a difference of 0.417 inches.

Core sites B2 and B3 were located within transition sections between two eight-inch SHRP pavements. The average core thickness for B2 is 7.917 inches while the

average reported GPR thickness is 7.150 inches, a difference of 0.767 inches. The average core thickness for B3 is 8.167 inches while the average reported GPR thickness is 8.520 inches, a difference of -0.353 inches.

<b>SITE B</b>											
<b>I-30 West Bound – US 70 to Old Military Road (Log Mile 106.60 to 110.70)</b>											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	A	B		C		D	
					CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
<b>B1</b>	0.435	0.455	RWP	10.750	10.750	11.250	10.917	10.50	10.55	0.200	0.417
<b>B2</b>	1.620	1.639	RWP	7.875	7.875	8.000	7.917	7.15	7.12	0.755	0.767
<b>B3</b>	2.596	2.615	RWP	8.000	8.250	8.250	8.167	8.52	8.51	-0.260	-0.353
<b>B4</b>	3.678	3.709	RWP	12.000	12.000	12.125	12.042	12.99	13.03	-1.030	-0.948
<b>End</b>		4.100		AVERAGE DIFFERENCE OF ALL CORE SITES:						0.561	0.621

Figure 2.

Core site B4 was located within the original design cross-section area that had a twelve-inch pavement thickness. The average core thickness is 12.042 inches while the average reported GPR thickness is 12.990 inches, a difference of -0.948 inches.

As mentioned earlier, the SHRP sites were composed of several cross-sections. The differences in the concrete surface layer were the strength of the concrete and the thickness, either eight inches or eleven inches; however, the base materials were used in various combinations. The materials used were a Permeable Asphalt Treated Base (PATB), a Dense Graded Aggregate Base (DGAB), and a Lean Concrete Base (LCB). Six-inch layers of LCB or DGAB were used in eight of the SHRP sites. Four sites used a combination of four inches of PATB and four inches of DGAB, with the PATB layer sandwiched between the concrete surface layer and the DGAB layer. Without exception, the GPR reported a concrete layer thickness one to two inches thicker than the design thickness.

Core site B4 was located in the section of pavement as it was originally designed. That section of pavement also had a layer of PATB under the twelve-inch concrete surface layer. This could explain why the reported GPR thickness was nearly one inch more than the validation core thickness.

**Site C** is a 4.21-mile section of rubblized jointed concrete pavement with an asphalt overlay located on Interstate 40 west of Little Rock, between the junction of Interstate 430 and State Highway 365 in Morgan. The GPR data was used to determine the thickness of the asphalt layer of the section. Five core sites were selected for Site C and are labeled C1 through C5 in Figure 3.

<b>SITE C</b>											
<b>I-40 West Bound – I-430 to Morgan (Log Mile 142.63 to 146.84)</b>											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
<b>C1</b>	0.880	0.910	RWP	7.325	7.325	7.500	7.383	7.91	7.88	-0.555	-0.527
<b>C2</b>	1.210	1.230	RWP	9.250	8.500	8.500	8.750	8.46	8.48	0.020	0.290
<b>C3</b>	2.760	2.790	RWP	7.375	7.875	7.500	7.583	7.68	7.67	0.205	-0.097
<b>C4</b>	3.460	3.480	RWP	8.500	8.500	9.000	8.667	8.89	8.92	-0.420	-0.223
<b>C5</b>	3.870	3.890	RWP	12.000	11.875	11.750	11.875	10.08	10.11	1.765	1.795
<b>End</b>		4.210		AVERAGE DIFFERENCE OF ALL CORE SITES:						0.593	0.586

Figure 3.

The overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows that the range is from 1.765 inches to 0.555 inches, or 1.210 inches. The mean of the midpoint differences of the five core sites is 0.593 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.853 inches. The average difference of the five core sites is 0.586 inches. Several cores from the site exhibited some segregation and voids in the binder layers of the pavement.



Core sites C1 and C2 were located approximately 0.3 miles apart. C1 was located on the downhill side of a small crest vertical curve and C2 was located on a flat section of pavement. Midpoint comparisons show that the GPR value for site C1 was 0.555 inches thicker than the core thickness while site C2 showed the core thickness to be 0.020 inches greater than the GPR thickness.

Core sites C3 and C4 were located approximately 0.4 miles apart. C3 was located on a flat, straight section of pavement and C4 was located on a flat section of pavement in a curve to the right. The midpoint comparison shows that the core thickness for site C3 was 0.205 inches greater than the GPR value while site C4 showed the GPR value was 0.420 inches greater than the core thickness.

Site C5 was located at the peak of a crest vertical curve. The site was also located in a super-elevated section of a horizontal curve to the left. The midpoint comparison reveals that the measured core thickness was 1.765 inches greater than the reported GPR thickness.

**Site D** is a 3.437-mile section of rubblized jointed concrete pavement with an asphalt overlay located on Interstate 530 south of Little Rock, between the Pulaski County line and the junction of State Highway 46 in Redfield. The section was the first rubblized pavement used by the AHTD. The GPR was utilized to determine the thickness of the asphalt layer on the rubblized concrete. Four core sites were selected for Site D and are labeled D1 through D4 in Figure 4.

The test section also contains three bridges. Because of concerns with the rubblizing technique, the concrete pavement 500 feet before and after each bridge was not rubblized. The concrete was overlaid with asphalt and transitioned to meet the

asphalt overlay on the rubblized section. The GPR data reflects the transition areas in the proximity of the bridges.

<b>SITE D</b>											
<b>I-530 South Bound – Pulaski County Line To Redfield</b>											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	A	B		C	D		
					CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
<b>D1</b>	1.461	1.481	RWP	6.000	6.000	6.125	6.042	5.70	5.67	0.330	0.342
<b>D2</b>	1.063	1.083	RWP	6.500	6.250	6.250	6.333	5.89	5.93	0.320	0.443
<b>D3</b>	2.107	2.126	RWP	7.000	6.825	6.825	6.883	6.82	6.86	-0.035	0.063
<b>D4</b>	3.193	3.213	RWP	7.000	6.750	6.325	6.692	7.33	7.28	-0.530	-0.638
<b>End</b>		3.437		<b>AVERAGE DIFFERENCE OF ALL CORE SITES:</b>						<b>0.304</b>	<b>0.372</b>

Figure 4.

The overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows that the range is from 0.035 inches to 0.530 inches, or 0.495 inches. The mean of the midpoint differences of the five core sites is 0.304 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.351 inches. The average difference of the five core sites is 0.372 inches.

After the original site selection, it was found that site D1 was located within a SHRP test section. Another site was chosen that was 0.4 miles beyond site D2. The sites D1 and D2 are not sequential with relation to the beginning of Site D.

Site D2 was located on a flat and straight section of pavement approximately 600 feet before the lead edge of the third bridge mentioned earlier. The midpoint comparison shows the measured core thickness was 0.320 inches greater than the reported midpoint GPR thickness.

Site D1 was located on an uphill leg of a crest vertical curve. It was also located in a horizontal curve to the left in an area of superelevation. The midpoint comparison

shows the measured core thickness was 0.330 inches greater than the reported midpoint GPR thickness.

Site D3 was located just over the crest, on the downhill leg of a crest vertical curve. The site was near the end of a horizontal curve to the right with no superelevation involved. The midpoint comparison shows the reported GPR thickness was 0.035 inches greater than the measured midpoint core thickness.

Site D4 was located on the uphill leg of a sag vertical curve with no horizontal curvature or superelevation involved. The midpoint comparison shows the reported GPR thickness was 0.530 inches greater than the measured midpoint core thickness.

**Site F** is a 2.919-mile section of asphalt pavement that begins at the trail edge of the underpass of Interstate 440 in North Little Rock and ends at the intersection of Trickey Lane in Jacksonville. The pavement is referred to as a “notch and widen” section. It was originally constructed with two nine-foot wide concrete lanes and was widened to two eleven-foot asphalt lanes. The outside two-foot section of each lane was built up to match the existing pavement surface. A full width overlay was then placed on the widened pavement section. The site was chosen to determine if the GPR could measure the thickness of the asphalt layer of the inner and outer wheel paths.

Site F presented several challenges with regards to field verification of the GPR results. First, field collection of the two wheel paths had to be performed at different times. The pavement in the notched section, or outside wheel path was too thick to core with the Research Section’s sixteen-inch core barrels. The outside wheel path had to be cored with a larger core rig belonging to the Materials Division. The inside wheel path was collected in the spring and the outside wheel path was collected in the summer.

Second, and most challenging, an overlay was applied to the pavement between the time GPR was used and the cores could be collected. The pavement section was not only overlaid, but was milled in several locations.

After the milled sections were located, three core sites were selected for Site F and are labeled F1 through F3 in Figure 5. Each of the cores was measured and the thickness of the overlay was subtracted from the total core thickness. This provided the pavement thickness at the time the GPR data was collected. The values in Figure 4 are for the inside, or left wheel path.

The overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows that the range is from 0.230 inches to 0.580 inches, or 0.350 inches. The mean of the midpoint differences of the five core sites is 0.455 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.482 inches. The average difference of the five core sites is 0.523 inches.

SITE F											
SH 161 North Bound Left Wheel Path – I-440 (Trail Edge Underpass) to Trickey Lane											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
			OVL	2.000	2.000	2.125	2.042				
<b>F1</b>	0.738	0.767	LWP	8.375	8.000	8.500	6.250	5.74	5.77	0.230	0.510
			OVL	2.125	1.875	1.875	1.958				
<b>F2</b>	1.580	1.600	LWP	8.000	7.750	7.625	5.833	5.36	5.32	0.555	0.473
			OVL	2.125	2.000	2.000	2.042				
<b>F3</b>	2.490	2.511	LWP	8.000	7.750	7.375	5.667	5.08	5.17	0.580	0.587
<b>End</b>		2.919		AVERAGE DIFFERENCE OF ALL CORE SITES:						0.455	0.523

Figure 5.

Core site F1 was located on the crest of a crest vertical curve on a straight section of roadway. The thickness of the core at the midpoint was eight inches. The overlay

thickness of the midpoint core was two inches. The core thickness of the original pavement at the midpoint was calculated at six inches. The reported GPR thickness at the midpoint was 5.77 inches. The core at the midpoint was 0.230 inches thicker than the reported GPR thickness.

Site F2 and F3 were located on flat, straight sections of pavement. The thickness of the core at the midpoint for site F2 was 7.750 inches. The overlay thickness of the midpoint core was 1.875 inches. The calculated core thickness of the original pavement at the midpoint was 5.875 inches. The reported GPR thickness at the midpoint was 5.32 inches. The midpoint core was 0.555 inches thicker than the reported GPR thickness. For Site F3 the thickness of the core at the midpoint was 7.750 inches. The overlay thickness of the midpoint core was two inches. The calculated core thickness of the original pavement at the midpoint was 5.750 inches. The reported GPR thickness at the midpoint was 5.17 inches. The midpoint core was 0.580 inches thicker than the reported GPR thickness.

The core work for the right wheel path did not produce results that were usable. Because of the thickness of the asphalt and the condition of the lower asphalt layers, only three measurable cores could be collected. The cores for Site F1 produced two cores and Site F2 produced one. The upper layers of each core remained entirely intact; however, the lower layers were stripped and either fell completely apart or they came apart at a layer interface within the core. The core thickness could not be determined on the incomplete cores and trying to measure the depth of the holes left by the removed cores could not be done with any degree of confidence because they were too deep to

accurately determine the bottom surface of the pavement. Figure 6 is provided to show the results that were obtained.

SITE F											
SH 161 North Bound Right Wheel Path – I-440 (Trail Edge Underpass) to Trickey Lane											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
			OVLV	1.875	NA	2.000	1.938				
<b>F1</b>	0.738	0.767	RWP	17.625	NA	18.625	16.188	16.75	16.68	NA	-0.562
			OVLV	NA	2.125	NA	2.125				
<b>F2</b>	1.580	1.600	RWP	NA	18.000	NA	15.875	15.89	16.01	-0.135	-0.015
			OVLV	NA	NA	NA	NA				
<b>F3</b>	2.490	2.511	RWP	NA	NA	NA	NA	15.96	15.87	NA	NA
<b>End</b>		2.919		AVERAGE DIFFERENCE OF ALL CORE SITES:						NA	NA

Figure 6.

Site G is a 5-mile long section of State Highway 46 in Grant County. State Highway 46 is a low volume road that connects the towns of Redfield and Sheridan and at times it provides access for trucks hauling timber from adjacent property and has been patched numerous times. The pavement thickness varies considerably within the five-mile test section because of the various levels of work that have been performed on the pavement. Five core sites were chosen on the section and are labeled G1 through G5 in Figure 7.

SITE G											
SH 46 East Bound – Hurricane Creek East											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
<b>G1</b>	0.355	0.395	RWP	2.575	3.500	4.875	3.650	3.18	3.18	0.320	0.470
<b>G2</b>	1.017	1.036	RWP	1.750	1.750	2.250	1.917	1.60	1.63	0.120	0.317
<b>G3</b>	3.642	3.672	RWP	1.875	2.000	2.000	1.958	1.91	1.94	0.060	0.048
<b>G4</b>	4.327	4.356	RWP	3.000	3.000	3.325	3.108	2.96	2.99	0.010	0.148
<b>G5</b>	4.625	4.644	RWP	6.500	6.000	6.250	6.250	5.86	5.92	0.080	0.390
<b>End</b>		5.002		AVERAGE DIFFERENCE OF ALL CORE SITES:						0.118	0.275

Figure 7.

The overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows that the range is from 0.010 inches to 0.320 inches, or 0.310 inches. The mean of the midpoint differences of the five core sites is 0.118 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.159 inches. The average difference of the five core sites is 0.275 inches.

All five of the core sites are on similar geometric alignments and exhibit similar surface characteristics. Site G1 was unique because the difference in the measured core thickness from core 1 to core 3 (50 feet apart) was 2.300 inches. All of the other core sites within Site G were separated by one half inch or less across the same span.

The midpoint comparison of Site G1 shows that the measured core thickness was 0.320 inches more than the reported GPR thickness. Site G2 reveals the difference at 0.120 inches while Site G3 shows a 0.060-inch gap. Site G4 had the lowest difference at 0.010 inches and Site G5 had a difference of 0.080 inches. The difference in the core thickness at the individual core sites indicates the dramatic difference in the pavement profile over the five-mile section, from a minimum pavement thickness of 1.75 inches up to 6.50 inches.

**Site H** is a 1.64-mile long section of State Highway 270 in Hot Springs. It is part of the Hot Springs Bypass and is a four-lane divided asphalt pavement. The first 3,000 feet of the test section was part of a single lane access ramp that could not be closed to traffic. This left about 1.2 miles of pavement to locate suitable core locations. Three core sites were selected in the section and are labeled H1 through H3 in Figure 8.

The overall comparison of the average thickness of the midpoint cores to the average midpoint thickness provided by GPR for the site shows that the range is from 0.020 inches to 0.700 inches, or 0.680 inches. The mean of the midpoint differences of the five core sites is 0.383 inches. The variance between the midpoint core thickness and the midpoint GPR thickness for the site is 0.474 inches. The average difference of the five core sites is 0.168 inches.

<b>SITE H</b>											
<b>US 270 East Bound – East End of Hot Springs Bypass</b>											
CORE SITE	BEGIN (mi)	END (mi)	WHEEL PATH	THICKNESS (in)							
				CORE 1	CORE 2 (MIDPOINT)	CORE 3	AVG CORE THICK	AVG GPR THICK	MIDPT GPR THICK	A MINUS D	B MINUS C
<b>Begin</b>	0.000										
<b>H1</b>	0.930	0.970	RWP	8.500	9.000	8.750	8.750	8.37	8.30	0.700	0.380
<b>H2</b>	1.200	1.230	RWP	8.875	8.500	8.500	8.625	8.55	8.52	-0.020	0.075
<b>H3</b>	1.370	1.410	RWP	7.750	7.000	7.125	7.292	7.35	7.43	-0.430	-0.058
<b>End</b>		1.640		AVERAGE DIFFERENCE OF ALL CORE SITES:						0.383	0.168

Figure 8.

The three core sites are located on similar pavement alignments within a 0.6-mile section of pavement. The midpoint comparison of Site H1 shows that the measured core thickness was 0.7 inches more than the reported GPR thickness. Site H2 reveals the midpoint GPR thickness is 0.020 inches more than the midpoint core thickness and Site H3 shows the difference is 0.430 inches.

A composite chart comparing the six sites that had core data collected is shown in Figure 9. The basic statistical data tabulated for the midpoint core at each site is shown. The calculated difference and the percent difference for each core sample and its corresponding GPR predicted thickness is shown. The Root Mean Square Error (RMSE), variance,  $R^2$ , and correlation (R), are shown for each site as a whole, not individual core samples.



The measured thickness of each of the midpoint cores was compared to the GPR predicted thickness of the midpoint to determine the difference in the predicted pavement thickness versus the actual thickness. It can be seen from the data in the percent difference column that the majority of the sites reflect a difference between the GPR predicted thickness and the actual thickness at the site midpoint of less than ten percent. Only five of the twenty-four cores, 20.8 percent, had calculated differences greater than ten percent and eleven of the twenty-four cores, 45.8 percent, had calculated differences less than five percent. The range in the percent differences is from 0.23 percent (Sites C and H) to 17.46 percent (Site C), or 17.23 percent. The average percent difference for all of the sites combined is 5.70 percent.

The RMSE was highest at Site B (0.659) and Site C (0.853), where the greatest measured differences existed between the core and GPR predicted thickness. Site C included the greatest measured difference at 1.765 inches and Site B included the second highest difference at 1.030 inches. The calculated variance for the sites was also greatest at Sites B and C, 0.761 for Site B and 0.954 for Site C. The lowest RMSE and variance was recorded for Site G with values of 0.159 and 0.178, respectively. The overall RMSE for all of the core sites is 0.554 with a corresponding variance of 0.566.

The  $R^2$  values for each site indicate a strong correlation between the measured pavement thickness and the GPR predicted pavement thickness. The  $R^2$  values range from a low of 0.8227 at Site H to a high of 0.9950 at Site G. These are, interestingly, the two full depth HMA sites. The  $R^2$  for all of the midpoint values is 0.9585. The  $R^2$  for all seventy-two cores and their corresponding GPR values is 0.9493.

A comparison of the data on three basic pavement cross-sections (full depth asphalt, composite, and concrete) indicates a strong correlation between the measured pavement thickness and the GPR predicted thickness. With the exception of two core sites, one in Site B and one in Site C, the majority of the GPR predicted thickness values are within one-half inch of the measured thickness.

		THICKNESS (in)				STATISTICS					
		CORE	GPR	DIFF	% DIFF	RMSE	VAR	RANGE		R <sup>2</sup>	CORR (R)
SITE B	CONC	10.750	10.55	0.200	1.90	0.659	0.761	MIN	0.200	0.9562	0.9778
		7.875	7.12	0.755	10.60			MAX	1.030		
		8.250	8.51	-0.260	3.06			RANGE	0.830		
		12.000	13.03	-1.030	7.90						
SITE C	HMA/RUBB	7.325	7.88	-0.555	7.04	0.853	0.954	MIN	0.020	0.8838	0.9401
		8.500	8.48	0.020	0.23			MAX	1.765		
		7.875	7.67	0.205	2.67			RANGE	1.745		
		8.500	8.92	-0.420	4.71						
		11.875	10.11	1.765	17.46						
SITE D	HMA/RUBB	6.000	5.67	0.330	5.82	0.351	0.406	MIN	0.035	0.8974	0.9473
		6.250	5.93	0.320	5.40			MAX	0.530		
		6.825	6.86	-0.035	0.51			RANGE	0.495		
		6.750	7.28	-0.530	7.28						
SITE F	HMA/CONC					0.482	0.590	MIN	0.230	0.9231	0.9608
		6.000	5.77	0.230	3.99			MAX	0.580		
		5.875	5.32	0.555	10.43			RANGE	0.350		
		5.750	5.17	0.580	11.22						
SITE G	HMA	3.500	3.18	0.320	10.06	0.159	0.178	MIN	0.010	0.9950	0.9975
		1.750	1.63	0.120	7.36			MAX	0.320		
		2.000	1.94	0.060	3.09			RANGE	0.310		
		3.000	2.99	0.010	0.33						
		6.000	5.92	0.080	1.35						
SITE H	HMA					0.474	0.581	MIN	0.020	0.8227	0.9070
		9.000	8.30	0.700	8.43			MAX	0.700		
		8.500	8.52	-0.020	0.23			RANGE	0.680		
		7.000	7.43	-0.430	5.79						

Figure 9.

## 6.0 Discussion of Results

Of the eight sites originally evaluated with the GPR technology, six of the sites could be compared with cores. A total of 27 individual core sites were chosen from the six test sites. Of the 27 core sites selected, three were not included in the evaluation

because an adequate sample could not be acquired. The pavement thickness could not be accurately determined from the cores or an inspection of the holes. Three cores were taken from each of the remaining sites. This provided a total of 72 measurable cores for comparison purposes.

The core thickness values and reported GPR thickness values were tabulated and compared. Figure 10 shows the distribution of the difference in the measured midpoint core thickness values versus the reported midpoint GPR values. The midpoint core thickness is for one four-inch core at a single point, whereas the midpoint GPR thickness value is for an average of 25 thickness values for a 50-foot distance. Figure 10 shows the distribution of the difference in the average thickness of the cores per site and the average reported thickness for the GPR results for the site. It should be restated that the average of the core values for each site include three cores measured 25 feet apart while the average of the GPR values for each site includes three thickness values provided at 50-foot intervals. The value for each interval represents an average of thickness values collected every two feet by the GPR equipment. The site comparison is between a 50-foot sample average and a 150-foot sample average.

The data displayed in Figures 10 and 11 show the thickness values relative to their difference from zero inches. The zero inch value represents the point where the core thickness and the reported GPR thickness would match exactly. There were no average values that matched exactly.

The chart displayed in Figure 10 shows that the measured midpoint core thickness at sixteen of the twenty-four core sites (66.7 %) was greater than the reported GPR thickness at the midpoint. Ten of the twenty-four (41.7 %) GPR thickness values were

within one-quarter inch of the zero point. Twenty-one of the twenty-four midpoint core thickness values (87.5 %) were within three-quarter inches of the zero point and twenty-two of the twenty-four midpoint core thickness values (91.7 %) were within one inch of the zero point.

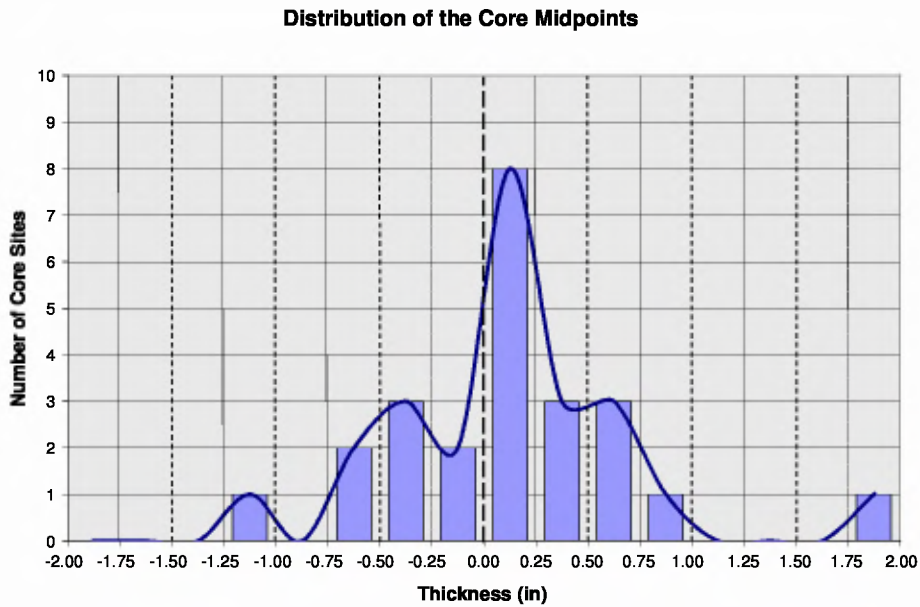


Figure 10.

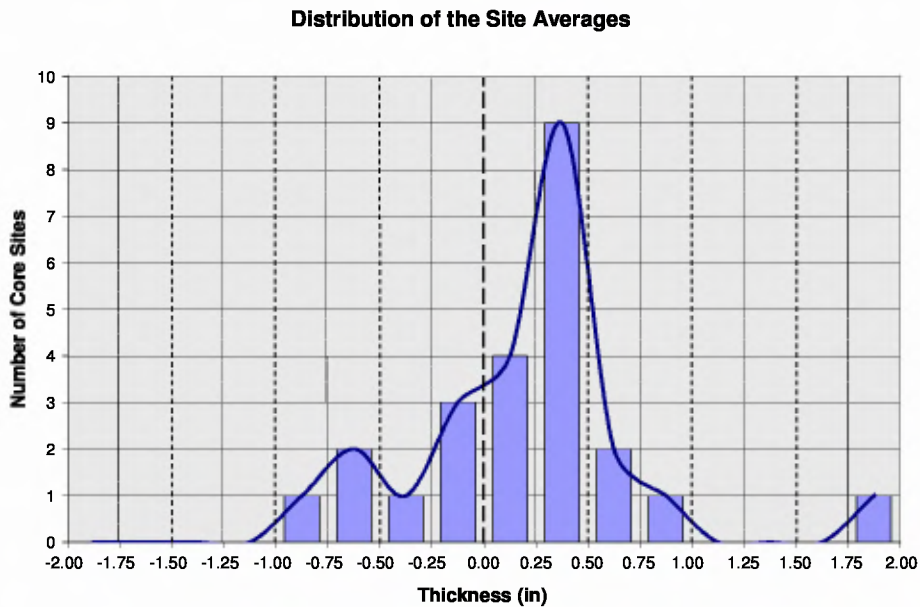


Figure 11.

The chart displayed in Figure 11 shows that the measured average site core thickness at seventeen of the twenty-four core sites (70.8 %) was greater than the reported average GPR thickness at the site. Only seven of the twenty-four (29.2 %) average GPR site thickness values were within one-quarter inch of the zero point. Twenty-one of the twenty-four core sites (87.5 %) were within three-quarter inches of the zero point and twenty-three of the twenty-four (95.8 %) were within one inch of the zero point.

The evaluation of ancillary data provided some interesting information. Change orders in a pavement construction job can either void or dramatically alter the original cross-section design of a pavement structure. The concrete pavement of Site B contained a 2.6-mile SHRP SPS-2 test section that was change ordered into the original job. The original cross-section was a twelve-inch jointed concrete surface with six inches of DGAB. The SHRP section was composed of twelve five-hundred-foot long pavement test sites with transition areas between each site. The test sites were constructed with an eight or eleven inch surface with either six inches of DGAB or four inches of PATB over four inches of DGAB.

Figure 12 shows the GPR thickness report for the entire section. The chart shows the location of each of the core test sites (B1 through B4) and each of the SHRP sites (SHRP 1 through SHRP 12). Each SHRP test site has two or three lines indicating the thickness of each pavement layer as it was designed.

Core samples cannot be obtained from within the SHRP sites to confirm the results of the GPR report. However, construction of the sites requires very rigorous quality control. If it is assumed that the sites were built according to the SHRP SPS-2

design specifications, the reported GPR predicted thickness data revealed the location of each SHRP site within the SHRP test section. Some sections, SHRP 5 and SHRP 6 in particular reported GPR thickness values significantly less than the design thickness. The GPR values do indicate where the SHRP section ended and the original design cross-section began (approximately log mile 107.75).

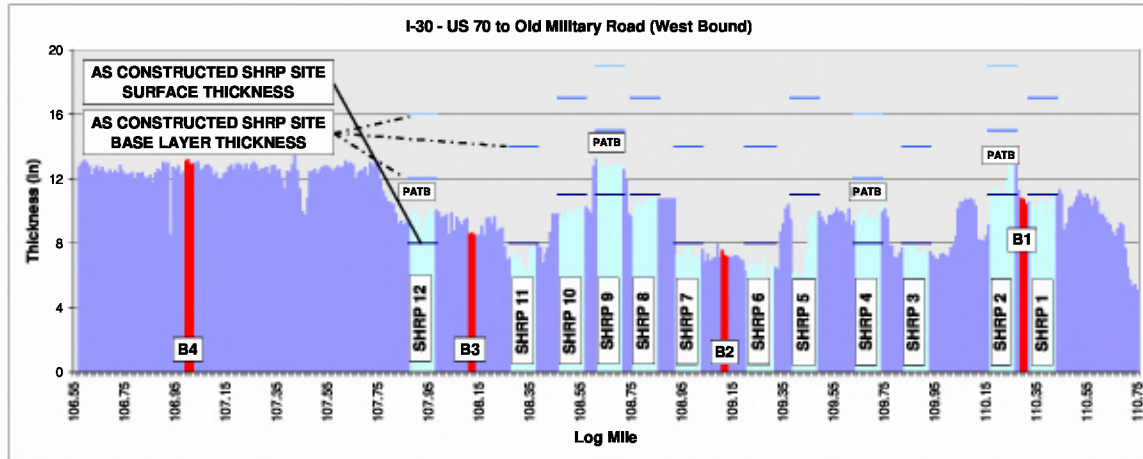


Figure 12.

Also indicated on the chart is the location of the sites with a four-inch layer of PATB. Of the twelve SHRP sites, only the four sites with the PATB showed a reported GPR thickness greater than the design depth. This is of interest because the original design cross-section surface layer was eleven inches thick. The GPR thickness indicated the surface layer was between twelve and thirteen inches thick. The cores from Site B4 had PATB on the bottom surface of the concrete. The original design had apparently been changed to PATB instead of DGAB. Each of the GPR sites with a PATB layer indicated that the surface layer was between one and two inches thicker than the actual pavement.

Site A was located on a high volume section of Interstate 30 that could not be closed to traffic to allow coring of the sites. This section of Interstate 30 was originally

built with a nine-inch jointed concrete pavement surface. The pavement was overlaid with an eight and one-half inch asphalt overlay. The average concrete thickness reported by the GPR was 8.73 inches and the average asphalt thickness reported by the GPR was 8.56 inches. If the pavement was built according to the original design, the difference in the reported GPR thickness and the design thickness for the concrete layer is three percent and the difference in the reported GPR thickness and the design thickness of the asphalt layer is less than one percent.

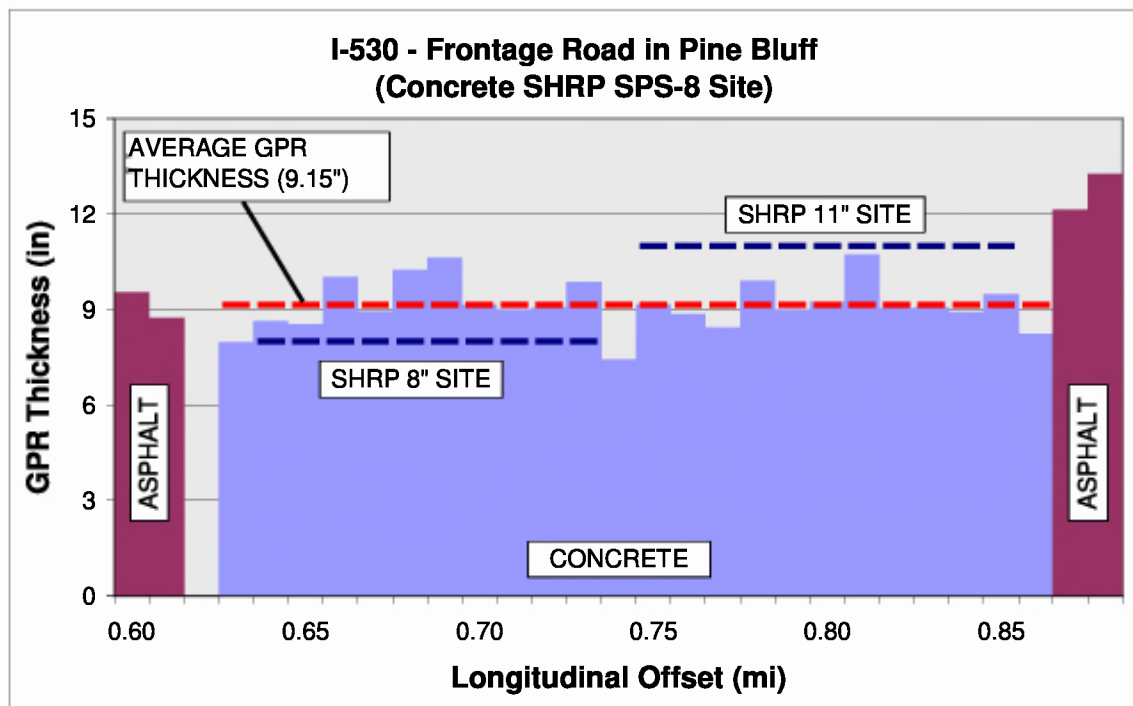


Figure 13.

Site E, the low volume Interstate 530 frontage road in Pine Bluff, was not cored because a large portion of the test site included part of a SHRP SPS-8 test section. The SHRP site design included two five hundred foot jointed concrete pavement surface sections with transition areas between them. The two SHRP sites were constructed with a six-inch DGAB over an embankment of selected fill material. One site had an eight-

inch jointed concrete surface applied and the other had an eleven-inch jointed concrete surface.

The average reported GPR layer thickness for the SHRP site was 9.15 inches. The plot of the GPR thickness data did not show a distinction between the eight inch and eleven inch surfaces. Figure 13 shows the plot of the reported GPR thickness and the average reported GPR thickness. Also shown are the two SHRP sites and their design thickness relative to the section.

## **7.0 Conclusions**

The purpose of this evaluation of GPR technology was to determine the ability of the technology to provide reliable pavement thickness data for a PMS without providing calibration cores. The results of the field verification have shown that GPR can provide reliable results in most instances. The data has shown that in over ninety percent of the samples, the pavement thickness could be determined to the nearest inch without the aid of calibration cores. The vendor was provided basic pavement structure information in the scope of work before the collection of data occurred. The vendor only knew how long the site was and if a site was concrete, asphalt, or asphalt over concrete or rubblized concrete. No thickness information was provided.

When compared with the arduous task of digging through engineer diaries and typical sections on design plans to establish an estimate of a pavement's thickness, the results provided by GPR can be used on a network level to render overall pavement thickness data in a timely manner. The results from one site proved that using the typical sections of design plans alone would have yielded a pavement thickness that was four inches thicker than actually constructed. The data shows that the thickness information



provided by the GPR is reliable enough to use for a network level PMS. Overall homogenous pavement sections can be determined from the data.

Comparing the eight test sites, with or without core data, seven could be considered successes for GPR technology. Of the six sites verified with thickness data provided by coring, all of them could be considered successful. These sites showed that GPR could predict pavement thickness to within about one-half inch without the aid of calibration cores. The only site that could be considered a failure would be the Interstate 530 frontage road in Pine Bluff where GPR did not predict the thickness of the pavement in the SHRP sections. The pavement thickness in this section could not be validated with cores; however, the SHRP sections were constructed with very strict quality control and it is assumed that the site was built according to the original design.

## **8.0 Recommendations**

The use of GPR as a network level tool for providing overall pavement thickness information should be considered a viable option. GPR can provide an economical means of collecting network level thickness data for a PMS. The data can be collected and processed relatively quickly without the need for traffic control or lane closures. GPR can provide the information in a way that is safe both to agency personnel and the motoring public.

The data has shown that for a typical network level analysis, the results are adequate. However, further research should be performed to determine if there are certain pavement structures that consistently result in inaccurate pavement thickness results such as the concrete surface over a PATB material.

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