Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-05/5-4414-01-3		

4. Title and Subtitle PILOT IMPLEMENTATION OF CONCRETE PAVEMENT THICKNESS GPR	5. Report Date November 2004 6. Performing Organization Code
7. Author(s) Richard Liu, Jing Li, Xuemin Chen, Huichun Xing	8. Performing Organization Report No. 5-4414-01-3
9. Performing Organization Name and Address Department of Electrical and Computer Engineering University of Houston 4800 Calhoun Rd. Houston, TX 77204-4005	10. Work Unit No. 11. Contract or Grant No. 5-4414-01
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080	13. Type of Report and Period Covered Implementation Report: September 1, 2003 – August 31, 2004 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Pilot Implementation of Concrete Pavement Thickness GPR

16. Abstract:

Research Project 5-4414 "Pilot Implementation of Concrete Pavement Thickness GPR (CPT-GPR)" has been successfully completed. In this project, two CPT-GPR systems were manufactured, including GPR electronics, thickness and dielectric constant calculation algorithm, software interface, distance-measuring encoder, LCD displays, and pushcart. The GPR operation manuals and training materials were composed and distributed to TxDOT district engineers. Using the training materials, three training classes were held in Beaumont, Dallas, and Austin districts, respectively. Field tests were also conducted in the above three districts. The test data on the fields will be presented in this report.

17. Key Words	18. Distribution Statement
GPR Development, Pavement Thickness, Dielectric Constant, Training Class, Field Tests	No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	30	

Pilot Implementation of Concrete Pavement Thickness GPR

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Implementation Report 5-4414-01-3

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Performed in Cooperation with the
Texas Department of Transportation
and the Federal Highway Administration

by the

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November 2004

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ACKNOWLEDGMENTS

We greatly appreciate the financial support from the Texas Department of Transportation that made this project possible. The support of the project director, Hua Chen, and program coordinator, Ed Oshinski, is also very much appreciated. We also thank the Project Monitoring Committee member Dr. German Claros.

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CHAPTER 1: INTRODUCTION

Ground penetrating radar (GPR) has been demonstrated to be an efficient and nondestructive tool for subsurface detection. The previous feasibility study of GPR system proved that the GPR system is able to measure the concrete pavement thickness and dielectric constant accurately. The purpose of this project is to carry out a pilot implementation of Concrete Pavement Thickness GPR (CPT-GPR), including 1) manufacturing two pulse GPR units; 2) conducting field tests in the Beaumont District, Dallas District, and Austin District; 3) composing and printing training materials and user's manual of CPT-GPR; and 4) hosting training classes in the above listed three pilot districts.

The GPR unit developed in this project is mainly composed of: a transmitter, a transmitting antenna, a receiving antenna, a radar signal receiver, a data acquisition unit, a control/circuit unit (including controlling, signal filtering and amplifying), an encoder for distance measurement, and a laptop computer used to operate the GPR system and display the results. The working principle of the GPR system is very straightforward (see Figure 2.1). When the control unit receives a command from the host computer, it triggers the transmitter to emit a short pulse wave into space via the transmitting antenna. At the same time, the control unit also sends a command to the sampling unit to pick up the coming reflected signals. The transmitted wave from the transmitting antenna usually propagates in all directions in space, and part of it will penetrate into the pavement. When the penetrated wave encounters the subsurface interface or rebar, it will be reflected back and be picked up by the receiving antenna. There is also another part of the transmitted wave propagating directly from the transmitting antenna to the receiving antenna or from the transmitting antenna to the pavement surface and then bouncing up to the receiving antenna, which is called the direct wave. The received direct wave and subsurface reflected wave are both transferred to the host laptop by sampling unit and data acquisition card. By processing the received signals like removing rebar's influence [1] and finding coming time of reflected waves [2], the thickness, dielectric constant and rebar information of the pavement can be obtained and displayed [3][4].

CHAPTER 2: MANUFACTURED CPT-GPR SYSTEM

2.1 SYSTEM BLOCK DIAGRAM

The block diagram of CPT-GPR system is shown in Figure 2.1.

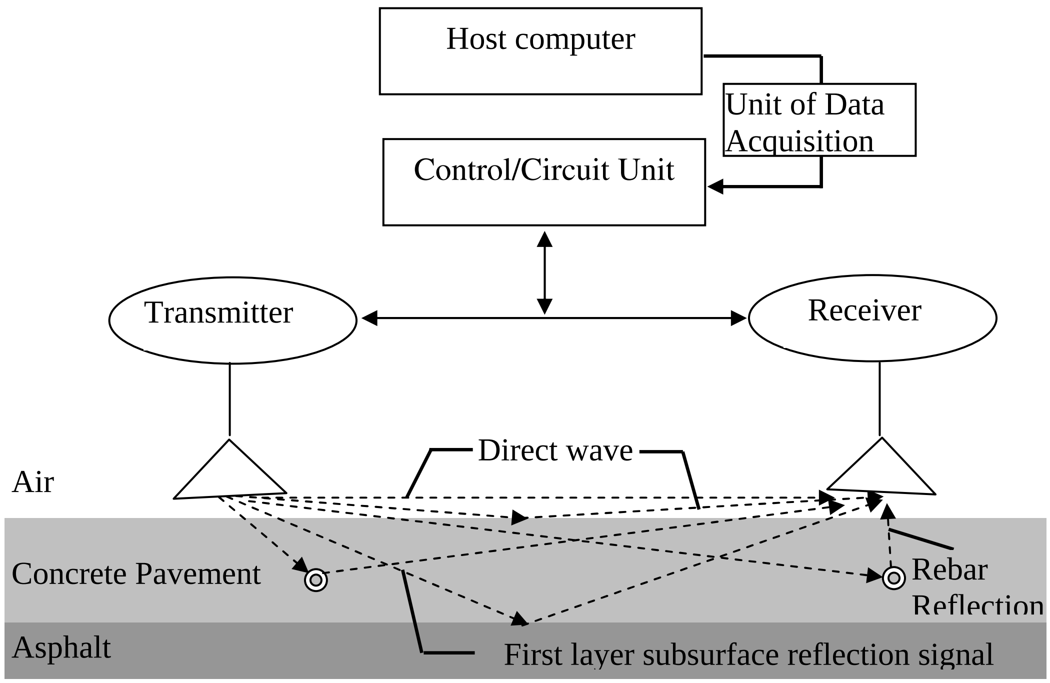

Figure 2.1 Block diagram of the CPT-GPR system.

2.2 SYSTEM PERFORMANCE DESCRIPTION

One of the two GPR systems manufactured in this project is shown in Figure 2.2. Here the GPR system is mounted on a pushing cart. The black box on top of the pushing cart contains the GPR receiver, the control/circuit unit, power supply, the host computer and the data acquisition unit, on the lid the box installs two LCD displays; and on the back side of the box installed the connection sockets to the encoder, transmitter, and receiver and the power for charging the battery; the big flat black enclosure at the bottom of the cart holds the transmitter, the transmitting antenna, and the receiving antenna; an encoder is installed on the shaft of the pushing cart beside its left rear wheel, that is used for distance measurement. The output signal is processed and displayed in a laptop computer or the LCD displays.

Figure 2.2 GPR system in measurement configuration.

The system performance is as follows:

(1) Maximum Penetration Depth: 30 inches in soil

The radar has been verified to detect pipes buried 30 inches deep in soil; however, it is not the penetration limit of the radar system.

(2) Transmit Pulse Amplitude: 250 - 530 Vp-p

Usually the higher the transmit pulse amplitude is, the deeper the radar wave can penetrate. However, the amplitude of the direct wave also increases with the strength of the transmitted pulse, and hinders the recognition of the reflected signals. The amplitudes of the transmitter pulse are compromised based on experimental results.

(3) Transmit Pulse Width: 5 ns – 10 ns

The pulse width is chosen based on its corresponding frequencies, detection resolution and penetration depth. The higher frequency provides the GPR with a higher detection resolution, but decays faster during propagation and decreases the detection depth. The GPR waves of lower frequency can propagate deeper, but have a lower resolution.

(4) System Bandwidth: DC-1.3 GHz

The transmitting waves are operated in the frequency range from 0 to 1.3 GHz.

(5) Receiver Window: 20 – 60 ns adjustable

The receiver has a time window to accept signals. Out of this time window the signals will not be recorded in the computer. In the manufactured CPT-GPR system, the time window is set at 40 ns to cover a depth range over 10 feet underground.

(6) System Clock: 100 kHz

(7) Digitization Resolution: 12 bits

(8) Antenna Type: Bowtie antenna

The Bowtie antenna is chosen for the GPR system because it has a wide bandwidth and is easy to construct.

(9) Power Consumption:

0.5 A at 12 V, this is the total power consumed by the GPR system. A car battery provides enough energy for the system to last for a few hours.

(10) Distance encoder resolution: 0.033 inch

(11) Maximum recorded trace number: 10240

(12) Maximum trace number in one page for multi-trace display: 512, total maximum 20 pages=10240/512.

(13) Thickness calculation is based on one cycle of signal traces that covers a physical range greater than the space of two adjacent transversely oriented rebars; here approximately 0.5 inch per trace, 4-4.5 feet per calculation.

(14) The algorithms for the thickness calculation include the consideration of the rebar effect. Together with the hardware, they are quite suitable for the continuous highway measurement.

(15) The GPR software is developed to operate the system, acquire data, process signals, calculate the thickness and dielectric constant of pavements, and display detection results quantitatively and graphically. All operations can be performed through the software interface shown in Figure 2.3.

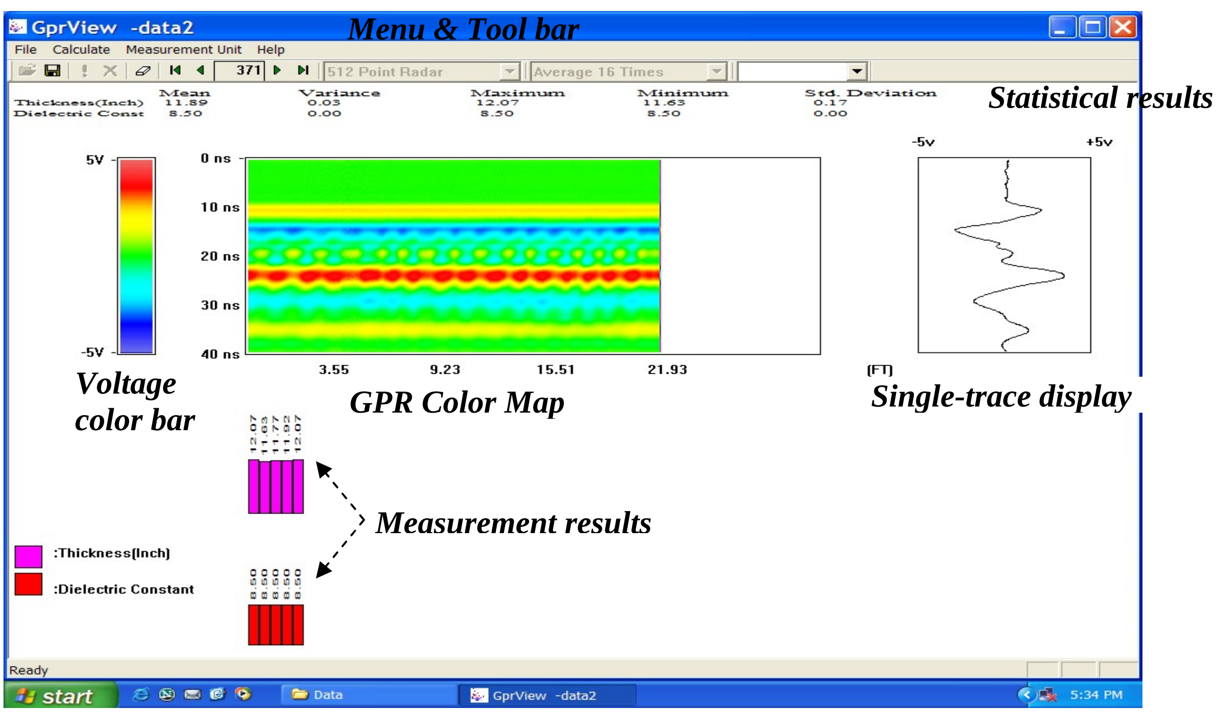

Figure 2.3 GPR software interface.

CHAPTER 3: TRAINING CLASSES AND DEMO IN TXDOT DISTRICTS

In this project, three training classes were held in the Beaumont District, Dallas District, and Austin District, respectively. The engineers in each district showed great interest in the CPT-GPR device and provided some useful advice to the researchers.

3.1 TRAINING CLASS AND DEMO IN BEAUMONT DISTRICT

A field training and demo of CPT-GPR was held in the Beaumont District on March 24, 2004. Dr. Richard Liu gave two presentations in the training class. The first presentation talked about the background, the significance and the achievements of this project; and the second presentation introduced the installation and operation of the developed GPR. The computer interface of the GPR was also discussed interactively with the engineers of Beaumont District. The field demo was carried out in the afternoon on SH 327. The following are a few photos taken at the demo site.

Figure 3.1 Demo on the interface features and operation.

Figure 3.2 Engineers are operating the equipment.

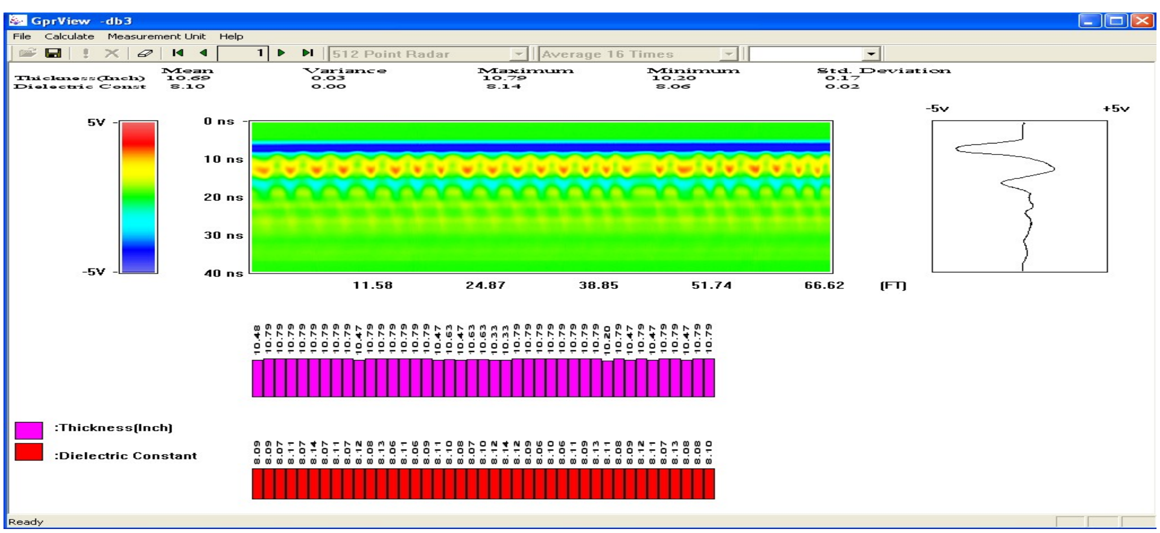

Figure 3.3 The result measured by engineers at the demo site.

3.2 TRAINING CLASS AND DEMO IN DALLAS DISTRICT

A field training class and a demo of CPT-GPR were held in the Dallas District on May 14, 2004. In the class, Dr. Richard Liu not only explained the background, the significance and the achievements of this project, but also introduced the installation and operation of the developed GPR system in detail. The field demo was carried out on Highway 30. After the demo, the engineers of Dallas District proposed some very good suggestions on how to modify the computer interface of GPR for ordinary users, such as directly displaying a real pavement structure with rebars on the computer screen instead of current color map; indicating the positions of pavement surface, rebars, and the pavement bottom on the computer screen; putting the current thickness-indicating bars upside down to represent a flat top surface, and so on. The suggestions and the interests of the Dallas District engineers encourage the researchers to develop newer versions of GPR. The following are a few photos taken at the demo site.

Figure 3.4 The test Team.

Figure 3.5 The thickness is displayed on top the GPR enclosure.

Figure 3.6 Operation of CPT-GPR by district engineers.

3.3 TRAINING CLASS AND DEMO IN AUSTIN DISTRICT

On August 3, 2004, a training class and demo were held in the Austin District. Dr. Richard Liu delivered similar lectures as he did in the Beaumont District and Dallas District. Before this training class, several field tests on Texas 183 had been performed. In the next chapter, the measured data in the Austin District (Texas 183), Beaumont District (SH 327, SH 73), and Dallas District (Highway 30), will be presented and discussed.

Special thanks should be given to all the engineers in Beaumont, Dallas, and Austin Districts for reserving conference rooms, choosing demo sites, arranging traffic control, and other efforts. Their comments and needs on using the GPR for other applications such as moisture, voids, and sinkholes in base, sub base, and overlay thickness inspire the researchers.

CHAPTER 4: MEASURED RESULTS IN THE THREE PILOT IMPLEMENTATION DISTRICTS

Due to the size of this report, it is not necessary to include all measured data here. We only present part of the data from each test site.

4.1 MEASURED DATA FROM DALLAS DISTRICT (HIGHWAY 30)

The measurement was carried out on Highway 30 over a newly paved section, where the true thickness of the pavement is known. The measurement locations were distributed on four lanes as shown in Figure 4.1. The location numbers, the real thickness, and the GPR measured results are listed in the following tables. A comparison of GPR results and the true thickness is given in Figure 4.2.

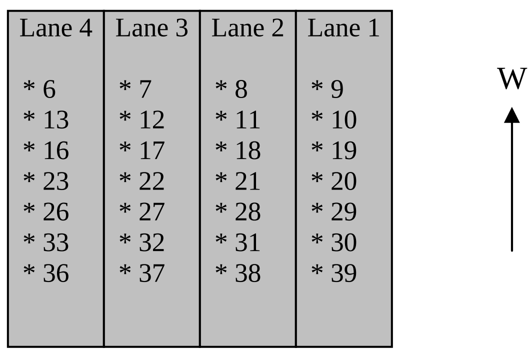

Figure 4.1 Distributions of the measurement locations on Highway 30, Dallas.

Table 4.1 Thicknesses on Lanes 1 and 2.

Lane 1				Lane 2			
Location Number	Real (mm)	GPR (mm)	Relative Error	Location Number	Real (mm)	GPR (mm)	Relative Error
9	323	323.0	0	8	318	330.0	3.77 %
10	329	315.0	-4.26 %	11	319	331.6	3.95 %
19	325	315.0	-3.08 %	18	322	319.2	-0.87 %
20	325	335.7	3.29 %	21	327	302.6	-7.46 %
29	321	302.4	-5.79 %	28	330	310.6	-5.88 %
30	314	290.1	7.61 %	31	315	330.1	4.79 %
39	312	294.1	5.74 %	38	323	306.8	-5.01 %

Table 4.2 Thicknesses on Lanes 3 and 4.

Lane 3				Lane 4			
Location Number	Real (mm)	GPR (mm)	Relative Error	Location Number	Real (mm)	GPR (mm)	Relative Error
7	318	327.4	2.96 %	6	322	335.1	4.07 %
12	323	323.3	0.09 %	13	322	321.3	-0.22 %
17	320	319.1	-0.28 %	16	321	331.6	3.30 %
22	322	335.1	4.07 %	23	324	310.8	-4.07 %
27	318	306.6	3.58 %	26	327	323.3	-1.13 %
32	319	323.3	1.35 %	33	332	335.0	0.90 %
37	321	311.5	-2.96 %	36	339	335.0	-1.18 %

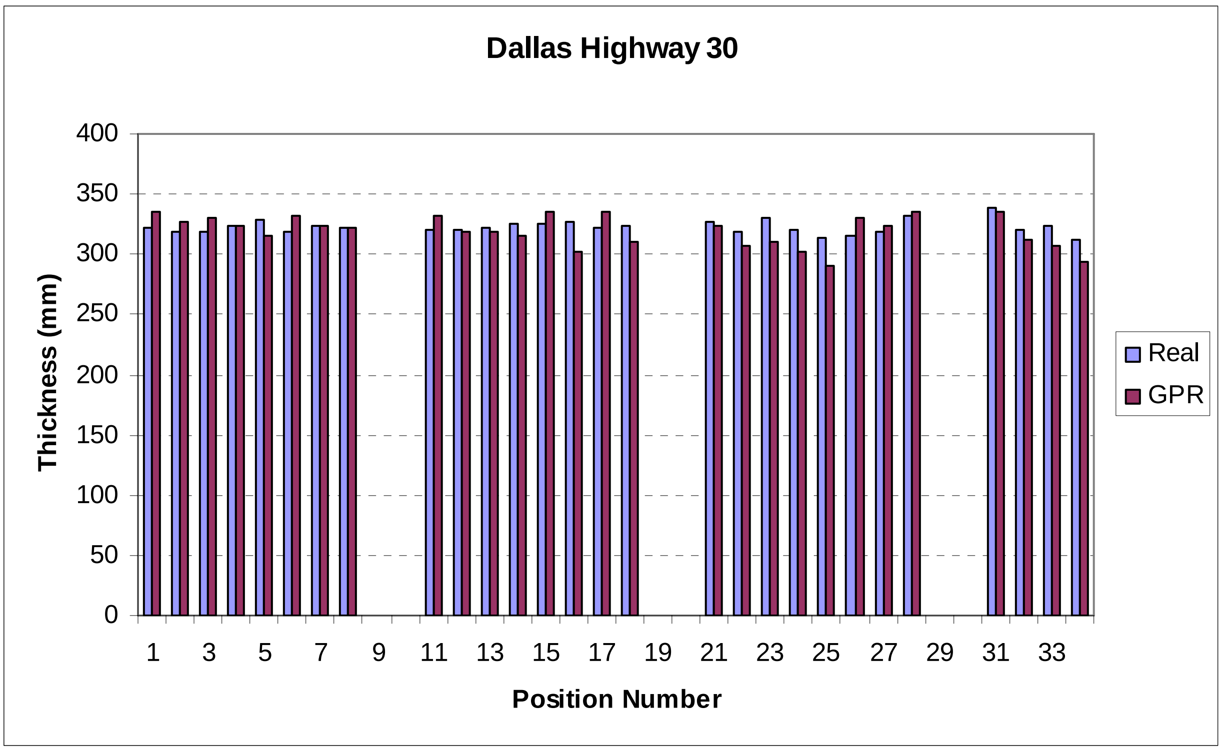

Figure 4.2 Comparison of the GPR measured thickness with real thickness on Highway 30, Dallas.

In this test, twenty-two out of twenty-eight measurements are pretty accurate, having relative errors below 5%, but six out of twenty-eight measurements showed a slightly larger error, ranging from 5% to 8%. The error is most probably due to the heavy rain the day before the test. The rainwater often blurs the reflection interface between the pavement and the base layer.

4.2 MEASURED DATA FROM AUSTIN DISTRICT (SH 183)

The pavement about one and a half miles on Texas 183 southbound was measured using the CPT-GPR system, and 42 data files were recorded. Figure 4.3 and Figure 4.4 show the first data file measured over a 317-feet-long pavement starting from Station 974+63.

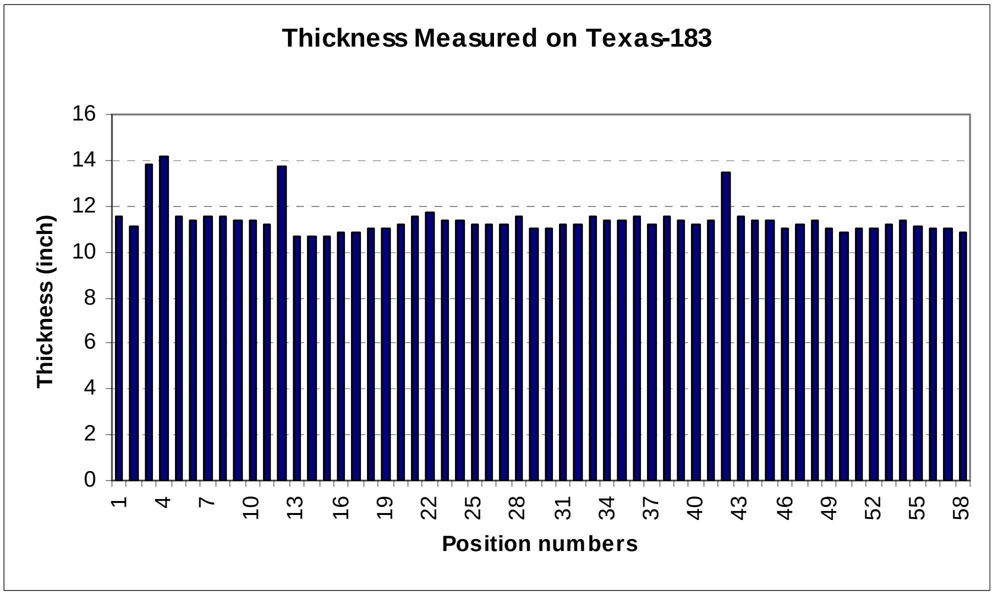

Figure 4.3 Measured thickness on Texas 183 southbound.

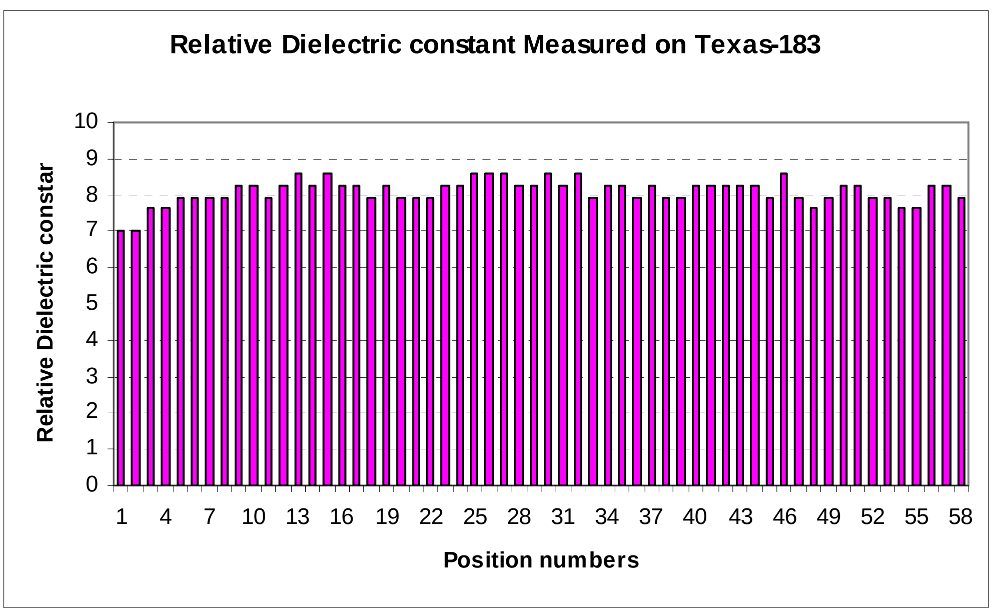

Figure 4.4 Measured dielectric constants on Texas 183 southbound.

The designed pavement thickness is 11 inches. The measured results are mostly between 10.6 to 11.2 inches. However, there are four data in Figure 4.3 showing thicknesses larger than 13 inches. They were caused by other interferences and should be removed. The other 41 data files give the similar results and they are ready to be delivered upon request.

4.3 MEASURED DATA FROM BEAUMONT DISTRICT (SH 327 AND SH 73)

Two tests have been performed in the Beaumont District, one for thickness measurement on SH 327 and the other one on SH 73 for possible underground defects or water invasion. Figure 4.5 and Figure 4.6 give the thickness and dielectric constant measured on SH 327. According to the GPR results, the average thickness of the pavement is 10.99 inch; the maximum thickness is 11.20 inch, and the minimum thickness is 10.53 inch.

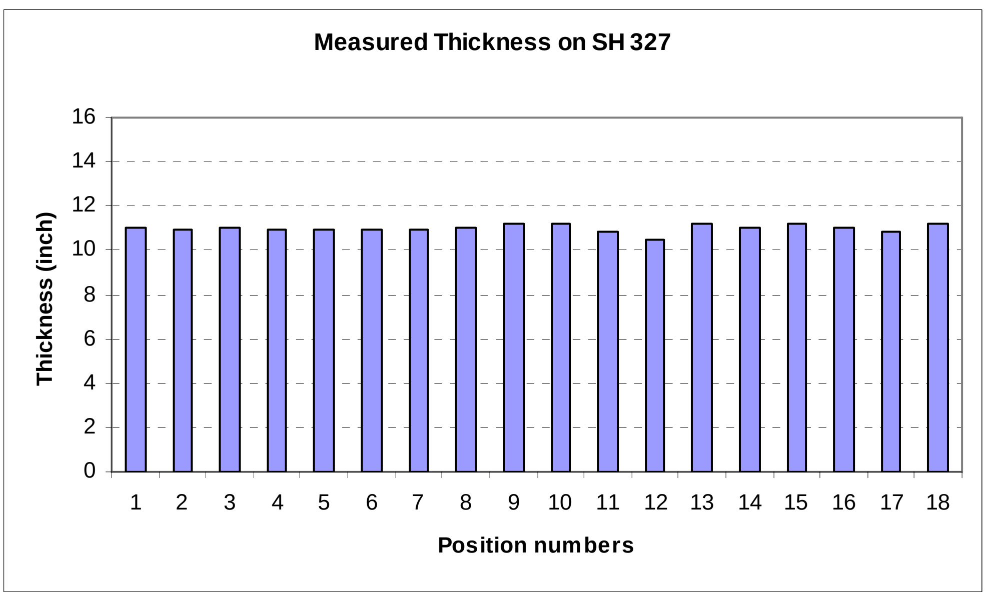

Figure 4.5 Measured thickness on SH 327.

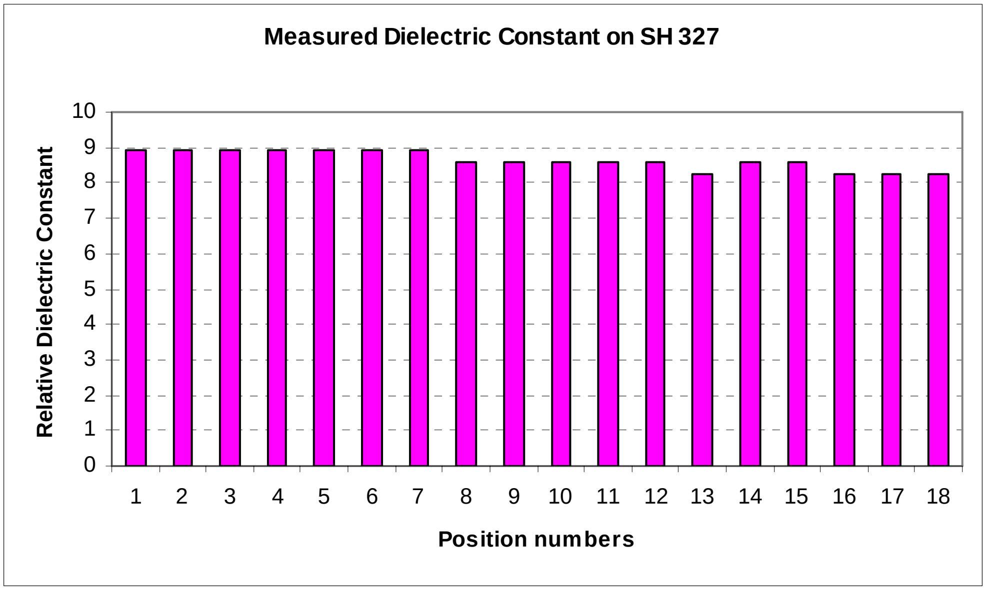

Figure 4.6 Measured dielectric constants on SH 327.

The above data have demonstrated that the manufactured CPT-GPR can measure the thickness and dielectric constant of the concrete pavement. Is it possible to use the same GPR for defects and moisture constant measurement of pavement base? To answer this question, another test was conducted to explore the possible extension of the CPT-GPR application, i.e., applying the GPR to base moisture content detection. Figure 4.7 shows one of the qualitative results measured on SH 73. In this figure, the vertical axis gives the depth (in inches) downwards, where the "0 inch" corresponds to the pavement surface; the horizontal axis denotes the distance from origin. Since the purpose here is to find possible defects, such as voids, and waters, the variation of the subsurface structure becomes the main target. To increase the accuracy of detection, the measured GPR traces are all subtracted by a selected reference signal obtained at a specified position. The color maps are composed of spatially differential signals with respect to the reference signal. Hence the map displays the regions with formation properties varying.

On the right upper corner of this figure, four blue dots can be seen at the pavement surface (0 inch). They are caused by the cracks starting from the surface downward through the pavement. The other blue spots under the pavement surface are most possibly the images of higher-moisture regions.

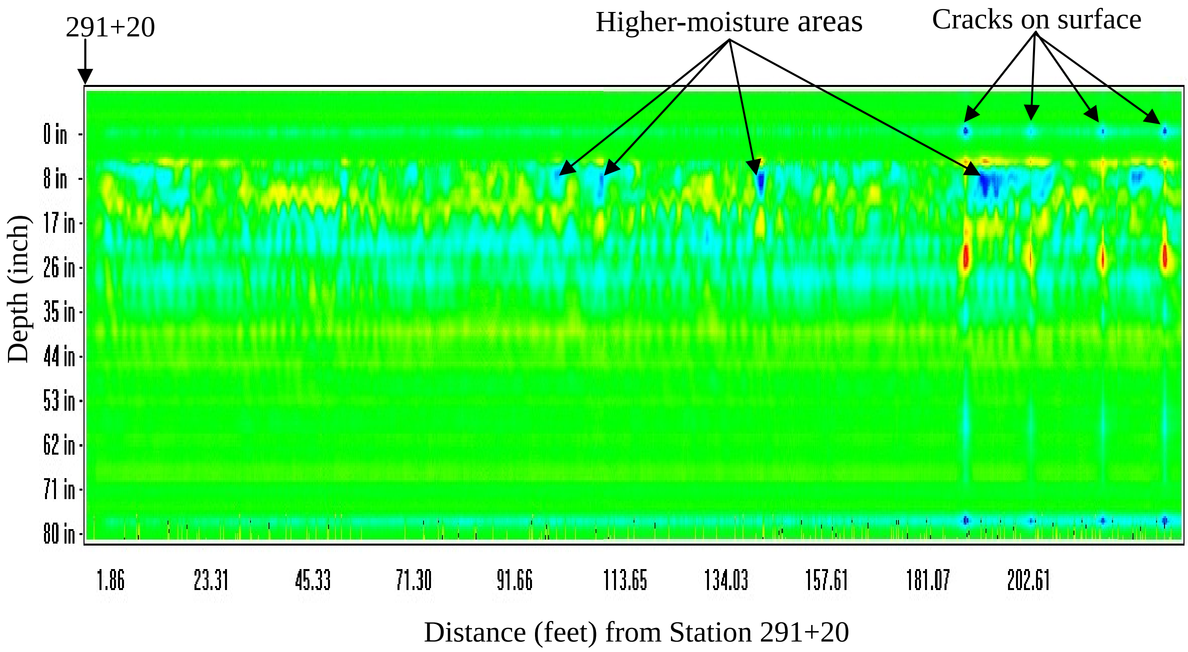

Figure 4.7 GPR Color Map 8 of SH 73 westbound.

The measured GPR image does demonstrate a high possibility of measuring the base moisture constant and defects by the manufactured CPT-GPR.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this project, two CPT-GPR units have been successfully manufactured, including electronics, thickness and dielectric constant algorithm, mechanical parts and casing, LCD displays, distance-measuring encoder, pushcart and software interface.

The GPR user manual and training materials were developed and distributed to TxDOT engineers and technicians in Austin, Beaumont, and Dallas districts. The training courses for CPT-GPR were also held in the above TxDOT districts.

Field tests of the CPT-GPR have been conducted in the Austin District, Beaumont District, and Dallas District. The measured thickness agreed with the real thickness very well.

5.2 FUTURE WORK

The manufactured CPT-GPR units are able to measure the concrete pavement thickness accurately. The measured data on SH 73 demonstrated that it is practical to apply the GPR systems to measuring moisture content and base defects of pavements if the system is properly modified. The researchers recommend the following future work:

1. Modify the hardware and software, such as antenna structure and transmitter frequency band in hardware, and data processing method for extracting moisture-content-related or subsurface defect-correlated signals in software, so that the moisture content in base materials can be accurately measured using GPR.
2. Modify the GPR cart and the cable connections so that the CPT-GPR can be hitched to a motor vehicle for easy field operations.
3. Modify software to remove the current limit on measuring range to make the CPT-GPR more flexible and reliable.

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