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16. Abstract

An accurate reliable pavement layer database (PLDB) is viewed as essential for the development of improved network and project-level pavement management applications within TxDOT. Very little layer thickness data is available within TxDOT's Pavement Management Information System. This severely impacts its capability to predict future performance and network funding requirements. In the districts, pavement layer information such as the surfacing thickness and the date of last surfacing is needed to assist with pavement rehabilitation decisions. For example, to interpret Falling Weight Deflectometer data, accurate layer thicknesses are required. While some of this data can be obtained from plans, the accuracy of plan thicknesses is often inadequate.

In recent years TxDOT has initiated several internal efforts to establish a pavement layer database. Two districts, Houston and Brownwood, have already stored plan thickness information on a large portion of their networks. In this one-year feasibility study an evaluation is made of the accuracy of the existing databases in these districts, together with an assessment of capability of using Ground Penetrating Radar (GPR) in the validation process. It was found that the plan sheets normally provide the adequate base information (although a few errors were found); however, they do not, in general, provide accurate information on the top layer thicknesses. It is concluded that the current system of using the existing plan sheets to generate the basic database is adequate, but this system must be updated with thickness information from both GPR and coring surveys. The GPR system has the additional benefit of being able to identify defects within the pavement structure. Once established, PLDB updates must become a routine operation upon any project's completion.

Recommendations include action items for both short-term and long-term PLDB development.

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RECOMMENDATIONS ON BUILDING A PAVEMENT LAYER DATABASE FOR TxDOT

by

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Report 1779-1
Project Number 0-1779
Research Project Title: Investigation of Methods and Procedures for Populating a Pavement Layer Database

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DISCLAIMER

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There is no invention or discovery conceived or reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design, or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent law of the United States of America or any foreign country.

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Mr. Guy Godfrey of the Brownwood District and Ms. Angela Batiz of the Houston District provided their district data and supplied many helpful comments about problems with the existing Road Life system. Mr. David Fink, P.E., of the Houston District initiated the study and provided continued support in his role as project director. Mr. Seungwook Lim of the Texas Transportation Institute processed much of the GPR data reported in this study. The Texas Department of Transportation and the Federal Highways Administration jointly funded this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

The Texas Department of Transportation (TxDOT) currently maintains a Pavement Management Information System (PMIS) which contains detailed pavement condition information on the entire TxDOT road network of almost 80,000 center line miles. Although detailed information is stored on the current and historic pavement conditions, very little information is available on the existing layer thicknesses and maintenance history of each individual highway segment. The principal layer information within PMIS is the pavement type field which is a 1 through 10 classification, with 1 representing Continuously Reinforced Concrete Pavements (CRCP) and 10 representing a surface treated highway. The inaccuracies and limitations of the current system are well known to the PMIS engineers within TxDOT.

Accurate knowledge of pavement layer thicknesses and material properties are important in many aspects of pavement management including:

- modeling of pavement deterioration, and
- evaluating the *"life"* of various treatments that can be used for maintenance and rehabilitation works.

As a matter of fact, ***<u>every PMIS function needs pavement layer data</u>***. Often this information is unknown, and records are inaccurate, out-of-date, or difficult to access. The pavement layer thicknesses represent an important element of the PMIS database and are needed for load rating, overlay design, and setting maintenance and rehabilitation priorities.

Knowledge of layer thicknesses is also critical in the interpretation of pavement structural test data, such as that produced by the Falling Weight Deflectometer (FWD). Incorrect assumptions regarding thickness in the data analysis will produce erroneous results, and may lead to incorrect conclusions regarding the pavement condition and the optimum rehabilitation strategy. Many state highway agencies have inaccurate records of the pavement layer thicknesses, and the actual thicknesses are often unknown.

To do a more effective job of using the existing condition data within PMIS, an accurate pavement layer/Road Life (RL) database is essential. The benefits of such a database are many; however, populating the database with accurate and current information presents a large problem. How much effort should be put into populating the database before the cost outweighs the benefits gained needs to be determined? How good is the existing RL system? Should TxDOT initiate detailed field coring to establish and verify the database or can new Nondestructive Testing (NDT) techniques assist? These questions have been addressed in this study. The focus of this report will be on developing a Pavement Layer Database (PLDB) for the flexible pavements or asphalt covered rigid pavements in Texas. It is thought that the required information on rigid pavements in their first performance period can be readily obtained from the existing plan sheets. The vast majority of the Texas highway network is flexible or asphalt surfaced pavements. Developing a reliable PLDB for flexible pavements is more challenging because of the amount of maintenance that flexible pavements receive.

In Chapter 2 a discussion is presented as to the key elements to include in a pavement layer database, this is based largely upon the recommendations of the Pavement Management Task Force which was active in the early 1990s in establishing PMIS. Chapter 3 will describe the status of the current Road Life development effort. The strengths and weaknesses of the system will be described together with action items for system improvement. The accuracy of the current system will be described in Chapter 4 based on a field evaluation of two pilot areas, one in the Houston District the other in Brownwood. GPR testing and field coring was undertaken to judge the adequacy of the stored information. Recommendations for both short- and long-term development efforts are presented in Chapter 5. The short-term recommendations are based on developing a basic pavement layer system to meet the current needs of TxDOT. The long-term recommendations will look at potential use of new technologies in future system development.

CHAPTER 2

WHAT TO INCLUDE IN A PAVEMENT LAYER DATABASE

2.1 INTRODUCTION

To be successfully implemented, the objectives of establishing an automated PLDB must be supported by both the pavement management engineers in Austin who are interested in improving network level decision-making capabilities and the district pavement management engineers who are interested primarily in project level decisions. It is the district offices which currently maintain and update the plan profile sheets and it is these sheets which will form the basis for any development effort. Any efforts to build the PLDB by in-house forces or through outside consultants will need district support, as a minimum. District help will be needed to help the contractors find all necessary information. As will be discussed below, district "buy-in" to the development of a PLDB is uncertain primarily because the scope and objectives of the system have not been defined, and how the proposed system will assist their everyday project level duties is unclear.

In this chapter the researcher proposes to discuss the current uses of pavement layer information at both the network and project levels. The researcher recommends the development of a "minimum PLDB" with only those items judged critical at this time being stored. The background to these recommendations will be presented in this chapter. As will be presented in Chapter 5 both short-term and long-term development efforts are proposed. It is proposed that the short-term development of the minimum system will meet most of the network level needs but only some of the project level data requirements. It is the long-term development effort that will be aimed at expanding the availability of subsurface pavement layer data and condition that will truly help with project level decisions.

Network Level Uses of Pavement Layer Data. The only Pavement Layer Data that is stored with PMIS is the pavement type field, a numeric value applied to each 0.8 km (0.5 m) inspection unit. The definition of the pavement types is shown in Table 1, and the limitations of this system were described in TTI Report 1420-1 (1). In summary,

a) The existing pavement types are often wrong since they do not match existing structure. This field was initially generated from TxDOT automated Road Life system in the early 1980s, and it was supposed to be maintained by district users of the PMIS system but few have provided updates.

b) Not all of the commonly used pavement design types fall into one of the 10 available categories, for example chemically stabilized bases can not be identified.

In addition within PMIS the date of last surfacing and the type of last surfacing is not known. This severely limits the usefulness of the system to identify poorly performing sections. The biggest fault with the current PMIS is its inability to distinguish good from poorly performing pavements. This is because a pavement can have a high score primarily because it has just received a thin maintenance treatment. Following historical trends in pavement condition may help in this regard but with pavements in the good/fair category, which receive frequent maintenance, trends are difficult to establish. Efforts to address this problem with the development of a Structural Strength Index, TTI Report 409-3F(2), have had limited success primarily because of the lack of a PLDB.

In addition to this problem, the lack of a PLDB restricts the PMS engineers from addressing many of the material-specific problems being proposed by TxDOT's senior management. For example "How long are Coarse Matrix high Binder (CMHB) surfacings lasting?" Needless to say the pavement management engineers are big proponents for the development of a reliable PLDB.

<u>Project (District) Level Uses of Pavement Layer Data</u>. The main function of the district pavement engineers is to assist the area offices with the selection and prioritization of maintenance and rehabilitation projects. As part of this process they will review proposed pavement design and rehabilitation options. On major projects they will supervise nondestructive FWD testing and coordinate with the district lab on coring and lab testing.

When evaluating area office proposals, the district pavement engineers often consider the PMIS condition ratings, the date of last surfacing, and the typical section for the project. The date and typical section information is usually available in the district or area offices. Several districts (Fort Worth, for example) are developing graphical maps showing date and type of last surfacing for their networks. Once available this information can readily be used to assist in checking the adequacy of treatment proposed. Once a review of these data is complete, the district pavement engineer can classify the pavements into a) those performing adequately and in need of resurfacing or b) those with structural or performance problems which need a project level investigation.

Because most of the information needed to make these project level decisions can (with some difficulty) be found in the districts offices, it is often difficult to justify how the development of an automated PLDB will improve this situation, particularly if, as originally proposed, most of the development cost and time was to be from limited district resources. With the question in mind "Why should a district support the development of a PLDB?" the following arguments are presented in support of system development:

1) The current plan profile sheets often do not reflect the current pavement structure. All of the pavement design analysis and design decisions are based on reasonable layer thickness estimates. In particular the thickness of the top layer is critical in structural analysis and load zoning decisions. It is the top layer which is most inaccurate when referencing plan sheet thicknesses.
2) Improved PLDB will permit the PMIS group to provide more useful reports of our pavement condition. For example "list all sections that are less than eight years old and have more than 30% alligator cracking." This cannot be answered with the current PMIS. The districts annually spend a large amount of money collecting PMIS data, the value of the data would be greatly improved with a PLDB.
3) It is very difficult to evaluate how maintenance or rehabilitation treatments are performing in any district. This currently requires a manual tie-in between treatment and condition data. Feedback on design decisions is critical but this is rarely done because of the difficulty of merging different data sets.
4) The long-term PLDB discussed in Chapter 5 includes a recommendation to collect GPR data on a large segment of major highways. GPR data has the added advantage of being able to identify potential defects in the subsurface which will be critical in evaluating rehabilitation alternatives.

In the remainder of this report the components of a PLDB will be discussed and the problems with the current efforts will be documented. To be of value to a district the PLDB must include accurate structure information in both the longitudinal and transverse direction. The plan profile sheets provide much critical transverse information particularly when sections are widened. The longitudinal profiles demonstrate how these thicknesses vary along the section. This is critical in FWD analysis.

2.2 PMIS INFORMATION REQUIREMENTS (CIRCA. 1990)

In the development of the PMIS system in the early 1990s a task force was assembled to identify the long-term data requirements for system development. As part of that mission, the pavement layer information requirements were identified. These are summarized in Appendix A of this report. The items were prioritized as Mandatory (M), Desirable (D), and Optional (O). The mandatory items were judged as essential for the development of an effective Pavement Management System. These system requirements were part of the driving force behind the prototype RL Development effort that is currently underway in TxDOT which will be described in Chapter 3 of this report.

2.3 RECOMMENDATIONS ON MINIMUM SYSTEM REQUIREMENTS

In the short-term it is proposed that a minimum PLDB be developed to meet most of the needs of the Austin based PMIS group. This system will contain only critical items that will be of immediate use in network and project level applications. This current system as a minimum must include the pavement structural information from the plan sheets for the outside lane outside wheel path. The following five items are considered the mandatory minimum:

1. Total Asphalt Thickness (accumulation of all layers above original base)
2. Type of Last Surfacing (expanded code from that shown in Appendices A and B, as a minimum the type of HMAC, CHMB, Asphalt Rubber, Type C, etc. should be specified. Similar detail is required for maintenance treatments.)
3. Date of Last Surfacing

4. Type of Base (ASB, CRCP, Jointed Concrete, Concrete with Granular overlay, Flexible base, Lightly stabilized, Heavily stabilized, etc.)
5. Base Thickness

Two additional items, subbase type and subbase thickness, are highly desirable and should potentially be included on the list. The state has many pavements where a new structural base layer and surface are laid directly on top of an old structure. Also a capability of defining both base and subbase layers would handle coding of the bondbreaker and base layers currently placed beneath most concrete pavements.

None of the existing coding systems, examples of which are shown in Appendices A and B, are comprehensive enough to completely handle the variety of material types used around the state. A poll of district pavement engineers should be undertaken to determine a satisfactory list of base and surfacing types.

In developing a short list of mandatory items for the basic system, it is recognized that several legitimate information needs may go unaddressed. However, in defense of the minimum system, the following points are raised:

1) TxDOT has made little progress in the past 10 years in the development of a system, and there is still considerable confusion and a lack of support for such an effort in some senior levels. By making a comprehensive data collection plan, the initial cost may kill the project.
2) By establishing a minimum system, TxDOT should not just focus on the one time build activity. It is essential to build and implement a system update capability as a standard procedure which captures all maintenance and rehabilitation work completed on the pavement.
3) The minimum system concept is viewed as a simple expansion of the RL system development effort to be discussed in the next section of this report.
4) The successful initial implementation of the minimum system will provide impetus to the long-term Road Life development plan to be proposed in Chapter 5 which

includes the use of new technologies, Geographic Information System (GIS), GPR, and digitized pavement images combined with digitized plan profile sheets. If the costs/benefits of the minimal system implementation can not be defined, then there will be little justification for full-scale statewide implementation of a more comprehensive and expensive system.

CHAPTER 3

STATUS OF ROAD LIFE DEVELOPMENT PROJECT WITHIN TxDOT

3.1 INTRODUCTION

This chapter will describe the current RL system and the efforts by the Houston and Brownwood Districts to build an automated PLDB from both the available plan sheets and the old RL files. The problems of automating the plans will be described. The current activities result in a flat file which, in itself, is of little use to district personnel. Output reports must be developed to provide input into both the network and project level decision-making process. It is acknowledged that if TxDOT is to build a PLDB then automating the existing plans will be a crucial part of that process. There are several critical data elements (base type/thickness) that can only be accurately and economically obtained from the plans. An action plan is proposed to improve the existing system.

3.2 ROAD LIFE SYSTEM

TxDOT has maintained a manual paper pavement layer tracking system since the early days of the department. This is called the *Road Life (RL) System.* A example of a single page in the manual "Log Record of Project Construction and Retirements" is shown in Figure 1. As new projects were completed, the plans were forwarded to the old Transportation Planning Division (D10) where a team of draftsmen collated the information on pavement layer thickness changes. At its height in the late 1970s almost 30 draftsmen were employed in maintaining the RL system. The updated logs were distributed to every district office and widely used by district design and maintenance engineers.

With the advent of computerized databases, efforts were made to automate the manual system into a computer-based pavement layer database. An automated file has been maintained since the 1960s. Clearly the automated RL system must be the starting point for developing an improved pavement layer database to support PMIS applications. In recent years efforts have been made to access this information and to reformat it into a data file of use to district pavement engineers. An example of one of these new output reports is shown in Figure 2 for IH 35 in the Austin District.

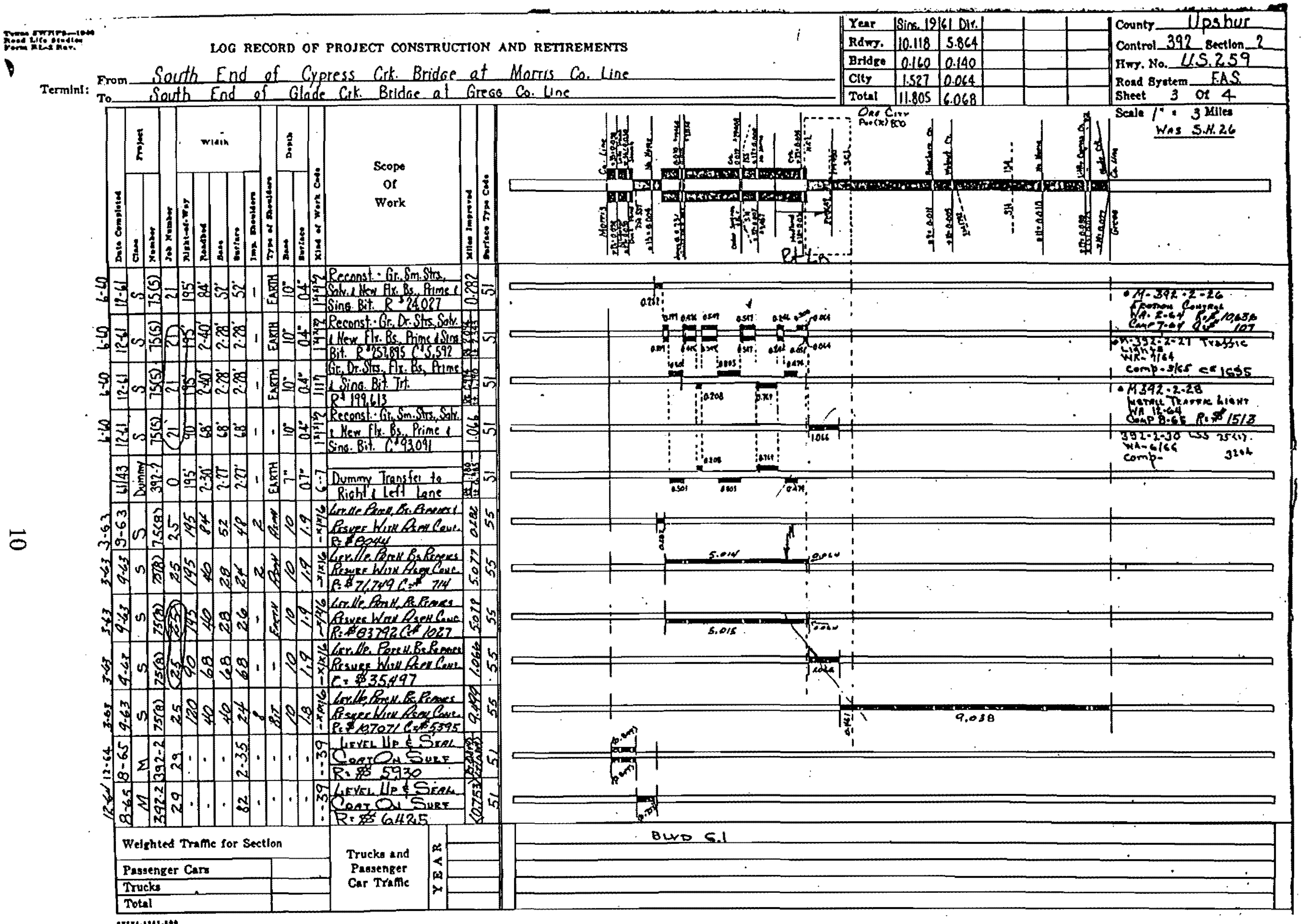


Figure 1. Example of the Manual TxDOT Road Life Logs.

TEXAS DEPARTMENT OF TRANSPORTATION
ROADWAY LIFE DATA ENTRY SYSTEM
DSN=D48.RLS.DATA.KSDS

14:23 THURSDAY, NOVEMBER 14, 1996 1

DIST	CNTY	CSJ	HIGHWAY	BEGINNING REFERENCE MARKER	ENDING REFERENCE MARKER	RDBD	LAYER	MATERIAL USED	WIDTH (FEET)	THICKNESS (INCHES)	DATE
14	106	0016-02-023	IH0035	0212 +00.321	0221 +00.968	L	SUBGRADE	UNKNOWN	65.0	6.0	09/1961
							SUBBASE	CRUSHED LIMESTONE	40.0	12.0	09/1961
							BASE	CRUSHED LIMESTONE	40.0	12.0	09/1961
							ORIGINAL SURFACE	SURFACE TREATMENT	40.0	.	09/1961
							ORIGINAL SURFACE	ASPHALT CONCRETE PAVEMENT	24.0	2.5	09/1961
						R	SUBGRADE	UNKNOWN	65.0	6.0	09/1961
							SUBBASE	CRUSHED LIMESTONE	40.0	12.0	09/1961
							BASE	CRUSHED LIMESTONE	40.0	12.0	09/1961
							ORIGINAL SURFACE	SURFACE TREATMENT	40.0	.	09/1961
							ORIGINAL SURFACE	ASPHALT CONCRETE PAVEMENT	24.0	2.5	09/1961
		0016-02-025	IH0035	0206 +00.621	0212 +00.321	L	SUBGRADE	UNKNOWN	65.0	6.0	02/1962
							SUBBASE	CRUSHED LIMESTONE	40.0	12.0	02/1962
							BASE	CRUSHED LIMESTONE	40.0	12.0	02/1962
							ORIGINAL SURFACE	SURFACE TREATMENT	40.0	.	02/1962
							ORIGINAL SURFACE	ASPHALT CONCRETE PAVEMENT	40.0	2.3	02/1962
						R	SUBGRADE	UNKNOWN	65.0	6.0	02/1962
							SUBBASE	CRUSHED LIMESTONE	40.0	12.0	02/1962
							BASE	CRUSHED LIMESTONE	40.0	12.0	02/1962
							ORIGINAL SURFACE	SURFACE TREATMENT	40.0	.	02/1962
							ORIGINAL SURFACE	ASPHALT CONCRETE PAVEMENT	40.0	2.3	02/1962
		0016-02-059	IH0035	0206 +00.621	0221 +00.968	L	OVERLAY	SURFACE TREATMENT	40.0	.	06/1975
							OVERLAY	ASPHALT CONCRETE PAVEMENT	24.0	1.5	06/1975
						R	OVERLAY	SURFACE TREATMENT	40.0	.	06/1975
							OVERLAY	ASPHALT CONCRETE PAVEMENT	24.0	1.5	06/1975
		0016-02-064	IH0035	0206 +00.621	0221 +00.968	L	OVERLAY	ASPHALT CONCRETE PAVEMENT	40.0	3.0	02/1984
						R	OVERLAY	ASPHALT CONCRETE PAVEMENT	40.0	3.0	02/1984

Figure 2. Output from TxDOT's Automated Road Life File (Fink 1996).

This file was created by pulling the plan sheets identified in the Road Life logs and manually entering them into the proposed RL file. This file was created by Mr. David Fink, P.E., formerly of the Pavement Design Division, as a prototype system. As can be observed from Reference Markers 206 to 212, the pavement was constructed in 1962 and maintained in 1975 and 1984 with 1.5 and 3 in overlays. Therefore the current structure should be 6.8 in of asphalt over a 24 in flexible base. How good are the thickness estimates obtained from this automation of the as-built plans? The validation study will be described in Chapter 4 of this report.

Two factors have occurred which raise questions concerning the accuracy and usefulness of the data stored in the RL system. The first is that in the early 1980s, in a recessionary period, less resources were dedicated to maintaining the RL system, and for several years no updates were made. In the mid 1980s the updates to the RL system were assigned to the TxDOT districts rather than the headquarters in Austin. While it is acknowledged that several districts have done an excellent job in maintaining and updating the RL logs and maintaining a library of the as-built plans, other districts did not have the manpower to adequately maintain the RL files. Another concern was that the RL system did not keep track of non-contract work or maintenance activities, some of which may have been substantial such as milling and overlaying. The definition of what constitutes maintenance is also a concern, it is usual that maintenance is any activity that occurs over a limited length of pavement. Therefore on lower volume highways a complete reconstruction of a 1 mi section of highway may be classified as maintenance and therefore no updates will be made to the RL system.

3.3 DISTRICT PAVEMENT LAYER DATABASES

In the mid 1990s the Pavement Management group recognized the need for an updated PLDB and initiated an in-house development effort. The layer coding system shown in Appendix B was developed. A mainframe updating system was developed and two districts, Brownwood and Houston, volunteered to field test the new system. The district approaches were different. In Brownwood a person experienced with plan sheets and TxDOT automation (Mr. G. Godfrey) was selected to build the system. In Houston summer students were hired and trained to interpret the plan sheets and input the data.

2638-05-002	09/1961	23	42	SH0206	K	0324	+00.000	0324	+01.149	2	ORIGINAL SURF	SURFACE TREATMENT	36.0	.
2638-05-002	09/1961	23	42	SH0206	K	0324	+00.000	0324	+01.149	3	SEAL COAT	CHIP SEAL	24.0	0.2
2638-05-002	09/1961	23	42	SH0206	K	0324	+00.000	0324	+01.149	1	BASE	CRUSHED LIMESTONE	36.0	15.0
0452-03-013	09/1961	23	42	SH0206	K	0324	+01.149	0328	+01.310	2	ORIGINAL SURF	SURFACE TREATMENT	36.0	.
0452-03-013	09/1961	23	42	SH0206	K	0324	+01.149	0328	+01.310	3	SEAL COAT	CHIP SEAL	24.0	0.2
0452-03-013	09/1961	23	42	SH0206	K	0324	+01.149	0328	+01.310	1	BASE	CRUSHED LIMESTONE	36.0	15.0
0452-03-019	09/1988	23	42	SH0206	K	0328	+01.310	0344	+01.940	2	ORIGINAL SURF	SURFACE TREATMENT	36.0	.
0452-03-019	09/1988	23	42	SH0206	K	0328	+01.310	0344	+01.940	3	SEAL COAT	CHIP SEAL	24.0	0.2
0452-03-019	09/1988	23	42	SH0206	K	0328	+01.310	0344	+01.940	1	BASE	CRUSHED LIMESTONE	36.0	9.0
0054-05-004	06/1988	23	42	SH0206	K	0347	+00.000	0347	+01.061	1			36.0	2.0
0054-05-004	06/1988	23	42	SH0206	K	0347	+00.000	0347	+01.061	3	OVERLAY	ASPHALT CONCRETE PAV	36.0	1.5
0054-05-004	06/1988	23	42	SH0206	K	0347	+00.000	0347	+01.061	2	SEAL COAT	CHIP SEAL	36.0	0.2
0078-03-029	11/1988	23	42	SH0206	K	0347	+01.309	0350	+00.018	4	ORIGINAL SURF	ASPHALT CONCRETE PAV	62.0	1.5
0078-03-029	11/1988	23	42	SH0206	K	0347	+01.309	0350	+00.018	3	BASE	CRUSHED LIMESTONE	64.0	8.0
0078-03-029	11/1988	23	42	SH0206	K	0347	+01.309	0350	+00.018	2	SUBBASE	CRUSHED LIMESTONE	64.0	6.0
0078-03-029	11/1988	23	42	SH0206	K	0347	+01.309	0350	+00.018	1	SUBGRADE	UNKNOWN	64.0	6.0
0078-03-034	10/1991	23	42	SH0206	K	0347	+01.309	0350	+00.018	1	SEAL COAT	MICRO SEAL	86.0	0.2
0078-03-999	01/1917	23	42	SH0206	K	0350	+00.018	0354	+00.326	2	ORIGINAL SURF	ASPHALT CONCRETE PAV	26.0	1.5
0078-03-999	01/1917	23	42	SH0206	K	0350	+00.018	0354	+00.326	1	BASE	CRUSHED LIMESTONE	44.0	10.0
0078-03-027	07/1985	23	42	SH0206	K	0350	+00.018	0354	+00.326	2	ORIGINAL SURF	SURFACE TREATMENT	40.0	.
0078-03-027	07/1985	23	42	SH0206	K	0350	+00.018	0354	+00.326	3	SEAL COAT	CHIP SEAL	24.0	0.2
0078-03-027	07/1985	23	42	SH0206	K	0350	+00.018	0354	+00.326	1	BASE	CRUSHED LIMESTONE	40.0	5.5
0078-03-035	06/1992	23	42	SH0206	K	0350	+00.027	0354	+00.168	1	SEAL COAT	CHIP SEAL	40.0	0.2
0054-04-082	07/1996	23	42	US0067	K	0586	+00.000	0592	+00.839	1	SEAL COAT	CHIP SEAL	48.0	0.2
0054-04-018	08/1940	23	42	US0067	K	0586	+00.000	0592	+01.917	3	ORIGINAL SURF	ASPHALT CONCRETE PAV	22.0	1.5
0054-04-018	08/1940	23	42	US0067	K	0586	+00.000	0592	+01.917	2	BASE	CRUSHED LIMESTONE	36.0	6.0
0054-04-018	08/1940	23	42	US0067	K	0586	+00.000	0592	+01.917	1	SUBBASE	CALICHE	44.0	4.0
0054-04-053	08/1977	23	42	US0067	K	0586	+00.000	0592	+01.917	2	ORIGINAL SURF	SURFACE TREATMENT	56.0	.
0054-04-053	08/1977	23	42	US0067	K	0586	+00.000	0592	+01.917	3	SEAL COAT	CHIP SEAL	48.0	0.2
0054-04-053	08/1977	23	42	US0067	K	0586	+00.000	0592	+01.917	1	BASE	CRUSHED LIMESTONE	42.0	6.0
0078-05-006	10/1966	23	42	US0067	L	0592	+01.917	0594	+00.328	6	ORIGINAL SURF	ASPHALT CONCRETE PAV	52.0	2.5
0078-05-006	10/1966	23	42	US0067	L	0592	+01.917	0594	+00.328	3	BASE	CRUSHED LIMESTONE	60.0	10.0
0078-05-006	10/1966	23	42	US0067	R	0592	+01.917	0594	+00.328	5	ORIGINAL SURF	ASPHALT CONCRETE PAV	52.0	2.5
0078-05-006	10/1966	23	42	US0067	R	0592	+01.917	0594	+00.328	4	BASE	CRUSHED LIMESTONE	60.0	10.0
0078-05-999	01/1917	23	42	US0067	K	0594	+00.328	0602	+00.187	2	ORIGINAL SURF	SURFACE TREATMENT	26.0	.
0078-05-999	01/1917	23	42	US0067	K	0594	+00.328	0602	+00.187	1	BASE	CRUSHED LIMESTONE	42.0	10.0
0078-05-006	10/1966	23	42	US0067	K	0594	+00.328	0602	+00.187	2	ORIGINAL SURF	ASPHALT CONCRETE PAV	26.0	1.5
0078-05-006	10/1966	23	42	US0067	K	0594	+00.328	0602	+00.187	1	BASE	CRUSHED LIMESTONE	42.0	8.0
0078-03-032	08/1991	23	42	US0067	K	0602	+00.187	0606	+00.525	4	ORIGINAL SURF	SURFACE TREATMENT	44.0	.
0078-03-032	08/1991	23	42	US0067	K	0602	+00.187	0606	+00.525	5	SEAL COAT	CHIP SEAL	24.0	0.2
0078-03-032	08/1991	23	42	US0067	K	0602	+00.187	0606	+00.525	3	BASE	CRUSHED LIMESTONE	44.0	4.0
0078-03-032	08/1991	23	42	US0067	K	0602	+00.187	0606	+00.525	2	SUBBASE	CRUSHED LIMESTONE	57.0	8.0
0078-03-032	08/1991	23	42	US0067	K	0602	+00.187	0606	+00.525	1	SUBGRADE	UNKNOWN	64.0	8.0

Figure 3. Extract from the TxDOT Road Life Data File Developed by Mr. G. Godfrey of the Brownwood District.

In Brownwood a total of three counties were entered into the database. An example of the resulting flat file is shown in Figure 3. The current system does not have any output capabilities, such as graphical representation of the data; therefore, it is very difficult to perform basic functions such as checking for missing data items. The problems with the current system will be described in the next section. It was estimated that it takes approximately one man-month per county to extract, interpret, and enter the thickness data from the plan sheets.

The Houston District did not focus on a fixed area but updated sections based on the accessibility of the plans. Approximately 30% of the highways were entered into the proposed RL file.

Of the two approaches the use of experienced personnel is the preferred approach. The interpretation of plan sheets, particularly the old sheets, is difficult. It requires someone familiar with TxDOT terminology and design practices. In the next section of this report the problems identified with the current RL automation project will be summarized together with an action plan on how to improve future efforts.

3.4 PROBLEMS WITH CURRENT RL SYSTEM AND ACTION ITEMS

During the current system of interpreting the plan sheets, several difficulties were documented primarily by Mr. Godfrey of the Brownwood District, as listed below.

1. Standard Coding Manual

   If a statewide effort is going to be undertaken to automate the plan sheets, then it will be essential to develop a set of standards for all districts to follow. Many questions will arise, and these should be documented. If a large effort is to be undertaken then training schools should be initiated to ensure uniformity.

2. Missing Codes

   The available codes for storing layer thickness data are shown in Appendix B of this report. Currently there are no codes to enter fabric underseals, bondbreaker layers beneath CRCP, or stabilized bases such as used in the Houston District. There is an urgent need to update these available codes on a regular basis.

3. Missing Plans

   Although it was reported as rare in several instances, no plan sheets are available for a section of highway. No guidelines are given on what to do in these cases.

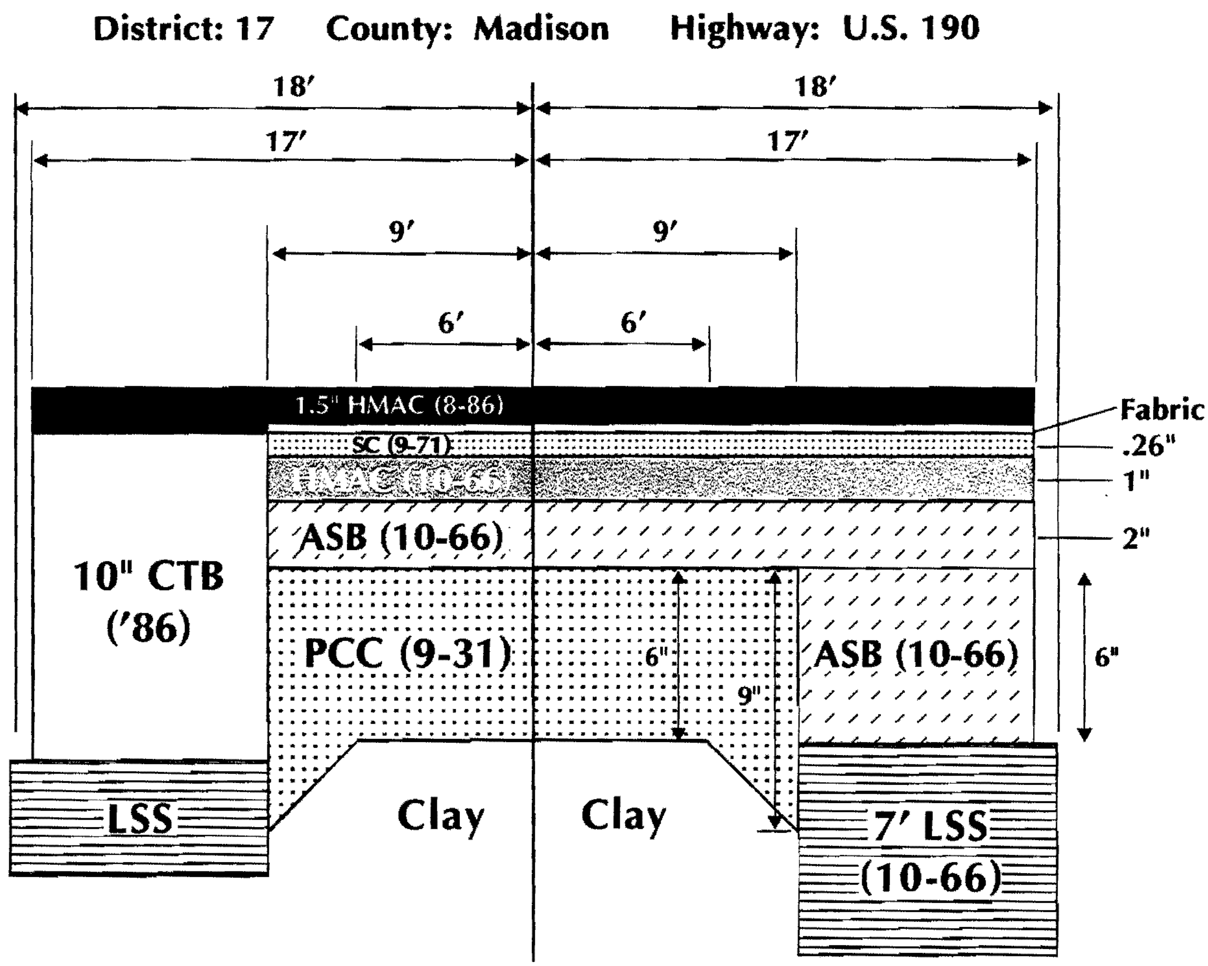
4. Complexity of Plan Sheets

   Figure 4 gives examples of complex typical sections. The upper structure has received two different widenings and has a Portland Cement Concrete (PCC) slab in the central portion of the highways. The lower section shows the widened section has a tapered base throughout the outside lane. In both cases the coder has to enter a base type and thickness. This type of problem is fairly common particularly on widened sections. In some cases the new roadbed will switch alignments from the right of the existing to the left and back again several times. Often the old plans do not show where these changes occur, and this makes it impossible to show the true pavement structure with any accuracy. Guidelines are clearly required to handle these complex cases.

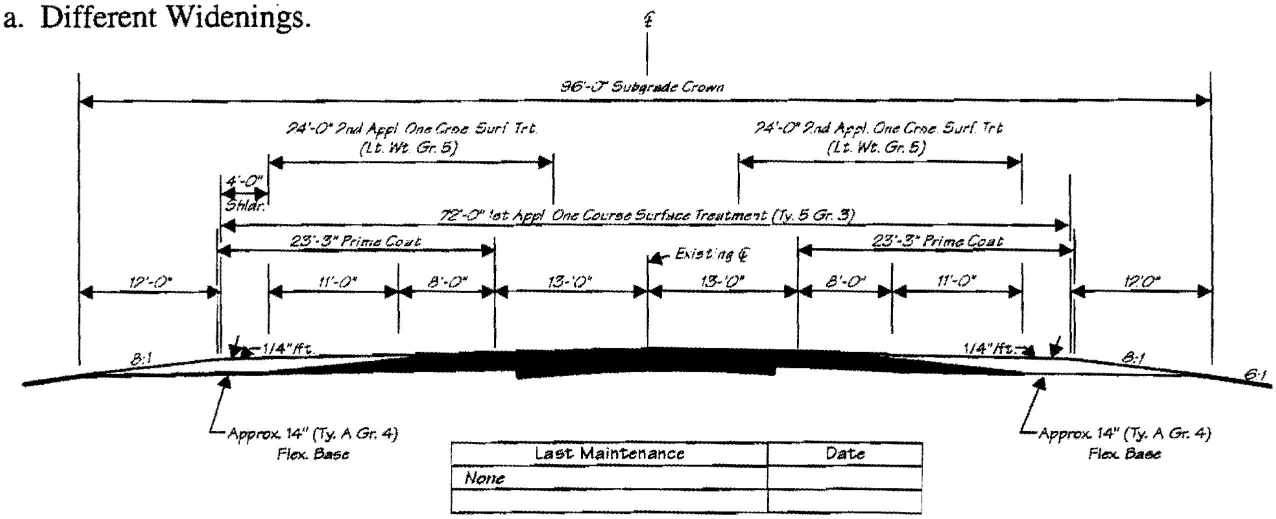
   The problem sections shown in Figure 4 demonstrate the 3-D nature of a PLDB. The current focus within the RL project is to store thicknesses in two dimensions, longitudinally along the highway. Clearly in many pavements around the state a uniform section does not exist across the highway. It must be acknowledged that the typical transverse section sheets are of great interest to district pavement engineers in their efforts to understand pavement performance and to plan future rehabilitation activities. If the automated PLDB is to be of use to districts, it should include both the longitudinal and transverse pavement profiles. This is discussed later in Section 5 under the long-term recommendations.

5. Develop System Outputs

   The current RL development effort is focused upon building a flat file of layer type and thickness information. In its current form it is of limited use to either Austin Divisions or Districts. For example, it is very difficult to check for completeness or missing sections. As a top priority item it will be necessary to create output for this system. Figure 5 shows a graphic output which was manually developed in this research study from the Brownwood District's new RL file. All of the information is available in the flat file (Figure 3) but it becomes much more useful when placed in graphic form. As a minimum both a graphical



a. Different Widenings.



b. Tapered Base Layer in Outside Lane.

Figure 4. Complex Typical Sections.

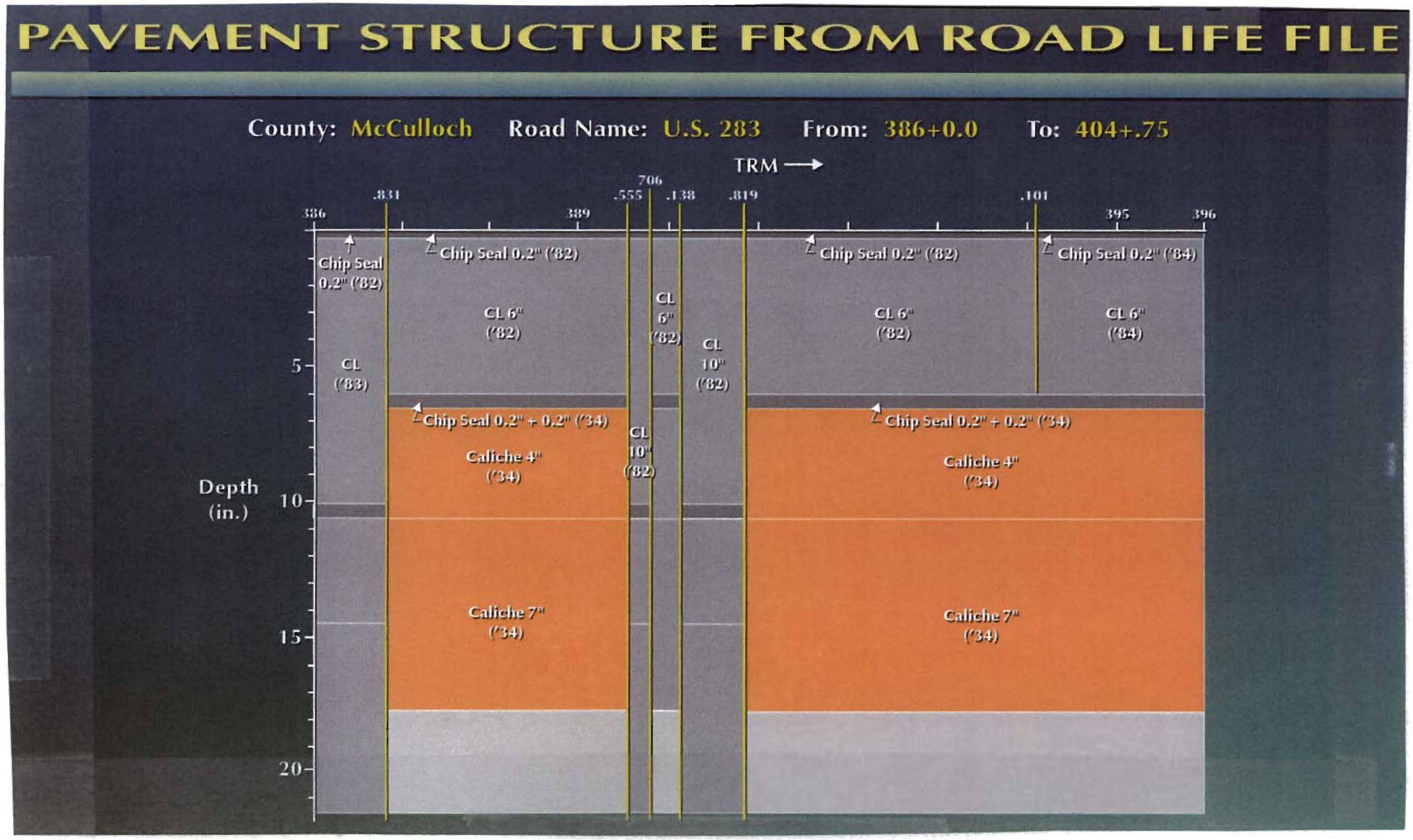


Figure 5. GPR Display of Pavement Structure Extracted from TxDOT's Road Life File.

display format and a network level PMIS report should be developed. The PMIS report will display the pavement types for each PMIS section along a highway.

6. Climbing Lanes

   Should these be considered in new Road Life files? It is common to find that the plan sheet states "to be used at 39 stations." The main question is accuracy of data input. The location and extent of climbing lanes can be determined from the field but is it worth it?

7. Terminology

   Most of the personnel entering the information will be fairly young and will not be familiar with the terminology used in the 1950s and 1960s. This will cause problems with older plan sheets.

8. Base Overlays

   Many questions arise with granular base overlays when the base is laid directly on top of the existing structure. In some instances the old structure is scarified, and in others only the top few inches is scarified. What will the base thickness be in these cases? Many questions such as these will arise.

The use of the existing plans to form the basis of the new PLDB is recommended in the short-term development effort described in Chapter 5. However, as the above comments show, there is an urgent need to build on the experiences of the two districts that have tried to develop a system. These systems must be incorporated into a coding manual to guide future efforts.

CHAPTER 4

FIELD EVALUATION OF TxDOT'S EXISTING LAYER DATABASES

4.1 INTRODUCTION

The aim of this evaluation was to validate the layer thickness information stored within the existing RL PLDB with nondestructive testing using TTIs GPR system. When major differences were observed between the PLDBs and GPR thicknesses then validation cores were taken. The two districts actively involved with building their own pavement layer databases, Houston and Brownwood, were contacted. Two pilot areas were selected for this study. These are shown in Figure 6. For each of the highways included in the study the layer thickness plots, shown in Figure 5, were manually built from the flat file (Figure 3). In the Houston study, the required information was not always found in the existing PLDB. In those cases, the thickness plots were built directly by the researchers from the as-built plan sheets.

The GPR data was collected traveling at the posted speed limit. A GPR trace was collected at 10 foot intervals in the outside lane outside wheel path. For two-lane highways, data was collected in one direction only, for all other cases data was collected in both directions. The basics of GPR are presented in the next section. This is followed by a comparison of the thickness plots obtained from plan thicknesses and GPR testing. The remainder of this section will present seven different comparisons between the plans and GPR data. Where appropriate, the results of the field validation cores will also be presented.

4.2 BASICS OF GROUND PENETRATING RADAR

The TTI's GPR unit is shown in Figure 7. This system sends discrete pulses of radar energy into the pavement system and captures the reflections from each layer interface within the structure. This particular GPR unit transmits and receives 50 pulses per second and can effectively penetrate to a depth of 0.6 m (2 ft). A typical plot of captured reflected energy versus arrival time for one pulse is shown at the bottom of Figure 7, as a graph of volts versus time in nanoseconds. The automated COLORMAP software (3), developed by TTI to process this data, measures the amplitudes of reflection and time delays between peaks to compute both layer dielectrics and thicknesses.

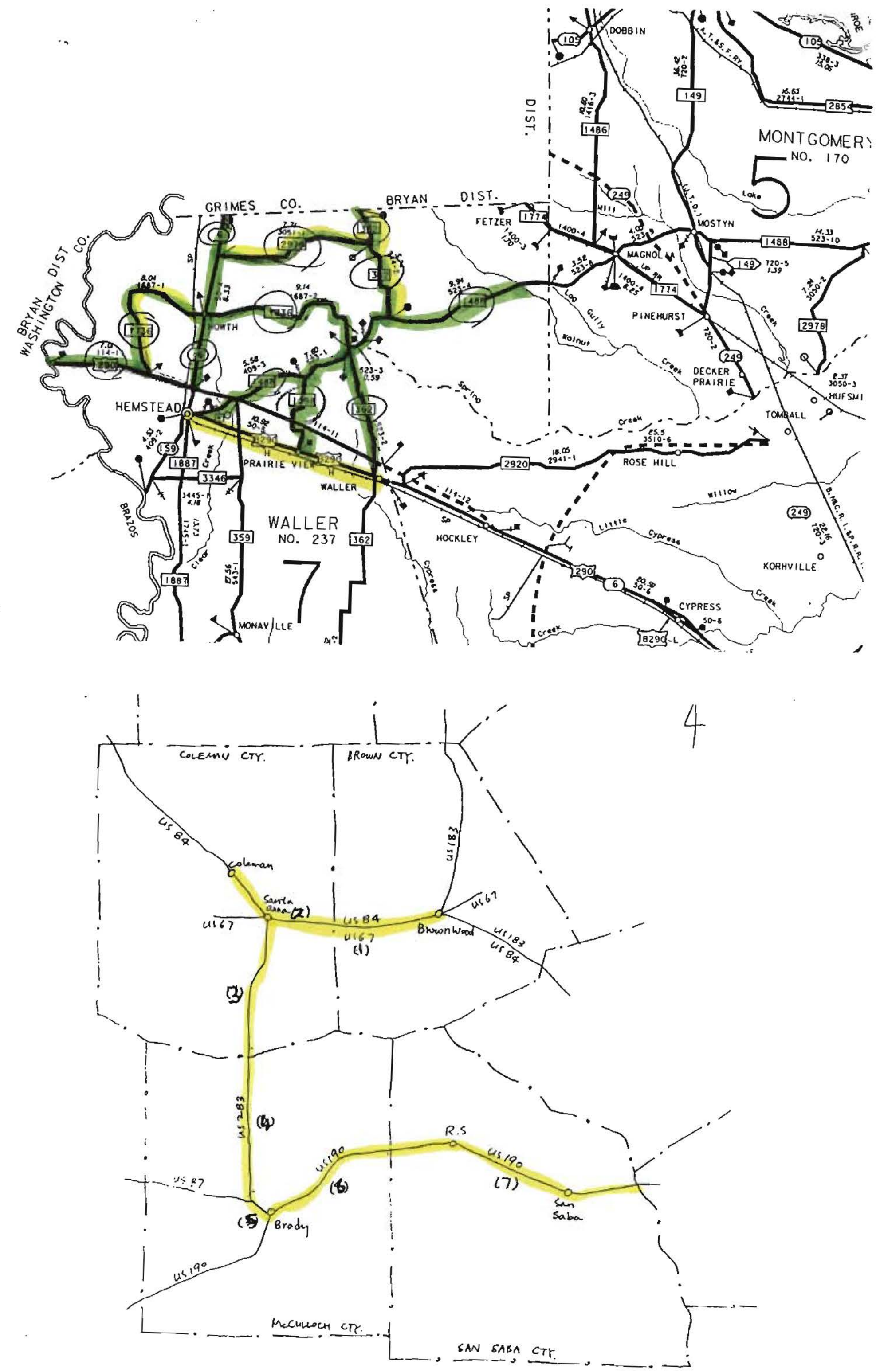
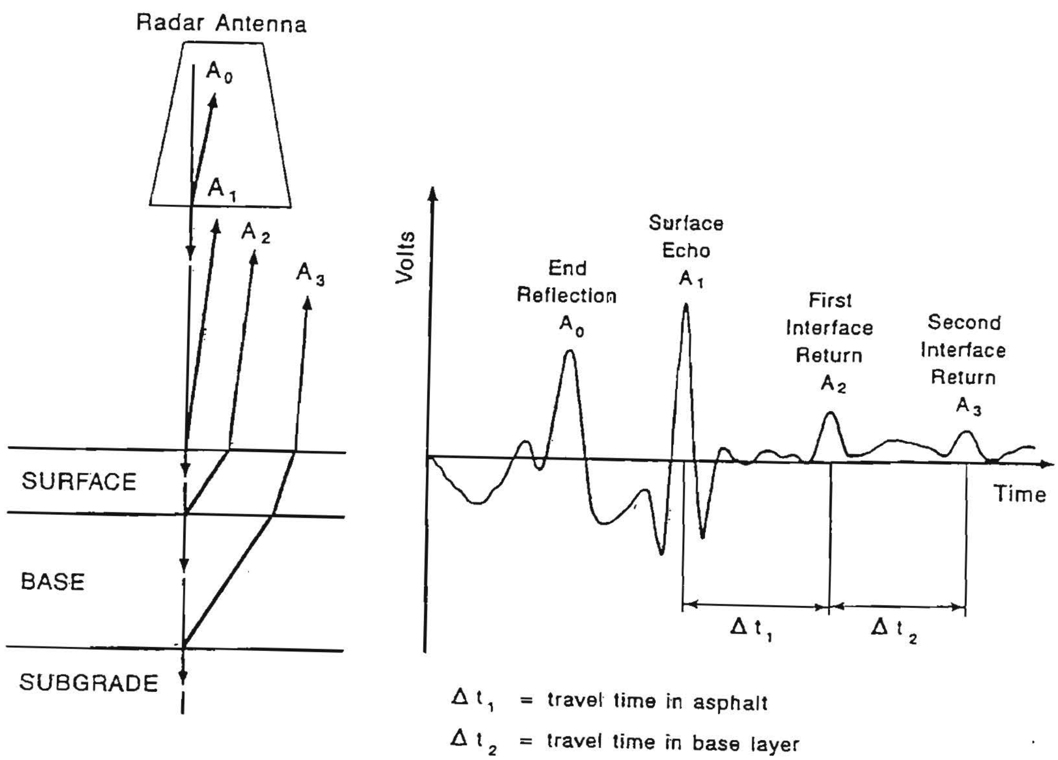


Figure 6. Pilot Areas Used to Evaluate the Pavement Layer Database Built from Construction Records.

a. TTI GPR Equipment.



b. Principles of Ground Penetrating Radar. The Incident Wave is Reflected at Each Layer Interface and Plotted as Return Voltage Against Time of Arrival in Nanoseconds.

Figure 7. GPR Equipment and Principles of Operations.

With reference to Figure 7 the reflection A_1 is the energy reflected from the surface of the pavement, A_2 and A_3 are from the top of the base and subgrade, respectively. These amplitudes of reflection are used to calculate individual layer dielectrics. These are electrical properties of the pavement materials. The engineering properties which most influence these dielectrics are the moisture content and density of the individual layers. If the moisture content for a layer increases, then the amount of energy reflected from the top of the layer would increase resulting in an increase in calculated layer dielectrics. An increase in air voids would have the opposite effect. If the amount of air in a layer increases, the energy reflected and resulting dielectric would decrease. TTI has established a range of typical dielectrics for most paving materials. For example HMA layers normally have a dielectric value between 4.5 and 6.5, depending on the coarse aggregate type. Computed values significantly higher than this would indicate the presence of excessive moisture, lower values could indicate a density problem or indicate that an unusual aggregate, such as lightweight, has been used in the Hot Mix Asphalt (HMA).

The examples below illustrate how changes in materials properties and structure would influence GPR return signals shown in the lower part of Figure 7.

1) If the thickness of the surface layer increases, then the time interval between A_1 and A_2 would increase.
2) If the base layer becomes wetter, then the amplitude of reflection from the top of the base A_2 would increase.
3) If there is a significant defect within the surface layer then a reflection will be observed between A_1 and A_2. This could be either a positive reflection for trapped moisture or a negative reflection for stripping.
4) As the unit travels along the highway it collects traces at regular intervals; therefore, GPR has the potential to monitor the uniformity of the surfacing layer. Large changes in the surface reflection A_1 would indicate changes in either the density (decrease in amplitude) or moisture content (increase in amplitude) along the section.

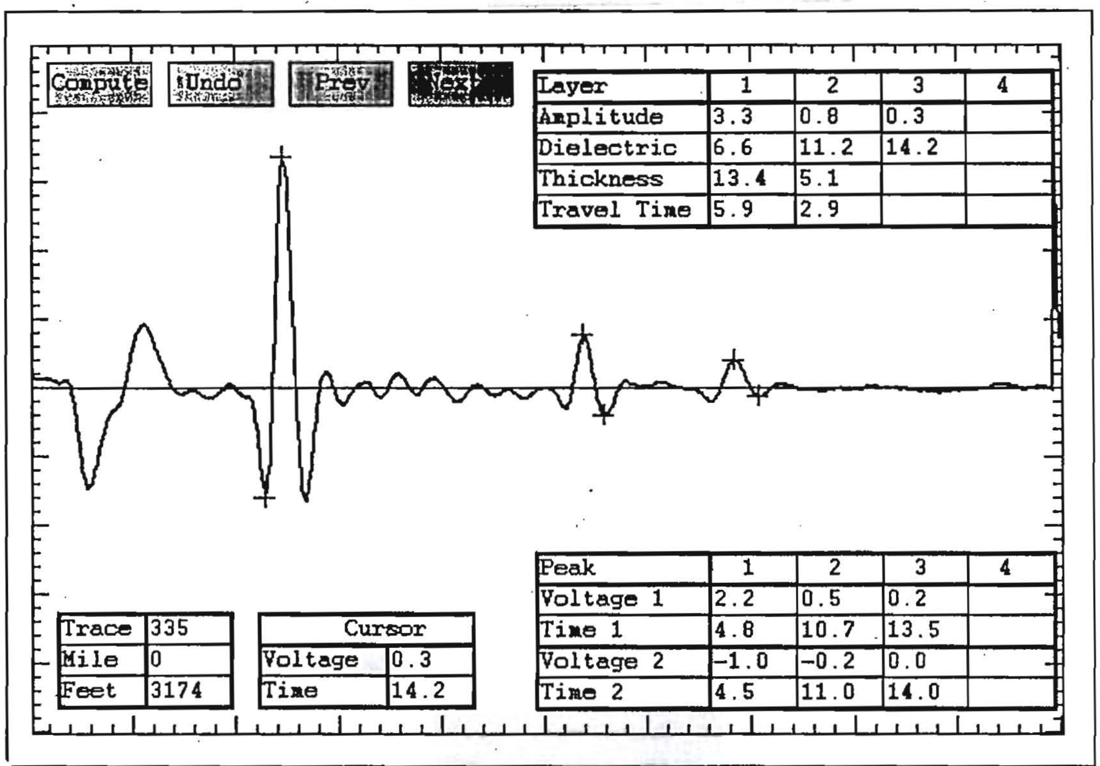


Figure 8. GPR Trace a Field Validation Core from a Thick Homogeneous HMA Pavement.

4.2.1 GPR Reflections from Pavements with Thick HMA Layers

An example of an actual GPR reflection from a flexible pavement with thick HMA layers is shown in Figure 8. This is judged to be an "ideal" reflection, with a clear reflection from the surface A_1, the top of base (A_2), and top of subgrade (A_3). These types of GPR reflections are found with newly constructed homogeneous flexible pavements. As the core shows, well-compacted defect-free cores can be taken when GPR traces such as this are obtained. The COLORMAP software automatically measures the amplitudes and time delays between peaks and computes layer thicknesses and dielectrics. For this trace the calculated values are shown in the box in the upper right-hand corner of the figure.

With older pavements the GPR traces are often more complex than that shown in Figure 8. The fact that there are no significant reflections within the HMA layer indicates that it is homogeneous; however, with older pavements, strong reflections are often found within the HMA. Large positive reflections indicate the presence of trapped moisture, and large negative reflections indicate either the presence of a low-density layer, which could be lightweight aggregates, or a buried defect such as stripping.

4.2.2 GPR Reflections from Thin Surfacings

Figure 9 contains a single GPR reflection from one location on a flexible pavement containing a thin 40 mm (1.5 in) overlay. The blue line in Figure 9 is the raw data, as before A_1 and A_2 are reflections from the top of the HMA and top of the base layer. With GPR systems operating at a frequency of 1 GHz, one complicating issue is that reflection from layers less than 75 mm thick will overlap and it is impossible to detect the layer interface without additional signal processing. The pavement in Figure 9 had a recent 40 mm overlay and the reflection from the surface will be merged with that from the top of the old HMA layer. To handle this situation, a surface subtraction technique has been built into COLORMAP. This technique has been applied to the reflection in Figure 9 (blue line), and after surface removal, the result is the red line. The reflection from the top of the old HMA layer is shown as reflection B_1. One point which must be emphasized is that GPR only works if there is an electrical contrast between pavement layers, if two layers have exactly the same electrical properties and they are bonded together, then there will be little energy reflected from that interface, and it will be impossible to detect it in the reflected trace.

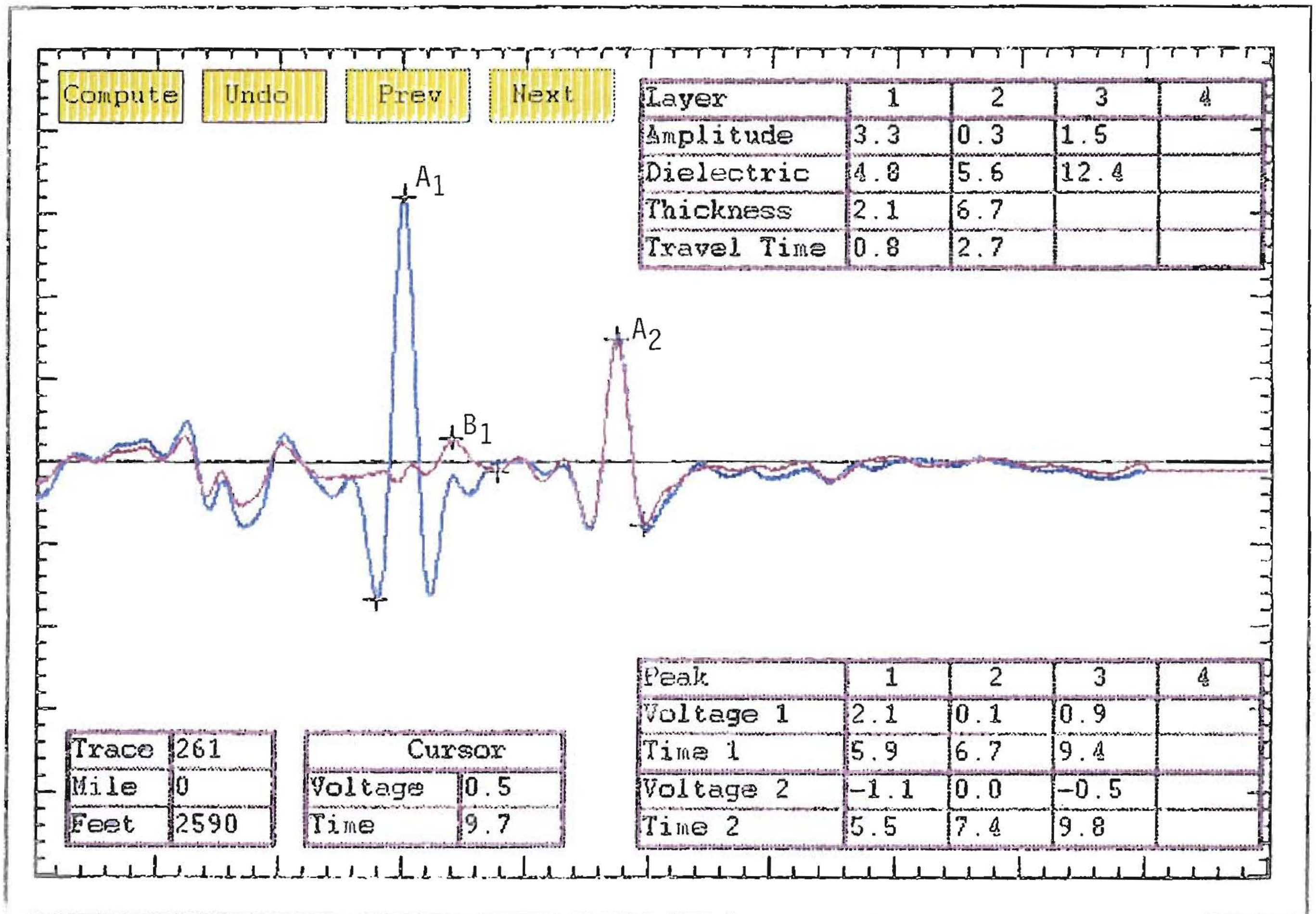


Figure 9. Typical GPR Return Signal from a Flexible Pavement with a Thin Overlay.

Note: Reflections A_1, B_1, and A_2 are from surface, bottom of overlay, and top of flexible base, respectively. This is viewed as the "Ideal" Case 1, well-bonded overlay, no deflects in lower HMA. The blue line is raw GPR return signal, the red line is obtained after surface removal.

This is often the case with thick ASBs consisting of many thin lifts. With these pavements a significant interface reflection would be a cause for concern. However, with a new thin HMA overlay placed over an existing flexible pavement there is often sufficient contrast between the old and new layers to provide a small reflection from the interface.

The trace shown in Figure 9 is classified as an ideal trace for a recent thin HMA overlay over an existing flexible pavement. The small reflection at the interface (B_1), which is found after surface removal, indicates that there is only a small contrast between the old and new layers. The calculated dielectrics for the upper and lower layers were computed to be 4.8 and 5.6, respectively, which are considered to be normal. The thickness of the overlay was computed to be 2.1 in and the old HMA layer at 6.7 in. As there are no strong reflections in the lower HMA layer between B_1 and A_2; therefore, this layer is judged to be homogeneous and defect free. It should be possible to extract a solid core from this pavement. The dielectric from the top of the flexible base was calculated to be 12.4 which is classified as marginal for granular material. Top quality flexible base materials have been found to have a calculated dielectric of below 10, saturated layers have a value greater than 16.

4.2.3 Color-Coded Display of GPR Data

Figures 8 and 9 show individual GPR reflections from a single location on a highway. When GPR data is collected for any project, similar reflections are collected at regular intervals along the highway, typically at 5 or 10 ft spacings. Therefore for any project, several thousand GPR traces could be collected. To conveniently display the information from numerous traces, a color-coding scheme is used. In this scheme the plot of voltage versus arrival time is transformed into a single vertical line scan of different colors. In the current scheme the high positive voltages are colored red, and the high negatives are colored blue. The color-coded GPR traces are then stacked side by side to generate a subsurface picture of the pavement. A typical color-coded display is shown in Figure 10, the bottom axis is distance along the highway, the axis on the right of the figure is a depth scale in inches, and on the left is the color-coding scheme. The surface of the highway is the top horizontal line of the figure. Normally when providing these color-coded printouts to TxDOT, districts annotations are applied to the figure to identify important features, such as bridges, strong reflections from interfaces, and potential defects. For example, the section of pavement shown in Figure 10 consists of a thick HMA layer over a granular base. This pavement has recently received

TYPICAL COLORMAP DISPLAY (10A) WITH ANNOTATION

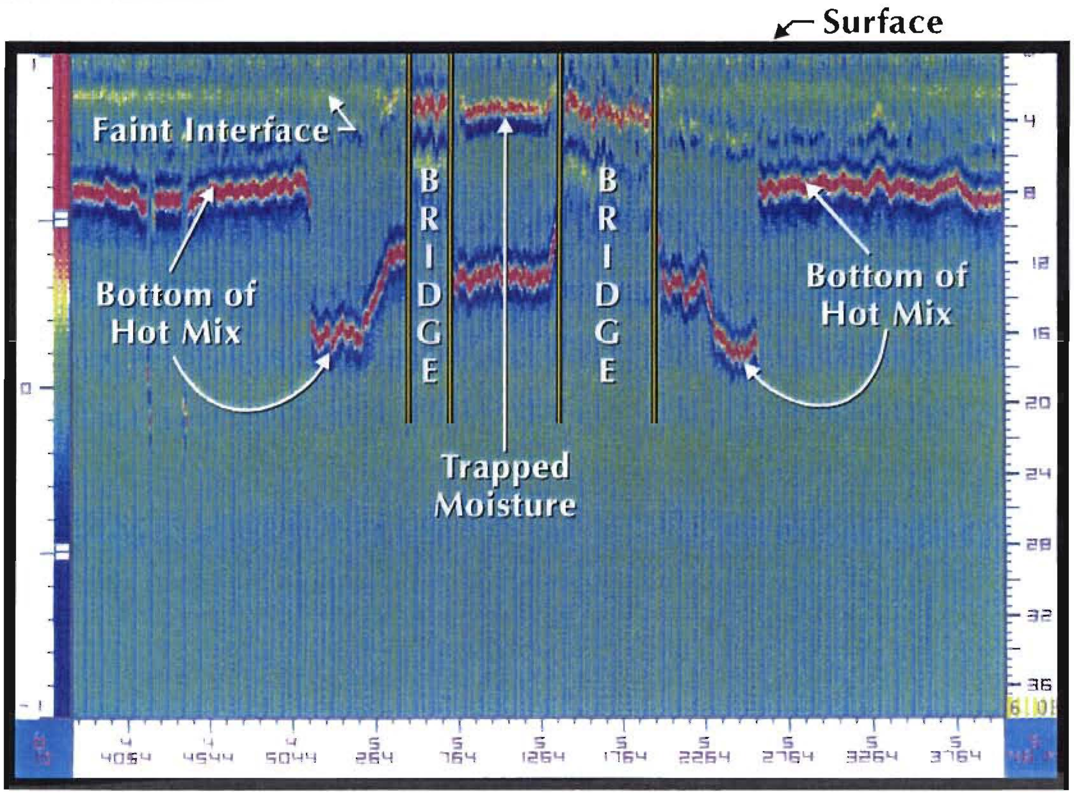


Figure 10. Annotated GPR Results from a Section of US 59 in the Atlanta District. The Scale at the Left is Depth in Inches. The Scale at the Bottom is Distance in Miles and Feet.

a thin overlay. Significant features of this figure are a) the large change in HMA thickness on the approach to the bridge, b) away from the bridges there is no significant reflection from the bottom of the last overlay which indicates similar materials bonded together, and c) a clear old/new HMA interface between the bridges, this as will be described later, indicates moisture trapped at a depth of 3 to 4 in below the surface.

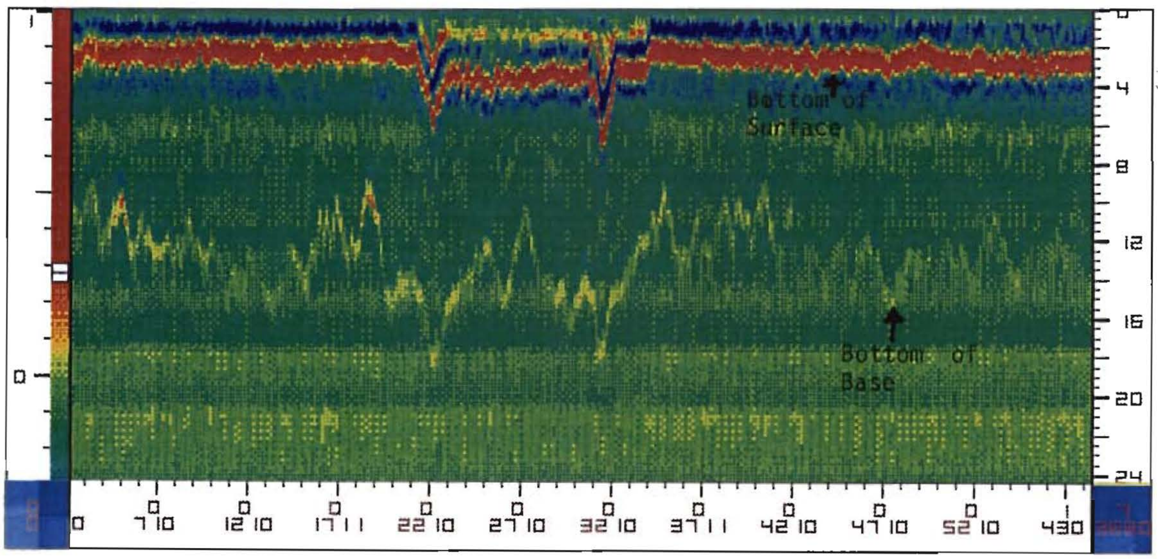
4.2.4 Thickness Computing within COLORMAP

A full description of the COLORMAP system is given in TTI Report 1341-1 (3). This system has interface tracking capabilities which permit the automated computation of layer thicknesses over long sections of highway. Also the computed thickness can be summarized in either graphical or tabular form, examples of both will be shown in the case studies presented later in this chapter. The user selects the section length, for example 500 ft, and the COLORMAP system computes the high, low, and average layer thickness for each 500 ft section along the highway.

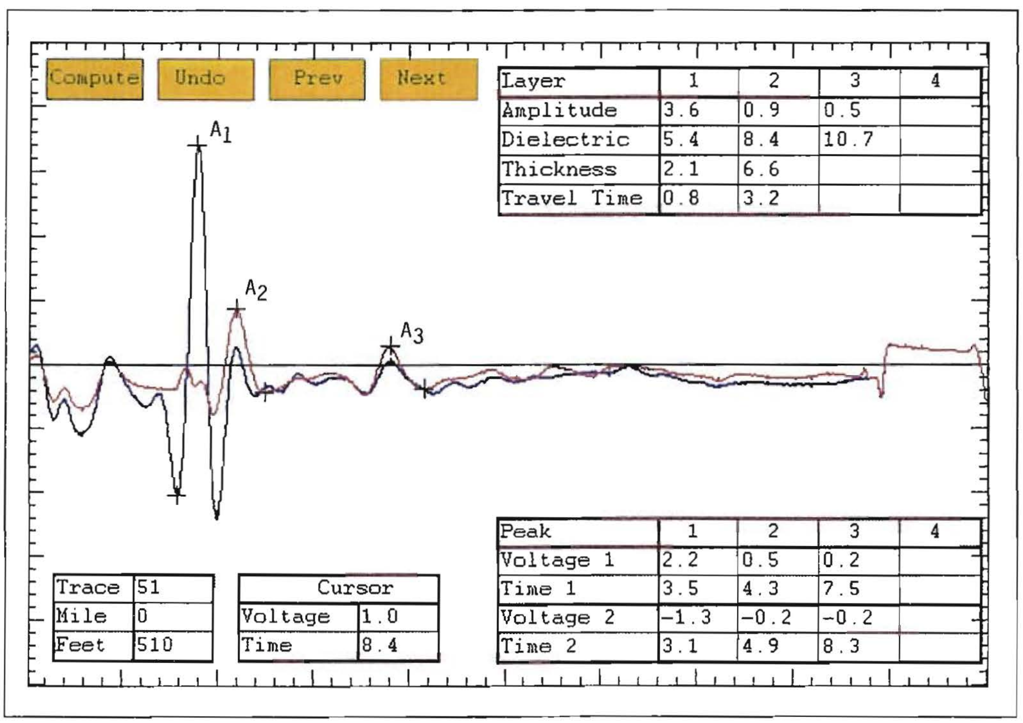
4.3 COMPARING ROAD LIFE DATA TO COLORMAP OUTPUTS

To demonstrate the capabilities of GPR in validating the PLDB, the data from a short section of FM 2979 in the Houston District will be described. The most recent set of plans state that this highway has a 150 mm (6 in) lime-treated subgrade (in clay cuts where required), a 200 mm (8 in) flexible base, an initial surface treatment surfacing, and two subsequent seal coats (the last one being placed in 1990). The plans do not show any HMA. The total thickness of the multiple seals should be around 25 mm (1 in).

The GPR data collected on this section is shown in Figure 11, and the processed thickness data and validation core are shown in Figure 12. The top figure in Figure 11 is the standard COLORMAP color-coded printout for this section. The bright red line at a depth of 65 to 100 mm (2.5 to 4 in) is the reflection from the top of the base layer. In one location a localized thickening of the surface layer was found with thicknesses up to 6 in. A validation core (Figure 12) was taken in the thickened section, and a total of 100 mm (4 in) of surfacing including two thin HMA layers was found. It was concluded that the entire section had received at least one HMA resurfacing which was not reported in the plans. The lower part of Figure 11 shows a single GPR trace from the section,

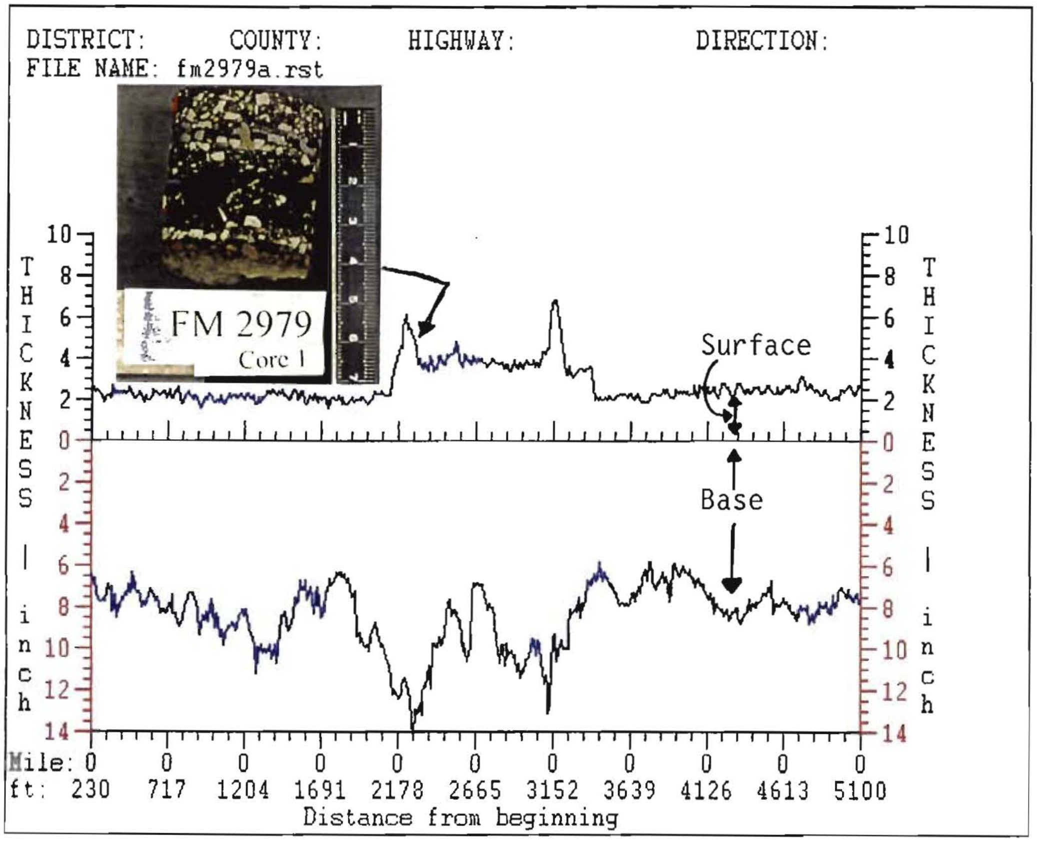


a. COLORMAP Display with Annotation.



b. Individual GPR Trace.

Figure 11. GPR Data from FM 2979.



a. Layer Thickness Computed from GPR.

Distance (ft)	*Layer 1 Thickness*			*Layer 2 Thickness*		
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*
230 - 730	1.8	2.6	2.2	6.4	8.6	7.5
730 - 1230	1.5	2.5	2.1	7.3	9.9	8.4
1230 - 1730	1.8	2.5	2.1	6.7	11.2	8.8
1730 - 2230	1.6	5.8	2.4	6.3	12.5	9.0
2230 - 2730	3.3	6.1	4.0	6.9	14.2	10.0
2730 - 3230	3.3	6.7	4.1	7.6	13.2	10.2
3230 - 3730	1.8	3.6	2.5	5.9	10.1	7.5
3730 - 4230	1.8	2.7	2.3	5.8	8.4	6.8
4230 - 4730	2.1	3.0	2.5	6.8	8.8	8.0

b. Summarized GPR Thicknesses.

Figure 12. Layer Thicknesses from GPR.

the reflections from the surface, top of base, and top of subgrade are noted as A_1, A_2, and A_3, respectively. Figure 12a shows the computed surface and base thicknesses for the section together with a validation core. The lower part of Figure 12 shows the computed GPR surface and base thicknesses summarized in 150 m (500 ft) sections. If GPR is to be used to update the PLDB it would be the average layer thickness values from Figure 12b which would be used. For newer pavements with few overlays and no defects, GPR has been found to compute layer thicknesses to within 5% of actual core thickness without taking a calibration core.

This section is somewhat unusual in that it is an old section but both the bottom of the surface and base are clearly visible in the GPR data. With older sections it is always possible to see the bottom of the surfacing layer but it is often difficult to find the reflection from the top of the subgrade. This is because over time the base and subgrade tend to mix leaving no clear break in dielectric properties.

If GPR is to be used to validate the TxDOT PLDB then the surface layer should be updated with thickness estimates from GPR, this would include the average layer thickness for the chosen section length. For FM 2979 the PLDB would be updated with the values from the average columns in Figure 12b.

4.4 CASE STUDIES

One of the main objectives of this one-year study was to evaluate the adequacy of the PLDBs developed by the Houston and Brownwood Districts from the as-built plan sheets. The difficulties of using plans for this purpose were discussed in Chapter 3 of this report. In general the results from Brownwood were encouraging, for most of the pavements the tie between PLDB and GPR data was good. This is attributed to firstly the experience of the person building the PLDB, and secondly to the fact that Brownwood is a rural district with little traffic growth and generally good performing pavements requiring minimal maintenance. Problems were encountered in only a few areas namely:

a) (Case 6) It was difficult to interpret plans. In one section of US 84 the plans sheets were unclear. The section was a two-lane highway which had been widened to four lanes divided. There was confusion about what happened to the original section and there was dispute over what was actually built.

b) (Case 2) In several area localized repairs by maintenance forces have gone unreported. In one expansive clay area almost 500 mm (20 in) of HMA level-up has been applied, the PLDB had 100 mm (4 in) as the surfacing thickness. In several other areas thin maintenance level-ups usually 37 mm (1.5 in) have been applied and are not recorded in the PLDB.

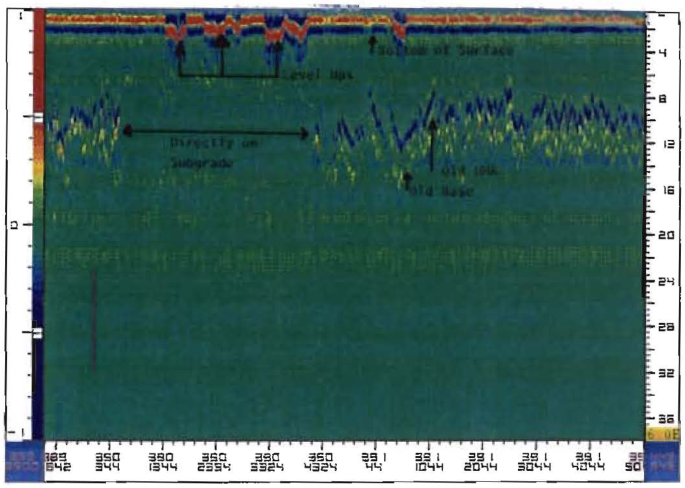
In Houston the comparison is not so favorable. Many more maintenance overlays have been applied. Almost every surface layer thickness was less than the actual field thickness. In one case the base type was found to be incorrect (Case 5). The GPR data was more difficult to process in Houston primarily because many of the pavements have buried defects. Several of the projects were found to have buried stripping. Potential defects can be observed in the GPR data, but care must be exercised not to confuse an unusual aggregate with stripping. From past work with GPR, stripping has been found to correlate with negative reflections from within the HMA layer. On US 290 a negative reflection (Cases 4 and 5) was found throughout the layer about 4 in below the surface. This turned out to be a layer of dry river gravel which had a lower dielectric than the surfacing layer. The key to locating defects is that they are intermittent throughout the section, if the reflection is uniform then it is probably a layer of lower dielectric properties. Another problem with defect situations is when the GPR return waves are more complex, HMA thickness estimates are less accurate.

The following seven case studies have been selected to provide a thorough review of the different comparisons obtained in this study:

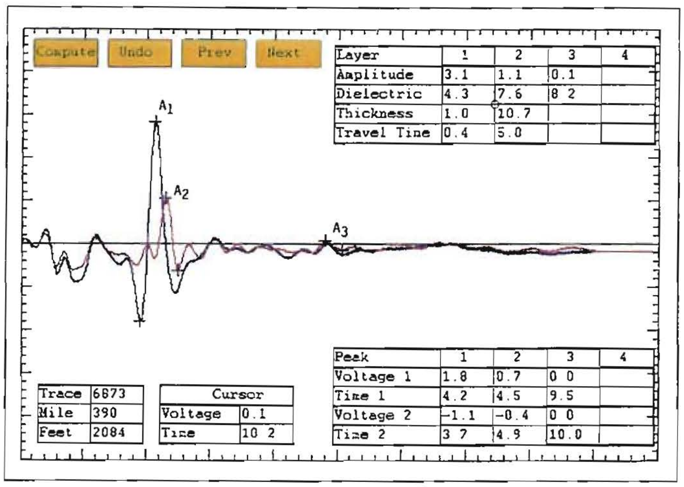
Case 1 Good Tie between Plan Thicknesses and GPR Data (US 283 SB Brownwood)

The section of US 283 between TRM 386 and 396 was rehabilitated in 1985. In most of the section, 150 mm (6 in) of new flexible base was laid directly on top of the old pavement. In a few places the old pavement was removed and a new thicker base was placed directly on top of the subgrade. The GPR/PLDB comparison for a short section of US 283 including both cross-sections is shown in Figures 13 and 14 . Figure 13a shows the COLORMAP display of the GPR data for a 2 mi section. The surface is the horizontal line at the top of the figure, the surface is very thin (less than 50 mm (2 in)) and is seen as the thin red line near the surface, and the bottom of the base is marked by the blue reflections approximately 250 to 300 mm (10 to 12 in) below the surface. The change in pavement structure is shown as a clear break in reflection from the bottom of the base. The blue reflector from the bottom of the base is a transition from a high dielectric to a lower dielectric which is an unusual case. Normally the transition is marked by a positive reflection indicating an increase in moisture content from base to subbase layer. In this case the new base was placed directly on top of an existing HMA surfacing, and the negative (blue) reflection is from the top of the old HMA layer. The section where this blue reflector disappears is where the base was placed directly on top of the subgrade. Figure 13b shows an individual GPR trace from the area where the new base was placed on the subgrade. In this trace the reflection from the top of the base A_2 can only be clearly identified after surface removal, small positive reflector A_3 is from the top of the subgrade. As the amplitude of A_3 is small, the contrast in dielectrics (moisture content) between the base and subgrade is also small. Figure 13c is from an area where the new base was placed on top of the old HMA layer. The difference between 13b and 13c is the negative reflection (B_1) in 13c, this is the reflection from the top of the old HMA layer.

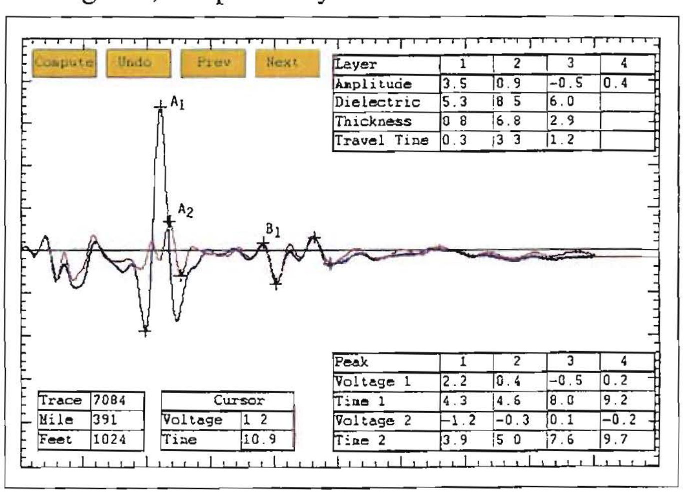
The plan versus GPR layer thickness profiles are shown in Figure 14. The top figure was sketched directly from the PLDB built by Mr. Godfrey. The lower figure was automatically generated from COLORMAP. In general, the correspondence is very good. The only difference between the plans and the GPR is the apparent localized level-ups placed on the surfacing layer primarily in the section built directly on the subgrade. These are maintenance treatments which can be clearly seen in the video.



a. COLORMAP Display.

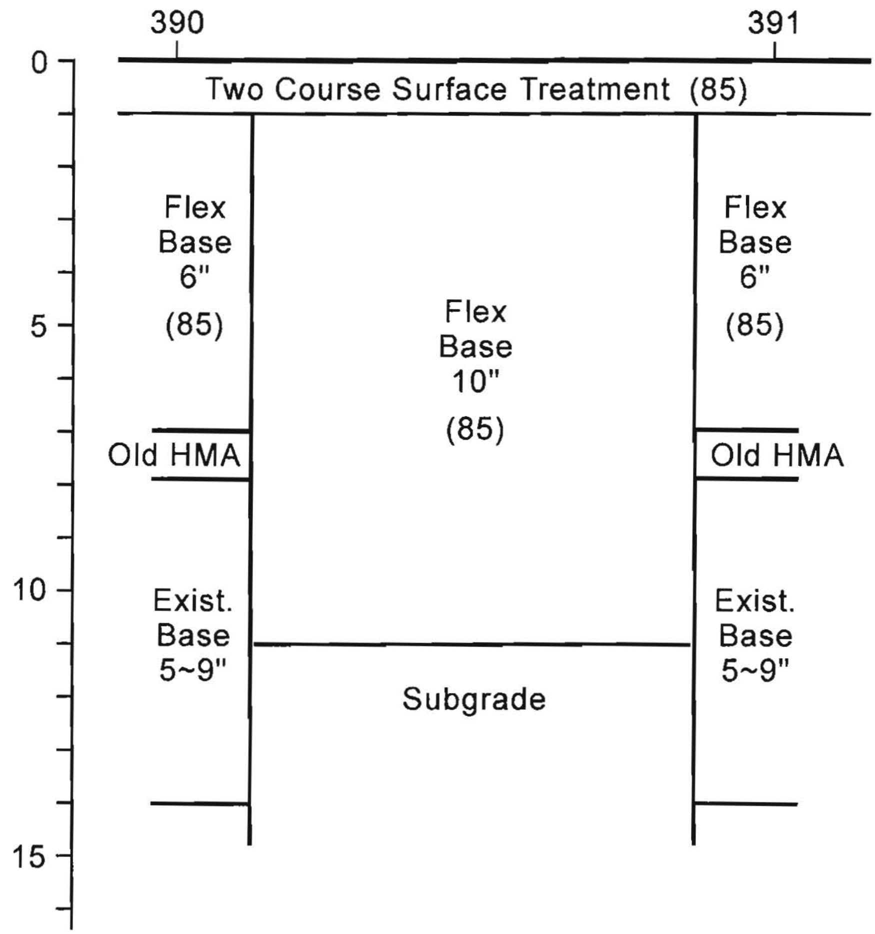


b. GPR Trace in New Section on Subgrade A_1, A_2, A_3 Reflection from Top of Surface, Base Subgrade, Respectively.

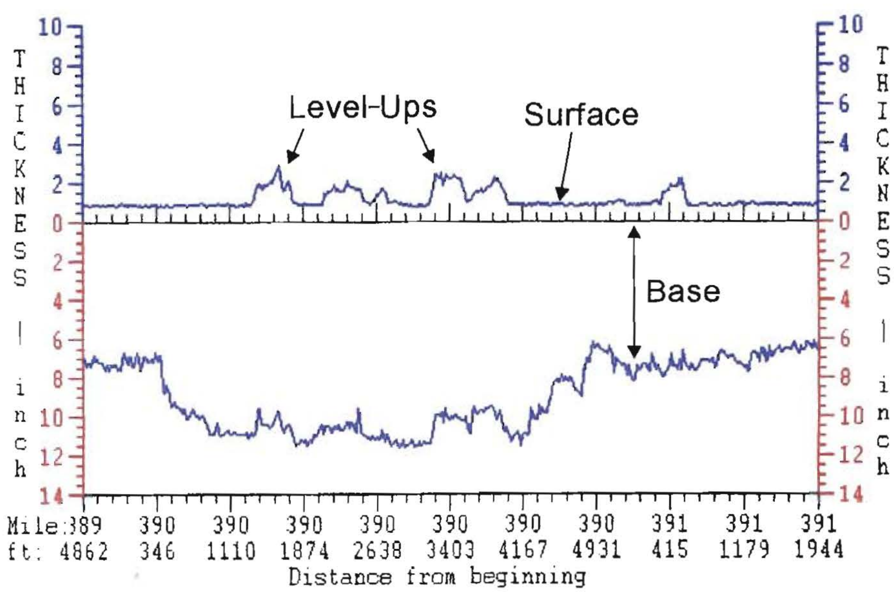


c. GPR Trace with New Base Directly on Top of Old HMA Layer. Reflection B_1 from Top of Old HMA Layer.

Figure 13. Case 1 Good Tie in between Plans and GPR US 283 SB (Brownwood).



a. Pavement Structure from Brownwood PLDB.



b. Layer Thickness from GPR.

Figure 14. Summary Results from US 283 (Case 1).

Case 2 Using GPR to Identify Localized Thick Sections (US 190, McCullough County)

The plan thickness from US 190 west of Brady indicated a uniform 100 mm (4 in) of HMA over a thick granular base. However, close to the San Saba county line the section goes through an expansive clay area which has received substantial maintenance. The COLORMAP display for a 2.2 mi section is shown in Figure 15. Again the surface is at the top of the figure, and the solid red line at a depth of 100 mm (4 in) below the surface is from the top of the base layer. The scale at the bottom of the figure is distance converted into the TRM referencing scheme (Miles + Feet). As can be seen in Figure 15 around TRM 470 +5000 ft, a sudden major thickening of the HMA layer occurs. This overlaid section is approximately 1 mi in length.

Using the COLORMAP layer thickness calculation procedures, the data in Figure 15 was converted into an HMA thickness profile as shown in Figure 16a. Within COLORMAP the thickness data is further summarized into 0.1 mi sections in the table at the bottom of Figure 16. For each 10th mile section a minimum, maximum, and average HMA thickness is calculated. From experience with similar pavements these estimates are typically within 5% of the actual core thickness. As will be recommended later in this report, it is proposed that the initial PLDB be built with plan thicknesses which will then be validated with a GPR survey. In this case the plan thicknesses will be updated with the thickness from the average HMA thickness column of Figure 16b.

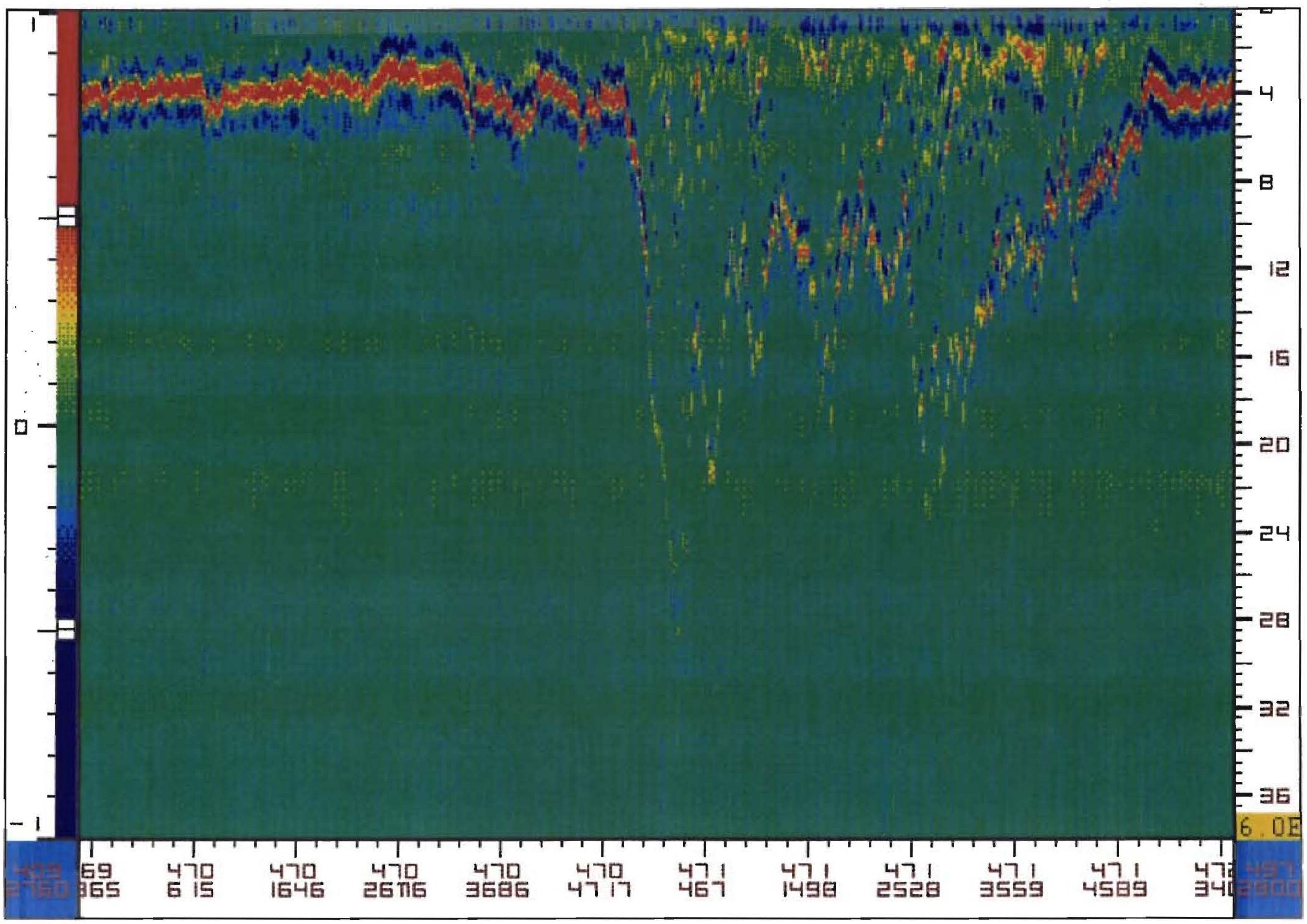
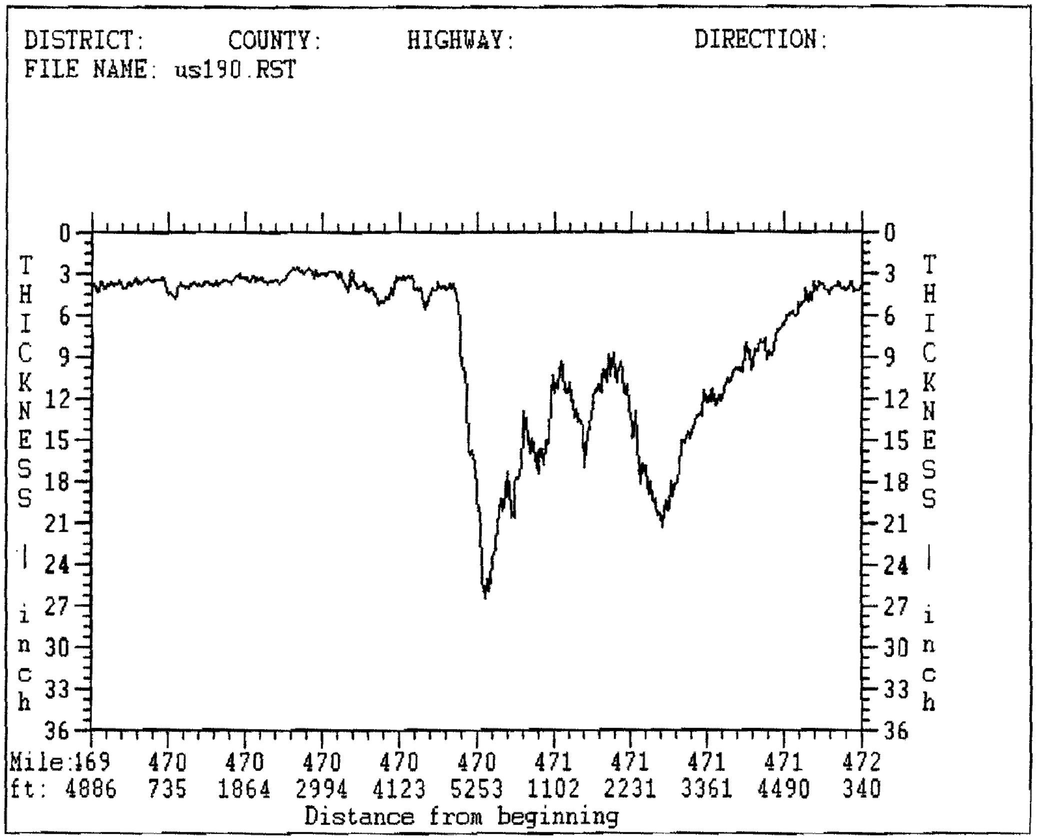


Figure 15. COLORMAP Display from an Expensive Clay Section on US 190 (Brownwood District).



a. Thickness of HMA as Computed by COLORMAP.

TRM		*Layer 1 Thickness*			*TRM*		*Layer 1 Thickness*		
From	***To***	***Min***	***Max***	***Avg***	***From***	***To***	***Min***	***Max***	***Avg***
470.0	470.1	3.4	4.1	3.6	471.0	471.1	11.7	26.5	20.8
470.1	470.2	3.4	4.9	4.1	471.1	471.2	13.0	20.6	17.2
470.2	470.3	3.5	4.0	3.8	471.2	471.3	9.4	17.5	13.2
470.3	470.4	3.1	3.8	3.5	471.3	471.4	10.9	17.1	13.1
470.4	470.5	2.6	.9	3.4	471.4	471.5	8.8	14.9	11.1
470.5	470.6	2.6	3.3	2.9	471.5	471.6	15.0	21.3	18.9
470.6	470.7	2.8	4.4	3.4	471.6	471.7	13.0	19.1	15.4
470.7	470.8	3.2	5.3	4.5	471.7	471.8	9.9	12.6	11.4
470.8	470.9	3.2	5.6	4.0	471.8	471.9	7.8	10.1	8.8
470.9	471.0	3.7	10.3	5.1	471.9	472.0	4.2	8.5	6.2

b. Thicknesses Summarized into 0.1 Mi Sections - The Plan Thickness is 4 in (100 mm).

Figure 16. Case 2 Localized Thick Section Using GPR to Define the Limits and Depth of HMA on an Expansive Clay Section on US 190 (Brownwood).

Case 3 Using GPR to Correct Surface Thickness

Figure 17 shows the complete GPR thickness profile for all of FM 2979 in Waller County. This is an 8 mi section from SH 6 to FM 362. Figures 11 and 12, presented earlier, gave the surface and base thickness profiles from a short section at the start of this highway. The plans stated that the entire 8 mi section had multiple seal coats but no HMA with an estimated total thickness of approximately 25 mm (1 in). As can be seen from Figure 17, a short section in the middle of the highway does have close to the plan thickness. However the majority of the project has a total surface thickness of between 65 and 100 mm (2.5 and 4 in). Validation cores were taken from this project, and their locations are noted on Figure 17. Photographs of the actual cores are shown in Figure 18. The actual core thickness correlates well with the GPR thickness estimates. No defects were obvious in either core.

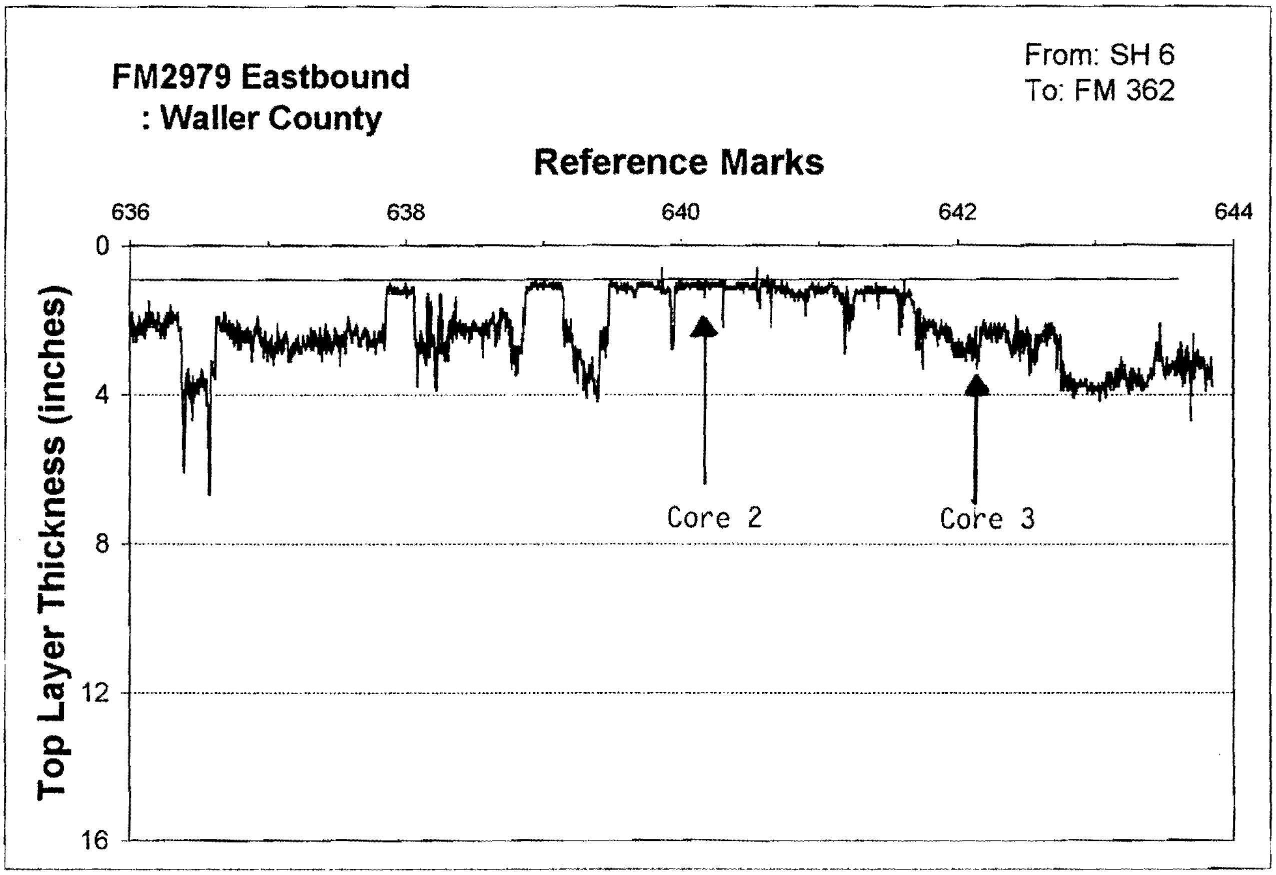


Figure 17. Case 3 Using GPR to Correct Surface Thickness (Plan Thickness = 1 in) FM 2979 (Waller County, Houston).

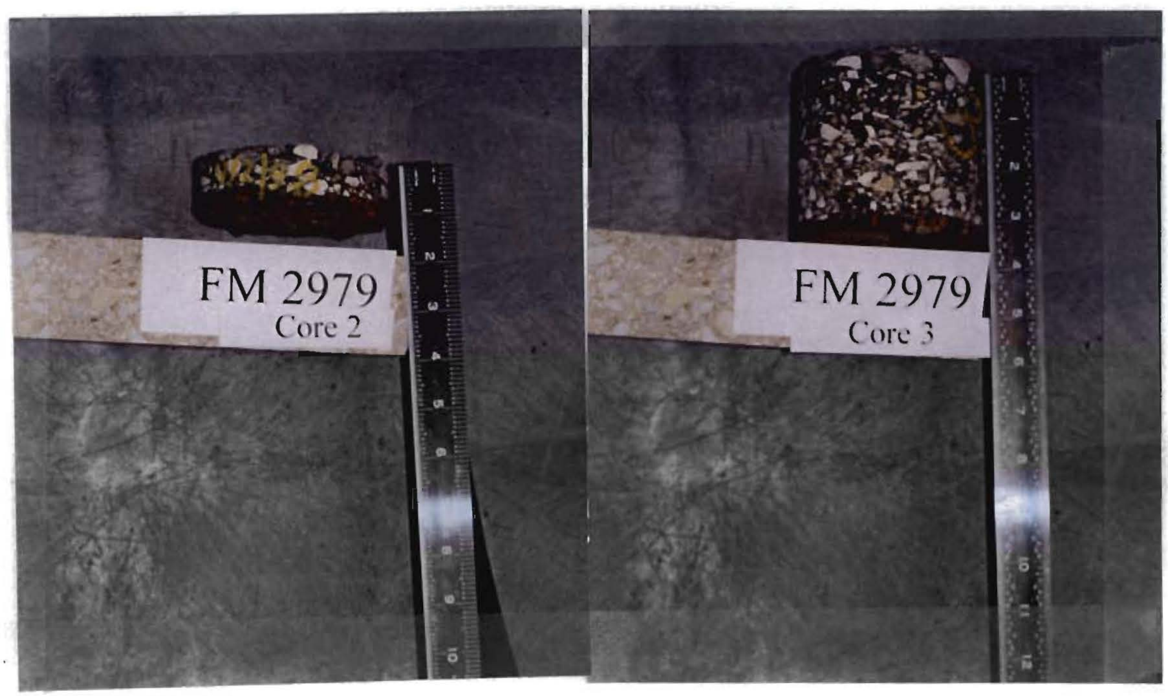


Figure 18. Validations Cores from FM 2979.

Case 4 Using GPR to Identify Change in Section (US 290 Waller County, Houston)

In developing its pavement layer database, the Houston District went back to its most recent set of plans and extracted the base and surface type information. However, on this section of US 290 the plans stated that the base was either Asphalt Stabilized Base (ASB) or Flexible Base (Iron Ore Gravel). Because of the confusion, no entries were made to the database for this section. To identify the location of the change in base types, it was necessary to dig back through the historical plan sheets for this section. It was found that as more and more projects are performed on the same section less and less accurate information gets passed from plan sheet to plan sheet. In this case the old plan sheets identified a change in base at the location that was identified in Figure 19. However, in Case Study 5, no change in base type was identified in the plans for this highway, whereas a clear break was indicated in the GPR data.

From Figure 19 section 1 was found to contain three HMA layers (25 mm, 50 mm, 25 mm) over an asphalt stabilized gravel base. Section 2 was found to contain between 125 and 200 mm (5 to 8 in) over an Iron Ore Base. The cores taken from this pavement are shown at the bottom of the figure. One word of caution here, the GPR data was collected while traveling at 60 mph over the pavement collecting one trace for every 3 m (10 ft) of pavement. Core locations were identified from the video images so they may not be a perfect match between the GPR trace and the resulting core. The individual GPR traces from the location of cores 1 and 3 are shown in Figure 20. Cores 1 and 2 were solid with only minor defects. Core 3 disintegrated on coring and appears to have substantial moisture damage (stripping) 75 to 100 mm below the surface. This GPR data is complex and warrants further discussion.

In section 1 a continuous blue line is observed at a depth of 100 to 125 mm below the surface. This is also apparent in Figure 20a as the negative reflection is calculated to be approximately 100 mm below the surface. The negative reflection indicates a transition from a higher dielectric to a lower dielectric. This is the reflection from the top of the asphalt-stabilized gravel layer indicating that the limestone surfacing layers have a higher dielectric than the river gravel mix. This was confirmed in the laboratory where surface dielectric measurements were made with the Adek Dielectric Probe (4). The lower HMA layer was found on average to have a 30% lower dielectric value than the upper limestone layer.

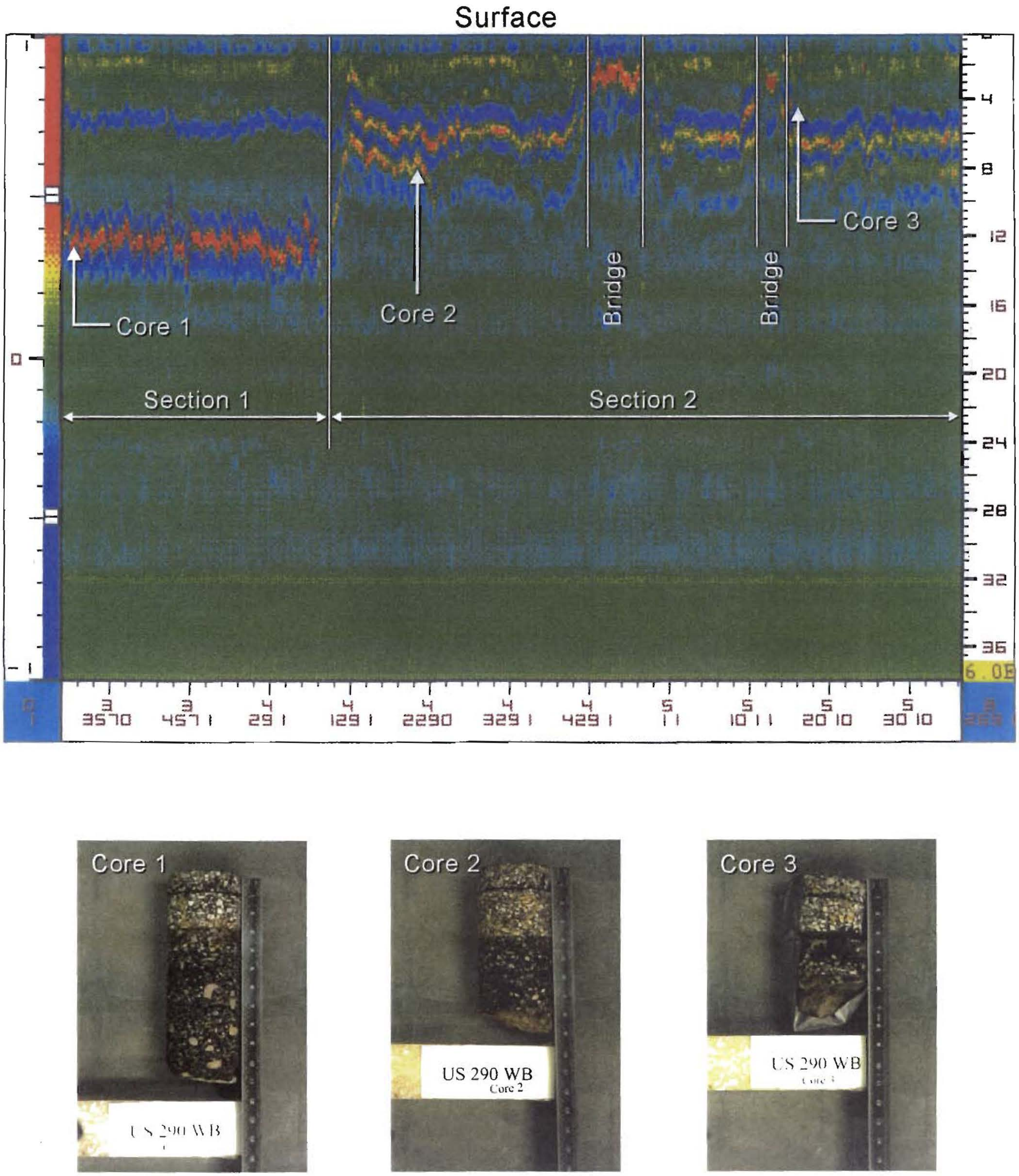
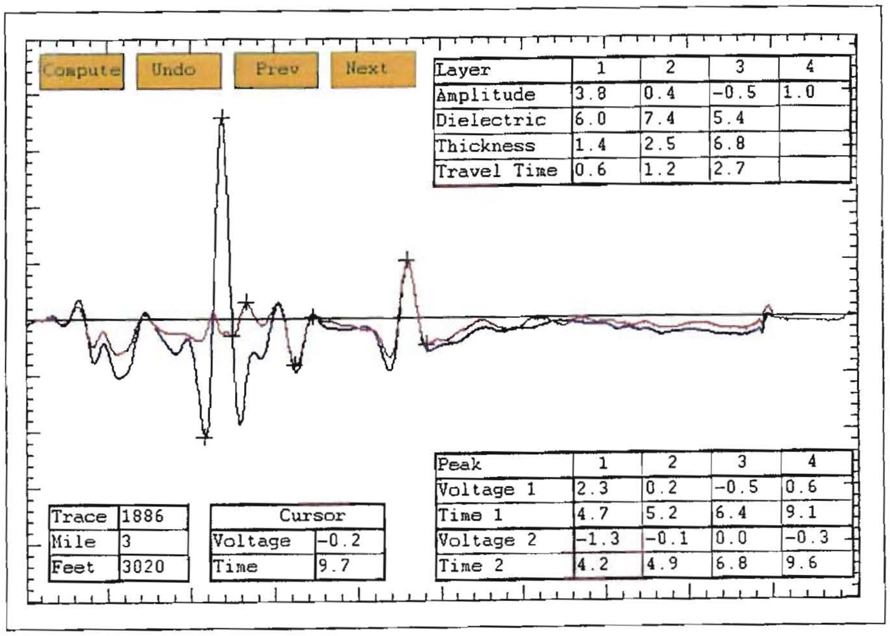
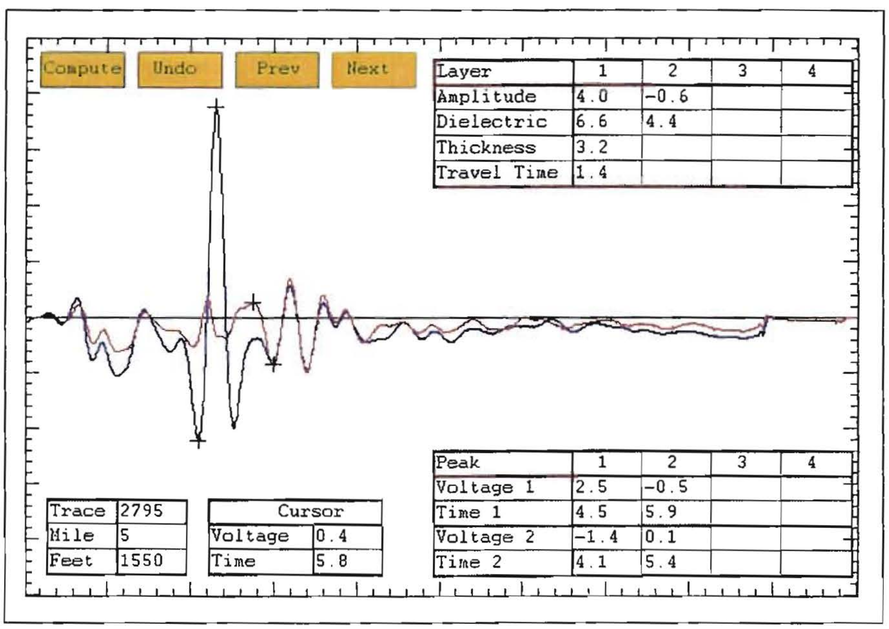


Figure 19. Identifying Section Breaks on US 290.



a. GPR Reflection for Core 1 Location.

(No Defect, Change in HMA Layer Materials)



b. GPR Reflection for Core 3 Location.

(Complex, Change in Materials and Defect)

Figure 20. Individual GPR Traces from US 290.

The problem becomes more complex when reviewing the core and GPR trace for core location 3. This core has about 75 mm of limestone HMA over 50 mm of deteriorated gravel HMA over an iron ore gravel base. Past work at TTI (5) has indicated that when stripping is found in HMA layers, it usually appears as a low-density layer in the GPR reflection. Low dielectric generates negative reflections. With Figure 20b the GPR trace after the surface reflection is complex as both the natural materials and deteriorations are both generating negative reflections which are superimposed upon one another. In these cases it is impossible to identify whether the negative reflections are naturally occurring or the result of subsurface deterioration. All that can be defined from the GPR interpretation is that at a certain depth below the surface a lower dielectric layer will be encountered. The only guidelines that can help interpret whether the reflection is natural or if it is the result of deterioration is if the reflection is consistent or intermittent along the section. From section 1 in Figure 19 the negative (blue) reflection is constant along the section which indicates a uniform nondeteriorated low dielectric layer.

Case 5 Wrong Base Type

Figure 21 shows the COLORMAP display from another section of US 290. For this section, the plans indicated that there was a change in construction in the middle of this section. However, it was reported that the base in both sections was Iron Ore Gravel. Cores were taken in both sections, and section 1 was found to have an asphalt-stabilized gravel base, whereas section 2 had an iron ore gravel base. On reviewing the complete set of plans, it was discovered that the error was caused by wrongly transferring the base type information from an earlier set of plans.

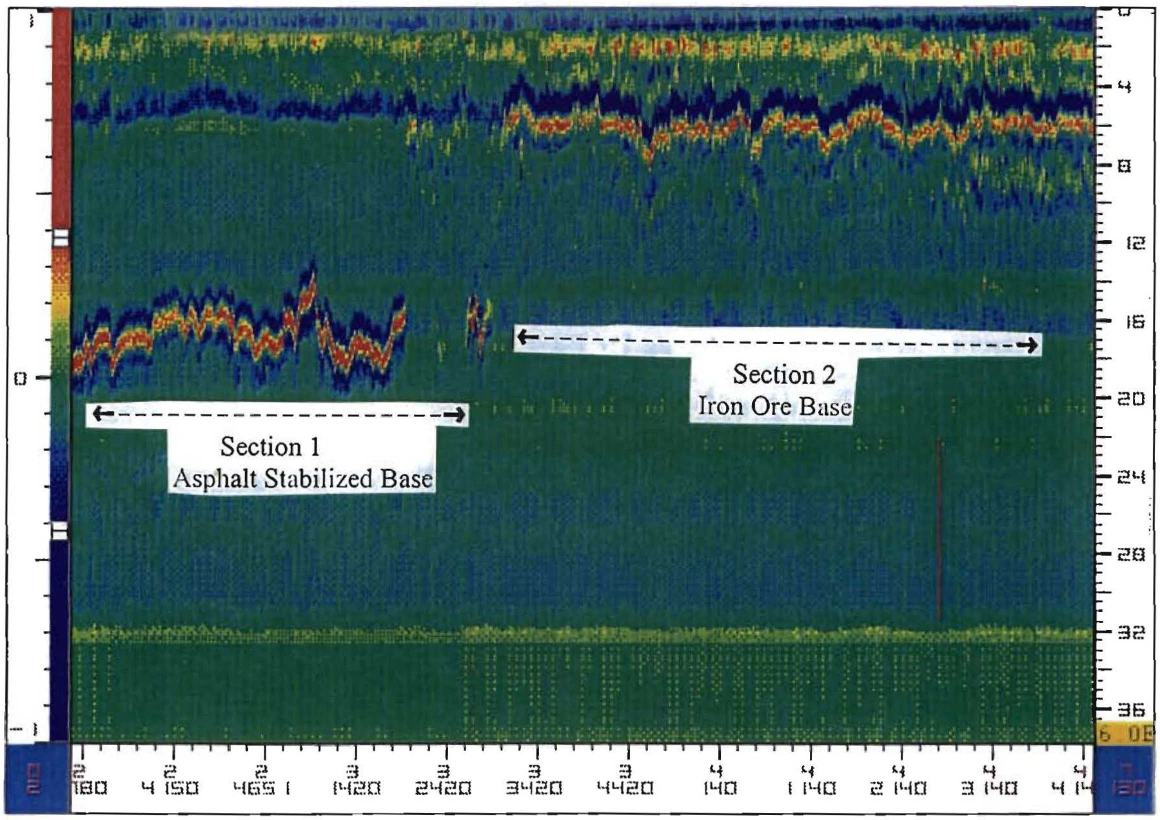


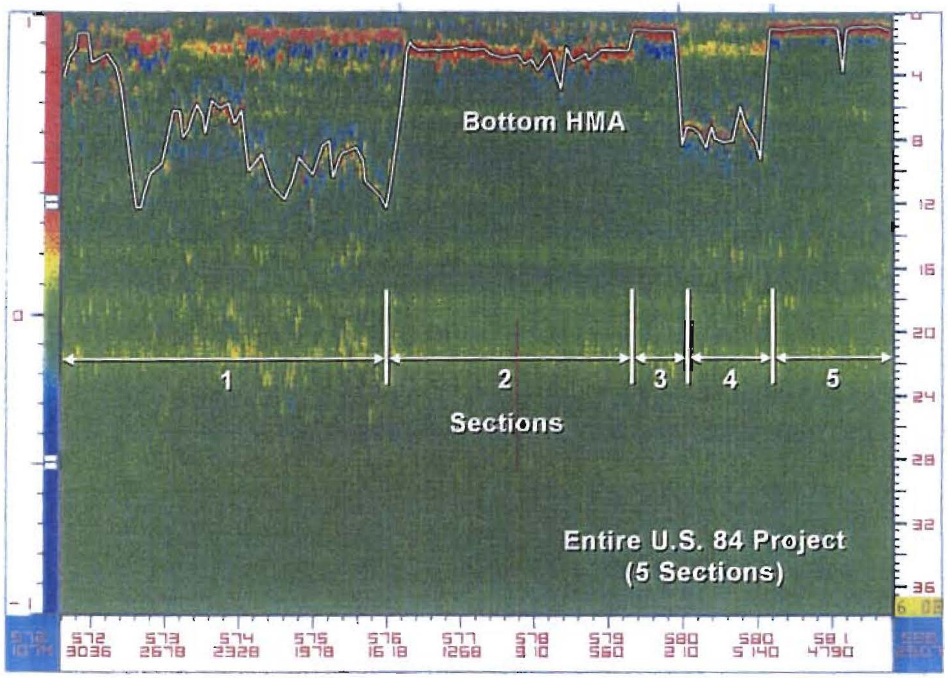
Figure 21. Case 5 Wrong Base Type. Plans Wrongly State Both Sections Have Same Base Type (ASB).

Case 6 Section Breaks US 84

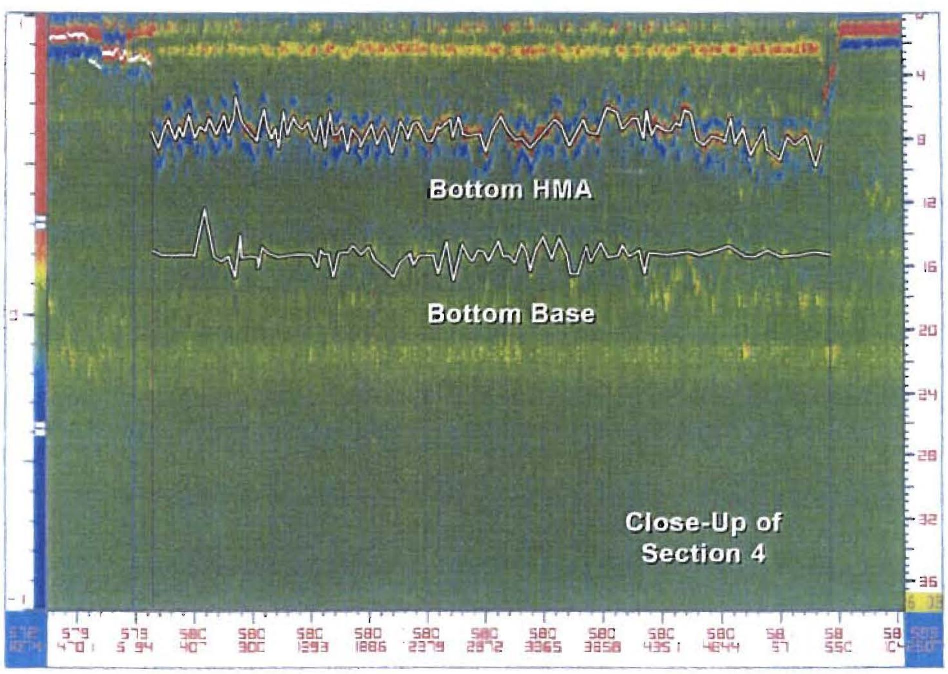
This case study illustrates the value of using GPR for checking the pavement layer database developed from plan sheets. The section is a 10 mi stretch of US 84 from Brownwood to the Coleman county line. The COLORMAP display for the entire section is shown in Figure 22a. A blowup of section 4 is shown in Figure 22b, this being for a short section of thick HMA pavement through the city of Bangs. The data available within the RL file built by Mr. Godfrey of the Brownwood District is shown in Figure 23a. From the GPR data the highway was broken up into five sections. The GPR is most useful for checking the thickness of the upper pavement layers. For sections 2 through 5 the comparison between plan and GPR thickness is fairly good. The only minor discrepancy appears to be in section 4 where the most recent overlay was not included in the plan sheets. In this section the plans showed 110 mm (4.5 in) of ASB with several chip seals. The GPR total HMA thickness was computed to be between 160 and 200 mm (6.5 to 8 in) and the current surface is HMA.

The major discrepancy between the plan thicknesses and GPR results was on section 1. In this section the plans were confusing. This was a two-lane section that was eventually widened to be four lane divided. There was confusion in the district about the thicknesses in this section. The database included 30 mm (1.2 in) of HMA with a thick granular base. The GPR thickness estimates ranged from 100 mm at the start of the section to almost 300 mm in some locations. The GPR estimates compared reasonably with the core thickness in section 1 as shown in Figure 23b.

If GPR is to be used to update the existing RL data file, it is proposed that the surfacing layer thicknesses shown in Figure 23b would be used.

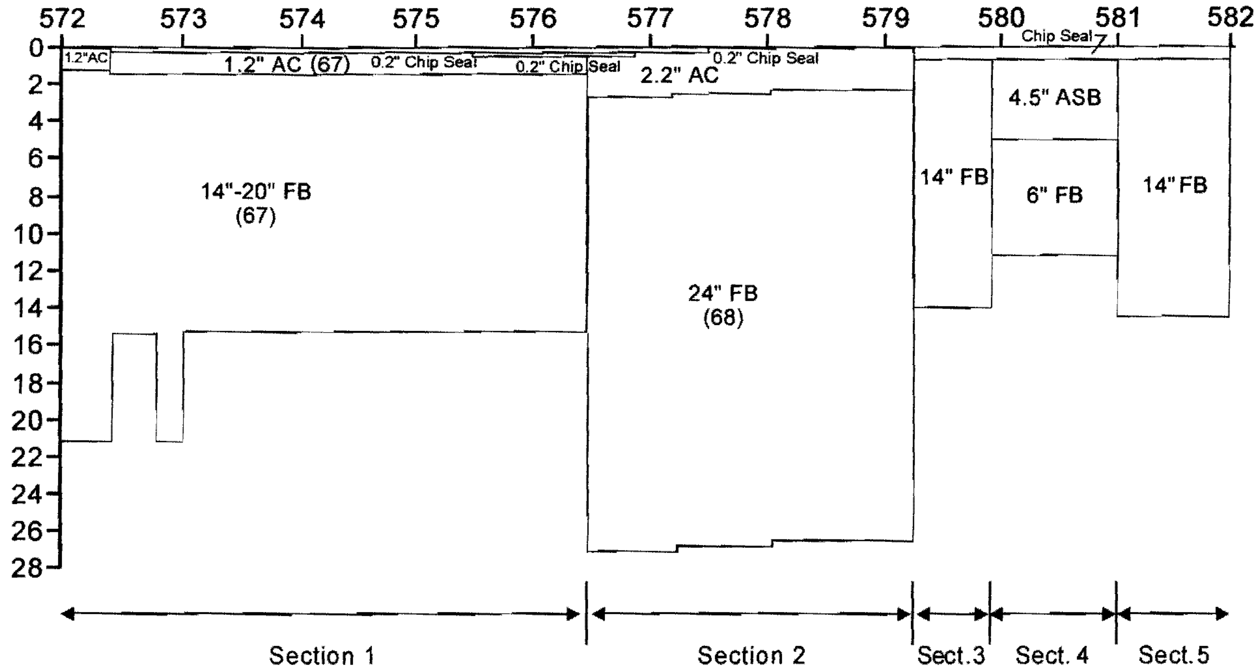


a. Entire 10 Mile Section.

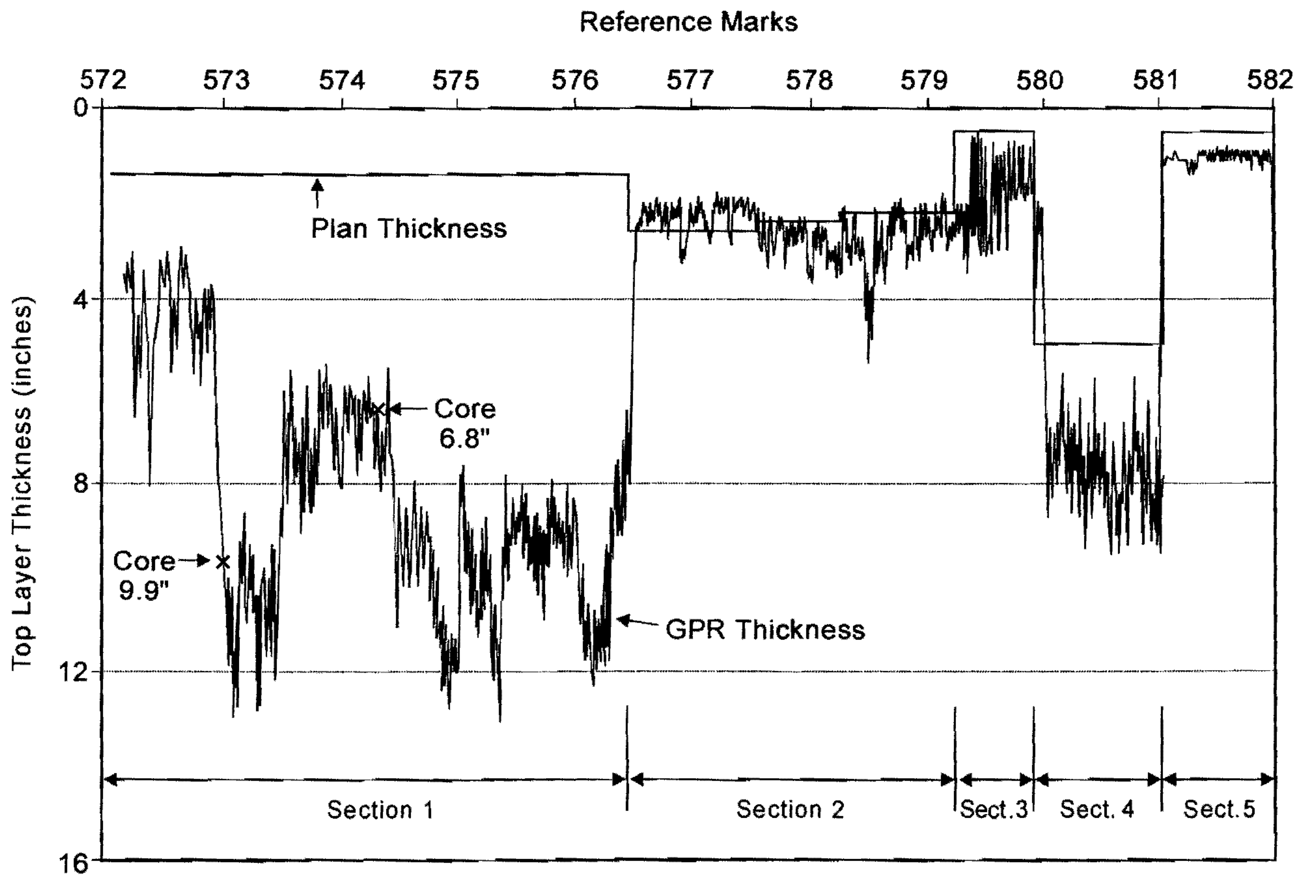


b. Close-up of Section 4.

Figure 22. US Section Breaks on US 84.



a. Plot of Road Life Thickness.



b. Comparison of Plan Thickness and GPR Thickness for the HMA Layer.

Figure 23. Plan vs. GPR Thickness for US 84.

Case 7 Defects in HMAC (FM 362, Waller County, Houston)

The problem of identifying defects in HMA was discussed earlier in Case 4. In that case the identification of the defect was complicated by the variety of the materials used, some of which produced similar GPR reflections to a low-density type defect such as stripping. On FM 362 the situation is a little easier to detect. Figure 24 shows the COLORMAP display from a section of FM 362. The plans sheets show around 75 mm of HMA with localized thickening close to bridges. The bridge is observed in the data around 3 mi + 2,500 ft from the start of testing. The 75 mm (3 in) thick section begins around 4 mi and 3,200 ft. Between these two locations the HMA thickness is variable.

The GPR trace from the 75 mm section (Figure 25b) is viewed as an ideal GPR reflection from a thin HMA on top of a dry (good) flexible base. The trace consists of two positive reflections, one from the surface the other from the top of the flexible base. The computed thickness and dielectric values shown in Figure 25b are reasonable and the core was homogeneous defect free.

The trace from the thicker section nearer the bridge was somewhat more complex as shown in Figure 25a. The trace has three positive peaks and an overlapping negative peak between positive peaks 2 and 3. All that can be inferred from this trace is that approximately 3 in below the surface a layer with a lower dielectric will be found. In this instance it turned out to be a thin stripped layer as shown on the photograph. When complex overlapping reflections are found in GPR signals, it becomes difficult to make an accurate estimate of total GPR thickness. In these cases the best estimate is probably to assume a constant dielectric for the entire layer such as is done in the COLORMAP display shown in Figure 24 where an asphalt dielectric of 6 is assumed. For complex traces such as Figure 25a with this simplifying assumption the computed thickness is typically within 10% of the actual.

With traces such as those shown in Figure 25b, a dielectric value is computed for each reflection received from the amplitude of surface reflection from each layer. Experience has shown that with traces similar to this thickness, estimates from GPR will be within 5% of the actual core thickness.

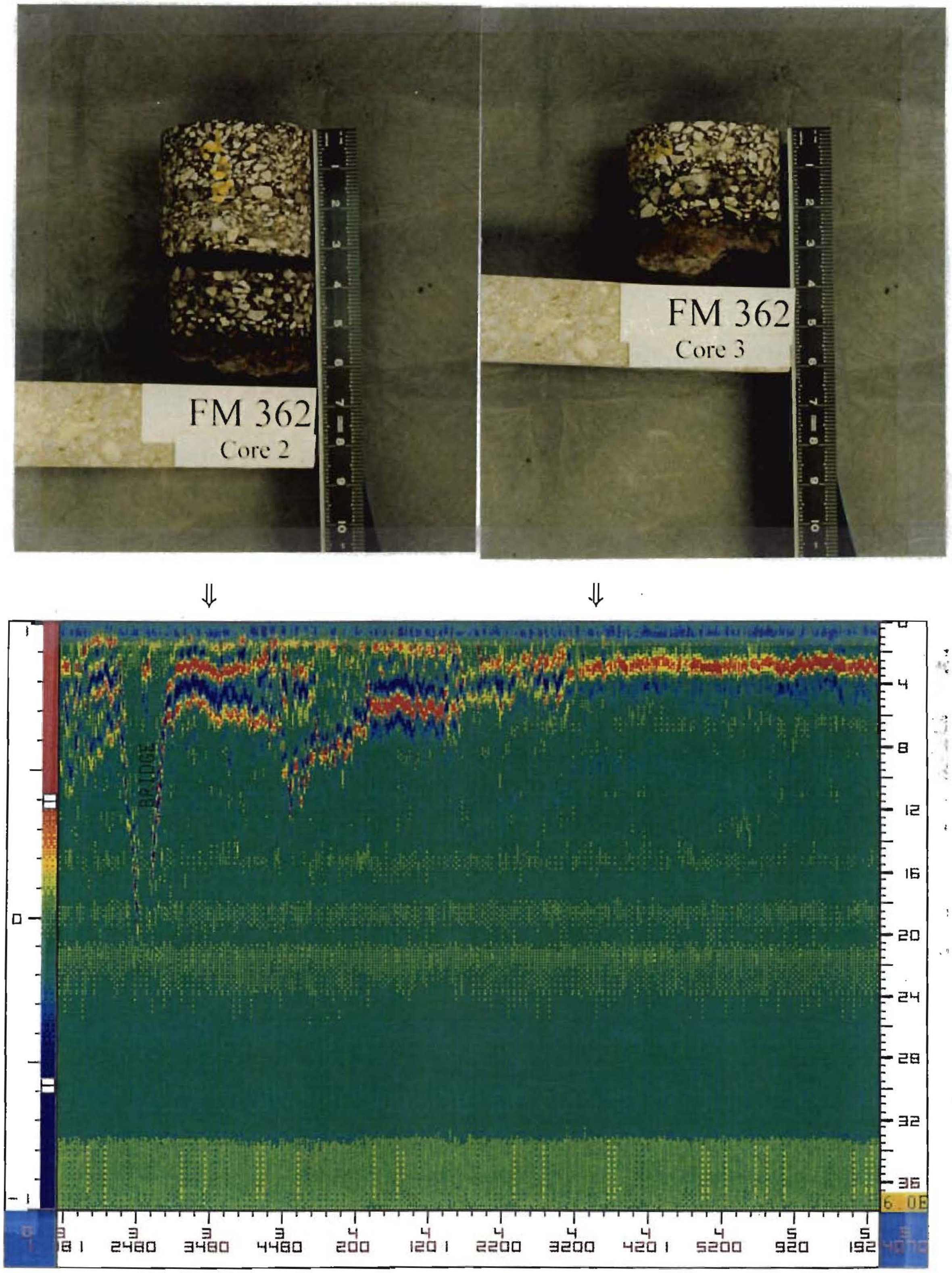
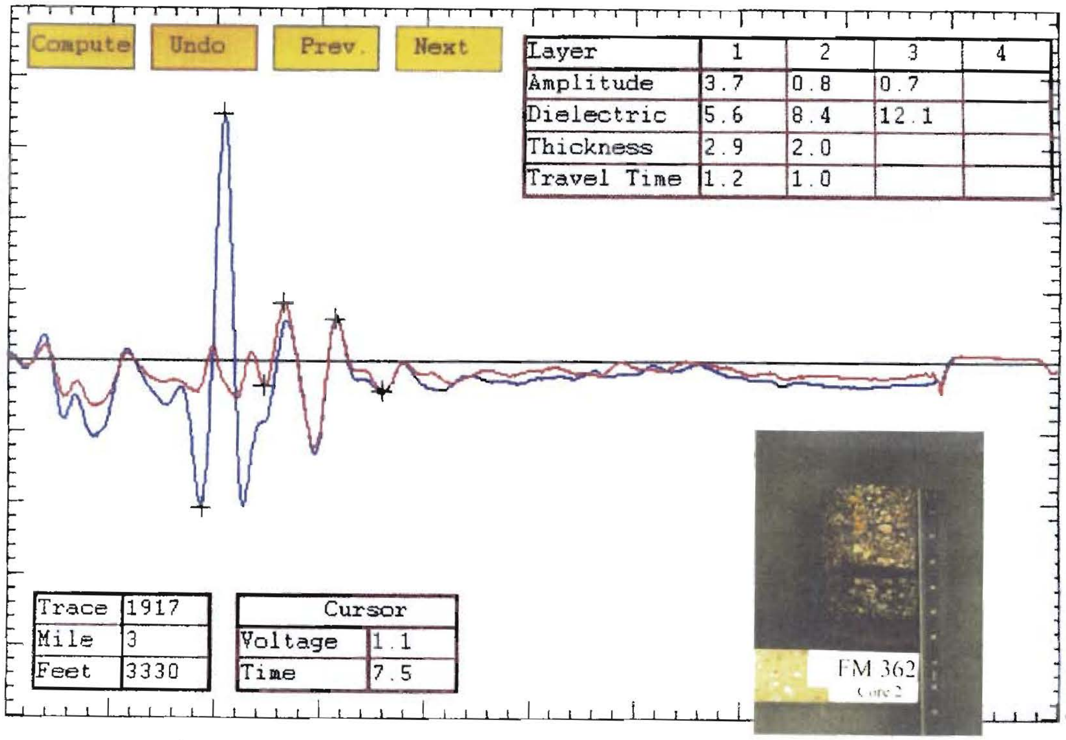
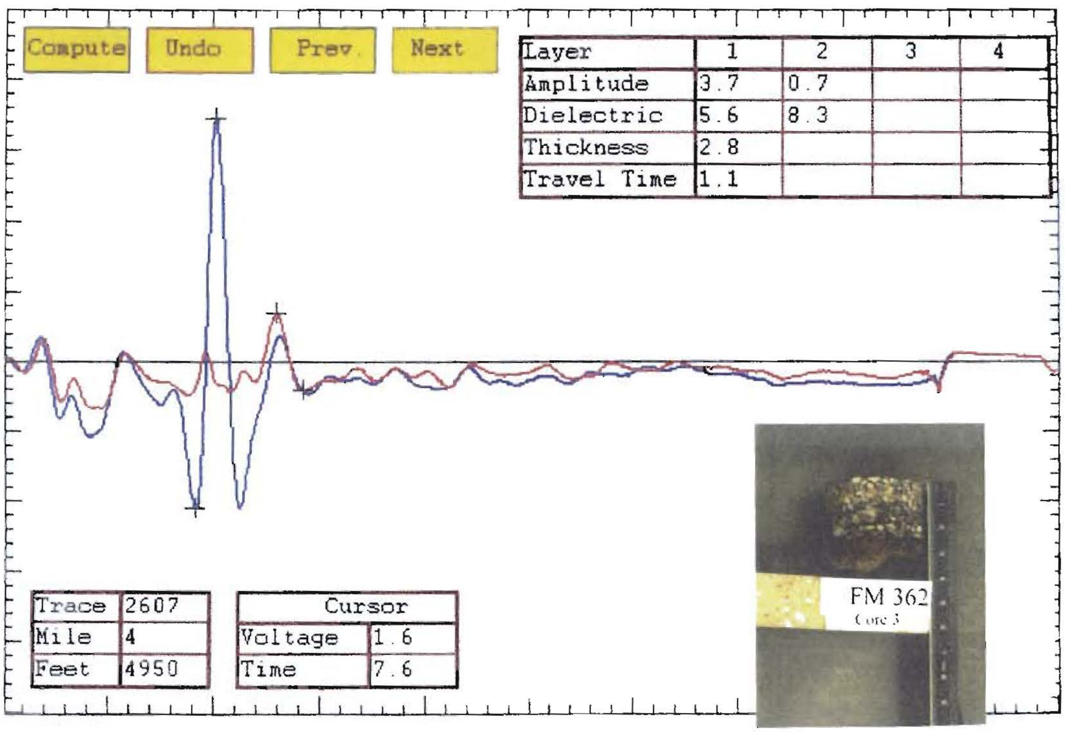


Figure 24. Case 7 Defects in HMA (FM 362, Houston).



a. Defect in HMA.



b. No Defect Trace.

Figure 25. GPR Traces from Core Locations.

4.5 SUMMARY OF RESULTS FROM DISTRICT SURVEYS

The case studies presented earlier demonstrate the benefits of using GPR to collect surface thickness data for flexible pavements. Table 1 presents a summary comparing the different methods of obtaining top layer thickness (plans, coring, GPR) for US 84 in the Brownwood District. The results were shown in graphical form in Figure 23b). To accommodate the Texas PMIS section limits (0.8 km or 0.5 mi) the thickness information has been summarized in half-mile increments. The zero position in Table 1 corresponds to TRM 573 in Figure 23 b. From Table 1 the following observations are made:

1) The plan thicknesses invariably underestimate actual layer thicknesses for the HMA layer. This is a well-known problem where the initial as-built thicknesses are accurate and readily available. However, it is currently difficult to update these thicknesses when maintenance and rehabilitation treatments are applied.
2) For the four core locations, the single core taken in each half-mile section did a reasonable job at estimating the average thickness for the half-mile section. This will be discussed later.
3) Several half-mi sections straddle major changes in layer thickness. For example, the section from 6.5 to 7.0 mi has a thickness range from 10 mm (0.4 in) to 216 mm (8.5 in), the standard deviation of thickness was 56 mm (2.22 in). This more than anything demonstrates the problems with fixed length sections as currently used within PMIS.

Two questions remain to be addressed, firstly "if a district wishes to build its database by coring only, then what sampling interval should be used ?" and secondly "what is the cost per mile for each of the data collection options?".

A basic requirement of the PLDB is that it provides a reasonable thickness estimate so that the correct pavement type classification can be given to each PMIS section. Currently the pavement types are based primarily on the thickness of the HMA layer. For flexible pavements the options include either surface treatment (< 25 mm), less than 60 mm, less than 125 mm, or greater than 125 mm. As far as sample size is concerned, the results shown in Table 1 provide sufficient information

Table 1. Comparing HMA Thickness from GPR, Plans, and Coring. SH 84, Beginning Location TRM 573.

Distance (mi)	Hot Mix Thickness Estimates (ins)					
	GPR				Plans	Cores
	Min	Max	Avg	Std. Dev.		
0 - 0.5	6.1	13.2	10.2	1.38	1.5	9.9
0.5 - 1.0	5.5	8.9	7.3	0.77	1.5	-
1.0 - 1.5	5.5	9.6	6.8	0.56	1.5	6.8
1.5 - 2.0	8.4	12.7	10.0	1.10	1.5	-
2.0 - 2.5	7.4	12.0	10.0	1.01	1.5	-
2.5 - 3.0	7.4	10.8	9.0	0.53	1.5	-
3.0 - 3.5	3.4	13.7	10.3	1.83	1.5	-
3.5 - 4.0	1.0	3.7	2.4	0.49	1.5	-
4.0 - 4.5	1.8	2.9	2.2	0.34	2.5	-
4.5 - 5.0	2.0	3.6	2.7	0.33	2.5	2.5
5.0 - 5.5	2.1	5.5	3.1	0.35	2.2	-
5.5 - 6.0	1.9	4.9	2.7	0.72	2.2	-
6.0 - 6.5	0.9	3.2	2.2	0.30	2.2	-
6.5 - 7.0	0.4	8.5	2.0	2.22	4.8	-
7.0 - 7.5	6.7	9.0	7.6	0.49	4.8	-
7.5 - 8.0	6.3	9.2	8.2	0.51	4.8	-
8.0 - 8.5	0.7	8.7	1.8	3.63	0.5	
8.5 - 9.0	0.8	3.3	1.0	0.10	0.5	-
9.0 - 9.5	0.8	3.5	1.1	0.50	0.5	1.5
9.5 - 10.0	0.8	1.4	1.1	0.11	0.5	-
10.0 - 10.5	1.0	3.7	2.6	0.77	0.5	-
10.5 - 11.0	0.7	2.8	1.2	0.37	0.5	-
11.0 - 11.5	0.6	1.5	0.9	0.23	0.5	-

to perform a statistical evaluation of the number of cores required to predict the mean section thickness to a desired level of confidence. This would involve random sampling of the frequency distribution of actual thicknesses as predicted by the GPR; however, such an analysis would probably result in an unrealistic number of cores for each PMIS section. It is highly unlikely that any district would take more than one core per PMIS section, and given the variability of results in Table 1 at least one core per section appears necessary.

4.6 COST OF DATA COLLECTION

Based on discussions with district and TxDOT personnel, the following cost of data collection are provided.

Manual Interpretation of Plan Sheets

One man-month of experienced technician per county (300 mi)	\$10/mi

GPR Survey

Based on TxDOT design division estimates (Bertrand 1996), the cost of data collection and processing are:

a) TxDOT personnel	\$10/mi
b) University personnel	\$15/mi
c) Private consultant (Pulse Radar Inc., Houston)	\$33/mi

The TxDOT and TTI figures include manpower estimates only. The private consultant's estimate presumably includes both equipment depreciation and profit. Based on this discussion the estimate for GPR data collection and analysis should be close to \$30/mi.

Coring

One core in every PMIS section, (2 per mile)

Asphalt cores $30/core + $20/core traffic control (based on $1000 /day)	$100/mi
Concrete $11 per inch + $20/core traffic control	$260/mi

Coring is not recommended for concrete pavements as the plan thicknesses should be adequate. Coring should only be undertaken on concrete if the plans are missing.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The development of an acceptable PLDB has been under consideration within TxDOT for the last 20 years. The limitations of the current PMIS and RL systems are well known and the urgent need for timely and accurate pavement data is recognized. Despite this need only limited resources have been applied to system development. Senior management has not been fully convinced on the benefits of such a system, and many districts are not convinced that the benefits of the system will outweigh the cost of its development. This has been compounded in recent years when prototype development efforts required large district data collection efforts with little or no clearly defined district benefits. Convincing senior management of the necessity for a PLDB is the main obstacle to its development and implementation. What has been missing in the past is a clear, concise mission statement and action plan to define what is to be collected, how it will be updated, what the costs will be, and how it will help TxDOT perform its job more effectively. It is hoped that the action plan proposed below will form the basis for a future PLDB system development.

In recent years several changes have occurred which make the necessity for a PLDB more obvious, these are:

1) PMIS is increasingly being used for fund allocation purposes. The major flaw in PMIS is the lack of adequate structural layer data. Districts know that regular maintenance will generate a temporarily high pavement score which will count against a district in the fund allocation process. This is clearly not desirable. A PLDB including date of last surface and layer thicknesses will be a critical component in estimating pavement performance trends and future pavement rehabilitation fund requirements.

2) The retirement of many senior engineers has meant that many district pavement engineers and area engineers are relatively young and many have been in their current positions less that three years. The senior engineers had a wealth of knowledge about the history of their road networks which is now lost. The new generation of

engineers is generally more receptive to the PLDB concept.

3) The district pavement design engineers have mostly been trained to use the new analysis techniques for interpreting the FWD data, and they understand the importance of correct thickness in their pavement evaluation decisions.

4) Several new technologies such as GPR, video imaging, and GIS are now available which can greatly assist in the development and implementation of the PLDB.

To be accepted and used within TxDOT, the proposed PLDB will need to provide Austin and district personnel with accurate and timely information to influence their pavement management decisions. A PLDB must be capable of providing layer thickness and layer type information in three dimensions, both longitudinally along the highway and transversely across the highway. The transverse profiles (typical sections) are critical to the districts in project level evaluations. Typical section sheets are usually available from old plan sheets, but as described in Chapter 4, they often do not represent what is in the highway, with the thickness of the top layer being mostly less than what is on the highway. Longitudinal profiles (especially in the outside lane outside wheel path) are not available but these are critical at both the network and project level in processing FWD data and in classifying pavement types for PMIS applications.

In developing these recommendations for PLDB development the following items were considered:

1) Long-Term versus Short-Term Development

A short-term effort (1-2 years) is proposed to implement the basic PLDB in selected districts meeting the minimum information and reporting requirements. A successful implementation will permit a cost/benefit assessment of statewide and long-term system implementation. A longer term effort (2-5 years) can build on this short-term effort to field test many of the new technologies which are now available.

2) Pavement Layer Database Steering Committee

None of these recommendations will take place without a "champion" within the department. Development responsibility should be assigned to a senior engineer within the design division. A small steering committee should be assembled consisting of design division, automation division, district, and university personnel. Their challenge will be to prepare a development plan to obtain senior management support and the required resources for system development.

Action Item 1 *A PLDB champion should be appointed from the Pavements Section of the Design Division. The champion's duties will be to form a steering committee to plan PLDB development, to seek approval for resources from senior management, and to prototype the system in selected districts. TXDOT has recently allocated a substantial amount of funds into implementation of the products of research. This is a potential source of funds for pilot testing the prototype PLDB and evaluating the new technologies proposed in the long-term system development.*

5.1 RECOMMENDATIONS FOR SHORT-TERM PLDB DEVELOPMENT

Goal: To improve the existing manual Road Life development effort by creating system outputs and automated PLDB update procedures when Maintenance and Rehabilitation (M&R) jobs are completed. To also validate the PLDB entries with GPR surveys. The initial focus will be on longitudinal variations in thickness in the outside lane outside wheel path.

Minimum data requirements:

At the initial stages the minimum data items should be collected. Only five data items are considered mandatory at this time for flexible pavements, these being a) total HMAC thickness, b) base type, c) base thickness, d) date of last surface, and e) type of last surface. This short list will answer most of the major needs but many more items could be added to the list, for example, subbase type and thickness. The final minimum list should be one of the duties of the PLDB steering committee. It cannot be emphasized strongly enough that including "nice to have" items will doom this data collection effort to failure.

Table 2 below proposes which items need to be collected and how they will be validated.

Table 2. Source of Items in Initial PLDB.

Item	*Established From*	*Validated*
Total HMA Thickness	Plan Sheets (1)	GPR
Base Type	Plan Sheets (2)	GPR/Coring (3)
Base Thickness	Plan Sheets (2)	Coring/GPR (3)
Date of Last Surface	DCIS or Interviews	-
Type of Last Surface	DCIS or Interviews	-

(1) If plan sheets are missing perform GPR survey.

(2) If plan sheets are missing - GPR followed by coring.

(3) Only if discrepancy between plans and GPR.

Action Item 2 **_Develop a Coding Manual_**

Manual coding of the existing plan sheets will be the basis for the system development. As described in Chapter 3 there are many unresolved issues in this area. As the top priority the PLDB steering committee should develop a standardized coding manual. The experiences of the Brownwood and Houston Districts must be included.

Action Item 3 **_Develop Output Formats_**

The current Road Life system is simply a flat file with little or no use at the moment. Output formats must be developed to provide point-specific thickness estimates and graphical plots of subsurface thickness over a user-defined reporting interval, several examples of these graphical plots have been given in this report. (See Figure 5) A linkage to the PMIS system must also be developed to provide pavement type classification for each PMIS 0.8 km (0.5 mi) section.

Action Item 4 **_Develop System Update Capabilities_**

It must be clearly understood that the system, once established, must be updated as a routine operation. This will require changes or additions to the job closeout procedures. Construction, maintenance, and rehabilitation activities must be included.

Action Item 5 **_Prototype System in Four Districts_**

Providing the qualified FTEs to develop the PLDB in-house seems not to be feasible for most districts. This would be a one time effort and possibly best handled by an engineering contract in a similar manner to the current PMIS data collection effort. To minimize start-up problems, this would appear to be an ideal project for recent TxDOT retirees who are familiar with TxDOT plan sheets, terminology, and filing systems. The prototype PLDB should be established in four districts, two with large urban areas and two with mostly rural highways.

Action Item 6 **_GPR Data Collection_**

As described in Chapter 4, GPR can play an important role in validating the PLDB entries and in updating the thickness of the HMA layer. GPR is the only technology available which can provide subsurface information at highway speed. A combined GPR/video survey should be made of all the flexible pavements in the four districts selected for prototype system development. This information will also be used in the long-term development effort to be described later.

Action Item 7 **_Limited Field Coring_**

Funds will need to be provided for a limited amount of field coring. This will be undertaken on a limited basis when there is a major discrepancy between the plan and GPR thickness profiles.

5.2 RECOMMENDATIONS FOR LONG-TERM PLDB DEVELOPMENT

Goal: To integrate video, GPR, and scanned pavement profiles to provide on-line displays of layer properties in both the longitudinal and transverse directions. The proposed system would primarily meet the districts' need in identifying potential causes of pavement distress, in interpreting FWD data, and in developing optimal pavement rehabilitation strategies.

The short-term development effort described in the last section is aimed at getting the minimal system working in a relatively short period of time. However, in the last five years major changes have occurred in computer technology, nondestructive testing, and data storage capabilities. These new technologies will be integrated in the long-term development of a "state-of-the-art" PLDB for TxDOT.

The proposed system will rely heavily on automation and map-based reporting. It should be the task of the PLDB steering committee to plan and support the building of the prototype system. Possible scenarios for this system are shown in Figures 26 through 29. These figures are included for illustration purposes only. A starting place for the long-term system could be a highway map upon which the user identifies the section of interest. An annotated control section diagram for the selected location is then displayed. A possible example is shown in Figure 26. This control section is from the Brownwood District. It was broken up into six distinct sections. The drill symbols on the figure are locations where detailed drill log information is available. If these are requested the standard drill log sheets for that location will be displayed. This control section is broken up into six design sections as identified by the GPR data. The user can then request either transverse or longitudinal thickness profiles for any location on the control section. If the transverse profile is requested then the typical section sheet will be displayed for the section with the date of last surface identified. An example of this is shown in Figure 27. These sheets will be automated by either scanning them or redrawing them with an automation package. Several options will be available to display information in the longitudinal direction. These included thickness plots such as the one shown earlier in Figure 23 or annotated GPR outputs such as the one shown in Figure 28. Another option could be to display a merged video image and GPR trace as shown in Figure 29. The video will show the surface condition, and the GPR trace will identify potential subsurface defects.

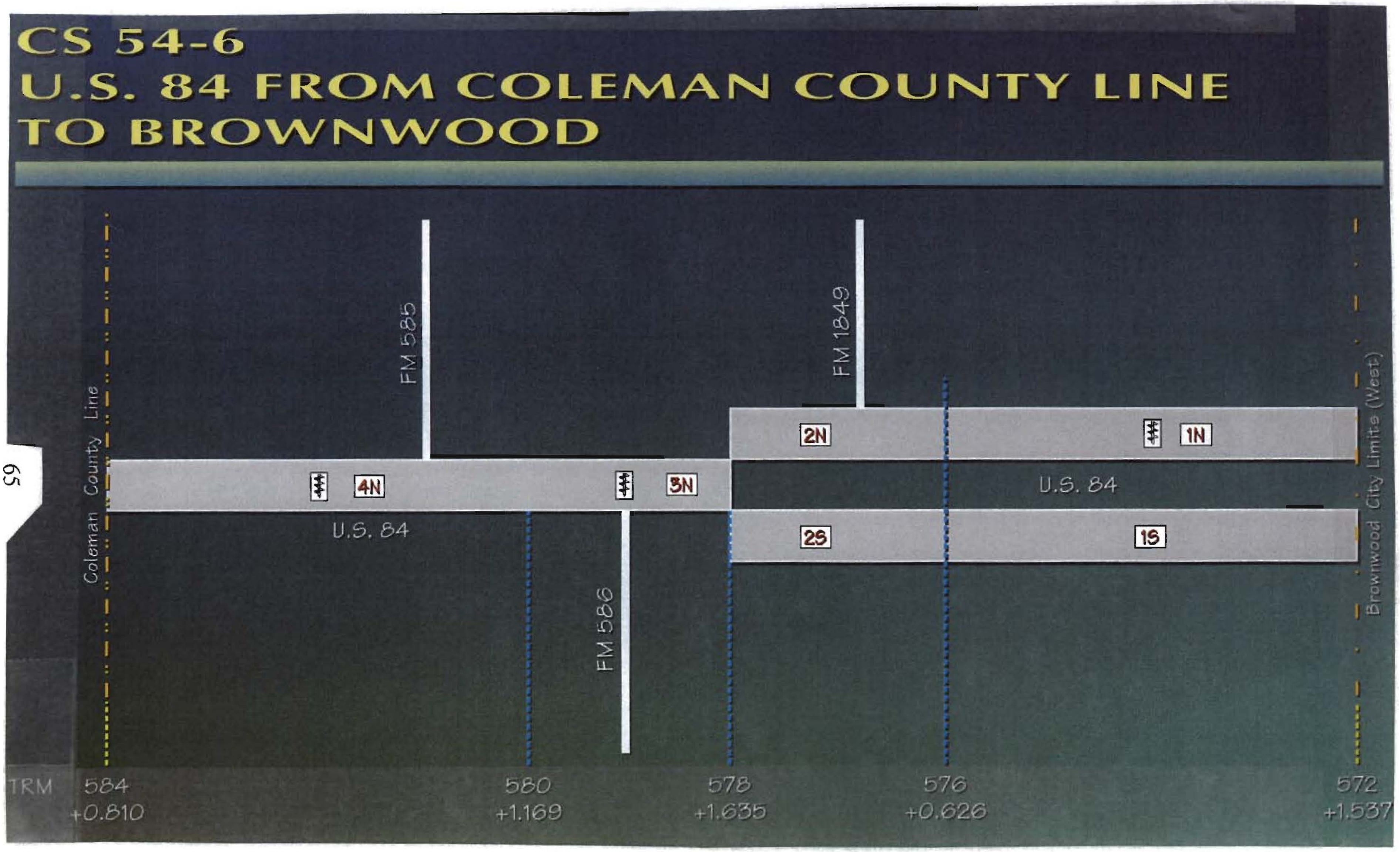
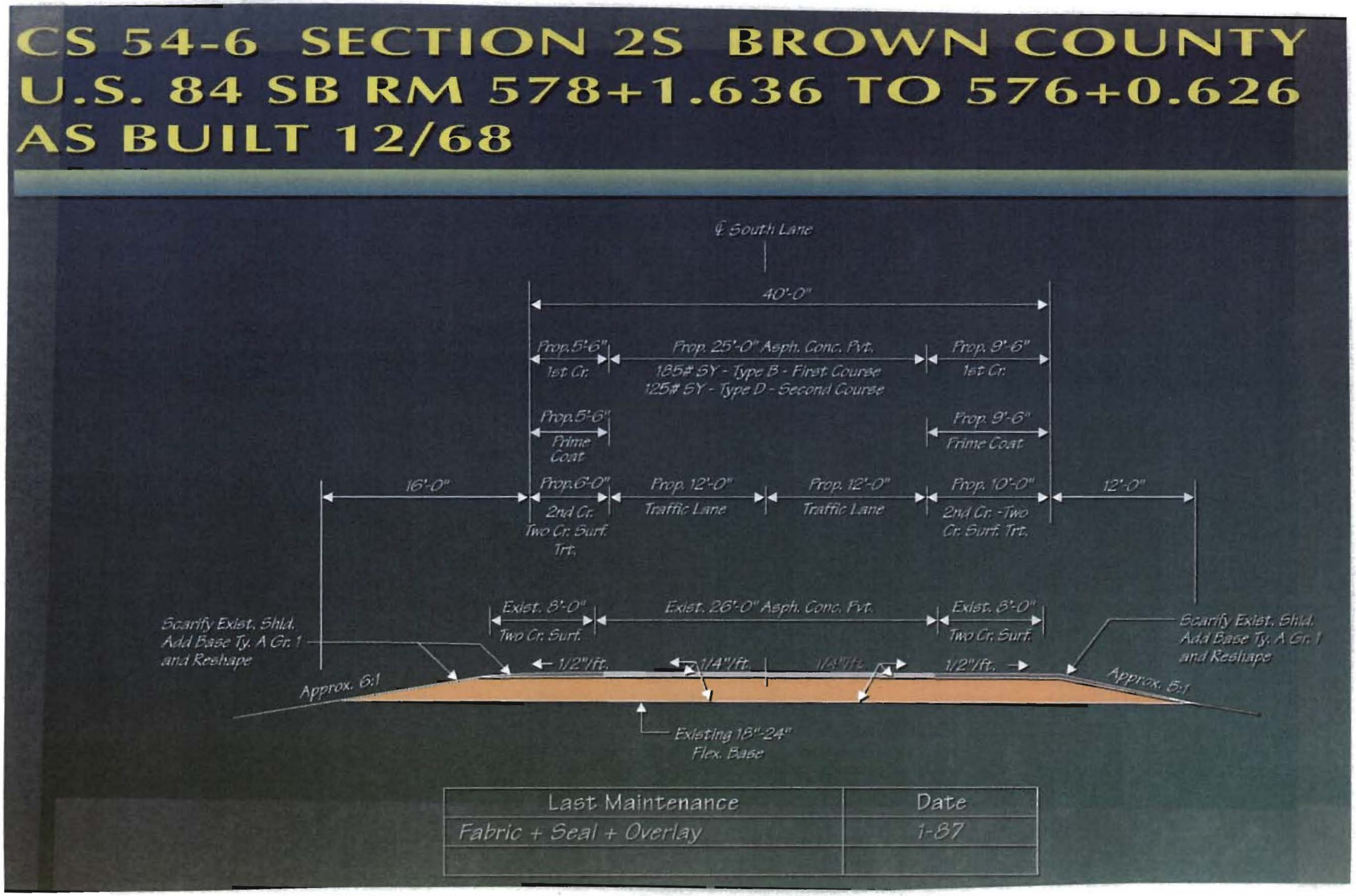


Figure 26. Annotated Control Section Map for CS 54-6. Section Breaks Identified by GPR.



Last Maintenance	Date
Fabric + Seal + Overlay	1-87

Figure 27. Automated Typical Sections for CS 54-6.

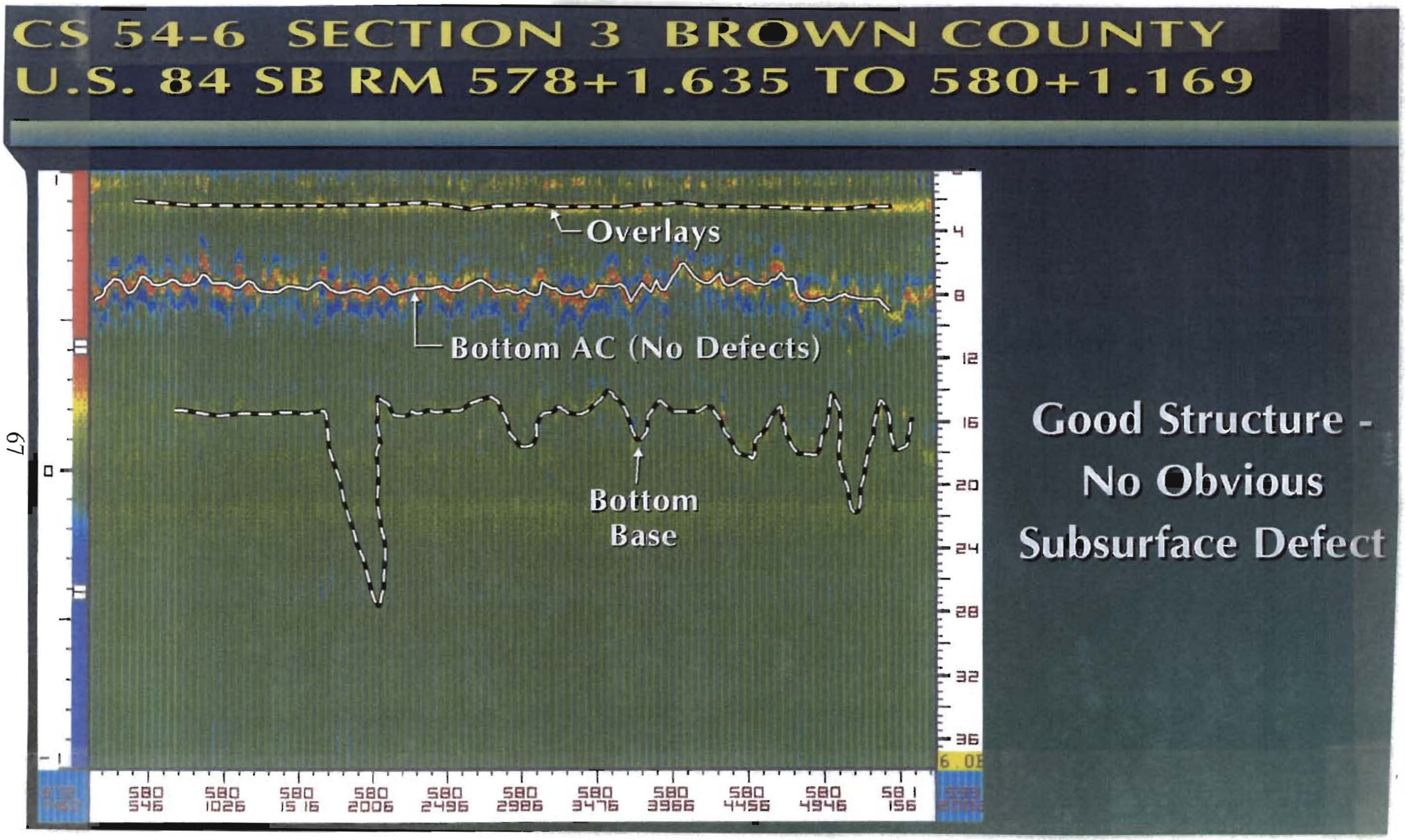


Figure 28. Annotated GPR Data for a One Mile Section of CS 54-6.

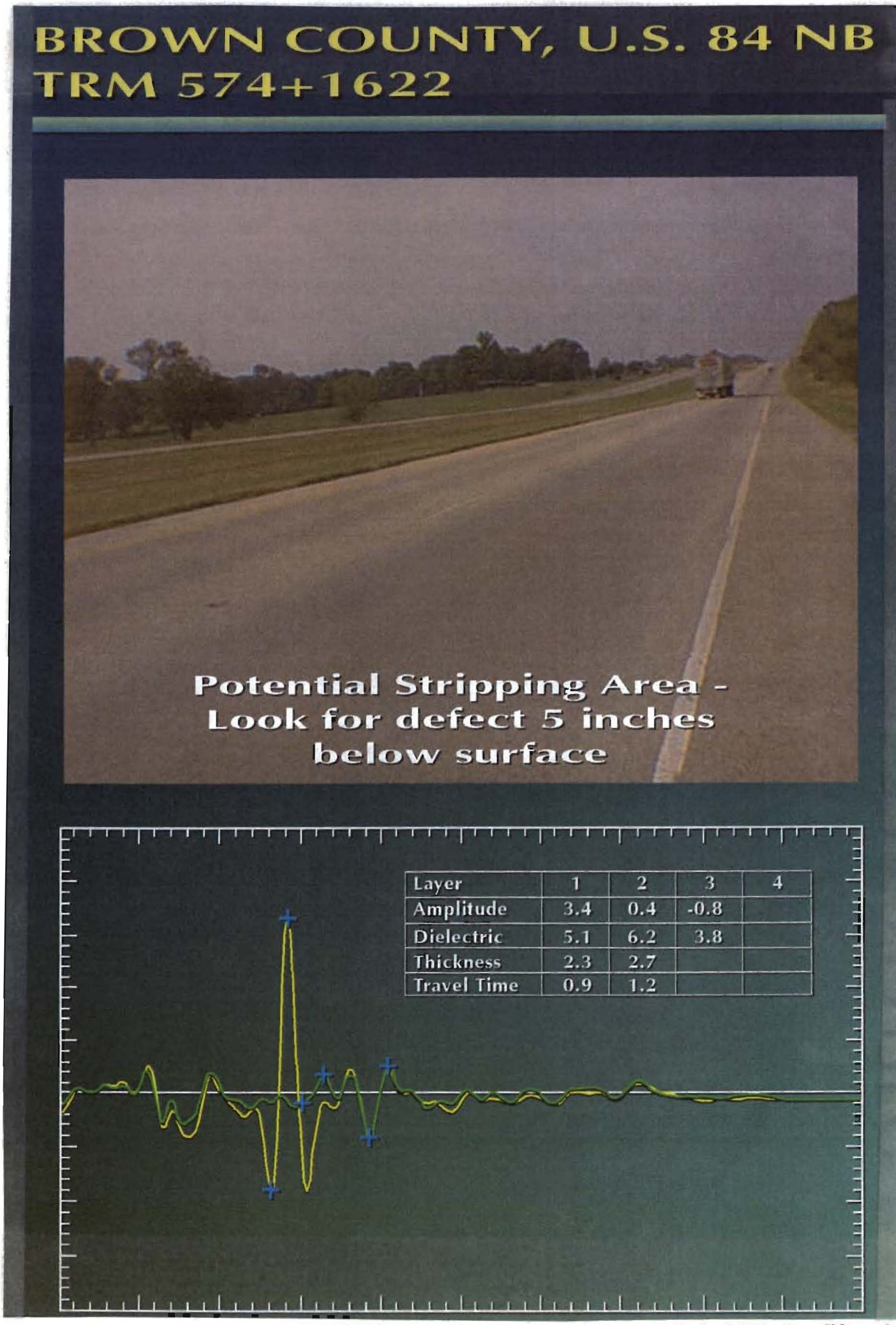


Figure 29. Merging Video and GPR Data to Assist with Pavement Rehabilitation Planning.

Selected video images (one every 10 or 20 ft) could be digitized, stored, and synchronized with the GPR images. The merging of video and GPR data is currently being done at the project level. Again these last four figures were presented as possible scenarios. The PLDB steering committee should arrive at a consensus and a prototype system should be developed. As before, a prototype system is pilot tested in one or two counties before full-scale implementation is considered.

Below is a continuation of action items which are viewed as critical in the development of a prototype comprehensive PLDB:

Action Item 8 ***Complete Development of TxDOT's Multi-Functional Vehicle***

Most of the data needed to develop the envisioned system can already be collected with the department's existing equipment. This will be streamlined when the MFV becomes fully operational. Integrating the video, GPR, and roughness data with global positioning coordinates will provide data for potential map-based applications.

Action Item 9 ***Scan Typical Sections and Control Sections***

An effort should be undertaken to automate the most recent typical section sheets for the prototype development area. These must show, as a minimum, the base and surface thicknesses. Some of the old sheets are in poor shape so several may have to be redrawn.

Action Item 10 ***Collect and Interpret Integrated Video and GPR Data***

The department is in the process of purchasing additional GPR units, and training schools are available to assist with interpretation.

Action Item 11 ***Automate the Drill Log Information Sheets for the Prototype Area***

Action Item 12 ***Put the Entire System on a GIS-Based Platform***

REFERENCES

1) Scullion, T., and Smith, R., "Recommended Improvements to TxDOT's PMIS," TTI Report, 1420-1 F, Nov. 1997.

2) Scullion, T., "Incorporating a Structural Strength Index into the Texas Pavement Evaluation System," TTI Report 409-3 F, Nov. 1988.

3) Scullion, T., Chen, Y., and Lau, L. L., "COLORMAP- User's Manual with Case Studies," TTI Report 1341-1, Nov. 1995.

4) Personnel Communication with Tiit Plakk, Estonia concerning the Percometer Dielectric Probe.

5) Rmeili, E., and Scullion, T., "Detecting Stripping in Asphalt Concrete Layers Using GPR," TRB Paper 970508, Jan. 1997.

6) Personnel Communication with Carl Bertrand, TxDOT Design Division, Sept. 1996.

APPENDIX A

LAYER INFORMATION RECOMMENDED BY PMIS TASK FORCE

Table A1 below shows the PLDB information recommended by the Task Force assembled by TxDOT in the early 1990s to plan the development of PMIS. M, D, and O are mandatory, desirable, and optional.

Table A1. Layer Information Recommended by TxDOT Pavement Management Task Force.

Data Item	*Priority*
1. Section Identification	M
2. Subgrade Type	D
2a. Texas Triaxial Class	O
3. Subgrade Stabilization	D
4. Stabilization Depth	O
5. Swelling Potential	O
6. Subbase Type	D
7. Subbase Thickness	D
8. Base Type	D
9. Base Thickness	D
10. Original Surface Type	M
11. Original Surface Thickness	M
12. Date of Original Surface	M
13. Total Overlay Thickness	M
14. Date of Last Overlay	M
15. Type of Last Overlay	M
16. Thickness of Last Overlay	M
17. Date of Last Surface Seal	M
18. Type of Last Surface Seal	M

Key

2. Subgrade Type - Table A2

2a. Texas Triaxial Class - District Input

3. Subgrade Stabilization

0	None
1	Asphalt
2	Cement
3	Lime
4	Other

4. Thickness of Stabilization - in inches to the nearest inch

5. Swelling Potential (obtained from county soil series reports or experience)

0	Unknown
1	Slight
2	Moderate
3	Severe

6. Subbase Type - Table A3

7. Subbase Thickness

Minimum Accuracy - specify by range as indicated below:

0	No subbase
1	<6"
2	6-8"
3	8-10"
4	10-12"
5	>12"

Desirable Accuracy - specify subbase thickness to nearest inch

8. Base Type - Table A3

9. Base Thickness

Minimum Accuracy - specify by range as indicated below:

a	No Base

1 <6"

2 6-8"

3 8-10"

4 10-12"

5 >12"

Desirable Accuracy - specify base thickness to nearest inch

10. Original Surface Type - Table 3
11. Original Surface Thickness

    Minimum Accuracy - specify original surface thickness to nearest 1 inch

    Desirable Accuracy - specify original surface thickness to nearest 0.5 inch

12. Date of Original Surface (MMYY)
13. Total Overlay Thickness

    This is the total thickness of material above the original surface, excluding the last overlay

    Minimum Accuracy - nearest 0.5 inch

    Desirable Accuracy - nearest 0.25 inch

14. Date of Last Overlay (MMYY)
15. Type of Last Overlay - Table 3
16. Thickness of Last Overlay

    This thickness represents the last major addition to or reworking of the existing pavement surface. This can be an overlay, hot-in-place recycling, or other such activity.

    Information on overlays is mandatory on all hot mix asphalt concrete pavements. It is not applicable if the pavement structure only includes surface treatments and seal coats.

    Minimum Accuracy - nearest 0.5 inch

    Desirable Accuracy - nearest 0.25 inch

17. Date of Last Surface Seal - Date last seal coat or other surface seal applied.

    This is mandatory if the pavement structure only includes surface treatments and seal coats.

18. Type of Last Surface Seal - Table 3

    Update Cycle

    1. Whenever changes occur to RL file, this file will be updated annually at the beginning of PMS cycle.

Table A2. Subgrade Soil Descriptions.

Soil Description	*Code*
Clay (Liquid Limit >50)	51
Sandy Clay	52
Silty Clay	53
Silt	54
Sandy Silt	55
Clayey Silt	56
Sand	57
Poorly Graded Sand	58
Silty Sand	59
Clayey Sand	60
Gravel	61
Poorly Graded Gravel	62
Clayey Gravel	63
Shale	64
Rock	65

Table A3. Base and Subbase Material Type Codes.

Soil Description	*Code*
No Base	21
Rives Gravel	22
Crushed Limestone	23
Iron Ore Gravel	24
Soil Aggregate (Predominately Soil)	25
Bituminous Treated Soil-Aggregate	26
Bituminous Aggregate Mixture (Plan Mix)	27
Asphalt Concrete Hot Mix	28
Open Graded Asphalt Treated	29
Thin Asphalt Concrete Layer Over Granular Material	30
Soil Cement	31
Cement-Aggregate Mixture (Gravel and Crushed Stone)	32
Cement-Aggregate Mixture Over Granular Material	33
Lean Concrete Mixture	34
Recycled Concrete Mixture	35
Lime-Treated Clay Soil	36
Cement-Treated Clay Soil	37
Pozzolanic-Aggregate Mixture	38
Recycled Asphalt Concrete	39

Table A4. Pavement Surface Material Type Codes.

Material Type	*Code*
Asphalt Concrete	1
Cold Mix Bituminous Material	2
Sand Asphalt	3
Portland Cement Concrete (JPCP)	4
Portland Cement Concrete (JRCP)	5
Portland Cement Concrete (CRCP)	6
Portland Cement Concrete (Prestressed)	7
Portland Cement Concrete (Fibrous)	8
Bituminous Surface Treatment	9
Recycled Asphalt Concrete	10
Recycled Portland Cement Concrete	-
JPCP	11
JRCP	12
CRCP	13

APPENDIX B

CODING SYSTEM FOR CURRENT ROAD LIFE SYSTEM

Required Layer Inputs

<table>
<tr><th colspan="3">Layer ID Inputs</th></tr>
<tr><td colspan="3">BS - BASE
ML - Milled Surface
OS - Original Surface
OV - Overlay
SB - Subbase
SC - Seal Coat
SG - Subgrade</td></tr>
<tr><th colspan="3">Material Types Inputs</th></tr>
<tr><th>Base and Subbases</th><th>Milled Layer</th><th>Original Surface and Overlay</th></tr>
<tr><td>0 - Unknown
1 - River Gravel
2 - Crushed limestone
3 - Iron Ore Gravel
4 - Caliche
5 - Sand Stone
6 - Lime Stone Asphalt
7 - Recycled Asphalt Concrete
9 - Other</td><td>No input required</td><td>A - Asphalt Concrete Pavement
C - Continuous Reinforced Concrete
P - Plain Jointed Concrete
R - Reinforced Joined Concrete
S - Surface Treatment</td></tr>
<tr><th colspan="3">Material Types Inputs (Continued)</th></tr>
<tr><th>Seal Coat</th><th colspan="2">SubGrade</th></tr>
<tr><td>C - Chip Seal
D - Double Chip Seal
F - Fog Seal
M - Micro-Surfacing
R - Rubberized Chip Seal
S - Slurry Seal
T - Triple Chip Seal</td><td>0 - Unknown
1 - Clay
2 - Sandy Clay
3 - Silty Clay
4 - Silt
5 - Sandy Silt
6 - Clayey Silt
7 - Sand</td><td>8 - Poorly Graded Sand
9 - Silty Sand
10 - Clayey Sand
11 - Gravel
12 - Poorly Graded Sand
13 - Clayey Gravel
14 - Shale
15 - Rock</td></tr>
<tr><th colspan="2">Stabilization Types</th><th>Drainable</th></tr>
<tr><th colspan="2">Base, Subbase, and Subgrade</th><th>Base and Subbase</th></tr>
<tr><td colspan="2">0 - Unknown
1 - None
2 - Asphalt
3 - Portland Cement
4 - Lime
5 - Fly Ash
9 - Other</td><td>0 - Unknown
Not Drainable
2 - Drainable
9 - Other</td></tr>
</table>

Optional Data Elements

Optional Field Inputs for Seal Coats			
Aggregate Type	Aggregate Grade	Precoated	Polished Value
0 - Unknown 1 - Siliceous River Gravel 2 - Limestone 3 - Limestone Rock Asphalt 4 - Lightweight 9 - Other	0 - Unknown 1 - Grade 1 2 - Grade 2 3 - Grade 3 4 - Grade 4 5 - Grade 5 9 - Other	Y - Yes Precoated N - No Precoat	0 -99 Value
Optional Field Inputs for Asphalt Concrete Pavement (ACP)			
Aggregate Type	Aggregate Grade	Binder/Type	% Rap
0 - Unknown 1 - Siliceous River Gravel 2 - Limestone 4 - Limestone Rock Asphalt 9 - Other	0 - Unknown 1 - Type C (Coarse Surface) 2 - Type D (Fine Surface) 3 - Type F (Fine Mixture) 9 - Other	0 - Unknown 1 - AC - 1.5 2 - AC - 3 3 - AC - 5 4 - AC - 10 5 - AC - 20 6 - AC - 30 9 - Other	0-99 Value
Optional Field Inputs for Rigid Pavements (CRCP, JCP, JRCP)			
Aggregate Type	Coarse Aggregate Grade	Cement Type	% Fly Ash
0 - Unknown 1 - Siliceous River Gravel 2 - Limestone 9 - Other	0 - Unknown 1 - Grade 2 2 - Grade 3 9 - Other	0 - Unknown 1 - Type I 2 - Type II 3 - Type III 4 - Type IP 9 - Other	0-99 Value