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16. Abstract


The Texas Department of Transportation (TxDOT) has used both Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) technology for over 10 years to provide structural information about its pavements. With the current systems, GPR data are processed independently of the FWD analysis. The GPR data are processed with the COLORMAP analysis system, and the FWD data are processed with MODULUS 6.0. There is substantial synergy in combining the analysis capabilities of both systems.

In Project 0-4495 an integrated software package called PAVECHECK was developed to merge the FWD and GPR data together with digital video images of surface condition. The new feature in this analysis is that point-specific layer thickness estimates from the GPR can be used within the layer backcalculation process. Most of the features of the existing COLORMAP and MODULUS programs have been incorporated into PAVECHECK. This report provides a user's manual for the new program. This report is accompanied by a CD which contains the software and several test data sets. The data set named Annex is used throughout this report to demonstrate the features of PAVECHECK.

This system has tremendous potential to assist TxDOT engineers with future forensic and pavement rehabilitation studies. The PAVECHECK framework can also serve for as basis for future pavement layer database efforts and for documenting and evaluating the performance of research test sections.


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# PAVECHECK: INTEGRATING DEFLECTION AND GROUND PENETRATING RADAR DATA FOR PAVEMENT EVALUATION

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- Brian Michalk
- Jeff Howdeshell

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# CHAPTER 1

# INTRODUCTION

The Texas Department of Transportation (TxDOT) has used both Falling Weight Deflectometers (FWD) and Ground Penetrating Radar (GPR) technology for over 10 years to provide structural information about its pavements. With the current systems, GPR data are processed independently of the FWD analysis. The GPR data are processed with the COLORMAP analysis system (*1*), and the FWD data are processed with MODULUS 6.0 (*2*), which is the latest version of TxDOT backcalculation software. There is substantial synergy in combining the analysis capabilities of both systems. For example, to perform backcalculation the layer thickness at the location of the deflection data must be input. These thicknesses are typically obtained from either plan thicknesses or limited coring. Inaccuracies in these thickness estimates are known to be a large source of error in the resulting layer modulus values. One major concern is that the thickness of the surface layer may not be constant and can vary substantially along a project. It is important to realize that the computed layer moduli are highly dependent on all input thicknesses, especially for the surface layer. Studies completed almost 20 years ago at Texas Transportation Institute (TTI) found that a 10 percent error in estimating surfacing thickness results in a 20 to 30 percent error in backcalculated base modulus (*3*). In many instances the error in estimating surface thickness is well over 10 percent.

In addition to providing more accurate layer thickness information, GPR can also identify defects in subsurface layers, such as the presence of deteriorated layers in the hot mix or areas of high base moisture contents (*4, 5*). Both of these explain changes in results from the FWD backcalculation process.

## 1.1 CURRENT GPR DATA COLLECTION AND PROCESSING SYSTEM

TxDOT currently uses a noncontact GPR system as shown in Figure 1 to collect radar data. GPR data are collected using a software package called Radar 2K. At the same time that the GPR data are collected, a video image is also collected showing the pavement surface under test. The video images are currently collected on a standard VHS videotape. To process the data, GPR data are processed using a setup as shown in Figure 2.

**Figure 1. Air Coupled GPR System.**

**Figure 2. Current GPR Processing System Setup.**

The GPR data are viewed with COLORMAP software, and the video data are viewed on a television screen using a standard, videocassette recorder (VCR) player. To cross reference the GPR and video data, the distance information from the distance measuring instrument (DMI) is split and entered in the header of the VHS tape as shown in Figure 3. Once the user finds an anomaly in the GPR data, the distance of the GPR trace is noted, and the video is advanced to that location to check surface condition.

The COLORMAP system permits computation of the following:

- Layer dielectrics (up to four layers)
- Layer thicknesses (up to three layers)

This system also has the capability of correcting for antenna bounce and performing signal deconvolution so that the thickness of thin layers (<1.5 inches) can be accurately estimated. To complete the GPR analysis system, TTI developed a Windows-based software package for data acquisition, which also can perform limited real-time processing (5). The COLORMAP system meets most of the needs of both the project and network level thickness determination. COLORMAP also color-codes and stacks GPR traces so that the operator can look at a long length of highway on a single screen, permitting easy identification of layer interfaces and layer defects.


**Figure 3. VHS Video with Distance Location.**

In most GPR projects, several thousand GPR traces are collected. In order to conveniently display the subsurface information, a color-coding scheme converts the individual GPR reflections into line scans and stacks them side-by-side to obtain a subsurface image of the pavement structure. Figure 4 shows a typical display from the COLORMAP system for a thick hot mix pavement. This pavement was taken from a section of newly constructed thick asphalt pavement over a thin granular base. The layer interfaces are the red and blue lines in the figure. The labels on this figure are as follows A) files containing data, B) main pull-down menu, C) button to define the color-coding scheme, D) distance scale (miles and feet), E) end location, G) default dielectric value used to convert the measure time scale into a depth scale, and F) depth scale. The important features of this figure are the lines marked H, I, and J. These lines are the reflections from the surface, top, and bottom of base, respectively. This pavement is homogeneous, and the layer interfaces are easy to detect. The variation in surface dielectric is shown at the bottom of the figure. This value is useful for detecting areas of low density.

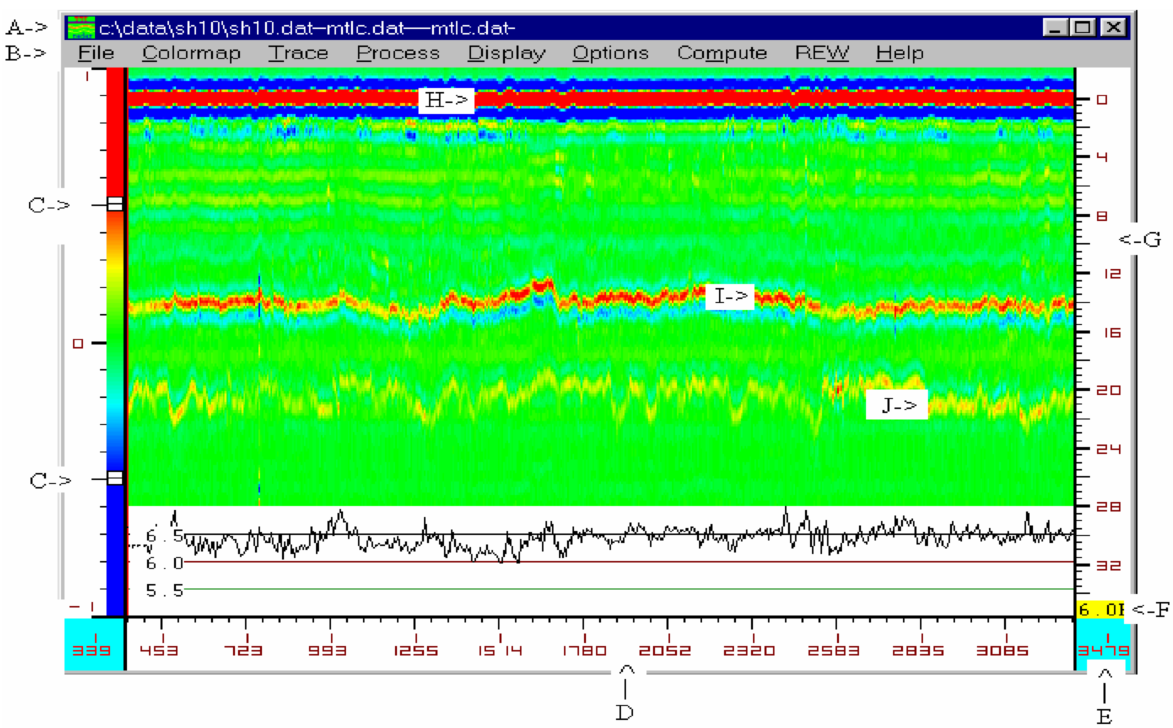



**Figure 4. Color-Coded GPR Traces.**

When processing GPR data the first step is to develop displays such as these shown in Figure 4. It is then possible to identify clear breaks in pavement structure and significant anomalies. The intensity of the subsurface colors relates to the amplitude of reflection. Therefore, areas of wet base are observed as bright red reflections (*1*).

### 1.2 MODULUS 6.0 FOR WINDOWS (*2*)

TxDOT uses the MODULUS program to process FWD data. This system has been used since the early 1990s to perform structural evaluation of the pavements and to provide layer moduli values for use in TxDOT structural design programs.

The most recent research study in the FWD analysis area was Project 0-1869, which was initiated in 1998 to expand the analysis and design capabilities of this system. Report 0-1869-2 provides a user's manual for the new Windows version of MODULUS 6.0 (*2*). The basic features of the pre-existing DOS MODULUS 5.1 system were transferred to Windows. Substantial improvements were also made to the system, in terms of data editing, data reporting, and segmentation. Figure 5 shows the method of specifying layer thickness and acceptable moduli ranges within MODULUS 6.0.

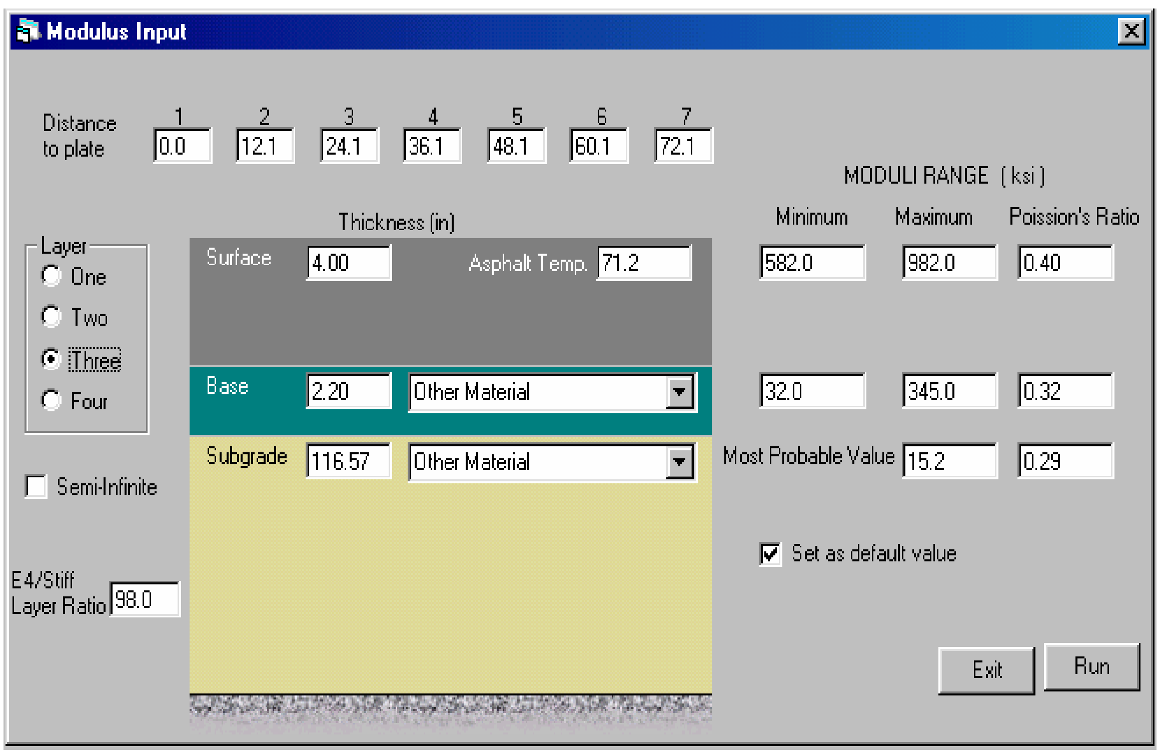



**Figure 5. Data Input Screen within MODULUS 6.0.**

## 1.3 PAVECHECK: INTEGRATING DEFLECTION AND RADAR DATA FOR PAVEMENT ANALYSIS

Based on the review of TxDOT's existing GPR analysis system, FWD backcalculation, and video capture systems are made up of three independent systems that share a reference marker system. GPR and video data are collected simultaneously using the same reference system. FWD data are collected using a separate vehicle. Currently the data for each system are processed separately and integrated based on reference markers. The videotape is reviewed to locate areas of significant distress, and the GPR data are analyzed to note layer thicknesses and their variation along the roadway and to locate obvious subsurface defects. Finally, the FWD data are processed to obtain pavement strength information. There are numerous integration problems with the current system; these include:

- The analog video system uses a VHS tape, which does not have random access capability, making it difficult to browse and synchronize the data.
- The analog video system currently does not produce good-quality images compared to existing digital images.
- The analog video data acquisition hardware is relatively complicated and expensive, and this system requires a high-quality VCR, monitor, and a video splitter device.
- The COLORMAP and MODULUS programs are not currently integrated. Average layer thickness information from COLORMAP must be manually input into the backcalculation program.

The PAVECHECK system developed in this project attempts to combine deflection, radar, and video data to form an integrated system to overcome the limitations described above. Figure 6 is an illustration of the PAVECHECK system setup.

The integrated analysis program PAVECHECK accepts multiple input file formats obtained by utilizing various data acquisition programs. For example, PAVECHECK accepts GPR data from TxDOT's current RADAR2K program. With this data format no integration of the GPR and video images is possible, but PAVECHECK is downwardly compatible. Two other input data types can also be used with the PAVECHECK program. Both of these input data files integrate the GPR, digital images, and distance traveled. One data file type, PF99, is generated by TxDOT data collection systems. The other is generated by TTI's data collection software.

PF99 data format, which was developed by TxDOT, is a versatile ASCII coded format that captures many data types from different subsystems installed on a data collection vehicle. Figure 7 shows a sample of this format.

TTI format was generated to obtain the GPR data and digital video data along with distance traveled. The data are then integrated, providing random access to the user. The TTI format contains multiple files which are read by the PAVECHECK program. A video image zip format was designed to increase the number of images that can be stored and displayed using a single data file. The following is an example of the amount of data contained in the zipped file. Researchers performed tests on 12 miles of SH 36. The video image collection interval was set to 15 feet. A total of 4200 images were collected and stored in the zipped file. The file size of the zipped image was about 154 MB.

The PAVECHECK program uses only the TTI data file format as input. To use the TxDOT PF99 file format the user must convert the PF99 into the TTI file format prior to processing. This function is handled by a drop-down menu in the PAVECHECK program. See Figure 6 for a block diagram of this file conversion process.

The following list represents the main functions of PAVECHECK program:

- GPR data browsing is easier than in the COLORMAP program.
- Single trace analysis has been reduced to fewer mouse clicks.
- Using the automatic peak tracking method saves GPR processing time.
- FWD deflection data can be input and browsed within of the program.
- Video data can be input and browsed within of the program.
- Data are synchronized to the same DMI reference.
- The program automatically finds the GPR thicknesses for the FWD drop locations when the FWD backcalculations are performed.
- Core images and other pavement structure information can be processed in the program.
- The program accepts both TxDOT PF99 format and TTI format data as input.
- The program will map data collection locations if Global Positioning System (GPS) coordinates are collected. GPS coordinates are collected and stored in TxDOT PF99 data format.
- The dielectric values of the first pavement layer are displayed on the bottom of the GPR color-coded map. This function helps the user locate subsurface defects.

- The thickness scale beside the GPR color-coded map helps the user evaluate the thickness of each identified layer.
- The result output function can output PF99 formatted results and the TTI-defined ASCII formatted file.
- The print function can create printouts of analysis results.

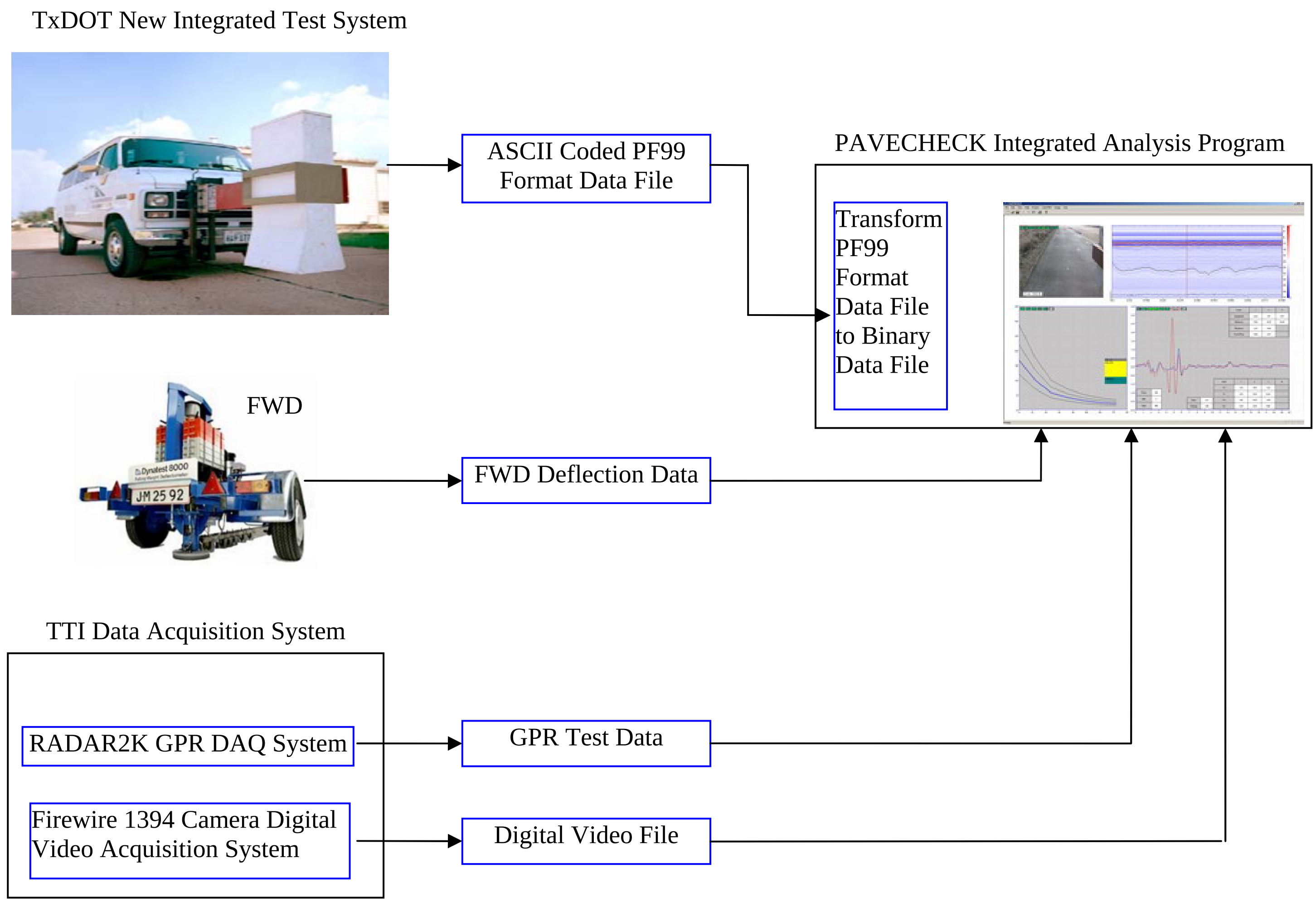



**Figure 6. Overview of PAVECHECK Input Options.**

```
START,20050712171248.694
PMET1,,0.0,0.0,base_vnet:20050708#base_debug:20030409#base_cvtunits:20030505#
#PMET1,,DMI,DMI,Versions,Softwaredesc,node and stream tuples
#META1,GPRP0,DMI,DMI,METAVERSION,Versions,Ver_facility,Manufacturer,Radar,Tra
#META1,GPS04,DMI,DMI,METAVERSION,MGPSRCVRMODEL,MGPSCOLRATE,MGPSDIFFMODE,MGPSD
#META1,GPS05,DMI,DMI,METAVERSION,MGPSRCVRMODEL,MGPSCOLRATE,MGPSDIFFMODE,MGPSD
#META1,STAT4,DMI,DMI,METAVERSION,Versions,Description,Dmiunits,Speedunits,Rat
#META1,VID00,DMI,DMI,METAVERSION,Versions,Softwaredesc,Cam_model,Cam_number,V
#HEAD4,Comment,DMI_1,DMI_2,DateTimeymdhms,HeaderType,Purpose,District,County,
#PTYP3,Comment,DMI_1,DMI_2,PavType
UMET1,GPRP0,MI,MI
UMET1,GPS04,MI,MI,DEG,DEG,,M,MI/HR,DEG
UMET1,GPS05,MI,MI
UMET1,HEAD4,MI,MI
UMET1,PTYPE3,MI,MI
UMET1,STAT4,MI,MI,MI/HR,MI/HR,MI/HR,MI/HR
UMET1,VID00,MI,MI
CMET4,03_FORD_E350,10BT,13809,2903203H,1FMNE31F33HB83276,20030117
META1,DMI,0.0,0.0,1,base_vnet:20050708#base_debug:20030409#base_cvtunits:2003
META1,GPRP0,0.0,0.0,1,base_vnet:20050708#base_debug:20030409#base_cvtunits:20
META1,GPS04,0.0,0.0,1,ZODIAK,1S,OFF,,10,1.1M,3,WGS84,LATLON,10M,base_vnet:200
META1,GPS05,0.0,0.0,1,ZODIAK,1S,OFF,,10,1.1M,3,WGS84,LATLON,10M,base_vnet:200
META1,HEAD4,0.0,0.0,1,Rel 2005.07.06,TxDOT Software
META1,PTYP3,0.0,0.0,1,Rel 2005.07.06,TxDOT Software
META1,STAT4,0.0,0.0,1,base_vnet:20050708 base_debug:20030409 base_cvtunits:20
META1,VID00,0.0,0.0,1,base_vnet:20050708#base_debug:20030409#base_cvtunits:20
HEAD4,,0.00000,0.00000,20050712171248.694,PROJ,,00,227,PR0000 ,0000 +00.000,K
GPS04,,0.01064,0.01064,30.79337246,-96.25662260,20050712171249.000,73.05,0.3,
GPRP0,MTL_20050711205551.403030,0.01542,0.01542,-848,-773,-655,-537,-386,-236
GPRP0,REF_20050711162737.521465,0.01542,0.01542,-1126,-1068,-961,-855,-714,-5
GPRP0,,0.01542,0.01542,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
PTYP3,,0.02101,0.02101,20,
VID00,,0.03050,0.03050,FROW,/9j//gAoaAkAAAAAAECMZSNQOx8y3W5ugIABAAHQAAAARgA5Z
GPRP0,,0.03050,0.03050,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
```

…………………

(Note: this sample data is cut from a big file, some columns are also cut.)

**Figure 7. Sample of PF99 Data Format.**

## 1.4 HARDWARE REQUIREMENTS FOR THE PAVECHECK PROGRAM

PAVECHECK is a Windows-based program developed using the Microsoft Visual C++ 6.0 compiler. Running the program requires the operation system Microsoft Windows 98/2000/XP. Windows XP is recommended. PAVECHECK is designed to process large volumes of GPR, video, FWD, and GPS data. The computer for running this program requires a fast processing speed. The lowest central processing unit (CPU) speed requirement should be at least 1.8 GHz. The program also needs at least 512 MB random-access memory (RAM) for running without delay problems; however, 1 GB RAM is recommended for better performance.

Since this is an integrated program, many functions of the program are related to viewing or browsing different data types. The program then synchronizes all of the data to a common DMI reference. The program divides the computer screen into several frames, which display different data items. Figure 8 is a sample screen from PAVECHECK. To display this amount of data requires a minimum screen resolution of 1024×768 pixels. For the current version of the system, 1280×1024 pixel resolution is recommended; however, resolutions of 1400×1050 or 1600×1200 pixels give better performance.

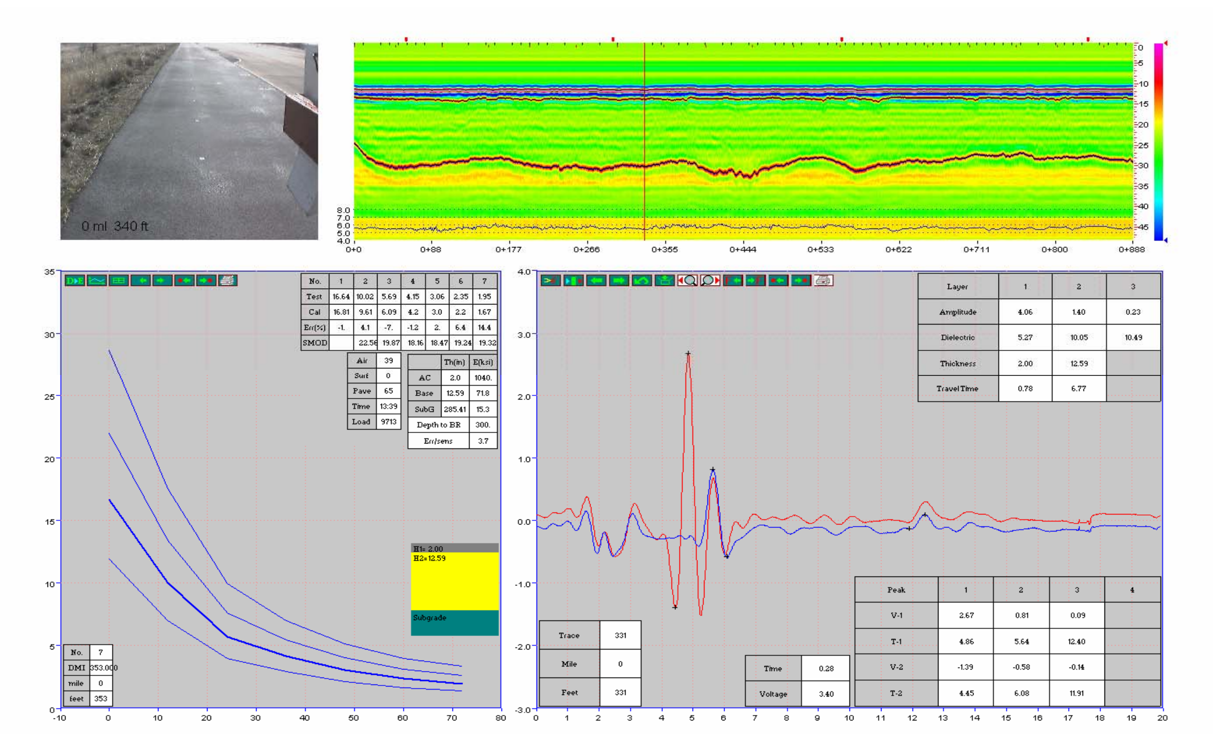



**Figure 8. Sample Screen from the PAVECHECK Program.**

A large hard drive also is needed for this program, since the video and GPR test data will require lots of storage space. Video file size depends on the size of the individual images, frequency of the video acquisition rate (how many feet between images), and the video format. The current video acquisition program sets the video resolution to 640×480 pixels, which is close to digital video data DVD quality (720×480 pixels). For most projects, this video setup will give good video quality. For this video resolution, we use the JPEG image format because its compression factor stores the image on the hard drive in fewer bytes than the image is when it actually displays. In the TTI video acquisition system, each image only takes about 37 KB. If we take video at a rate of 5 feet per image, a project running 40 miles will generate a video file with 42,240 images, and the total size of this video file will be around 1563 MB (about two compact disks [CDs]). Therefore, 5 GB of free hard drive space is needed to run this program. However, 20 GB of hard drive space is recommended to create several projects.

Also a USB 2.0 supported external storage device is necessary for transforming or copying projects.

The requirements discussed above are critical for good system performance. A few other requirements are basic to most machines, such as a mouse and CD-ROM drive. Table 1 lists the hardware requirements.

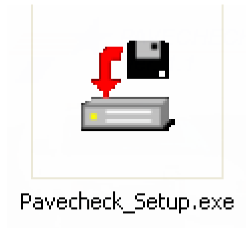
**Table 1. Hardware Requirements for Running the PAVECHECK.**

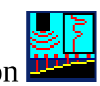
| No. | Requirements | Basic Requirement | Recommended Value |
|---|---|---|---|
| 1 | Operating System | Windows 98 | Windows XP |
| 2 | System Memory (RAM) | 512 MB | 1.0 GB |
| 3 | Monitor Resolution | 1024×768 pixels | 1280×1024 pixels or higher |
| 4 | Free Hard Drive Space | 5 GB | 20 GB |

## 1.5 INSTALLING OF THE PAVECHECK PROGRAM

The installation program is distributed on a CD, which contains the PAVECHECK setup program and other resources required to run the program. A sample data test, from a thin flexible pavement test site at the Riverside Campus of Texas A&M University, is included on the distribution CD-ROM. This sample project (Annex) covers 1800 feet, and it is a good sample data set for learning to use this program. Another data set from a longer section (SH 36 in the Bryan District) is also provided to exercise this program. This data set is much larger than the Annex data, and is saved in a separate folder.

Start the installation by double clicking the setup program on the CD-ROM.




The Installation screen (Figure 9) is the first setup screen displayed. Click the button "Next," as shown in Figure 10, to determine where to store the program. The default folder is C:\PAVECHECK. The setup program installs many dynamic link library files (DLL) to the Windows System folder. If any of the DLL files from the CD already exist, and the file on the computer is more recent, then the screen shown in Figure 11 asks the user to decide to overwrite this file or keep the original file. Clicking "No" is recommended to keep the current file. If "Yes" is selected, other applications may not work. Figure 12 shows the last screen of the installation. Click "Exit" to finish the installation process. Finally, users can find the desktop shortcut for this program with the following icon . This icon reflects the functions of this program, combining the GPR antenna and the FWD deflection bowl in a small icon.

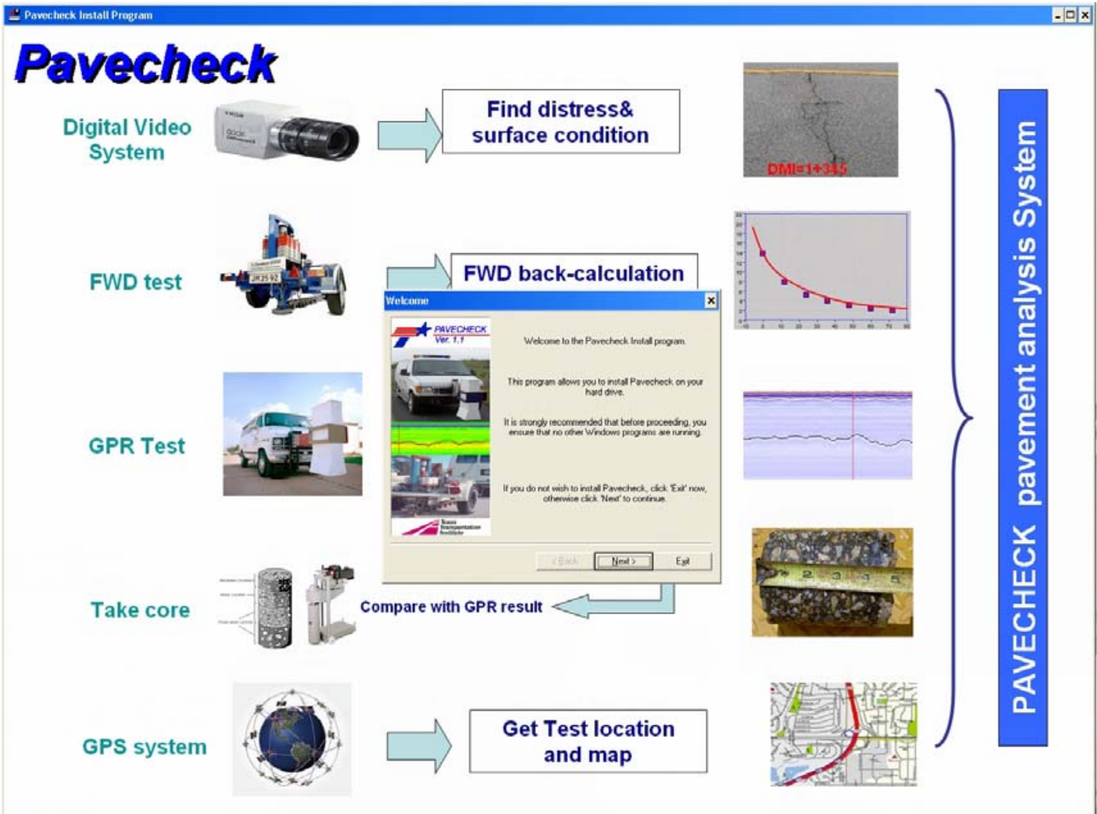



Figure 9. First Installation Screen.

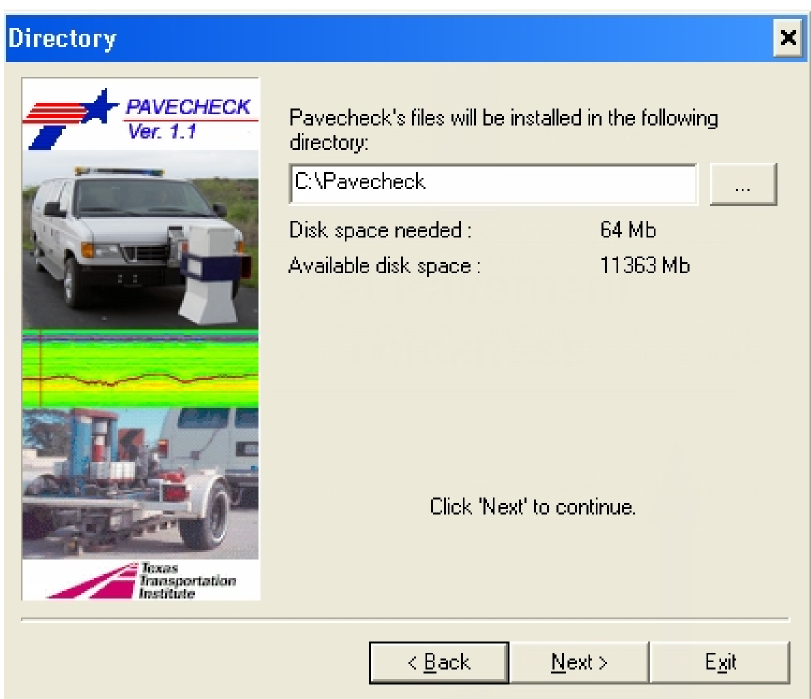



Figure 10. Installation Screen for the Installation Folder.

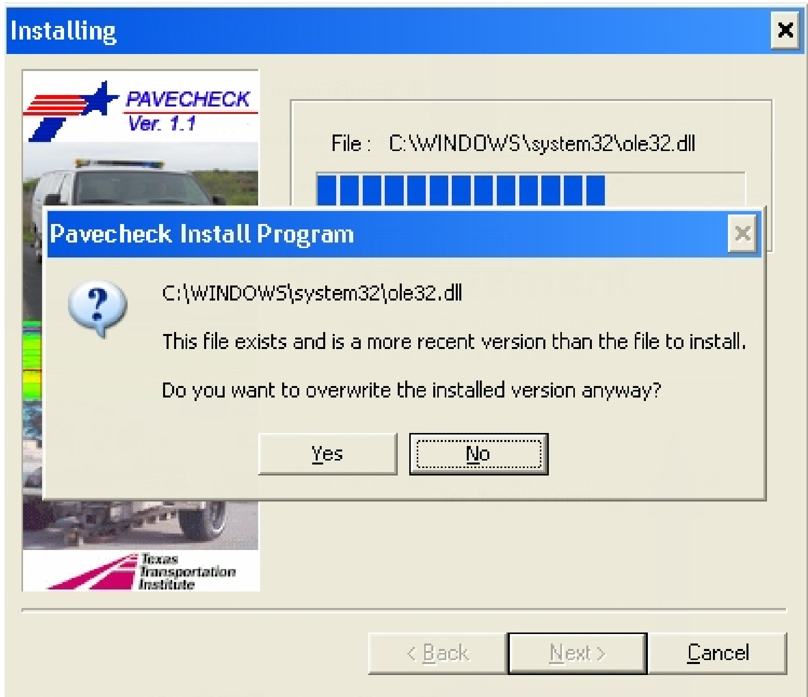



**Figure 11. Always Click "No" if This Message Is Displayed.**

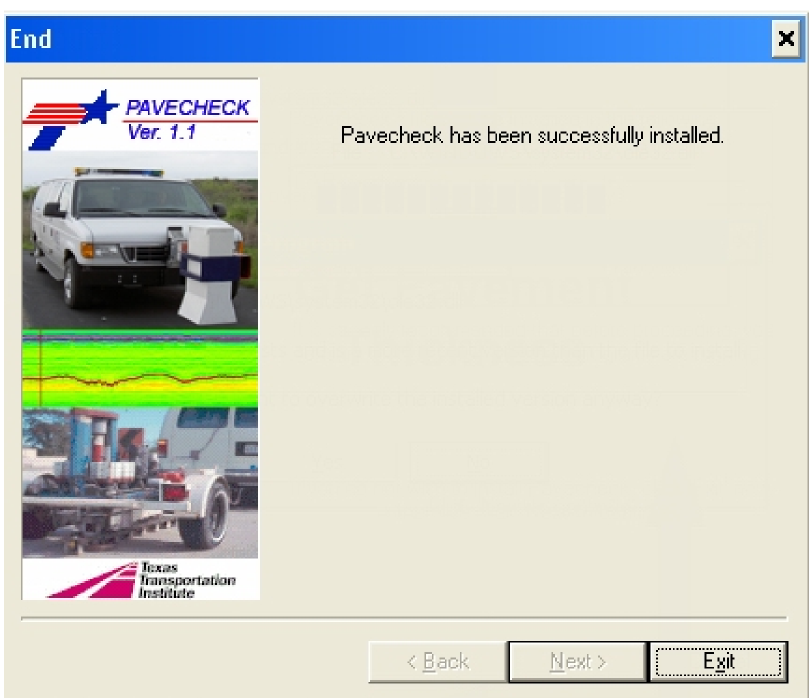



**Figure 12. Last Screen of Installation.**

**Getting Started**

The installation program creates a program folder on the hard drive. If the default folder C:\PAVECHECK is used, Figure 13 lists the files installed on the computer. The Un-install program un-installs PAVECHECK from the hard drive. If any file in the PAVECHECK folder is deleted, the program will not run properly.

The installation procedure also installs a small test folder called Annex for user training. The test site is located at the Riverside Campus of Texas A&M University, in College Station. GPR data and digital pavement images were collected by TTI's GPR system. The GPS data were collected by the TxDOT GPR vehicle. The FWD data were collected with TxDOT's Dynatest 8000 FWD test system, using the R80 data format. The images of cores from the pavement are provided for demonstration purposes only.

A PF99 data set is also included in the setup CD-ROM. As shown in Figure 13, a test data folder contains a TTI_SH36 data set and a TDOT_PF99 data set. The TTI_SH36 folder contains data from SH 36. TTI collected the GPR data on August 30, 2005, on the southbound K-1 and the northbound K-6 lanes. The reference markers for the southbound section (K-1 lane) cover 558+000 to 570+4124, and the total project length is 12.783 miles. The reference markers for the northbound section (K-6 lane) cover 570+4124 to 558+528, and the total project length is 12.683 miles. Two subfolders, NB and SB, under the TTI_SH36 folder contain the entire test data sets for these sections. TxDOT collected the FWD data on September 1, 2005. No GPS data were collected for this project.

The TxDOT_PF99 folder contains test data for SH 21 which were collected by TxDOT on July 12, 2005, using its prototype integrated GPR system. The start location is (30.79337246,-96.25662260) and the end location is (30.77859416,-96.27253650) based on the onboard GPS instrument. There are two repeat runs for one section. The data from both repeat runs are included in the TxDOT_SH21.PF99 file. Conversion of this PF99 data file by the PAVECHECK program creates two subfolders under the TxDOT_PF99 folder. The FWD data for this section were collected separately by the TxDOT FWD on the same day. These sample data sets are included for training purposes and prove the PAVECHECK program functionality. Not all of the sample data sets contain all of the data that can be used as inputs to the PAVECHECK program. For example, there are no GPS and core data for the SH 36 sample data sets, and there are no core data for the SH 21 data sets.

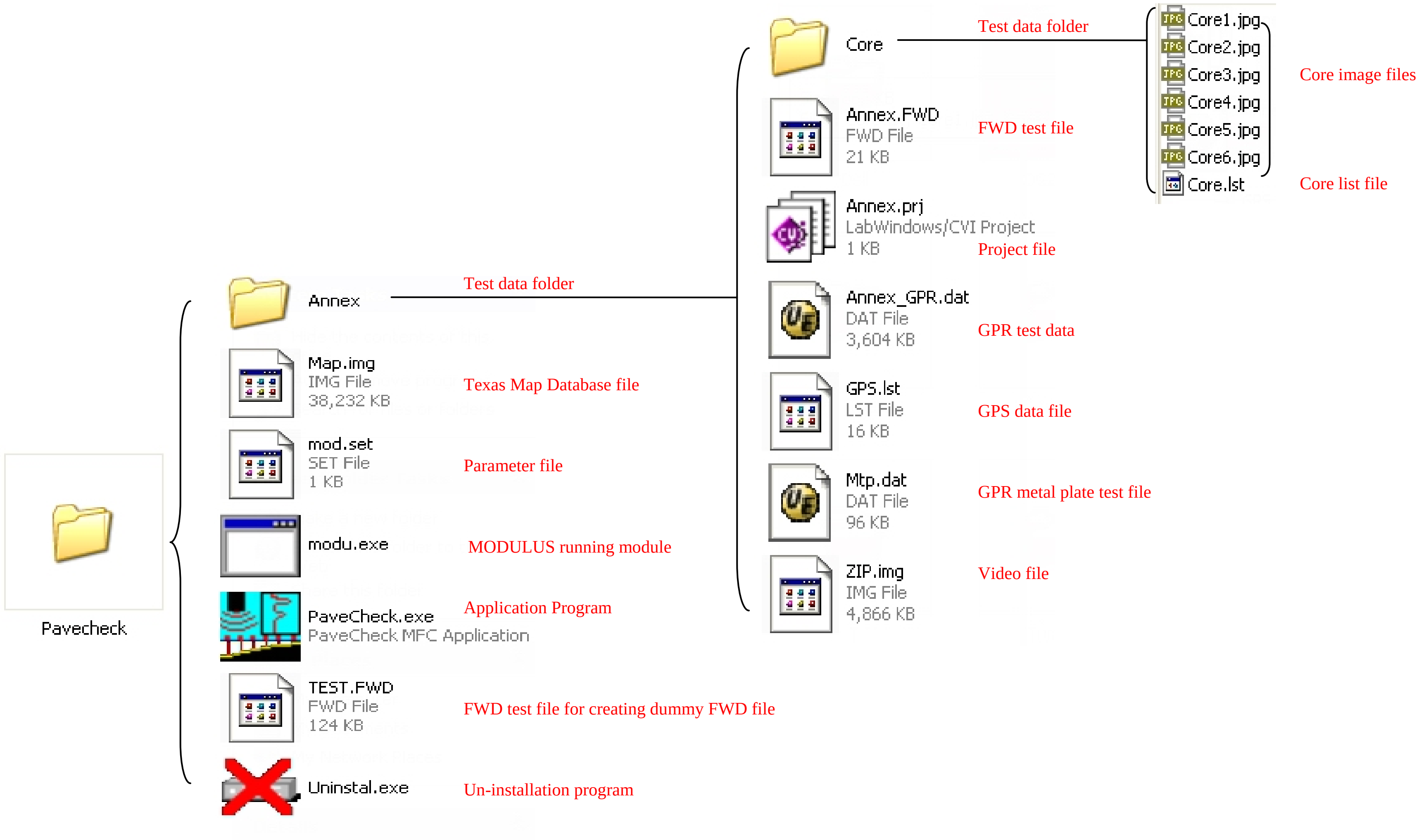



**Figure 13. File List after Installation of PAVECHECK.**

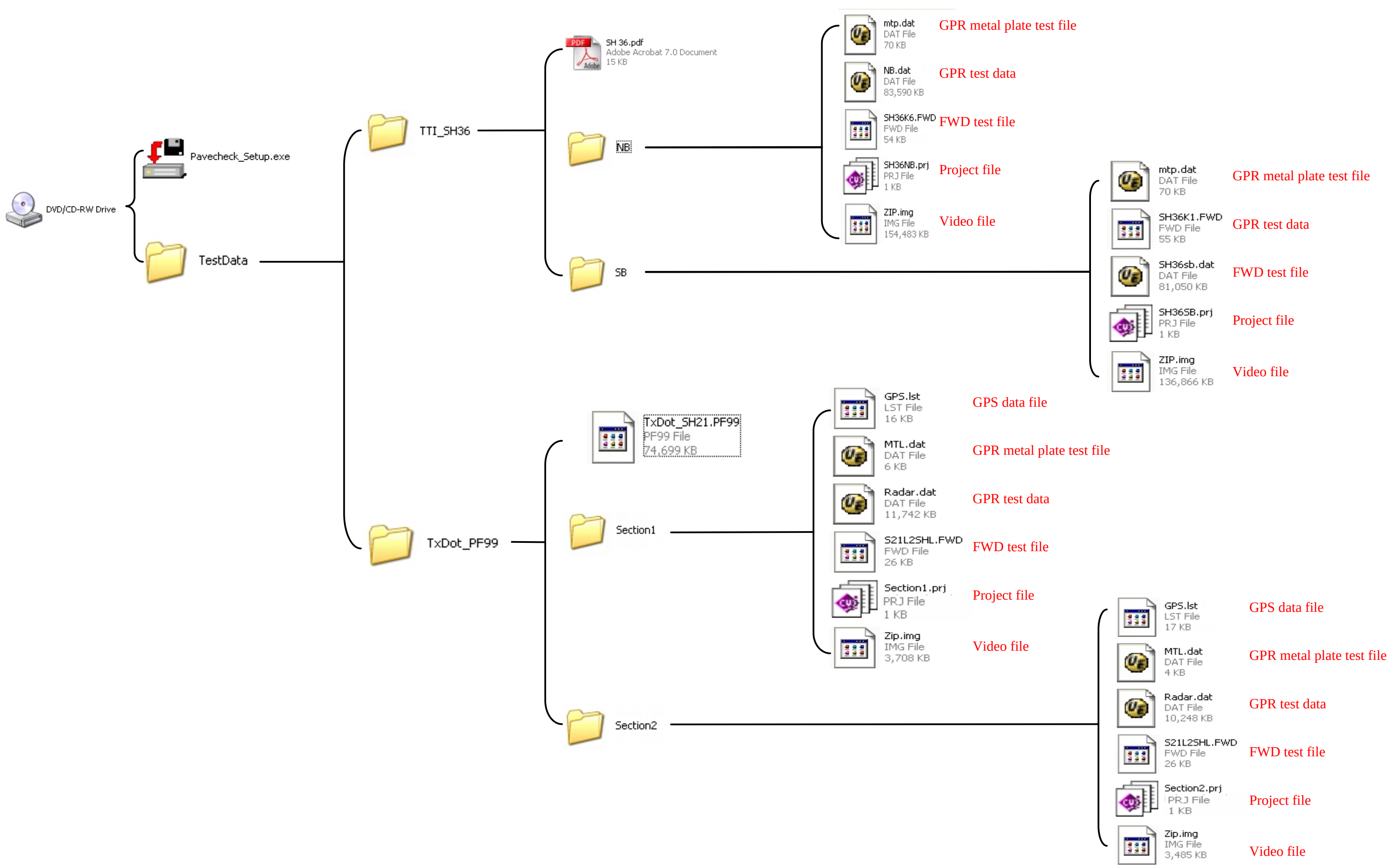



**Figure 14. Content of Installation CD and Its Files List.**

# CHAPTER 2

# USER'S GUIDE FOR PAVECHECK

This chapter describes all of the data processing schemes available in PAVECHECK and uses the sample data from the Riverside Campus (included in the setup program) to demonstrate the functionality of the program. Since the SH 36 and PF 99 data from SH 21 are included on the distribution CD, users can also test these data at their leisure.

The design of the PAVECHECK program makes it very flexible and versatile to use. This guide details the functions included in each module and describes the tasks associated with each button. Based on the functions of the PAVECHECK program, this guide is divided into the following modules:

- Getting started with PAVECHECK (Section 2.1)
- Converting TxDOT PF99 data into the TTI format (Section 2.2)
    - PF99 is one very large single file, with all of the available data included, this option strips out the individual data items into a set of files
- Browsing the GPR data within the GPR COLORMAP module (Section 2.3)
- Processing a single GPR trace (Section 2.4)
- Using the digital video module (Section 2.5)
- Functions in the FWD data display module (Section 2.6)
- Modulus backcalculation module (Section 2.7)
- Generating an analysis result output file (Section 2.8)
- Producing data and result printouts (Section 2.9)
- Toolbar functions summary (Section 2.10)
- Special tools (Section 2.11)

The following sections describe the general contents of each module. Section 2.1 introduces how to start the PAVECHECK program and how to read the project data set(s). Switching screen styles and how to use each screen setup to browse data are also discussed.

Section 2.2 focuses on how to convert the TxDOT PF99 format to TTI binary format. The PF99 format is briefly introduced. First-time users could skip this section.

Sections 2.3 through 2.7 cover the main modules of the PAVECHECK program. Each module relates to one frame on the screen, and each frame has its own functional buttons. These buttons are normally hidden but can be activated by clicking the individual frame with a pointing device such as a mouse.

Sections 2.8 and 2.9 cover the post-processing of the analyzed data. Section 2.8 documents the ASCII formatted file for the analysis results. Section 2.9 documents the printout function for the analysis results.

Section 2.11 introduces user tools that are included with the PAVECHECK program. These two tools are used to create the zipped single image files from many individual images into a single folder and to create an ASCII file for a single GPR trace.

## 2.1 GETTING STARTED WITH PAVECHECK

The PAVECHECK program must first be installed onto the computer using the instructions given in Chapter 1. Start the program by double clicking the PAVECHECK icon 

on the desktop. The main screen shown in Figure 15 displays. Figure 16 lists the functions of the buttons on the toolbar. These functions will be described in more detail later in this chapter. To open a data set click the  button, to activate a dialog box that asks the user to select a folder. Double click with the left mouse button on the Annex folder, and the screen shown in Figure 18 displays.

The project file (*.prj) contains a list of the data sets to be processed in the analysis. The files in the Annex data set are listed in Figure 17. The annex.prj file shows the files contained within the Annex folder. These files contain the actual data sets to be processed during this run. Table 2 provides a description of the file within the Annex folder.


**Figure 15. Main Screen of PAVECHECK.**

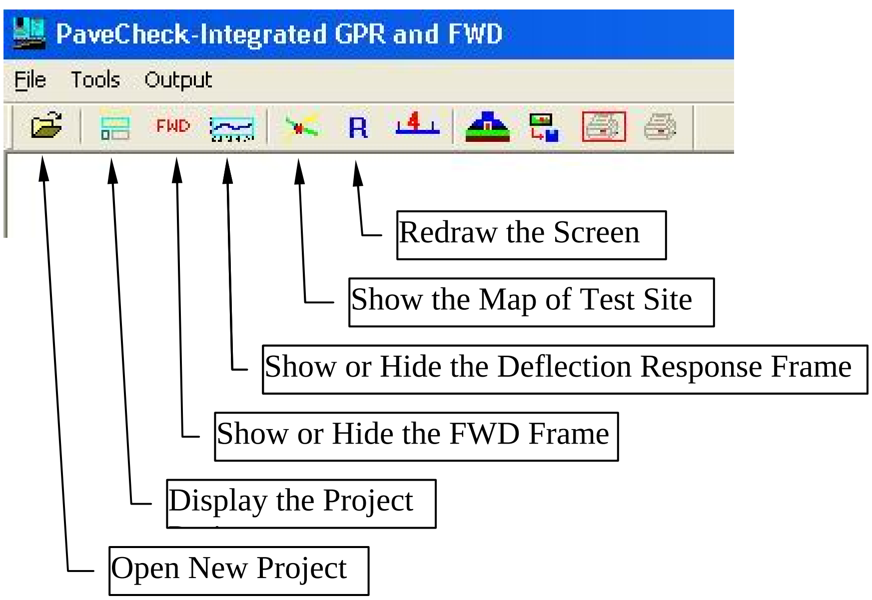



**Figure 16. Functions of the Toolbar Buttons.**

```
Project name   :Annex.prj
Project comment:Annex Test site about 1800 ft long
Project folder :C:\PAVECHECK\Annex
Radar   folder :
Image   folder :
FWD     folder :
GPS     folder :
Core    folder :Core
Radar   file   :Annex_GPR.dat
Metal   file   :Mtp.dat
Image   file   :ZIP.img
FWD     file   :Annex.FWD
GPS     file   :GPS.lst
Core    file   :Core.lst
```

**Figure 17. Annex Test Data Project File.**

**Table 2. Project Information for the Annex Sample Data.**

| Items | Value | Comments |
|---|---|---|
| Project file name | Annex.prj | prj is the default extension name |
| Project comment | Annex Test site about 1800 ft long | Must be less than 120 characters |
| Project folder | C:\PAVECHECK\Annex | Location of project file |
| Radar folder | | Subfolder, if left blank, these test data are kept in the project folder |
| Image folder | | |
| FWD folder | | |
| GPS folder | | |
| Core folder | Core | Core information kept in subfolder "core" |
| Radar file | Annex_GPR.dat | GPR file name |
| Metal file | Mtp.dat | Metal plate GPR file |
| Image file | ZIP.img | Zipped video file |
| FWD file | Annex.FWD | FWD field test file with Dynatest R80 format |
| GPS file | GPS.lst | |
| Core file | Core.lst | |

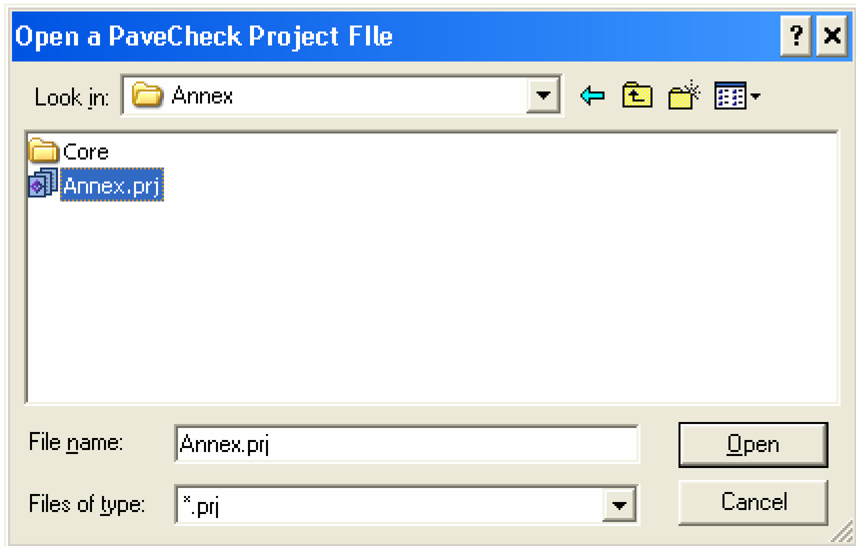



**Figure 18. Open Project Dialog Box.**

Click the left mouse button to open the annex.prj file. Click the button (Figure 17) to display the project data on the screen as shown in Figure 18. Initially, only the GPR COLORMAP display, a single GPR trace waveform, and a digital video frame are displayed. No FWD data display at this time. Typically, upon opening the data set, the first step is to browse the GPR and video data. After reviewing and processing the pavement thickness data, the user may then view and process the FWD data. The user may display the FWD data any time by clicking the FWD button on the toolbar. Figure 20 shows the resultant screen style which has the FWD frame in the bottom left corner and the previous video frame in the top left corner. Also, the GPR color map size adjusts to fit the screen. In Figure 20 the four lines represent the deflection bowls generated at the four FWD load levels. The button (Figure 20) displays the FWD deflection under the GPR data (Figure 21). This function is useful when comparing GPR data with FWD deflection data along the length of the project.

Clicking the FWD button switches the screen style between those shown in Figure 19 and Figure 20; the button switches the screen between those shown in Figure 19 and Figure 21. Clicking the button always returns the screen style to that of Figure 19. The user can click these three buttons to switch between these three basic screen styles.

This user's guide is based on the Riverside Campus (Annex) test data, which as shown in Figure 13 has all the data needed to run this program. However, the program will run without a complete data set. If, for example, only GPR data are loaded in the project folder, then the GPR processing functions can still be activated and run within PAVECHECK.

Because this program is designed for high screen resolution, the program automatically adjusts each frame based on the size of the screen. Higher screen resolutions give better performance when running this program. The "ReDraw" button  (Figure 16) resets the entire screen when clicked.

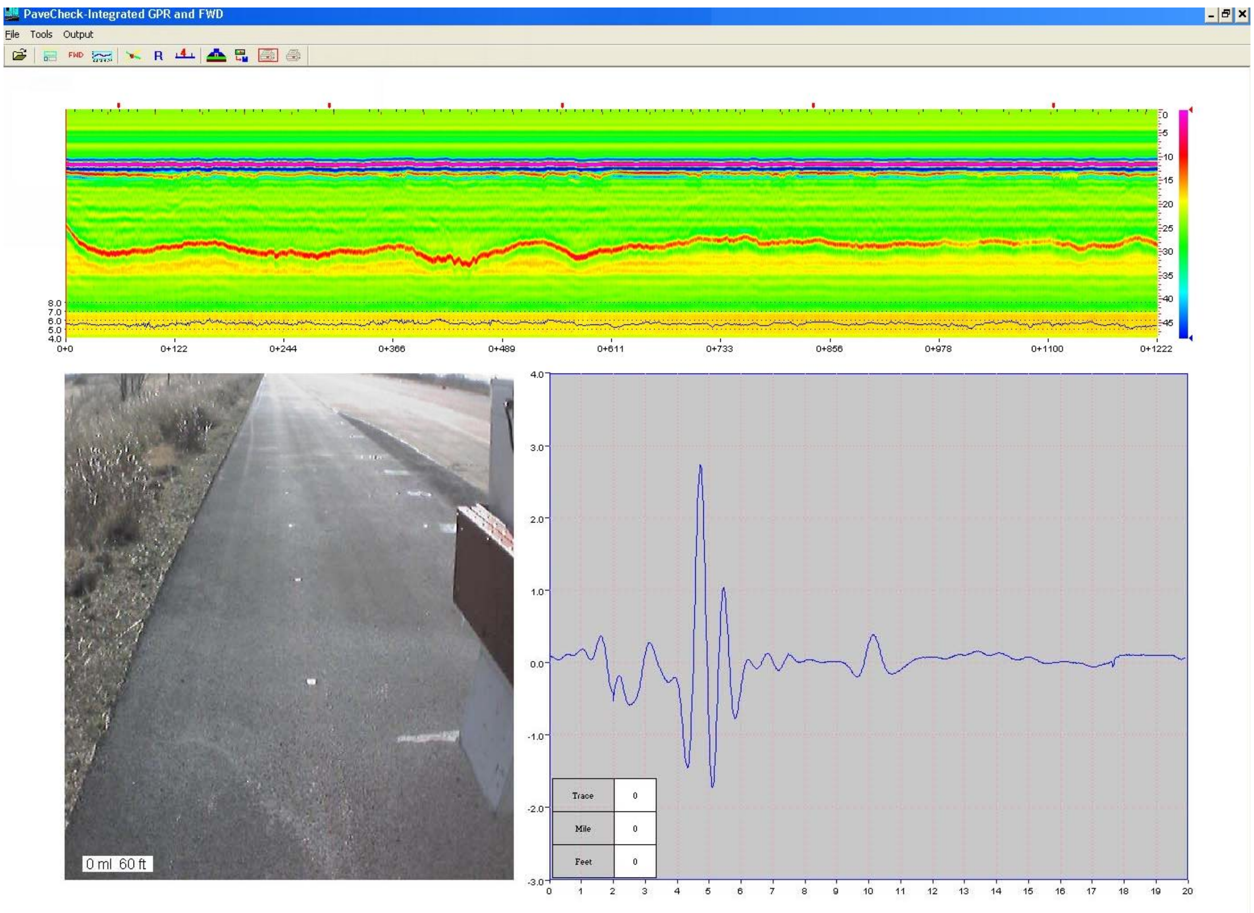



**Figure 19. Initial Screen after Loading the Project Data.**

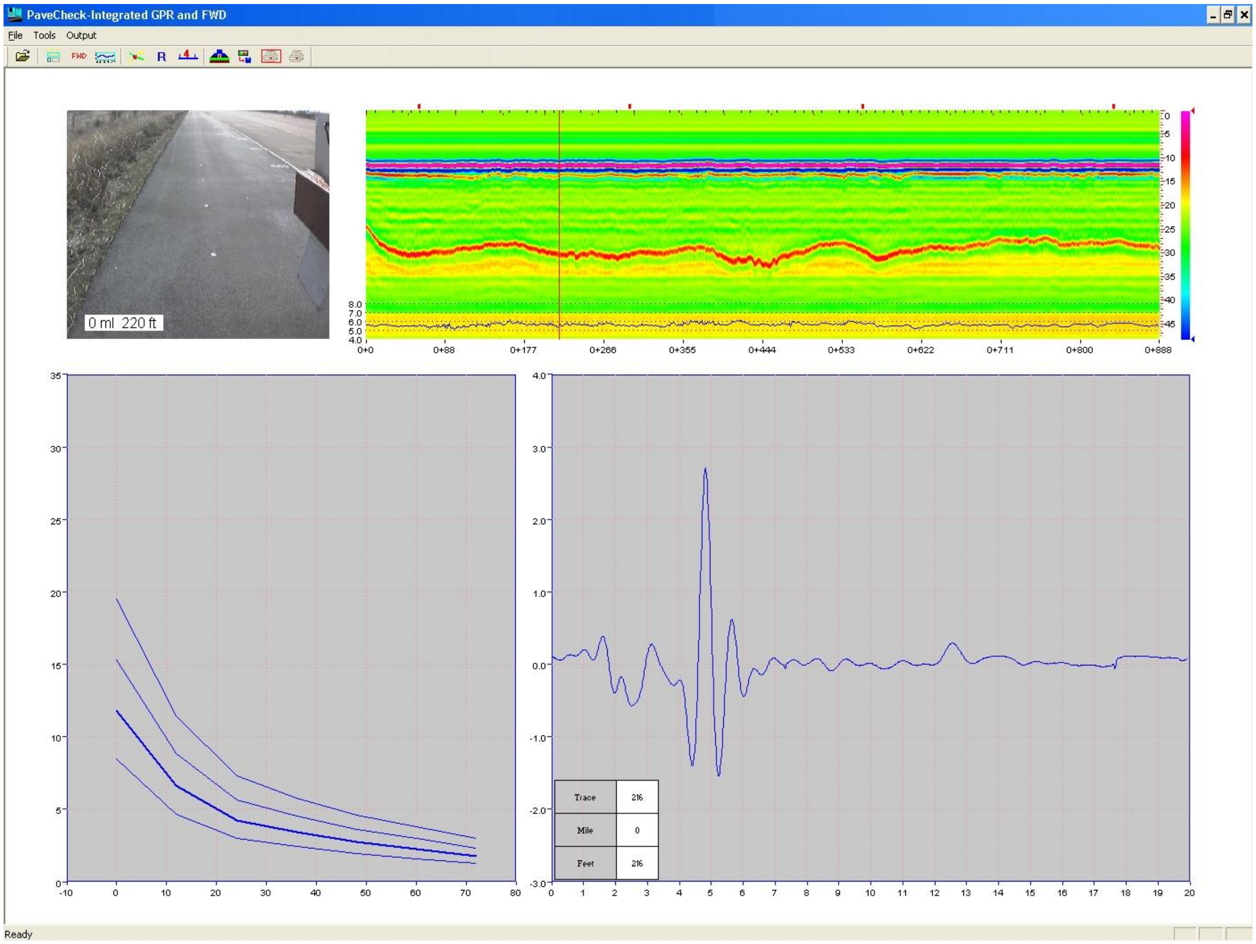



**Figure 20. Screen Frame Style Including the FWD Deflection Bowls.**

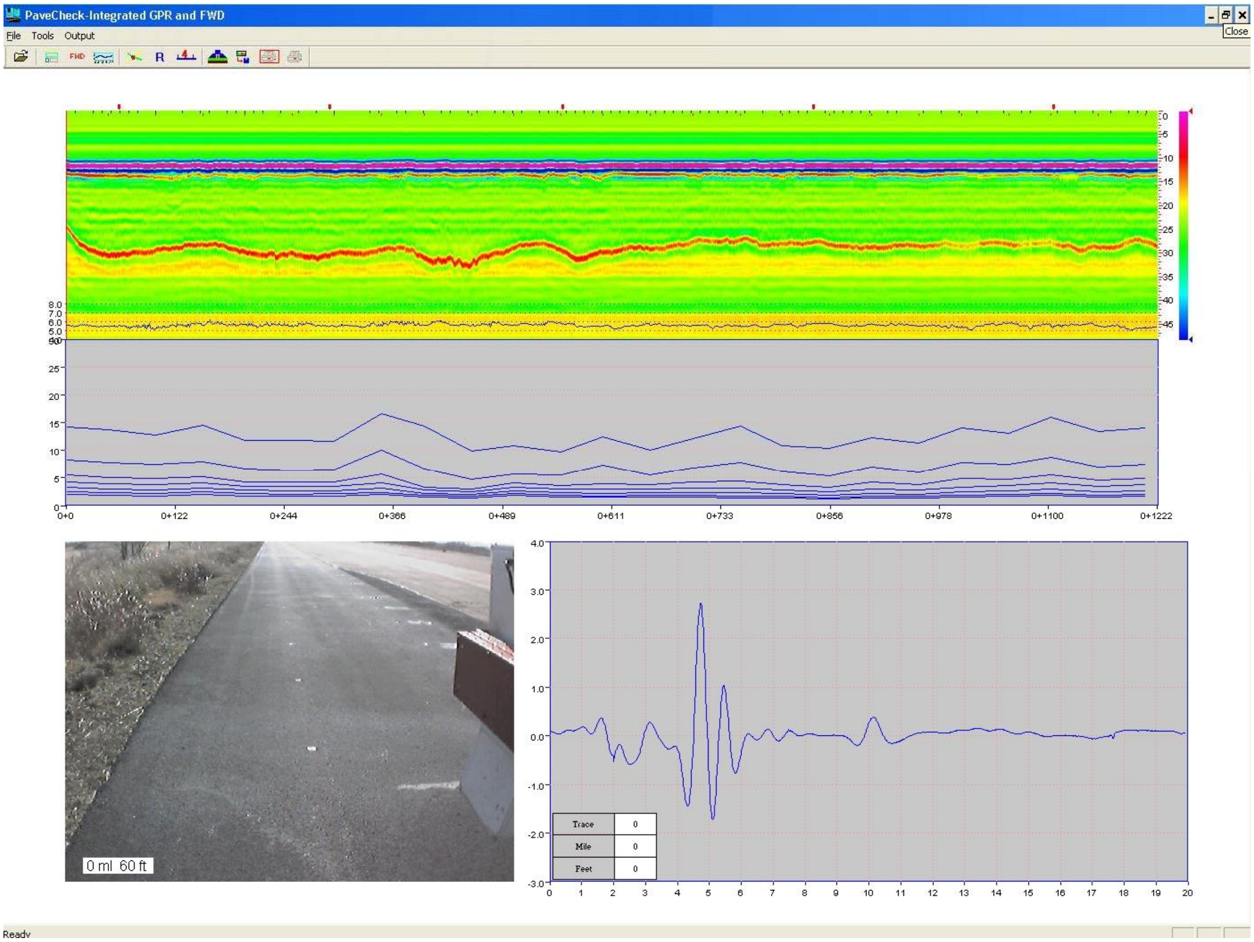



**Figure 21. Screen Style Displaying the FWD Deflection with Radar COLORMAP.**

## 2.2 CONVERTING TXDOT PF99 DATA INTO TTI FORMAT

The TxDOT PF99 format is the next-generation data format for the TxDOT integrated field test vehicle. In the future, all TxDOT data will be collected in this format, by the data acquisition vehicles currently under development by TxDOT's Construction Division. The file format is ASCII coded. Each record in the PF99 file is identified by its header; the recorded data are saved depending on the time sequence during data collection. The PF99 data format allows multiple instruments to be integrated and synchronized based on distance and/or time. This format is very useful for database management applications. Figure 22 shows a sample PF99 data file. At the time of writing this report, the PF99 file format is still under development. In order to understand the use of PAVECHECK, first-time users are encouraged to skip this section of the report and start at Section 2.3 to learn the program functions.

The TxDOT data acquisition system also includes digital imaging equipment, a web camera to collect JPEG image files. The JPEG image format is a compressed format, which supports full 24-bit color and is saved in a binary format. The benefit of this format is that it takes less space than other image formats. Most digital camera drivers support this format.

The TxDOT image file is in binary format, and the PF99 file is an ASCII coded format. An encode program encodes the original binary JPEG to ASCII. For example, if a 24 KB JPEG (640×480 pixel resolution) file is encoded to ASCII format, it will need 33,000 characters per line of PF99 format. For better performance of the PAVECHECK program, the TxDOT encoded images are converted to the TTI binary format for processing.

Another feature of the TxDOT PF99 format is that one PF99 file can include several repeat tests as well as multiple project data. The beginning and end of each data set are marked with the start and end points for each run in a project run. The following is an example of the start and stop indicators for the PF99 data file format.

START,20050712172108.554
STOP0,20050712172108.554,20050712172421.866

Following the record names (START and STOP0) are time stamps that tell the start and end time for each project run.

Following each of the data records (GPR, image, and GPS) in the PF99 data file is a DMI location (in miles) from the beginning of the run. The individual instrument test data follow each DMI reading. The sampling rate of each instrument is controlled by the operator. Figure 22 illustrates the TxDOT PF99 data structure. The first GPR data set is always the metal plate file and can be recognized by its subname tag, "MTL_20050711205551.403030." The extra information in the time tag tells when this metal plate test data were collected. All the PF99 data are comma delimited. PAVECHECK includes a conversion program that reads TxDOT PF99 data set and transforms it into the format required for processing. This conversion is activated using the PF99 button in Figure 23. The transform processing within the PAVECHECK program includes finding all the comma locations and decoding each image. The conversion process is slow.

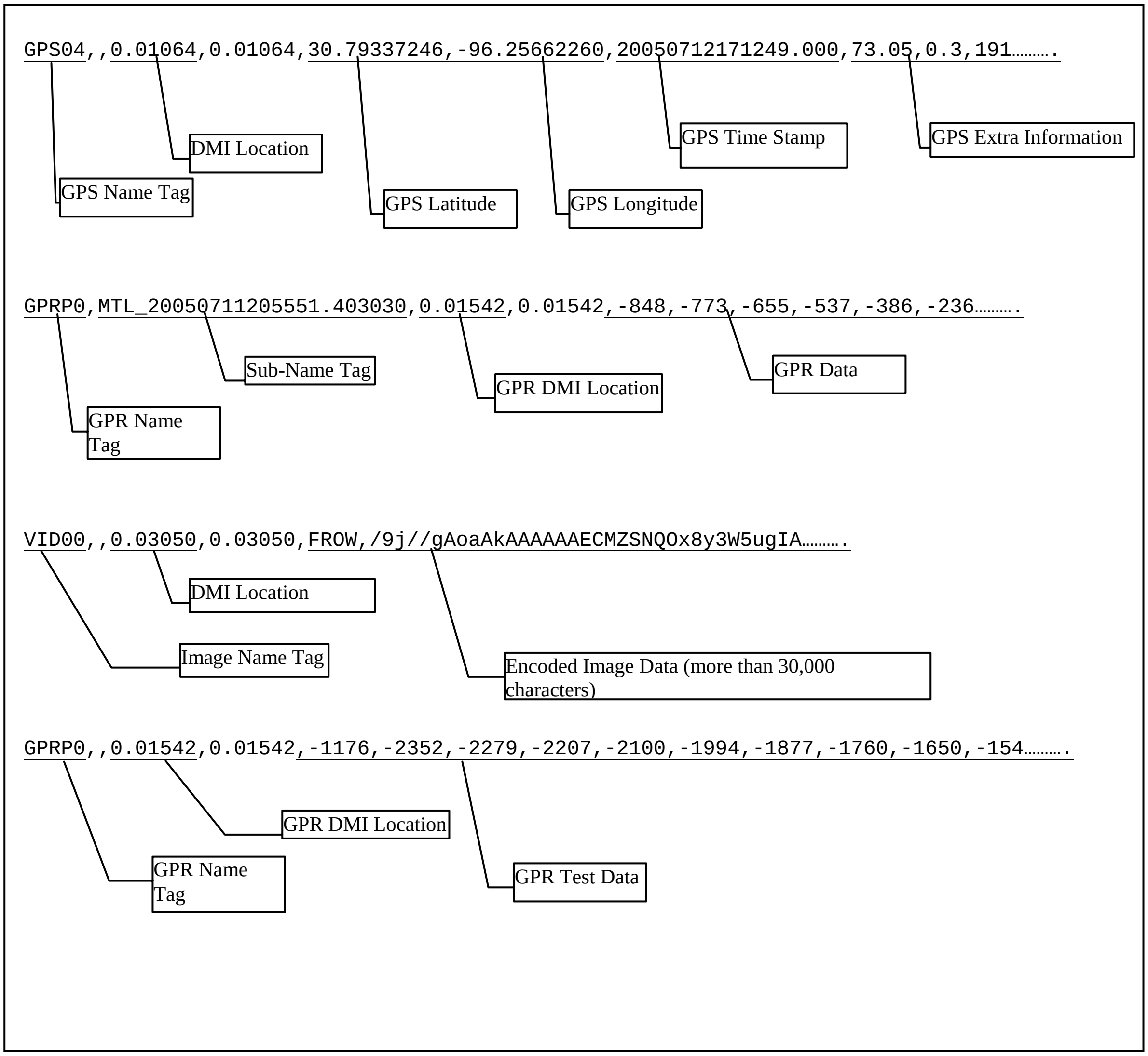



**Figure 22. Illustration Chart for PF99 Format.**


**Figure 23. PF99 Convert Button on the Menu.**

Click the  convert button on the toolbar (Figure 23) to start the PF99 conversion process. An open file dialog box asks the user to select the PF99 file to be converted (Figure 24).

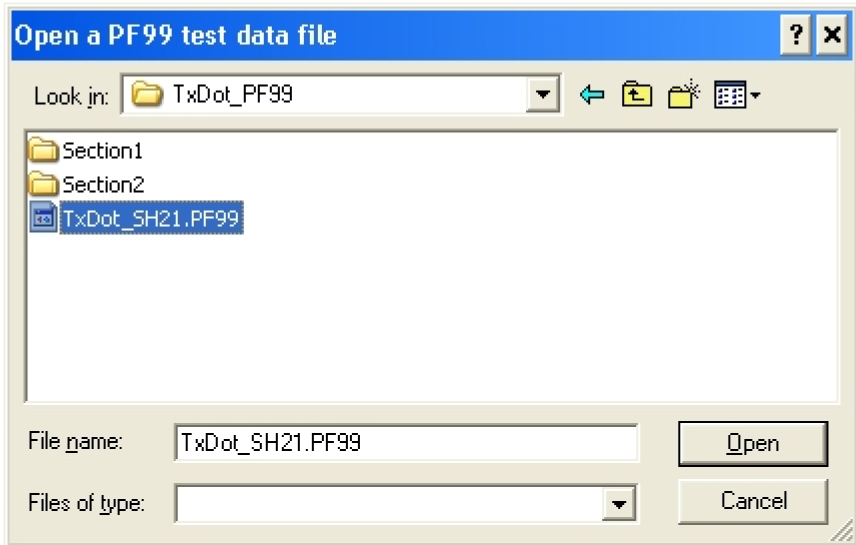



**Figure 24. Open File Dialog Box to Select PF99 File.**

Select the file and click "Open" to cause the PAVECHECK program to begin reading the selected PF99 file. Data file information includes how many data runs are in the file, how many GPR traces for each data were run, how many images were captured, and how many GPS readings were captured. This information is displayed after PAVECHECK finishes reading the file. The reading time depends on the size of the file and the computer's speed. Figure 25 shows the display screen after reading the sample PF99 data (included with the setup CD-ROM).

The display screen in Figure 25 provides the following information:

- two sections (or two repeat runs) were found,
- each section's start and end time stamps,
- how many GPR traces as well as the start and end DMI locations,
- how many images as well as the start and end DMI locations, and
- how many GPS data points as well as the start and end DMI locations.

The dialog box also allows the user to select which section to convert, where the file is to be saved, and the project name for the saved file. Normally the converted data are saved in a subfolder under the same folder as the original PF99 file. Click the "OK" button to start the conversion process.

The conversion process takes time to complete. The PAVECHECK program displays a progress bar showing the images it has read from the PF99 file (Figure 26). When the images reach the right side of the screen, the conversion process is complete. The number above each image is the current processed image number.

The display screen returns to Figure 24 once the conversion process is completed . The user can continue to convert other files or click the “Cancel” button to exit the conversion function.

The current practice is to collect the FWD data separately using an FWD vehicle and trailer. The FWD data are integrated to the project by editing the project file (Figure 17).

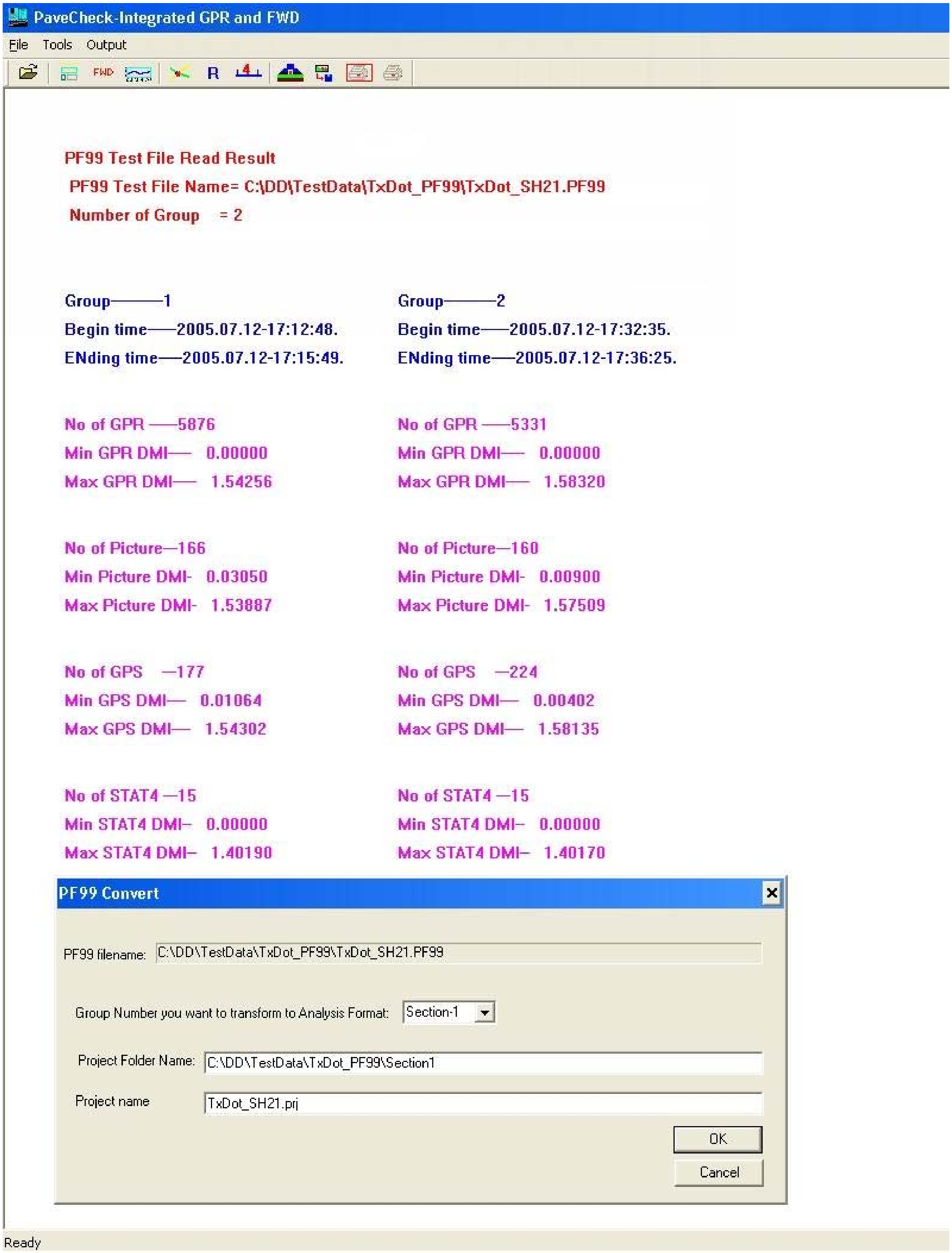



**Figure 25. PF99 File Information Screen.**

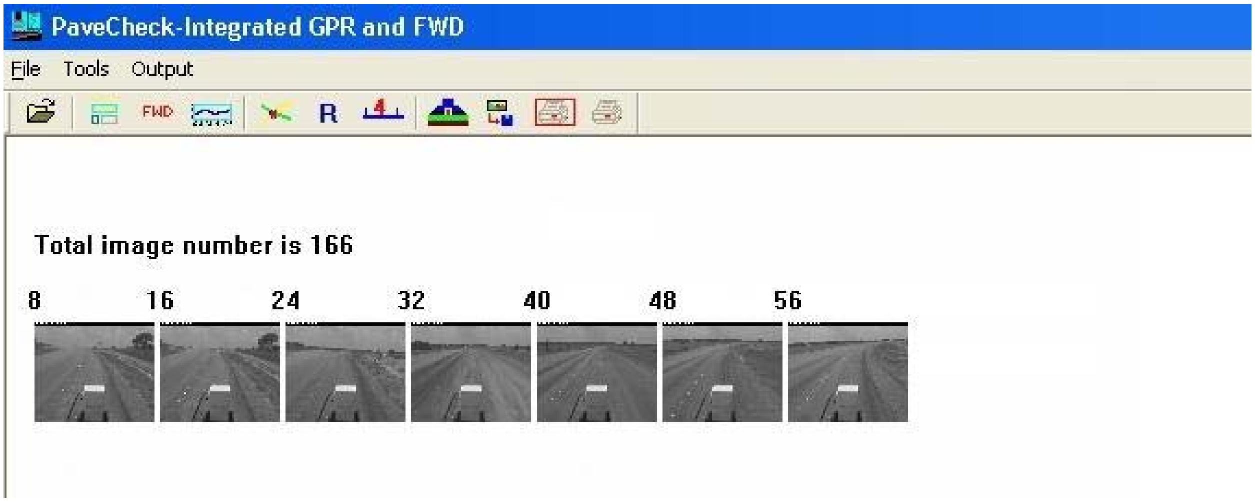



**Figure 26. Progress Bar for PF99 Conversion Task.**

## 2.3 BROWSING GPR DATA WITHIN THE GPR COLORMAP MODULE

All three basic screen styles (Figure 19, Figure 20, Figure 21) include the color-coded GPR data frame, which displays the GPR data. This format is widely used in TxDOT's existing GPR software, COLORMAP (*1*).

### The GPR COLORMAP Screen

PAVECHECK displays the GPR COLORMAP image shown in Figure 27. Each vertical line represents a single GPR trace. The number of traces that one screen can display depends on the resolution and the screen style.

The COLORMAP screen is the key frame for browsing many of the other stored data items. This frame was designed to fulfill this purpose. Several new features of the PAVECHECK program are listed below:

- The pavement surface dielectric curve is drawn at the bottom of the GPR COLORMAP display in Figure 27. The dielectric values are automatically calculated by the peak value of the surface reflection and the metal plate trace information. The surface layer's dielectric value is valuable information for locating defects such as wet spots or low-density areas. Earlier studies have directly related the asphalt layer's density with surface dielectric. The left side of this plot, shows a dielectric scale. A later section gives more detail on how to set and adjust the scale for this plot.

- The top of the GPR COLORMAP screen shows information about other test data and their locations. Other data items include locations of photo images, where the FWD deflection bowls were collected, and where cores were taken. Clicking on the core location displays the core image in the image frame.
- On the bottom scale of the GPR COLORMAP, DMI information is marked in miles and feet.
- Place the cursor inside the COLORMAP display and left click on the display to add a vertical line that shows the current location. Once a location is selected, the video display and FWD data are shown for that location. This is one advantage of the new digital data collection system over the old VHS tape system. It is now very easy to display locations of interest on the same screen.
- Close to the right side of the GPR COLORMAP screen is the pavement depth scale that is used to approximate the thickness of the pavement layer (see Figure 28). This scale is not fixed and can be moved to any location vertically. Place the curser over the depth scale, click the left mouse button and hold it down to lock the scale, then move it up or down with the mouse. The raw GPR data are collected in terms of arrival time in nanoseconds then converted to a depth scale by assuming a layer dielectric. In the default display mode, a surface layer dielectric of 6 is assumed. This layer can be changed by the user (for example, for a concrete pavement a default value of 8 is recommended).
- The color scale on the far right of the COLORMAP screen defines how the trace waveforms are transformed to the color-coded image. High positive reflections are color- coded red, and negatives are blue. Reflections close to zero volts (most of the trace) are color-coded green. Therefore, when reviewing the GPR color displays, the red and blue reflections, are highly significant because they indicate strong reflections, normally layer interfaces. Green is simply a background color of no major significance. Clicking the color bar with the left mouse button, changes the color scheme of the color scale bar to other stored schemes. Thirteen color schemes are available for the PAVECHECK program (Figure 29). Figure 30 shows the COLORMAP display after changing the color schemes.

- The intensity of the display can be changed by moving the upper and lower scale limits in Figure 27.
- Figure 31 shows an example of the impact of changing on the same GPR data set. The image on the left uses the full scale, but the right side has been compressed, which makes small peaks more visible to the user.

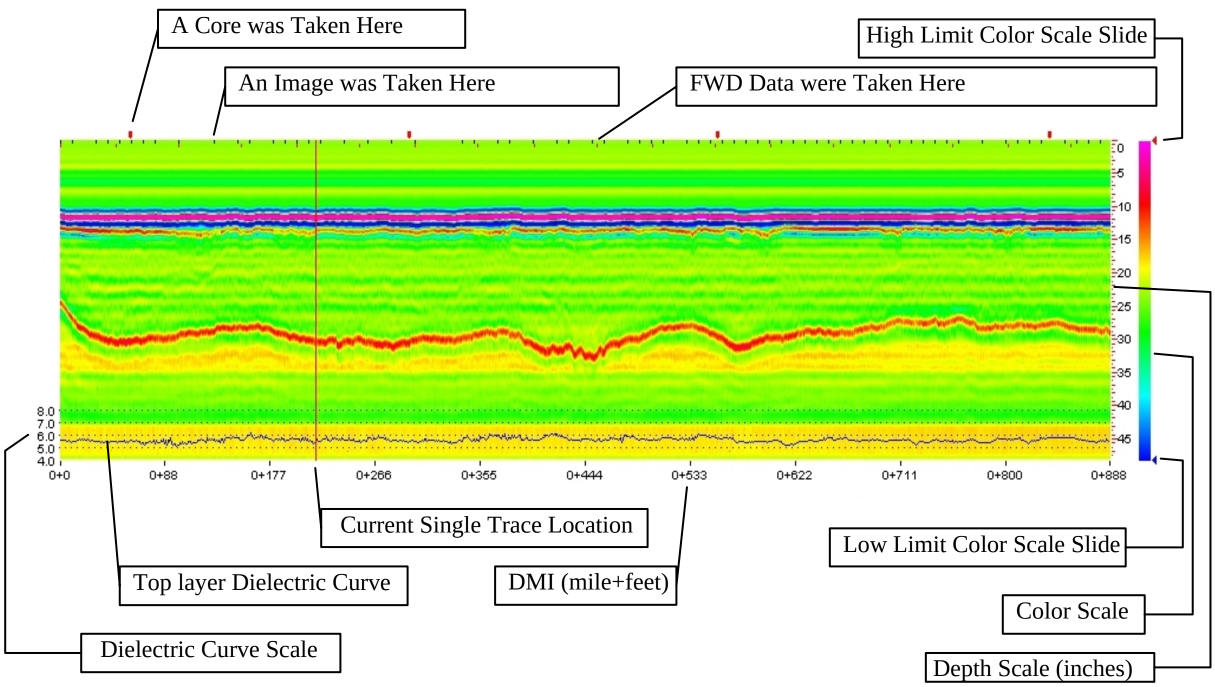



**Figure 27. GPR COLORMAP Screen Illustration.**

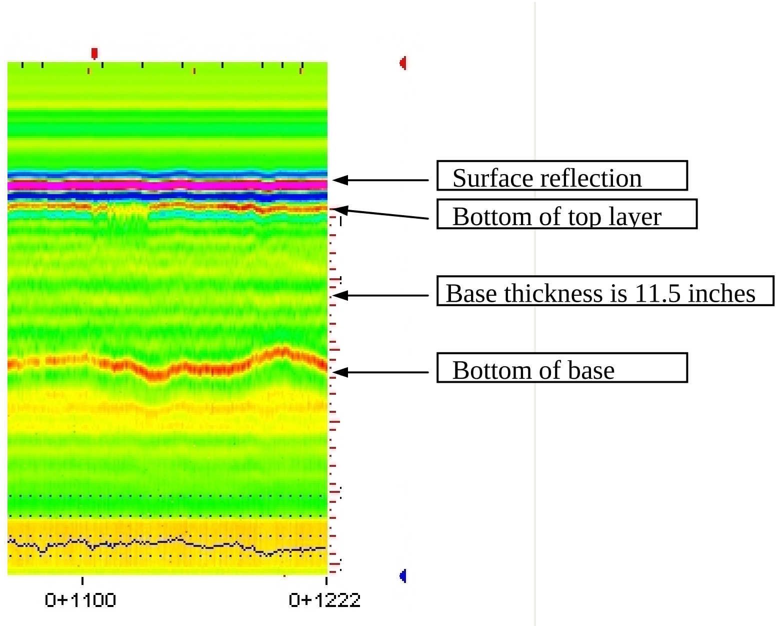



**Figure 28. Slide the Depth Scale to Measure the Thickness.**

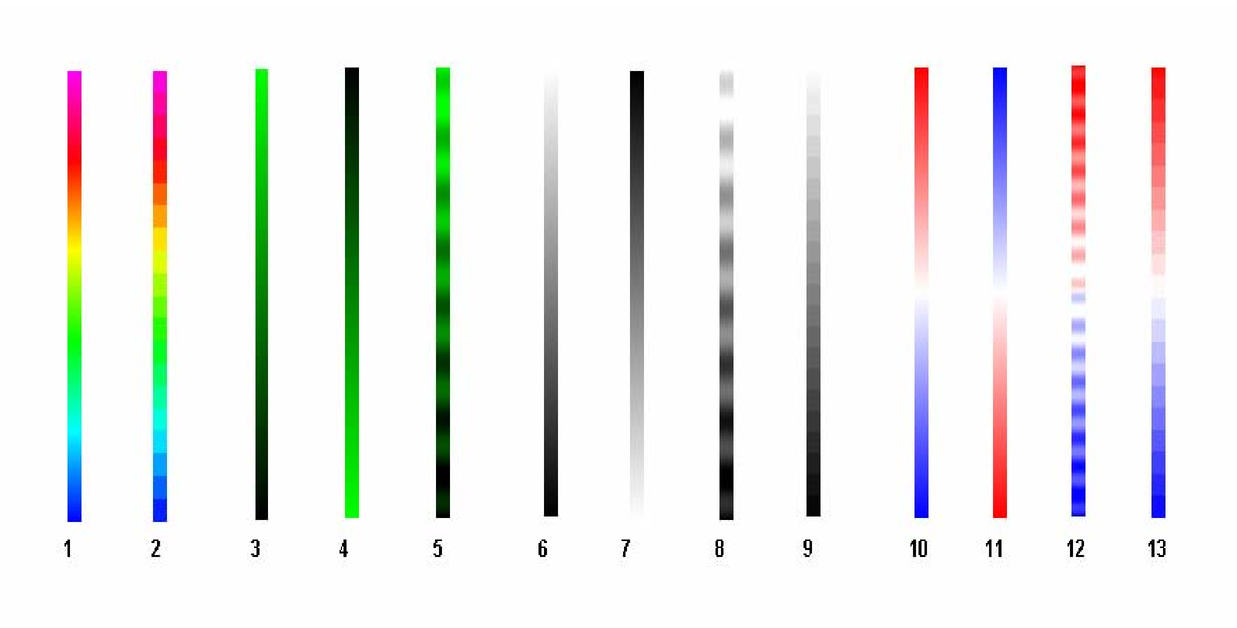



**Figure 29. Thirteen Color Schemes for the PAVECHECK Program.**

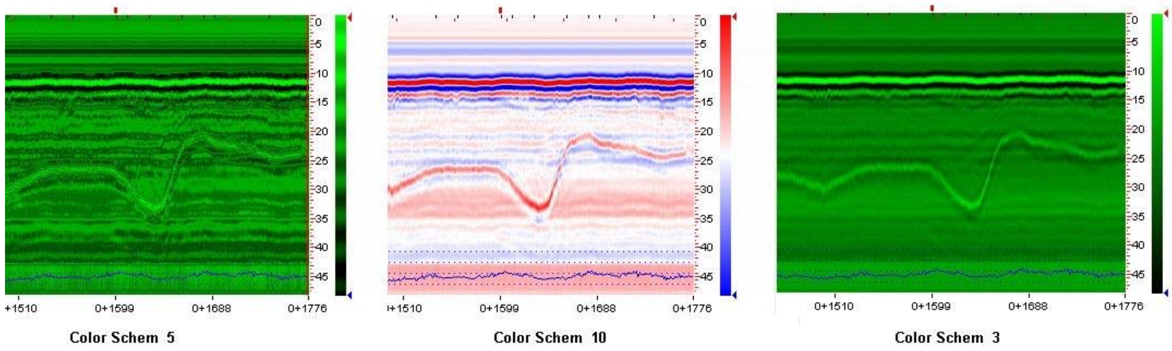



**Figure 30. COLORMAP Changes after Changing Color Scheme.**

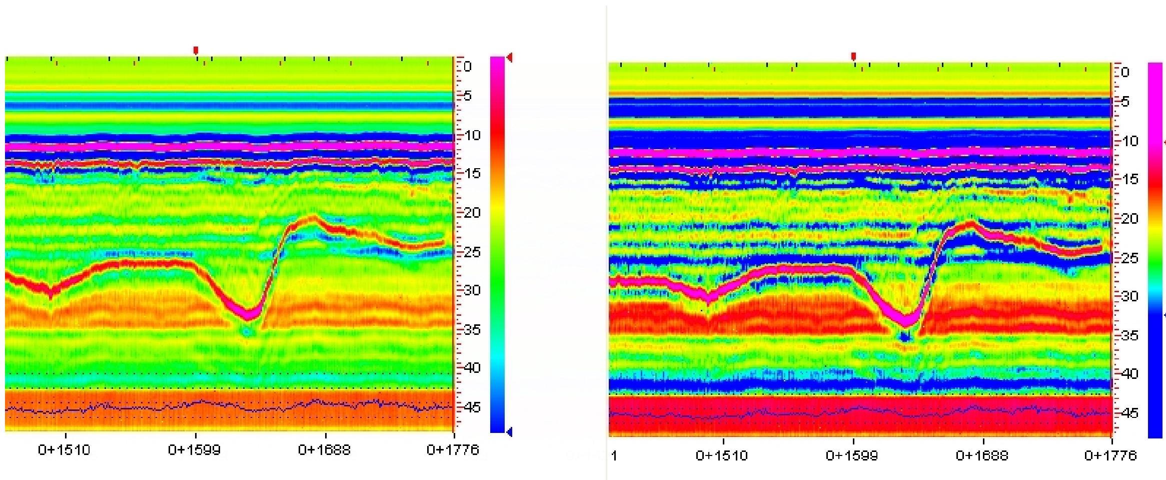



**Figure 31. Impact of Changing High and Low Color Scale Limits.**

### How to View Other Pages

The preceding section is limited to a discussion on how to view one screen display. A horizontal monitor resolution of 1280 pixels displays about 1000 traces. If the GPR sample rate is one trace per foot, this screen displays about 1000 feet of GPR data. GPR data are often collected on very long sections, often several miles in length. For example, a 30 mile test section at this sample data collection interval requires about 150 pages to view. Therefore, the PAVECHECK program has tools to allow the user to turn pages.

There are two methods to turn pages: one is to move to a full page, and another is to move part of a page.

Hold the right mouse button down and dragging on the COLORMAP display to move the display forward or backward. Hold the "CTRL" key and left mouse button down, and drag on the COLORMAP screen will move the GPR display forward or backwards.

**Depth Scale Setting**

The depth scale is a useful tool to help the user estimate the thickness of each pavement layer. Since the GPR thickness calculation depends on each layer's dielectric value, the depth scale must be adjusted for different materials. Click the circled button on the toolbar in Figure 32 to display the dialog box shown in Figure 33.

There are two tabs on this setup window; click the "Thick Scale" tab used to adjust the depth scale setting by changing one of these three fields:

1. Velocity factor is obtained from the GPR antenna height calibration. Each TxDOT antenna has its own velocity factor, which is typically a number close to 5.9 inches/nanosecond. It defines the velocity when radar travels through the air. Typically, once set, this value is not changed.
2. Step value defines the interval at which the depth scale is labeled. For example in Figure 33, the step value is 5, meaning every 5 inches, a label is added.
3. The default dielectric value is used to calculate the thickness scale. This may change based on the pavement type under test. For asphalt pavements, a value of 6 is recommended. For concrete, 8 is typical.

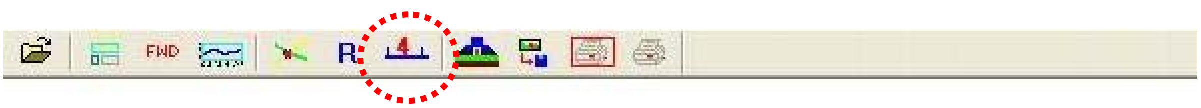



**Figure 32. Toolbar Button to Set the Depth Scale.**

Changing any of the above values changes the total thickness estimate. This value helps the user estimate the thickness of the upper layers and the depth of penetration. This is only a first-order estimate of layer thickness. A more accurate estimate is based on the signal trace analysis technique described later.

Click the "OK" button to update the depth scale; "Cancel" to exit this screen.

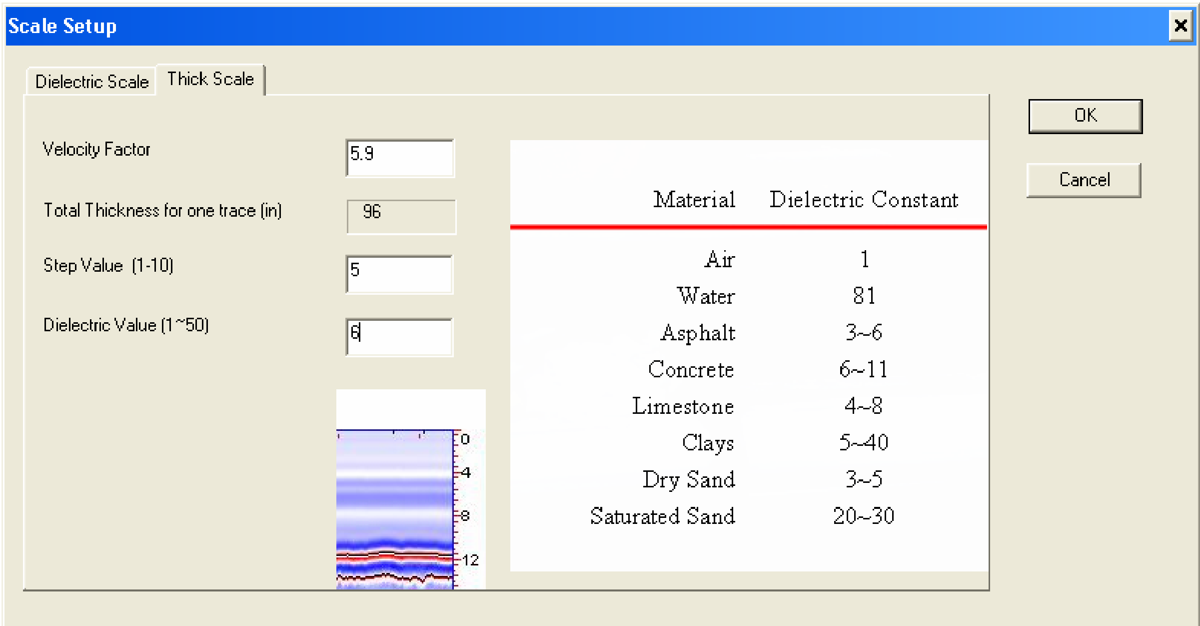



**Figure 33. Depth Scale Setup Dialog Box.**

**Dielectric Scale Setting**

The top layer's dielectric value gives important information for identifying defect locations in new pavement. When the GPR data are loaded into the program, the top layer's dielectric value is automatically calculated and displayed at the bottom of the COLORMAP. Sometimes the display settings need to be modified. The user can change the default dielectric scale settings by selecting the "Dielectric Scale" tab in Figure 33, which displays the dialog box shown in Figure 34.

The "Dielectric Scale" tab allows the user to set the dielectric scale. Four fields can be changed as follows:

1. Minimum Surface Dielectric Limit: defines the minimum value of the scale.
2. Number of Steps: defines how many ticks on the scale.
3. Step Value: defines the interval at which the program labels the scale.
4. Pixel Step for One Step: defines the number of pixels for each tick. Normally 10 is a good, a value too large makes the dielectric plot take up too much space on the COLORMAP frame.

Changing any of the above values changes the surface dielectric plot at the bottom of the COLORMAP plot.

Click the "OK" button to update the dielectric scale; "Cancel" to exit this screen.

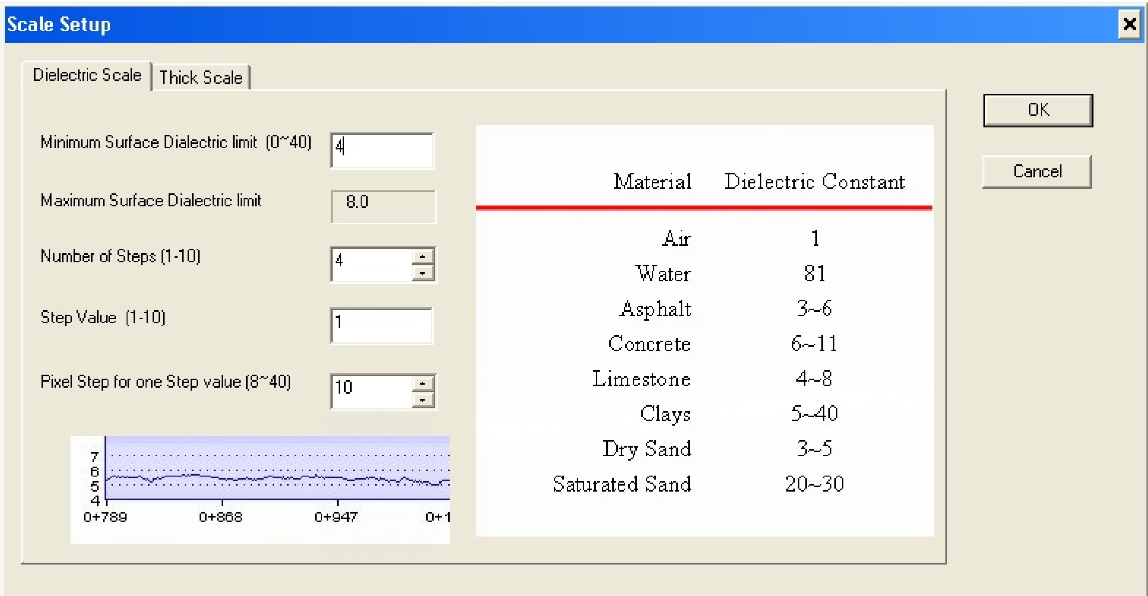



**Figure 34. Dielectric Scale Setting Dialog Box.**

## 2.4 PROCESSING A SINGLE GPR TRACE

It's necessary to introduce the basis of GPR trace processing before starting this section.

### Basis of Single Trace Analysis

Figure 35 shows the principles of ground penetrating radar. The antenna at the left side of this figure transmits pulses of radar energy, with a central frequency of 1 GHz, into the pavement. This wave is reflected at significant layer interfaces in the pavement. The data acquisition system captures and displays these reflected waves as a plot of return voltage versus arrival time. The largest voltage peak is the reflection from the pavement surface; the signal reflections before the surface reflection are internally generated noise known as the "end reflection." Although not related to the pavement structure, the time between the end reflection and the surface reflection is related to the height of the antenna above the ground; this measurement provides a means of accounting for antenna bounce as the system drives over rough highway. The reflections of major significance to pavement engineers are those that occur after the surface reflection. These reflections represent significant interfaces within the pavement, and the measured travel time is related to the thickness of the layer. Travel speed within one layer is related to the reflection peaks from the interfaces. So the main task of single trace analysis is to find the amplitude of each significant peak and the time between these peaks. To find the amplitude of each peak, positive peak and negative peak are needed.

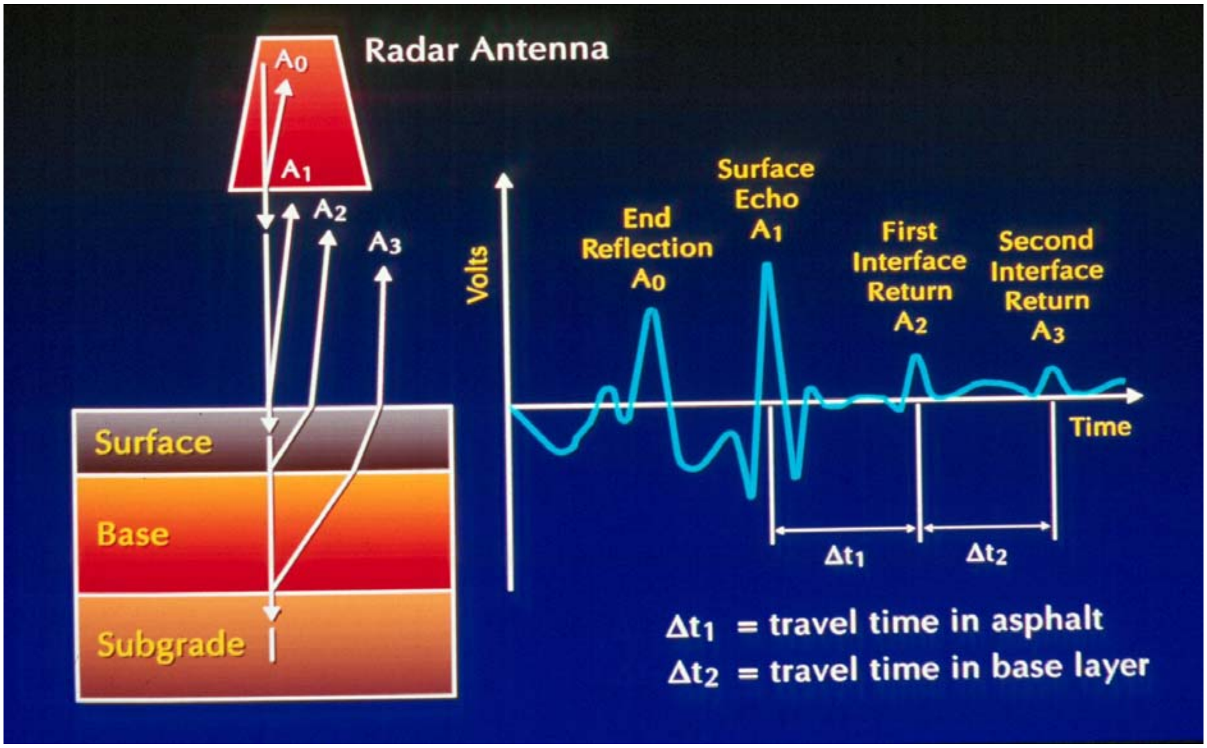



**Figure 35. Principles of Ground Penetrating Radar.**

**Overview of Single Trace Analysis**

The Single Trace Analysis module is used to perform analysis of a single GPR trace. There are three methods included in the program to perform single trace analysis. The first is the traditional way, where the user manually selects all of the peaks to calculate the amplitudes and the layer thicknesses. Another way is by preprocessing the raw GPR data by removing the surface reflection using a surface subtraction technique. If this method is used, a template trace or metal plate trace is needed to subtract from the surface reflection. This technique must be used if thin layers are present. The surface subtraction technique is required when processing the Annex data because the hot mix asphalt (HMA) surface of that section is around 2 inches thick. This method is very effective in finding the thin layer and clearly identifying the amplitude of reflection from the top of the base layer. The third method of processing the GPR traces is by using the automatic tracking feature, which is repeat applications of the previously defined signal trace analysis scheme. This method is useful when the section is relatively uniform and the peaks are easy to visually identify. It cannot, however, be used in all cases. These three procedures are described further in the next section.

When the PAVECHECK program is started, the single trace analysis frame is automatically displayed on the right bottom of the screen of Figure 19.   By placing the curser in this frame and clicking the left mouse button, Figure 36 displays.

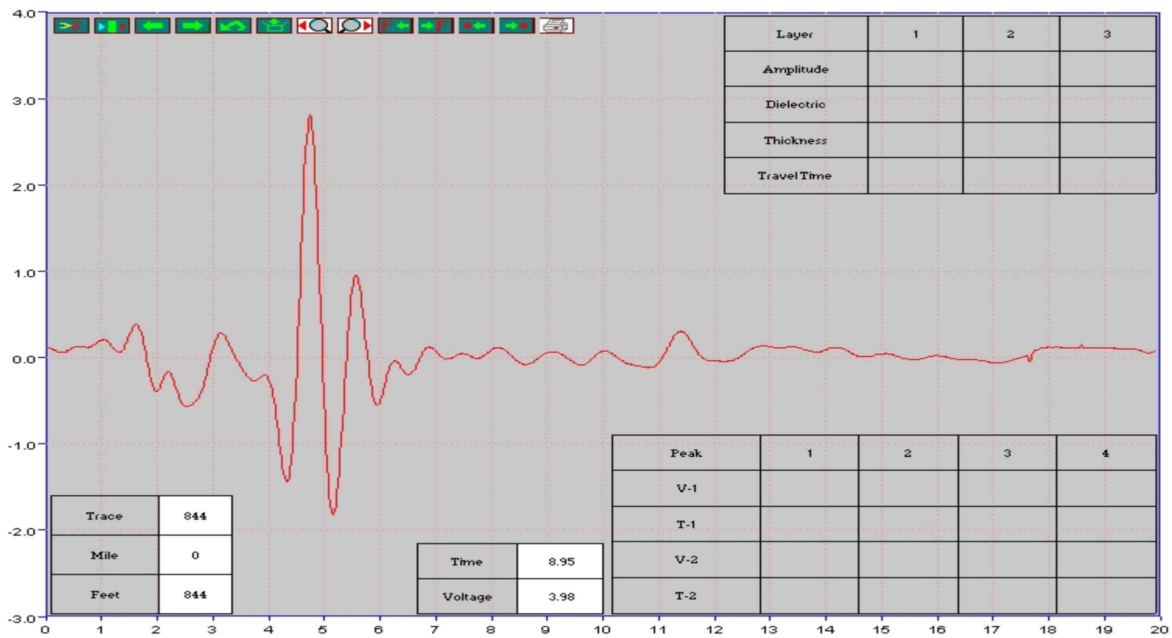


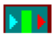
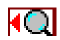
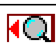
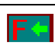
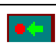
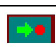
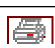

**Figure 36. Single Trace Analysis Screen.**

Figure 36 displays four different results tables and 13 control buttons.   The functions of the four tables are as follows:

- The DMI table shows the current trace number and milepost location.
- The current cursor location table shows the time and voltage value of current cursor location.
- The peak value table displays the peak value which the user selected.
- The results table presents the single trace result, which includes peak amplitude, travel time, dielectric value, and layer thickness.

Table 3 lists the functions of the 13 buttons.

**Table 3. Functions of Single Trace Analysis Buttons.**

| No. | Button | Function |
|---|---|---|
| 1 |  | Subtract the surface reflection based on the metal plate trace or the template trace. This technique is very effective if thin asphalt layers exist. |
| 2 |  | Automatically perform the single trace analysis. This function is not available on this version, but will be added later. |
| 3 |  | Move to the previous trace. |
| 4 |  | Move to the next trace. |
| 5 |  | Undo; go back to the beginning and restart the calculations. |
| 6 |  | Save the analysis results to the memory. If the user does not click this button, the results are discarded. The   buttons also save the result before further action. |
| 7 |  | Automatically track peaks in the backward direction and perform layer thickness calculations. |
| 8 |  | Automatically track peaks in the forward direction and perform layer thickness calculations. |
| 9 |  | Back: go to the trace which has the FWD test data. This button helps users to locate the GPR trace at which the FWD field test data were collected. |
| 10 |  | Forward: go to the trace which has the FWD test data. |
| 11 |  | Move backward to the trace which has already finished the single trace analysis. |
| 12 |  | Move forward to the trace which has already finished the single trace analysis. |
| 13 |  | Print out the single trace analysis results in detail. |

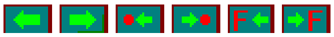
The  buttons are used to find a particular trace upon which to perform the single trace analysis. When clicking one of these buttons, the single trace frame is updated to another trace and all the tables are automatically updated. This updating depends on the status of the traces. If the trace has not been analyzed, the update processing updates the trace waveform and DMI table and clears the content of all other tables. If the trace has been processed and the thickness and dielectric values have been saved, then the updated information trace displays in all of the tables.

Figure 37 shows an example of a frame where the user has performed the single trace analysis. The user has identified the significant reflections (positive and negative peaks) using the left mouse button; each selected peak has a blue cross on it. When clicking the mouse to select these peaks, the computed peak values and the result are instantly presented in the tables. For the trace shown in Figure 37, the upper HMA layer thickness is 1.99 inches, and its dielectric value is 5.91. The base material thickness is 10.59 inches with a dielectric of 10.55. Once this trace has been processed and stored, the user may browse the trace at a later time using one of the control buttons shown in Figure 38. Figure 38 is identical to Figure 37 except that the peaks are now marked with a triangle.

Since the single trace analysis result depends on the peaks that user selects, it is critical to select the appropriate peaks on the GPR trace. The following rules are required to perform the single trace analysis:

- Always select the positive peak and then the negative peak.
- Always pick from the top to the bottom of the trace or from the left to the right on the GPR trace waveform.
- The first peak selected is always the positive peak from the surface reflection. The second peak selected is always the left negative peak of the surface reflection.
- Clicking the mouse close to the appropriate peak is sufficient. Before this trace is loaded, all its possible peaks are identified and saved to the memory. If the mouse click location is close to a peak, the peak is automatically selected.
- The maximum capacity of this single trace analysis is four pavement interfaces or three pavement layers.
- When the surface subtraction method is used, the first two peaks from the surface reflection are automatically picked.

- The user can use the button at any time to clear all the tables and restart the single trace analysis.
- The button saves the results for this trace; otherwise, the calculated results are discarded.

Figure 38 shows a sample calculation without surface subtracting, while Figure 39 is the analysis using the surface subtracting technique. The surface removal is activated using the button. The red waveform is the original trace. The user identifies the surface reflection (largest peak). As soon as the surface is identified, the blue line is generated. This is the resultant GPR trace for that location with the surface reflection removed. The user must select all remaining interfaces (such as the top and bottom of the base) on the blue line. This is a deconvolution technique, which is highly recommended if the HMA thickness is less than 3 inches.

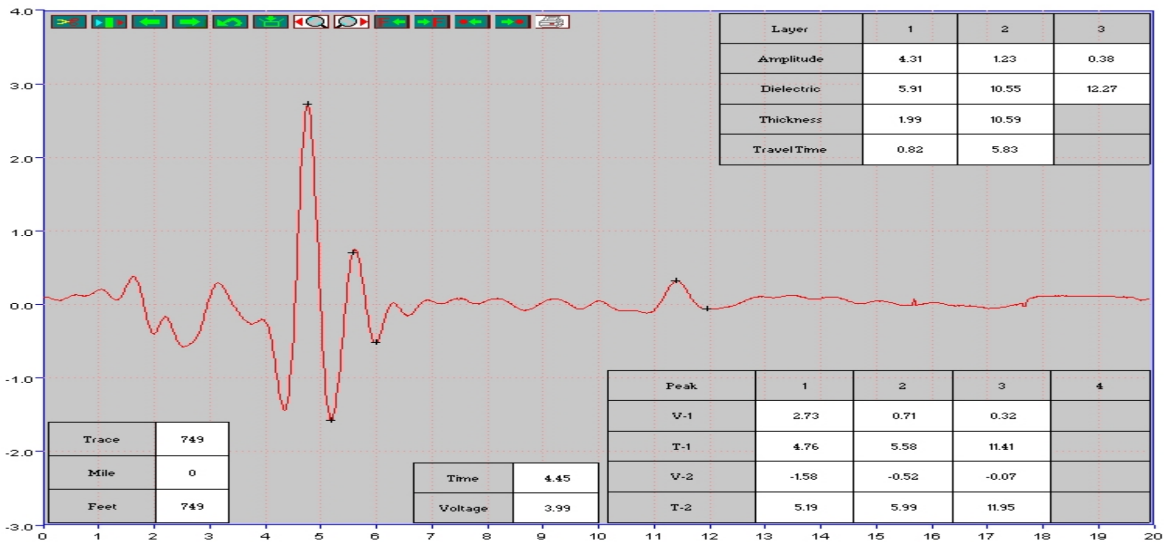



**Figure 37. Single Trace Analysis for a Sample Trace.**

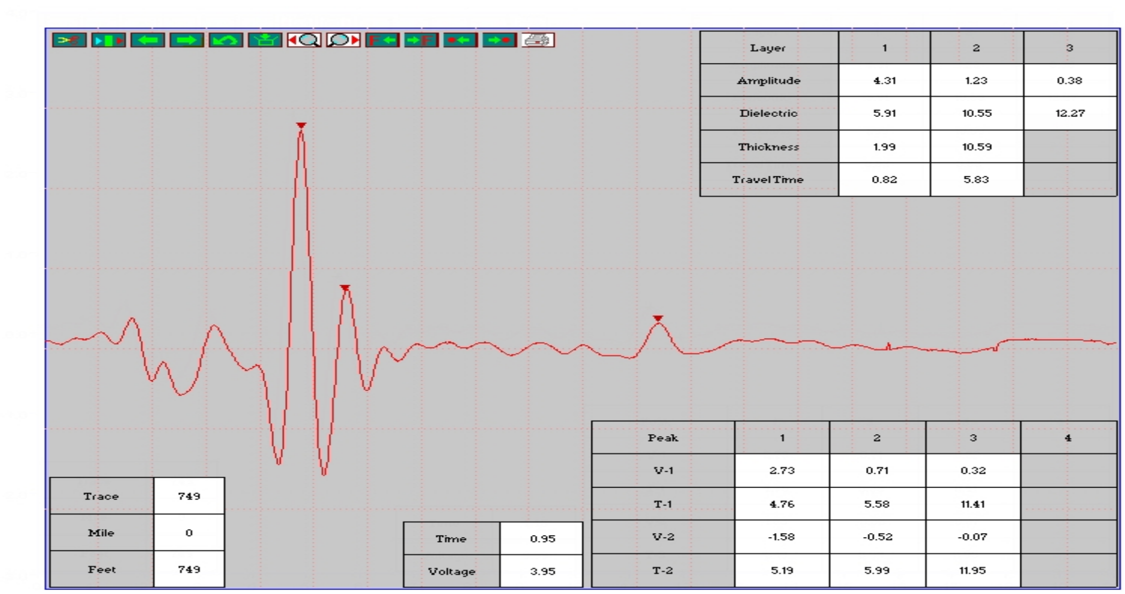



**Figure 38. View a Trace Already Analyzed.**

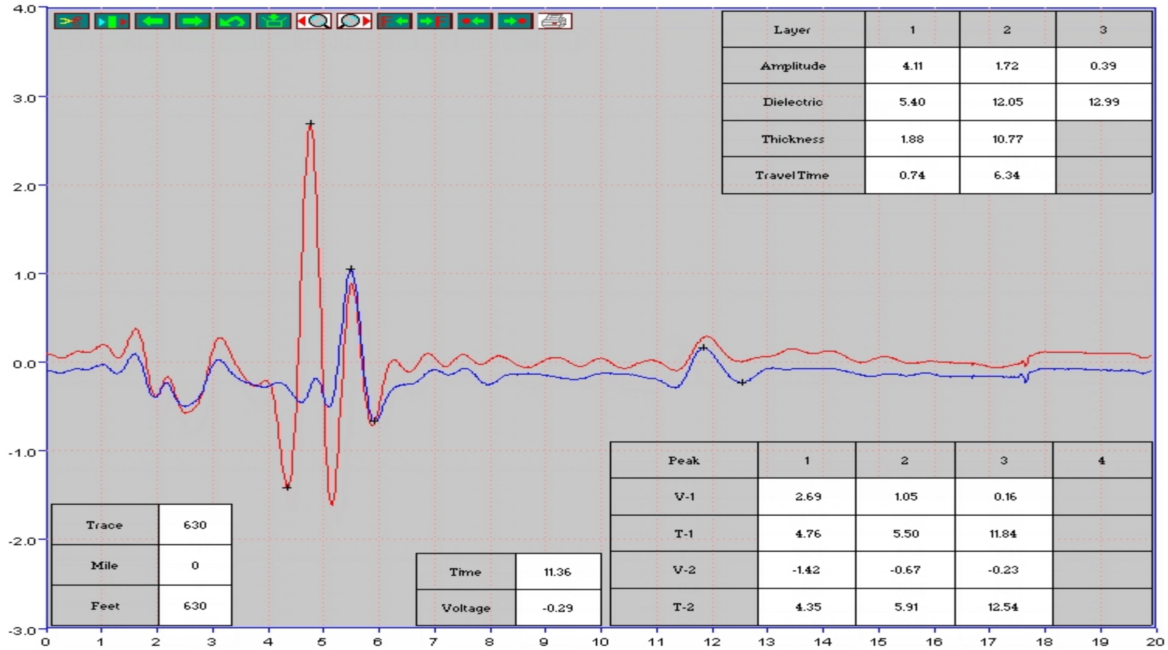



**Figure 39. Analysis by Subtracting the Surface Reflection.**

### Automatic Peaks Tracking

The preceding section describes single trace analysis. For the normal GPR field survey, as many as 30,000 traces may be collected. It is not practical to use the single trace method to process all these data. PAVECHECK has an automatic tracking method to provide an efficient way of processing large volumes of GPR traces.

Before using the tracking action, it is necessary to first perform the single trace analysis. The program then follows the same setup to track forward or backward to find the peaks for the other traces, until one of the following conditions occurs:

- It reaches the end or beginning of the GPR data.
- It reaches user-defined section limits (discussed below).
- The peak tracker cannot find a significant peak in the scanning window.

Section limits are defined by the user to limit the peak tracking process to a specific set of traces. The user can define the left limit by holding the “SHIFT” key and left clicking the mouse on the COLORMAP display. The right limit is defined using the “SHIFT”/ right mouse click. As shown in Figure 40 the limits are defined as vertical blue and red lines. This figure shows an example of tracking with the section limits defined. To complete this tracking the user must first process a single trace from within the specified limits. After this, clicking the button processes the traces in a backward direction until reaching the limit. Similarly, the button will do the forward or right tracking. The automatically tracked interface is drawn as a black line. The user can immediately see if the tracking has been successful.

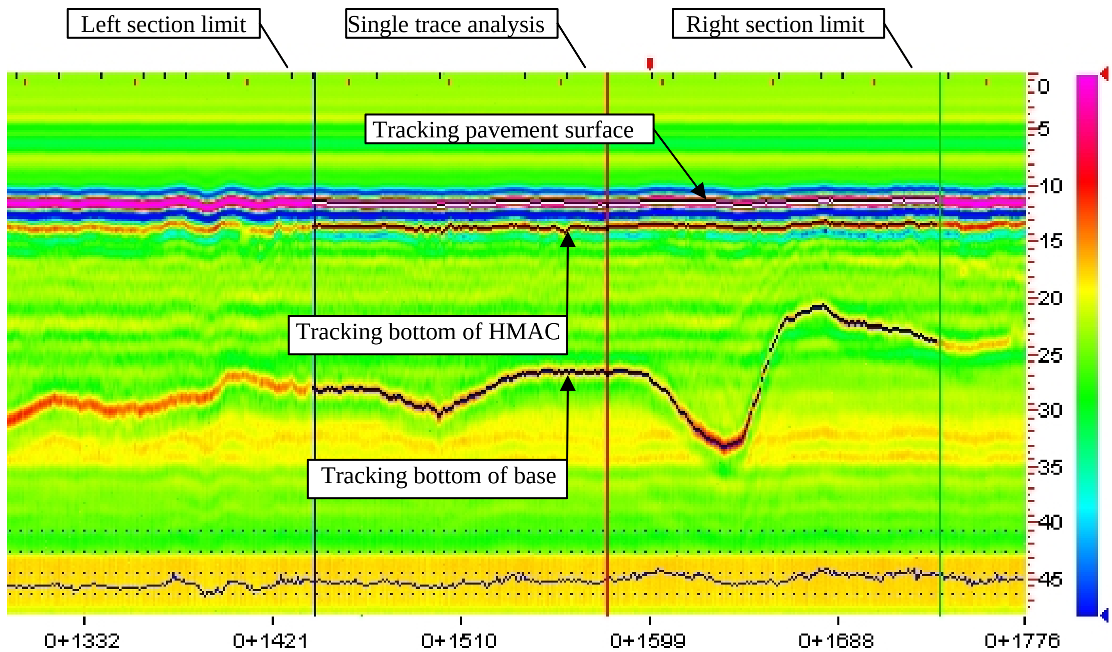



**Figure 40. Automatic Tracking Method with Section Limits Defined.**

Some of the factors that can influence success of the peak tracking function are listed below:

- The age of the pavement. Newly constructed pavements are easier to track.
- Multiple overlays create many subinterfaces, which make the tracking much more difficult.
- Pavement deterioration like cracks influence the quality of the captured GPR traces.
- Moist conditions change the dielectric values. Localized moisture makes the peak tracking difficult.
- Thin layers make two adjacent peaks overlap.
- Defects or localized variation in the pavement structure challenges peak tracking.
- Buried pipelines or metal objects change the waveform of the GPR traces.

- Sections of the GPR survey containing a bridge or that are close to a bridge “confuse” peak tracking.

Figure 41 and Figure 42 are two sample data sets that show some of the problem areas for automatic peak tracking. In Figure 41 the interfaces of base or subbase have large variations, and in some areas the bottom of the base is not clear. Figure 42 shows some small localized patched sections, which cause the COLORMAP display to change sharply. Automatic tracking of sections that are extensively patched is very difficult. When tracking the second case, it is necessary to use the define section option discussed above; this limits the automatic tracking method to areas where the tracking is possible.

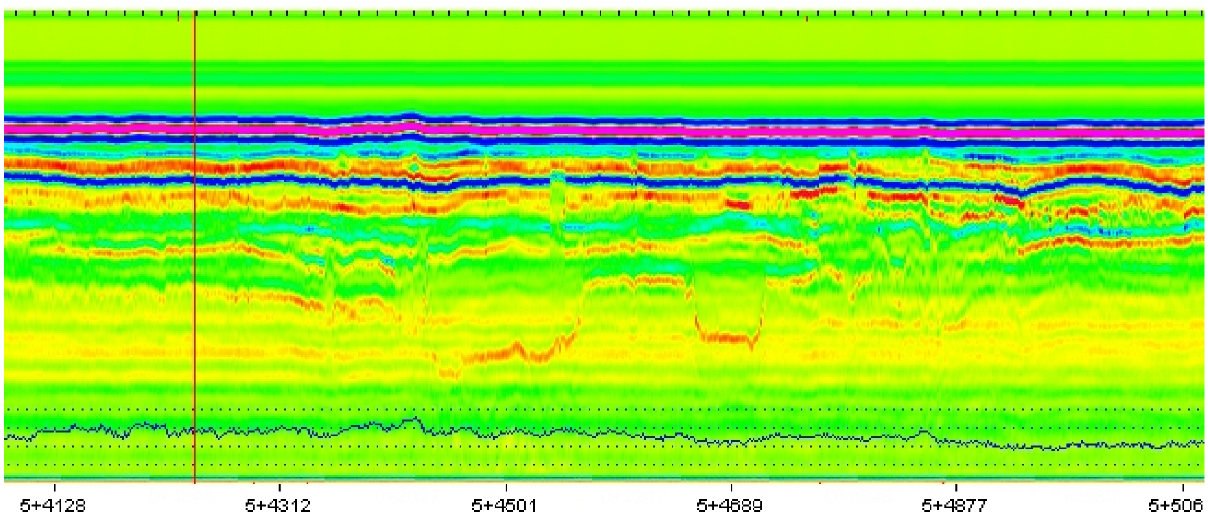



**Figure 41. Sample GPR COLORMAP from SH 6 That Shows Some Variation.**

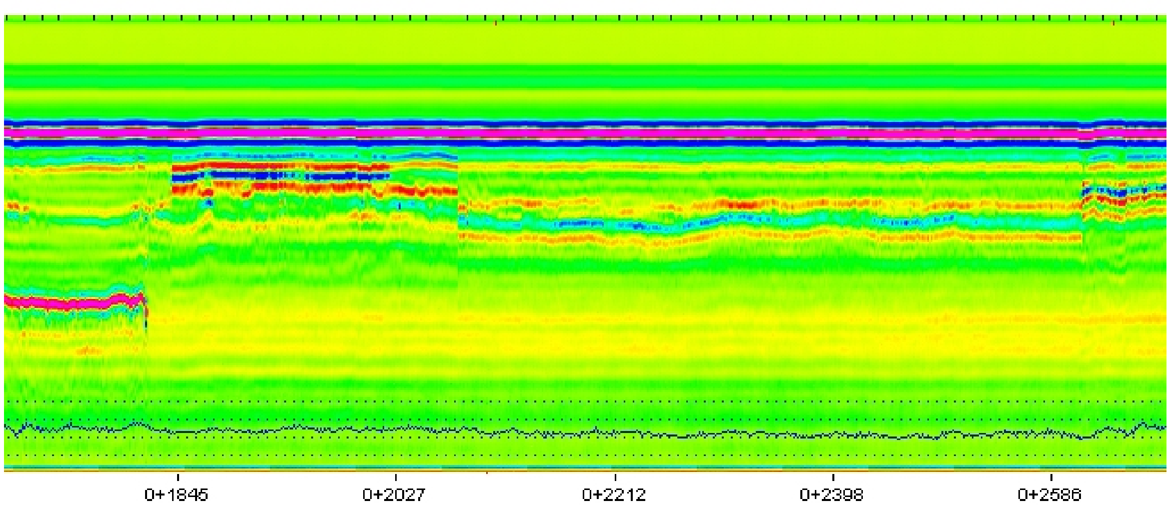



**Figure 42. Sample GPR COLORMAP from SH 6 That Shows Some Small Sections.**

## 2.5 USING THE DIGITAL VIDEO MODULE

The digital video's functions are similar to that of a digital VCR system, which helps the users browse digital video frames. This module can process the TTI video format, which is a zipped video format, with JPEG images and DMI information included. TxDOT's PF99 test file, if it includes a video frame, first needs be converted to the TTI video format as explained earlier before using the options described below.

When the project is started and shown on the screen a video frame displays as shown in Figure 19. Click on this video frame and 11 buttons appear at the top of the video frame (Figure 43).


**Figure 43. Video Frame Showing the Image with Buttons and Milepost.**

Table 4 lists the functions of each button. The first six buttons are easy to understand. They are used to browse the video data. Clicking the button changes the GPR COLORMAP display, single trace analysis, and the FWD frame and synchronizes all these frames to the same DMI location. If the button is clicked and held down, some basic information will be shown in the middle of the video frame (Figure 44).

**Table 4. Functions of Image Frame Buttons.**

| No. | Button | Function |
|---|---|---|
| 1 |  | Show the first image of the project. |
| 2 |  | Play the images backward from the current location; clicking the mouse button in the image frame stops the video. |
| 3 |  | Move the image frame to the previous one. |
| 4 |  | Move the image frame to the next one. |
| 5 |  | Play the image forward from the current location; clicking the mouse button in the image frame stops the video. |
| 6 |  | Move the image frame to the last one in the project. |
| 7 |  | Show the GPR and FWD data at the current image frame location. This action synchronizes all the other data to the image frame location. |
| 8 |  | Display the information about this image frame. |
| 9 |  | Clicking this button and holding it down makes the image resize itself to its original resolution. Releasing the button will bring the image frame to its normal size. |
| 10 |  | Clicking this button will display the nearest core image and information, if present. |
| 11 |  | Show the image frame location on the map, if GPS data are present. |


**Figure 44. Image Frame Information.**

Clicking the  button displays the core image that is closest to this video frame DMI location. As an example, if the GPR trace shown is at DMI 0+520 feet, by clicking this button the core image at DMI=556 feet (Figure 45) displays.

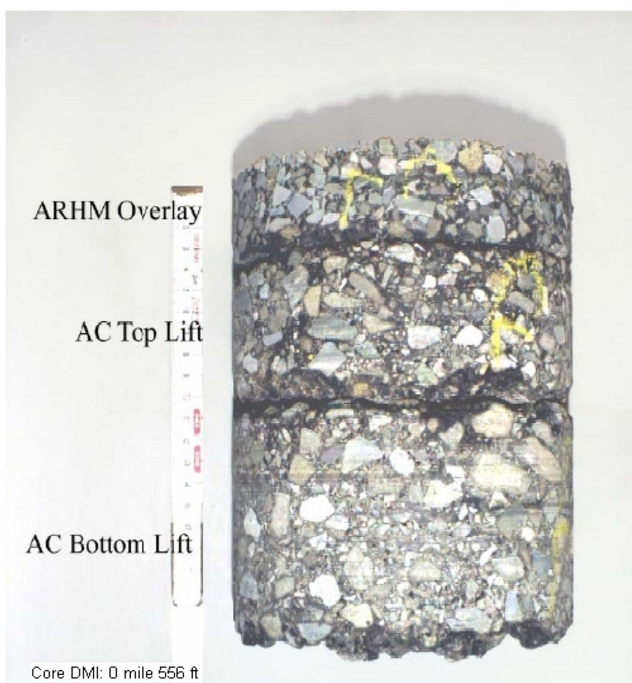



**Figure 45. Core Image.**

The button will displays a Geographic Information System (GIS) map of the test location. The requirements for this function to work are the following:

- The project must have GPS data to track the test route.
- The test site must be within the state of Texas.

Figure 46 is an example of the Annex test site. The blue line on the map shows the testing route, and red circle shows the current image frame location.

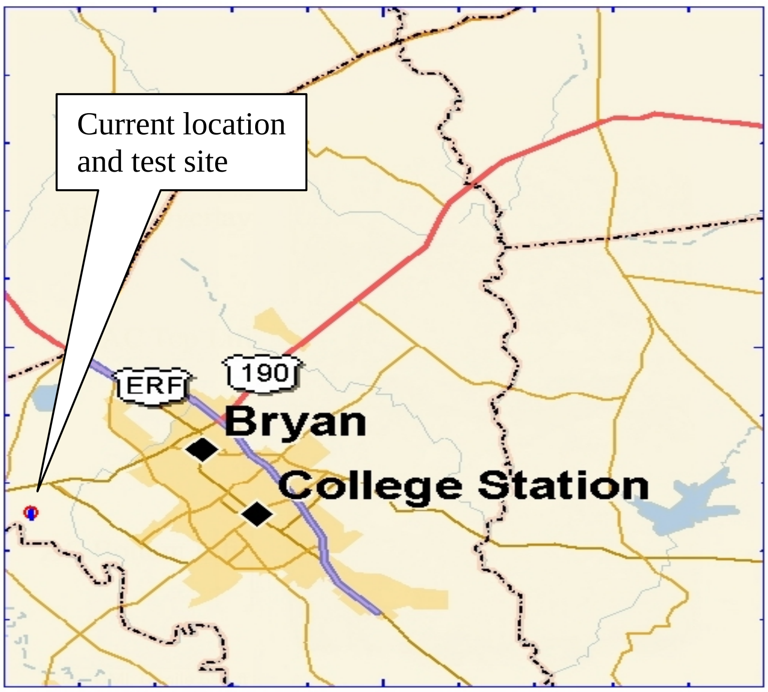



**Figure 46. Map of Test Location.**

## 2.6 FUNCTIONS IN THE FWD DATA DISPLAY MODULE

When the PAVECHECK program starts, the FWD data are not displayed. If the user wants to view the FWD deflection bowls or to analyze the FWD test data based on the GPR calculated thickness, clicking the FWD button on the toolbar (Figure 47) brings the FWD frame into the bottom left corner of the screen. The four lines plotted show the deflection bowls at the four FWD test loads at this one test location. Clicking on the GPR COLORMAP displays the FWD frame showing the FWD deflection bowl as shown in Figure 48. To activate the FWD analysis options it is necessary to left click on the FWD frame, then a set of buttons appears in the top left of the FWD frame as shown in Figure 49.


Figure 47. Toolbar Button to Open or Close the FWD Frame.

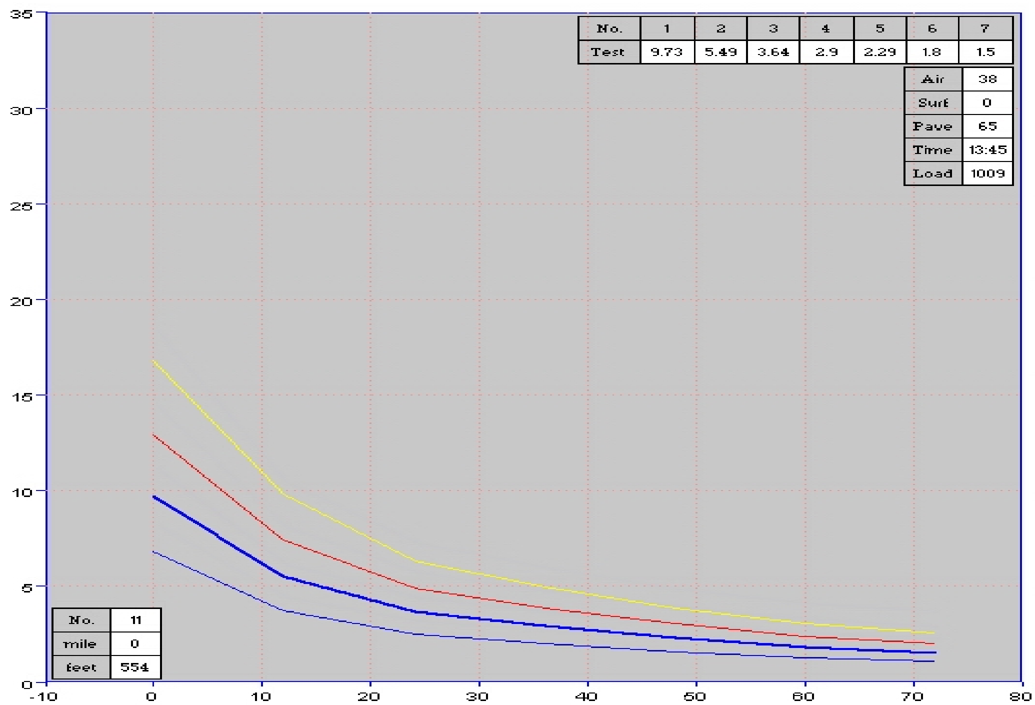



Figure 48. FWD Deflection Bowl Frame.

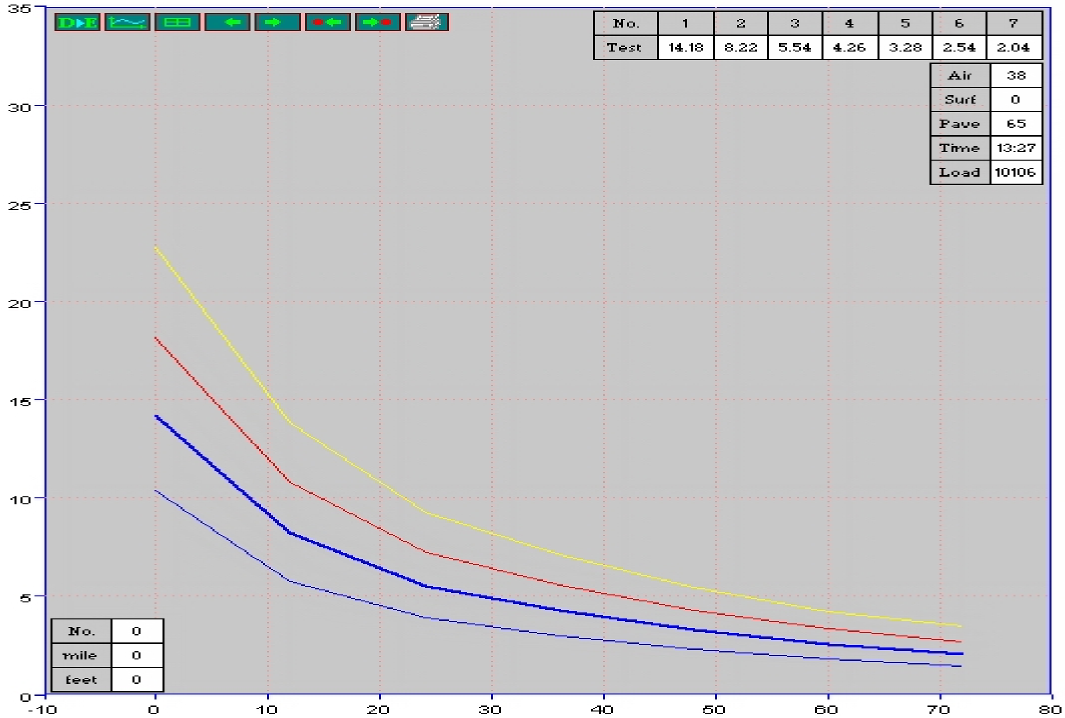
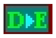
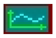



**Figure 49. FWD Frame with Buttons.**

Figure 48 shows the FWD deflection bowl at DMI=554 feet. There are four lines that show the deflection bowls of four load levels used in the FWD test. The thick blue line is the load level used for backcalculation. This is the load level closest to 9000 lb. The raw data tables in the top right corner of the FWD frame are also for this load level.

Table 5 lists the functions of each of the buttons in the FWD frame. Buttons  and  are only active when there are FWD stations for which the backcalculation analysis has been completed.

**Table 5. FWD Control Buttons Set-1.**

| No. | Button | Function |
|---|---|---|
| 1 |  | Show the FWD back-calculation dialog box to do the FWD backcalculation analysis. (This will be discussed in a separate chapter.) |
| 2 |  | Change the buttons set to a graphical display. |
| 3 |  | Show the values in tabular form. |
| 4 |  | Show the previous FWD station. |
| 5 |  | Show the next FWD station. |
| 6 |  | Show the previous FWD station that has already finished the backcalculation analysis. |
| 7 |  | Show the next FWD station that has had the backcalculation analysis performed. |
| 8 |  | Print the FWD analysis result. (This will be discussed in a separate chapter.) |

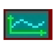
The  button changes the display to a plot of FWD deflections as shown in Figure 51. A new set of control buttons appears at the top of this screen. These buttons are explained in Table 6. Clicking the first button  changes the display back to the original deflections bowls shown in Figure 50. Figure 51 to Figure 56 are examples for the Annex field test data when each of the buttons in Table 6 is selected.

**Table 6. FWD Response Display Control Buttons**

| No. | Button | Function |
|---|---|---|
| 1 |  | Change the current button set to deflection bowl control button as in Table 5. |
| 2 |  | Display the center geophones deflection response. |
| 3 |  | Display the deflection graph for all seven sensors. |
| 4 |  | Display the center and outer geophones deflection response graph. |
| 5 |  | Display the outer geophones deflection response graph. |
| 6 |  | Display the load cell response graph. |
| 7 |  | Display the air, surface, and pavement temperature graphs. |

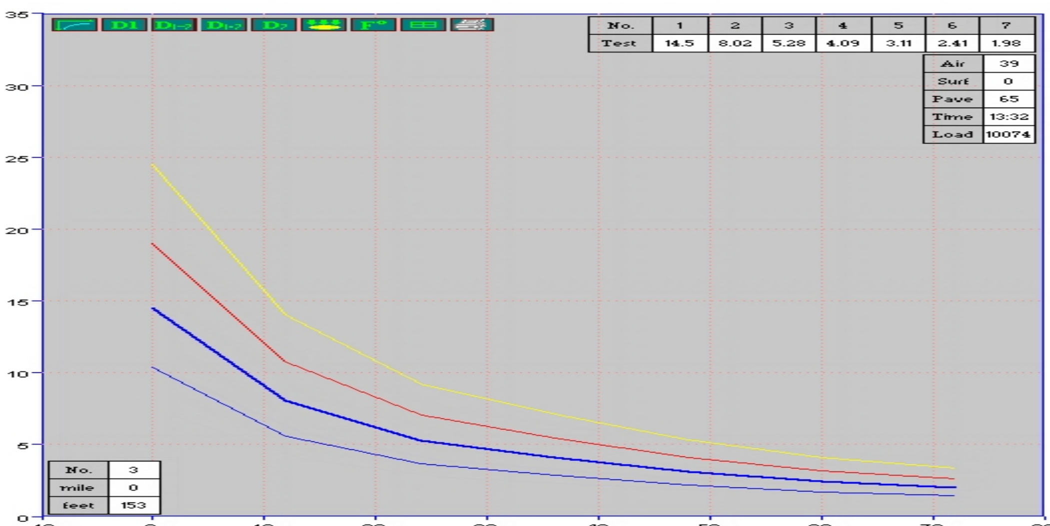



**Figure 50. FWD Display Frame with Control Buttons.**

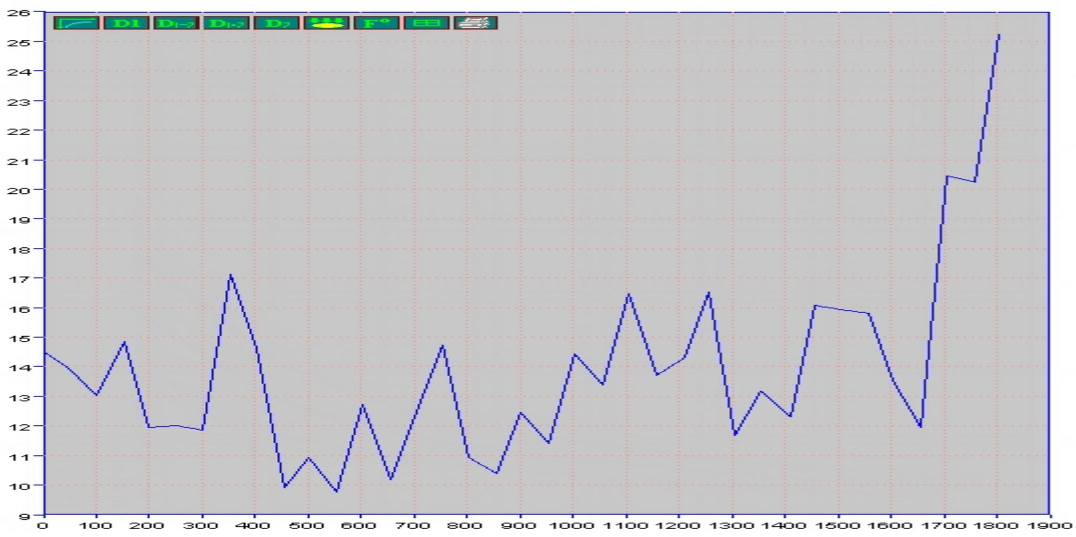



**Figure 51. Center Geophones Deflection Response Plot (button D1).**

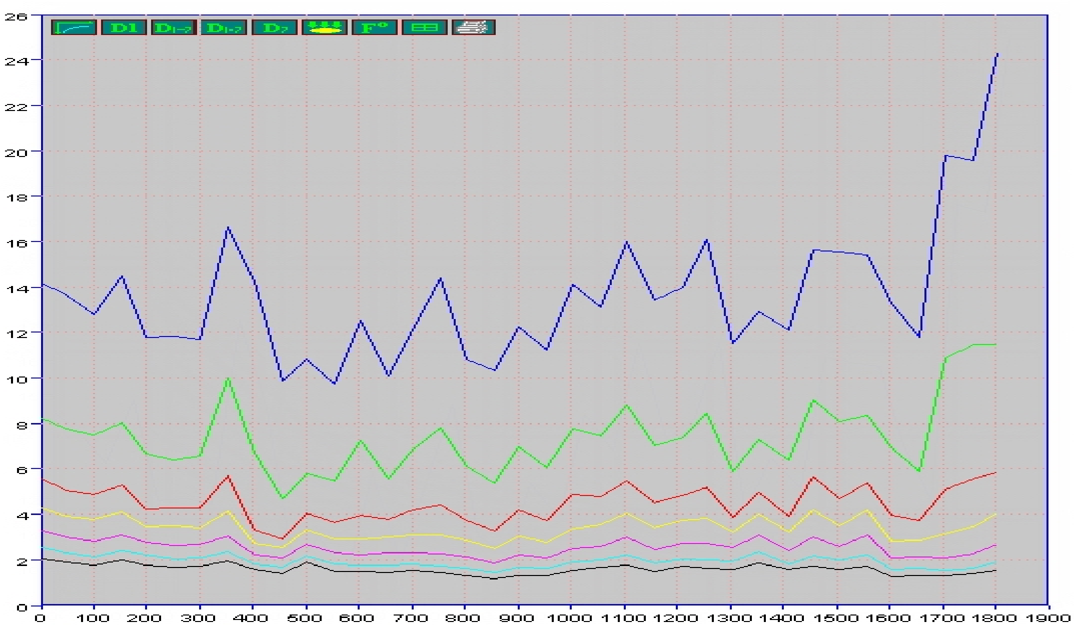



**Figure 52. All Seven Geophones Deflection Response Plots (button D1-7).**

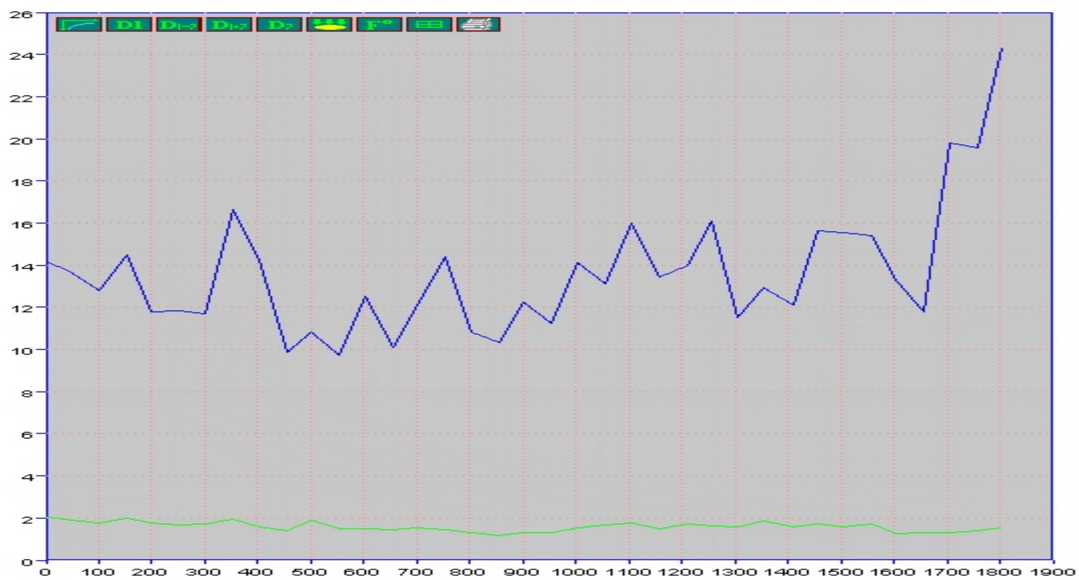



**Figure 53. Center and Out Geophones Deflection Waveform (button Dl-7).**

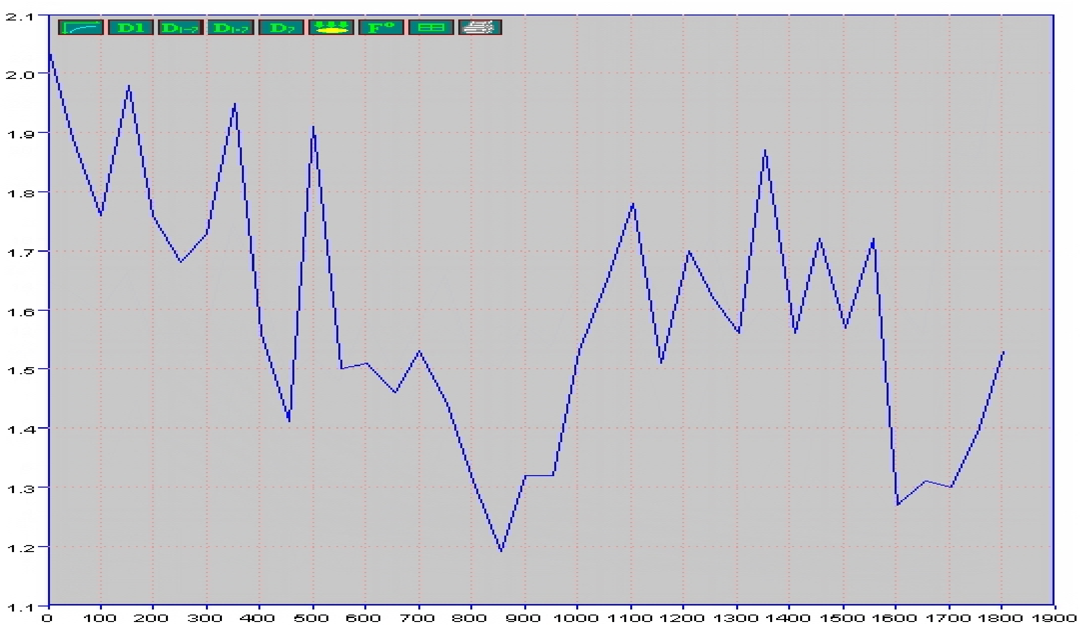



**Figure 54. Outer Geophones Deflection Waveform (button D7 ).**

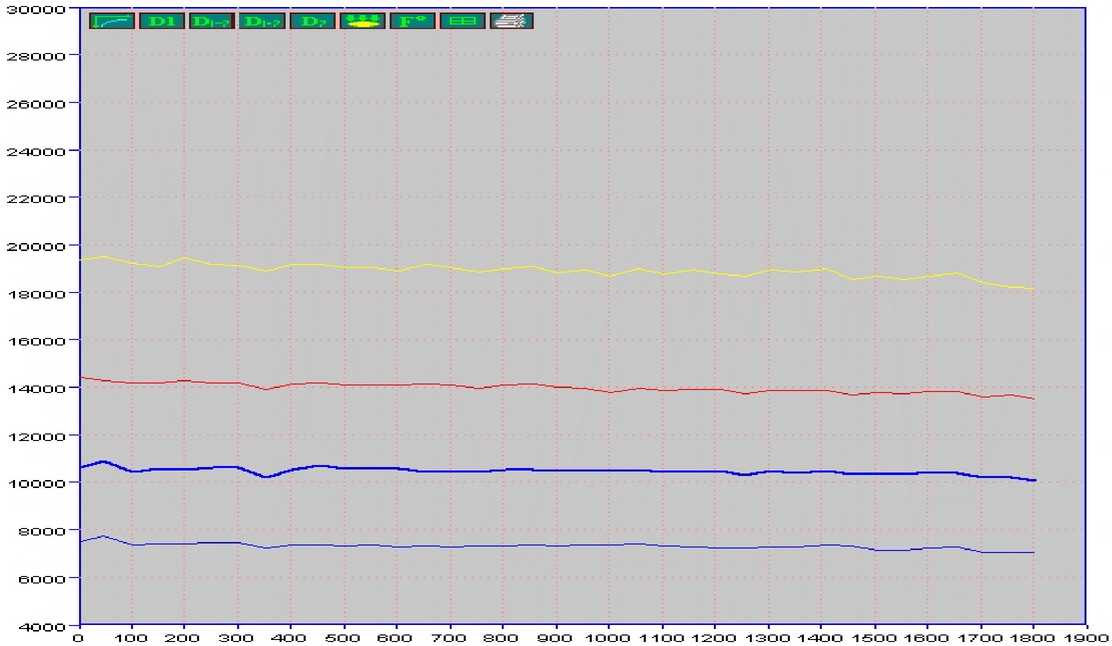



**Figure 55. FWD Dynamic Load Cell Response Plot (button ).**

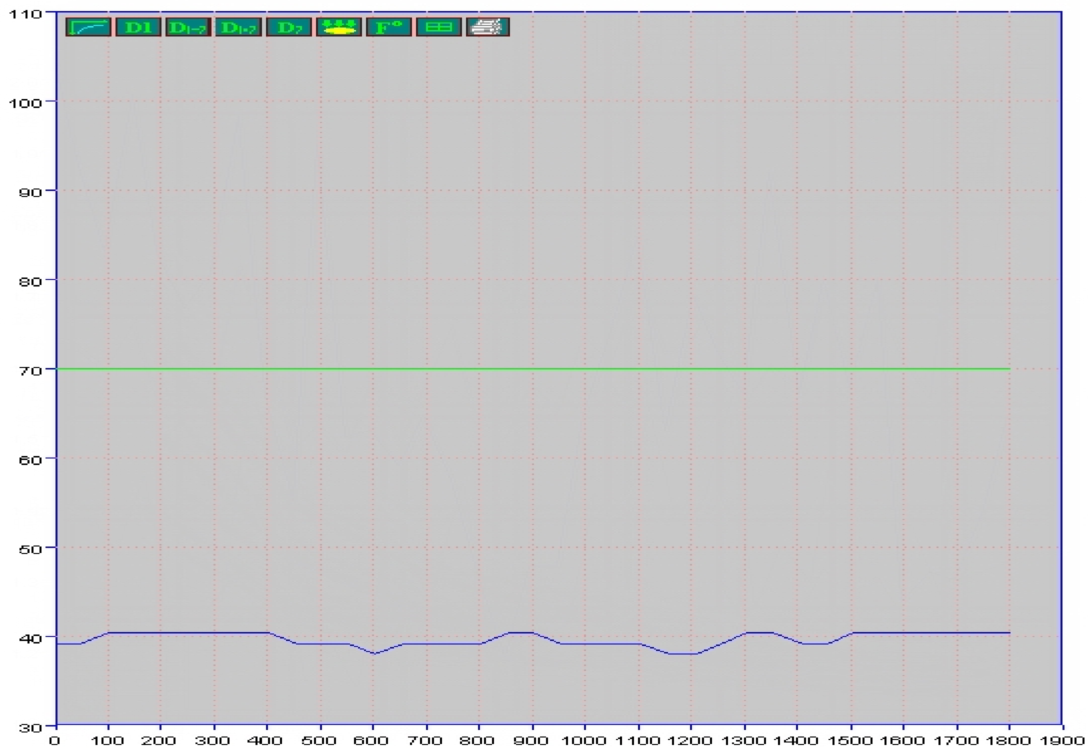



**Figure 56. Field Temperature Plot (button F°).**

Figure 49 through Figure 56 show the raw deflection and load data. No processing of the data has been performed, and none of the layer thicknesses at the FWD test locations have been defined.

If the GPR trace closest to this FWD station has already been processed and there are thickness values for the GPR trace, then the PAVECHECK program assigns thickness values to this FWD location. There are several methods to assign the thickness values to the FWD data; these include point specific estimates or averages over a given distance (for example, 12 feet). First, the point specific GPR thicknesses closest to the FWD data station can be used. Second, the average GPR thicknesses for all of the GPR traces located within a radial distance of the FWD station can be used. In the current version of the PAVECHECK program, this distance is set to 72 inches. This means that all GPR thickness data within 12 feet of the current FWD station are analyzed, and the average thicknesses are used for the FWD backcalculation processing. The second method gives more accurate backcalculation results, especially when the GPR COLORMAP shows large pavement thickness changes around the FWD station to be analyzed. The first method used the GPR thickness from the trace closet to the FWD load plate station. Figure 57 is an example of the FWD frame when GPR thicknesses are available. The pavement structure is drawn on the right side of the FWD frame. The unit for the thickness measurement is in inches. Figure 58 shows the FWD frame when the FWD data have already completed the backcalculation process. The detailed layer moduli results are listed in the table. Only the load level that was used for FWD backcalculation is plotted, and the red squares represent the raw FWD deflection data. The blue line represents the calculated deflections. In most cases, the error per sensor is used to determine if the backcalculation processing provides accurate deflection estimates.

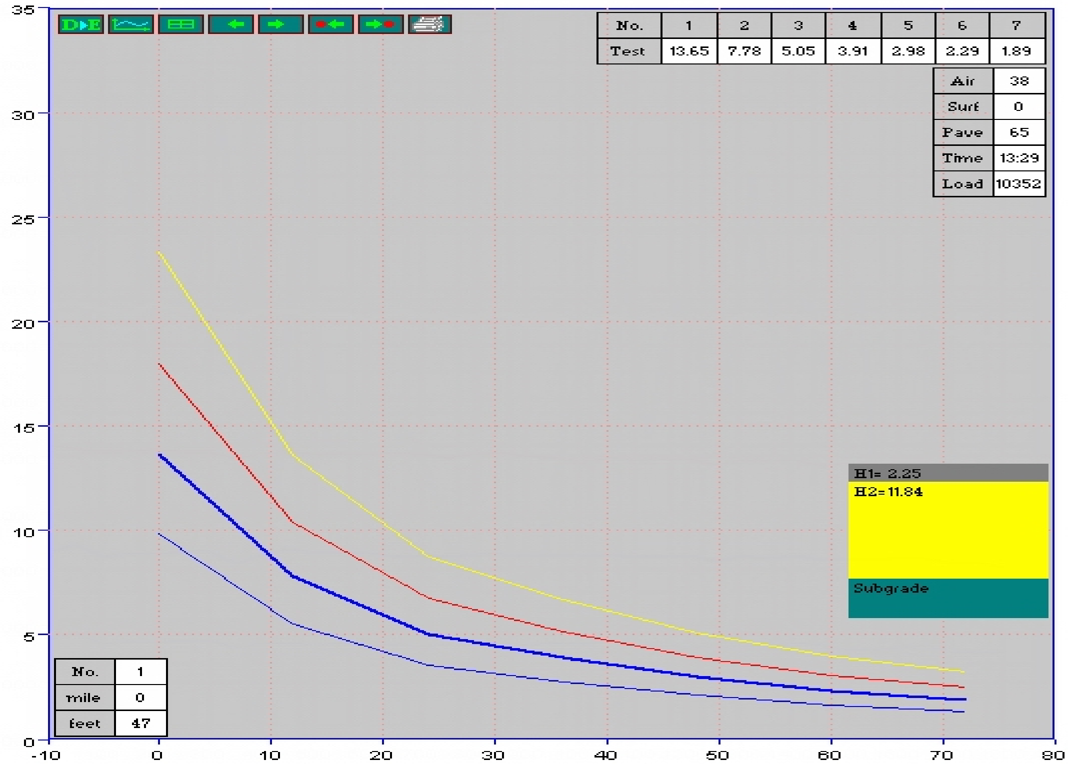



**Figure 57. FWD Display with Thickness from GPR Traces.**

For any station for which the FWD data have already been analyzed and the layer moduli have been backcalculated, then detailed results are listed on the table as shown in Figure 58. In this case only the load level used for the FWD backcalculation analysis is plotted, and the red squares show the raw measured deflection data, and the solid line shows the calculated deflection bowl. An additional results box has been added to Figure 58 which shows the results of the analysis in terms of layer thickness and moduli and the average error per sensor.

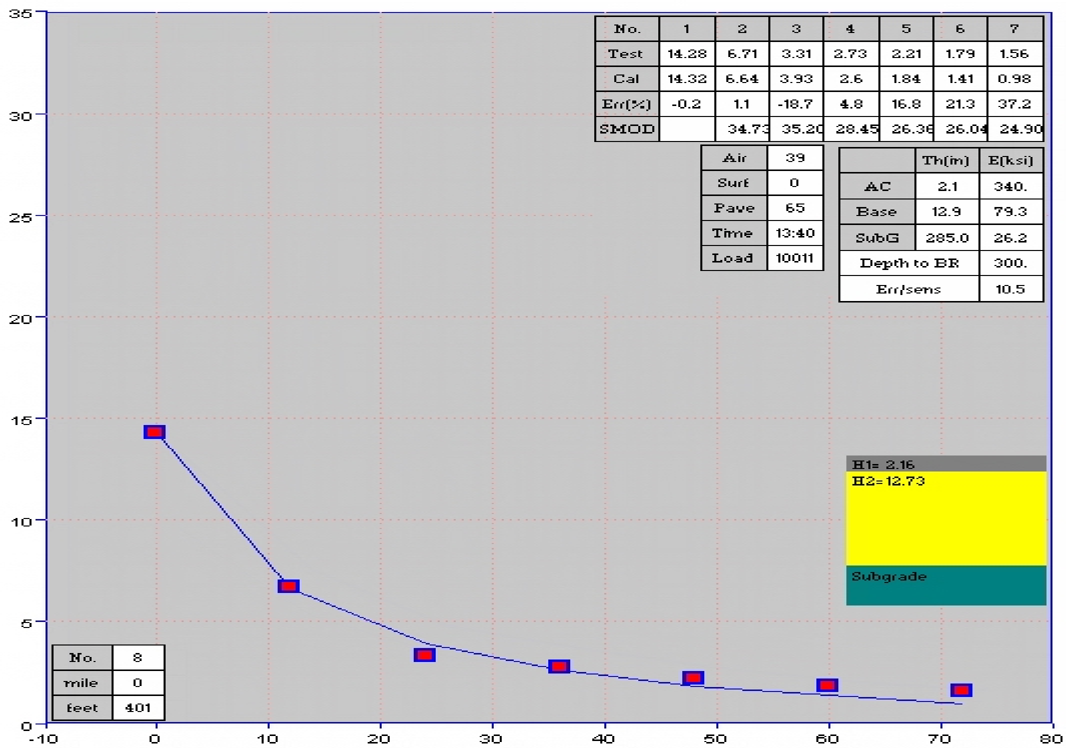


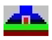

**Figure 58. When This Station Is Already Backcalculated, Detail Result Is Displayed.**

The main feature of the PAVECHECK program is the ability to merge FWD and GPR analysis schemes. The main integration feat is to provide the pavement layer thickness from the GPR analysis to the FWD backcalculation process. In the current version of PAVECHECK there are several ways of assigning the thickness values to the FWD analysis scheme. One way is by directly using the thickness from the GPR trace closest to the FWD station. As the GPR data are normally collected at 1 or 2 foot spacing, this provides a very close point specific estimate of the thickness directly under the loading plate. Another way is by using the average thickness of all the traces within some radius of the FWD loading plate. In the current version of program, this radius is set to 72 inches. So around the FWD station, all 12 feet of GPR data are analyzed and the average thickness is used for the FWD backcalculation. As described below, the user selects whether to use the point specific thickness estimate or the average value.

The user can make this decision by reviewing the COLORMAP frame. If COLORMAP shows large changes in thickness around this FWD station, then the average procedure will give a more accurate result than the point specific method, which directly uses the trace nearest to the FWD loading plate location.

## 2.7 MODULUS BACKCALCULATION MODULE

This module is the most complicated part of the PAVECHECK program. The purpose of this section is to perform the FWD backcalculation with the thickness from the GPR trace analysis. Before doing the FWD backcalculation, make sure that the FWD field test data file is the correct format. The current version of this program only accepts the Dynatest FWD R80 data format (this is standard TxDOT format).

When the program reads the FWD data, the deflection bowls from all of the load levels are read. A separate dialog box allows the user to select the load level and other FWD information before completing the FWD backcalculation. To access this dialog box, click the  button as shown in Figure 59. Once selected, the dialog box shown in Figure 60 appears. In this box the user can change the sensor locations, the radius of loading plate, and select the drop height to be processed. When the FWD data are loaded, the program automatically selects a drop height closest to 9000 lb. If all the drop heights are the same, the last drop is selected. Sensor location and radius are input from the FWD field file. This box would only be changed if the user wishes to process data collected at a different load level or if the sensor locations are changed. Under normal operations this box would not be changed. Click the “OK” button to update the information and exit this dialog box.

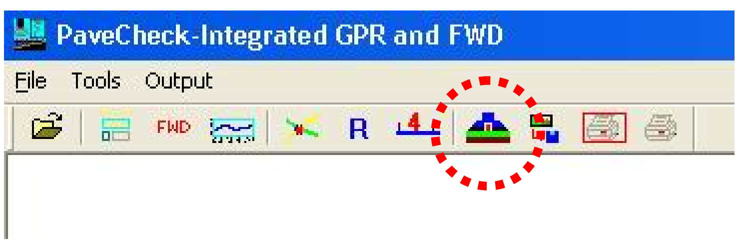



**Figure 59. Toolbar Button to Access the FWD Device Information Dialog Box.**

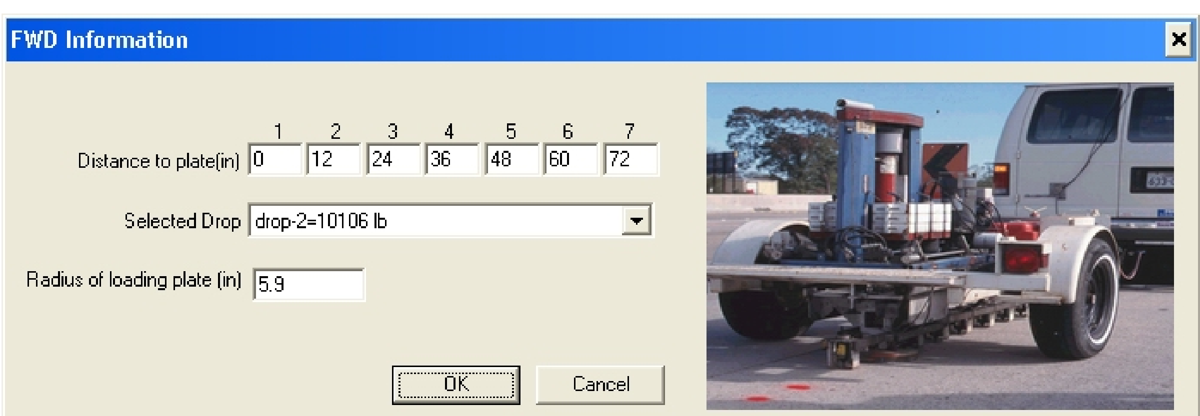



**Figure 60. FWD Device Information Input Dialog Box.**

The main FWD backcalculation is activated by clicking the button as in Figure 49, which is the first button on the FWD frame, and the dialog box shown in Figure 61 appears. Most of the left side of this dialog box is for the input data, and the right side is for the display of the results.

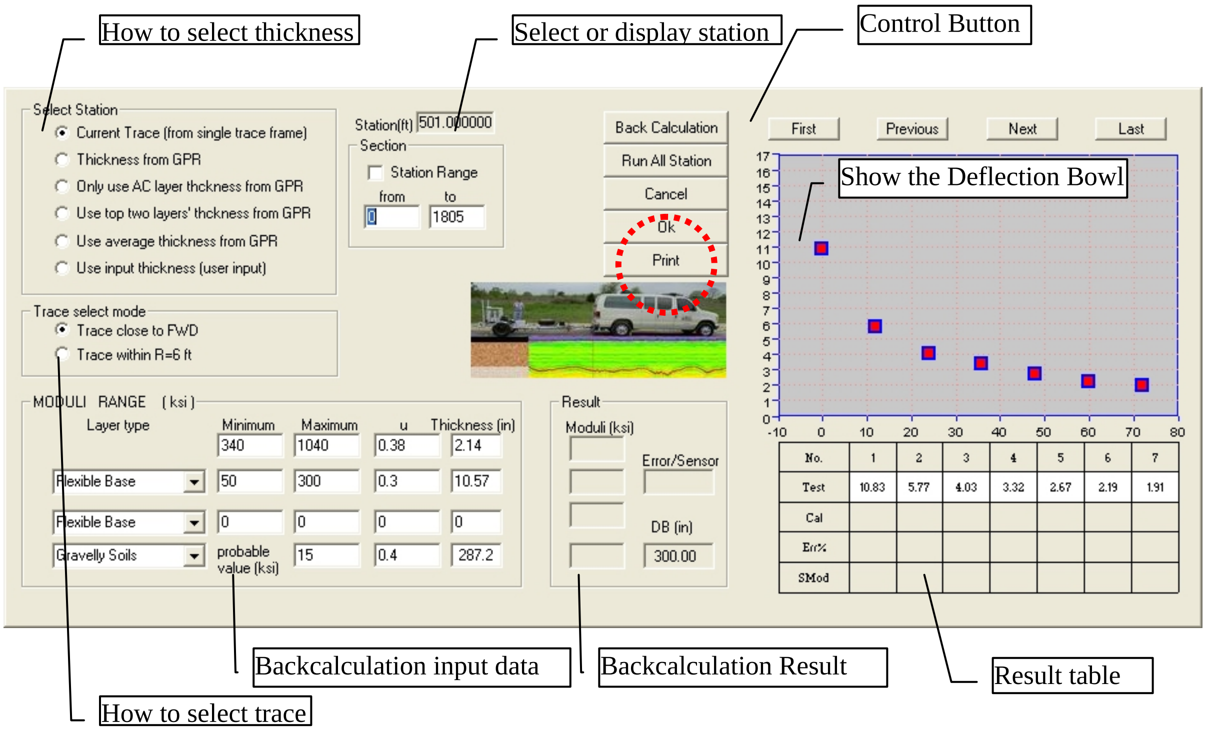



**Figure 61. FWD Backcalculation Analysis Dialog Box.**

Providing inputs to Figure 61 is described in the next section of this report.

## Select Station (top left)

The buttons on the top left are used to select the thickness modes. There are six options to select as explained in Table 7. These options were added to provide the user flexibility in how to merge the GPR thickness information with the FWD bowl information. In option 1 the user has already processed the GPR data for one station and saved those results. Using option 1, this one set of thickness data will be used to process all the deflection bowls. To use options 2, 3, or 4 the user must have already computed and saved thickness information for all the FWD test locations. Using options 2, 3, or 4, the layer thickness at each FWD test location will vary in the backcalculation process.

**Table 7. Thickness Selection Option Table.**

| Options | Names | Functions |
|---|---|---|
| 1 | Use Current GPR Trace | Directly use the current single trace analysis thickness result for each FWD bowl. However, the subgrade thickness is obtained from the depth to bedrock calculation from the deflection data using the supplied AC layer thickness. |
| 2 | Use Thickness from GPR | Directly use the thickness from the trace which is closest to or within 6 feet of the FWD loading plate. Calculate bowl specific subgrade thickness. |
| 3 | Only use the top Asphalt Concrete (AC) layer thickness from GPR | Directly use the top layer's thickness from the trace closest to or within 6 feet of the FWD loading plate. This option is very useful if the base thickness is difficult to find from the GPR data. Other layer thicknesses are input by the user. The subgrade thickness is calculated by depth to bedrock calculation from the deflection data and AC layer's thickness. |
| 4 | Use only the top two layers' thickness from GPR | Same as option 3, except use the top two layers' thickness from GPR. |
| 5 | Use average thicknesses from the GPR | Average thickness from all traces' analysis. If the GPR section is not very long and the interfaces between layers are clear, this is a simple way to get the thickness. |
| 6 | User input thickness | User can input all the thickness just like the current MODULUS version 6.0 program. The thickness is no longer related to the GPR trace thickness. |

## Moduli Ranges

In addition to the thickness input discussed above, other data items are required for the backcalculation process. These data are input in the lower left part of the backcalculation dialog box. The analysis routine within PAVECHECK is essentially the system included in MODULUS 6. Therefore, the process is limited to a maximum four-layer analysis, where the lower layer is a semi-infinite stiff layer buried under a calculated subgrade thickness layer. The user-required inputs to run the backcalculation analysis are as follows:

- moduli range for each layer, including minimum and maximum moduli values;
- Poisson's ratio for each layer;
- last layer, or the subgrade layer, needs to input the most probable moduli value; and
- add any additional layers such as subbases.

For the lower layers the user can select the material type to define the input values using the drop-down list. The material types provide a "first-cut" set of moduli values that can be overwritten by the user.

## Control Buttons

There are two ways to run the FWD backcalculation: one is a single bowl FWD backcalculation with the first button "Back Calculation"; another is running all stations with the button "Run All Station."

In the single bowl backcalculation, the user can process one bowl at a time by using the "First," "Next," "Previous," or "Last" buttons. If the thickness data are available and the user selects options 2, 3, or 4 in the "Station Select" box, the layer thicknesses will vary for each bowl being processed. Once the "Backcalculation" button is selected, the result displays as shown in Figure 62. The resulting moduli values are in the results table, together with the average error per sensor. The solid line on the graph is the computed deflection bowl for the calculated moduli values.

When running all stations, the program, depending on the station select box selection, automatically changes the layer thicknesses for each bowl. If the user checks the "Section Range" check box and inputs a valid DMI range, the "Run all" button calculates only the stations within this DMI limit. Without checking the "Section Range" check box, all the stations will be analyzed.

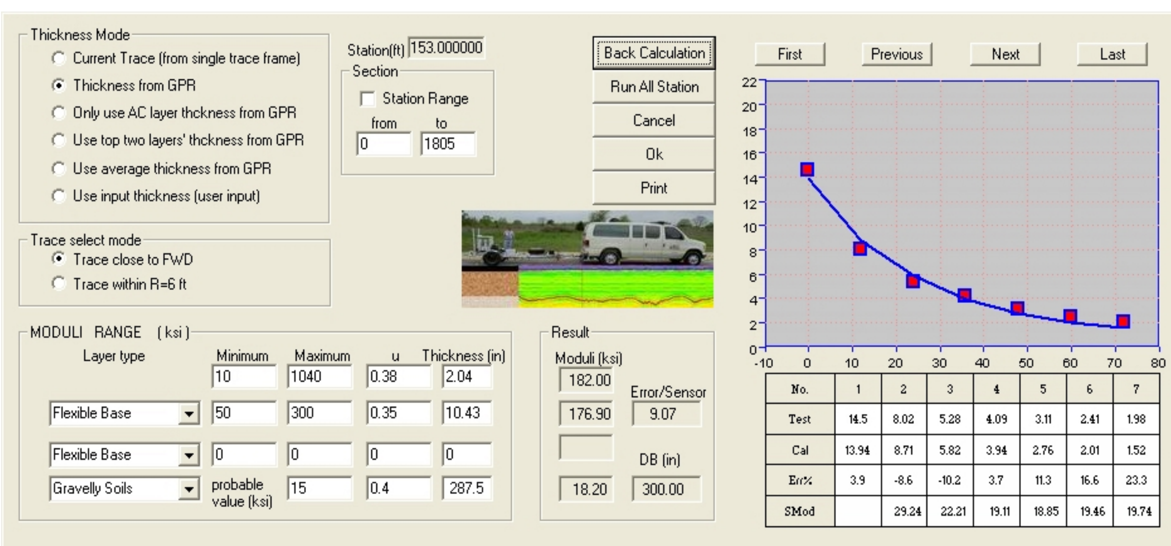



**Figure 62. Backcalculation of Single Bowl Analysis.**

### 2.8 GENERATING AN ANALYSIS RESULT OUTPUT FILE

In this section, we discuss how to save the result to output files for documentation and printout. The main part of the PAVECHECK program performs the FWD backcalculation based on the actual GPR thicknesses. The output files are divided into a FWD backcalculation result file and the GPR thickness calculation result file. As shown in Figure 63, the program provides options to save the data in ASCII or PF99 format. For most applications the ACSII format will be used.

The PF99 is TxDOT's special comma-delimited file. Each record has its name tag at the beginning, following the DMI and other test value. This format is still under development in TxDOT, and it will possibly be widely used in the near future to set up the test data database system. This PAVECHECK program can read the PF99 data and change it to TTI binary format for fast reading. However, the PF99 format is an efficient format for a database system, but not for reading or documentation. So in this program we also output the ASCII formatted result files. The GPR result file is similar to the existing COLORMAP program GPR output file, and the FWD result file is similar to the MODULUS 6.0 output file.

After completing the GPR trace analysis and FWD backcalculation, the user can use the menu bar shown in Figure 63 to save the results. Click any of the four menu items to activate a file save dialog box asking the user to identify the folder and filename to be used to save the result file.

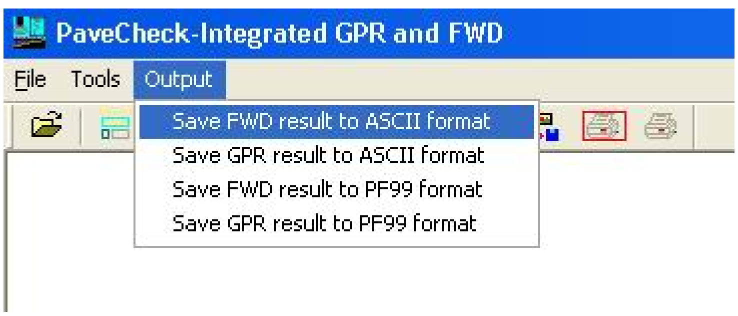



**Figure 63. Menu for Saving the Output File.**

**GPR ASCII Formatted Output File**

Table 8 gives an abbreviated example of a GPR ASCII formatted output file. This format includes the header, test result, and statistic part. The header covers the basic information about the GPR trace calculation. The test result part is in the middle, which shows the thickness and dielectric calculation results. The last column indicates what method was used to do the thickness calculation (as follows):

| Method Code | Description |
|---|---|
| 1 | Normal single trace analysis |
| 2 | Surface reflection subtracting method |
| 3 | Automatic tracking method |

In the last section the statistics (average and standard deviation values) are presented. These statistics can help the user to determine the variation of the thickness of each layer within the project.

**GPR PF99 Formatted Output File**

Table 9 shows an example of the output of a GPR PF99 formatted file from the Annex test data.  The actual PF99 data begins on the 22$^{nd}$ row.  The first record defines the format for the following data records.  The name tag for the GPR result records is GPRR1.  The GPR analysis results for each station follow the .GPR1 tag.

Table 10 defines the format for each PF99 results data record.  The unit for the peak voltage represents the number of data points from the start of the trace compared to the total number of data points (1024) for each GPR trace.  The time interval of the trace is 0.0195 milliseconds.

**Table 8. GPR ASCII Formatted Output File.**

```
------------------------------------------------------------------------------------------
TTI PAVECHECK Backcalculation Analysis Result         (Version 1.0)
------------------------------------------------------------------------------------------
Basic Information:
        Project folder name:E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\
        Project name       :Annex.prj
        FWD test file name :Annex.FWD
        GPR test file name :Annex_GPR.dat
        Metal plate file   :Mtp.dat
        Iamge list file    :ZIP.img (112 total images)
        GPS  file  name    :GPS.lst (0 total GPS reading)
        Core image file    :Core.lst
------------------------------------------------------------------------------------------
GPR Test File Information:
        Metal Plate Peak   :  6.94  (volts)
        Total traces       : 1801
        Velocity factor    : 11.8
------------------------------------------------------------------------------------------
GPR CALCULATION SUMMARY REPORT (in ASCII Format):
------------------------------------------------------------------------------------------

Trace   Feet    Time1  Time2  Time3  Thick1  Thick2  Thick3   E1     E2     E3  AnaMethod
    0      0    4.72   5.50  10.14    1.98    8.48    0.00   5.59   0.00   0.00    3
    1      1    4.74   5.52  10.22    1.98    8.58    0.00   5.56   0.00   0.00    3
    2      2    4.76   5.54  10.32    1.98    8.73    0.00   5.56   0.00   0.00    3
    3      3    4.76   5.54  10.39    1.98    8.87    0.00   5.52   0.00   0.00    3
    4      4    4.80   5.56  10.49    1.93    9.01    0.00   5.56   0.00   0.00    3
    5      5    4.82   5.58  10.63    1.93    9.22    0.00   5.47   0.00   0.00    3
    6      6    4.82   5.60  10.74    1.98    9.40    0.00   5.42   0.00   0.00    3


●●●●●●●●●●●●

 1797   1797    4.70   5.56   9.93    2.09    7.55    0.00   5.66   0.00   0.00    3
 1798   1798    4.72   5.58   9.91    2.09    7.48    0.00   5.77   0.00   0.00    3
 1799   1799    4.68   5.54   9.93    2.09    7.58    0.00   5.74   0.00   0.00    3
 1800   1800    4.66   5.50   9.89    2.05    7.58    0.00   5.74   0.00   0.00    3
------------------------------------------------------------------------------------------

Trace   Feet    Time1  Time2  Time3  Thick1  Thick2  Thick3   E1     E2     E3  AnaMethod
------------------------------------------------------------------------------------------
Average :       4.76   5.64  11.77    2.20   11.33    0.00   5.55  10.25  10.99
Stdev   :      0.035  0.125  0.980   0.183   1.669   0.000  0.195  1.241  1.238
------------------------------------------------------------------------------------------
```

## Table 9. GPR PF99 Formatted Output File.

```
------------------------------------------------------------------------------------------
TTI PAVECHECK Backcalculation Analysis Result         (Version 1.0)
------------------------------------------------------------------------------------------
Basic Information:
        Project folder name:E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\
        Project name       :Annex.prj
        FWD test file name :Annex.FWD
        GPR test file name :Annex_GPR.dat
        Metal plate file   :Mtp.dat
        Iamge list file    :ZIP.img (112 total images)
        GPS  file  name    :GPS.lst (0 total GPS reading)
        Core image file    :Core.lst
------------------------------------------------------------------------------------------
GPR Test File Information:
        Metal Plate Peak   :  6.94  (volts)
        Total traces       : 1801
        Velocity factor    : 11.8
------------------------------------------------------------------------------------------
GPR CALCULATION SUMMARY REPORT (in PF99 Format):
------------------------------------------------------------------------------------------

#META1,GPRR1,Trace_Number,mile,feet,analysis_method,Number_of_Pavement_Layer,thickness_1,thicknes
s_2,thickness_3,thickness_4,Peak_1,Peak_2,Peak_3,Peak_4,Peak_5,Peak_6,Peak_7,Peak_8,Peak_9,Peak_1
0,Dielectric_1,Dielectric_2,Dielectric_3,Dielectric_4,Dielectric_5
GPRR1,0,0,0,3,2,242,5.59,1.98,8.48,0,0,242,282,520,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,1,0,1,3,2,243,5.56,1.98,8.58,0,0,243,283,524,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,2,0,2,3,2,244,5.56,1.98,8.73,0,0,244,284,529,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,3,0,3,3,2,244,5.52,1.98,8.87,0,0,244,284,533,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,4,0,4,3,2,246,5.56,1.93,9.01,0,0,246,285,538,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,5,0,5,3,2,247,5.47,1.93,9.22,0,0,247,286,545,0,0,0,0,0,0,0,0,0,0,0.00,0.00
●●●●●●●●●●●●

GPRR1,1797,1797,3,2,241,5.66,2.09,7.55,0,0,241,285,509,0,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,1798,1798,3,2,242,5.77,2.09,7.48,0,0,242,286,508,0,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,1799,1799,3,2,240,5.74,2.09,7.58,0,0,240,284,509,0,0,0,0,0,0,0,0,0,0,0,0.00,0.00
GPRR1,1800,1800,3,2,239,5.74,2.05,7.58,0,0,239,282,507,0,0,0,0,0,0,0,0,0,0,0,0.00,0.00
```

**Table 10. PF99 GPRR1 Record Definition.**

| No. | Data | Data type | Meaning of Data |
|---|---|---|---|
| 1 | GPRR1 | String | Trace analysis result name tag |
| 2 | 0 | Integer | Serial number of trace (first trace is 0) |
| 3 | 0 | Integer | Mile |
| 4 | 0 | Integer | Feet |
| 5 | 3 | Integer | Trace analysis method |
| 6 | 2 | Integer | Number of layer of the pavement |
| 7 | 242 | Integer | Trace surface peak location (one trace has 1024 points) |
| 8 | 5.59 | Float | First layer dielectric value |
| 9 | 1.98 | Float | 1st layer thickness (in inches) |
| 10 | 8.48 | Float | 2nd layer thickness |
| 11 | 0 | Float | 3rd layer thickness |
| 12 | 0 | Float | 4th layer thickness |
| 13 | 242 | Integer | 1st peak location |
| 14 | 282 | Integer | 2nd peak location |
| 15 | 520 | Integer | 3rd peak location |
| 16 | 0 | Integer | 4th peak location |
| 17 | 0 | Integer | 5th peak location |
| 18 | 0 | Integer | 6th peak location |
| 19 | 0 | Integer | 7th peak location |
| 20 | 0 | Integer | 8th peak location |
| 21 | 0 | Integer | 9th peak location |
| 22 | 0 | Integer | 10th peak location |
| 23 | 0 | Float | 1st layer dielectric value |
| 24 | 0 | Float | 2nd layer dielectric value |
| 25 | 0 | Float | 3rd layer dielectric value |
| 26 | 0 | Float | 4th layer dielectric value |
| 27 | 0 | Float | 5th layer dielectric value |

**FWD ASCII Format Output File**

Table 11 is an example output from the Annex test site (the Annex data are included in the setup program). This file can be divided into the following parts:

- Header
    - PAVECHECK basic information
    - FWD test file information
- FWD backcalculation summary result
- FWD backcalculation detail result for each station

The Modulus summary result section is identical to the output from the MODULUS 6.0 program, including a bowl by bowl analysis and the summary statistics at the bottom of the report. The main difference between this and MODULUS 6 is that depending on the options selected, these moduli values were computed by varying the layer thickness for each test location.

The last part is specially designed for the PAVECHECK program, which includes details about the backcalculation for each station. Most of the parameters can be recognized by the name tag and are very similar to MODULUS 6.0 program output; the new items are described below:

**Image No. & DMI:** Gives the number and DMI of the image closest to this FWD station.

**Trace No. & DMI:** Gives the number and DMI of the GPR trace closest to this FWD station.

**Th (in):** Gives the thickness used for the FWD backcalculation.

**Th (Trace):** Gives the thickness from the trace, and this trace closest to this FWD station.

**TraceSelect:** Describes if the thickness is from the single trace closest to the FWD station or the average trace thickness from the traces within a 6 foot diameter.

**Thickness Mode:** Describes how the backcalculation thickness was selected from the GPR radar trace.

## Table 11. FWD Backcalculation Analysis Result Output (ASCII Format).

```
--------------------------------------------------------------------------------------------------------------------------------------
                                  TTI PAVECHECK Backcalculation Analysis Result         (Version 1.0)
--------------------------------------------------------------------------------------------------------------------------------------
Basic Information:
        Project folder name:E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\
        Project name       :Annex.prj
        FWD test file name :Annex.FWD
        GPR test file name :Annex_GPR.dat (1801 total traces)
        Metal plate file   :Mtp.dat
        Iamge list file    :ZIP.img (112 total images)
        GPS  file  name    :GPS.lst (0 total GPS reading)
        Core image file    :Core.lst
--------------------------------------------------------------------------------------------------------------------------------------
FWD Test File Information:
        FWD full path name :E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\Annex.FWD
        Roadway ID         :Ride RUt Test Pad @ TTI
        Test date          :030123
        Plate Radius       :5.9 (inches)
        FWD Operater       :Roy Pilgrim
        Select Load Level  : 2 (10106 lb)
        No of drops        : 4  (drops)
        No of Stations     : 37  (stations)
        No of Sensors      : 7
        Sensor Location(in):      R1      R2      R3      R4      R5      R6      R7
                                 0.00   12.00   24.00   36.00   48.00   60.00   72.00
--------------------------------------------------------------------------------------------------------------------------------------
MODULUS SUMMARY REPORT:
--------------------------------------------------------------------------------------------------------------------------------------
             Load    Measured Deflection (mils):                         Calculated Moduli values (ksi):       Absolute Dpth to
  Station   (lbs)    R1       R2       R3       R4       R5       R6       R7     SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4) ERR/Sens Bedrock
--------------------------------------------------------------------------------------------------------------------------------------
    0.000    10106  14.18     8.22     5.54     4.26     3.28     2.54     2.04    1040.0     191.7      16.4      16.4      9.30  300.0
   47.000    10352  13.65     7.78     5.05     3.91     2.98     2.29     1.89     737.1     115.7      17.9      17.9      5.16  300.0
  100.000     9943  12.78     7.47     4.88     3.78     2.82     2.13     1.76     430.9     137.5      18.4      18.4      5.11  300.0
  153.000    10074  14.50     8.02     5.28     4.09     3.11     2.41     1.98     446.7     127.2      17.5      17.5      7.63  300.0
  200.000    10019  11.78     6.64     4.24     3.44     2.76     2.24     1.76     574.6     149.6      19.9      19.9      8.82  300.0
  253.000    10090  11.83     6.38     4.30     3.51     2.65     2.02     1.68     435.5     154.1      20.8      20.8      8.09  300.0

 ••••••••••••
  1758.000     9737  19.57    11.48     5.58     3.44     2.27     1.64     1.40    1040.0      63.0      16.2      16.2      3.65  187.8
 1805.000     9602  24.31    11.45     5.85     4.04     2.70     1.90     1.53     352.7      50.0      16.7      16.7      3.25  300.0
--------------------------------------------------------------------------------------------------------------------------------------
  Mean:             13.63     7.41     4.51     3.40     2.54     1.94     1.59     641.1     125.0      20.9      20.9      6.60  291.6
  Std. Dev:          3.00     1.62     0.77     0.51     0.37     0.28     0.22     297.9      39.9       3.7       3.7      2.94   28.1
  Var Coeff(%):     22.00    21.87    17.04    15.09    14.72    14.51    13.74      46.5      31.9      17.8      17.8     44.64    9.7
--------------------------------------------------------------------------------------------------------------------------------------
```

## Table 11. FWD Backcalculation Analysis Result Output (ASCII Format) (Continued).

```
MODULUS DETAIL REPORT:
--------------------------------------------------------------------------------------------------------------------------------------

  1    Station:    0.000 mile  (0 feet)
--------------------------------------------------------------------------------------------------------------------------------------
FWD   No. & DMI:     1  0 mile    0 ft    Temperature:(pav)   38'F        Test time  : 13:27      Thickness Mode :Use top two layers
```

Trace No. & DMI: 2 0 mile 1 ft (air) 0'F TraceSelect: Close FWD Error/Sensor : 9.30
Image No. & DMI: 1 0 mile 0 ft (suf) 65'F Load (lb) : 10106 Dpth to Bedrock: 300.0 inches

| | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|---|---|---|---|---|---|---|---|
| Meas. Defl (mils) | 14.18 | 8.22 | 5.54 | 4.26 | 3.28 | 2.54 | 2.04 |
| Calc. Defl (mils) | 13.41 | 9.05 | 6.09 | 4.17 | 2.92 | 2.10 | 1.57 |
| Percent Err( % ) | 5.43 | -10.10 | -9.93 | 2.11 | 10.98 | 17.32 | 23.04 |
| S-Moduli (ksi ) | | 28.62 | 21.23 | 18.41 | 17.93 | 18.52 | 19.22 |

| | Th(in) | Th(trace) | MODULI RANGE(psi) Min | Max | Poisson | Moduli(ksi) |
|---|---|---|---|---|---|---|
| AC: | 2.0 | 2.0 | 340.0 | 1040.0 | 0.38 | 1040.0 |
| BS: | 8.6 | 8.6 | 50.0 | 300.0 | 0.30 | 191.7 |
| SB: | | | | | | |
| SG: | 289.4 | 0.0 | 15.0 | 15.0 | 0.40 | 16.4 |

---

2 Station: 0.009 mile (47 feet)

---

FWD No. & DMI: 2 0 mile 47 ft Temperature:(pav) 38'F Test time : 13:29 Thickness Mode :Use top two layers
Trace No. & DMI: 48 0 mile 47 ft (air) 0'F TraceSelect: Close FWD Error/Sensor : 5.16
Image No. & DMI: 5 0 mile 50 ft (suf) 65'F Load (lb) : 10352 Dpth to Bedrock: 300.0 inches

| | R1 | R2 | R3 | R4 | R5 | R6 | R7 | Th(in) | Th(trace) | MODULI RANGE(psi) Min | Max | Poisson | Moduli(ksi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

••••••••••••

---

37 Station: 0.342 mile (1805 feet)

---

FWD No. & DMI: 37 0 mile 1805 ft Temperature:(pav) 39'F Test time : 14:25 Thickness Mode :Use top two layers
Trace No. & DMI: 1801 0 mile 1800 ft (air) 0'F TraceSelect: Close FWD Error/Sensor : 3.25
Image No. & DMI: 112 0 mile 1800 ft (suf) 65'F Load (lb) : 9602 Dpth to Bedrock: 300.0 inches

| | R1 | R2 | R3 | R4 | R5 | R6 | R7 |
|---|---|---|---|---|---|---|---|
| Meas. Defl (mils) | 24.31 | 11.45 | 5.85 | 4.04 | 2.70 | 1.90 | 1.53 |
| Calc. Defl (mils) | 24.22 | 11.57 | 6.11 | 3.77 | 2.60 | 1.96 | 1.47 |
| Percent Err( % ) | 0.37 | -1.05 | -4.44 | 6.68 | 3.70 | -3.16 | 3.92 |
| S-Moduli (ksi ) | | 19.52 | 19.10 | 18.44 | 20.69 | 23.53 | 24.35 |

| | Th(in) | Th(trace) | MODULI RANGE(psi) Min | Max | Poisson | Moduli(ksi) |
|---|---|---|---|---|---|---|
| AC: | 2.0 | 2.0 | 340.0 | 1040.0 | 0.38 | 352.7 |
| BS: | 7.6 | 7.6 | 50.0 | 300.0 | 0.30 | 50.0 |
| SB: | | | | | | |
| SG: | 290.4 | 0.0 | 15.0 | 15.0 | 0.40 | 16.7 |

---

**FWD PF99 Format Output File**

Table 12 is an example output from the Annex test site in PF99 format. Since the PF99 format requires that only one record can be put in one line, these records can reach to more than 600 rows. In order to display it the Enter keys are added to the long line.

As with the GPR PF99 output the FWD PF99 format file also includes the header information, which is not in the PF99 format. After the header, there are the PF99 records. The file can be divided into the following parts:

- Header (Not PF99 Format)
    - PAVECHECK basic information
    - FWD test file information
- PF99 records
    - Structure of the project information record (#META1,PCPJ1)
    - Structure of the FWD backcalculation information record (#META1,FWDR1)
    - Structure of the FWD backcalculation record for each station
    - Project information record (META1, FWDR1)
    - FWD backcalculation information record (META1, FWDR1)
    - FWD backcalculation record for each station (FWDR1)

From the above list of the structure of the PF99 file output it is found that there are three kinds of records. Table 13 and Table 14 list the structure of each record.

## Table 12. FWD Backcalculation PF99 Format Output File.

```
------------------------------------------------------------------------------------------------------------------------------------------
                                  TTI PAVECHECK Backcalculation Analysis Result         (Version 1.0)
------------------------------------------------------------------------------------------------------------------------------------------
Basic Information:
        Project folder name:E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\
        Project name       :Annex.prj
        FWD test file name :Annex.FWD
        GPR test file name :Annex_GPR.dat (1801 total traces)
        Metal plate file   :Mtp.dat
        Iamge list file    :ZIP.img (112 total images)
        GPS  file  name    :GPS.lst (0 total GPS reading)
        Core image file    :Core.lst
------------------------------------------------------------------------------------------------------------------------------------------
FWD Test File Information:
        FWD full path name :E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\Annex.FWD
        Roadway ID         :Ride RUt Test Pad @ TTI
        Test date          :030123
        Plate Radius       :5.9 (inches)
        FWD Operater       :Roy Pilgrim
        Select Load Level  : 2 (10106 lb)
        No of drops        : 4  (drops)
        No of Stations     : 37  (stations)
        No of Sensors      : 7
        Sensor Location(in):      R1      R2      R3      R4      R5      R6      R7
                                 0.00   12.00   24.00   36.00   48.00   60.00   72.00
------------------------------------------------------------------------------------------------------------------------------------------
MODULUS PF99 FORMAT OUTPUT:
------------------------------------------------------------------------------------------------------------------------------------------
#META1,PCPJ1,Proj_Folder,Proj_File,FWD_File,GPR_File,Metal_File,Image_File,GPS_File,Core_File
#META1,META1,FWDR1,FWD_File,RoadwayID,Test_Date,Operator,Drops,Select_Drop,N_Sensor,Plate_Radius,N_Station
```

## Table 12. FWD Backcalculation PF99 Format Output File (Continued).

```
#META1,FWDR1,Number,DMI_mile,DMI_feet,Drop_Select,Time,Lane,Load,Temperature_Air,Temperature_Surface,Temperature_Pavement,GPR_trace,
       GPR_DMI,Image,Image_DMI,Def_1,Def_2,Def_3,Def_4,Def_5,Def_6,Def_7,Def_8,Def_9,Def_10,Cal_1,Cal_2,Cal_3,Cal_4,Cal_5,Cal_6,Cal_7,
       Cal_8,Cal_9,Cal_10,N_layer,Thickness_Option,Trace_Option,Thickness_1,Thickness_2,Thickness_3,Thickness_4,Thickness_5,
       Depth_Bedrock,Error_Sensor,Moduli_1,Moduli_2,Moduli_3,Moduli_4,Poisson_1,Poisson_2,Poisson_3,Poisson_4,Emax_1,Emax_2,Emax_3,Emax_4,
```

```
       Emin_1,Emin_2,Emin_3,Emin_4,Ave_th_1,Ave_th_2,Ave_th_3,Ave_th_4,Trace_th_1,Trace_th_2,Trace_th_3,Trace_th_4
META1,PCPJ1,E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\,Annex.prj,Annex.FWD,Annex_GPR.dat,Mtp.dat,ZIP.img,GPS.lst,Core.lst
META1,FWDR1,E:\Tom\PAVECHECK\Prog\PAVECHECK\Annex\Annex.FWD,Ride RUt Test Pad @ TTI,030123,Roy Pilgrim,4,2,7,5.90,37,0.00,
            12.00,24.00,36.00,48.00,60.00,72.00
FWDR1,1,0.0000,0,0,13:27,K1  ,10106.0,38.0,0.0,65.0,1,1,0,0,14.18,8.22,5.54,4.26,3.28,2.54,2.04,0.00,0.00,0.00,13.41,
      9.05,6.09,4.17, 2.92,2.10,1.57,0.00,0.00,0.00,3,0,0,1.98,8.58,0.00,0,0,300.00,9.30,1040.00,191.70,16.40,16.40,0.38,0.30,
      0.00,0.40,1040.0,300.0,0.0,15.0,340.0,50.0,0.0,15.0,1.95,9.53,0.00,0.00,1.98,8.58,0.00,0.00
FWDR1,2,0.0089,47,0,13:29,K1  ,10352.0,38.0,0.0,65.0,47,47,4,50,13.65,7.78,5.05,3.91,2.98,2.29,1.89,0.00,0.00,0.00,13.33,
      8.07,5.45,3.86,2.79,2.08,1.58,0.00,0.00,0.00,3,0,0,2.27,12.74,0.00,0,0,300.00,5.16,737.10,115.70,17.90,17.90,0.38,0.30,
      0.00,0.40,1040.0,300.0,0.0,15.0,340.0,50.0,0.0,15.0,2.23,12.54,0.00,0.00,2.27,12.74,0.00,0.00
```



••••••••••••

```
FWDR1,36,0.3330,1758,0,14:24,K1  ,9737.0,39.0,0.0,65.0,1758,1758,108,1740,19.57,11.48,5.58,3.44,2.27,1.64,1.40,0.00,0.00,0.00,19.86,
      11.00,5.86,3.49,2.23,1.51,1.06,0.00,0.00,0.00,3,0,0,2.14,7.45,0.00,0,0,187.85,3.65,1040.00,63.00,16.20,16.20,0.38,0.30,
      0.00,0.40,1040.0,300.0,0.0,15.0,340.0,50.0,0.0,15.0,2.13,7.54,0.00,0.00,2.14,7.45,0.00,0.00
FWDR1,37,0.3419,1805,0,14:25,K1  ,9602.0,39.0,0.0,65.0,1800,1800,111,1800,24.31,11.45,5.85,4.04,2.70,1.90,1.53,0.00,0.00,0.00,24.22,
      11.57,6.11,3.77,2.60,1.96,1.47,0.00,0.00,0.00,3,0,0,2.05,7.58,0.00,0,0,300.00,3.25,352.70,50.00,16.70,16.70,0.38,0.30,
      0.00,0.40,1040.0,300.0,0.0,15.0,340.0,50.0,0.0,15.0,2.05,7.47,0.00,0.00,2.05,7.58,0.00,0.00
```

**Table 13. Structure of Project Information Record (Name Tag PCPJ1).**

| No. | Data | Data type | Meaning of data |
|---|---|---|---|
| 1 | C:\PAVECHECK\Annex\ | String | Project folder name |
| 2 | Annex.prj | String | Project file name |
| 3 | Annex.FWD | String | FWD field test file name |
| 4 | Annex_GPR.dat | String | GPR field test file name |
| 5 | Mtp.dat | String | GPR metal plate test file name |
| 6 | ZIP.img | String | Video file name |
| 7 | GPS.lst | String | GPS file name |
| 8 | Core.lst | String | Core data file name |

**Table 14. Structure of FWD Basic Information Record (Name Tag META1 FWDR1).**

| No. | Data | Data type | Meaning of data |
|---|---|---|---|
| 1 | C:\PAVECHECK\Annex\Annex.FWD | String | FWD field test file name |
| 2 | Ride Rut Test Pad @ TTI | String | FWD roadway ID |
| 3 | 030123 | String | FWD field test date |
| 4 | Roy Pilgrim | String | FWD operator name |
| 5 | 4 | Integer | Total load level |
| 6 | 2 | Integer | Selected load level for analysis |
| 7 | 7 | Integer | Number of sensors |
| 8 | 5.90 | Float | Radius of loading plate |
| 9 | 37 | Integer | Number of stations |
| 10 | 0.00,12.00,24.00,36.00, 48.00,60.00,72.00 | Float | Sensor location to loading plate |

**Table 15. Structure of FWD Analysis Result Record (Name Tag FWDRI).**

| No. | Data | Data type | Meaning of data |
|---|---|---|---|
| 1 | 36 | Integer | Station number of this station |
| 2 | 0.3330 | Float | Mile |
| 3 | 1758 | Integer | Feet |
| 4 | 0 | Integer | Selected drop number |
| 5 | 14:24 | String | Test time of this station (24H) |
| 6 | K1 | String | Lane of this station |
| 7 | 9737.0 | Float | Load in pounds |
| 8 | 39.0 | Float | Air temperature |
| 9 | 0.0 | Float | Pavement surface temperature |
| 10 | 65.0 | Float | Pavement temperature (AC layer) |
| 11 | 1758 | Integer | Trace number close to this station |
| 12 | 1758 | Integer | DMI of the above trace |
| 13 | 108 | Integer | Image number close to this station |
| 14 | 1740 | Integer | DMI of the above image |
| 15 | 19.57 | Float | FWD deflection 1 |
| 16 | 11.48 | Float | FWD deflection 2 |
| 17 | 5.58 | Float | FWD deflection 3 |
| 18 | 3.44 | Float | FWD deflection 4 |
| 19 | 2.27 | Float | FWD deflection 5 |
| 20 | 1.64 | Float | FWD deflection 6 |
| 21 | 1.40 | Float | FWD deflection 7 |
| 22 | 0.00 | Float | FWD deflection 8 |
| 23 | 0.00 | Float | FWD deflection 9 |
| 24 | 0.00 | Float | FWD deflection 10 |
| 25 | 19.86 | Float | Calculated deflection 1 |
| 26 | 11.0 | Float | Calculated deflection 2 |
| 27 | 5.86 | Float | Calculated deflection 3 |

**Table 15. Structure of FWD Analysis Result Record (Name Tag FWDRI).**

| | | | |
|---|---|---|---|
| 28 | 3.49 | Float | Calculated deflection 4 |
| 29 | 2.23 | Float | Calculated deflection 5 |
| 30 | 1.51 | Float | Calculated deflection 6 |
| 31 | 1.06 | Float | Calculated deflection 7 |
| 32 | 0.00 | Float | Calculated deflection 8 |
| 33 | 0.00 | Float | Calculated deflection 9 |
| 34 | 0.00 | Float | Calculated deflection 10 |
| 35 | 3 | Integer | Pavement layer number |
| 36 | 0 | Integer | Thickness mode, determine how the FWD thickness is set |
| 37 | 0 | Integer | Trace option, use single or average trace thickness close to FWD station |
| 38 | 2.14 | Float | Pavement layer thickness 1 |
| 39 | 7.45 | Float | Pavement layer thickness 2 |
| 40 | 0.00 | Float | Pavement layer thickness 3 |
| 41 | 0 | Float | Pavement layer thickness 4 |
| 42 | 0 | Float | Pavement layer thickness 5 |
| 43 | 187.85 | Float | Depth to Bedrock |
| 44 | 3.65 | Float | Error per sensor |
| 45 | 1040.00 | Float | Backcalculated Moduli for layer 1 |
| 46 | 63.00 | Float | Backcalculated Moduli for layer 2 |
| 47 | 16.20 | Float | Backcalculated Moduli for layer 3 |
| 48 | 16.20 | Float | Backcalculated Moduli for layer 4 |
| 49 | 0.38 | Float | Poisson’s ratio for layer 1 |
| 50 | 0.30 | Float | Poisson’s ratio for layer 2 |
| 51 | 0.00 | Float | Poisson’s ratio for layer 3 |
| 52 | 0.40 | Float | Poisson’s ratio for layer 4 |
| 53 | 1040.0 | Float | Moduli maximum limit for layer 1 |
| 54 | 300.0 | Float | Moduli maximum limit for layer 2 |
| 55 | 0.0 | Float | Moduli maximum limit for layer 3 |

**Table 15. Structure of FWD Analysis Result Record (Name Tag FWDRI).**

| | | | |
|---|---|---|---|
| 56 | 15.0 | Float | Moduli maximum limit for layer 4 |
| 57 | 340.0 | Float | Moduli minimum limit for layer 1 |
| 58 | 50.0 | Float | Moduli minimum limit for layer 2 |
| 59 | 0.0 | Float | Moduli minimum limit for layer 3 |
| 60 | 15.0 | Float | Moduli minimum limit for layer 4 |
| 61 | 2.13 | Float | Average GPR thickness for layer 1 |
| 62 | 7.54 | Float | Average GPR thickness for layer 2 |
| 63 | 0.00 | Float | Average GPR thickness for layer 3 |
| 64 | 0.00 | Float | Average GPR thickness for layer 4 |
| 65 | 2.14 | Float | Trace thickness for layer 1 |
| 66 | 7.45 | Float | Trace thickness for layer 2 |
| 67 | 0.00 | Float | Trace thickness for layer 3 |
| 68 | 0.00 | Float | Trace thickness for layer 4 |

## 2.9 PRODUCING DATA AND RESULT PRINTOUTS

In this section we discuss how to print out the test data and analysis results directly from the PAVECHECK program. Figure 64 is an example of how to set up the printer. The dialog box may be different depending on different printers. It is recommended that the user does this before processing the data. The most important features include:

- Select correct online printer (a color printer is preferable for better quality).
- In most cases the landscape option is the preferred paper orientation.

The print job of this program includes the following four parts:

- screen print;
- trace COLORMAP print;
- single trace analysis print; and
- FWD backcalculation print.

For the screen print, it is easy to simply copy the screen and print. The user can access this function by clicking the  button on the toolbar as in Figure 65.

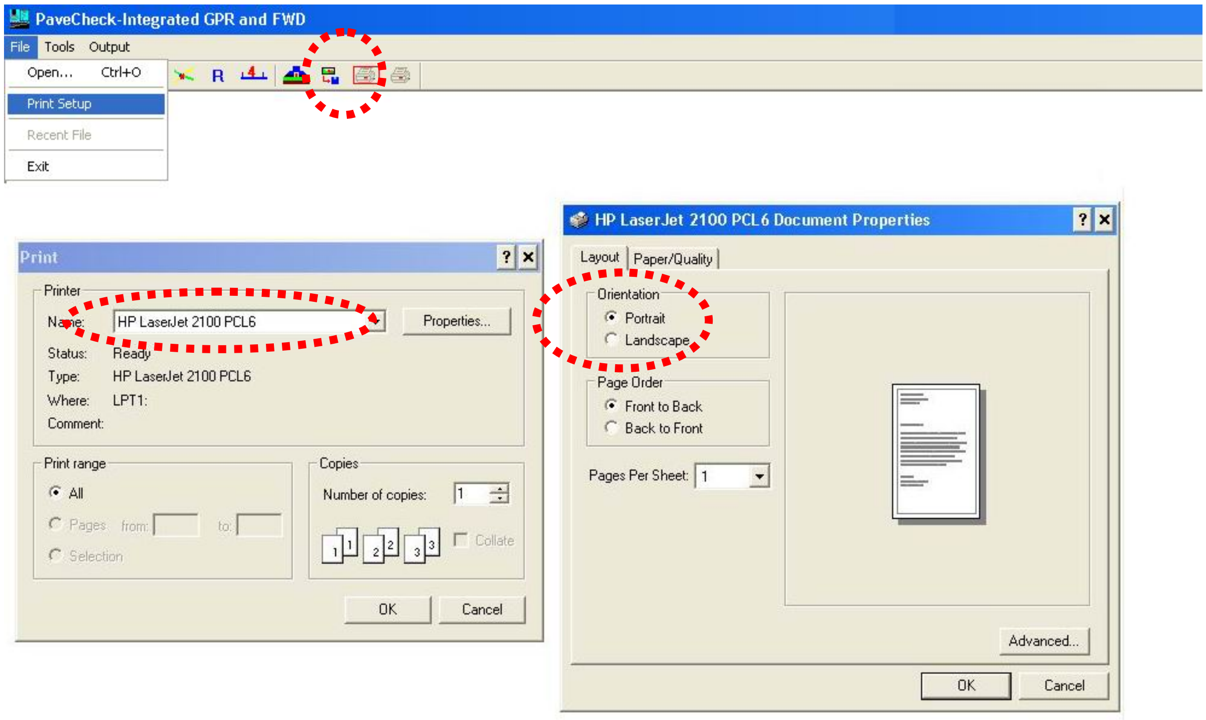



**Figure 64. Printer Setup Options.**

### GPR COLORMAP Print Job

Figure 65 shows the button to print the GPR COLORMAP. After the printer is set up and the GPR data are loaded, printing of the GPR COLORMAP can proceed.

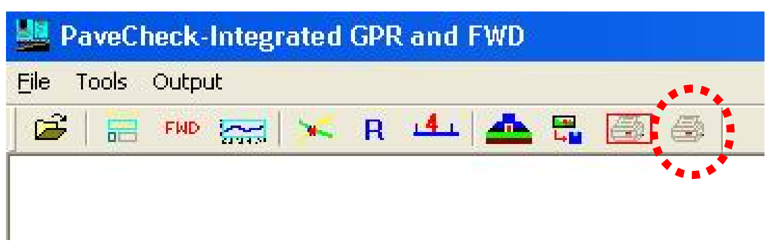



**Figure 65. Button to Print the GPR COLORMAP.**

### GPR Single Trace Analysis Printout

Figure 66 is the single trace analysis screen. The single trace printout button is marked. It is the last button on the list. Changing the orientation of the paper changes the printout of the result. Landscape orientation normally is preferred to portrait.

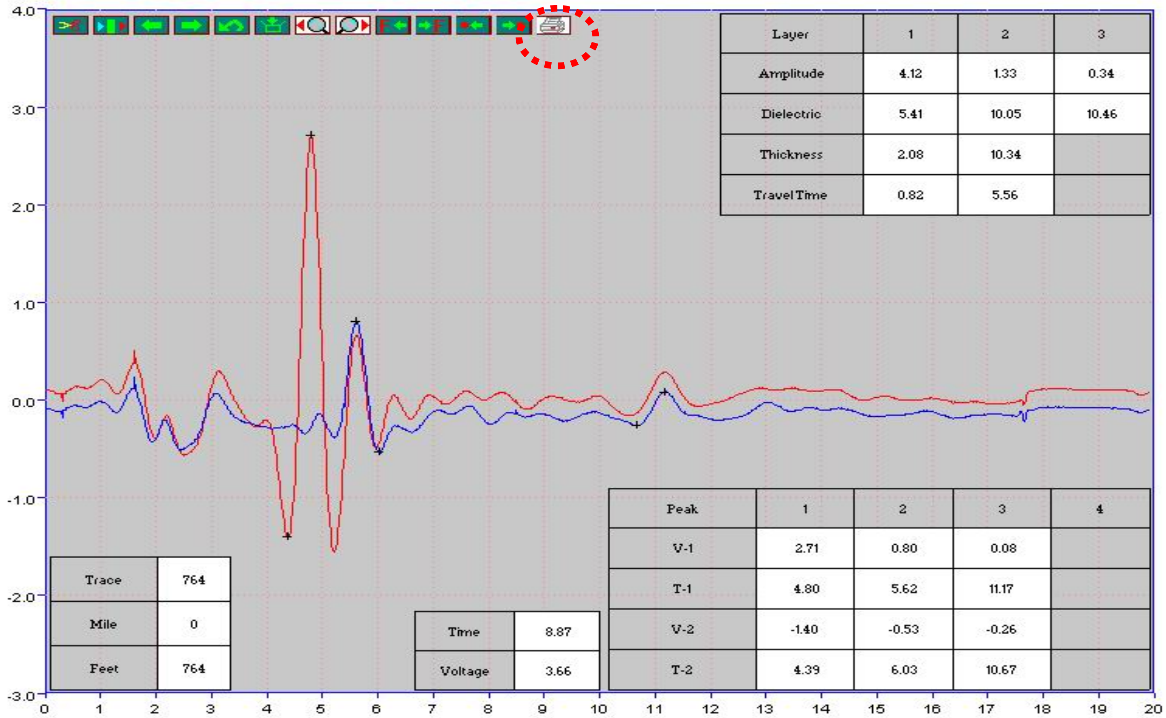



**Figure 66. GPR Single Trace Analysis Print Button.**

### FWD Backcalculation Analysis Printout

The main purpose of this PAVECHECK program is to do the backcalculation with the thickness from the GPR radar analysis. The graphic printout includes trace analysis results and an image that is close to this FWD test station. There are two buttons to launch the FWD print job: one is located on the FWD deflection frame as in Figure 67, and another one is on the backcalculation dialog box as in Figure 62.

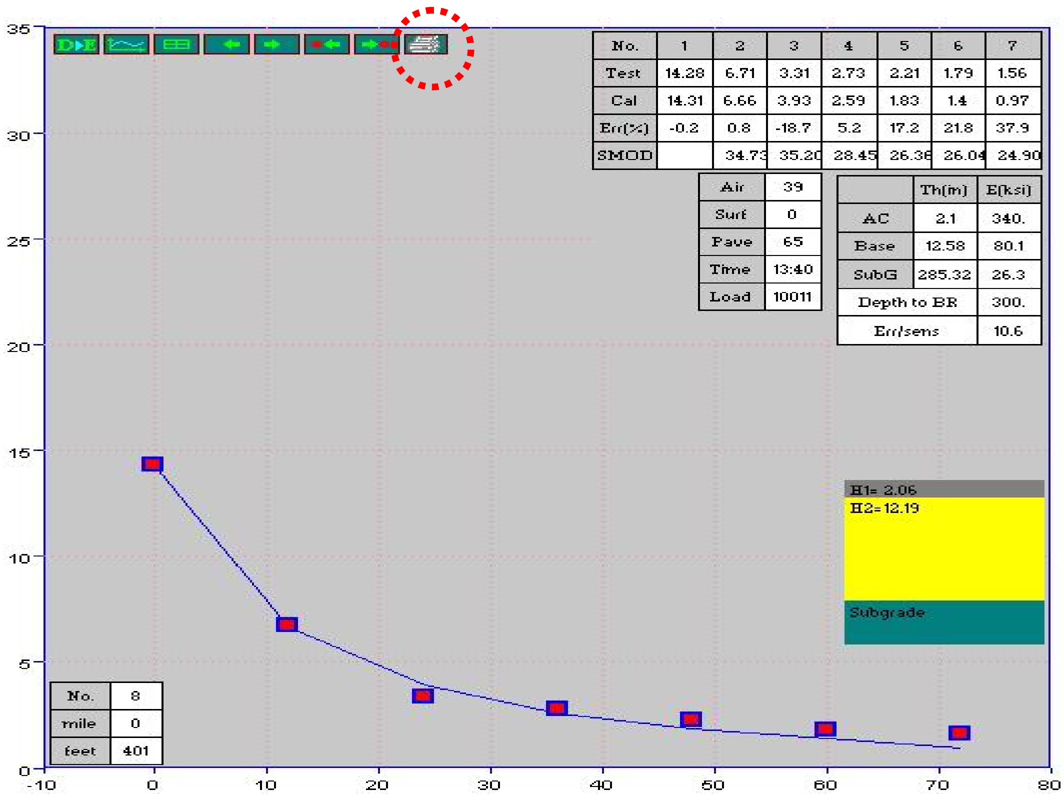


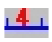
Figure 67. FWD Print Button.

## 2.10 TOOLBAR FUNCTIONS SUMMARY

Figure 68 shows the main toolbar of the PAVECHECK program. Most of the buttons have already been introduced in the previous sections. This section summarizes the toolbar functions. Table 16 lists all the toolbar buttons and their functions.


Figure 68. PAVECHECK Program Toolbar.

**Table 16. Function of Toolbar Buttons.**

| No. | Button | Function |
|---|---|---|
| 1 |  | Open a new project. |
| 2 |  | Display the project on screen. |
| 3 |  | Display the project with the FWD frame. |
| 4 |  | Display the project with the deflection response frame. |
| 5 |  | Display the map and show the map location of the test site. |
| 6 |  | Redraw the screen. |
| 7 |  | Set the scales for the dielectric curve and thickness ruler. |
| 8 |  | Set up FWD basic information (select drop, sensor location, and radius of loading plate). |
| 9 |  | Save the current screen to bitmap file. |
| 10 |  | Print the screen. |
| 11 |  | Print the COLORMAP of GPR trace data. |

## 2.11 SPECIAL TOOLS

Two special tools are included in this program. One saves the GPR trace data in ASCII format; another allows the user to convert the images folder to a zipped single video file. These two functions are accessible in the drop-down menu shown in Figure 69.

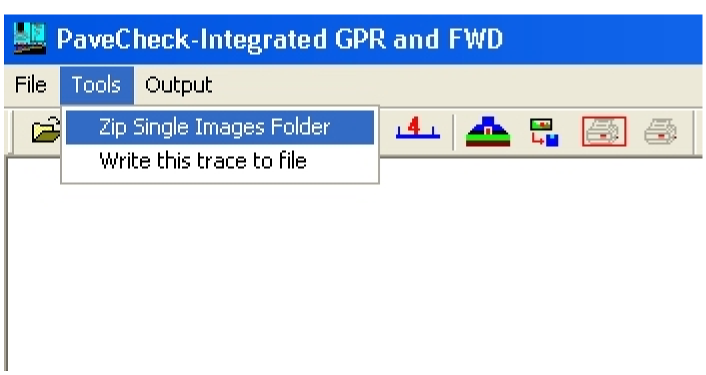



**Figure 69. Menu to Access the Special Tools.**

**Save GPR Data in ASCII Format File**

The TTI GPR format is a binary format file that has a header which keeps the information about hardware and the field test condition data. This function will save the single analysis trace to an ASCII format file. The following list shows a sample of a saved trace. The second column is the time in milliseconds. These are traces 715, 716, and 717 from the GPR data file. These traces were collected at 1 foot spacing so the DMI locations are 715, 716, and 717 feet. The trace is output with the unit of voltage (volts). There is a total 1022 data points in each trace.

| No. | Time | 1 | 2 | 3 |
|---|---|---|---|---|
| | T-No. | 0- 715 | 0- 716 | 0- 717 |
| | M-Ft | 715 | 716 | 717 |
| 1 | 0.000 | -0.049 | -0.063 | -0.049 |
| 2 | 0.020 | -0.049 | -0.063 | -0.054 |
| 3 | 0.039 | -0.049 | -0.063 | -0.049 |
| 4 | 0.058 | -0.049 | -0.063 | -0.049 |
| 5 | 0.078 | -0.054 | -0.068 | -0.059 |
| 6 | 0.098 | -0.054 | -0.068 | -0.054 |
| 7 | 0.117 | -0.063 | -0.073 | -0.059 |
| 8 | 0.137 | -0.068 | -0.078 | -0.068 |
| 9 | 0.156 | -0.073 | -0.083 | -0.073 |
| 10 | 0.175 | -0.078 | -0.088 | -0.078 |
| 11 | 0.195 | -0.078 | -0.098 | -0.088 |
| 12 | 0.215 | -0.088 | -0.103 | -0.093 |
| 13 | 0.234 | -0.093 | -0.107 | -0.093 |
| ●●●●●●●●●●●● | | | | |
| 1015 | 19.773 | -0.107 | -0.103 | -0.103 |
| 1016 | 19.793 | -0.107 | -0.103 | -0.098 |
| 1017 | 19.812 | -0.107 | -0.103 | -0.098 |
| 1018 | 19.831 | -0.103 | -0.093 | -0.098 |
| 1019 | 19.851 | -0.098 | -0.093 | -0.093 |
| 1020 | 19.871 | -0.088 | -0.083 | -0.083 |
| 1021 | 19.890 | -0.083 | -0.083 | -0.083 |
| 1022 | 19.910 | -0.078 | -0.073 | -0.073 |

Once this list is created, the user can load the individual GPR traces into other graphic plotting programs to create additional reports.

### Convert Image Folder to Single Zipped Image File

In the PAVECHECK program, a zipped image video file is used to browse the pavement images. However, the digital video acquisition software collects only images and saves them to an image folder. If the length of the project is long, there can be more than 10,000 images in a single folder. It is difficult to manage so many files when copying or distributing this test data. This conversion process compacts all of the images into a single file, which can be read directly by PAVECHECK.

Before converting, the user must prepare the image list file, which includes the image file names and DMI information. All the individual image files in the image list file must also be included in a single image folder. Once this is done, clicking the menu "Zip Single Image Folder" button starts the conversion process by asking for the name of the image list and the zipped video file name. The screen displays a progress bar that is made up of many small images that are read from the image file. Figure 70 is an example, which shows the progress bar and number of images still to be zipped.

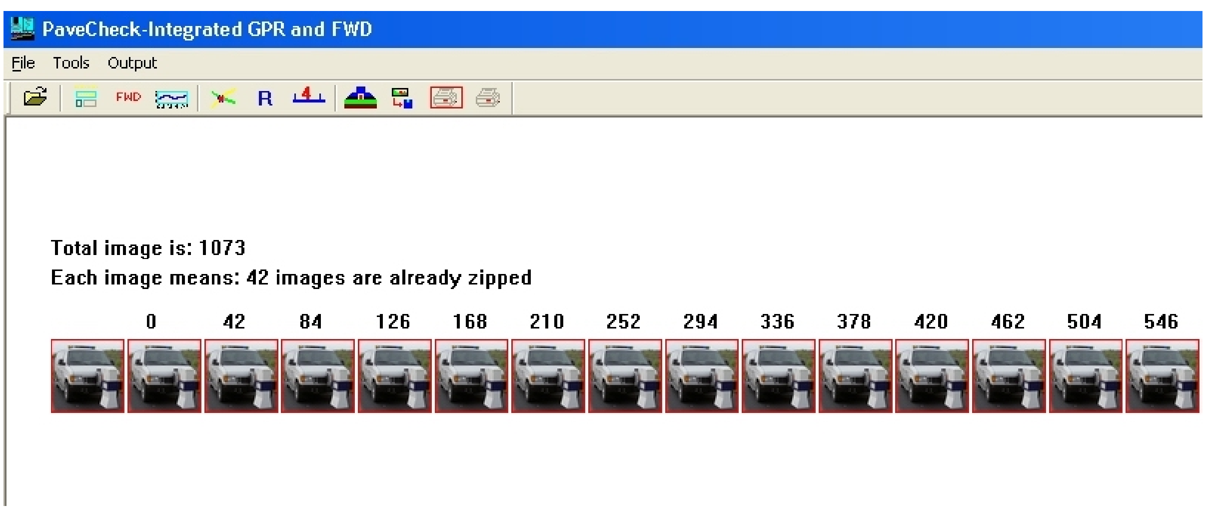



**Figure 70. Progress Bar Shows How Many Files Are Processed.**

# CHAPTER 3

# CONCLUSIONS AND RECOMMENDATIONS

The structural integrity of Texas roadways is of major concern to the Texas Department of Transportation, the stewards of these highways. To date, pavement engineers within TxDOT have utilized nondestructive and destructive testing methods to determine the pavements' structural integrity. This research effort concentrates on two nondestructive, non-invasive test instruments that provide TxDOT engineers with objective assessments of the pavements' structural condition so that good rehabilitation decisions can be made. The TxDOT engineers also use these two instruments to provide forensic information regarding early failure of new pavement sections.

The two instruments are the ground penetrating radar and the falling weight deflectometer. In the past, TxDOT engineers have had to process the data from the GPR and FWD separately using the following software. The COLORMAP program is used with the GPR data, and the MODULUS program is used with the FWD data. The intent of this research effort is to provide TxDOT engineers with an integrated software package so that layer and homogeneous pavement data from the GPR can be used to provide more accurate FWD data analysis. The integrated software package developed under this research effort is called PAVECHECK. The PAVECHECK program also allows the user to input other data types such as right-of-way (R-O-W) digital images, pavement core information, GPS coordinates, and test location distances for a more complete analysis of the pavement being tested. Each data type must be captured using independent instruments. Therefore, it is critical that the operators of these instruments begin and end at the same pavement locations.

The PAVECHECK program is a power analysis tool that should be implemented on a statewide basis. The program allows the user to process and analyze the structural integrity of a pavement using a single computer once the instrument data have collected. Data types from ancillary testing efforts such as coring and Dynamic Cone Penetrometer (DCP) can be utilized as inputs to the PAVECHECK analysis process. R-O-W images can be played backward or forward along the project to help the user interpret the structural analysis results. GPS data allow the project to be plotted along a map of the data collection route. The analysis results from the GPR processing allow the user to break the test pavement into homogeneous sections and provide pavement layer thicknesses, which increases the accuracy of the MODULUS backcalculations.

Based on the results of the research effort, the following recommendations and implementations strategies are proposed:

1. The PAVECHECK program should be thoroughly evaluated on several rehabilitation projects beyond the scope of this research effort.
2. Standards for core and DCP data collection and reporting should be established so that these data can be used as inputs without exception.
3. The PAVECHECK program should be revised as necessary based on the results of this evaluation effort.
4. A training session for the PAVECHECK program should be established.
5. Selected TxDOT engineers should be provided training on the PAVECHECK program.
6. Feedback from the trained TxDOT engineers should be used to revise and enhance the PAVECHECK program as necessary.
7. The TxDOT Texas Modular Vehicle (TMV) complaint GPR system should be finalized.
8. The TxDOT PF99 data format should be used as input to the PAVECHECK program so that revisions and enhancements can be made.
9. The analysis results from the PAVECHECK program should be used to revise the original PF99 data. The results should be added to the PF99 data file after analysis has been completed. This process was started under this research effort but coordination between TTI staff and TxDOT staff is needed once the PAVECHECK program has been evaluated under actual rehabilitation projects.
10. A statewide implementation effort should be undertaken so that TxDOT pavement engineers around the state can benefit from the analysis results for this data integration effort.
11. TxDOT should consider the creation of a TMV complaint FWD system so that data from the GPR and FWD instruments can be lined up along the roadway without distance-offset concerns.
12. TxDOT should consider adding the results from the analysis of the PAVECHECK program to its Pavement Management Information System (PMIS). If this task becomes a reality, TxDOT would have the beginning of a pavement layer database. The analysis results would also be available on demand to other engineers within TxDOT over time.

# REFERENCES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