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16. Abstract

COLORMAP is a signal processing system for ground-penetrating radar (GPR) data. It is intended to convert the raw GPR signals into information useful for pavement engineers. This system has been in use by TxDOT since 1996. This report provides an updated user's manual for COLORMAP together with a discussion of the new on-line help menus. These menus are based on a series of case studies conducted in Texas. They illustrate the influence of subsurface defects, unusual materials, and construction quality control problems on GPR signals.

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COLORMAP VERSION 2 USER'S GUIDE WITH HELP MENUS

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

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CHAPTER 1

INTRODUCTION

Ground-penetrating radar (GPR) is a nondestructive testing technique used for evaluating the subsurface conditions of pavement systems. The background work on GPR, performed by the Texas Transportation Institute (TTI) for the Texas Department of Transportation (TxDOT), has been documented in TTI Research Report 1233-1 (1). Reference should be made to that report for discussion of GPR principles, data collection, and data interpretation techniques. In a follow-on study 1341, work focused on evaluating the capabilities of GPR to assist in a range of new applications, including detecting subsurface problems in hot mix surfacings and asphalt-stabilized bases, measuring the thickness of recently constructed concrete pavements, and assisting with pavement evaluations as the first step in the pavement rehabilitation process. The successful case studies performed in these earlier research projects convinced TxDOT to purchase and provide GPR testing as a service to district offices. However, before full implementation of the system could be accomplished, it was necessary to develop a signal processing system so that the masses of waveforms collected in a GPR survey could be readily transformed into information meaningful to highway engineers. A software system called COLORMAP has been developed for this purpose. This system was first described in TTI report 1341-1 (2); it has now been in use by TxDOT engineers for over four years. In this current project 0-1702, the software has been significantly upgraded based on both field experience and the comments of TxDOT engineers.

The software package known as COLORMAP is a Windows-based microcomputer system written in Microsoft Quick C for Windows®. The system is intended to be simple to use so that non-GPR experts can rapidly review and interpret GPR data after a short introductory training school. It is hoped that GPR will become a routine, district-based testing system to assist with the following applications:

- As quality control testing of new asphalt layers, which checks thickness, density, and uniformity;

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- as the first step in pavement rehabilitation planning where GPR can identify uniform sections, locate areas of surface or base deterioration, and give layer thicknesses in advance of structural strength testing and coring;

- as a forensic engineering tool to investigate unexpected pavement failures; and

- as part of TxDOT's Network Level Pavement Management System, where GPR can assist in building and maintaining a Pavement Layer Data Base.

1.1 BASIS OF GPR TESTING

Figure 1a shows the TTI Ground-Penetrating Radar vehicle with the Pulse Radar antenna. The antenna 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 system captures and displays these reflected waves as a plot of return voltage versus arrival time. As shown in Figure 1, the largest peak is the reflection from the pavement surface; the amplitudes 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 highways. The reflections of major significance to pavement engineers are those that occur after the surface echo. These represent significant interfaces within the pavement, and the measured travel time is related to the thickness of the layer. For example, the time between the surface echoes A_1 and A_2 is related to the thickness of the top layer.

Figure 2 shows the GPR return waveform from a pavement with a homogeneous surface layer and in generally "good" condition. Peaks A, B, and C are reflections from the top of the surface, base, and subgrade, respectively. The hot-mix surfacing is classified as "homogeneous and uniform" because there are no significant peaks between A and B. If the asphalt layer was placed at different times with different aggregates, then there may be small positive reflections at each asphalt layer interface. One common defect found in many older Texas pavements is moisture damage (stripping) of an old buried hot-mix asphalt (HMA) layer. As will be described in the Help Menus in Chapter 3, a stripped layer generates a significant reflection from within the HMA layer.

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a. TTI GPR Equipment.

Δt_1 = travel time in asphalt

Δt_2 = travel time in base layer
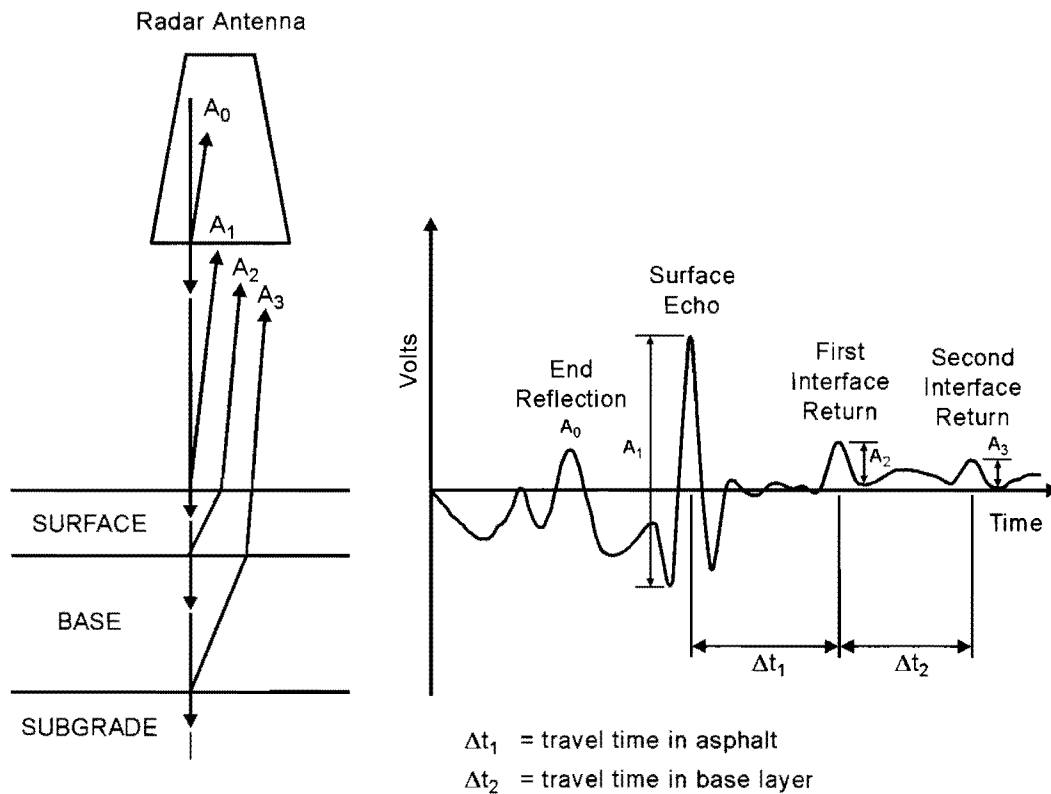
b. Principles of Ground-Penetrating Radar. The incident wave is reflected at each layer interface and plotted as return voltage against time of arrival in nanoseconds.

Figure 1. GPR Equipment and Principles of Operation.

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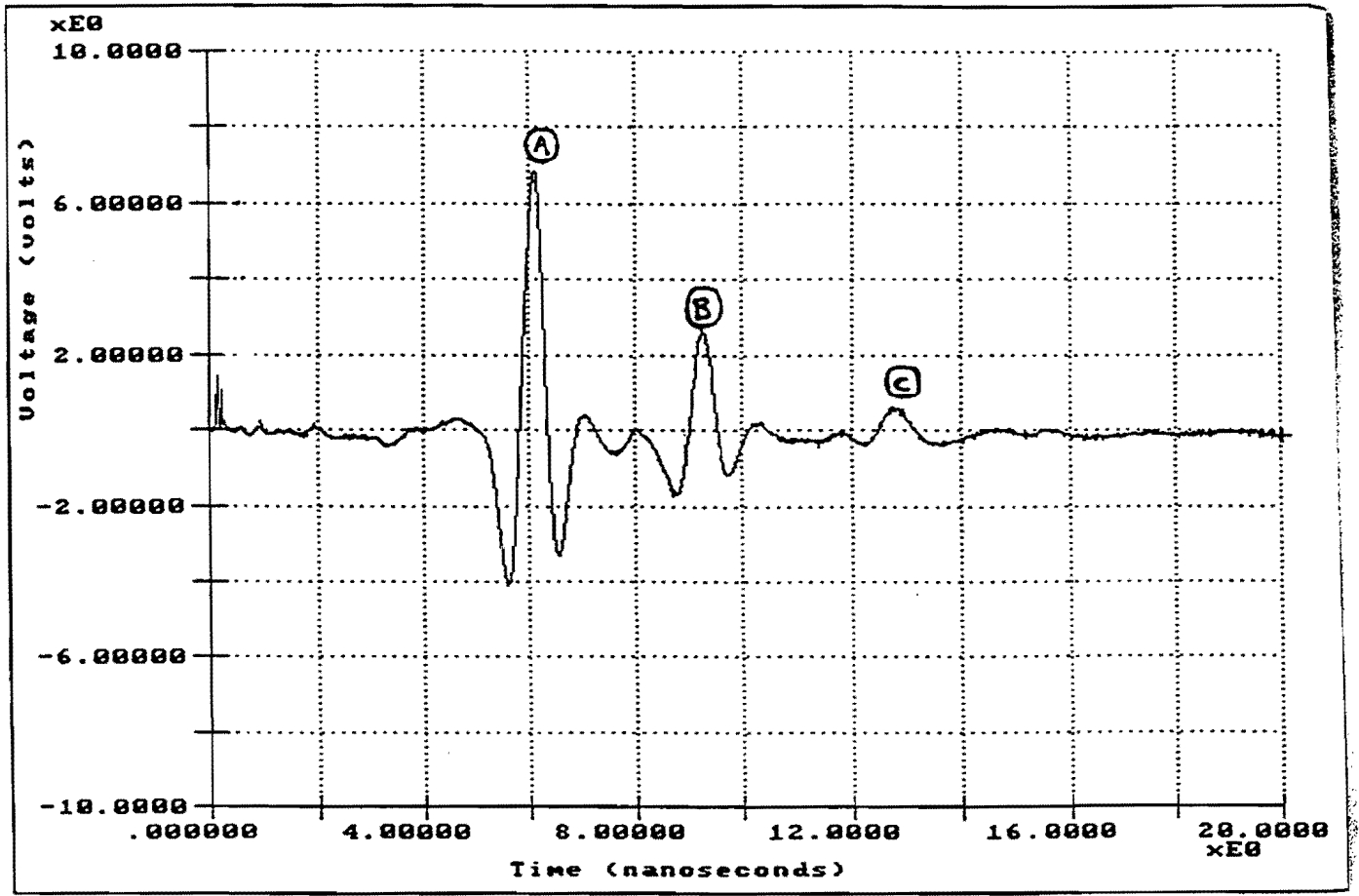
Figure 2. Typical GPR Waveform. Peaks A, B, and C are reflections from the surface, top of the base, and top of the subgrade, respectively.

In Texas, many of the surface layers are relatively thin, frequently less than 3 inches thick. With 1 GHz GPR systems, this presents a problem in that the reflections from the top of the layer overlap with those from the bottom of the layer, making it difficult to detect the true amplitude of reflection from the lower layer. To account for this common occurrence, the COLORMAP system uses a surface de-convolution (subtraction) technique. This technique has been described elsewhere (1). Figure 3 demonstrates this technique, which shows a reflection from a thin 3 in HMA layer over a thick granular base. The red line is the remaining signal once the surface reflection has been subtracted from the raw data. After subtraction, the true location and amplitude of the base reflection can be calculated. This technique is essential on all structures with thin layers; it is used extensively in the Help Menus described in Chapter 3 of this report.

When conducting GPR surveys, traces such as those shown in Figures 2 and 3 are collected at regular intervals along the highway. In most instances, several thousand traces will be collected on any particular survey. In order to evaluate such a massive amount of data in a timely fashion, COLORMAP employs several innovative data processing techniques. To assist in reviewing the GPR data, each individual trace is color coded into a single line scan. Figure 4 shows the process of color coding GPR traces. Within COLORMAP, the high positive voltages are colored "red" and the high negative voltages are colored "blue." As will be demonstrated later, the user defines what voltage levels are high positive and high negative. Once color coded, the individual traces are then stacked side by side so that several hundred traces can be displayed on a single computer screen. Examples of these color-coded, stacked traces will be shown later in this report. The benefit of this approach is that it permits the user to quickly and easily identify section breaks, obtain approximate layer thicknesses, and locate anomalies within layers.

1.2 DATA COLLECTION REQUIREMENTS

In any GPR survey, two standard data files are collected, as described below; one contains the GPR data for the pavement section, and the other contains GPR reflections from a large metal plate. Typical file names and extensions are shown below; both of these files are included on the

Compute	Undo	Prev.	Next

Layer	1	2	3	4
Amplitude	3.7	1.2		
Dielectric	5.5	10.3		
Thickness	2.9			
Travel Time	1.2			

Trace	971
Mile	0
Feet	971

Cursor	
Voltage	0.8
Time	7.9

Peak	1	2	3	4
Voltage 1	2.3	0.8		
Time 1	4.0	5.2		
Voltage 2	-1.3	-0.3		
Time 2	3.6	5.7		
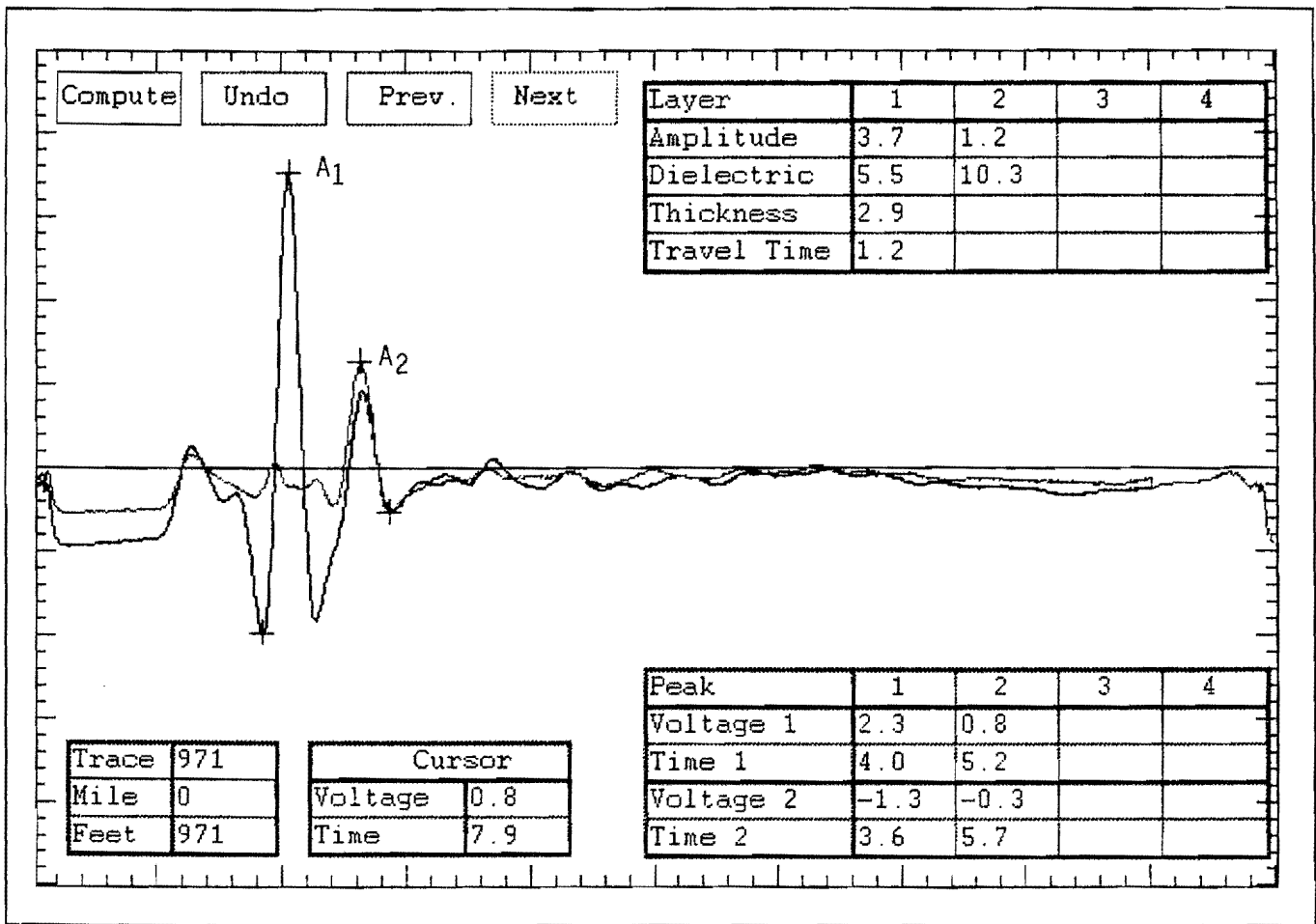
Figure 3. Typical GPR Reflection from a Newly Constructed Pavement Consisting of a Thick Granular Base and Thin Surfacing. Reflections A_1 and A_2 are from the surface and top of base, respectively. This is the ideal case. The red line is obtained after surface removal.

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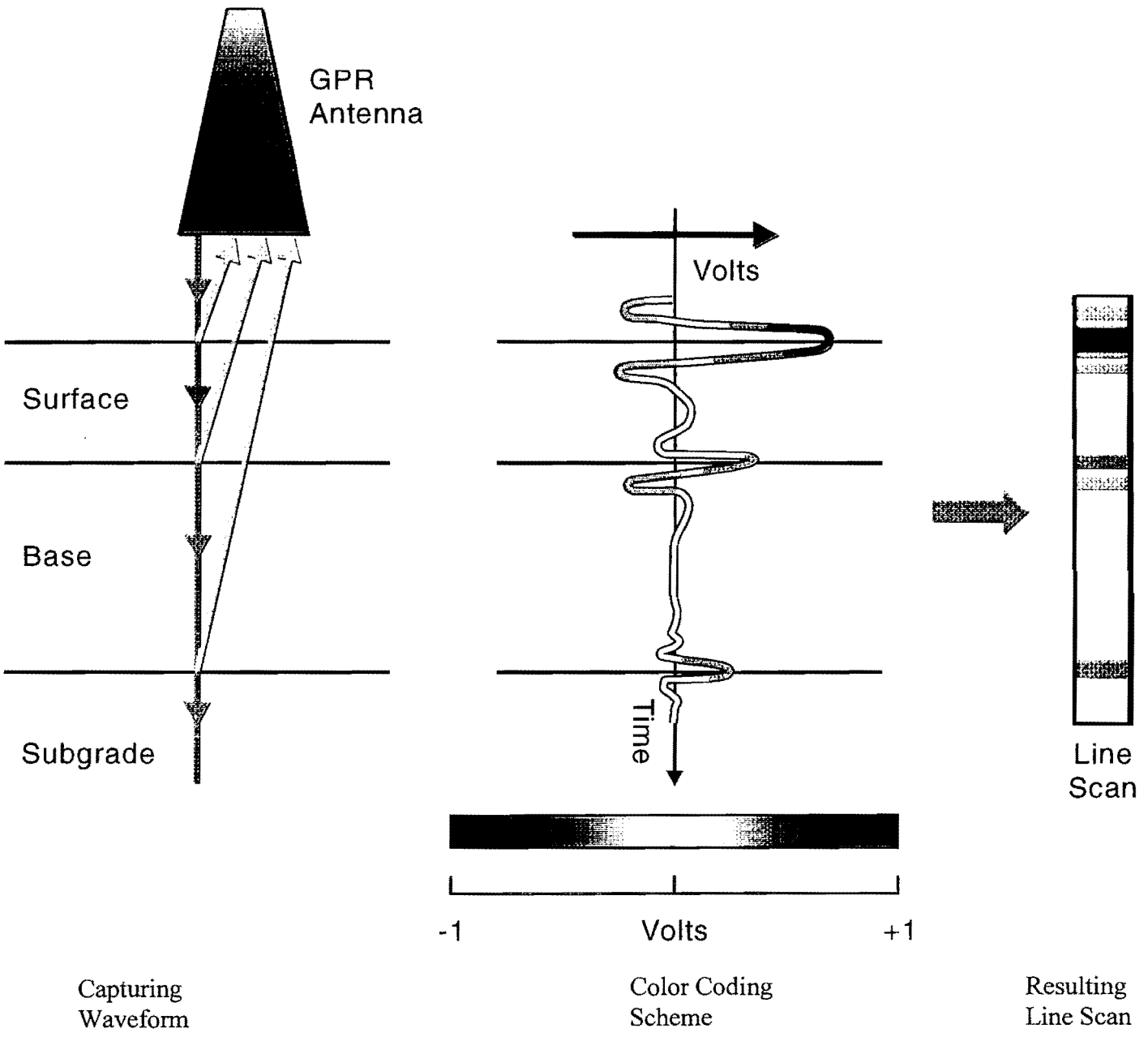
Figure 4. Color Coding of Individual GPR Waveforms.

distribution diskette. These data are used extensively in Chapter 2 to describe the options available within COLORMAP:

- SH10.DAT contains typical GPR traces from a newly constructed thick HMA section containing no defects;
- MTLC.DAT contains the metal plate reflection; this is a small file containing a few records collected with the antenna placed at its operating height directly over a large metal plate.

These two files are required in all cases where layer thickness computations are to be made. For GPR systems with low levels of system noise, these two files are adequate; however, on some monostatic GPR systems, a third file, the "End Reflection" file, is often required. As explained in detail in Report 1233-1, monostatic systems can generate significant internal noise, which may superimpose itself on the reflections from the pavement layers (1). The End Reflection file is obtained by turning the antenna towards the sky and capturing the no-reflection wave. This file contains only internally generated system noise. If required, COLORMAP contains procedures to scale, align, and subtract these internal reflections from the collected waveform. In general, bistatic GPR systems do not require "end reflection" subtraction.

A fourth input file is needed for applications in which the top layer is very thin or consists of multiple, significantly different asphalt layers. The GPR pulse has a known time width (1 ns); as described earlier, this causes reflection overlap for layers less than 3 in thick. To address the overlap problem, a Template file is used which contains a representative trace from a thick homogeneous asphalt layer. The use of the Template file (surface removal) was demonstrated in Figure 3. If the user does not define a Template file, the Metal Plate file is automatically used.

COLORMAP uses the first record in the Metal Plate, End Reflection, and Template files for computation purposes.

1.3 SIGNAL PROCESSING PHILOSOPHY

TTI report 1233-1 (1) describes a signal processing system named DACQ. The main feature of this package was an automated peak tracking system in which the user identified significant peaks within the GPR trace, and the software automatically traced these peaks throughout the entire file. For each peak, the amplitude and arrival time were calculated, and the layer dielectrics and thicknesses were computed for each trace. The DACQ system had many advanced features, including accounting for antenna bounce and several signal clean-up routines which could be applied prior to processing. The DACQ package was successfully used on several projects, but it did have a number of limitations. The data processing was slow, primarily if long lengths of highway were being processed. It was difficult to use the package to identify section breaks, and the peak tracking systems were difficult to use on several projects. The peak detection system had problems with badly distressed pavements where severe transverse cracking would generate one or two distorted GPR waveforms. It also had difficulty tracking faint interfaces, which often happen at the base/ subgrade interface. The system was expanded to handle many of these problem cases; however, it was concluded that the DACQ system was an excellent research tool but it was not adequate for routine measurements.

Because of the limitations of DACQ, it was decided to develop a new processing package to more closely meet TxDOT's needs. These needs include the capability to rapidly evaluate long sections of highway, define changes in section, estimate layer thickness, and locate potential subsurface problem areas. Based on these needs, the COLORMAP system was developed. This system relies on color graphic displays of GPR data to identify section breaks and subsurface problems, and either manual or automated tracking of layer interfaces in the layer thickness computation routine. This system is described in Chapter 2 of this report.

1.4 HARDWARE REQUIREMENTS

Figure 5 shows the recommended hardware requirements for COLORMAP. A color printer is highly recommended so that the color-coded GPR traces can be output. The system will work with a regular black and white printer; however, color is recommended to more easily identify defects and layer interfaces.

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Color Inkjet or Laser Printer

4 gigabytes of Hard Disk + zip drive

Software
Windows 95/98/NT

64 megabytes of memory

VGA graphics:
640 X 480 resolution
High Color (16-bit)

Pentium or better processor

mouse
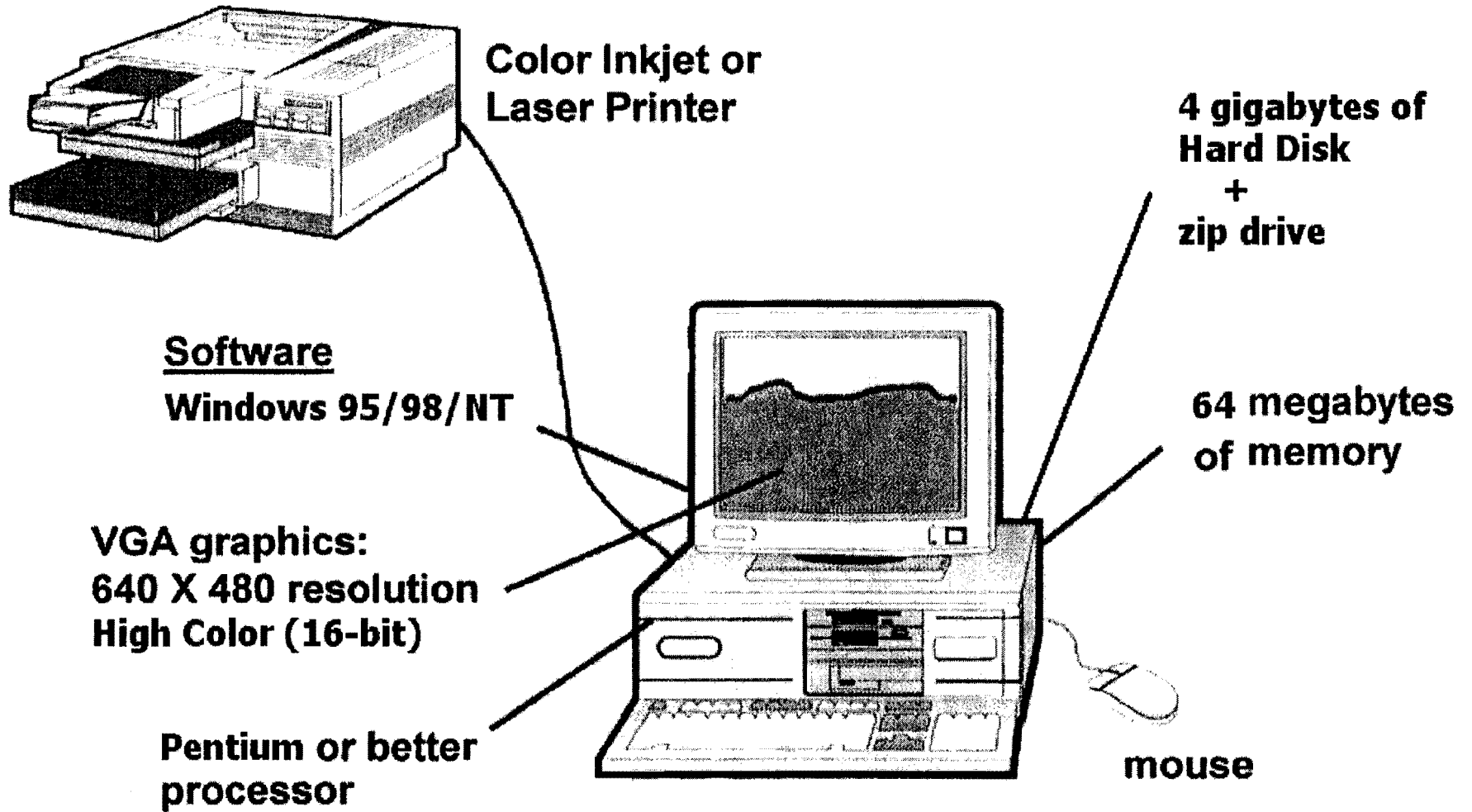
Figure 5. Computer Requirements to Run COLORMAP.

1.5 GETTING STARTED

The TxDOT Distribution Diskettes contain the following four files:

1.   SH10.DAT, which contains several hundred GPR traces from a newly constructed thick HMA pavement;
2.   MTLC.DAT, the metal plate reflection collected after testing SH10;
3.   COLORMAP.EXE, the executable program.
4.   COLORMAP.HLP, the help menus.

These files should be copied into a RADAR directory, and a Windows icon should be created for COLORMAP. These files are used extensively in the User's Manual discussed in Chapter 2. The reader is encouraged to generate each screen while reading through this chapter.

CHAPTER 2

COLORMAP USER'S MANUAL VERSION 2.1

2.1 MAIN MENU SCREEN

Figure 6 shows an example of the main COLORMAP screen. To obtain this screen:

1. Double click the COLORMAP icon.

2. Open a Pavement Data (SH10.dat) and Metal Plate file (mtlc.dat) under the FILE pull-down menu.

3. Hit the "right" mouse button for Forward Play.

This is taken from a section of newly constructed thick asphalt pavement over a thin granular base. A description of each of the denoted elements in this figure is given on the next page.
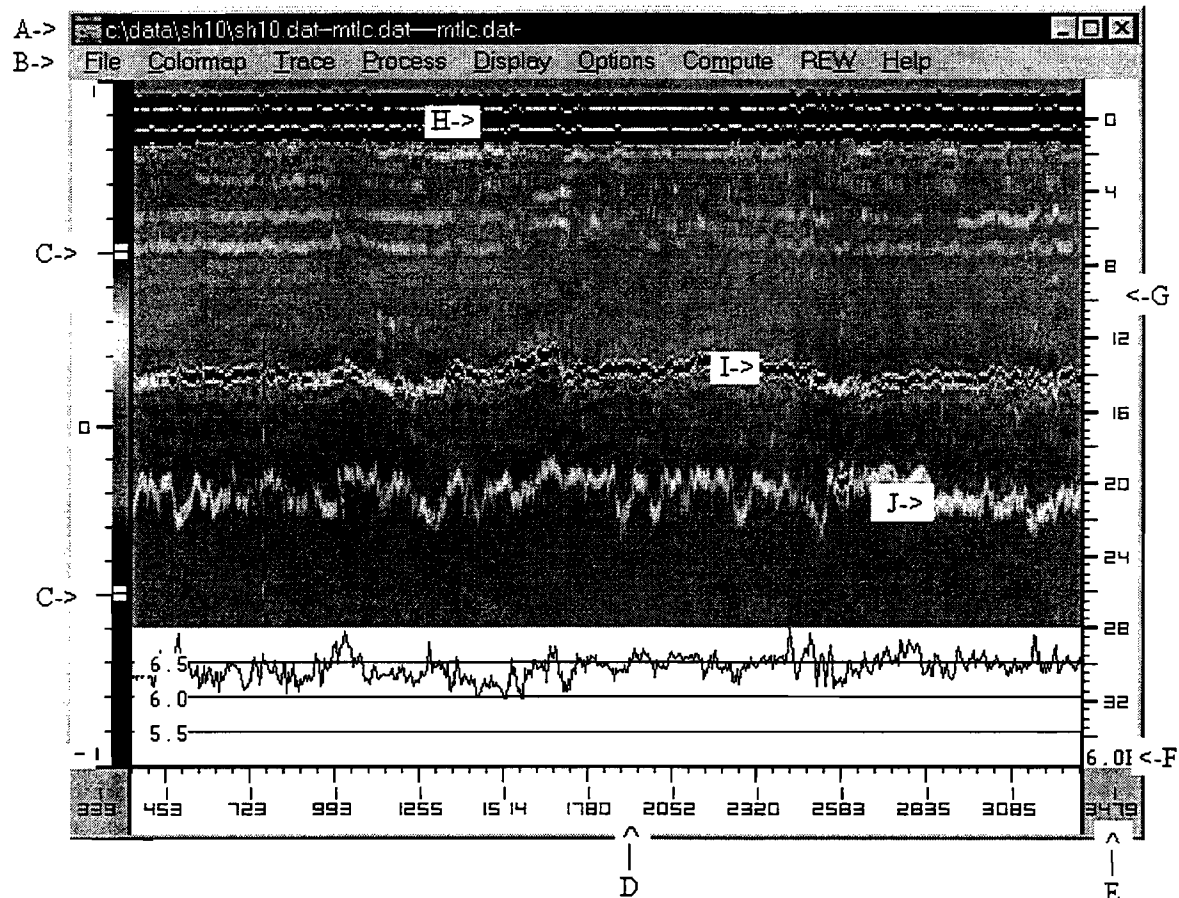
Figure 6. COLORMAP's Color-Coded GPR Traces.

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A. Header information showing the directory in use and the list of files that have been opened for either data processing or for storing results.

B. Main pull down menu bar in COLORMAP. The use of the pull-down options will be described in detail in the remainder of this chapter.

C. User-defined color control buttons, the procedures by which the individual GPR waveforms are color coded and transformed into line scans (shown in Figure 4). The +1 and -1 at the top and bottom of this scale are in units of volts. The upper box indicates the voltage level at which all segments of the GPR trace above this level will be colored "red;" the lower button indicates the level at which all negative voltage will be colored "blue." All voltages between the two boxes are assigned the color shown on this scale.

The user can change the color-coding scheme by moving these boxes up or down. Click on the box with the mouse (left button), and drag it to the desired level. Options within the COLORMAP pull-down menu permit the user to assign different scales, changing the +1 and -1 volt range to whatever range is required. Normally, for 1 GHz antenna data the +1 to -1 volts range is recommended.

D. Distance scale in miles and feet as collected by the GPR's distance measuring instrument (DMI). Distance in feet is coded into each GPR trace collected along the highway. In the OPTIONS pull-down menu, the user can change this designation to represent the actual highway milepost designation. Other options available are: a) to have this scale represent GPR trace numbers rather than distance; b) to have the scale in station (100 ft) intervals; and c) to use metric units (kilometers and meters).

E Total distance in miles and feet within the data file. If the metric option is chosen, this will be kilometers and meters.

F. Default dielectric value used to generate the depth scale (G) at the right of the figure. This value is intended as a first-order estimate of layer thickness of the top layer. For asphalt, a value of six is recommended; for concrete pavements, a value of eight should be used. The user can change this value in the OPTIONS pull-down menu.

G.   This is a depth scale in inches. Use the left button to click on any part of this scale; drag it vertically to align the surface reflection with zero on the depth scale.

H.   This solid line at zero depth is the surface of the pavement. The line at 16 inches is the bottom of the asphalt-stabilized base (I) and at 20 inches is the bottom of the granular base (J).

K.   This is a plot of surface dielectric, which is automatically computed from the amplitude of surface reflection (peak A, Figure 2). This function is activated in the COLORMAP pull-down menu. As will be described in the case studies presented in Chapter 3, this plot is useful in identifying surface anomalies, including areas of low density materials or poorly compacted longitudinal joints.

If the surface removal option (Remove Template) is activated in the OPTIONS pull-down menu, the surface will be aligned with the top of Figure 6. This feature is required when the pavement surfacing layer is less than 3 in thick.

2.2 DESCRIPTION OF COLORMAP'S PULL-DOWN MENUS

2.2.1 FILE Pull-Down Menu

Figure 7. FILE Pull-Down Menu Screen.
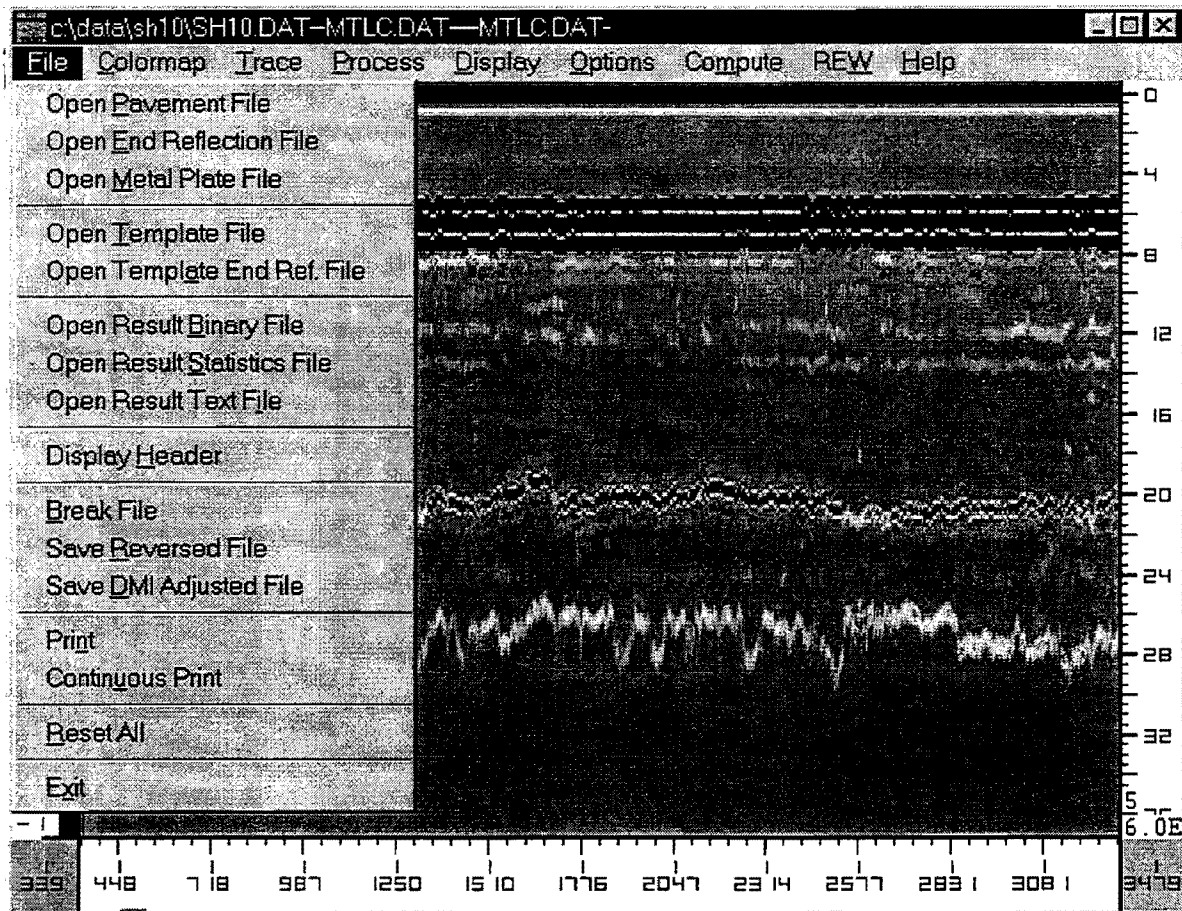
Objective

      This menu is used to open the files containing GPR data and to declare the output files. This menu also controls the printing of all screens.

Open Pavement File

      This file is a <u>mandatory file</u> containing GPR waveforms collected with TTI's data acquisition software. A Pavement Data file must be opened (left mouse button) before proceeding. Although

not essential, it is recommended that during data collection the file be given the *.DAT extension; the file name is user-supplied and should include the highway number and lane under test.

Once this file has been selected, its name will appear in the header information at the top of the COLORMAP screen. Place the cursor inside the COLORMAP display then click on the right mouse button and the color-coded GPR data will scroll across the page.

Open End Reflection File

This file is an optional file collected by pointing the antenna to the sky and recording one or more traces. This "sky wave" or "end reflection" is internally generated noise which is superimposed on every trace collected. The selection of this file will automatically set the "Remove End Reflection" flag in the OPTIONS pull-down menu. During the end reflection removal process, the software locates the largest positive peak in the end reflection trace. COLORMAP then aligns this peak with the positive peak preceding the surface reflection. The end reflection trace is then subtracted from the GPR data trace. The default option is for aligning positive peaks; however, in the OPTIONS pull-down menu, the user can specify a positive or negative peak for aligning the two traces. Although this is not an essential file or process, and the system will work without removing the end reflection, this process is recommended for data collected with the monostatic Penetradar antenna. The end reflection subtraction is not essential with bistatic GPR systems, such as the Pulse Radar system currently used by TxDOT.

Open Metal Plate File

This file is a mandatory file if layer thicknesses are to be computed. It is generated by capturing one or more GPR reflections from a large metal plate, typically 4 ft × 4 ft, with the antenna operating at the same height and same gain as used to collect the Pavement file. It is recommended that the metal plate reflection be collected after the pavement data, with the antenna directly above the center of the metal plate. The amplitude of the metal plate reflection is used in all layer dielectric calculations.

Under normal operations, this file is usually present. However, it can be excluded if the user inputs a metal plate amplitude in the TRACE pull-down menu or directly inputs layer dielectrics in the PROCESS pull-down menu.

Open Template File

This file is used to minimize problems caused by thin surfacings in which reflection overlaps can make true reflections from the top of the base layer difficult to identify. With 1 GHz antennas, reflection overlap will occur with layers less than 3 in thick. The template file should contain traces from either a metal plate reflection or from a pavement with a known thick homogeneous surface layer. The Metal Plate file is automatically opened as the default Template file. Using this option, the default Metal Plate file may be overwritten with a file from a thick homogeneous layer, if needed. It is the shape of the reflected waveform that is important. This template subtraction process will align, scale, and subtract the Template file surface reflection from the surface reflection collected on the pavement with a suspected thin surfacing. Template subtraction permits the amplitude of the reflection from the top of the base to be more clearly determined. Template subtraction is activated in the OPTIONS menu. It is recommended for pavement with thin surfacings. In most cases, the default metal plate reflection works well for surface removal. Therefore, this option (overwriting the default file) is rarely used.

Open Template End Ref. File

This file is optional. It serves the same function as the End Reflection file described above. Even if the template is to be removed, it is not mandatory to remove the end reflection from the Template file. This option is normally useful only for monostatic antennae.

Open Result Binary File

This file is <u>mandatory</u> if and only if the PROCESS menu is to be used. This resulting binary file is a storage file for the computed layer dielectrics and thicknesses. These values are calculated in the Thickness Computing option under the PROCESS pull-down menu. This file stores all the information necessary to generate the graphical and statistical outputs. The user is requested to assign a name so that it can be permanently saved for later processing. Once defined, the system automatically opens a .TXT and .STA file with the same name. The user can define a different name with the options below.

Open Result Statistics File

This file is <u>mandatory</u> if and only if the Statistic Computing option in the PROCESS menu is to be used. The Result Statistics file contains the statistical summary data generated from the Binary file. It contains the low, high, and average layer thicknesses for layer thicknesses at user-specified intervals along the highway. These statistical values and data are calculated in the Statistical Computing option under the PROCESS pull-down menu.

Open Result Text File

Opening this file is optional. If data are required in an ASCII format, a text file must be opened before computing thicknesses. The computed thickness and dielectrics will be stored in this file. During the thickness calculation process, the layer thicknesses are computed for each section. The text file retains only the last section processed.

Display Header

The first line in the Pavement file contains information on the site. This information is input during data acquisition; it can be displayed with this option.

Break File

The Break file permits the user to break long files into several shorter files. Use the Select Begin Position and Select End Position under the PROCESS pull-down menu to define the limits of the new file before selecting this option. The program will prompt you to define a new output file name.

Save Reversed File

The Saved Reversed file permits the user to reverse the Pavement file. This file is used to align data collected in opposite directions. COLORMAP creates a new Pavement file with following two changes:

Assume that the total number of trace is n. The maximum Distance Measurement Index (DMI) is *dmax*.

1) The k trace in the old pavement file will be the $(n-k+1)$ trace in the new file (e.g., the last trace will be first trace, first trace will be last trace).

2) If a trace has a DMI d in the original file, its DMI will be changed to $(dmax-d)$ in the new file.

Save DMI Adjusted File

The distance adjustments are made under the OPTIONS pull-down menu. This option permits the user to save the adjusted file for later processing traces.

Print

This Print option prints the page which is currently displayed. It is used to print the color-coded trace (such as Figure 6), individual traces, statistical graphics, and tabular outputs on a page-by- page basis. When the color-coded traces are printed, the printout includes the pavement thickness scales and file characteristics, all features which are not available through the Continuous Print mode.

Continuous Print

When used, Continuous Print will print successive COLORMAP screens without page separation. The user must select a starting position and then choose Continuous Print to print the screen in landscape format. Once the first screen has been printed, scroll to the next full screen and again select Continuous Print. Continue until all desired screens have been printed. A thickness scale will not be printed, but one may be obtained through the single page Print mode described above. To use this option, it is essential to have a printer with continuous feed operation.

Reset All

Reset All clears all settings and closes all files.

Exit

The Exit command quits COLORMAP.

2.2.2 COLORMAP Pull-Down Menu
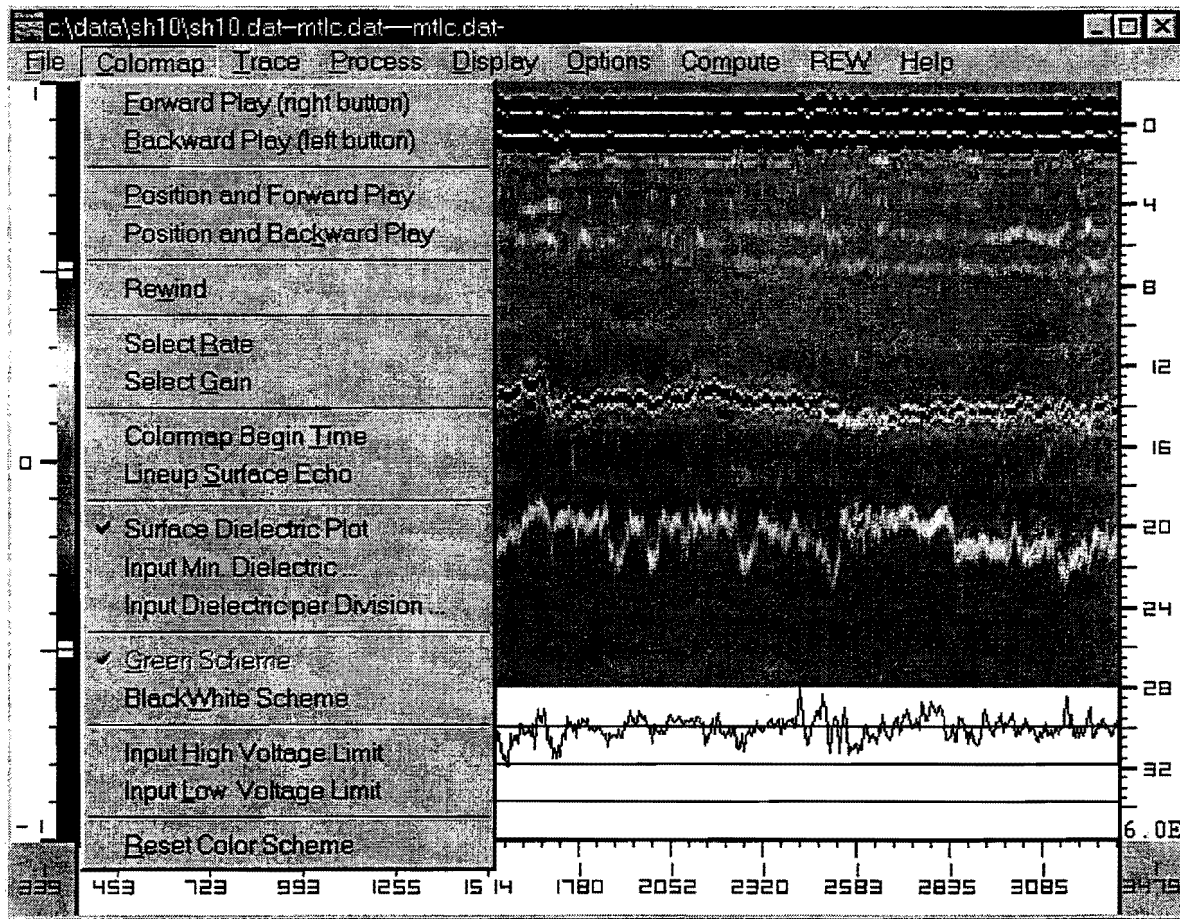
Figure 8. COLORMAP Pull-Down Menu Screen.

Objective

This option permits the user to generate the color-coded displays, an example of which is shown above in Figure 8. Various options permit the user to line up the surface echoes, to start the display at a certain position, and to change the color-coding scheme.

Forward Play

Single click (left button) on Forward Play to begin to scroll the screen to the right. The screen will scroll until it is full, and a display similar to that shown in Figure 6 is shown. Once the screen is full, it is paused; the user can change the color scheme by clicking and sliding the buttons at the left side of the screen. The thickness scale at the right should be adjusted so that the zero

depth on the scale is alongside the surface reflection. To pause the scroll, click any mouse button. Under normal operations these buttons are rarely used. Once the file has been opened the left and right mouse buttons are used to move forward and backwards through the data file.

Backward Play

Single click on the left mouse button to begin to scroll the screen to the left. The screen will scroll until the screen is full. To pause the scroll, click any mouse button.

Position and Forward Play

This option opens up an additional window so that the user can select a starting location by distance, in miles and feet. When the user selects this location, COLORMAP will advance to that position in the data file and begin to scroll the screen forward.

Position and Backward Play

This allows the user to select a starting location by distance, in miles and feet. When the user selects this location, COLORMAP will advance to that point in the data file and begin to scroll the screen backwards.

Rewind

Rewind clears the screen and repositions the location to the beginning of the file.

Select Rate

Select Rate will designate the interval of displayed traces. For example, a 1 will display every trace in the data file; a 2 will display every second trace. This command allows a large file to be reduced for ease of analysis. The rate must be input as a whole number. The default value is preset at 1, to display all traces.

Select Gain

The Gain option linearly amplifies the entire waveform for visual color clarity. Personal preference controls the amount of gain used. If the trace contains small peaks, it may be necessary

to amplify them so that they will be easier to detect in the color display. The Gain default value is preset at 1 and can be changed to any number greater than zero.

COLORMAP Begin Time

A typical GPR trace was shown earlier in Figure 2. The total time scale is typically 20 ns, and the important pavement layer information occurs after the surface reflection. In Figure 2, the surface echo occurs at 6 ns. The information prior to the surface echo is system noise and of little significance. This Begin Time option lets the user specify at which point in time the COLORMAP display will begin. After color coding the individual traces, the input Begin Time is aligned with the top of the display in Figure 6. Changing the Begin Time will essentially move the color display up or down.

Lineup Surface Echo

The Lineup command automatically detects the largest peak in the waveform and positions it at the top of the COLORMAP screen. This option sets the surface reflection at the top of the screen; this is then the zero depth position.

Surface Dielectric Plot

This on/off switch decides whether the surface dielectric graph will be displayed on the lower portion of the COLORMAP display (marker k in Figure 6).

Input Min. Dielectric

The lower limit of the dielectric graph is entered here. There is a four-scale division in the graph. The minimum dielectric input box accepts only integer numbers. All input digits after the decimal point will be cut off (not rounded up). Normally, for HMA surfacings, a minimum dielectric value of three or four is adequate.

Input Dielectric per Division

This value sets the scale on the surface dielectric plot. Normally, for HMA surfaces, a value of one is used. With a minimum dielectric value of three, the displayed scale will range from three

to seven. In Figure 6, the minimum value of five was used with a dielectrics/division of 0.5, giving a range of five to seven.

Green Scheme

This is the normal color scheme in which the high positive voltages are assigned a red color and negatives are blue. The values around zero volts are colored green.

Black and White Scheme

The Black and White Scheme displays the data with a black and white color scheme. It is used if only a black and white printer is available.

Input High Voltage Limit

This value is the voltage level above which all segments of the GPR trace will be colored red. The voltage limit may be changed to enhance the color display of the GPR data. It is used if the GPR signals are either very big or very small, or if the base line of the GPR data file is not zero. Before adjusting these limits, it is beneficial to look at an individual trace using the pull-down TRACE menu. The default value is +1 volts.

Input Low Voltage Limit

This value is the voltage level below which all segments of the GPR trace will be colored blue. The voltage limit may be decreased to enhance the clarity of the color display; the default value is -1 volts.

Reset Color Scheme

If the voltage in the color scheme scale has been altered, the values are automatically returned to the default values (+1 and -1 volts).

2.3 TRACE PULL-DOWN MENU
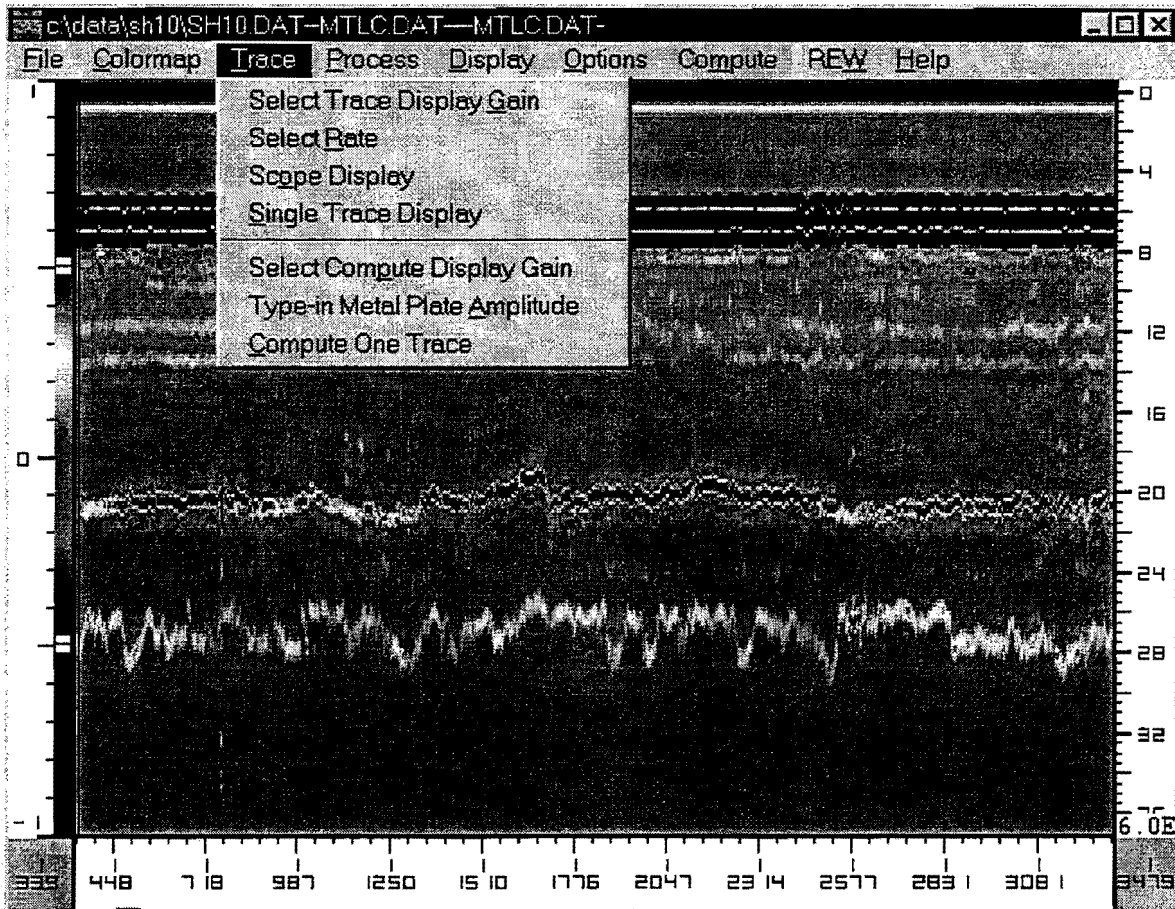
Figure 9. TRACE Pull-Down Menu Screen.

Objective

This option permits the user to view individual GPR waveforms from any position in the data file or to review the entire data file. Also, the user can process a single trace in this menu.

Select Trace Display Gain

The Gain factor linearly amplifies the waveform. Personal preference controls the amount of gain to use. The Gain default value is preset at 1.0 and can be changed to any number greater than zero. The TRACE-Select Gain is independent of the COLORMAP-Select Gain; it is used only with the scope display function described below.

Select Rate

Enter a two and every second trace will be displayed. This command allows a large file to be reduced for ease of analysis. The rate must be inputted as a whole number. The default value is preset at one to display every trace. This Select Rate command is independent of the other COLORMAP menu Select Rate. This Select Rate is only for use with the Scope Display function.

Scope Display

To review all of the collected GPR waveforms, the Scope Display option will open a window in the screen, and each trace will flash onto the window. Press the left mouse button, and a vertical line will appear on the color display; using the mouse, move this line to the required starting position and click the left button again. The window will open as shown in Figure 10, and the traces will be displayed. To pause, click the left mouse button once. To continue, click the left mouse button again. To quit the Scope Display mode, click the right mouse button while the display is in the paused position.
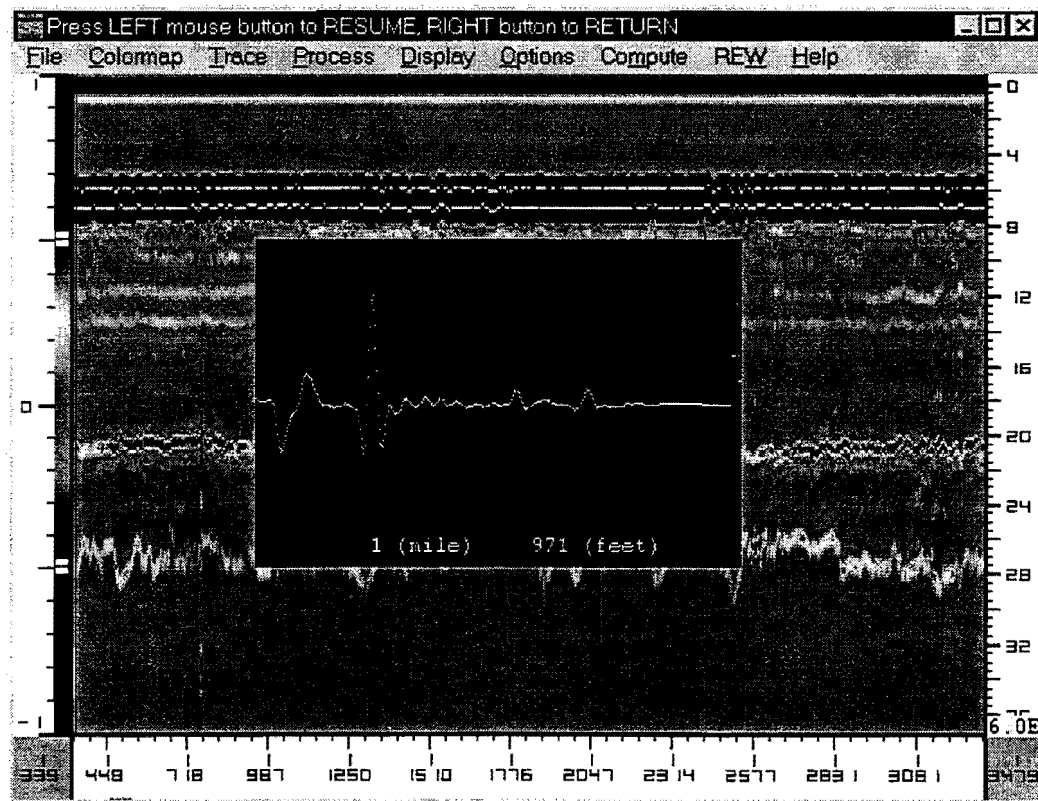
Figure 10. Scope Display Continuously Showing GPR Waveforms for Entire File.

Single Trace Display

The Single Trace Display will show one waveform but will not allow computation of thickness and dielectrics. Once selected, a vertical line will appear on the color-coded display; this is moved by the mouse to the required location. A single click on the left mouse button and the actual GPR waveform for that location will be displayed. The vertical scale is in volts, and the horizontal scale is time in nanoseconds. To end, click on the right mouse button. A typical, single-trace display is shown in Figure 11.
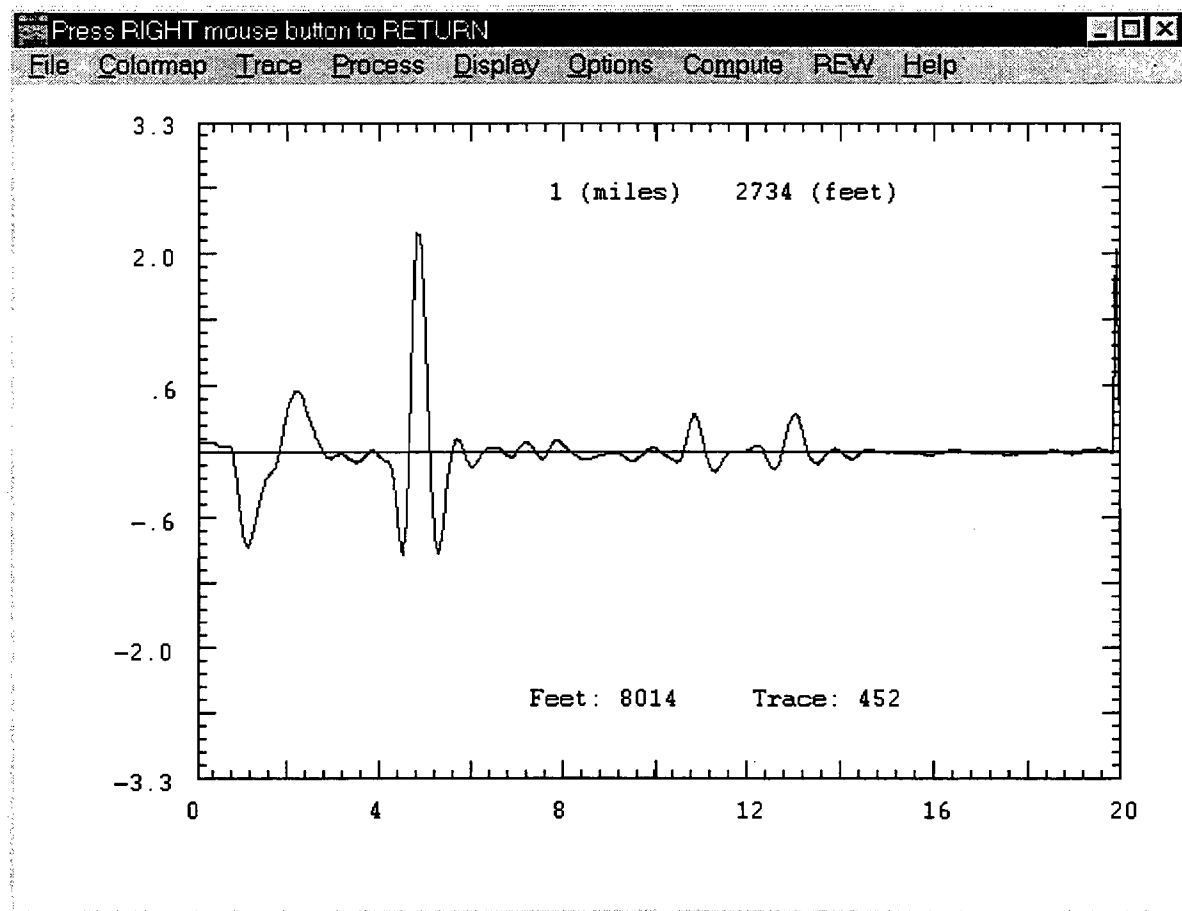
Figure 11. Single Trace Display.

Select Compute Display Gain

Select Compute Display Gain sets the vertical amplification gain for a single GPR trace. For a 1 GHz horn antenna, a default value of three is used for pavement data. The value used is for display purposes only; it does not affect the calculation. When reviewing a Metal Plate file, this value should be set to 1.0.

Type-in Metal Plate Amplitude

This option overwrites the metal plate amplitude measured from the first trace in the Metal Plate file entered under the FILE menu. If the metal plate and pavement data were collected at different gains, then the gain-corrected metal plate amplitude must be input. This input metal plate amplitude will then be used in all dielectric calculations.

Compute One Trace

This function is identical to the COMPUTE pull-down menu function. Refer to that discussion.

2.4 PROCESS PULL-DOWN MENU
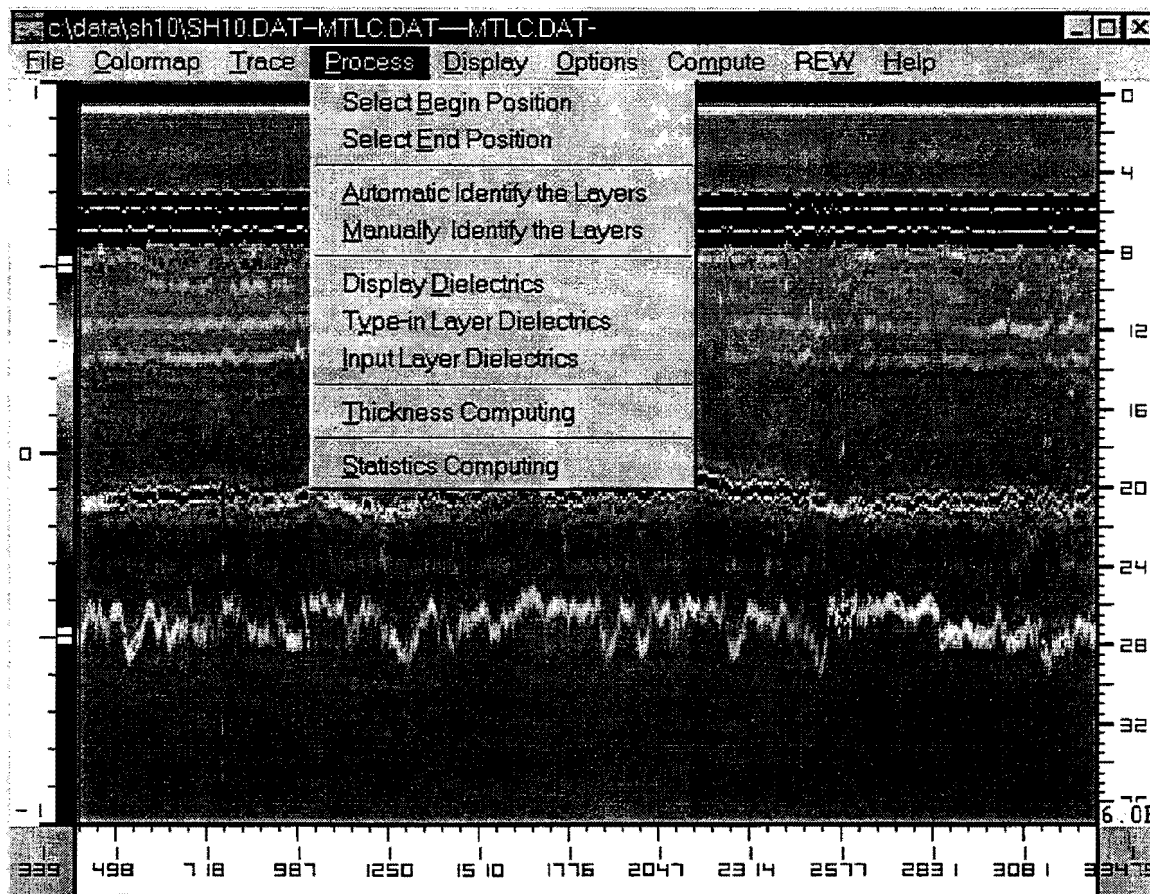
Figure 12. PROCESS Pull-Down Menu Screen.

Objective

The PROCESS pull-down menu calculates the layer thicknesses and dielectrics within a user-defined section. In normal operation, a Binary (output) file is opened in the FILE menu prior to using this menu.

Select Begin Position

This option is used to select a subset of the file for processing or to define limits to break the file, as described under the Break File option. The default value is the first trace of the GPR data file. After clicking this option, a vertical line appears; this line is moved by the mouse to the desired position. The left button is then clicked to select the begin position, and a red vertical line is placed at that location.

Select End Position

This command selects the end location of the section to be processed (or the end of the section break). The default value is the last trace of the pavement file. This option is activated using the left button. Once selected, a blue vertical line is placed on the display.

Automated Identify the Layers

Automatic interface identification uses the "moving window" method to continuously find the peak position in every trace in the defined section. It will automatically search a peak position within a window of width of 2 ns (1 ns from each side of the peak position of current trace).

To begin the automatic identification, click on the menu item "PROCESS - Automatic Identify the Layers." A dialog box will appear and ask for the layer number. This layer number tells the program that the user is going to identify the bottom of the layer. For example, one is bottom of first layer, etc. By clicking on the OK button, the cursor will change from an ARROW to a CROSS, which means that now the user can select a start point in the COLORMAP display and begin the automatic identification process. To select a start point, move the cursor to the desired point on the interface to be tracked, and click the left mouse button. This point tells the program two pieces of information. The first is the beginning trace of the automatic identification routine; the second is the initial peak (layer interface) position.

Once this point selected, the computer traces the interface between the user-defined section limits. However, the tracking routine sometimes "gets lost." When the computer does not follow the correct interface, hit any button to stop tracking, and repeat the process. This time, start the cursor just after the location where the problem occurred.

The whole identification process or the identification result can be monitored, and any unwanted results can be easily overwritten by doing another automatic identification or by manual identification on part of the section. The manual overwrite is described below. The system uses only the last line traced in the computation process. Refresh the screen with the (REWIND/FORWARD Play) option.

Manually Identify the Layers

If not satisfied with the automatic layer identification, the user can overwrite part of the section or even the whole section by using the manual layer identification. Click on menu item "Manually Identify the Layers;" select the layer number; the cursor will change to a CROSS. By holding the left mouse button down and moving the mouse, the user can "draw" a line on the COLORMAP display until releasing the button. This line is the user's choice of the layer interface. Repeating the same process, the user can define other parts of the section. Clicking the right mouse button will end this manual layer identification mode.

If the user "draws" the line too fast, there will be gaps between line points. This does not mean the user did not identify the part. The program linearly fills all the gaps. Refreshing the screen (REWIND/FORWARD Play) will show the defined layer interface.

Display Section Dielectrics

This option, when used in conjunction with the COMPUTE-Select Location command, will allow the calculated or input value of the dielectrics to be displayed. Click right button to exit.

Type-in Layer Dielectrics

This selection is a flag. If the user checks this menu item, the dielectrics will need to be input either by using "Input Layer Dielectric" or by using the COMPUTE pull-down menu. The COMPUTE menu will average up to five computed dielectrics for thickness computation. Switch this flag off for automated dielectric calculation. The default value is "off;" this option is rarely used.

Input Section Layer Dielectric

The dielectric of a layer in a section may be inputted manually. When selecting the Input Section Layer Dielectric command, there will be a prompt to input layer number. Then the dielectrics can be entered. This value will replace values computed in the COMPUTE menu. This option would be used only: a) if there was a problem with the Metal Plate file which caused the automatic layer dielectric calculation procedure to give unreasonable values, or b) if the user has a dielectric value calculated from actual core thicknesses. This step will fix the dielectric value in all

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computations. In general, the asphalt layer dielectrics should be between 5.5 and 6.5, concrete between 6 and 8, and flexible base between 8 and 12. The user should carefully review numbers outside of these ranges.

Thickness Computing

To use the Thickness Computing command, the FILE-Open Results Binary File must be opened, and the layer interface identified as described above. COLORMAP processes the data in the defined section and stores the results in both the user-defined .RST file and .TXT file. The user can view the computed thicknesses or dielectrics by using the DISPLAY menu.

The .TXT file is automatically created when the user open a .RST file. The resulting text file uses the same name as the .RST file, but it uses a different extension (.TXT). To change to a new .TXT file name, the user should open the file in the File Open Results Text File option. An example of this .TXT file is shown in Figure 13.

Statistics Computing

The statistics option permits the user to define reporting intervals in the data file; for example, every 500 m or 0.5 mi. The system then calculates the low, mean, and high values of layer thickness and dielectric within these intervals. The computed values are stored in the .STA file, which was defined in the FILE pull-down menu. An example of a typical .STA file is shown in Figure 14.

Trace	Feet	Time1	Time2	Time3	Thick1	Thick2	Thick3	E1	E2	E3
91	6111	5.9	2.8	0.0	13.6	5.1	0.0	6.5	10.5	11.0
92	6117	5.9	2.5	0.0	13.8	4.4	0.0	6.5	11.0	12.0
93	6121	5.8	2.7	0.0	13.9	5.2	0.0	6.0	9.7	10.8
94	6127	6.0	2.7	0.0	14.1	5.1	0.0	6.3	9.7	11.5
95	6132	5.9	2.8	0.0	14.1	5.5	0.0	6.2	9.2	11.3
96	6139	6.2	2.6	0.0	14.5	5.2	0.0	6.3	8.5	10.1
97	6144	6.0	2.6	0.0	14.0	4.8	0.0	6.5	10.1	11.8
98	6150	5.9	2.7	0.0	13.9	5.3	0.0	6.1	9.2	10.1
99	6156	5.9	2.8	0.0	14.1	5.6	0.0	6.2	8.7	10.4
100	6160	6.0	2.7	0.0	14.4	5.7	0.0	6.1	8.0	9.5
101	6166	6.0	2.8	0.0	14.2	5.4	0.0	6.2	9.4	10.8
102	6170	5.9	2.9	0.0	14.1	5.2	0.0	6.2	10.8	12.4
103	6176	5.9	2.8	0.0	14.0	5.1	0.0	6.3	10.4	12.5
104	6181	5.9	2.7	0.0	14.0	5.3	0.0	6.3	9.2	10.7
105	6187	5.9	2.8	0.0	14.1	5.5	0.0	6.2	9.1	10.1
106	6192	5.9	2.9	0.0	14.0	5.5	0.0	6.3	9.5	10.6
107	6198	6.0	2.9	0.0	14.2	5.7	0.0	6.2	8.9	9.8
108	6203	6.0	3.0	0.0	14.2	6.0	0.0	6.2	8.6	9.1
109	6210	6.0	3.0	0.0	14.1	6.1	0.0	6.3	8.2	8.6
110	6214	6.1	2.7	0.0	14.0	5.3	0.0	6.6	8.7	10.0
111	6221	5.9	2.6	0.0	13.7	5.1	0.0	6.5	9.0	10.2
112	6226	5.9	2.7	0.0	13.7	5.3	0.0	6.5	9.4	11.2
113	6229	5.9	2.7	0.0	14.2	5.5	0.0	6.1	8.7	10.1
114	6235	5.9	2.9	0.0	14.0	5.8	0.0	6.2	8.7	10.2
115	6240	5.9	3.0	0.0	13.5	5.9	0.0	6.5	9.2	11.7
116	6246	5.9	2.9	0.0	13.8	5.8	0.0	6.5	8.7	10.7
117	6251	5.9	3.0	0.0	13.9	6.1	0.0	6.4	8.3	11.1
118	6258	5.9	3.0	0.0	13.6	5.9	0.0	6.5	8.7	10.4
119	6261	5.9	3.0	0.0	13.7	5.9	0.0	6.4	9.2	10.9

Figure 13. Typical .TXT File Created in the Thickness Computing Option.

Distance(Ft)		Layer 1 Thickness			Layer 2 Thickness			Layer 3 Thickness		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
6111-	6116	13.6	13.6	13.6	5.1	5.1	5.1	0.0	0.0	0.0
6116-	6121	13.8	13.8	13.8	4.4	4.4	4.4	0.0	0.0	0.0
6121-	6126	13.9	13.9	13.9	5.2	5.2	5.2	0.0	0.0	0.0
6126-	6131	14.1	14.1	14.1	5.1	5.1	5.1	0.0	0.0	0.0
6131-	6136	14.1	14.1	14.1	5.5	5.5	5.5	0.0	0.0	0.0
6136-	6141	14.5	14.5	14.5	5.2	5.2	5.2	0.0	0.0	0.0
6141-	6146	14.0	14.0	14.0	4.8	4.8	4.8	0.0	0.0	0.0
6146-	6151	13.9	13.9	13.9	5.3	5.3	5.3	0.0	0.0	0.0
6156-	6161	14.1	14.4	14.2	5.6	5.7	5.7	0.0	0.0	0.0
6166-	6171	14.1	14.2	14.2	5.2	5.4	5.3	0.0	0.0	0.0
6176-	6181	14.0	14.0	14.0	5.1	5.1	5.1	0.0	0.0	0.0
6181-	6186	14.0	14.0	14.0	5.3	5.3	5.3	0.0	0.0	0.0
6186-	6191	14.1	14.1	14.1	5.5	5.5	5.5	0.0	0.0	0.0
6191-	6196	14.0	14.0	14.0	5.5	5.5	5.5	0.0	0.0	0.0
6196-	6201	14.2	14.2	14.2	5.7	5.7	5.7	0.0	0.0	0.0
6201-	6206	14.2	14.2	14.2	6.0	6.0	6.0	0.0	0.0	0.0
6206-	6211	14.1	14.1	14.1	6.1	6.1	6.1	0.0	0.0	0.0
6211-	6216	14.0	14.0	14.0	5.3	5.3	5.3	0.0	0.0	0.0
6221-	6226	13.7	13.7	13.7	5.1	5.1	5.1	0.0	0.0	0.0
6226-	6231	13.7	14.2	13.9	5.3	5.5	5.4	0.0	0.0	0.0
6231-	6236	14.0	14.0	14.0	5.8	5.8	5.8	0.0	0.0	0.0
6236-	6241	13.5	13.5	13.5	5.9	5.9	5.9	0.0	0.0	0.0
6246-	6251	13.8	13.8	13.8	5.8	5.8	5.8	0.0	0.0	0.0
6251-	6256	13.9	13.9	13.9	6.1	6.1	6.1	0.0	0.0	0.0
6256-	6261	13.6	13.6	13.6	5.9	5.9	5.9	0.0	0.0	0.0
6261-	6266	13.7	13.7	13.7	5.9	5.9	5.9	0.0	0.0	0.0
6266-	6271	13.5	13.5	13.5	5.7	5.7	5.7	0.0	0.0	0.0
6271-	6276	13.5	13.5	13.5	5.4	5.4	5.4	0.0	0.0	0.0

Figure 14. Example of Output from the Statistical Computing Option.

2.5 DISPLAY PULL-DOWN MENU
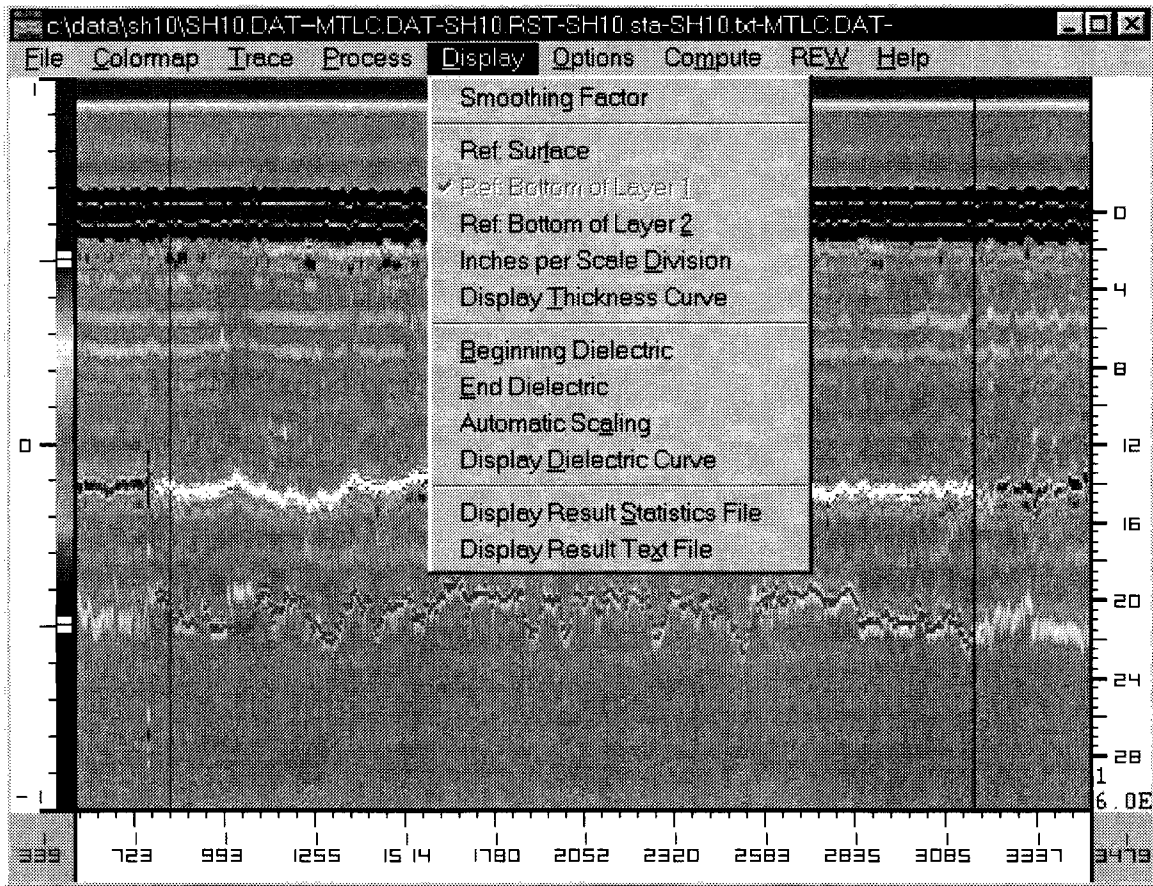
Figure 15. DISPLAY Pull-Down Menu Screen.

Objective

This option provides the user with flexibility in viewing and printing the thickness and dielectric plots and statistical information prior to printing.

Smoothing Factor

Smoothing Factor is the number of points used to average the display parameter. This rolling average procedure filters out some high frequency noise, thus allowing a smoother display curve.

The default value is 1 (no smoothing). This averaging function would be used if the result data are highly variable and the user wishes to identify trends.

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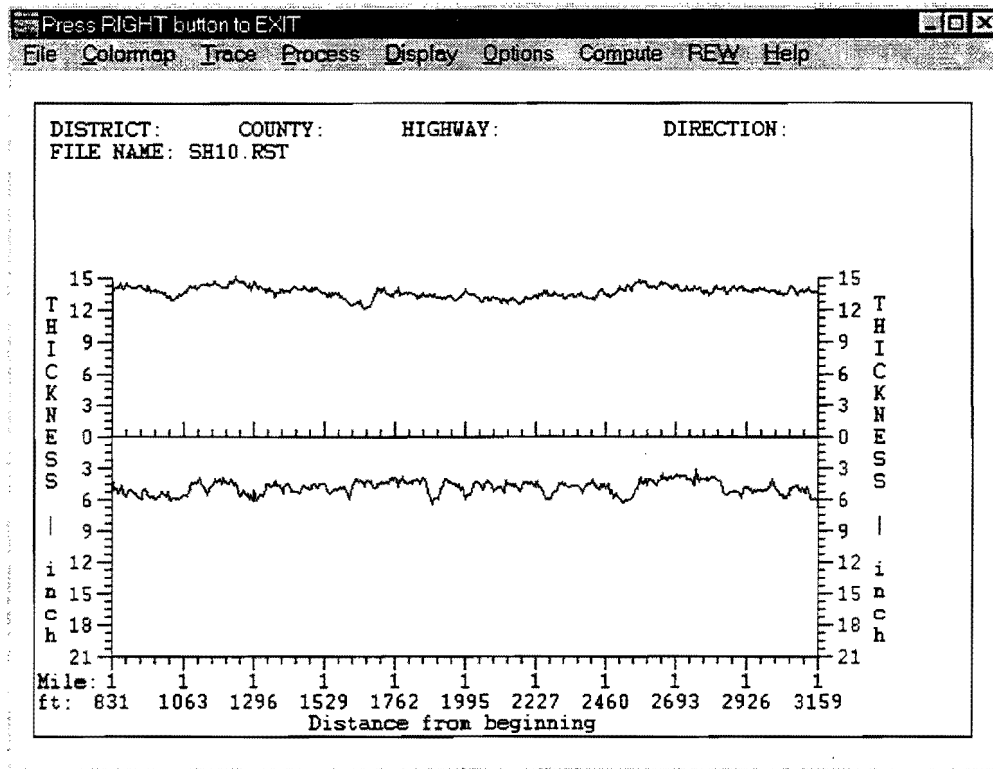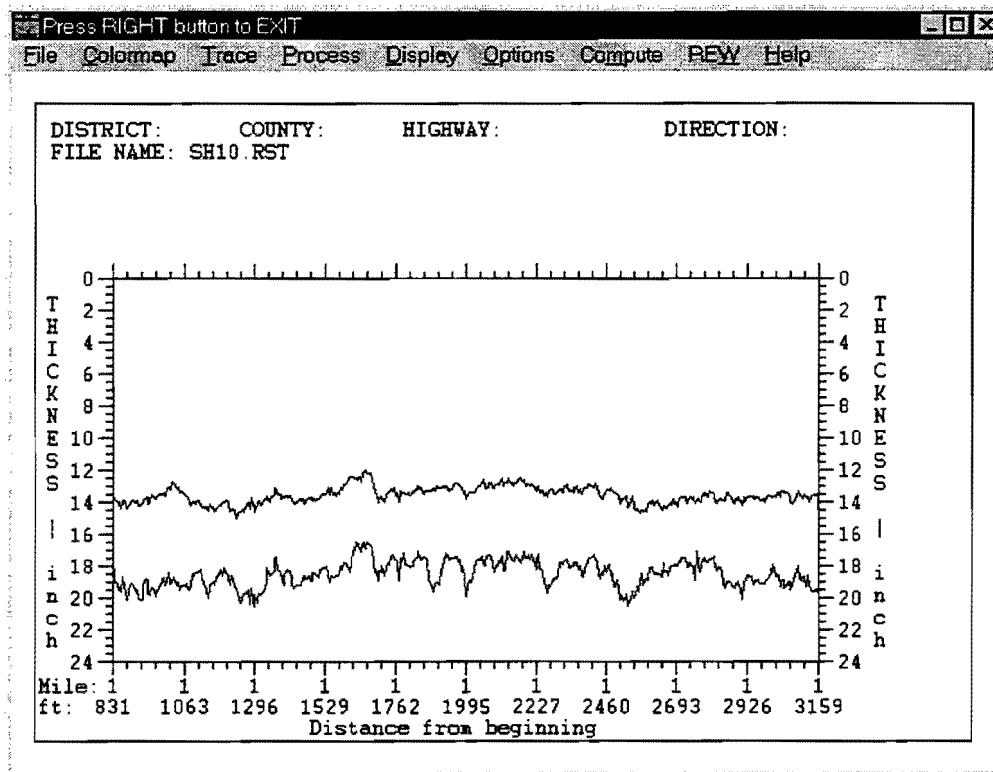
Figure 16. Thickness Plot (Ref. Bottom of Layer 1).

Ref: Surface

This command is one of the options available; it is used together with the Display Thickness Option described below. Clicking on this command will cause all thickness plots to be referenced to the surface reflection. The pavement surface will appear as a horizontal line at the top of the plot; see the top plot in Figure 16.

Ref: Bottom of Layer 1

Clicking on this command will cause all thickness plots to be referenced to the bottom of the first layer. The bottom of the first layer (top of the base) will appear as a horizontal line in the middle of the plot. See the lower plot in Figure 16.

Ref: Bottom of Layer 2

Clicking on this command will cause all thickness plots to be referenced to the bottom of the second layer. The bottom of the base layer will appear as a horizontal line at the bottom of the plot.

Inches per Scale Division

This option permits the user to change the thickness scale along the vertical axis of the Display Thickness Curve shown in Figure 16.

Display Thickness Curve

After doing the PROCESS-Thickness Computing step, the Display Thickness Curve option will cause a graph, similar to Figure 16, to appear on the screen. Clicking the right mouse button will return to the COLORMAP main screen. If a printed copy is desired, use the Print option in the FILE menu.

Beginning Dielectric

This option is used along with the Display Dielectric Curve option described below. It allows the user to set a lower limit on the vertical axis of the dielectric plot.

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End Dielectric

This option allows the user to set an upper limit on the vertical axis dielectric plot.

Automatic Scaling

This option lets the program decide on the vertical scale on all dielectric plots.

Display Dielectric Curve

This option plots the computed dielectric values along the section, between the selected beginning and end locations (see Figure 17). The user defines which layer to plot, 1 being the surface dielectric, 2 being for the base layer.
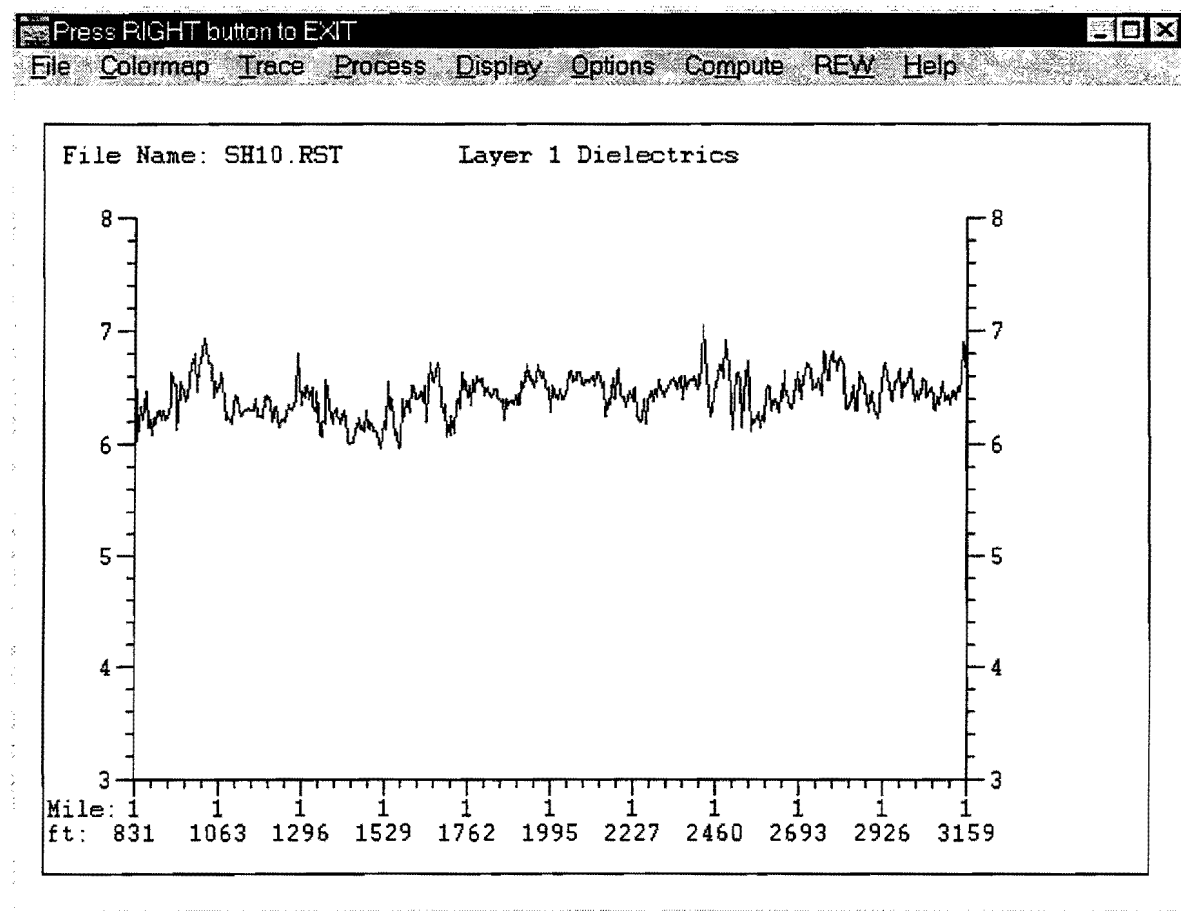
Figure 17. Dielectric Plot.

Display Result Statistics File

     This option displays the Result Statistics file on the screen (see Figure 14).

Display Result Text File

     This option displays the Result Text file on the screen (see Figure 13).

2.6 OPTIONS PULL-DOWN MENU
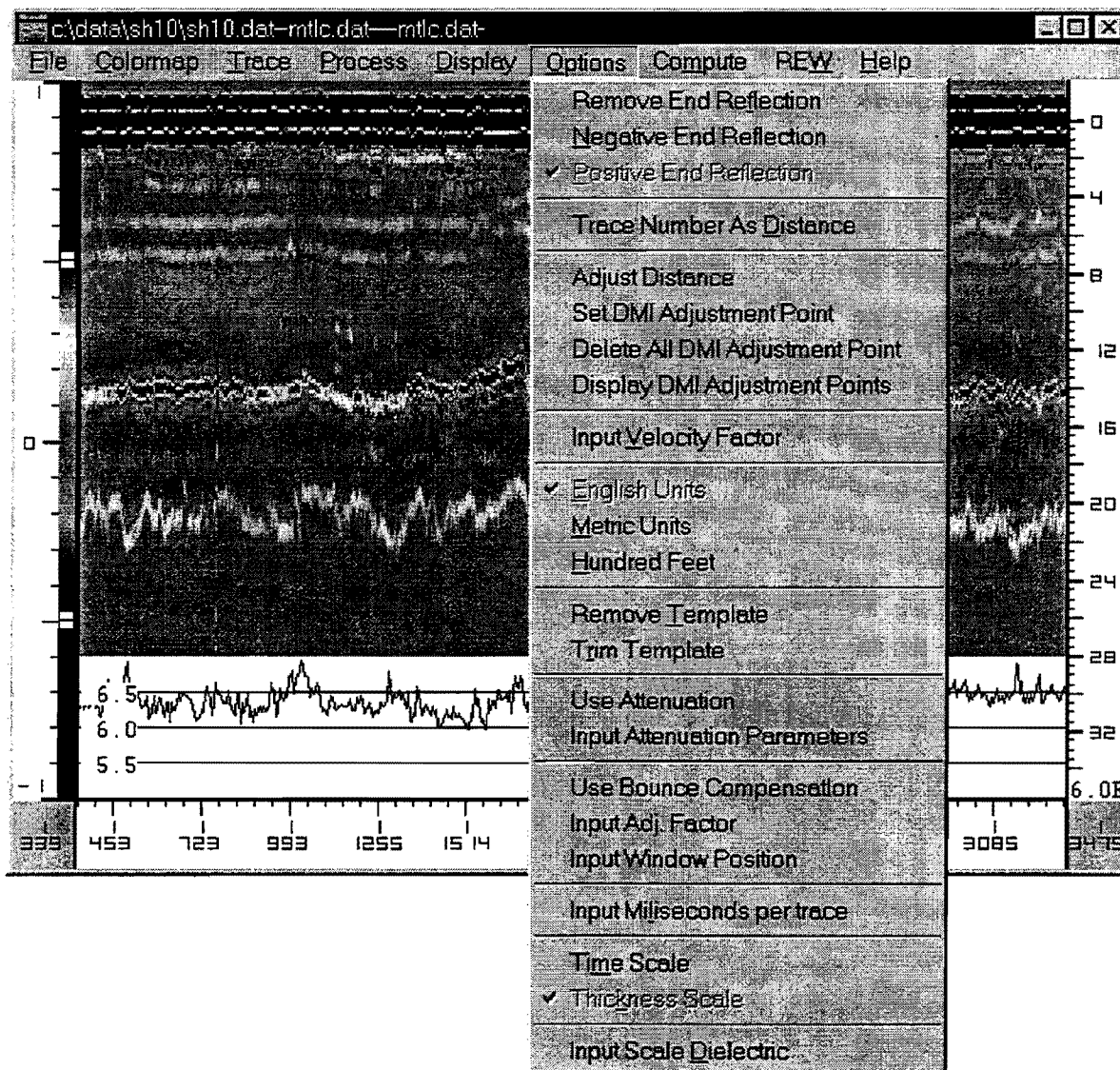
Figure 18. OPTIONS Pull-Down Menu Screen.

Objective

The OPTIONS pull-down menu provides the user with several options to clean up the input GPR waveforms prior to processing and display. The user should decide whether end reflection subtraction is required. Typically with monostatic antenna systems, end reflection subtraction should be used. Bistatic systems may not require end reflection subtraction. This decision is based on the size of the end reflection and the degree of overlap with the surface reflection.

Using OPTIONS, it is also possible to modify both the horizontal distance scale and the vertical depth scale on the color graphics display. A template subtraction can also be specified to remove the surface reflection so that thin layers can be detected.

This menu also provides flexibility in modifying the color graphics display. The changes made in the scale-related menu items only influence the depth scale at the right of Figure 18.

Remove End Reflection

With some horn antennas, it is essential to clean up the GPR waveform prior to signal processing. The simplest method is by use of the end reflection subtraction technique. An End Reflection file contains one or more "sky wave" traces where the antenna is pointed towards the sky and the no reflection waveform is captured and declared in the FILE pull-down menu. This waveform, therefore, contains only the internally generated system noise. If an End Reflection file is identified, then the Remove End Reflection option will be automatically activated. When activated, the end reflection trace is aligned and subtracted from each waveform, removing background noise from each data trace. Currently with bistatic systems, this option is not used.

Negative End Reflection

This option is used to specify how the end reflection will be aligned with the pavement GPR waveform. In performing the end reflection subtraction, the software automatically locates the maximum positive reflection from the Pavement Data file, which is assumed to be the surface reflection. In this option, the software then aligns the largest negative reflection prior to the surface reflection with the largest negative peak in the end reflection trace.

The user must decide whether end reflection subtraction is warranted and whether a positive or negative peak match should be used. This second decision is based on the shape of the end reflection waveform.

Positive End Reflection

This option is identical to the Negative End Reflection option discussed above, but this time the software looks for a positive end reflection match. The positive match is the default setting.

Trace Number as Distance

Under normal operations, the horizontal scale on the color display is the distance along the highway, as measured by the system DMI device. However, in some instances, if a DMI is not available, the user can use trace numbers as the distance scale.

Adjust Distance

Checking or unchecking this item allows the selection of whether or not the distance adjustment will be used. Using this option the distance scale can be changed to highway reference markers (mileposts).

This option changes the distance markers at the bottom of the color graphic display to match the actual field mileposts. For example, the starting position in the GPR file may correspond to Reference Milepost 634 +00 in the field. With the current system, the DMI is measured in feet from a known starting location.

The starting point, the adjustment points, and the ending point divide the file into n+1 DMI adjustment sections (n is the total number adjustment points). The program automatically offsets and linearly rescales the DMI information on the output color display for each section. Only offset is applied to the first and last section. For the other sections, the surrounding two adjustment points decide the offset and gain factor.

Note that this selection is for display and output purposes only; it makes the referencing system match the field referencing system. The data in the GPR file are not changed. If the user wants the data in the file to be changed, "FILE – Save DMI Adjusted File" can be used. However, it is good practice not to overwrite the original file.

Set DMI Adjustment Point

After Adjust Distance has been selected, this option lets the user define the new DMI information. This option allows the user to input one DMI adjustment point. Activate with the left button, then use the mouse to move the vertical red line to the desired location. Next, click on the exact location. Finally, input the new DMI for that location. Repeat for each reference location; a maximum number of 15 adjustment points are allowed.

Note that an adjustment point can be inserted into any location regardless of previously input points. The program will automatically sort all points in an increasing order.

Delete All DMI Adjust Points

This option resets the number of DMI adjustment points to zero.

Display DMI Adjustment Points

In a pop-up window, for each adjustment point, the trace number, original DMI, and new DMI will be displayed.

Input Velocity Factor

This factor is the system measured speed of the GPR wave as measured in air in inches per nanosecond of two-way travel. The speed of an electromagnetic wave in air is 5.9 in per ns (two-way travel). The velocity as measured by the system should be close to this value. It is calculated using the time calibration procedure described in TTI Report 1233-1, which involves capturing metal plate reflections at different heights and comparing the increased travel time to the distance traveled (1).

As a systems check, this calibration factor should be calculated every six months; however, this factor should not change significantly. If it does, the system may require servicing.

English Units

Select the English Units (in, ft, mi) for the thickness, distance (x-axis), and statistical data to be displayed. The default is preset to be English.

Metric Units

If the desired units to be used are metric (mm, m, km), select the Metric Units option. It will override the default English units.

Hundred Units

The distance will be in stations (100 ft intervals). This selection is useful when tying the GPR data to plan sheets which use station numbers.

Remove Template

This option is used whenever the surface thickness is less than 3 inches. The Template file contains a GPR trace from either a pavement with a thick homogeneous surface layer or from the metal plate reflection. The Metal Plate file is automatically used as the default Template file. This may be overwritten in the FILE menu. The shape of the trace in the Template file is used to remove the surface reflection from a Pavement Data file suspected of having a thin surfacing layer. Use the left button to activate this option. To turn the subtraction off, the user must click on the Remove Template option.

When the Remove Template is activated, the user will observe the following two changes to the system:

1. In the COMPUTE pull-down menu, once the surface reflection maxima and minima have been located, the template reflection is automatically subtracted and the new trace displayed. All subsurface peaks are then located on the resulting trace.

2. On the color graphics display, the display will show the waveforms after subtraction. The surface of the pavement will be positioned at the top of the screen.

It is recommended that this option be activated for most applications, particularly with older pavements containing overlays.

Trim Template

This option permits the user to decide what amount of the template trace to use in the subtraction process. Once activated, the template trace will be displayed. To trim a template trace, click the left mouse button on the left side of the trace, and click again on the right side of the trace; after this, the trace outside of the identified area will be set to zero volts. An example of a trimmed template is shown in Figure 19. Click the right mouse button to exit the command.
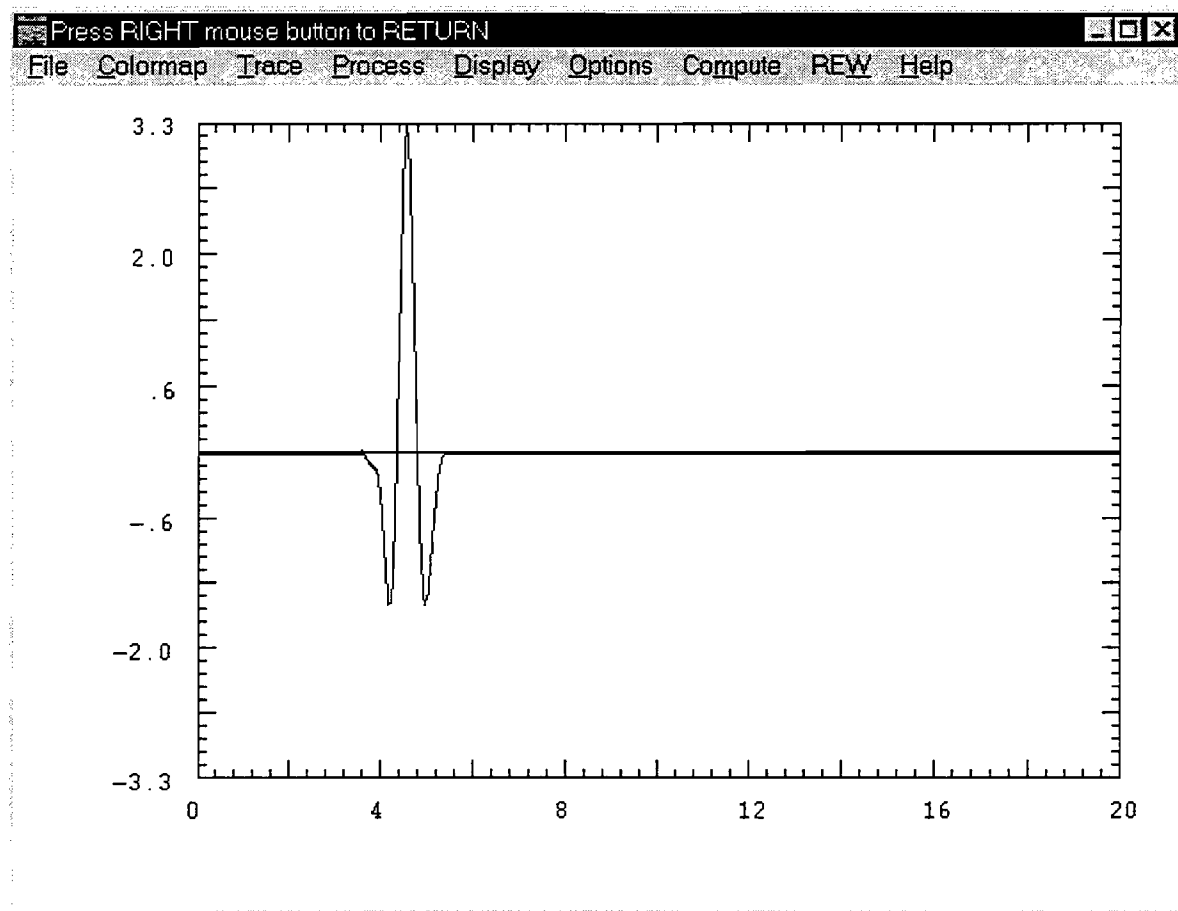
Figure 19. Typical Trimmed Waveform Used in Template Subtraction Process.

Use Attenuation

Checking this menu item will enable the attenuation compensation routine to be used during single trace computing or multiple trace thickness computing. This feature is experimental and should not be used at this time.

Input Attenuation Parameters

The equations used to calculate layer dielectrics and thicknesses do not account for attenuation of the signal as it passes through the layer. With some materials, attenuation is minor (HMAC and dry base), but with others, it can be significant (concrete). Failure to account for attenuation will introduce errors in predicting the lower layer dielectrics. The lower layer dielectric will be underestimated and the lower layer thicknesses overestimated.

In this option, the percentage loss in volts per inch of travel through the layer is input. This percentage is based on laboratory results at TTI. For some materials (flexible base), it is proposed that the percentage loss is a linear function of the real part of the dielectric. Therefore, slope and intercept values are input. For a flexible base, values of 1.187 percent and −4.25 percent are proposed. For asphalt and concrete materials, fixed values appear reasonable; values of 1.76 percent and 4.3 percent per inch are recommended. The asphalt and flexible base values are used as defaults.

When this item is selected, a dialog window appears with these factors. These factors can be overwritten by the user. This option is viewed as experimental and should not be routinely used.

Use Bounce Compensation

This option will activate the antenna bounce function. Bounce Compensation was called "Height Function" in the previous TTI GPR data processing program, DACQ. This feature permits the user to correct for antenna bounce as the vehicle moves along the pavement. Effectively, this option adjusts the metal plate amplitude for every trace.

Input Adj. Factor

The bounce compensation adjustment factor is obtained for a GPR through a high calibration test, as described in TTI Report 1123-1 (1). In the test, a linear approximation relation between the

height of the antenna and the amplitude of the reflection from a metal plate is established. The height of the antenna is computed from the time interval between the end reflection and surface reflection. The slope of the line is input in units of volts/ns. A typical value is −1.52 volts/ns, but it must be calculated for each antenna.

Input Window Position

The antenna bounce compensation is dependent on getting the time between end reflection and the surface reflection. Therefore, finding a constant end reflection peak is essential. By examining radar traces from both metal plate and pavement, the user should be able to identify a constant peak in the region of 1 ns before the surface peak. The program will search for a peak of 0.5 ns from the user's input position. The selection of menu item Positive End Reflection or Negative End Reflection will decide whether the program is searching for a positive or a negative peak.

Input Milliseconds per Trace

The default value is set to 20 ns. If the collected GPR trace has a different time scale, then this new scale can be entered in this option. This action will change the scale at the right hand side of the color display; it will also affect all thickness calculations.

Time Scale

The default setting for the vertical scale at the right of the color display is depth in inches. By selecting this option, this scale will become time in nanoseconds. The scale can be moved up and down by clicking and holding down the left mouse button and moving it up or down. The zero position on both the time or thickness scale is normally aligned with the surface reflection, which is a solid red line near the top of the screen.

Thickness Scale

This setting is the default setting where the vertical scale is in terms of depth in inches. The depth scale is calculated by using the two parameters input on this menu, namely the Input Dielectric value and the Input Milliseconds per Trace. The scale can be moved up and down by clicking and

holding on it with the left mouse button and moving it up or down.

Input Scale Dielectric

The default value of this dielectric is preset to six, which is a reasonable value for an asphalt pavement. However, if the scale on the right needs to be adjusted, it is done by changing the dielectric value. For example, for a concrete pavement, a value of eight is recommended.

2.7 COMPUTE MENU

Objective

This is a short cut to the menu item "TRACE--Compute One Trace." This menu permits the user to select and process any single GPR trace. Once selected, the trace is displayed on the screen, and the user defines the peaks to be used in the dielectric and thickness computation. The computed values will be displayed in the box at the top of the screen. The user decides if these values are reasonable and representative of the section. The accepted dielectric results are stored and used in the computation of thickness for the entire section.

Computing Dielectrics and Thicknesses for One Trace

An open Metal Plate file or a manually entered metal plate amplitude is a requirement to run this function. Once selected, the user moves the cursor to the trace to be processed. When the left mouse button is clicked, the individual GPR return waveform is displayed (Figure 20). The user then uses the mouse to move the crosshair to the peaks to be used in the dielectric calculation process. For each peak, a maximum and a minimum must be identified so that the amplitude of reflection can be calculated. This amplitude will be compared with the metal plate amplitude to perform the dielectric calculation. The time between selected peaks is used in the thickness calculation.

Under normal operating conditions, when the layer dielectrics increase with depth, the positive peak is identified first, followed by the negative peak. The left button is used to select the peaks, first the positive and then the negative. Once all the peaks are selected, the right button is pressed, and the computed dielectrics and thicknesses are displayed in the box in the upper right-hand corner of the display. For the surface reflection, it is recommended that the minima be selected

on the left side of the surface peak; for all subsequent peaks, the minima should be selected on the right side of the maxima. An example of this, together with the computed values, is shown in Figure 20. These recommendations on side selection are intended to minimize problems with thin surfacings where the surface and first layer reflections are close enough together to distort the overlapping portions of the wave.

Layer	1	2	3	4
Amplitude	3.3	0.6	0.3	
Dielectric	6.5	9.3	11.4	
Thickness	14.2	5.4		
Travel Time	6.1	2.8		

Trace	540
Mile	1
Feet	3180

Cursor	
Voltage	0.6
Time	8.5

Peak	1	2	3	4
Voltage 1	2.2	0.3	0.2	
Time 1	4.8	10.9	13.7	
Voltage 2	-0.9	-0.1	0.0	
Time 2	4.5	11.3	14.2	
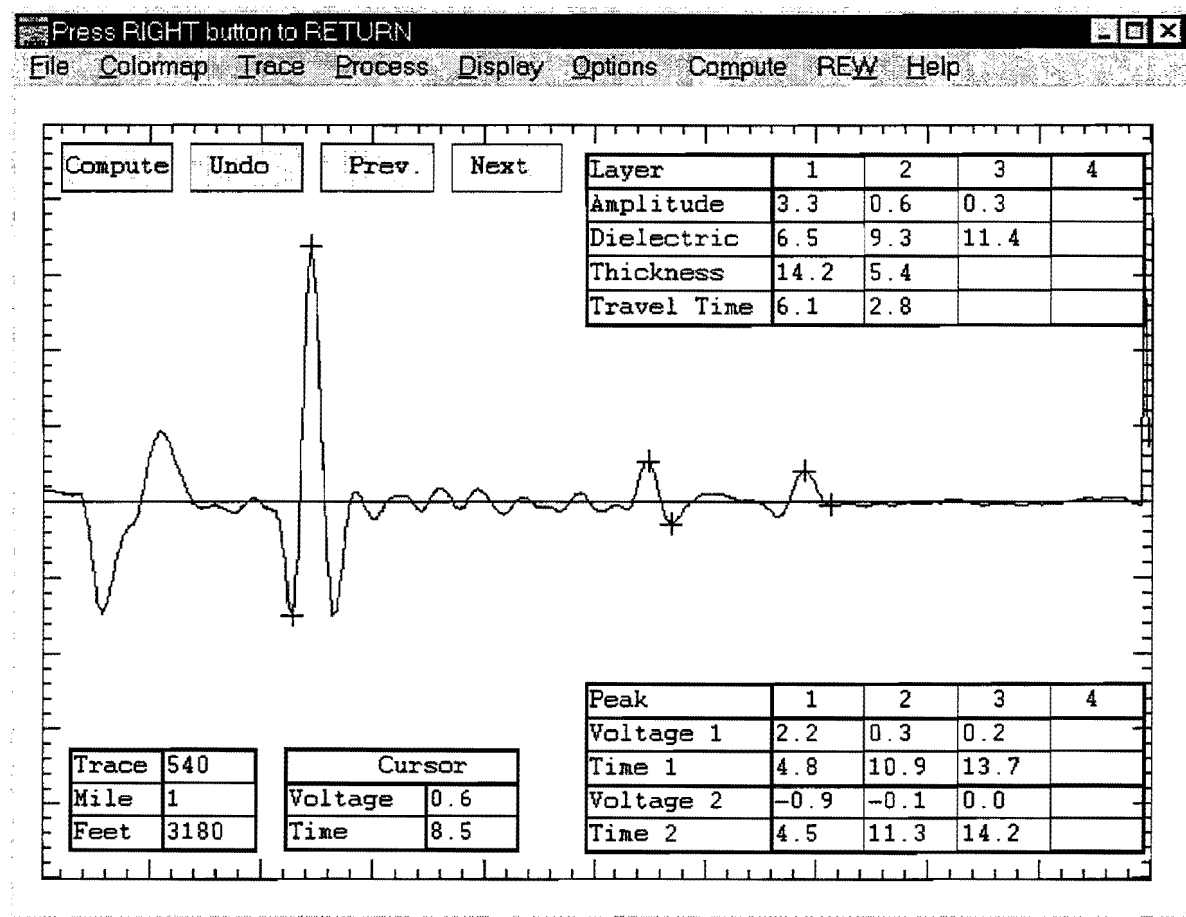
Figure 20.   GPR Trace with User-Defined Peaks with the Computed Dielectrics and Thickness.

In some rare instances, the layer dielectrics do not increase with depth. Sometimes a negative reflection is observed in the trace. This reflection has been observed with some unusual asphalt layers, such as sand asphalt. For negative reflections, the negative peak must be identified first followed by the positive peak. In this instance, the computed lower layer

dielectric will be less than calculated for the upper layer.

If Remove Template has been selected in the OPTIONS pull-down menu, then after the surface reflection has been identified, the template will be subtracted from the waveform. The resulting waveform will be displayed on the screen; all subsequent peaks must be defined on this waveform.

Once the calculations have been made, the user must decide whether the calculated dielectrics are acceptable. If the OK button is chosen, these values will be used to update the Section Layer Dielectrics table discussed earlier. With experience, the user will recognize reasonable values for layer dielectrics. From Texas experience, the dielectric for a hot-mix asphaltic concrete layer should be between 5.5 and 6.5, and Portland cement concrete should be between 6 and 8. Dielectrics outside these ranges should be reviewed. The four boxes in the upper left corner of Figure 20 have the following functions:

Compute Box:	Cause the computer to calculate the dielectrics and thicknesses.
Undo Box:	Clear all peak selections and reset the display.
Prev. Box:	Read in the previous trace for computing.
Next Box:	Read in the next trace for computing.

To return to the COLORMAP display, hit the right button.

CHAPTER 3
COLORMAP HELP MENUS

INTRODUCTION

Interpreting GPR data can be complex, particularly with older pavements which may have received multiple maintenance treatments. In order to assist TxDOT in interpreting these reflection patterns, a series of HELP menus has been developed. These menus are based on field investigations conducted in Texas from 1995 to 1999. In each case, the pavement condition was verified by field coring and, in some instances, additional laboratory testing.

To activate the help menu system, the HELP menu option is selected from the main COLORMAP screen (Figure 6) by using the left mouse button. By selecting the Contents option, a list of 20 different case studies is displayed. The titles of these studies are shown in Figure 21. For example, Case Study 1 is taken from a Thick Hot-Mix Asphaltic Concrete pavement (thick HMAC) over a granular base with no defects apparent in the GPR data. To select any particular case study, the user points to it with the computer mouse and clicks the left button. For each study, the HELP menu provides a COLORMAP display and information about typical GPR traces for the specified case. In general, each case study is broken into the following four subsections:

1) <u>General</u>

A discussion of the problem. This discussion may be a description of the defect or a general discussion of where and when this condition has been found in Texas.

2) <u>COLORMAP Display</u>

For each case, an annotated COLORMAP display is printed together with a discussion about the significant features in the color scheme. Each significant reflection is identified as a layer interface or possible defect. In several instances, the COLORMAP display is shown after template (surface) removal; in this instance, the surface of the highway is automatically set as the horizontal line at the top of the figure.

≈ Colormap Help

TTI
radar

Texas Transportation Institute, Texas A&M University System

Introduction
Colormap is a user friendly window driven software package for processing Ground Penetrating Radar waveforms. It is intended for highway engineers who wish to obtain subsurface information from pavement structures.

Case Studies
1. Thick HMAC -- Granular Base -- No Defects
2. Thick HMAC -- Moisture at Interface within HMAC
3. Thick HMAC -- Stripping at the Bottom HMAC
4. Thick HMAC -- Stripping within HMAC
5. Thick HMAC -- Metal Wire Reinforcement at Mid-depth
6. Thin HMAC -- Granular Base -- No defects
7. Thin HMAC -- Stabilized Base -- Moisture in Base
8. Thin HMAC -- Flexible Base over Old HMAC
9. Thin HMAC -- Granular Base -- Localized Wet Spots
10. Thin HMAC -- Granular Base -- Poor Low Density Base
11. Thin HMAC -- over HMAC -- no defects
12. Thin HMAC -- over HMAC -- Moisture at interface
13. HMAC -- over PCC -- Good condition
14. HMAC -- over PCC -- Stripping in lower HMAC
15. Plant Mix Seals -- on the Surface or Buried beneath Overlays
16. Light-weight Aggregate Layers
17. Chip Seal -- Moisture Trapped Beneath a Surface Seal
18. Poor Longitudinal Construction Joints
19. Segregation in a New HMAC Overlay
20. Jointed Concrete -- Water Filled Voids

Figure 21. COLORMAP Help - Menu.

3) <u>Typical Trace</u>

A typical trace from the COLORMAP display is shown. A number sequence is also shown identifying how the reflection amplitudes were defined in order to compute the layer thicknesses and dielectrics. This selection process was described in Chapter 2. Under normal operation, the surface reflection is defined as the amplitude in volts from the positive peak to the preceding negative, whereas the positive and trailing negative are used for all lower layer reflections. This convention was adopted to minimize problems when the surface layer is thin. The box in the upper right corner of this figure shows the measured amplitudes (in volts) and time delays (nanoseconds), as well as the computed layer thicknesses and dielectrics.

4) <u>Core</u>

This describes what the user would find if a core was taken at the same location as the individual trace.

The following pages show the on-line help menus as they appear in COLORMAP.

CASE 1 THICK HMAC–GRANULAR BASE, NO DEFECTS

General

Typical GPR data from a homogeneous thick HMAC with no problems in any of the HMAC lifts.

COLORMAP

With the typical COLORMAP color-coded displays, strong positive (blue-red-blue) reflections should be observed indicating the top and bottom of HMAC layer. No major intermediate peaks within the layer indicate that the asphalt layer is homogeneous.
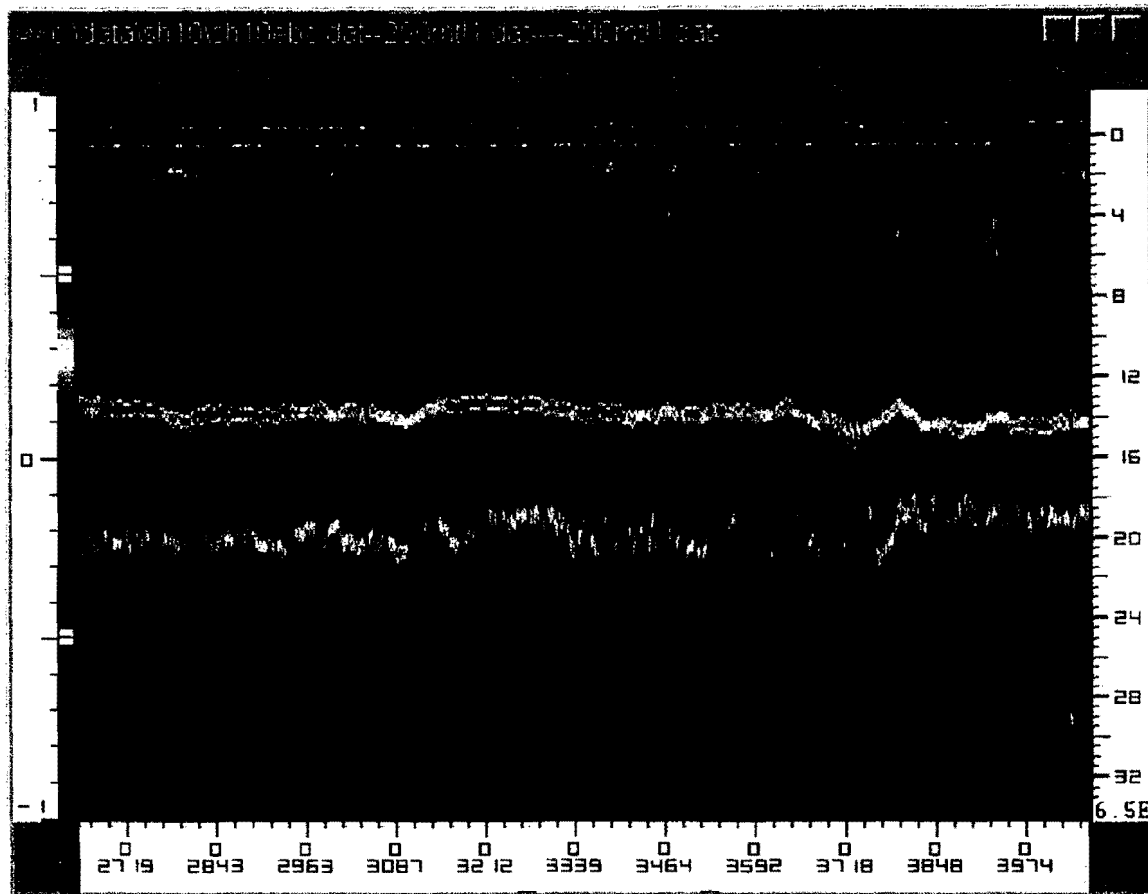
Typical Trace

Clear positive peaks at layer interfaces and no significant intermediate reflections. To make the thickness and dielectric calculations within COLORMAP, the user identifies the layer amplitudes as shown on the trace. (1) and (2) define the amplitude of surface reflection, (3) and (4) the amplitude of reflection from the top of the base, (5) and (6) from the top of the subgrade. The computed results are shown in the box in the upper right corner.
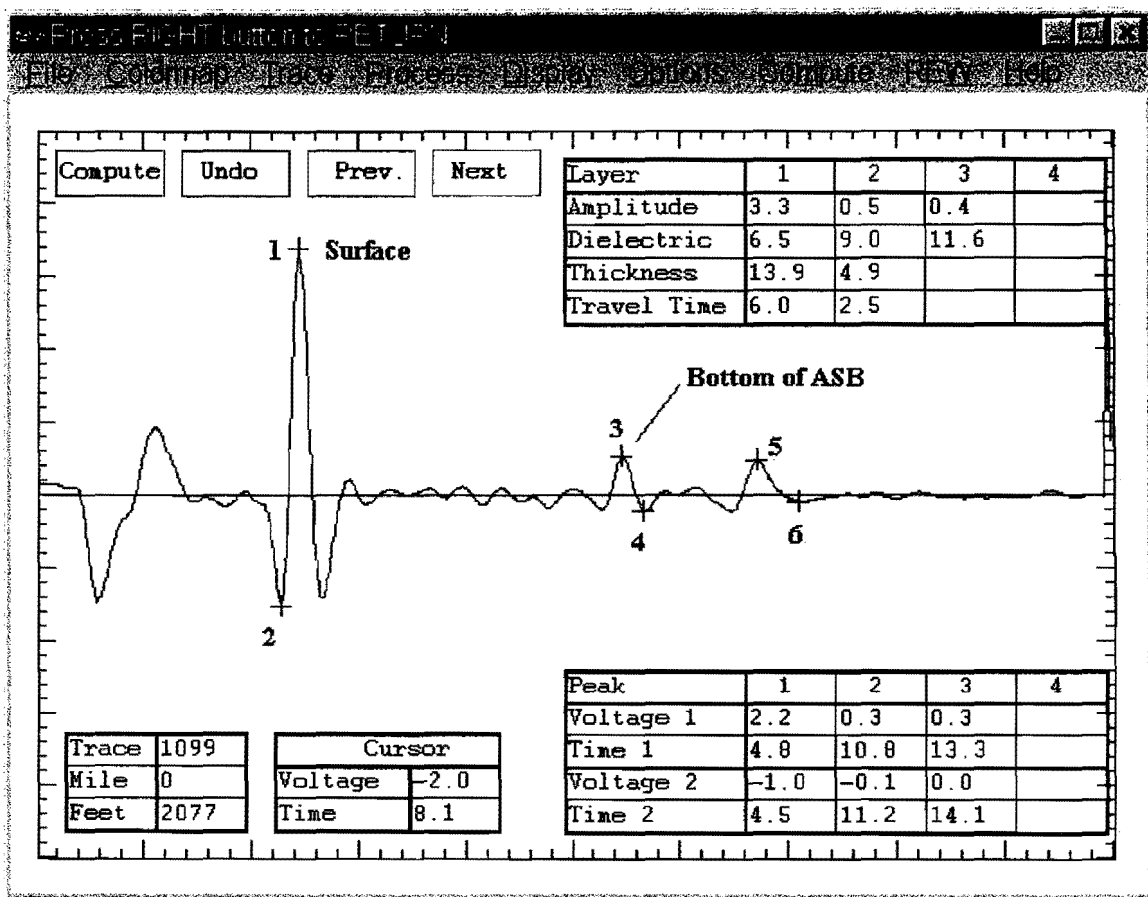
Core

With GPR data such as these, there should be no problem within this layer; solid cores should be obtained. The accuracy of thickness prediction is ±3 percent.

CASE 2 THICK HMAC–MOISTURE AT INTERFACE WITHIN HMAC

General

Observed frequently after rainfall. It indicates that a thin layer of moisture is trapped above a less permeable HMAC layer, chip seal or fabric layer. It appears that moisture enters the asphalt layers through either construction joints or permeable upper layers. This moisture builds up at a lower layer interface within the HMAC. This build-up could be a problem if the moisture becomes trapped and the upper layer is susceptible to stripping.

COLORMAP

When a thin layer of trapped moisture is present, it is observed as a strong red reflection immediately followed by a strong blue. The red reflection is from the top of the wet layer (transition from low to high dielectric); the blue is an indication of the wave entering normal asphalt (high to low dielectric). If the layer is thin, these reflections will overlap causing the blue to immediately follow the red. These patterns could be intermittent several days after rain or constant through the entire selection (for example, open graded layer over fabric immediately after rain). If the reflection is primarily blue, this could indicate a different problem, such as stripping with HMAC see Case Study 4.
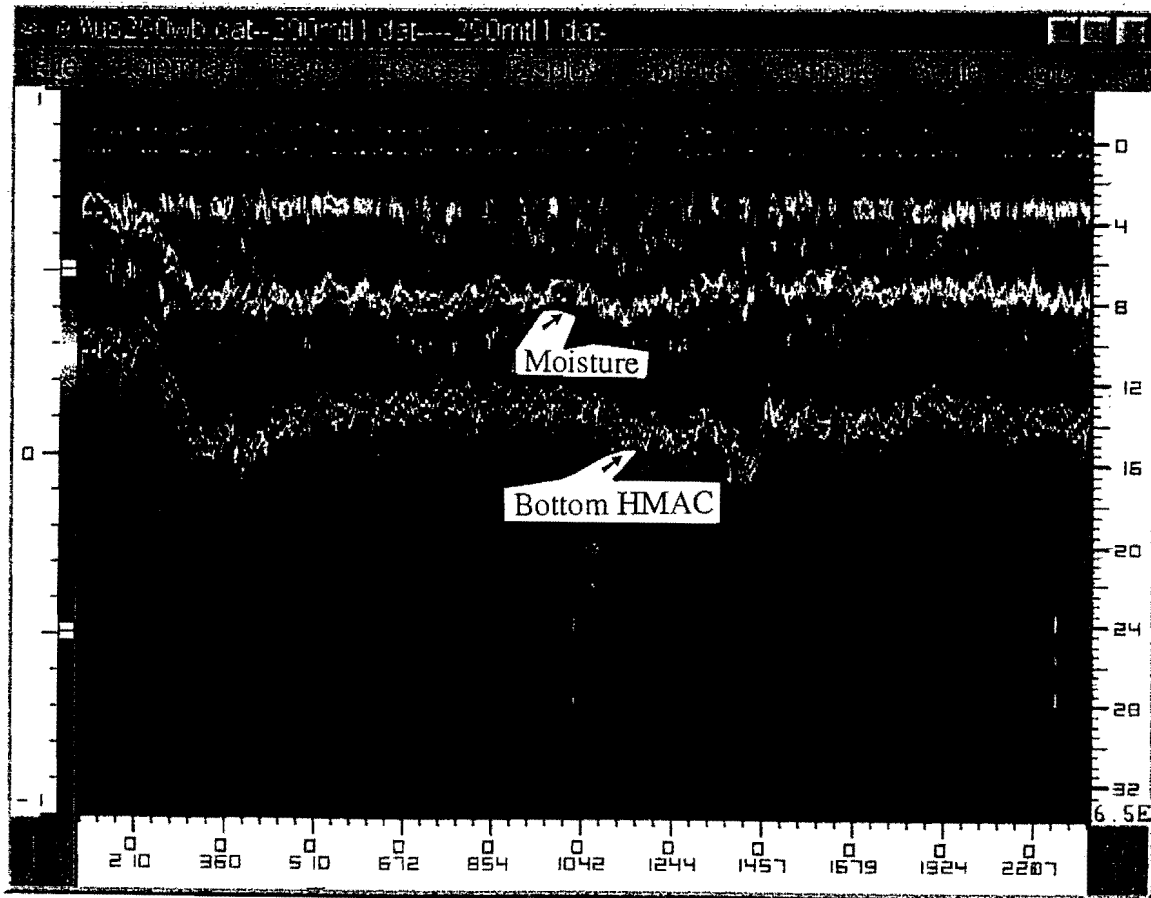
Trace

To calculate the dielectrics and thickness of this wet layer and the dielectric of lower asphalt layer (use positive (3), preceding negative (4), then negative (5), trailing positive (6)).

In this trace, the bottom 0.8 in of the upper HMAC layer has a high dielectric of 9.7. The lower 4.2 inch of the HMAC layer has reasonable dielectric of 6.6.

Software screen showing:

Buttons: Compute | Undo | Prev. | Next

Layer	1	2	3	4
Amplitude	3.5	0.6	-0.5	1.2
Dielectric	6.5	9.7	6.6	
Thickness	7.5	0.8	4.2	
Travel Time	3.2	0.4	1.8	

Trace	276
Mile	0
Feet	871

Cursor	
Voltage	0.7
Time	11.7

Peak	1	2	3	4
Voltage 1	2.4	0.5	-0.5	0.8
Time 1	5.0	8.3	8.7	10.5
Voltage 2	-1.1	-0.1	0.0	-0.3
Time 2	4.5	7.8	9.1	10.9
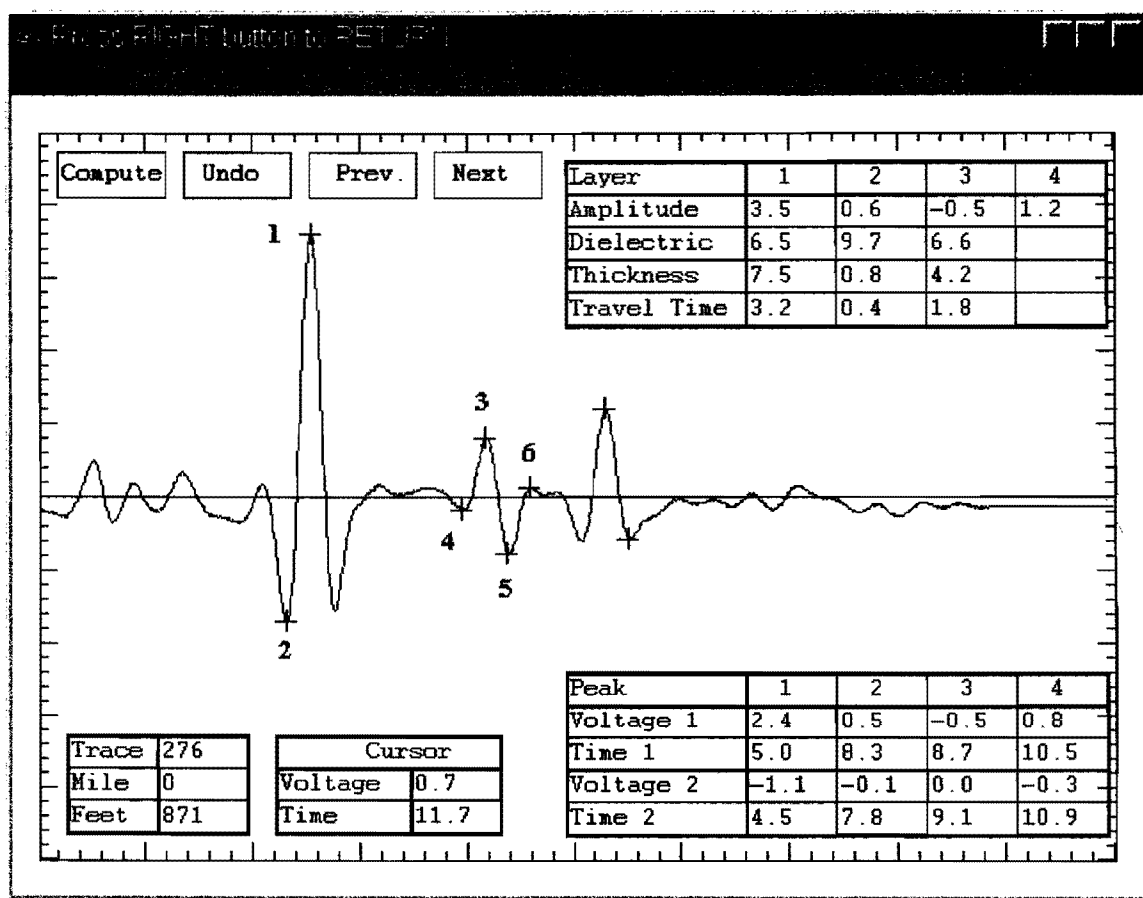
Core

A solid core is usually extracted. For the example shown above the interface 7.5 to 8.5 inches below the surface should be checked for moisture damage.

CASE 3 THICK HMAC–STRIPPING AT THE BOTTOM HMAC

General

Occurs in older pavement with multiple overlays; the deterioration often occurs in old buried HMAC layers.

COLORMAP

Dark blue then red (or yellow) pattern at the bottom of HMAC. Stripping is usually observed as an intermittent problem. A constant reflection pattern is probably not stripping; a uniform blue/red interface could indicate a light-weight aggregate or an open-graded layer.
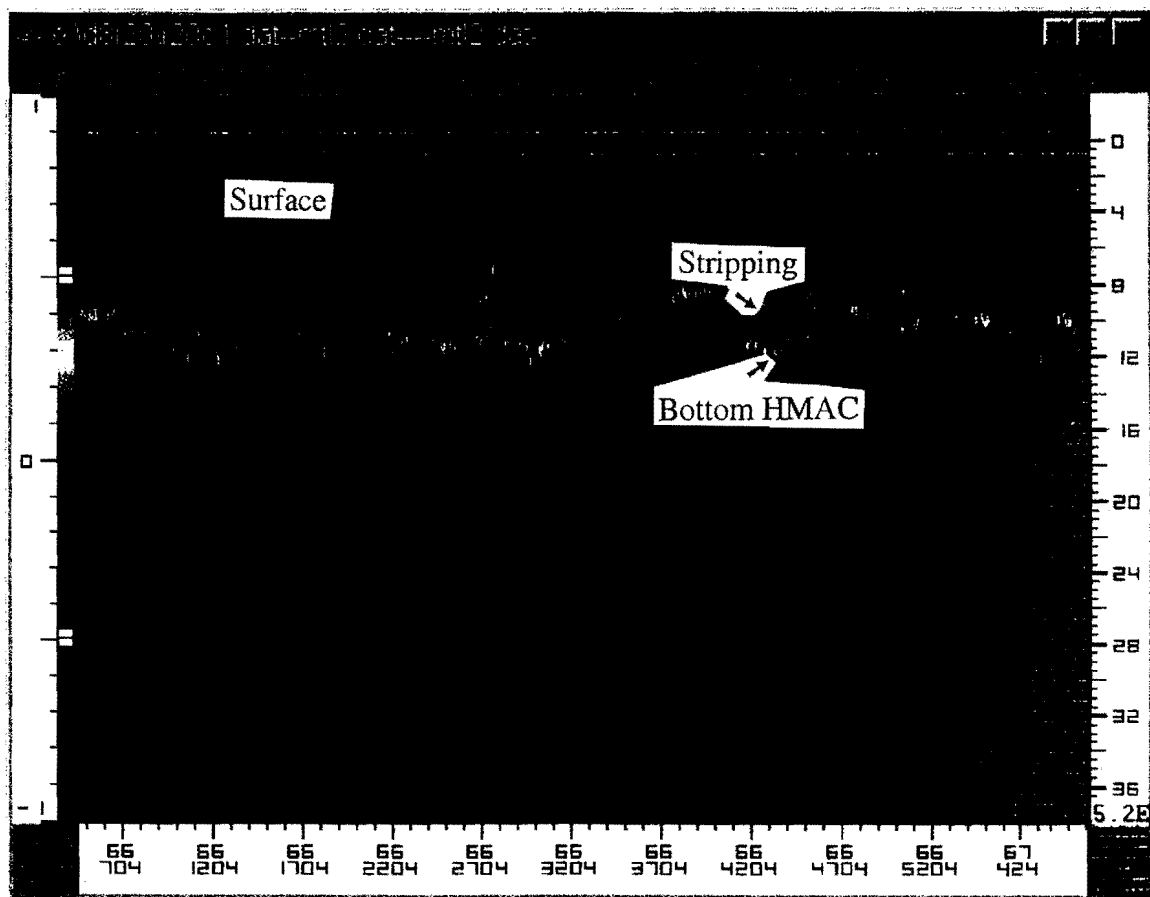
Trace

Reflections at the bottom of layer are overlapping negative and positive. The negative indicates that the wave has entered a layer with lower dielectric.

| Compute | Undo | Prev. | Next |

Layer	1	2	3	4
Amplitude	3.5	0.6	0.5	
Dielectric	5.2	7.1	9.0	
Thickness	9.1	2.2		
Travel Time	3.5	1.0		

Trace	35323
Mile	66
Feet	4334

Cursor	
Voltage	-1.4
Time	12.0

Peak	1	2	3	4
Voltage 1	2.2	0.0	0.2	
Time 1	5.0	8.5	9.4	
Voltage 2	-1.2	-0.5	-0.1	
Time 2	4.5	9.0	10.0	
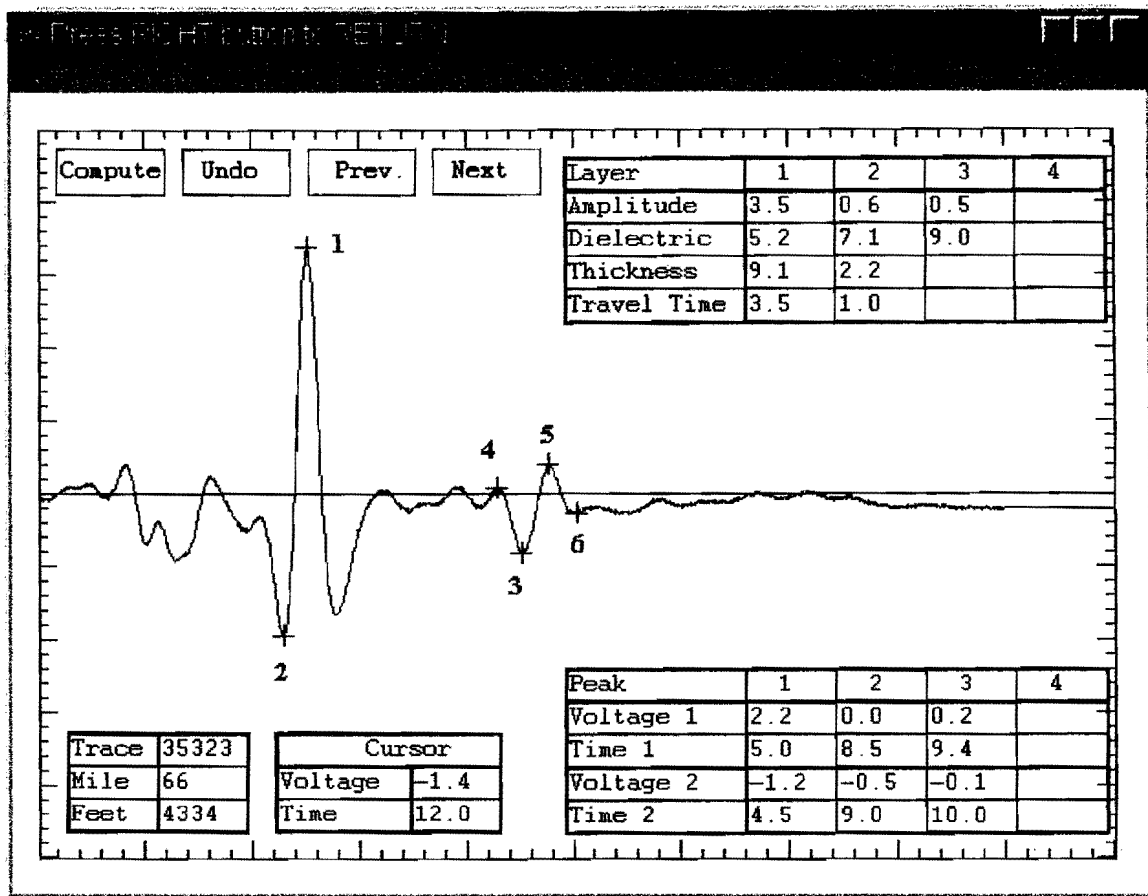
Core

A core is required to confirm the stripping condition. In the above case, the bottom of the core was disintegrating. However, a similar GPR pattern is obtained with unusual mixes and aggregates. For example, buried light-weight aggregate hot-mix, sand asphalt layers, or drainage layers will produce similar reflections. The key to identifying stripping is that the pattern is intermittent along the project.

CASE 4 THICK HMAC–STRIPPING WITHIN HMAC

General

Severe stripping is observed as a negative reflection (red/blue/red). The larger the negative, the more severe the deterioration. Be careful: negative reflections can also be found with buried light-weight aggregates, sand asphalts, and some drainage layers. Also be careful not to get confused with moisture at a lower layer interface. One important feature is that stripping is often intermittent. For near surface problems, it is critical to remove the surface reflection with the Surface Subtraction (Remove Template) option.

COLORMAP: After Surface/Template Subtraction

After surface removal, COLORMAP displays the surface as the flat line at the top of the display. The blue reflection at the left of the figure (Location 0+2266) is approximately at the mid-depth of the HMAC layer. Coring confirmed this to be a stripped layer. The stripping problem moved closer to the surface in the remainder of the project. In general, a stripping problem is usually found to be intermittent throughout any project. If a strong constant blue reflection is found throughout a project, then this problem is probably not stripping but rather an unusual aggregate or very low density dry layer.
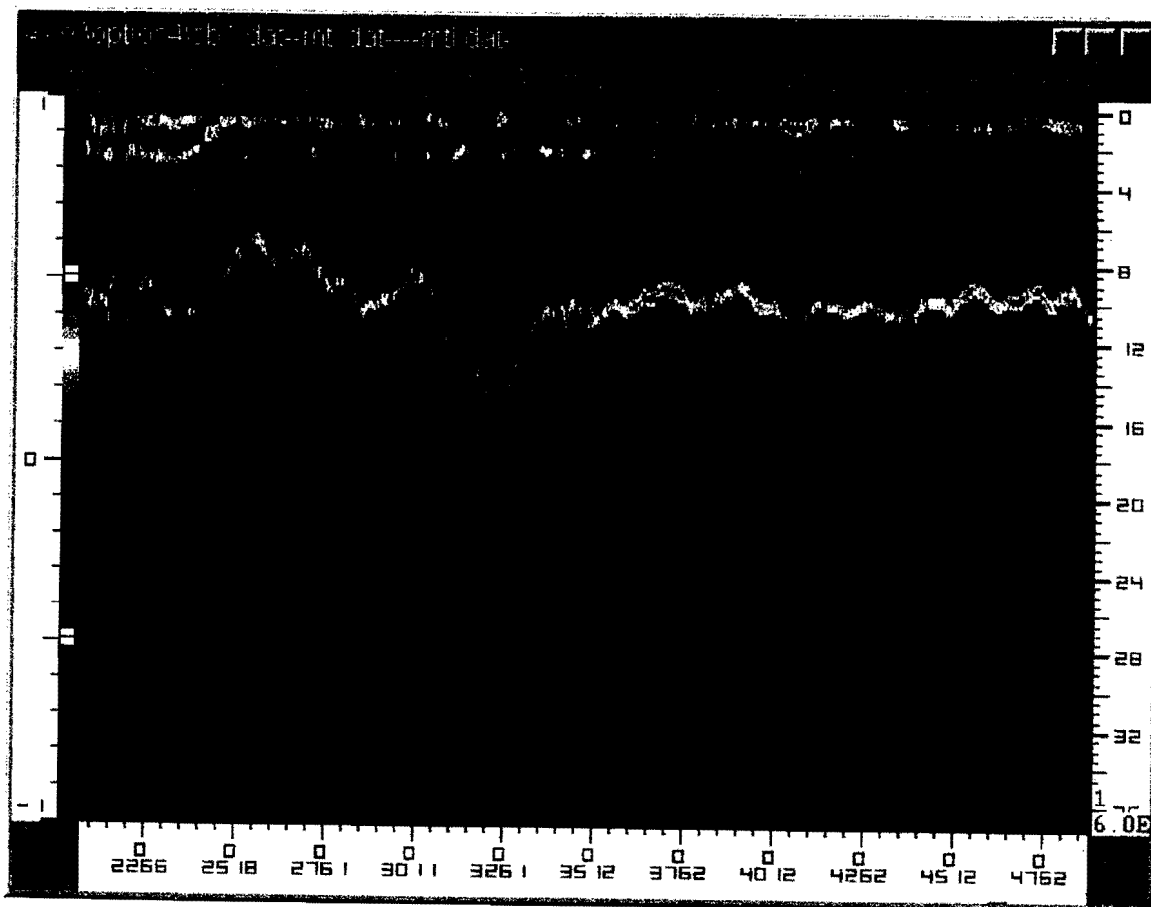
Typical Trace: After Surface/Template Subtraction

As this is a near surface problem the surface removal technique has been used. The blue line is the raw data, the red line is after surface removal. The negative reflection (stripping) was calculated to be 4.6 inches below surface. For the trace shown the surface reflection amplitude would be defined by clicking on peaks (1) and (2). For distinct negatives, identify the amplitude by clicking negative (3) then following positive (4). It is very difficult to obtain accurate total HMAC thickness estimates when the layer contains severe deterioration; however, the depth estimate to the deteriorated layer will be reasonable.

Layer	1	2	3	4
Amplitude	3.4	-0.7		
Dielectric	4.9	3.2		
Thickness	4.6			
Travel Time	1.7			

Trace	439
Mile	0
Feet	2356

Cursor	
Voltage	2.9
Time	1.6

Peak	1	2	3	4
Voltage 1	2.1	-0.6		
Time 1	5.5	7.2		
Voltage 2	-1.2	0.1		
Time 2	5.1	7.7		
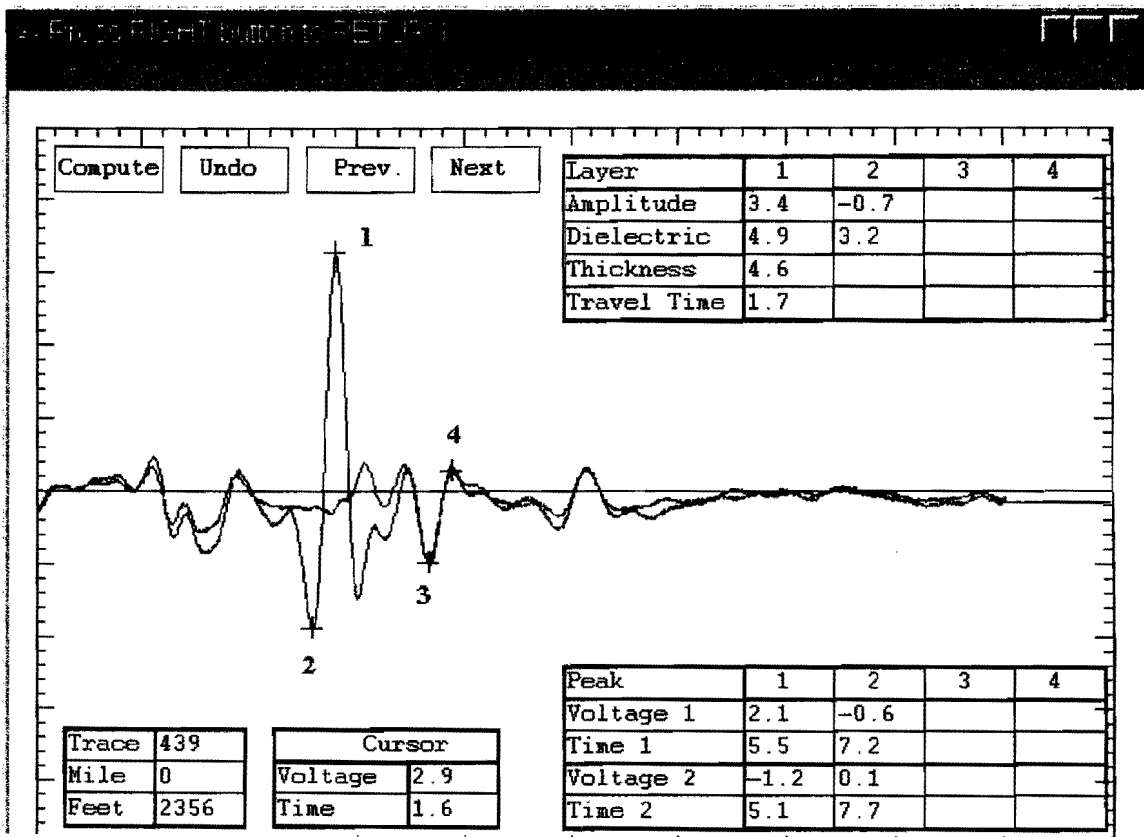
Core

Providing the HMAC layer does not contain any unusual aggregates, and if a core was removed at the location of the trace shown above, it should either break or show severe deterioration somewhere between 4 and 5 inches below the surface.

CASE 5 THICK HMAC–METAL WIRE REINFORCEMENT AT MID-DEPTH

General

This occurrence is very unusual, although several overlays were placed in the Houston area in the 1960s with metal wire mesh reinforcement beneath the overlay.

COLORMAP

A broad strong positive interface will appear within the HMAC layer. It will have a relatively constant width along the section. Metal is a strong reflector of GPR energy. Overlapping reflections from the mesh will cause the broad interface.

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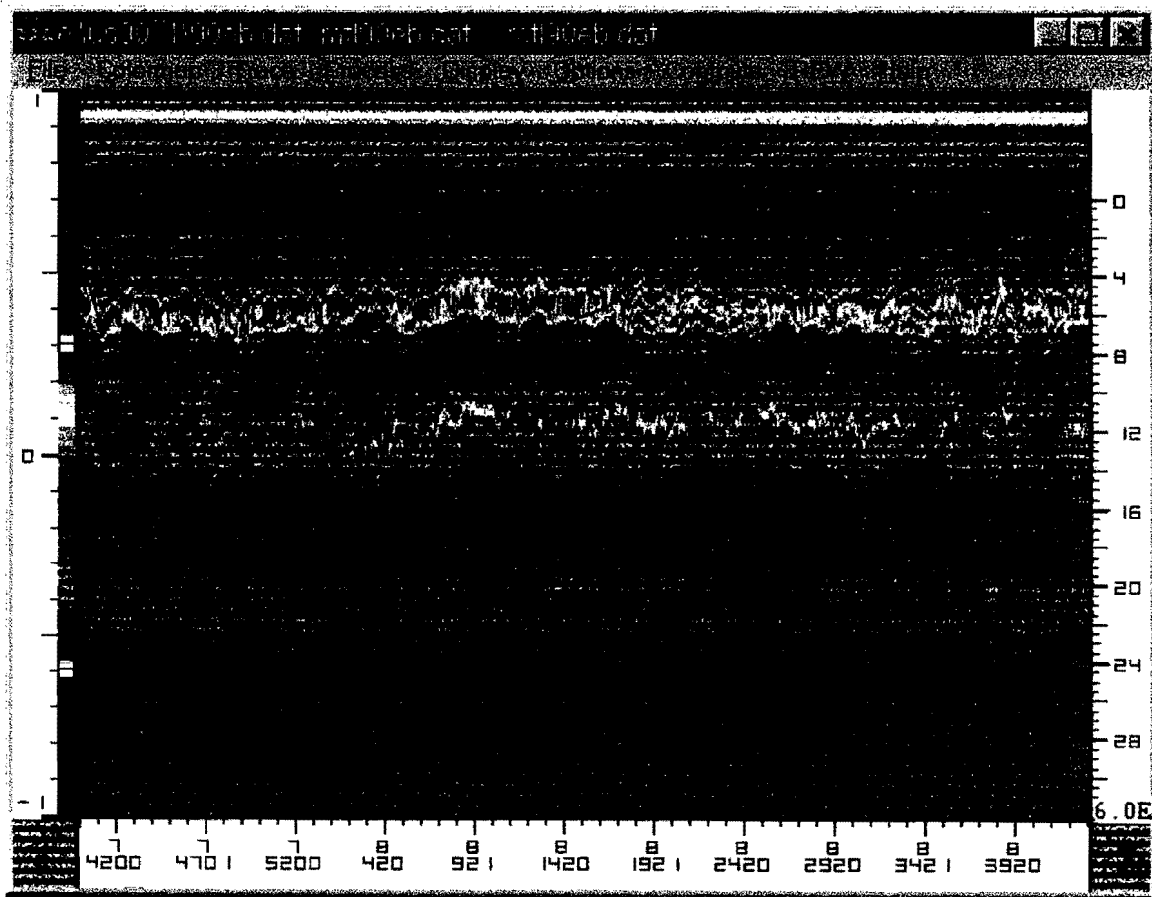
Trace

Reflections (a) and (b) are from the top of the surface and base. Reflector (c) is overlapping reflections from the wire mesh. This broad positive reflection will be on every trace.

Layer	1	2	3	4
Amplitude	3.9	0.5		
Dielectric	5.8	7.4		
Thickness	11.7			
Travel Time	4.8			

Compute	Undo	Prev.	Next

Trace	4160
Mile	7
Feet	4641

Cursor	
Voltage	0.5
Time	9.8

Peak	1	2	3	4
Voltage 1	2.4	0.0		
Time 1	4.3	9.1		
Voltage 2	-1.4	-0.4		
Time 2	3.9	9.5		

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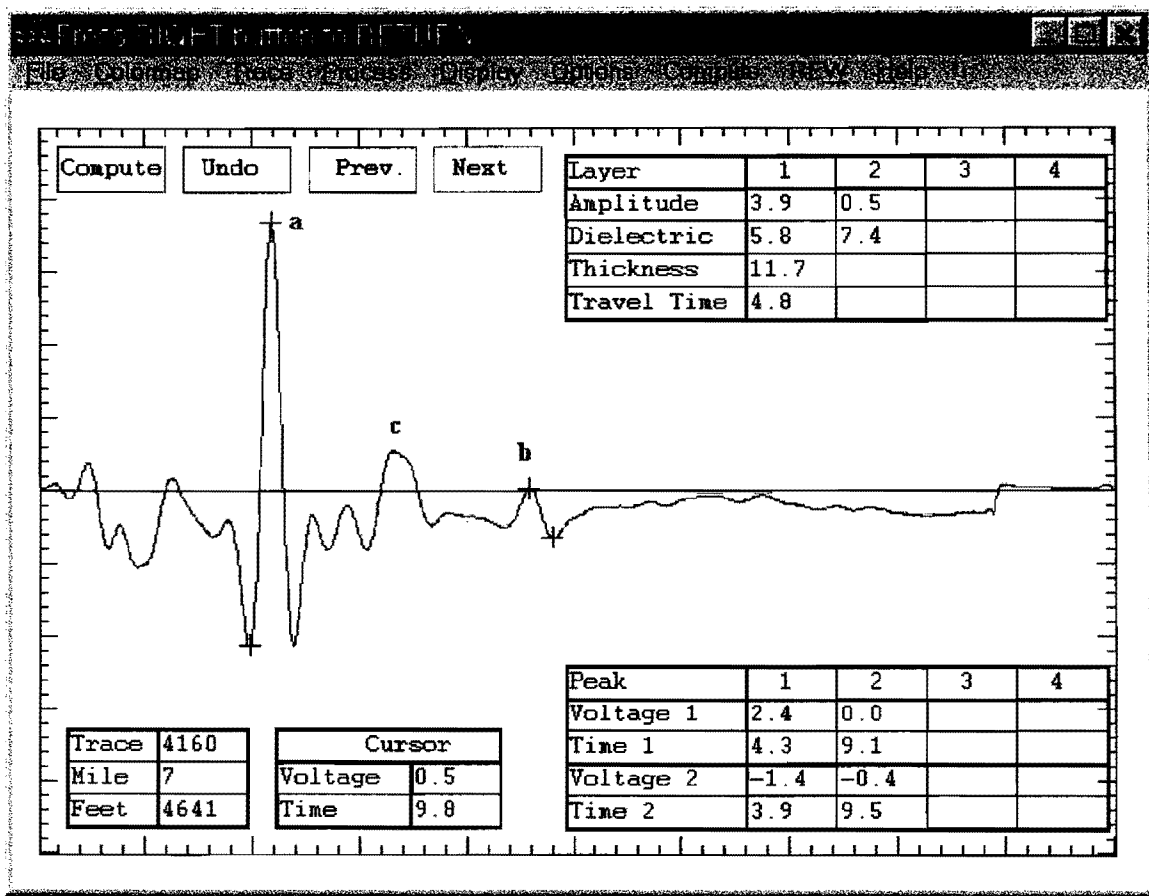
CASE 6 THIN HMAC–GRANULAR BASE, NO DEFECTS

General

With new construction for top quality aggregates, the calculated base dielectric should be between 7 to 10. It is also usually possible to see the bottom of the base. Surface subtraction must be used in dielectric and thickness calculation for all surfacing less than 3 inches thick. For typical Texas base materials, calculate dielectrics between 10 and 16 are warning signs; values above 16 indicate a moist base with a large amount of free "water." These high dielectric bases are potentially susceptible to both environmental and load-associated damage.

COLORMAP: After Surface/Template Subtraction

Reflections from top and bottom of the base are clear. After surface subtraction, the surface is at the top of the figure. The HMAC thickness is approximately 2 inches (strong red reflection).
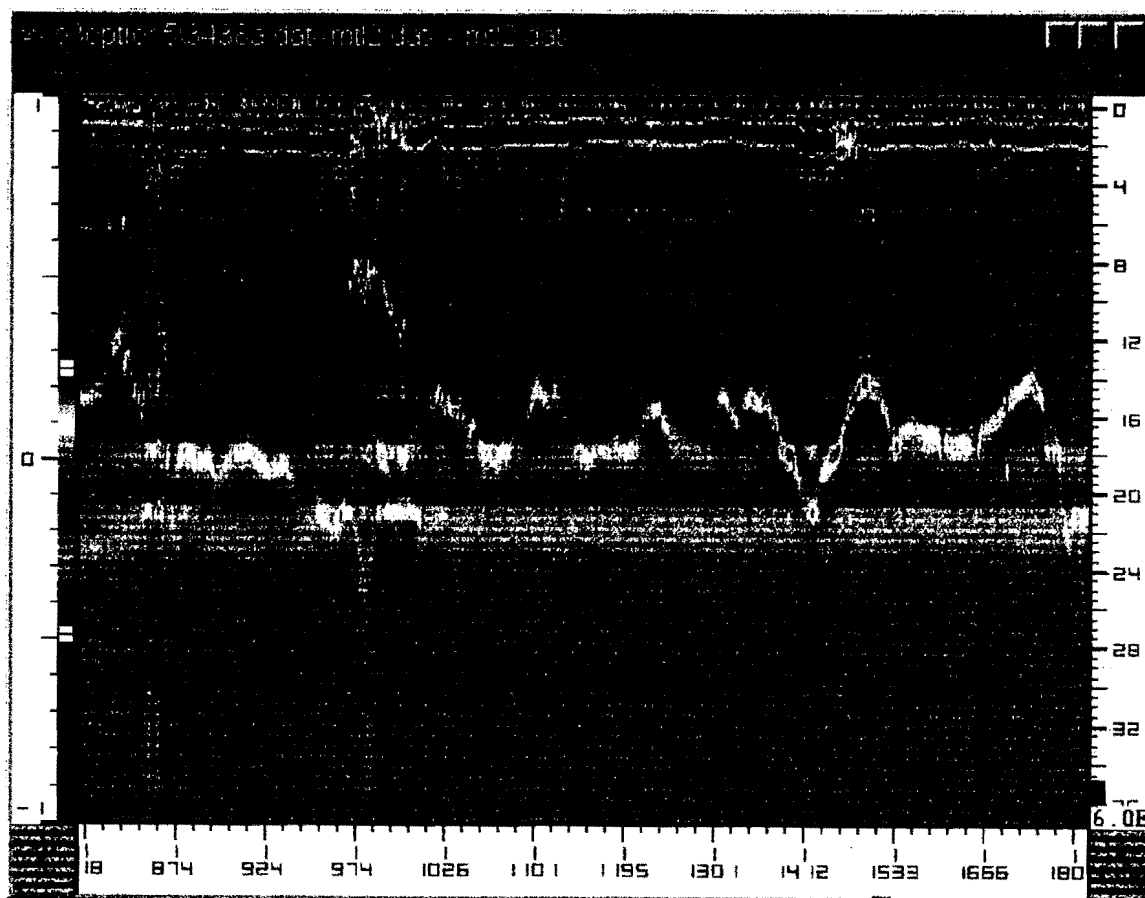
Individual Trace with Template Subtraction

Prior to subtraction (blue line), there are no clear reflections from the top of the base. This is because the reflections from the surface and base overlap. After surface (template) subtraction (red line), the reflection from the top of the base becomes clear. With positive reflections, the dielectric calculations use the numeric sequence shown (1 through 6). In general, for the surface, use positive and preceding negative (1, 2) to define surface amplitude. For all subsequent peaks, use the peak and trailing negative, for example (3, 4) for base amplitude.
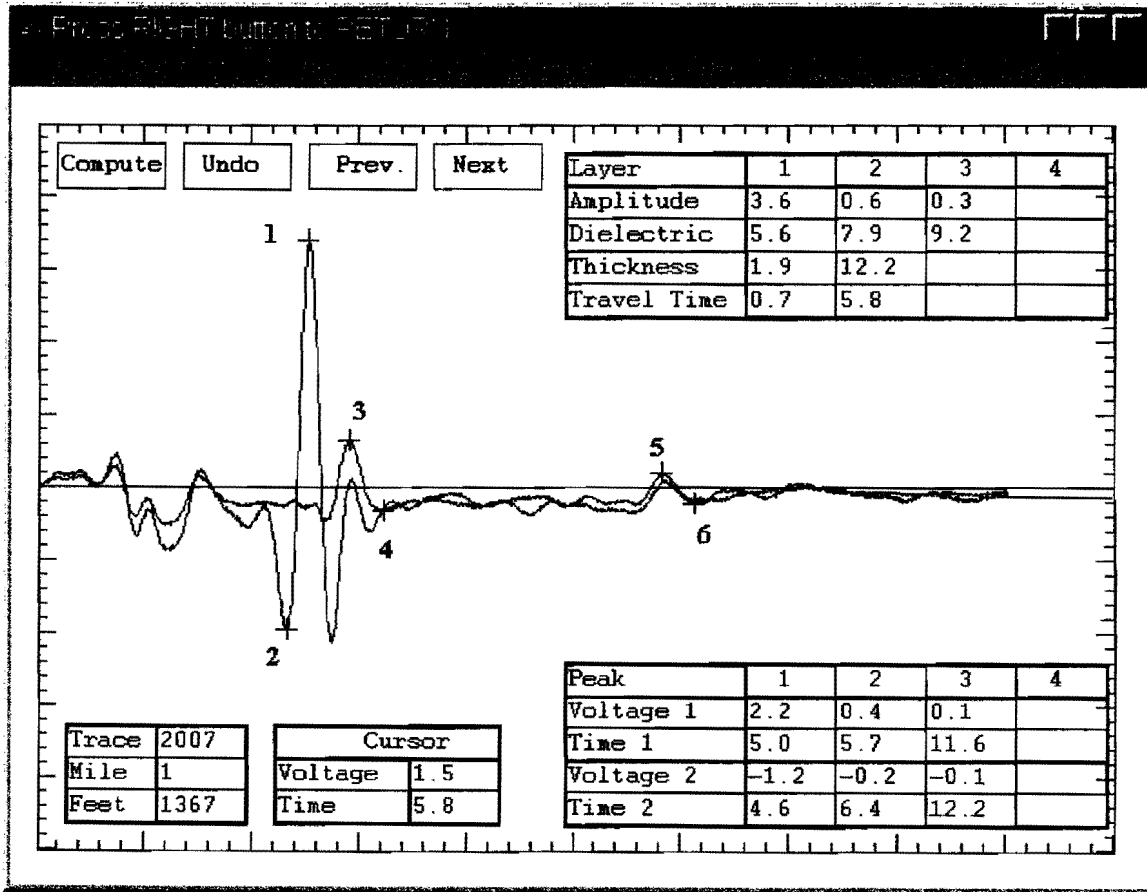
Core

At this location, no problems are anticipated. There is a solid 2 inch thick core and dry base approximately 12 inches thick.

CASE 7 THIN HMAC–STABILIZED BASE, MOISTURE IN BASE

General

Well stabilized bases should be dry, relatively impermeable to moisture, and have low suction. The typical calculated base dielectrics should be in the range of 7 to 10. Severe durability problems can be anticipated if the stabilized base is holding moisture.

COLORMAP: After Surface/Template Subtraction

This highway has unusually strong reflections from the top of the stabilized base, 3-4 inches below the surface. When the base layers are this wet, they attenuate the GPR signals, and frequently it is impossible to see the bottom of the base layer.
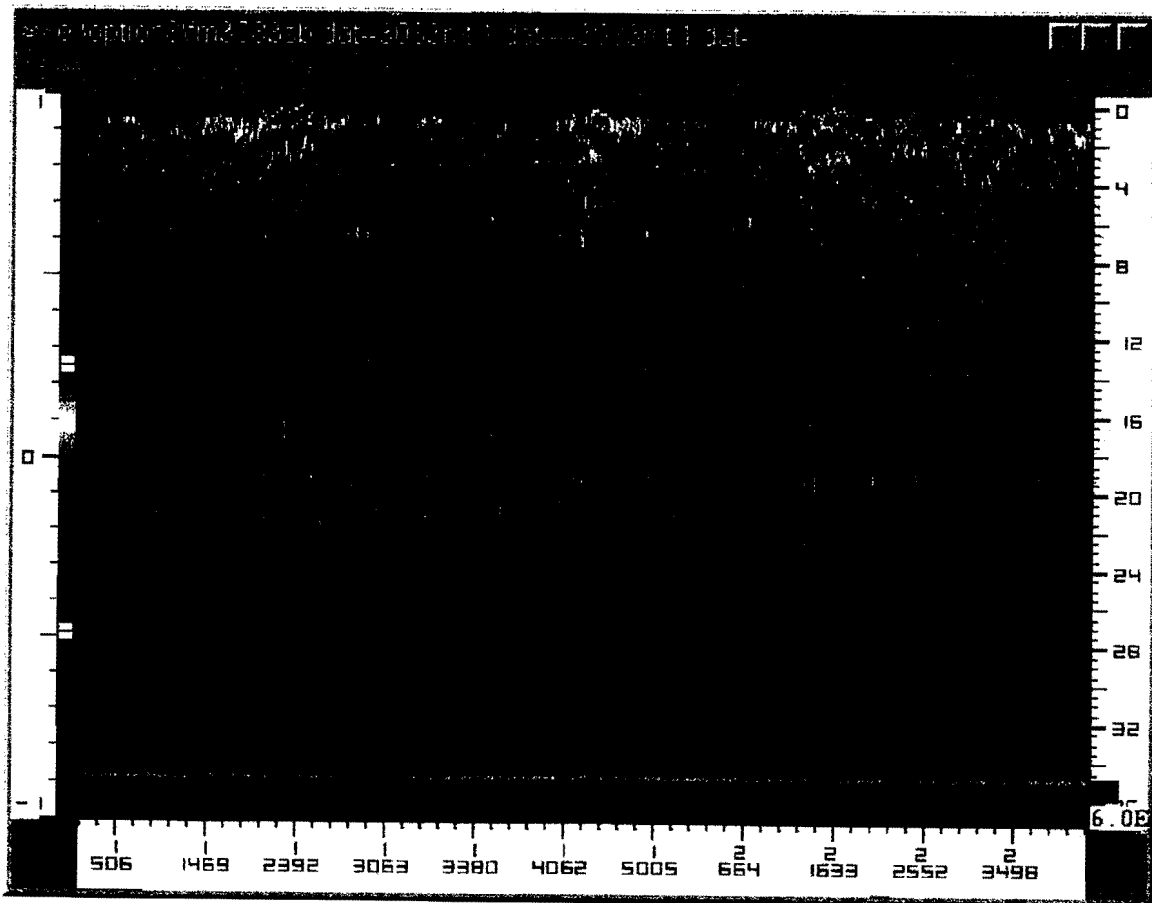
Individual Trace: After Surface/Template Subtraction

Strong (high positive) reflections from the top of the base. This display indicates a moist base with a very high base dielectric (>17).
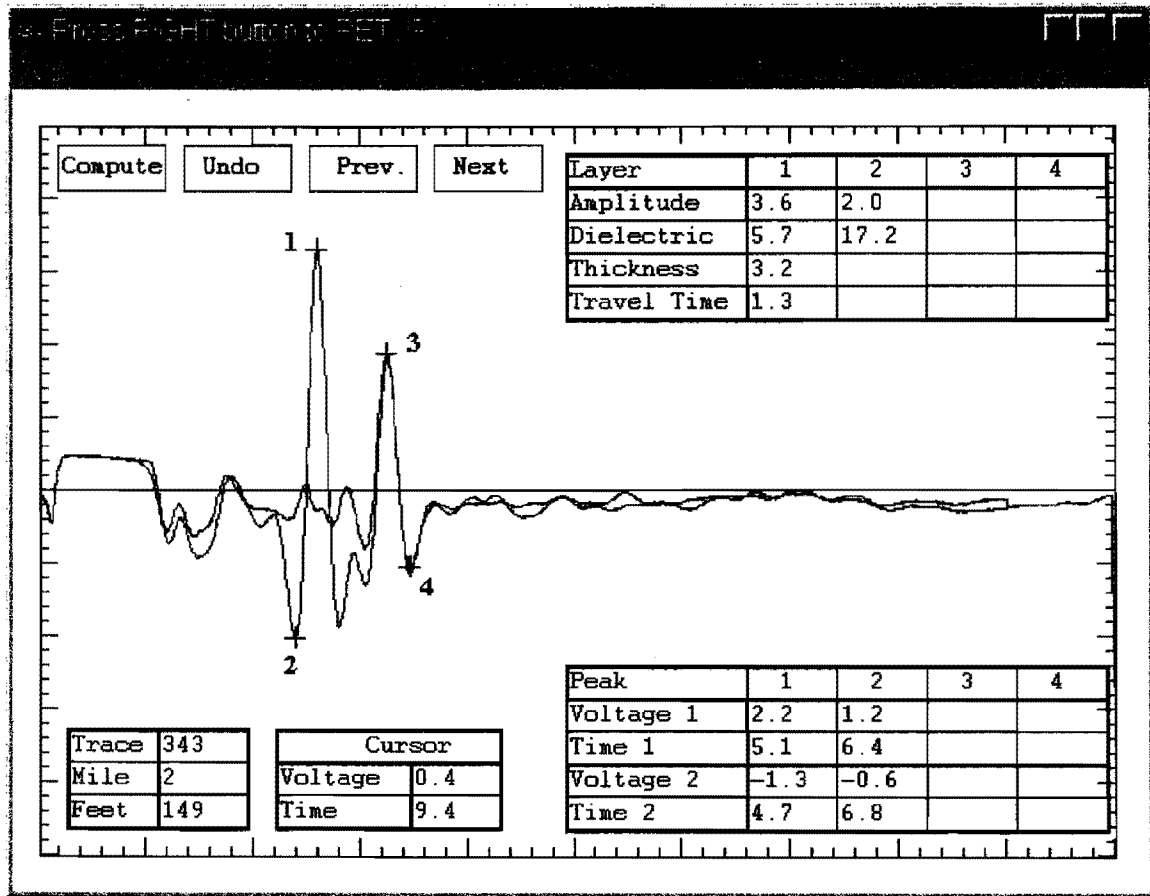
Core

When traces such as this are found with stabilized layers, it is often difficult to obtain an intact core. This level of moisture in the base layer is usually related to poor aggregate properties, poor quality control (clay contamination), or the use of the wrong stabilizer. It often leads to leaching of the stabilizer and disintegration of the layer. This base severely deteriorated after only a few years in service.

CASE 8 THIN HMAC–FLEXIBLE BASE OVER OLD HMAC

General

A common rehabilitation technique used in many parts of Texas is to place between 6-11 inches of flexible base over an existing flexible pavement. A new two-course surface treatment or thin overlay is used as the final surface.

COLORMAP: After Surface/Template Subtraction

This structure is characterized by a negative reflection (blue) at the bottom of the flexible base overlay. This reflection occur at the interface between base (higher dielectric) and old HMAC (lower dielectric).
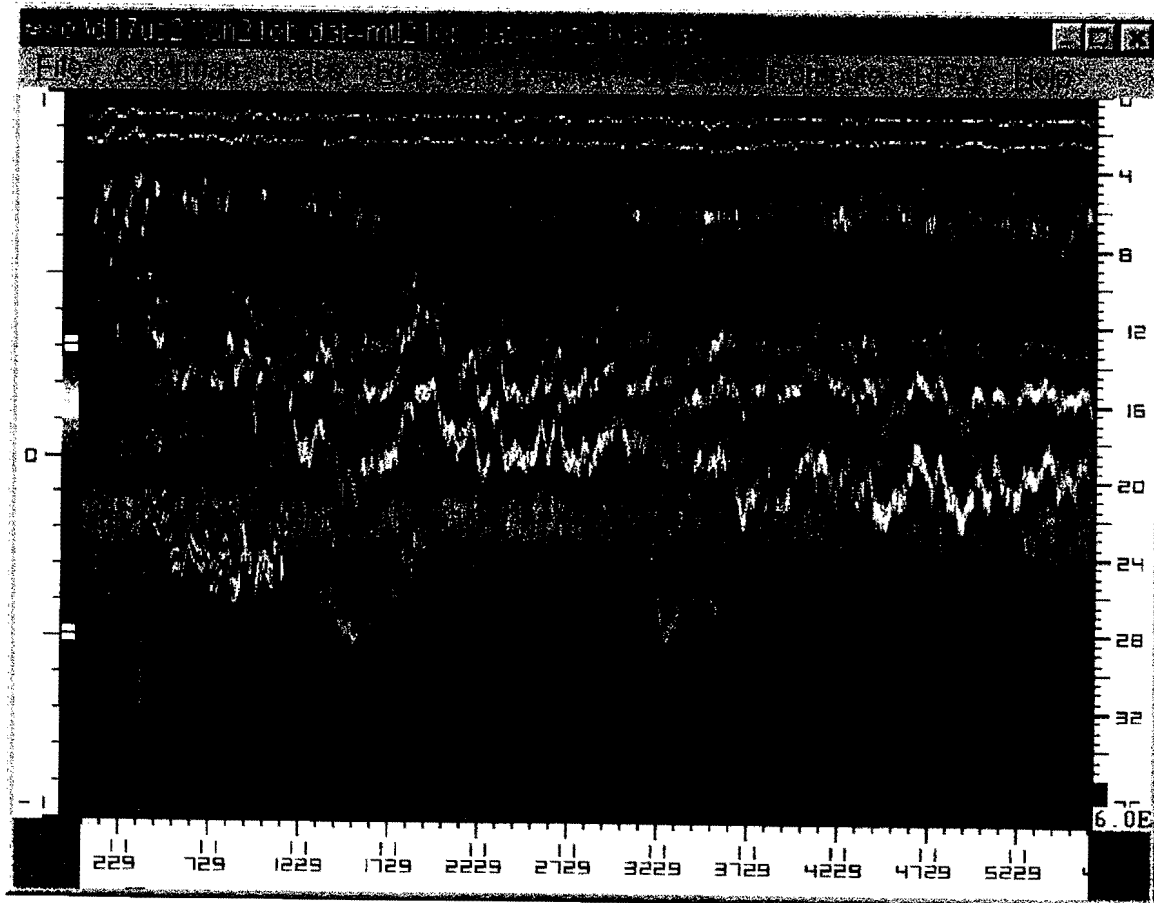
Typical Trace: After Surface/Template Subtraction

A clear negative reflection (5, 6) is observed as the GPR wave hits the top of the old HMAC layer. This pavement has a thin HMAC layer (2 in) and base overlay (10 in).

Colormap Trace Picture Display Options Compute Print Help

| Compute | Undo | Prev. | Next |

Layer	1	2	3	4
Amplitude	3.4	1.1	-0.3	0.2
Dielectric	4.9	8.8	7.0	
Thickness	1.9	10.7	4.6	
Travel Time	0.7	5.4	2.1	

Trace	6036
Mile	11
Feet	2239

Cursor	
Voltage	0.4
Time	16.0

Peak	1	2	3	4
Voltage 1	2.1	0.7	-0.3	0.1
Time 1	6.1	6.8	12.2	14.2
Voltage 2	-1.2	-0.3	0.0	0.0
Time 2	5.7	7.3	11.7	14.7
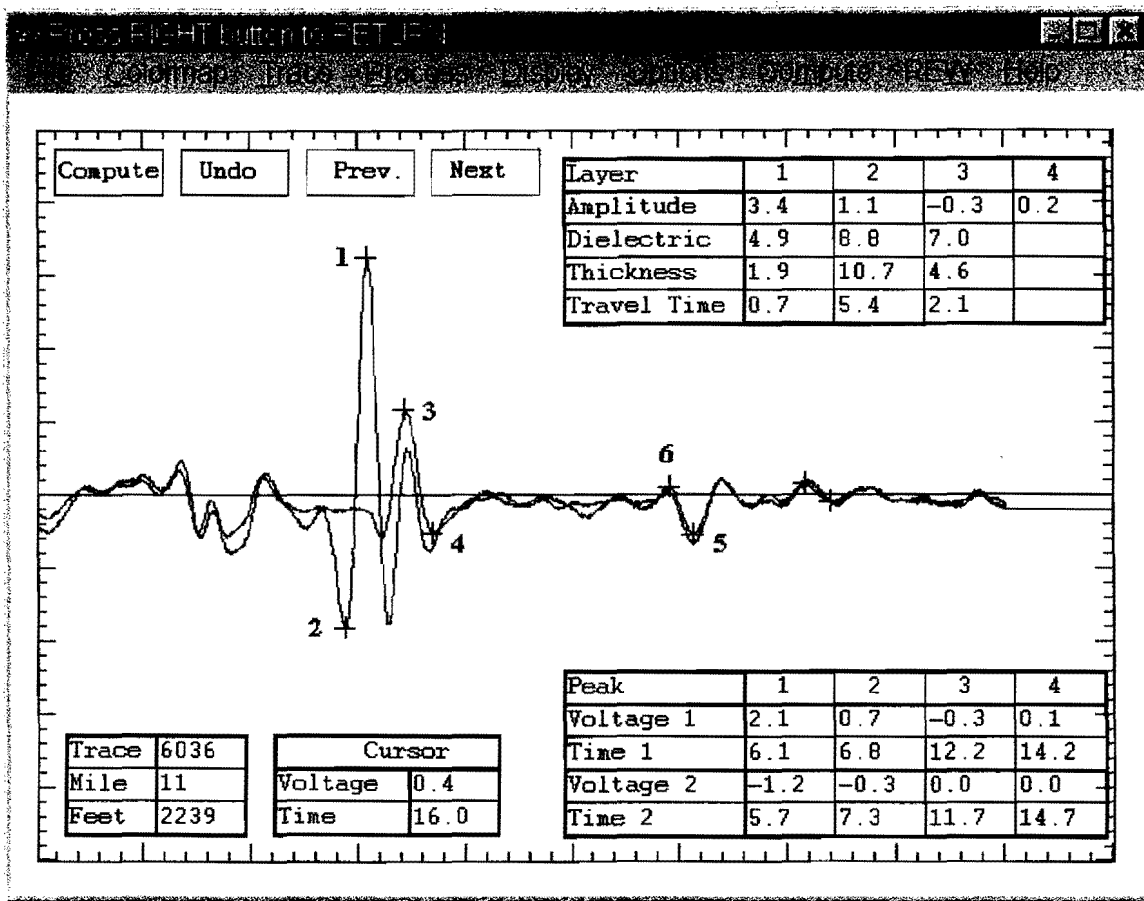
Core

No problems are anticipated if this type of GPR data are observed in a base overlay project. The concern with this structure is that the new base will trap moisture. The base dielectric is a good indicator of the moisture content of the base. Values less than 10 are ideal.

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CASE 9 THIN HMAC–GRANULAR BASE, LOCALIZED WET SPOTS

General

Pavement failures on thin HMAC pavements are frequently caused by localized wetting of the base layer. This wetting is caused by leaking surface layers, poor base materials which "wick" moisture, underground springs, or the presence of a perched water table.

COLORMAP: With Surface Removed/Template Subtraction

Characterized by a strong positive reflection (bright red) at the top of the base. The vertical lines are user-defined section limits. The white line is the automatic interface tracing routine within COLORMAP.
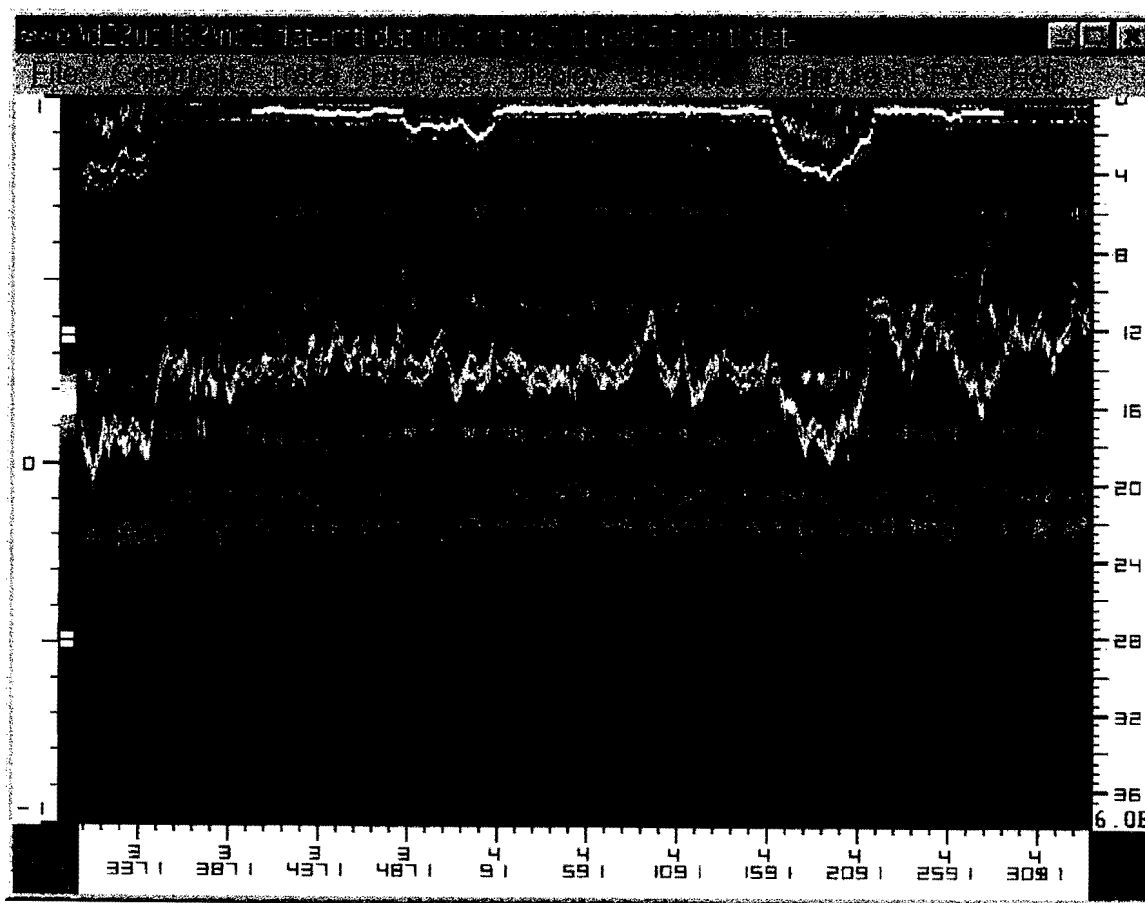
Typical Trace: With Surface Removed/Template Subtraction

Characterized by a high reflection from the top of the base. Regular HMAC should have a dielectric less than 7, and a top quality flexible base should be less than 10. The computed value of 21 indicates that the base layer is probably saturated.

Colormap Trace Process Display Options Acquire Help

| Compute | Undo | Prev. | Next |

Layer	1	2	3	4
Amplitude	3.9	1.8		
Dielectric	7.1	21.1		
Thickness	1.6			
Travel Time	0.7			

Trace	2103
Mile	3
Feet	5191

Cursor	
Voltage	0.5
Time	5.4

Peak	1	2	3	4
Voltage 1	2.4	1.2		
Time 1	4.0	4.7		
Voltage 2	-1.4	-0.5		
Time 2	3.6	5.1		

71
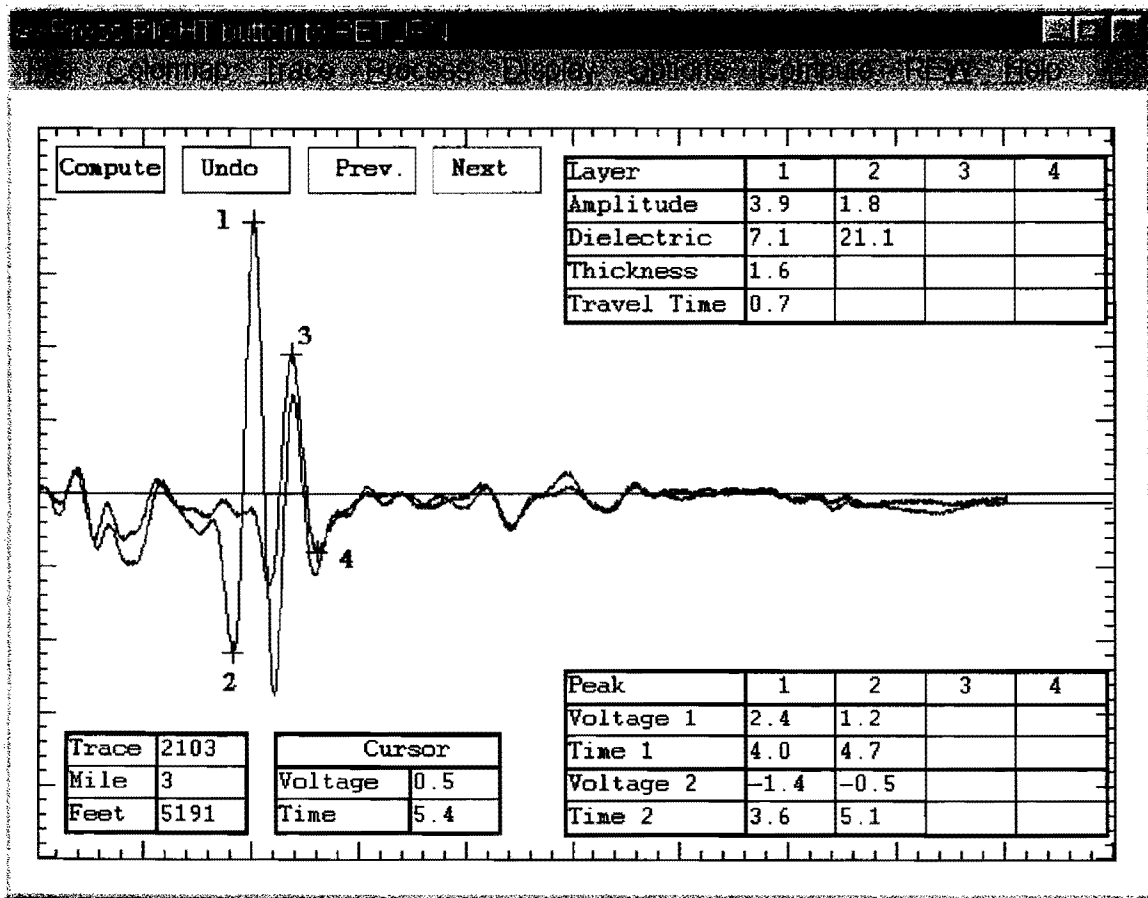
Dielectric Plot

The extent of the problem area can be found by defining a section within COLORMAP then automatically computing the base dielectric for each trace in the section. The graph below shows base dielectric vs. distance for the section defined in the COLORMAP display. The extent and severity of the problem is easy to define from the plot. To rank typical Texas flexible bases, the following table is recommended:

Dielectric	*Rating*
less than 10	dry–good quality
10 - 16	marginal–some moisture
16+	moist–susceptible to load and environmental damage

In Texas, if the base dielectric is greater than 16, then this value is cause for concern. To permanently repair sections such as these, the source of moisture should be determined. Alternatives such as stabilization, addition of drains, fabrics, etc. should be considered. Areas of high base moisture are easy to detect with this plot.
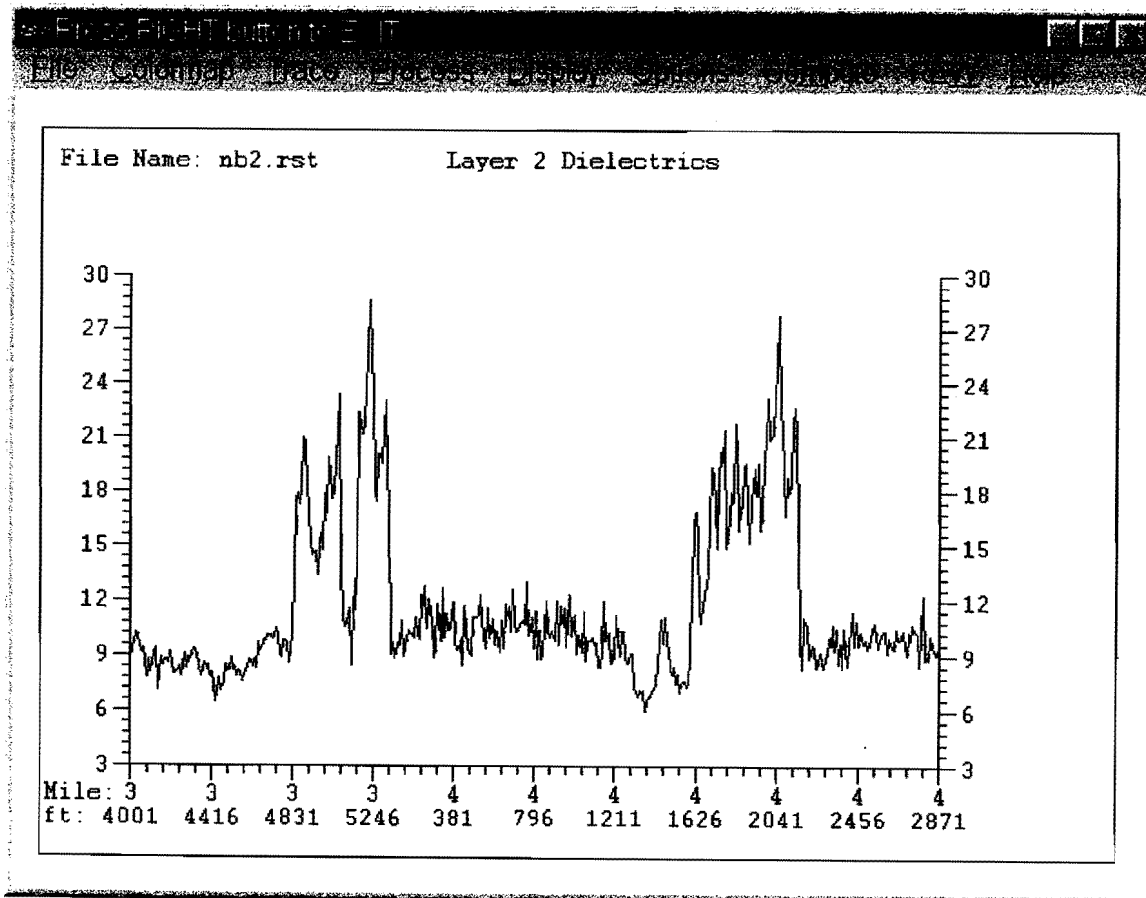
CASE 10 THIN HMAC–GRANULAR BASE, POOR LOW DENSITY BASE

General

The dielectric values for flexible base are generally classified in terms of less than 10 (good) and greater than 16 (moist). However, if very low base dielectric values are encountered, this could also indicate a density problem. Values of base dielectric less than 6.5 are unusual and should be investigated.

COLORMAP: After Surface/Template Subtraction

No major problems observed in COLORMAP. Very thin surfacing layer (multiple seal coats) with localized patches.
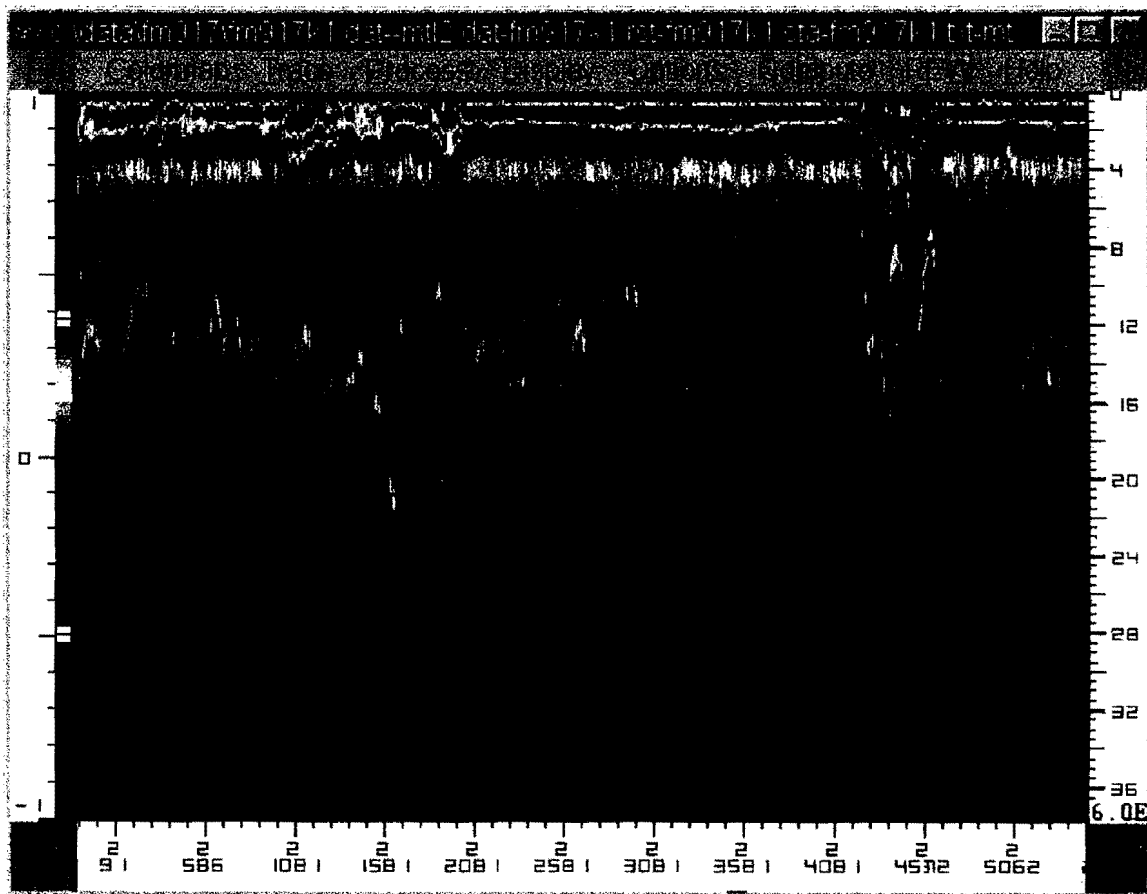
Typical Trace: After Surface/Template Subtraction

Very low dielectrics for both surface and base. Possible porous friction course and dry/low

density base. The computed base value of 5.1 is very low.

Layer	1	2	3	4
Amplitude	2.5	0.5		
Dielectric	3.8	5.1		
Thickness	1.2			
Travel Time	0.4			

Peak	1	2	3	4
Voltage 1	1.5	0.3		
Time 1	5.3	5.7		
Voltage 2	-0.9	-0.1		
Time 2	4.8	6.2		

Trace	6346
Mile	11
Feet	5076

Cursor	
Voltage	-0.2
Time	11.3
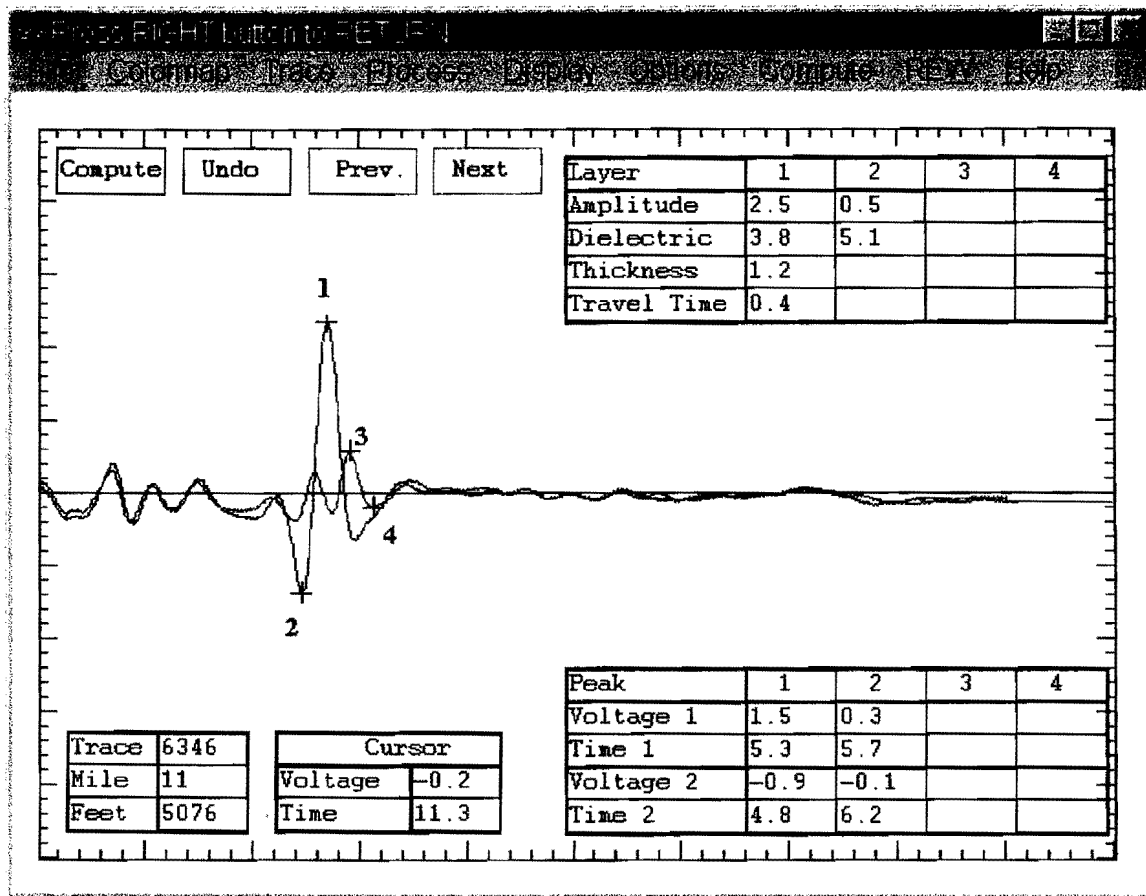
Dielectric Plot

Several areas with base dielectric less than 6.5.
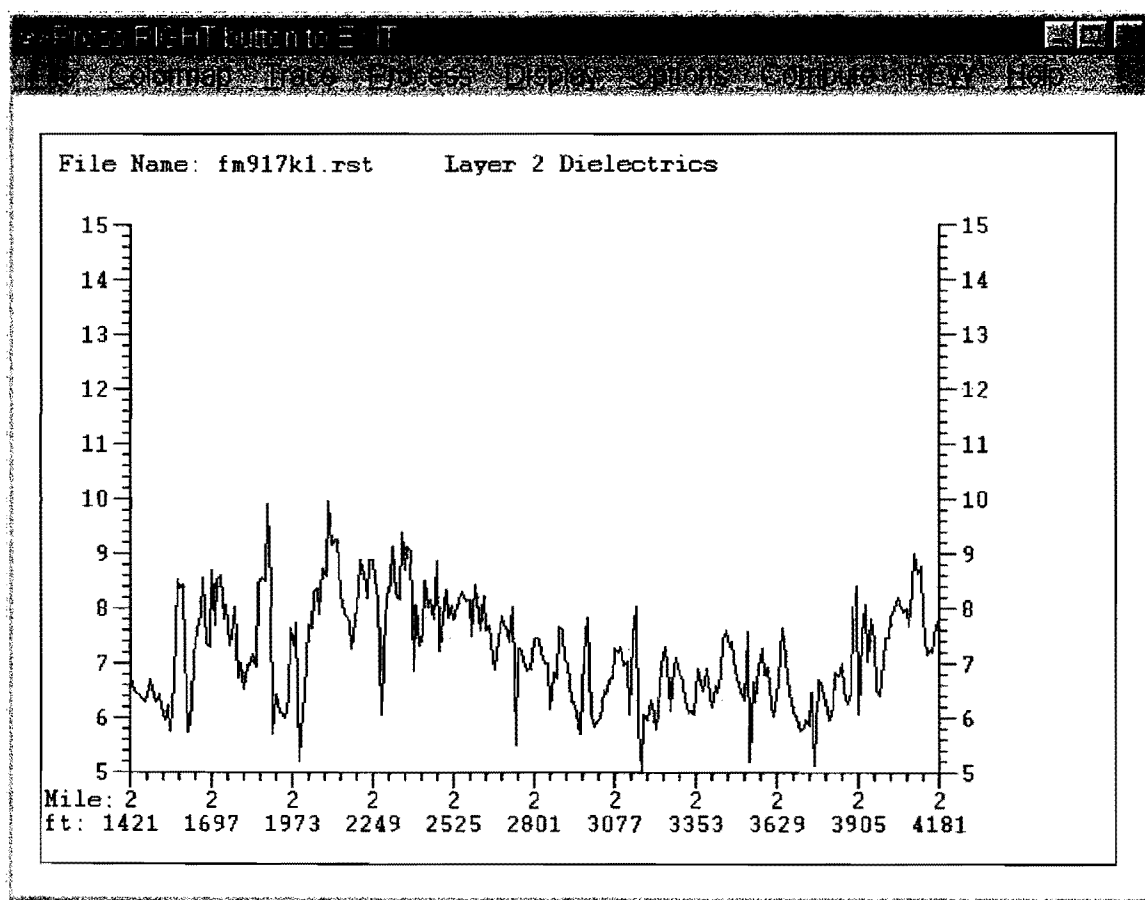
Core

These data are from a problem pavement in the Fort Worth District. The pavement was performing poorly and maintenance forces had placed multiple patches. It was concluded that this sandy base was losing fines. Note: Cores should be taken when interpreting results from low dielectric bases. FWD/DCP testing are also recommended.

CASE 11 THIN HMAC–OVER HMAC, NO DEFECTS

General

GPR has good potential for evaluating the quality of asphalt overlays. The variation in the amplitude of surface reflection is a measure of the change in layer density; significant decreases in amplitude denote low density areas (see Case Study 19). Under normal conditions, there is little or no electrical contrast between the new HMAC overlay and the existing HMAC; therefore, only a very small reflection can be anticipated from this interface.

COLORMAP: After Surface/Template Subtraction

In Texas, the normal overlay thickness is 2 inches or less; therefore, the surface subtraction must be activated to identify the interface between the old and new HMAC. In the COLORMAP display below, the surface of the pavement is the horizontal line at the top of the figure. The strong (blue/red/blue) reflection at a depth of 8 in is from the top of the flexible base. The faint yellow/red line at a depth of 2 inches is a reflection from the top of the old HMAC layer. The surface dielectric plot at the bottom of the figure shows some minor variations; these variations are primarily related to changes in density of the mat. These variations are typical for normal HMAC; they should be contrasted with those shown in Case Studies 18 and 19 where significant segregation and low joint densities were observed.
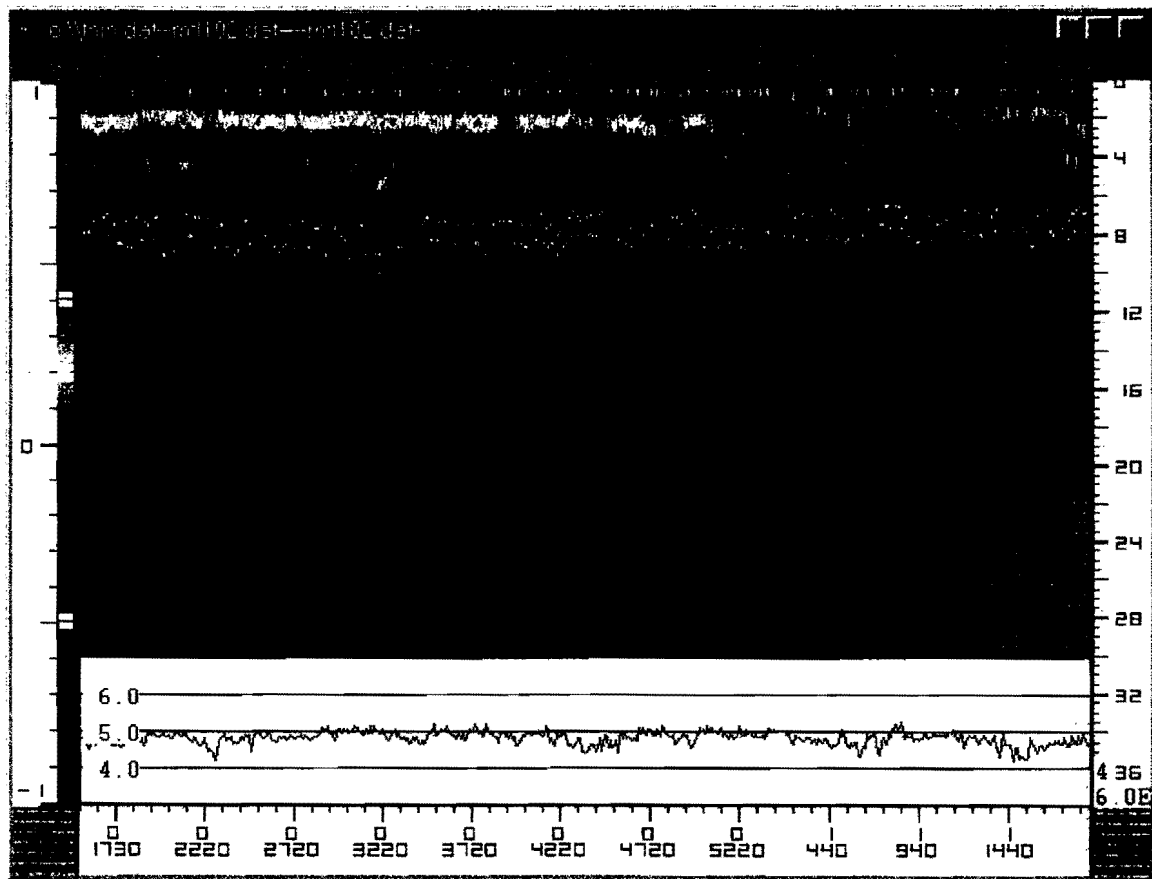
Typical Trace: After Surface/Template Subtraction

The blue line represents the original GPR trace; the red line is after surface removal. This reflection pattern is characterized as normal for a thin HMAC overlay over a good lower HMAC layer; there are no defects in either layer. The amplitude of surface reflection is identified by (1, 2). The top of the old HMAC is (3, 4) and the top of the base is (5, 6). If accurate layer thickness estimates are required, the Antenna Bounce option must be used in COLORMAP. This function accounts for the variation in height of the antenna as it travels over the pavement.

Compute	Undo	Prev.	Next

Layer	1	2	3	4
Amplitude	3.3	0.4	1.0	
Dielectric	4.9	5.9	10.2	
Thickness	2.2	6.0		
Travel Time	0.8	2.5		

Trace	213
Mile	0
Feet	3640

Cursor	
Voltage	-0.7
Time	9.6

Peak	1	2	3	4
Voltage 1	2.1	0.2	0.6	
Time 1	6.0	6.8	9.3	
Voltage 2	-1.1	-0.1	-0.3	
Time 2	5.6	6.4	9.7	
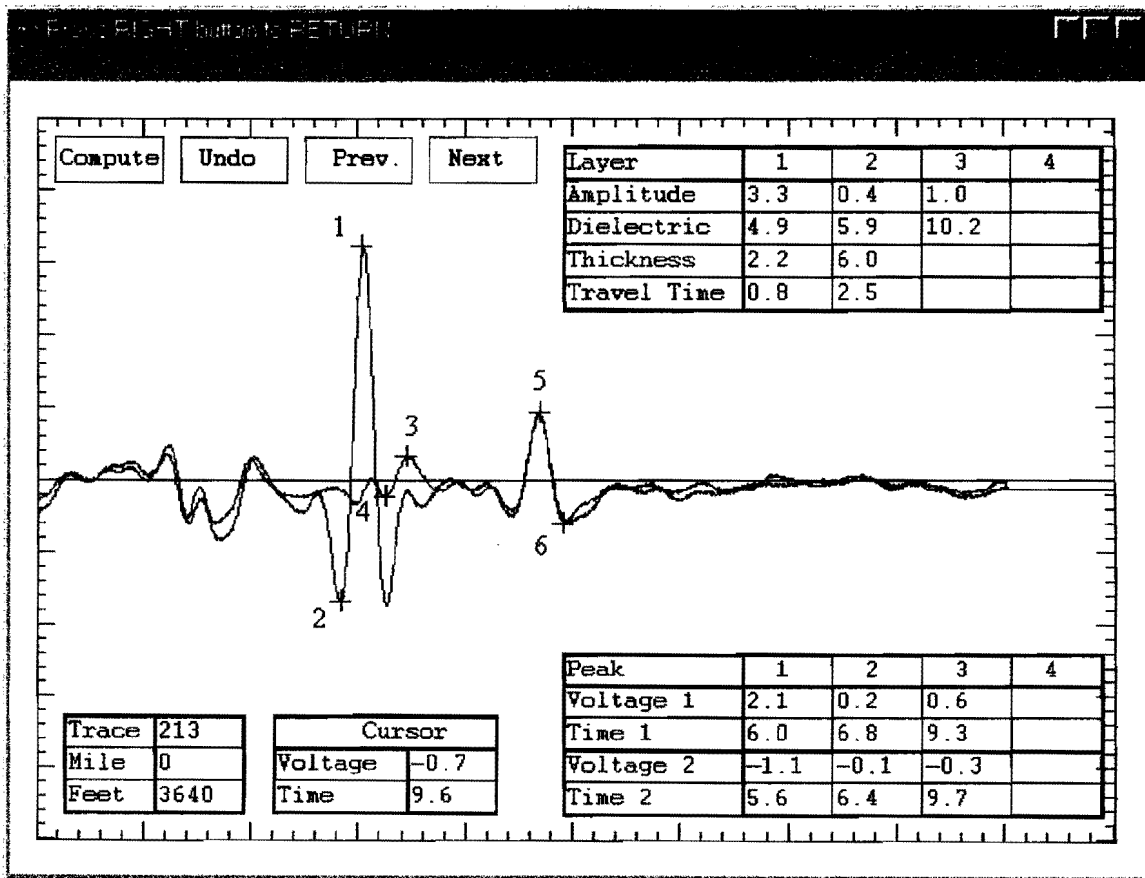
Core

No problems with this layer; solid cores should be obtained. If the Antenna Bounce function is active, the thickness accuracies should be ±3 percent.

CASE 12 THIN HMAC–OVER HMAC, MOISTURE AT INTERFACE

General

This type of pattern is often observed if the GPR data are collected shortly after significant rainfall. It is common if a chip seal is placed over the old HMAC before the new overlay. It may or may not signify a problem with the pavement. If the pattern disappears after a short time, it perhaps indicates that the new overlay is significantly more permeable than the lower HMAC layer. If this pattern is still present several days after significant rainfall, then the moisture is being trapped under the overlay. In this case, the moisture probably entered via a poorly constructed construction joint and moved horizontally over the chip seal. If it is still present two days after rain, then it is clearly trapped and not capable of evaporating through the new overlay. This moisture could then cause stripping of the lower part of the overlay. (Note: This type of pattern is not only found with thin overlays; it has also been observed within thick HMAC layers, see Case 2).
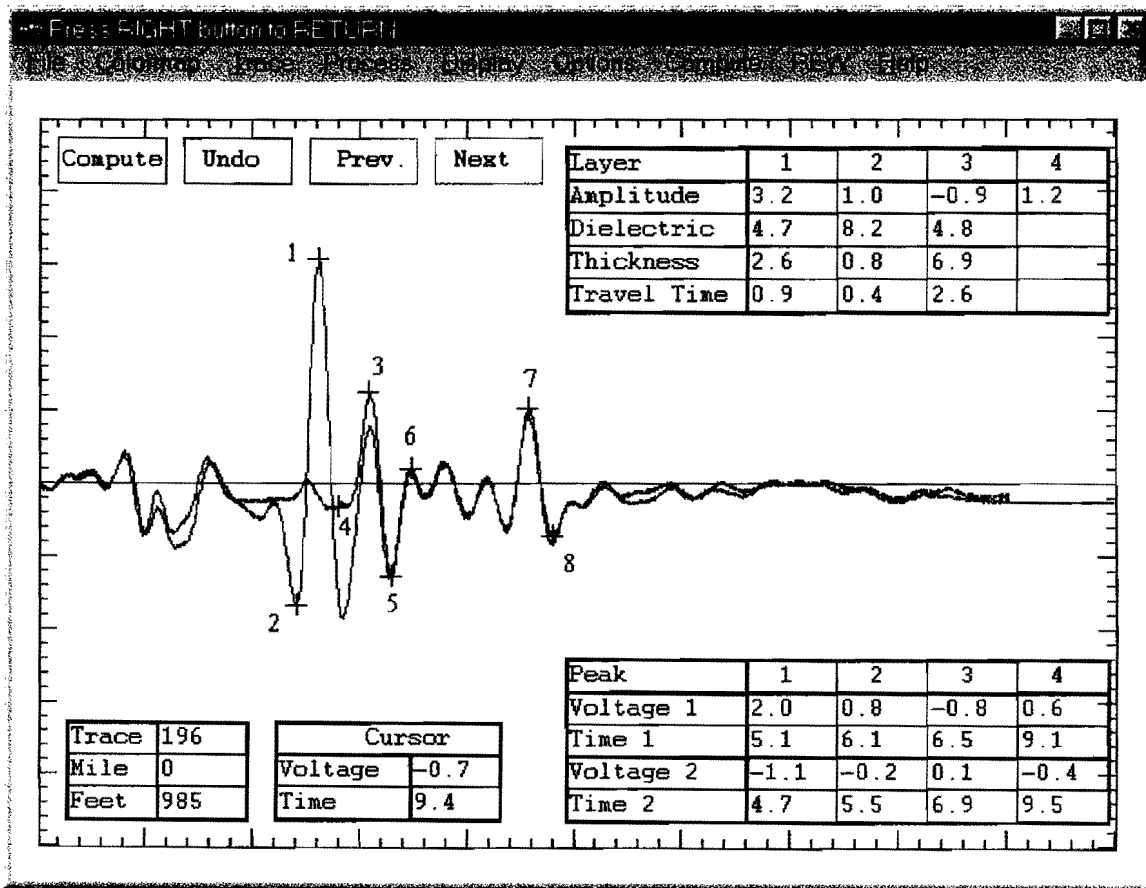
COLORMAP: After Surface/Template Subtraction

The surface of the highway is the horizontal line at the top of the display. The gap in the COLORMAP display shown below is from a concrete intersection; either side the pavement consists of an old HMAC layer which has recently received a chip seal and thin overlay. These data were collected one day after significant rainfall. The blue/red/blue reflection at depth of 8 to 10 in is from the top of the flexible base, it is normal. What is not normal is the strong red/blue reflection at a depth of 2 in; this reflection is from a thin layer of moisture sitting at the bottom of the overlay. The red is a positive reflection generated when the GPR wave encounters the moisture; the blue is when the GPR wave travels from the high dielectric wet asphalt to the low dielectric regular asphalt below the seal. As the wet layer is very thin, less than 1 inch thick, the positive and negative reflections overlap resulting in a red/blue interface reflection.
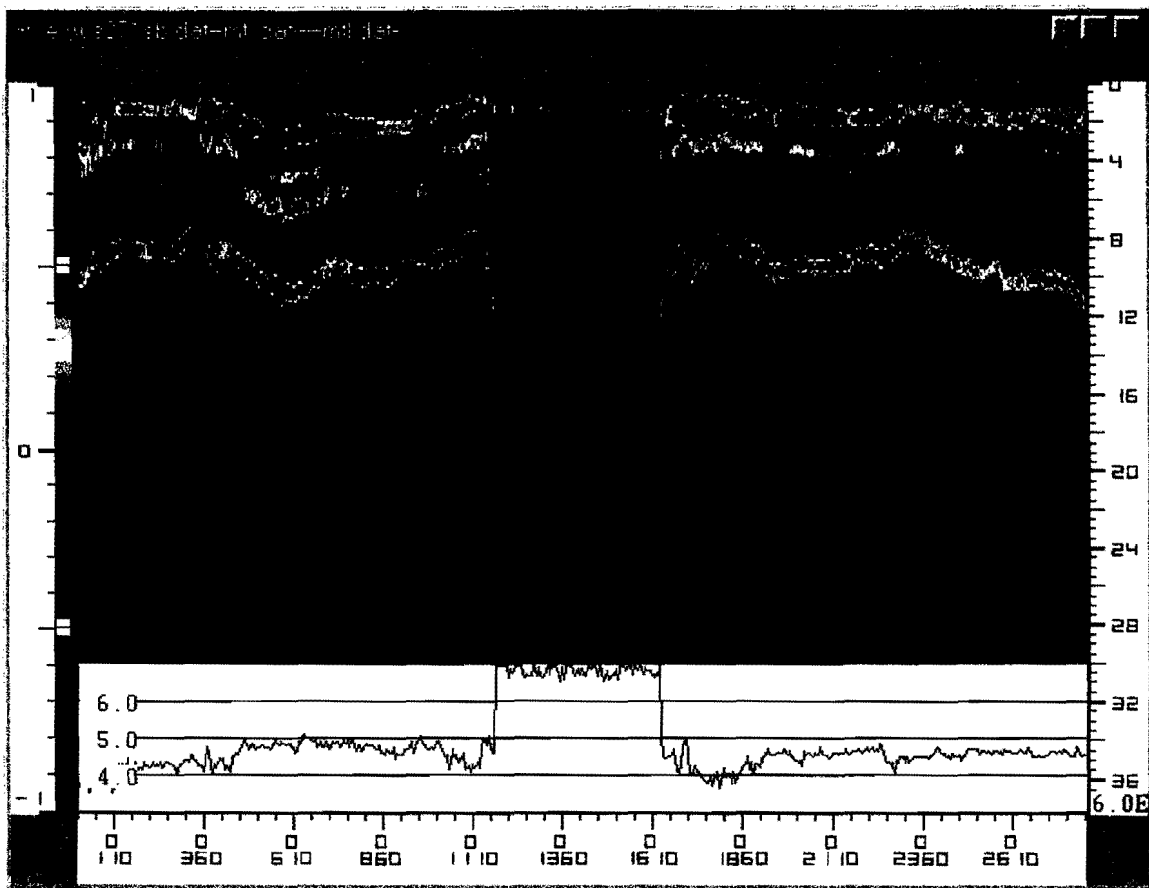
Typical Trace: After Surface/Template Subtraction

The blue line is the raw data; the red is after surface removal. The surface reflection and reflection from the top of the base are identified by (1, 2) and (7, 8). The thin moist HMAC layer is denoted by (3, 4), a positive reflection as the wave travels from a low to a high dielectric layer (normal HMAC to moist HMAC). The top of the HMAC layer is (5, 6), a negative reflection as the wave travels from a high to a low dielectric layer (moist HMAC to normal HMAC). (Note: As the moist layer is thin [0.8 in] these reflections are overlapping).

-- Press RIGHT button to RETURN

Compute	Undo	Prev.	Next

Layer	1	2	3	4
Amplitude	3.2	1.0	-0.9	1.2
Dielectric	4.7	8.2	4.8	
Thickness	2.6	0.8	6.9	
Travel Time	0.9	0.4	2.6	

Trace	196
Mile	0
Feet	985

Cursor	
Voltage	-0.7
Time	9.4

Peak	1	2	3	4
Voltage 1	2.0	0.8	-0.8	0.6
Time 1	5.1	6.1	6.5	9.1
Voltage 2	-1.1	-0.2	0.1	-0.4
Time 2	4.7	5.5	6.9	9.5

Core

Verifying the presence of moisture trapped in the HMAC layer is not possible with normal wet coring operations. Dry drilling should be attempted. Once the core is removed, use the Dielectric Probe to verify the difference in layer dielectric between the top and the bottom of the core. Check the interface 2.5 inches below the surface for moisture damage.

CASE 13 HMAC–OVER PCC, GOOD CONDITION

General

One important use of GPR is to assess the thickness and condition of HMAC overlays over PCC bases. It is critical to be aware of any subsurface deterioration when considering rehabilitation alternatives.
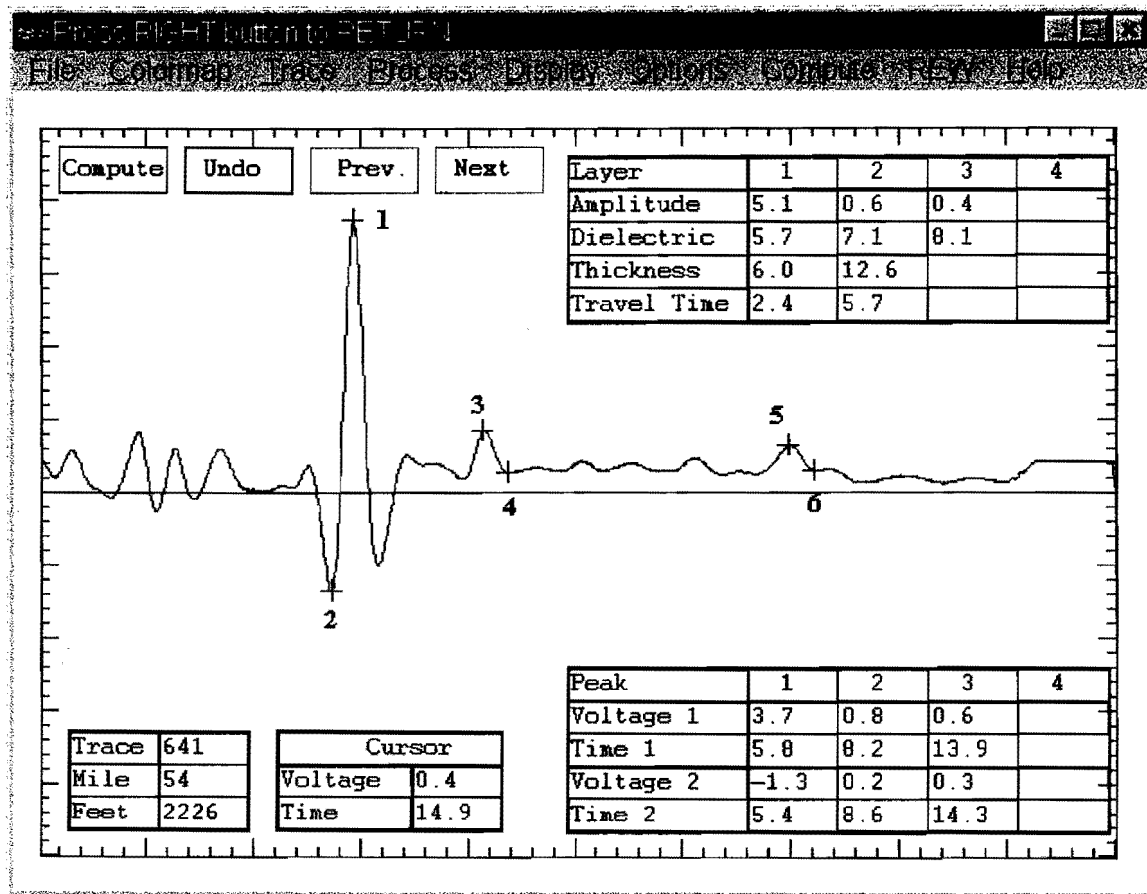
COLORMAP

The COLORMAP display below shows a section with HMAC over PCC. The HMAC varies in thickness from 4 to 8 in. The transition from HMAC to concrete is a transition from a low dielectric to higher dielectric material, which is characterized by a positive interface reflection (red line). If there is no deterioration in the asphalt layer, there will be no strong reflections between the surface and top of the concrete.
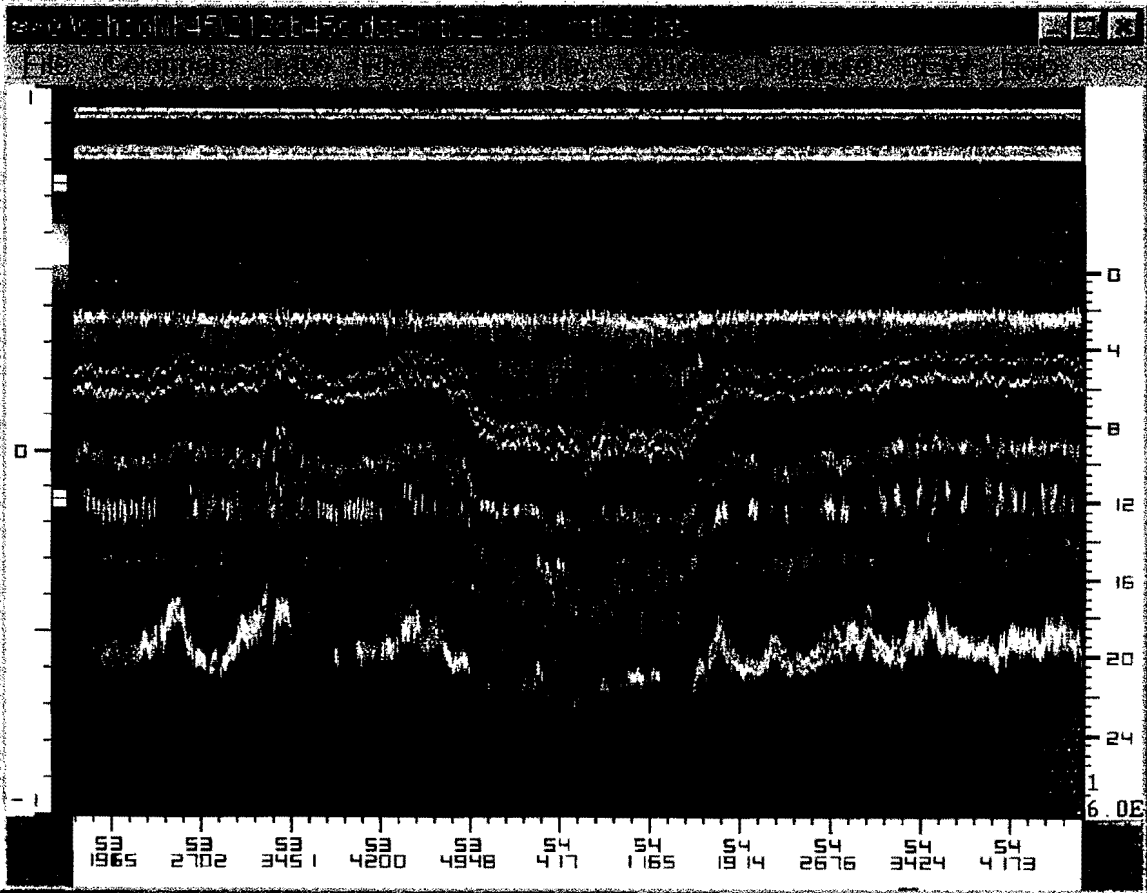
Typical Trace

With good HMAC over PCC, there will be a series of positive reflections from the layer interfaces with no major reflections between them. Normal concrete has a dielectric value between 7 and 8.

File   Colormap   Trace   Process   Display   Options   Compute   Key   Help

Compute	Undo	Prev.	Next

Layer	1	2	3	4
Amplitude	5.1	0.6	0.4	
Dielectric	5.7	7.1	8.1	
Thickness	6.0	12.6		
Travel Time	2.4	5.7		

Trace	641
Mile	54
Feet	2226

Cursor	
Voltage	0.4
Time	14.9

Peak	1	2	3	4
Voltage 1	3.7	0.8	0.6	
Time 1	5.8	8.2	13.9	
Voltage 2	-1.3	0.2	0.3	
Time 2	5.4	8.6	14.3	

Core

With traces such as these, it is anticipated that a good quality solid core will be obtained.

CASE 14 HMAC–OVER PCC, STRIPPING IN LOWER HMAC

General

It is important to detect the extent, depth and severity of any buried stripping and to use this information when planning major rehabilitation projects. GPR has the potential to do this, however, problem areas <u>must</u> be cored to confirm condition. Several naturally occurring conditions can give reflections similar to those found with stripping.

COLORMAP

The surface reflection is always positive and characterized by a blue/red/blue pattern with the color scheme within COLORMAP. Stripped areas normally give negative reflections within the HMAC layer; this would be a red/blue/red pattern for severe cases or simply a blue reflection for less severe occurrences. Another feature about stripping is that it is often intermittent. If the red/blue/red or blue reflection is present throughout the entire trace, then this probably is not deterioration; most probably it is a buried light-weight aggregate layer or drainage layer.
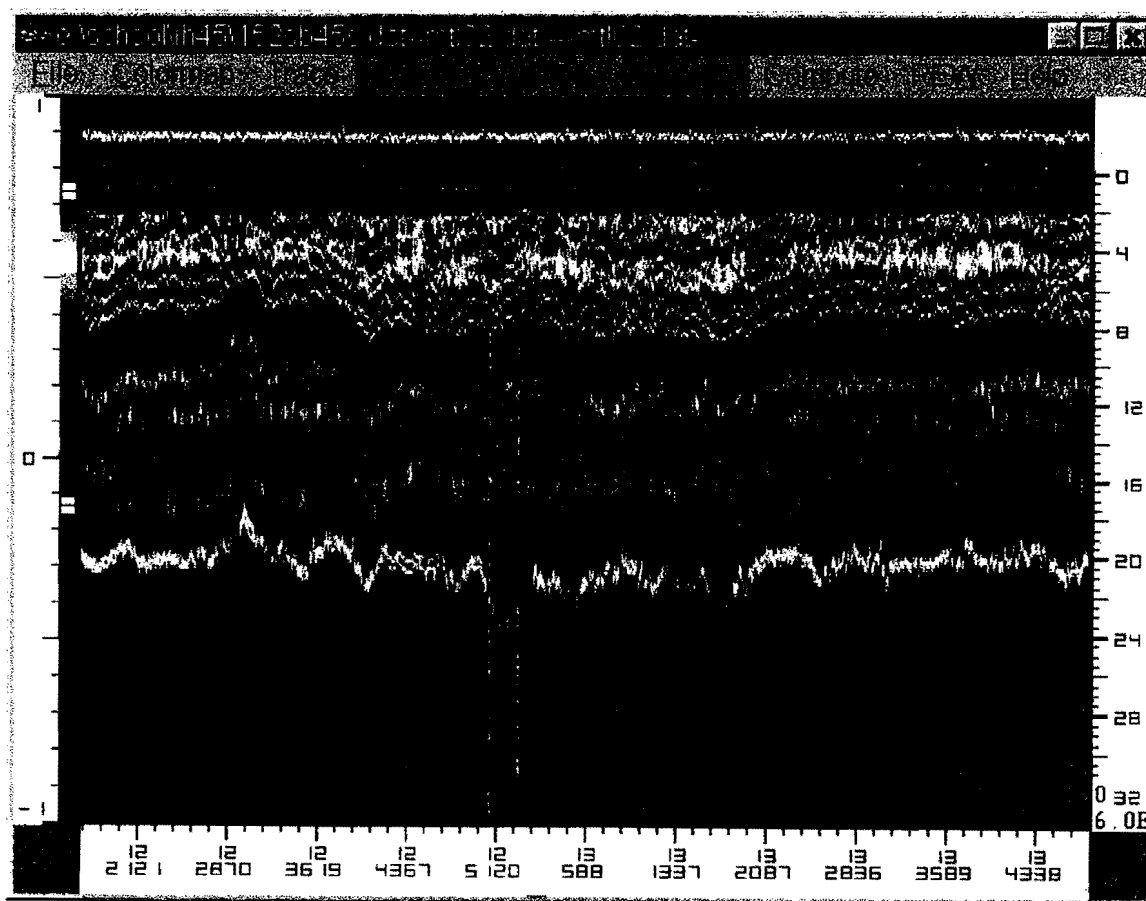
Typical Trace

Deteriorated asphalt layers are characterized by multiple reflections from within the asphalt layer. The surface (positive) reflection is identified by (1, 2), the stripped area (negative reflection) is identified by (3, 4).
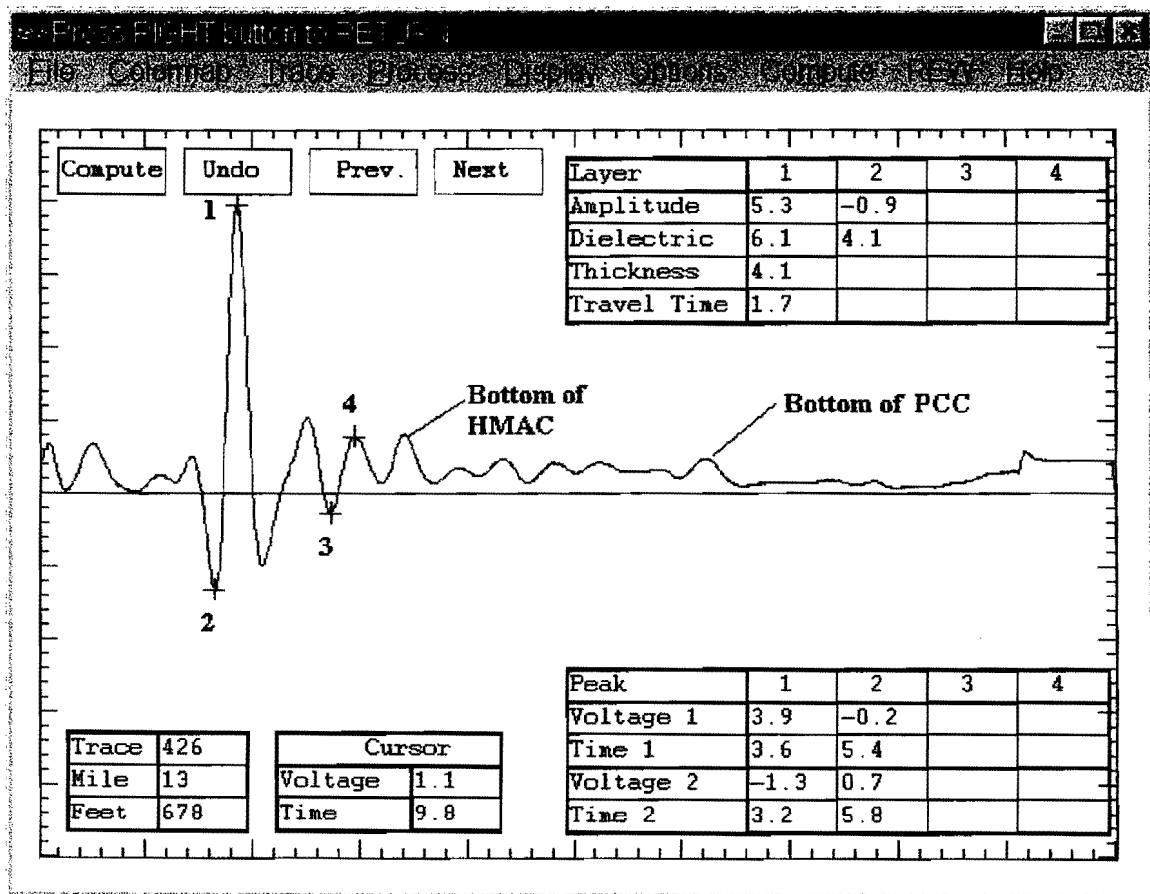
Core

With the above trace, it would be expected that a problem layer would be detected about 4 inches beneath the surface.

CASE 15 PLANT MIX SEALS–ON THE SURFACE OR BURIED BENEATH OVERLAYS

General

Plant mix seals are open graded layers applied to the surface of a pavement. They offer good skid resistance and the ability to rapidly remove surface water. These layers have very high air voids and consequently have very low dielectrics.

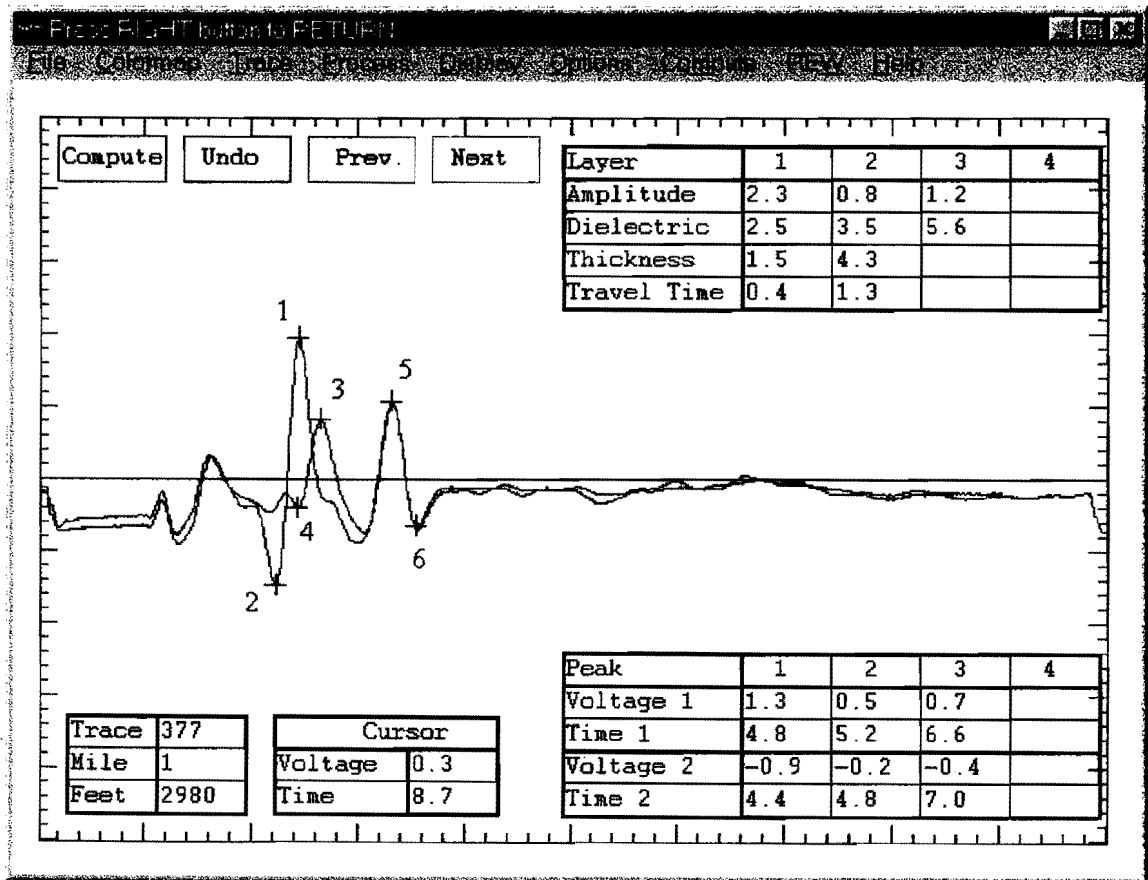*COLORMAP: After Surface/Template Subtraction*

The surface of this highway consisted of primarily a plant mix seal (constructed with a light-weight aggregate). In several locations, this surface has been a overlaid with a thin HMAC layer. The surface dielectric plot at the bottom of the figure clearly shows the overlay locations. The dielectric from the plant mix seal is in the 2 to 3 range, whereas in the overlay areas, the surface dielectric is greater than 6.
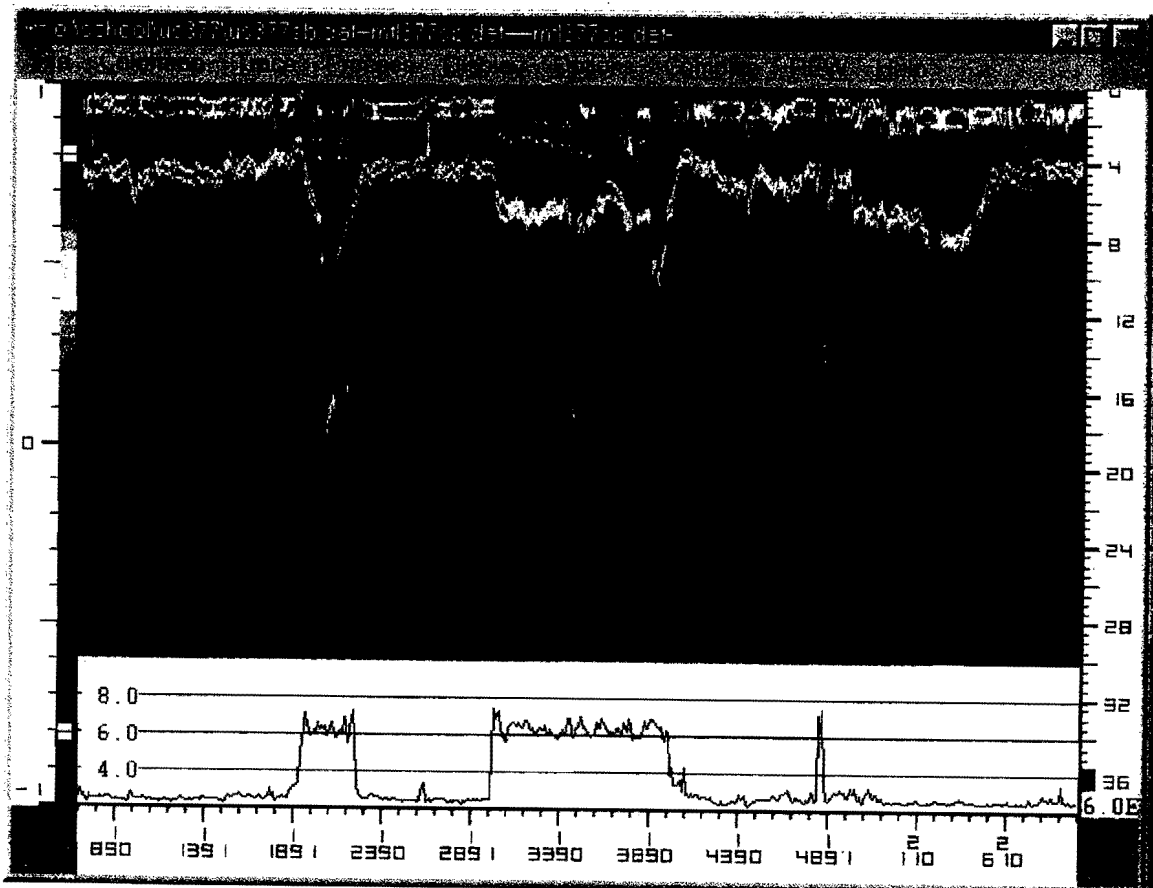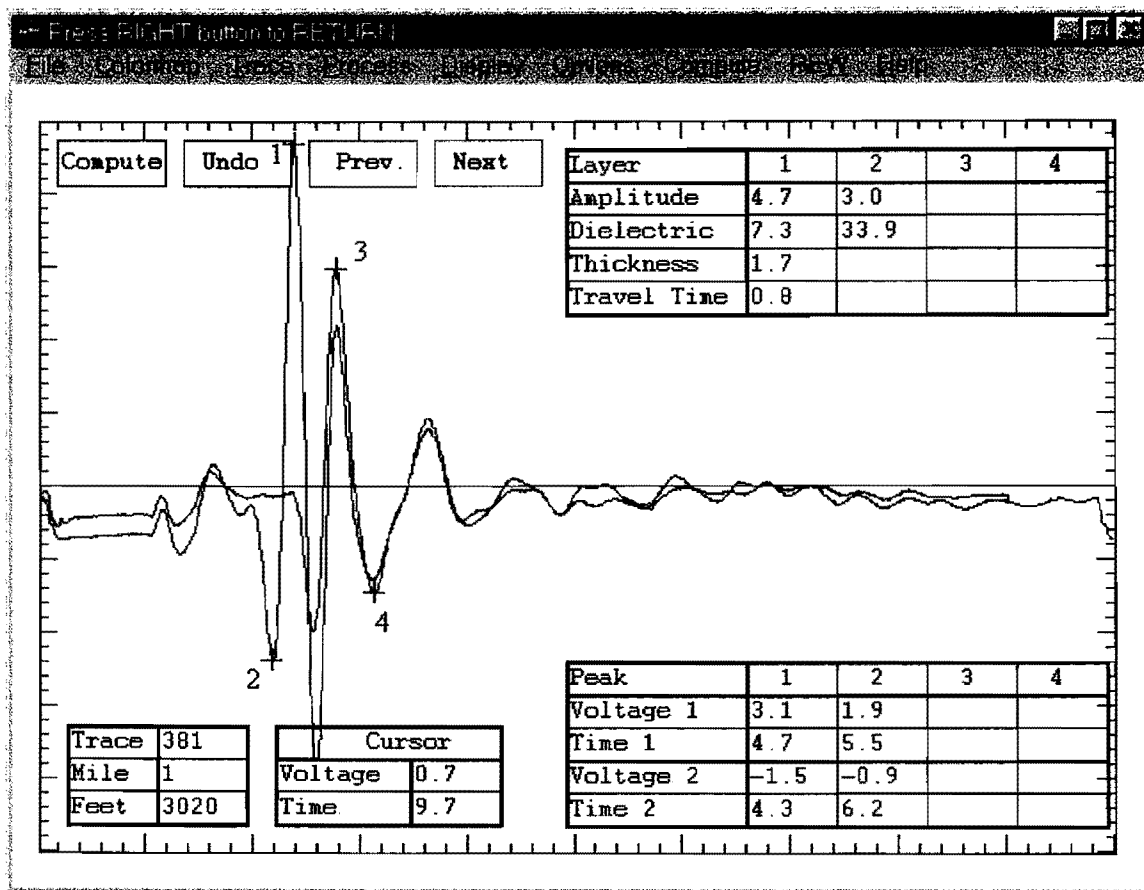
Typical Traces: After Surface/Template Subtraction

The figure below shows a single trace from a location where the plant mix seal is on the surface. This was at 1 mile and 2980 ft from the previous figure. The computed surface dielectric is very low at 2.5.

Layer	1	2	3	4
Amplitude	2.3	0.8	1.2	
Dielectric	2.5	3.5	5.6	
Thickness	1.5	4.3		
Travel Time	0.4	1.3		

Peak	1	2	3	4
Voltage 1	1.3	0.5	0.7	
Time 1	4.8	5.2	6.6	
Voltage 2	-0.9	-0.2	-0.4	
Time 2	4.4	4.8	7.0	

The following figure shows the GPR reflection from 1 mile and 3020 ft. At this location, the plant mix seal has been overlaid with a thin asphalt overlay. This is a completely different picture from that shown above, where the plant mix seal is on the surface. The dielectric of the plant mix seal layer is now 33.9, indicating that it is full of moisture. Overlaying plant mix seals does not appear to be a good idea, as these data show, unless the layer is adequately day-lighted; then there is strong possibility that it will trap moisture.

87

| Compute | Undo | Prev. | Next |

Layer	1	2	3	4
Amplitude	4.7	3.0		
Dielectric	7.3	33.9		
Thickness	1.7			
Travel Time	0.8			

Trace	381
Mile	1
Feet	3020

Cursor	
Voltage	0.7
Time	9.7

Peak	1	2	3	4
Voltage 1	3.1	1.9		
Time 1	4.7	5.5		
Voltage 2	-1.5	-0.9		
Time 2	4.3	6.2		

This situation is undesirable. The trapped moisture will eventually strip the plant mix seal layer. Major problems would be anticipated in severe freezing conditions.

CASE 16 LIGHT–WEIGHT AGGREGATE LAYERS

General

Several districts around the state have used light-weight aggregates in their hot-mix. These mixtures are synthetic aggregates made by firing clay materials. The resulting aggregate has a very open structure and, therefore, a very low dielectric. When used as an aggregate for the surface layer, these materials will typically have a dielectric in the range of 3.5 to 4.5. Once the material is buried beneath a new asphalt layer of higher dielectric material, this arrangement results in a negative reflection. The major concern here is in GPR interpretation. The negative reflections with the HMAC layers are normally associated with defects such as stripping; however, buried light-weight aggregate layers give the same reflection patterns. Interpretation should not be attempted without validation cores.
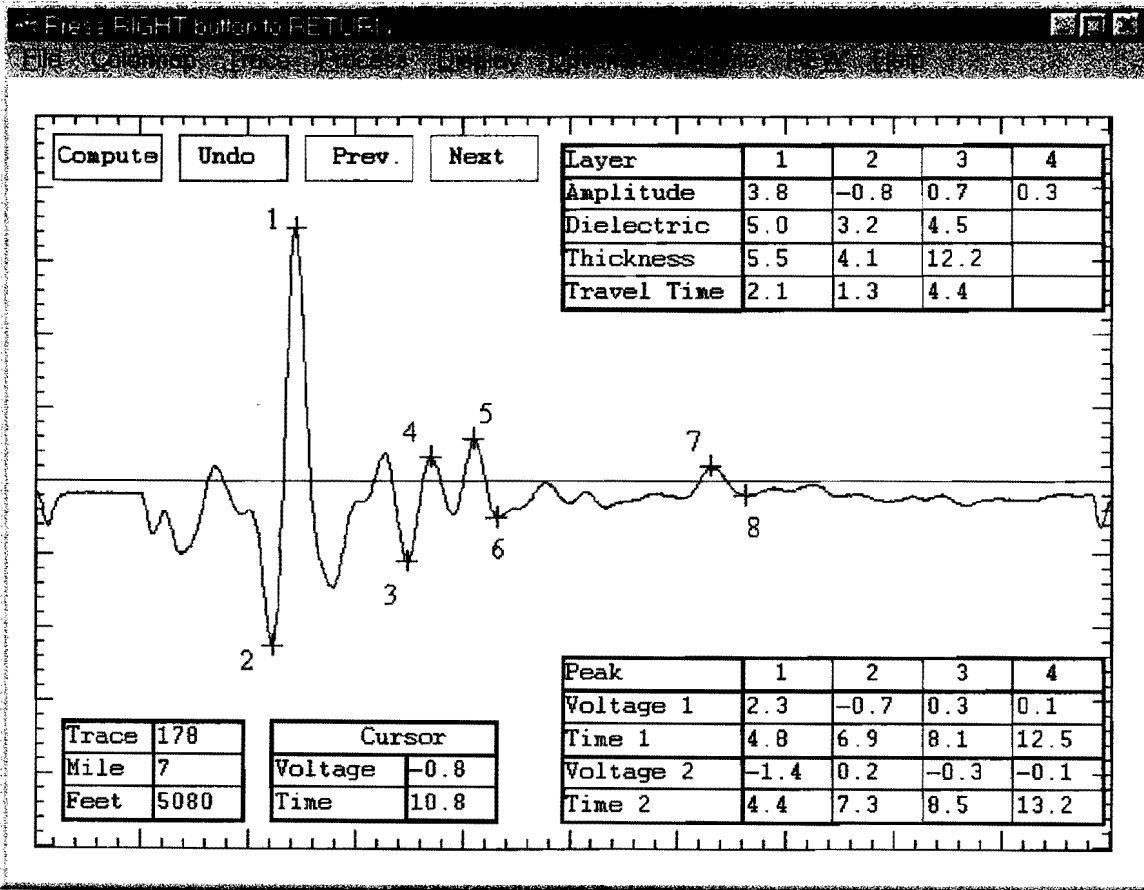
COLORMAP: After Surface/Template Subtraction

The red/blue/red pattern at a depth of 4 in below the surface at 7 mi and 5000 ft, is normally associated with asphalt stripping. In this case, it turned out to be an area of buried light-weight aggregate hot-mix. In attempting to distinguish between buried light-weight mix and stripping, it was proposed that stripping would be intermittent because of its varying severity, whereas buried light-weight mix would give a consistent reflection throughout the project. This rule often works, but in the case below it did not. In this case, the light-weight layer had been removed by maintenance operations in some places, but in others it was still present.
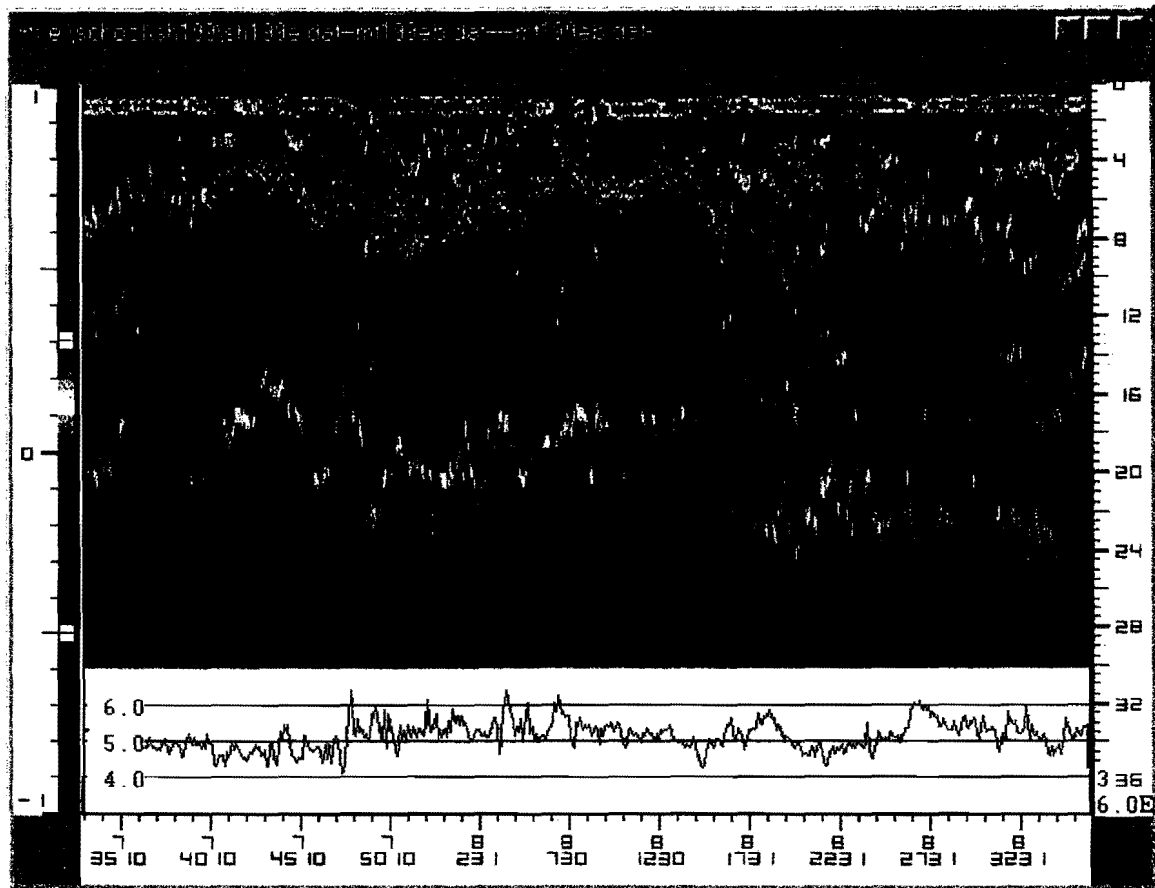
Typical Trace: After Surface/Template Subtraction

A clear negative reflection (3, 4) is observed after the positive surface reflection (1, 2). The numbers on the figure show the sequence in which the peaks were identified in computing both thickness and dielectric.

Layer	1	2	3	4
Amplitude	3.8	−0.8	0.7	0.3
Dielectric	5.0	3.2	4.5	
Thickness	5.5	4.1	12.2	
Travel Time	2.1	1.3	4.4	

Trace	178
Mile	7
Feet	5080

Cursor	
Voltage	−0.8
Time	10.8

Peak	1	2	3	4
Voltage 1	2.3	−0.7	0.3	0.1
Time 1	4.8	6.9	8.1	12.5
Voltage 2	−1.4	0.2	−0.3	−0.1
Time 2	4.4	7.3	8.5	13.2

Core

This example highlights the importance of taking validation cores. Pavements which have been maintained are often extremely complex. It is impossible to be 100 percent certain in distinguishing between unusual aggregates and buried defects. However, the GPR can identify coring locations, and once one or two validation cores have been taken the extent and severity of the problem areas can be defined.

CASE 17 CHIP SEAL–MOISTURE TRAPPED BENEATH A SURFACE SEAL

General

Single or multiple seals are very common on many Texas highways. On low volume highways they are placed over a granular base and act as the riding surface. For new pavements the total thickness of the seal is normally less than 0.5 in. With older pavements, multiple maintenance seals may be applied. In these cases, the combined thickness may be greater than 1 inch. The GPR surface reflection is influenced by the properties of the top 1.5 inches of the pavement structure. Clearly when a pavement has a very thin surface the surface reflection will be influenced by the density and moisture content of the base layer.

COLORMAP: After Surface/Template Subtraction

The COLORMAP display below is from a section of pavement with both a HMAC surface (right side of figure) and chip seal surface (center). The reflection from the top of the base can be observed only when the surface reflection is removed. This reflection is faint under the chip seal surface. The surface dielectric plot at the bottom of the figure is used to identify locations of wet base under the chip seal. Around 0 miles and 2500 ft, there is an area where the surface dielectric is greater than 12. At this location, the surface is approximately 0.5 inches thick, and the high dielectric is caused by wet base directly beneath the seal. The surface dielectric in the HMAC section is around 5.5 and relatively constant. As the HMAC surface is around 2 in the surface dielectric values are not influenced by the base moisture content.
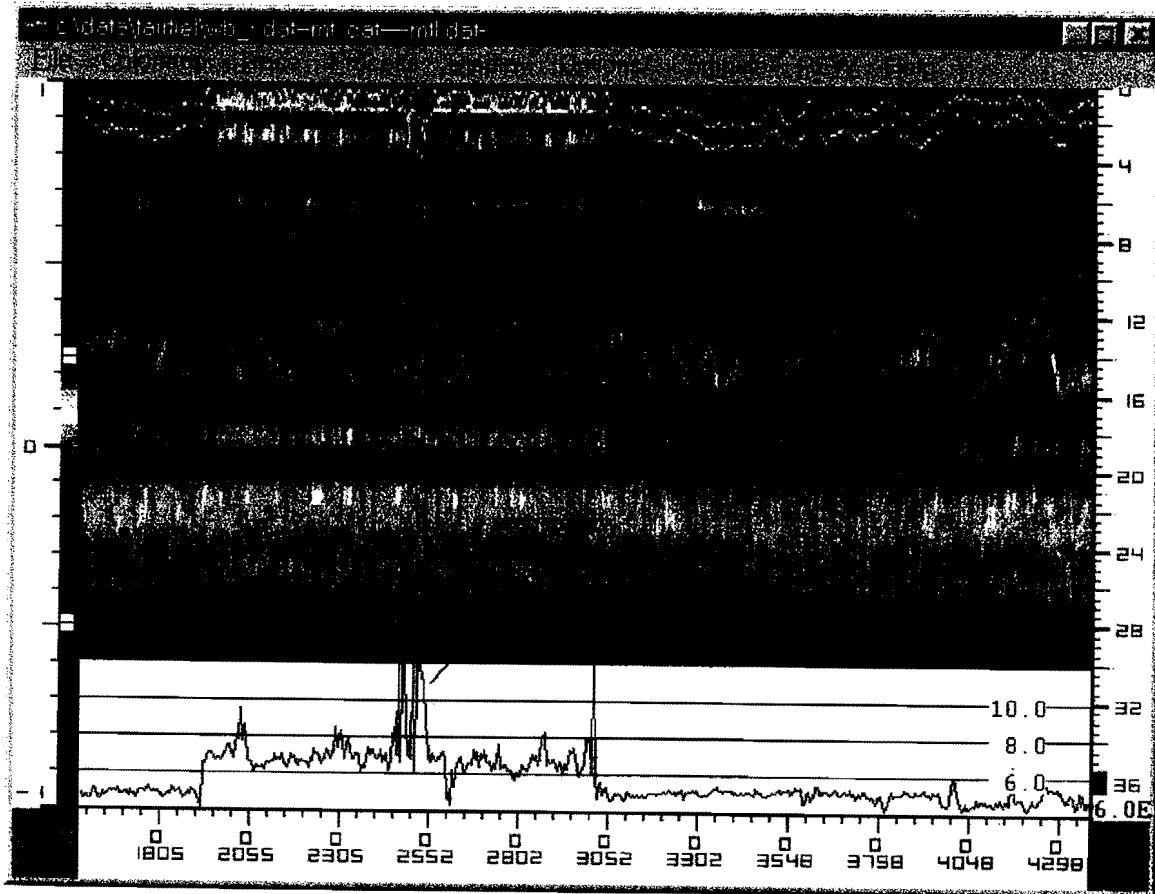
Typical Trace: After Surface/Template Subtraction

Under normal conditions with good materials, the surface dielectric from a chip seal surface should be in the range of 6.5 to 8.5. Values higher than this indicate that the base is holding significant moisture. With the trace below, the computed surface dielectric is 11.3.
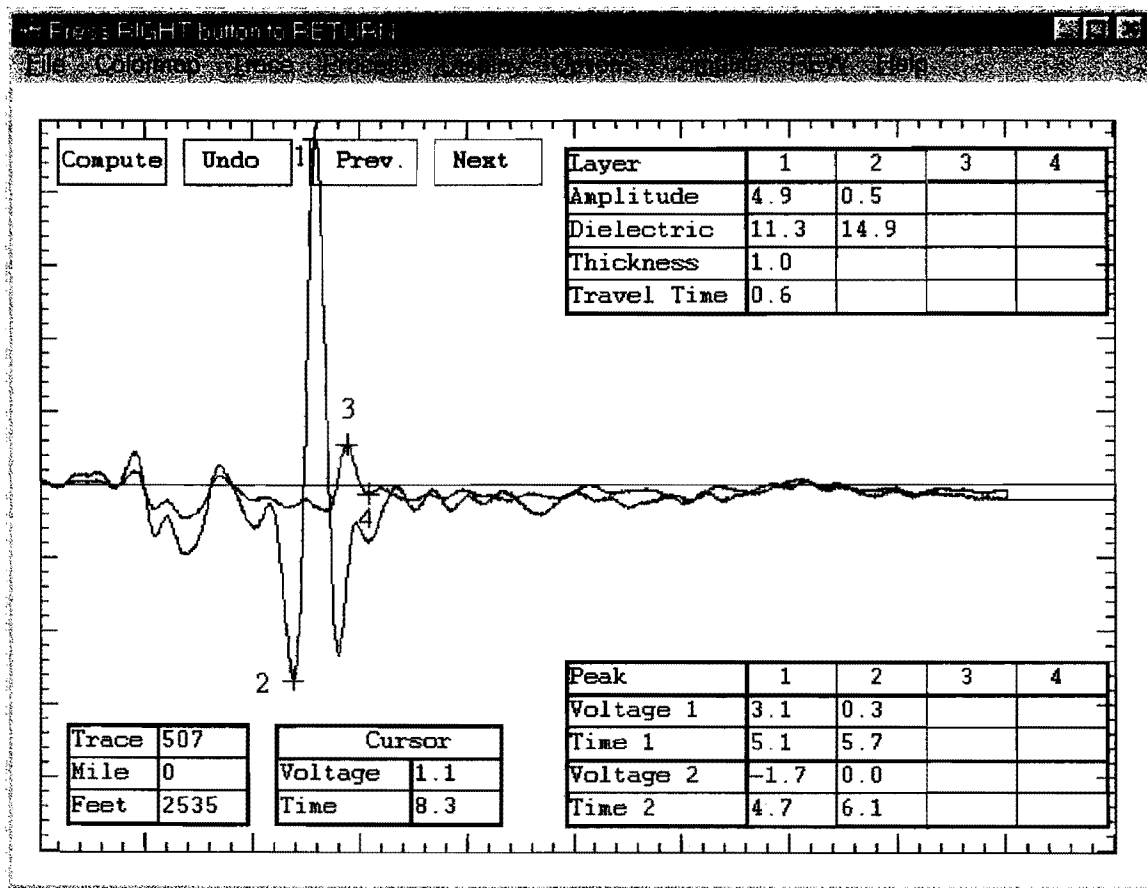
CASE 18 POOR LONGITUDINAL CONSTRUCTION JOINTS

General

In normal quality control testing of new HMAC surfacings, density measurements are made on cores taken from the mat. It is usual policy to take these cores from locations several feet away from longitudinal construction joints. Yet there is growing concern that these joints are major conduits for moisture to enter lower pavement layers. If the joint has a significantly lower density than the rest of the mat then this location will have a lower surface dielectric. Areas of low density will be observed as significant decreases in the computed surface dielectric.

COLORMAP: After Surface/Template Subtraction

This display is from a newly constructed HMAC surfacing which was failing prematurely. The data were collected while driving in a zig-zag pattern over the longitudinal construction joint. The solid red line in the display is the reflection from the top of the granular base. The result of interest is the surface dielectric plot at the bottom of the figure. The major dips in the surface dielectric were found each time the GPR unit passed over the longitudinal construction joint. If the HMAC surfacing has uniform density, the surface dielectric plot will be a horizontal line.
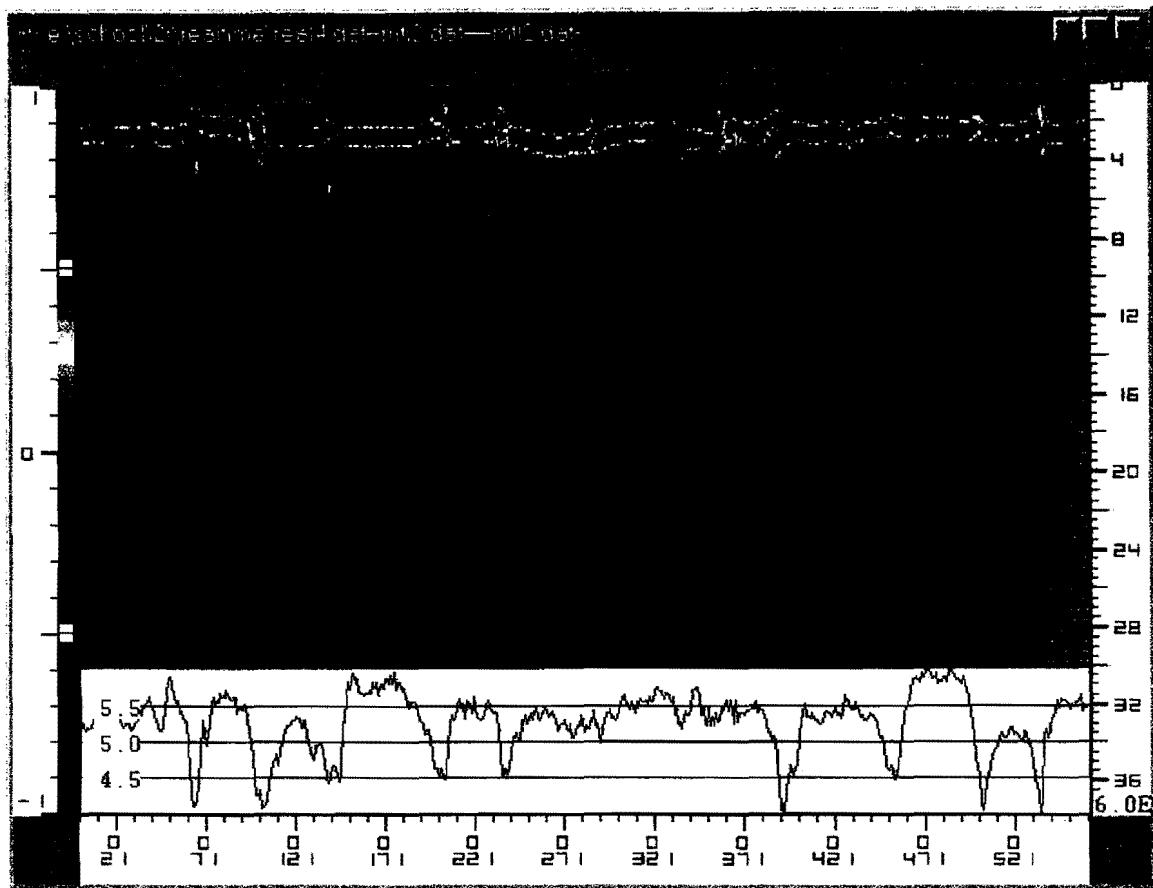
Typical Trace: After Surface/Template Subtraction

Below is a typical single trace from the COLORMAP display. Clear positive reflections are observed from the surface and top of the base. The surface reflection amplitude is defined by (1, 2). This amplitude is used to compute the surface dielectric. This value is influenced primarily by two factors, namely moisture and density. Moisture will generate an increase in reflection and increase in surface dielectric, density; (high air content) will result in a decrease in amplitude and surface dielectric.
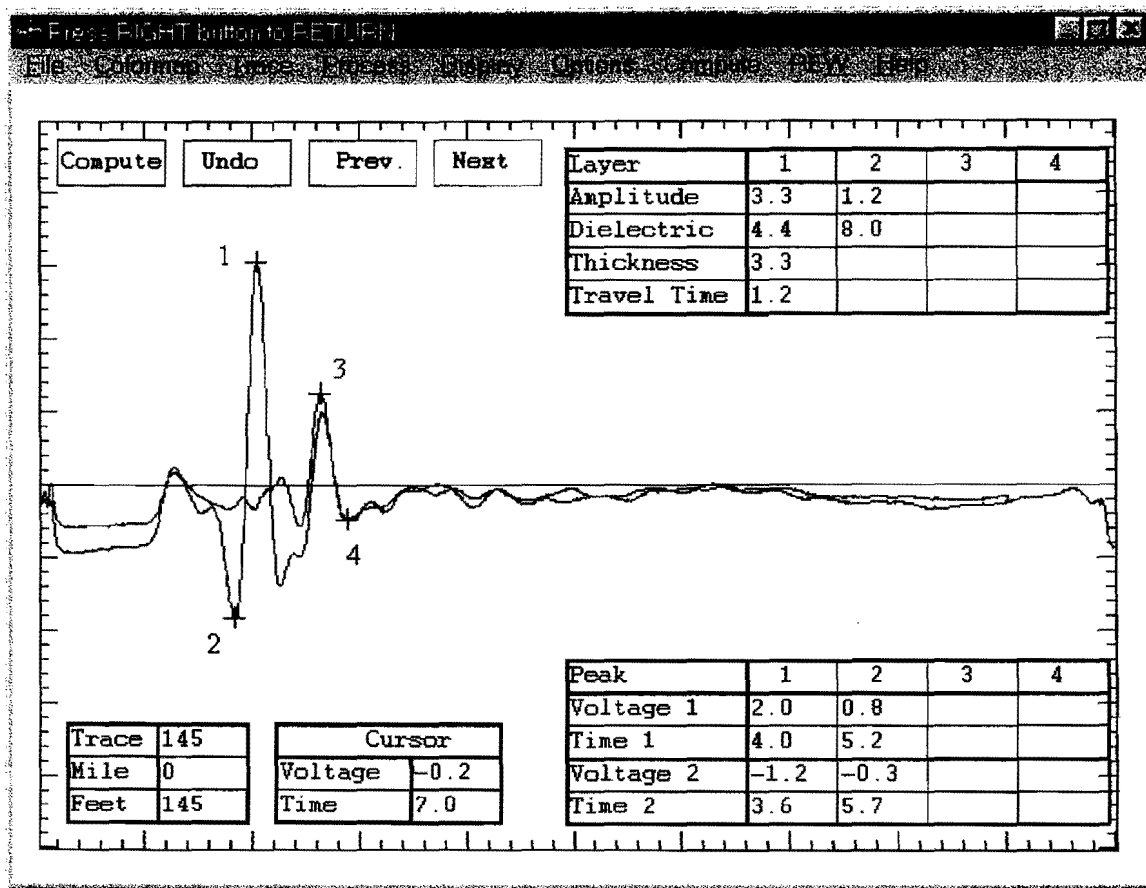
Core

Cores should be take to validate the high air void contents near the joints. Cores were taken from the project shown above. Near the construction joint, the air void content was measured to be from 17 to 19 percent, this corresponded to a dielectric value of close to 4.5. The air voids in the regular mat were around 8 percent, which corresponded to a dielectric of 5.5. The dielectric value for any layer is primarily a function of the aggregate type used and the number of air voids. Calibration is required for each HMAC material when converting surface dielectric to air void content.

CASE 19 SEGREGATION IN A NEW HMAC OVERLAY

General

Temperature, longitudinal, and "end-load" segregation continue to be major concerns with dense graded HMAC layers in Texas. This typically manifests itself as periodic coarse, open areas in the mat. These areas are often the starting location of future pavement distress. GPR appears to have some potential to identify and measure the severity of this problem.
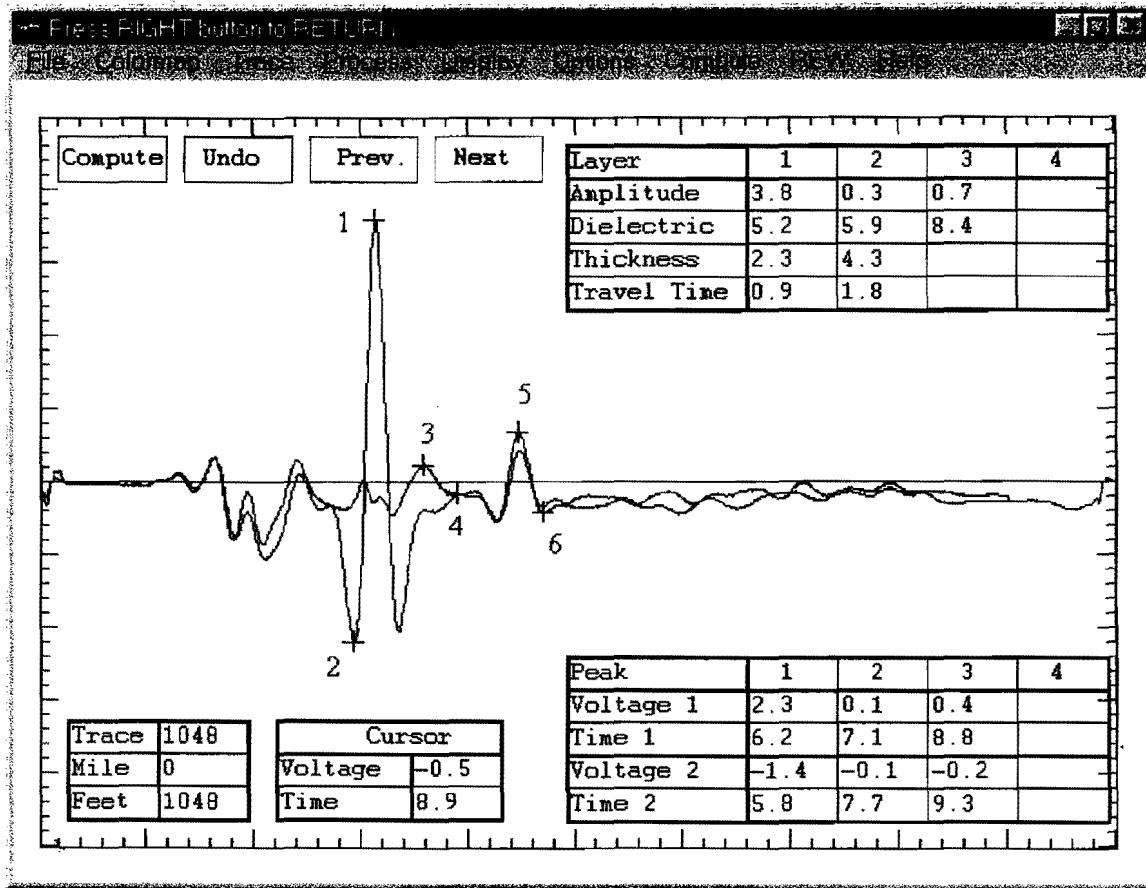
COLORMAP: After Surface/Template Subtraction

These data were collected on a new HMAC surface. The faint intermittent yellow line at a depth of 2 inches is the reflection from the top of the old HMAC. The stronger reflection from a depth of 7 in is the reflection from the top of the flexible base. The result of interest is the surface dielectric plot at the bottom of this figure. The clear periodic decreases in surface dielectric are areas where segregation was visually observed on the surface. Between the segregated areas, the surface dielectric plot is a relatively flat horizontal line. This plot is typical of a well-compacted, dense-graded HMAC. In recent studies, it was found that a 1 unit change in surface dielectric corresponds to over a 10 percent change in air voids.
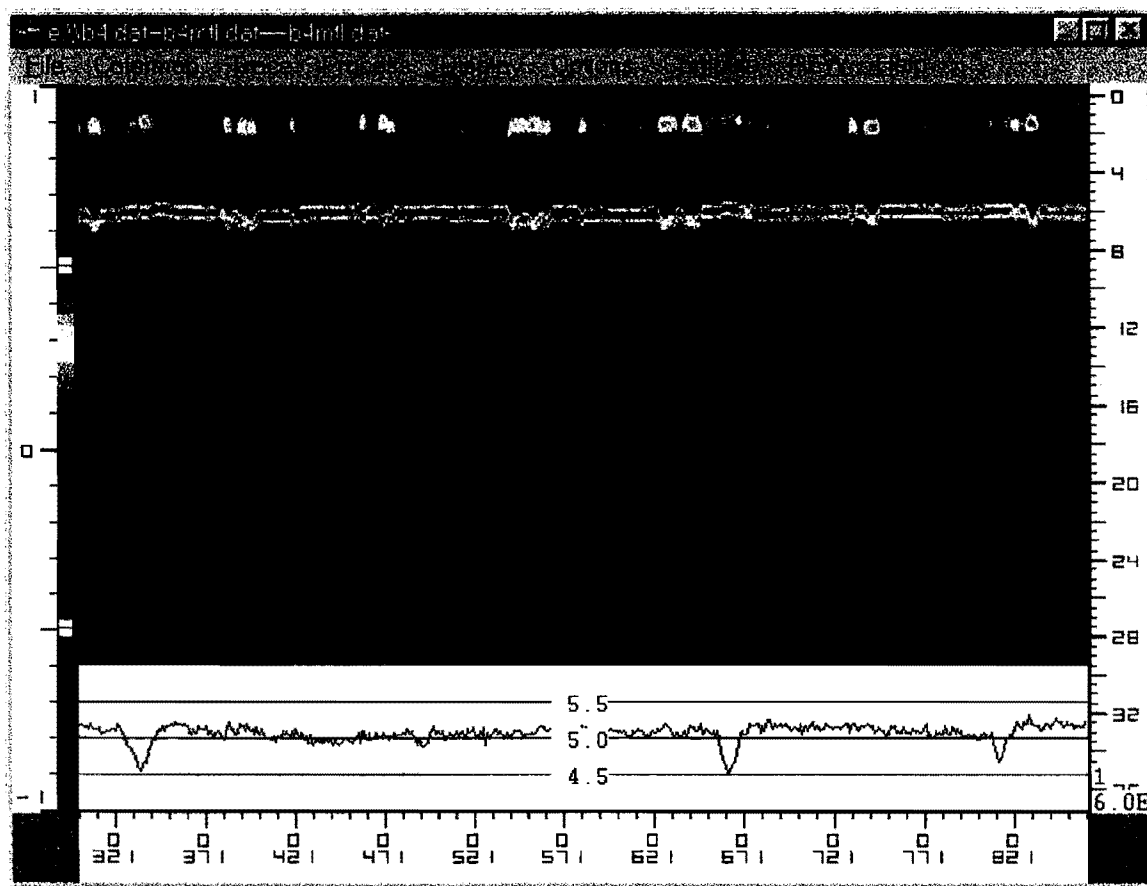
Typical Trace: After Surface/Template Subtraction

Clear positive reflections are observed at all layer interfaces. The amplitudes of reflections are surface (1, 2), top of old HMAC (3, 4), and top of base (5, 6). An area of segregation would produce a significant reduction in the amplitude of surface reflection (1, 2). With data such as these it is possible to use GPR for both thickness and density control.

Layer	1	2	3	4
Amplitude	3.8	0.3	0.7	
Dielectric	5.2	5.9	8.4	
Thickness	2.3	4.3		
Travel Time	0.9	1.8		

Peak	1	2	3	4
Voltage 1	2.3	0.1	0.4	
Time 1	6.2	7.1	8.8	
Voltage 2	-1.4	-0.1	-0.2	
Time 2	5.8	7.7	9.3	

Trace	1048
Mile	0
Feet	1048

Cursor	
Voltage	-0.5
Time	8.9

Core

Cores should be taken in at least at two locations to correlate air voids with surface dielectric. Locations of both high and how dielectric should be used. Based on extensive laboratory and field studies in Finland, Saarenketo (3) proposed the following relationship between air voids and computed dielectric (D):

Air Voids in HMAC = A * (exp - (B*D))

Where D is the computed surface dielectric and A and B are regression coefficients computed for field cores. Once the values of A and B are calculated, it is possible to convert the surface dielectric profile into an air voids profile.

CASE 20 JOINTED CONCRETE–WATER FILLED VOIDS

General

Voids often occur under the joints in jointed concrete pavements. If these hold moisture, they can usually be detected with GPR. In general, GPR does not work too well with concrete pavements; the concrete severely attenuates the GPR signals. Air-filled voids cannot be detected with 1 GHz air-launched antennas unless they are greater than 17 mm thick. Problems also exist when attempting to distinguish between water-filled voids and areas of saturated base.

COLORMAP

The interface between the bottom of the slab and the base is typically very faint with PCC pavements. It may not be discernable if the concrete is resting on a cement-stabilized base (similar dielectric). It could also be negative if the slab is resting on an asphalt-stabilized base (high to low dielectric). If water filled voids are present, they will be normally observed as intermittent positive reflections (solid red areas) at the slab/base interface. Areas of saturated base will not produce localized reflections but continuous high reflections over a substantial distance. Major air-filled voids will give a negative reflection at the slab/base interface and be seen in the COLORMAP display as small blue areas.
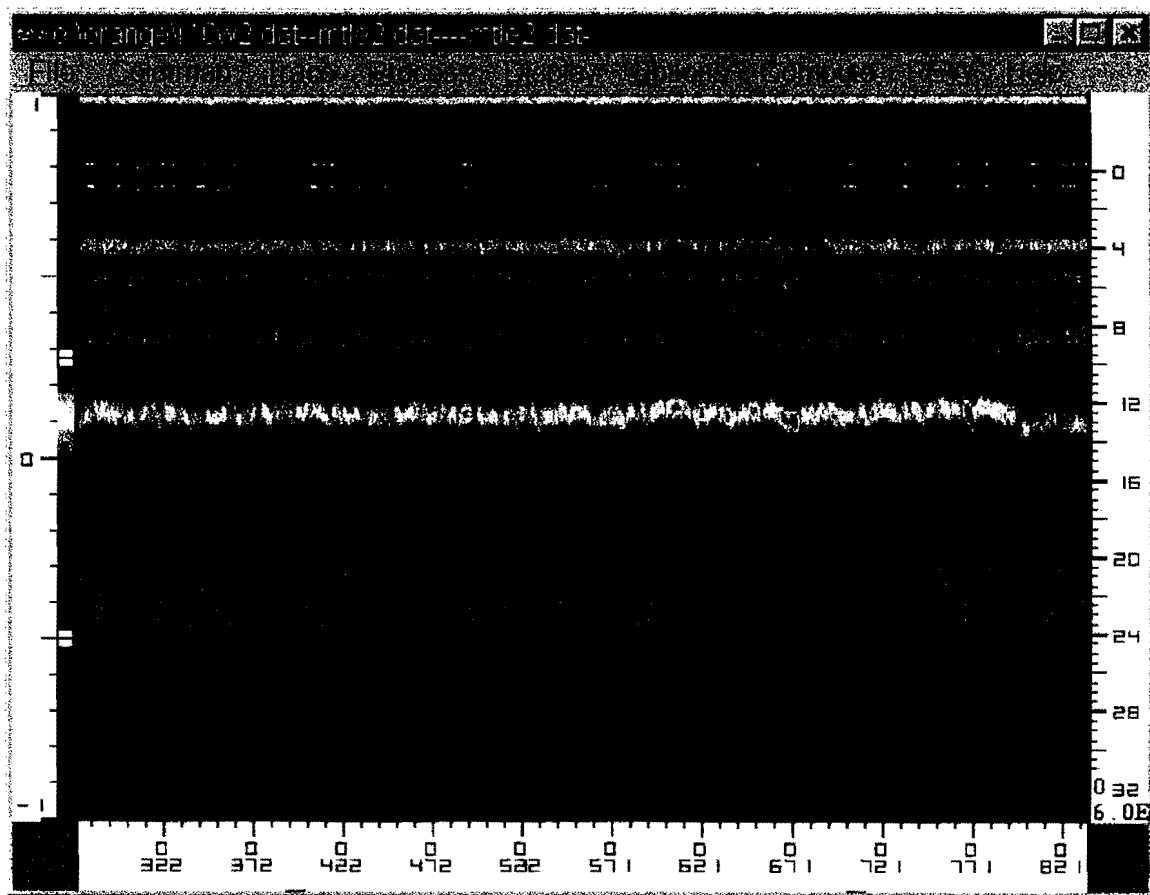
Typical Trace

Large positive reflections occur when water is beneath PCC slabs. Significant moisture will cause an increase in amplitude (3, 4).
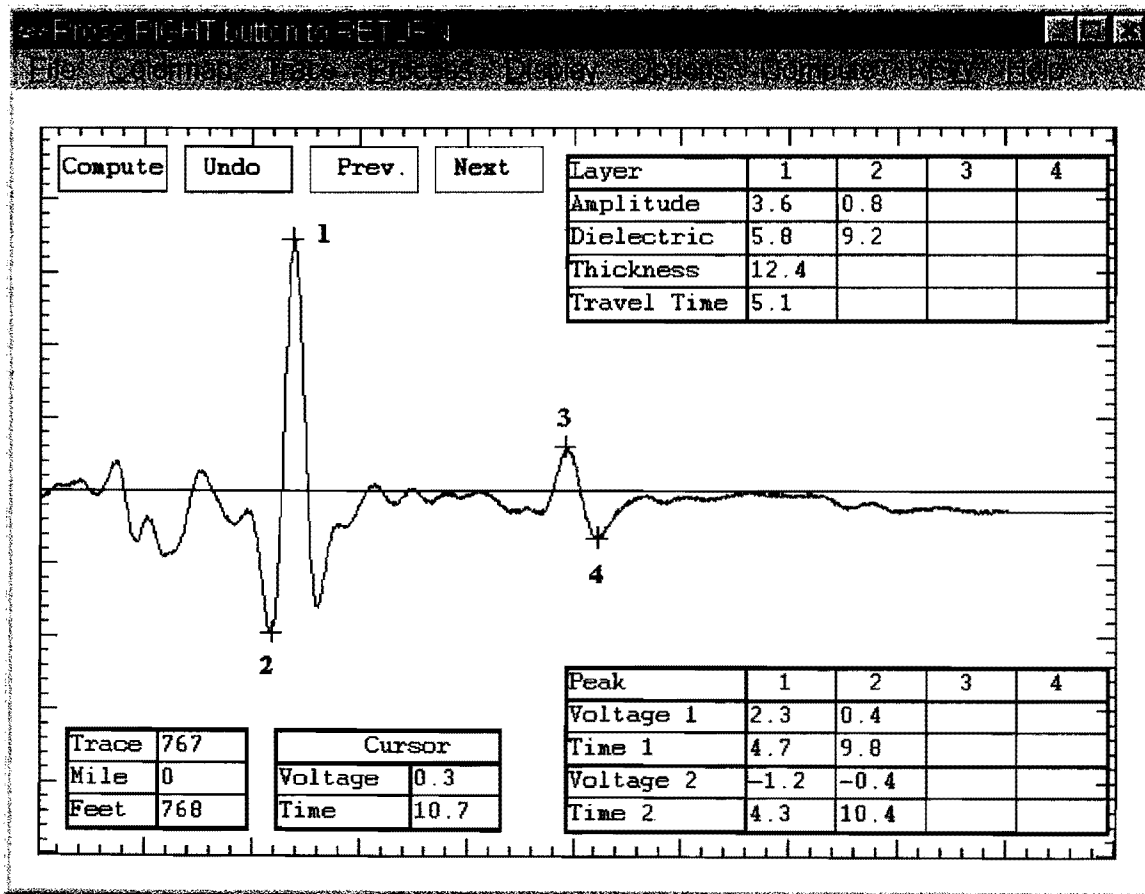
Core

Void thickness is best measured by using the epoxy core test. A small (25 mm) diameter hole is dry-drilled through the slab and base, and a fluid fast-setting epoxy is poured into the hole. A 100 mm core is taken by cutting directly through the existing small hole, and the epoxy fills the void under the slab.

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