RADAN® 6.6

Bridge Deterioration Assessment Module

MN43-172 Rev G

Geophysical Survey Systems, Inc.
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Chapter 1: Introduction and Data Collection Requirements

The Bridge Assessment (BA) module in RADAN is a specialized data analysis tool that efficiently processes data obtained with GSSI's air-launched Model 4208, 4108 and 4105 horn antennas and its Model 5100, or 5100B antenna over bridge decks for two different applications:

1. Concrete cover assessment on new bridge decks
2. Bridge deck condition analysis.

An ASCII data file containing the desired information (cover thickness or areas of deterioration) is the final output following the data processing. This file can then be used to run descriptive statistics or to graph change across the area.

Antennas

The module can only process data obtained using GSSI's Model 4208, 4108 and 4105 air-launched horn antennas and GSSI's Model 5100 and 5100B, ground-coupled antenna with a survey wheel.

Note: The hardware settings listed in this manual must be used during data collection.

Brief Overview of this Manual

Chapter 2 – Data collection and processing methodology using ground coupled antennas is described.

Chapter 3 – Concrete Condition Assessment methodology using the Model 5100(B) antenna is described.

Chapter 4 – Concrete Condition Assessment methodology using the Horn antennas is described.

Chapter 5 – EZ Tracker Processing of Horn antenna data is described.

Chapter 6 – Interactive Interpretation features and options are described in detail.

Chapter 7 – Constructing contour maps using rebar reflection amplitudes.

References

Appendix A – Procedure to follow for using a calibration hole to calculate the propagation velocity for concrete cover assessment is summarized.

Appendix B – List of problems that may be encountered during data processing and the solutions.

Appendix C – "How-To" quick reference details the procedure for changing the input and output directories for *.dzt files and the units used during data display and processing (i.e., meters, inches, feet, etc.).

Chapter 2: Data Collection and Processing Methodology for Concrete Cover Assessment on New Bridge Decks Using Ground Coupled Antennas

Overview

This section describes data collection for quality assurance (QA) studies on new concrete cover bridge decks. This technique is not applicable to asphalt overlaid decks. The goal of this application is to ensure that there is adequate concrete cover over the top layer of reinforcing steel.

Unlike the Bridge Deterioration Mapping application, a Bridge QA project does not require a 3D collection. A single representative profile per travel lane is all that is needed. Typically, this profile is along the wheel path of the lane opposed to the shoulder. There is one important caveat to this: the data must be collected perpendicular to the trend of the top layer of rebar. This means that if the rebar are longitudinal, then you must take profiles across the bridge, not along it.

If a complete map of cover thickness is required, then a 3D file can be collected following the instructions given in your SIR System manual. Be sure to configure the data collection settings (Gain, Position, Range, Scan and Sample density) as they are described in this guide. Also be sure to orient profile lines perpendicular to the trend of the top bars.

There are a number of steps that must be precisely followed to collect high quality GPR data for the purpose of concrete cover assessment. The following sections describe, in detail, all of the steps involved in collecting and processing high-quality GPR data. The end result is an ASCII output file containing the locations and depths of the topmost rebar in a concrete structure.

Data Collection

1 Turn on your SIR System and recall the saved radar setting used for new bridge decks.

- If no previously saved setting is available, set up the parameters described at the end of this chapter.

2 Let the SIR control unit run in setup mode for a recommended warm-up time of 5-10 minutes **with the scan showing on the screen.**

- During the warm-up period, it is recommended to physically mark the profile lines on the structure over which data will be collected, and to measure the position of these marked lines with respect to fixed reference points on the bridge deck. The profile lines should be straight, and perpendicular to the trend of the top rebar.

3 Next, after the 5-10 minute warm-up and just prior to collecting data, check the position and gain of the scan in the display window and adjust if necessary.

- Generally, during warm-up, the scan position will drift upward in the window. The scan position and gain should look similar to that shown in Figure 1.

Caution: Remember, if a portion of the direct wave is missing during data collection or if the gain is too high, the data won't be processed correctly in RADAN. Figures 2 and 3 illustrate a badly positioned scan and a clipped scan, respectively.

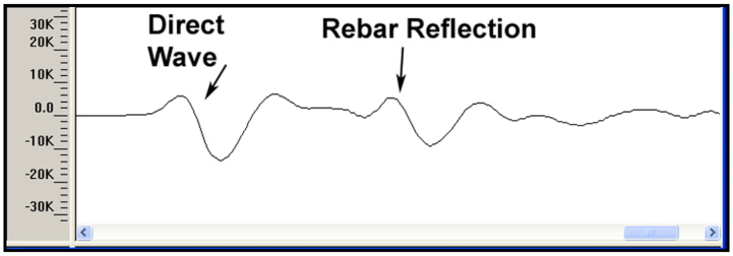


Figure 1: Typical waveform shape with antenna positioned over rebar. The signal is set up so that the direct wave and the peak amplitudes are well within the boundaries of the sampling window.

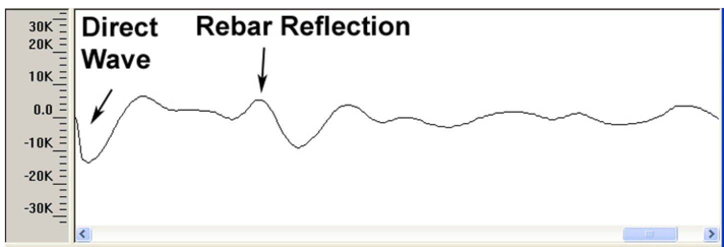


Figure 2: Badly positioned waveform. The direct wave is not located in the window. Using the signal positioned as shown in this figure would cause the program to give erroneous results. Prior to collecting data the user must manually adjust the signal position until the direct coupling is located entirely in the window (see Figure 1).

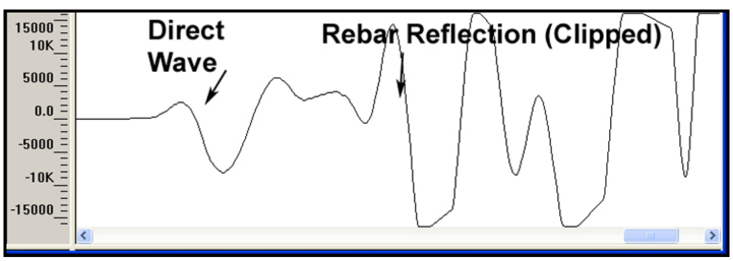


Figure 3: Example of clipped waveform (gain set much too high). Clipping must be prevented for accurate rebar depth and amplitude measurements. Prior to collecting the data the user must manually decrease the gain.

4 Position the antenna midpoint at the start of the marked profile line.

- The antenna midpoint is denoted by vertical indented lines on the red outer case on either side of the Model 5100(B) antenna.

5 Collect the profile. If the SIR system beeps, the antenna is being moved too fast, so the person moving the antenna should slow down.

- If the SIR system beeps more than 2 or 3 times during data collection along a single profile line, reject this file and collect the profile again.

6 After collecting the whole dataset, obtain a calibration core to measure the depth to the top of one of the rebar. The calculated GPR velocity resulting from this calibration is used for calculating the remaining rebar depths from the data.

- Locate a rebar along the profile line, preferably within 6 feet (2 meters) from the starting point of the profile line. (Suggestion: Use the deepest bar in this zone for calibration.)
- After drilling a hole and measuring to the **top** of the rebar from the concrete surface, record the distance from the start of the profile line to the calibration hole.
- More details on the calibration procedure are given in Appendix B.

7 Data collection should now be complete. It is up to the operator to make sure that data are acceptable for processing using RADAN. The three important things to check before leaving the bridge are:

1. The data files were properly stored.
2. The direct wave did not drift outside the window on any data files.
3. The gain during data collection was not too high.

Data Transfer and Processing

1 Transfer the data from the SIR system to the computer that will process the data using the Windows transfer utility, Data Transfer Util.

2 **After data transfer is complete, start RADAN on the computer.**

3 Select the source (i.e., input) and output directories and the vertical and horizontal units that will be used during data processing. (See Appendix C for details.)

4 In RADAN, open the data file collected along the profile line where the calibration core was drilled (if a calibration core is to be used in the analysis, as recommended). A typical file will appear like the one shown in Figure 4 below.

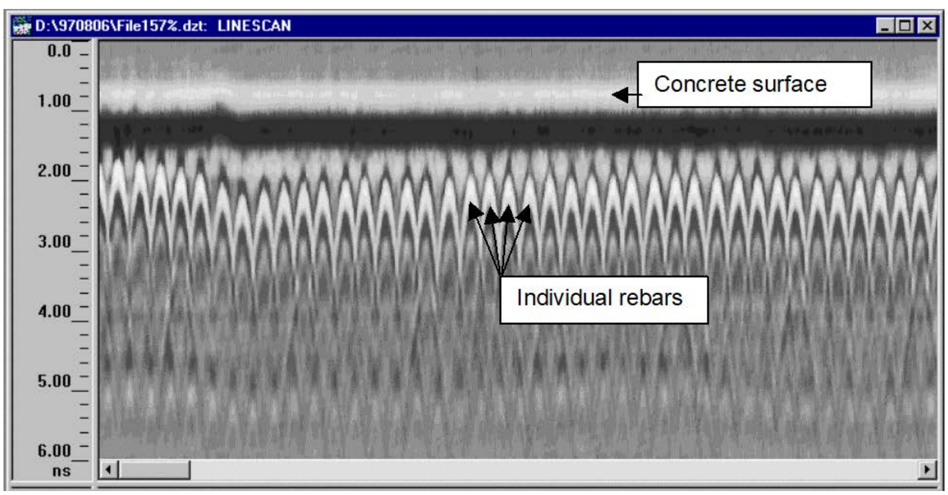


Figure 4: Typical raw data file (Display Color Table #6, Color Transform #3).

Note: The data appearance is significantly affected by the display parameters used. Much of the data shown in this manual are displayed with Color Table #6 and Transform #3.

5 Activate the Bridge QA process by clicking the button. The Bridge QA dialog box shown in Figure 5 will appear. The user must make several decisions:

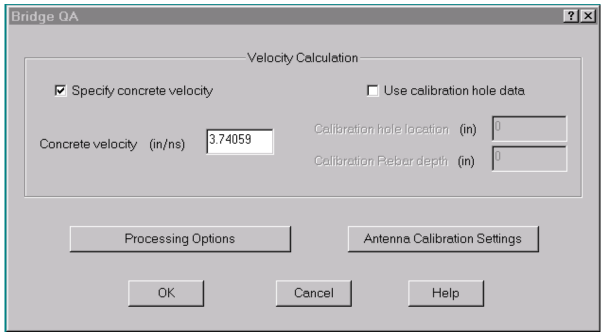


Figure 5: Bridge QA dialog box.

Velocity Calculation: The first decision is how the radar wave velocity will be calculated. The velocity is a critical parameter because it directly influences the calculated rebar depths.

The only recommended method is to use calibration hole data obtained from measuring the depth to one of the rebar that the antenna passed directly over during data collection.

- To implement calibration hole data, select the Use Calibration Hole Data option, then enter the calibration hole location relative to the start of the profile line and the measured rebar depth.
- If the decision was made not to use calibration hole data, then the user should select Specify Concrete Velocity (if it is not already selected) and then enter the estimated or previously known concrete velocity.
- The default velocity is 3.74 inches/nanosecond (9.5 cm/ns).

Processing Options: The most common use for the Bridge QA module has been on newly constructed concrete bridge decks containing rebar between 1-4 inches (2.5-10 cm) in depth and at a spacing of 6 inches (15 cm) between rebar.

- The data processing algorithm uses these values to locate rebar unless the user changes these settings.
- When the user clicks the Processing Options button, a dialog box opens that allows the user to modify the rebar location and spacing parameters.
- The other parameter in the Processing Options dialog box is the Antenna ID option, which only applies to users with more than one Model 5100.
- Each Model 5100 used for the bridge QA module should be calibrated at GSSI with the calibration settings entered into the dialog that opens when the user clicks Antenna Calibration Settings. See below for more details. **Note:** This function is not typically used anymore and is only important if you are collecting with multiple antennas.

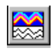
Antenna Calibration Settings: Clicking the Antenna Calibration Settings button opens a dialog box that allows the user to enter various antenna calibration parameters. **Note:** This function is not typically used anymore.

- These parameters are automatically saved so the user only needs to enter them once.
- If the user has only 1 antenna, the calibration parameters should be entered on the line corresponding to Antenna ID A.
- The only important calibration parameter for Bridge QA work is the Time Zero calibration #. If the time-zero calibration # for your antenna is not known, call GSSI to obtain it.

6 After viewing the options, click OK to start processing the data file.

- Yellow dots appear on the computer screen showing the locations of the automatically picked rebar.
- When the processing is completed, a dialog will appear with a prompt to save the output file.
- By default, the file will be written to the output folder specified in Step 13 unless otherwise specified at this point.
- An ASCII file with the same root name as the output file and the extension .reb will be written to the output folder along with the processed .dzt file. This ASCII file contains all of the rebar pick information and associated statistics (see ASCII Output File section for details).

7 Close the raw data file. The processed file should be the only file left open.

8 The automatic rebar-locating algorithm does not always correctly locate all of the rebar. You will need to edit the output of the auto pick process in order to delete incorrect locations and to add missed rebar picks. This is done in a part of RADAN called Interactive Interpretation. Start the Interactive Interpretation by clicking the  icon, with the processed file open. You can also go to View>Interactive. You will see that the correct pick file will be selected in the Get Pick File window. It will have the same root name as the processed data file, but it will have the extension .reb.

9 A window similar in appearance to the one shown in Figure 6 will appear. The data are shown in the upper half of the window (referred to as the data pane) and the rebar locations and depths on the lower pane.

- Maximize the window for easiest examination.
- The size of either the data or depth pane can be increased, depending on whether the data or the output picks are being more closely examined. A pick simply refers to an automatically or interactively selected data location (position and depth), represented by a colored dot.
- You can increase thescreen display gain on the data pane by right clicking on it and choosing display gain from the pop-up window.

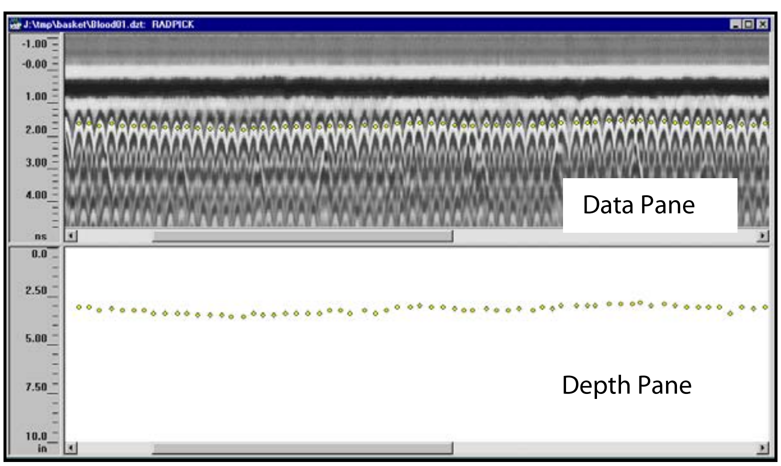


Figure 6: Example of processed data shown in Interactive Interpretation window. The top half showing the picks on top of the data is the data pane. The bottom half showing the pick depths is the depth pane.

Figure 7 shows examples of incorrectly and correctly picked rebar reflections. The reflection from a rebar appears as an arch or hyperbola. The correct location for the rebar reflection is near the center of the white portion of the arch (for Color Table #6 and Color Transform #3).

(a) Incorrectly picked rebar

(b) Correctly picked rebar

Figure 7: Example of incorrectly and correctly picked rebar reflections.

10 Look for areas in the data where a rebar pick may be missing or misplaced. Missing and misplaced rebar picks can be edited in Interactive Interpretation by opening the Pick Options pop-up dialog box.

- **a)** Open the dialog box by placing the mouse cursor anywhere within the data pane (the upper half of the Interactive Interpretation window) and clicking the right mouse button.
- **b)** When the right mouse button is pressed, the Main pop-up menu shown in Figure 8 appears.

Figure 8: Main pop-up menu accessed by clicking the right mouse button when the mouse is positioned over data within the upper half of the Interactive Interpretation window.

- **c)** Choose Pick Options. The Pick Options dialog box will appear (Figure 9).

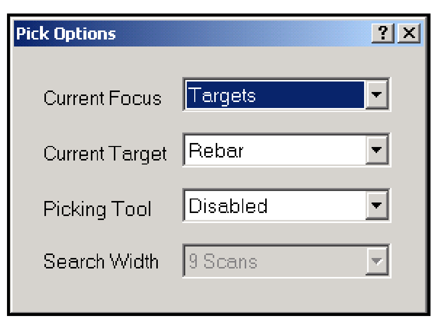


Figure 9: Pick Options dialog box. Use this dialog to select the picking tool to be used for adding and deleting rebar picks.

Adding and Deleting Single Picks

1 To add or delete picks, change the picking tool from Disabled to Single Point as shown in Figure 10.

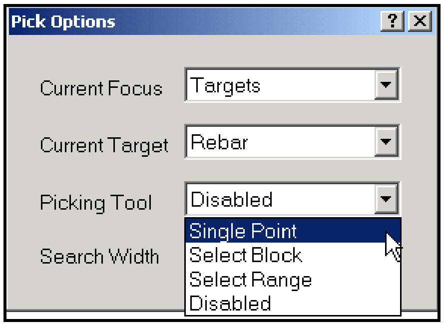


Figure 10: Selecting the Single Point Picking tool.

2 Position the mouse cursor where a pick is to be added or deleted.

- To add a pick, click the left mouse button.
- To delete a pick, click the right mouse button.
- The left and right mouse buttons will be reserved for adding and deleting picks until the Picking tool is changed from Single Point to a different tool, is disabled, or if the Pick Options dialog box is closed by the user.

Figure 11 shows the process of adding a pick. The user has positioned the mouse cursor over the area where a rebar pick is missing and only needs to click the left mouse button. After clicking the left mouse button, a search process is performed on all of the scans between the left and right inside edges of the mouse cursor to locate the scan corresponding the center of the rebar.

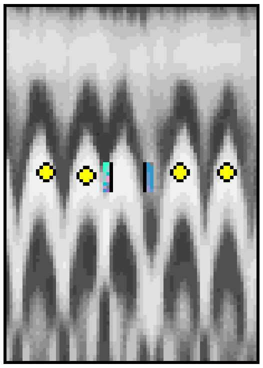


Figure 11: Example of mouse cursor placement prior to adding a pick.

If the search is successful, a yellow (or other desired color, see section on Other Options) will appear on the data as shown in Figure 12. If no pick is added after clicking the left mouse button, reposition the mouse cursor and click the left mouse button again.

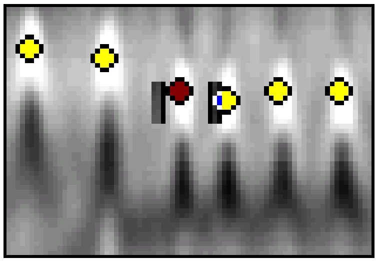


Figure 12: Successfully added pick.

Figure 13 shows a correctly positioned mouse cursor prior to deleting a pick. Even if a portion of the pick circle bisects the vertical midpoint of the cursor, the pick will be deleted from the database and from the screen once the right mouse button is clicked.

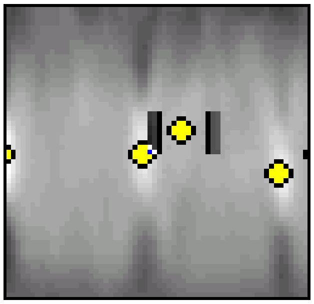


Figure 13: Example of correct mouse cursor position prior to deleting a poor pick.

Adding and Deleting Multiple Picks

1 To add or delete multiple picks, change the picking tool to Select Block as shown in Figure 14.

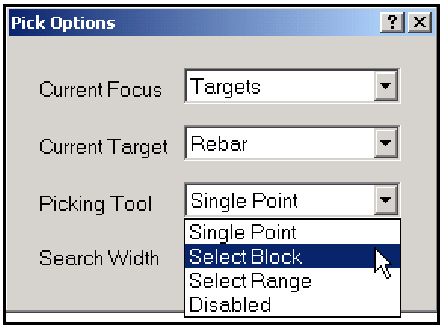


Figure 14: Activating the Select Block option as the current Picking tool.

2 Position the mouse cursor where picks are to be added or deleted.

3 Click the left mouse button to create a Select Block. The Select Block appears as a translucent square over the data with tiny square handles at each corner and on the centers of each side. These squares act as handles that can be used to resize the Select Block. Generally, the corner handles are more useful because they can resize both the height and length of the Select Block.

4 Click one of these handles and hold the mouse button down as you drag the mouse cursor to resize the Select Block.

Release the mouse button when the Select Block reaches its desired size. Figure 15 shows a Select Block during resizing. The Select Block shown in Figure 15 has been extended so that it overlays a number of poor picks.

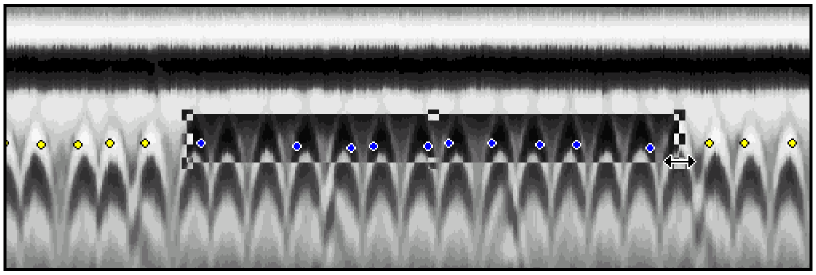


Figure 15: Select block being resized. The user is dragging the bottom right corner of the Select Block with the mouse. This is evident by the " ↔" symbol.

5 Picks are added and deleted using a pop-up menu that appears when the user clicks the right mouse button while the mouse cursor is placed inside the Select Block (Figure 16).

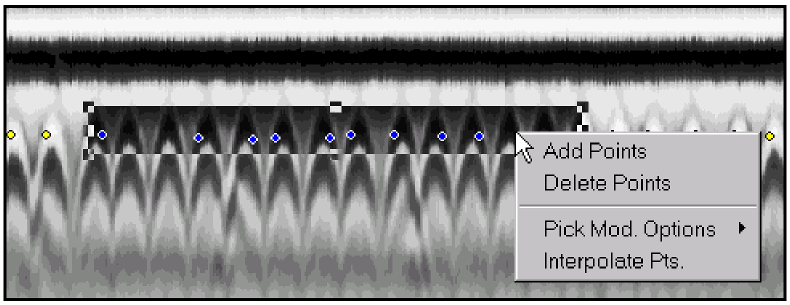


Figure 16: Accessing the select block pick options by right clicking the mouse inside the select block.

For the scenario shown in Figure 15 there are a number of poor picks. The best solution is to delete all of the picks, then add new picks.

- In general, it is best to keep the Select Block vertical width to a minimum. The vertical dimension of the Select Block shown in Figure 16 is approximately correct.
- Once all of the Select Block operations are completed, close the Pick Options dialog or select a different picking tool.

6 After finishing adding and deleting picks, position the mouse in the Interactive Interpretation data window and click the right mouse button to access the Main menu. From the Main menu, select Save Changes > Current File as shown in Figure 17.

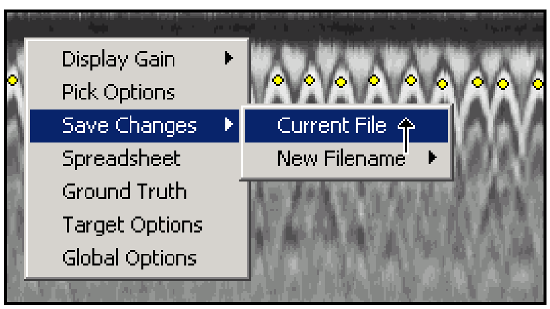


Figure 17: Saving changes to the *.reb file prior to exiting RADAN.

7 Data processing is complete.

- All of the processing results are stored in ASCII format in the *.reb file. The *.reb file will be located in the default output directory (unless you specify otherwise).
- The .reb file can be opened and viewed in Notepad, or as an ASCII, comma-separated-value (.csv) file in a wide range of spreadsheet and word processing software programs. Data can also be plotted using appropriate plotting or mapping software.

There are additional options and features associated with the Interactive Interpretation process that are described in detail in Chapter 5.

Setup Requirements

In order for the Bridge QA module to work properly, the data must have certain characteristics. These characteristics include the hardware setups on the SIR unit during data collection. These setups are listed below:

Hardware Settings: SIR-20, and SIR-3000

Scans/m (ft)	80 (24)**
Vertical FIR Low Pass Filter	3000 MHz
Vertical FIR High Pass Filter	250 MHz
# of Gain Pts	1
Bits Per Sample	16
Samples/Scan	512**
Range	6
Gain	ŧ
Position	ŧ

** Denotes minimum requirement – can be set higher.
ŧ Denotes manual adjustment required.

Data Collection Procedure Requirements

The data collection procedure used to obtain high quality data depends on the application.

The following conditions must be strictly followed during data collection for accurate concrete cover assessment.

- The data must be obtained over a concrete bridge deck or similar type of concrete construction using a Model 5100(B) antenna.
- Data must be collected perpendicular to the direction of the bars within the top layer (mat) of reinforcement. For example, if the transverse bars are on top, the data should be collected along profile lines directed parallel to the direction of traffic. If longitudinal bars are on top, profile lines should be collected perpendicular to the direction of traffic.
- The rebar must be spaced at a minimum of 4” (10 cm).
- The bottom of the antenna (or its enclosure) must be in contact with the bridge surface at all times.
- The survey wheel must be in contact with the bridge surface at all times.
- The portion of the bridge deck surface being surveyed must be cleared of pebbles and other construction debris, including small metal objects such as wire or nails.
- The bridge deck surface must not contain puddled water but may be wet.

Figure 18 shows the antenna setup used during data collection on a bridge deck. The Model 5100 antenna is placed in the protective bucket of the survey cart. Survey wheel control is provided by the distance encoder mounted on the cart. BridgeScan will also work with the 5100B antenna and survey wheel encoder adaptor cable.

Note: This module will not process data properly without survey wheel scan control, nor can it currently be used to process data obtained with other GSSI antennas.

Figure 18: Antenna setup used to obtain rebar data over a concrete bridge deck.

ASCII Output File

The final product from the Bridge QA process is the ASCII database file written with the input file root name and the extension .reb. This file contains the location (X and Y coordinates of a 3D file)), depth (in user-defined units), arrival time, and amplitude of each rebar reflection detected in the GPR data. The ASCII file can be examined using all software packages that can read text files.

Caution: A previously generated ASCII file associated with a data file is automatically overwritten when the REBAR process is rerun on the data file. To prevent this, rename the ASCII file to a different name prior to rerunning the REBAR process.

The first 6 lines of the ASCII output file shown in Figure 19 contain statistical information calculated from the rebar depths. Each statistical category is discussed briefly below.

Average Rebar Depth: Mean depth to the top of rebar in the concrete structure.

Concrete Velocity: Propagation velocity of the radar waves in the concrete. This value is either specified by the user or calculated from the core information obtained from a rebar located in the profile. (See Appendix A for details regarding calibration cores.)

Number of Rebar: Total number of rebar detected in the GPR data.

Minimum Rebar Depth: Minimum rebar depth, in user-defined units, in the entire data file.

Maximum Rebar Depth: Maximum rebar depth, in user-defined units, in the entire data file.

Standard Deviation: Standard deviation of the rebar depths, in user-defined units.

The X and Y coordinates, depths, reflection amplitudes, and reflection arrival times of each detected rebar are listed following the header information. The X-distance is relative to the start of the file, and the depth is in user-defined units, representing the calculated depth from the concrete surface to the top of the rebar.

Note: The first line of the ASCII file contains a warning about modifying the file, which may prevent it from being used again in RADAN. To prevent modifying the ASCII file, make a copy of the file:

1. Right-click the file name in Windows Explorer.
2. Select Copy from the pop-up menu.
3. Paste the new file into the same directory.
4. A new file, named "copy of *.reb" will appear in the folder along with the original ASCII file.

WARNING: Modification of this ASCII file outside of RADAN may cause unpredictable behavior when this file is reloaded into RADAN.

Data Filename = FILE290.DZT

Calibration Core Depth = 2.600000 in

Calibration Core Location = 4.040000 ft

Average rebar depth = 2.589036 in

Concrete Velocity = 4.327070 in/ns

Number of rebar = 232

Minimum rebar depth = 1.676456 in at 82.069160 ft

Maximum rebar depth = 3.037834 in at 57.110989 ft

Standard Deviation = 0.242212 in

File	X(ft)	Y(ft)	Depth(in)	Time(ns)	Amplitude
FILE290	0.14	0	2.71	1.359	6577
FILE290	0.61	0	2.655	1.336	8027
FILE290	1.37	0	2.628	1.324	9563
FILE290	2.01	0	2.6	1.313	9241
FILE290	2.73	0	2.655	1.336	7450
FILE290	3.35	0	2.628	1.324	7865
FILE290	4.04	0	2.6	1.313	9161
FILE290	4.68	0	2.628	1.324	9680
FILE290	5.33	0	2.628	1.324	8694
FILE290	5.88	0	2.6	1.313	10939
FILE290	6.5	0	2.6	1.313	8136
FILE290	7.47	0	2.6	1.313	8927
FILE290	9.15	0	2.655	1.336	7755
FILE290	10.09	0	2.71	1.359	7072
FILE290	10.49	0	2.655	1.336	8460
FILE290	11.43	0	2.683	1.348	7210
FILE290	11.8	0	2.6	1.313	8544
FILE290	12.55	0	2.6	1.313	8154
FILE290	13.39	0	2.628	1.324	8707

Figure 19: Typical ASCII output file from the Bridge QA process.

Chapter 3: Concrete Condition Assessment of Bridge Decks Using the Model 5100(B) Antenna

Overview

This technique allows you to locate areas of probable concrete deterioration in a bare concrete or asphalt overlaid concrete deck. This is done by graphing the relative reflection amplitudes across the survey area and assigning threshold values to the amplitude range. The basic premise is that areas of deterioration will attenuate (weaken) the radar signal. It is important to note that this technique does not indicate the type or cause of the deterioration, merely its presence.

This application does have some limitations. Because the technique shows relative change across the single deck, data from different decks cannot be compared. Each deck must be understood in a vacuum. Furthermore since the application depends on mapping differences, this technique is not appropriate for a deck with no deterioration or a deck with near total deterioration.

Any meaningful deterioration map is created by a fusion of the radar data with a comprehensive visual inspection of the deck. The analyst should take careful notes of the location of any surface defect on the top or the bottom of the deck. This allows the analyst to identify areas of extreme deterioration and thus "calibrate" the map output. The presence of any patch or crack should be noted on the top surface and any spalling, staining, or efflorescence should be noted on the bottom. If possible, obtain any maintenance records.

Data Collection

1. Turn on the SIR unit and recall the saved radar setting for concrete condition assessment of bridge decks.
   - If no previously saved setting is available, use the setup parameters described at the end of this chapter.
2. Let the SIR unit warm up for a recommended time of 5-10 minutes **with the scan showing on the screen.**
3. During the warm-up period, it is recommended that the number and spacing of the profile lines be established.
   - A 2-foot (0.6 m) spacing or less between adjacent profile lines (Y-spacing) is recommended. Mark the profile lines over which data will be collected.
   - It is good practice to record the distance of the first and last profile lines from the bridge curb relative to permanent reference points.
   - It is also important to map asphalt patches and cracks.

Note: It is also essential that the profile line direction be perpendicular to the direction of the top layer of rebars. This means if the transverse bars are tied on top in the top rebar mat, the data should be collected along the lane in the direction of traffic. For the case when longitudinal rebars are on top, data should be collected across the lanes.

4 Next, after the 5-10 minute warm-up period and just prior to collecting data, check the position and gain of the scan in the display window and adjust if necessary. The scan position and gain should look similar to that shown in Figure 20. **Note:** Your SIR System may display the scan trace in a vertical orientation. The direct wave will then be near the top.

Caution: Remember, if a portion of the direct wave is missing during data collection or if the gain is too high, the data won't be processed correctly in RADAN. Figures 21 and 22 illustrate a badly positioned scan and a clipped scan, respectively.

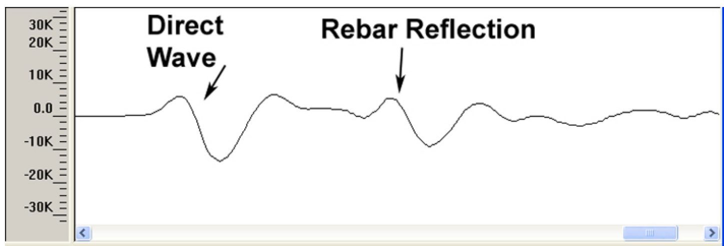


Figure 20: Typical waveform shape with antenna positioned over rebar. The signal is set up so that the direct wave and the peak amplitudes are well within the boundaries of the sampling window.

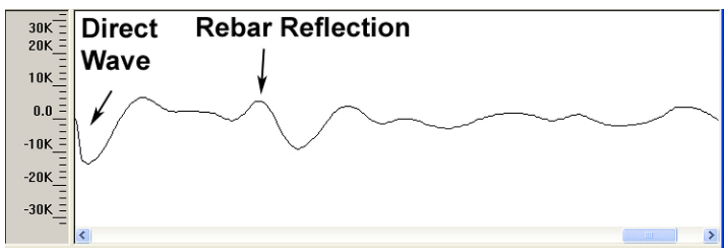


Figure 21: Badly positioned waveform. The direct wave is not located in the window. Using the signal positioned as shown in this figure would cause the program to give erroneous results. Prior to collecting data the user must manually adjust the signal position until the direct coupling is located entirely in the window (see Figure 20).

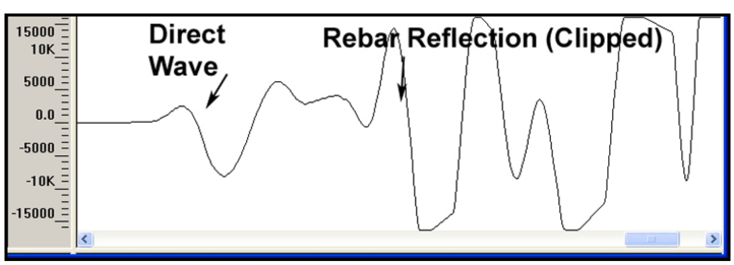


Figure 22: Example of clipped waveform. Clipping must be prevented for accurate rebar depth and amplitude measurements. Prior to collecting the data the user must manually decrease the gain.

5 Position the antenna so it is at the correct Y-distance from the bridge curb or lane stripe.

- Also make sure the antenna is positioned directly on top of the start of the bridge or is positioned some distance before the start of the bridge. Normally you will be able to locate the start of the bridge from examination of the data during post processing in cases where you begin collecting data prior to the start of the bridge. Typically, a strong reflection from the expansion joint (metal) is seen at one or both ends of the deck.
- It is not crucial to start and end each profile at the same point as long as each profile begins before the bridge joint and ends after the bridge joint.

6 Collect the profiles. If the SIR system beeps, the antenna is being moved too fast, so the person or vehicle dragging the antenna must slow down. If the SIR system beeps more than 2 or 3 times during data collection along a single profile line, reject this file and collect the profile again..

- Cracks and patches can be mapped along with the data by using a marker switch on either the SIR system or the survey wheel/handle assembly.
- Collect and store a single data file per profile line.
- Separate or alternating profile lines can be collected in opposing directions (e.g., one line starting at the beginning of the bridge and traversing to the end of the bridge; with the next line starting at the end of the bridge and traveling to the beginning of the bridge.
- There is an option in RADAN to reverse the direction of data in the files during processing of single channel data files. The reverse file option is disabled for multiple channel data files. Therefore, it is recommended that if multiple channel Model 5100 data files are collected that they all be collected in the same direction.

Data Transfer and Processing

1 Transfer the data from the SIR unit to the computer that will process the data following the steps outlined in your SIR System manual. After data transfer is complete, start RADAN on the computer.

2 Select the source (i.e., input) and output directories and the vertical and horizontal units that will be used during data processing (see Appendix C for details).

3 In RADAN, open a data file collected along a profile line. A typical file will appear like the one shown in Figure 23. However, the rebar spacing, hyperbola shapes, and asphalt thickness may vary widely from one bridge deck to another.

- The data appearance is significantly affected by the display parameters used. Most of the data shown in this manual are displayed with color table #6 and color transform #3.

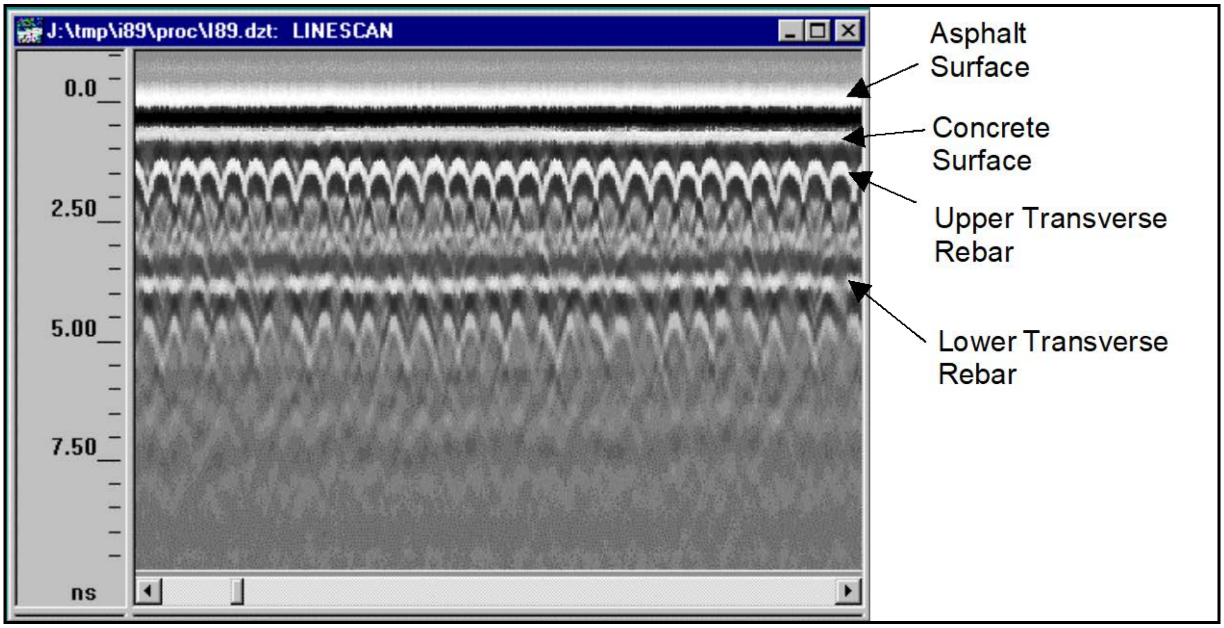


Figure 23: Typical single-channel, raw data file of an asphalt-overlaid bridge deck (Display Color Table #6, Color Transform #3).

4 The first major objective is to create a 3-D data file from the individual files. Before this is done, a macro must be created. A macro is a set of processing steps, or instructions, attached to individual data files in a project. The macro will be different depending on whether single- or multiple-channel data files were collected.

Macro Creation for Single Channel Data Files

For single channel files this macro will contain a transparent process that will not effect the data, but its presence is necessary for running the project.

1 With the data file open, click the Create Macro button .

2 A dialog box appears that prompts the user to enter a name for the macro. Supply a name and click OK.

3 The new macro is ready to add processing steps. Click the Arithmetic Functions Processing button .

4 A dialog box will appear; don't make any changes to the items in the dialog.

5 Click OK.

6 Close the macro by clicking the Close Macro button .

7 A dummy macro has been created. In effect, you will be multiplying each data sample in the profile (data file) by one; so this macro will not influence the data, but is necessary to run a project.

Macro Creation for Multiple Channel Data Files

The macro created for multiple channel data files will correct for differences in the amplitude of data collected by different Model 5100 antennas. The relative differences in amplitude between the antennas should be known beforehand. There are a number of ways to obtain relative amplitudes.

- The user could place the antennas at a known height above a metal plate and compare the reflection amplitudes, or
- Collect data on a concrete slab along a repeatable profile line containing a number of rebars and measure the average differences in amplitude of the rebar reflections between the antennas. This is the recommended approach.

For all calibration measurements it is essential that the user use straight gain (i.e., one gain point or two gain points with the same gain for each point). The objective of the calibration measurements is obtaining the ratio of reflection amplitudes between the antennas. The reflection amplitudes between Model 5100 antennas should differ by less than 10%. Once this amplitude ratio is obtained, the user needs to create a macro that allows this number to be put to use on the collected data. **Note:** This technique is not used for data collected with one antenna.

1 With the data file open, click the Create Macro button.

2 A dialog box appears that prompts the user to enter a name for the macro. Supply a name and click OK.

3 The new macro is ready for adding processing steps. Click the Deterioration Mapping button to open the dialog box shown in Figure 24.

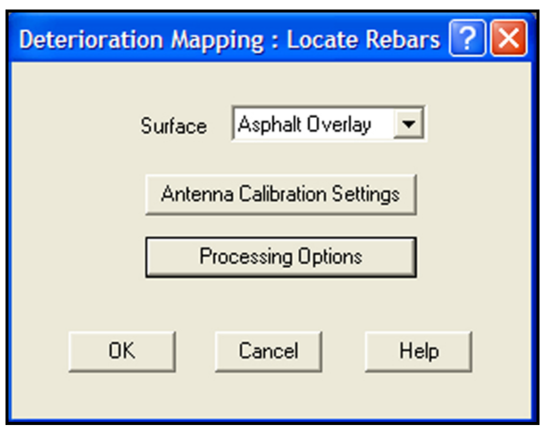


Figure 24: Dialog box that appears after clicking the Deterioration Mapping button with a multi-channel file open.

4 Click the Antenna Calibration Settings button to open the Antenna Calibration Settings dialog box shown in Figure 25.

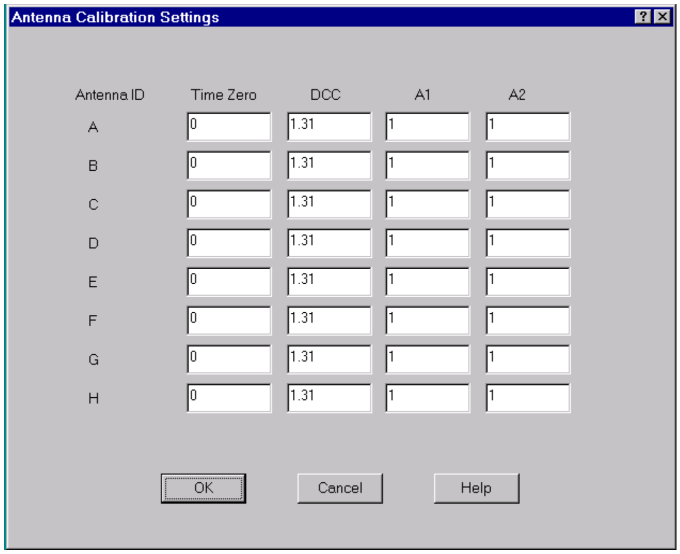


Figure 25: Dialog used to enter pre-generated calibration amplitude ratios for different antennas.

5 Enter the amplitude ratio values for the different antennas in the A2 column and remember which antenna belongs to which antenna ID. (The other calibration parameters, Time Zero, DCC, and A1, aren't currently used in the bridge condition mapping portion of the Bridge Assessment module.) If using only one antenna, skip this step.

For example:

Two Model 5100 antennas were used to collect data and antenna A (assuming it is to be considered a reference antenna) had an average rebar reflection amplitude that was 1.03 times the reflection amplitude of antenna B –

- The user would enter 1.03 into the A2 column associated with Antenna ID B and leave the value 1 in the A2 column associated with Antenna ID A. The A2 parameter is multiplied with the data from the associated antenna to correct it relative to the data from the reference antenna. The same principle would apply to antenna combinations greater than two.

6 Close the macro by clicking the Close Macro button **.** A macro is now created. This macro will be used while the project is running.

7 Close the data file and any other open files.

Creating the 3D File

1 Choose File > New. The Create New Project dialog box will appear (Figure 26). Enter a project filename and select RADBridge Project (as shown in the figure). Click Save.

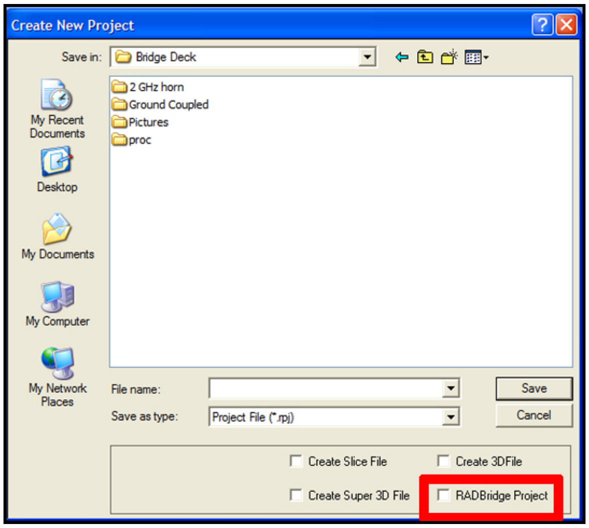


Figure 26: Create New Project dialog. Enter a filename and click RADBridge Project as shown.

2 The Project Information dialog box will appear (Figure 27).

- Check to make sure the Output Path listed in the dialog is the desired path.
- If it isn't, click the Output Path button to select a different Output path. The Output Path is the directory that stores the intermediate processed data files.

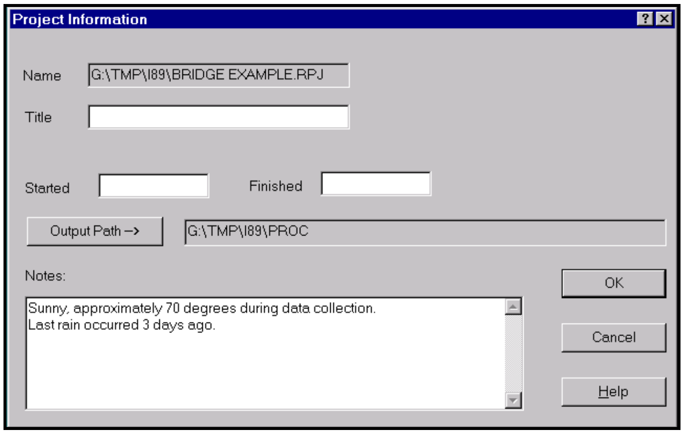


Figure 27: Project information dialog box.

All of the other information entered in the Project Information dialog is for the user's benefit only. It does not influence how the project runs. When you have finished entering information in the Project Information dialog box, click OK.

3 Enter the data files in the Edit Project File List dialog box (Figure 28).

- Data files can be added by clicking on the data file and clicking the Add button as shown in Figure 28, or by double clicking on the file.
- For bridge deck evaluations, each file will have a different Y coordinate associated with its position relative to the right lane stripe, bridge-curb or other fixed reference. In all RADAN data files (profiles), distance increases in the positive X-direction.
- Files can be removed from the project by clicking on the added file and clicking the Remove button.
- The example in Figure 28 shows the naming and numbering sequence of the files, relative to Y-distance from the right lane-stripe and to the direction of the scan relative to traffic flow in the bridge.
- In this case, 12 eastbound lane profiles were collected spaced sequentially from 1 to 23 feet left of the right lane-stripe. Those with an "*r.dzt" indicate that data were collected in the direction opposing traffic flow on the bridge. (It has been found that renaming data files so that their relative position and direction are indicated in the filename helps to prevent confusion and errors during post-processing.)
- When all of the files have been added in order of increasing Y-coordinate, click Done.

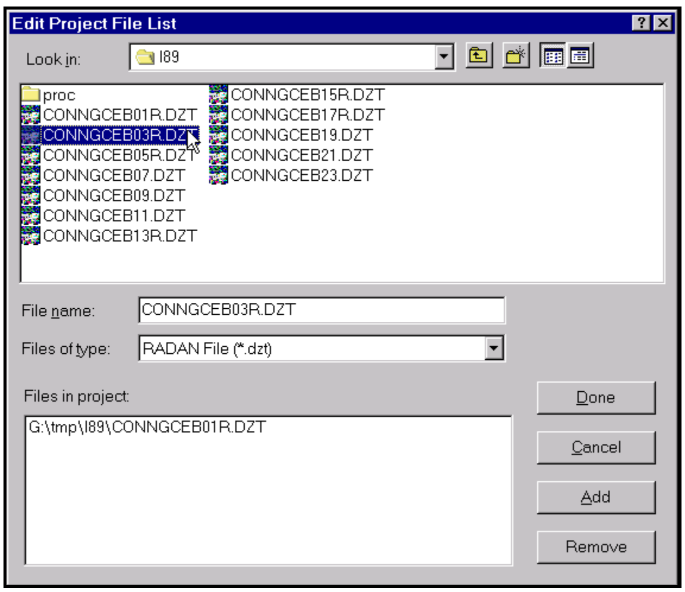


Figure 28: Adding files to a project.

4 The next step is to attach the macro to the files in the project. The Edit Macro List dialog box will appear.

a) Click on the macro previously created. Figure 29 shows an example with the macro called Addsub.cmf. Note that its name now appears in the Filename dialog box.

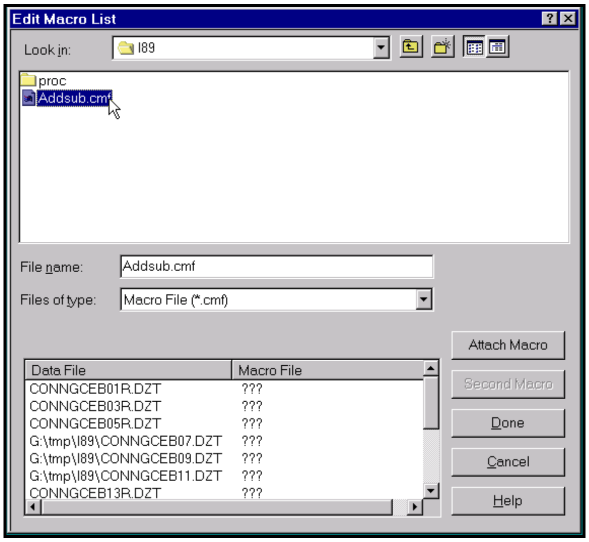


Figure 29: The user has just clicked on the macro "Addsub.cmf"

b) Next, click on a data file to highlight it and click the Attach Macro button as shown in Figure 30. You will see the name of your macro file immediately to the right of the file to which it will be attached.

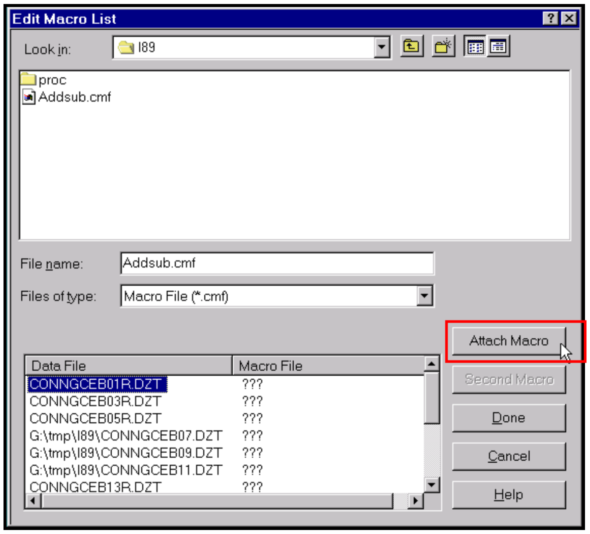


Figure 30: Attaching the macro Addsub.cmf to a data file.

c) Repeat the process for all of the data files listed in the project.

- To select all the data files in the project, click the first file in the list. Hold down the shift key and click the last file in the list.
- To select multiple files, hold down the Control (CTRL) key and click each desired file name.

5 Click Done to advance to the next dialog box. The next dialog box is 3D File Parameters. The 3-D output filename, 3-D grid dimensions, and the X and Y coordinates of the files are entered using this multi-page dialog box.

a) Click the 3D Output Filename button and enter the desired name of the output 3-D file (Figure 31).

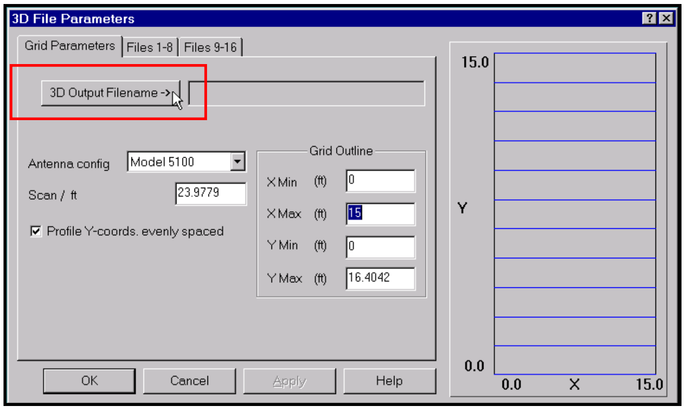


Figure 31: Selecting the 3-D output filename using the button.

b) In the Grid Parameters tab, enter the starting and ending X- and Y-coordinates of the grid.

- The X-direction is profile direction and the Y-direction is perpendicular to the profile line direction.
- For example, if the bridge is constructed with transverse rebars on top of longitudinal rebars, and data were obtained over a 100 ft length in 2 lanes that were 12 feet wide, the grid coordinates in units of ft (meters) would be:

  X Min = 0.0 (0.0)

  X Max = 100.0 (30.48)

  Y Min = 0.0 (0.0)

  Y Max = 24. (7.315)

c) If the profile lines were uniformly spaced, keep the Y Profile Lines Evenly-Spaced checkbox checked as shown in Figure 31. Otherwise, deselect it so you can enter actual Y-coordinates for each data profile.

d) **Don't change the scan/unit value.** This number is for display purposes only and is taken from the header of the first file entered in the project.

e) Click on the Files 1-8 tab (Figure 31) then enter the starting X-coordinate and the Y-coordinate of the profile lines. Generally, the Starting X coordinate corresponds to the start of the bridge.

- To locate the start of the bridge on any given profile, click the button Click, in the column Get Xo.
- The associated file will open on the screen. Move the mouse cursor to the start of the bridge and click the left mouse button at the interpreted start of the bridge as shown in Figure 32. The new X-coordinate of the start of the data file will automatically be displayed in the Xo box associated with the file. The number entered in the box will generally be a negative number, or zero if the start of the file is at the start of the deck. Xo refers to the start of the deck.

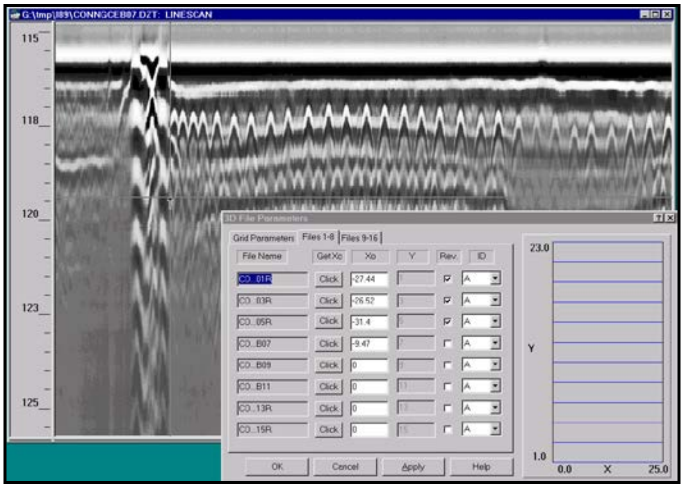


Figure 32: Selecting the X Start (Xo) value for the bridge by clicking the left mouse button at the bridge joint/ bridge deck junction.

Note: The bridge deck/bridge joint junction at the end of the data file is entered when selecting Xo for data profiles collected in the reverse direction. The Rev box must also be selected in these cases.

f) Continue selecting the Xo for all of the files, then manually enter the Y coordinates if the profiles were not evenly spaced. In the example presented in Figure 32, the profile lines were obtained at 2-foot (0.6 m) intervals starting 1 ft (0.3 m) from the right lane stripe.

g) After all of the X- and Y-coordinates of the files have been selected for all of the File tabs, (more file tabs appear when there are more than 16 files) click OK. The project is now ready to be run.

6 To run an open project, choose Project>Run.

The project may take some time to process the data files, depending on the size of the files, the RAM memory in the computer, and the speed of the processor(s) in the computer. Please be patient, and DO NOT DISTURB the computer in any way until the project has finished running.

Running the Deterioration Mapping Process

Next, the output 3-D file must be processed through the Deterioration Mapping process. Click the Deterioration Mapping button to open the dialog box.

1 Click the Processing Options button.

2 There are two parameters that may be adjusted in the Processing Options dialog box (Figure 33) - the Time-Zero Amplitude Threshold and the Migration Velocity.

- **Time-Zero Amplitude Threshold** is important for locating the time-zero in the scan. The program will use the peak immediately following the first portion of the scan that exceeds the time-zero amplitude threshold.

- The value of 3000 generally works well. If the peak amplitude of the direct coupling is less than 3000, you will need to lower the time-zero amplitude threshold. Figure 34 shows a scan in O-Scope display mode with the direct-coupling peak labeled. In this case, the direct-coupling peak has a value of 20000 (20K = 20000), well above the 3000 threshold.

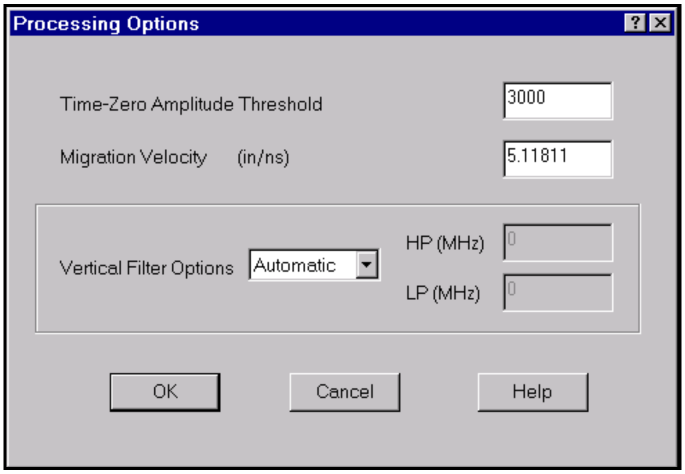


Figure 33: Processing Options dialog box.

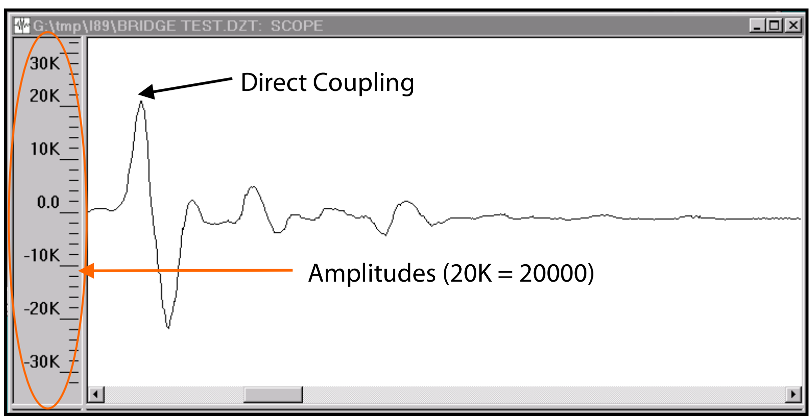


Figure 34: O-scope display of scan.

Migration Velocity, the second important parameter, is the radar wave propagation velocity used in the migration process. Migration is basically an imaging process that collapses the arches (or hyperbolas) associated with rebar reflections.

For this process we need an estimate of how fast the radar wave propagates through the asphalt and concrete. The typical ranges of velocities are 4-6 in/ns (10-15 cm/ns). It is up to the user to choose the correct velocity.

You may not pick the correct migration velocity the first time, so observe the processed data (after clicking OK to close the dialogs) and click the Stop button to stop the process, and restart the process with a different migration velocity.

Figure 35 shows data processed using 3 different migration velocities. The migration velocity of 4 in/ns (10 cm/ns) was too low. Note that the hyperbolas weren't totally collapsed. The migration velocity of 6 in/ns (15 cm/ns) was too high. The hyperbolas were reversed – they now look like the letter "V." The best migration velocity for this dataset was 5 in/ns (12.5 cm/ns).

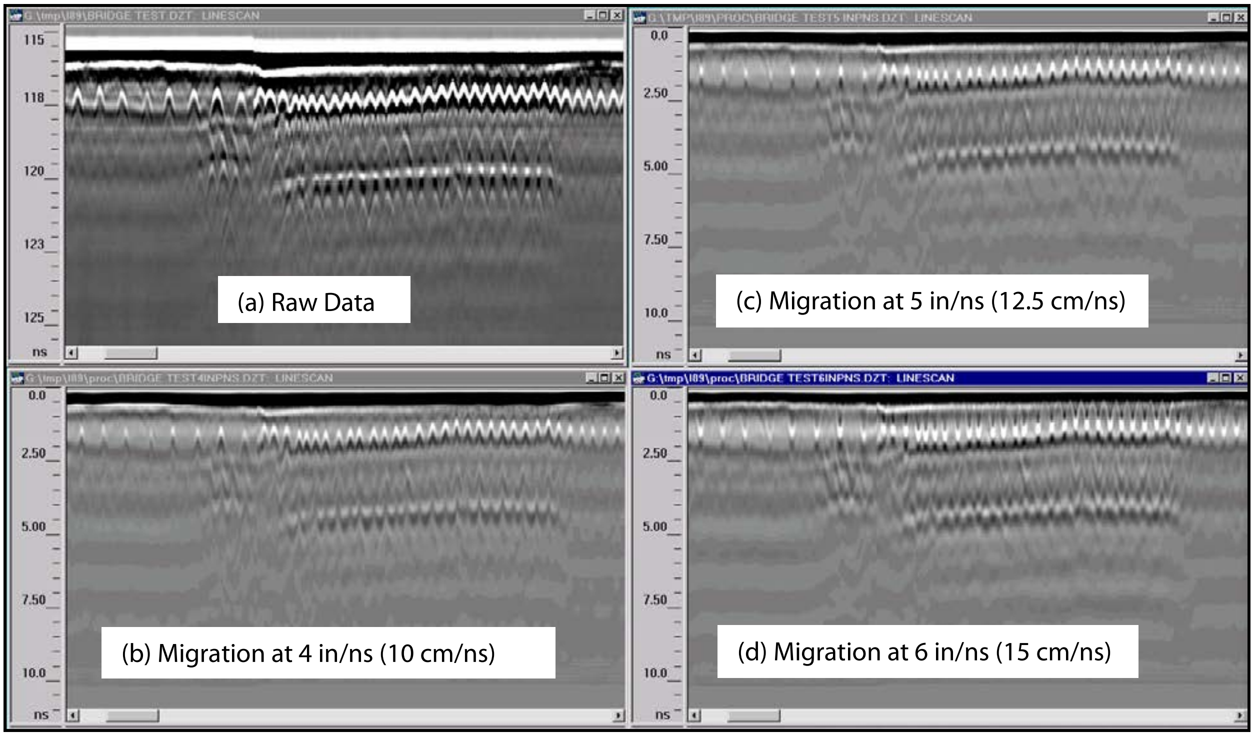


Figure 35: Comparison of data processed with 3 different migration velocities: (a) raw data, (b) migration at 4 in/ns (10 cm/ns), (c) migration at 5 in/ns (12.5 cm/ns), and (d) migration at 6 in/ns (15 cm/ns). The best migration velocity was 5 in/ns (12.5 cm/ns).

3 You won't normally have to change the Vertical Filter options in Figure 33. By keeping the option set at Automatic, Vertical Boxcar filters will be applied to the data only if no filters or improper filters were applied in the data file's processing history.

- For unusual cases, you can select Specified and apply your own Vertical filters. The specified frequencies correspond to the cutoff frequencies of the Boxcar filters.

4 The Calibration Settings are not used in the Deterioration mapping process.

a) Click OK to exit the Processing Options dialog box.

b) Next, click OK in the Locate Rebars dialog box to start the deterioration mapping process. The data are processed in 1000 scan batches, so be patient.

c) If the data are not being migrated properly (see Figure 35 for comparison), click the Stop button and restart the process with a different migration velocity. Do this until the desired results are achieved.

d) Once the entire process is completed, save the output file. An ASCII file with the same root name as the data file and the extension .det will be created in the same folder as the output file.

5 The next step is to examine the performance of the automatic rebar picking process and edit poor picks. This will be done in the Interactive Interpretation module.

a) With the output file open and active, click the Interactive Interpretation button .

b) The Get Pick File dialog box will appear (Figure 36). You will need to select the ASCII file created in the deterioration mapping process.

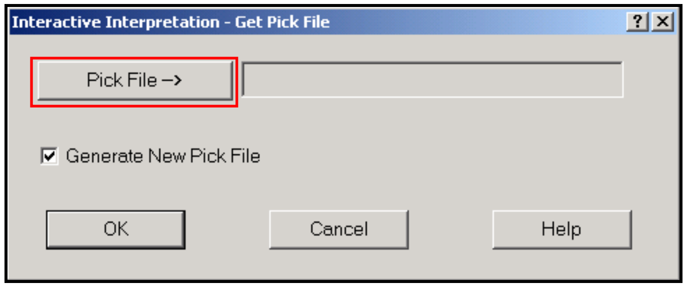


Figure 36: Get Pick File dialog box. For newly processed files, select the output ASCII file.

c) Click the Pick File button to open up the dialog box that allows you select the ASCII file. It has the same root name as the data file and the extension .det.

- For example, if the output file name is BRG EXAMPLE.DZT, the ASCII file name will be BRG EXAMPLE.DET.
- You could also leave the Generate New Pick File box checked if you want to do all of the rebar picking manually, but this is not recommended.

d) After clicking OK, a new window will appear containing the data in the top pane and a depth chart on the bottom pane. The rebar picks will be overlain on top of the data in the data pane and at the calculated depths in the depth pane (Figure 37).

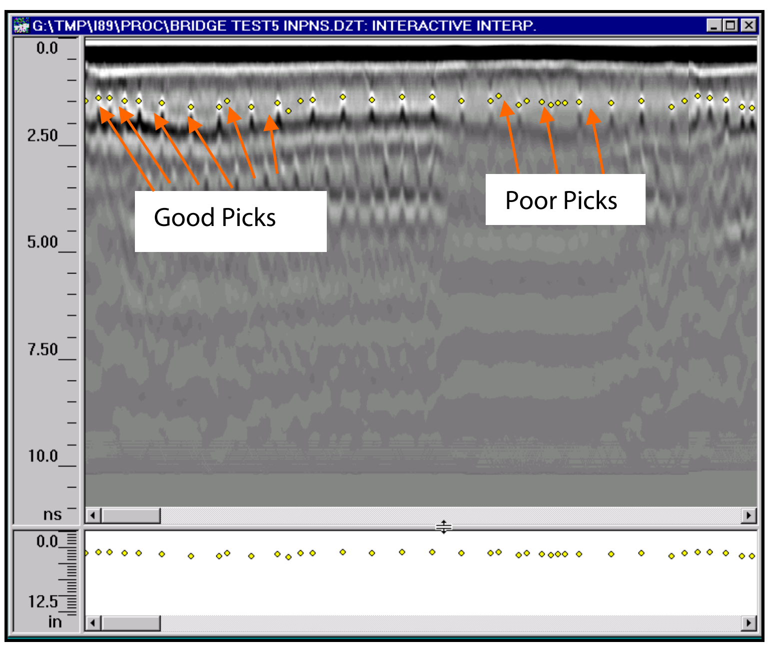


Figure 37: Rebar picks from deterioration mapping process shown in the Interactive Interpretation window. Good rebar picks and poor rebar picks are illustrated. Color Table 17 and a Display Gain of 8 were used for this figure.

Figure 37 illustrates good rebar picks, whereby the yellow dot is placed in the middle of the white area of the rebar reflection. This is the objective. Figure 37 also contains some yellow dots where there are no rebar reflections. These need to be removed.

All of the Interactive Interpretation options are selected from the Main pop-up menu that is accessed by right clicking the mouse anywhere inside the data pane, as shown in Figure 38.

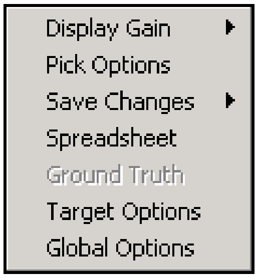


Figure 38: Main pop-up menu accessed by clicking the right mouse button inside the Interactive Interpretation data pane.

From the Main pop-up menu, select Pick Options to open the Pick Options dialog box (Figure 39). The Pick options dialog box contains different pick editing tools.

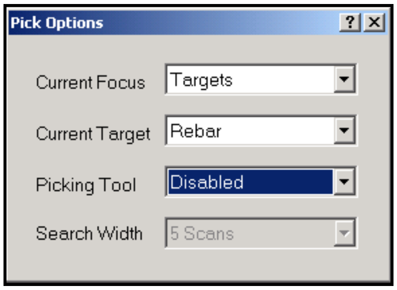


Figure 39: Pick Options dialog box.

Adding and Deleting Single Picks

1 To add or delete picks, change the picking tool from Disabled to Single Point as shown in Figure 40.

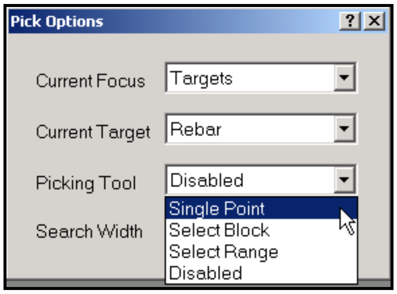


Figure 40: Selecting the Single Point picking tool.

2 Position the mouse cursor where a pick is to be added or deleted.

- To add a pick, click the left mouse button.
- To delete a pick, click the right mouse button.
- The left and right mouse buttons will be reserved for adding and deleting picks until the Picking tool is changed from Single Point to a different tool or is disabled or if the Pick Options Dialog is closed by the user.

Figure 41 shows the process of adding a pick. The user has positioned the mouse cursor over the area where a rebar pick is missing and only needs to click the left mouse button. After clicking the left mouse button a search process is automatically performed on all of the scans between the left and right inside edges of the mouse cursor to locate the scan corresponding the center of the rebar.

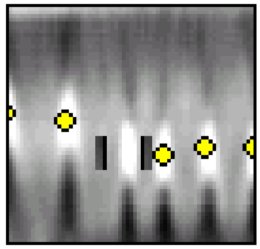


Figure 41: Example of mouse cursor placement prior to adding a pick.

If the search is successful, a yellow (or other desired color, see section on Other Options) will appear on the data as shown in Figure 42. If no pick is added after clicking the left mouse button, reposition the mouse cursor and click the left mouse button again.

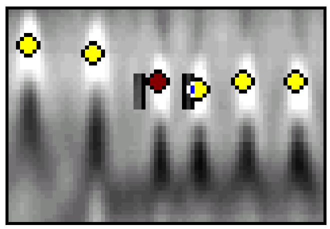


Figure 42: Successfully added pick.

Figure 43 shows a correctly positioned mouse cursor prior to deleting a pick. If a portion of the pick circle bisects the vertical midpoint of the cursor, then the pick will be deleted from the database and from the screen.

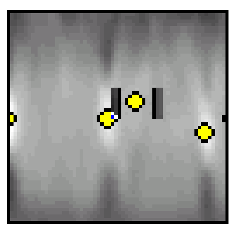


Figure 43: Example of correct mouse cursor position prior to deleting a poor pick.

Adding and Deleting Multiple Picks

1 To add or delete multiple picks, change the Picking tool to Select Block as shown in Figure 44.

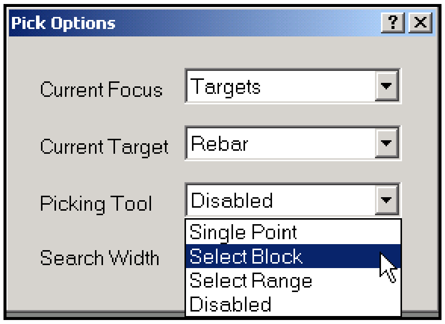


Figure 44: Selecting the Select Block option as the current Picking tool.

2 Position the mouse cursor where picks are to be added or deleted.

3 Click the left mouse button to create a Select Block. The Select Block appears as a translucent square over the data with tiny square handles at each corner and on each side.

4 Click on one of these handles and hold the mouse button down as you move the mouse cursor to resize the Select Block.

5 Release the mouse button when the Select Block reaches its desired size. Figure 45 shows a Select Block during resizing. The Select Block shown in Figure 45 has been extended so that it overlays a number of poor picks.

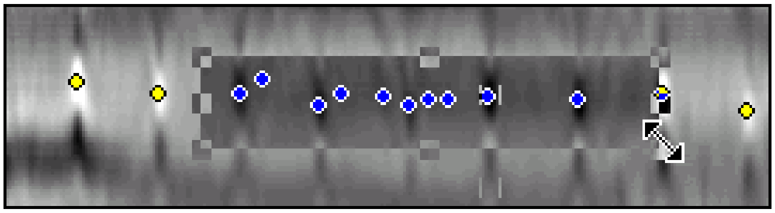


Figure 45: Select Block being resized. The user is dragging the bottom right corner of the Select Block with the mouse. This is evident by the "↔ ⃡" symbol.

6 Picks are added and deleted using a pop-up menu that appears when the user clicks the right mouse button while the mouse cursor is inside the Select Block (Figure 46).

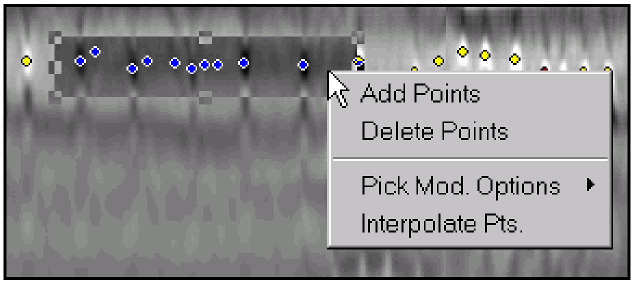


Figure 46: Accessing The Select Block pick options by right clicking inside the Select Block.

For the scenario shown in Figure 46, there are a number of poor picks. The best solution is to delete all of the picks, then add new picks.

In general, it is best to keep the Select Block vertical width to a minimum. The vertical dimension of the Select Block shown in Figure 46 is approximately correct.

7 Once all of the Select Block operations are completed, the user should close the Pick Options Dialog, or select a different Picking tool.

Exporting Data

After finishing adding and deleting picks, position the mouse in the Interactive Interpretation data window and click the right mouse button to access the Main pop-up menu.

1 From the Main pop-up menu, select Save Changes > Current File as shown in Figure 47.

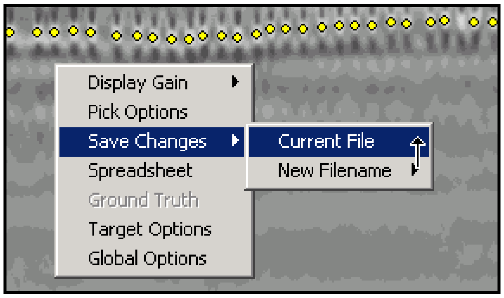


Figure 47: Saving changes to the *.det file prior to exiting RADAN.

2 After saving changes to the ASCII file, you can exit RADAN. Data processing is complete.

- All of the processing results are stored in ASCII format in the *.det file. The *.det file will be located in the default output directory (unless otherwise specified).
- The .det file can be opened and viewed in Notepad, or as an ASCII, comma-separated-value (.csv) file in a wide range of spreadsheet and word processing software programs.
- This *.det file can be reloaded into RADAN at any time to make further modifications.

There are additional options and features associated with the Interactive Interpretation process that are described in detail in Chapter 5. For example, if you need to correct the (X,Y) coordinates of the profile lines for bridge joint skew angle, please see Chapter 5 for details.

ASCII Output File

Figure 48 shows a typical ASCII output file from the concrete condition assessment portion of the Bridge Analysis module.

Note: You should never try to modify this file outside of RADAN, then reopen the file in RADAN.

WARNING: Modification of this ASCII file outside of RADAN may cause unpredictable behavior when this file is reloaded into RADAN.

Version = 5

Skew angle at start of bridge = 0.000000

Amplitude Units = Normalized Decibels

Data Filename = NLOWELL P.DZT

File	Ch#	Scan#	x(ft)	y(ft)	Target	z(in)	Amp	Vel. Type	v(in/ns)	t(ns)	Color	Size	Diam (in)	Pick Crit.	Group	Hide	Link	Mat erial	Confid.
NLOWELL P1	1	0	0	0	Rebar	6.954	-35.56	Specify	5.118	2.754	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	7	0.287	0	Rebar	6.954	-30.19	Specify	5.118	2.754	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	16	0.656	0	Rebar	6.701	-27.2	Specify	5.118	2.656	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	25	1.025	0	Rebar	6.701	-27.7	Specify	5.118	2.656	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	33	1.353	0	Rebar	6.65	-28.06	Specify	5.118	2.637	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	44	1.804	0	Rebar	6.346	-26.37	Specify	5.118	2.52	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	59	2.42	0	Rebar	6.244	-24.85	Specify	5.118	2.48	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	67	2.748	0	Rebar	5.939	-24.63	Specify	5.118	2.363	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	75	3.076	0	Rebar	6.193	-25.22	Specify	5.118	2.461	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	87	3.568	0	Rebar	6.142	-25.53	Specify	5.118	2.441	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	98	4.019	0	Rebar	6.193	-24.74	Specify	5.118	2.461	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	107	4.388	0	Rebar	6.041	-24.78	Specify	5.118	2.402	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	118	4.839	0	Rebar	5.99	-26.26	Specify	5.118	2.383	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	126	5.167	0	Rebar	5.99	-25.18	Specify	5.118	2.383	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	138	5.659	0	Rebar	5.837	-25.88	Specify	5.118	2.324	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	146	5.988	0	Rebar	5.786	-25.72	Specify	5.118	2.305	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	160	6.562	0	Rebar	5.582	-25.21	Specify	5.118	2.227	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	166	6.808	0	Rebar	5.48	-25.32	Specify	5.118	2.188	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	179	7.341	0	Rebar	5.531	-26.16	Specify	5.118	2.207	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	188	7.71	0	Rebar	5.582	-26.57	Specify	5.118	2.227	2	3	0	0	0	0	0	0	0
NLOWELL P1	1	201	8.243	0	Rebar	5.48	-26.04	Specify	5.118	2.188	2	3	0	0	0	0	0	12	1
NLOWELL P1	1	214	8.776	0	Rebar	5.633	-23.14	Specify	5.118	2.246	2	3	0	0	0	0	0	12	1
NLOWELL P1	1	239	9.802	0	Rebar	5.99	-26.05	Specify	5.118	2.383	2	3	0	0	0	0	0	12	1
NLOWELL P1	1	259	10.62	0	Rebar	5.684	-22.61	Specify	5.118	2.266	2	3	0	0	0	0	0	12	1
NLOWELL P1	1	279	11.44	0	Rebar	5.531	-24.12	Specify	5.118	2.207	2	3	0	0	0	0	0	12	1
NLOWELL P1	1	300	12.3	0	Rebar	5.48	-22.89	Specify	5.118	2.188	2	3	0	0	0	0	0	12	1

Figure 48: Typical ASCII output from condition assessment using the Model 5100 antenna.

Data Collection Settings

In order for the Bridge Condition Assessment post-processing software to work properly with Model 5100 data, the data must have certain invariant characteristics. These characteristics include the hardware setups on the SIR unit during data collection. These setups are listed below:

Hardware Settings:

Scans/m	40 minimum, 80 recommended, 24/ft
Vertical IIR Low Pass Filter	3000 MHz
Vertical IIR High Pass Filter	250 MHz
# of Gain Pts	1
Bits Per Sample	16
Samples/Scan	256 minimum, 512 recommended
Range	8
Gain	**
Position	**

** Denotes manual adjustment required.

Chapter 4: Concrete Condition Assessment on Bridge Decks Using Horn Antennas

GSSI manufactures two different models of horn antenna, the Model 4108 and the Model 4105. For the 4108, on asphalt overlaid bridge decks two antennas must be used and they must be mounted cross-polarized as shown in Figure 49. This is because the lower frequency signals of the antennas must be compared and subtracted from each other in order to achieve the necessary resolution of the top layer of reinforcing. If the 4105 is used, then the survey can be performed with only one antenna on asphalt-overlaid bridge decks. The 4105 should be mounted so that the long axis of the antenna is parallel to the long axis of the vehicle.

Hardware Setup

Mount the two pairs of Model 4108 horn antennas on the back of the data collection vehicle. Figure 49 shows a typical setup for the Model 4108 antennas.

4105 Note: If using the 4105, then only a single antenna is needed. The long axis of the 4105 should be parallel to the long axis of the vehicle.

- The holes in the fiberglass rails are drilled so that the distance between the antenna centers is 15.75” (40.0 cm).

Note the other setup features:

1. Antenna height approximately 19” (47.5 cm).
2. Straps used to restrain antenna movement.
3. Cables taped down.
4. Channel 1 is the outer antenna and channel 2 is the inner antenna.

Note: A single 4105 is channel 1.

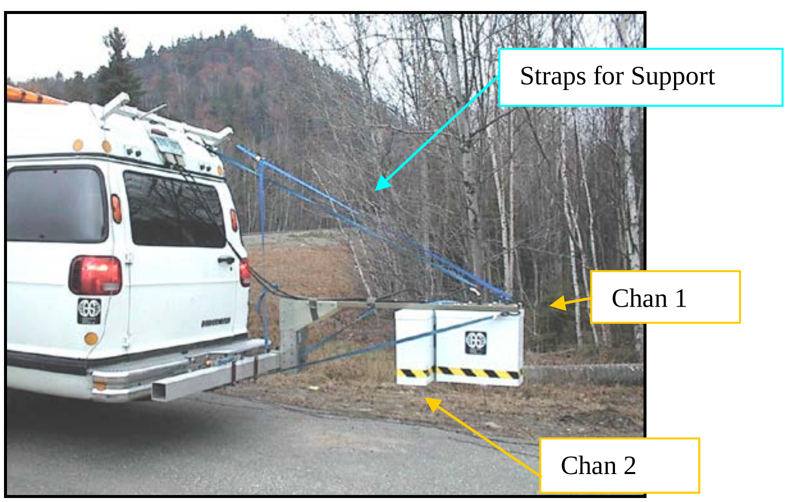


Figure 49: Setup for Model 4108 horn antennas for collecting bridge analysis data.
The spacing between antenna centers is 15.75” (40 cm).

Data Collection

In general:

- Mark the profile lines over which data will be collected.
- A 2-foot (0.6 m) spacing or less between adjacent profile lines (Y-spacing) is recommended.
- The profile lines should be measured in a straight line generally parallel to travel direction along the lanes.
- It is good practice to record the distance of the first and last profile lines from the bridge curb and the lane stripes or permanent reference to fixed structure positions.
- It is also important to map asphalt patches and cracks.

The following instructions assume that the SIR-20 control unit is being used for this application.

1. Turn on the SIR-20 unit and double-click on the SIR-20 icon to enter the collection program. Set working directories and linear units under View>Customize.

2. Create a new data collection project. Click on the File>New and enter a new file name. This will be the root name for all of the individual profiles. Click Save to move to the next screen.

3. Review project information. This window will allow you to enter any notes that you want to preserve with the data collection project file. Also check to make sure that the output file path is correct. Then click Next.

4. Check collection mode. Data must be collected with a properly calibrated survey wheel. Click on the Survey Wheel button and calibrate the survey wheel or DMI as described in the SIR-20 manual. Click Next.

5. Configuration**.** On this screen check:
   - Config Type: Bridge.
   - Config Name: H2.0GHz for the 4105 or H1.0GHz for the 4108(F).
   - Set Scans/ft to 6 or 20/m.
   - Click the Antenna Calibration File button. This will collect the first data file in continuous mode (no survey wheel). This is because your first file is the metal plate calibration (bumper jump) file.
   - Click Next.

6. This screen allows you to create a new data collection macro or to use an existing one. The macro is nothing more than a saved list of collection parameter. The name of the macro is derived from the project name. The default is to create a new macro with the factory saved parameters for the antenna you selected in Step 5.
   - **<u>Put the metal plate under the antenna</u>** and click Next to initialize the antenna. You will see a stopwatch count and the laptop will beep several times (if the sound is turned on).

Move on to the next section.

Data Collection Settings Review

In order for the Bridge Condition Assessment post-processing software to work properly with Model 4105 and 4108 data, the data must have certain invariant characteristics. These characteristics include the hardware setups on the SIR unit during data collection. These setups are listed below:

SIR-20 Hardware Settings

Setting	Model 4108	Model 4105
Ticks/m	Depends on the encoder used for the survey	Depends on the encoder used for the survey
Scans/m	20 6/ft	20 6/ft
Vertical Boxcar Low Pass Filter	3000 MHz	5000 MHz
Vertical Boxcar High Pass Filter	250 MHz	250 MHz
# of Gain Pts	1	1
Bits Per Sample	16	16
Samples/Scan	256 minimum	512 minimum
Scans/Sec	Maximum permitted by the SIR unit	Maximum permitted by the SIR unit
Range	12	12
Gain	Auto, 1 point	Auto, 1 point
Position	**	**

** Denotes manual adjustment required.

Configuring the Scan

1 Signal Position.

The position and gain of the waveform shown on the screen of the SIR system are critical parameters that must be correctly adjusted in order for the data to be post-processed correctly.

The horn antennas are typically mounted approximately 19” (47.5 cm) above the pavement surface, high enough to see the direct coupling and surface reflection separately.
Figure 50 shows incorrectly positioned signals for the Model 4105 horn antenna. The same features apply for a single channel 4108 survey. The key point is to make sure that you have both the ground surface reflection and the direct wave (internal transmit-receive reflection) visible in the window. You can test them by pushing the antenna up and down. The ground surface reflection will move up and down, but the direct wave will stay horizontal.

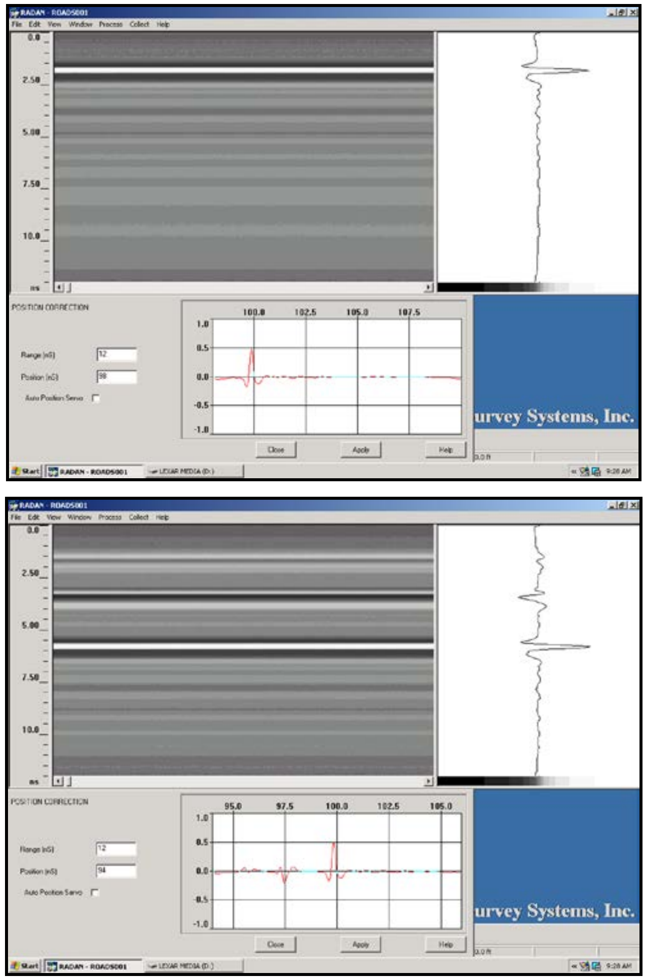


Figure 50: Incorrect Position, Too Little and Too Much of the Scan Trace

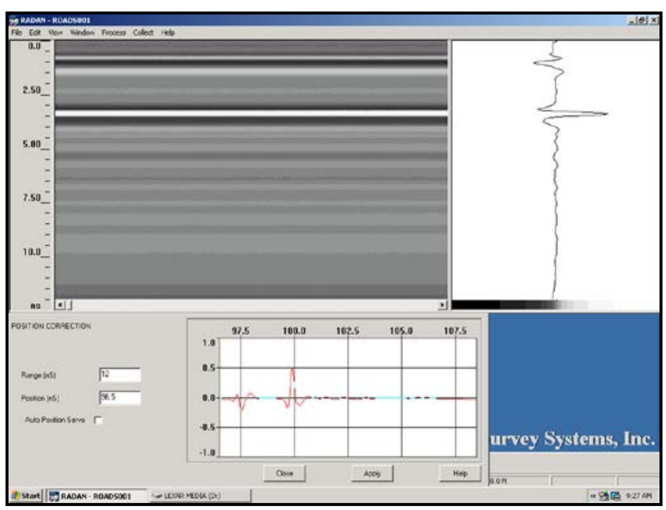


Figure 51: Correctly positioned 4105 wave

2 Gain.

The second very important parameter is the Gain adjustment. Single point gain is used for this application. (Number of Gain points = 1)

The Gain must be set so that no part of the signal clips (i.e., flattens at the edges of the window). Your SIR System is designed to automatically set the gain within acceptable parameters. It does this during the antenna initialization period. In order to make sure that the gains are correct, you need to make sure that the antenna is positioned over representative conditions before initializing the antenna. That means that if you are collecting the first file as a metal plate calibration file, you must put the plate under the antenna before you initialize and remove it before you reinitialize for the next file.

Move on to the next section.

Collecting the First File as a Metal Plate Calibration File

Now, it is time to collect a “bumper jump” calibration file. The metal plate should be under the antenna, you should see data scrolling across the screen, and the trace on the right side of the screen should look like Figure 51.

1. Click the green arrow (Run) to begin collecting the file. The SIR-20 will run in continuous mode (no Survey Wheel).
2. Jump up and down on the bumper. The ground reflection will turn into a wavy line. Keep jumping until the whole screen width is filled up with data.
3. Click the red button with the white dot in it to save the data.
4. Remove the metal plate from underneath the antenna **(IMPORTANT!)**

Move on to the next section.

Collecting the Data

1. Click the green square (Run Project) and wait for the antenna to initialize.
2. Start before the bridge so that you will have the reflection from the bridge joint in the data.
3. Click the green arrow (Run) and wait for the screen to maximize.
4. Drive across the bridge. If the SIR system beeps, the antenna is being moved too fast, and the person driving the vehicle must slow down. If the SIR system beeps more than 2 or 3 times, data collection along the profile line should be repeated. When you have crossed off of the bridge, click the red button with the white dot to stop and save data collection.
    - Move on to the next profile and follow steps 1-4 until you are done. It is OK to collect data in a zig-zag fashion with profiles running in alternate directions. Make sure to specify in your notes which files are in which direction.

Data Processing

1 Transfer the data from the SIR unit to the computer that will process the data. You can also use the collection laptop on the SIR-20. Close the SIR-20 program and open RADAN.

2 Go to View>Customize and select the source (i.e., input) and output directories and the vertical and horizontal linear units that will be used during data processing (see Appendix C for details).

Generate Metal Plate Calibration File

1 In RADAN, open the calibration file collected over the metal plates. A typical file will appear like the one shown in Figure 52.

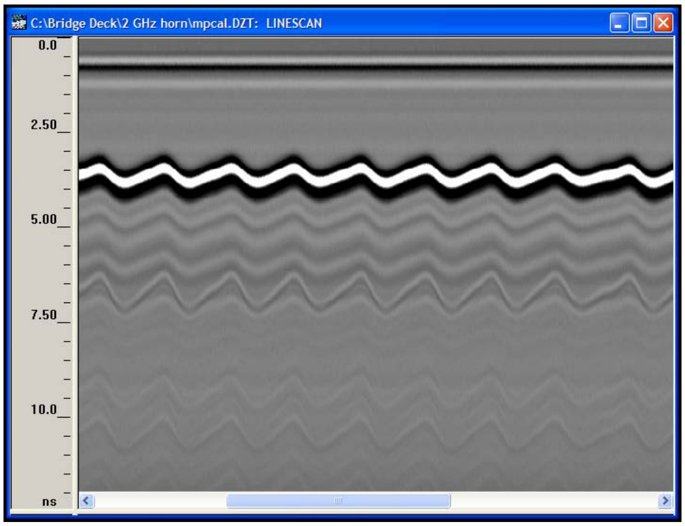


Figure 52: Typical raw metal plate calibration file (Color Table #17, Display Gain = 8)

2 The first major objective is to process the metal plate calibration file. Click the Generate Horn Calibration File button  and adjust the parameters in the dialog box so that they match the parameters shown in Figure 53.

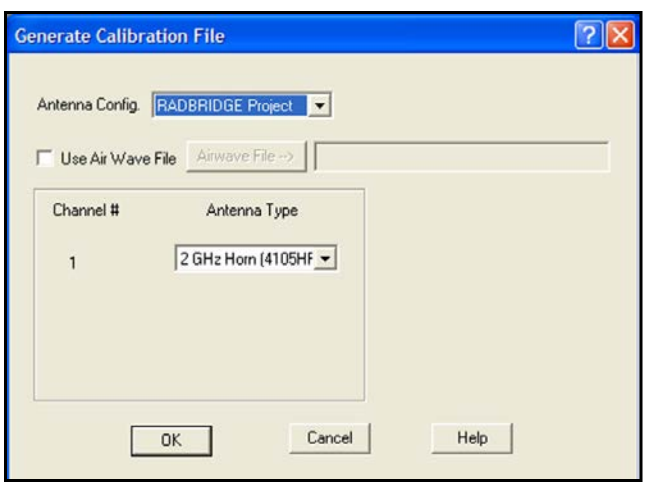


Figure 53: Generate Calibration File dialog just prior to clicking OK.

Specifically, you will change the Antenna Config to RADBRIDGE Project and the antenna types to match the antenna you used. Click OK to begin processing. The output calibration file will have the extension .czt and will have an appearance similar to the one shown in Figure 54.

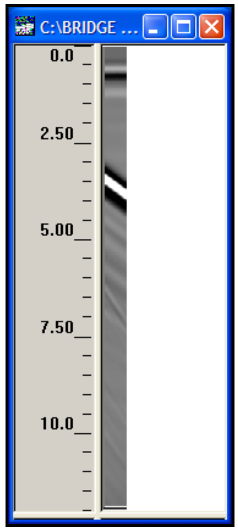


Figure 54: Typical processed horn antenna metal plate calibration file

Create the Reflection Picking Macro

Now, we must create a macro that will use the processed metal plate calibration file.

1 Close all open data files.

2 Open a data file collected over the bridge deck (any data file will do). With the data file open, click the Create Macro button. A dialog will appear that prompts you to enter a name for the macro. Supply a name and click OK. The new macro is ready for adding processing steps.

3 Click on the Horn Reflection Picking button. The Reflections Picking – Processing Options dialog box shown in Figure 55 will appear.

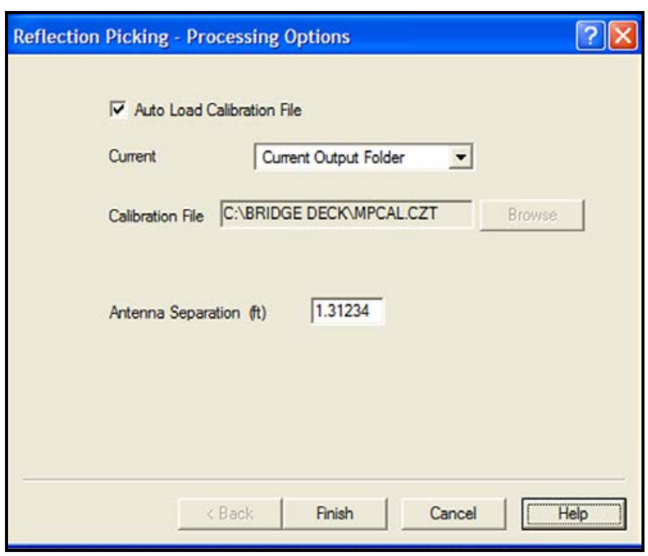


Figure 55: Reflection Picking dialog box.

4 Make sure that the correct metal plate calibration file is specified. In not, Click the Calib File button and select the processed calibration file. The file you select will have a .czt extension.

4105 Note: If you are using single polarization 4108 or 4105, then you must set this separation value to 0. Click Finish after changing the value.

5 Close the macro by clicking the Close Macro button .

6 A macro is now created. This macro is necessary for running a project. Close all open data files and move on to the next step.

Creating a Process Project

The next step involves creating a RADAN Project.

1 Choose File > New. A New Project window will come up. Type in a name and check the box for RADBridge project. Click Save. The Project Information dialog box will appear. Check to make sure the Output Path listed in the dialog is the desired path. If it isn't, click the Output Path button to select a different Output path. The rest of the screen is for optional notes. Click OK.

2 Enter the data files in the Edit Project File List dialog box (Figure 56). Data files are added by double-clicking on them in order. For bridge deck evaluations, each file will have a different Y-coordinate associated with its position relative to the right lane stripe or bridge-curb. When all of the files are added in order, click Done.

3 Attach Macro. Click on a data file and click the Attach Macro button as shown in Figure 56. The same macro must be attached to all of the files. Click done.

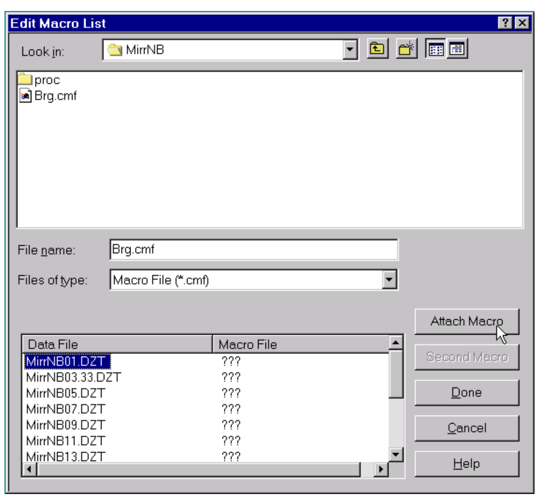


Figure 56: Attaching the macro Brg.cmf to a data file.

4 Enter **3D file parameters**. The 3-D filename, 3-D grid dimensions, and the X- and Y-coordinates of the files are entered using this multi-tab dialog box.

a) Click the 3D Output Filename button and enter the name that you want to call the resulting 3D file.

b) Change the Antenna Config to Single Pol for the 4105 Horn or the 5100 ground coupled antenna (or for single polarization 4108 antennas used on concrete surface bridge decks). If you are using the 4108 antennas in the dual polarization configuration, then change to Dual Pol.

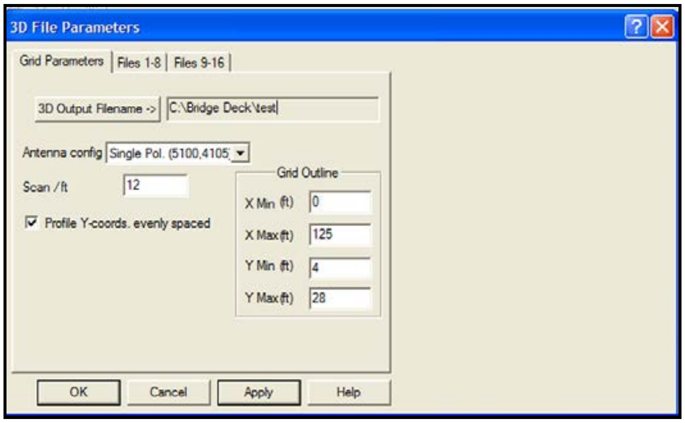


Figure 57: Entering in 3D File Parameters

c) Specify the grid outline.

- XMin should be the x-value relative to the start of the bridge deck. Generally, except for exceptionally long bridges (where you may want to divide up and process the bridge data in segments), you will want to specify "0" for XMin.
- The XMax parameter will correspond to the length of the bridge, except for exceptionally long bridges (where you may want to divide up and process the bridge data in segments.
- The YMin value corresponds to the Y-coordinate of the first profile line and the YMax value corresponds to the Y-coordinate of the last profile line.

For example, data collected in the project shown here were obtained over a 125-foot long bridge. The first profile line was obtained 4 feet from the right lane stripe and the last profile line was collected 28 feet from the right lane stripe. Therefore, the following coordinates were entered in the dialog shown in Figure 57:

X Min = 0.0 ft (0.0 m)

X Max = 125 ft

Y Min = 4.0 ft

Y Max = 28 ft

d) If the profile lines were collected at evenly spaced Y-increments, keep the Profile Y-Coords Evenly Spaced box checked. Otherwise, deselect it.

e) **Don't change the scans/meter indicated in the Grid Parameters dialog tab.** This number is for display purposes only and is taken from the header of the first file entered in the project.

f) In the Files 1-8 tab, enter the Starting X-coordinate (Xo) and the Y-coordinate of the profile lines. Generally, the Starting X coordinate corresponds to the start of the bridge.

g) To locate the start of the bridge, press the button Click.

h) The associated file will open on the screen. Move the mouse cursor to the start of the bridge and click the left mouse button at the interpreted start of the bridge as shown in Figure 58.

- The corresponding X-coordinate of the start of the bridge will automatically be entered in the Xo box associated with the file.

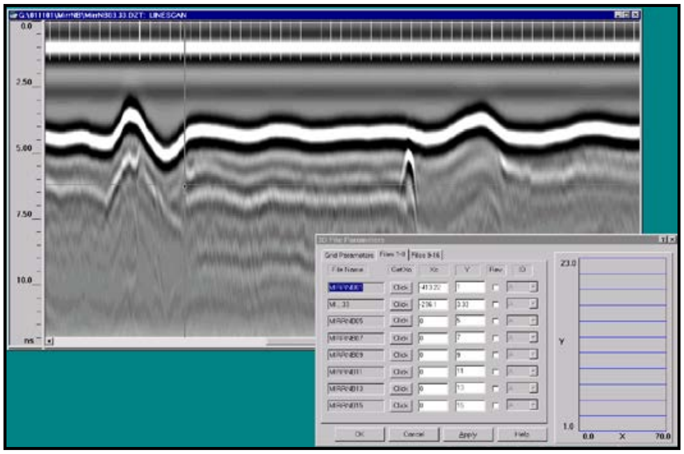


Figure 58: Selecting the Xo value for the bridge by clicking the left mouse button at the location of the bridge joint/ bridge deck junction.

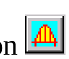
Note: The bridge deck/bridge joint junction at the end of the data file is entered when selecting the Xo for data profiles collected in the reverse direction. The Rev box must also be selected in these cases.

After all of the Xo and Y-coordinates of the files have been selected for all of the File tabs, (when there are more than 8 files) click OK. Everything on the screen will disappear. The project is now ready to be run.

5 To run an open project, choose Project > Run.

Run Horn Antenna Process

Next, the output 3-D file must be processed through the Horn Antenna Bridge Analysis process.

1 Click the Horn Antenna Bridge Analysis process button  to open the dialog box (Figure 59).

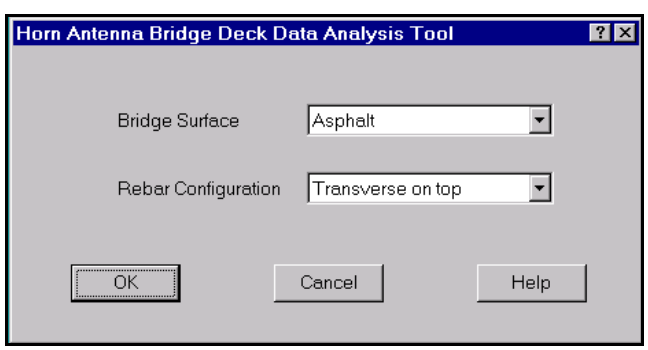


Figure 59: Horn Antenna Bridge Deck Analysis Tool dialog box.

2 Select the Bridge Surface – Asphalt or Concrete.

3 Specify the Rebar Configuration.

- If the transverse rebar are located on top of the longitudinal rebar, select Transverse on top. If you are using a pair of 4108's in dual polarization and the top rebar is longitudinal AND closer together than 8 inches, you can select Longitudinal rebar configuration.

4 Click OK to start the data processing. The software will prepare a .lay file with preset target classes that you will work with in Interactive Interpretation.

Note: The Horn Antenna Bridge Analysis Tool will not track the rebar layer for non-dual polarization projects with asphalt overlays. The reason for this is that it is extremely difficult to do with a high degree of success. This means that you will have to do your own layer picking using interactive interpretation.

5 After the processing is complete, save the output file. An ASCII file with the same root name as the output file and the extension .lay is saved in the same folder as the output file. This ASCII file contains all of the rebar reflection pick information.

Make Picks in Interactive Interpretation

The next step is to examine the performance of the automatic rebar picking process and edit poor picks. This will be done in the Interactive Interpretation module.

1 With the output file open and active, click the Interactive Interpretation button .

2 The Get Pick File dialog box will appear (Figure 60). The name of the ASCII file created by the previous process will be displayed in the Pick File window.

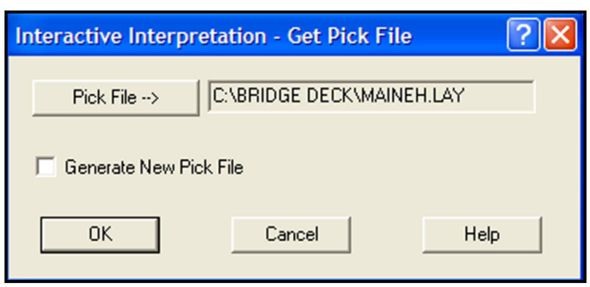


Figure 60: Get Pick File dialog.

3 After clicking OK, a new window will appear containing the data in the top pane and a depth chart on the bottom pane.

4 Use EZ Tracker to make picks for the asphalt bottom (if asphalt overlay), rebar, and bridge bottom (if seen).

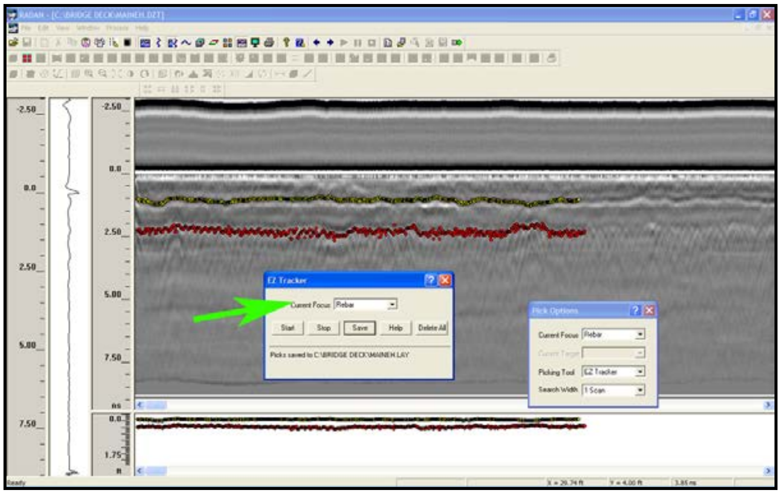


Figure 61: Make Picks with EZ Tracker.

EZ Tracker: EZ Tracker can be accessed by right clicking on the data pane and then clicking on Pick Options.

- Set the Picking Tool to EZ Tracker and it will open the EZ Tracker control window.
- Select the desired target in the current focus and click Start. Left click on the target and EZ Tracker will draw dots on the target to follow it through the data.
- If it gets off track, right click to undo the previous short segment.
- If you come to a gap, click Stop and then Start again on the other side of the gap.
- Save every once in a while to save your picks.

In general, it is not necessary to pick the asphalt bottom if you are doing concrete deterioration mapping. However, picking the asphalt bottom does provide you with extra useful information such as asphalt thickness. Regardless of whether you pick the asphalt bottom or not, it is still essential to note the location of any patches or cracking in the asphalt. This information is used for the development of the deterioration map.

5 Once you are finished making picks, click save on EZ Tracker one more time to make sure that your data is saved. Close EZ Tracker.

6 Enter Skew Angle. The last step is to enter the bridge joint skew angle. The is typically at a non-normal angle to the bridge and is easy to measure from the bridge plans. Right click on the data pane and go to Global Options. Type in the skew angle in degrees counter-clockwise and close the Global Options window.

7 Right click on the data pane and do a final save of the data by selecting Save Changes>Current Filename.

8 You can now close RADAN.

You have created a spreadsheet of information for each location that can be opening in Microsoft Excel and graphed in any graphing program that accepts ASCII .CSV data (very common).

Viewing the Data in Microsoft Excel

1 Open Microsoft Excel and select File>Open.

2 In the "Files of Type" dialogue, select All Files. The pick file will have the root filename of your data file with the extension ".lay."

3 Select that one and an import window will pop up. Select "Delimited" on Step 1 and then click Next to move to Step 2. Select "Comma" and then click Finish. You will see a spreadsheet similar to Figure 62.

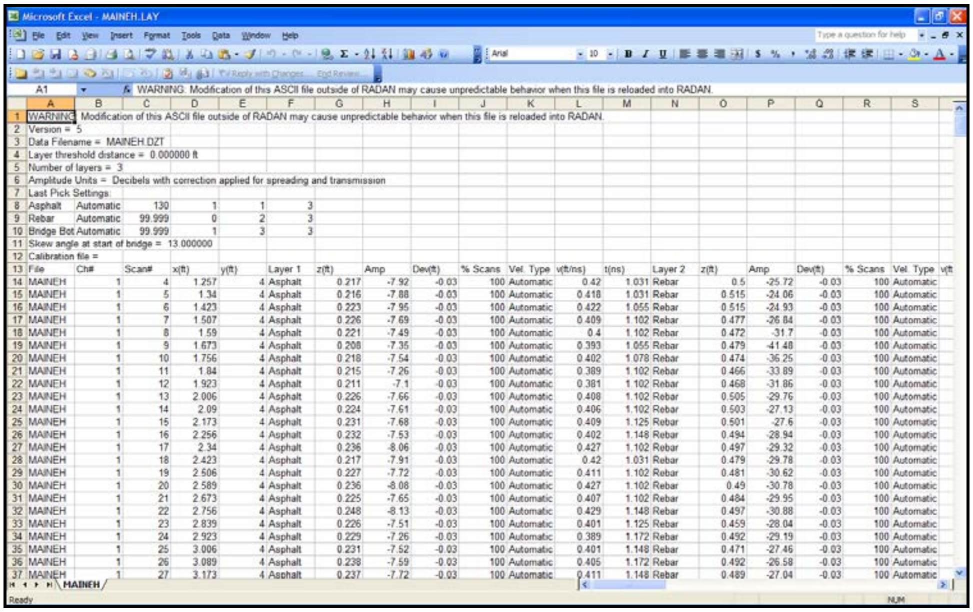
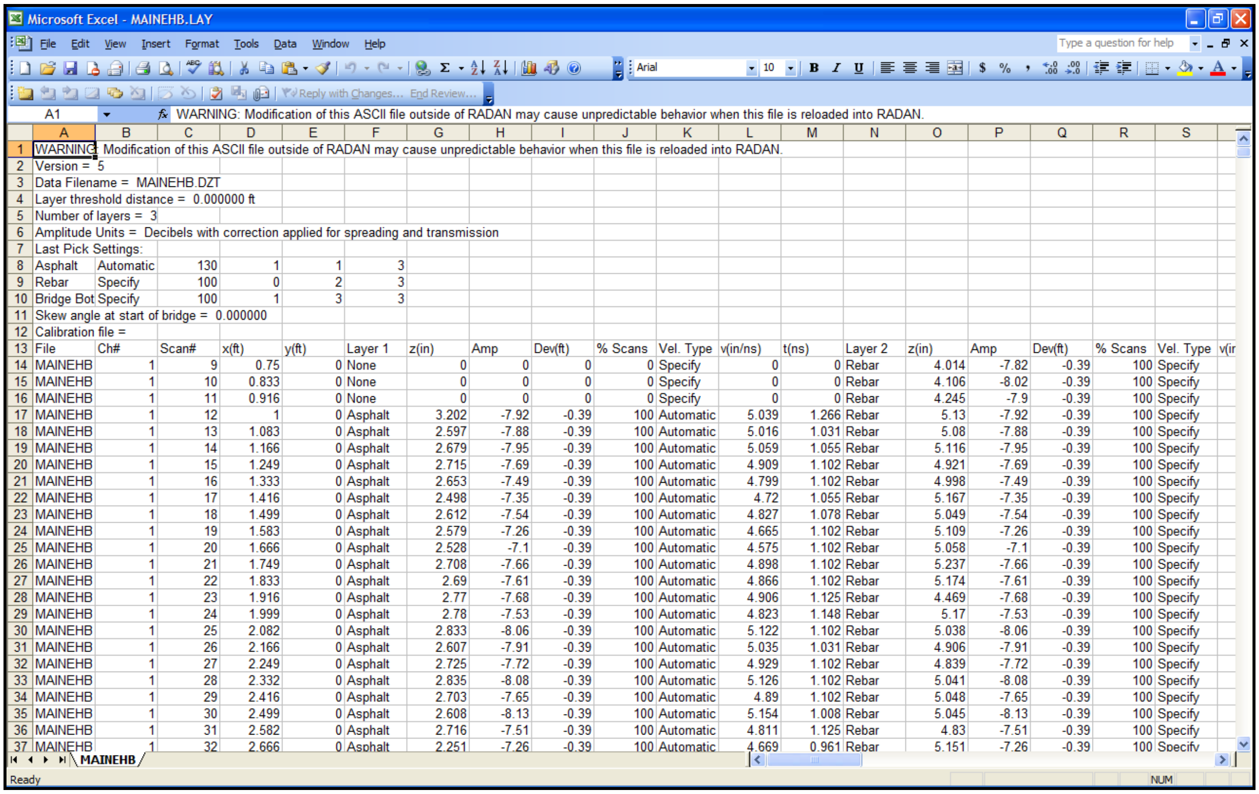


Figure 62: Excel Output.

Understanding the Output File



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	
1	WARNING: Modification of this ASCII file outside of RADAN may cause unpredictable behavior when this file is reloaded into RADAN.																			
2	Version = 5																			
3	Data Filename = MAINEHB.DZT																			
4	Layer threshold distance = 0.000000 ft																			
5	Number of layers = 3																			
6	Amplitude Units = Decibels with correction applied for spreading and transmission																			
7	Last Pick Settings:																			
8	Asphalt	Automatic	130	1	1	3														
9	Rebar	Specify	100	0	2	3														
10	Bridge Bot	Specify	100	1	3	3														
11	Skew angle at start of bridge = 0.000000																			
12	Calibration file =																			
13	File	Ch#	Scan#	x(ft)	y(ft)	Layer 1	z(in)	Amp	Dev(ft)	% Scans	Vel. Type	v(in/ns)	t(ns)	Layer 2	z(in)	Amp	Dev(ft)	% Scans	Vel. Type	v(ir
14	MAINEHB	1	9	0.75	0	None	0	0	0	0	Specify	0	0	Rebar	4.014	-7.82	-0.39	100	Specify	
15	MAINEHB	1	10	0.833	0	None	0	0	0	0	Specify	0	0	Rebar	4.106	-8.02	-0.39	100	Specify	
16	MAINEHB	1	11	0.916	0	None	0	0	0	0	Specify	0	0	Rebar	4.245	-7.9	-0.39	100	Specify	
17	MAINEHB	1	12	1	0	Asphalt	3.202	-7.92	-0.39	100	Automatic	5.039	1.266	Rebar	5.13	-7.92	-0.39	100	Specify	
18	MAINEHB	1	13	1.083	0	Asphalt	2.597	-7.88	-0.39	100	Automatic	5.016	1.031	Rebar	5.08	-7.88	-0.39	100	Specify	
19	MAINEHB	1	14	1.166	0	Asphalt	2.679	-7.95	-0.39	100	Automatic	5.059	1.055	Rebar	5.116	-7.95	-0.39	100	Specify	
20	MAINEHB	1	15	1.249	0	Asphalt	2.715	-7.69	-0.39	100	Automatic	4.909	1.102	Rebar	4.921	-7.69	-0.39	100	Specify	
21	MAINEHB	1	16	1.333	0	Asphalt	2.653	-7.49	-0.39	100	Automatic	4.799	1.102	Rebar	4.998	-7.49	-0.39	100	Specify	
22	MAINEHB	1	17	1.416	0	Asphalt	2.498	-7.35	-0.39	100	Automatic	4.72	1.055	Rebar	5.167	-7.35	-0.39	100	Specify	
23	MAINEHB	1	18	1.499	0	Asphalt	2.612	-7.54	-0.39	100	Automatic	4.827	1.078	Rebar	5.049	-7.54	-0.39	100	Specify	
24	MAINEHB	1	19	1.583	0	Asphalt	2.579	-7.26	-0.39	100	Automatic	4.665	1.102	Rebar	5.109	-7.26	-0.39	100	Specify	
25	MAINEHB	1	20	1.666	0	Asphalt	2.528	-7.1	-0.39	100	Automatic	4.575	1.102	Rebar	5.058	-7.1	-0.39	100	Specify	
26	MAINEHB	1	21	1.749	0	Asphalt	2.708	-7.66	-0.39	100	Automatic	4.898	1.102	Rebar	5.237	-7.66	-0.39	100	Specify	
27	MAINEHB	1	22	1.833	0	Asphalt	2.69	-7.61	-0.39	100	Automatic	4.866	1.102	Rebar	5.174	-7.61	-0.39	100	Specify	
28	MAINEHB	1	23	1.916	0	Asphalt	2.77	-7.68	-0.39	100	Automatic	4.906	1.125	Rebar	4.469	-7.68	-0.39	100	Specify	
29	MAINEHB	1	24	1.999	0	Asphalt	2.78	-7.53	-0.39	100	Automatic	4.823	1.148	Rebar	5.17	-7.53	-0.39	100	Specify	
30	MAINEHB	1	25	2.082	0	Asphalt	2.833	-8.06	-0.39	100	Automatic	5.122	1.102	Rebar	5.038	-8.06	-0.39	100	Specify	
31	MAINEHB	1	26	2.166	0	Asphalt	2.607	-7.91	-0.39	100	Automatic	5.035	1.031	Rebar	4.906	-7.91	-0.39	100	Specify	
32	MAINEHB	1	27	2.249	0	Asphalt	2.725	-7.72	-0.39	100	Automatic	4.929	1.102	Rebar	4.839	-7.72	-0.39	100	Specify	
33	MAINEHB	1	28	2.332	0	Asphalt	2.835	-8.08	-0.39	100	Automatic	5.126	1.102	Rebar	5.041	-8.08	-0.39	100	Specify	
34	MAINEHB	1	29	2.416	0	Asphalt	2.703	-7.65	-0.39	100	Automatic	4.89	1.102	Rebar	5.048	-7.65	-0.39	100	Specify	
35	MAINEHB	1	30	2.499	0	Asphalt	2.608	-8.13	-0.39	100	Automatic	5.154	1.008	Rebar	5.045	-8.13	-0.39	100	Specify	
36	MAINEHB	1	31	2.582	0	Asphalt	2.716	-7.51	-0.39	100	Automatic	4.811	1.125	Rebar	4.83	-7.51	-0.39	100	Specify	
37	MAINEHB	1	32	2.666	0	Asphalt	2.251	-7.26	-0.39	100	Automatic	4.669	0.961	Rebar	5.151	-7.26	-0.39	100	Specify	

Figure 63: Data Output.

Figure 63 shows the Excel worksheet output from the picking process. The first 12 rows are file header information that shows some of the background information about the data set. In Figure 63, the data begins with the column headers at row 13. Each row is a pick location. EZ Tracker assigns three layers by default. If there is a pick for a scan location on one layer and not another, then that layer will show a zero for much of the other information.

Each pick will have the following information:

X: This is the pick's location along the survey profile line. This value will be in the horizontal units which were selected under View>Customize.

Y: This is the pick's location along the Y axis of the survey area. This will typically be the same value for all picks from a given survey profile. This value will be in the horizontal units whichwere selected under View>Customize.

Layer 1/2/3: This column shows the pick ID. This will be Asphalt for Layer 1, Rebar for Layer 2, and Bridge Bottom for Layer 3. If there is no pick for that layer at the given location, then it will display "None."

Z: This is the pick's depth from the surface. This value will be in whichever vertical units were selected under View>Customize. This depth is cumulative. This means that if you would like to know the amount of concrete cover over the rebar in an asphalt overlay concrete deck, then you must subtract the asphalt bottom from the rebar depth.

Amp: This column shows the reflection amplitude for each pick. This information is used in creating deterioration plots. These values are in decibels with a correction applied for radar spreading and transmission.

Dev(units): If you used automatic reflection picking with a filter length, then this column is a statistic that shows the deviation over a least square fit line of a defined filter length. This option is not often used with EZ Tracker. This value will be in whichever units were selected under View>Customize.

% Scans: This column shows the percentage of scans within the filter length that are classified as part of the layer. If you have filters enabled, then this will be an indication of confidence. This option is not often used with EZ Tracker.

Vel. Type: This column indicates the source of the velocity information for the pick. This is set under Layer Properties.

V, or Perm: This column shows the radar wave velocity or the dielectric permittivity at the current pick location. You can choose to output dielectric permittivity under the Save Changes>New Filename>Save Options window. If you are outputting velocities, then this value will be in the vertical units selected under View>Customize.

t(ns): This column shows the reflection time in nanoseconds for that pick.

Chapter 6: Interactive Interpretation Feature Overview

All of the features in the Interactive Interpretation process that may be useful while working on a data file are briefly described below.

Main Menu Options

Figure 64: Main pop-up menu accessed by clicking the right mouse button when the mouse is positioned over data within the upper half of the Interactive Interpretation window.

Display Gain

The Display Gain option is found in the Main pop-up menu (accessed by right clicking in the data pane). Figure 65 shows the Display Gain option.

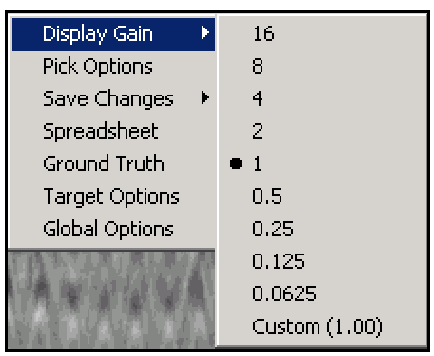


Figure 65: Display Gain option selected from Main pop-up menu.

Display Gain is the multiplication factor applied to the data to increase or decrease their display amplitude. It is called Display Gain because this multiplication factor will not change the data values in the file.

- Clicking the left mouse button when the cursor is positioned over one of the gain values changes the display gain.
- A gain of 1 is set by default.
- Clicking on Custom allows the user to specify a different multiplier than those listed.

Pick Options

Selecting Pick Options from the Main pop-up menu opens a dialog box containing the available options for adding and deleting picks. This process is useful for editing poor reflection picks and adding new picks.

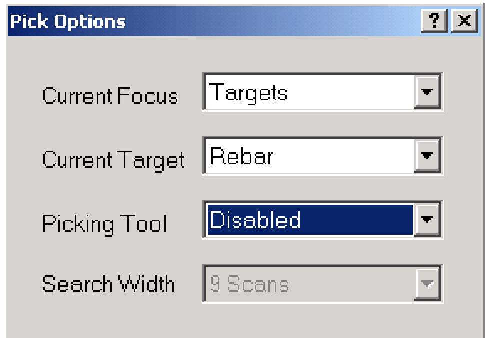


Figure 66: Pick Options dialog box.

Current Focus

There are three options for Current focus in the Bridge Assessment module – Asphalt, Rebar, or Bridge Bottom. The Rebar option allows the user to add single independent picks to mark objects such as pipes, culverts, voids, or events such as road intersections, starting and ending points of new pavement, etc.

Current Target

There is only 1 target name permitted in the Bridge assessment module. The default name for this target is “rebar”. (Other modules in RADAN permit the user to enter multiple target names with their own properties).

Picking Tool

The Picking Tool is the method employed to add and delete picks. There are four tools: (1) Single Point, (2) Select Block, (3) EZ Tracker, and (4) Select Range.

Single Point

Picks are added each time the user clicks the left mouse button and deleted each time the user clicks the right mouse button. Only one pick can be added at a time with this option, but multiple picks can be deleted depending on the Search Width.

EZ Tracker

EZ Tracker is designed to trace layers. It will not work for single point picking. Select the focus and click Start. Click on the layer and EZ Tracker will try to follow the layer by examining the amplitude values. If incorrect picks are made, then right click to remove the last selection. Click on Stop and Save when finished.

Select Block and Select Range

The Select Block and Select Range picking tools are designed to operate over a large number of scans.

Select Block

When Select Block is activated, a multi-colored, translucent square will appear over the data when the user clicks the left mouse button. The select block contains tiny squares on each face and corner. These squares act as handles that can be used to resize the select block.

To Resize Select Block

1. Position the mouse cursor over one of the handles and click and hold the left mouse button.
2. Move the mouse cursor to the desired location.
3. When the desired size is reached, release the left mouse button.

To Move Select Block

1. Position the mouse cursor within the select block and click and hold the left mouse button.
2. Move the mouse cursor until the block is in the desired position, and release the left mouse button.

Select Range:

When Select Range is activated, a multicolored translucent overlay appears over the data, extending from the beginning to the end of the file. It operates similarly to the Select Block, except that all operations performed using the Select Range picking tool are performed within the time interval (slice width) of the selected area on all of the scans in the file.

- The slice width can be changed by clicking the left mouse button on one of the handles (located at the top and bottom of the horizontal midpoint of the slice) and with the left mouse button still pressed, dragging the handle to the desired location.
- Adding and deleting points are performed within the Select Block and Select Range areas.
- These options are activated by clicking the right mouse button while the mouse cursor is positioned within the multicolored Select Block or Select Range area.

Select Block and Select Range Menu Options

Add Points: Clicking on Add Points will activate the program to begin a smart search for reflection peaks within the selected region. Circles will overlay the data where reflection peaks are identified by the search algorithm

Delete Points: Clicking on Delete Points will activate the program to start deleting target picks of the located within the selected region.

Pick Mod. Options:

- **Change Velocity** changes the velocity of the currently selected picks located in the selected region. Clicking on Change Velocity opens a dialog box for entering the desired velocity. The new velocity is used for all of the currently selected picks.
- **Interpolate Points** will interpolate target picks (add new picks between existing ones) using the interpolation method (Linear or Nearest Neighbor) specified in Global Options dialog, which is accessed from the Main Menu

Search Width

The search width is only applicable to the Single Point mode. Figure 67 shows the different search widths available.

Figure 67: Different Search Widths indicated by the cursor size that can be used to add and delete picks in single point mode in Interactive Interpretation. The cursors correspond, from left to right, to 1 scan, 3 scans, 5 scans, 9 scans, and 17 scans.

Save Changes

The layer and rebar picks are stored to an ASCII file when Save Changes is selected from the Main pop-up menu. The user has an option of saving the changes to an existing ASCII file or to a new file.

When the user selects to save changes to a new ASCII file, the Save Options menu item can be selected. Figure 68 shows the save options that can be implemented to the data written to the new ASCII file. The various save options are described below.

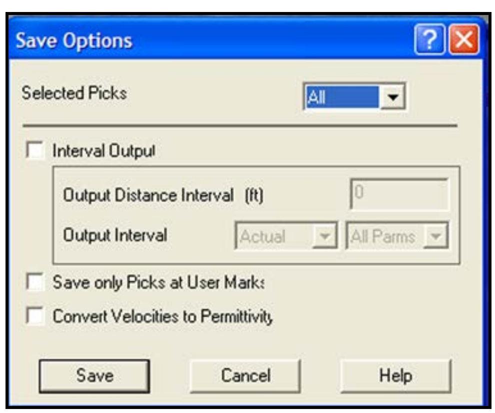


Figure 68: Save Options dialog box with various features that can be applied to the data written to a new ASCII file.

Output Distance Interval

This value defines the spacing between rebar reflection picks output to the ASCII data file. For example, if the user selects the output distance interval to be 1.0 ft (0.3 m), and the data were obtained at a distance increment of 6.1 scans/ft (20 scans/m), then the pick from only 1 of the 6 scans will be output per 1 foot (0.3 m) increment to the ASCII file. The depth, amplitude, velocity and time values associated with the output pick are determined by the Interval Options (Actual, Average, Minimum or Maximum) specified next to each respective category.

Selected Picks

This sets the desired output picks. Only the selected picks will be output to the ASCII file. The only option for the Bridge Assessment module is Targets.

Output Interval Options

Only specific picks meeting the criteria specified on this line are output to the ASCII file.

For example, if Maximum and Amplitude are chosen as the options, and the output distance interval is 1 foot (0.3 m), the third pick in the output ASCII file will be the pick with the largest amplitude located between 2 and 3 feet (0.6 and 0.9 m).

Selecting an output distance interval corresponding to the transverse rebar spacing (providing the transverse rebar are on top of the longitudinal rebar) and specifying Maximum and Amplitude as the Output Interval Options will occasionally be necessary when using the Horn Antenna Bridge Analysis module.

Save only Picks at User Marks

When this option is checked, only the picks located on scans containing user marks are saved. This option isn't used often in the Bridge Assessment module.

Convert Velocities to Permittivity

This will output the relative dielectric permittivity at the given pick.

Viewing and Deleting Picks Using Spreadsheet

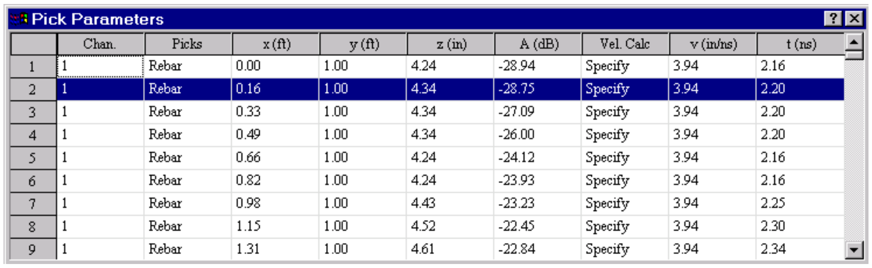
Selecting the Spreadsheet option from the Main pop-up menu shown in Figure 64 brings up an MS Excel®-style spreadsheet containing the pick information contained in the ASCII database files. An example of the spreadsheet is shown in Figure 69.

Pick Parameters

	Chan.	Picks	x (ft)	y (ft)	z (in)	A (dB)	Vel. Calc	v (in/ns)	t (ns)
1	1	Rebar	0.00	1.00	4.24	-28.94	Specify	3.94	2.16
2	1	Rebar	0.16	1.00	4.34	-28.75	Specify	3.94	2.20
3	1	Rebar	0.33	1.00	4.34	-27.09	Specify	3.94	2.20
4	1	Rebar	0.49	1.00	4.34	-26.00	Specify	3.94	2.20
5	1	Rebar	0.66	1.00	4.24	-24.12	Specify	3.94	2.16
6	1	Rebar	0.82	1.00	4.24	-23.93	Specify	3.94	2.16
7	1	Rebar	0.98	1.00	4.43	-23.23	Specify	3.94	2.25
8	1	Rebar	1.15	1.00	4.52	-22.45	Specify	3.94	2.30
9	1	Rebar	1.31	1.00	4.61	-22.84	Specify	3.94	2.34

Figure 69: Pop-up spreadsheet containing rebar pick information.
The spreadsheet is useful for viewing and deleting picks.

Single picks can be deleted from the spreadsheet and database by clicking on the leftmost column containing the row numbers to highlight the row (Figure 70), then pressing the Delete key on the computer keyboard.


Pick Parameters

	Chan.	Picks	x (ft)	y (ft)	z (in)	A (dB)	Vel. Calc	v (in/ns)	t (ns)
1	1	Rebar	0.00	1.00	4.24	-28.94	Specify	3.94	2.16
2	1	Rebar	0.16	1.00	4.34	-28.75	Specify	3.94	2.20
3	1	Rebar	0.33	1.00	4.34	-27.09	Specify	3.94	2.20
4	1	Rebar	0.49	1.00	4.34	-26.00	Specify	3.94	2.20
5	1	Rebar	0.66	1.00	4.24	-24.12	Specify	3.94	2.16
6	1	Rebar	0.82	1.00	4.24	-23.93	Specify	3.94	2.16
7	1	Rebar	0.98	1.00	4.43	-23.23	Specify	3.94	2.25
8	1	Rebar	1.15	1.00	4.52	-22.45	Specify	3.94	2.30
9	1	Rebar	1.31	1.00	4.61	-22.84	Specify	3.94	2.34

Figure 70: Highlighted row prior to being deleted.

Target Options

Selecting Target Options from the Main Menu allows the user to view and edit the target properties. Figure 71 shows the different target properties that can be modified.

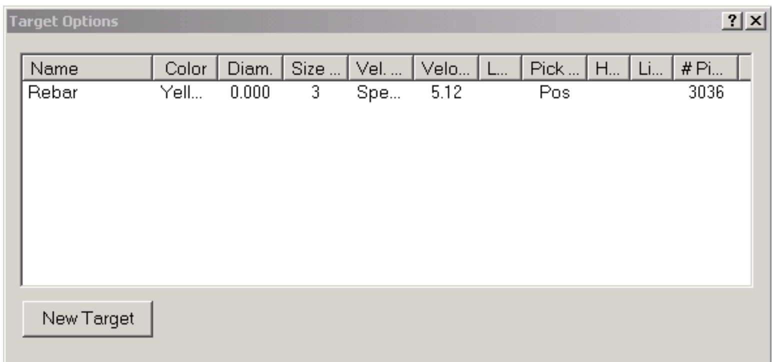


Figure 71: Modifiable target options that are accessed by selecting the Target Options menu item from the Main Menu.

Double-clicking on the name of the target, as shown in Figure 72, opens up a dialog that permits the user to edit the target properties.

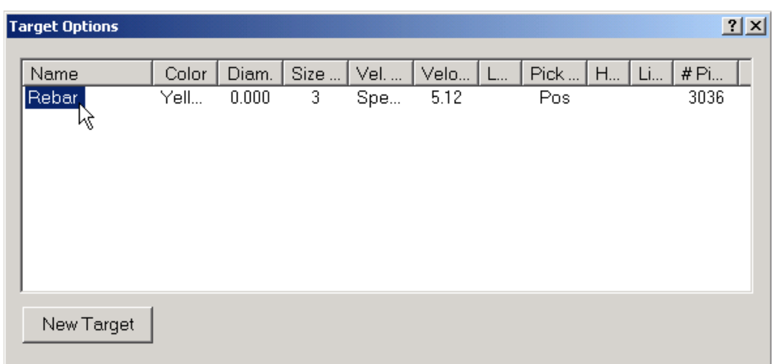


Figure 72: Double-clicking on the target name opens up a dialog that permits the target properties to be edited.

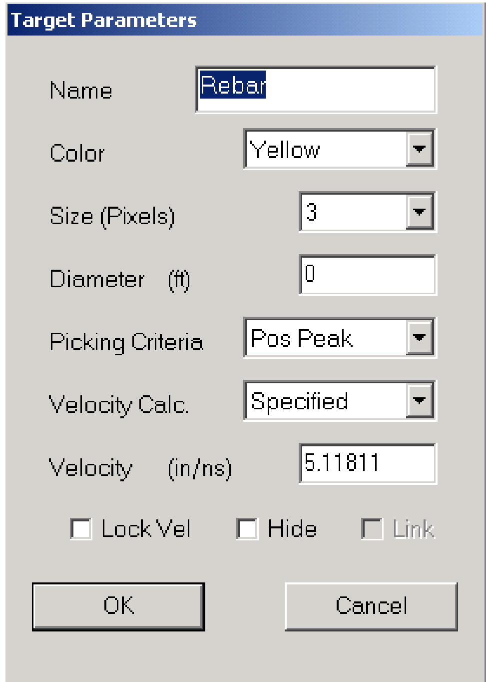


Figure 73: Target Parameters dialog.

Name: The name of the target. This name will appear in the spreadsheet and in the output ASCII file.

Color: The color of the circle drawn at the target location in the data pane and corresponding target depth in the depth pane.

Size: The size, in pixels, of the circle drawn at the target location in the data pane.

Diameter: The diameter of the target. The width of the circle drawn in the depth pane is directly proportional to the target diameter when this value is greater than zero. When this value is zero, the size of the target circle drawn in the depth pane corresponds to the specified pixel size.

Picking Criteria: The criteria used to pick targets in the data. The options are: (1) Positive Peak, (2) Negative Peak, (3) Absolute peak, and (4) None. When options 1-3 are used, the location of the target will correspond to a reflection peak. For option (4), the location of the target will directly correspond to the location of the mouse cursor or select block.

Velocity Calc.: Sets the propagation velocity used to calculate the depth of each target. The options are: (1) User-specified, and (2) Core Data. To enter a user-specified option, select Specify and enter the value in the box next to Velocity.

Velocity: This is the user-specified velocity.

Lock Vel: Checking this box prevents the user from selecting a different velocity method or user-specified velocity for individual targets within the group of targets possessing the same target name.

Hide: Checking this box hides all the target picks from view and prevents them from being selected using the select block or select range picking tools.

Link: Checking this box connects the target picks together to form pipes and other linear objects that can be viewed in RADAN QuickDraw This option is only available for users who have purchased the I3D and QuickDraw modules.

Global Options

Global options are applied to all picks. Figure 74 shows the global options available with the Bridge Assessment Module.

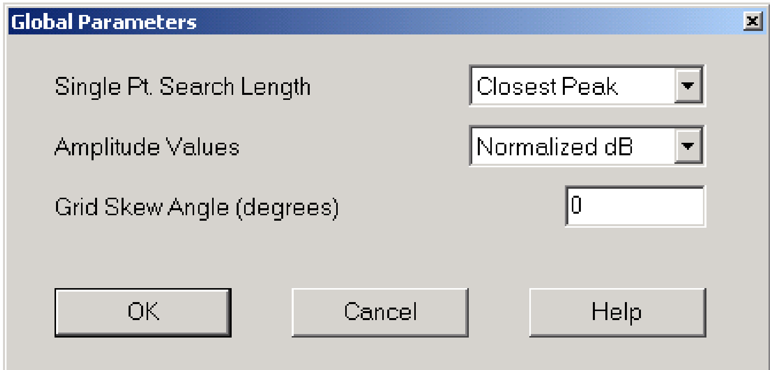


Figure 74: Global Parameters accessed by clicking on the Global Options item in the Main Menu.

Single Pt. Search Length

This option permits the user to select the search distance when adding single points. There are two options: (1) Closest Peak and (2) Cursor Length.

- The Closest Peak search type will perform a search until the nearest peak is located or the start or end of the scan is reached. In other words, the search may potentially extend over the entire scan.
- The Cursor Length search method only performs a search for a peak over the vertical length shown by the mouse cursor.
- The Closest Peak method is the default option.

Amplitude Values

This option allows the user to specify how the amplitude values for each pick are calculated. The different options are: (1) Data Units, (2) dB, and (3) Normalized dB.

- The Data Units option provides the layer bottom reflection amplitudes in the actual data values.
- The dB option converts the data units amplitudes to decibels (dB) by using the equation 20*log10(x) where x is the absolute value of the data amplitude.
- The Normalized dB option normalizes the data amplitude relative to 32767 before converting to dB.

Grid Skew Angle (degrees)

This option corrects the GPR coordinates for bridge skew angles. All bridge deck 3-D files are initially created using some reference observable in the data to specify the start of the bridge. Commonly this reference corresponds to a joint.

Many bridges have joints that are at non-normal angles relative to the direction of travel. Consequently, the GPR data coordinates must also be skewed to accurately represent correct spatial geometry of the bridge in the output contour map of rebar reflection amplitudes.

Figure 75 shows the correct way to implement skew angles. Clockwise angles are positive, counter clockwise angles should be negative.

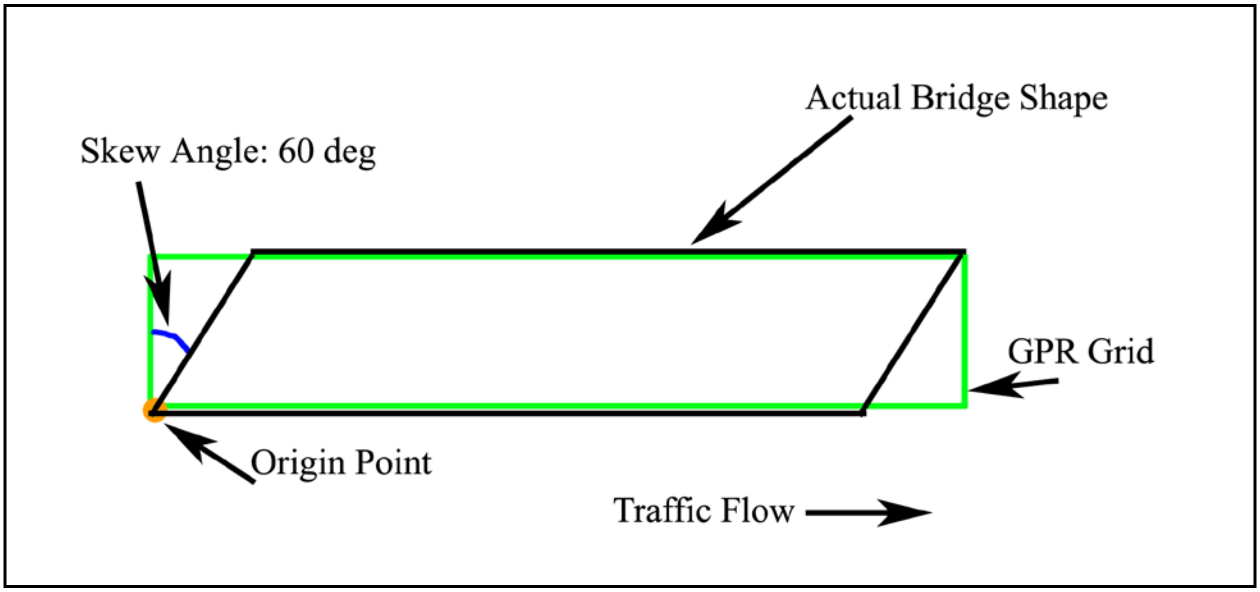


Figure 75: Examples of skew angles that should be put in the Grid Skew Angle category to convert the GPR Grid coordinates to the actual bridge coordinates.

Chapter 7: Using Rebar Reflection Amplitudes to Create Deterioration Maps

By default, the rebar reflection amplitudes are stored in units of dB. The relative rebar reflection amplitude strengths have been shown to be directly correlated to bridge deck deterioration in a number of studies. See the references at the end of this manual for specific case studies. GSSI has found that the contouring and plotting package Surfer™ to be extremely flexible and easy to use for displaying rebar reflection amplitude contour maps.

An example of a bridge deck condition map is shown in Figure 76. The deteriorated areas, shown in black in the figure, were mapped using hammer sounding once the asphalt overlay was removed from the concrete bridge deck.

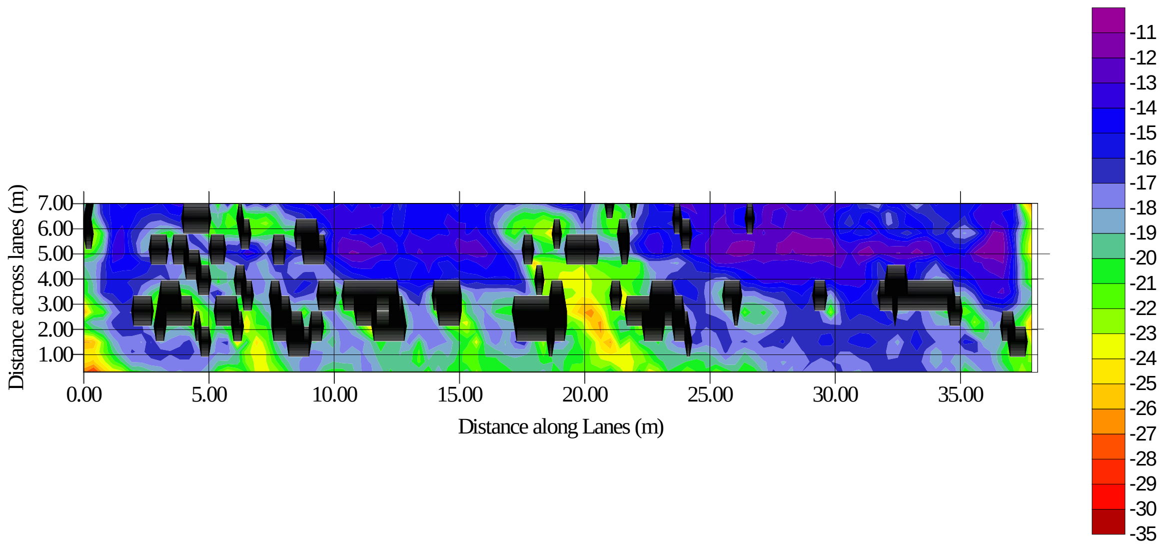


Figure 76: Contour map of rebar reflection amplitudes. The black areas superimposed on the contour map represent areas verified to be deteriorated based on hammer sounding after the asphalt overlay was removed.

The following papers are presented in their entirety in order to illustrate the most effective technique for creating deterioration maps.

BRIDGE DECK CONDITION ASSESSMENT USING GPR
COMPARISON OF 2 GHZ HORN AND 1.5 GHZ GROUND-COUPLED ANTENNAS

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ABSTRACT

A well established and accepted application of Ground Penetrating Radar (GPR) is the accurate condition assessment of bridge decks as well as other reinforced concrete structures. Significant advantages of using GPR for bridge deck assessment include the non-destructive nature of the technique; the ability of GPR to be used without requiring the removal of an existing asphalt overlay; and the ability to provide a quantitative record independent of interpretation. The most accurate bridge assessments using GPR have been performed using high frequency (1.5 GHz) ground-coupled antennas. The high frequency ground-coupled antenna provides excellent resolution of the reinforcing steel however; since the antenna must remain sufficiently ground-coupled it necessitates a slow data acquisition speed. Some GPR bridge assessments have been performed using 1 GHz air-launched horn antennas. The air-launched antenna permits faster data collection, at the expense of resolution. In a collaborative effort between GSSI and the Maine DOT, both a 1.5 GHz ground-coupled antenna and GSSI's 2 GHz air-launched horn antenna were used to evaluate the condition of an asphalt overlaid bridge deck located in Lewiston, Maine. GPR data lines were acquired at two foot spacing by simply walking the ground-coupled antenna system and by driving a vehicle with the air-launched horn antenna system. The GPR data was processed using GSSI's RADAN software program and Bridge Assessment Module. The results were used to produce color-coded deterioration maps of the bridge deck. Results from the ground-coupled antenna and the air-launched horn antenna demonstrated excellent correlation. Deterioration maps from both antennas were compared with visual data obtained from top-side and bottom-side visual inspections and exhibited excellent correlation. Correlation was further confirmed by the Maine DOT through hammer sounding and opening the bridge deck to expose the actual areas of deterioration. It was concluded that the 2 GHz air-launched horn antenna is an effective tool to provide an accurate assessment of the condition of bridge decks.

INTRODUCTION

The American Society of Civil Engineers reported that as of 2003, 27.1% of the nation's bridges (160,570) were structurally deficient or functionally obsolete (ASCE, 2003). The Federal Highway Administration's (FHWA's) strategic plan states that, by 2008, less than 25% of the nation's bridges should be classified as deficient.

Traditional bridge deck inspection methods include hammer soundings and chain dragging. These familiar techniques rely on the ability of an operator to correctly and consistently interpret acoustical feedback to determine good and bad areas of concrete and produce an overall condition assessment of the deck. Existing asphalt overlays must be removed prior to using acoustical methods, and results can vary depending on the operator's technique and determination of results. Assessment data normally consists of areas of the deck marked simply as good or bad.

Ground Penetrating Radar (GPR) is an accepted electromagnetic evaluation technique used for the transportation infrastructure and a variety of other applications, including concrete inspection, utility detection, geology and archeology. An established application of GPR is the accurate condition assessment of bridge decks as well as other reinforced concrete structures (Parrillo and others, 2005; Romero and others, 2000; Schongar, 2004; Romero, 2003).

Hundreds of bridge decks have been evaluated using GPR. The most accurate bridge deck condition assessments using GPR have been performed using high frequency (1.5 GHz) ground-coupled antennas. The high frequency ground-coupled antenna provides excellent identification and resolution of the reinforcing steel. When performing a condition assessment of a bridge deck using GPR, it is common to use the relative reflections from the reinforcing steel (rebar) to produce deterioration maps and determine the extent of deterioration. Use of ground-coupled antennas dictates slower data acquisition speeds since the antenna must remain sufficiently ground-coupled. GSSI's BridgeScan system includes a SIR-3000 Windows CE based portable GPR data collection system with 1.5 GHz ground-coupled antenna. The 1.5 GHz antenna has a depth of penetration of approximately 18 inches in concrete, which is more than adequate to accurately locate the top layer of rebar. An optional small hand-cart configuration is available and allows the 1.5 GHz ground-coupled system to be used for applications where the 3-wheeled push cart may not be appropriate due to size limitations (i.e. condominium balconies). Ground-coupled antennas may also be towed behind a vehicle at slow speeds. Dual channel GPR data collection systems such as GSSI's SIR-20, may be used to collect two paths (channels) of data simultaneously to reduce data acquisition time.

Vehicle-mounted 1 GHz horn antennas have been successfully used to evaluate concrete surface bridge decks (Maser and Bernhardt, 2000). This technique is most effective for concrete bridge decks with the top rebar oriented transverse to the direction of traffic. In 1998, Geophysical Survey Systems developed a novel technique using two vehicle-mounted 1 GHz air-launched horn antennas. The two antennas are mounted perpendicular to each other in a configuration termed "dual polarization" and are suspended approximately 18 inches (46 cm) above the pavement surface. With the dual polarization technique, one antenna is more sensitive to rebar in the transverse direction while the other antenna is more sensitive to rebar in the longitudinal direction. Both antennas would receive similar reflections from the planar interface occurring at the bottom of an asphalt overlay. Since the GPR antenna emits electromagnetic energy in conical shaped pattern, the energy from air-launched antenna is less focused when it reaches the surface of the bridge deck. The energy travels through the pavement surface and reaches the reinforcing steel, producing the desired reflection. As the result of the decreased resolution, it is normally not possible to resolve each individual rebar. However, a rebar "layer" may be identified and, as with the ground-coupled system, the reflection amplitudes are used to determine the condition of the bridge deck. When an asphalt overlay is present, the reflections obtained from the bottom of the asphalt may interfere and affect the reflection from the rebar. By subtracting the data of one 1 GHz horn antenna from the other (mounted perpendicular), the result is an improved dataset with minimal interference from randomly encountered longitudinal steel reflections and planar interfaces.

In 2003 Geophysical Survey Systems developed a 2 GHz air-launched horn antenna that provides vertical resolution sufficient to distinguish the reflections from the asphalt-concrete interface and the top layer of reinforcing in asphalt overlaid bridge decks. This development potentially meant that bridge deck assessment could be accomplished using a single horn antenna. However, this antenna needed to be evaluated on existing bridge decks. In a collaborative effort between Geophysical Survey Systems and the Maine Department of Transportation, both the 1.5 GHz ground-coupled antenna and the 2 GHz air-launched horn antenna were used on April 13th, 2005 to evaluate the condition of an asphalt overlaid bridge deck located in Lewiston, Maine known as the Ramp D from Main Street over Maine Central Railroad Bridge. Ramp D is a portion of the Veterans Memorial Bridge which crosses the Maine Central Railroad and the Androscoggin River (see Figures 1 and 2).

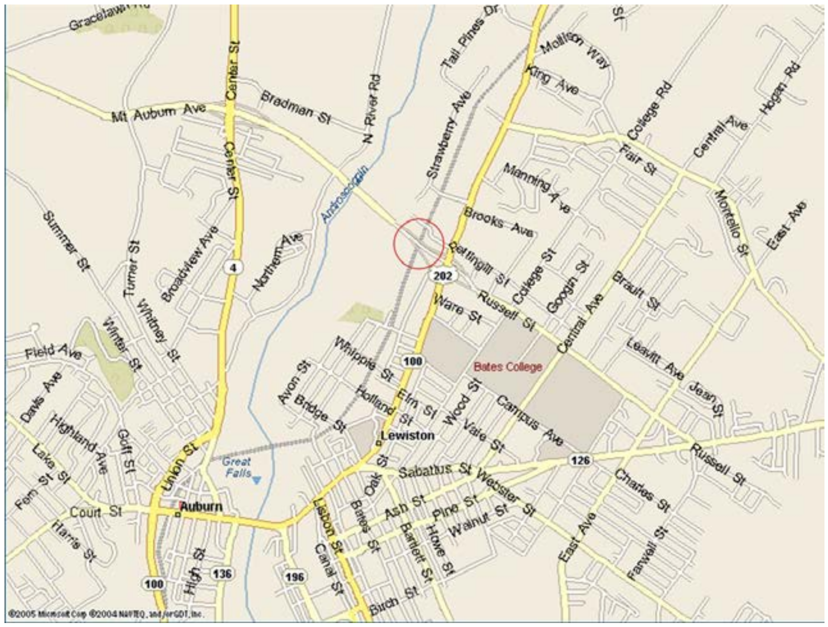


Figure 1. Location of Bridge Deck

Figure 2. Bridge Deck Photos

Constructed in 1971, the deck is a 9 inch reinforced structural concrete slab and measures approximately 32 feet wide by 180 long. A 2 inch concrete cover was specified above the reinforcing steel. The hot bituminous wearing surface was replaced in 1991. A variety of repairs were performed and some are evident as patches in the deck surface (see Figure 3). The Maine DOT suspected the deck was considerably deteriorated and had scheduled the bridge for repair. Consequently, this particular bridge deck presented the DOT with an excellent opportunity for evaluating the GPR technique.

Figure 3. Repaired area and nearby cracked asphalt

In addition to collecting GPR data, visual inspections were performed on both the topside and bottom-side of the bridge deck. The locations of cracking and patching on the topside and locations of cracking, rusting, and efflorescence on the bottom-side were recorded (see Figure 4). This data was used to create top-side and bottom-side maps of the defects for comparison with the GPR data.

Figure 4. Bottom-side pictures

The following four sections of the paper consist of descriptions of the ground-coupled and air-launched antenna data collection and processing methodology. These sections are followed by an overview of the data analysis approach, which is consistent for data collected by both the air-launched and ground-coupled antennas. The paper concludes with a side-by-side comparison of the bridge deck deterioration assessment maps produced by these two approaches.

DATA COLLECTION – 1.5 GHz Ground-coupled antenna

For a bridge deck condition assessment project, GPR data is typically collected in the direction perpendicular to the upper most rebar orientation. Thus, if the upper rebar orientation is transverse, then the data would be collected in the direction of traffic. If the orientation of the rebar is unknown, it can easily be determined with by acquiring sample GPR data in both directions and then simply comparing the arrival times of the rebar reflections in the data.

Design plans for the Ramp D bridge deck indicated that the upper rebar was in the transverse orientation. This was quickly confirmed by using the BridgeScan system to acquire data in both directions and comparing the arrival times of the rebar targets.

GPR data along the bridge deck is normally collected in parallel lines approximately 2 feet apart. Since the upper rebar was transverse, 14 data files were collected in lines parallel to the direction of traffic starting 4 feet from the edge of the bridge deck (2 feet from the traveling lane curb) and continuing to 30 feet from the edge of the bridge deck (28 feet from the traveling lane curb) (see Figure 5).

Figure 5. Data collection – 1.5 GHz ground-coupled antenna

Data was collected at a density of 24 scans per foot or one scan every half inch. This data density was sufficient to clearly image the individual rebar locations, which varied from 6 inch spacing to 1 foot spacing and back to 6 inch spacing along the width of the bridge deck. The data collection process was completed in less than one hour.

Rebar appear in the GPR data as small hyperbolas. These hyperbolas occur because the antenna transmits energy in a conical pattern, and consequently, receives reflections from the rebar at decreasing two-way travel times as it approaches the rebar, then increasing two-way travel times after the antenna passes over the rebar. Rebar locations were evident in the unprocessed data as well as obvious areas of deterioration where rebar reflections were weak. Areas of the bridge deck exhibiting weak reflection amplitude values are typically indicative of deterioration. These weaker reflections can be due to several factors, including elevated chloride content, concrete degradation or corrosion of the rebar, which all attenuate the radar signal (see Figure 6).

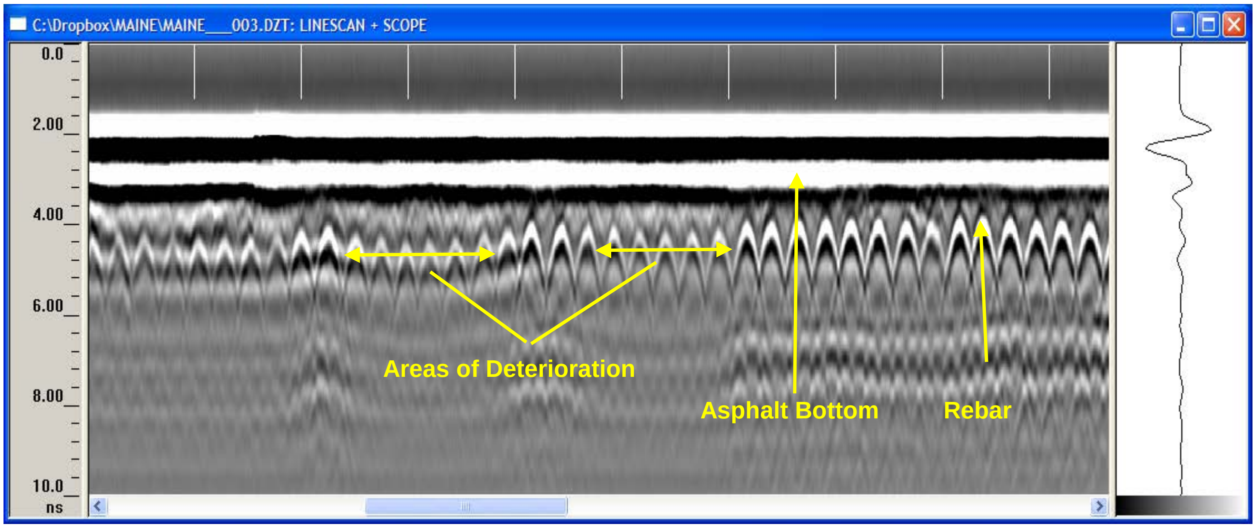


Figure 6. Unprocessed GPR data 6 feet from curb (Ground Coupled Antenna)

It should be noted that the bottom of the bridge deck is also visible in the GPR data and appears as a white-black-white horizontal band that can be seen at approximately 7.5 ns in the unprocessed data shown above in Figure 6.

DATA PROCESSING – 1.5 GHz GROUND-COUPLED ANTENNA

Following data collection, the individual GPR data files were transferred from the BridgeScan system to a PC for processing. Using the RADAN Bridge Assessment Module, the 14 individual 2D GPR files were combined into a single file. Each data point in the file is position-referenced relative to known bridge features, such as the traveling lane bridge curb and starting joint. There are three processing steps involved in creating a deterioration map from the 3-D file. The first processing step, implemented in a semi-automated manner, performs time-zero correction, migration, and rebar reflection mapping. The next step is interactive interpretation. The last step is the presentation of the deterioration data in the form of a contour map. From start to finish, the GPR data processing time for the Ramp D bridge deck was less than two hours. Each important task performed during the data processing is described below.

Time-Zero Correction

The first step in data processing is to shift each scan of data so that the top of the scan corresponds to the surface of the bridge deck. This step is typically referred to as the time-zero correction.

Migration

Migration is a mathematical hyperbolic summation process that collapses hyperbolic diffractions associated with the rebar locations and focus on their subsurface position (see Figure 7).

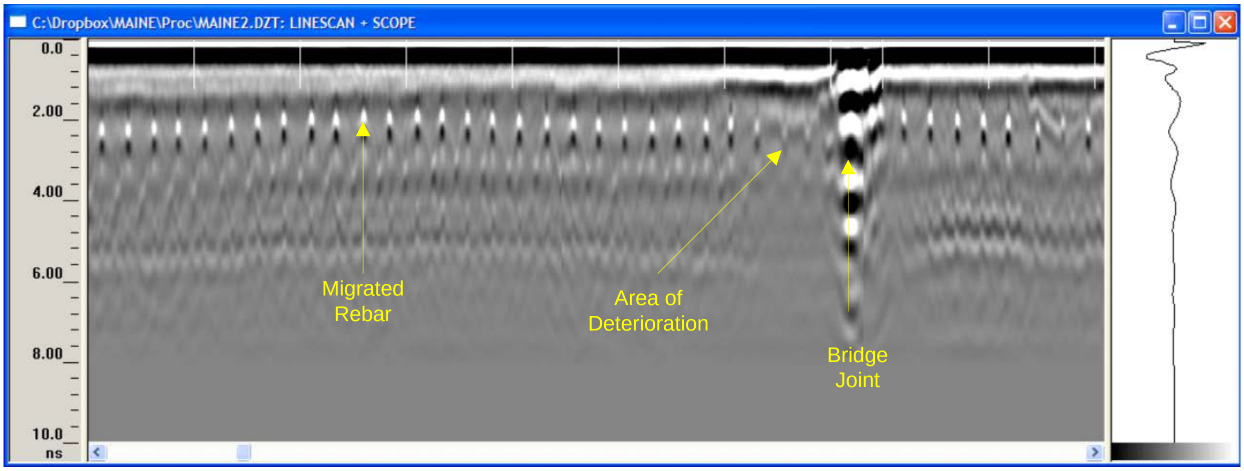


Figure 7. Processed GPR data (Ground Coupled Antenna)

Automatic Rebar Reflection Mapping

The migration process provides data containing rebar reflections that are typically easily detected using automated algorithms. The algorithm implemented for deterioration mapping locates each rebar reflection and records its spatial location in the bridge deck along with the amplitude of the rebar reflection. These values are written to an ASCII comma-separated value (CSV) file.

Interactive Interpretation

The user will normally want to view the performance of the automatic rebar reflection-picking algorithm. In many instances, the rebar reflection picks will need to be edited. This may occur, for example, when the bridge deck is very deteriorated and the reflections from the rebar are very weak. During the interactive interpretation process, circular markers overlain on top of the GPR data indicate the located rebar reflections (see Figure 8).

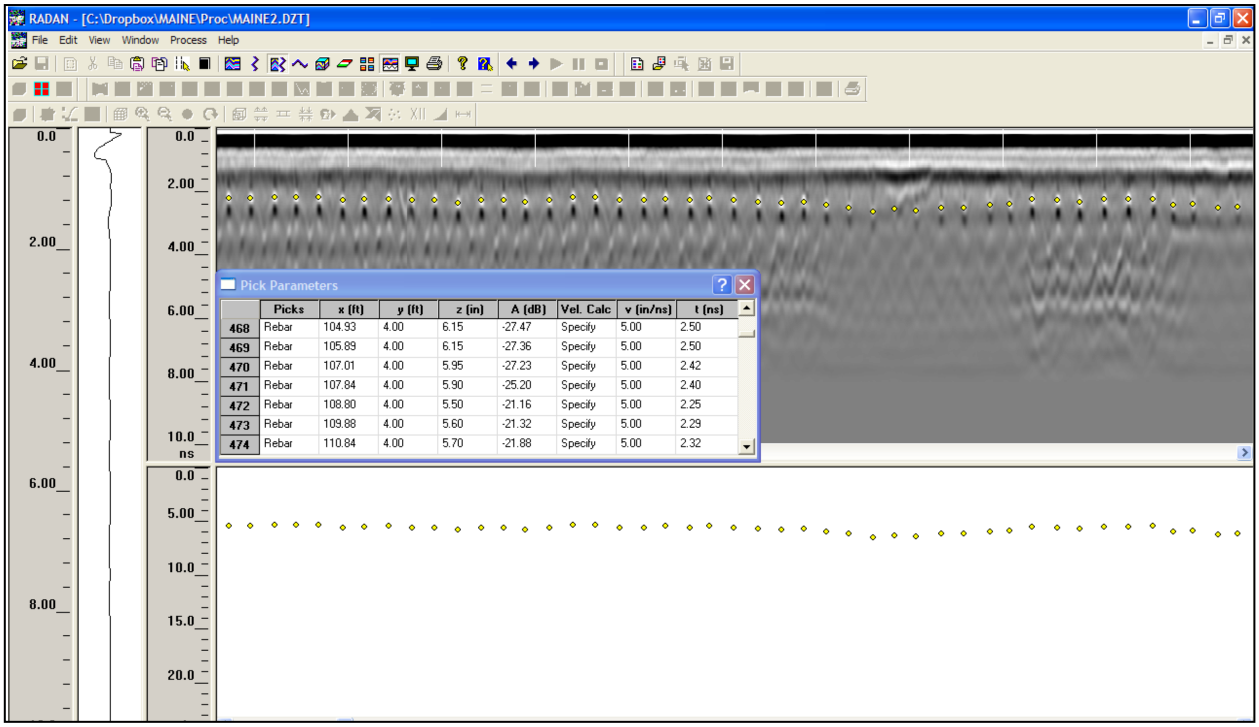


Figure 8. Interactive interpretation process

Contouring

Using a contour mapping program, such as Surfer® from Golden Software, or DPolt from HydeSoft Computing, the X, Y, and reflection amplitude data for each rebar location are imported from the ASCII CSV file and used to create a color-coded contour map of the bridge deck. Weaker rebar reflections were mapped as “hotter” colors to indicate the areas of the bridge deck suspected of greater deterioration (see Figure 9).

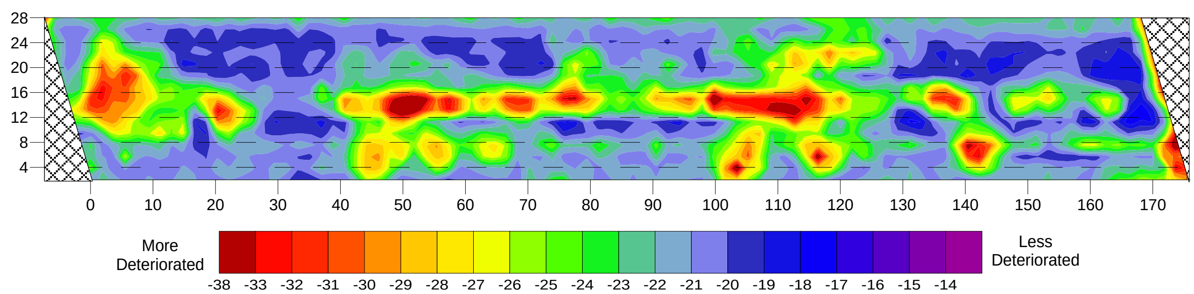


Figure *9. Deterioration Map of Bridge Deck (Ground-coupled Antenna)*

DATA COLLECTION – 2 GHz AIR-LAUNCHED HORN ANTENNA

The 2 GHz air-launched horn antenna was attached to the rear of a van using a universal antenna mount. The bottom of the antenna was positioned approximately 17 inches (43 cm) from the pavement surface. A wheel-mounted Distance Measuring Instrument (DMI) was attached to the rear wheel of the vehicle to provide incremental distance information to the radar control unit. The antenna and DMI were connected to a GSSI SIR-20 dual channel radar control unit mounted inside the vehicle (See Figure 10).

First, a metal plate data file ("Bumper Jump") was obtained for the horn antenna. This file captures reflections from a metal plate placed on the road surface under the antenna. Jumping up and down on the rear of the vehicle allows metal plate reflections to be recorded at different heights that the antenna may experience during data collection. This file is later processed in RADAN to produce a horn antenna calibration file that is used to calculate the radar wave velocity of the first layer of pavement. Velocities for subsequent layers are calculated in a similar manner. (A detailed description of the technique used for horn antenna calibration and data processing is available in Geophysical Survey Systems Handbook for GPR Inspection of Road Structures.) Thirteen data files were collected in lines parallel to the direction of traffic starting 6 feet from the edge of the bridge deck (4 feet from the traveling lane curb) and continuing to 30 feet from the edge of the bridge deck (28 feet from the traveling lane curb).

Figure 10. Data collection using the 2 GHz horn antenna

Data was collected at a density of 12 scans per foot, or one scan every inch. This data density was sufficient to clearly image the rebar layer. The data collection process was completed in less than one hour.

Since the horn antenna is suspended approximately 17 inches above the ground surface, the energy transmitted from antenna is less focused as it reached the surface of the pavement and travels to the rebar. Consequently, rebar from the 2 GHz air-launched horn antenna appear in the GPR data as a layer rather than the individual hyperbolas produced with the ground-coupled antenna. (See Figure 11)

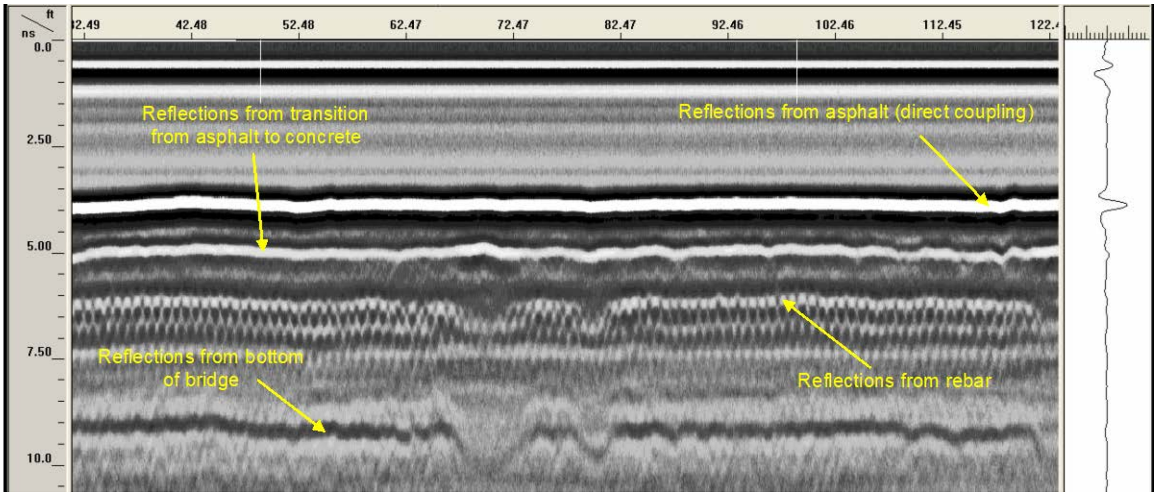


Figure 11. Unprocessed 2 GHz horn antenna data

DATA PROCESSING – 2 GHZ AIR-LAUNCHED HORN ANTENNA

Following data collection, the individual GPR data files were processed by first, applying the metal plate calibration file. Applying the metal plate calibration file performs two important processing steps. A ring down removal filter is applied to eliminate horizontal features such as ringing in the data and a calibration plate scan subtraction is performed to remove coherent clutter in the data. The calibration scan obtained at the height most closely matching the data scan is selected. The peak amplitude of the calibration plate scan is then normalized relative to the peak amplitude of the data scan and subtracted from the data scan starting at the peak of the pavement reflection and continuing downward to the bottom of the scan.

Next, the 13 individual 2D files were combined into a single 3D file (similar to the process described for the ground-coupled antenna processing). The next step is an interactive interpretation process where the rebar layer is identified. This is accomplished by opening the 3D file in the Interactive Interpretation Mode, then using an innovative processing tool called EZ Tracker to identify the rebar layer. Using the mouse, the cursor is placed at the start of rebar layer and clicked to identify the first point on the layer. Then, the cursor is moved to right and a second point on the layer identified by clicking. The layer is then created by connecting the two points using an algorithm with criteria of searching for successive positive reflections and conforming to a best-fit line. This process is repeated by continuing to position the cursor on the rebar layer and select additional points. The created layer may be edited if necessary using other picking tools available in Interactive Interpretation. Other layers (i.e. bottom of the asphalt or bottom of the bridge deck) may also be identified in the same manner however, the polarity criteria may not always be positive. For example, when defining the bottom of the bridge deck, a negative polarity would be specified (see Figure 12).

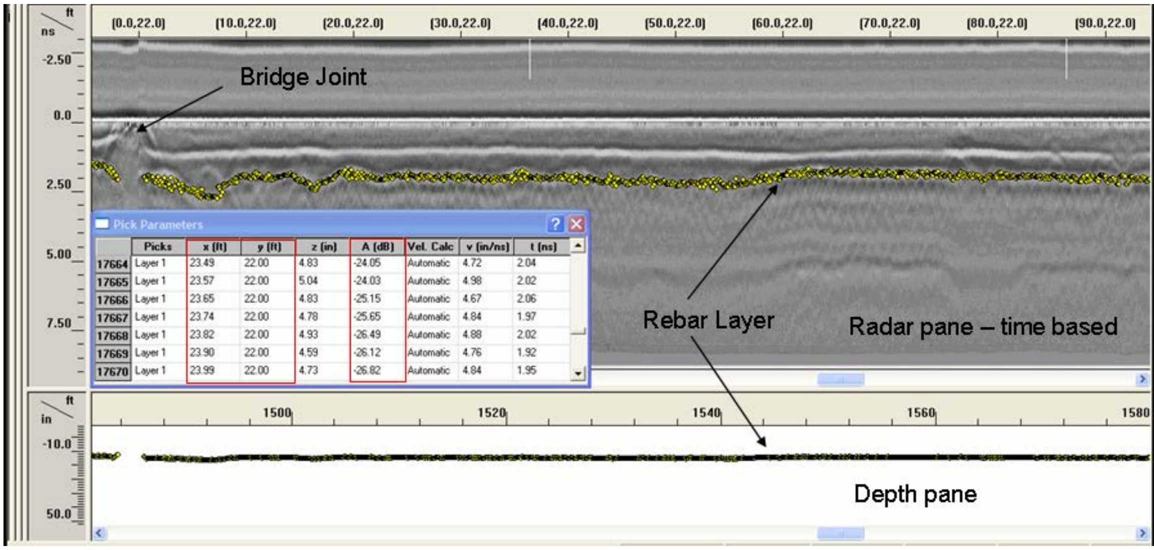


Figure 12. Identifying the rebar layer in Interactive Interpretation

As previously described for the ground-coupled antenna, the last step is the presentation of the deterioration data (X & Y location and corresponding reflection amplitude) in the form of a contour map (See Figure 13). From start to finish, the GPR data processing time for the Ramp D bridge deck was less than two hours.

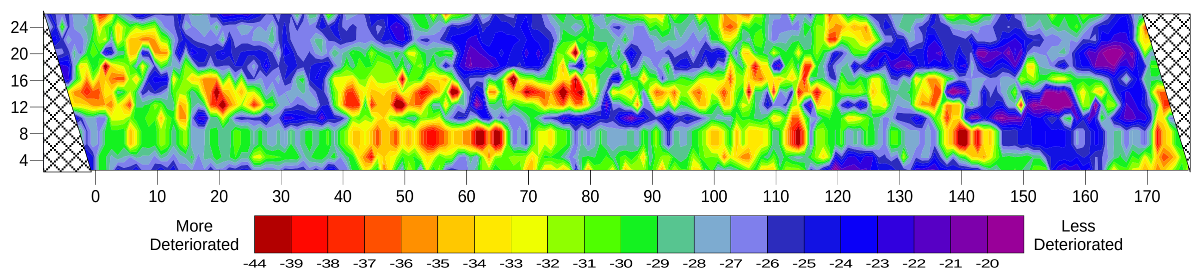


Figure 13. Deterioration Map of Bridge Deck (Air-launched Antenna)

ANALYSIS AND INTERPRETATION

The weaker rebar reflections indicated by the "hot" colors observed in Figures 9 and 13 can be due to several factors including elevated chloride content, concrete degradation and/or corrosion of the rebar, which all attenuate the radar signal. Areas of moderate to severe deterioration are visible in raw GPR data as it is being collected. This was clearly evident on the Ramp D bridge deck as the GPR data was acquired near the center line of the deck.

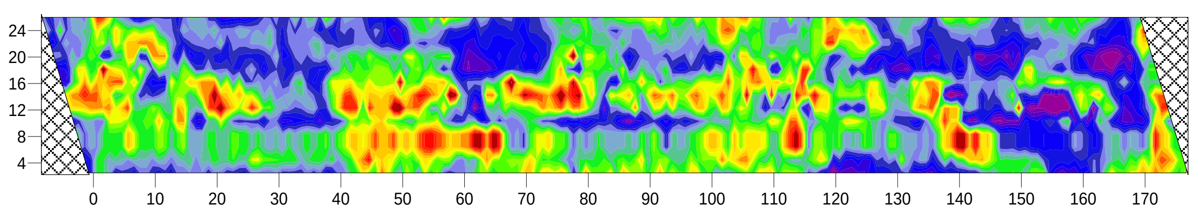
However, it is important to note an estimate of the amount of deterioration should not be determined by merely considering colors on the contour map. Indeed, a GPR evaluation of a new bridge deck will contain some range in rebar reflection amplitudes that are associated with rebar at different depths. It is more important to consider the total range of rebar reflection amplitudes when assessing the quantity of deterioration on a bridge deck.

As the bridge ages, deterioration mechanisms selectively attack portions of the bridge deck that are subjected to mechanical, chemical and/or thermal stress. Mechanical stress could be associated with loading and unloading from traffic; chemical stress from chloride infiltration; and thermal stress from freeze-thaw cycles. Thus, the onset of deterioration is often localized to areas of the bridge-deck subject to the most stress. These areas may grow in dimension as the bridge ages. The rebar reflection maps produced from GPR data are useful in locating these areas. The areas of weakest rebar reflections in the rebar reflection maps shown in Figures 9 and 13 do not possess sharp boundaries. Rather, there is a gradational change in amplitude. For this reason, it is difficult to clearly state where deterioration stops and starts from inspection of deterioration maps produced from GPR data alone. It is preferable to use the GPR deterioration maps as a tool for classifying maintenance action level required on the bridge and to determine the sections of the bridge deck requiring repair.

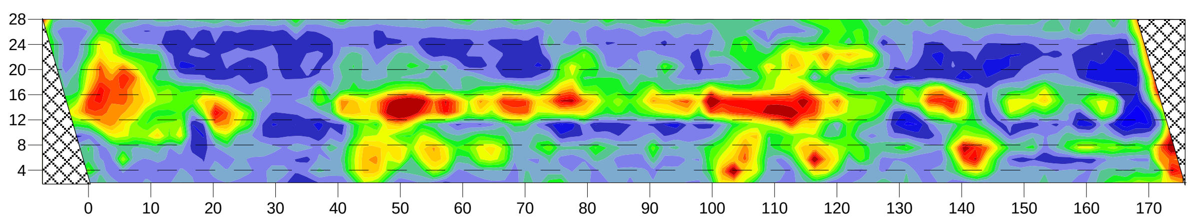
The bridge maintenance action-level decision typically incorporates information from a number of sources, including inspection of the bridge deck surface, inspection of the bridge deck underside (if possible), deterioration maps produced by GPR (or other techniques such as corrosion potential, chain drag or chloride analysis), traffic control requirements for different types of rehabilitation, man-hour costs and budget constraints. It is in the context of determining a maintenance action level that the GPR deterioration maps from the Ramp D bridge deck are examined.

The green, yellow and red colors in the deterioration maps shown in Figures 9 and 13 along the center of the bridge correspond to significant cracking in the asphalt layer on the surface of the bridge and evidence of cracking and corrosion from the underside inspection map. In addition, all of the yellow and red areas associated with other sections of the bridge deck can be correlated to topside or bottom side cracking or corrosion. It is clear that the bridge deck is significantly deteriorated beneath the cracked sections of asphalt and in many cases the deterioration extents through the bridge deck.

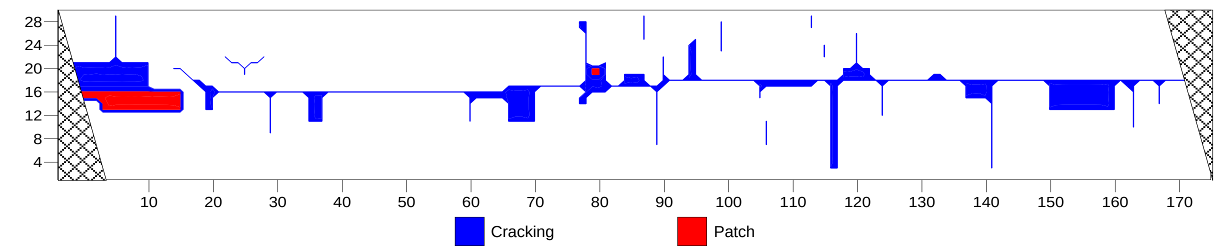
Comparison of 1.5 GHz ground-coupled and 2 GHz air-launched antennas



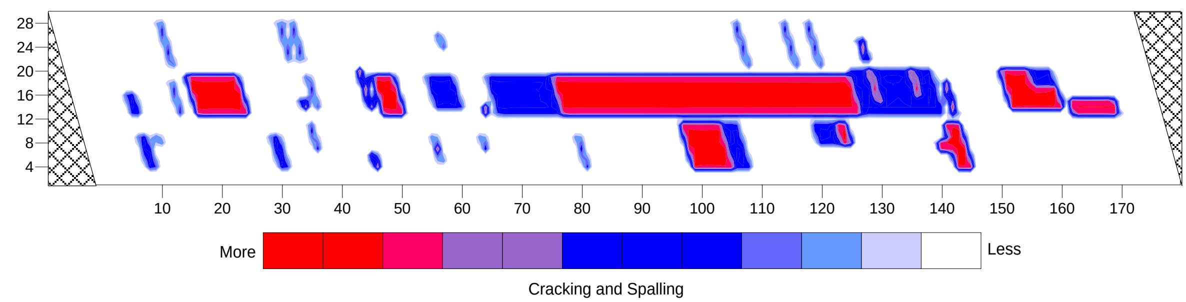
Deterioration map produced from 2 GHz air-launched antenna



Deterioration map produced from 1.5 GHz ground-coupled antenna



Top-side map



Bottom-side map

Figure 14. Data Comparisons

A side-by-side comparison of the deterioration maps produced from the 2 GHz air-launched antenna and the 1.5 GHz ground-coupled antenna yields practically identical results. Both maps show the majority of deterioration located in the center of the bridge deck and strong correlation with both the top-side and bottom-side maps produced from visual inspection. (See Figure 14).

The areas of deterioration in the bridge deck were further confirmed by the Maine Department of Transportation. The asphalt overlay was removed and hammer soundings performed which identified nearly the identical areas of deterioration. Later, the actual bridge repair was performed by removing the areas of deteriorated concrete, identifying and repairing damaged rebar, and replacing with new concrete (see Figure 15).

Figure 15. Repairing the bridge deck

CONCLUSION

Although condition assessments from additional bridge decks are required, the preliminary conclusion is that the 2 GHz air-launched horn antenna appears to be an effective alternative to the well established ground-coupled antenna approach for the condition assessment of bridge decks. The air-launched antenna offers the advantages of a vehicle mounted solution with faster data collection speeds and a safer working environment.

References

ASCE, 2003, American Society of Civil Engineers Report Card for America's Infrastructure. http://www.asce.org/reportcard/2005/page.cfm?id=22#policy

Parrillo, R., Roberts, R.L., and Haggan, A., 2005, Bridge Deck Condition Assessment Using Ground Penetrating Radar, International Bridge Conference, June 13-15, 2005, Pittsburgh, PA.

Romero, F.A., Roberts, G.E., and Roberts, R.L., 2000, Evaluation of GPR bridge deck survey results used for delineation of removal/maintenance quantity boundaries on asphalt-overlaid, reinforced concrete deck, Structural Material Technology IV, February 28-March 3, 2000, Technomic Publishing Co, p. 23-30.

Schongar, G., 2004, GPR Demonstration Project on Two Steel Reinforced Concrete Bridge Decks, Client Report 87, Transportation Research and Development Bureau, NYSDOT, 27 p.

Romero, F.A., New York State Department of Transportation Ground Penetrating Radar Demonstration on Route 378 Bridge over D&H Railroad and Route 66 Bridge over Kinderhook Creek, October 2003.

Maser, K. and M. Bernhardt, Statewide Bridge Deck Survey using Ground Penetrating Radar, Proceedings of Structural Materials Technology IV, Atlantic City, NJ, 2000

Perkins, A.D., Amrol, J.J., Romero, F.A., and Roberts, R.L., 2000, "DOT Specification Development Based on Evaluation of Ground Penetrating Radar System Performance in Measuring Concrete Cover (Reinforcement Depth) on New Bridge Deck Construction", *Structural Materials Tech. IV*, Technomic Publishing Co., Lancaster, PA, p. 53-60.

Roberts, R.L., and Romero, F.A., 1998, "High Resolution GPR Bridge Deck Evaluation Surveys", *Highway Applications of Engineering Geophysics with an Emphasis on Previously Mined Ground*, Missouri DOT, Jefferson City, Missouri.

Roberts, G., Roberts, R., and Tarussov, A., 2001, "Identifying Concrete Deterioration using Ground Penetrating Radar Technology", *ASNT Conference Proceedings*, Columbus, OH, October 16-19, 2001.

Romero, F.A., Roberts, G.E., and Roberts, R.L., 2000, "Evaluation of GPR bridge deck survey results used for delineation of removal/maintenance quantity boundaries on asphalt-overlaid, reinforced concrete deck", *Structural Materials Tech. IV*, Technomic Publishing Co., Lancaster, PA, p. 23-30.

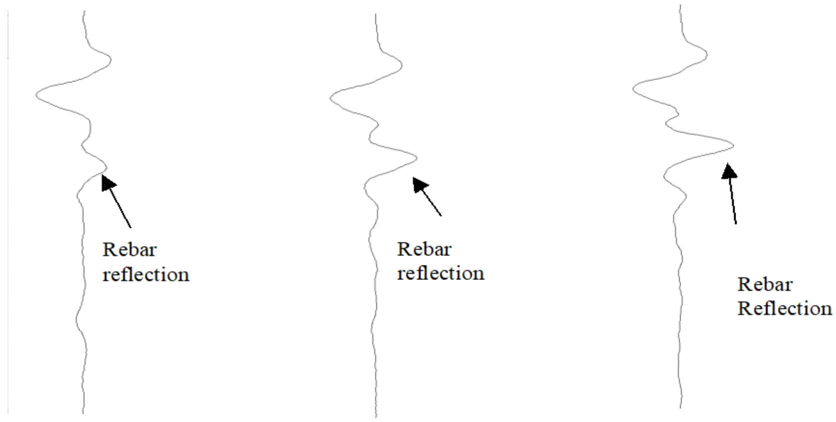
Appendix A: Velocity Calibration Procedure

The GPR data collected with the Model 5100 antenna measures the travel time of the radar waves from the surface of the concrete, down to the rebar and back to the surface. It is necessary to determine the velocity of the radar waves to calculate the depth of the rebar. This is done by drilling a calibration hole and measuring the vertical depth to the top of one of the rebar in the concrete.

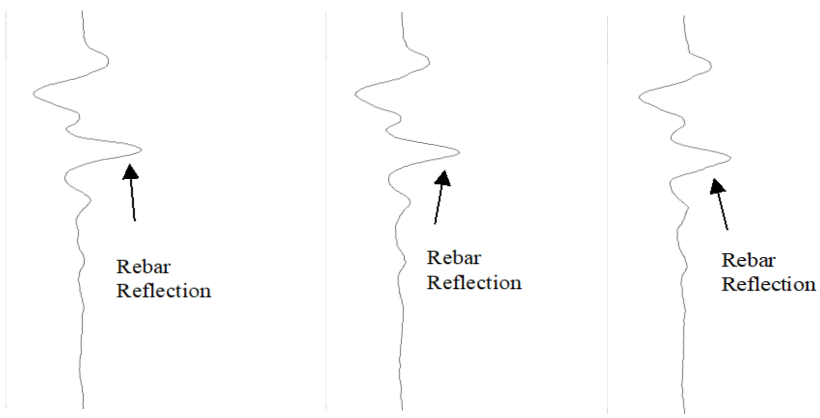
The location of this rebar relative to the start of the line, and the rebar depth must be accurately measured to ensure that the correct rebar is located in the GPR data to obtain the most accurate velocity. When processing the GPR data with the Bridge QA process in RADAN, the user is prompted to enter the location and depth of the calibration rebar. The program then automatically locates the rebar in the data and calculates the velocity used to process the entire file. The entire calibration process is described in more detail below.

Steps for Collecting Calibration Hole Data

1. Make sure that the survey wheel is accurately calibrated. The calibration number in the saved setup for the rebar data collection is good as long as the diameter of the survey wheel does not change.
2. If the survey wheel shows significant signs of wearing, a recalibration may be required. To recalibrate the survey wheel, see the recalibration procedure in the SIR-2, SIR-10 or SIR-20 manual.
3. Mark the starting position of the line along which data will be collected. Place the center of the 5100 antenna on the line. The center of the antenna corresponds to the indentation marks in either side of the antenna case.
4. Collect a data file by towing the Model 5100 antenna along the line. This line is generally called a profile line. This type of data is called profile line data.
5. Select a rebar location along the profile line and determine its depth via drilling. The exact location of the rebar should be obtained prior to drilling by scanning the Model 5100 over the approximate location of the rebar while watching the signal and marking the location where the amplitude of the reflection is the highest, or by using a handheld pachometer.
    - To use the SIR-2 or SIR-10 with the 5100 antenna for locating the exact position of the rebar, set the screen to Collect Data mode and watch the amplitude of the rebar reflection while slowly moving the 5100 antenna as shown in Figure 77.



(a) Away from rebar (b) Closer to rebar (c) Almost on top of rebar



(d) Over top of rebar (e) Near top of rebar (f) Away from rebar

Figure 77: Illustration of waveform appearance as 5100 antenna crosses over a rebar. The center of the antenna is located over the top of the rebar in Figure A1(d).

- Be sure to record the exact distance of the rebar relative to the start of the profile line and the depth to the top of the rebar relative to the concrete surface.

Appendix B: Troubleshooting Problems

Problem: Extra scans are added to end of data file after the file has been opened in RADAN.

Solution: Extra scans (black area at the end of the file or scans with zero amplitude) are added to the end of a data file in two cases:

1. If RADAN crashes and the data file is open.
2. If the data file was collected with the SIR-20.

The only way to remove these extra scans from the data file is to use the Select and Cut options in RADAN. Select the black scans, then click the Cut button and save the file to a new filename.

Problem: After running a RadBridge project, the output 3-D file contains blank gaps.

Solution: This problem happens when the user puts RADAN in the background (behind another program window) while running the project. RADAN must be kept in the foreground while the project is running. While a project is running, don’t switch to any other application (even Explorer); and don’t try to adjust any parameters in RADAN, including the size of the window.

Problem: Unable to open an existing Project (*. rpj) file in RADAN:

Solution:

1. None of the data files in the RADBRIDGE project can be write-protected; otherwise, they cannot be used by the program. Check to see if some of the data files are write-protected. If they are, use Explorer to change their status.
2. The names of some of the data files or macros may have been changed.
3. The directory path to the data files or macros in the project may have changed.
4. See the next problem and its solution

Problem: Unable to open a data file in RADAN:

Solution: When a data file is opened in RADAN, a temporary file is created in the directory specified as the TEMP environment variable (accessed by selecting System in the Control Panel and then selecting the Environment dialog page).

For example, the TEMP directory may be c:\temp. If there is not enough space in this directory to write a temporary RADAN file, then a message will appear in RADAN that it is unable to open the file. To solve this problem, increase the space on the disk containing the TEMP directory.

Problem: RADAN crashes while trying to write a file:

Solution: There are two possibilities:

1. Check to make sure there is enough disk space on the disk containing the Output file path. Allow for at least twice the combined space taken up by the input file (*.dzt) and the *.ind file.

2. Check to make sure the default output path exists. The output path is specified in the Customize menu item. See Appendix C for details on locating and setting the default output path.

Appendix C: How To Quick Reference

Change Input And Output Directories

1 To select source (i.e., input) and output directories and units, close all open data files.

2 Choose View > Customize, as shown in Figure 78.

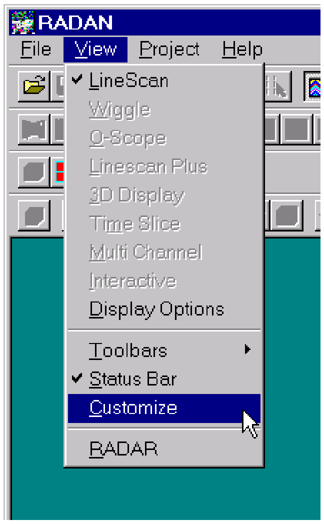


Figure 78: Accessing the dialog to customize input and output directories and the unit convention used during data interpretation.

3 A pop-up dialog will appear as shown Figure 79:

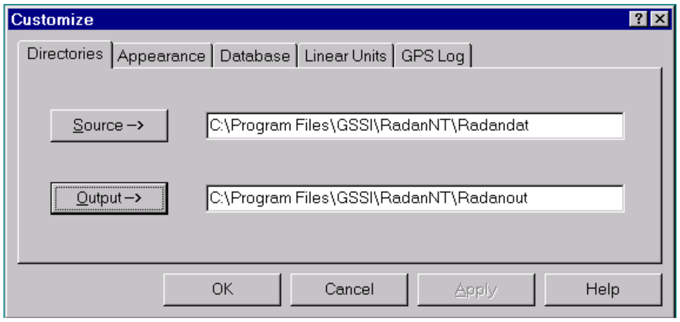


Figure 79: The default source and output directories are specified in this dialog. All processed data will be written to the default output directory unless overridden by the user.

Change Distance Or Depth Units

1 Choose View > Customize.

2 Click the Linear Units tab (Figure 80) to select the desired vertical (i.e., depth in cm, inches, etc.) and horizontal (i.e., distance in meters, ft, etc.) units.

- These selections and the selections of the source and output directories are stored between RADAN sessions. Therefore, it is not necessary to change these settings each time RADAN is run, as they will remain as default settings until they are changed.

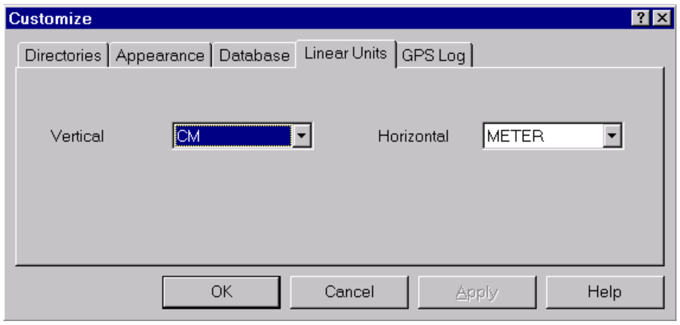


Figure 80: Customize dialog box used to specify the vertical (depth) and horizontal (distance) units in the output ASCII file containing the rebar locations and depths.