TRC1001

Ground Penetrating Radar (GPR) for Pavement Evaluation

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Final Report

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16. Abstract

Ground penetrating radar (GPR) is a rapid nondestructive geophysical method that produces two- or three-dimensional graphical images of subsurface features and built structures. Ground penetrating radar images have been used successfully in a variety of highway-related applications. An air-coupled GPR unit was obtained and tested. A study of the 'accuracy' of pavement layer thicknesses estimated using GPR methods (compared to measurements of pavement cores) demonstrated that GPR data could be used to estimate layer thickness to within +/- 0.2 inches. Guidelines for field data collection and data analysis were developed to assist in the implementation of the GPR system into AHTD routine pavement management practice.

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RESEARCH

GROUND PENETRATING RADAR (GPR) FOR PAVEMENT EVALUATION

PROJECT OBJECTIVES

Ground penetrating radar (GPR) is a rapid nondestructive geophysical method that produces two- or three-dimensional graphical images of subsurface features and built structures. Ground penetrating radar images have been used successfully in a variety of highway-related applications. The primary product arising from the project is a calibrated GPR unit that can be directly implemented for network-level pavement surveys by AHTD personnel. Specifically, the project seeks to:

- Obtain the Ground Penetrating Radar (GPR) unit;
- Investigate the ‘accuracy’ of pavement layer thickness estimated using GPR methods;
- Prepare field data collection and data analysis guidelines suitable for implementation into AHTD routine pavement management practice.

RECOMMENDATIONS

Major findings from the study include:

- The AHTD ground penetrating radar (GPR) unit obtained and tested under this project should be implemented for network-level pavement thickness surveys, using the field data collection and data analysis procedures developed in this study.
- A study of the ‘accuracy’ of pavement layer thicknesses estimated using GPR methods (compared to measurements of pavement cores) demonstrated that GPR data could be used to estimate layer thickness to within +/- 0.2 inches.

ADDITIONAL WORK

The study recommends additional work related to implementation efforts:

- AHTD should continue to refine data collection and analysis techniques related to pavement layer thickness estimation. While the accuracy of these estimates is demonstrated to be adequate for current purposes, improvements are likely possible.
- Ground penetrating radar has been used successfully for a variety of purposes other than pavement layer thickness estimation; AHTD should seek to expand the types of analyses performed using GPR – such as identifying bridge deck deficiencies, locating buried utilities, and others.

FINAL REPORT

TRC-1001

Ground Penetrating Radar (GPR) for Pavement Evaluation

by

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Conducted by

Department of Civil Engineering
University of Arkansas

In cooperation with

Arkansas State Highway and Transportation Department

U.S. Department of Transportation
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ABSTRACT

Ground penetrating radar (GPR) is a rapid nondestructive geophysical method that produces two- or three-dimensional graphical images of subsurface features and built structures. Ground penetrating radar images have been used successfully in a variety of highway-related applications. An air-coupled GPR unit was obtained and tested. A study of the 'accuracy' of pavement layer thicknesses estimated using GPR methods (compared to measurements of pavement cores) demonstrated that GPR data could be used to estimate layer thickness to within +/- 0.2 inches. Guidelines for field data collection and data analysis were developed to assist in the implementation of the GPR system into AHTD routine pavement management practice.

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CHAPTER 1: INTRODUCTION

Ground penetrating radar (GPR) is a rapid nondestructive geophysical method that produces two- or three-dimensional graphical images of subsurface features and built structures. Ground penetrating radar images have been used successfully in a variety of applications, including determining the location and depth of buried objects (including tanks, pipes and other utilities), investigating the presence and continuity of natural subsurface features, evaluating the condition of new or existing pavement, and identifying zones of deterioration in aging bridges

The ground penetrating radar tool essentially consists of a transmitter antenna and a receiver antenna, both of which may be housed in a single unit. Ground penetrating radar antenna are either air-launched (horn) or ground coupled and of variable frequency (25 MHz – 2500 MHz). Figure 1 shows the AHTD air-launched unit. The transmitter antenna emits high-frequency, short-duration electromagnetic pulses as it is moved along the surface of the earth or structure. These electromagnetic pulses are partially reflected when they encounter surfaces across which there is a change in electrical properties (dielectric constant). The receiver antenna records the travel times and magnitudes of the reflected pulsed electromagnetic energy.

Figure 1. AHTD Air-Coupled GPR Unit

Typically, magnitudes of reflected GPR pulses are displayed as a function of travel time (vertical scale) and antenna unit location (horizontal scale). The relative magnitude of a reflected GPR pulse is a direct function of the contrast in electrical properties on either side of the reflecting interface. Vertical and horizontal resolution is dependent mostly upon the frequency of the antenna employed and ranges from millimeters (highest frequency antenna) to meters (lowest frequency antenna).

Several state DOTs, SHRP, MnROAD, and the FHWA have conducted pavement evaluation studies and compared the GPR results to core samples. The overall results indicated that when comparing the newly constructed pavement thickness GPR results were within 5% of the core samples. Because GPR data is collected continuously at various speeds, large numbers of data points can be collected economically which enhances the quality assurance.

Accurate measurement of pavement thickness is an important aspect of the quality assurance of newly constructed pavement. Current, both the asphalt and concrete paving surfaces are cored at a specified interval along the roadway (about 300 m intervals) for QA/QC compliance. Allowable tolerances vary within State DOTs but are generally ± 13mm for asphalt and ± 5mm for concrete surfaces. Although coring has been the standard testing method for several years, recently, high-speed, air-launched horn antenna GPR systems (1.0 to 1.5 GHz) have been developed and tested for imaging through paved surfaces, including asphalt and concrete and bridge decks to evaluate the condition and thickness of the material examined in a non-destructive environment. The main advantage of using GPR systems is the continuous data collection at posted highway speeds. Generally, the pavement survey using GPR is performed in multiple passes, each pass with one sensor along the lane centerline, and two sensors one on each wheel path.

CHAPTER 2: PROJECT OBJECTIVES AND IMPLEMENTATION

The primary product arising from the project is a calibrated GPR unit that can be directly implemented for network-level pavement surveys by AHTD personnel. Major tasks accomplished to realize this goal include:

- Obtain the Ground Penetrating Radar (GPR) unit;
- Investigate the ‘accuracy’ of pavement layer thickness estimated using GPR methods;
- Prepare field data collection and data analysis guidelines suitable for implementation into AHTD routine pavement management practice.

Subsequent sections of this report provide details regarding these tasks.

CHAPTER 3: ESTIMATION OF GPR ACCURACY

An initial estimation of the accuracy of GPR measurements, in the context of pavement layer thickness, was not particularly promising. However, GPR measurements were taken on pavements for which ‘ground truth’ layer thickness (by coring) was not part of this project; only reported core thicknesses were available to the research team – and those thicknesses were reported only to the nearest 0.25 in. Thus, the margin of ‘error’ (core thickness versus GPR thickness) ranged as high as 0.8 in.

Hattiesville Test Site

An additional investigation was completed to better estimate the accuracy of GPR-based pavement thickness. A flexible pavement test section was selected on Arkansas Highway 213 located in Hattieville, Arkansas for the work.

Measurements

A total of ten (10) coring sites were identified – five cores to be taken approximately 5 feet to the right of the centerline, and five cores to be taken approximately 5 feet left of the centerline. At the site of each core sample, the research team would set up four metal strips on the pavement. Two metal strips were placed 10 ft ahead of where the core sample was acquired. Two additional metal strips were placed 10 ft behind the core sample location. The metal strips were placed on the pavement due to their reflective properties. The metal exhibits a strong reading on the GPR survey, enabling the pavement thickness measurement estimated by GPR to be precisely located at the site of coring. Figure 2 illustrates the testing setup. Figure 3 provides a GPR survey result, which clearly shows the metal strips.

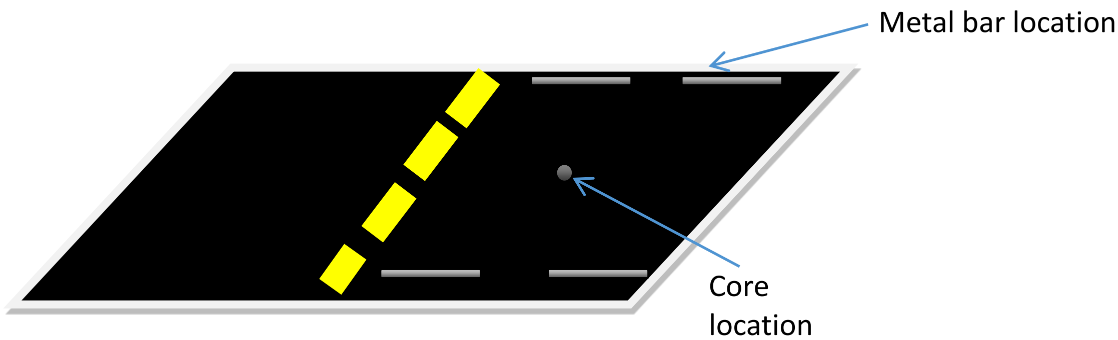


Figure 2. Hattiesville Test Site – Test Section Setup

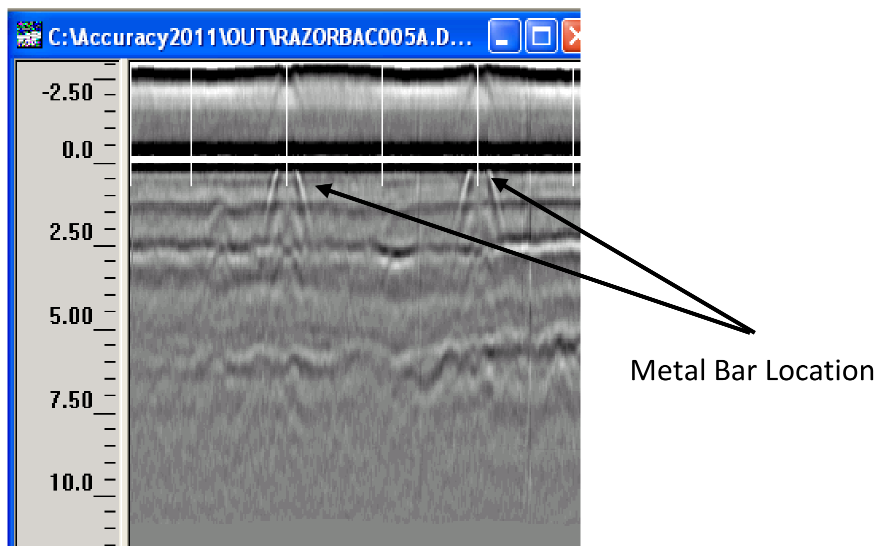


Figure 3. Hattiesville Test Site – GPR Result

Three GPR surveys were acquired at each core setup. For each survey, there were two antennas that were placed in the wheel path. Each survey had a resolution of six scans/ft. For each 20-ft section, there were 120 data points for each wheel path. After the 10 sites were complete, one continuous survey at a resolution of one scan/ft in was collected in each direction.

Data Analysis: Field Core Measurements

To illustrate the effect of field measurements on the estimation of GPR accuracy, cores taken at the Hattiesville Test Site were measured using both a procedure similar to the the Long Term Pavement Performance (LTPP) method (which averages four areas of the core, measured to the nearest 0.1 in) and the AHTD procedure (report thickness to nearest 0.25 in, measured by a ruler). It is noted that for this project, the cores were separated into eight sections and a digital caliper was used to measure the core samples to the nearest 0.01 in. Table 1 lists the measurements of the two different procedures. "Error" in Table 1 refers to the difference between the average of the eight caliper measurements compared to the ruler measurement.

Table 1: Core Sample Comparison of Measurement Procedure.

Sample	Log Mile	Location	Layer	Ruler	Measure 1	Measure 2	Measure 3	Measure 4	Measure 5	Measure 6	Measure 7	Measure 8	Average	Error(%)
5A	4.05	5' Lt	1	1.75	1.71	1.75	1.76	1.72	1.65	1.79	1.79	1.75	1.74	0.6
			2	1.75	1.92	1.81	1.83	1.64	1.88	1.85	1.85	1.78	1.82	3.8
			3	0.50	0.65	0.56	0.62	0.63	0.78	0.50	0.51	0.74	0.62	19.8
5B	4.35	5' Rt	1	0.50	0.52	0.44	0.47	0.44	0.36	0.48	0.36	0.39	0.43	15.6
			2	2.00	1.69	1.73	1.83	1.58	1.86	1.81	1.87	1.85	1.78	12.5
			3	0.75	0.71	0.76	0.79	0.72	0.75	0.59	0.59	0.65	0.70	7.9
4A	3.45	5' Lt	1	1.75	1.73	1.75	1.77	1.73	1.85	1.87	1.78	1.76	1.78	1.7
			2	2.00	1.84	1.80	1.96	1.84	1.80	1.73	1.70	1.64	1.79	11.8
4B	3.75	5' Rt	1	2.00	1.87	2.07	2.03	2.00	1.78	2.14	2.12	2.04	2.01	0.3
			2	1.25	1.30	1.15	0.83	1.25	1.36	1.18	1.05	1.10	1.15	8.5
3A	2.85	5' Lt	1	1.50	1.61	1.69	1.78	1.76	1.71	1.64	1.57	1.67	1.68	10.6
			Base	3.00	3.04	2.67	2.81	3.08	2.93	3.07	3.06	2.99	2.96	1.5
3B	3.15	5' Rt	1	1.25	1.19	1.12	1.05	1.10	1.09	1.13	1.16	1.29	1.14	9.5
2A	2.25	5' Lt	1	1.50	1.30	1.30	1.36	1.31	1.20	1.27	1.21	1.28	1.28	17.3
			2	1.50	1.20	1.14	1.18	1.04	1.13	1.03	1.07	1.02	1.10	36.2
2B	2.55	5' Rt	1	2.00	1.94	1.86	1.88	1.70	1.80	1.92	1.98	1.92	1.88	6.7
			2	1.50	1.54	1.70	1.75	1.70	1.54	1.68	1.67	1.58	1.65	8.8
1A	1.65	5' Lt	1	1.50	1.66	1.65	1.58	1.70	1.66	1.79	1.60	1.71	1.67	10.1
			2	1.50	1.43	1.50	1.52	1.46	1.47	1.42	1.43	1.52	1.47	2.1
			3	1.00	0.90	0.95	1.05	0.94	0.86	0.88	0.90	0.72	0.90	11.1
1B	1.95	5' Rt	1	0.75	0.82	0.81	0.84	0.86	0.90	0.80	0.80	0.80	0.83	9.5
			2	1.25	1.31	1.30	1.33	1.25	1.31	1.23	1.22	1.36	1.29	3.0
			3	1.00	0.88	1.00	0.90	0.90	0.86	0.89	0.96	0.93	0.92	9.3

Data Analysis: Individual Test Location Measurements

Table 2 provides pavement layer thickness data for the 10 individual test locations at the Hattiesville Test Site. The average difference from the ground truth is approximately 0.20 in for the left wheel path and 0.47 in for the right wheel path. The range in the difference from the ground truth is approximately 0.05 in to 0.54 in for the left wheel path and 0.12 in to 0.47 in for the right wheel path.

Table 2. Layer Thickness Data for Individual Test Locations

Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
5A	3.56	Thickness Average (in.)	3.69	3.45	3.13	3.42	3.96	3.91	3.80	3.89
Log Mile		Difference from the truth (in.)	0.13	0.11	0.43	0.22	0.40	0.35	0.24	0.33
4.05		Percent Difference (%)	3.67	3.14	11.97	6.26	11.33	9.69	6.65	9.23
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
5B	2.21	Thickness Average (in.)	2.27	2.28	2.19	2.25	1.80	1.76	2.08	1.88
Log Mile		Difference from the truth (in.)	0.06	0.07	0.02	0.05	0.41	0.45	0.13	0.33
4.35		Percent Difference (%)	2.55	3.18	0.80	2.18	18.41	20.51	5.74	14.88
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
4A	3.57	Thickness Average (in.)	3.57	3.55	3.43	3.52	4.03	3.98	4.07	4.03
Log Mile		Difference from the truth (in.)	0.00	0.02	0.14	0.05	0.46	0.41	0.50	0.46
3.45		Percent Difference (%)	0.06	0.49	4.04	1.53	13.02	11.58	13.87	12.82
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
4B	3.16	Thickness Average (in.)	2.66	2.54	2.66	2.62	3.11	2.85	3.16	3.04
Log Mile		Difference from the truth (in.)	0.50	0.62	0.50	0.54	0.05	0.31	0.00	0.12
3.75		Percent Difference (%)	15.81	19.77	15.79	17.12	1.67	9.75	0.13	3.85
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
3A	1.68	Thickness Average (in.)	1.22	1.65	1.77	1.55	1.96	1.82	1.95	1.91
Log Mile		Difference from the truth (in.)	0.46	0.03	0.09	0.19	0.28	0.14	0.27	0.23
2.85		Percent Difference (%)	27.14	1.77	5.30	11.40	16.96	8.23	16.29	13.82
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
3B	1.55	Thickness Average (in.)	1.69	2.06	1.76	1.84	1.71	1.76	1.73	1.73
Log Mile		Difference from the truth (in.)	0.14	0.51	0.21	0.29	0.16	0.21	0.18	0.18
3.15		Percent Difference (%)	9.30	33.03	13.50	18.61	10.11	13.59	11.56	11.76

Table 2. Layer Thickness Data for Individual Test Locations (continued)

Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
2A	2.38	Thickness Average (in.)	2.25	2.24	2.28	2.25	1.72	1.61	1.59	1.64
Log Mile		Difference from the truth (in.)	0.13	0.14	0.10	0.13	0.66	0.77	0.79	0.74
2.25		Percent Difference (%)	5.63	6.02	4.16	5.27	27.53	32.38	33.36	31.09
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
2B	3.53	Thickness Average (in.)	3.55	3.64	3.61	3.60	4.91	4.98	4.97	4.95
Log Mile		Difference from the truth (in.)	0.02	0.11	0.08	0.07	1.38	1.45	1.44	1.42
2.55		Percent Difference (%)	0.62	2.98	2.35	1.98	38.97	41.06	40.67	40.23
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
1A	3.14	Thickness Average (in.)	3.35	3.36	3.34	3.35	3.38	3.34	3.37	3.37
Log Mile		Difference from the truth (in.)	0.21	0.22	0.20	0.21	0.24	0.20	0.23	0.23
1.65		Percent Difference (%)	6.83	7.00	6.29	6.70	7.71	6.46	7.39	7.19
Sample	Ground Truth		L Air 1	L Air 2	L Air 3	L Air Average	R Air 1	R Air 2	R Air 3	R Air Average
1B	2.12	Thickness Average (in.)	2.41	2.34	2.35	2.36	2.85	2.76	2.74	2.79
Log Mile		Difference from the truth (in.)	0.29	0.22	0.23	0.24	0.73	0.64	0.62	0.67
1.95		Percent Difference (%)	13.63	10.28	10.65	11.52	34.53	30.38	29.43	31.44

Data Analysis: Continuous Measurements

The metal strips used to delineate core locations were not used for the continuous surveys; GPS coordinates from the sample site surveys were used to locate the core locations. After the sample sites were located on the continuous survey, the 20-ft sections were used for the continuous survey analysis. These 20-ft sections only have 20 data point for each wheel path due to the lower data resolution.

Table 3 provides layer thickness data for the continuous measurements. The average difference from the ground truth is approximately 0.20 in for the left wheel path and 0.48 in for the right wheel path. The range in the difference from the ground truth is approximately 0.02 in to 0.70 in for the left wheel path and 0.01 in to 1.70 in for the right wheel path.

Table 3. Layer Thickness Data for Continuous GPS Measurements

Sample and Log Mile	5A LWP	5A RWP	5B LWP	5B RWP	4A LWP	4A RWP	4B LWP	4B RWP	3A LWP	3A RWP
Thickness Average (in.)	3.58	4.17	2.3	1.85	3.29	3.84	3.19	3.55	1.75	1.96
Thickness Standard Deviation	0.19	0.56	0.08	0.11	0.18	0.21	0.25	0.29	0.09	0.08
Difference from the truth (in.)	0.02	0.61	0.09	0.36	0.28	0.27	0.03	0.39	0.07	0.28
Percent Difference (%)	0.49	17.26	3.95	16.08	7.98	7.67	0.84	12.21	4.29	16.71
Ground Truth (in.)	3.56	3.56	2.21	2.21	3.57	3.57	3.16	3.16	1.68	1.68
Sample and Log Mile	3B LWP	3B RWP	2A LWP	2A RWP	2B LWP	2B RWP	1A LWP	1A RWP	1B LWP	1B RWP
Thickness Average (in.)	1.46	1.69	2.3	1.56	4.23	5.23	3.42	3.36	1.85	2.13
Thickness Standard Deviation	0.13	0.15	0.26	0.08	0.34	0.59	0.21	0.19	0.31	0.22
Difference from the truth (in.)	0.09	0.14	0.08	0.82	0.7	1.7	0.28	0.22	0.27	0.01
Percent Difference (%)	6.06	9.28	3.17	34.48	19.73	48.21	8.85	7.07	12.51	0.3
Ground Truth (in.)	1.55	1.55	2.38	2.38	3.53	3.53	3.14	3.14	2.12	2.12

Discussion of Results

For the individual test location measurements, the GPR system provided an average of 93.2 % accuracy for the left wheel path and 83.1 % accuracy for the right wheel path. For the continuous survey, the GPR system provided an average 91.7 % accuracy for the left wheel path and 82.4 % accuracy for the right wheel path. In both cases, the GPR system provided a higher average accuracy in the left wheel path compared to the right wheel path. Two possible factors which may affect these results include:

1. The location of the core sample. The core sample was located between the wheel paths, which may not represent the true layer depth in the wheel paths themselves. In other words, the transverse profile for the pavement may not be homogenous.
2. One core was obtained and measured, to provide a reference thickness for the entire 20-ft test location. Actual thickness in the location may vary in both the transverse and longitudinal directions.

Overall, the results from the Hattiesville Test Site generally agree with previous studies of layer thickness 'accuracy' using GPS. It is notable that the continuous-measurement data – the mode under which the GPS will be used for network-level work – provides a similar accuracy to the more tightly controlled location-by-location measurements. It is also noted that the level of 'accuracy' provided by the GPS thickness estimates is suitable for network-level pavement inventory data, and is likely suitable for pavement analyses needing pavement layer thickness.

CHAPTER 4: DATA COLLECTION AND ANALYSIS PROCEDURES

The overall goal of this project is to deliver a GPS system suitable for implementation into AHTD routine pavement management practice. To ensure success of implementation, guidelines regarding the use of the GPR for field data collection and the analysis of GPR field data are required.

Appendix A presents a draft manual for collecting GPR data. Appendix B presents draft guidelines for GPR data analysis.

CHAPTER 5: RECOMMENDATIONS

The recommendations which follow are based on the work performed under TRC-1001.

- The AHTD ground penetrating radar (GPR) unit obtained and tested under this project should be implemented for network-level pavement thickness surveys, using the field data collection and data analysis procedures described.
- AHTD should continue to refine data collection and analysis techniques related to pavement layer thickness estimation. While the accuracy of these estimates is demonstrated to be adequate for current purposes, improvements are likely possible.
- Ground penetrating radar has been used successfully for a variety of purposes other than pavement layer thickness estimation; AHTD should seek to expand the types of analyses performed using GPR – such as identifying bridge deck deficiencies, locating buried utilities, and others.

APPENDIX A

Guidelines for Field Data Collection Using Ground Penetrating Radar (GPR)

Arkansas State Highway and Transportation Department (AHTD)
Ground Penetrating Radar (GPR) Data Collection Process Manual

Introduction

Setting up the ground penetrating radar (GPR) for a day of collection requires setting up the physical equipment and setting up the RADAN software. The system requires a laptop that contains the license for RADAN from Geophysical Survey (GSSI). Setting up the equipment and collecting the data requires two people for safety aspects. At the beginning of the day, make sure to check the fuel gauge. The control unit and the antennas are powered by the battery on the van. The manual should guide the users to set the equipment up and set up the parameters to collect raw GPR data. The raw GPR data can be used to be analyzed later on.

Equipment List:

Two 2 GHz GSSI Model 4105 air-horn antennas

Distance Measurement Instrument (DMI) unit

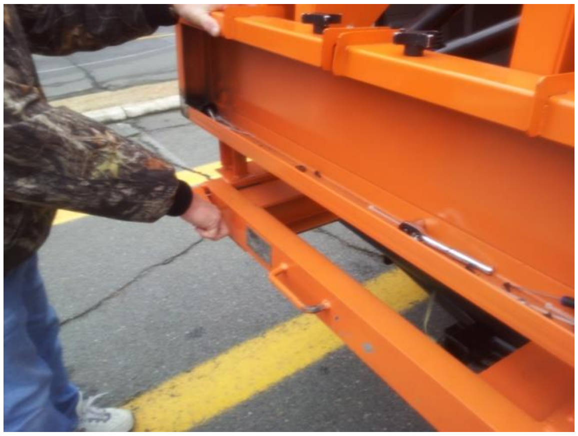
Panasonic Toughbook Laptop

SIR-20 control unit system

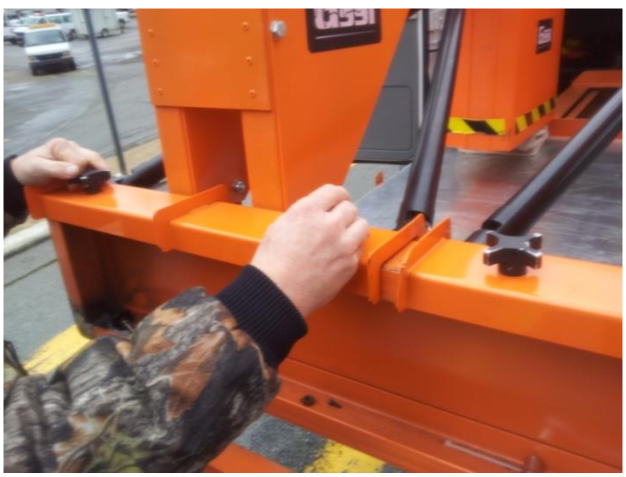
Global Positioning System (GPS)

Equipment Setup

Extend the **antenna rack** from out of the back of the E-350. *The lever on the left needs to be lifted the entire length until the rack is fully extended.*




Remove the **4 screw caps** from the rack to release the antennas' saddle from the **rack**.




Remove the **antenna** from the rack and align them on the **re-enforced front bumper**. *It's recommended that 2 people carry the antenna due to the awkward shape.*

Place **antenna 4012** on the driver side of the bumper.

Place **antenna 4013** on the passenger side of the bumper.

Screw **4 bolts** and **washers** to attach each of the antennas' saddle to the front bumper with a **socket wrench**. *2 bolts should be above the saddle and 2 bolts should be on the side of the saddle for each bolt.*

Connect the **antennas** to the **blue control cables**. *When connecting the cables to the antenna, the GSSI logos should align with each other and screw together.*

Clip the **karabiners** on the **blue control cables** to the clips on the **grill**.

Run the **blue control cables** through the passenger side window.

Connect the **blue control cables** to the **control unit**. *When connecting the cables to the control unit, make sure the correct antenna is connected to the right transducer. Antenna 4012 connects to transducer 1 and antenna 4013 connects to transducer 2.*

Remove the **GPS's circular metal plate** to expose the magnet.

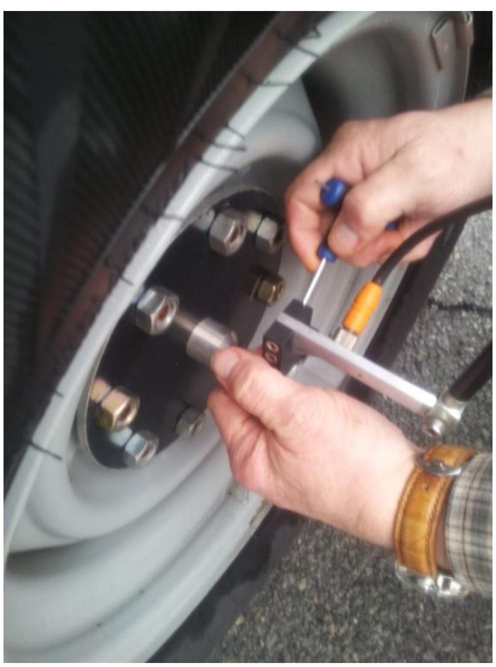
Place the **GPS unit** on the center front of the E-350 roof and run the **GPS cable** through the passenger side window.

Attach the **GPS cable** to the **data logger box** and insert the **power supply cord** into the **cigarette lighter receptacle**.

Plug in the **data logger box's** power supply into the **inverter**.

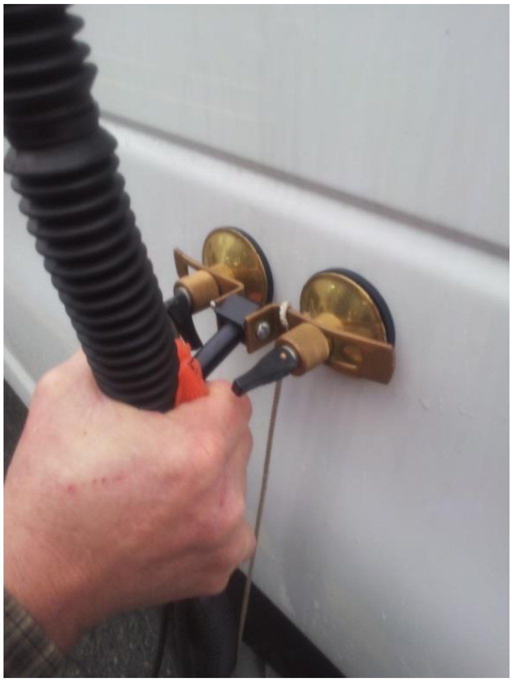
Attach the **data box** to the back or the **Panasonic Toughbook** via the grey **VGA cord**.

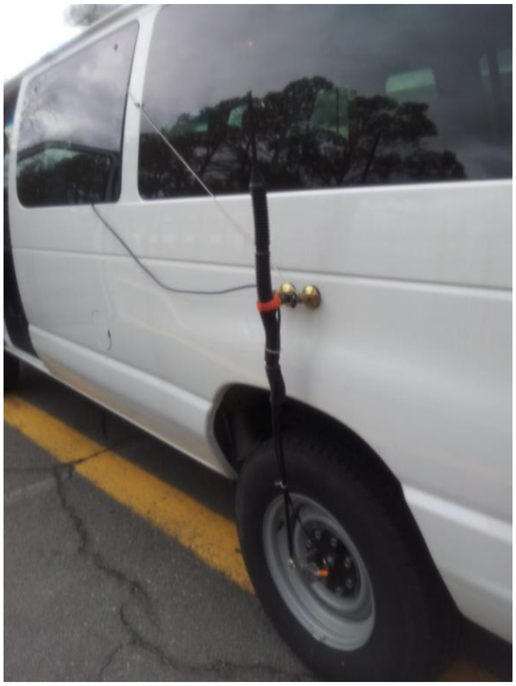
Attach the **DMI unit** onto the **rear driver side wheel**.



Use an **Allen wrench** to tighten the **DMI unit** to the wheel.

Attach the **DMI's suction pad** to the side of the **van**.



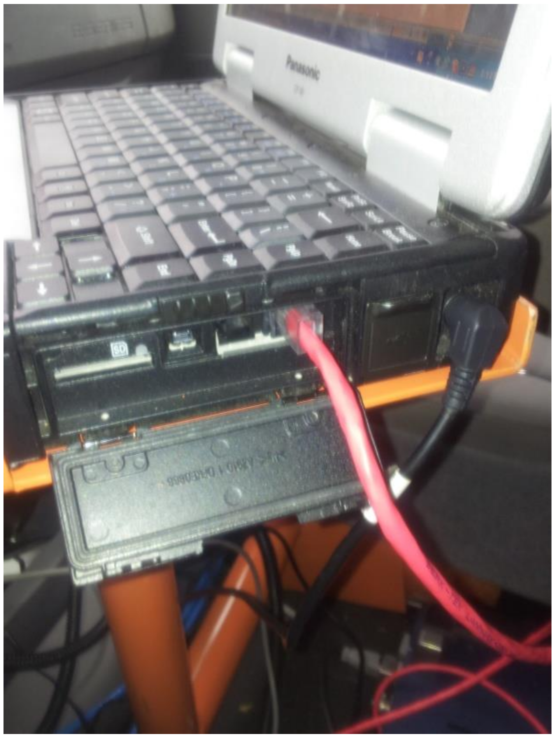


Run the **DMI's cord** and **safety string** through the **rear window**.

Insert the **control unit's power supply** into the **cigarette lighter receptacle** behind the driver's seat.

Attach the **DMI's cord** to the **control unit** and the **safety string** to the seat belt. *The receptacle for the DMI cord is located to the lower left of transducer and make sure there is tension on the safety string in case the suction pads fail. The safety string will catch the DMI unit.*

Place the **Panasonic Toughbook** on the orange stand and connect the **Ethernet cable** and **power cord** to the right side of the **Panasonic Toughbook** from the **control unit**.



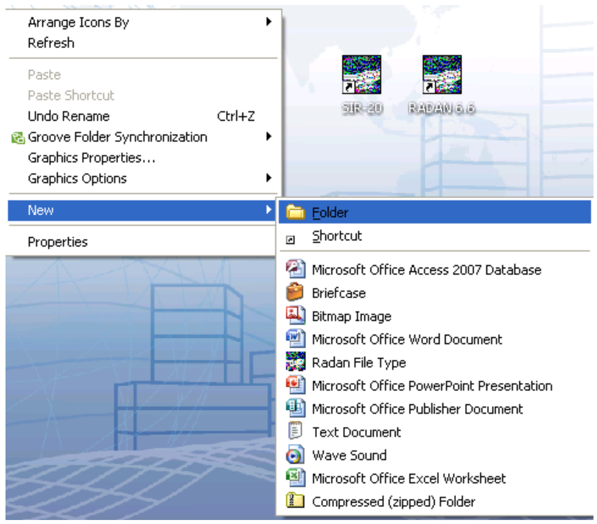
Start the ignition to the **van** and turn on the **Panasonic Toughbook**.

Remove the **2 aluminum plate** located on the **orange rack** and place them beneath the **antenna casing**. *Try and have the van on a flat surface area with an empty 15 foot radius around the antenna.*

The equipment is now ready for the software to be set up.

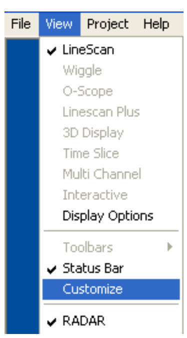
Software Setup

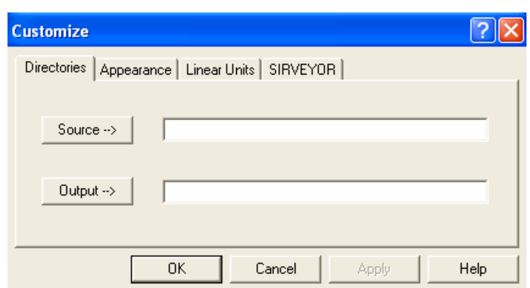
Right click the **mouse** and create a new **folder** for the site. Name the folder after the project and create 2 more folders inside it and name one “IN” and “OUT”.



Open the **SIR-20 program** on the desktop. 

Click **View**-> **Customize** on the toolbar.

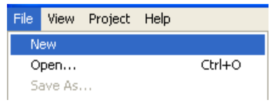




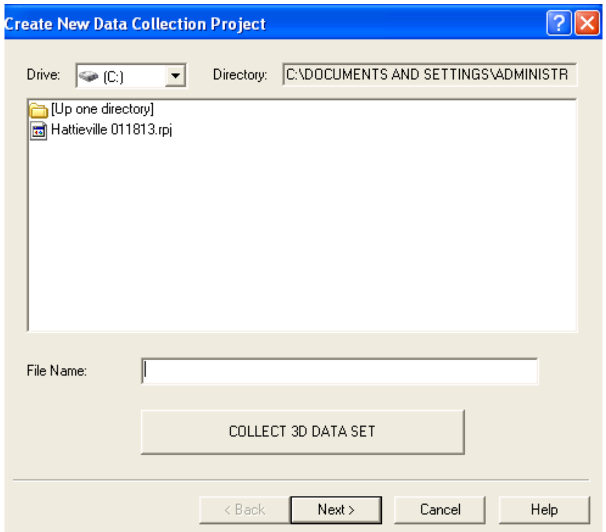
In the Customize box under **Directories** tab, choose the pathway of the “IN” folder created earlier for the **Source -->** line.

Choose the pathway of the “OUT” folder created earlier for the **Output -->** line, then click **OK**.

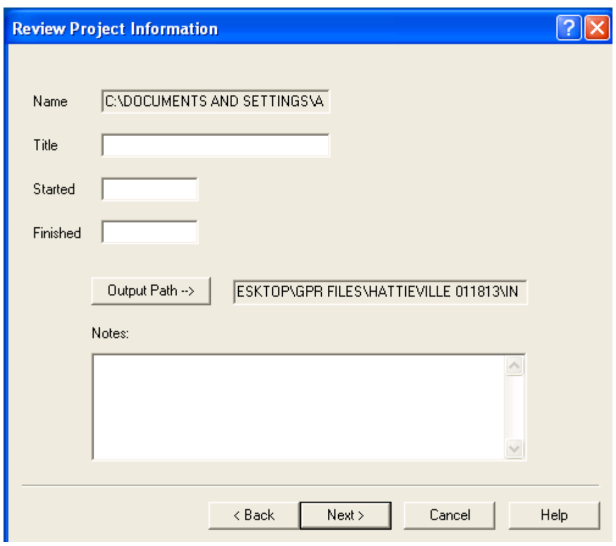
Click **File** -> **New** in the toolbar.



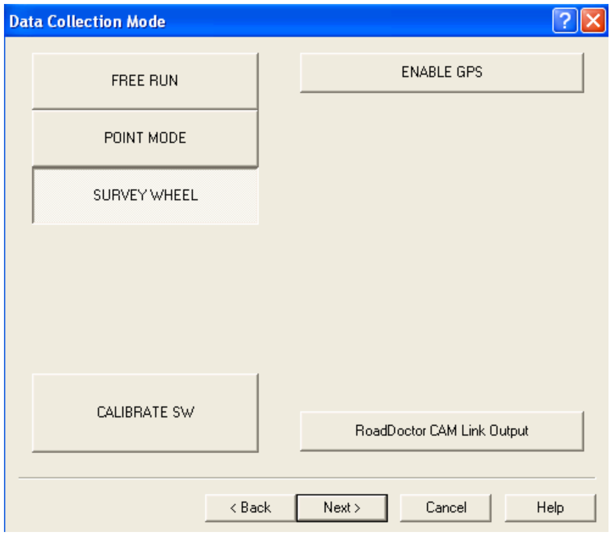
In the **File Name:** line, type in the file name (city and date: Bryant121511) and then click **Next** >.



In Review Project Information window, enter the file name in the **Title** line and click **Next** >.



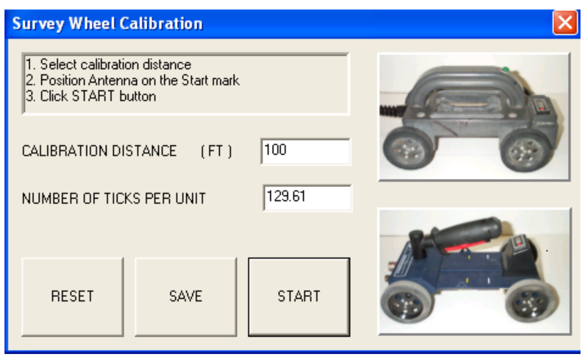
In Data Collection Mode window, click **SURVEY WHEEL**.



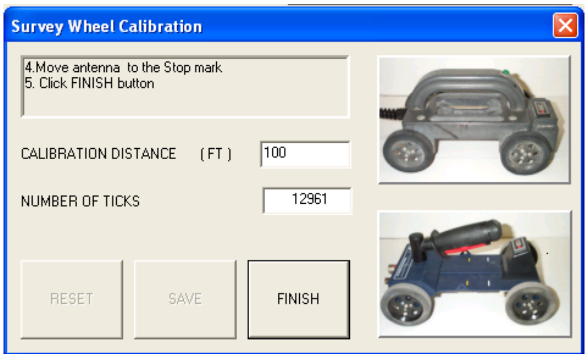
The calibration process for the survey wheel must be done once a week than this process can be skipped to the Enable GPS button. A 100 ft section must be mark out in order to calibrate the Survey Wheel.

In Data Collection Mode window, click **CALIBRATE SW**.

In the Survey Wheel Calibration window, click **START**.

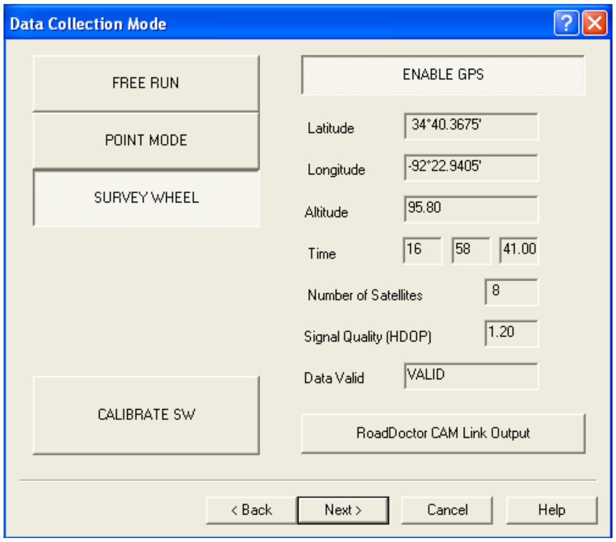


In the Survey Wheel Calibration box, type "100" in the **CALIBRATION DISTANCE (FT)** line, then drive the van approximately 100 feet.



Click **FINISH**, and then click **SAVE**. *The number of tick per unit should be approximately 129.*

In Data Collection Mode box, click **ENABLE GPS** then click **Next >**. *There should be numbers after the ENABLE GPS button was clicked and should display Valid.*

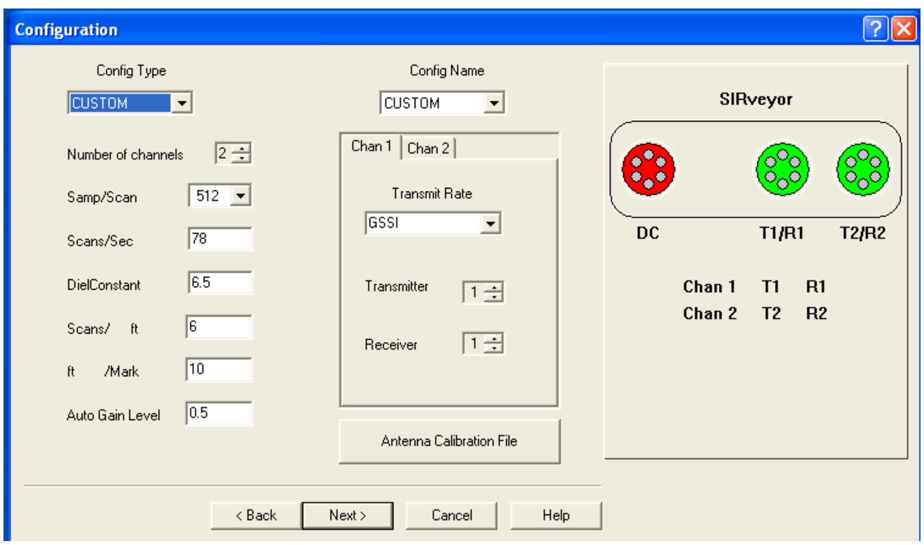


In the next configuration window, the parameters for data collection process must be determined. The parameters are based upon the desired vehicle speed during the collection process. Vehicle speed is determined by purpose of the project. Table 1 below suggests the values for varying operating speeds:

Table 1: Configuration Parameters

Vehicle Speed	0-5 mph	6-15 mph	16-25 mph	26-50 mph	51-70 mph	71-80 mph
Samples/Scan	512	512	512	512	512	512
Scans/Sec	78	78	78	78	78	78
DielConstant	6.5	6.5	6.5	6.5	6.5	6.5
Scans/ ft	6	3	2	1	0.5	0.2
ft / Mark	10	50	50	100	200	528
Auto Gain Level	0.5	0.5	0.5	0.5	0.5	0.5

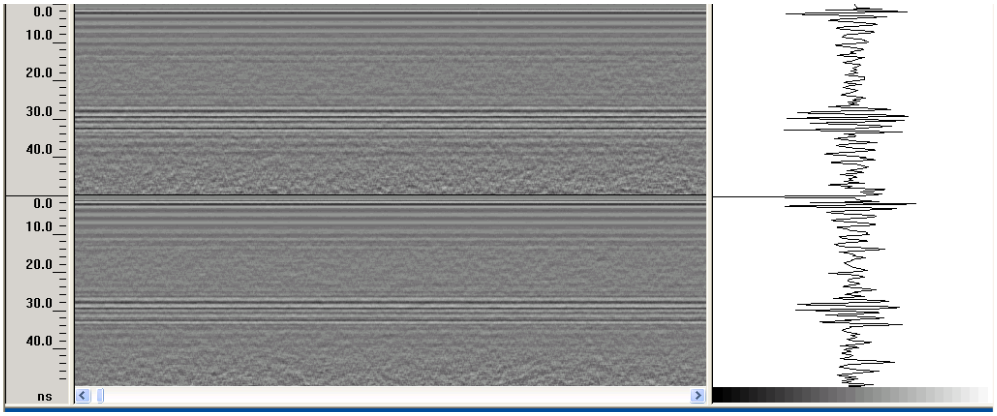
Determine the parameters and type the data in the text lines in the **Configuration** box.

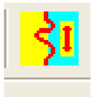


Click **Next** >, then **Finish**

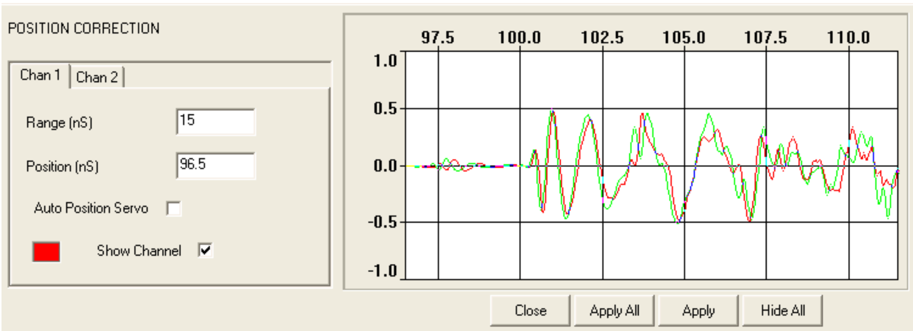
The system will initiate the antenna. There should be a bing sound while the system is initiating the antennas. After the antennas are initiated, there should be 2 radar trace continuously moving. The antennas must stay for 20-30 minutes to warm up.

The Wave Setup



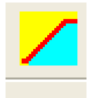
After the antennas warm up, click on the **Position/Range** icon on the bottom row. 

Uncheck the **Auto Position Servo** box and input “15” into the **Range (nS)** line and “96.5” in the **Position (nS)** line.

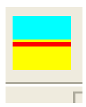


Click on the **Chan 2** tab and input the same values in the **Range (nS)** and **Position (nS)** lines.

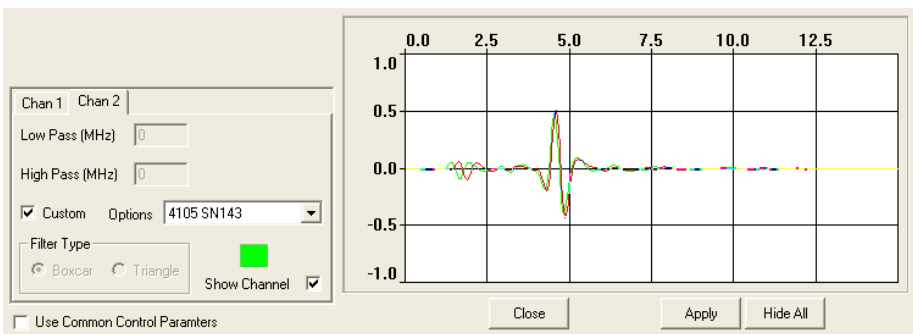
Click **Apply All** and wait till the program is done initiating, then click **Close**.

Click on the **Range Gain** icon on the bottom row. 

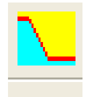
Reduce the **Number of Points** to “1”, uncheck **Auto Gain Servo**, check **Use Common Channel Parameters**, recheck **Auto Gain Servo**, wait till the program is done initiating, and then click **Close**.

Click on the **FIR Filter** icon on the bottom row. 

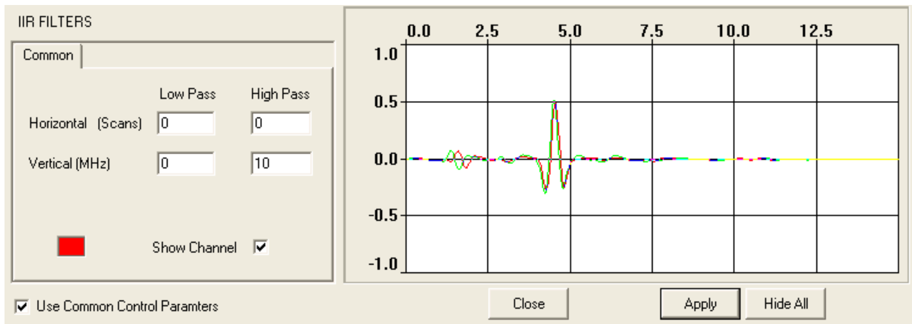
Check the **Custom** box and under the drop down box for **Options**, select “4105 SN142” and click **Apply**.

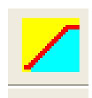


Click on the **Chan 2** tab and check the **Custom** box and under the drop down box for **Options**, select “4105 SN143”, click **Apply**, and then click **Close**.

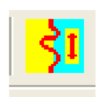
Click on the **IIR Filter** on the bottom row. 

Check the **Use Common Channel Parameters** box, than input “10” for the **High Pass** and **Vertical (MHz)** box and “0” for the rest of the boxes and click **Apply** than **Close**.

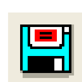


Click on the **Range Gain** icon on the bottom row. 

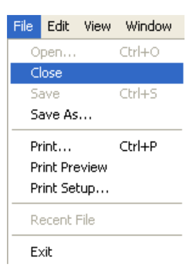
Uncheck the **Auto Gain Servo** box and then recheck it than click **Close**.

Click on the **Position/Range** icon on the bottom row. 

Check if the two antennas are lined up. If they are not lined up, alter the **Position (nS)** box value by the nearest tenth of a decimal for just **Chan 1** tab and click Apply. Continue until the two lines match up and click **Close**.

Click the **Save Macro As** icon on the bottom row. 

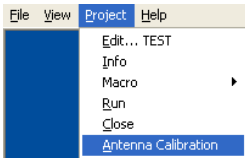
Click the **File** -> **Close** in the toolbar.

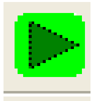


Bumper Test and Calibration File

The bumper test requires a person to jump up and down on the front bumper to allow the system to store the range of the vehicle vertical movements.

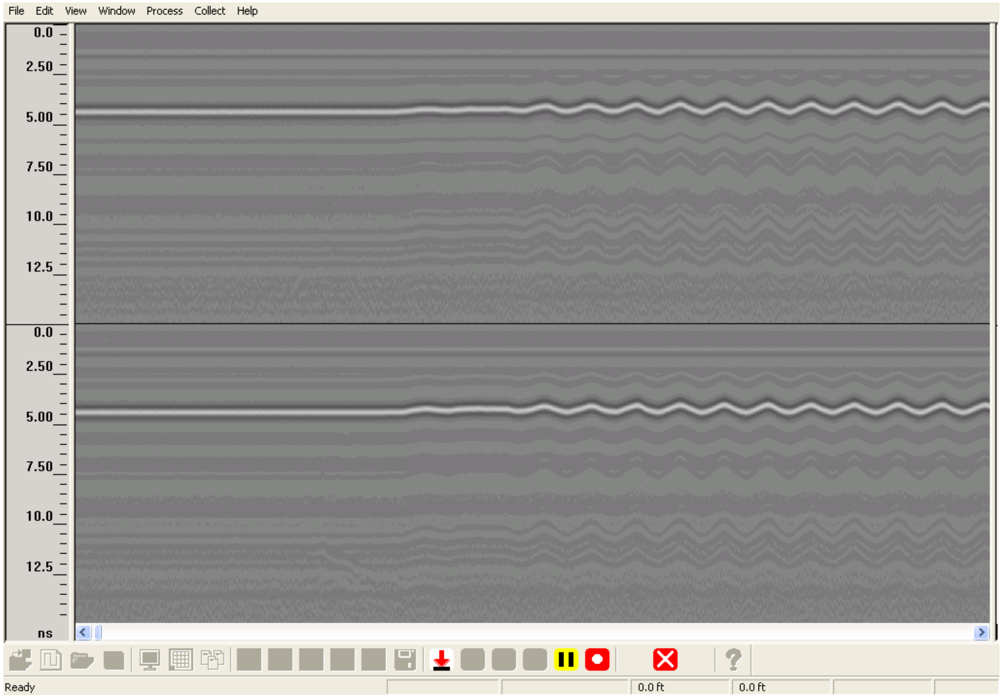
Click the **Project -> Antenna Calibration** in the toolbar.



Click the **Run** icon on the bottom row. 

Allow time for Radan trace to record an entire screen being flat.

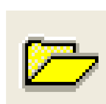
After an entire screen has been recorded, allow the person to jump on the bumper for around 15 seconds.



There should be an oscillating wave for an entire screen, then wait for it to flatten out for an entire screen.

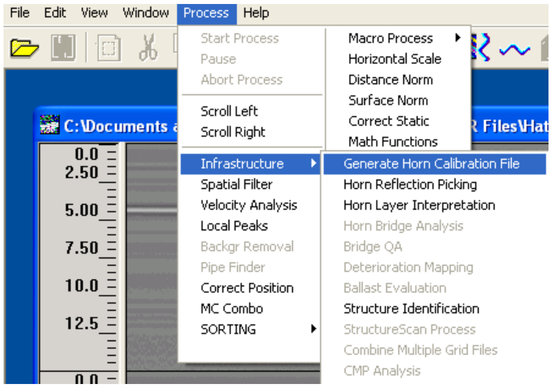
Click the **Stop** icon on the bottom row. 

Close out of the **SIR-20 Program** and open the **RADAN 6.6** icon on the desktop. 

Click the **Open** icon on the top row. 

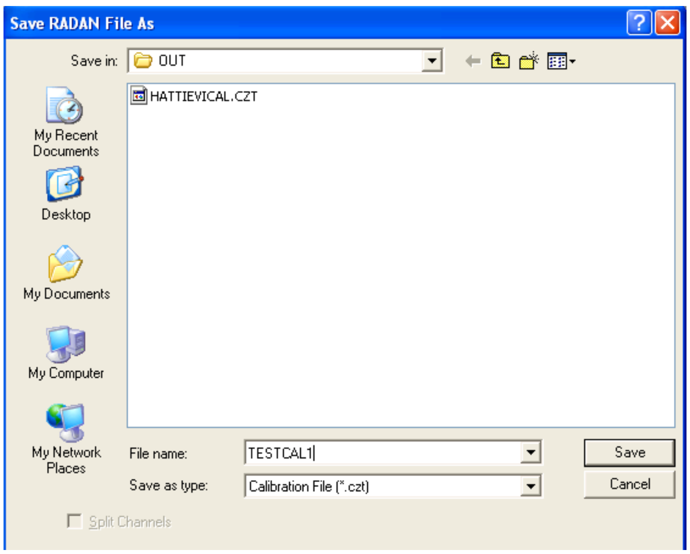
Open the file that was previously created. *The file should be the first file to be collected so it should be named with 001 in the filename.*

Click **Process** -> **Infrastructure** -> **Generate Horn Calibration File**.

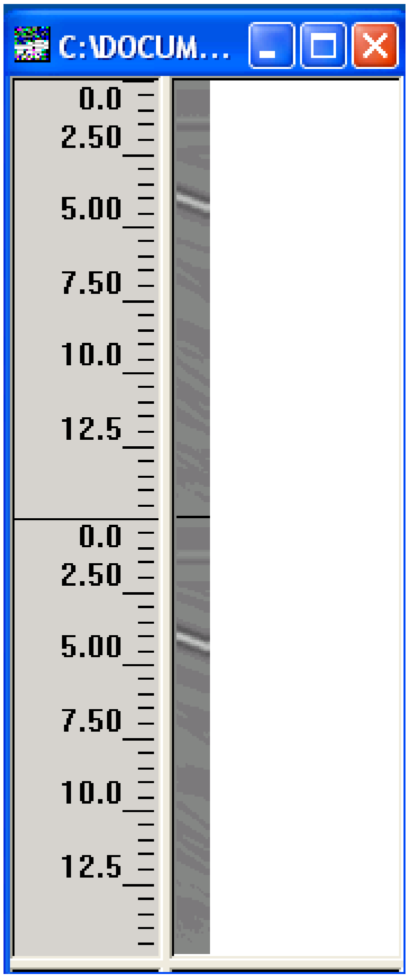


Click **OK** on the **Generate Calibration File** box.

In the Save RADAN File As box, rename the file with "CAL1" in the name.



The calibration file will pop up and should look like the picture below.



This file is important in post processing to eliminate the range of antenna movement to create a flat profile for the top layer in the survey. The calibration file should have two diagonal lines that are located in the grey area. If the file is bad, repeat the bumper test again to get a correct calibration file.

Close the **Radan 6.6** program.

Pick up the two **aluminum plates** underneath the antennas and place them on the **rack** in the back of the **E-350**.

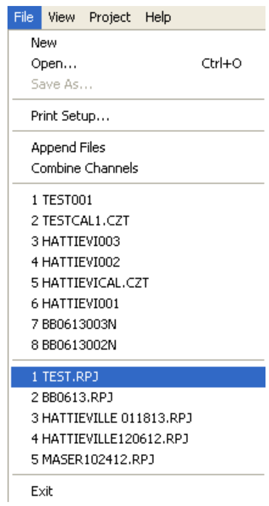
Bring the **rack** into the back of the **E-350** and close the **doors**.

The software is set to begin the data collection process.

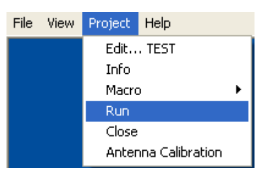
Data Collection

Open the **SIR-20 program** on the desktop. 

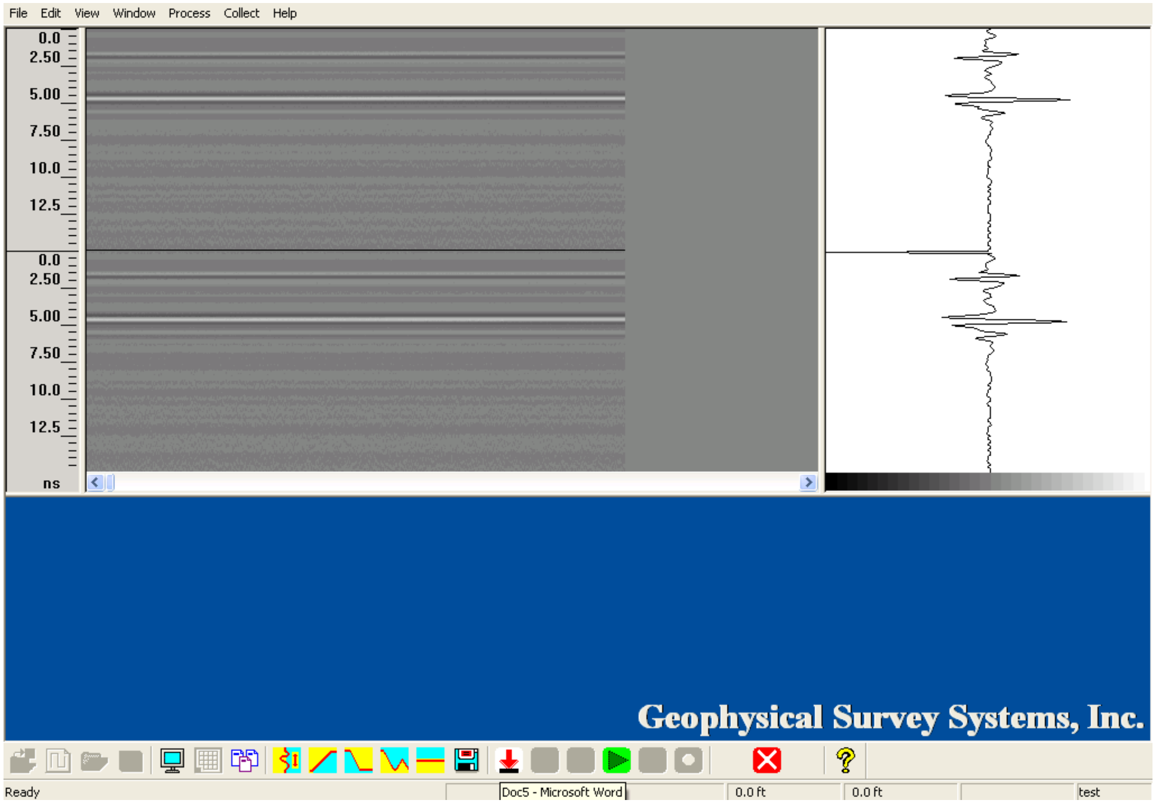
Click **File** -> **TEST.RPJ**. *This is the project file that the user just created. It will be named differently for each test site.*

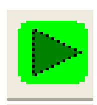


Click **Project** -> **Run** and let the antenna initiate. *The sound of 5 bings will occur when it is done.*



Data should be ready when the screen appears like the picture below.

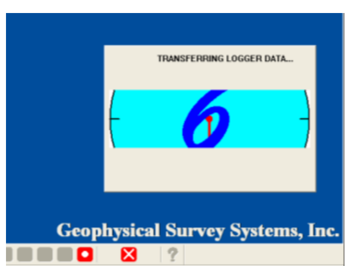


Click the **Run** icon on the bottom row. 

Allow a few seconds for the antennas to initiate. The sound of 1 bing will indicate the system is working. The driver can follow the route of the project and the system will collect data when the van is moving based on the DMI.

Click the **Stop** icon on the bottom once the section is complete. 

A screen will appear counting up allowing the data to be synced with GPS data and recorded.

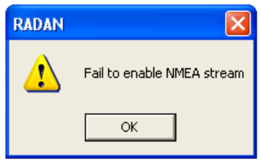


Click **Project** -> **Run** again to collect another file and repeat the process.

When all the sites of the project are recorded, close out of the SIR-20 program.

Frequent Problem

The most common error during the data collection process is not syncing up with the GPS system. The window below will appear if the sync did not perform before data is collected.

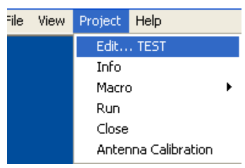


Click **Ok** than click the **Discard Data** icon on the bottom row. 

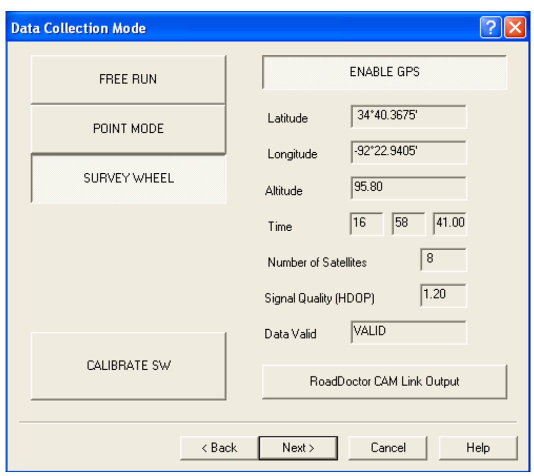
Click **Project** -> **Run** again to collect another file and repeat the process. *This is to see if it would connect by re initiating the antennas.*

If it does not, click **Ok** than click the **Discard Data** icon on the bottom row. 

Click **Project** -> **Edit… TEST** to validate the GPS signal.



Click **Next** then click **ENABLE GPS** to see if there is a valid signal.



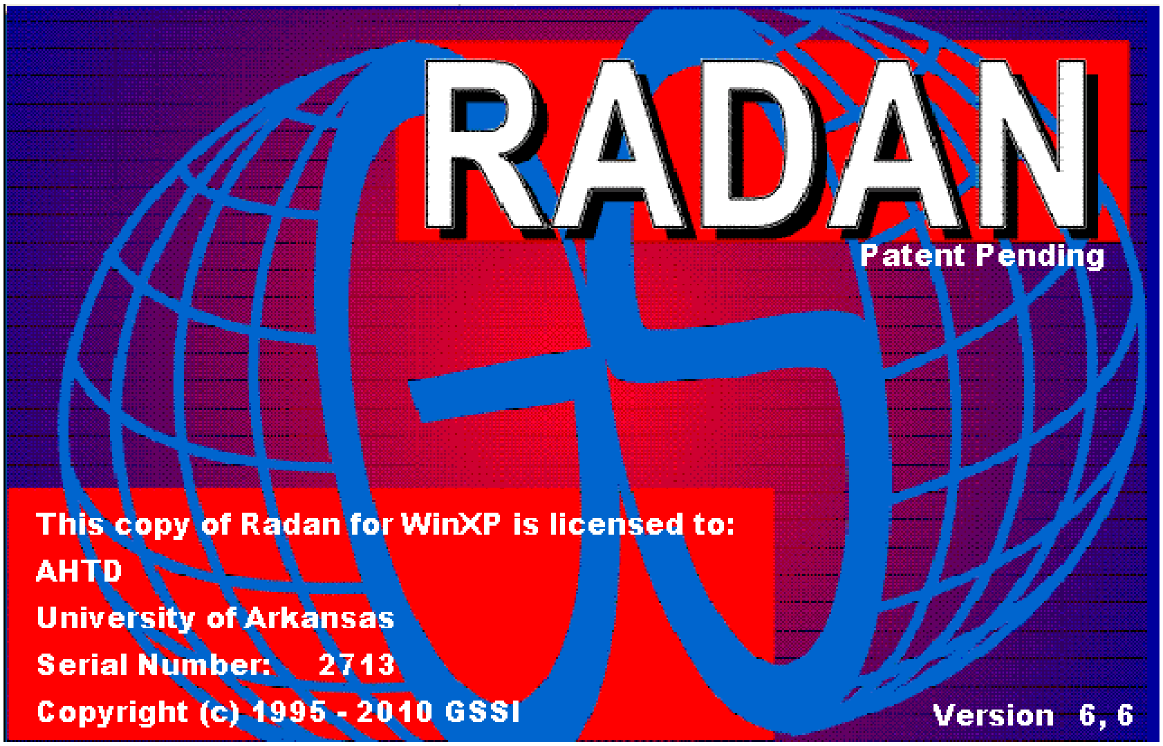
Click **Next** then **Next** then **Finish**.

Click **Project** -> **Run** again to collect another file and repeat the process. There are times when this will occur several times. It is important to sync the GPS system so the data can be tied to a map.

APPENDIX B

Guidelines for Ground Penetrating Radar (GPR) Data Analysis

Arkansas State Highway and Transportation Department (AHTD)
Ground Penetrating Radar (GPR) Analysis Process Manual



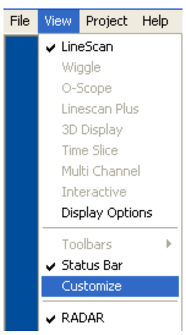
Introduction

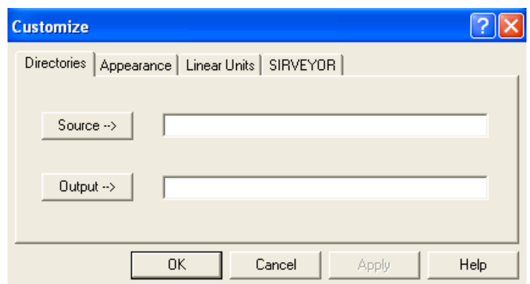
Once the ground penetrating radar (GPR) data has been collected over recent days, the data will be ready for analysis. The data should be located in the GPR files folder located on the desktop of the Panasonic Toughbook. In the GPR files folder, each folder should have a location and date of where the GPR files were collected. For each of these folders, there should be an input folder and an output folder labeled IN and OUT. The input folder will have all the raw data from the collection day. The output folder should have a calibration file that was created during the collection date.

Opening a File

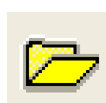
Open **Radan 6.6** by clicking on the icon on the desktop. 

Make sure the folder with the raw data and output folder correctly selected. Click **View**-> **Customize** on the toolbar.

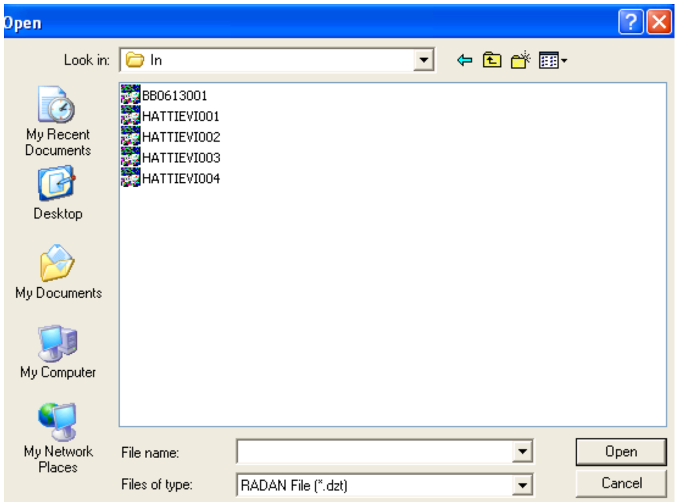




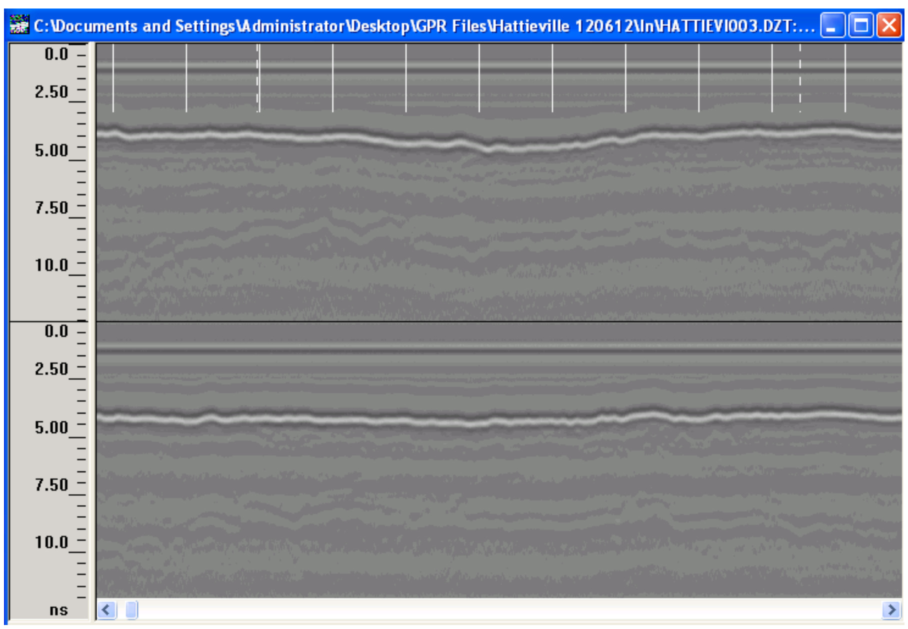
In the Customize box under **Directories** tab, choose the pathway of the "IN" folder created for that date in the **Source -->** line. *This will pre load all the raw data from the collection date.* Choose the pathway of the "OUT" folder created earlier for that date in the **Output -->** line, and then click **OK**. *This path will allow all the saved files from the analysis process to save in the "OUT" folder.*

Click the **Open** icon on the top row. 

Locate the GPR raw data file located in the date folder created during the collection process (i.e. > C:\Documents and Settings\Administrator\Desktop\GPR Files\##########\IN). *Typically the first file should be used as the Calibration file describe in the Collection Process Manual.*

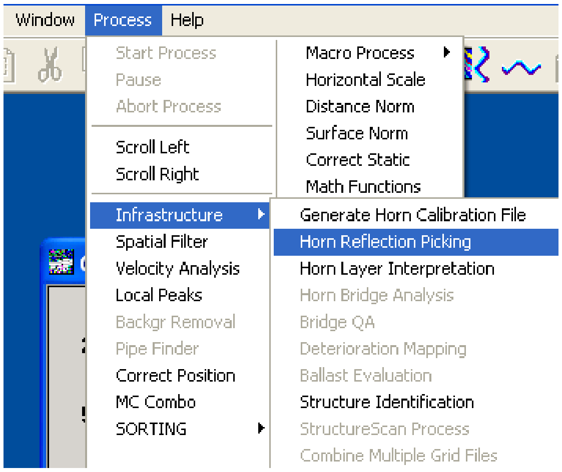


After opening the raw file, it should look as the top layer is not flat. Here is an example below:

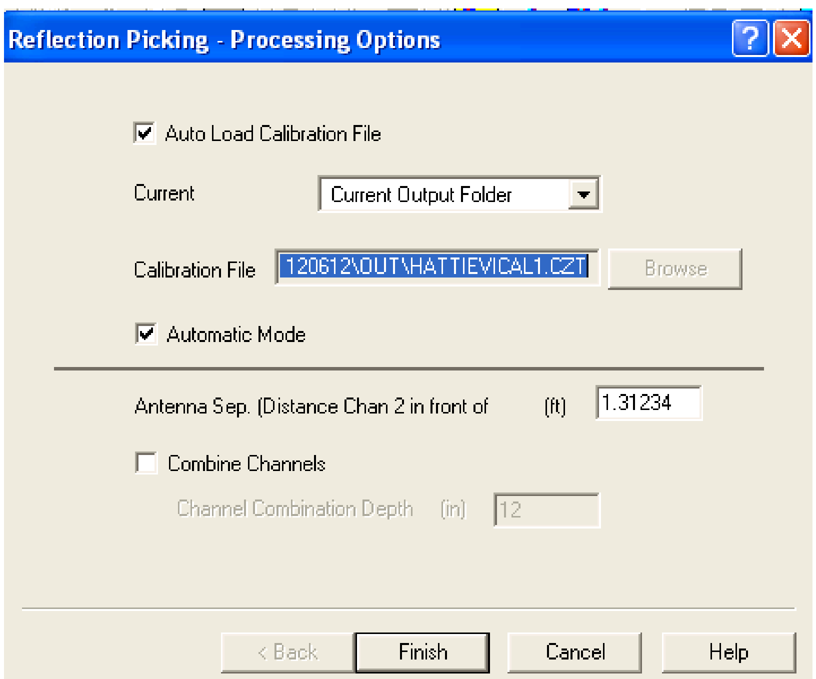


Horn Reflection Picking Process

On the toolbar, click **Process** -> **Infrastructure** -> **Horn Reflection Picking**.

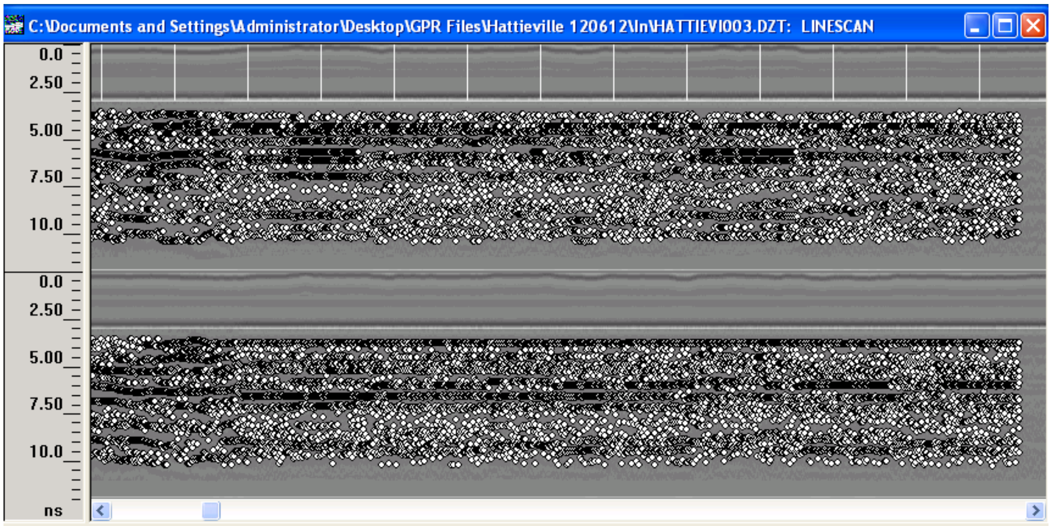


*The **Reflection Picking – Processing Options** windows should appear.*



*The Calibration File that was created during the data collection process will automatically be loaded. Browsing for a different calibration file can be performed by un-checking the **Auto Load Calibration File** box and then clicking the **Browse** button.*

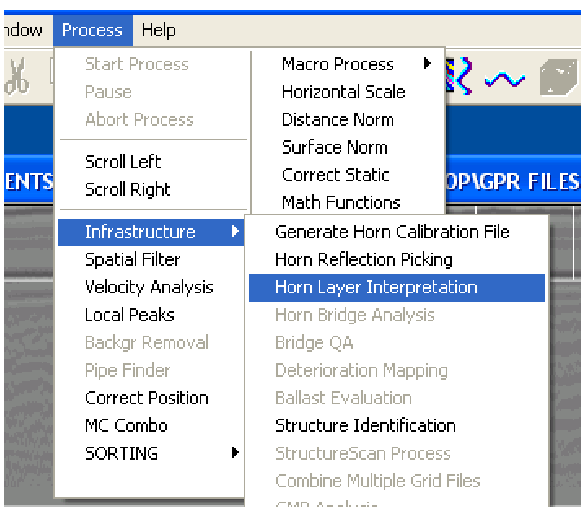
Once the **Calibration File** is selected, click the **Finish** button.



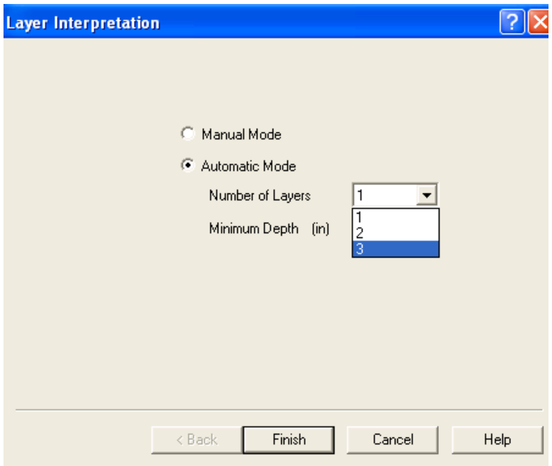
The horn reflection picking process repositions the surface of the pavement to be flat. The image above is a screen shot during the horn reflection picking process. Once the process is complete, a **Save RADAN File As** window will appear. Name the file and click the **Save** button.

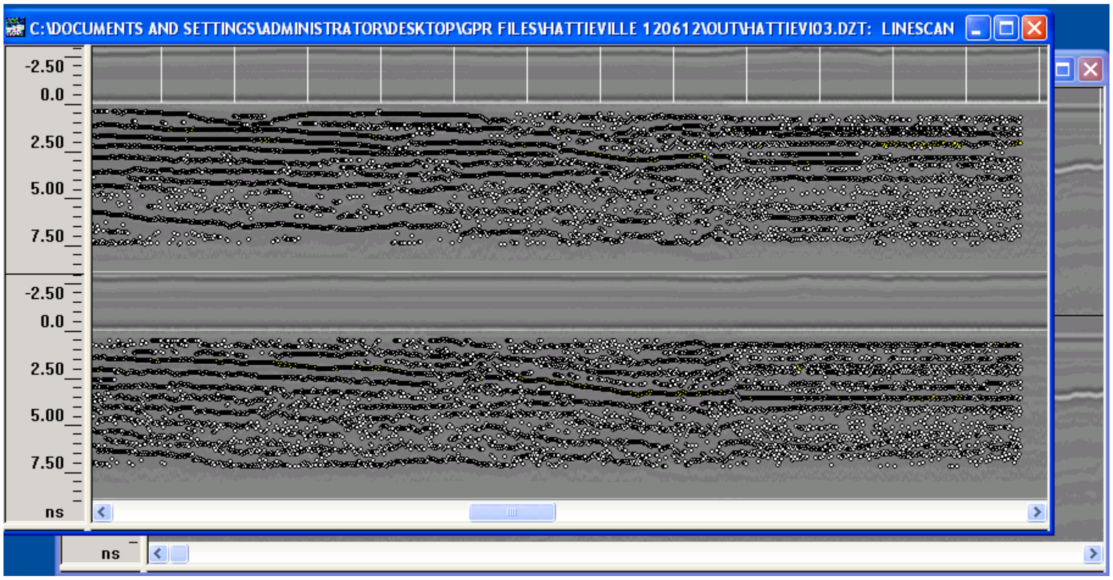
Horn Reflection Picking Process

Two windows will appear. Click **Process -> Infrastructure -> Horn Layer Interpretation**.



Click the **Number of Layer** drop box, select **3**, and then click the **Finish** button.



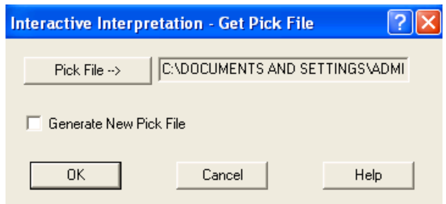


The horn layer interpretation process selects the different layer interface. The image above is a screen shot during the horn layer interpretation process. Once the process is complete, a **Save RADAN File As** window will appear. Name the file and click the **Save** button. *When naming this file, add a letter or number to differentiate from the Horn Reflection Pickings file.*

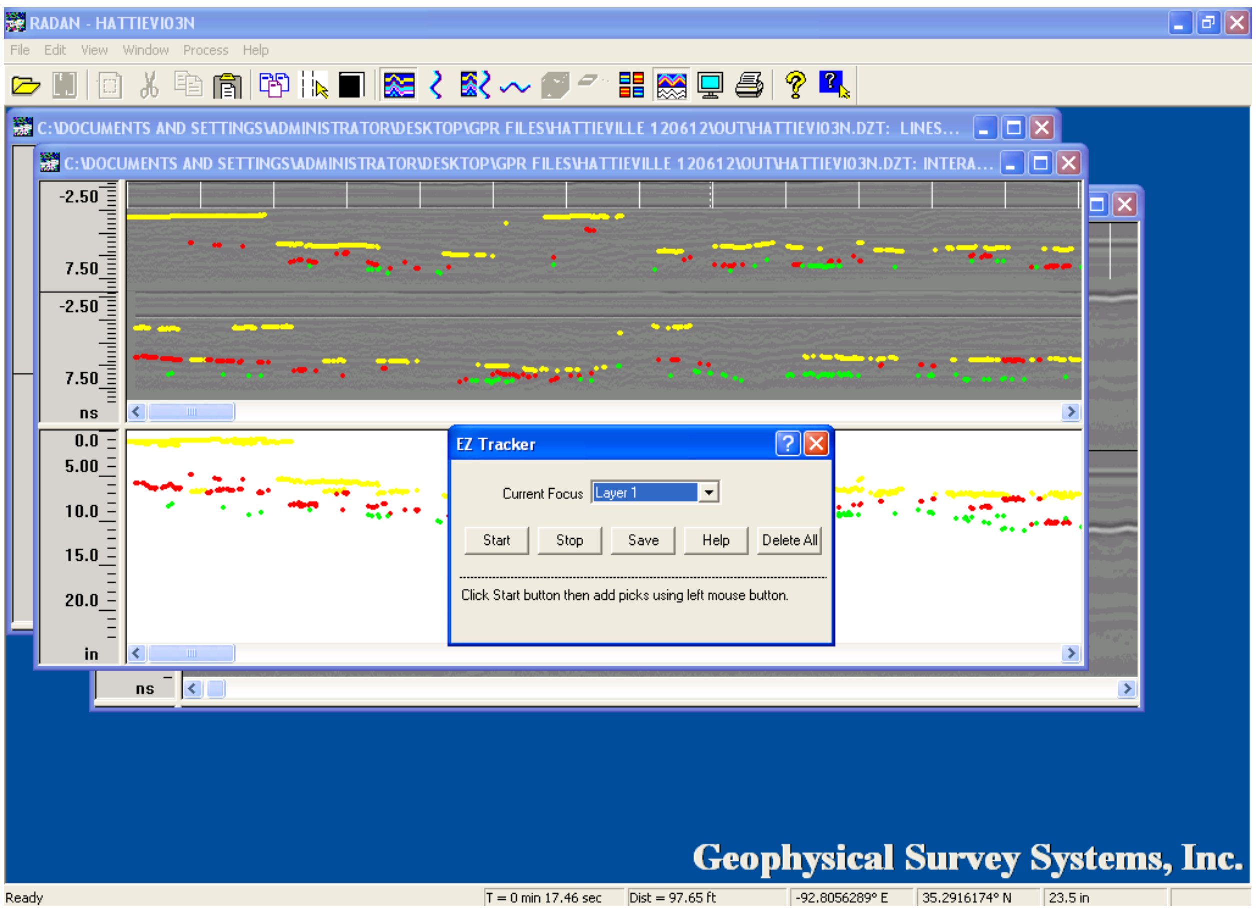
A third window will appear.

Interactive Interpretation Process

Click on the **Interactive Interpretation** icon on the top row. 

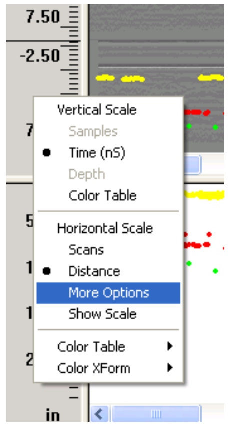


*The saved **RADAN file**, which is in **Lay file** format, from the horn layer interpretation process should load automatically in the window.* Click the **OK** button.

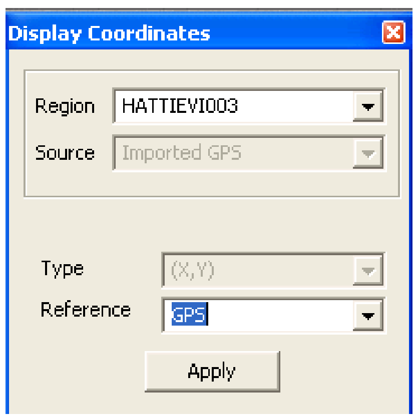


The image above displays the interactive interpretation window. This displays the different layer points in the automated process for picking the layer interface. This window is used to manually pick the layer interface based on the users' interpretation.

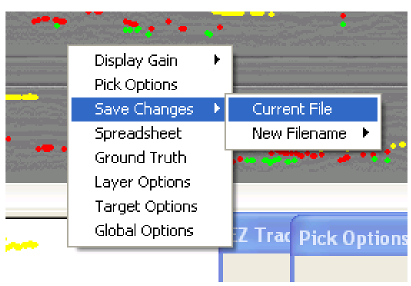
Right click on the **Grey Vertical Scale** of the left side of the interactive interpretation window and then click on **More Option**.



Click on the **Reference** drop box and select **GPS**. Click the **Apply** button and close out the **Display Coordinates** window.



Right click on the **Interactive Interpretation** window and Click on **Save Changes** -> **Current Files**

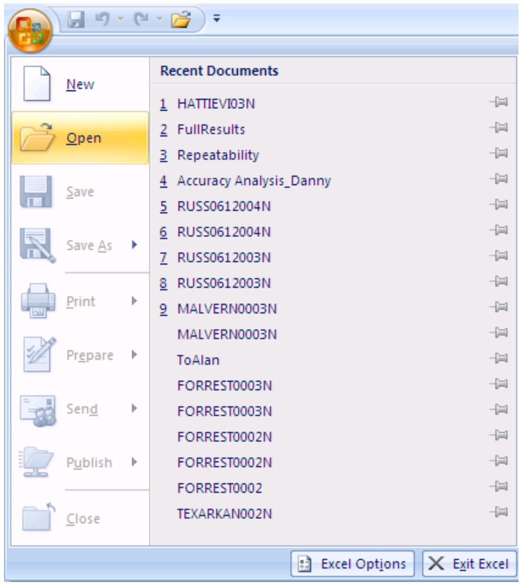


Exit out of the **Radan 6.6**.

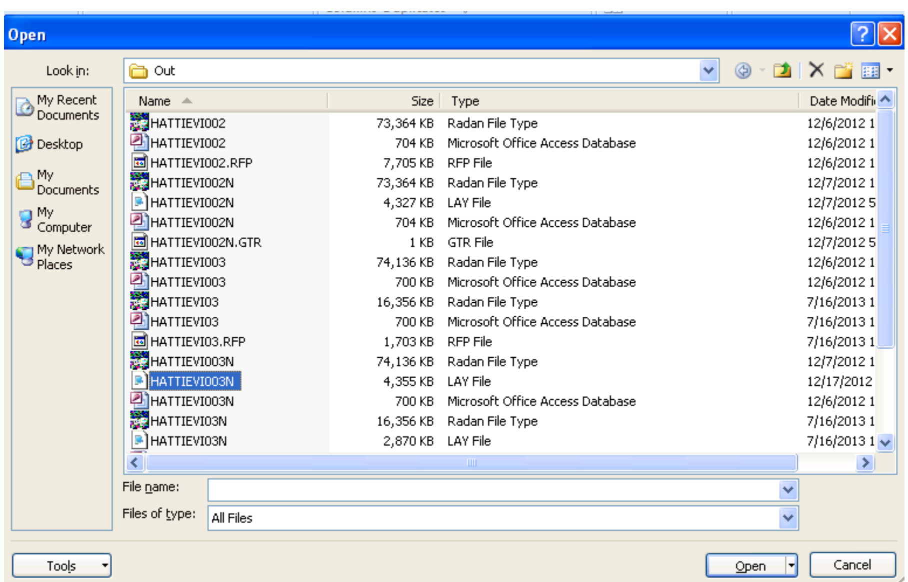
Creating the Spreadsheet

Open **Microsoft Excel**.

Click the **Menu** button and click the **Open** button.

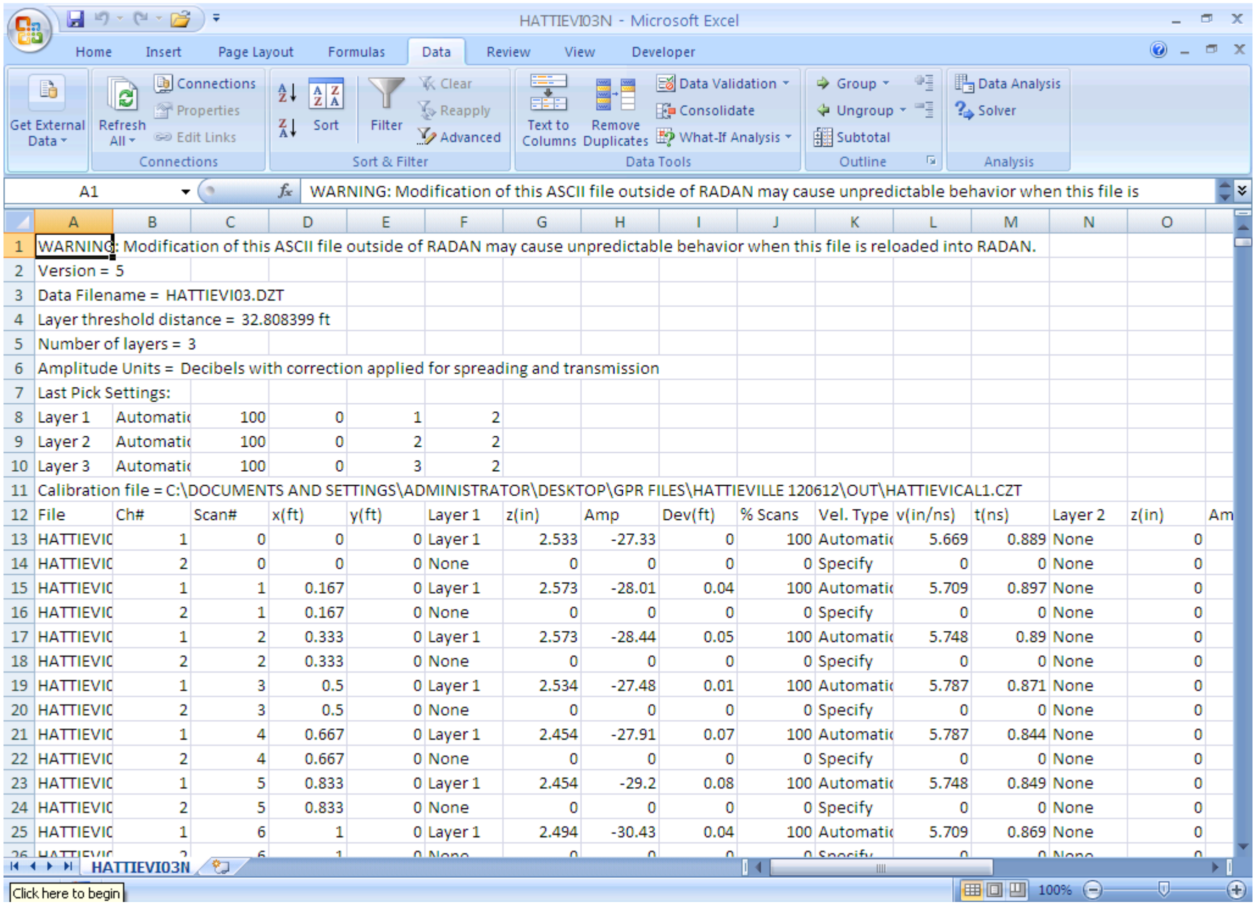


Locate the **GPR data folder** and click the **OUT** folder for that day. Click on the **Files of type:** drop box and select **All Files**. Select the file **Lay file** of the **Radan File** and click **Open**.



The **Text Import Wizard** window will appear.   Click the **Next** button.

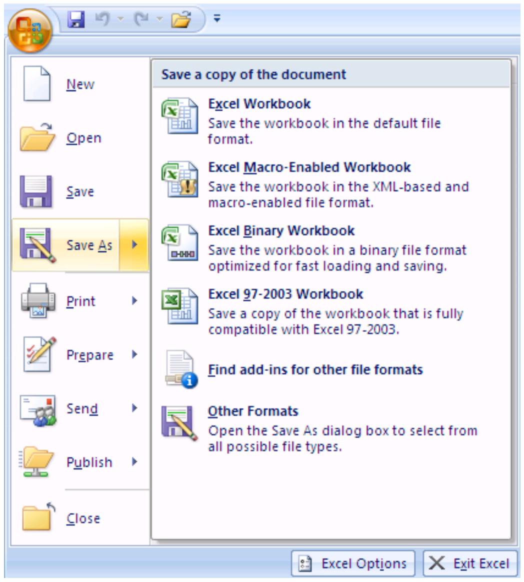
On the Un-check the **Tab** box and check the **Comma** box. Click the **Finish** button.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
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 = HATTIEVI03.DZT															
4	Layer threshold distance = 32.808399 ft															
5	Number of layers = 3															
6	Amplitude Units = Decibels with correction applied for spreading and transmission															
7	Last Pick Settings:															
8	Layer 1	Automati	100	0	1	2										
9	Layer 2	Automati	100	0	2	2										
10	Layer 3	Automati	100	0	3	2										
11	Calibration file = C:\DOCUMENTS AND SETTINGS\ADMINISTRATOR\DESKTOP\GPR FILES\HATTIEVILLE 120612\OUT\HATTIEVICAL1.CZT															
12	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)	Am
13	HATTIEVI	1	0	0	0	Layer 1	2.533	-27.33	0	100	Automati	5.669	0.889	None	0	
14	HATTIEVI	2	0	0	0	None	0	0	0	0	Specify	0	0	None	0	
15	HATTIEVI	1	1	0.167	0	Layer 1	2.573	-28.01	0.04	100	Automati	5.709	0.897	None	0	
16	HATTIEVI	2	1	0.167	0	None	0	0	0	0	Specify	0	0	None	0	
17	HATTIEVI	1	2	0.333	0	Layer 1	2.573	-28.44	0.05	100	Automati	5.748	0.89	None	0	
18	HATTIEVI	2	2	0.333	0	None	0	0	0	0	Specify	0	0	None	0	
19	HATTIEVI	1	3	0.5	0	Layer 1	2.534	-27.48	0.01	100	Automati	5.787	0.871	None	0	
20	HATTIEVI	2	3	0.5	0	None	0	0	0	0	Specify	0	0	None	0	
21	HATTIEVI	1	4	0.667	0	Layer 1	2.454	-27.91	0.07	100	Automati	5.787	0.844	None	0	
22	HATTIEVI	2	4	0.667	0	None	0	0	0	0	Specify	0	0	None	0	
23	HATTIEVI	1	5	0.833	0	Layer 1	2.454	-29.2	0.08	100	Automati	5.748	0.849	None	0	
24	HATTIEVI	2	5	0.833	0	None	0	0	0	0	Specify	0	0	None	0	
25	HATTIEVI	1	6	1	0	Layer 1	2.494	-30.43	0.04	100	Automati	5.709	0.869	None	0	

The excel file should look like the image above. In this spreadsheet, the values for layers can be sorted so specific analysis can be preformed.

Click the **Menu** button and click the **Save As** button. *Make sure you save as, so that the original lay file will not be lost.*



Name the file and click the **Save** button. *Make sure to save it as an **Excel Workbook** in the **Save as type:** drop box.*

Repeat the process for all the other raw GPR files that where collected in the date folder.