



RESEARCH

2007-34

Implementation of Ground Penetrating Radar

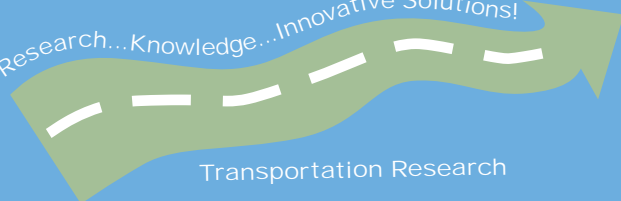


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16. Abstract (Limit: 200 words) The objective of this project was to demonstrate the capabilities and limitations of ground penetrating radar (GPR) for use in local road applications. The effectiveness of a GPR survey is a function of site conditions, the equipment used, and experience of personnel interpreting the results. In addition, not all site conditions are appropriate for GPR applications. GPR is a nondestructive field test that can provide a continuous profile of existing road conditions. GPR utilizes high-speed data collection at speeds up to 50 mph, thus requiring less traffic control and resulting in greater safety. GPR has the potential to be used for a variety of pavement applications, including measuring the thickness of asphalt pavement, base and sub-grade; assisting in the analysis of rutting mechanisms; calculating and verifying material properties; locating subsurface objects; detecting stripping and/or layer separation; detecting subsurface moisture; and determining depth to near-surface bedrock and peat deposits. These applications are discussed in reference to 22 projects completed throughout the State of Minnesota. Three reports were produced. (1) A technical summary report provides an overview of the project. (2) A comprehensive review of GPR applications for use on local roads is also available. (3) The final report describes the results of the GPR surveys.			
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Implementation of Ground Penetrating Radar

Final Report

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EXECUTIVE SUMMARY

The objective of this project was to demonstrate the capabilities and limitations of ground penetrating radar (GPR) for use in local roadway applications. The effectiveness of a GPR survey is a function of site conditions, the equipment used, and experience of personnel interpreting the results. In addition, not all site conditions are appropriate for GPR applications.

This report will give the local engineer a brief overview of GPR equipment. It will help the engineer understand the potential GPR applications for use on local roads, and assist in determining what site conditions are appropriate for using GPR.

GPR is a nondestructive field test that can provide a continuous profile of existing road conditions. GPR utilizes high-speed data collection at speeds up to 50 mph, thus requiring less traffic control and resulting in greater safety. GPR has the potential to be used for a variety of pavement applications, including measuring the thickness of asphalt pavement, base and sub-grade; assisting in the analysis of rutting mechanisms; calculating and verifying material properties; locating subsurface objects; detecting stripping and/or layer separation; detecting subsurface moisture; and determining depth to near-surface bedrock and peat deposits. These applications are discussed in reference to 22 projects completed throughout the State of Minnesota.

Chapter 1

Introduction

Ground penetrating radar (GPR) is a noninvasive, continuous, high-speed tool that has been used to map subsurface conditions in a wide variety of applications. Many of these applications are well suited for evaluation of highway systems. GPR is basically a subsurface “anomaly” detector; as such it will map changes in the underground profile due to contrasts in the electromagnetic conductivity across material interfaces.

GPR technology has a relative recent history. Radar was developed and used during World War II to detect and track metal objects, such as aircraft or ships. The first radar specifically designed to penetrate the ground was developed at MIT in the late 1960’s for the U.S. military to find shallow tunnels in Vietnam. In 1970, the first commercial company was established to manufacture and sell GPR equipment and services. In 1974, the first GPR patent was issued. Since that time the GPR technology has boomed, paralleling the technological advances in the computer industry.

Local road authorities are faced with unknowns when planning projects. GPR surveys may be successful in determining stripping zones in asphalt pavements, detecting subsurface voids, detecting subsurface anomalies (bedrock/peat), bridge deck delaminations, underground utility locates, subgrade profiling, and pavement thickness. The objective of this project is to educate and demonstrate to local road engineers the capabilities and limitation of GPR surveys for use in local roadway applications. The effectiveness of GPR surveys is a function of site conditions, the equipment used, and experience of personnel using the equipment and reading the results. Not all site conditions are appropriate for GPR applications.

This report will give the local engineer a brief overview of GPR equipment, use and applications. It will help the engineer understand the potential GPR applications for use on local roads, assist in determining what situations or site conditions that GPR is appropriate, and where it is not.

In addition to this report, MnDOT will provide demonstration projects throughout the state on city, county, and state roads. The demonstration projects selected will cover applications for pavement evaluation, pavement deterioration, void detection, utility location, and subsurface anomalies (bedrock/peat). Following the demonstration projects, a report will be presented summarizing the results of the demonstration projects.

This project is a joint effort between the Office of Materials Research (OMR) of MnDOT, the pavement Research Institute (PRI) at the University of Minnesota, and the Research Implementation Committee (RIC) of the Local Road Research Board (LRRB).

Chapter 2 Mathematical Principles

GPR operates by transmitting short pulses of electromagnetic energy downward into the ground. The reflected images of these pulses are analyzed using one-dimensional electromagnetic wave propagation theory. These pulses are reflected back to the antenna with amplitudes and arrival times that are related to the electrical conductivities (equivalently, dielectric constants) of the material layers (Figure 2.1). Across the interfaces, part of the energy is reflected and part is absorbed, depending on the dielectric contrast of the materials. The observed peaks in amplitude (in their order of occurrence) represent the antenna end reflection (A_0), the surface (pavement) reflection (A_1), and the base reflection (A_2), respectively. The time interval (t_1) between peaks A_1 and A_2 represents the two-way travel time through the pavement layer. The thickness of the pavement layer (h) as shown in Figure 2.2, can be calculated as:

$$h = v \Delta t / 2 \tag{1}$$

where v = propagation velocity through each layer and $\Delta t = t_2 - t_1$

The propagation velocity is related to the electromagnetic behavior of the asphalt layer:

$$v = c / \sqrt{\epsilon} \tag{2}$$

where ϵ = dielectric constant of asphalt layer

c = speed of light in air
 = 11.8 in./ns (0.30 m/ns)

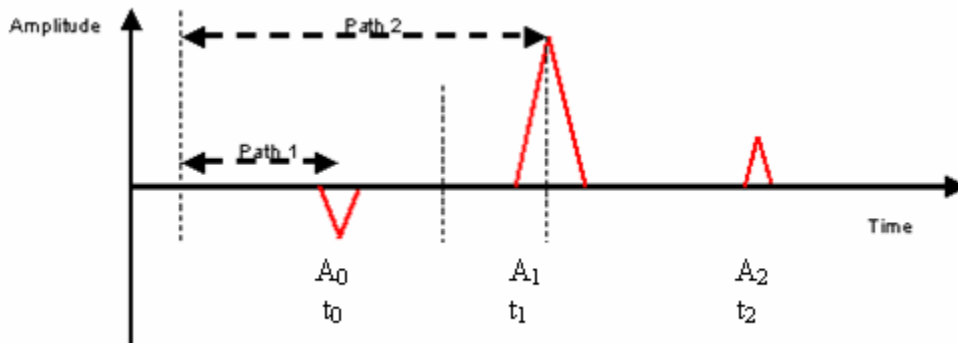


Figure 2.1 Typical Amplitude Time History from GPR Antenna

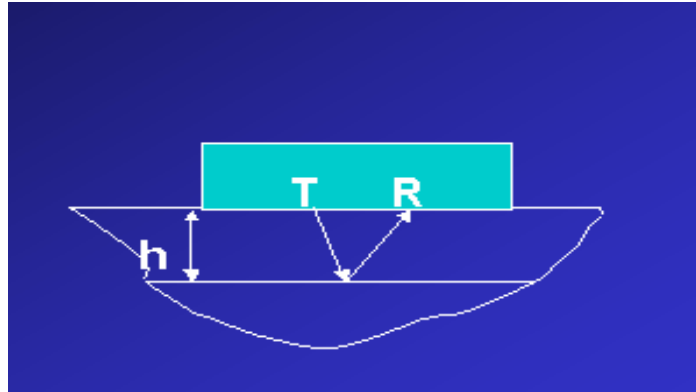


Figure 2.2 GPR Signal Across Asphalt Layer from Transmitter (T) to Receiver (R)

Ranges in dielectric constants for typical pavement materials are given in Table 2.1.

Table 2.1 Dielectric Constants and Propagation Velocities of Pavement Materials

Material	Dielectric Constant (-)	Propagation Velocity (m/ns)
Air	1	.30
Ice (Frozen soil)	4	.15
Granite	9	0.10
Limestone	6	0.12
Sandstone	4	0.15
Dry sand	4 to 6	0.12 to 0.15
Wet sand	30	0.055
Dry clay	8	0.11
Wet clay	33	0.052
Asphalt	3 to 6	0.12 to 0.17
Concrete	9 to 12	0.087 to 0.10
Water	81	0.033
Metal	∞	0

Chapter 3

GPR Equipment

The GPR equipment currently used by MnDOT is summarized in Table 3.1. All of this equipment has been purchased from Geophysical Survey Systems Inc. in North Salem, NH. This equipment consists of two data collection systems (SIR-020 shown in Figure 3.1 and SIR-2000), two data collection and analysis software packages (RADAN and ROADDOCTOR), 3 ground-coupled antennas (100 MHz, 400MHz, 1.5 GHz, shown in Figure 3.2) and 2 air-coupled antennas (1.0 GHz and 2.0 GHz, shown in Figure 3.3). The approximate depths of penetration for each of these antennas are given in Table 3.1. In general the depth of penetration is inversely proportional to the antenna transmission speed. In addition, MnDOT maintains a vehicle totally dedicated to GPR data collection that includes an independent power source, GPS data collection, electronic DMI device, and a Video camera. Also, for “offroad” projects, a baby buggy has been modified for GPR data collection, which includes a battery power source and survey wheel (Figure 3.4).

Table 3.1 MnDOT GPR Equipment

<i>MnDOT GPR Equipment</i>	
■	Data Collection Units
◆	SIR-020
◆	SIR-2000
■	Collection/Analysis Software
◆	RADAN
◆	ROADDOCTOR
■	Antennas/Depth of Penetration
◆	100 MHz Ground Coupled/40 ft
◆	400 MHz Ground Coupled/10 ft
◆	1000 MHz Air Coupled/3 ft
◆	1500 MHz Ground Coupled/1.5 ft
◆	2000 MHz Air Coupled/2 ft



Figure 3.1 SIR-020 GPR Data Collection System



Figure 3.2 Ground Coupled GPR Antennas



Figure 3.3 Air Coupled GPR Antennas



Figure 3.4 "Offroad" GPR Equipment

Chapter 4

Potential GPR Applications

GPR has been used successfully in a variety of highway applications (Figure 4.1), including: (1) measuring layer thickness of asphalt pavements, concrete pavements, and granular base layers; (2) estimating asphalt densities; (3) determining moisture content of base materials; (4) identifying stripping zones in asphalt layers; (5) detecting air-filled and water-filled voids; (6) locating subsurface vertical cracks; (7) locating subsurface “anomalies” including buried objects, peat deposits, and near-surface bedrock; and analyzing rutting mechanisms. These applications are discussed separately in the following subsections.

Potential Applications of GPR

- ***Determine Pavement Layer Thickness (AC)***
- ***Estimate Material Properties (AC)***
- ***Identify Stripping Zones within Asphalt (AC)***
- ***Detect Subsurface Voids(AC,GC)***
- ***Analyze Rutting Mechanisms (AC)***
- ***Detect Subsurface Anomalies (GC)***
- ***Bridge Deck Delamination (AC,GC)***
- ***Rebar and Dowel Bar Locates(AC,GC)***

Figure 4.1 GPR Applications to Highway Engineering

4.1 Pavement Layer Thickness

Existing pavement layer thickness measurement methods include coring and test pit excavations (Figure 4.2). These measurements are input to assess the stiffness (and/or strength) of the layered system, using falling-weight deflectometer (FWD). These direct methods are both time consuming and expensive. Furthermore, they only provide information at the test location, i.e., they are point measurements. In contrast, GPR surveys are much less time consuming and provide a continuous description of the road structure. Thus, determination of pavement layer thickness is one of the more successful applications of GPR. The American Society for Testing and Materials (ASTM) Standard D 4748-87 [ASTM Standard Designation: D4748-87, 1987] presents detailed procedures for determining the thickness of pavements using GPR. In determining layer thickness, air coupled antennas (1.0 or 2.0 GHz) are attached to a vehicle. This allows for data collection at speeds up to normal highway speeds, at a collection density of 3 scans/ft, and a depth of penetration of approximately 30 in.

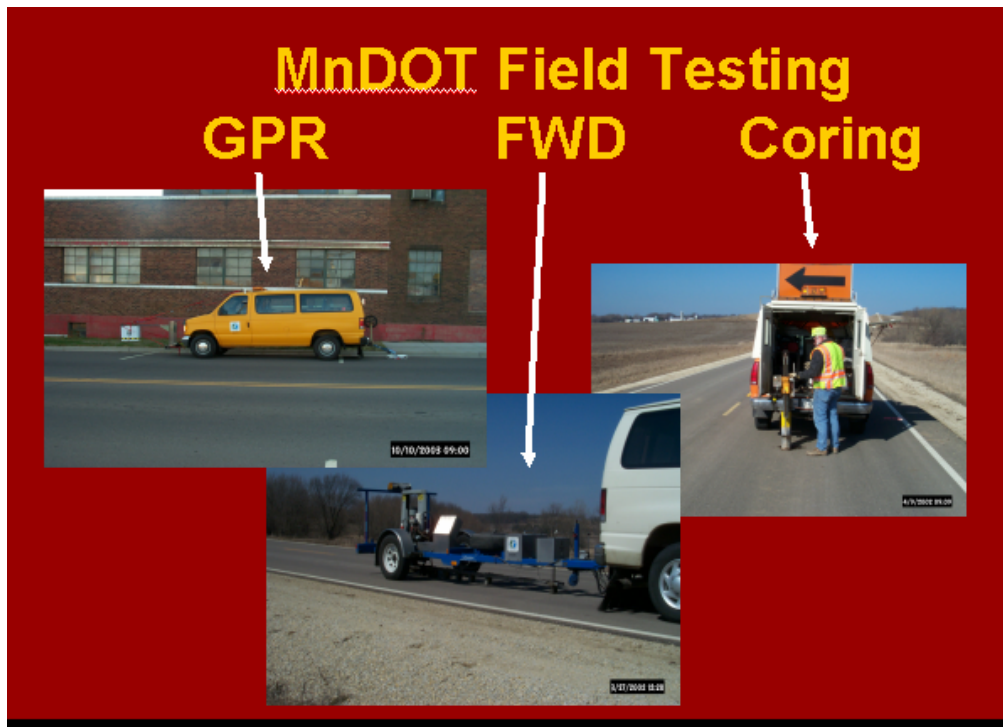


Figure 4.2 Types of MnDOT Field Tests to Assess Layer Thickness

Pavement thickness evaluation is based on the measurement of the time difference between layer reflections and knowing the propagation velocity (or equivalently, the dielectric constant) within each layer. The reflections from the interfaces must be strong enough to be interpreted and tracked for reasonably consistent results. Experience has shown that GPR works well on flexible pavements (asphalt) where there is a strong dielectric contrast between layers, but may be less effective on rigid pavements (concrete) where the presence of moisture tends to attenuate the radar signal, or where the contrast between layers is minimal such as between concrete and granular base materials.

Despite limitations associated with weak signals and material dielectric uncertainties, the advantages of determining thickness with GPR are considerable, since it is a nondestructive, continuous, and high-speed field test. Using GPR technology to determine pavement layer thickness is appropriate for asphalt pavements and dry concrete roadways. It is not appropriate for evaluating wet, high-clay content subgrade layers.

4.2 Asphalt Pavement Density

GPR has been demonstrated to be fairly successful in estimating variations in density (equivalently, void content) of asphalt pavements (Figure 4.3). The basic idea here is that compaction of the pavement reduces the fractional volume of air and increases the relative proportion of the other components (bitumen and aggregate). Since the dielectric value of air (1.0) is substantially lower than that of either bitumen (2.6) or aggregate (6.0), as the asphalt is compacted its dielectric value will increase. A recent study was performed to quantify this dependence [Saarenketo et al., 1992]. A series of laboratory tests was performed on asphalt

mixtures over a range in aggregate types, mixture types, bitumen contents and void contents. These tests included 108 measurements in which the void content ranged from 0.02% to 6.5% and the dielectric values ranged from 2.8 to 5.0. To evaluate asphalt density, two air coupled antennas (1.0 and 2.0 GHz) are required, in which one is both a transmitter and a receiver and the second is a receiver only. This creates two independent measurements (along independent paths) of the same information (road structure). Data collection is possible at up to highway speeds at a collection density of 1 scan/ft and a penetration depth of 30 inches. This use of GPR is appropriate for new pavements where the interface between asphalt and base is sharp, and under dry conditions. It is not useful for wet, older pavements, or for pavements exhibiting stripping, surface cracking, or separation with base.

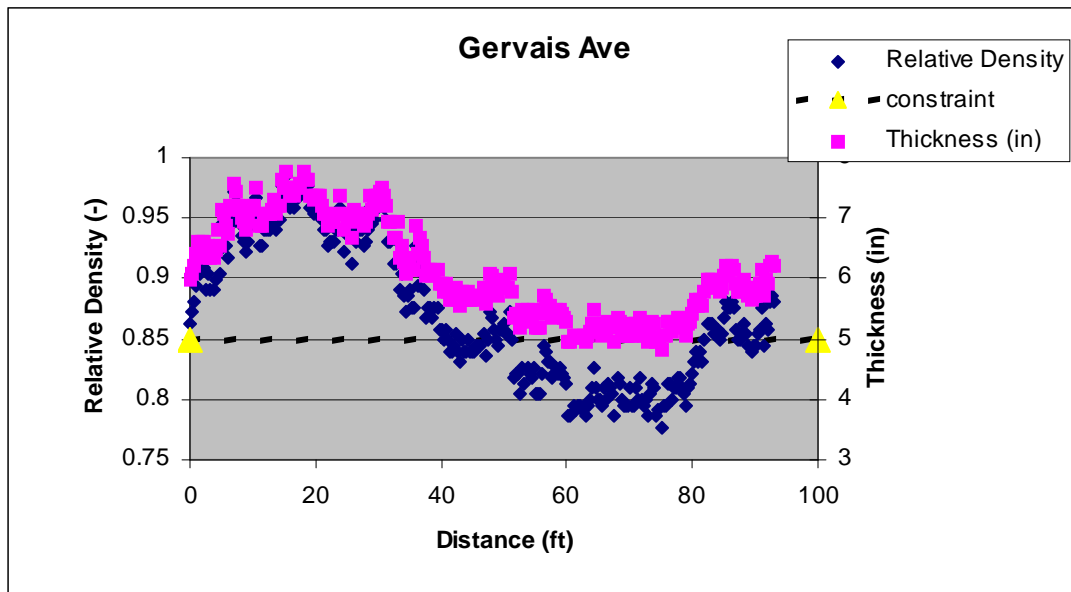


Figure 4.3 Using GPR to Calculate Density and Thickness Simultaneously

4.3 Asphalt Pavement Stripping

Stripping in asphalt pavement is a moisture-related mechanism that occurs in asphalt when the bond between the bitumen and the aggregate is broken, leaving an unstable lower-density layer within the asphalt. Stripping may not be visibly apparent since the pathway for moisture is through subsurface cracks that propagate upward from the asphalt-base interface. This mechanism is accelerated by repeated wet and dry cycles, and the final result is total failure of the bond, leaving a weak unstable layer. GPR may be used to detect stripping, in a nondestructive fashion since the reflections from a lower density material will result in a large negative peak in the waveform. The Texas Department of Transportation (TxDOT) has performed several GPR surveys [Saarenkento and Scullion, 1994] to identify sections of asphalt road systems where stripping may be a concern. Where the asphalt layer is homogeneous (no stripping), the GPR waveform will indicate reflections only at the surface and at the asphalt/base interface. If stripping is present, an additional negative peak (indicative of a lower density material) will be observed between the surface and base reflections (Figure 4.4). It may be possible to estimate the thickness of the stripped sections as well, if the frequency of the antenna is high enough to delineate sublayering. These above mentioned studies surveyed 220 miles of

asphalt roads and identified sections of stripping. These results were compared with “ground-truth” measurements in which cores were taken at 1 mile intervals. The sections identified with the GPR survey matched the coring results, in the cases where stripping was severe. The depth and thickness of the severely stripped sections were “reasonable” in comparison to the actual results. The thickness estimates from homogeneous sections (no stripping) were close (within 10%) to the actual core thicknesses. To assess stripping, an air-coupled antenna (1.0 or 2.0 GHz) is used. Data collection is possible at up to highway speeds, at a collection density of 1 scan/ft, and a penetration depth of 30 inches. This GPR technology is appropriate in spring, when the stripped zones are saturated, and not appropriate in the fall, or during dry times of the year, because the dielectric contrast between asphalt and water is much greater than the contrast to air.

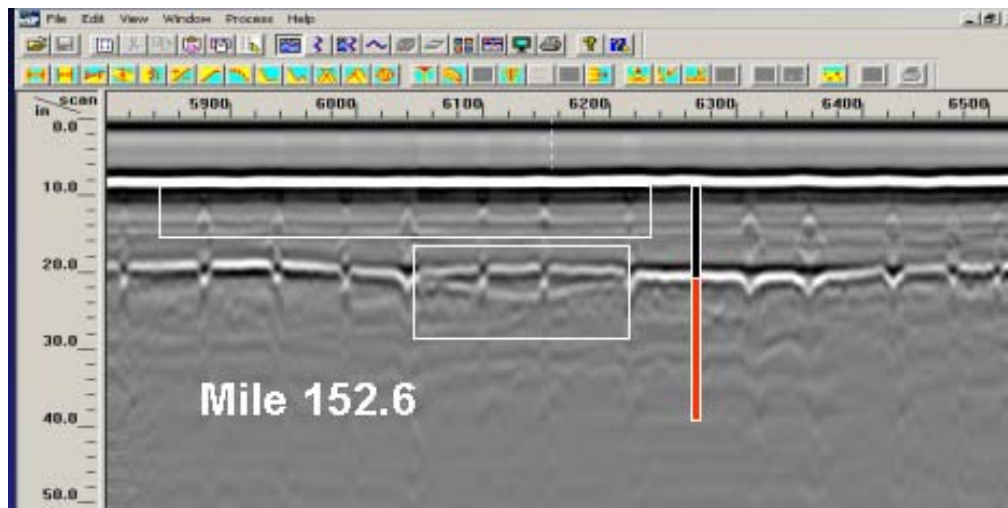


Figure 4.4 GPR Evidence of Stripping

4.4 Void Detection

The nondestructive mapping of voids under pavements is of interest because of the potential loss of support. Voids develop because of consolidation, subsidence, and erosion of the base material. Generally, voids occur beneath joints where water enters the layer and carries out the fines. In theory air voids and water filled voids are both detectable using GPR because the dielectric constants of both air (1.0) and water (81) are substantially different than most pavement materials (3-10). If the void is air-filled, a large negative peak will appear in the waveform (Figure 4.5), since the dielectric constant of air is much less than pavement material. Conversely, a large positive peak in the waveform will appear at the surface of a water-filled void, because the dielectric increases substantially at the interface. In performing a void detection a ground-coupled antenna is used. Depending on the depth of interest, either the 400 MHz (to depths of 10 ft) or 100 MHz (30-50 ft) are used. These surveys are performed at walking speed, at a collection rate of 64 sc/s. This technology is appropriate for near-surface voids (less than 1 ft below surface) to depth of nearly 50 ft. Void detection is best when the voids are water filled, when the dielectric contrast is highest. Void detection is nearly impossible beneath reinforced concrete roadways, since the metal reinforcement reflects and disperses the signal from reaching the void of interest.

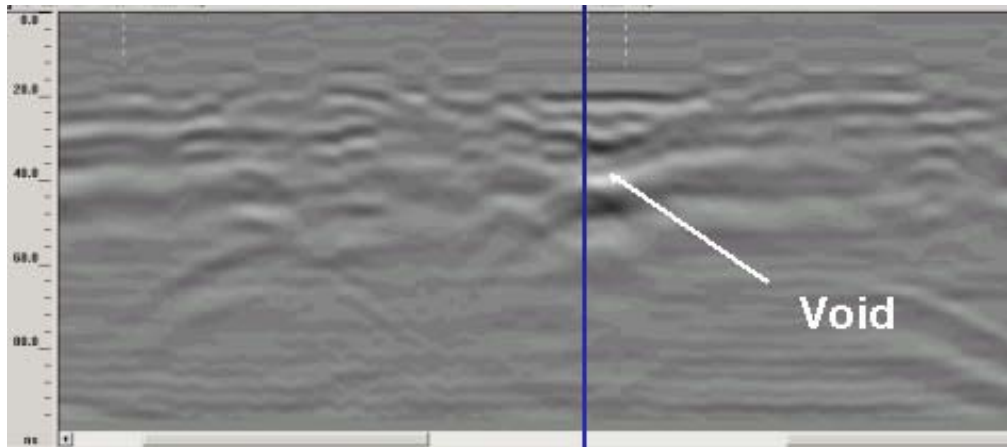


Figure 4.5 GPR Evidence of Subsurface Void

4.5 Subsurface Anomalies

GPR has been used successfully to identify subsurface anomalies. The most common applications to highway engineering include locating buried objects, identifying peat deposits and bedrock, locating underground utilities and locating near-surface bedrock deposits. In the baseline study, LRRB 771, GPR was attempted to locate peat and bedrock deposits to depths of 5 ft. Since that study, GPR has been used to locate (1) a buried cattlepass in Hutchinson, (2) buried dumbwaiters along Lake Street, (3) buried power lines at MnROAD. This technology is best where the dielectric contrast is greatest between the buried anomaly of interest and the in situ formation. GPR can be used to locate both metal and non metal objects to depth of 50 ft, depending on the type of material lying between the anomaly and the surface.

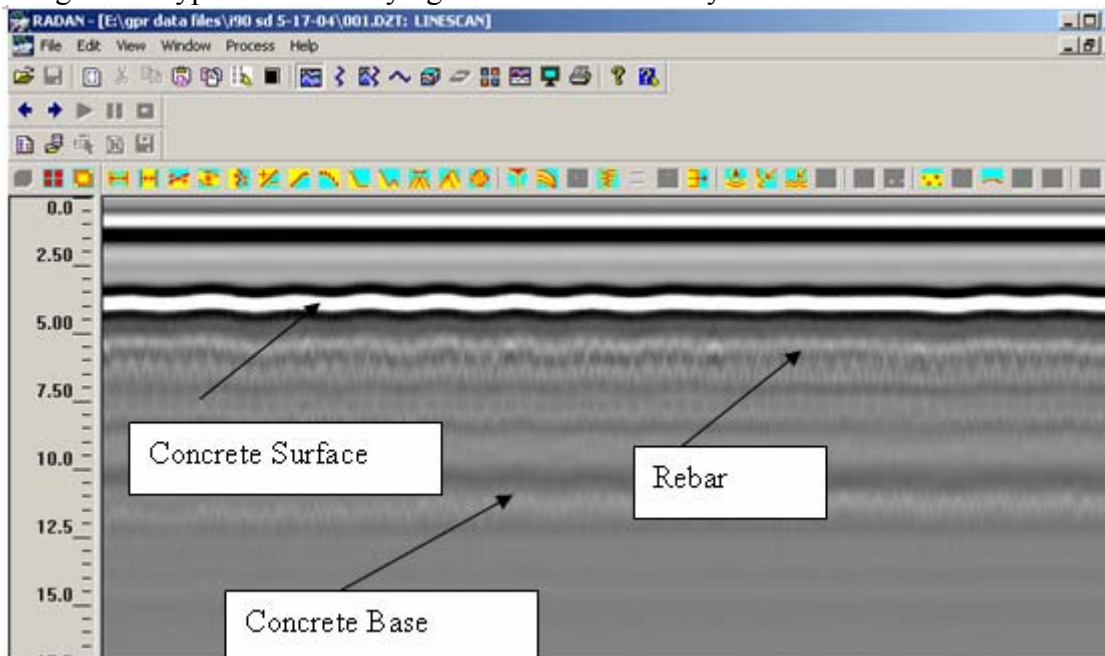


Figure 4.6 GPR Used to Locate Reinforcing Rebar in Concrete Highway

4.6 Rutting

Rutting is a localized depression in the wheel-paths of asphalt highways that occurs because of the concentration of loading. There are two possible mechanisms for rutting: (1) compaction of the asphalt pavement layer; and (2) compaction of the base layer. GPR can be used to identify the mechanisms of rutting, and more importantly, identify possible corrective actions. By comparing the layer thicknesses of two GPR surveys (in the wheel-path and in the lane center), one can identify the layer in which the rutting (compaction) has actually occurred [Roddis et al., 1992]. Because of the relatively high accuracy in asphalt and base layer thickness calculations using GPR, differential layer thicknesses of as small as 0.5 in. are possible. By monitoring the time-history of the rutting, one can more accurately project the life of the highway, and even identify which layers have been adequately designed or under-designed. Since rutting is basically a near-surface phenomenon, air-coupled antennas are appropriate at the survey speeds, collection density, and depth of penetration listed previously. GPR can be used to detect rutting mechanisms best under severe conditions, i.e., the magnitude of rutting deformation is greater than 10% of the overall thickness of the layer. However, this use of GPR is time-consuming, both in data collection and analysis, since both precise measurement and data examination are required, as well as a control location to compare results to.

Chapter 5

GPR Experience in Minnesota

MnDOT has been using GPR technology since 1999. Since then MnDOT's experience and use of GPR technology has been on a rapid increase. Following is a snapshot of various GPR projects MnDOT has conducted across the state over the past several years. The location of these projects are shown below in shown in Figure 5.1 and Table 5.1. These are briefly discussed in the following sections. The collection parameters for each survey are specified in each section. As noted, these represent near ideal conditions. Nevertheless, one should be aware of any special existing conditions that should be avoided, because they may interfere with the results. These conditions include:

- Standing water or snow on highway
- High-ground water conditions
- Use of cellular phones
- Unseen subsurface anomalies (e.g., geotextiles, electric cables, conduits, storm sewers)
- Nearby transmission towers (noisy signals)
- Closely spaced metal reinforcement at near-surface that may shield underlying GPR signal
- Materials containing high contents of iron ore bearing rock (e.g., taconite), which tends to absorb signal

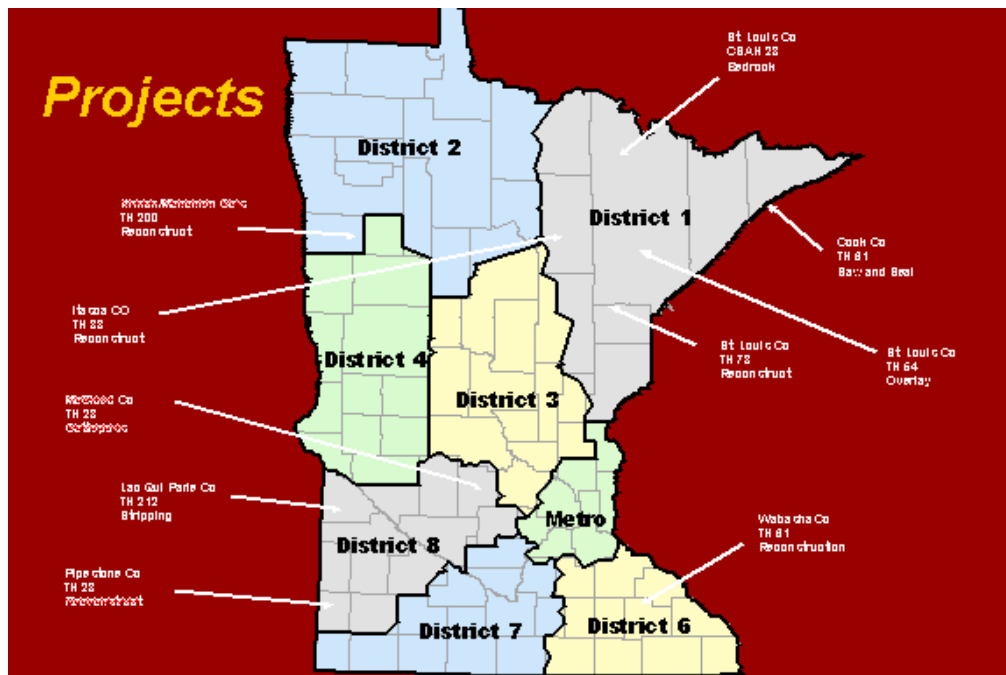


Figure 5.1 GPR Projects in Minnesota

Table 5.1 Various GPR Projects in Minnesota

Description	Highway	Location
Layer History	CSAH 61	Pine City
Bedrock, Peat	CSAH 48	Proctor
Underground Void	TH 10	Biglake
Underground Void	I 94	Melrose
Shoulder Thickness	I 694/35E	Vadnais Heights
BOC	TH8	Taylor's Falls
Stripping	TH 212	Near Dawson
Sinkhole	TH 371	Baxter

5.1 CSAH 61 Study

The objectives of the GPR survey of CSAH 61 in Pine County were (1) to measure the asphalt layer thickness, (2) to estimate the road mix thickness, (3) to detect areas of potential stripping, and (4) to estimate the aggregate base thickness (as shown in Figure 5.2). The GPR data collection parameters for this survey were:

- Air temperature = 60 deg F
- Surface Road Conditions = Dry
- Antenna = 1.0 AC
- Time Window = 20 ns
- Collection speed = 30 mph
- Collection density = 3 sc/ft
- Approximate Penetration depth = 30 in
- Survey length = 10 mi in each direction

A typical result is shown in Figure 5.3.

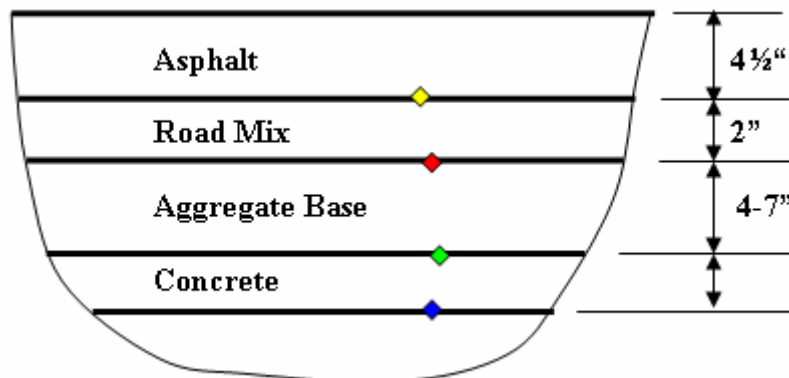


Figure 5.2 Typical Cross-Section of CSAH 61

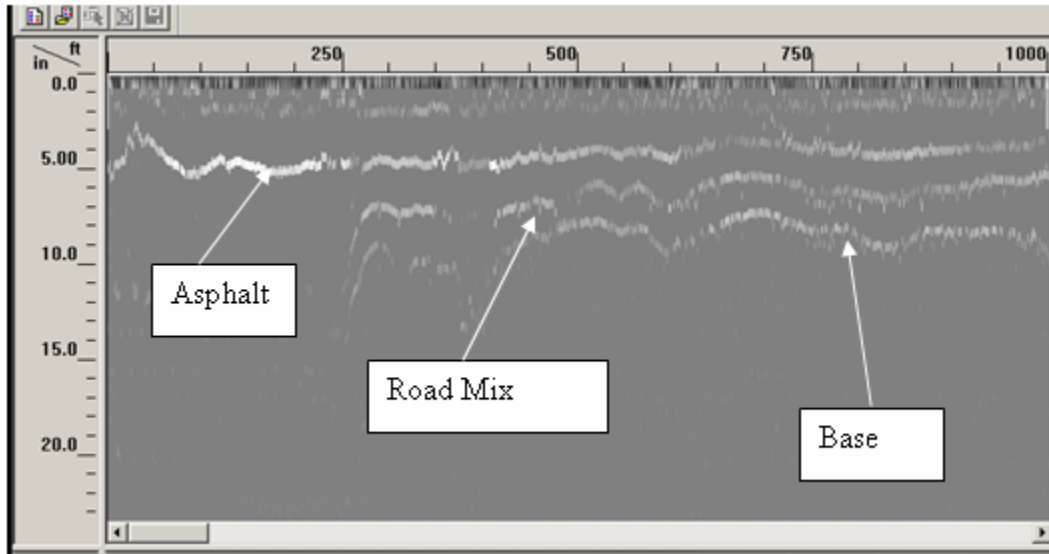


Figure 5.3 Typical GPR Scan of CSAH 61 and Layer Interpretation

In this study, GPR was successful at

- identify the asphalt, road mix, and aggregate base layer thicknesses along a ten-mile stretch of CSAH 61.
- Asphalt-road mix interface
- Stripping in isolated zones
- Concrete base is spot locations

Also in this study, GPR was unsuccessfully at

- distinguish asphalt lift surfaces (i.e., between base and wearing course) because of the dielectric similarities between the two materials.

5.2 CSAH 48 Study – Bedrock and Peat Deposits

The objectives of this study are to use GPR to locate near-surface bedrock deposits and/or peat deposits underlying CSAH 48, in St. Louis County; and to correlate the results with coring results.) The GPR data collection parameters for this survey were:

- Air temperature = 60 deg F
- Surface Road Conditions = Dry
- Antenna = 400 MHz Ground-Coupled
- Time Window = 80 ns
- Collection speed = 10 mph
- Collection density = 1 sc/ft
- Approximate Penetration depth = 8 ft
- Survey length = 6 mi SB

In this study, GPR identified locations and depths to subsurface interfaces (Figure 5.4). However, GPR did not identify near-surface peat deposits or bedrock, as indicated in the soil borings report because of the presence of a geotextile membrane. We believe that we would have achieved better results if we would have used the 100 MHz at a lower survey speed.

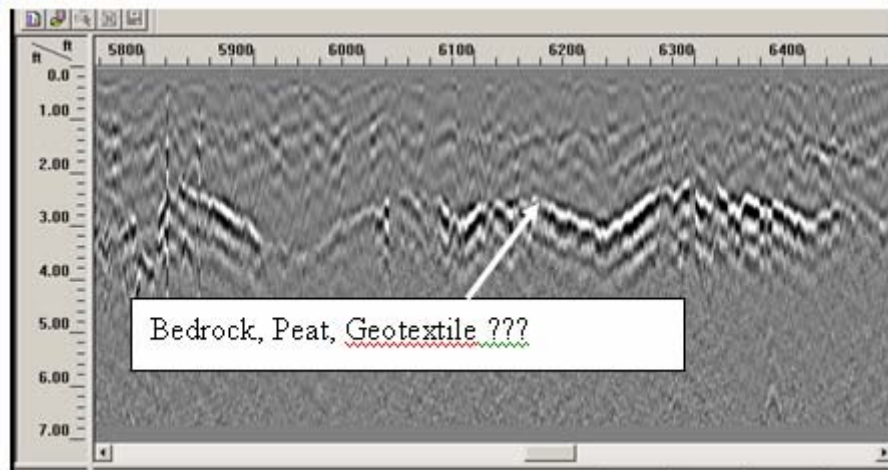


Figure 5.4 Typical GPR Scan From CSAH 48 Survey

5.3 TH 10 Study – Void Detection

A GPR survey of TH 10 near Big Lake was performed to investigate the potential of a subsurface void in the west bound (WB) lane (Figure 5.5). The GPR data collection parameters for this survey were:

- Air temperature = 70 deg F
- Surface Road Conditions = Dry
- Antenna = 100 MHz Ground-Coupled
- Time Window = 200 ns
- Collection speed = 3 mph
- Collection density = 5 sc/ft
- Approximate Penetration depth = 25 ft
- Survey length = 30 ft

The survey identified the void at an approximate depth of 10 ft along survey line 2.

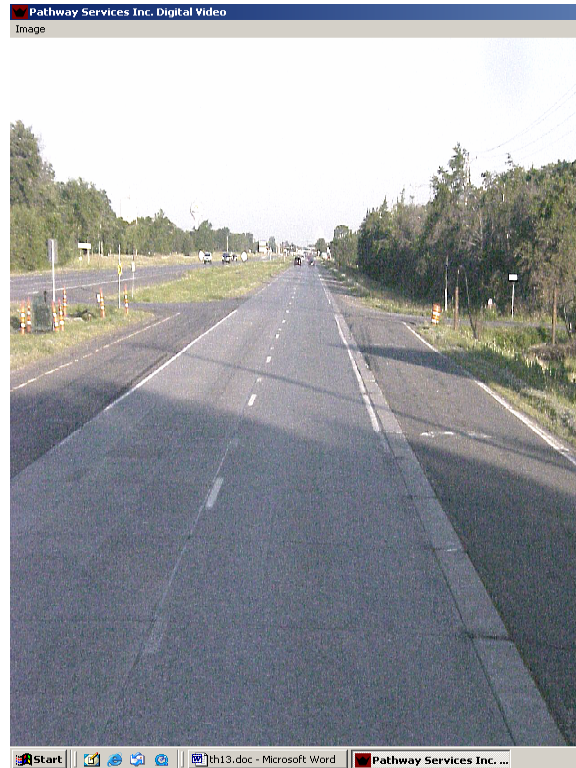


Figure 5.5 Video Image of Test Site (TH10, RP 205.7, WB), Showing approximate locations of GPR Surveys (Lines 1 and 2 at Grid Lines A, B and C)

5.4 I-94 Study – Void Detection

A GPR survey of Interstate 94 at Reference Post (RP) 134+00 was performed on May 10, 2005. The purpose of this survey was to investigate the potential of subsurface voids surrounding two steel-encased water and force mains that underlie the roadway at this location, at an approximate depth of 13 ft below surface. This potential manifests itself in a noticeable surface dip, especially in the EB driving lane. The GPR data collection parameters for this survey were:

- Air temperature = 70 deg F
- Surface Road Conditions = Dry
- Antenna = 100 MHz Ground-Coupled
- Time Window = 200 ns
- Collection speed = 3 mph
- Collection density = 5 sc/ft
- Approximate Penetration depth = 25 ft
- Survey length = 30 ft

Two surveys were taken, one in the eastbound passing lane and the other in the westbound passing lane at the location where three pipes have been. The GPR images indicate the potential

presence of an underground void in the WB driving lane and the EB passing lane at a depth ranging from 12.5 ft to 17 ft.

5.5 I694/35E Study – Asphalt Layer Thickness

A GPR survey of Interstates 35E and 694 was performed on October 13, 2003. The objectives of this survey were (1) to determine the asphalt layer thickness of the right shoulders and (2) to locate sections of bituminous-over-concrete in the shoulders, across the “weave”, i.e., the intersection of I-35E and I-694. The GPR data collection parameters for this survey were:

- Air temperature = 70 deg F
- Surface Road Conditions = Dry
- Antenna = 1.5 GHz Ground-Coupled, 1.0 GHz Air-Coupled
- Time Window = 12-20 ns
- Collection speed = 10 mph
- Collection density = 3 sc/ft
- Approximate Penetration depth = 20,30 in
- Survey length = 10 mi

The use of two antennas (with a horizontal separation distance between the transmitter and receiver) allows for simultaneous calculation of the layer thickness and dielectric constant, without the aid of supplemental ground-truth information. Based on this analysis, the dielectric constant of the asphalt is approximately 6.0 and the concrete is 10.0. The results of this survey indicate that the shoulder thickness is approximately 3 inches west of TH 61 and approximately 8-12 inches east of TH61

5.6 TH 8 Study – Bituminous over Concrete

A GPR survey of TH 8 was performed in 2003, from the intersection of TH 95 (RP 18.755) to Taylor’s Falls (RP 22.00). This highway is a bituminous asphalt over concrete (BOC) roadway, with an approximate total thickness of 11.5 inches, and with the most recent overlay of 2 inches performed in 1993. The objective of this survey was to determine the thickness of the bituminous asphalt layer in the outer most section of the roadway. The entire 3 ¼ mi stretch of this highway has experienced longitudinal cracking immediately outside the right wheel path, indicating that the underlying rigid concrete layer may be narrower than the current flexible, bituminous surface, which might cause severe surface bending stresses resulting ultimately in failure. GPR surveys may be useful in establishing a continuous profile of the bituminous asphalt layer thickness in this section, and provide insight for possible remediation efforts. The GPR data collection parameters for this survey were:

- Air temperature = 70 deg F
- Surface Road Conditions = Dry
- Antenna = 1.5 GHz Ground-Coupled, 1.0 GHz Air-Coupled
- Time Window = 12-20 ns
- Collection speed = 10 mph

- Collection density = 3 sc/ft
- Approximate Penetration depth = 20,30 in
- Survey length = 3 1/4 mi

The results of this study indicate that there is considerable variation in the layer thickness, ranging from less than 2 inches to more than 12 inches. Overall the results indicate a mean thickness of 5.1 inches and a standard deviation of 2.3 inches. The results also indicate that less than 5 percent of the highway has a layer thickness of less than 2 inches.

5.7 TH 212 Study – Stripping

A GPR survey of TH 212 between Dawson and TH 75 was performed on May 1, 2003. The purpose of this survey was to determine the locations and extent of stripping within the full-depth asphalt section. Two antennas were used in this survey, a 1500 MHz ground-coupled antenna with a time window of 12 ns and a 1000 MHz air-coupled antenna with a time window of 20 ns. Using an average dielectric constant of 6 this allows for penetration depths of approximately 20 in and 36 in, respectively, for the two antennas. The survey distance was 29,157 feet (5.52 miles) from RP 18.285 to RP 12.76 at a sampling density of approximately 3 scans/ft and a survey speed of approximately 10 mph. The GPR images were used in conjunction with video images and FWD testing results to classify the extent of stripping according to the following five subjective criteria:

1. Digital video images which show transverse cracks along the surface, along with localized downward bending of the asphalt near the cracks are indicative of a higher stripping potential (i.e., weaker) within the near-surface asphalt.
2. GPR images that indicate a high deviation of the surface dielectric value (i.e., oscillations in the surface amplitudes) are indicative of near-surface stripping.
3. GPR images that show a strong internal reflection (i.e., within the asphalt matrix) that varies in depth are indicative of internal stripping, since in this case the reflections can't account for horizontal interfaces along the asphalt layer boundaries.
4. If there has been rain recently and the GPR images along the asphalt base are strongly “bending” downward, especially under the surface cracks, this is indicative that the asphalt is severely stripped since the dielectric value increases significantly in lower density (stripped) asphalt when the voids are water filled.
5. FWD deflection values close to the load plate are higher than normal indicates a higher stripping potential, i.e., higher deflections indicate a lower surface modulus and possibly a weaker material.

These five criteria were used to evaluate the stripping potential by averaging each condition across each 0.1 mile increment of TH 212, using three qualitative measures HIGH, MEDIUM, and LOW. Based on these results, the stripping potential is highest in RP's 12.9 and 15.7 and the lowest in RP's 13.7 and 14.5.

5.8 TH 371 Study – Utility and Void Detection

A GPR survey of TH 371 near Baxter was performed in 2005. The purpose of this survey was to investigate the potential of subsurface voids surrounding a steel-encased water main that underlies the highway at this location, at an approximate depth of 10 ft below the road surface. This potential has manifested itself in a surface depression and subsequent patch in the southbound passing lane. A 100 MHz antenna with a time window of 200 ns was used in this survey. Using an average dielectric constant of 10 (typical of a mixture of asphalt, medium-dry aggregate base, and reasonable subgrade) this allows for a penetration depth of approximately 30 ft. The survey distance was 50 ft along all survey lines, centered above the water main.

The GPR images indicate the potential presence of an underground void surrounding the pipe in the southbound passing lane and the northbound right turning lane at a depth of about 10 ft (approximate depth of water main).

Chapter 6 Summary

GPR is a high-speed, continuous, nondestructive field test that has been demonstrated in to give reasonable results in a variety of highway applications, including:

- estimating layer thicknesses for asphalt, concrete, base, and subgrade
- estimating asphalt density
- identifying stripping zones
- detecting subsurface voids
- locating subsurface anomalies
- identifying rutting

MnDOT has used GPR successfully on some of these types of projects (layer thickness underground void detection), moderately successfully (stripping), and unsuccessfully (bedrock and peat). MnDOT engineers have been using GPR technology since 1998. It takes years of experience to use GPR equipment and interpret GPR results. MnDOT engineers will continue to improve their understanding of this technology to implement this application in the future. Whether GPR is a good candidate for your project is a function of the site conditions. GPR works best for near-surface, dry soil conditions where the dielectric contrast is greatest, and conversely does not work well in wet, clayey soil conditions where the dielectric contrast is negligible.

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