Implementation of Ground Penetrating Radar

Technical Summary Report

PROJECT TITLE
Implementation of Ground Penetrating Radar

SPONSOR
Local Road Research Board

This project was a joint effort between the Office of Materials (OM) 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). The authors are responsible for the content of the report.

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Objective

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 summary report will give the local engineer a brief overview of GPR. A review of GPR applications for use on local roads is also available. The Final Report describes the results of GPR surveys performed throughout the State of Minnesota.

Problem Statement

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.

Technology Description

GPR operates by transmitting short pulses of electromagnetic energy 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 dielectric constants of the material layers. Across the interfaces, part of the energy is reflected and part is absorbed, depending on the dielectric contrast of the materials (Table 1).

Table 1. Dielectric constants for typical pavement materials.

Material	Dielectric
Air	1
Frozen soil	4
Dry sand	4 to 6
Wet sand	30
Dry clay	8
Wet clay	33
Asphalt	3 to 6
Concrete	9 to 12
Water	81
Metal	∞

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 (Δt_1) between peaks A_1 and A_2 represents the two-way travel time through the pavement layer (Figure 1).

MnDOT maintains an inventory of GPR equipment: two data collection units, one analysis software program (RADAN), three ground-coupled antennas (100 MHz, 400MHz, 1.5 GHz) and two air-coupled antennas (1.0 GHz and 2.0 GHz). In addition, MnDOT maintains a vehicle dedicated to GPR data collection that includes an independent power source, a GPS unit, an electronic DMI device, and a Video camera (Figure 2). Also, for "off-road" projects, a buggy has been modified for GPR use.

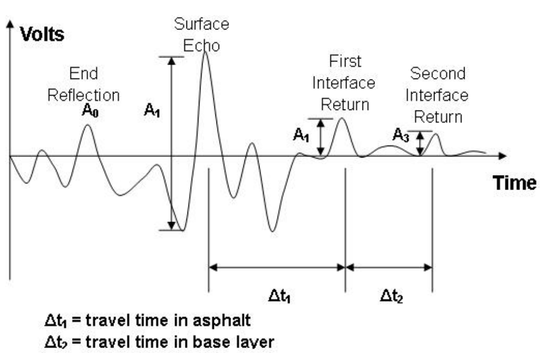

Figure 1. Schematic representation of a time history from a pavement section.

Figure 2. Mn/DOT van dedicated to GPR.

GPR Applications

GPR has been used successfully in a variety of roadway applications, including: (1) measuring layer thickness of asphalt 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 buried objects such as metal pipes and near-surface bedrock. These applications are discussed separately in an attachment that contains detailed reports of 22 projects completed throughout the State of Minnesota.

GPR Primer

The GPR technique has an advantage over other non-destructive techniques in that the source and receiver do not need to be attached to the pavement; this arrangement is referred to as an air-coupled antenna and allows surveys to be performed near highway speed. MnDOT has two such antennas that operate at 1.0 or 2.0 GHz and these penetrate 2-3 ft into the ground. To improve penetration depth, a ground-coupled antenna can be used at walking speed and MnDOT has such three antennas: 100, 400, and 1,500 MHz, with the 100 MHz antenna penetrating 10-30 ft into the ground. A GPR image (Figure 3) is developed by combining a number of time histories obtained during the survey. The GPR image reflects certain features due to either the road surface or underground objects. In order to better understand and interpret GPR images, several "ideal" GPR images associated with certain features are reviewed. It is important to note that the GPR image is different from the road profile.

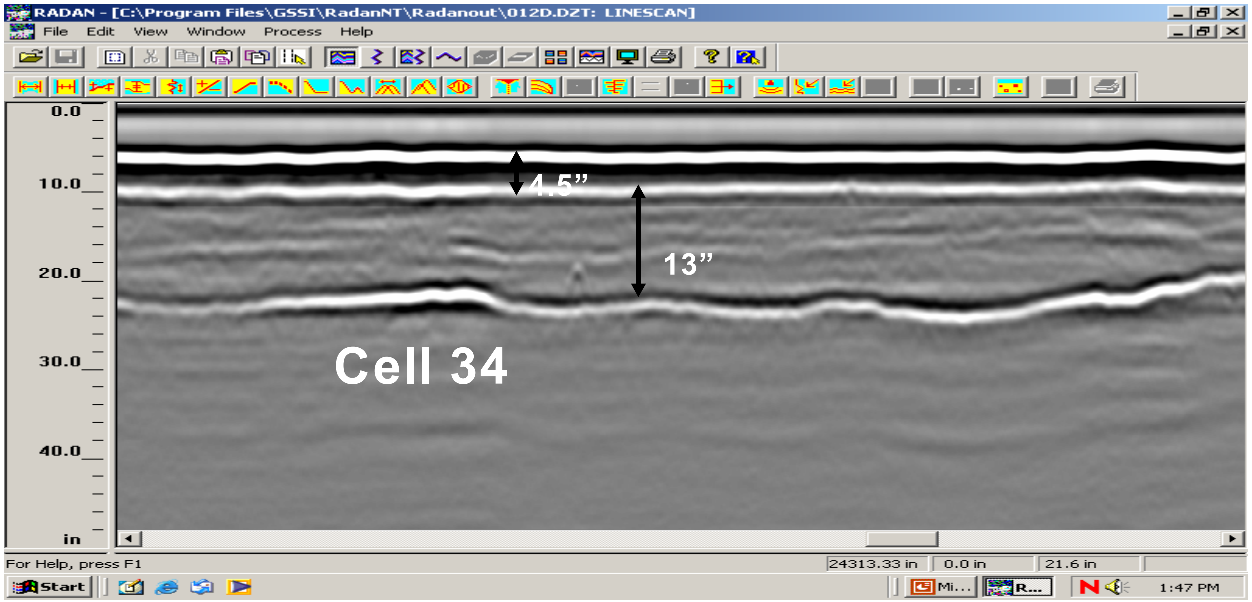

Figure 3. GPR image obtained from Cell 34 at MnROAD. The asphalt layer was estimated to be 4.5 in. and the base thickness was 13 in.

The GPR technique is an effective tool to evaluate asphalt pavement thickness and the near surface profile. In particular, GPR is usually successful in estimating depths (less than a few feet) of the pavement structure over long distances (several miles). Figure 4 illustrates a depression on the surface of the road that may be caused by rutting or other form of pavement distress. Figures 5 and 6 are the resulting GPR images for a ground- and air-coupled antenna.

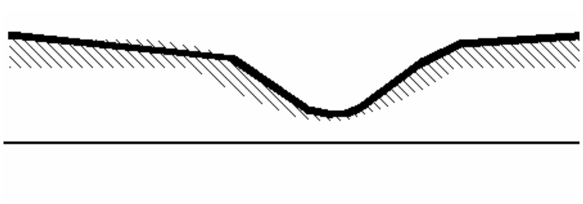

Figure 4. Sketch of a pavement profile.

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.

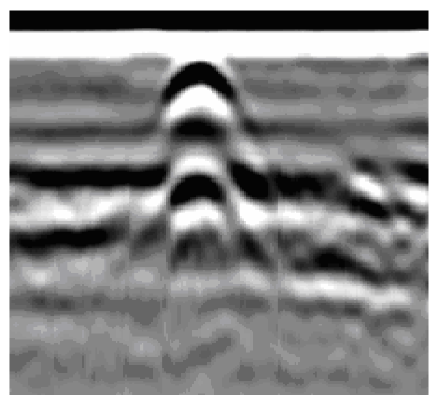

Figure 5. Ground-coupled antenna surveying a road with a depression.

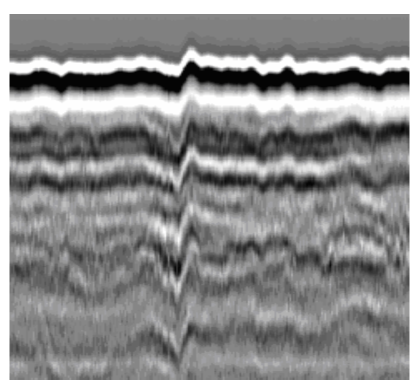

Figure 6. Air--coupled antenna surveying a road with a depression.

Pavement Thickness

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 presents detailed procedures for determining the thickness of pavements using GPR. For data collection at normal highway speeds, an air coupled antenna (1.0 or 2.0 GHz) is attached to a vehicle and a collection density of 3 scans/ft is used, with a penetration depth of approximately 30 in.

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. Thus, 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. Figure 3 is an example of the high-quality data that can be obtained.

Subsurface Anomalies

Subsurface anomalies (Figure 6) such as a void (cavity) or an obstacle (metal pipe) may be detected using GPR. For example, a void can develop because of consolidation, subsidence, or erosion of the base material. Generally, voids occur beneath joints where water enters the layer and carries out fines. In theory, voids filled with air or water are both detectable using GPR because the dielectric constants of 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, and the resulting GPR image appears as multiple hyperbole (Figure 7a). A metal object is a perfect reflector and one hyperbole appears in the image (Figure 7b).

Figure 7. Sketch of object that represents (a) void (Figure 8a) or (b) obstacle (Figure 8b).

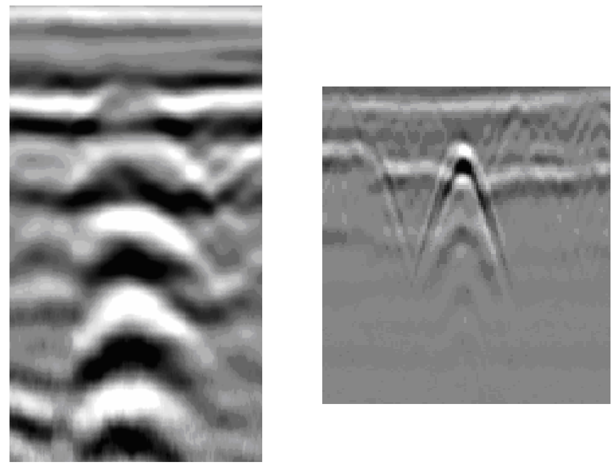

Figure 8. GPR image (a) void; (b) obstacle.

Experience in Minnesota

Twenty-two projects were completed throughout the State of Minnesota, with at least two projects from each district. GRP surveys were conducted between June and November, 2006. The surveys included pavement thickness and profile evaluation (12 projects), void detection (7 projects), and utility location (3 projects). The appendices of the Final Report contain a summary from each survey. In general, the GPR technique was successful in pavement thickness and profile evaluation. However, it has some problems with void detection. Special existing conditions that should be avoided because they may interfere with the GPR signal include

- standing water or snow on the highway,
- high-ground water conditions,
- use of cellular phones,
- nearby transmission towers (noisy signals),
- metal reinforcement near-surface, or materials containing high contents of iron ore bearing rock (e.g., taconite).

Profile Evaluation

A GPR survey was performed on CSAH 37 south of Erskine in Polk County. The objective of the survey was to identify the variation of an overlay and pavement thickness. The survey length was 32,400 ft using a 2.0 GHz air-coupled antenna. A GPR image is shown in Figure 8; the horizontal dimension is feet and the vertical dimension is depth below the road surface. The white horizontal line at a vertical depth of 0 in. is the road surface (indicated by yellow dashed line). The red and green dashed lines indicate the bottom of the overlay and bottom of the surface layer, respectively. For this project (Figure 9), the overlay depth varied from 1.5 – 2 in., with an average of 1.7 in. and a standard deviation of 0.1 in. The surface layer depth varied from 2.5 – 5 in., with an average of 3.5 in. and a standard deviation of 0.5 in.

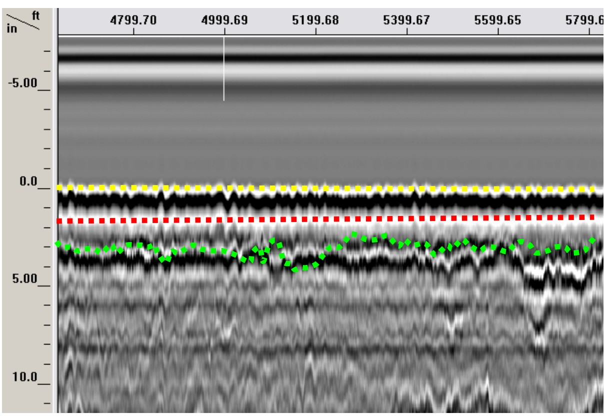

Figure 8. GPR image from CASH37.

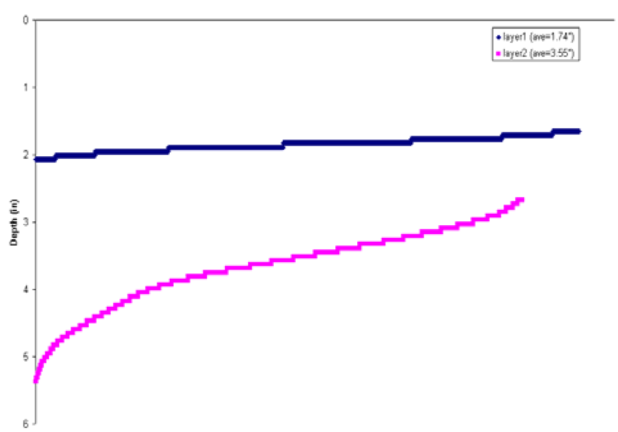

Figure 9. CASH37 pavement thicknesses.

Void Detection

If a void or cavity a few feet in size is air-filled, a large negative peak will appear in the waveform, because the dielectric constant of air is much less than pavement material. Void detection is nicely illustrated by a GPR image of buried culverts (Figure 10), where multiple hyperbole identify the buried pipe.

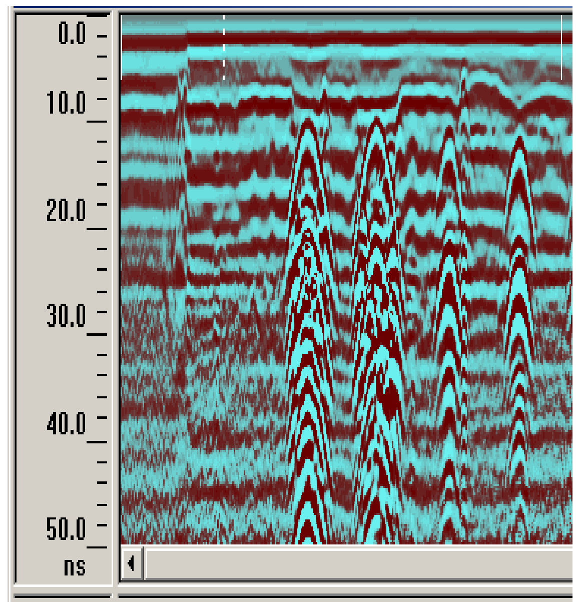

Figure 10. GPR image from buried culverts.

Utility Location

Utilities such a water pipe or other metal object can be located if sufficient penetration is achieved. MnROAD provided an opportunity to probe a pavement where metal plates were placed 10.5 and 17.0 in. below the surface. A single hyperbole is associated with each metal plate (Figure 11).

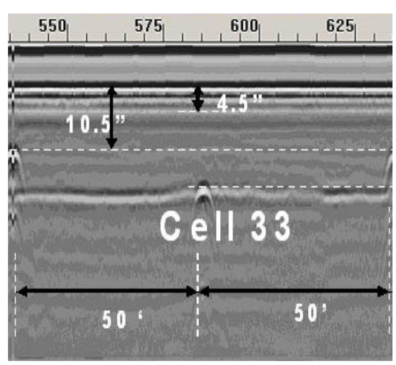

Figure 11. GPR image from metal plates.