GPR (Base, Subbase, Subgrade Thickness)

Target of Investigation

Ground penetrating radar (GPR) can be used for a range of subsurface investigation in pavement applications. For condition assessment of the base and subbase course of pavement, GPR can be used for measurement of the thickness levels of different layers.

Description

GPR testing is a widely used nondestructive evaluation technique for detecting subsurface structural elements and anomalies in structures. Two types of GPR systems are available:
air coupled (figure 1) and ground coupled (figure 2).

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Figure 1. Photo. Air-coupled GPR system mounted on a vehicle.[3]

> *This photo shows data collection using an air-coupled ground penetrating radar (GPR) system. A 2-gigahertz air-coupled antenna is mounted on the rear of a van driving on an asphalt pavement. The antenna is a box approximately 2 feet tall by 2 feet long by 1 foot wide (0.6 by 0.6 by 0.3 meters). The antenna is resting on a support at bumper level and held by straps attached to a roof rack. The blue cable of the GPR runs from the antenna to the interior of the van.*

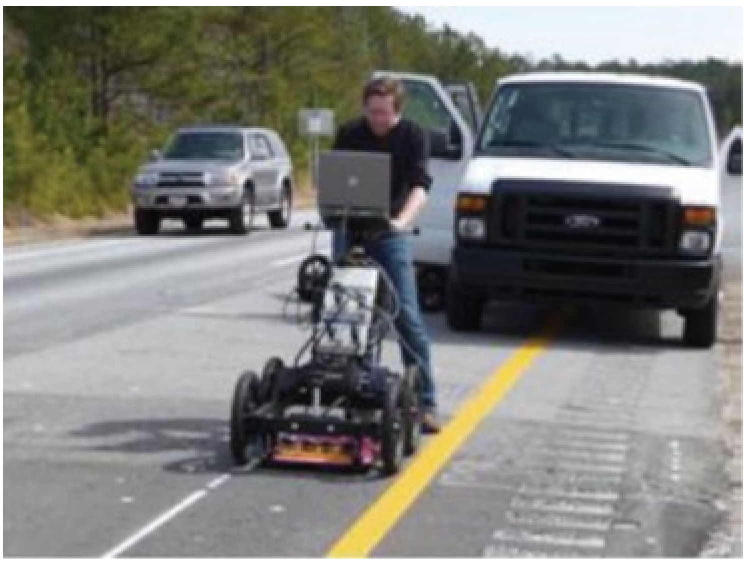


Figure 2. Photo. Data collection with a ground-coupled GPR system.[2]

This photo shows data collection with a ground-coupled ground penetrating radar (GPR) system from an asphalt pavement. The GPR is installed on a cart. An operator is pushing the cart along the yellow edgeline of the road. The cart has four wheels, and the GPR antenna is attached at the bottom of the cart. The laptop of the GPR system is installed on the cart at waist height.

Air-Coupled GPR

Air-coupled antennas are noncontact systems (i.e., they do not touch the surface during surveying). Air-coupled GPR systems are usually faster than ground-coupled systems; generally, they are used as a scanning tool to indicate locations where indepth testing with other systems (including groundcoupled GPR) is needed.[4]

Ground-Coupled GPR

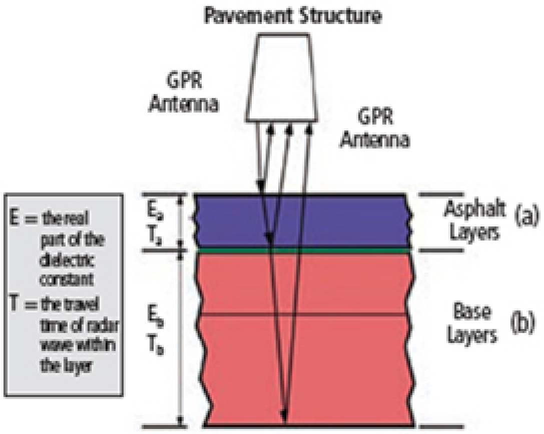
Ground-coupled antennas, unlike air-coupled systems, must remain in contact with the surface while surveying. They are able to detect defects containing sizable air pockets or significant moisture under the surface. GPR signals are reflected at layer interfaces (including objects and defects) where different dielectric constants exist within the pavement. The collected data are processed and analyzed to create a condition map of the structure or an image of the subsurface structure, including thickness and defects.

Physical Principal

GPR operates by sending discrete electromagnetic wave pulses (with a frequency range of 100–5,000 MHz) into a structure and then capturing the reflections from layer interfaces or other reflectors within the structure. Radar obeys the laws governing reflection and transmission of electromagnetic waves and is affected by the dielectric properties of the material: conductivity and the dielectric constant.[1] At each interface, part of the incident energy will be reflected back, and part will be transmitted beyond the interface. The ratio of reflected to transmitted energy depends on the contrast in dielectric properties of the materials on either side of the interface.

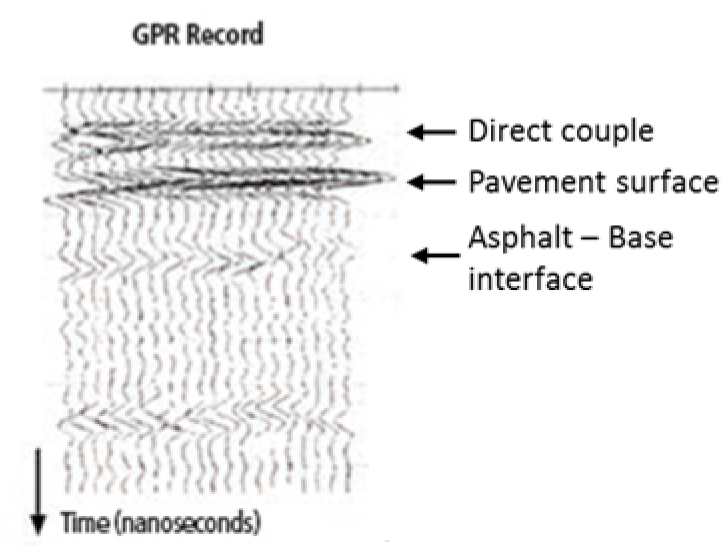
Air-Coupled GPR

As shown in figure 3, the largest peak of air-coupled GPR is the reflection from the pavement surface. The amplitudes before the direct couple are internally generated noise, and they should be removed from the trace prior to signal processing. Reflections that occur after the surface echo represent significant interfaces within the pavement, and the measured travel time is related to the depth of the layer. These reflections could be used to estimate the thickness of different layers of the pavement. Figure 4 is an equation to calculate layer thickness.



Source: FHWA.
A. GPR propagation and reflection.

This illustration is a schematic showing the reflection of an air-coupled ground penetrating radar (GPR) signal from a pavement structure. The box at the top of the figure represents a GPR antenna. Below this box is a section that represents the asphalt layer, and below that is another section that represents the base layers of the pavement structure. Arrows represent the propagation and reflection of the GPR signal at the interface of multiple layers. At each layer, some of the signal is reflected back toward the antenna. E subscript a and E subscript b are the dielectric constants of the asphalt layer and base layer. T subscript a and T subscript b are the travel time of the GPR signal in the asphalt layer and base layer.



Source: FHWA.
B. Multiple GPR A-scans.
Figure 3. Illustrations. Principle of air-coupled GPR for measuring pavement thickness.[5]

This illustration depicts waveforms of the ground penetrating radar signal. Each curve in the graph is an A-scan. The first obvious peak on each A-scan represents the direct couple. The second peak (the largest peak) represents the air–pavement interface. The third peak represents the asphalt–base interface.

$$h_1 = \frac{(c\Delta t_1)}{\sqrt{\varepsilon_a}}$$

h subscript 1 equals the quotient of open parenthesis c times Delta t subscript 1 close parenthesis divided by the square root of epsilon subscript a."/>

Figure 4. Equation. Calculation of layer thickness.

Where:

h_1 = thickness of a layer.

c = speed of the radar wave in air.

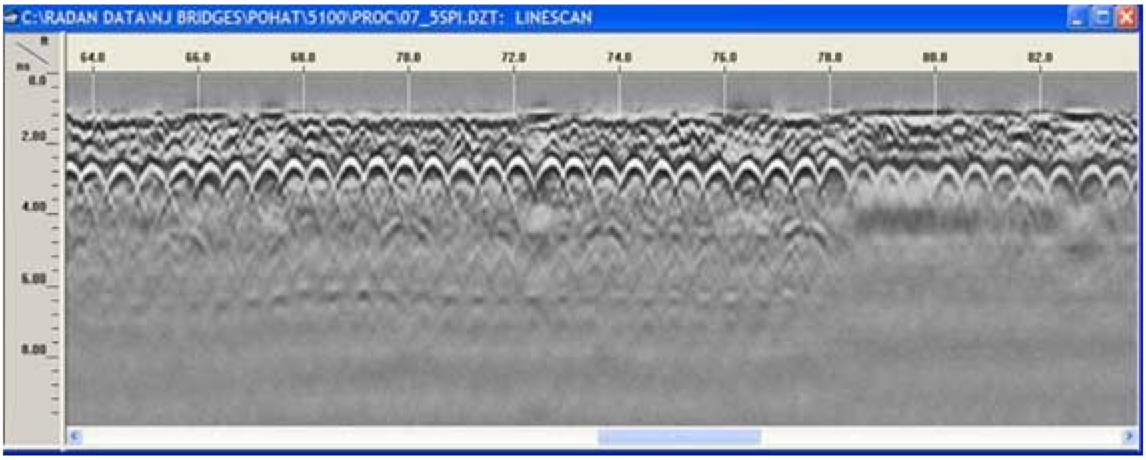
Δt_1 = time delay between two adjacent peaks.

ε_a = dielectric of the pavement surface.

Ground-Coupled GPR

The physical principles of ground-coupled GPR systems are similar to those for air-coupled GPR systems. Although slow compared to air-coupled systems, ground-coupled systems provide better depth penetration and a higher amount of readings. Thus, ground-coupled systems are better suited for indepth data collection and defining subsurface interfaces or defects.

A GPR signal attenuates as it travels in a structure. Signal attenuation depends on geometric attenuation, signal scattering, reflections, and thermal losses. Two-way travel time and reflection amplitudes are recorded with a receiver antenna. When measurements are made over sequential survey points, they can be viewed as a GPR B-scan or profile (figure 5). The thickness of a layer within the structure can be calculated with the equation in figure 4. Rebars and dowels are seen as bright hyperbolas.



Source: FHWA.
1 ft = 0.3 m.
Figure 5. Graph. Example GPR B-scan.

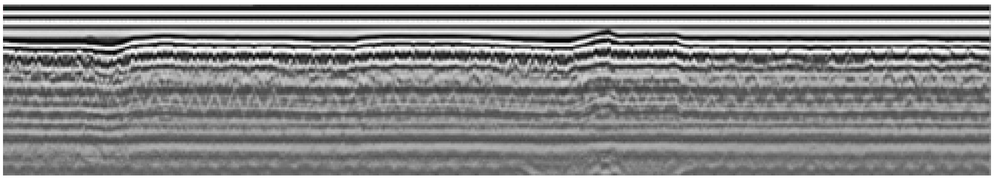
This graph has an x-axis representing distance in feet ranging from 64.8 to about 83, and a y-axis representing two-way travel time in nanoseconds ranging from 0 to 10. Valid data start at the two-way travel time of about 1.2 nanoseconds, representing a signal reflected from the surface of the pavement. Many bright hyperbolas with two-way travel times of about 2.5 nanoseconds indicate the reinforcement in the pavement.

Data Acquisition

Manufacturers of GPR (air and ground coupled) recommend following their system-specific testing procedures when collecting data. These procedures are available in the user manuals supplied by manufacturers.

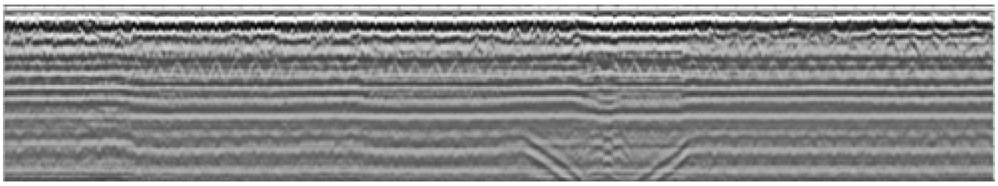
Data Processing

Data processing should be performed by personnel with extensive training and experience. Data processing can be done using analysis software. Preprocessing, which does not change the signal content of the original data, includes data channel splitting, data scaling, data reversing, and zero-level correction. Processing operations consist mainly of filtering operations and amplitude and dielectric value calculations. The primary objective of processing is to make GPR data more informative and easy to interpret. Figure 6 shows raw, preprocessed, and processed data. Software can be used to “pick” individual objects for analysis and to calculate the depth of suspected defects or layers using the two-way travel time.



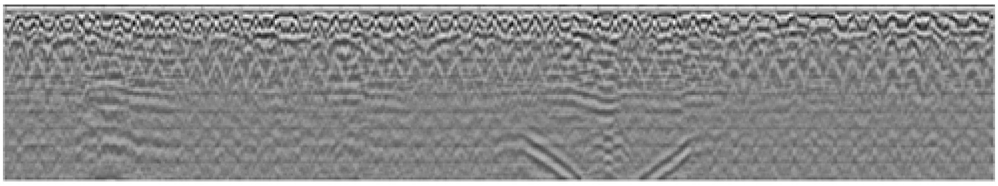
A. Raw GPR data.

This screenshot is of a B-scan of raw data. There are a few straight horizontal lines. The x-axis represents distance, and the y-axis represents depth. The GPR raw output shows noise and offset depth.



B. Preprocessed GPR data.

This screenshot is of a B-scan of preprocessed data. The straight lines have been removed by deleting data with two-way travel times less than certain values. The x-axis represents distance, and the y-axis represents depth.

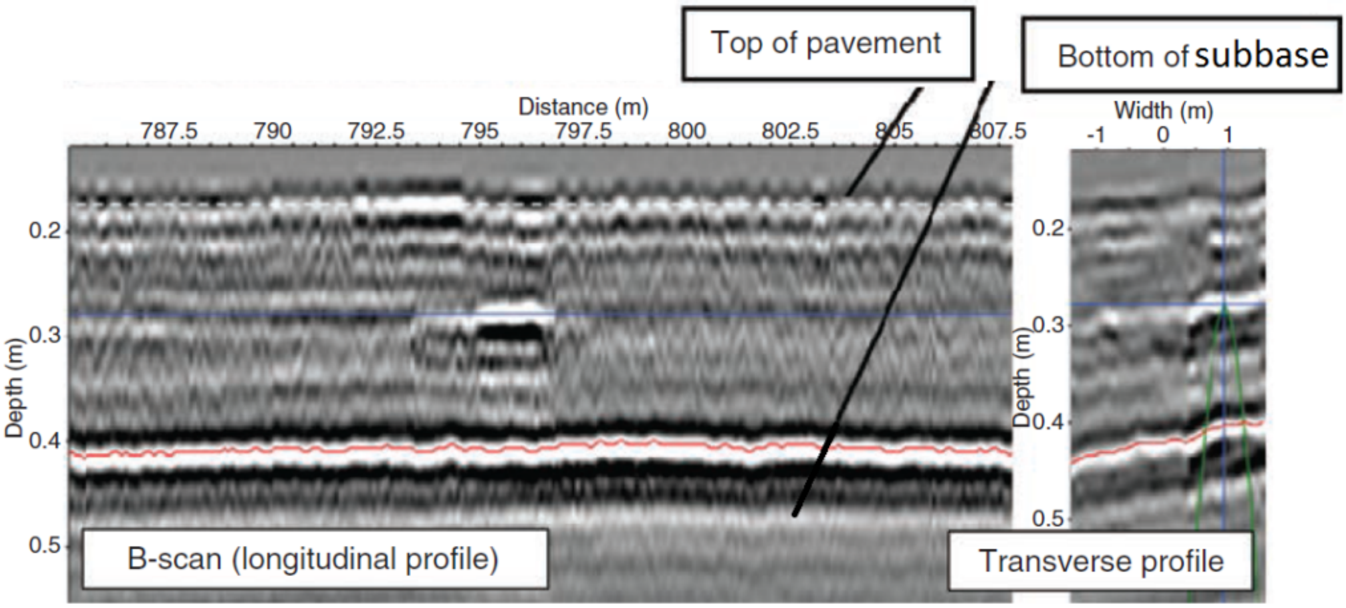


C. Processed GPR data.
Figure 6. Screenshots. Raw, preprocessed, and processed GPR data.[(4)]

This screenshot is of a B-scan of processed data. A constant signal has been removed, leaving variations in the data. The x-axis represents distance, and the y-axis represents depth.

Data Interpretation

Data interpretation should be performed by personnel with extensive training and experience. Layers can be visible in GPR B- and C-scans. Figure 7 shows an example of pavement scans measured with ground-coupled GPR. Each layer thickness can be determined from the GPR processed data.



1 m = 3.3 ft.
Figure 7. Graph. GPR scans showing subbase layer thickness in a pavement.[(2)]

This graph contains two components. On the left of the figure is a B-scan, which is the longitudinal profile of the pavement. The x-axis is the distance ranging from 785 to 807.5 meters. The y-axis is the depth ranging from 0.1 to 0.5 meters. The horizontal, dashed line at a depth of 0.18 meters is labeled "Top of pavement," and the solid line at a depth of 0.4 meters is labeled "Bottom of subbase." On the lower right of the figure is the transverse profile. The x-axis represents width ranging from negative 1.5 to positive 1.5 meters. The y-axis represents depth ranging from 0.1 to 0.5 meters.

Advantages

Advantages of GPR include the following:

- Well-established field data collection processes.
- Rapid test methods.
- Reliable and repeatable results.

Limitations

Limitations of GPR include the following:

- Extensive training and experience are required for operation, data processing, and data interpretation.
- Steel reinforcement mesh in the surface course may prevent signal penetration.
- Salts in concrete (from deicing operations or seawater) may cause signal penetration problems.
- External electromagnetic radiation (from cell phone, radio, and television antennas) can cause signal degradation.

References

1. Gucunski, N., Imani, A., Romero, F., Nazarian, S., Yuan, D., Wiggenhauser, H., Shokouhi, P., Taffee, A., and Kutrubes, D. (2013). *Nondestructive Testing to Identify Concrete Bridge Deck Deterioration*, Report No. S2-R06A-RR-1, Transportation Research

Board, Washington, DC.
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4. Wimsatt, A., White, J., Leung, C., Scullion, T., Hurlebaus, S., Zollinger, D., Grasley, Z., et al. (2014). *Mapping Voids, Debonding, Delaminations, Moisture, and Other Defects Behind or Within Tunnel Linings*, Report No. S2-R06G-RR-1, Transportation Research Board, Washington, DC.
5. Arnold, J.A., Gibson, D.R.P., Mills, M.K., Scott, M., and Youtcheff, J. (2011). "Using GPR to Unearth Sensor Malfunctions." *Public Roads*, *74*(4), Federal Highway Administration, Washington, DC.