GPR (Asphalt Compaction Assessment)

Target of Investigation

Ground penetrating radar (GPR) can be used for surface investigation of asphalt pavements. In assessing the density of the hot mix asphalt (HMA) surface course, GPR can be used for the following applications:

- Measurement of uniformity of HMA density during construction.[1]
- Detection of segregation and mix densification.

A device that uses the GPR technology for the evaluation of pavement density is referred to density profiling system (DPS) that continuously measure asphalt compaction quality. DPS improves the measurement coverage over current quality assurance methods and mitigates destructive approaches.

Description

The density of asphalt concrete plays a significant role in long-term pavement performance. It has been shown that each 1% increase in air content beyond 7% ,leads to a 10% loss in pavement life .[2] Traditionally, cores at random locations were taken to investigate the asphalt concrete density. However, this process is labor-intensive, time-consuming, and provides information at discrete locations. Furthermore, selecting locations of coring, and the number of cores can be subjective. DPS is capable of providing continues HMA dielectric measurements that can be converted to the mat compaction level using calibration curves based on limited core data or plant mixed material samples. [3] A DPS can be deployed on a single or multiple GPR antennas and may carry by a push cart (figure 1) or a vehicle.

Source. FHWA.

Figure 1. Photo. Data collection with a DPS.

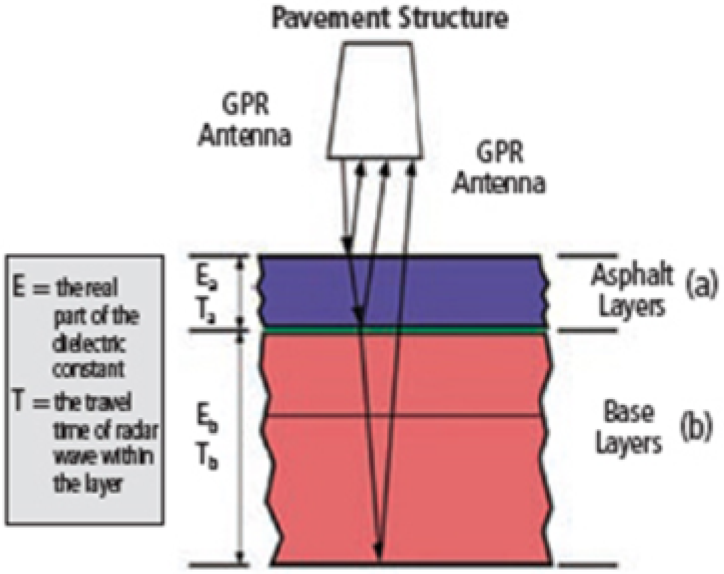
Figure 1. Data collection with a DPS. The photo shows a worker collecting data with a DPS. The DPS deployed on a push cart with three air-coupled antennas attached on a metal bar. The system has a computer that shows data in a real time

DPS uses air-coupled GPR system that are noncontact (i.e., they do not touch the surface during surveying) and usually faster than ground-coupled systems.

Physical Principal

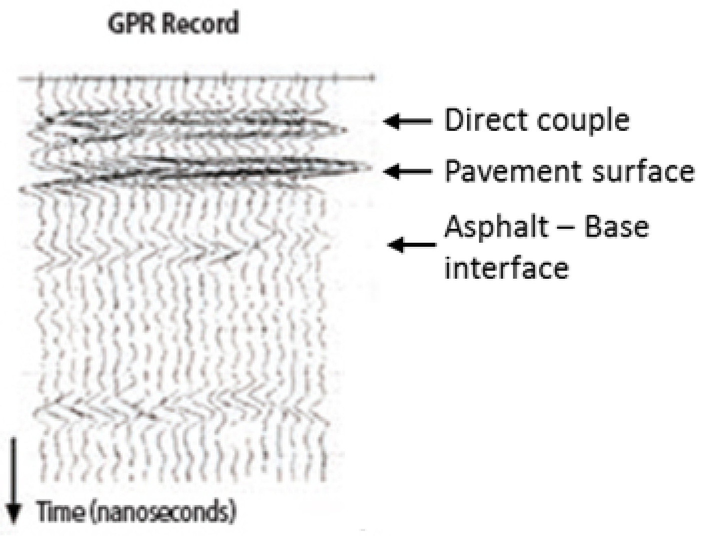
In general, GPR systems operate by sending discrete electromagnetic wave pulses (with a frequency range of 100–5,000 MHz) into a structure and then capturing the reflections from layer interfaces or other reflectors within the structure. Radar obeys the laws governing reflection and transmission of electromagnetic waves and is affected by the dielectric properties of the material: conductivity and the dielectric constant.[4] 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.

As shown in figure 2, 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. By using the signal reflected by the pavement surface, the dielectric constant of the surface can be estimated using the amplitude of signal reflected from the pavement surface and the signal reflected off a metal plate. An equation for calculating the dielectric of a HMA surface is presented in figure 3.



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

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.

Figure 2. Illustrations. Principle of air-coupled GPR for measuring pavement.[(5)]

$$\varepsilon_a = \left[\frac{1 + \left(\frac{A_1}{A_m}\right)}{1 - \left(\frac{A_1}{A_m}\right)}\right]^2$$

Figure 3. Equation. Calculation of the dielectric of a pavement surface.(5)

epsilon a equals the square of open bracket one plus open parenthesis A subscript 1 over A subscript m close parenthesis all over one minus open parenthesis A subscript 1 over A subscript m close parenthesis close bracket.

Where:

A_1 = amplitude of reflection from the surface.

A_m = amplitude of reflection from a large metal plate on the surface.

Data Acquisition

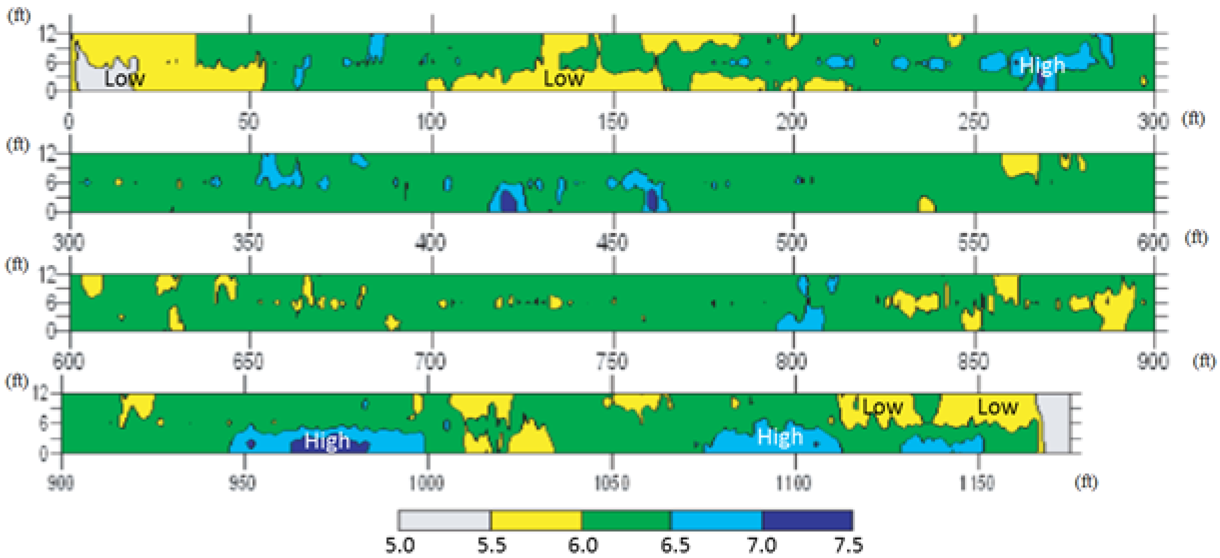
Manufacturers of DPS recommend following their system-specific testing procedures when collecting dielectric data of the field. These procedures are available in the user manuals supplied by manufacturers. AASHTO PP98-20 provides the equipment and software requirements for DPS testing. [(6)]

Data Processing

After collecting data from the field, the second step is to correlate the dielectric constant with the density of asphalt concrete. This step includes taking a few cores from regions of the field with low to high dielectric values, and then measuring the density of the cores in the laboratory. Subsequently, a calibration curve that relates dielectrics to densities of a paving project is developed. The calibration curve can be used to convert all dielectric data of the field to the density of asphalt concrete. AASHTO PP98-20 specifies calibration and verification procedures.(6) Recent developments propose procedures to create calibration curves using plant mix material samples.(3)

Data Interpretation

The dielectric value of an asphalt pavement that was measured using a 2.0-GHz air-coupled GPR antenna is depicted in figure 4. Quality control can be performed based on the relationship between the dielectric value and air-void ratio for in-place HMA.(3) A low dielectric value usually indicates a large air-void ratio in HMA.



1 ft = 0.3 m.

Figure 4. Graph. Dielectric value of an asphalt pavement.(3)

This graph is a composite of four graphs of the dielectric constant collected from an asphalt pavement surface. A color-coded legend is at the bottom of the graph showing dielectric ranges from 5 to 7.5. The x- and y-axes measure distance in feet. All of the y-axes range from 0 to 12 feet. For the top graph, the x-axis ranges from 0 to 300 feet. For the second graph, the x-axis ranges from 300 to 600 feet. For the third graph, the x-axis ranges from 600 to 900 feet. For the bottom graph, the x-axis ranges from 900 to 1,175 feet. Most of the dielectric values are between 6.0 and 6.5. Large areas of low dielectric values (i.e., less than 6.0) are found with x coordinates between 0 and 50; between 100 and 200; and between 1,115 and 1,175 feet, and are labeled "Low." Large areas of high dielectric values (i.e., greater than 6.5), are found in the graph with x coordinates between 250 and 290; between 950 and 1,000; and between 1,075 and 1,115 feet, and are labeled "High."

Advantages

Advantages of DPS GPR include the following:

- Well-established field data collection processes.
- Real-time compaction and density data for the entire paving project.
- Rapid test methods.
- Reliable and repeatable results.

Limitations

Limitations of GPR include the following:

- Moisture on the surface of asphalt may cause changes in acquired dielectric values and bias in

calibration curves.
- External electromagnetic radiation (from cell phone, radio, and television antennas) can cause signal degradation.

References

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2. Linden, Robert N., Joe P. Mahoney, and Newton C. Jackson. (1989). “Effect of compaction on asphalt concrete performance.” Report No. 1217, Transportation Research Board, Washington, DC.
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