
Standard Practice for Application of Ground Penetrating Radar (GPR) to Highways

AASHTO Designation: R 37-04 (2022)¹

Technically Revised: 2004

Reviewed but Not Updated: 2022

Technical Subcommittee: 5a, Pavement Measurement



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Application of Ground Penetrating Radar (GPR) to Highways

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1. SCOPE

- 1.1. This standard practice provides guidance to the highway engineer in the application of noncontact ground penetrating radar (GPR) to transportation facilities. It is intended to instruct the engineer regarding the specific uses of noncontact radar for pavement layer thickness surveys, quality control of new pavement construction, evaluation of granular base material, identification of zones of asphalt stripping, and assessment of bridge decks. GPR has numerous applications for the transportation industry, but at this time requires extensive training in its use and interpretation of the data output, as well as experience in local pavement conditions.
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2. REFERENCED DOCUMENTS

- 2.1. *ASTM Standard:*
- [D4748](#), Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar
- 2.2. *Federal Highway Administration Standard:*
- FHWA/TX-92/1233-1, Implementation of the Texas Ground Penetrating Radar System, Texas Transportation Institute with the Federal Highway Administration, 1992
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3. SUMMARY OF METHOD

- 3.1. *Principles of GPR*—GPR utilizes radio waves as an energy source. They are transmitted into the pavement and reflected at layer interfaces. Radio waves have free space wavelengths on the electromagnetic spectrum ranging from 0.001 m to 10 m. GPR operates in the range of 0.1 m to 10 m, which is the low end of the radio wavelength spectrum. As with all electromagnetic waves, radio waves travel through a vacuum at the speed of light. When the radar waves pass through a medium other than a vacuum, the velocity of propagation becomes a function of the dielectric constant of the medium. A dielectric is defined as an insulator between two electrical conductors; the dielectric constant for any material measures its effectiveness when used as the dielectric of a capacitor. For example, air has a dielectric constant of one. If air in a capacitor is replaced by mica, the resulting capacitance is six times greater, so mica has a dielectric constant of six. Some representative dielectric constant values for earth materials are given in Table 1.

Table 1—Dielectric Constants for Construction Materials (Reference 9.9)

Material	Relative Dielectric Constant (ϵ_r)
Air	1
Water (fresh)	81
Water (salt)	80
Sand (dry)	3–5
Sand (wet)	20–30
Silts	5–30
Clays	5–40
Granite	4–6
Limestone	4–8
Portland cement concrete (cured)	6–11
Bituminous concrete	3–6

- 3.2. The velocity of a radar wave through a given medium varies in inverse proportion to the square root of the material's relative dielectric constant ϵ_r . For example, if a material with a dielectric constant value of 4 has a radar wave passing through it, the wave travels half as fast as it does through air ($\epsilon_r = 1$) and twice as fast as it would through a material having an ϵ_r value of 16. In general, radio waves propagate through dielectric materials, but are reflected from conductive materials. When there is a boundary between two materials having different dielectric properties, some of the radar energy will be reflected, and a portion will pass through the boundary. The time required for a radar pulse to travel from the source to an interface and back is the two-way travel time, and is dependent on the depth of the interface and the dielectric constant of the material overlying the interface. Converting two-way travel time to information about the depth to the interface can be done by means of the following formula:

$$d = v \times t/2 \quad (1)$$

where:

d = depth,
 v = velocity, and
 t = two-way time.

- 3.3. The velocity of the radar wave is primarily dependent on the dielectric constant of the medium, and can be calculated with the following equation:

$$v = c / \sqrt{\epsilon_r} \quad (2)$$

where:

c = speed of light.

As can be seen from the data in Table 1, the moisture content has a large influence on the dielectric constant, and therefore affects the two-way travel time, so that the greater the amount of water saturation, the lower the radar wave velocity.

- 3.4. There is another electrical property upon which GPR depends, and that is conductivity. Attenuation of the radar waves (which causes the waves to decrease in amplitude and energy) is caused by higher conductivity of a medium and results in less depth of penetration. Attenuation is related to the frequency spectrum emitted by the radar—the higher the frequency, the greater the attenuation of the signal. For most pavement materials in dry condition, attenuation of the wave is not a serious problem. However, with some materials, particularly new concrete (within at least 180 days of placement), signal attenuation can have a significant impact on the amount of energy reflected from the pavement structure.

- 3.5. In discussing frequency of GPR antennae, it is to be noted that the signal output is not a single frequency, but rather is a frequency spectrum (bandwidth). An antenna that has a 1-GHz output actually produces a bandwidth frequency distribution having a mean value of 1 GHz. This signal is produced in short pulses, with a comparatively long period of time between pulses, so that the reflected signals may be recorded. The electromagnetic signal pulse is on the order of 1 ns in duration, while the time between pulses may be tens of thousands of ns. Higher-frequency signal pulses have shorter pulse periods; a 1-GHz signal will have a 1-ns pulse, while a 2-GHz signal will have a pulse of 0.5 ns in duration.

4. SIGNIFICANCE AND USE

- 4.1. GPR is a geophysical technique that uses radio waves to acquire subsurface information. The system operates by transmitting energy waves into the earth and recording the waves that are reflected off interfaces between layers of material with different electrical properties. GPR has been used for several decades as a tool for geologic investigations, particularly for environmental and groundwater applications. In more recent times, a type of radar system developed specifically for transportation applications has evolved using high-frequency, noncontact antennas that can travel over highways and bridges at the speed of traffic while acquiring data. The information from these GPR systems can be used to find voids under pavement, study pavement layer thicknesses, evaluate moisture or density variations, and assess the condition of bridge decks.
- 4.2. Agencies planning to use a great deal of GPR data; e.g., using GPR as part of a network-level pavement management system, are likely to find it most cost-effective to purchase one or more GPR systems and invest in the personnel training necessary for its usage. The cost of training is largely a function of the data processing software used to evaluate data. As the software packages become more user-friendly, there will be progressively less training required for the user.
- 4.3. Transportation agencies that plan to use a limited amount of GPR data, such as occasional distressed pavement examinations on discrete stretches of highway, may find it advantageous to hire consultant contractors to conduct the surveys and perform the analysis, rather than investing in the equipment and training necessary to do it themselves.

5. EQUIPMENT

- 5.1. *Types of GPR Systems*—There are two basic types of GPR systems, the difference being in the type of antenna used to produce the radar waves. Ground-coupled antennas are used primarily in geologic and environmental applications. They generate radar waves with frequencies of 50 to 500 MHz, although some systems can produce radar wave frequencies of greater than 1 GHz. As the name implies, ground-coupled radar antennas must keep in contact with the ground during a GPR survey so that they are dragged by hand or towed slowly (at speeds less than 10 kph). The antenna in a ground-coupled system is generally a bowtie (dipole) antenna that generates a signal that covers a wide area and has scattered reflections. The system is capable of providing subsurface information to a depth of up to 15 or 16 m, depending on the geologic conditions encountered and selection of antenna frequency, but often will yield little information in the uppermost meter of the surface layer because of a phenomenon known as “ringing” caused by a bistatic coupling mismatch. This problem can be minimized by selecting a high-frequency GPR system if the desired target is known to be near the surface. Ground-coupled GPR systems are used for mapping bedrock and soil strata, detecting buried drums and pipelines, and tracing contaminant plumes.
- 5.1.1. The type of GPR system most used for transportation facilities, and which is the main focus of this standard practice, utilizes the noncontact horn antenna, which is suspended over the surface of the ground and which can perform surveys at speeds of up to 80 km/h. Usually, the antenna in this system is designed with a narrowly focused beam of electromagnetic energy, rather than the larger