

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

AASHTO Designation: PP40-00¹

1. Scope

1.1 This recommended practice will provide guidance to the highway engineer in the application of ground penetrating radar to transportation facilities. It is intended to instruct the engineer as to the specific uses of the air coupled radar for pavement layer thickness surveys, quality control of new pavement construction, evaluation of granular base material, identifying 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. Most GPR data interpretation is currently being performed by consultant contractors.

2. Referenced Documents

2.1 ASTM Standards:

D4748-87 "Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar"

2.2 Other Standards or Reports:

2.2.1 FHWA/TX-92/1233-1, "Implementation of the Texas Ground Penetrating Radar System," Texas Transportation Institute with the Federal Highway Administration, 1992.

2.2.2 NCHRP Synthesis 255, "Ground Penetrating Radar (GPR) for Evaluating Subsurface Conditions for Transportation Facilities: Synthesis of Highway Practice," Transportation Research Board, National Research Council, 1998.

2.2.3 NCHRP Report 237, "Locating Voids Beneath Pavement Using Pulsed Electromagnetic Waves," Transportation Research Board, National Research Council, 1981.

2.2.4 SHRP-P-397, "Ground Penetrating Radar Surveys to Characterize Pavement Layer Thickness

Variations at GPS Sites," Strategic Highway Research Program, National Research Council, 1994.

2.2.5 SHRP-S/FR-92-105, "Condition of Concrete Bridges Relative to Reinforcement Corrosion, Vol. 3: Method for Evaluating the Condition of Asphalt-Covered Decks," Strategic Highway Research Program, National Research Council, 1992.

2.2.6 SHRP-H-672, "Development of Ground-Penetrating Radar Equipment for Detecting Pavement Condition for Preventive Maintenance," Strategic Highway Research Program, National Research Council, 1993.

2.2.7 Transportation Research Record 1304, "Bridge Deck Condition Surveys Using Radar: Case Studies of 28 New England Decks," Transportation Research Board, 1991.

2.2.8 Transportation Research Record 1344, "Automated Pavement Subsurface Profiling Using Radar--Case Studies of Four Experimental Field Sites," Transportation Research Board, 1992.

3. Summary of Method

3.1 Principles of GPR: Ground penetrating radar utilizes radio waves as an energy source which is transmitted into the ground and is reflected off interfaces. Radio waves have free space wavelengths on the electromagnetic spectrum ranging from 0.001 meters to 10 meters. 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

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a dielectric constant of six. Some representative dielectric constant values for earth materials are given in Table 1.

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 having a dielectric constant value of 4 has a radar wave passing through it, the wave does travel 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:

$$d = v \times t/2$$

where:

d = depth

v = velocity

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:

$$v = c/\sqrt{\epsilon_r}$$

where c equals the 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.

Changing to a lower frequency signal will increase the depth of penetration, but because the wavelength is also increased the radar system resolution of the recorded signal will decrease, and a small target may be missed. A high frequency signal, 500 to 900 MHz, will resolve objects a few centimeters in size, but will have poor depth penetration. A low frequency signal, 80 to 125 MHz, will have a resolution of only about one meter, but will have good depth penetration and will suffer less attenuation than a high frequency signal.

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 which has a one gigahertz output actually produces a bandwidth frequency distribution having a mean value of one 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 one nanosecond in length, while the time between pulses may be tens of thousands of nanoseconds. Higher frequency signal pulses have shorter pulse periods: a 1 GHz signal will have a 1 nanosecond pulse, while a 2 GHz signal will have a pulse 0.5 nanoseconds in length.

4. Significance and Use

4.1 Ground penetrating radar (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 having 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, air-coupled 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, and assess the condition of bridge decks.

4.2 Ground penetrating radar can be used as a non-destructive testing tool in assessing transportation facilities, particularly in the areas of pavement management and bridge deck evaluation. It is an evolving science which has not yet reached the stage

of being commonplace in state transportation departments, but it shows promise as an emerging technology to replace or augment more traditional and labor-intensive testing methods, such as core drilling. The development of GPR is evolving rapidly, which is common to computer-dependent systems, so that it may become a more commonly used application in transportation engineering projects in the future, depending on level of commitment to more sophisticated technology on the federal and state level.

4.3 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 sophisticated, there will be progressively less training required for the user.

4.4 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 over 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 very slowly. The antenna in a ground-coupled system is generally a bowtie (dipole) antenna, which 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 m or 16 m (50 feet), depending on the geologic conditions encountered and selection of antenna/pulsar, but often will yield little information in the uppermost few feet 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 recommended practice, utilizes the air-coupled horn antenna, which is suspended over the surface of the ground and which can perform surveys at speeds of up to 80 km/hr. Usually the antenna in an air-coupled system is designed with a narrowly-focused beam of electromagnetic energy, rather than the larger beam width used in ground-coupled GPR, so that this results in less back scatter from the surrounding area. The operating center frequency range is typically around 1 GHz, but some systems are now available that have frequencies as low as 0.5 GHz and as high as 2.5 GHz. These high frequency broad band radar signals yield excellent resolution, permitting identification of very thin layers. The air-coupled systems have the advantage of providing near-surface information, unlike most ground-coupled GPR systems. The drawback of high-frequency signal generation is that, under typical conditions, the depth of penetration is limited to about 0.5 m. Therefore, air-coupled GPR can yield information about pavement and subbase strata, but will yield very little information below that.

5.2 GPR Equipment: A GPR system consists of the following components: a signal generator; an antenna, which transmits and receives the radar pulse signal; a sampler/recorder, which collects the returned signal and stores it; a signal processing system, to convert the pulse data into a waveform; a monitor for viewing the data; a recording system for storing data. The antenna is on a boom directly attached to the front or the back of the vehicle. All the other equipment is contained within the survey vehicle. A distance calibration system is tied into the GPR survey so that anomalies can be located precisely. It is useful to operate a synchronized video imaging during the GPR survey, so that a visual record of the pavement surface is available during the data processing. Generally, two operators are needed during the survey, one to drive the vehicle and one to operate the equipment.

5.2.1 The minimum GPR configuration is a single antenna radar system. For pavement surveys, a single antenna pass per lane is adequate for thickness evaluation. For condition surveys (void mapping and bridge deck evaluation), multiple antenna passes per lane are preferable to achieve the required level of