Designation: D4748 – 10 (Reapproved 2015)

Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar[1]

1. Scope

1.1 This test method covers the nondestructive determination of the thickness of bound pavement layers using Ground Penetrating Radar (GPR).

1.2 This test method may not be suitable for application to pavements which exhibit increased conductivity due to the increased attenuation of the electromagnetic signal. Examples of scenarios which may cause this are: extremely moist or wet (saturated) pavements if free electrolytes are present and slag aggregate with high iron content.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazard statements are given in Section 11.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D6087 Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar

D6429 Guide for Selecting Surface Geophysical Methods

D6432 Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation

E1778 Terminology Relating to Pavement Distress

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions shall be in accordance with the terms and symbols given in Terminologies D653 and E1778.

3.1.2 Additional definitions can be found in section 3.1.3 of Guide D6432, and in Ref (1).[3]

3.1.3 *Additional definitions:*

3.1.3.1 *bound pavement layer*—upper layers of a pavement structure consisting of aggregate materials mixed with cementitious binder such as bitumen or Portland cement paste. Examples of bound pavement layers include bituminous concrete, portland cement concrete, and stabilized bases. Bound pavement layers do not include granular base and subbase materials.

3.1.3.2 *unbound pavement layer*—lower layers of a pavement structure consisting of untreated aggregate materials such as sand, gravel, crushed stone, slag, and other stabilized materials. Unbound pavement layers include base, subbase and compacted subgrade.

4. Apparatus

4.1 The apparatus may consist of a vehicle or a cart that is equipped with the following:

4.1.1 One or more GPR antennas mounted on the vehicle, cart, or on a trailer

4.1.1.1 The antenna for this application typically has a center frequency that ranges from 1.0 to 2.6 GHz. A typical 1.0 GHz antenna usually has a resolution sufficient to determine a minimum layer thickness of 40 mm (1.5 in.) to an accuracy of ±5.0 mm (±0.2 in.). Antennas emitting short pulses containing a center frequency of 2.0 GHz and higher provide resolution sufficient for determination of a minimum layer thickness less than 25 mm (1.0 in.) to an accuracy of ±2.5 mm (±0.1 in.).

4.1.1.2 Two basic types of antenna systems are in use:

(1) Air-launched antennas that are specifically designed to radiate into the air and are to be used at some distance above the pavement surface, typically 20 to 50 cm (8 to 20 inches).

(2) Ground-coupled antennas that are specifically designed to operate in contact with the pavement surface.

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[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

4.1.2 Control Unit consisting of a transmitter, receiver, and timing control electronics. It transmits and receives low-power broad band Radio Frequency (RF) signals through the antenna. The RF signals are then converted into a signal suitable for display and resulting interpretation.

4.1.3 Distance Measuring Instrument (DMI) with an accuracy of ±190 mm/km (±1ft/mile) and a resolution of 305 mm (12 in.) or better.

4.1.4 An optional Global Positioning System (GPS) with an instantaneous positioning accuracy of 1 m (3 ft.) or better.

4.1.5 Personal computer suitable for data acquisition, display and storage.

4.2 The schematic drawing in Fig. 1 illustrates a typical equipment configuration

5. Summary of Test Method

5.1 Since this test method is based upon measurements performed by a GPR system, a brief description of the operating principles of a system is included herein.

5.2 The GPR system transmits and receives electromagnetic signals by means of an antenna. As the transmitted electromagnetic wave propagates through the pavement layers, the wave is refracted and reflected at layer interfaces and received by the antenna. The received signal is recorded by the GPR system in terms of amplitude and two-way travel time. Fig. 2 and Fig. 3 show the schematics of the two antennas types (air-launched and ground-coupled) and the typical data collected from them. Fig. 4 shows an example of the air-launched GPR data stacked in series with respect to the travel distance along the survey line.

5.3 Layer thickness can be determined using the following equation if the velocity and the two-way travel time for the radar wave to travel through a given layer are known.

$$T = v \times \frac{\Delta t}{2} \tag{1}$$

where:

T = layer thickness,
v = velocity of the radar wave through a given material,
Δt = two-way travel time through layer.

The GPR system measures two-way travel time, so it is easily obtainable from analysis of the data. For monostatic GPR systems, the velocity of the radar wave can be estimated from the following relationship:

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

where:

c = speed of light in air, 300 mm/nsec (11.8 in/nsec),
ε_r = relative dielectric constant of layer,

Substituting Eq. (2) in Eq. (1) results in the following equation for layer thickness. Note that this equation is necessarily different for bistatic antennas in order to accommodate for the separation distance between the transmit and receive antennas.

$$T = \frac{\Delta t \times c}{2\sqrt{\varepsilon_r}} \tag{3}$$

NOTE 1—Definitions of the terms monostatic and bistatic are provided in Sections 3.1.3.17 and 3.1.3.4, respectively, of Guide D6432. For convenience, these definitions are excerpted from Guide D6432 and repeated below.

Monostatic – (1) a survey method that utilizes a single antenna acting as both the transmitter and receiver of EM waves. (2) Two antennas, one transmitting and one receiving, that are separated by a small distance relative to the depth of interest are sometimes referred to as operating in "monostatic mode".

Bistatic – the survey method that utilizes two antennas. One antenna

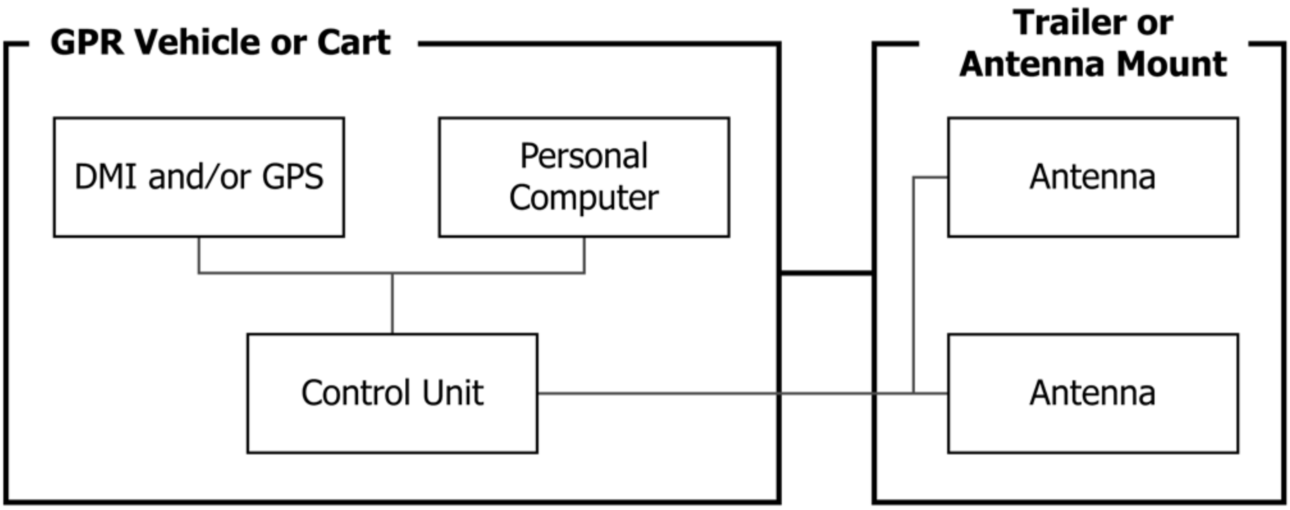

FIG. 1 Equipment Configuration

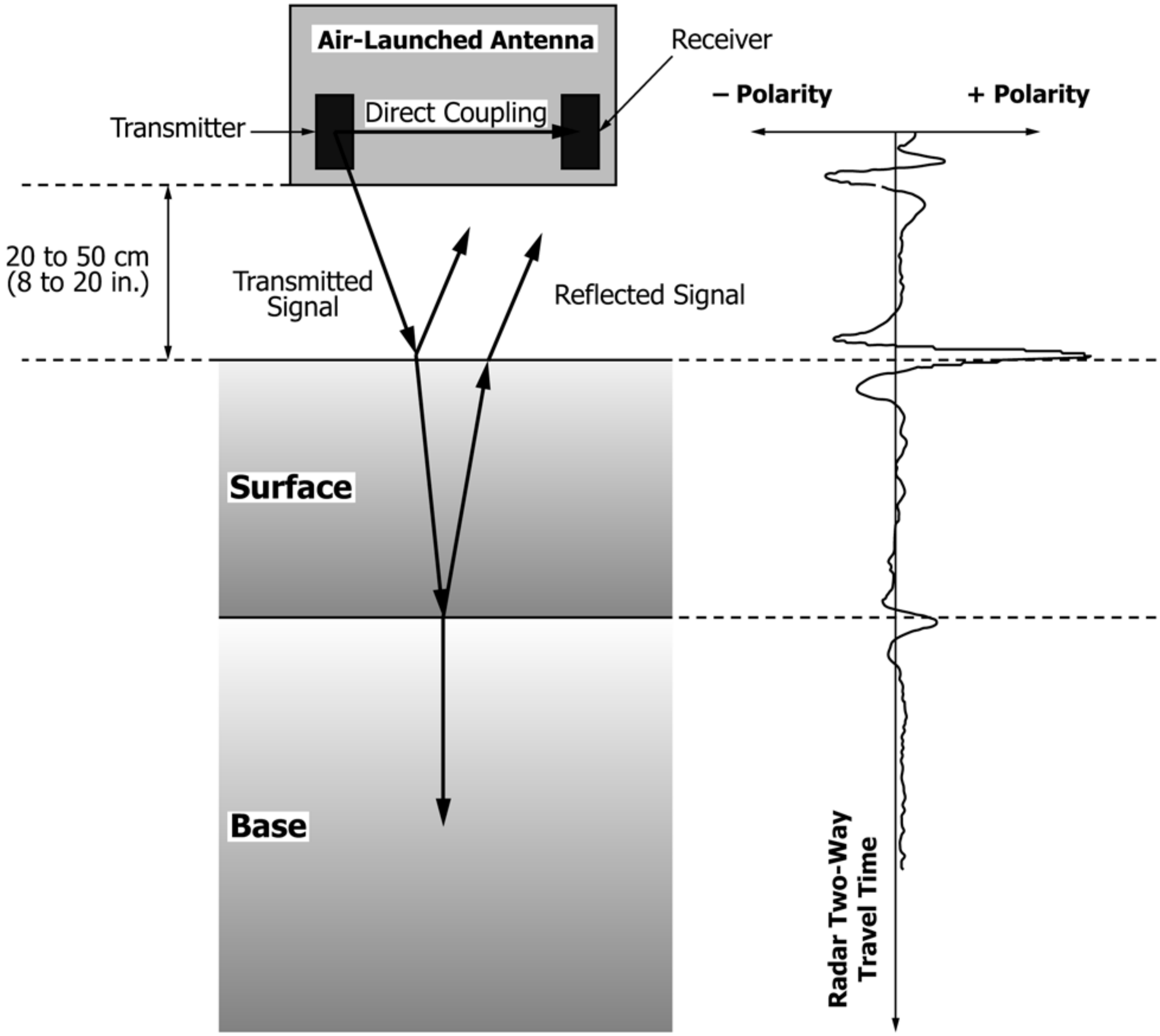

FIG. 2 Schematics of air-launched antenna

radiates the EM waves and the other antenna receives the reflected waves.

5.4 The relative dielectric constant or the radar wave velocity of a layer can be obtained in one of three ways: (1) metal plate calibration; (2) ground truth cores at locations where GPR data were collected; or (3) Common Midpoint (CMP) method.

5.4.1 *Metal plate calibration*—The metal plate calibration procedure involves obtaining GPR data with the antenna placed at operating height over a large metal plate, then using the amplitude of the metal plate reflection in an equation that also incorporates the amplitude of the pavement reflection to calculate the pavement dielectric constant. This method only applies to air-coupled GPR antennas. This method allows calibration at every GPR scan location.

5.4.2 *Ground truth core*—This procedure involves coring the pavement at a known location where GPR data have been obtained. The radar wave velocity at the core location is calculated using the core thickness and the two-way travel time of the radar reflection from the pavement bottom. This method assumes that the velocity is uniform over the test area.

5.4.3 *Common midpoint method*—This procedure involves collecting data while moving two ground-coupled GPR antennas away from each other while transmitting from one antenna and receiving on the other antenna. Mathematical equations are used to calculate the dielectric constant of the pavement based on the change in two-way travel time of the reflection from pavement bottom versus separation distance between the two antennas.

5.5 The ability to detect a layer depends on the contrast between the dielectric constant of that layer and the layer beneath. A sufficient contrast for thickness determination usually exists between asphaltic layers and unbound pavement layers such as soil or aggregate base materials. Such a contrast may not always be sufficient between concrete and aggregate base materials, between individual layers of asphalt, or between concrete and cement stabilized base materials. Relative dielectric constants of typical pavement materials are given in Table 1 of this standard and also in Table 1 of Guide D6432.

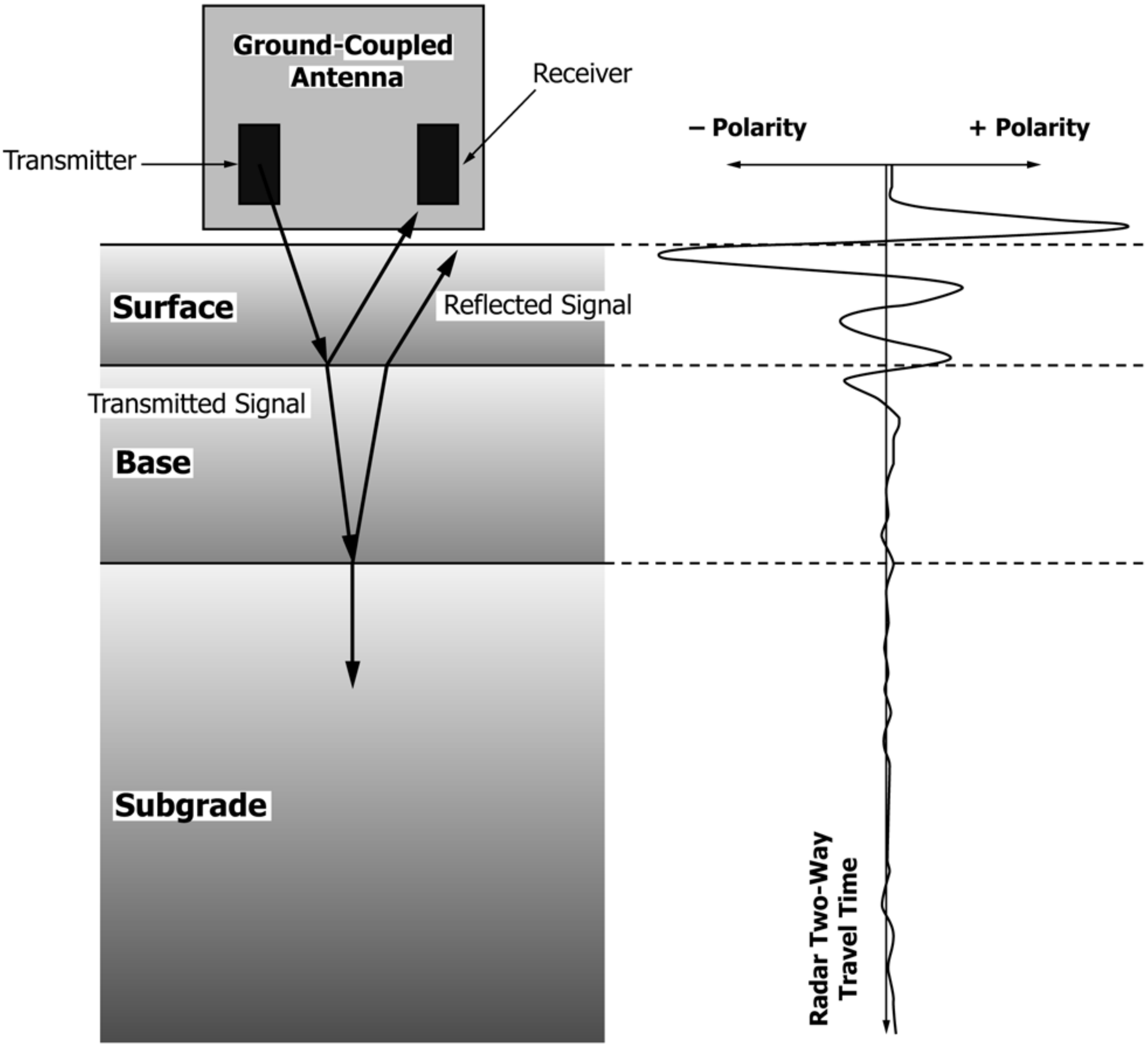

FIG. 3 Schematics of ground-coupled antenna

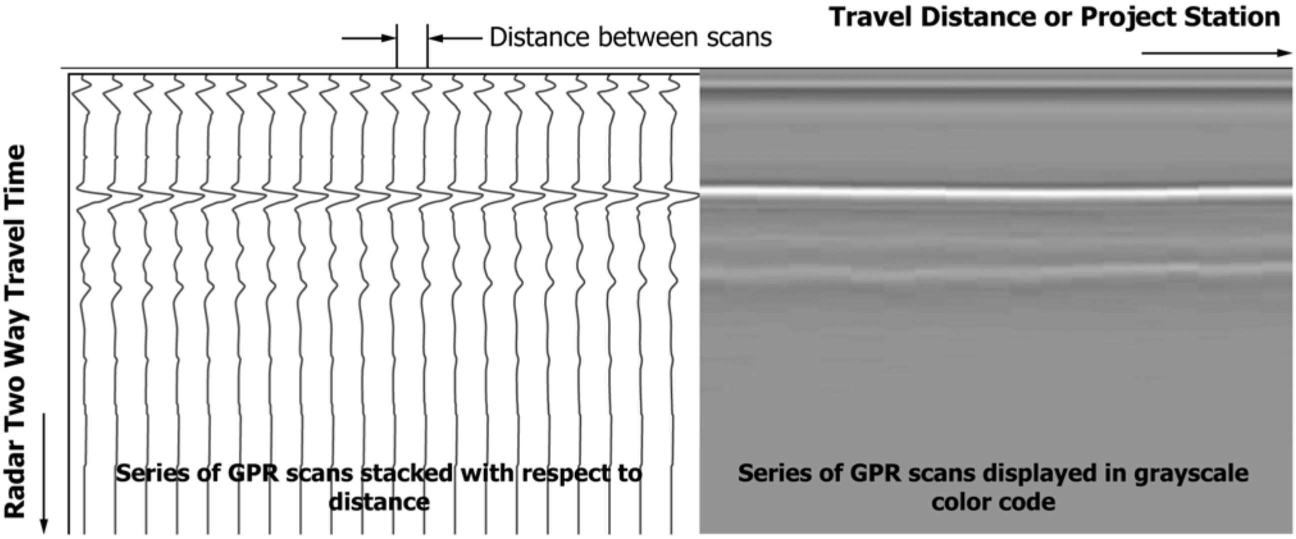

FIG. 4 Series of GPR data displayed with respect to travel distance

TABLE 1 Relative Dielectric Constants and radar wave velocity through the materials

Material	Relative dielectric constants	Radar velocity, m/ns	Radar velocity, inch/ns
Air	1	0.30	11.8
Water	81	0.03	1.3
Asphalt	2 to 4	0.15 to 0.21	5.9 to 8.4
Clay	2 to 10	0.05 to 0.21	1.9 to 8.4
Concrete	4 to 10	0.010 to 0.15	3.7 to 5.9
Granite	5 to 8	0.11 to 0.15	4.4 to 5.9
Limestone	4 to 8	0.10 to 0.15	4.2 to 5.9
Sand	4 to 6	0.12 to 0.15	4.8 to 5.9
Sandstone	2 to 3	0.17 to 0.21	6.8 to 8.4
Sandy Soil	4 to 6	0.12 to 0.15	4.8 to 5.9
Clayey Soil	4 to 6	0.12 to 0.15	4.8 to 5.9
Gravel	4 to 8	0.10 to 0.15	4.2 to 5.9

5.6 At some depth, the reflections at the layer interfaces cannot be detected by the GPR. This maximum penetration depth is a complex function of GPR system parameters such as transmitted power, receiver sensitivity, center frequency and bandwidth of the GPR system and signal processing, as well as the electromagnetic properties of the pavement materials and environmental factors such as moisture content.

6. Significance and Use

6.1 This test method permits accurate and nondestructive thickness determination of bound pavement layers. As such, this test method is widely applicable as a pavement system-assessment technique.

6.2 Although this test method, under the right conditions, can be highly accurate as a layer-thickness indicator, consistently reliable interpretation of the received radar signal to determine layer thicknesses can be performed only by an experienced data analyst. Such experience can be gained through use of the system and through training courses supplied by various equipment manufacturers or consulting companies. Alternatively, the operator may wish to use computer software to automatically track the layer boundaries and layer thickness, where applicable.

7. Calibration and Standardization

7.1 The system should be calibrated and its performance should be verified per the manufacturer's specifications. Typical calibration procedures can be found in Section 6.2 of Guide D6087 and shall not be repeated in this standard. However, it is the manufacturer's specifications that take preference, as emphasized in D6087.

8. Procedure

8.1 Determine the following prior to the survey:

8.1.1 Transverse offset of the longitudinal scan line to be surveyed. Typically, the scan lines are in the wheel paths and/or along the center of the lane of interest.

8.1.2 Number of scans per unit distance or the spacing between GPR scans. The speed of the traverse is dependent on the number of scans per unit distance. For air-launched GPR antennas, the traverse speed is constrained only by the desired spacing of radar scans. For typical ground coupled antennas, the traverse speed is limited to approximately 8 km/h (5 mph) in order to maintain steady ground contact.

8.2 Warm up the GPR system prior to the survey for a period recommended by the manufacturer, typically between 30 minutes and an hour.

8.3 Calibrate the GPR system per the manufacturer specifications if any.

8.4 Continuously traverse the radar antenna along the longitudinal scan line to be tested with minimal vehicle wander.

8.4.1 Ensure that the collected GPR data is associated with at least one reference location so that the thickness information can be reported accurately with respect to the roadway station and transverse offset.

8.5 Process the GPR data using a software available for the analysis. The outcome of this process should be a thickness profile of the bound pavement layer with respect to the roadway station.

9. Interferences

9.1 Determinations made with GPR are adversely affected by surface and subsurface water. Standing water on the surface of the pavement decreases the amount of energy that penetrates the pavement. This effect is difficult to measure and may vary dramatically over a short time interval due to variations in the thickness of the water layer caused by run-off or evaporation. However, in general, testing shall not be conducted in the presence of standing water.

9.2 The apparatus is subject to interference from other sources of electromagnetic radiation. Interference from nearby highpower transmitters manifests itself as large, high-frequency variations in the radar return across the entire measurement depth. Other sources of intermittent interference may include mobile phones and radios. Testing shall not be conducted in the presence of observed interference.

9.3 Large objects such as vehicles have the potential to interfere with the radar return. A conservative, equipment independent approach to minimize the effects of large objects is to maintain these objects at a distance outside the zone of influence as calculated by the following expression:

$$d = \frac{t}{2 \times k} \quad (4)$$

where

D = the zone of influence,
K = multiplication constant, 3.28 for d in meters (1 for d in feet), and
T = time in nanoseconds of the measured data

10. Report

10.1 Report at a minimum, the following information:

10.1.1 Location and limits of the survey (project ID and beginning/ending stations).

10.1.2 Survey date and weather conditions.

10.1.3 Pavement material type (Bituminous, Portland cement, or composite pavement)

10.1.3.1 In case of composite pavements such as a bituminous overlaid Portland cement concrete pavement, it may not always be possible to extract the thickness of the bound pavement layer below the existing surface layer. Report the thickness for the surface layer as a minimum, and both bound pavement layers if attainable.

10.1.4 Transverse offset(s) of the longitudinal lines scanned.

10.1.5 For each longitudinal line scanned, report the thickness of the bound pavement layer with respect to project station or GPS coordinates in a tabulated and/or plotted manner.

10.1.5.1 If more than one antenna were used to collect the data along several longitudinal lines, the thickness may be averaged prior to reporting, provided that the difference in thickness from the multiple longitudinal scan lines is insignificant.

10.1.6 Summary statistics of thickness such as average, standard deviation, minimum and maximum.

10.1.6.1 If there is a change in the pavement structure resulting in an abrupt difference in the bound layer thickness, report the summary statistics for each structure, before and after the pavement change.

11. Hazards

11.1 **Warning—**The radar apparatus used in this test method is potentially a microwave radiation hazard. All personnel shall stand clear of the region directly under the antenna when the system is energized.

11.2 Electromagnetic emissions from the radar apparatus, if the system is improperly operated, could potentially interfere with commercial communications, especially if the antenna is not properly oriented toward the ground. Take care to ensure that all such emissions from the system comply with Part 15 of the Federal Communications Commission (FCC) Regulations.

11.3 Ensure that appropriate traffic control measures are employed when operating the radar apparatus on highways, roads, and airports. Such measures are essential for the safety of system operators as well as that of the general traveling public.

12. Precision and Bias

12.1 Precision and bias of the GPR results depend highly not only on the existing pavement structure but also on the surrounding environment of the project under survey due to the interferences introduced in Section 9, even if they are minor. As a consequence, it is not possible to determine the universal precision and bias statements for the GPR systems and they should be evaluated on a project by project basis. Past research studies conducted in Illinois (2), Virginia (3), Kentucky (4), New York (5), and Florida (6) reported the accuracy of the GPR system in terms of percent error to be within 15 percent or less.

13. Keywords

13.1 GPR; ground penetrating radar; layer thickness; pavement thickness; radar

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