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Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar[1]

This standard is issued under the fixed designation D6087; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers several ground penetrating radar (GPR) evaluation procedures that can be used to evaluate the condition of concrete bridge decks overlaid with asphaltic concrete wearing surfaces. These procedures can also be used for bridge decks overlaid with portland cement concrete and for bridge decks without an overlay. Specifically, this test method predicts the presence or absence of concrete or rebar deterioration at or above the level of the top layer of reinforcing bar.

1.2 Deterioration in concrete bridge decks is manifested by the corrosion of embedded reinforcement or the decomposition of concrete, or both. The most serious form of deterioration is that which is caused by corrosion of embedded reinforcement. Corrosion may be initiated by deicing salts, used for snow and ice control in the winter months, penetrating the concrete. In arid climates, the corrosion can be initiated by chloride ions contained in the mix ingredients. Deterioration may also be initiated by the intrusion of water and aggravated by subsequent freeze/thaw cycles, causing damage to the concrete and subsequent debonding of the reinforcing steel with the surrounding compromised concrete.

1.2.1 As the reinforcing steel corrodes, it expands and creates a crack or subsurface fracture plane in the concrete at or just above the level of the reinforcement. The fracture plane, or delamination, may be localized or may extend over a substantial area, especially if the concrete cover to the reinforcement is small. It is not uncommon for more than one delamination to occur on different planes between the concrete surface and the reinforcing steel. Delaminations are not visible on the concrete surface. However, if repairs are not made, the delaminations progress to open spalls and, with continued corrosion, eventually affect the structural integrity of the deck.

1.2.2 The portion of concrete contaminated with excessive chlorides is generally structurally deficient compared with non-contaminated concrete. Additionally, the chloride-contaminated concrete provides a pathway for the chloride ions to initiate corrosion of the reinforcing steel. It is therefore of particular interest in bridge deck condition investigations to locate not only the areas of active reinforcement corrosion, but also areas of chloride-contaminated and otherwise deteriorated concrete.

1.3 This test method may not be suitable for evaluating bridges with delaminations that are localized over the diameter of the reinforcement, or for those bridges that have cathodic protection (coke breeze as cathode) installed on the bridge or for which a conductive aggregate has been used in the asphalt (that is, blast furnace slag). This is because metals are perfect reflectors of electromagnetic waves, since the wave impedances for metals are zero.

1.4 Since a precision estimate for this standard has not been developed, the test method is to be used for research and informational purposes only. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes.

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

1.6 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 5.

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.32 on Bridges and Structures.

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2. Summary of Test Method

2.1 The data collection equipment consists of a GPR device, data acquisition device, recording device, and data processing and interpretation equipment. The user makes repeated passes with the data collection equipment in a direction parallel or perpendicular to the centerline across a bridge deck at specified locations. Bridge deck condition is quantified based on the data obtained.

3. Significance and Use

3.1 This test method provides information on the condition of concrete bridge decks overlaid with asphaltic concrete without necessitating removal of the overlay, or other destructive procedures.

3.2 This test method also provides information on the condition of bridge decks without overlays and with portland cement concrete overlays.

3.3 A systematic approach to bridge deck rehabilitation requires considerable data on the condition of the decks. In the past, data has been collected using the traditional methods of visual inspection supplemented by physical testing and coring. Such methods have proven to be tedious, expensive, and of limited accuracy. Consequently, GPR provides a mechanism to rapidly survey bridges in an efficient, nondestructive manner.

3.4 Information on the condition of asphalt-covered concrete bridge decks is needed to estimate bridge deck condition for maintenance and rehabilitation, to provide cost-effective information necessary for rehabilitation contracts.

3.5 GPR is currently the only nondestructive method that can evaluate bridge deck condition on bridge decks containing an asphalt overlay.

4. Apparatus

4.1 *GPR System*—There are two categories of GPR systems, depending on the type of antenna utilized for data collection.

4.1.1 GPR systems using air-launched horn antennas with central frequencies 1 GHz and greater. The equipment may consist of an air-coupled, short-pulse monostatic or bistatic antenna(s) with sufficient central frequency to provide the accurate measurement of a 5 cm thick asphalt pavement.

4.1.2 GPR systems using ground-coupled antennas with central frequencies greater than 1 GHz.

4.2 *Data Acquisition System*—A data acquisition system, consisting of equipment for gathering GPR data at the minimum frequencies specified in 4.1.1 and 4.1.2. The system shall be capable of accurately acquiring GPR data with a minimum of 60 dB dynamic range.

4.3 *Distance Measurement System*—A distance measurement system consisting of a fifth-wheel or appropriate distance measurement instrument (DMI) with accuracy of ±100 mm/km and a resolution of 25 mm.

NOTE 1—Fig. 1 shows a functional block diagram for multiple GPRs and support equipment.

5. Hazards

5.1 During operation of the GPR system, observe the manufacturer's safety directions at all times. When conducting inspections, ensure that appropriate traffic protection is utilized in accordance with accepted standards.

5.2 Electromagnetic emissions from the GPR apparatus, if the system is improperly operated, could potentially interfere with commercial communications, especially if the antenna is not properly oriented toward the ground. Ensure that all such

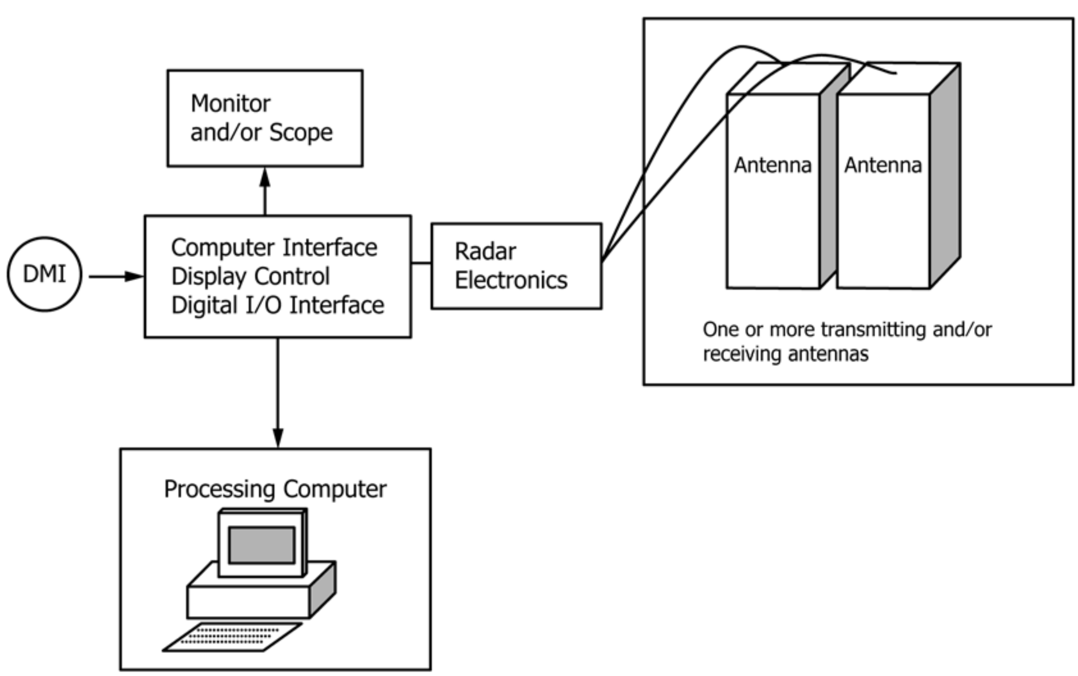

FIG. 1 Block Diagram of GPR and Support Equipment

emissions from the system comply with Part 15 of the Federal Communications Commission (FCC) Regulations.

6. Procedure

6.1 *Conditions for Testing:*

6.1.1 If soil, aggregate, or other particulate debris is present on the bridge deck surface, clean the bridge deck.

6.1.2 Test the bridge deck in a surface dry condition.

6.2 *System Performance Compliance*—The system should be calibrated and performance verified in accordance with the manufacturer's recommendations and specifications. The following information is included for reference only and describes typical calibration procedures for different types of systems. Compliance with the following procedures is not required and the manufacturer's calibration procedure takes preference. For air-launched antennas, this test shall consist of the following:

6.2.1 *Signal-to-Noise Ratio:*

6.2.1.1 *Signal-to-Noise Ratio Test*—Position the antenna at its far field distance approximately equal to maximum dimension of antenna aperture above a square metal plate with a width of 4× antenna aperture, minimum. Turn on the GPR unit and allow to operate for a 20-min warm-up period or the time recommended by the manufacturer. After warming up the unit, record 100 waveforms. Then evaluate the recorded waveform for signal-to-noise ratio. The signal-to-noise ratio is described by the following equation:

$$\frac{\text{Signal Level } (A_{mp})}{\text{Noise Level } (A_n)} > 20 \, (26.0 \text{ dB}) \tag{1}$$

6.2.1.2 This will be performed on each of the 100 waveforms and the average signal-to-noise value of the 100 waveforms will be taken as the "signal-to-noise of the system." Noise voltage (A_n) is defined as the maximum amplitude occurring between metal plate reflection and region up to 50 % of the time window after the metal plate reflection, normally used with the antenna (that is, 1.0 GHz/20 ns: 10 ns.). The signal level (A_{mp}) is defined as the amplitude of the echo from the metal plate.

6.2.1.3 The signal-to-noise ratio test results for the GPR unit should be greater than or equal to 20 (+26.0 dB).

6.2.2 *Signal Stability:*

6.2.2.1 *Signal Stability Test*—Use the same test configuration as described in the signal-to-noise ratio test. Record 100 traces at the maximum data acquisition rate. Evaluate the signal stability using the following equation:

$$\frac{A_{max} - A_{min}}{A_{avg}} < 0.01 \, (1 \, \%) \tag{2}$$

where:

A_{max} = the maximum amplitude of the metal plate reflection for all 100 traces,
A_{min} = the minimum amplitude of the metal plate reflection for all 100 traces, and
A_{avg} = the average trace amplitude of all 100 traces.

6.2.2.2 The signal stability test results for the GPR system should be less than or equal to 1 %.

6.2.3 *Linearity in the Time Axis and Time Window Accuracy:*

6.2.3.1 *Variations in Time Calibration Factor*—Use the same test configuration as described in the signal-to-noise ratio test, except that the metal plate can be replaced by any reflecting object. Collect a single waveform and measure the distance from the antenna to the reflector. Perform this test at three different distances corresponding to approximately 15, 30, and 50 % of the time window normally used with the system. The time delay between the echo from the aperture of the transmitting antenna and that from the reflecting object is measured as time t_1 (where subscript $_1$ represents position 1, and so forth). The difference between t_2 and t_1 and between t_3 and t_2 represents the travel time for a fixed distance in air. The factor *Ci* represents the speed between distance *i* and *i*+1. The allowable variation in measured speed is shown as follows:

$$\frac{C_1 - C_2}{\text{Mean of } C_1 \text{ and } C_2} < 2 \, \%, \tag{3}$$

where:

$$C_1 = \frac{\text{Distance from Position 2 to Position 1}}{T_1}$$

$$C_2 = \frac{\text{Distance from Position 3 to Position 2}}{t_2}$$

6.2.3.2 The variation in time calibration factor should be less than 2 %.

6.2.4 *Long-Term Stability Test:*

6.2.4.1 *Long-Term Amplitude Variation*—Use the same test configuration as described in the signal-to-noise ratio test. Switch on the GPR and allow to operate for 2 h continuously. As a minimum, capture a single waveform every 1 min, 120 total. Calculate the amplitude of a metal plate reflection and plot against time for each waveform. For the system to perform adequately, the amplitude of reflection should remain constant after a short warm-up period. The stability criteria is as follows:

$$\frac{A_{max} - A_{20}}{A_{20}} < 0.03 \, (3 \, \%) \tag{4}$$

where:

A_{20} = the amplitude measured after 20 min, and
A_{max} = the largest amplitude measured between 20 min and 120 min.

6.3 *Pre-Operation Measurement:*

6.3.1 *Free Space Signal (FSP)*—The equipment manufacturer can require the GPR antenna to be mounted in an operational configuration, and at least 100 waveforms gathered in the absence of the material to be inspected. Use the average of the gathered waveforms as a template for clutter removal.

6.3.2 *Flat Metal Plate (FMP)*—Position the GPR in an operation configuration, and gather at least 100 waveforms while illuminating a flat plate with dimensions recommended by the manufacturer. This is a measure of the emitted energy to be used in subsequent measurements, and as a template for decorrelation or background removal, or both.

6.4 *GPR Data Acquisition:*

6.4.1 *Air-Launched Antenna Systems:*

6.4.1.1 Make GPR inspection passes in a longitudinal direction parallel to the centerline of the bridge deck with the antenna mounted to maintain a manufacturer-recommended distance from the bridge deck surface.

6.4.1.2 Use a transverse distance (*dt*) between GPR inspection passes; <1 m is suggested.

6.4.1.3 Use a longitudinal distance (*dl*) between GPR scans ≤150 mm.

6.4.1.4 Determine the starting location for passes, that is, at abutments, joints, or a predetermined location.

6.4.1.5 Determine the optimum speed of operation for contiguous longitudinal coverage based on GPR range sweep rate and the scan-spacing.

6.4.2 *Ground-Coupled Antenna Systems:*

6.4.2.1 Make GPR inspection passes either parallel to the direction of traffic or perpendicular to the direction of traffic, depending on the direction of the top layer of reinforcing. The pass direction should be chosen so that the antenna crosses over the top layer of reinforcing at an angle nearest to 90°.

6.4.2.2 Use a transverse distance (*dt*) between GPR inspection passes <0.6 m.

6.4.2.3 Use a longitudinal distance (*dl*) between GPR scans necessary to obtain sufficient data; <150 mm is suggested.

6.4.2.4 Determine the starting location for passes, that is, at abutments, joints, or a predetermined location.

7. Data Processing

7.1 There are two different accepted GPR data processing methodologies. Both methods employ reflection amplitudes. The first method, the bottom deck reflection attenuation technique, calculates deterioration based on the relative reflection amplitudes from the bridge deck bottom relative to the bridge deck surface. The second method, the top reinforcing reflection attenuation technique, utilizes the relative reflection amplitudes from the top layer of reinforcing to assess deterioration.

7.2 *Deterioration Measurements at Top Reinforcing Steel Using the Bottom Deck Reflection Attenuation Technique:*

7.2.1 Measure and record the applied signal strength, V_t, at the deck surface.

7.2.2 Measure and record the maximum signal strength of the deck bottom echo, V_{bs}.

7.2.3 If V_{bs} is ≥0.0264 V_t for a longitudinal GPR inspection pass, proceed to 7.2.5. (The number 0.0264 is a constant derived from research data.)

7.2.4 If V_{bs} is <0.0264 V_t after repeating the longitudinal GPR inspection pass, the data are not reliable for determining removal quantities of bridge deck concrete. Processing of the data will require an alternative technique, such as the technique described in 7.3 of this test method, or that described in Ontario Ministry of Transportation (MTO) reports.[2]

7.2.5 Measure and record the amplitude of the deck bottom echo, V_b, for each waveform.

7.2.6 Determine delamination at the top reinforcing steel using the attenuation technique as follows:

7.2.7 Consider the concrete delaminated if:

$$V_b \leq 0.385\ V_{bs} \tag{5}$$

where:

V_b = bottom echo amplitude, each scan,
V_{bs} = bottom echo maximum amplitude, all scans, and
0.385 = a constant derived from research data.

7.2.8 Calculate the percent delaminated at the top steel in each GPR inspection pass using the following equation:

$$X_{tn} = [(W_{dt})/(W_{dt} + W_{st})][100] \tag{6}$$

where:

X_{tn} = percent delaminated in a GPR inspection pass, *n*, at top steel,
n = GPR inspection pass identification number,
W_{dt} = concrete delaminated at top steel, m, and
W_{st} = sound concrete at top steel, m.

7.2.9 Calculate the estimated quantity of deck delaminated at top steel for each GPR inspection pass using the following equation:

$$Q_t = (X_{tn})(L_n)(d_t) \tag{7}$$

where:

Q_t = square metres of deck delaminated at top steel,
L_n = length of GPR inspection pass, *n*, m, and
d_t = transverse distance between GPR inspection passes, m.

7.2.10 Calculate the total estimated quantity of deck delaminated at top steel using the following equation:

$$Q_{Tt} = \Sigma Q_t \tag{8}$$

where:

Q_{Tt} = total square metres of deck delaminated at top steel for all GPR inspection passes.

7.3 *Deterioration Measurements at or Above Top Reinforcing Steel Using the Top Reinforcing Reflection Attenuation Technique:*

7.3.1 Extract the reflection amplitudes from the top layer of reinforcing.

7.3.2 *Air-Launched Antenna Data*—This method can be used when the dominant deck reinforcing steel is aligned transversely to the direction of the movement of the antenna and has uniform density in that direction, such as occurs for decks supported by concrete or steel girders. For decks whose dominant steel is longitudinal, that is, parallel to the direction of travel (such as one-way slabs and arch slabs), the method of this section is not appropriate. This is because the density of top steel varies with longitudinal position. The alternate methods for these decks is either the method of 7.2 (bottom reflection), or to use the ground-coupled antenna with the method of 7.3.3, with survey lines transverse to the direction of travel.

7.3.2.1 *1 GHz Horn Antenna:*

(1) Asphalt-Overlaid Bridge Decks with Rebar Cover Greater Than 5 cm—One antenna is required per lane position. The antenna must be positioned with its radiated polarization

[2] Reel, R., Tharmabala, T., Wood, D., Chung, T., and Carter, C. R., *New Impulse Radar Strategies for Bridge Deck Assessment*, March 1993; and Carter, C. R., Chung, T., Reel, R., Tharmabala, T., and Wood, D., *Nondestructive Evaluation of Aging Bridges and Highways*, June 1995.