Designation: D 6087 – 03

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

This standard is issued under the fixed designation D 6087; 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 radar evaluation procedures that can be used to evaluate the condition of concrete bridge decks overlaid with asphaltic concrete wearing surfaces. Specifically, this test method predicts the presence or absence of delamination.

1.2 The most serious form of deterioration is that which is caused by corrosion of embedded reinforcement. Corrosion is 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.

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.

1.3 This test method may not be suitable for evaluating bridges with delaminations which are localized over the diameter of the reinforcement, or for those bridges which 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 EM waves, since the wave impedances for metals are zero.

1.4 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only. Specific precautionary statements are given in Section 5.

1.5 *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.*

1.6 A precision and bias statement has not been developed at this time. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes.

2. Summary of Test Method

2.1 A vehicle equipped with a short-pulse ground penetrating radar, data acquisition device, recording device, and data processing and interpretation equipment makes repeated passes, parallel to centerline across an asphalt covered 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 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, radar provides a mechanism to rapidly survey bridges in a non-contact, non-destructive manner.

3.3 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.

4. Apparatus

4.1 *Radar System*—Air-coupled, short-pulse monostatic radar(s) with a monocycle pulse, 150 mm (6 in.) free space resolution and a 50 scan/s data rate, minimum.

4.2 *Data Acquisition System*—A data acquisition system, consisting of equipment for gathering radar data at the maximum data rate of the radar system(s), 50 kHz for one radar, 100

[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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kHz for two radars, and 150 kHz for three radars. The system shall be capable of accurately acquiring radar data with a 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 (± 6.5 in./mile) and a resolution of 25 mm (1 in.).

4.4 *Test Vehicle*—A vehicle with all equipment necessary to perform the test and proper warning and safety devices installed.

NOTE 1—Fig. 1 shows a functional block diagram for multiple radars and support equipment. Real-time digital data acquisition and high-speed radar signal processing equipment and software have been designed around the Penetradar Model PS-24[2] radar system to meet the needs of this test method.

5. Hazards

5.1 During operation of the radar 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.

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.

[2] Information regarding availability, use, or licensing of this product may be obtained from Penetradar Corporation, 2509 Niagara Falls Boulevard, PO Box 246, Niagara Falls, NY 14304.

6.1.2 Test the bridge deck in a surface dry condition.

6.2 *System Performance Compliance*—Conduct a test on the radar equipment to ensure proper performance, at least once per year, or after periods of prolonged storage, or in accordance with manufacturers recommendations. 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 radar 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:

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

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*:

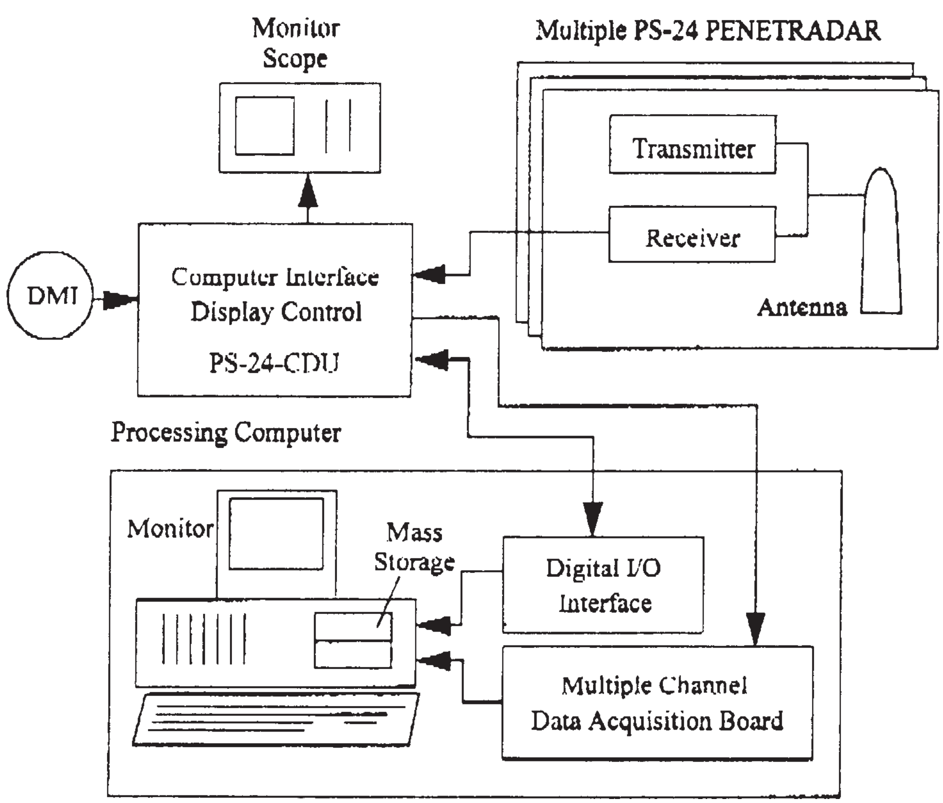

FIG. 1 Block Diagram of Radar and Support Equipment

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:

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

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 the distance from the antenna to the reflector is measured. Perform this test at three different distances corresponding to approximately 15, 30, 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, etc.). 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:

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

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 radar 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:

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

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 Measurements*:

6.3.1 *Free Space Signal (FSP)*—Mount the radar antenna in an operational configuration, and 100 waveforms gathered in the absense of the material to be inspected. Use the average of 100 waveforms as a template for clutter removal.

6.3.2 *Flat Metal Plate (FMP)*—Position the radar in an operation configuration, and gather 100 waveforms while illuminating a flat plate 1 × 1 m, minimum. This is a measure of the emitted energy to be used in subsequent measurements, and as a template for decorrelation.

6.4 *Radar Data Acquisition*:

6.4.1 Make radar inspection passes in a longitudinal direction parallel to the centerline of the bridge deck with the antenna mounted to maintain a distance of 225 ± 75 mm (9 ± 3 in.) from the bridge deck surface.

6.4.2 Use a transverse distance (*dt*) between radar inspection passes < 1 m (3 ft).

6.4.3 Use a longitudinal distance (*dl*) between radar scans < 150 mm (6 in).

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

6.4.5 Determine the speed of operation for contiguous longitudinal coverage based on the radar range sweep rate, and the length of the antenna ground footprint. Specifically, the radar antenna longitudinal travel, during an inspection, shall be less than or equal to the longitudinal length of the antenna ground beam coverage (footprint) or 15 cm (6 in.) whichever is less. Typically, for a:

6.4.5.1 *50 Hz Range Sweep*—Maximum travel speed is 17 mph, resulting in radar scans spaced 15 cm approximately.

6.4.5.2 *100 Hz Range Sweep*—Maximum travel speed is 35 mph, resulting in radar scans spaced 15 cm approximately.

6.5 *Delamination Measurements at Top Reinforcing Steel—Attenuation Technique*:

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

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

6.5.3 If $V_{bs} \geq 0.0264\ V_t$ for a longitudinal radar inspection pass, proceed to 6.5.5. (The number 0.0264 is a constant derived from research data).

6.5.4 If $V_{bs} < 0.0264\ V_t$ *after repeating the longitudinal radar 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 Ontario Ministry of Transportation (MTO) reports.*[3]

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

7. Data Processing

7.1 Determine delaminations at the top reinforcing steel using the attenuation technique as follows:

7.1.1 Consider the concrete delaminated if:

[3] 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.

$$V_b \leq 0.385\, V_{bs} \quad (5)$$

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.

7.1.2 Calculate the percent delaminated at the top steel in each radar inspection pass using the following formula:

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

where:

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

7.1.3 Calculate the estimated quantity of deck delaminated at top steel for each radar inspection pass using the following formula:

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

where:

Q_t = m^2 of deck delaminated at top steel,
L_n = length of radar inspection pass *n*, m, and
d_t = transverse distance between radar inspection passes, m.

7.1.4 Calculate the total estimated quantity of deck delaminated at top steel using the following formula:

$$Q_{Tt} = \Sigma Q_t \quad (8)$$

where:

Q_{Tt} = total m^2 of deck delaminated at top steel for all radar inspection passes.

8. Report

8.1 Report as a minimum, the following:

8.1.1 Bridge identification and location,

8.1.2 Date and weather conditions,

8.1.3 General deck status relative to moisture and debris,

8.1.4 Any unusual conditions or circumstances,

8.1.5 Radar results, in the following forms:

8.1.5.1 Percent of bridge deck area delaminated for each radar pass, at top steel, in tabular form,

8.1.5.2 Bridge deck area, in square meters delaminated for each radar pass, at top steel, in tabular form,

8.1.5.3 Total bridge deck area, in square metres, delaminated for the bridge deck, at top steel, in tabular form, and

8.1.5.4 Plan view map of bridge deck, depicting radar inspection pass versus longitudinal distance and showing location and extent of detected delamination at top steel.

9. Precision and Bias

9.1 *Precision*—Insufficient data are available to determine the precision of this test method. However, for a sample of ten bridge decks in New York, Virginia, and Vermont, an average error in radar prediction of ± 11.2 % occurred with respect to top reinforcement delaminated area using the attenuation technique as determined from chain drag, core samples, and actual repair quantities. The processing technique described in Section 7 is a suggested method, if applicable, however, other techniques can be utilized. Repeatability tests are currently being run in order to determine the precision of the test methods.

9.2 *Bias*—The research necessary to determine the bias of this test method has not been performed.

10. Keywords

10.1 asphalt-covered decks; bridge decks; delaminations; ground-penetrating radar; nondestructive testing; radar