COMPUTEDPARAMETERS

An Input for Moisture Calculations—Dielectric Constant From Apparent Length

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Introduction

Time domain reflectometer (TDR) probes are used in the Long Term Pavement Performance (LTPP) Seasonal Monitoring Program to obtain the moisture content in unbound base and subgrade materials. The TDR technique is based on the measurement of the travel time by an electromagnetic wave induced into a waveguide, in this application, a moisture probe. The apparent length is the length between the beginning and end points on the waveform that correspond to the beginning and end of the metal tube portion of the moisture probe. This apparent length of the probe can be used to calculate the dielectric constant of the material surrounding the probe. The dielectric constant is an input to the calculation of moisture content.

Benefits

Values for apparent length and dielectric constant are computed to provide results for traces collected manually and automatically, which would not otherwise be available, and to allow a user to avoid reinterpreting TDR data found in the Information Management System (IMS) database in the **SMP_TDR_AUTO** table. The results are found in the IMS tables **SMP_TDR_MANUAL_DIELETRIC** and **SMP_TDR_AUTO_ DIELECTRICS**.

The moisture calculations that have been done using dielectric constants based on the interpreted traces are also available. They are discussed in the computed parameters document *Moisture Content for Unbound Materials at Seasonal Monitoring Program Sites*, also available at this site.

Process Implementation

The TDR probes used in the LTPP program consist of three straight stainless steel metal tubes, 0.203 m long, held parallel to each other by a plastic spacer at one end and a printed circuit board at the other end. The printed circuit board contains a connection with the shielded coaxial metallic lead cable. The measurement procedure involves connecting the probe to a cable tester. The cable tester generates an ultrafast rise time voltage pulse down the cable and records the reflected signal. The pulse propagates as an electromagnetic wave through the cable. Changes in impedance and other faults in the cable cause partial reflection of energy back to the source where it is sampled and recorded.

Due to the construction of the moisture probe, the impedance transitions at the beginning and end of the metal tubes create changes in the reflected waveform that can be identified. This waveform is also called a TDR trace. When the probe is inserted in soil, the distance between the points on the trace corresponding to the beginning and end of the tubes depends on the moisture content. As the moisture content increases, the apparent distance between the tube end points increases.

A TDR trace usually contains a relatively sharp peak at the beginning point and a sharp dip at the end point of the metal tubes on the moisture probe. Figure 1 below shows the output from a TDR probe connected to a cable tester. As shown in the figure, starting from the left side, the trace rises from the nearly flat portion of the curve, representing the signal in the coaxial cable, to a peak at point A, or local maxima point, where the slope of the curve reverses sign from positive to negative. From this point, the curve drops to a minimum at point B and then

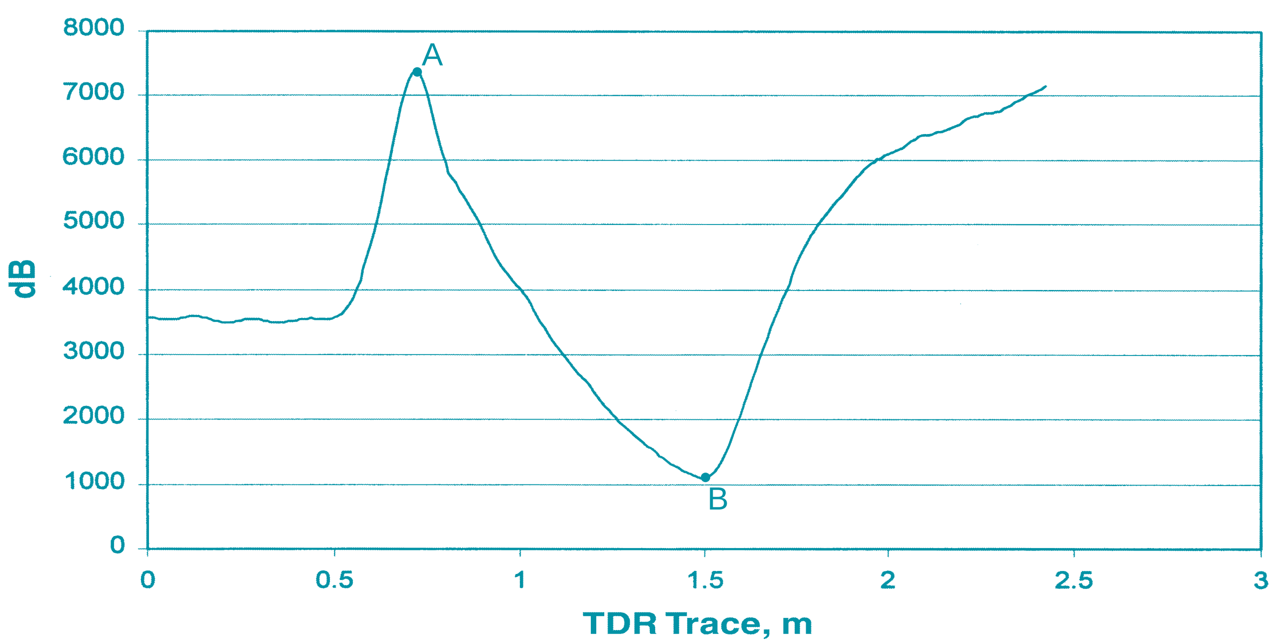

Figure 1. A classic recorded TDR trace.

rebounds upward, i.e., the slope of the curve reverses sign from negative to positive.

Analysis Steps

There are two kinds of traces that can be obtained from the TDR probes: manual and automatic. A trace is interpreted for every one of the probes at the site and the dielectric constant associated with it is calculated. The TDR trace type classification and bulk conductivity class can be used to identify changes in the vertical soil profile due to material variations, the presence of frost, and moisture changes.

Traces that have been recorded on stripchart paper and are to be manually analyzed are called manual traces. Manual traces are interpreted on a 27.9-cm by 43.2-cm (11-in by 17-in) sheet of paper using an engineer's scale, straight edge, and right triangles. The original manual trace is recorded following the instructions in *LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines*.[1] The explicit interpretation instructions are found in LTPP Directive SM-28.[2]

Traces that are available in an electronic format and can be analyzed by a computer are called automatic traces. A Windows®-based program, Moister, was created for use by the research team to permit the processing of the TDR traces in an Access® database table. Data taken from the IMS table **SMP_TDR_ AUTO** can also be plotted and interpreted manually. The points in each record should be plotted to scale using the value DIST_WAV_ POINTS as the increment in the x-direction and the successive values of WAVP (1-245) as the value in the y-direction. A separate plot is required for each probe.

The principle behind the analysis for both the automatic and manual traces is the same. There are two methods that have been selected for analyzing TDR traces—the Method of Tangents and the Method of Peaks.

Method of Tangents

The determination of apparent length using the Method of Tangents involves the following steps:

Determine the first inflection point, A:

1. Identify the first waveform maximum point, A1, and draw a horizontal line at A1.
2. Identify the waveform minimum point, B1.
3. Take half the distance between A1 and B1 and call that A3, or (A1+(B1-A1)/2.
4. Identify the sharpest negative slope between point A1 and point A3 and call that A2.
5. Draw the tangent line at point A2.
6. The intersection point of these straight lines is the first inflection point, A.

Determine the second inflection point, B:

1. Draw a horizontal line at the minimum point, B1, as identified above.
2. Identify the sharpest positive slope point between B1 and B1+60 (or B1(m)+0.6 m), which gives point B2.
3. Draw the tangent line at point B2.
4. The intersection point of these two straight lines is the second inflection point, B.

Figure 2 (on the following page) illustrates the Method of Tangents, showing the location of points A and B and $L_{analysis}$, which is the apparent length. Most manual traces were interpreted using this methodology.

Figure 2. Illustration of the Method of Tangents.

Method of Peaks

The Method of Peaks, illustrated in figure 3 (on the following pages), was used primarily for interpreting automated traces. The following steps are required:

Determine the first inflection point, A:

1. Identify the first maximum

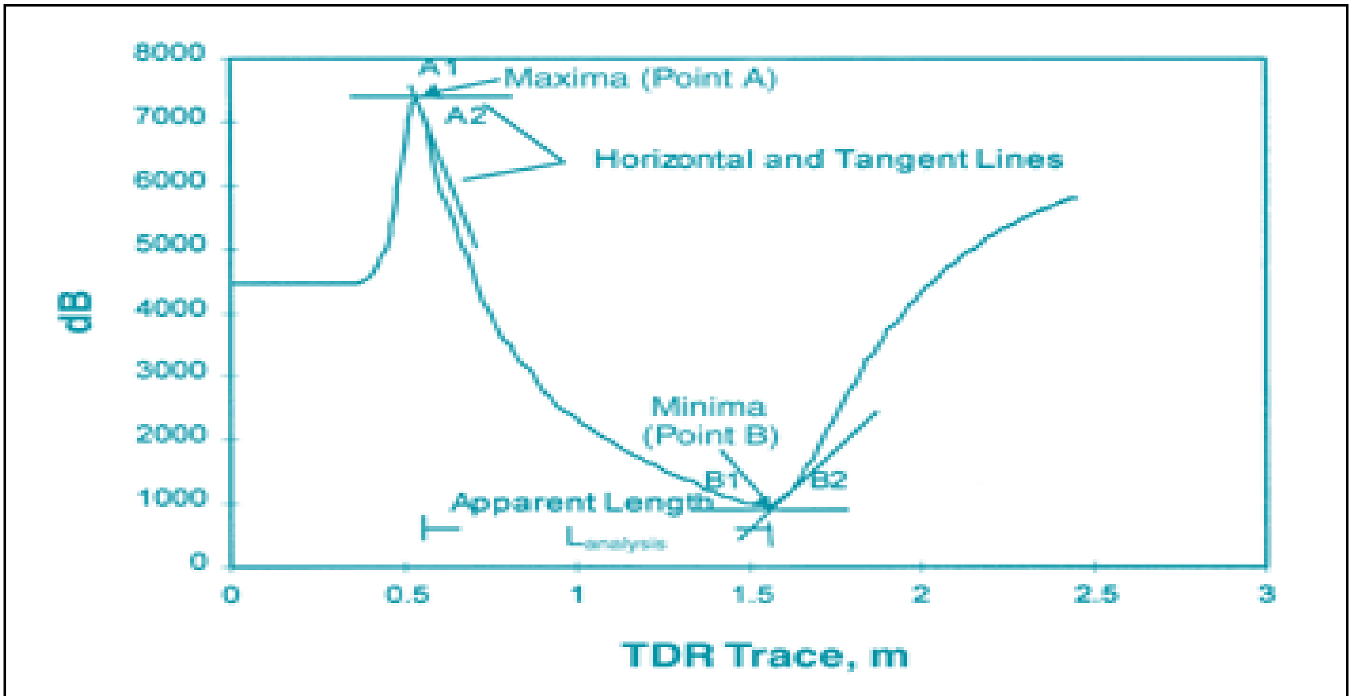

Figure 2. Illustration of the Method of Tangents.

rise point (sharpest positive slope point), A1.

2. Identify the minimum slope point between point A1 and the global minimum. This gives point A2.
3. Draw the tangent line at point A1 and the tangent line at point A2.
4. The intersection point of these straight lines is the first inflection point, A.

Determine the second inflection point, B:

1. Identify the smallest or flattest slope point between a point halfway between the first maximum point and the global minimum. This gives point B1.
2. Identify the sharpest positive slope point between B1 and B1+60 (or B1(m)+0.6 m), which gives B2.
3. Draw the tangent line at point B1 and the tangent line at point B2.
4. The intersection point of these two straight lines is the second inflection point, B.

The horizontal distance between A and B gives $L_{analysis}$ for the Method of Peaks.

Determination of Apparent Length

The apparent length, L_a, for either method is given by:

L_a = (Inflection Point B, m - Inflection Point A, m)

In turn, the dielectric constant of the soil surrounding the probe, K_a, ε, is determined as follows:

$$K_a, \varepsilon = \frac{L_a}{[L * V_p]^2}$$

where:

K_a, ε = Dielectric constant (between 1.0 and 80).

L_a = Apparent length scaled from trace, m.

L = Physical length of the metal tube portion of the moisture probe, m; 0.203 m (8 in) for FHWA probes.

V_p = Phase velocity setting on TDR cable tester (usually 0.99).

The tables with dielectric information contain the location of

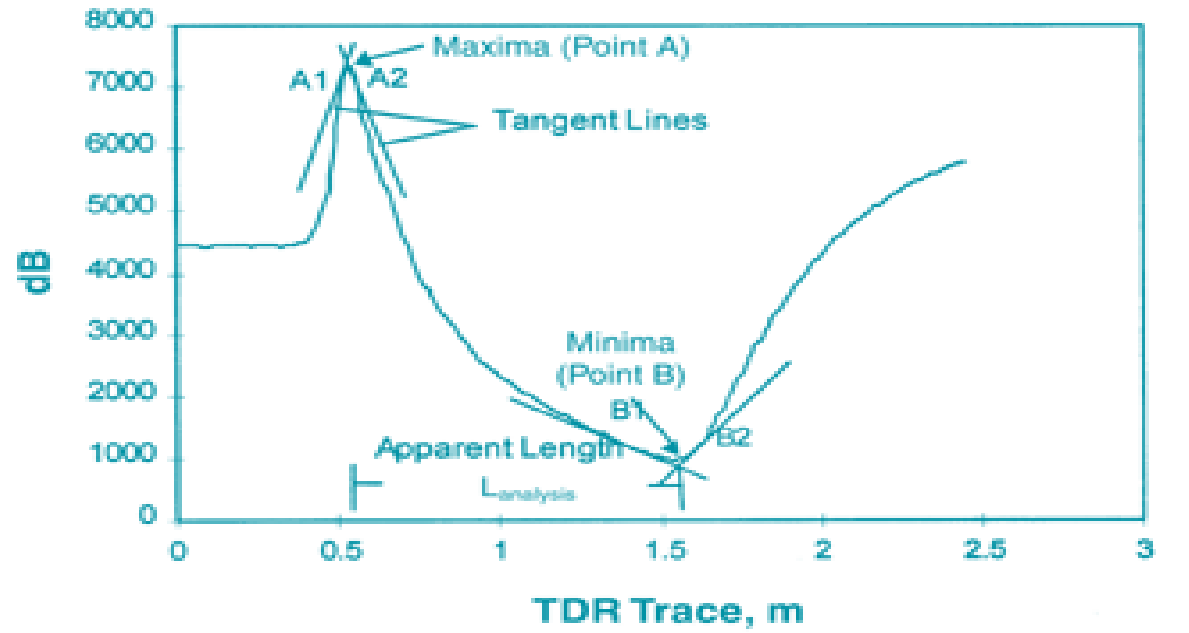

Figure 3. Illustration of the Method of Peaks.

the inflection points, trace type, apparent length, probe length, and value of the dielectric constant. More detailed information on the various types of traces that can be observed and the application of the interpretation methods are found in references 2 and 3.

References

1. G. Rada, G.E. Elkins, B. Henderson, R.J. Van Sambeek, and A. Lopez, Jr. *LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines*, Report No. FHWA-RD-94-110, Federal Highway Administration, McLean, VA, January 1995.
2. LTPP Seasonal Monitoring Program Directive No. 28, Subject: Interpretation Manual TDR Traces, August 7, 1998.
3. Y.J. Jiang and S. Tayabji. *Analysis of Time Domain Reflectometry Data From LTPP Seasonal Monitoring Program Test Sections, Final Report*, Report No. FHWA-RD-99-115, Federal Highway Administration, McLean, VA, April 1999.

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Availability: This publication is available in PDF format from the LTPP homepage at http://www.tfhrc.gov. Copies are also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Key Words: Time Domain Re-

flectometry (TDR), moisture content.

Note: This Computed Parameter Brief is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The purpose of this brief is to provide users of the LTPP Information Management System (IMS) database with succinct, but complete, information as to how a specific computed parameter contained in the IMS is/was computed. Full documentation of the original analysis conducted to derive this parameter is provided in the referenced research report.