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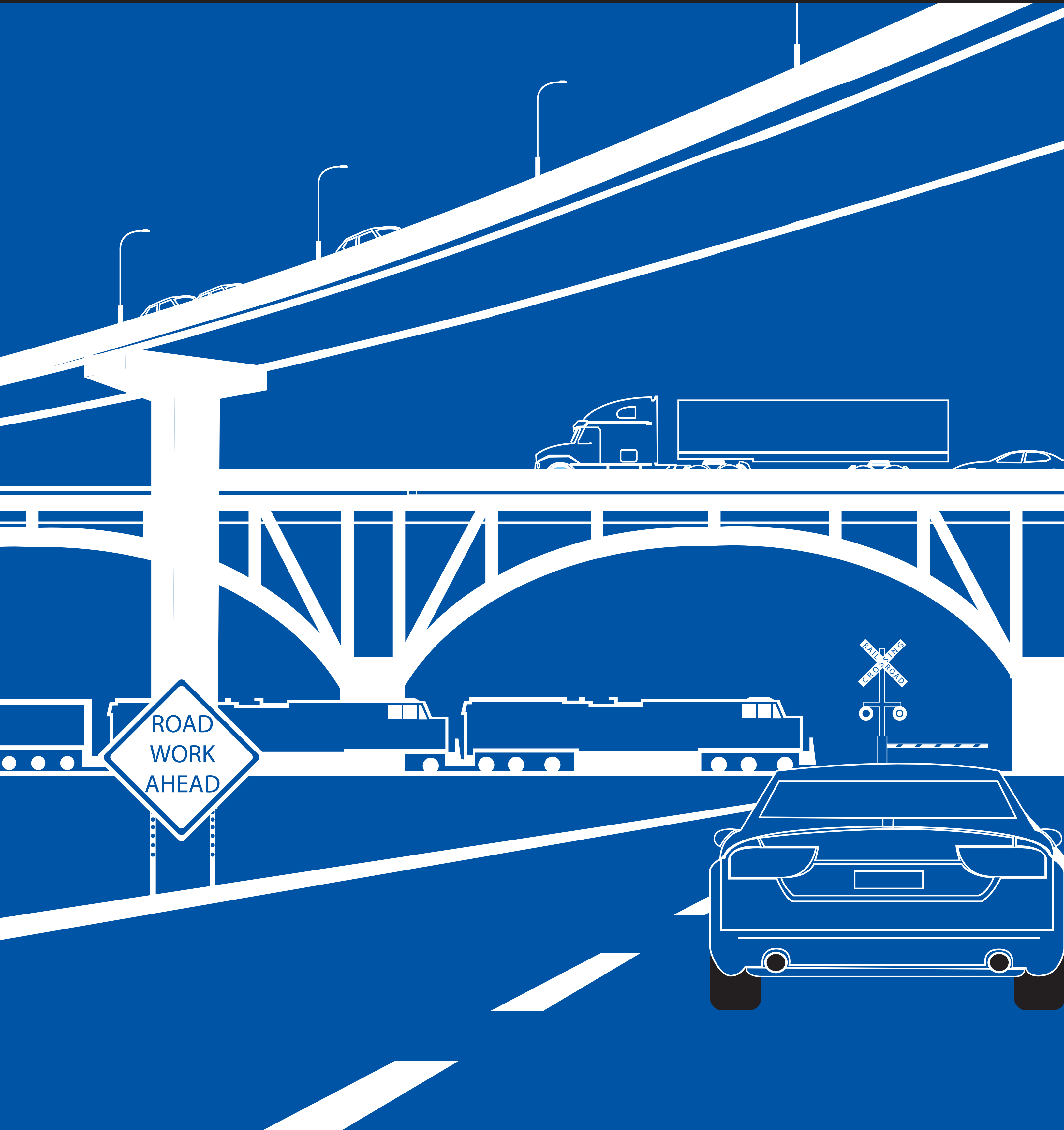
Determination of Constructed Pavement Layer Thicknesses Using Nondestructive Testing (NDT)

Report Number: KTC-19-05/SPR17-539-1F

DOI: https://doi.org/10.13023/ktc.rr.2019.05



Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report
KTC-19-05/SPR17-539-1F

Determination of Constructed Pavement Layer Thicknesses Using Nondestructive Testing (NDT)

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Commonwealth of Kentucky

April 2019

1. Report No. KTC-19-05/SPR17-539-1F	**2. Government Accession No.**	**3. Recipient's Catalog No**

4. Title and Subtitle Determination of Constructed Pavement Layer Thicknesses Using Nondestructive Testing (NDT)	**5. Report Date** April 2019 **6. Performing Organization Code**
7. Author(s): Brad Rister, Jamie Creech, Kean Ashurst	**8. Performing Organization Report No.** KTC-19-05/SPR17-539-1F
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** SPR 17-539
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622	**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**

15. Supplementary Notes
Prepared in cooperation with the Kentucky Transportation Cabinet

16. Abstract
Using nondestructive testing (NDT) to measure the thickness of pavement layers can improve the overall life of a new concrete and/or asphalt pavement. Conventional test methods require the extraction of a core from the pavement section to verify its thickness. Currently, two NDT technologies are commercially available which eliminate or reduce the need to core the existing pavement for thickness verification. The MIT-Scan-T2 (T2) utilizes magnetic pulse induction coupled with preset metal plates to obtain a thickness value. Measurements can be obtained quickly to an accuracy of +/– 2 mm. Ground Penetrating Radar (GPR) uses electromagnetic radiation to determine pavement layer thickness. However, GPR data need to be calibrated with an actual core during the post-processing phase to obtain the highest accuracy. Additionally, the dielectric properties of pavement sections being assessed with GPR must first stabilize to accurately measure thickness. Generally, stabilization occurs approximately 28 days after the initial placement of the pavement.

17. Key Words MIT Scan T2, ground penetrating radar	**18. Distribution Statement** Unlimited with approval of the Kentucky Transportation Cabinet

19. Security Classification (report) Unclassified	**20. Security Classification (this page)** Unclassified	**21. No. of Pages** 20	**19. Security Classification (report)**

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Acknowledgments

The authors of this paper would like to acknowledge the KYTC Division of Construction for its participation throughout this project.

Implementation Statement

This study evaluated two methods of nondestructive testing (NDT) to measure pavement thickness — Ground Penetrating Radar (GPR) and the MIT-Scan-T2. Although each technology has limitations, there are several factors which recommend use of the T2.[3]

1. Rapid measurements. Once the approximate locations for targets are known, finding the exact location and measuring pavement thickness take less than 3 minutes per location.

2. Measurements any time. Measurements with the T2 can be taken as soon as pavement can be walked on. Unlike some other NDTs, T2 measurements can be taken when concrete is at any level of maturity.

3. Ease of use. The T2 is very easy to use and does not require user interpretation, unlike some other NDT methods. One person can operate the device, which can store hundreds of thickness measurements.

4. Lower cost. The cost per measurement (including the cost of the equipment and targets in the long run) is significantly less than taking cores. According to conversations with state transportation agency personnel, the cost of taking cores is $90 to $110 per core. With the T2, cost per measurement is under $20 (including the target). Because of the low cost per measurement, measurements can be taken at more locations, which will yield more robust statistical measures of pavement thickness.

5. Nondestructive. There is no need to extract cores on new pavements, thereby eliminating the need to patch core holes, which can require additional maintenance in later years.

6. Grinding and overlay. If the existing concrete pavement contains targets underneath and is then diamond ground or overlaid, pavement thickness after the diamond grinding or overlay can be measured accurately.

7. Base material. Measurement accuracy is independent of the type of base material. When the base material has properties similar to concrete, other technologies may not provide results that are as accurate. The target defines the bottom of the pavement and eliminates the problem of mortar penetrating into a subbase.

1. Introduction and Background

The Kentucky Transportation Cabinet (KYTC) requires coring of rigid and flexible pavements to evaluate pavement thickness. While this method accurately measures thickness, it is destructive, labor intensive, and time consuming. Coring new pavements can also produce weak spots that may eventually result in maintenance problems, even if the core hole is filled in using accepted practices. Moreover, cores are usually taken only at random locations, as prescribed in Division 400 of the KYTC's Standard Specifications in Kentucky Method 64-420. Oftentimes these specifications and methods are inadequate for estimating the actual thickness profile of an entire pavement section.

This study evaluated new technologies for rapidly measuring of pavement layer thicknesses without obtaining core samples. The motivation for this study was to provide new guidance for determining pavement layer thickness using nondestructive testing (NDT) with the aim extending the service lives of pavement.

2. Methodology

To identify NDT devices for evaluating pavement thickness that are currently on the market, we conducted a thorough literature review. We identified two commercially available technologies: ground penetrating radar (GPR) and the MIT-Scan-T2 (T2). We explain how each technology works as well as their respective advantages and disadvantages. Additionally, we discuss the experiences other state transportation agencies have had with each technology.

With respect to the technical specifications of each equipment type, GPR technology utilizes electromagnetic radiation and the T2 uses magnetic pulse induction. Environmental factors should be considered when determining which solution is most appropriate. GPR emits electromagnetic radiation that may be affected by moisture and/or other electromagnetic frequencies operating within the same frequency domain.[1] The T2's magnetic pulse induction may be affected by other metallic objects within the magnetic field of the device. [2] A brief discussion of each equipment type proceeds below.

GPR operates by transmitting a series of electromagnetic pulses into the pavement surface by either an air-launched horn (Figure 1) or ground-coupled antenna. Transmitted pulses are reflected back to the antenna, indicating pavement properties by measuring pulse amplitude and arrival time (Figure 2).

Figure 1 1.0 GHz. Air Launched Antenna

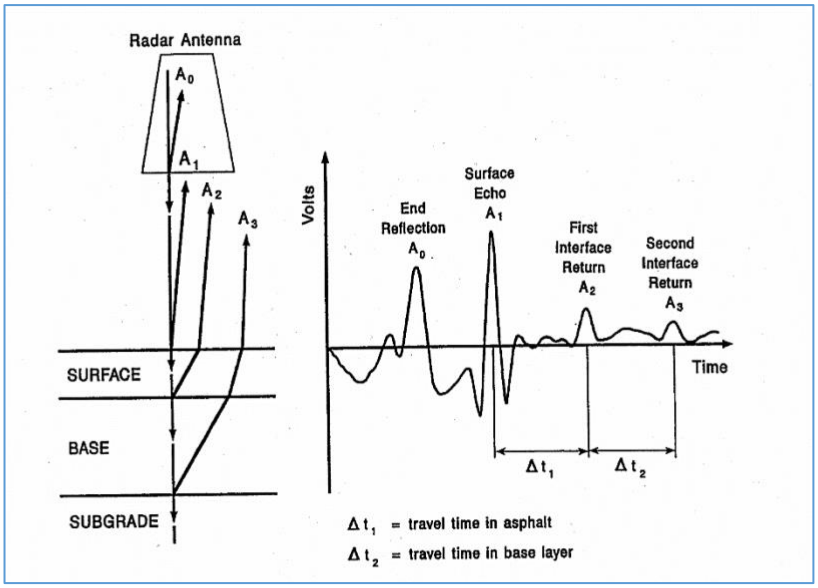

Figure 2 GPR Signal Transmittal

The change in the amplitude and arrival time of the pulse is directly related to the change of the electrical properties of the pavement. How electrical properties of the material change is referred to as the change in dielectric constant.

Different highway-related building materials have different dielectric constants (Table 1). The dielectric property of any material is critical for enabling radar assessments. Without variations in the dielectric constant between materials, radar technology could not identify the interface between different layers.

Table 1 Dielectric Constants

Material	Dielectric Constant
Air	1
Water	81
Asphalt	3 to 6
Concrete	6 to 11
Limestone	4 to 8
Clays	5 to 40
Dry Sand	3 to 5
Saturated Sand	20 to 30

After a radar wave has been transmitted, the amplitude and arrival time of each radar wave is then collected on a central processing unit (CPU). The CPU then calculates the necessary data that will be used in a post-processing to determine the surface layer thickness using the equations below.

Eq. 1 is used to calculate velocity, with ε signifying the dielectric constant of the material. The constant 11.8 is the velocity of the radar wave in free space or air. Velocity (*v*) is given in inches per nanosecond.

(Eq. 1) $\text{Velocity} = \frac{11.8}{\sqrt{\varepsilon}}$

Eq. 2 is the formula for determining thickness. Time (*t*) is divided by two because the value is the amount of time required for the radar wave's roundtrip. Thickness is measured in inches.

(Eq. 2) $\text{Thickness} = v \times \frac{t}{2}$

Combining the velocity and thickness formulas yields the following equation:

(Eq. 3) $\text{Thickness} = \frac{(5.9 \times t)}{\sqrt{\varepsilon}}$

Comparing the dielectric constant of successive pavement layers — subscripts 1 and 2 in Eq. 4 — is done by correlating the amplitude of the waveform peaks and reflections of the successive layers.

(Eq. 4) $\text{Reflection Coefficient } (1-2) = \frac{\sqrt{\varepsilon_1}-\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}-\sqrt{\varepsilon_2}}$

The surface layer dielectric constant, ε_a, is calculated from the amplitude of the reflection from the surface layer and from a metal calibration plate. A metal calibration plate is used because it is 100 percent reflective. It is placed directly on the ground surface below the horn antenna. The formula is:

(Eq. 5) $\varepsilon_a = [(A_{pl} + A) / (A_{pl} - A)]^2$

A = amplitude of the reflection from the surface layer
A_{pl} = amplitude of the reflection from the metal calibration plate

Calculating the dielectric constant of subsequent layers — namely the base layer, ε_b — is done in a similar fashion.

(Eq. 6) $\varepsilon_b = \varepsilon_a [(F - R2) / (F + R2)]^2$

where:

$$F = \frac{4\sqrt{\varepsilon_a}}{(1 - \varepsilon_a)}$$

R2 = ratio of the reflected amplitude from the top of the base layer to the top of the surface layer.[1]

The T2 uses magnetic pulse induction technology to measure the distance from a sensor to a metal reflector (usually referred to as a target). During scanning, the T2 generates a variable magnetic field that creates an eddy current in the target (Figure 3). The eddy current will generate an induced magnetic field inside the target. Sensors within the T2 detect the intensity of this field. For a given target, the intensity of the induced magnetic field is determined primarily by the distance from the T2 device to the target. A calibration file that records the relationship between the induced magnetic field intensity and the distance is developed for unique target types produced by the manufacturer. Targets supplied by the manufacturer are circular and consist of 0.6-mm-thick galvanized sheet metal. Targets are available in different sizes; investigators should select a target based on the thickness of the pavement being measured.[1]

Figure 3 MIT-T2 Scanning Device (Courtesy J. Gudimettla TRB 2019)

3. Literature Review

Several research studies have used radar technology to measure pavement layer thicknesses. All testing described in this section was conducted using a 1.0 GHz air launched horn antenna. A brief overview of their results follows.

Texas Transportation Institute

- Recent studies using GPR to determine pavement layer thickness yielded accuracies of +/– 5% to 7.5%, or +/– 0.33 inches, for asphalt thickness and +/– 9.5%, or +/– 0.77 inches, for base thickness.[6]

Infrasense Inc.

- GPR was used to determine the pavement layer thickness for ten SHRP Long Term Pavement Performance (LTPP) asphalt sections ranging from 3 to 16 inches. The evaluation showed deviations from the cores of +/– 8% for blind evaluations and +/– 5% when calibration cores were used. [7]
- Four Texas SHRP asphalt pavement test sites found radar prediction accuracies for asphalt thickness were within +/– 0.32 inches, or +/– 5%, when using radar alone. When one calibration core was used per site, accuracy improved to +/– 0.11 inches. Accuracy of the radar predictions for base thickness was within +/– 1.00 inch. The nominal layer thickness at these sites ranged from 1 to 8 inches of asphalt and 6 to 10 inches of base. [7]

Florida DOT State Project 99700-7550

- Of five sites considered in the demonstration of radar's capability to predict layer thicknesses, the means of the blind predictions for asphalt surface thickness at three sites were within 0.1 inch or 2 percent of the corresponding measured core. However, at one site, asphalt thickness was underestimated by over 1 inch. For base thickness, blind radar results indicated deviations from core values of between 0 and 2.1 inches. Calculated means of the predicted base thicknesses were, on average, within 0.9 inches of the measured core value in the blind comparisons. However, differences between predicted and measured means for base thickness fell to within 0.5 inches after calibration.[2]

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- KTC identified surface layer thickness between GPR, calibrated with multiple core data, and actual measured cores one may expect GPR results to range between:
    - Asphalt less than two inches:
        - +/– 10.32% to +/– 0.40%
        - +/– 0.20 to +/– 0.01 inches
    - Asphalt bases of eight to nine inches:
        - +/– 2.73% to +/– 1.34%
        - +/– 0.24 to +/– 0.12 inches

- Concrete nine to twelve inches:
    - +/– 14.24 to +/– 0.05%
    - +/– 1.66 to +/– 0.01 inches

Figures 4 and 5, identify the correlation between the number of cores taken and accuracy of the processed data for asphalt and concrete, respectively. As these graphs show, taking more cores resulted in more accuracy for overall GPR thickness measurements.

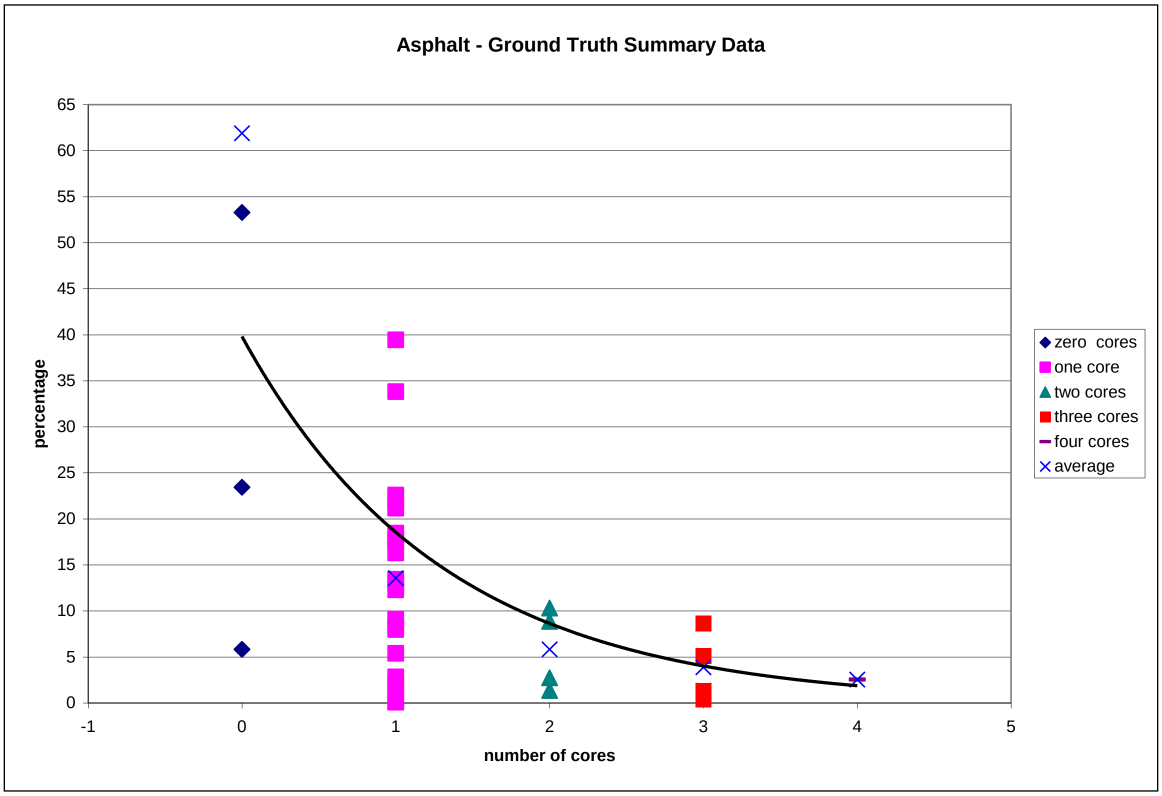

Figure 4 GPR Calibration to Core Data (Asphalt)

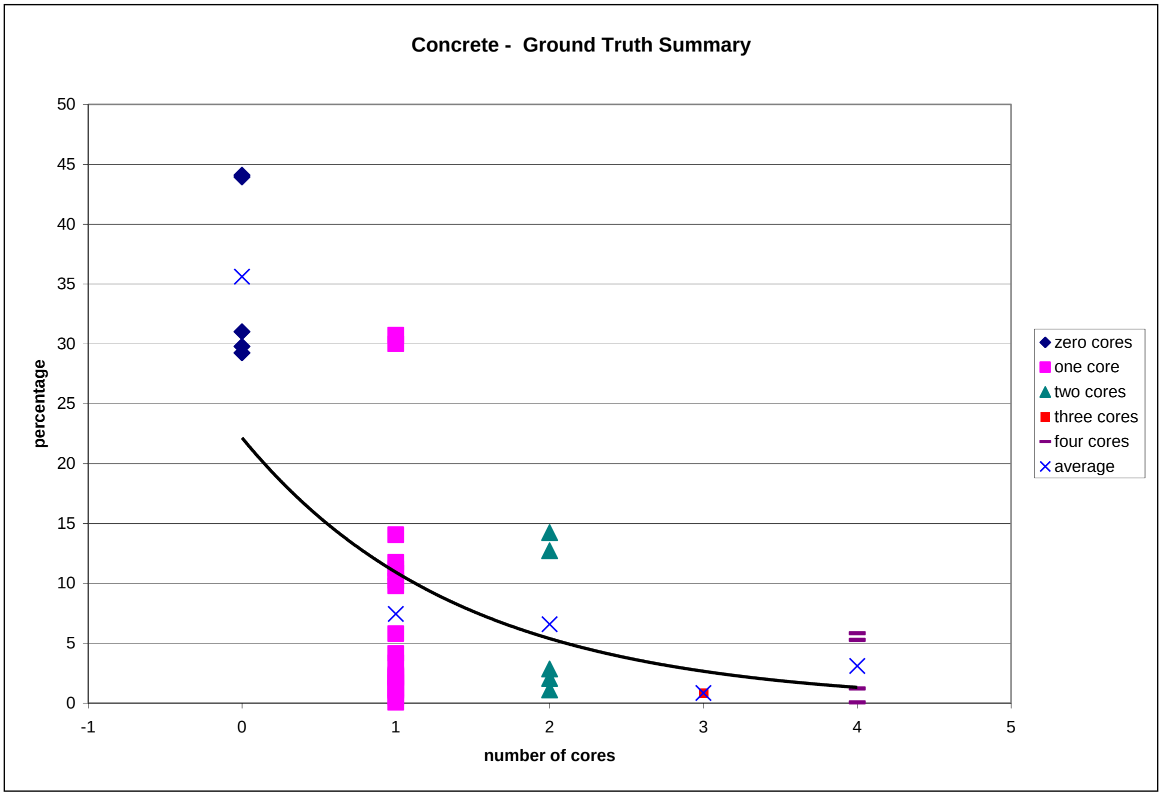

Figure 5 GPR Calibration to Core Data (Concrete)

Our literature review uncovered several state transportation agencies that have used the T2 to determine pavement layer thicknesses: Iowa, Illinois, Hawaii, Florida, Indiana, Delaware, Tennessee, Alabama, Michigan, New York, West Virginia, North Dakota, North Carolina, and Washington State. To measure thickness with a T2, a target is installed and then paved over. The T2 is then used to locate the target and measure the thickness (Figure 6).

Figure 6 Steps for Using the T2 (Ref. TRB 2268)

Studies of the T2 by multiple agencies on multiple products found a strong relationship between actual core thickness and pulse induction measurements (R_2 = 0.9967; Figure 6). Figure 6 consolidates testing data from multiple states and provides a good representation of the T2's reliability.

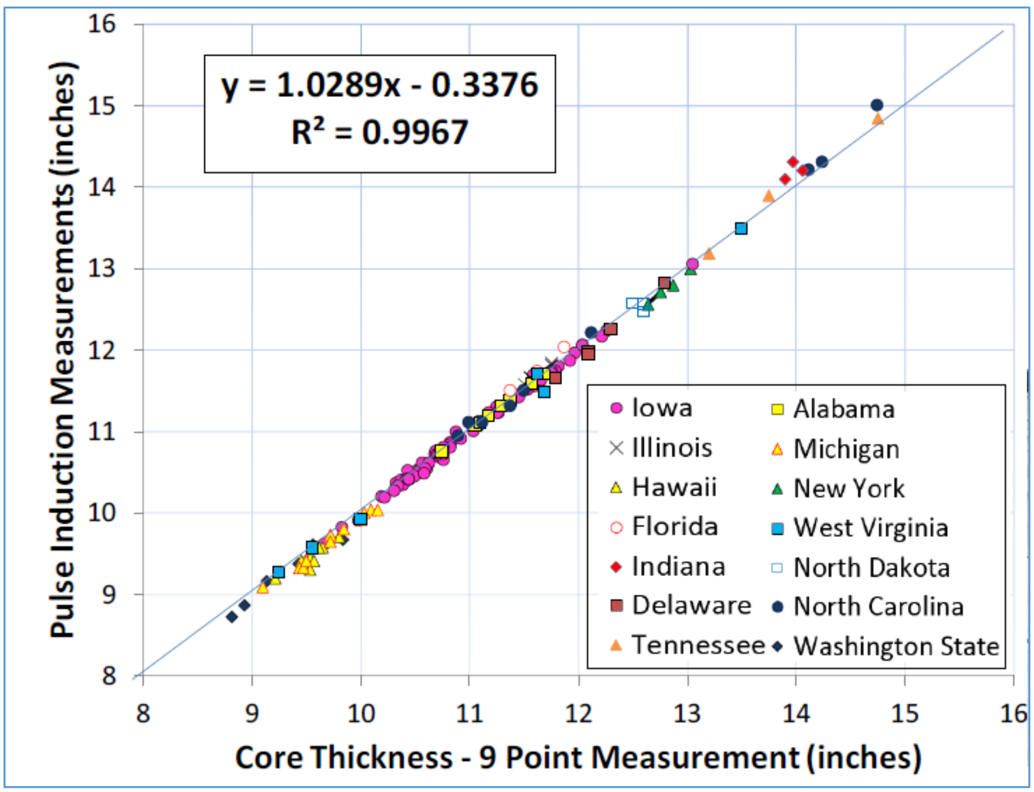

Figure 7 Correlation Between Actual Core Thickness and T2 Measured Thickness (Ref. TRB 2268)

Previous research has also found that the "cost per measurement (including the cost of the equipment and targets on the long run) is significantly cheaper than taking cores. According to conversations with DOT personnel, the cost of taking cores is about $90 to $110 per core. The cost per measurement with the T2 is less than $20 (including the target). Because of the low cost per measurement, measurements can be taken at more locations, which will yield a more robust [statistical] measure of pavement thickness."[3] A cost matrix for GPR would include equipment cost, collection cost, processing cost, and a core validation cost. On a per unit basis, cumulative costs might exceed those for adopting the T2 at the project level.

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4. Analysis and Results

Nineteen state transportation agencies have thoroughly tested the T2. Test results show it consistently measures pavement layer thickness to an accuracy of +/– 2 mm.[3] A demonstration project in Iowa which compared the performance of two T2 devices when applied to 388 targets found the average difference in measured pavement thickness between devices was 1 mm or less. One challenge mentioned in earlier studies is that a contractor may see where a disk is placed before paving over it. Some may argue that this could alert them to the need to apply a thicker layer of pavement at only these locations. To avoid any bias created by prior knowledge of the disk location some agencies randomly select which disk is used to measure paving thickness. Some states hope to utilize the T2 by adopting it into their current specifications in lieu cutting cores for thickness verification.

Using GPR to measure pavement thickness presents few more challenges for verifying the actual thickness. First, a core is needed to calibrate the equipment. Second, once data are collected they must be post-processed. Third, on concrete pavements, the pavement moisture content needs to stabilize before using GPR. As Figure 7 indicates the dielectric properties of curing concrete pavement change over time. Concrete pavements should cure for at least 28 days to obtain for a more stable thickness reading. Also, when measuring asphalt thickness, the complete asphalt block thickness should be measured — not the thickness of individual layers.

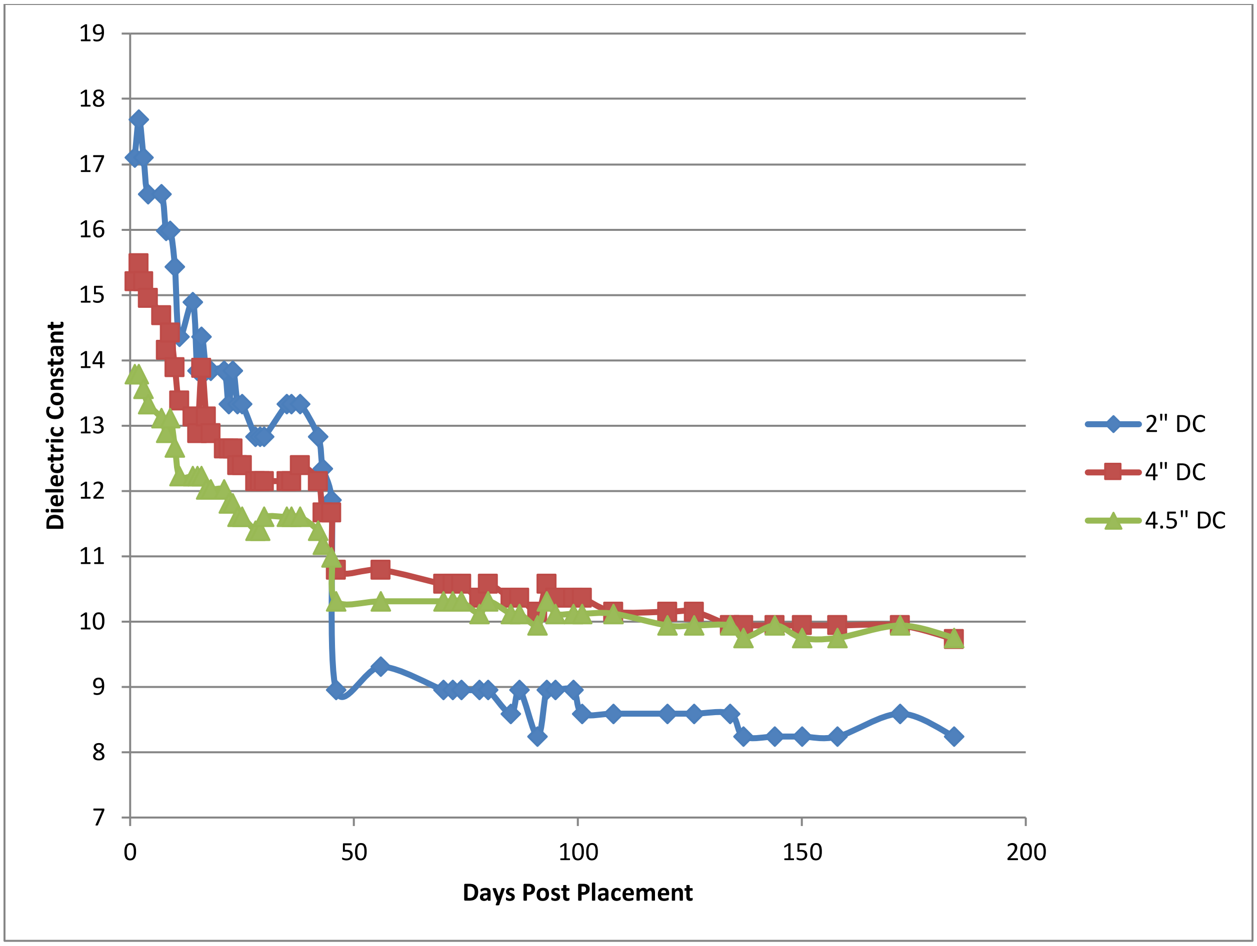

Figure 8 Dielectric Change Over Time for Concrete

5. Summary

Both the T2 and GPR can be used to measure pavement layer thickness. While the T2 requires placement of metal plates before paving, with GPR a core must be extracted for calibration purposes to generate the most accurate data. GPR can depict the entire length of the roadway section once scanned whereas T2 captures thicknesses only in spot locations. Based on a review of both technologies, it appears that the T2 is capable of greater accuracy and works in any type of weather conditions. State transportation agencies that use a core thickness per lot verification process can substitute a T2 device into their specifications in lieu of taking cores.

6. Conclusions and Recommendations

Compared to the traditional method of taking cores, magnetic pulse induction technology offers a faster, easier, nondestructive, and significantly cheaper way to measure pavement thickness. The T2 is accurate to +/− 2 mm for a wide range of pavement thicknesses[3]. The consistency of results — an important measure of any test method's reliability and trustworthiness — is excellent.

GPR also holds promise, however, at least one core must be taken for calibration purposes. When testing concrete pavements with GPR, the dielectric properties of the new pavement must first stabilize to obtain an accurate thickness value. Stabilization often occurs 28 days following initial placement and corresponds to the concrete nearing its optimal compressive strength. This waiting period may not be suitable for all projects.

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