TechBrief

The Concrete Pavement Technol ogy Program (CPTP) is an inte grated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP s primary goals are to reduce congestion, im prove safety, lower costs, improve performance, and foster innova tion. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materi als selection, mixture proportion ing, and the design, construction, and rehabilitation of concrete pavements..

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U.S. Department of Transportation
Federal Highway Administration

Determination of Concrete Pavement Thickness Using the Magnetic Imaging Tomography Technique

This technical summary discusses the application of a recently introduced technique, based on magnetic imaging tomography, to determine the thickness of freshly placed concrete. This technique may be used for process testing and for acceptance testing during construction of new concrete pavements. The technique is applicable only to plain (nonreinforced) concrete pavements. The results of recent field trials using this technique are presented.

BACKGROUND

Concrete slab thickness plays a critical role in the performance of concrete pavements. A small deficit in slab thickness can significantly reduce the service life of a concrete pavement. Based on the structural design procedures for concrete pavements, a reduction in concrete slab thickness by an inch (2.54 cm) can result in as much as a 50 percent reduction in the service life of the pavement. Many highway agencies have tight specifications for concrete pavement thickness. Typically, a large reduction in lot payment may result if the concrete pavement thickness is 12.5 mm (0.5 in.) less than specified for as-designed pavement thicknesses in the range of 250 mm to 300 mm (9.8 in. to 11.8 in.). Such requirements make the measurement of concrete pavement thickness an important activity to determine the compliance of concrete pavement construction with the project construction specifications.

For most highway agencies, ASTM C 174 (ASTM 2006a), "Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores," is the standard method to determine the thickness of as-constructed concrete pavement. Although this method produces accurate thickness measurement, the testing procedure is destructive, time consuming, labor intensive, and costly. Normally only one core is drilled per sublot (typically every few hundred feet of pavement). With these few sampling points, it is hard to establish a statistically robust representation of the pavement thickness in a constructed lot. In addition, the measurement of the core length can also be affected by base type, particularly by open-graded permeable base where concrete can penetrate significantly into the base.

Some nondestructive tests are available for measuring concrete pavement thickness, such as the ASTM C 1383, "Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method" (ASTM 2006c), and ASTM D 4748, "Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse

Radar" (ASTM 2006b). The accuracy of both the impact-echo technique and ground-penetrating radar is limited when freshly placed concrete is tested, and results are also affected by base type. A key limitation is inherent in both techniques: they generate certain types of stress waves and measure the travel time of these waves as they move through the concrete medium, so the properties of newly placed concrete, such as water content and electromagnetism, affect measurement significantly. These techniques are not considered as accurate or reliable as the ASTM C 174 procedure and are not used currently for production testing of freshly placed concrete. There is a need for a technique to measure concrete pavement thickness, that is:

- Simple, easy, and fast to operate.
- Able to produce accurate measurements.
- Relatively inexpensive.

MIT-SCAN-T2 DEVICE

The MIT-SCAN-T2 (denoted as T2 in this publication) (as shown in Figure 1), a product from MIT Mess- und Prüftechnik GmbH, a firm in Dresden, Germany, is a simple and easy-to-use handheld device that is able to accurately measure the thickness of pavement layers. The device, introduced in 2007, is based on magnetic imaging tomography. The coil mounted in the device generates a pulse of magnetic field, which induces an eddy current in a pre-placed metal reflector on the surface of the base. Electromagnetic sensors in the device then measure the intensity of the magnetic field caused by the eddy current in the reflector. Since most concrete materials have no effect on magnetic fields, the eddy current approach eliminates thickness measurement biases caused by variations in the properties of concrete materials. This technique is medium-independent and can be used to measure concrete thickness of up to 508 mm (20 in.). Using only one hand, the operator uses the device to locate reflectors that have been pre-placed randomly on the base. The device is then used to measure and record the thickness of the pavement above the reflector. Each test requires less than a minute to perform.

Figure 1. The MIT-SCAN-T2 device in use.

For determining the thickness of concrete pavement, the standard reflector plate is 300 mm (11.8 in.) in diameter. The plate material is high-strength steel with a thickness of 0.65 mm (0.03 in.).

Operation of the T2

Operational procedures comprise two phases:

1. Prior to concrete placement: The reflectors are placed at the desired locations on the surface of the base (Figure 2). The reflectors need to be fastened to the base using dowel basket nails or an asphaltic tack coat. Reflectors should be placed away from dowel bars and tie bars.

2. Following concrete placement: Testing can be conducted as soon as the concrete can be walked upon. In this phase, three easy steps are involved.

a. Assemble the device. The T2 is usually dismantled for storage with other accessories in a compact case for easy transport (Figure 3).

b. Locate the reflector. Although the approximate location of the reflector is marked when it is placed, the T2 has a built-in capacity to locate the reflector more accurately.

c. Scan over the reflector. Once the location of the reflector is determined, the T2 is moved over the reflector at a steady speed (Figure 4). A calculated thickness is displayed immediately after completion of the scan (Figure 5) and recorded. Ideally, five measurements should be taken at each reflector plate and the average value used.

Accuracy and Precision

The accuracy of the T2 is reported to be within 0.5 percent of the measured thickness plus 1 mm (0.04 in.), which translates to an accuracy of 3 mm (0.1 in.) for a concrete pavement 330 mm (12.9 in.) thick. The field trials conducted in the United States have consistently produced measurements with errors less than 3 mm (0.1 in.).

Limitations—Use of Calibrated Reflector Plates

A unique parameter file for each type of reflector is necessary for accurate thickness measurement. Any difference in shape, size, or material constitutes a different reflector type. Currently, the device manufacturer supplies the calibrated reflectors for use with the T2.

Recently, limited studies have been conducted to evaluate the use of reflectors fabricated from domestic sheet metals and to determine if these plates can produce accurate and repeatable measurements. A calibration process has also been developed for domestically fabricated reflectors.

Figure 2. Preplacement of a reflector on the base.

Figure 3. The T2 in storage case.

Figure 4. T2 located over the reflector plate.

Figure 5. Thickness display.

STATE EXPERIENCE WITH THE T2

During 2008, the Iowa Department of Transportation (DOT) evaluated the use of the T2 device as part of the Equipment Loan Program sponsored by the Federal Highway Administration's (FHWA's) Concrete Pavement Technology Program. The device was used at a concrete pavement construction project in Jefferson County. The conclusions from the Iowa study are summarized below:

1. The unit was simple, easy, and quick to operate.
2. The unit has acceptable accuracy and repeatability for quality assurance testing, based on the limited testing performed.
3. Care must be taken to make sure that the base material is level under the target.
4. There is significant difference between thickness measured to the top of the base (smooth bottom using the reflector plates) and core thickness (uneven core bottom) determined using the current Iowa DOT method, as illustrated in Figure 6. (Note: The difference will depend on the base type. For a dense-graded or stabilized base, the results should be very close. But, for an open-graded permeable base, the results may vary due to the penetration of the mortar into the voids in the base.)

Figure 6. Core over the reflector plate (smooth bottom) and normal core (uneven bottom).

SUMMARY

MIT-SCAN-T2 is a quick, easy, accurate, and cost-efficient technique for process control and acceptance testing of concrete pavement thickness. The T2 can be used directly, without calibration, if standard 300-mm (11.8-in.) plates provided by the vendor are used. The limited laboratory and field investigations, documented in Appendix A, indicate that domestically fabricated square and circular reflector plates, used with calibration functions, can also produce reliable and consistent measurements. The recommended calibration procedure is outlined in Appendix B. Based on the testing conducted and recommendations from the device manufacturer, the following plate sizes are recommended:

- 14 in. by 14 in. for concrete thickness up to 600 mm (24.0 in.)
- 10 in. by 10 in. for thickness up to 350 mm (13.8 in.)
- 5 in. by 5 in. for thickness up to 150 mm (6.0 in.)

REFERENCES

ASTM C 174/C 174M. 2006a. Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores. American Testing and Material Standards, West Conshohocken, PA.

ASTM A 653. 2008. Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process. American Testing and Material Standards, West Conshohocken, PA.

ASTM C 1383. 2006b. Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method. American Testing and Material Standards, West Conshohocken, PA.

ASTM D 4748. 2006c. Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar. American Testing and Material Standards, West Conshohocken, PA.

Jones, K. B., and T. Hanson. 2008. *Evaluation of the MIT SCAN T2 for Non-destructive PCC Pavement Thickness Determination*. Iowa Department of Transportation, Office of Materials, Ames.

APPENDIX A
CONCRETE PAVEMENT TECHNOLOGY PROGRAM REFLECTOR STUDY

The FHWA Mobile Concrete Laboratory (MCL) and Fugro Consultants, Inc., conducted a preliminary study of reflectors in response to needs identified during implementation of the MIT-SCAN-T2 technique.

MCL Test Summary

MCL conducted testing to investigate the effect of using nails to fasten the plates to the base and to evaluate the use of locally fabricated rectangular reflectors. The nail fastening study indicated that use of up to four nails (partially or fully driven into the base) did not affect the accuracy of the T2 measurements.

Using galvanized sheet metal 0.3 mm (0.0125 in.) thick and 610 mm by 914 mm (24 in. by 36 in.), MCL fabricated 265-mm (10.5-in.) square reflectors; rectangular reflectors 208 mm by 340 mm (8.2 in. by 13.4 in.); and circular reflectors with a diameter of 300 mm (11.8 in.). The surface areas of MCL-fabricated reflectors were the same as MIT-supplied reflectors; however, MIT-supplied reflectors have a thickness of 0.65 mm (0.03 in.). The T2 measured 4 mm (0.1 in.) and 3 mm (0.1 in.) deeper using square reflectors than using the MIT-supplied reflectors at the depths of 345 mm (13.5 in.) and 255 mm (10 in.), respectively, and measured 13 mm (0.51 in.) and 8 mm (0.3 in.) deeper using rectangular reflectors at those two depths, respectively. MCL-fabricated circular reflectors produced almost the same measurements as MIT-supplied reflectors in spite of the different thicknesses of the reflectors.

Fugro Test Program

Based on MCL's testing, square reflectors appeared to be possible substitutes for circular reflectors from MIT. To fully understand the behavior of square reflectors, develop calibration procedures, and investigate the repeatability of measurements using reflectors made from domestic sheet metals, Fugro carried out a limited test program. In addition, domestically fabricated circular reflectors were also investigated. The sheet metals that were used to fabricate square targets conform to ASTM A 653 CS type II (ASTM 2008).

Square Reflector Testing Program

The objectives of the square reflector testing program were the following:

1. Investigate the effect of the thickness of the reflector.
2. Investigate the effect of reflector orientation.
3. Investigate the effect of wandered path.
4. Establish calibration functions for square reflectors.
5. Investigate the repeatability of reflectors from different suppliers and evaluate calibration functions.

Square reflectors were fabricated from three suppliers located in Austin, Texas. Square reflectors of sizes 254 mm, 273 mm, 279 mm, 305 mm, 330 mm, and 356 mm (10.0 in., 10.7 in., 11.0 in., 12.0 in., 12.9 in., and 14.0 in.) were fabricated by Supplier A from gauge 24 galvanized sheet metal to serve Objectives 1 through 4.[1] Square reflectors from the other two suppliers (Suppliers B and C) were used for Objective 5. Supplier B had gauge 28 sheet metal available. Some gauge 28 reflectors were also made for Objective 1.

A special platform was set up to facilitate the testing process. Both the surface panel and the base panel were adjusted to be level and marked with parallel guiding lines with a 25.4-mm (1-in.) offset. These guiding lines helped to control the way that the scanner traversed the reflectors. The reflectors could be placed at desired heights with the support of a cushion.

Square Reflector Test Results and Discussion

Objective 1. Two reflectors were overlapped to create a double thickness. Two reflector sizes, 279 mm and 356 mm (11 in. and 14 in.) square, were used. No difference between single reflector and double reflectors was observed for the 279-mm (11-in.) reflectors, and only a 0.4-mm (0.02-in.) difference was measured for the 305-mm (12-in.) reflectors.

[1] The sheet metal gauge (sometimes spelled "gage") indicates the standard thickness of sheet metal for a specific material. As the gauge number increases, the material thickness decreases. A gauge 24 galvanized sheet is approximately 0.7 mm (0.03 in.) thick, and a gauge 28 galvanized sheet is approximately 0.4 mm (0.02 in.) thick.

These results correspond well with MCL's finding that MCL-fabricated circular reflectors produced the same measurement as MIT-supplied ones despite their different thicknesses. However, gauge 28 reflectors, from Supplier B, produced significantly different measurements (about 4 mm [0.16 in.] less than the measurements from gauge 24 reflectors of the same size). Therefore it is necessary to specify the gauge of the sheet metals to eliminate plate thickness as a cause for inconsistent measurement.

Objective 2. Different-sized reflectors (279 mm, 305 mm, 330 mm, and 356 mm [11.0 in., 12.0 in., 12.9 in., and 14.0 in.]) were tested at various depths (92 mm, 142 mm, 187 mm, 267 mm, 302 mm, and 338 mm [3.6 in., 5.6 in., 7.4 in., 10.5 in., 11.9 in., and 13.3 in.]) with different orientations. Table A-1 presents the test results. It was observed that orientation of the reflector has very marginal effect on measurement.

Objective 3. The effect of wandered path on measurement. Measurements with different offsets from the centerline of the reflector plate were taken. Figure A-1 presents the typical trend of measurement while the device wanders from the centerline. A wandered path 152 mm (6 in.) away from the centerline can cause a difference of more than 10 mm (0.4 in.), as shown in Figure A-1 for the 356-mm (14-in.) square reflectors. Special care needs to be exercised to locate the center of the square reflector to mitigate false measurement due to wandered paths.

Objective 4. MIT-SCAN-T2 requires a parameter file to analyze the scanned signal. Each type of reflector has its unique parameter file. The parameter file for the T2 devices used by FHWA was customized for MIT-supplied circular reflectors 300 mm (11.8 in.) in diameter for concrete pavement application. Using this parameter file to analyze data from a different type of reflector can result in a false depth reading. A calibration function is needed to transfer the false reading to the actual depth. Since measurements from MIT-supplied reflectors were also taken together with newly fabricated square reflectors at various depths, calibration functions were obtained by best fitting the data. Square reflectors of sizes 279 mm and 305 mm (11.0 and 12.0 in.) produced the best correlations, as shown in Figure A-2 and Figure A-3.

Objective 5. Square reflectors of sizes 279 mm and 305 mm (11.0 in. and 12.0 in.) were selected as potential substitutes. Reflectors of such sizes were fabricated by Supplier B and C to investigate the repeatability of reflectors from different suppliers and to evaluate the calibration functions obtained in Objective 4.

Repeatability testing was carried out at depths of 224.0 mm, 299.5 mm, and 336.6 mm (8.8 in., 11.8 in., and 13.3 in.). Table A-2 presents the original readings and calibrated readings of the reflectors from different suppliers. Repeatable results were obtained from the reflectors of different suppliers. The calibration functions worked well to convert T2

Table A-1. Comparison of Measurements From Parallel and Diagonal Scanning Paths

Plate Size, in.	Path	Measurements at Different Depths, mm					
		92	142	187	267	302	338
11	Parallel	90	139	182	260	295	331
	Diagonal	91	139	182	260	294	330
12	Parallel	87	133	172	246	280	314
	Diagonal	87	133	172	247	280	313
13	Parallel	84	128	164	235	268	300
	Diagonal	84	128	164	235	268	300
14	Parallel	81	125	157	226	257	288
	Diagonal	81	125	157	226	257	287

displayed readings to actual depths, and the maximum difference observed was 2 mm (0.08 in.) for Supplier C's reflectors at the depth of 224 mm (8.8 in.).

Based on Fugro's study, it is concluded that it is feasible to use domestically fabricated square reflectors for MIT-SCAN-T2. Domestically fabricated square reflectors do produce consistent measurements, and calibration functions can be developed to compute the actual measurement depth with good accuracy (±2.5 mm [±0.098 in.]).

Circular Reflector Testing Program

Fugro received nine circular reflectors from Iowa DOT that were 300 mm (11.8 in.) in diameter, fabricated from ASTM A 653 CS Type II gauge 24 sheet metal. These reflectors were evaluated at different depths.

An improved testing platform (Figure A-4) was used in the testing program. Two panels were held parallel to each other by six threaded rods made of fiberglass. The distance between the two panels was adjustable to simulate different pavement thicknesses. With precise control of the distance between panels, seven different depths, ranging from 100 mm to 400 mm (3.9 in. to 15.8 in.), with an interval of 50 mm (1.95 in.), were used. The MIT-specified applicable scanning depth for a circular reflector 300 mm (11.8 in.) in diameter is about 350 mm (13.8 in.). The measurements fluctuated significantly for repeated scanning at the depth of 400 mm (15.8 in.), thus the measurements at this depth were excluded from the analysis.

Two types of reflectors were tested, the nine domestically fabricated

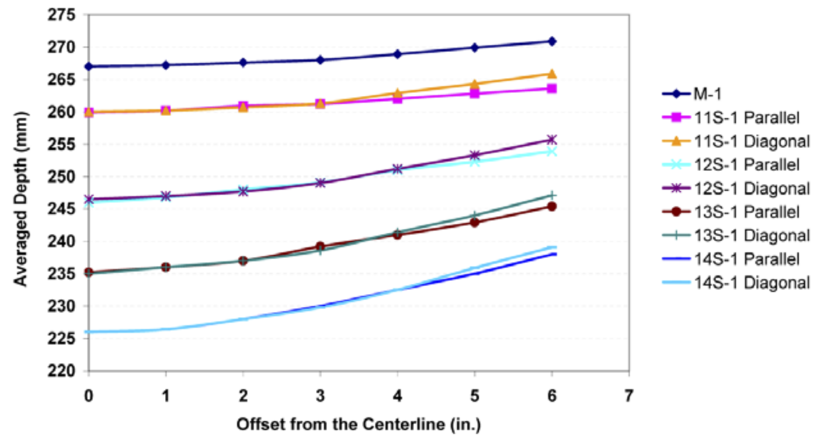


Figure A-1. Thickness measurements for different wandered paths.

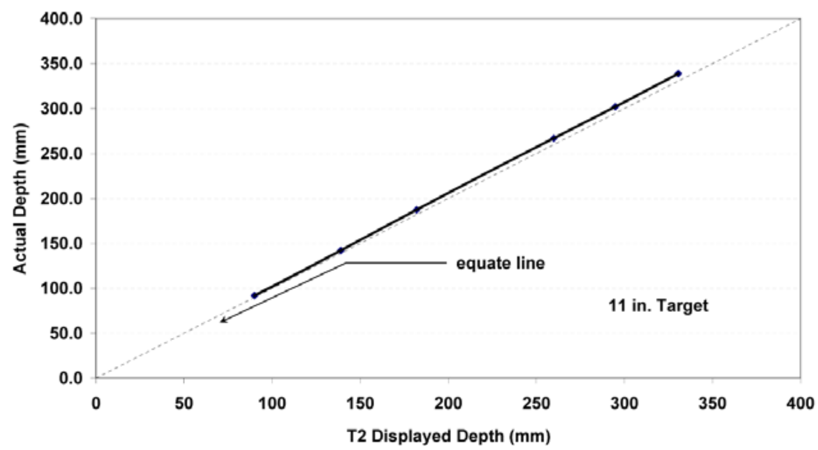


Figure A-2. Calibration function for 11-in. reflectors.

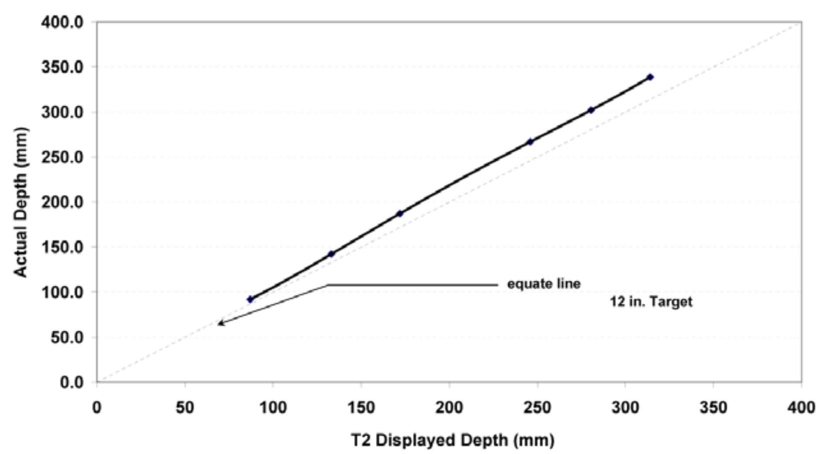


Figure A-3. Calibration function for 12-in. reflectors.

Table A-2. Measured Depth and Calibrated Depth (mm), Domestically Fabricated Square Reflectors

Plate Size, in.	Supplier	Measured	Calibrated	Measured	Calibrated	Measured	Calibrated
11	A	328	337	291	298	217	224
	B	329	337	292	299	218	225
	C	329	337	292	299	218	225
12	A	312	336	276	298	206	225
	B	313	337	277	299	207	226
	C	312	337	277	298	207	226
Actual Depth		337		300		224	

1 mm = 0.039 in.

circular reflector plates and a MIT-supplied circular plate. Ten measurements were taken for each reflector at each depth. Each individual reflector exhibited good repeatability. The maximum difference in the measured depth for a reflector was 3 mm (0.12 in.) when the depth was 350 mm (13.8 in.). As the depth decreased, the difference decreased, indicating better repeatability. The repeatability between the two reflector types was assessed by the difference between the average values of 10 measurements for each reflector. The maximum difference of the average measurements between the two reflector types was 1.4 mm (0.06 in.). Based on these results, the nine domestically fabricated circular reflectors were considered able to produce consistent and repeatable measurements.

As discussed earlier, the T2 device relies on the MIT-developed parameter files to interpret the detected eddy current signal. Different types of reflectors have different parameter files. Even though the domestically fabricated circular reflectors have the same diameter as the MIT-supplied circular reflectors, they differ in material composition and thickness. The displayed depth measurements for the domestically fabricated circular reflectors need to be adjusted to establish the actual depths.

Table A-3 presents the averaged displayed measurements for all nine domestically fabricated reflectors at different depths. It is observed that the averaged displayed depth is always about 3 mm (0.12 in.) less than the actual depth. Thus, it would be appropriate to add 3 mm (0.12 in.) to the displayed depth to establish the actual depth when using such circular reflectors.

Figure A-4. Improved testing platform.

Field Evaluation of Circular Reflectors

During May 2009, a field evaluation of the Iowa reflector plates was conducted along a section of I-90, near Syracuse, New York, that is under reconstruction. Reflectors were nailed at the center onto the cement-treated permeable base. Each reflector was placed approxi-

Table A-3. Actual Depth and Averaged Displayed Depth (mm)

Actual Depth	Averaged Displayed Depth
350	347
300	297
250	246
200	197
150	147
100	97

1 mm = 0.039 in.

mately in the center of the slab to eliminate the effect of dowel bars and tie bars. Five MIT-SCAN-T2 measurements for each reflector plate were taken before coring. A core was drilled directly over each of the reflectors, and the core thickness was measured at three locations around the core's perimeter (on-site measurements).

Table A-4 presents the T2 measurements and the corresponding core thickness measurements. The Iowa reflector plates produced very accurate thickness measurements as compared to the core thicknesses. The maximum difference of averaged T2 measurements and core thicknesses was 2 mm (0.08 in.). It should be noted that for the field testing, the T2 measurements were 0.4 mm to 2.0 mm (0.02 in. to 0.08 in.) less than the core thicknesses, while the T2 measurements were about 3 mm (0.12 in.) less than the actual depth in the laboratory testing program.

REFERENCE

ASTM A 653. 2008. Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process. American Testing and Material Standards, West Conshohocken, PA.

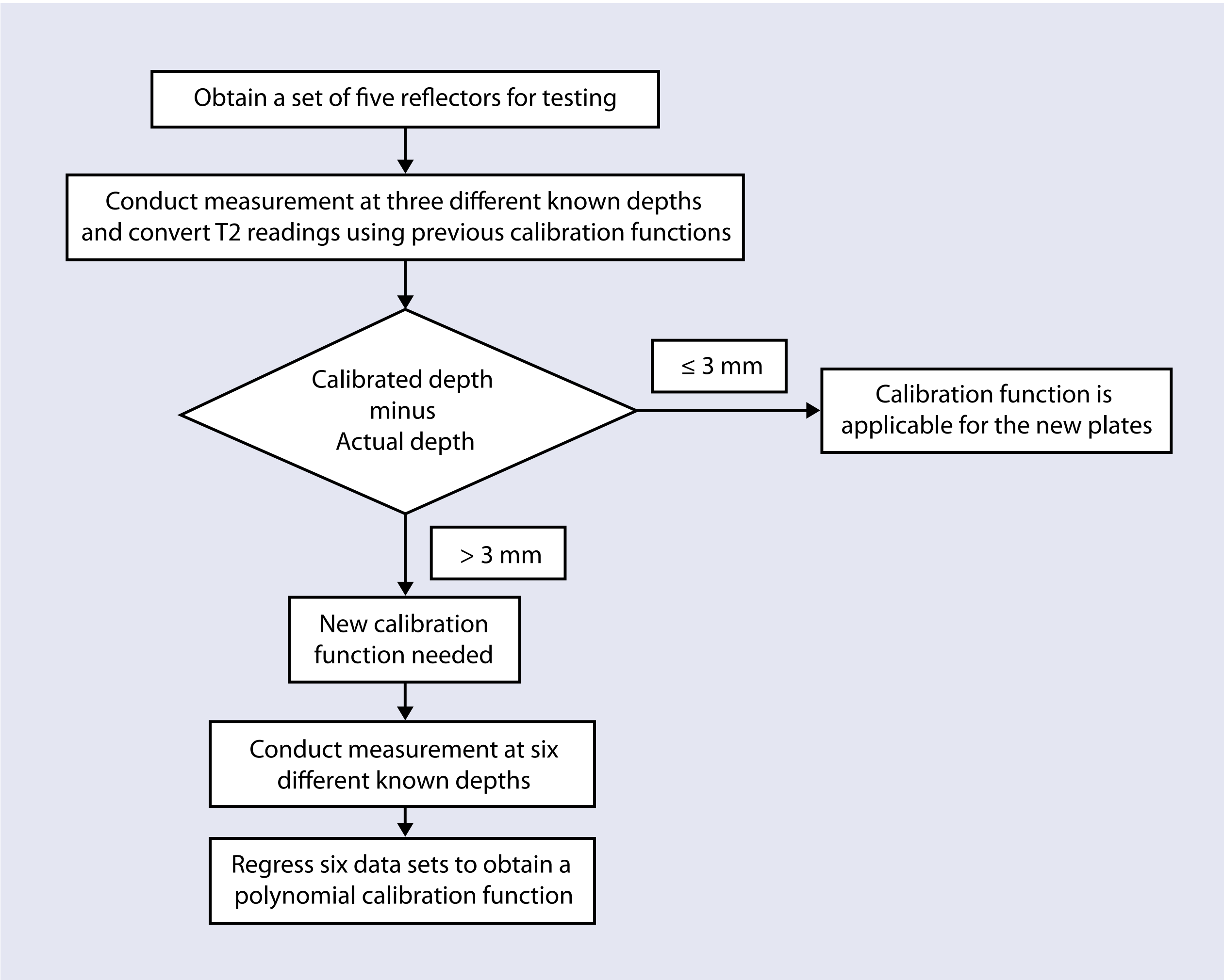
Table A-4. T2 Measurements and Core Thicknesses (mm), Domestically Fabricated Circular Reflectors

Measurement No.	Reflector 1		Reflector 2		Reflector 3		Reflector 4	
	T2	Core	T2	Core	T2	Core	T2	Core
1	331	329	324	327	323	323	319	321
2	330	332	325	326	323	324	319	321
3	331	332	325	327	323	325	319	321
4	330		325		324		319	
5	331		327		323		319	
Average	330	331	325	327	323	324	319	321

Note: The cores were directly over the reflector plates. As a result, 0.7 mm (the thickness of the reflector) should be added to the core thickness to establish the slab thickness.

APPENDIX B
RECOMMENDED REFLECTOR PLATE CALIBRATION PROCEDURE

Before any reflector is produced from a new source of sheet metal, samples of the sheet metal need to be tested to verify compatibility with the calibration functions. New reflectors need to go through the calibration process shown below.



Contact—For information related to the use of MIT-SCAN-T2 device, please contact the following:

Federal Highway Administration Office of Pavement Technology
Sam Tyson—sam.tyson@dot.gov

CPTP Implementation Team
Shiraz Tayabji, Fugro Consultants, Inc.—stayabji@aol.com

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THE CONCRETE PAVEMENT TECHNOLOGY PROGRAM

The Concrete Pavement Technology Program (CPTP) is a national program of research, development, and technology transfer that operates within the Federal Highway Administration (FHWA) Office of Pavement Technology.

The CPTP includes some 30 research and demonstration projects, each of which is delivering products for improved design, construction, repair, and rehabilitation of concrete pavements.

The focus areas for the CPTP include advanced designs, optimized concrete materials, improved construction processes, rapid repair and rehabilitation, and user satisfaction. The CPTP continues to produce implementable products that result in safer, smoother, quieter, and longer lasting concrete pavements. Longer lasting pavements, in turn, contribute to FHWA's success in the areas of safety, congestion mitigation, and environmental stewardship and streamlining.

Technology transfer of products resulting from the CPTP is being accomplished under CPTP Task 65. This 5-year activity was initiated in September 2003 and is overseen by an Executive Expert Task Group (ETG) that includes State department of transportation (DOT) chief engineers and representatives from industry and academia.

An Engineering ETG, made up of pavement and materials engineers from State DOTs, FHWA field offices, plus representatives from industry and academia, reviews the technical aspects of CPTP products.

These products include:

- Guidelines / Technical briefs
- Test protocols / Draft specifications
- Software
- Workshops / Conferences
- Presentations / Videos
- Field demonstrations
- Equipment loans

The delivery of CPTP products, in workshops and other formats, is tailored to meet the needs of each State DOT and its related industry groups. For more information, please contact:

Sam Tyson
Office of Pavement Technology
Federal Highway Administration
E-mail: sam.tyson@dot.gov

Shiraz Tayabji
CPTP Implementation Team
Fugro Consultants, Inc.
E-mail: stayabji@aol.com