State DOT: Iowa

State Report Questions on NDT Testing

1. What NDT testing methods for concrete materials, concrete pavements, and overlays are you trying?

Iowa is currently in the process of implementing use of the MIT Scan T2 device for NDT thickness evaluation of PCC pavements. Work began in 2008 to evaluate the device and whether or not it would be a viable replacement for coring. The device was used on several trial projects, and the results correlated very well with coring. The device is currently being used for thickness evaluation on most large PCC projects (50,000 SY and greater) with future plans to implement use on all projects. See the Developmental Specification and TRB submittal for additional information on the TTCC/National Concrete Consortium web page: http://www.cptechcenter.org/t2/ttcc_ncc_meeting.cfm.

2. In your experience, how does the reliability of NDT testing methods compare to traditional testing methods?

The reliability of the MIT Scan T2 device for use in evaluating PCC pavement thickness has been found to be very good. Use of the device reduces the opportunity for human error since data is collected, stored, and transferred electronically.

NDT Thickness Measurements for Concrete Pavements- It really works!

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TRB 2012

ABSTRACT

Magnetic Imaging Tomography is a technology that can be utilized to determine the thickness of concrete pavement in a nondestructive manner. It provides the same level of accuracy and can save time and money for state agencies when compared to coring the pavement for thickness determination.

The MIT-SCAN-T2 (T2) is a commercially available device that uses magnetic imaging tomography to measure pavement thickness. The technology and operation of this device is described. Field experience from various states is provided. The accuracy and repeatability, when compared to measuring core lengths, is very good based on data collected to date. The advantages of using this nondestructive testing are presented. A specification that was developed by Iowa DOT is included. The paper also includes a discussion of other issues that may be raised from the use of this technique and ongoing work related to implementation.

INTRODUCTION

The American Association of State Highway and Transportation Officials (AASHTO) has recently released the software for a new mechanistic-empirical pavement design procedure *(1).* This new methodology incorporates traffic, climate, material and design inputs into a software program to predict the pavement performance over its design life and determine the required pavement thickness. The software is used to predict the long term performance of the pavement. But, unless the pavement is constructed to meet or exceed the design thickness, the pavement may not provide the desired performance over its intended design life. Therefore measuring the thickness of the as-constructed pavement is an important agency acceptance activity. For years, most agencies have drilled cores from the new pavement as a sampling tool to determine compliance with the plans and specifications *(2,3).* This is normally effective, but in cases where a permeable base is used and the mortar fills some of the surface voids, the determination of the thickness is not as easy and the accuracy is reduced. Also coring is destructive, expensive and time consuming task. Today highway agencies do not have the personnel to core, inspect, and test these samples and patch core holes as they did in the past.

In the past few years, considerable effort has been expended to compare pavement core measurements with non-destructive tests such as the Ground Penetrating Radar, Impact Echo, laser method, probing *(4,5,6)* etc. The primary intent of all these studies is to reduce the number of cores that are to be taken for pavement thickness measurements. The GPR and Impact Echo methods have limitations with freshly placed concrete. Most consider the accuracy of these two techniques not to be reliable or accurate enough for specification compliance determination.

A new, non-destructive test that is fast, accurate and independent of the maturity of concrete is needed. Magnetic Imaging Tomography has gained popularity in the last five years to measure pavement thickness non-destructively. This technology has been used by one manufacturer to develop a testing device that is both accurate and reliable. The MIT-SCAN-T2 (T2) is an easy to use, accurate, non-destructive, and relatively inexpensive device that is able to determine pavement thickness with the accuracy similar to core measurements for pavement thickness (AASHTO T148 / ASTM C 174).

This paper describes this technique. It presents the experience of agency users, offers an example specification, and provides data from comparison studies aimed at determining the accuracies comparing the conventional coring techniques to the NDT method.

THE TECHNOLOGY

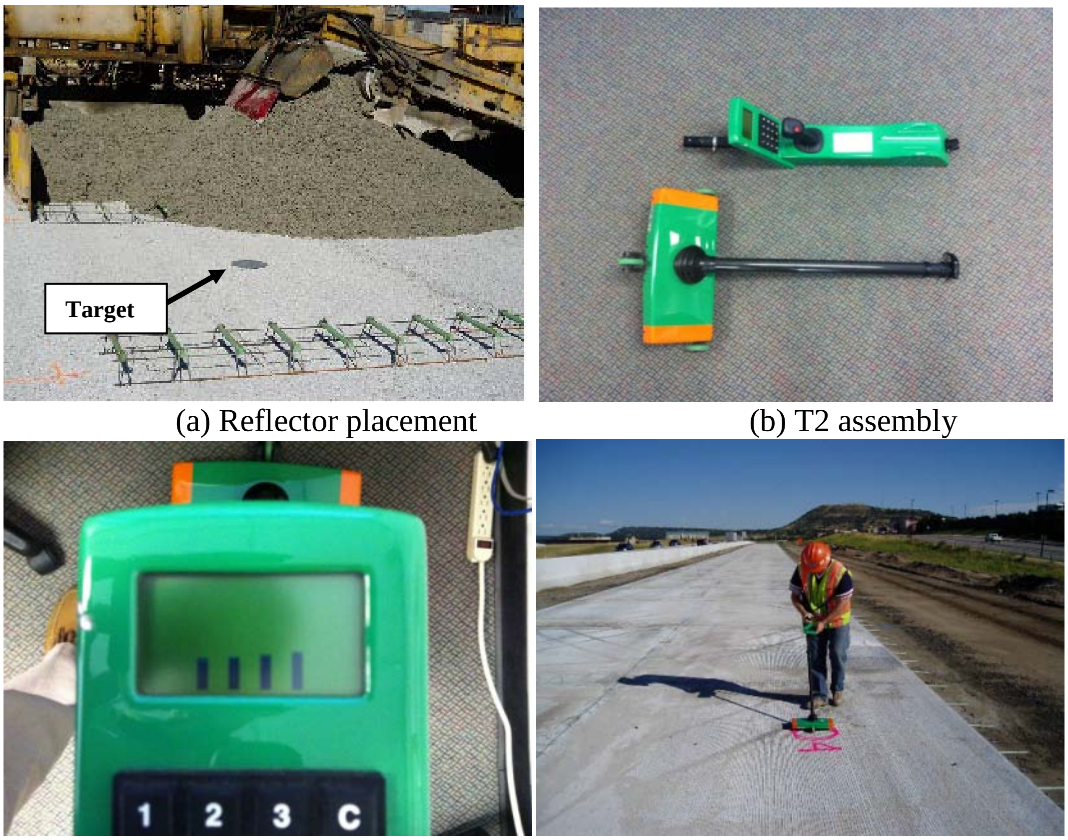
The T2 device utilizes a magnetic tomography technology to measure the distance from a sensor to a metal reflector. The metal reflector is usually referred to as a “target” and is identified in this manor throughout the rest of the paper. While scanning, the T2 device generates a variant magnetic field that creates an Eddy current in the target. The Eddy current will generate an induced magnetic field inside the target, the intensity of which is detected by sensors from the T2 device. For a given type of target, the intensity of the induced magnetic field is primarily determined by the distance from the T2 device to the target. A calibration file, recording the relationship between the induced magnetic field intensity and the distance, is developed for each unique type of target produced by the manufacturer. The manufacture supplied targets are circular in shape made of 0.6 mm thick galvanized sheet metal. Different size targets are available from the manufacturer depending on the thickness of pavement to be measured.

OPERATION OF THE T2

Operation procedures comprise two phases:

Pre-concrete placement

Place targets (FIGURE 1(a)) at desired locations on the surface of the base/subbase. Targets should be placed at least 3 feet away from any foreign metal (dowels or tie bars) to mitigate the influence of other metal objects.



(a) Reflector placement (b) T2 assembly

(c) Reflector locating (d) Scanning operation

FIGURE 1 Operation of T2

Post-concrete placement

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

1) Assemble the device (FIGURE 1 (b)). T2 is usually dismantled in two parts for storage with other accessories in a compact case for easy transport.

2) Locate the target (FIGURE 1 (c)). Although the approximate location of the target should be marked while placing the target, T2 has a built-in capability to locate the target more accurately. As will be discussed later, ensuring the scanner is directly above the target is key to obtaining accurate measurements.

3) Perform the scanning over the target (Figure 1 (d)). Once the general location of the target is determined, set the T2 approximately 10 inches away from the target and scan over the target at a steady speed. A thickness measurement will be displayed once the T2 scans over a distance of roughly 3 feet.

FIELD PERFORMANCE

The Federal Highway Administration's (FHWA) Concrete Pavement Technology Program (CPTP) and Mobile Concrete Laboratory (MCL) are national programs of research, development and technology transfer that operates within the FHWA's Office of Pavement Technology. During the past five years, the T2 was used / demonstrated at several field projects in various states across the country either by the CPTP program or the MCL as part of the ongoing technology transfer activities.

Iowa DOT Experience

In 2008, Iowa DOT took advantage of an Equipment Loan Program sponsored by FHWA's CPTP program and evaluated the T2 on several projects *(7)*. The results were encouraging so in 2009 the Iowa DOT purchased 2 units and 100 targets. The manufacturer's targets were not available in the US for a reasonable price, so the Iowa DOT had 500 targets fabricated locally using sheet metal meeting ASTM A653 CS, Type 2, G90, 24 gage. A calibration equation was developed for these targets by Iowa. Further testing and evaluation was conducted on 3 paving projects.

The results of the further testing were positive so the non-destructive method was specified in place of coring for incentive/ disincentive on two projects in 2010. In addition further comparative testing was done on two other projects. About 1000 targets were used in 2010.

Based on the positive results and feedback from inspectors and contractors, three more T2 devices were purchased and a specification and test method were written for use in 2011. The specification was applied to four large paving projects. About 2000 targets were used on these four projects.

Some of the early observations were:

- The targets needed to be nailed down to keep them from being blown off the grade or moved by the concrete placement.
- Locating the targets on or near an even station made placing, finding, and referencing the target locations easier.
- The targets needed to be located at a spacing that would discourage the up and down adjustment of the paver.
- Marking the pavement at the target center location made taking repeat reading simpler.
- The project inspectors said the non-destructive thickness method was less time consuming than the effort spent locating, witnessing, hauling, preparing, and measuring concrete cores.
- The core measurement test procedure and the non-destructive thickness procedure do not measure to the same point on the pavement cross section. The core measurement test

procedure allows for some of the granular base material to remain on the bottom of the core. The non-destructive procedure is always measuring to the top of the granular base.

Accuracy

Table 1 shows a comparison between Scan T2 measurements and lengths of cores at 106 locations from 13 concrete pavement projects across the country. Eight of the projects shown in Table 1 were from Iowa (2010 construction season) and the remaining five were from other states where the T2 was demonstrated / used as part of the MCL and CPTP programs.

For brevity, Table 1 only shows the average pavement thickness measurements using the T2 at each of the 13 projects. In order to validate the T2 measurements, cores were taken from the concrete pavement on top of the targets after T2 measurements were taken. Since T2 can detect the exact location of the targets, it was easy to locate and core on top of the targets. The cores were later measured for their length using 9 point measurements *(2)* that is typically used by most state DOTs. The average pavement thickness, based on core measurements, for each of the 13 projects is also shown in Table 1. Figure 2 shows the individual T2 versus core length measurements for all the 106 locations shown in Table 1. Figure 2 shows excellent correlation between T2 and core length measurements for a range of pavement lengths from 224 mm (8.8 inches) to 375 mm (14.8 inches). Table 1 shows that except for one project in Indiana (3 data points), the difference between T2 and core lengths measurements were 2 mm or less. The average and standard deviation of the difference between the core and T2 measurements for all the 106 locations were 1.3 mm and 1.3 mm respectively.

TABLE 1 Average T2 and Core Length Measurements

State	Project	Number of Locations	Average Core Lengths (mm)	Average T2 Measurements (mm)	Difference between Average Core lengths and Average T2 measurements (mm)	Standard Deviation, Core Lengths (mm)	Standard Deviation, T2 Measurements (mm)
IA	US 34	8	272	273	**-1**	6.8	6.8
IA	US 63	10	275	275	**0**	12.3	12.9
IA	I29	8	282	281	**1**	12.0	12.4
IA	US 20	8	277	276	**1**	15.1	15.3
IA	I35	10	291	291	**0**	13.9	13.7
IA	US 20	10	270	269	**1**	15.1	15.3
IA	I35	10	303	301	**1**	12.2	12.5
IA	US 30	10	267	266	**1**	4.0	4.0
WA	I 5	6	236	235	**1**	10.0	9.8
AL	I 59	10	285	285	**0**	6.7	7.0
NY	I 90	4	326	324	**2**	4.3	4.6
IN	I 465	3	355	361	**-6**	2.1	2.8
NC	I 540	9	314	315	**-1**	39.8	41.4
	Total Count	106					

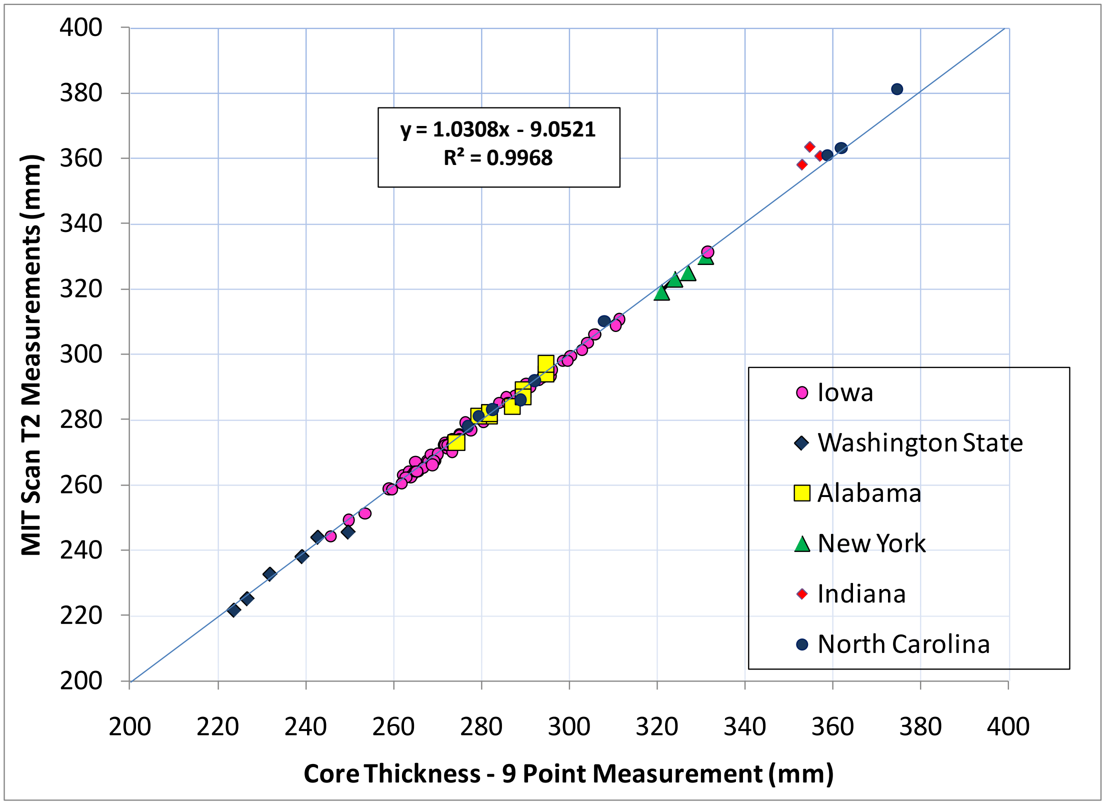


FIGURE 2 Pavement Thickness Measurements using T2 and Cores from the Pavement

Repeatability

The repeatability of T2 was checked by Iowa DOT by measuring the same targets using two different T2 devices (T2-A and T2-B). Table 2 shows the average and standard deviation of T2 measurements using two T2 devices at four different projects in Iowa. A total of 388 targets were placed in four projects and measurements were taken using both T2 devices. Since the primarily objective was only to check the repeatability of the T2, cores were not taken at these locations. Figure 3 plots the pavement thickness measurements at the 388 targets from both the devices. Figure 3 indicates that the repeatability of T2 is excellent irrespective of the thickness of the pavement. Based on Table 2, the average difference in pavement thickness measurements between the two T2 devices was 1 mm or less. The average and standard deviation of the difference between the two T2 devices for all the 388 locations were 0.9 mm and 0.9 mm respectively.

TABLE 2 Average Thickness Measurements using two T2 Devices

Project	Number of Target Locations	Average T2-A Measurements (mm)	Average T2-B Measurements (mm)	Difference between Average T2-A and Average T2-B Measurements (mm)	Standard Deviation, T2-A (mm)	Standard Deviation, T2-B (mm)
US 63	20	274	273	0	13.41	13.59
Dallas Co.	79	208	208	0	6.87	6.82
I29	83	285	284	1	9.88	9.65
I 29 south	206	277	277	0	12.67	12.91

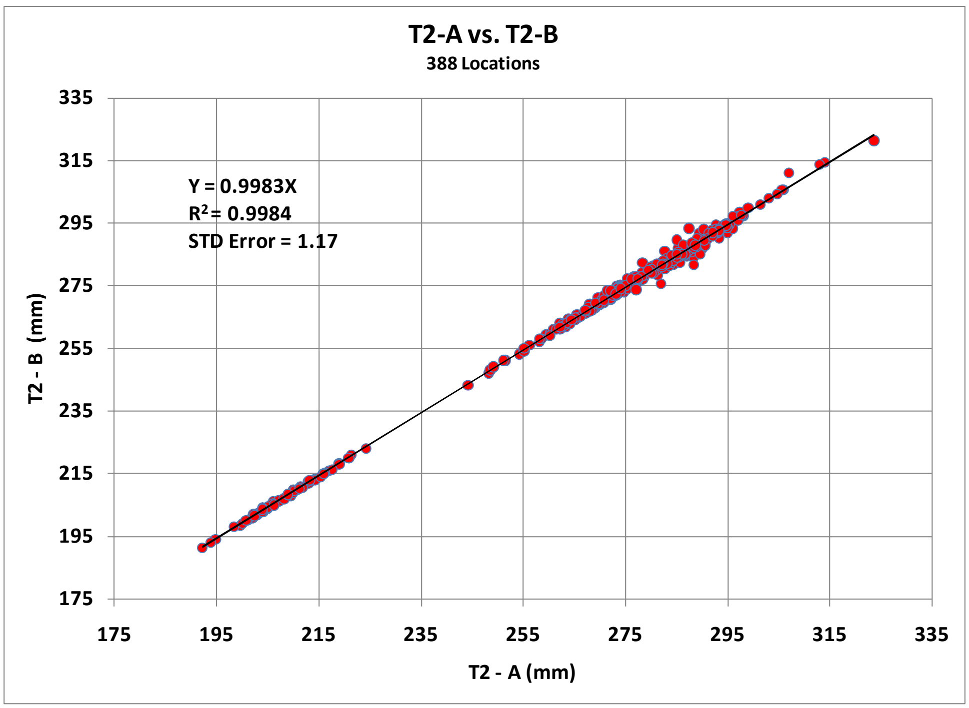


FIGURE 3 Pavement Thickness Measurements using Two T2 Devices

Advantages of T2

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

2) Maturity of Concrete – Measurements with the T2 can be taken as soon as the pavement can be walked upon. Unlike some other non-destructive tests, T2 measurements can be taken at any maturity level of concrete.

3) Ease of use – It is very easy to use and does not require user interpretation unlike some of the other non-destructive technologies. One person can operate, and store hundreds of thickness measurements in the device.

4) Cheaper – The cost per measurement (including the cost of the equipment and targets on the long run) is significantly cheaper than taking cores. Based on conversations with DOT personnel, it costs approximately $90-$110 per core. The cost per measurement using the T2 is less than $20 (including the target). Due to the low cost per measurement, measurements can be taken at more locations which will yield a statistically more robust measure of pavement thickness.

5) Non-destructive – Eliminates the need to cut cores on new pavements and thereby reduces the need to patch core holes which may require additional maintenance at later years.

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

7) Base Material– Accuracy of the device is independent of the type of base material. When the base material has similar properties as 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 granular or permeable base, which can make core length determination difficult.

8) Accuracy – As described in the preceding section, T2 results are very accurate (within 2 mm) when compared to cores.

IMPLEMENTATION ACTIVITIES

Iowa DOT NDT Pavement Thickness Specification

The first Iowa DOT specification employing the non-destructive thickness testing was a slight modification to the current specification with core drilling. Retaining much of the current specification and test procedure made the adjustment to the non-destructive method easier for the contractor staff and the DOT inspection staff. The major modifications were:

1. The random test location method was changed.
    - The targets are located at 50 meter or 200 foot intervals.
    - The target offset location from centerline is stratified random.
    - The target test location is random.

2. Three repeat readings are to be taken. If the difference between any of the readings is more than 3 mm, take 2 additional readings. If the two additional readings are within 3 mm of any of the first 3 readings, the measurement is valid for that location. If not, note that the location is not valid and select the next target location not originally selected for testing.

3. When a thin area is identified, the target is re-tested. If re-testing confirms a thin area, a core is drilled to confirm. If the core measurement confirms a thin area. Core drilling continues to determine the extent of the thin area.

4. An adjustment to the current thickness incentive and disincentive levels was applied to specification. Testing had shown that the pavement cores over granular base consistently measured longer than the NDT testing results. An example of that testing is shown in Figure 4.

FIGURE 4 Cores taken on Dense Graded versus Open Graded Bases

5. Independent assurance testing is done by checking a minimum of 10% of the locations with a different T2 and a different tester not associated with the project verification testing.

The non-destructive thickness determination method would fit well into a percent within limit (PWL) specification. After 2011, there should be sufficient data to establish a PWL specification for future projects on a trial basis.

T2 TARGET STUDIES

CPTP Study

A target study*(8)* was carried out under the CPTP program to assess the feasibility of domestic substitutes for targets. Findings of that study are summarized as follows:

1) Domestic targets are able to produce repetitive measurements.
2) Orientation of square reflectors has a negligible impact on measurements (Figure 5).

3) As the scanning path wanders away (as shown as the dashed lines in Figure 5) from the centroid of a reflector, the thickness measurements increase (Figure 6).

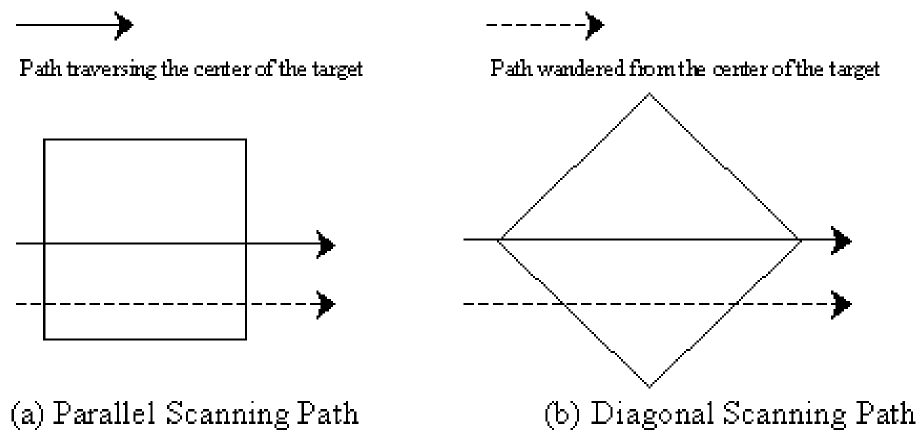


FIGURE 5 Illustrations of Square Reflector Orientation and Scanning Path

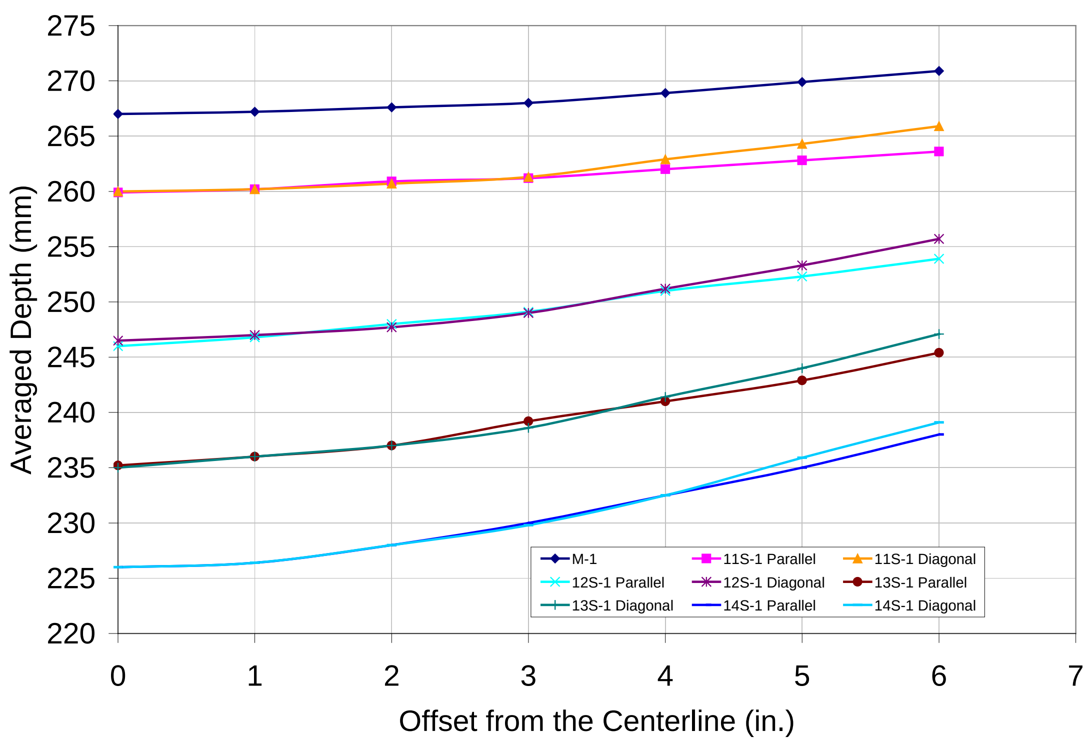


FIGURE 6 Effect of Wandered Path on Thickness Measurement

Iowa DOT work with Targets

In order to establish a consistent source of targets, the Iowa DOT contacted several metal fabricators that had the equipment and the interest to fabricate the targets as needed. Rather than trying to match the European standard for galvanized sheet steel, a readily available commercial grade of galvanized sheet steel was tested. The surface area, shape, galvanizing thickness, and base steel properties all have an influence on the T2 readings. ASTM A653 Type 2 Commercial Grade, G90 galvanized sheet steel from two Midwest steel mills produced similar responses on the T2 readings. The target thickness does not seem to be a critical property. To stay consistent with the manufacturer's targets, a 24 gage steel was used which was a readily available gage thickness and closely matched the manufacturer's target thickness of 0.6 mm.

The fabricator used a computer controlled laser cutter to cut the targets to a 300 mm +/- 0.1 mm diameter. Each new shipment of targets is checked for coating thickness and dimensions and then tested with the T2 at preset depths. The G90 galvanizing is much thicker than the manufacturer's targets and produces a slightly greater thickness reading, but consistent response on the T2.

OTHER ISSUES

- Since the targets are placed before the concrete is placed, it is often asked, whether there is a tendency from the contractors to adjust operations to increase the thickness of the pavement at the target locations. This is not an issue since pavement smoothness is also a specification item and any sudden changes to the thickness of the pavement at the target locations may not comply with the smoothness requirement. Additionally, more targets can be placed than required and targets can be selected at random at a later time for pavement thickness measurement. The advent of stringless paving, where the paver grade is controlled by digital models, makes it even less likely that random thickness adjustments could or would be attempted.

- As mentioned elsewhere in the paper, using the target defines the bottom of the pavement and eliminated the problem of mortar penetrating into open graded bases. Iowa DOT testing had shown that the pavement cores over granular or open graded bases consistently measured longer than the T2 results due to mortar penetration.

CONCLUSIONS

The Magnetic Imaging Tomography offers a faster, easier, non-destructive and significantly cheaper way to measure pavement thickness compared to the traditional method of taking cores. Based on the data shown for the T2 device, which uses the magnetic imaging tomography technology, the accuracy of this technique is within 2 mm of the core test results for a wide range of pavement thickness. The repeatability, which is an important criterion for any test method, is excellent. Clearly there are many advantages compared to other non-destructive pavement thickness measuring techniques.

ONGOING EFFORTS

- There are currently efforts to identify US sources for targets for easy access and further reduction in their cost.

- In addition to Iowa, other states such as Minnesota are also evaluating the T2 and have plans to adopt this technology in their specifications.

- There is also an effort to develop an AASHTO standard test method for using this technology.

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DS-09063
(Replaces DS-09043)

Iowa Department of Transportation

DEVELOPMENTAL SPECIFICATIONS
FOR
PCC PAVEMENT NON-DESTRUCTIVE THICKNESS DETERMINATION

Effective Date
May 17, 2011

THE STANDARD SPECIFICATIONS, SERIES OF 2009, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

Replace all of Articles 2301.04 and 2301.05 of the Standard Specifications with the following. Differences from the Standard Specifications are highlighted.

2301.04 METHOD OF MEASUREMENT.
Measurement will be as follows:

A. Portland Cement Concrete Pavement.

1. Square yards (square meters), of the type specified, shown in the contract documents.

2. The ~~coring~~ measurement requirements for thickness do not apply to detour pavements, paved drives, and temporary pavements. The thickness of pavement constructed will be determined from ~~core depths~~ thickness measurements as follows:

a. The division of sections, lots, and ~~core~~ measurement locations will be according to ~~Materials I.M. 346~~ Appendix A.

b. At locations determined by the Engineer~~, cut samples from the pavement, as directed above, by drilling with a core drill that will provide samples with a 4 inch (101.6 mm) outside diameter~~ the Engineer will measure for thickness according to Appendix A. ~~Restore the surface by tamping low-slump concrete into the hole, finishing, and texturing. The Engineer will witness the core drilling, and identify and measure the cores immediately. The Engineer will measure the cores and determine the thickness index according to Materials I.M. 346. After measurement on the grade, deliver the cores to the Engineer's office or field laboratory. When cores are not measured on the grade, the Engineer will take immediate possession of the cores.~~

c. ~~Coring of pavement and other~~ Measurement work for thickness determination may be waived by mutual agreement for sections of the same design thickness less than 5000 square yards (4200 m^2).

d. Only sections which are ~~cored~~ measured for thickness will be included in the thickness index determination. Areas not ~~cored~~ measured for thickness will be paid for at the contract unit price.

B. Integral Curb.
Incidental to the other items of work. Not measured for payment.

C. Concrete Median.
Square yards (square meters) shown in the contract documents. This will be calculated to the nearest 0.1 foot (0.1 m) of the length along the surface and the overall width of median when no integral curb is involved, or the width from back to back of curb when integral curb is involved.

D. Bridge Approach Sections.
Square yards (square meters) shown in the contract documents.

E. Excavation.

1. When the contract provides a unit price per station (meter) for earth shoulder finishing and a price per cubic yard (cubic meter) for excavation, the excavation required for preparation of natural subgrade will be measured as provided in Article 2102.04. The volume measured for payment will include only the materials actually removed above the elevation of the pavement subgrade and between vertical planes 1 foot (0.3 m) outside the edge of the finished pavement.

2. Other work connected with preparation of natural subgrade will not be measured for payment.

3. When the contract provides a unit price for earth shoulder construction (whether or not a unit price per cubic yard (cubic meter) of excavation is provided in the contract), excavation required for preparation of natural subgrade will not be measured for payment. Unless otherwise provided in the contract documents, work connected with preparation of natural subgrade will not be measured for payment.

F. Driveway Surfacing Material.
Tons (megagrams) or cubic yards (cubic meters), as provided in the contract and in Section 2315, placed at intersecting roads, drives, and turnouts. Excavation required for placement of this material will not be measured for payment.

~~**G. Portland Cement Concrete Pavement Samples.**~~
~~Not individually counted for payment when furnished according to Article 2301.04, A, or when required in the contract documents.~~

H. Saw Cut and Joint Sealing.

1. Saw cut for constructing joints in new pavement will not be measured for payment.

2. Saw cut for cutting old existing pavement, which is to be abutted with new pavement, will not be measured for payment.

3. Joint sealing will not be measured for payment.

I. Safety Fence for Pavement.
Not measured for payment.

J. Rumble Strip Panel (PCC Surface)
By count for Rumble Strip Panels properly installed at locations designated in the contract documents.

2301.05 BASIS OF PAYMENT.
Payment will be as follows:

A. Portland Cement Concrete Pavement.

1. Contract unit price for Standard or Slip-Form Portland Cement Concrete Pavement of the type specified per square yard (square meter).

2. Payment for the quantities of pavement in square yards (square meters) will be at a percentage of the contract unit price according to Table 2301.05-1.

Table 2301.05-1: Payment Schedule for Quantities of Pavement

Thickness Index Range	Percent Payment	Thickness Index Range	Percent Payment
English (Metric)		English (Metric)	
0.00 or more (0.00 or more)	103	-0.56 to -0.60 (-13.98 to -15.24)	91

-0.01 to -0.05 (-0.01 to -1.27)	102	-0.61 to -0.65 (-15.25 to -16.51)	90
-0.06 to -0.10 (-1.28 to -2.54)	101	-0.66 to -0.70 (-16.52 to -17.78)	89
-0.11 to -0.15 (-2.55 to -3.81)	100	-0.71 to -0.75 (-17.79 to -19.05)	88
-0.16 to -0.20 (-3.82 to -5.08)	99	-0.76 to -0.80 (-19.06 to -20.32)	87
-0.21 to -0.25 (-5.09 to -6.35)	98	-0.81 to -0.85 (-20.33 to -21.59)	86
-0.26 to -0.30 (-6.36 to - 7.62)	97	-0.86 to -0.90 (-21.69 to -22.86)	85
-0.31 to -0.35 (-7.63 to -8.89)	96	-0.91 to -0.95 (-22.87 to -24.13)	84
-0.36 to -0.40 (-8.90 to -10.16)	95	-0.96 to -1.00 (-24.14 to -25.40)	83
-0.41 to -0.45 (-10.17 to -11.43)	94	-1.01 to -1.05 (-25.41 to -26.67)	82
-0.46 to -0.50 (-11.44 to -12.70)	93	-1.06 to -1.10 (-26.68 to - 27.94)	81
-0.51 to -0.55 (-12.71 to -13.97)	92	-1.11 or less (-27.95 or less)	80

3. Use the following formula to determine the thickness index for the section of pavement thickness:

$$TI = (\overline{X} - S) - T$$

Where:

TI = thickness index for the section.
$\overline{X}$ = mean ~~core length~~ thickness for the section.
T = ~~design thickness~~ see Table 2301.05-2.
S = ~~core length~~ measurement thickness standard deviation (of the sample) for the section.

Table 2301.05-2: Thickness Value for determining Thickness Index

Type of Base, Subbase, Subgrade just below the concrete	**Value of T in Inches**
Natural Subgrade or Soil Aggregate Subbase	Design Thickness
HMA Base, PCC Base, or Asphalt or Cement Treated Base	Design Thickness
Modified Subbase or Special Subbase	Design Thickness minus 0.25 inches (6 mm)
Granular Subbase	Design Thickness minus 0.35 inches (9 mm)

4. Replace pavement represented by cores deficient from design thickness by 1 inch (25 mm) or greater. The deficient areas and the replacement of the deficient cores will be determined according to ~~Materials I.M. 346~~ Appendix A. The cost for coring that confirms deficient pavement or determines deficient areas shall be incidental to the price paid for Portland Cement Concrete Pavement. The cost for coring that indicates that pavement is sufficient shall be paid as extra work, according to Article 1109.03, B of the Standard Specifications. The cost for coring replacement pavement to verify compliance shall be incidental to the price paid for Portland Cement Concrete Pavement.

5. At the Contractor's option, ~~cores that are~~ measurement readings that are larger than the thickness value (from Table 2301.05-2) by three standard deviations or greater ~~than design thickness~~ may be removed from analysis for thickness index determination. Do not remove more than 10% of the total ~~cores~~ measurements in a section. Do not replace ~~cores~~ measurements removed from the analysis.

6. Gaps in the pavement less than 500 feet (150 m), required by staging, will be considered irregular areas for analysis of pavement thickness determinations.

7. The percent payment for projects which have all ~~core lengths~~ measurement readings greater than ~~design thickness~~ T in Table 2301.05-2 will be at least 100%.

B. Integral Curb.
Not paid for separately.

C. Concrete Median.
Contract unit price per square yard (square meter).

D. Bridge Approach Sections.

1. Contract unit price for bridge approach pavement per square yard (square meter).

2. Payment is full compensation for:
   - Excavation for modified subbase and subdrain.
   - Furnishing and installing subdrain.
   - Furnishing and installing subdrain outlet.
   - Furnishing and installing polymer grid.
   - Furnishing and placing porous backfill material.
   - Furnishing and placing modified subbase backfill material.
   - Saw cutting.
   - Furnishing and installing reinforcing steel, tie bars, and dowel assemblies.
   - Placing, finishing, texturing, grooving, and curing.
   - All joint construction.
   - All other materials and labor to construct the Bridge Approach Section as shown in the contract documents.

E. Excavation.

1. When the contract provides a unit price per station (meter) for earth shoulder finishing and the contract also provides a price per cubic yard (cubic meter) for excavation, payment will be the contract unit price per cubic yard (cubic meter) for excavation in connection with subgrade preparation and building shoulders.

2. When the contract provides a unit price for earth shoulder construction, the excavation required for preparation of subgrade and construction of shoulders will not be paid for as a separate item. It is incidental to pavement construction and earth shoulder construction and is to be included in those contract prices.

3. When no price per cubic yard (cubic meter) for excavation is provided in the contract and no unit price is provided for earth shoulder finishing or earth shoulder construction, excavation necessary for subgrade preparation is incidental to pavement construction and is to be included in that contract unit price.

F. Driveway Surfacing Material.
Contract unit price as provided in Section 2315 for the quantity of driveway surfacing placed.

~~**G. Portland Cement Concrete Pavement Samples.**~~

~~1. Lump sum contract price for furnishing samples of finished pavement or other course according to Article 2301.04, A, or when required in the contract documents.~~

~~2. Payment is full compensation for furnishing all such samples for all courses or items of work.~~

H. Saw Cut and Joint Sealing
Incidental to the price for pavement.

I. Safety Fence for Pavement.
Incidental to the price for pavement.

J. Rumble Strip Panel (PCC Surface)
Each. Payment is full compensation for construction of the panels as detailed in the contract documents.

K. General.

1. Deduction will not be made from the area of pavement for fixtures with an area less than 9 square feet (1 m^2).

2. When any of the types of additional protection described in Article 2301.03, K, 3, is necessary, additional payment will be made as extra work at the rate of $1.00 per square yard ($1.20 per square meter) of surface protected. Payment will be limited to protection necessary within the contract period. Protection necessary after November 15 will be paid for only when the Engineer authorizes the work.

3. Furnish concrete for test specimens and transport the specimens and molds between the grade and plant as directed by the Engineer, at no additional cost to the Contracting Authority.

4. The above prices are full compensation for furnishing all tools, equipment, labor, and materials necessary for construction of the pavement in accordance with the contract documents.

5. The cost of furnishing, installing, and monitoring vibrators, as well as the vibrator monitoring device itself, is incidental to the contract unit price for PCC pavement.

APPENDIX A
EVALUATING PORTLAND CEMENT
CONCRETE PAVEMENT THICKNESS

SCOPE

Thickness measurements will be taken on Portland Cement Concrete (PCC) pavement, to determine the pavement thickness and the thickness index for each section. Refer to Specification DS-09043.

APPARATUS

1. An MIT Scan T2 gauge will be used to perform thickness measures.
2. Steel Targets will be 11.81 inches (300.0 mm) in diameter, 24 gauge, meeting ASTM A 653, commercial steel with a G90 coating (about 275 g/m^2 total both sides).

DEFINITIONS

Section: All Portland Cement Concrete in a project of the same bid item. Irregular areas, as defined herein, of the same bid item shall form a separate section.

Lot: A portion of a section normally 200 feet (50 m) in length and 2 traffic lanes wide.

Regular area pavement sections:

- All mainline pavement for normal travel lanes. Includes middle (both direction) turn lanes
- Paved shoulder – if same thickness as pavement and part of pavement bid item include with pavement. If separate bid item, treat as separate section.
- Paved median - if same thickness as pavement and part of pavement bid item, and longer than 300 feet (100 m), include with pavement.
- Auxiliary lanes of full width longer 300 feet (100 m).
- Widening greater than 6 feet (2 m).

Irregular areas:

- Widening less than 6 feet (2 m).
- Side street connections.
- Ramps, including gore areas, and collector distributor roads.
- Deceleration and acceleration lanes.
- Turn lanes, including taper sections.
- Tapers.
- Radiuses.
- Median crossovers

PROCEDURES

The District Materials Engineer will determine the location of each lot, the random location of each metal target, and the random thickness measuring scheme for each section using an Iowa DOT developed MSExcel spreadsheet.

A. Target Location for Regular Areas

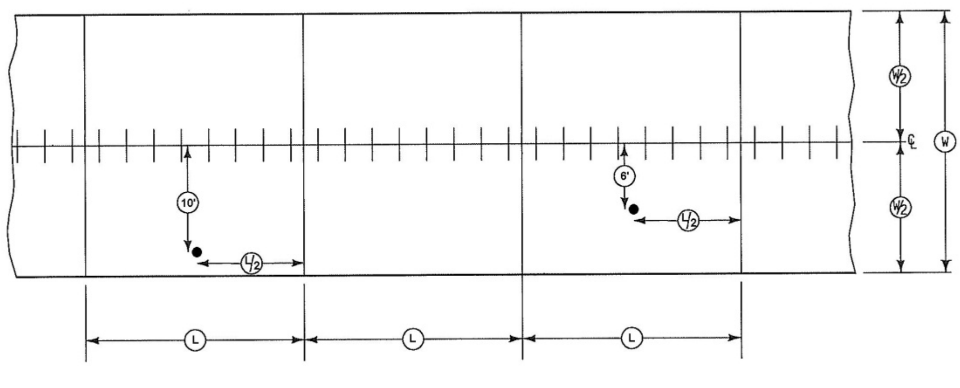
1. Divide the section longitudinally into 200 foot (50 m) long lots. One target will be located in each lot based on the spreadsheet selection (The targets should be placed half way between dowel baskets). See Figure 1. A minimum of ten targets will be tested. If a target location falls on a bridge or in an approach section, it will be eliminated.

2. The transverse location of the targets will be randomly determined by the spreadsheet program. The random locations will be either 6 or 10 feet (2 or 3 m) left or right of centerline. When tie steel is present at the edge of the pavement or lane, the locations will be 5 or 9 feet (1.5 or 2.5 m).

3. The program will randomly determine which targets to measure. If a measurement location falls on a bridge or bridge approach pavement, it will be eliminated and the next closest target not in the original random selection will be used for measurement.

4. Shoulders. Divide the section into 200 foot (50 m) long lots. Place targets approximately mid-point transversely on shoulders wider than 6 feet (1.82 m). On 6 foot (1.82 m) shoulders, the targets should be 4 feet (1.2 m) from the edge of the pavement.

Figure1. Target Location



B. Target Location for Irregular Areas

1. All irregular areas of the same design thickness will be grouped together for determining the number of lots. The Engineer may waive sections of the same design thickness that total less than 5,000 square yards (4200 sq. m).

2. Place targets randomly in all irregular areas larger than 100 square feet (10 m^2). One target will be randomly located in each selected irregular area, unless one or more of the areas are significantly larger than the others, then more than one target may be located in the large area. Targets must be placed at least 2 feet (0.6 m) away from tie steel and 4 feet (1.2 m) from dowel bars. A minimum of ten targets will be tested to represent each section of irregular areas. All targets will be measured.

C. Testing
Follow the manufacturer's instructions for operating the thickness gauge. It is important to avoid testing close to any steel including vehicles, equipment, steel toed shoes as well as tie bars, dowel bars and baskets, and manhole covers. When wearing steel toed shoes, always keep both toes at least 2 feet (0.6 m) from the gauge during the test. Three repeat readings will be taken. The readings should all be within 1 to 2 mm of each other. If the difference between any of the readings is more than 3 mm, take 2 additional readings. If the two additional readings are within 3 mm of any of the first 3 readings, the measurement is valid for that location. If not, note that the location is not valid and select the next target location not originally selected for testing.

The US made targets produce a slight bias on the T2 unit (approximately 3 mm less than the actual thickness). The correction factor is programmed into the reporting spreadsheet. The correlation factor is:

$$\text{Corrected Thickness Reading} = -0.00003723X(\text{T2 reading})^2 + 1.01629229X(\text{T2 reading}) + 1.44772852$$

D. Section Evaluation

1. Use the following formula to determine the mean thickness for the section:

$$\overline{X} = \frac{\sum X}{n}$$

Where: $\overline{X}$ = mean length for the section

$\sum X$ = sum of core lengths for the section

n = number of cores taken within the section

Round the mean thickness to two decimal places.

2. Use the following formula to determine the sample standard deviation of the thickness of the section:

$$S = \sqrt{\frac{\sum (X - \overline{X})^2}{n - 1}}$$

Where:

S = thickness standard deviation for the section.
$\overline{X}$ = mean thickness for the section
X = individual thickness values for the section.
n = number of tests representing the section.

$\sum$ = sign indicating the sum of all values of $(X - \overline{X})^2$

Round the sample standard deviation to two decimal places.

NOTE: Calculations of the standard deviation are best made with an electronic calculator with standard deviation capability that uses the formula containing the quantity (n-1).

3. Use the following formula to determine the thickness index for the section of pavement thickness.

$$TI = (\overline{X} - S) - T$$

Where:

TI = thickness index for the section
$\overline{X}$ = mean thickness length for the section
T = from Table 2301.05-2
S = measurement thickness standard deviation (of the sample) for the section

Round the thickness index to two decimal places.

NOTE: If the mean thickness minus the standard deviation is less than T of the section, the thickness index will be a negative number.

4. Basis of Payment. Payment for the quantities of pavement in square yards (square meters) in each section will be as shown in Article 2301.05 and based on the thickness index as determined in accordance with these instructions.

E. Deficient Areas

1. If any measurement is deficient from T by 1 inch (25.4 mm) or more, the measurement should be rechecked to confirm the reading and the equipment. If the repeat measurement is also 1 inch (25.4 mm) or more below T, mark the location directly over the target. The Contractor shall drill a 4.0 inch (101.6 mm) diameter core at that location. If the core length confirms the ~~measurement~~ pavement is deficient by 1 inch or more, continue to drill cores as described below.

2. Deficient areas, represented by cores deficient in length by 1 inch (25.4 mm) or more from design thickness, are to be replaced. These areas will be determined by drilling a core 60 feet (18 m) in each direction longitudinally at the same transverse location from the deficient core. Drilling will be continued at 60 feet (18 m) intervals until a core is obtained which is not deficient by 1 inch (25.4 mm) or more from design thickness. Interpolate between this core and the adjacent core to determine the limits of the deficient area. This is the area to be removed and replaced at contractor's expense. These additional cores are to be used to define the deficient area and will not be used in the thickness index calculation. When an obstruction, such as a bridge, intersection, previous work, etc., prevents drilling a core at the required 60 feet (18 m) interval in either direction longitudinally, continue the balance of the distance on the other side of the obstruction.

3. Any readings taken in the area for removal will be eliminated from the analysis for the entire section. After replacement, the contractor will take cores as directed by the engineer to verify the thickness.