Evaluation of New PCC Maturity Technology

TDOT Go.

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16. Abstract

The objective of the project is to evaluate the ability of the new maturity technology to predict compressive strength development of Tennessee PCC pavements. The information generated in the project will assist TDOT in making a decision on allowing the new maturity technology to be used in lieu of cylinder compressive strength results for opening new PCC pavements to traffic.

Two field investigations (at I-65 Nashville and I-75 Chattanooga) were conducted to determine the accuracy of the maturity compressive strength predictions. At each location, two maturity-compressive strength correlations were generated using actual field mixtures, and twelve verifications were conducted using a maturity logger embedded in the pavement. For each verification, several types of PCC strength were measured at different times and compared to maturity predictions. The average maturity predicted compressive strengths for 4x8 cores and 6x12 field-cured cylinders (the best measures of in-place PCC pavement strength) were in the range of 91.75 to 100.48 percent of the average measured values for I-65 Nashville and in the range of 89.54 to 112.10 percent of the average measured values for I-75 Chattanooga. Maturity prediction accuracy was found to be sensitive to PCC batch-to-batch variability. However, the Modified AASHTO T 276-97 Method is an effective protection from opening PCC pavement to traffic with sub-standard compressive strength.

The new maturity method is capable of providing more relevant information on PCC curing progress than lab-cured PCC cylinders. The information can be provided more frequently and more conveniently compared to lab-cured or field-cured PCC cylinders. Lab-cured cylinders represent potential compressive strength at standard curing temperature, not the compressive strength of the PCC pavement which has experienced different curing conditions. Further, the new maturity technology appears to be robust and reliable enough for field use by TDOT.

A laboratory experiment, using 120 (4 groups of 30 each) 6x12 cylinders cured at different temperatures, was also used to validate the maturity concept. The difference between compressive strengths of 6x12 cylinders lab-cured at the same maturity index for curing temperatures between 7 and 32°C (45 and 90°F) is in the range of 3.8 to 12.5 percent for maturity indices of 2400°C-hours or more. At lower maturity indices the compressive strength difference in percent was much greater.

The research team recommends that TDOT consider using the new maturity technology experimentally on large projects (projects requiring more than 30 batches of the same PCC mixture design). Modified versions of AASHTO Test Methods TP 52-95 and T 276-97 (for use with the new maturity technology) are included in the appendices for guidance. Finally, in situations where the new maturity technology is not appropriate, the research team recommends that 6x12 field-cured cylinders be used to determine when to open a new PCC pavement to traffic.

17. Key Words		18. Distribution Statement
Maturity Method	Nondestructive Testing	
Concrete Strength	Temperature	
Maturity Logger	Maturity Reader	
Temperature Logger	In-place Strength	

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INTRODUCTION

Portland cement concrete (PCC) gains strength and durability from reactions between Portland cement, supplementary cementing materials and water. The continuation of the chemical reactions is commonly termed curing. Curing progress is most commonly measured with compressive strength development. Curing progress is a function of time, temperature, and moisture conditions. Provided that adequate moisture is available, curing progress is a function of time and temperature. The maturity index is a function of time and temperature. Nurse and Saul [1] performed some of the early research on the maturity concept and suggested the following equation.

$$M = \sum_{0}^{t} (T - T_0)\Delta t$$

where:

M = maturity index

T = average concrete temperature during time Δt

T_0 = datum temperature (usually -10°C (14°F)) [2]

t = elapsed time hours

Δt = time interval (hours)

Just as depressing the accelerator on a vehicle makes the vehicle speed up; increasing the curing temperature makes the chemical reactions in PCC speed up. To continue the analogy, the maturity index measures the progress of curing like mile markers on an interstate measure the distance the vehicle has traveled. The maturity index is simply an alternative to compressive strength development for measuring the progress of PCC curing.

The advantage of the maturity concept over casting, transporting, curing, capping and testing PCC cylinders is logistical. Casting, curing, transporting, capping and testing PCC cylinders requires considerable time and effort and affords many opportunities for mistakes that most often reduce observed compressive strength. Low observed compressive strengths cause delays in opening new PCC pavements to traffic, increasing cost and inconvenience for the motoring public. The maturity method requires a correlation curve based on PCC cylinder compressive strengths. However, it does not require cylinders to be cast, transported, cured, capped or tested after the initial correlation plot is developed for that PCC mixture. Fewer opportunities are available for mistakes, less labor is required and the maturity index can be measured nearly continuously rather than at discreet points like compressive strength.

The new concrete maturity system is not a theoretical breakthrough; it uses the same maturity concepts that have been available since the 1950s. However, it is a technological leap forward. The new system virtually eliminates the problems of vandalism, theft and accidental damage associated with traditional field maturity meters. The new concrete maturity system uses an independent embedded microprocessor (logger) that requires no permanent external connection. The logger calculates the maturity index every 15 minutes. The reader unit downloads maturity index values as well as maximum and minimum temperatures when connected to a logger. One reader unit can be used in conjunction with an unlimited number of independent embedded loggers, but may only store data from two hundred loggers at one time.

The TDOT Materials and Tests Division is considering allowing the new maturity technology to be used in lieu of cylinder compressive strength results for opening new PCC pavements to traffic. The objective of the project is to evaluate the ability of the new maturity system to predict compressive strength development of Tennessee PCC pavements. The information generated in the project will assist TDOT in making a decision.

The maturity index is typically used to predict compressive strength development. To determine how accurate these predictions were, two field investigations were conducted. At each investigation location, the research team:

- Produced two maturity-compressive strength correlations using actual field mixtures
- Conducted twelve verifications; For each verification:
    - A maturity logger was placed in the pavement
    - Several types of PCC strength were measured at different times and compared to maturity predictions

A laboratory experiment using 120 6x12 cylinders cured at different temperatures was also used to validate the maturity concept. Compressive strengths were measured at pre-determined maturity indices to determine the effect of curing temperature on the maturity-compressive strength relationship.

LITERATURE REVIEW

Evaluation of PCC with 6x12 compressive strength cylinders has long been standard practice. Richardson [3] showed that the vast majority of errors in casting, transporting, curing, capping and testing PCC cylinders lead to lower observed compressive strengths. Table 1 from Richardson's research summarizes possible errors and their effects on observed compressive strength of PCC cylinders.

The consequences of falsely lower observed compressive strengths include but are not limited to:

- Unnecessary delays
- Costly follow up testing
- Possible rejection of good concrete
- Wasteful over design

Most current specifications require either PCC compressive strength cylinders to reach design strength or a waiting period of 7 to 14 days prior to opening a new PCC pavement to traffic. The maturity method may allow new PCC pavements to be opened sooner with a high level of confidence that the pavements have achieved design strength. An article in the March 2002 issue of Roads and Bridges magazine entitled "Young and Eager – The days of waiting to drive on new concrete may be over" by Steven M. Waalkes [4] touts the advantages of concrete maturity over traditional specifications for opening new PCC pavements to traffic. Waalkes states:

Table 1. Measured Strength Reduction by Nonstandard Conditions after Richardson (3)

Variable	Strength loss (%)	Lab (L) or field (F)
Convex ends	Up to 75	L
Insufficient consolidation	Up to 61	F
Immediate freezing for 24 hours	Up to 56	F
Rubber cap, no restraint	Up to 53	L
Weak, soft capping compound	Up to 43	L
Flat particle vertical orientation	Up to 40	F
Concave ends	Up to 30	L
Rough end before capping	Up to 27	F
Seven days in the field, warm temperature	Up to 26	F
Reuse of plastic molds	Up to 22	L
Cardboard mold	Up to 21	F
Seven days in field at 73°F, no added moisture	Up to 18	F
Plastic mold	Up to 14	F
Rough end, air gaps under cap	Up to 12	F
Convex end, capped	Up to 12	F
Eccentric loading	Up to 12	L
Out-of-round diameter	Up to 10	F
Ends not perpendicular to axis	Up to 8	F
Rough handling	Up to 7	F
Three days at 37° F, mixed at 73° F	Up to 7	F
One day at 37° F, mixed at 46° F	Up to 7	F
Excessive tapping	Up to 6	F
Thick cap	Up to 6	L
Sloped end, leveled by cap	Up to 5	F
Wet mix subjected to vibrations	Up to 5	F
Chipped cap	Up to 4	L
Rebar rodding	Up to 2	F
Insufficient cap cure	Up to 2	L
Slick end cap	Up to 2	L
Slow loading rate	Up to 2	L

"The maturity method is a simple non-destructive way of determining the strength of concrete pavement so it can be opened to traffic as soon as it achieves the required strength. This story details the experiences of three states that have embraced the technology: Iowa, Indiana, and Texas. Although only a limited number of agencies currently use this methodology, there is growing interest in the cost-effective method."

"The biggest problem for the concrete industry is people thinking you have to wait seven to 14 days before putting traffic on a new pavement," said Denny Osipowicz, engineer from Lee County, Iowa. "Concrete really gains strength faster than we give it credit for. Now the Maturity method is speeding up the whole construction process."

Unfortunately, no technical publications were found on evaluation of the new maturity technology. This fact was made apparent to the research team when the manufacturer requested and obtained permission from TDOT to distribute the CD-ROM from the TDOT/TRMCA Maturity Project Update 2/07/03 to individuals seeking technical information on the new method.

Constantino and Carrasquillo [5] provided one of the more comprehensive reviews of the maturity method using older technology. The authors made several points which are relevant to the new maturity technology:

1. Component material quality and proportions determine the potential strength of PCC. However, a number of factors including curing are strong contributors to PCC in-place strength.

2. Time and temperature are the essential variables associated with PCC strength development.
3. Quality curing in the field and low batch-to-batch variability PCC are the primary factors in the successful use of the maturity method.
4. Maturity models can generally predict actual strengths (field-cured cylinders or cores) within 10 percent.
5. The maturity method is not useful in detecting mixture variability or in identifying factors detrimental to strength or variability. The maturity method should be supplemented with other testing methods that ensure quality and consistency of PCC.

NEW MATURITY TECHNOLOGY OVERVIEW

Equipment

The new maturity system is composed of one reader with case, twenty-five maturity loggers, a personal computer connection cable and computer software on CD. The cost of the starter kit containing these items is approximately $1,500. Logger data is downloaded to the reader. The data is then transferred to a personal computer via the cable and software included in the starter kit. Two types of files are then created: a text file and a secure file. The text file can be opened and altered in spreadsheet or word-processing software, but the secure file cannot be altered. The secure file ensures secure documentation and distribution of the data [6].

The central component of the new maturity system is the reader. It is a hand-held device that weighs approximately one pound. It requires four AA batteries as a power source and can store data from two hundred separate loggers. The reader is a communications device similar to a telephone for obtaining information from a logger with an onboard memory. By pressing the correct sequence of keys, the user is allowed to view and/or store information from a logger or transmit stored logger information to a personal computer. The reader will not alert the user to PCC problems, nor will it offer suggestions for addressing PCC problems. One reader purchased separately, costs $949 [6].

The two types of loggers available with the system are maturity loggers and temperature loggers. Each logger costs $25 and is dependent on the reader for activation and retrieval of stored data. Loggers are a combination of six things:

1. A thermometer
2. A stopwatch
3. A calculator with a memory
4. A battery
5. A hard shell case to carry and protect the other components
6. Wires for communication with the reader

During operation, the logger has no idea what material it is embedded in and will not alert the user to PCC problems. The logger measures temperature and time, and in the case of a maturity logger, performs a simple mathematical process involving multiplication and addition. The logger also stores data for transmission to the reader. Color pictures and additional details are provided on the manufacturer's web site [6] or on the TDOT Maturity Final Presentation CD-ROM. Table 2 contains specifications for each type of logger.

Table 2. Logger Specifications

Specification	Maturity Logger	Temperature Logger
Temperature Accuracy	± 1°C	± 1°C
Maturity Integration Period	15 minutes	N/A
Maturity Technique	ASTM C 1074 (Nurse-Saul Method)	N/A
Stored Historical Temperature and Maturity Points	Temperature and maturity at start, 4 hrs, 12 hrs and 1-7 days	Temperature at start, every 2 hrs for days 1-3, every 4 hrs for days 4-6 and every 12 hrs for days 7-28
Additional Stored Data	Time and value of minimum and maximum temperature and maturity	Time and value of minimum and maximum temperature
Dimensions	1-1/2" x 1-1/8" diameter	1-1/2" x 1-1/8" diameter
Cable Length	4' (custom lengths up to100')	4' (custom lengths up to100')
Wire Gauge	18	18
Operating Temperatures	-18°C to 85°C (0 to 185°F)	-18°C to 85°C (0 to 185°F)
Logging Battery Life	3 months	3 months
Battery Shelf Life	5 years	5 years

Operating Procedure for Reader and Loggers

The following is a list of keypad strokes (< >) and brief descriptions of basic operations for the new maturity system. Detailed instructions, including color pictures, are available on the TDOT Maturity Final Presentation CD-ROM.

1. Activating a Logger

    a. Hook up connections and hit <POWER>, device will indicate "Ready"

    b. Hit <CURRENT READING>, device will indicate "STDBY"

c. Hit <START/STOP>, device will indicate "RUN"

2. Setting the Datum Temperature*

   a. Hit <POWER>, device will indicate "Ready"

   b. Hit <DATUM>, device will indicate "Datum -10°C"

   c. Hit <UP ARROW> or <DOWN ARROW> to adjust

* The datum temperature is the threshold where the hydration reaction ceases. At this temperature, compressive strength gain is negligible. AASHTO T 276-97 [2] recommends a datum temperature of −10°C (14°F), which was used in this research. The manufacturer recommends using 0 or 5°C (32 or 41°F), but stresses that the datum temperature used in the correlation must be used for the verification [7].

3. Taking a Maturity Reading

   a. Hook up connections and hit <POWER>, device will indicate "Ready"

   b. Hit <CURRENT READING>, device will indicate "RUN"

   c. Hit <CURRENT READING>, device will indicate elapsed time

4. Storing a Maturity Reading

   a. Continue from Taking a Maturity Reading (Step 3c)

   b. Hit <CURRENT READING>, device will request Save Confirmation

   c. Hit <ENTER>, device will indicate Data Saved

5. Deactivating a Logger

   a. Hook up connections and hit <POWER>, device will indicate "Ready"

   b. Hit <CURRENT READING>, device will indicate "RUN"

   c. Hit <START/STOP> and <ENTER>, device will indicate "STDBY"

6. Downloading Stored Data to a PC or Clearing Memory

   a. Hook to PC and hit <POWER>, device will indicate "Computer Online"

   b. Computer software option #1: Download Data

   c. Computer software option #2: Erase Stored Data

Generating a Maturity-Compressive Strength Correlation Plot

Correlation curves should be established from field batches whenever possible, but laboratory batches may be used if necessary. However, it is critical that the same materials and mixture proportions that will be used in the field are used to establish the maturity-compressive strength correlation curve, due to the fact that correlation plots are PCC mixture specific.

Compressive strengths are determined with at least a pair of 6x12 lab-cured cylinders at ages of 1, 2, 3, 4, 7, 10, 14, 28, and 56 days. A minimum of twenty 6x12 cylinders should be fabricated so that two cylinders can contain maturity loggers. The following is a summary of the steps in generating a maturity-compressive strength correlation plot. Detailed instruction can be found in Appendix E.

1. Sample PCC in the field.
2. Cast cylinders.
3. Install a maturity logger in each of two cylinders.
4. Activate maturity loggers.
5. Perform initial curing at the jobsite.
6. Transport cylinders to the lab.
7. Cure cylinders in the lab.
8. Measure maturity index at the time each pair of cylinders is broken.
9. Determine compressive strength with at least two cylinders at each prescribed time.
10. Make a correlation plot (similar to Figure 1).

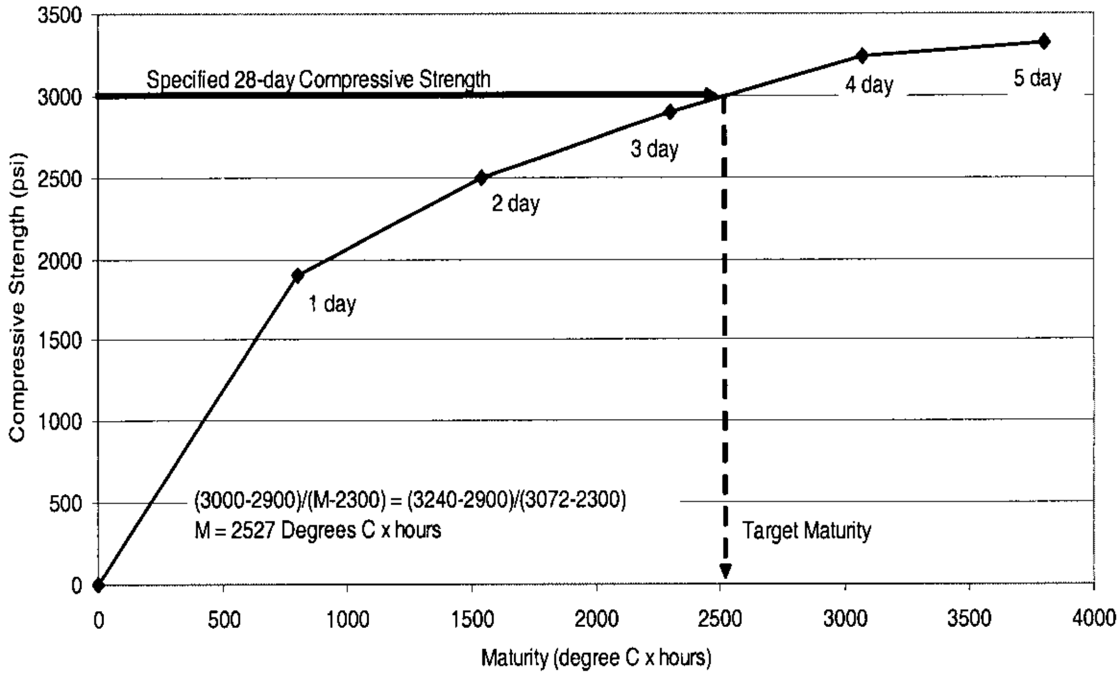

Figure 1. Example Maturity-Compressive Strength Correlation Plot with Target Maturity Determination

LABORATORY EVALUATION

Materials and Procedure

The validity of the maturity concept was evaluated by casting 120 6x12 cylinders from 1.25 cubic yards of TDOT Class A PCC and curing the cylinders at different temperatures encompassing the TDOT specification limits. Plastic properties of the PCC are shown in Table 3. Immediately after casting, the cylinders were placed into respective storage tanks and the loggers were activated. The limewater level in the tanks was elevated to the tops of the cylinder molds to ensure acclimation to the desired curing temperature as quickly as possible. At approximately 800°C·Hrs, the molds were removed and the limewater level was once again elevated to completely immerse all specimens within each tank.

Table 3. Plastic Properties of the Laboratory Evaluation Mixture

Property	Result	TDOT Specification (8)
Slump (inches)	2	0.5-2
Air Content (%)	6.1	3-8
Unit Weight (pcf)	143.2	No requirement
Temperature (°F)	43	50-90

Three curing temperatures were used 90, 73.4 and 45°F (32, 23, and 7°C). Thirty of the 120 cylinders were cured at each temperature. The remaining thirty cylinders began in the 90°F bath and changed curing temperatures approximately every 8 hours as shown in Figure 2. The rotation of cylinders in different curing temperature tanks was intended to simulate a daily cycle of temperature changes.

Testing protocol and approximate test ages in days, estimated using the Nurse-Saul equation with a datum temperature of 14°F (-10°C), are shown in Table 4. The predetermined maturity indices for compressive strength testing were based on standard curing for 1, 2, 3, 4, 5, 7, 14 and 28 days. Two 6x12 cylinders in each group contained maturity loggers, and two of each group contained temperature loggers. Actual maturity indices for compressive strength testing were determined by averaging the values from the two maturity loggers. During the experiment, one maturity logger failed to perform, and those logger values were no longer recorded for experimental use.

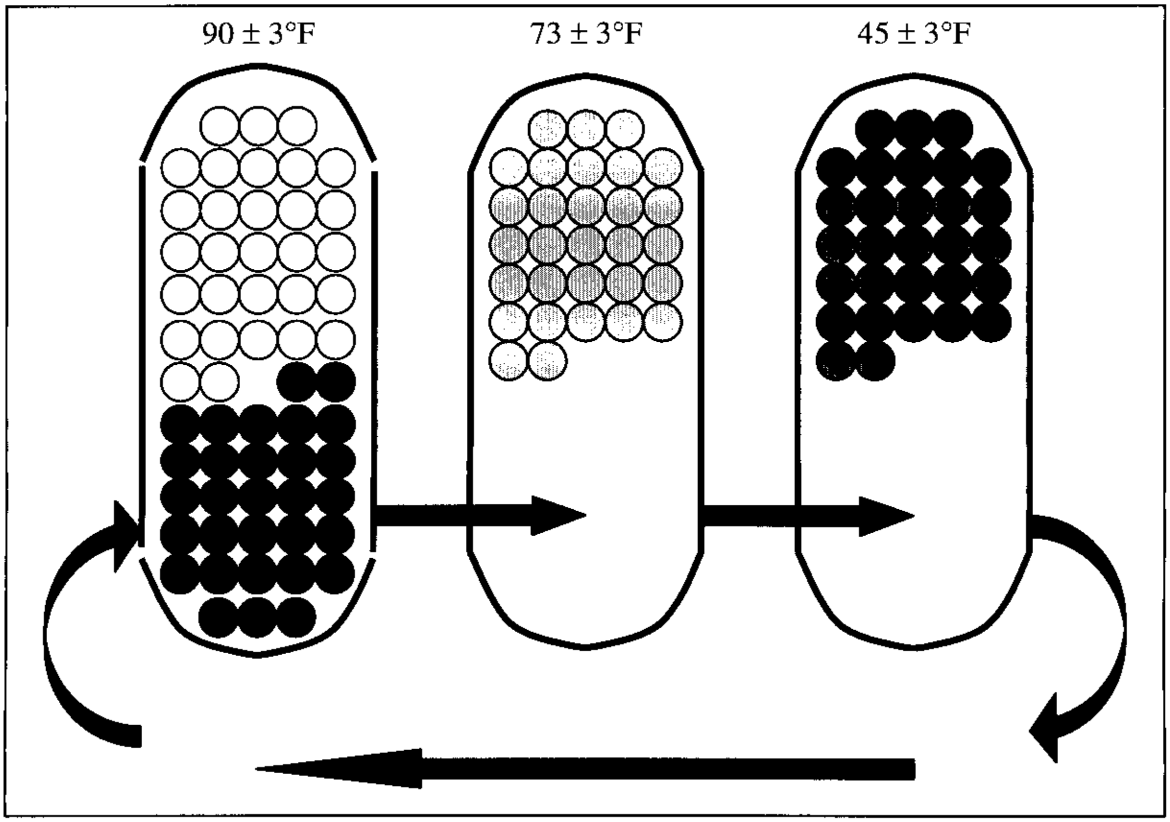

Figure 2. Schematic of Curing Tank Set-up and Rotation of Variable Cylinders

Table 4. Testing Schedule for Laboratory Experiment

Approximate Maturity Index (°C·Hrs)	Neoprene Durometer	Approximate Age of Hot (90 +/- 3 °F) [9] Cure Tank Specimens (Days)	Approximate Age of Standard 73.4 +/- 3 °F [10] Cure Tank Specimens (Days)	Approximate Age of Cold 45 +/- 3 °F [11] Cure Tank Specimens (Days)	Specimens Tested
800	50	0.8	1	2	2
1600	50	1.6	2	4	2
2400	60	2.4	3	6	3
3200	60	3.2	4	7.8	3
4000	60	3.9	5	9.7	3
5500	60	5.4	7	13.3	4
11000	60	10.9	14	26.6	3
22000	60	21.7	28	53.3	6

The laboratory storage tanks (depicted in Figure 2) were insulated on all surfaces to retain the desired temperature and equipped with two circulation pumps in either end. Each tank was also equipped with a steel grate placed upon masonry bricks to keep the cylinders exposed to the limewater conditions on all surfaces. A single tank heater provided the heat for the 90°F and 73.4°F tanks, while the installation of a circulation chiller was required for the 45°F tank. The chiller circulated a mixture of antifreeze and water through copper piping directly beneath the steel grating.

Results

A summary of the results of the laboratory evaluation of the new maturity technology are shown in Table 5. Complete results for the laboratory evaluation can be found in Appendix A. Temperature profiles for the constant temperature and variable temperature cylinders are shown in Figures 3 and 4 respectively.

Table 5. Average Compressive Strengths for Each Approximate Maturity Index

Approximate Maturity Level (°C-hours)	45°F Cylinders TDOT Lower Curing Temperature Limit	73°F Cylinders AASHTO Standard Curing Temperature	90°F Cylinders TDOT Upper Delivery Temperature Limit	Variable Temperature Cylinders
800	1048	1606	2048	1879
1600	1969	2710	2597	2705
2400	2922	3035	3026	3013
3200	3229	3444	3221	3492
4000	3757	3568	3595	3737
5500	4288	3785	3931	4099
11000	5192	4837	5055	4742
22000	6150	5678	6132	6015

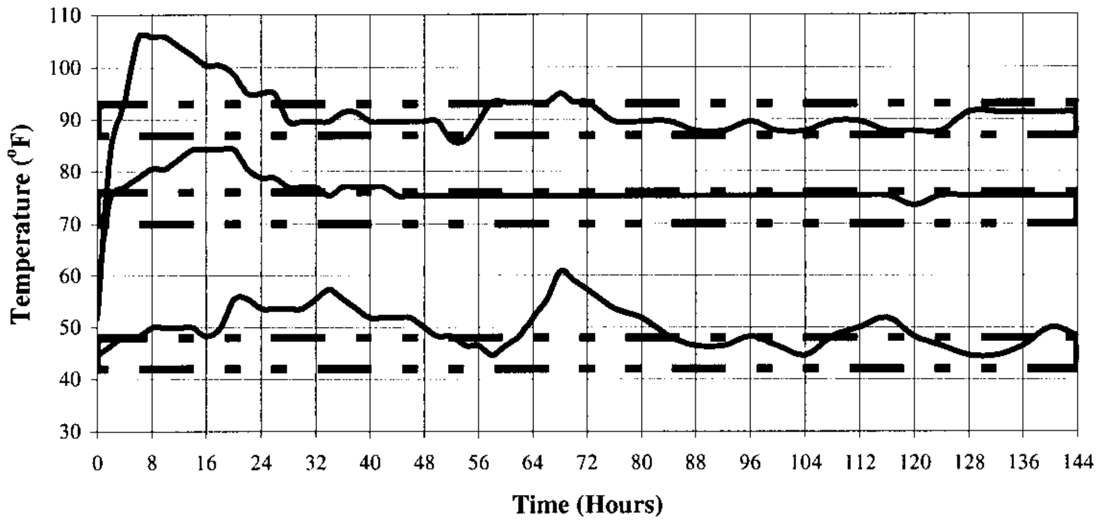

Figure 3. Temperature Logger Profiles for 90, 73, and 45° F Cylinders

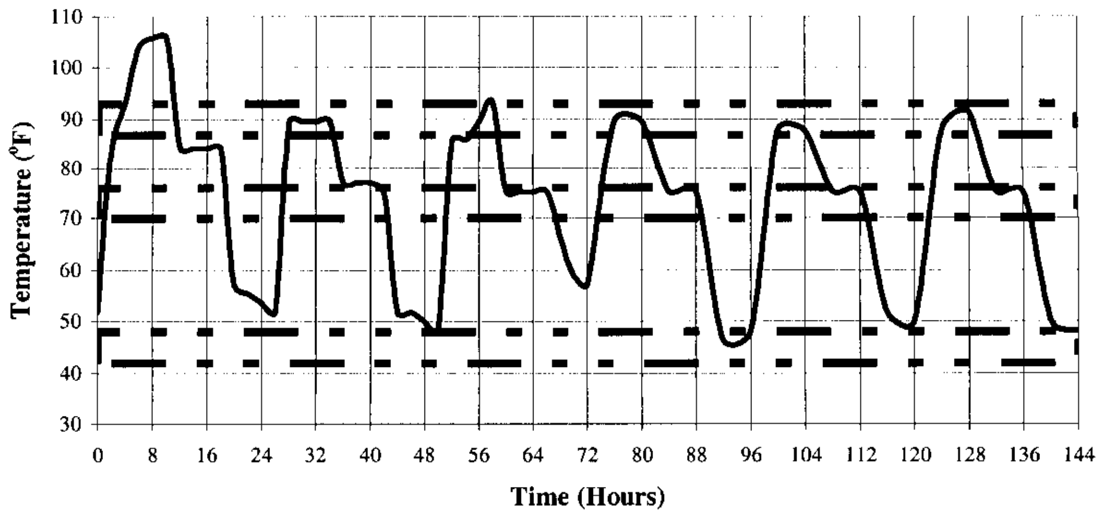

Figure 4. Temperature Logger Profiles for Variable Temperature Cylinders

Analysis of Results

The agreement between average compressive strengths obtained at various maturity indices from different curing regimes is shown in Table 6. The difference between compressive strengths of 6x12 cylinders lab-cured at temperatures between 45 and 90°F is in the range of 3.8 to 12.5% for maturities greater than or equal to 2400°C-hours (72.75 hours at 73°F). At lower maturity indices the difference is much greater.

Table 6. Comparison of Average Compressive Strengths at Each Approximate Maturity Level

Approximate Maturity Level (°C-hours)	Range (High Result – Low Result)	Range as a Percent of the Mean Result
800	1002	60.9
1600	741	29.7
2400	113	3.8
3200	271	8.1
4000	189	5.2
5500	503	12.5
11000	450	9.1
22000	472	7.9

FIELD EVALUATIONS

Procedure

Tables 7 and 8 show the correlation and verification protocol for the I-65 Nashville and I-75 Chattanooga field studies:

Table 7. Correlation Activities

Correlation Activity	Location
Acquisition and plastic properties for 2 correlation batches	I-65 and I-75
Placement, identification and initiation of 4 maturity loggers	I-65 and I-75
Placement, identification and initiation of 4 temperature loggers	I-75 only
Testing schedule	I-65 and I-75
Generation of 2 correlation curves	I-65 and I-75
Generation of verification prediction curve	I-65 and I-75
Reader comparison	I-65 and I-75
Jobsite temperature profiles	I-75 only

Table 8. Verification Activities

Verification Activity	Location and number	
	I-65	I-75
Acquisition and plastic properties of verification batches	12	12
Placement, identification and initiation of maturity loggers	12 all at mid-depth	18 some at variable depth
Placement, identification and initiation of temperature loggers	0	3
Testing schedule		
➢ 6 x 12-inch field-cured cylinders	96	96
➢ 6 x 12-inch lab-cured cylinders	96	96
➢ 4 x 8-inch cores	48	48
➢ Rebound hammer	600	720
➢ Windsor Probe	Attempted	0
Comparison of maturity at different logger depths		
Comparison of measured and predicted strengths		

Correlations

Field tests for generating compressive strength-maturity correlations were conducted on September 19, 2002 for I-65 and on July 22, 2003 for I-75. Table 9 shows the plastic properties evaluated and test method references. Two separate batches of PCC were acquired and tested for each location.

Table 9. Plastic PCC Property Evaluation Procedures

Property or Procedure	Test Method Reference
Slump	AASHTO T 119-99 (12)
Unit Weight	AASHTO T 121-97 (2001) (13)
Sampling	AASHTO T 141-01 (14)
Air Content by Pressure Method	AASHTO T 152-01 (15)
Temperature	AASHTO T 309-99 (16)

Two sets of twenty 6x12 cylindrical test specimens were then cast in accordance with AASHTO T 23-02 (10). The sets were labeled "C1" and "C2," and two specimens from each set were equipped with a maturity logger. The loggers were placed as close to the center of the specimen as possible (see Figure 5) and activated immediately after embedment. The specimens were then placed in storage boxes on site and remained there for approximately twenty-four hours for initial curing. Along with the maturity loggers, temperature loggers were embedded into the correlation test specimens for the I-75 correlations. The purpose for this addition was to monitor the temperature of the concrete specimens inside the storage boxes during the initial curing period on the jobsite and in transit. The temperature loggers store data at two-hour intervals up to seventy-two hours; however, the initial forty hours were the main focus.

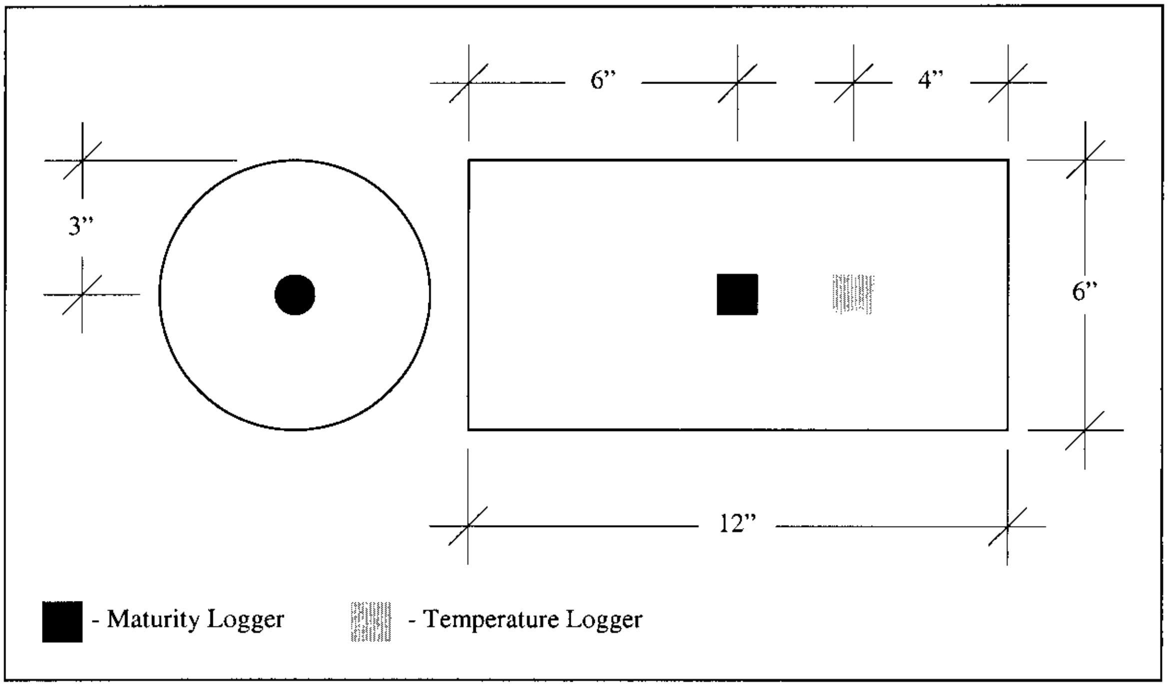

Figure 5. Logger Placement in Correlation Specimens

Table 10. Testing Schedule

Age (Days)	Date (I-65)	Date (I-75)	Maturity Readings				Specimens to Test	
			Reader 1		Reader 2			
			C1	C2	C1	C2	C1	C2
1	09/20/02	07/23/03	2	2	2	2	2	2
2	09/21/02	07/24/03	2	2	2	2	2	2
3	09/22/02	07/25/03	2	2	2	2	2	2
4	09/23/02	07/26/03	2	2	2	2	2	2
7	09/26/02	07/29/03	2	2	2	2	2	2
10	09/29/02	08/01/03	2	2	2	2	2	2
14	10/03/02	08/05/03	2	2	2	2	2	2
28	10/17/02	08/19/03	2	2	2	2	2	2
56	11/14/02	09/16/03	2	2	2	2	2	2

The following day the specimens were transported to the Tennessee Technological University materials laboratory, the molds were removed and permanent labels were applied. Two specimens from each set were retained for 1-day compressive strength testing in accordance with AASHTO T 22-97 [17]. The remaining specimens were placed in a limewater immersion at 73.4 ± 3°F in accordance with AASHTO T 126-01 [18], where they remained until testing (see Table 10).

On each test date an average compressive strength was obtained. The loggers that accompanied each set of cylinders provided an average maturity index that was then paired with its corresponding average compressive strength. Compressive strength versus maturity index plots were constructed by connecting the points with straight lines as per the manufacturer's recommendation [7]. Two separate correlation curves were constructed for each location and then averaged to produce a prediction curve for the specific PCC mixture. The resulting plot was used for predicting compressive strengths in the verification procedure.

During the correlation procedure the reliability of the maturity readers was investigated. On each testing date two readers were used to download the data stored by the loggers. The data were then transferred from the reader to a personal computer for comparison.

Verifications

The data obtained during the correlation were analyzed, and the appropriate test schedule was constructed for the verification. Twelve loggers were placed in the pavement for the I-65 verification. Specifically, on October 15, 2002, eight loggers were placed at mid-depth of a nine-inch off-ramp. Two days later on October 17, the remaining four loggers were placed at mid-depth into the mainline portion of I-65, which had a design depth of thirteen inches. At each logger location, a sample of the mixture was acquired, evaluated with plastic properties as in the correlation and sixteen 6" x 12" compressive strength specimens were cast. The verification procedure used in Nashville was slightly modified and replicated in Chattanooga beginning on August 4, 2003. Maturity loggers were placed at twelve verification locations along mainline I-75 on August 4 and 5. The first modification dealt with variable logger depths and the second addressed the temperature changes experienced by a pavement structure along its length.

The manufacturer recommends that maturity loggers be placed at approximately mid-depth of the concrete specimen or structure [7]. On February 7, 2003, this was questioned at a seminar at TDOT Division of Materials and Tests Division Headquarters. In response to this query, a modification was made to the verification procedure in Chattanooga. At verification locations 1, 6 and 12, maturity loggers were installed at third points of the slab's depth (see Figure 6) to evaluate the difference in their maturity indices. Maturity loggers at other verification locations were placed at mid-depth of the slab.

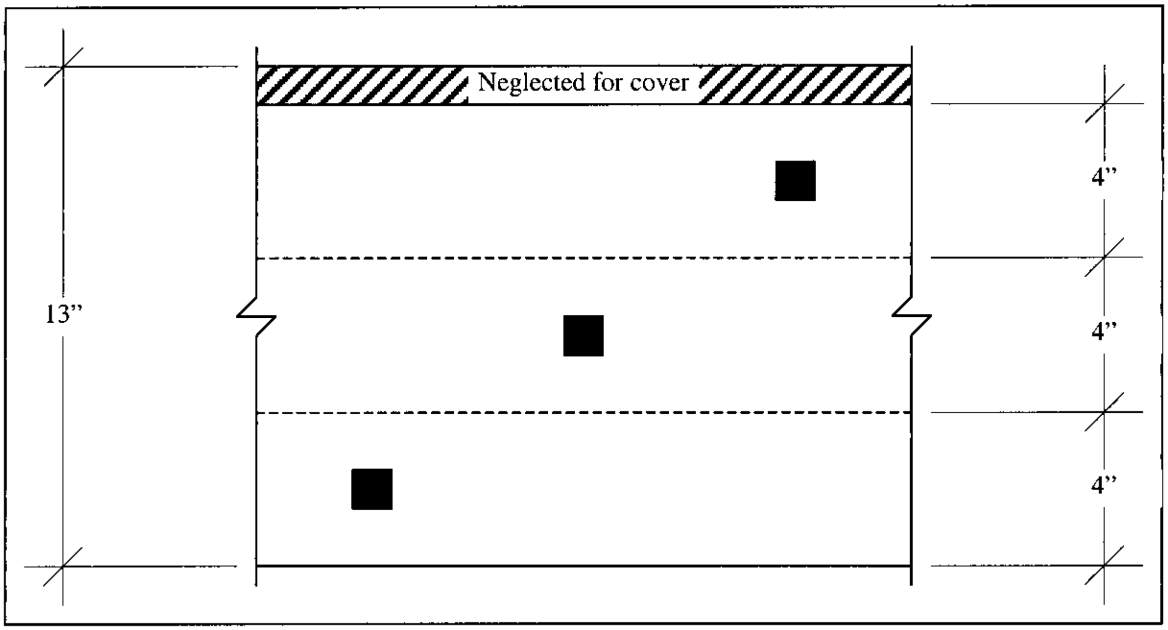

Figure 6. Logger Placement for Verifications 1, 6 & 12 at I-75

At verification locations 2, 7 and 11, temperature loggers were embedded in the slab. Each temperature logger was installed four inches from a maturity logger at mid-depth of the slab to monitor the temperature along the structure's length.

Approximately twenty-four hours after the embedment and activation of the loggers, the lab-cured cylinders were transported to TTU where they remained in a limewater immersion until testing. The field-cured cylinders were sprayed with curing compound and left on-site to experience the same conditions as the PCC pavement.

Table 11 shows the testing schedule for verifications, and Table 12 shows the procedural reference for each test procedure and who performed the testing.

Table 11. Verification Test Schedule

Test or Procedure	Daily until 125% TM	% Target Maturity			28-day
		75	100	125	
Compressive Strength of 4"x 8" Cores			2		2
Compressive Strength of 6" x 12" Field-Cured Cylinders		2	2	2	2
Compressive Strength of 6" x 12" Lab-Cured Cylinders		2	2	2	2
Rebound Hammer	10	10	10	10	10
Windsor Probe			3		3

Table 12. Test Procedures

Test or Procedure	Procedural Reference	Performed by
Compressive Strength of 4"x 8" Cores	AASHTO T 24-02 [19]	TDOT M & T
Compressive Strength of 6" x 12" Field-Cured Cylinders	AASHTO T 22-97 [17]	TDOT M & T
Compressive Strength of 6" x 12" Lab-Cured Cylinders	AASHTO T 22-97 [17]	TTU
Rebound Hammer	ASTM C 805-97 [20]	TTU
Windsor Probe	ASTM C 803/C 803M-$97^{\varepsilon 1}$ [21]	TDOT M & T

Immediately following each of the tests, the results and the corresponding maturity values were recorded on site. After the 28-day testing, the logger lead wires were trimmed to the surface of the pavement structure, and the verification testing ended. All tests were completed satisfactorily except two; the 28-day I-65 Rebound Hammer readings were neglected and the Windsor Probe testing was discontinued (see Appendix B).

Results

Correlations

Tables 13 and 14 show the plastic property measurements obtained during the acquisition of the two correlation samples for I-65 and I-75, respectively. Figures 7 and 8 show the prediction curves used in the verification procedure for I-65 and I-75, respectively. Target maturity values for a compressive strength of 3000-psi are shown in Table 15. Tables 16 through 19 show reader comparisons for each logger used during the correlation procedure. Figures 9 and 10 show I-75 Chattanooga correlation curve box temperatures over time. Complete correlation data can be found in Appendix C.

Table 13. I-65 Correlation Plastic Properties

Correlation Curve	Slump (inches)	Unit Weight (lbs/ft³)	Air Content (%)	Temperature (°F)
1	2.00	144	3.9	88
2	2.25	144	3.9	89

Table 14. I-75 Correlation Plastic Properties

Correlation Curve	Slump (inches)	Unit Weight (lbs/ft³)	Air Content (%)	Temperature (°F)
1	2.00	148	5.5	85
2	2.50	148	5.0	85

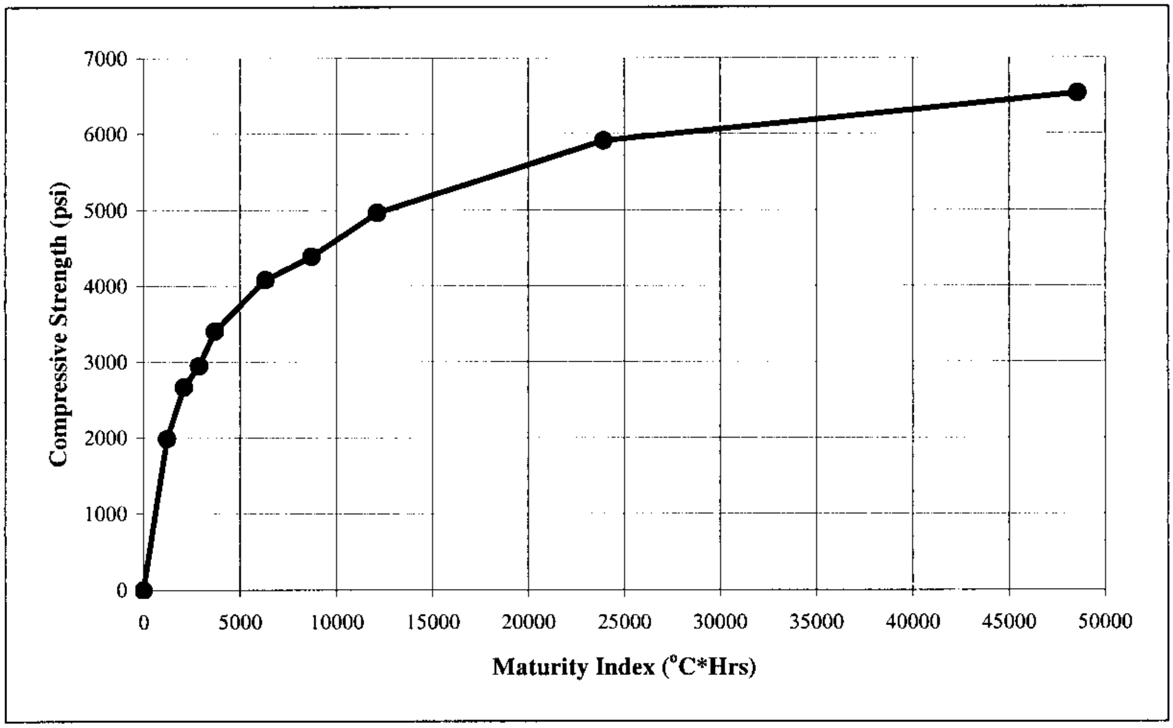

Figure 7. I-65 Verification Prediction Curve

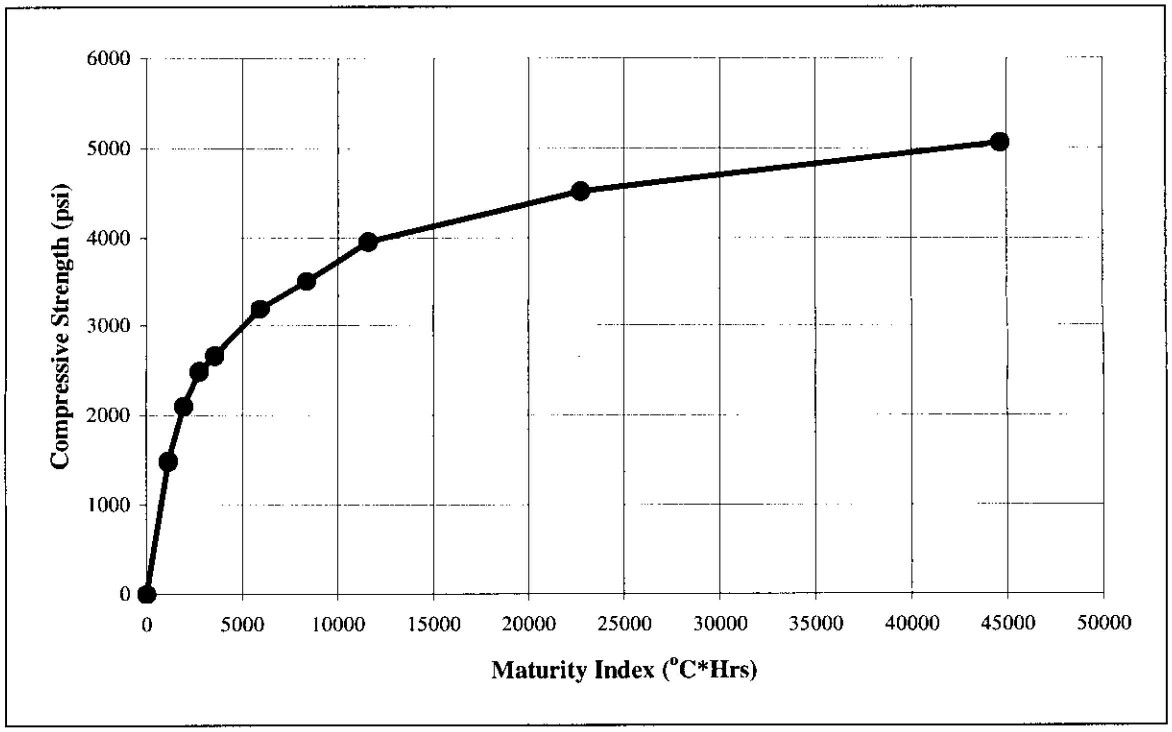

Figure 8. I-75 Verification Prediction Curve

Table 15. Target Maturity Indices

Location	75% Target Maturity (°C·Hrs)	Target Maturity (°C·Hrs)	125% Target Maturity (°C·Hrs)
I-65 Nashville	2225	2967	3708
I-75 Chattanooga	3823	5097	6371

Table 16. I-65 Correlation Curve 1 Reader Comparisons

	Curve 1 Logger 1		Curve 1 Logger 2	
Age in Days	Reader 1	Reader 2	Reader 1	Reader 2
0	0	0	0	0
1	1304	1304	1296	1296
2	2187	2187	2175	2175
3	2973	2973	2956	2956
4	3798	3798	3778	3778
7	6412	6412	6380	6380
10	8807	8807	8764	8764
14	12222	12222	12166	12166
28	24022	24022	23938	23938
56	48682	48682	48396	48396

Table 17. I-65 Correlation Curve 2 Reader Comparisons

	Curve 2 Logger 1		Curve 2 Logger 2	
Age in Days	Reader 1	Reader 2	Reader 1	Reader 2
0	0	0	0	0
1	1117	1117	1132	1132
2	1984	1984	2001	2001
3	2779	2779	2798	2798
4	3606	3606	3626	3626
7	6215	6215	6237	6237
10	8613	8613	8640	8640
14	12039	12039	12073	12073
28	22836	22836	23884	23884
56	48528	48528	48664	48664

Table 18. I-75 Correlation Curve 1 Reader Comparisons

Age in Days	Curve 1 Logger 1		Curve 1 Logger 2	
	Reader 1	Reader 2	Reader 1	Reader 2
0	0	0	0	0
1	1143	1143	1137	1137
2	1959	1959	1954	1954
3	2775	2775	2770	2770
4	3598	3598	3590	3590
7	5963	5963	5953	5953
10	8445	8445	8415	8415
14	11711	11711	11680	11680
28	22870	22870	22834	22834
56	44774	44774	44738	44738

Table 19. I-75 Correlation Curve 2 Reader Comparisons

	Curve 2 Logger 1		Curve 2 Logger 2	
Age in Days	Reader 1	Reader 2	Reader 1	Reader 2
0	0	0	0	0
1	1115	1115	1136	1136
2	1931	1931	1951	1951
3	2747	2747	2764	2764
4	3563	3563	3580	3580
7	5908	5908	5922	5922
10	8264	8264	8298	8298
14	11452	11452	11466	11466
28	22573	22573	22587	22587
56	44552	44552	44495	44495

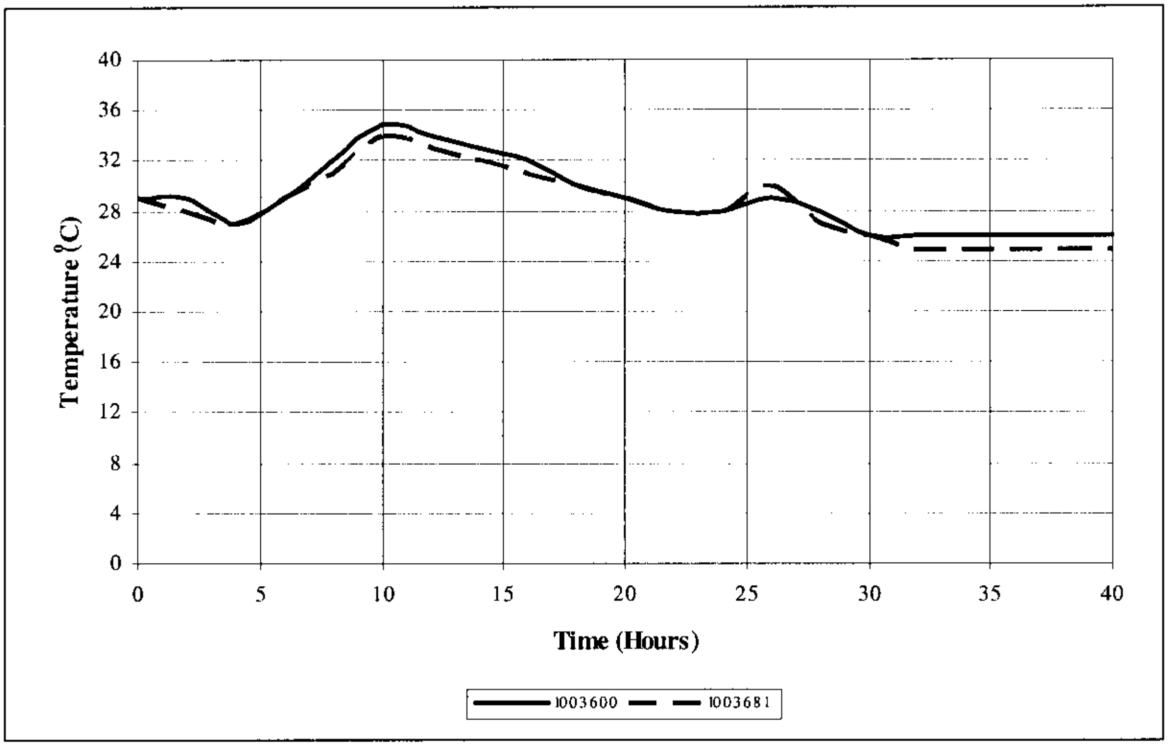

Figure 9. I-75 Correlation Curve 1 Box Temperatures

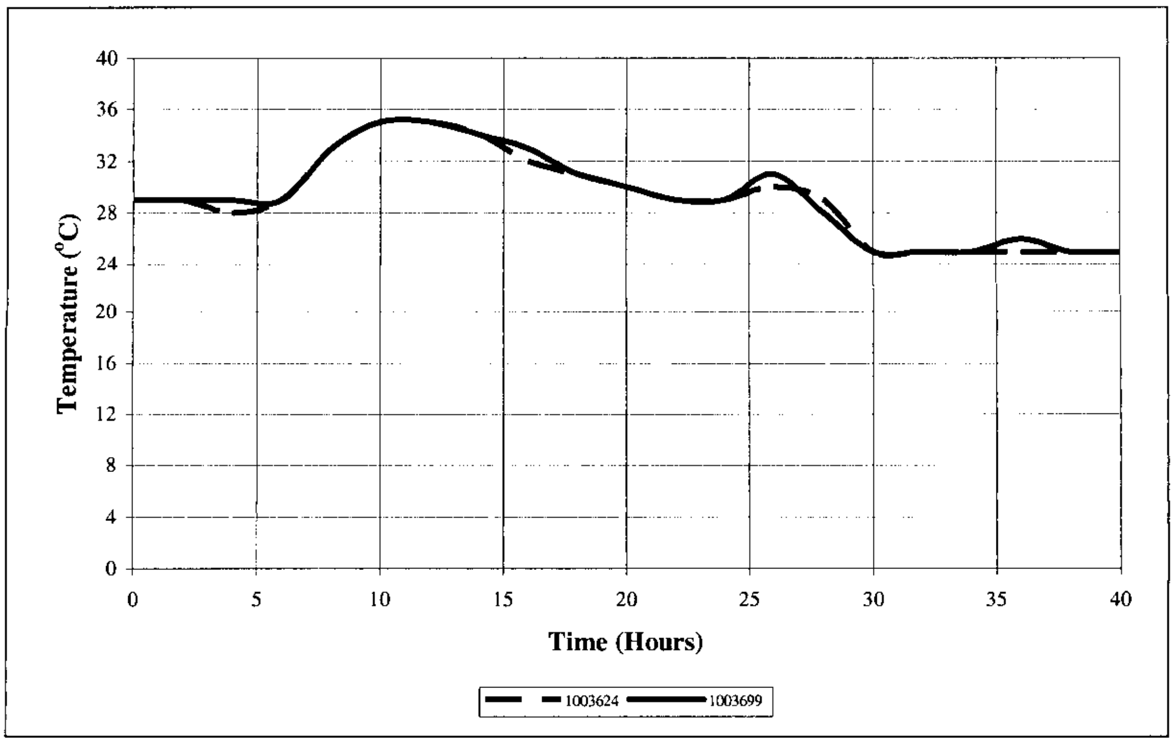

Figure 10. I-75 Correlation Curve 2 Box Temperatures

Verifications

Tables 20 and 21 contain the plastic property measurements obtained during the acquisition and evaluation of the twelve verification samples for I-65 and I-75, respectively. Tables 22 through 24 show maturity indices for various logger depths at I-75 Chattanooga verification locations 1, 6, and 12, respectively. Due to the large quantity of data obtained at each field verification, the research team elected to present a summary of the data in the body of the report. Tables 25 and 26 show predicted strengths divided by measured strengths expressed as a percentage for I-65 Nashville and I-75 Chattanooga, respectively. Complete verification data can be found in Appendix D.

Pavement temperature data for verification location 2 on I-75 Chattanooga is shown in Figure 11. The pavement temperature varies between 27 and 40°C (80 and 104°F). Complete temperature data for I-75 verification locations 2, 7, and 11, are contained in Appendix D.

Table 20. I-65 Verification Plastic Properties

Verification	Slump (inches)	Unit Weight (lbs/ft^3)	Air Content (%)	Temperature (°F)
1	1.50	144	3.7	71
2	1.00	144	---	71
3	2.00	144	3.7	74
4	1.50	141	3.8	75
5	1.50	142	4.0	74
6	2.00	144	3.4	80
7	2.50	143	3.8	77
8	2.00	144	3.8	76
9	3.00	148	3.8	70
10	1.00	148	3.4	66
11	1.50	144	1.5	70
12	0.75	144	3.5	70

--- Not Available

Table 21. I-75 Verification Plastic Properties

Verification	Slump (inches)	Unit Weight (lbs/ft^3)	Air Content (%)	Temperature (°F)
1	1.00	148	4.7	85
2	1.25	148	5.0	87
3	1.00	150	4.5	86
4	1.25	148	4.9	87
5	0.75	148	5.0	87
6	1.50	148	5.5	86
7	2.25	146	5.9	84
8	2.50	146	5.9	85
9	0.75	148	5.4	86
10	4.00	146	7.9	86
11	3.00	148	7.8	85
12	4.50	144	7.8	87

Table 22. Maturity Index at Various Slab Depths for I-75 Chattanooga Verification Location 1

Age (days)	Top Third of Slab	Mid-depth of Slab	Bottom Third of Slab
1	1132	1155	1185
2	2199	2236	2277
3	3352	3410	3470
4	4453	4521	4584
5	5508	5588	5651
28	28303	28664	28679

Table 23. Maturity Index at Various Slab Depths for I-75 Chattanooga Verification Location 6

Age (days)	Top Third of Slab	Mid-depth of Slab	Bottom Third of Slab
1	1071	1101	1121
2	2192	2230	2255
3	3389	3434	3479
4	4556	4594	4637
5	5623	5654	5697
28	29019	28922	28957

Table 24. Maturity Index at Various Slab Depths for I-75 Chattanooga Verification Location 12

Age (days)	Top Third of Slab	Mid-depth of Slab	Bottom Third of Slab
1	1195	1261	1239
2	2411	2532	2522
3	3570	3705	3691
4	4610	4761	4741
5	5621	5781	5757
28	28290	28600	28447

Table 25. Summary of Predicted Strengths Divided by Measured Strengths Expressed as a Percentage for I-65 Nashville Verifications

	Low	High	Average
100% TM Cores	74.49	112.65	91.75
28-day Cores	79.88	105.01	91.79
75% TM Field-cured Cylinders	82.23	137.84	100.48
100% TM Field-cured Cylinders	79.33	121.28	93.14
125% TM Field-cured Cylinders	78.50	126.52	97.29
28-day TM Field-cured Cylinders	79.34	109.69	92.61
75% TM Lab-cured Cylinders	74.90	94.94	81.76
100% TM Lab-cured Cylinders	72.15	91.86	78.85
125% TM Lab-cured Cylinders	74.87	92.06	81.37
28-day TM Lab-cured Cylinders	70.52	80.36	74.53
1-day Rebound Hammer	73.08	366.71	211.36
2-day Rebound Hammer	47.69	91.03	72.41
75% TM Rebound Hammer	61.93	103.76	85.72
100% TM Rebound Hammer	63.93	106.32	86.09
125% TM Rebound Hammer	73.17	122.61	94.55
28-day Rebound Hammer	NA	NA	NA

Table 26. Summary of Predicted Strengths Divided by Measured Strengths Expressed as a Percentage for I-75 Chattanooga Verifications

	Low	High	Average
100% TM Cores	72.74	108.47	89.54
28-day Cores	94.29	145.11	112.10
75% TM Field-cured Cylinders	72.82	113.87	90.75
100% TM Field-cured Cylinders	71.25	127.96	90.48
125% TM Field-cured Cylinders	72.90	119.12	92.70
28-day TM Field-cured Cylinders	83.50	136.53	103.25
75% TM Lab-cured Cylinders	78.10	119.70	96.55
100% TM Lab-cured Cylinders	77.40	120.82	95.58
125% TM Lab-cured Cylinders	81.69	119.99	98.34
28-day TM Lab-cured Cylinders	88.13	128.24	103.10
1-day Rebound Hammer	52.65	89.13	66.29
2-day Rebound Hammer	67.31	91.21	77.67
75% TM Rebound Hammer	77.22	95.02	85.86
100% TM Rebound Hammer	80.04	90.20	83.89
125% TM Rebound Hammer	76.42	95.89	86.53
28-day Rebound Hammer	84.94	108.21	100.04

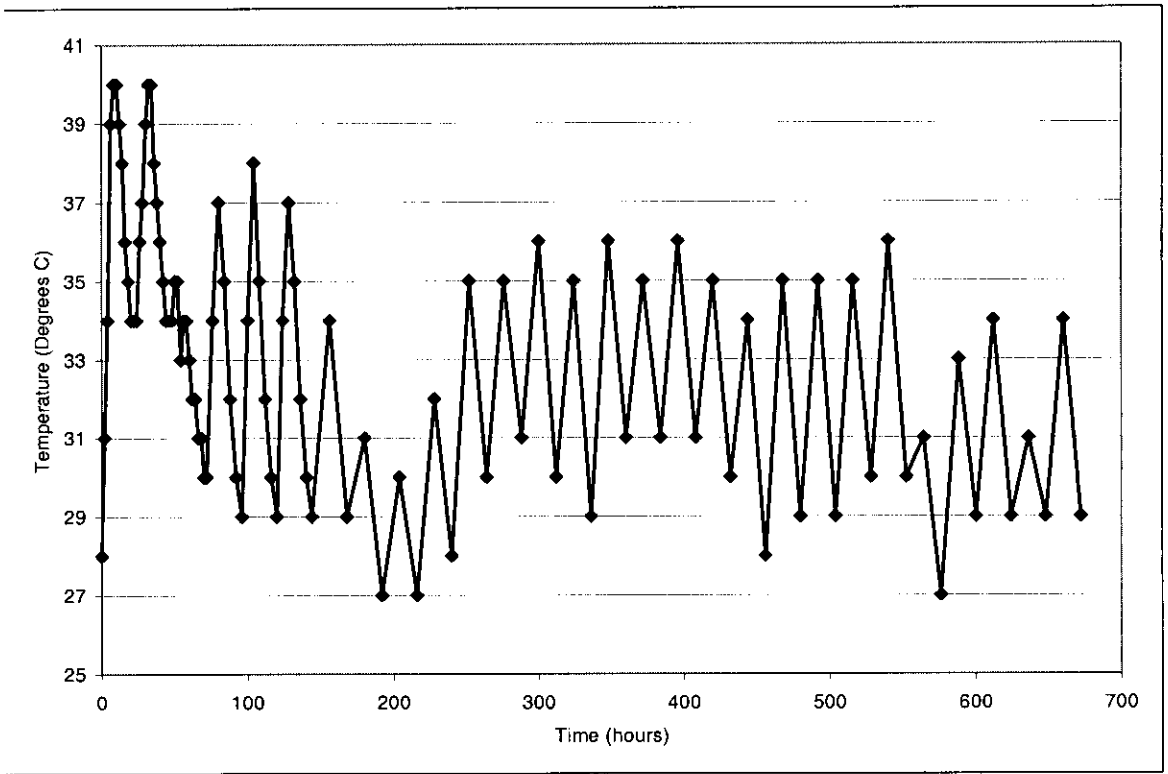

Figure 11. Temperature versus Time for Verification Location 2 I-75 Chattanooga

Analysis of Results

Correlations

The plastic properties of one correlation batch at each location failed to meet TDOT slump specifications of 0.5 to 2-inches [8]. Neither batch was out of specification by more than 0.5-inches, therefore, the deviation was not considered serious. All correlation batches met TDOT specifications for air, temperature, and compressive strength.

No difference was observed in maturity indices between the two different readers used on the project.

All four I-75 correlation curve temperature loggers indicated that initial curing temperatures exceeded AASHTO T 23 specification limits of 16 to 27°C (60 to 80°F). However, the cylinders never exceeded the specified temperature by more than 9°C or 16°F.

Verification Plastic Properties and Variable Depth Maturity Measurements

Sixty-seven percent of I-65 verification batches met TDOT plastic property specifications. Approximately 17 percent of the batches, 2 of 12, exceeded the slump specification by one inch or less. One batch fell 1.5 percent below the minimum air content. Air content data was not available for one batch to determine if it complied with specifications.

Fifty-eight percent of I-75 verification batches met TDOT plastic property specifications. Approximately 42 percent of the batches, 5 of 12, exceeded the slump specification by 2.5-inches or less.

Table 27 shows the effect of placement depth of the maturity logger in a 13-inch slab on the measured maturity index. The range divided by the mean expressed as a percentage never exceeded 5.4 percent and tended to decrease with increasing age. The average range divided by the mean expressed as a percent was 2.93. Although the difference was small, maturity loggers placed in the top third of the pavement slab reported the lowest maturity values in all cases. The lower maturities in top third of the slab were attributed to closer proximity to the pavement surface (less insulation).

Table 27. Effect of Maturity Logger Depth in Pavement Slab on Measured Maturity

Location	Age (days)	Mean Maturity	Range	Range/Mean (%)
1	1	1157	53	4.5
1	2	2237	78	3.5
1	3	3411	118	3.5
1	4	4519	131	2.9
1	5	5583	143	2.6
1	28	28549	376	1.3
6	1	1098	50	4.6
6	2	2226	63	2.8
6	3	3434	90	2.6
6	4	4596	81	1.8
6	5	5658	74	1.3
6	28	28966	62	0.2
12	1	1232	66	5.4
12	2	2488	121	4.9
12	3	3655	135	3.7
12	4	4704	151	3.2
12	5	5720	160	2.8
12	28	28446	310	1.1

Verification Data Quality

American Concrete Institute (ACI) Report 214 [22] variability standards are meant to be applied to 30+ batches of 28-day lab-cured 6x12-inch compressive strength cylinders. However, the research team wished to have some measure of data quality, so the ACI 214 overall variability standards were applied to the verification measured strengths. The results of the ACI 214 analysis are shown in Tables 28 and 29 for I-65 Nashville and I-75 Chattanooga, respectively. The numerical value shown is the overall standard deviation in pounds-per-square-inch. The qualitative rating is from ACI 214. All data sets except the 28-day 6x12 field-cured and lab-cured cylinders for I-75 Chattanooga were rated "Good" or better using the ACI 214 protocol. 28-day 6x12 cylinder data for I-75 Chattanooga had high variability.

Table 28. Overall Standard Deviation and ACI 214 Rating for I-65 Nashville Verification Data

	75% TM	100% TM	125% TM	28 days
Rebound Hammer	535 Good	599 Good	597 Good	Data Not Available
Field-cured 6x12 cylinders	353 Excellent	377 Excellent	437 Very Good	503 Good
Lab-cured 6x12 cylinders	220 Excellent	276 Excellent	257 Excellent	279 Excellent
4x8 cores		392 Excellent		443 Very Good

Table 29. Overall Standard Deviation and ACI 214 Rating for I-75 Chattanooga Verification Data

	75% TM	100% TM	125% TM	28 days
Rebound Hammer	210 Excellent	147 Excellent	275 Excellent	340 Excellent
Field-cured 6x12 cylinders	522 Good	570 Good	590 Good	770 Poor
Lab-cured 6x12 cylinders	459 Very Good	485 Very Good	499 Very Good	642 Fair
4x8 cores		380 Excellent		513 Good

Prediction Accuracy

The Tennessee Ready Mixed Concrete Association (TRMCA) and TTU conducted a maturity short course at TDOT Materials and Tests Division Headquarters on 3/27/00. A phone and e-mail survey of several state DOTs indicated that a maturity prediction within 10 percent of the measured strength was considered very accurate. Constantino and Carrasquillo [5] concur with the limit. The average maturity predicted strengths for 4x8 cores and 6x12 field-cured cylinders were in the range of 91.75 to 100.48 percent of the average measured values for I-65 Nashville. Values of predicted strength divided by measured strength for individual predictions ranged from 74.49 to 126.52 percent at I-65 Nashville. Similarly, The average maturity predicted strengths for 4x8 cores and 6x12 field-cured cylinders (the best measures of in-place PCC pavement strength) were in the range of 89.54 to 112.10 percent of the average measured values for I-75 Chattanooga. Values of predicted strength divided by measured strength for individual predictions ranged from 71.25 to 145.11 percent at I-75 Chattanooga. The larger ranges of predicted strength divided by measured strength for I-75 Chattanooga were attributed to the higher overall variability of the PCC compressive strength discussed in the last subsection. In the opinion of the research team, cores and field-cured cylinders are the best measures of in-place pavement strength, since these specimens experience the same curing conditions as the pavement slab. The average predictions are within, for I-65 Nashville, or very close to, in the case of Chattanooga, the range considered very accurate by several state DOTs.

The accuracy of maturity predicted strengths for lab-cured cylinders depends largely on the difference in curing temperatures between the maturity loggers embedded in the pavement and the lab-cured cylinders. Maturity loggers in the I-65 pavement slab at Nashville experienced cool temperatures in October and November of 2002. Therefore, lab-cured cylinders gained strength much faster than the pavement slab. Thus, predictions of lab-cured cylinder strengths from loggers embedded in I-65 were low (range 70.52 to 94.94 percent, mean 79.13 percent). However, maturity loggers in I-75 Chattanooga experienced temperatures closer to laboratory curing conditions in August and September of 2003. Therefore, the rate of strength gain was more similar. Thus, predictions of lab-cured cylinder strengths from loggers embedded in I-75 were closer (range 77.40 to 128.24 percent, mean 98.39 percent). The analysis presented in this paragraph serves to emphasize an already known fact: lab-cured cylinders do not indicate the strength of the pavement slab; rather lab-cured cylinders indicate potential compressive strength at standard curing conditions.

Maturity predictions of rebound hammer strengths ranged from 47.69 to 366.71 percent of measured values. However, the predictions tended to approach the measured value ± six percent and became less variable as the age of the slab increased.

There is one additional factor that is very important to maturity prediction accuracy. The relative compressive strength of the batches used to fabricate the correlation curve has a major impact on the prediction accuracy. The compressive strength of a concrete mixture design is a range of values rather than a point. If the batch(es) used to fabricate the maturity-compressive strength correlation curve are low in the range of compressive strengths for the mixture, maturity predictions will be conservative (predicted less than measured). If however, the batch(es) used to fabricate the maturity-compressive strength correlation curve are high in the range of compressive strengths for the mixture, maturity predictions will be optimistic (predicted greater than measured). To determine if the batch(es) used for the maturity-compressive strength correlation curve are low or high in range, 28-day lab-cured compressive strengths were compared since these specimens should have experienced a very similar curing temperature history. Maturity predictions for I-65 Nashville are conservative partially due to the batches used to fabricate the maturity-compressive strength correlation curves being very low in the range of mixture strengths (if the correlation batches were even from the same mixture design as the verification batches). The batches used to fabricate the maturity-compressive strength correlation curves at I-75 Chattanooga were more similar in compressive strength to the verification batches. More information on the I-65 Nashville mixture will be presented in the next subsection

Statistical Implications on Maturity

Compressive strengths for PCC mixtures are ranges rather than points. Small differences in component material proportions or qualities as well as mixing, transportation, placement, consolidation, and testing lead to differences in compressive strengths. If a large enough number of compressive data points are plotted in a frequency versus compressive strength histogram, a normal distribution curve typically results. Three observations about the normal distribution curve typically apply:

1. The curve is symmetrical about the mean of the data.
2. The curve is peaked at the mean.
3. The area under the curve is proportional to probability.

The standard deviation is a measure of how "peaked" the curve is. A low standard deviation indicates low variability (data grouped tightly about the mean). Probability computations show that regardless of the standard deviation value, 68.27 percent of the data lies within ± one standard deviation of the mean. Further, 95.45 percent of the data lies within ± two standard deviations of the mean. Therefore, a data point more than two standard deviations away from the mean is very unlikely [22].

Since the normal distribution curve is symmetrical about the mean, the probability of high or low compressive strengths is the same. Therefore, there is the same probability that a batch of the concrete mixture used to fabricate the maturity-compressive correlation curve will be above or below the mean compressive strength. Thus, the probability that a maturity compressive strength prediction will be above or below the measured compressive strength is the same. Fortunately, there is a 68.27 percent probability that a batch used to fabricate the maturity-compressive strength correlation curve will be within ± one standard deviation of the mean compressive strength for the mixture.

Probability can be used to determine if compressive strength data points are from the same mixture. For example, if the I-65 Nashville correlation and verification 28-day lab-cured compressive strengths are plotted together as one data set (see Figure 12), it is clear that the correlation batches are far weaker than the verification batches. The standard deviation of the combined correlation and verification data set is 555-psi. Both correlation batches (compressive strength results of 5919 and 5892-psi) have compressive strengths less than the mean compressive strength of the combined data set (7066-psi) minus two standard deviations. Either both correlation mixtures were highly unlikely statistical anomalies or the correlation batches were from a different mixture design. Unfortunately, mixture design differences cannot be positively detected in the plastic state in the field. Plastic properties and experience can provide some evidence but not a definitive determination. The inability to determine if the mixture design has been altered is an inherent weakness of the maturity method. Further, the maturity method does not positively or negatively impact concrete variability. The maturity method is only an observation tool.

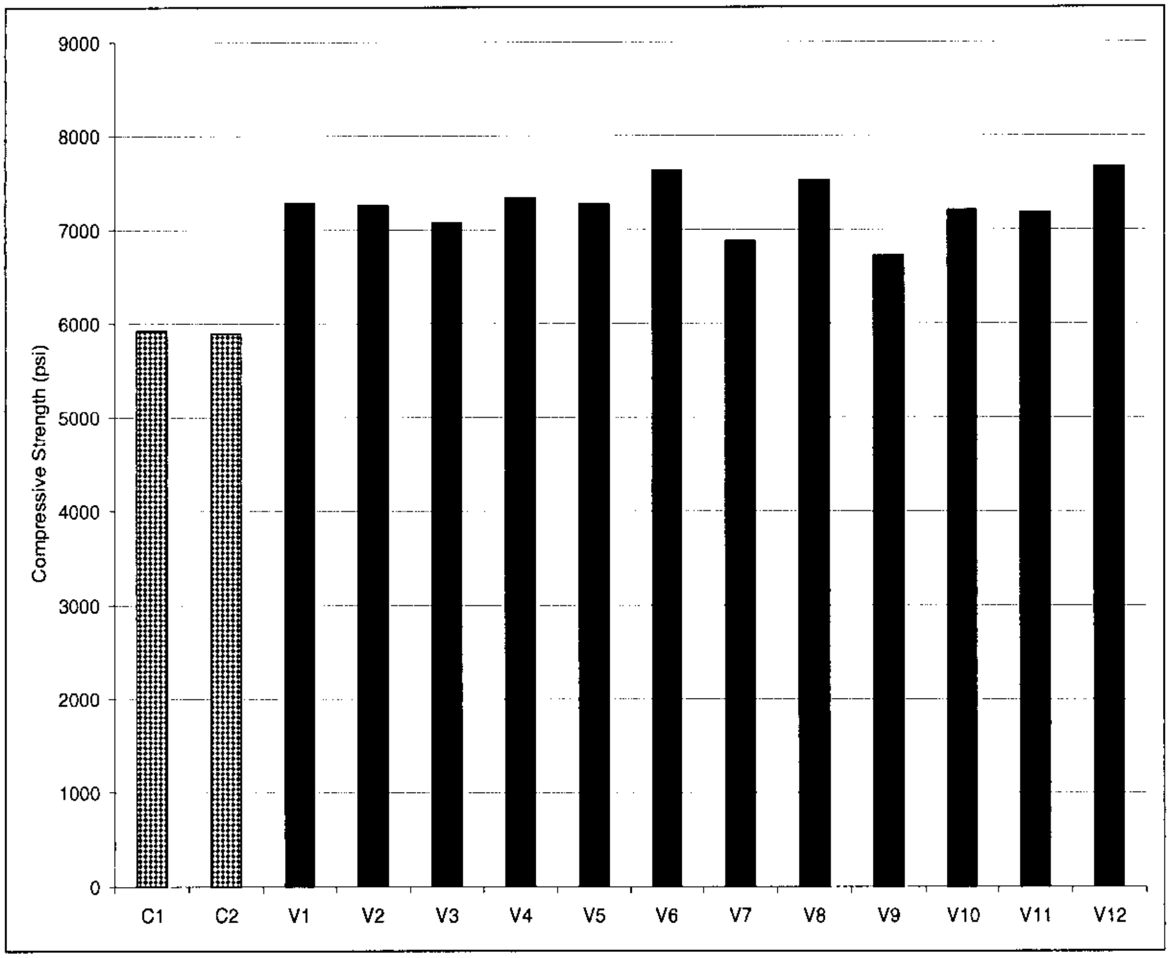

Figure 12. Compressive Strength Results of I-65 Nashville Correlation and Verification Batches

COMPARISON OF THE NEW MATURITY METHOD AND LAB-CURED CYLINDERS FOR MONITORING PCC CURING PROGRESS

Each technique for monitoring PCC curing progress has advantages and disadvantages. The methods were compared in four areas.

Information Availability

The new maturity method has a clear advantage in information availability. A new maturity value is calculated every fifteen minutes and is available at the jobsite. The availability of information for lab-cured cylinders depends on how many pairs of cylinders were fabricated (could run out if information is requested too frequently). Further, when using lab-cured cylinders the information is not available at the jobsite, hence the interested party must call the laboratory and request cylinder breaks.

Are Strengths Obtained Representative of Jobsite Conditions?

Again, the new maturity method has a clear advantage. Maturity indices from loggers embedded in the pavement reflect actual jobsite temperatures. Lab-cured cylinders are cured at the standard AASHTO [10] temperature of 73.4 ± 3°F. Sometimes, the standard temperature is cooler than jobsite conditions, while at other times the standard temperature is warmer than jobsite conditions. In extremely rare occasions, the standard curing temperature is the same as the jobsite temperature.

Is a Maturity-Compressive Strength Correlation Curve Required?

The maturity method requires additional upfront work, specifically, the preparation of a maturity-compressive strength correlation curve. The new maturity method is at a disadvantage to PCC cylinders in this case. The additional upfront time and effort may be justified for larger projects. However, it may be easier and more economical to use PCC cylinders on projects with less than thirty batches of the same PCC mixture.

Is Accuracy Sensitive to PCC Batch-to-Batch Variability?

The new maturity method assumes that each batch of PCC is identical or at least very similar to the correlation batch. Unfortunately, the assumption cannot be verified in the field. The inability to detect mixture design changes or batch-to-batch variability is a clear disadvantage of the new maturity method. PCC cylinders have a clear advantage since the actual PCC used in the placement of the pavement is used to determine compressive strength in the lab.

POSSIBLE IMPLEMENTATION PROTOCOL

Modified versions of AASHTO TP 52-95 and T 276-97 for using the new maturity method to allow new PCC pavements to be opened to traffic are contained in Appendix E. The procedure for making calculations to determine when a PCC pavement can be opened to traffic is described in this section.

The one-sided confidence limit for allowing a PCC to be opened to traffic is:

$$S_M > (LL + K)$$

where:

S_M = predicted strength near target maturity

LL = specified lower limit, 3000-psi.

K = $1.645\,(\Sigma\,(S_M - S_{MTM})^2/2n)^{0.5}$

K is the measure of variability obtained between predicted and measured strengths

1.645 = confidence coefficient for a 5% probability of accepting material with a strength below LL.

S_{MTM} = measured strength near target maturity

n = number of paired (S_M and S_{MTM}) values used in the analysis

Table 30 shows the I-65 Nashville maturity predicted and measured field-cured compressive near target maturity. Table 31 shows the solution of the one-sided confidence interval for opening the PCC pavement to traffic. Based on the calculations in Table 31, the pavement could be opened to traffic with a 95 percent confidence that no compressive strength in the selected lot was less than 3000-psi when the maturity index corresponding to 3534-psi was read on the logger embedded in the selected PCC pavement lot.

Table 30. Field-cured Measured and Maturity Predicted Compressive Strengths Near Target Maturity for I-65 Nashville

S_{MTM} (measured compressive strength near target maturity in pounds-per-square-inch)	S_M (maturity predicted compressive strength near target maturity in pounds-per-square-inch)
2482	3010
3498	2958
3234	3034
3235	3025
3494	3030
3064	3056
3024	3264
3053	3266
3181	2974
3610	2998
3762	2985
3708	2976

Table 31. Solution of the One-sided Confidence Interval for I-65 Nashville

Parameter	Value (pounds-per-square-inch)
$(\Sigma (S_M - S_{MTM})^2/2n)^{0.5}$	324.7
K	534.1
LL (TDOT Specified Compressive Strength)	3000
LL + K	3534

Tables 32 shows the I-75 Chattanooga maturity predicted and measured field-cured compressive near target maturity. Table 33 shows the solution of the one-sided confidence interval for opening the PCC pavement to traffic. Based on the calculations in Table 33, the pavement could be opened to traffic with a 95 percent confidence that no compressive strength in the selected lot was less than 3000-psi when the maturity index corresponding to 3792-psi was read on the logger embedded in the selected PCC pavement lot.

Table 32. Field-cured Measured and Maturity Predicted Compressive Strengths Near Target Maturity for I-75 Chattanooga

S_{MTM} (measured compressive strength near target maturity in pounds-per-square-inch)	S_M (maturity predicted compressive strength near target maturity in pounds-per-square-inch)
3609	2892
4059	2892
3841	2909
3379	2900
3645	2908
3652	2904
2924	2878
2823	2892
3882	2887
2268	2902
2955	2920
2616	2918

Table 33. Solution of the One-sided Confidence Interval for I-75 Chattanooga

Parameter	Value (pounds-per-square-inch)
$(\Sigma\ (S_M - S_{MTM})^2/2n)^{0.5}$	481.7
K	792.3
LL (TDOT Specified Compressive Strength)	3000
LL + K	3792

The previous two examples show that lower measured compressive strength (overall) variability results in a lower K value. The combination of compressive strengths that do not greatly exceed LL and high PCC compressive strength (overall) variability may preclude the use of the new maturity method for some projects. However, since the Modified AASHTO T 276-97 requires that a pair of field-cured 6x12 cylinders be cast for the first twelve logger placements on a project, the decision on when to open the PCC pavement to traffic can be made using the cylinder data.

The K value encourages PCC producers to address variability problems by requiring lower maturity indices to open PCC pavements to traffic, which contain lower overall variability PCC. In addition, the K value protects TDOT by minimizing the probability (five percent or less) that a pavement containing PCC with a compressive strength less than 3000-psi will be opened to traffic.

CONCLUSIONS

The following conclusions can be drawn from the limited data available in this study:

1. The difference between compressive strengths of 6x12 cylinders lab-cured at the same maturity index for curing temperatures between 7 and 32°C (45 and 90°F) is in the range of 3.8 to 12.5% for maturity indices of 2400°C-hours (72.75 hours at 73°F) or more. At lower maturity indices the compressive strength difference in percent is much greater.
2. The average maturity predicted strengths for 4x8 cores and 6x12 field-cured cylinders (the best measures of in-place PCC pavement strength) were in the range of 91.75 to 100.48 percent of the average measured values for I-65 Nashville. Values of predicted strength divided by measured strength for individual predictions ranged from 74.49 to 126.52 percent at I-65 Nashville.
3. The average maturity predicted strengths for 4x8 cores and 6x12 field-cured cylinders (the best measures of in-place PCC pavement strength) were in the range of 89.54 to 112.10 percent of the average measured values for I-75 Chattanooga. Values of predicted strength divided by measured strength for individual predictions ranged from 71.25 to 145.11 percent at I-75 Chattanooga. The larger ranges of predicted strength divided by measured strength for I-75 Chattanooga were attributed to the higher overall variability of the PCC compressive strength.

4. The inability to detect PCC mixture design changes or batch-to-batch variability in the field is an inherent weakness in the new maturity method.
5. Maturity prediction accuracy is sensitive to PCC batch-to-batch variability. However, the Modified AASHTO T 276-97 Method is an effective protection from accepting PCC with sub-standard compressive strength.
6. The new maturity method is capable of providing more relevant information on PCC curing progress than lab-cured PCC cylinders. The information can be provided more frequently and more conveniently compared to lab-cured or field-cured PCC cylinders.
7. Lab-cured cylinders represent potential compressive strength at standard curing temperature not the compressive strength of the PCC pavement that has experienced different curing conditions.
8. The maturity technology appears to be robust and reliable enough for field use by TDOT.

RECOMMENDATIONS

The research team offers the following recommendations for consideration by the TDOT Materials and Tests Division.

1. TDOT Materials & Tests Division should consider using the new maturity technology for large projects (those requiring more than 30 batches of the same PCC mixture design) on an experimental basis.
2. Further, the Modified AASHTO TP 52-95 / AASHTO T 276-97 protocol should be used for field operations and opening pavements to traffic on the experimental projects.
3. For projects where the new maturity method is not appropriate, field-cured 6x12 cylinders cured in close proximity to the pavement should be used for opening the pavement to traffic.

REFERENCES

1. Concrete, Second Edition, Sidney Mindess, J. Francis Young, and David Darwin, Pearson Education, Inc. Upper Saddle River, NJ 07458, 2003, pp 395.

2. AASHTO T 276-97 (2001), "Standard Method of Test for Developing Early-Age Compression Test Values and Projecting Later-Age Strengths, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2B Tests, 22nd Edition 2002, Washington, D.C., 2002.

3. Richardson, David N., "Review of Variables that Influence Measured Concrete Compressive Strength", Authorized Reprint from Copyrighted Journal of Materials in Civil Engineering, May 1991, American Society of Civil Engineers, NAA Circular No. 132, NRMCA Publication No. 179, National Aggregates Association and National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, Maryland 20910.

4. Waalkes, Steven M., "Young and eager – The days of waiting to drive on new concrete may be over", Roads & Bridges, Vol. 40, No. 3, March 2002, pp. 54-55.

5. Constantino, Cesar A. and Carrasquillo, Ramon L.," Investigation of the Maturity Concept as a New Quality Control / Quality Assurance Measure for Concrete", Preliminary Review Copy, Research Report Number 1714-3, Texas Department of Transportation, August 1998.

6. http://www.concretematurity.com

7. Concrete Maturity Resource Guide, intelliRock™, Nomadics Construction Labs, 1024 S. Innovation Way, Stillwater, OK, 74074.

8. Tennessee Department of Transportation, Standard Specifications for Road and Bridge Construction (Section 501.03), March 1995.

9. Tennessee Department of Transportation, Standard Specifications for Road and Bridge Construction (Section 501.11), March 1995.

10. AASHTO T 23-02[1], "Standard Method of Test for Making and Curing Concrete Test Specimens in the Field, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

11. Tennessee Department of Transportation, Standard Specifications for Road and Bridge Construction (Section 604.25), March 1995.

12. AASHTO T 119-99, "Standard Method of Test for Slump of Hydraulic Cement Concrete, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

13. AASHTO T 121-97 (2001), "Standard Method of Test for Mass per Cubic Meter (Cubic Foot), Yield, and Air Content (Gravimetric) of Concrete, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

14. AASHTO T 141-01[1], "Standard Method of Test for Sampling Freshly Mixed Concrete , " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

15. AASHTO T 152-01, "Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

16. AASHTO T 309-99, "Standard Method of Test for Temperature of Freshly Mixed Concrete by the Pressure Method, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2B Tests, 22nd Edition 2002, Washington, D.C., 2002.

17. AASHTO T 22-97[1], "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

18. AASHTO T 126-01, "Standard Method of Test for Making and Curing Concrete Test Specimens in the Laboratory, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

19. AASHTO T 24-02, "Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, " AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2A Tests, 22nd Edition 2002, Washington, D.C., 2002.

20. "Standard Test Method for Rebound Number of Hardened Concrete[1]" (ASTM C 805-97) 2002 Annual Book of ASTM Standards, V.04.02, ASTM, West Conshohocken, PA, 2002, pp. 426-428.

21. "Standard Test Method for Penetration Resistance of Hardened Concrete[1]" (ASTM C 803/C 803M-97$^{\varepsilon 1}$) 2002 Annual Book of ASTM Standards, V.04.02, ASTM, West Conshohocken, PA, 2002, pp. 422-425.

22. ACI Committee 214, "Evaluation of Strength Test Results of Concrete (ACI 214R-02), American Concrete Institute, Farmington Hills, Michigan 48333-9094, Second Printing March, 2003.

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DISCLAIMER

The opinions, findings, and conclusions expressed here are those of the authors and not necessarily those of the Tennessee Department of Transportation, the Federal Highway Administration or the Tennessee Ready Mixed Concrete Association.

APPENDIX A

LABORATORY STUDY

Table A-1. Logger Identification for Laboratory Experiment

Cure Tank	Logger	Serial Number	Activation Time (CDT)
Hot	1	0002803	1:00 PM
	2	0002994	
	1*	1002182	
	2*	1002135	
Standard	1	0002802	1:05 PM
	2	0002864	
	1*	1002151	
	2*	1002145	
Cold	1	0002837	1:10 PM
	2	0002844	
	1*	1002146	
	2*	1002185	
Variable	1	0002846	1:15 PM
	2**	0002847	
	1*	1002230	
	2*	1002186	

* Temperature Logger

** Logger dysfunctional, 01/08/03

Table A-2. Hot Tank (90 ± 3°F) Maturity Logger Data

Approximate Maturity (°C·Hrs)	Reader	Logger 1 (Serial # 0002803)		Logger 2 (Serial # 0002994)	
		Age (Hrs:Mins)	Maturity (°C·Hrs)	Age (Hrs:Mins)	Maturity (°C·Hrs)
0	1	00:00	0	00:00	0
	2	00:00	0	00:00	0
800	1	18:25	860	18:26	859
	2	18:26	860	18:27	859
1600	1	35:17	1604	35:17	1602
	2	35:18	1604	35:18	1602
2400	1	54:33	2409	54:32	2405
	2	54:33	2409	54:33	2405
3200	1	72:50	3207	72:50	3200
	2	72:51	3207	72:50	3200
4000	1	92:04	4014	92:04	4005
	2	92:05	4014	92:05	4005
5500	1	128:02	5509	128:03	5496
	2	128:03	5509	128:03	5496
11000	1	260:13	11021	260:14	10978
	2	260:14	11021	260:14	10978
22000	1	520:20	22056	520:19	21957
	2	520:21	22056	520:20	21957

Table A-3. Standard Tank (73 ± 3°F) Maturity Logger Data

Approximate Maturity (°C·Hrs)	Reader	Logger 1 (Serial # 0002802)		Logger 2 (Serial # 0002864)	
		Age (Hrs:Mins)	Maturity (°C·Hrs)	Age (Hrs:Mins)	Maturity (°C·Hrs)
0	1	00:00	0	00:00	0
	2	00:00	0	00:00	0
800	1	22:02	813	22:03	809
	2	22:03	813	22:03	809
1600	1	44:45	1612	44:45	1600
	2	44:46	1612	44:45	1600
2400	1	68:18	2411	68:19	2392
	2	68:19	2411	68:20	2392
3200	1	92:03	3216	92:02	3188
	2	92:03	3216	92:03	3188
4000	1	115:48	4023	115:48	3979
	2	115:49	4023	115:49	3979
5500	1	160:49	5539	160:49	5463
	2	160:49	5539	160:50	5463
11000	1	324:40	11062	324:40	10949
	2	324:41	11062	324:41	10949
22000	1	658:17	22081	658:16	21924
	2	658:17	22081	658:17	21924

Table A-4. Cold Tank (45 ± 3°F) Maturity Logger Data

Approximate Maturity (°C·Hrs)	Reader	Logger 1 (Serial # 0002837)		Logger 2 (Serial # 0002844)	
		Age (Hrs:Mins)	Maturity (°C·Hrs)	Age (Hrs:Mins)	Maturity (°C·Hrs)
0	1	00:00	0	00:00	0
	2	00:00	0	00:00	0
800	1	38:54	819	38:56	814
	2	38:55	819	38:56	814
1600	1	76:43	1610	76:43	1599
	2	76:43	1610	76:44	1599
2400	1	118:44	2408	118:44	2393
	2	118:44	2408	118:44	2393
3200	1	162:45	3213	162:45	3189
	2	162:45	3213	162:46	3189
4000	1	212:05	4017	212:05	3988
	2	212:06	4017	212:06	3988
5500	1	297:16	5523	297:16	5483
	2	297:16	5523	297:17	5483
11000	1	602:02	11040	602:03	10964
	2	602:03	11040	602:03	10964
22000	1	1196:02	22073	1196:02	21930
	2	1196:03	22073	1196:02	21930

Table A-5. Variable Tank Maturity Logger Data

Approximate Maturity (°C·Hrs)	Reader	Logger 1 (Serial # 0002846)		Logger 2 (Serial # 0002847)	
		Age (Hrs:Mins)	Maturity (°C·Hrs)	Age (Hrs:Mins)	Maturity (°C·Hrs)
0	1	00:00	0	00:00	0
	2	00:00	0	00:00	0
800	1	18:51	806	18:52	804
	2	18:52	806	18:53	804
1600	1	42:49	1607	42:48	1603
	2	42:49	1607	42:49	1603
2400	1	67:38	2407	67:39	2402
	2	67:39	2407	67:39	2402
3200	1	91:34	3205	91:35	3198
	2	91:35	3205	91:36	3198
4000	1	118:18	4008	---	---
	2	118:19	4008	---	---
5500	1	165:13	5501	---	---
	2	165:14	5501	---	---
11000	1	343:42	11006	---	---
	2	343:43	11006	---	---
22000	1	696:48	22002	---	---
	2	696:49	22002	---	---

--- Logger Dysfunctional, 01/08/03

Table A-6. Hot Tank (90 ± 3°F) Compressive Strength Data

Approximate Maturity (°C·Hrs)	Cylinder	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
0	---	---	---	0	0
800	1	28.72	55710	1970	155
	2	28.60	60080	2125	
1600	1	28.58	73560	2602	10
	2	28.42	73270	2591	
2400	1	28.38	79790	2822	311
	2	28.40	88590	3133	
	3	28.58	88300	3123	
3200	1	28.54	89980	3182	80
	2	28.64	90970	3217	
	3	28.54	92250	3263	
4000	1	28.52	98380	3479	241
	2	28.66	105200	3721	
	3	28.58	101340	3584	
5500	1	28.54	115380	4081	447
	2	28.62	102730	3633	
	3	28.54	114490	4049	
	4	28.60	112020	3962	
11000	1	28.70	155730	5508	1004
	2	28.62	127350	4504	
	3	28.66	145740	5154	
22000	1	28.78	170660	6036	1147
	2	28.84	158300	5599	
	3	28.72	174320	6165	
	4	28.54	168580	5962	
	5	28.74	177680	6284	
	6	28.84	190730	6746	

--- Cylinders were in plastic state and assumed to have no strength

Table A-7. Standard Tank (73 ± 3°F) Compressive Strength Data

Approximate Maturity (°C·Hrs)	Cylinder	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
0	---	---	---	0	0
800	1	28.48	44730	1582	48
	2	28.52	46080	1630	
1600	1	28.42	72280	2556	308
	2	28.66	80980	2864	
2400	1	28.58	88100	3116	133
	2	28.44	85030	3007	
	3	28.50	84340	2983	
3200	1	28.52	103120	3647	347
	2	28.30	93320	3301	
	3	28.50	95710	3385	
4000	1	28.52	99070	3504	533
	2	28.50	94230	3333	
	3	28.54	109310	3866	
5500	1	28.44	100250	3546	490
	2	28.68	114100	4035	
	3	28.38	108660	3843	
	4	28.44	105100	3717	
11000	1	28.48	136950	4844	199
	2	28.56	133870	4735	
	3	28.52	139510	4934	
22000	1	28.70	151690	5365	597
	2	28.74	156830	5547	
	3	28.86	168580	5962	
	4	28.80	161960	5728	
	5	28.72	160000	5659	
	6	28.64	164270	5810	

--- Cylinders were in plastic state and assumed to have no strength

Table A-8. Cold Tank (45 ± 3°F) Compressive Strength Data

Approximate Maturity (°C·Hrs)	Cylinder	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
0	---	---	---	0	0
800	1	28.58	29800	1054	17
	2	28.60	29330	1037	
1600	1	28.40	57350	2028	119
	2	28.32	53990	1910	
2400	1	28.48	85030	3007	276
	2	28.62	77520	2742	
	3	28.30	85330	3018	
3200	1	28.54	82960	2934	502
	2	28.46	97650	3454	
	3	28.58	93280	3299	
4000	1	28.68	106090	3752	273
	2	28.58	110140	2895	
	3	28.54	102430	3623	
5500	1	28.68	126660	4480	451
	2	28.54	122310	4326	
	3	28.46	122110	4319	
	4	28.58	113900	4028	
11000	1	28.54	144650	5116	682
	2	28.52	138220	4889	
	3	28.82	157510	5571	
22000	1	28.52	176710	6250	419
	2	28.58	169690	6002	
	3	28.46	168110	5946	
	4	28.74	170580	6033	
	5	28.78	178270	6305	
	6	28.62	179950	6364	

--- Cylinders were in plastic state and assumed to have no strength

Table A-9. Variable Tank Compressive Strength Data

Approximate Maturity (°C·Hrs)	Cylinder	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
0	---	---	---	0	0
800	1	28.68	51870	1835	88
	2	28.86	54360	1923	
1600	1	28.72	69310	2451	507
	2	28.64	83650	2959	
2400	1	28.56	84240	2979	94
	2	28.54	86910	3074	
	3	28.60	84460	2987	
3200	1	28.76	101150	3577	189
	2	28.54	95810	3389	
	3	28.64	99270	3511	
4000	1	28.40	103220	3651	140
	2	28.60	106580	3769	
	3	28.56	107180	3791	
5500	1	28.64	121320	4291	490
	2	28.62	107470	3801	
	3	28.58	118250	4182	
	4	28.60	116570	4123	
11000	1	28.76	129320	4574	326
	2	28.72	138550	4900	
	3	28.78	134380	4753	
22000	1	28.80	178460	6312	533
	2	28.74	164330	5812	
	3	28.56	163380	5778	
	4	28.64	171840	6078	
	5	28.76	168480	5959	
	6	28.80	173930	6152	

--- Cylinders were in plastic state and assumed to have no strength

Table A-10. Average Data for Hot and Standard Tank Cylinders

Hot (90 ± 3°F) Tank			Standard (73 ± 3°F) Tank		
Age (Days)	Maturity (°C·Hrs)	Strength (psi)	Age (Days)	Maturity (°C·Hrs)	Strength (psi)
0.00	0	0	0.00	0	0
0.77	860	2048	0.92	811	1606
1.47	1603	2597	1.86	1606	2710
2.27	2407	3026	2.85	2402	3035
3.03	3204	3221	3.84	3202	3444
3.84	4010	3595	4.83	4001	3568
5.34	5503	3931	6.70	5501	3785
10.84	11000	5055	13.53	11006	4837
21.68	22007	6132	27.43	22003	5678

Table A-11. Average Data for Cold and Variable Tank Cylinders

Cold (45 ± 3°F) Tank			Variable Tank		
Age (Days)	Maturity (°C·Hrs)	Strength (psi)	Age (Days)	Maturity (°C·Hrs)	Strength (psi)
0.00	0	0	0.00	0	0
1.62	817	1046	0.79	805	1879
3.20	1605	1969	1.78	1605	2705
4.95	2401	2922	2.82	2405	3013
6.78	3201	3229	3.82	3202	3492
8.84	4003	3757	4.93	4008	3737
12.39	5503	4288	6.88	5501	4099
25.09	11002	5192	14.32	11006	4742
49.83	22002	6150	29.03	22002	6015

Table A-12. Average Temperature Data for Hot and Standard Tank Cylinders

Age (Hours)	Hot (90 ± 3°F) Tank		Standard (73 ± 3°F) Tank	
	Temperature (°C)	Temperature (°F)	Temperature (°C)	Temperature (°F)
0	11	52	11	52
2	29	84	24	75
4	34	93	25	77
6	41	106	26	79
8	41	106	27	81
10	41	106	27	81
12	40	104	28	82
14	39	102	29	84
16	38	100	29	84
18	38	100	29	84
20	37	99	29	84
22	35	95	27	81
24	35	95	26	79
26	35	95	26	79
28	32	90	25	77
30	32	90	25	77
32	32	90	25	77
34	32	90	24	75
36	33	91	25	77
38	33	91	25	77
40	32	90	25	77
42	32	90	25	77
44	32	90	24	75
46	32	90	24	75
48	32	90	24	75
50	32	90	24	75
52	30	86	24	75
54	30	86	24	75
56	32	90	24	75
58	34	93	24	75

Table A-12. Average Temperature Data for Hot and Standard Tank Cylinders (Cont'd)

Age (Hours)	Hot (90 ± 3°F) Tank		Standard (73 ± 3°F) Tank	
	Temperature (°C)	Temperature (°F)	Temperature (°C)	Temperature (°F)
60	34	93	24	75
62	34	93	24	75
64	34	93	24	75
66	34	93	24	75
68	35	95	24	75
70	34	93	24	75
72	34	93	24	75
76	32	90	24	75
80	32	90	24	75
84	32	90	24	75
88	31	88	24	75
92	31	88	24	75
96	32	90	24	75
100	31	88	24	75
104	31	88	24	75
108	32	90	24	75
112	32	90	24	75
116	31	88	24	75
120	31	88	23	73
124	31	88	24	75
128	33	91	24	75
132	33	91	24	75
136	33	91	24	75
140	33	91	24	75
144	33	91	24	75

Table A-13. Average Temperature Data for Cold and Variable Tank Cylinders

Age (Hours)	Cold (45 ± 3°F) Tank		Variable	
	Temperature (°C)	Temperature (°F)	Temperature (°C)	Temperature (°F)
0	7	45	11	52
2	8	46	29	84
4	9	48	34	93
6	9	48	40	104
8	10	50	41	106
10	10	50	41	106
12	10	50	28	84
14	10	50	28	84
16	9	48	28	84
18	10	50	28	84
20	13	55	14	57
22	13	55	13	55
24	12	54	12	54
26	12	54	11	52
28	12	54	32	90
30	12	54	32	90
32	13	55	32	90
34	14	57	32	90
36	13	55	25	77
38	12	54	25	77
40	11	52	25	77
42	11	52	24	75
44	11	52	11	52
46	11	52	11	52
48	10	50	10	50
50	9	48	9	48
52	9	48	30	86
54	8	46	30	86
56	8	46	32	90
58	7	45	34	93

Table A-13. Average Temperature Data for Cold and Variable Tank Cylinders (Cont'd)

Age (Hours)	Cold (45 ± 3°F) Tank		Variable	
	Temperature (°C)	Temperature (°F)	Temperature (°C)	Temperature (°F)
60	8	46	24	75
62	9	48	24	75
64	11	52	24	75
66	13	55	24	75
68	16	61	19	66
70	15	59	15	59
72	14	57	14	57
76	12	54	32	90
80	11	52	32	90
84	9	48	24	75
88	8	46	24	75
92	8	46	8	46
96	9	48	9	48
100	8	46	31	88
104	7	45	31	88
108	9	48	24	75
112	10	50	24	75
116	11	52	11	52
120	9	48	10	50
124	8	46	31	88
128	7	45	33	91
132	7	45	24	75
136	8	46	24	75
140	10	50	10	50
144	9	48	9	48

APPENDIX B

WINDSOR PROBE

Windsor Probe data were to be taken at each verification location at Nashville and Chattanooga by TDOT Division of Materials and Tests at target maturity and 28 days. The target maturity tests were conducted in Nashville, but the results were inconclusive, and the testing was discontinued. The following document, prepared by TDOT personnel, details testing, results and reasons for cessation.

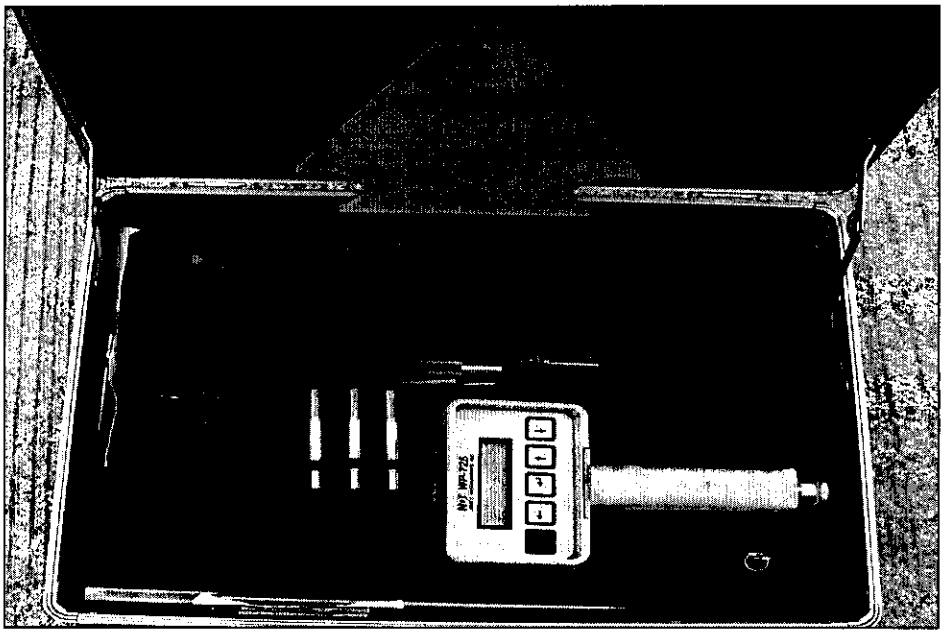

Figure B-1. Windsor Probe HP Test System

The Windsor Probe HP Test System (Figure B-1) estimates the compressive strength of concrete by driving a steel probe into the surface of a structure with a precisely governed explosive charge. After the probes (Figure B-2) are driven into the concrete structure, the exposed length is measured. The difference between the exposed length and the total length results in a penetration depth. Concrete strength is based on this penetration depth and the hardness of the coarse aggregate within the mixture.

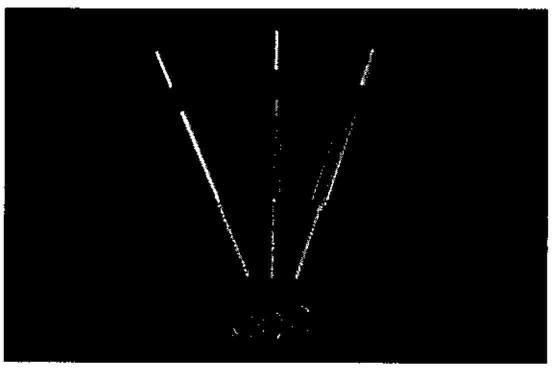

Figure B-2. One Set of Probes and Accompanying Explosive Charges

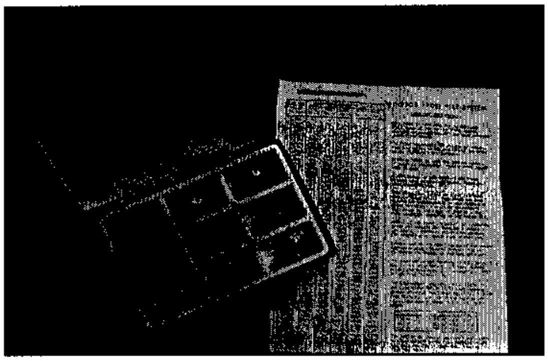

Figure C-3. Mohs' Hardness Scale

Each Windsor Probe HP Test System is equipped with a Mohs' Hardness Scale Kit (Figure B-3). This kit is a universally accepted system for classifying minerals by hardness. In order to obtain accurate results with the Windsor Probe HP Test System, the hardness of the coarse aggregate must be known. The kit is used to determine the hardness of the coarse aggregate, and a correlation can be made with compressive strength.

Figure B-4. Windsor Probe Being Placed into I-65 at Target Maturity

Figure B-5. Windsor Probe Results Being Measured and Recorded

Windsor Probe Tests (Figures B-4 & B-5) were performed at two verification locations at target maturity. The coarse aggregate for the concrete mixture was classified as Mohs' #6. At target maturity, the probes were placed at verification location 1 and an average of 1.42 inches of exposed probe was recorded. Similar results were recorded at verification location 2. Based on laboratory results of 4" x 8" cored compressive strength specimens, the Windsor Probe results showed no correlation with the Mohs' scale for strength that accompanied the test system (Figure B-6). Due to inconsistent results, the Windsor Probe Testing was discontinued for the remainder of the research project.

STANDARD POWER TABLE NO. [illegible]

EXPOSED PROBE (Inches)	COMPRESSIVE STRENGTH (p.s.i.)				
	Mohs' No. 3	Mohs' No. 4	Mohs' No. 5	Mohs' No. 6	Mohs' No. 7
1.275	-	-	-	-	-
1.300	-	-	-	-	-
1.325	-	-	-	-	-
1.350	-	-	-	-	-
1.375	-	-	-	-	-
1.400	3000	-	-	-	-
1.425	3175	-	-	-	-
1.450	3325	-	-	-	-
1.475	3500	-	-	-	-
1.500	3675	3000	-	-	-
1.525	3825	3175	-	-	-
1.550	4000	3350	[illegible]	[illegible]	[illegible]

WINDSOR PROBE TEST SYSTEM

IMPORTANT INSTRUCTIONS

This Table is used only for the STANDARD POWER range of the Windsor Probe System, operated in accordance with the manufacturers Instruction Manual.

The Table represents the results of calibrating the system to the velocity of the probe at the STANDARD POWER position.

STANDARD POWER is used for testing concrete, in existing structures, usually cured longer [illegible]

Figure B-6. Compressive Strength Estimation

APPENDIX C

CORRELATIONS

Table C-1. I-65 Correlation Logger Identification

Correlation Curve	Logger	Serial #	Time Sample Obtained (CDT)	Logger Activation Time (CDT)
1	1	0002826	8:50 AM	9:40 AM
	2	0002816		
2	1	0002896	10:15 AM	10:45 AM
	2	0002980		

Table C-2. I-65 Correlation Curve 1 Maturity Logger 1 Data

Date	Approximate Age (Days)	Reader	Logger 1 (Serial # 0002826)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
09/19/02	0	1	00:00	28	0
		2	00:00	28	0
09/20/02	1	1	28:54	32	1304
		2	28:57	32	1304
09/21/02	2	1	55:30	21	2187
		2	55:31	21	2187
09/22/02	3	1	77:01	28	2973
		2	77:02	28	2973
09/23/02	4	1	101:19	24	3798
		2	101:20	24	3798
09/26/02	7	1	172:45	26	6412
		2	172:45	26	6412
09/29/02	10	1	245:17	24	8807
		2	245:18	24	8807
10/03/02	14	1	340:51	26	12222
		2	340:52	26	12222
10/17/02	28	1	677:00	24	24022
		2	677:00	24	24022
11/14/02	56	1	997:46	25	48682
		2	997:47	25	48682

Table C-3. I-65 Correlation Curve 1 Maturity Logger 2 Data

Date	Approximate Age (Days)	Reader	Logger 2 (Serial # 0002816)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
09/19/02	0	1	00:00	29	0
		2	00:00	29	0
09/20/02	1	1	28:52	32	1296
		2	28:56	32	1296
09/21/02	2	1	55:30	21	2175
		2	55:31	21	2175
09/22/02	3	1	77:00	28	2956
		2	77:01	28	2956
09/23/02	4	1	101:18	23	3778
		2	101:19	23	3778
09/26/02	7	1	172:45	26	6380
		2	172:45	26	6380
09/29/02	10	1	245:15	24	8764
		2	245:16	24	8764
10/03/02	14	1	340:50	26	12166
		2	340:51	26	12166
10/17/02	28	1	677:01	24	23938
		2	677:02	24	23938
11/14/02	56	1	997:46	25	48396
		2	997:47	25	48396

Table C-4. I-65 Correlation Curve 1 Compressive Strength Data

Date	Approximate Age (Days)	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
09/19/02	0	---	---	0	0
		---	---	0	
09/20/02	1	28.90	59980	2121	68
		28.92	61900	2189	
09/21/02	2	28.96	73760	2609	164
		29.28	78410	2773	
09/22/02	3	29.00	83160	2941	108
		29.20	86220	3049	
09/23/02	4	29.20	98090	3469	49
		29.02	96700	3420	
09/26/02	7	29.18	111530	3945	346
		29.40	121320	4291	
09/29/02	10	29.30	129920	4595	199
		29.36	124280	4396	
10/03/02	14	29.36	141690	5011	39
		29.20	140600	4973	
10/17/02	28	28.96	161460	5710	416
		29.20	173230	6127	
11/14/02	56	29.52	186380	6592	38
		29.46	185300	6554	

--- Cylinders were in plastic state and assumed to have no strength

Table C-5. I-65 Correlation Curve 2 Maturity Logger 1 Data

Date	Approximate Age (Days)	Reader	Logger 1 (Serial # 0002896)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
09/19/02	0	1	00:00	29	0
		2	00:00	29	0
09/20/02	1	1	28:01	29	1117
		2	28:02	29	1117
09/21/02	2	1	54:18	21	1984
		2	54:19	21	1984
09/22/02	3	1	76:01	28	2779
		2	76:02	28	2779
09/23/02	4	1	100:15	24	3606
		2	100:16	24	3606
09/26/02	7	1	171:33	26	6215
		2	171:34	26	6215
09/29/02	10	1	244:05	24	8613
		2	244:06	24	8613
10/03/02	14	1	339:46	26	12039
		2	339:47	26	12039
10/17/02	28	1	675:51	24	23836
		2	675:52	24	23836
11/14/02	56	1	996:38	25	48528
		2	996:39	25	48528

Table C-6. I-65 Correlation Curve 2 Maturity Logger 2 Data

Date	Approximate Age (Days)	Reader	Logger 2 (Serial # 0002980)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
09/19/02	0	1	00:00	29	0
		2	00:00	29	0
09/20/02	1	1	28:00	29	1132
		2	28:01	29	1132
09/21/02	2	1	54:17	21	2001
		2	54:18	21	2001
09/22/02	3	1	76:00	28	2798
		2	76:01	28	2798
09/23/02	4	1	100:15	24	3626
		2	100:16	24	3626
09/26/02	7	1	171:31	26	6237
		2	171:32	26	6237
09/29/02	10	1	244:03	24	8640
		2	244:03	24	8640
10/03/02	14	1	339:46	26	12073
		2	339:47	26	12073
10/17/02	28	1	675:49	24	23884
		2	675:50	24	23884
11/14/02	56	1	996:37	26	48664
		2	996:38	26	48664

Table C-7. I-65 Correlation Curve 2 Compressive Strength Data

Date	Approximate Age (Days)	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
09/19/02	0	---	---	0	0
		---	---	0	
09/20/02	1	29.18	47660	1686	271
		29.16	55310	1956	
09/21/02	2	29.16	75440	2668	56
		29.16	73860	2612	
09/22/02	3	29.06	81080	2868	63
		29.30	82860	2931	
09/23/02	4	29.38	94330	3336	66
		28.92	96210	3403	
09/26/02	7	29.18	114300	4043	7
		29.30	114490	4049	
09/29/02	10	28.94	119640	4231	94
		29.34	122310	4326	
10/03/02	14	29.00	140500	4969	56
		29.24	138920	4913	
10/17/02	28	29.10	158400	5602	580
		28.92	174810	6183	
11/14/02	56	29.24	181830	6431	112
		29.48	184990	6543	

--- Cylinders were in plastic state and assumed to have no strength

Table C-8. Average I-65 Correlation Curve Data

Correlation Curve 1		Correlation Curve 2		Average Correlation Curve	
Maturity (°C·Hrs)	Strength (psi)	Maturity (°C·Hrs)	Strength (psi)	Maturity (°C·Hrs)	Strength (psi)
0	0	0	0	0	0
1300	2155	1125	1821	1212	1988
2181	2691	1993	2640	2087	2666
2965	2995	2789	2899	2877	2947
3788	3445	3616	3369	3702	3407
6396	4118	6226	4046	6311	4082
8786	4495	8627	4279	8706	4387
12194	4992	12056	4941	12125	4967
23980	5919	23860	5892	23920	5906
48539	6573	48596	6487	48568	6530

Table C-9. I-75 Correlation Logger Identification

Correlation Curve	Logger	Serial #	Time Sample Obtained (CDT)	Logger Activation Time (CDT)
1	1	2001223	9:15 AM	9:30 AM
	2	2000662		
	1*	1003600		
	2*	1003681		
2	1	2000672	9:40 AM	10:00 AM
	2	2001220		
	1*	1003624		
	2*	1003699		

* Temperature Logger

Table C-10. I-75 Correlation Curve 1 Maturity Logger 1 Data

Date	Approximate Age (Days)	Reader	Logger 1 (Serial # 2001223)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
07/22/03	0	1	00:00	30	0
		2	00:00	30	0
07/23/03	1	1	29:37	24	1143
		2	29:38	24	1143
07/24/03	2	1	53:34	24	1959
		2	53:35	24	1959
07/25/03	3	1	77:32	23	2775
		2	77:32	23	2775
07/26/03	4	1	101:35	24	3598
		2	101:36	24	3598
07/29/03	7	1	173:31	23	5963
		2	173:32	23	5963
08/01/03	10	1	245:35	23	8445
		2	245:36	23	8445
08/05/03	14	1	341:32	24	11711
		2	341:32	24	11711
08/19/03	28	1	678:36	23	22870
		2	678:37	23	22870
09/16/03	56	1	1342:45	23	44774
		2	1342:46	23	44774

Table C-11. I-75 Correlation Curve 1 Maturity Logger 2 Data

Date	Approximate Age (Days)	Reader	Logger 2 (Serial # 2000662)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
07/22/03	0	1	00:00	30	0
		2	00:00	30	0
07/23/03	1	1	29:37	24	1137
		2	29:37	24	1137
07/24/03	2	1	53:33	24	1954
		2	53:34	24	1954
07/25/03	3	1	77:31	23	2770
		2	77:33	23	2770
07/26/03	4	1	101:34	24	3590
		2	101:35	24	3590
07/29/03	7	1	173:30	23	5953
		2	173:32	23	5953
08/01/03	10	1	245:34	23	8415
		2	245:35	23	8415
08/05/03	14	1	341:32	24	11680
		2	341:33	24	11680
08/19/03	28	1	678:36	23	22834
		2	678:37	23	22834
09/16/03	56	1	1342:16	23	44738
		2	1342:17	23	44738

Table C-12. I-75 Correlation Curve 1 Compressive Strength Data

Date	Approximate Age (Days)	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
07/22/03	0	---	---	0	0
		---	---	0	
07/23/03	1	29.16	41980	1485	111
		29.04	45110	1595	
07/24/03	2	29.18	60550	2142	25
		29.28	59840	2116	
07/25/03	3	29.30	69420	2455	35
		29.80	70400	2490	
07/26/03	4	29.28	76060	2690	39
		29.06	74950	2651	
07/29/03	7	29.28	83250	2944	94
		29.32	80580	2850	
08/01/03	10	29.30	99270	3511	33
		29.54	98340	3478	
08/05/03	14	29.26	103120	3647	220
		29.22	109350	3867	
08/19/03	28	29.28	121710	4305	49
		29.38	123100	4354	
09/16/03	56	29.36	142870	5053	94
		29.46	140220	4959	

--- Cylinders were in plastic state and assumed to have no strength

Table C-13. I-75 Correlation Curve 2 Maturity Logger 1 Data

Date	Approximate Age (Days)	Reader	Logger 1 (Serial # 2000672)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
07/22/03	0	1	00:00	30	0
		2	00:00	30	0
07/23/03	1	1	29:07	24	1115
		2	29:08	24	1115
07/24/03	2	1	53:03	24	1931
		2	53:04	24	1931
07/25/03	3	1	77:01	23	2747
		2	77:02	23	2747
07/26/03	4	1	101:04	24	3563
		2	101:05	24	3563
07/29/03	7	1	173:00	23	5908
		2	173:02	23	5908
08/01/03	10	1	245:04	23	8284
		2	245:05	23	8284
08/05/03	14	1	341:02	24	11452
		2	341:03	24	11452
08/19/03	28	1	678:04	23	22573
		2	678:05	23	22573
09/16/03	56	1	1342:15	23	44552
		2	1342:16	23	44552

Table C-14. I-75 Correlation Curve 2 Maturity Logger 2 Data

Date	Approximate Age (Days)	Reader	Logger 2 (Serial # 2001220)		
			Age (Hrs:Mins)	Temperature (°C)	Maturity (°C·Hrs)
07/22/03	0	1	00:00	30	0
		2	00:00	30	0
07/23/03	1	1	29:09	24	1136
		2	29:09	24	1136
07/24/03	2	1	53:05	24	1951
		2	53:06	24	1951
07/25/03	3	1	77:03	23	2764
		2	77:04	23	2764
07/26/03	4	1	101:06	24	3580
		2	101:06	24	3580
07/29/03	7	1	173:02	23	5922
		2	173:03	23	5922
08/01/03	10	1	245:06	23	8298
		2	245:07	23	8298
08/05/03	14	1	341:03	24	11466
		2	341:04	24	11466
08/19/03	28	1	678:05	23	22587
		2	678:05	23	22587
09/16/03	56	1	1342:17	23	44495
		2	1342:18	23	44495

Table C-15. I-75 Correlation Curve 2 Compressive Strength Data

Date	Approximate Age (Days)	Weight (lbs)	Load (lbs)	Strength (psi)	Range (psi)
07/22/03	0	---	---	0	0
		---	---	0	
07/23/03	1	29.10	41130	1455	64
		29.22	39320	1391	
07/24/03	2	29.42	59920	2119	119
		29.04	56560	2000	
07/25/03	3	29.28	72480	2563	150
		29.20	68240	2413	
07/26/03	4	29.04	73180	2588	99
		29.24	75970	2687	
07/29/03	7	29.68	104010	3679	384
		29.44	93140	3294	
08/01/03	10	29.48	97380	3444	189
		29.24	102720	3633	
08/05/03	14	29.74	120030	4245	154
		29.40	115680	4091	
08/19/03	28	29.58	138820	4910	392
		29.50	127730	4518	
09/16/03	56	29.74	150090	5308	371
		29.48	139610	4938	

--- Cylinders were in plastic state and assumed to have no strength

Table C-16. Average Correlation Curve Data

Correlation Curve 1		Correlation Curve 2		Average Correlation Curve	
Maturity (°C·Hrs)	Strength (psi)	Maturity (°C·Hrs)	Strength (psi)	Maturity (°C·Hrs)	Strength (psi)
0	0	0	0	0	0
1140	1540	1126	1423	1133	1482
1957	2129	1941	2060	1949	2095
2773	2473	2756	2488	2765	2481
3594	2670	3572	2638	3583	2654
5958	2897	5915	3486	5937	3192
8430	3495	8291	3539	8361	3517
11696	3757	11459	4168	11578	3963
22852	4329	22580	4714	22716	4522
44756	5006	44524	5123	44640	5065

Table C-17. Temperature Logger Data for Storage Boxes

Age (Hours)	Correlation Curve 1		Correlation Curve 2	
	Logger 1 Serial # 1003600	Logger 2 Serial # 1003681	Logger 1 Serial # 1003624	Logger 2 Serial # 1003699
	Temperature (°C)	Temperature (°C)	Temperature (°C)	Temperature (°C)
0	29	29	29	29
2	29	28	29	29
4	27	27	28	29
6	29	29	29	29
8	32	31	33	33
10	35	34	35	35
12	34	33	35	35
14	33	32	34	34
16	32	31	32	33
18	30	30	31	31
20	29	29	30	30
22	28	28	29	29
24	28	28	29	29
26	29	30	30	31
28	28	27	29	28
30	26	26	25	25
32	26	25	25	25
34	26	25	25	25
36	26	25	25	26
38	26	25	25	25
40	26	25	25	25

APPENDIX D

VERIFICATIONS

Table D-1. I-65 Verification Logger Identification

Verification	Serial #	Date Sample Obtained	Time Sample Obtained (CDT)	Logger Activation Time (CDT)
1	0002856	10/15/02	7:55 AM	8:10 AM
2	0002886	10/15/02	8:15 AM	8:45 AM
3	0002990	10/15/02	8:50 AM	9:10 AM
4	0002853	10/15/02	9:15 AM	9:25 AM
5	0002806	10/15/02	9:30 AM	9:50 AM
6	0002993	10/15/02	9:50 AM	10:00 AM
7	0002852	10/15/02	10:05 AM	10:25 AM
8	0002901	10/15/02	10:30 AM	10:45 AM
9	0002832	10/17/02	7:45 AM	8:00 AM
10	0002985	10/17/02	8:45 AM	9:35 AM
11	0002986	10/17/02	9:50 AM	10:15 AM
12	0002950	10/17/02	11:00 AM	11:20 AM

Table D-2. I-65 Verification 1 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	105:21	3006	**	8.36	37620	2994	2950	3022
				8.38	36510	2905		
	680:24	17882	****	8.39	72950	5805	5738	5415
				8.53	71270	5671		
6x12 Field- Cured Cylinders	80:06	2267	*	28.56	59700	2111	1980	2729
				28.59	52260	1848		
	104:33	2985	**	28.40	70290	2486	2482	3010
				28.39	70060	2478		
	125:20	3547	***	28.92	74250	2626	2632	3330
				28.78	74580	2638		
	678:50	17844	****	28.74	143350	5070	4934	5412
				28.53	135650	4798		
6x12 Lab- Cured Cylinders	79:22	2242	*	29.16	94330	3336	3310	2721
				29.08	92850	3284		
	100:40	2869	**	29.30	106580	3769	3729	2944
				29.20	104310	3689		
	124:57	3534	***	29.18	115680	4091	4009	3322
				29.26	111030	3927		
	676:03	17769	****	29.22	208630	7379	7295	5406
				29.26	203880	7211		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-3. I-65 Verification 1 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	24:10	47:00	79:15	101:56	126:26	---
Maturity (°C·Hrs)	702	1361	2242	2905	3573	---
Reading 1	14	24	24	24	24	---
Reading 2	10	38	26	22	24	---
Reading 3	12	38	23	22	27	---
Reading 4	14	34	23	23	30	---
Reading 5	14	28	26	22	30	---
Reading 6	12	26	25	28	25	---
Reading 7	12	22	26	26	28	---
Reading 8	12	36	30	24	25	---
Reading 9	10	24	24	25	28	---
Reading 10	14	26	28	24	24	---
Average Reading	12.4	29.6	25.5	24.0	26.5	---
Measured Strength (psi)	681	4286	3334	3000	3561	---
Predicted Strength (psi)	1136	2044	2721	2965	3345	---

--- Not Available

* Approximately 75% Target Maturity

** Approximately 100% Target Maturity

*** Approximately 125% Target Maturity

Table D-4. I-65 Verification 2 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:54	2913	**	8.35	40960	3259	3233	2969
				8.39	40290	3206		
	679:10	17382	****	8.52	66270	5274	5601	5374
				8.45	74500	5929		
6x12 Field- Cured Cylinders	79:39	2187	*	28.88	76910	2720	2828	2703
				29.21	83030	2937		
	104:05	2892	**	28.81	99540	3521	3498	2958
				28.87	98290	3476		
	124:52	3434	***	29.02	93380	3303	3408	3266
				29.00	99320	3513		
	678:21	17345	****	28.84	169930	6010	5998	5371
				28.99	169240	5986		
6x12 Lab- Cured Cylinders	78:57	2163	*	29.14	99770	3529	3498	2695
				29.12	98050	3468		
	100:15	2783	**	28.96	109550	3875	3873	2897
				29.22	109450	3871		
	124:33	3428	***	29.06	114400	4046	4083	3262
				29.14	116470	4119		
	675:40	17268	****	29.32	203980	7214	7262	5365
				29.56	206650	7309		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-5. I-65 Verification 2 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	23:33	46:30	78:51	101:25	125:56	---
Maturity (°C·Hrs)	671	1310	2163	2812	3459	---
Reading 1	10	23	25	22	25	---
Reading 2	10	24	22	22	23	---
Reading 3	12	27	24	22	27	---
Reading 4	10	41	25	24	24	---
Reading 5	10	28	26	22	22	---
Reading 6	12	22	25	23	24	---
Reading 7	10	36	24	22	30	---
Reading 8	10	31	25	25	26	---
Reading 9	10	25	22	22	22	---
Reading 10	10	20	24	24	22	---
Average Reading	10.4	27.7	24.2	22.8	24.5	---
Measured Strength (psi)	328	3838	3044	2739	3111	---
Predicted Strength (psi)	1086	1996	2695	2912	3280	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-6. I-65 Verification 3 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:37	3048	**	8.40	33280	2648	2704	3046
				8.44	34680	2760		
	679:39	17913	****	8.47	55530	4419	5159	5417
				8.43	74120	5898		
6x12 Field- Cured Cylinders	79:26	2302	*	28.86	74920	2650	2745	2741
				28.69	80290	2840		
	103:51	3026	**	28.94	90710	3208	3234	3034
				28.86	92160	3259		
	124:39	3590	***	29.05	95780	3388	3438	3354
				29.12	98620	3488		
	678:14	17873	****	28.92	169600	5998	5802	5414
				28.83	158520	5606		
6x12 Lab- Cured Cylinders	79:29	2302	*	29.08	93040	3291	3275	2741
				28.98	92150	3259		
	100:08	2917	**	28.96	104900	3710	3838	2972
				29.22	112120	3965		
	124:23	3584	***	29.06	109950	3889	3824	3351
				29.08	106290	3759		
	675:28	17800	****	29.08	196360	6945	7083	5408
				29.22	204180	7221		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-7. I-65 Verification 3 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	23:10	46:15	80:22	101:10	125:41	---
Maturity (°C·Hrs)	702	1390	2335	2946	3616	---
Reading 1	12	24	26	26	24	---
Reading 2	10	23	24	25	22	---
Reading 3	10	23	25	27	26	---
Reading 4	12	23	24	24	24	---
Reading 5	12	28	22	26	23	---
Reading 6	10	29	22	24	22	---
Reading 7	12	26	22	25	26	---
Reading 8	14	30	24	23	24	---
Reading 9	10	26	21	28	22	---
Reading 10	10	21	25	26	24	---
Average Reading	11.2	25.3	23.5	25.4	23.7	---
Measured Strength (psi)	468	3289	2891	3312	2934	---
Predicted Strength (psi)	1136	2071	2751	2988	3369	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-8. I-65 Verification 4 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:24	3032	**	8.49	38090	3031	3063	3037
				8.56	38900	3096		
	679:27	---	****	8.42	75660	6021	5919	---
				8.45	73090	5816		
6x12 Field- Cured Cylinders	79:15	2298	*	28.84	82880	2931	2902	2739
				29.08	81250	2874		
	103:37	3010	**	28.83	87850	3107	3235	3025
				29.01	95110	3364		
	124:28	3570	***	29.06	95380	3373	3354	3343
				29.20	94290	3335		
	678:05	17700	****	28.97	155630	5504	5771	5400
				29.12	170710	6038		
6x12 Lab- Cured Cylinders	79:18	2298	*	29.24	98280	3476	3551	2739
				29.12	102530	3626		
	100:00	2908	**	29.02	111630	3948	3938	2967
				29.24	113600	4018		
	125:36	3602	***	29.20	117070	4141	4219	3361
				29.08	121510	4298		
	675:25	17626	****	29.54	207930	7354	7347	5394
				29.34	207540	7340		

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-9. I-65 Verification 4 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:49	46:01	80:09	100:56	124:28	---
Maturity (°C·Hrs)	700	1384	2323	2930	3596	---
Reading 1	10	22	24	24	25	---
Reading 2	12	24	21	26	24	---
Reading 3	10	21	26	22	22	---
Reading 4	10	21	25	24	20	---
Reading 5	11	24	23	24	22	---
Reading 6	10	24	27	24	27	---
Reading 7	10	24	24	28	23	---
Reading 8	10	23	29	23	21	---
Reading 9	10	21	25	24	22	---
Reading 10	11	21	23	24	22	---
Average Reading	10.4	22.5	24.7	24.3	22.8	---
Measured Strength (psi)	328	2674	3155	3066	2739	---
Predicted Strength (psi)	1133	2065	2747	2979	3358	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-10. I-65 Verification 5 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:05	3041	**	8.33	37220	2962	2782	3042
				8.37	32700	2602		
	679:08	17894	****	8.47	70430	5605	5502	5416
				8.44	67860	5400		
6x12 Field- Cured Cylinders	78:56	2297	*	28.71	79420	2809	2819	2739
				28.91	80010	2830		
	103:20	3020	**	28.83	97360	3443	3494	3030
				28.73	100220	3545		
	124:08	3585	***	28.94	102420	3622	3552	3351
				28.94	98450	3482		
	677:46	17860	****	28.96	160280	5669	5746	5413
				28.85	164630	5823		
6x12 Lab- Cured Cylinders	79:02	2305	*	29.08	102830	3637	3639	2742
				28.96	102930	3640		
	99:46	2918	**	29.10	114200	4039	4119	2972
				29.08	118750	4200		
	125:21	3618	***	29.06	116270	4112	4159	3370
				28.86	118940	4207		
	675:19	17791	****	29.16	206650	7309	7282	5407
				29.22	205160	7256		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-11. I-65 Verification 5 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:21	45:40	79:48	100:36	125:15	---
Maturity (°C·Hrs)	683	1374	2330	2940	3618	---
Reading 1	11	23	24	22	26	---
Reading 2	11	41	24	21	24	---
Reading 3	12	26	23	24	28	---
Reading 4	11	21	23	25	24	---
Reading 5	12	22	23	24	25	---
Reading 6	10	22	22	23	34	---
Reading 7	10	25	22	27	29	---
Reading 8	10	23	24	22	25	---
Reading 9	12	22	22	24	26	---
Reading 10	14	22	22	27	24	---
Average Reading	11.3	24.7	22.9	23.9	26.5	---
Measured Strength (psi)	485	3155	2760	2978	3561	---
Predicted Strength (psi)	1106	2056	2750	2985	3370	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-12. I-65 Verification 6 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:02	3094	**	8.43	40260	3204	3433	3072
				8.36	46030	3663		
	679:08	17943	****	8.42	81040	6449	6150	5420
				8.44	73520	5851		
6x12 Field- Cured Cylinders	78:51	2346	*	28.79	73090	2585	2675	2755
				28.84	78190	2765		
	103:14	3065	**	28.80	84580	2991	3064	3056
				28.74	88680	3136		
	124:05	3640	***	29.26	96080	3398	3314	3375
				29.11	91320	3230		
	677:41	17903	****	29.00	162130	5734	5847	5417
				28.82	168510	5960		
6x12 Lab- Cured Cylinders	79:14	2355	*	29.28	101440	3588	3682	2758
				29.20	106780	3777		
	99:46	2969	**	29.10	118550	4193	4146	3001
				29.04	115880	4098		
	125:21	3673	***	29.44	129030	4564	4520	3384
				29.38	126560	4476		
	675:26	17841	****	29.34	212090	7501	7632	5412
				29.32	219500	7763		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-13. I-65 Verification 6 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:07	45:33	79:40	100:30	125:14	---
Maturity (°C·Hrs)	701	1409	2371	2991	3666	---
Reading 1	12	21	22	26	24	---
Reading 2	11	21	23	28	22	---
Reading 3	12	25	20	26	24	---
Reading 4	13	22	24	25	25	---
Reading 5	14	24	24	26	26	---
Reading 6	10	19	23	25	24	---
Reading 7	13	22	22	30	24	---
Reading 8	12	25	22	24	22	---
Reading 9	12	18	26	24	22	---
Reading 10	11	20	24	26	25	---
Average Reading	12.0	21.7	23.0	26.0	23.8	---
Measured Strength (psi)	609	2504	2782	3447	2956	---
Predicted Strength (psi)	1135	2089	2763	3014	3382	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-14. I-65 Verification 7 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:35	2905	**	8.39	43980	3500	3389	2965
				8.46	41190	3278		
	678:36	17639	****	8.41	68020	5413	5685	5395
				8.45	74850	5956		
6x12 Field- Cured Cylinders	78:27	2168	*	28.61	66670	2358	2350	2697
				28.61	66220	2342		
	102:52	2883	**	28.54	81820	2894	2896	2952
				28.53	81930	2898		
	123:42	3431	***	28.79	85840	3036	3024	3264
				28.94	85170	3012		
	677:17	17606	****	28.98	148830	5264	5298	5392
				28.89	150770	5332		
6x12 Lab- Cured Cylinders	78:53	2185	*	29.22	86810	3070	3223	2702
				29.46	95420	3375		
	99:27	2782	**	29.06	112520	3980	3875	2897
				29.06	106580	3769		
	125:00	3469	***	29.06	112420	3976	4175	3285
				29.20	123690	4375		
	675:11	17545	****	29.26	194580	6882	6887	5387
				29.12	194880	6892		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-15. I-65 Verification 7 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	21:35	45:07	79:15	100:06	124:55	---
Maturity (°C·Hrs)	626	1277	2201	2804	3462	---
Reading 1	10	22	24	31	26	---
Reading 2	10	24	26	25	24	---
Reading 3	10	24	24	26	26	---
Reading 4	10	22	23	30	23	---
Reading 5	10	23	23	26	32	---
Reading 6	10	22	29	22	30	---
Reading 7	10	22	24	22	26	---
Reading 8	11	20	22	24	25	---
Reading 9	10	24	24	27	26	---
Reading 10	10	21	22	28	23	---
Average Reading	10.1	22.4	24.1	26.1	26.1	---
Measured Strength (psi)	276	2653	3022	3470	3470	---
Predicted Strength (psi)	1013	1964	2708	2908	3281	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-16. I-65 Verification 8 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:22	2903	**	8.38	44430	3536	3407	2964
				8.57	41190	3278		
	678:25	17689	****	8.38	71890	5721	5766	5399
				8.32	73030	5812		
6x12 Field- Cured Cylinders	78:17	2177	*	28.64	68360	2418	2504	2700
				28.75	73250	2591		
	102:42	2882	**	28.55	86390	3055	2953	2952
				28.74	80580	2850		
	123:32	3435	***	28.88	88720	3138	3053	3266
				28.82	83900	2967		
	677:04	17655	****	28.76	162800	5758	5671	5396
				28.66	157860	5583		
6x12 Lab- Cured Cylinders	78:45	2193	*	29.02	97200	3438	3359	2705
				29.16	92750	3280		
	99:19	2786	**	29.08	105500	3731	3702	2898
				29.06	103820	3672		
	124:55	3466	***	28.96	109060	3857	3899	3284
				29.06	111430	3941		
	675:14	17598	****	29.34	216540	7659	7531	5392
				29.28	209320	7403		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-17. I-65 Verification 8 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	21:12	44:53	79:02	99:55	124:37	---
Maturity (°C·Hrs)	605	1271	2201	2801	3466	---
Reading 1	10	34	24	28	24	---
Reading 2	10	21	22	24	24	---
Reading 3	10	21	22	24	32	---
Reading 4	10	24	22	26	26	---
Reading 5	10	20	21	27	24	---
Reading 6	10	22	22	28	26	---
Reading 7	10	21	22	25	23	---
Reading 8	11	23	21	23	25	---
Reading 9	10	23	24	24	34	---
Reading 10	10	22	22	26	27	---
Average Reading	10.1	23.1	22.2	25.5	26.5	---
Measured Strength (psi)	276	2804	2610	3334	3561	---
Predicted Strength (psi)	979	1959	2708	2906	3284	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-18. I-65 Verification 9 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:09	2928	**	8.37	45040	3584	3511	2978
				8.42	43200	3438		
	680:17	17860	****	8.32	78940	6282	6259	5413
				8.45	78360	6236		
6x12 Field- Cured Cylinders	77:59	2275	*	29.30	89080	3151	2994	2732
				28.84	80200	2836		
	102:52	2921	**	28.97	92860	3284	3181	2974
				28.94	87030	3078		
	122:22	3423	***	28.95	91270	3228	3477	3259
				28.83	105330	3725		
	679:50	17847	****	28.90	151840	5370	5987	5412
				28.85	186740	6605		
6x12 Lab- Cured Cylinders	79:25	214	*	28.76	84630	2993	2890	2744
				28.98	78800	2787		
	103:30	2942	**	28.98	91860	3249	3251	2986
				28.92	91960	3252		
	121:05	3392	***	29.10	98780	3494	3522	3242
				29.24	100360	3550		
	675:46	17744	****	29.28	184300	6518	6725	5404
				29.32	195970	6931		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-19. I-65 Verification 9 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	30:38	54:21	79:19	103:19	120:52	---
Maturity (°C·Hrs)	853	1610	2314	2935	3387	---
Reading 1	14	21	30	28	28	---
Reading 2	16	22	28	30	28	---
Reading 3	20	21	26	26	30	---
Reading 4	14	23	28	30	32	---
Reading 5	18	26	31	30	28	---
Reading 6	18	20	26	30	28	---
Reading 7	18	21	26	32	30	---
Reading 8	17	23	24	26	28	---
Reading 9	18	22	26	27	31	---
Reading 10	17	18	29	28	31	---
Average Reading	17.0	21.7	27.4	28.7	29.4	---
Measured Strength (psi)	1545	2504	3768	4072	4239	---
Predicted Strength (psi)	1381	2279	2744	2982	3239	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-20. I-65 Verification 10 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	101:56	2972	**	8.43	47640	3791	3691	3003
				8.39	45130	3591		
	679:05	18149	****	8.42	75710	6025	6351	5437
				8.48	83920	6678		
6x12 Field- Cured Cylinders	76:47	2312	*	29.23	78250	2768	3020	2744
				29.24	92550	3273		
	101:44	2964	**	29.16	101180	3579	3610	2998
				29.02	102950	3641		
	121:12	3475	***	29.13	110330	3902	3978	3289
				29.10	114630	4054		
	678:41	18136	****	28.85	181960	6436	6090	5436
				28.98	162430	5745		
6x12 Lab- Cured Cylinders	78:17	2353	*	29.36	90370	3196	3161	2757
				29.16	88400	3126		
	102:22	2986	**	29.24	100160	3542	3439	3011
				29.36	94330	3336		
	120:02	3451	***	29.34	111730	3952	4009	3275
				29.22	114990	4067		
	674:48	18040	****	29.58	206750	7312	7211	5428
				29.58	201010	7109		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-21. I-65 Verification 10 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	29:28	53:09	78:10	102:16	119:57	---
Maturity (°C·Hrs)	850	1629	2346	2986	3445	---
Reading 1	18	23	26	30	28	---
Reading 2	19	24	31	30	30	---
Reading 3	18	21	29	29	34	---
Reading 4	18	21	26	30	30	---
Reading 5	17	23	28	26	28	---
Reading 6	18	22	27	26	30	---
Reading 7	21	24	26	28	28	---
Reading 8	22	24	27	28	30	---
Reading 9	18	24	26	31	28	---
Reading 10	18	23	24	27	26	---
Average Reading	18.7	22.9	27.0	28.5	29.2	---
Measured Strength (psi)	1883	2760	3676	4025	4191	---
Predicted Strength (psi)	1376	2297	2755	3011	3272	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-22. I-65 Verification 11 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	101:23	2947	**	8.47	44880	3571	3690	2989
				8.49	47870	3809		
	678:32	18048	****	8.54	79020	6288	6220	5428
				8.55	77300	6151		
6x12 Field- Cured Cylinders	76:13	2285	*	29.06	79420	2809	3003	2735
				29.28	90410	3198		
	101:01	2940	**	29.28	106110	3753	3763	2985
				29.17	106670	3773		
	120:43	3440	***	28.90	114680	4056	3995	3269
				29.04	111240	3934		
	678:08	18035	****	28.87	188410	6664	6582	5427
				28.99	183810	6501		
6x12 Lab- Cured Cylinders	77:48	2332	*	29.20	92430	3269	3301	2750
				29.32	94230	3333		
	101:51	2961	**	29.20	92850	3284	3452	2997
				29.28	102360	3620		
	120:01	3427	***	29.26	115480	4084	4109	3262
				29.26	116870	4133		
	674:22	17937	****	29.38	199050	7040	7185	5419
				29.50	207240	7330		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-23. I-65 Verification 11 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	28:53	52:42	77:40	101:45	119:57	---
Maturity (°C·Hrs)	843	1616	2325	2961	3421	---
Reading 1	20	24	25	36	31	---
Reading 2	18	24	29	30	31	---
Reading 3	18	26	26	30	28	---
Reading 4	19	21	26	28	30	---
Reading 5	18	22	38	31	32	---
Reading 6	18	24	24	26	30	---
Reading 7	20	23	26	30	32	---
Reading 8	18	24	24	28	28	---
Reading 9	18	25	27	26	26	---
Reading 10	16	24	26	31	32	---
Average Reading	18.3	23.7	27.1	29.6	30.0	---
Measured Strength (psi)	1803	2934	3699	4286	4382	---
Predicted Strength (psi)	1365	2284	2748	2997	3258	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-24. I-65 Verification 12 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	100:17	2932	**	8.48	52470	4175	4001	2980
				8.46	48080	3826		
	677:29	17954	****	8.54	83700	6661	6786	5421
				8.57	86860	6912		
6x12 Field- Cured Cylinders	75:13	2274	*	29.13	92900	3286	3321	2731
				29.10	94910	3357		
	100:03	2925	**	28.96	106650	3772	3708	2976
				29.11	103030	3644		
	119:39	3408	***	29.20	114830	4061	4141	3251
				29.16	119360	4221		
	677:06	17948	****	29.25	196450	6948	6831	5420
				28.94	189840	6714		
6x12 Lab- Cured Cylinders	76:48	2320	*	29.26	95710	3385	3394	2746
				29.22	96210	3403		
	100:54	2946	**	29.32	111430	3941	3897	2988
				29.24	108960	3854		
	119:02	3392	***	29.24	121320	4291	4356	3242
				29.44	124980	4420		
	673:11	17845	****	29.42	211690	7487	7674	5412
				29.70	222270	7861		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-25. I-65 Verification 12 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	28:00	51:39	76:42	100:46	119:00	---
Maturity (°C·Hrs)	841	1609	2313	2946	3392	---
Reading 1	18	21	24	28	32	---
Reading 2	18	23	32	30	32	---
Reading 3	17	22	28	31	30	---
Reading 4	18	24	28	31	26	---
Reading 5	17	24	32	34	31	---
Reading 6	19	20	32	32	30	---
Reading 7	19	24	32	32	32	---
Reading 8	20	24	34	34	30	---
Reading 9	18	21	32	32	28	---
Reading 10	18	23	28	28	31	---
Average Reading	18.2	22.6	30.2	31.2	30.2	---
Measured Strength (psi)	1783	2696	4431	4674	4431	---
Predicted Strength (psi)	1361	2278	2744	2988	3242	---

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 100% Target Maturity

Table D-26. I-75 Verification Logger Identification

Verification	Serial #	Date Sample Obtained	Time Sample Obtained (CDT)	Logger Activation Time (CDT)
1	0024211*	08/14/03	7:15 AM	8:10 AM
	0024221**			8:10 AM
	0024142***			8:10 AM
2	0023809	08/14/03	7:45 AM	8:15 AM
	1002679****			8:15 AM
3	0023644	08/14/03	8:25 AM	9:05 AM
4	0002707	08/14/03	8:40 AM	9:15 AM
5	0002605	08/14/03	9:10 AM	10:05 AM
6	0002685*	08/14/03	9:30 AM	10:35 AM
	0002679**			10:35 AM
	0002645***			10:35 AM
7	0002850	08/14/03	10:00 AM	10:50 AM
	1004951****			10:50 AM
8	0002811	08/14/03	10:25 AM	10:55 AM
9	0002875	08/14/03	10:55 AM	11:30 AM
10	0002883	08/15/03	6:55 AM	7:05 AM
11	0002869	08/15/03	7:10 AM	7:25 AM
	1004894****			7:25 AM
12	0002825*	08/15/03	8:40 AM	9:15 AM
	0002982**			9:15 AM
	0002848***			9:15 AM

* Placed in top-third of slab
** Placed at mid-depth of slab
*** Placed in bottom-third of slab
**** Temperature logger

Table D-27. I-75 Verification Location 1 Variable Depth Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Top Third Of Slab Maturity (°C·Hrs)	Mid-Slab Maturity (°C·Hrs)	Bottom Third of Slab Maturity (°C·Hrs)	Average Maturity (°C·Hrs)	
4x8 Cores	105:47	4606	4674	4729	4670	**
	681:30	28428	28789	28797	28671	****
6x12 Field- Cured Cylinders	79:54	3503	3558	3612	3558	*
	104:47	4560	4627	4684	4624	**
	128:37	5553	5633	5695	5627	***
	680:27	28371	28732	28742	28615	****
6x12 Lab- Cured Cylinders	80:50	3550	3605	3657	3604	*
	106:38	4639	4708	4763	4703	**
	129:52	5610	5690	5750	5683	***
	679:02	28314	28675	28689	28559	****
Rebound Hammer Testing	25:17	1132	1155	1185	1157	1-Day
	48:48	2199	2236	2277	2237	2-Day
	76:37	3352	3410	3470	3411	*
	102:39	4453	4521	4584	4519	**
	127:32	5508	5588	5651	5582	***
	678:57	28303	28664	28679	28549	****

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-28. I-75 Verification Location 6 Variable Depth Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Top Third Of Slab Maturity (°C·Hrs)	Mid-Slab Maturity (°C·Hrs)	Bottom Third of Slab Maturity (°C·Hrs)	Average Maturity (°C·Hrs)	
4x8 Cores	103:35	4689	4722	4760	4724	**
	679:22	29123	29023	29053	29066	****
6x12 Field- Cured Cylinders	77:50	3559	3596	3634	3596	*
	102:43	4641	4675	4715	4677	**
	126:33	5682	5711	5752	5715	***
	678:30	29088	28989	29021	29033	****
6x12 Lab- Cured Cylinders	78:54	3607	3643	3680	3643	*
	104:45	4747	4780	4816	4781	**
	128:04	5752	5779	5819	5783	***
	677:17	29030	28934	28968	28977	****
Rebound Hammer Testing	23:03	1071	1101	1121	1098	1-Day
	46:33	2192	2230	2255	2226	2-Day
	74:23	3389	3434	3479	3434	*
	100:53	4556	4594	4637	4596	**
	125:18	5623	5654	5697	5658	***
	676:12	29019	28922	28957	28966	****

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-29. I-75 Verification Location 12 Variable Depth Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Top Third Of Slab	Mid-Slab	Bottom Third of Slab	Average Maturity (°C·Hrs)	
		Maturity (°C·Hrs)	Maturity (°C·Hrs)	Maturity (°C·Hrs)		
4x8 Cores	104:15	4681	4828	4807	4772	**
	671:43	28280	28590	28437	28436	****
6x12 Field- Cured Cylinders	79:35	3620	3752	3736	3703	*
	103:30	4645	4795	4774	4738	**
	127:27	5656	5815	5790	5754	***
	671:36	28280	28590	28437	28436	****
6x12 Lab- Cured Cylinders	81:29	3701	3834	3815	3783	*
	104:40	4692	4840	4818	4783	**
	126:55	5633	5793	5768	5731	***
	672:12	28300	28610	28457	28456	****
Rebound Hammer Testing	24:35	1195	1261	1239	1232	1-Day
	52:18	2411	2532	2522	2488	2-Day
	78:32	3570	3705	3691	3655	*
	102:56	4610	4761	4741	4704	**
	126:39	5621	5781	5757	5720	***
	671:55	28290	28600	28447	28446	****

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-30. I-75 Verification 1 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	105:47	4670	**	8.48	38440	3059	3067	2902
				8.39	38640	3075		
	681:30	28671	****	8.36	56150	4468	3895	4669
				8.36	41730	3321		
6x12 Field- Cured Cylinders	79:54	3558	*	29.04	100480	3554	3389	2649
				29.20	91150	3224		
	104:47	4624	**	29.54	105810	3742	3609	2892
				29.32	98280	3476		
	128:37	5627	***	29.05	111320	3937	3649	3121
				29.36	95040	3361		
	680:27	28615	****	29.14	154720	5472	5367	4668
				29.23	148770	5262		
6x12 Lab- Cured Cylinders	80:50	3604	*	29.54	87210	3084	3030	2659
				29.40	84140	2976		
	106:38	4703	**	29.62	95710	3385	3382	2910
				29.44	95520	3378		
	129:52	5683	***	29.52	103820	3672	3598	3134
				29.68	99670	3525		
	679:02	28559	****	29.72	149400	5284	5258	4667
				29.74	147910	5231		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-31. I-75 Verification 1 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	25:17	48:48	76:37	102:39	127:32	678:57
Maturity (°C·Hrs)	1157	2237	3411	4519	5582	28549
Reading 1	18	21	26	24	26	34
Reading 2	18	25	27	26	24	31
Reading 3	16	25	28	30	26	32
Reading 4	16	24	30	28	28	32
Reading 5	18	24	24	24	24	32
Reading 6	17	22	24	24	20	32
Reading 7	20	24	24	26	24	34
Reading 8	16	22	26	26	26	32
Reading 9	19	23	25	24	26	33
Reading 10	19	22	22	25	27	30
Average Reading	17.7	23.2	25.6	25.7	25.1	32.2
Measured Strength (psi)	1683	2825	3357	3379	3244	4920
Predicted Strength (psi)	1500	2231	2618	2868	3111	4666

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-32. I-75 Verification 2 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	105:40	4672	**	8.59	49800	3963	3991	2903
				8.58	50500	4019		
	681:23	28837	****	8.44	53780	4280	4448	4674
				8.45	58010	4616		
6x12 Field- Cured Cylinders	79:48	3566	*	29.38	105040	3715	3595	2650
				29.28	98270	3476		
	104:41	4625	**	29.24	114270	4041	4059	2892
				29.16	115260	4076		
	128:32	5645	***	28.86	115860	4098	4127	3125
				29.09	117500	4156		
	680:23	28791	****	29.04	158340	5600	5595	4672
				28.86	158060	5590		
6x12 Lab- Cured Cylinders	80:48	3613	*	29.82	95810	3389	3394	2661
				29.48	96110	3399		
	106:35	4717	**	29.52	105790	3742	3649	2913
				29.72	100550	3556		
	129:50	5702	***	29.58	106980	3784	3841	3138
				29.50	110240	3899		
	679:00	28734	****	29.42	147520	5217	5294	4671
				29.70	151870	5371		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-33. I-75 Verification 2 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	25:11	48:43	76:31	102:35	127:25	678:54
Maturity (°C·Hrs)	1144	2232	3417	4530	5587	28723
Reading 1	19	24	24	26	28	28
Reading 2	18	25	26	28	30	32
Reading 3	16	32	26	28	33	34
Reading 4	20	25	24	25	31	33
Reading 5	20	24	24	26	26	33
Reading 6	21	26	22	29	28	31
Reading 7	18	26	24	28	24	32
Reading 8	18	22	26	24	24	31
Reading 9	18	24	25	26	27	33
Reading 10	17	26	24	26	24	31
Average Reading	18.5	25.4	24.5	26.6	27.5	31.8
Measured Strength (psi)	1843	3312	3111	3379	3791	4821
Predicted Strength (psi)	1490	2229	2619	2870	3112	4671

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-34. I-75 Verification 3 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:55	4744	**	8.59	41420	3296	3467	2919
				8.61	45720	3638		
	680:41	28876	****	8.58	53800	4281	4358	4675
				8.39	55740	4436		
6x12 Field- Cured Cylinders	79:05	3635	*	29.20	101060	3574	3661	2666
				29.14	105970	3748		
	103:55	4697	**	29.13	109880	3886	3841	2909
				29.47	107320	3796		
	127:49	5716	***	28.83	123060	4352	4309	3141
				28.99	120580	4265		
	679:43	28831	****	29.03	162440	5745	5587	4673
				28.78	153490	5429		
6x12 Lab- Cured Cylinders	80:07	3682	*	29.40	94130	3329	3244	2677
				29.46	89290	3158		
	105:55	4789	**	29.54	103220	3651	3785	2930
				29.58	110840	3920		
	129:12	5772	***	29.66	112910	3993	3815	3154
				29.38	102830	3637		
	678:22	28775	****	29.40	147620	5221	5301	4672
				29.42	152170	5382		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-35. I-75 Verification 3 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	24:26	47:58	75:46	101:51	126:41	678:17
Maturity (°C·Hrs)	1169	2286	3487	4604	5660	28775
Reading 1	20	24	22	28	26	30
Reading 2	20	24	26	24	26	30
Reading 3	19	25	25	26	28	31
Reading 4	19	26	26	28	27	27
Reading 5	19	22	22	28	30	26
Reading 6	18	24	24	27	26	29
Reading 7	20	27	24	26	30	29
Reading 8	16	24	26	27	24	32
Reading 9	18	24	28	26	24	34
Reading 10	19	23	30	27	28	34
Average Reading	18.8	24.3	25.3	26.7	26.9	30.2
Measured Strength (psi)	1903	3066	3289	3607	3653	4431
Predicted Strength (psi)	1509	2254	2634	2887	3129	4672

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-36. I-75 Verification 4 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:52	4708	**	8.41	40280	3205	3251	2911
				8.41	41420	3296		
	680:37	28971	****	8.34	53850	4285	4428	4677
				8.48	57450	4572		
6x12 Field- Cured Cylinders	79:02	3596	*	29.02	91350	3231	3137	2657
				29.22	86050	3043		
	103:56	4661	**	29.08	98110	3470	3379	2900
				28.71	92970	3288		
	127:47	5684	***	29.12	100410	3551	3452	3134
				29.07	94820	3354		
	679:42	28925	****	29.09	127880	4523	4640	4676
				28.82	134510	4757		
6x12 Lab- Cured Cylinders	80:08	3644	*	29.74	80290	2840	2862	2668
				29.94	81570	2885		
	105:55	4754	**	29.72	89580	3168	3200	2922
				29.62	91360	3231		
	129:13	5740	***	29.70	97200	3438	3432	3147
				29.68	96900	3427		
	678:23	28868	****	29.76	129520	4581	4744	4674
				29.60	138720	4906		

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-37. I-75 Verification 4 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	24:22	47:52	75:41	101:49	126:36	678:19
Maturity (°C·Hrs)	1139	2247	3432	4567	5628	28868
Reading 1	20	24	24	24	28	32
Reading 2	20	23	24	26	25	38
Reading 3	23	22	24	27	28	34
Reading 4	20	23	22	29	34	34
Reading 5	21	27	31	26	30	32
Reading 6	22	28	26	26	29	31
Reading 7	25	24	25	28	32	30
Reading 8	22	23	22	30	28	29
Reading 9	21	20	22	24	25	32
Reading 10	22	22	20	24	22	32
Average Reading	21.6	23.6	24.0	26.4	28.1	32.4
Measured Strength (psi)	2482	2913	3000	3538	3931	4970
Predicted Strength (psi)	1487	2236	2622	2879	3121	4674

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-38. I-75 Verification 5 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:55	4729	**	8.41	42690	3397	3350	2916
				8.42	41510	3303		
	679:46	28982	****	8.42	57640	4587	4199	4677
				8.40	47880	3810		
6x12 Field- Cured Cylinders	78:12	3611	*	29.20	99910	3534	3368	2660
				29.32	90540	3202		
	103:07	4694	**	29.37	103320	3654	3645	2908
				29.02	102810	3636		
	126:56	5710	***	29.50	114060	4034	4038	3140
				29.19	114310	4043		
	678:53	28936	****	29.23	144610	5115	4959	4676
				29.08	135800	4803		
6x12 Lab- Cured Cylinders	79:20	3671	*	29.32	93440	3305	3282	2674
				29.56	92150	3259		
	105:08	4787	**	29.66	98280	3476	3336	2929
				29.70	90370	3196		
	128:26	5778	***	29.66	101540	3591	3563	3156
				29.54	99960	3535		
	677:37	28880	****	29.68	131110	4637	4780	4675
				29.54	139210	4924		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-39. I-75 Verification 5 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	23:30	47:00	74:49	101:01	125:45	677:31
Maturity (°C·Hrs)	1124	2257	3457	4600	5664	28880
Reading 1	21	25	26	26	30	34
Reading 2	22	24	26	26	30	34
Reading 3	25	26	25	24	30	34
Reading 4	21	24	26	32	26	33
Reading 5	23	33	28	28	29	31
Reading 6	21	24	26	24	28	33
Reading 7	20	22	25	26	29	28
Reading 8	24	24	25	25	32	28
Reading 9	21	26	27	28	26	30
Reading 10	20	24	24	23	28	32
Average Reading	21.8	25.2	25.8	26.2	28.8	31.7
Measured Strength (psi)	2525	3267	3402	3493	4096	4797
Predicted Strength (psi)	1470	2241	2627	2886	3130	4675

--- Not Available

* Approximately 75% Target Maturity

** Approximately 100% Target Maturity

*** Approximately 125% Target Maturity

Table D-40. I-75 Verification 6 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:35	4724	**	8.51	43310	3447	3317	2915
				8.48	40060	3188		
	679:22	29066	****	8.49	52180	4152	4158	4679
				8.62	52320	4163		
6x12 Field- Cured Cylinders	77:50	3596	*	29.33	94770	3352	3171	2657
				28.84	84550	2990		
	102:43	4677	**	29.08	100430	3552	3652	2904
				28.94	106060	3751		
	126:33	5715	***	28.75	105780	3741	3595	3141
				28.86	97520	3449		
	678:30	29033	****	29.05	141980	5022	5068	4678
				28.79	144630	5115		
6x12 Lab- Cured Cylinders	78:54	3643	*	29.16	82460	2916	2939	2668
				29.32	83750	2962		
	104:45	4781	**	29.18	92940	3287	3194	2928
				29.44	87700	3102		
	128:04	5783	***	29.40	97490	3448	3385	3157
				29.36	93930	3322		
	677:17	28977	****	29.34	131010	4634	4623	4677
				29.70	130410	4612		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-41. I-75 Verification 6 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	23:03	46:33	74:23	100:53	125:18	676:12
Maturity (°C·Hrs)	1098	2226	3434	4596	5658	28966
Reading 1	18	24	20	24	27	36
Reading 2	20	26	24	24	26	30
Reading 3	20	22	22	24	24	30
Reading 4	21	25	24	25	26	30
Reading 5	19	23	20	24	26	30
Reading 6	20	24	24	26	28	32
Reading 7	20	28	24	26	24	34
Reading 8	21	22	24	24	24	30
Reading 9	23	23	25	24	27	26
Reading 10	21	26	24	28	25	24
Average Reading	20.3	24.3	23.1	24.9	25.7	30.2
Measured Strength (psi)	2210	3066	2804	3200	3379	4431
Predicted Strength (psi)	1436	2226	2622	2886	3128	4677

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-42. I-75 Verification 7 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:25	4599	**	8.39	43340	3449	3492	2886
				8.48	44430	3536		
	679:12	28850	****	8.42	59640	4746	4667	4674
				8.37	57660	4588		
6x12 Field- Cured Cylinders	77:41	3481	*	28.61	72570	2567	2546	2632
				28.62	71380	2525		
	102:35	4564	**	28.57	87000	3077	2924	2878
				28.54	78370	2772		
	126:22	5582	***	28.79	88160	3118	3072	3111
				28.19	85530	3025		
	678:22	28815	****	28.12	121850	4310	4256	4673
				28.39	118830	4203		
6x12 Lab- Cured Cylinders	78:53	3541	*	29.12	77420	2738	2792	2645
				29.28	80490	2847		
	104:38	4657	**	29.24	83450	2951	3039	2899
				29.16	88400	3127		
	128:01	5662	***	29.36	94530	3343	3340	3129
				29.50	94330	3336		
	677:11	28759	****	29.54	130310	4609	4593	4672
				29.28	129420	4577		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-43. I-75 Verification 7 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:53	46:22	74:14	100:43	125:08	677:06
Maturity (°C·Hrs)	1039	2137	3317	4469	5524	28759
Reading 1	21	23	22	24	26	28
Reading 2	20	26	24	26	25	31
Reading 3	24	25	24	29	23	28
Reading 4	22	22	25	24	27	29
Reading 5	21	24	21	24	24	33
Reading 6	20	25	20	26	36	32
Reading 7	18	23	24	24	28	34
Reading 8	20	20	26	22	29	30
Reading 9	22	24	23	25	30	28
Reading 10	21	24	23	26	28	26
Average Reading	20.9	23.6	23.2	25.0	27.6	29.9
Measured Strength (psi)	2335	2913	2825	3222	3815	4358
Predicted Strength (psi)	1359	2184	2598	2856	3098	4672

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-44. I-75 Verification 8 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	103:20	4661	**	8.43	44220	3519	3593	2900
				8.39	46070	3666		
	679:12	29004	****	8.43	58280	4638	4961	4678
				8.37	66410	5285		
6x12 Field- Cured Cylinders	77:33	3538	*	28.73	66340	2346	2393	2644
				28.69	69000	2440		
	102:34	4625	**	28.70	79840	2824	2823	2892
				28.53	79780	2822		
	126:19	5646	***	28.83	81930	2898	2986	3125
				28.71	86930	3075		
	678:21	28971	****	28.60	118100	4177	4032	4677
				28.80	109930	3888		
6x12 Lab- Cured Cylinders	78:55	3596	*	28.96	63970	2262	2231	2657
				29.02	62190	2200		
	104:36	4718	**	29.84	71190	2518	2513	2913
				28.92	70890	2507		
	127:54	5714	***	29.08	76430	2703	2750	3141
				28.94	79100	2798		
	677:14	28914	****	29.04	113800	4025	3976	4676
				29.28	111030	3927		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-45. I-75 Verification 8 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:50	46:18	74:10	100:40	125:04	677:09
Maturity (°C·Hrs)	1068	2178	3375	4532	5590	28914
Reading 1	18	23	22	28	26	30
Reading 2	20	22	22	26	24	32
Reading 3	21	24	31	26	22	32
Reading 4	21	25	24	24	28	30
Reading 5	22	22	23	27	26	30
Reading 6	22	25	21	26	26	31
Reading 7	19	24	22	25	26	28
Reading 8	22	21	22	22	28	30
Reading 9	21	20	26	24	24	36
Reading 10	22	22	28	24	23	34
Average Reading	20.8	22.8	24.1	25.2	25.3	31.3
Measured Strength (psi)	2314	2739	3022	3267	3289	4698
Predicted Strength (psi)	1397	2203	2610	2871	3113	4676

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-46. I-75 Verification 9 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	102:48	4636	**	8.42	45230	3599	3601	2895
				8.54	45270	3602		
	678:42	28870	****	8.52	59560	4740	4873	4674
				8.50	62920	5007		
6x12 Field- Cured Cylinders	77:03	3516	*	29.31	103060	3645	3555	2640
				29.36	97980	3465		
	102:04	4601	**	29.31	110400	3905	3882	2887
				29.52	109150	3860		
	125:49	5613	***	29.37	116550	4122	4080	3118
				29.35	114170	4038		
	677:51	28836	****	29.14	148780	5262	5234	4674
				29.08	147200	5206		
6x12 Lab- Cured Cylinders	78:27	3575	*	29.36	90870	3214	3396	2652
				29.70	101150	3577		
	104:11	4693	**	29.68	100950	3570	3700	2908
				29.56	108270	3829		
	127:35	5692	***	29.52	106580	3769	3689	3136
				29.88	102040	3609		
	676:51	28791	****	29.56	155430	5497	5406	4672
				29.92	150290	5315		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-47. I-75 Verification 9 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	22:18	45:45	73:38	100:09	124:32	676:46
Maturity (°C·Hrs)	1042	2160	3354	4507	5557	28791
Reading 1	22	21	22	28	26	42
Reading 2	22	23	26	26	26	36
Reading 3	22	31	26	24	24	34
Reading 4	23	24	24	24	24	32
Reading 5	25	22	28	26	26	34
Reading 6	25	24	22	25	27	32
Reading 7	22	26	21	27	24	32
Reading 8	20	23	22	26	26	36
Reading 9	20	25	24	26	28	33
Reading 10	20	24	24	26	28	34
Average Reading	22.1	24.3	23.9	25.8	25.9	34.5
Measured Strength (psi)	2589	3066	2978	3402	3425	5500
Predicted Strength (psi)	1363	2195	2606	2865	3105	4672

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-48. I-75 Verification 10 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	106:27	4700	**	8.09	33990	2705	2682	2909
				8.17	33410	2659		
	673:54	28082	****	8.08	44480	3540	3578	4655
				8.02	45440	3616		
6x12 Field- Cured Cylinders	81:37	3649	*	28.70	66830	2364	2344	2669
				28.36	65720	2324		
	105:30	4666	**	28.57	65960	2333	2268	2902
				28.55	62290	2203		
	129:27	5661	***	28.63	79800	2822	2627	3129
				28.43	68740	2431		
	673:36	28072	****	28.55	97320	3442	3527	4655
				28.38	102120	3612		
6x12 Lab- Cured Cylinders	83:24	3731	*	28.68	60610	2144	2154	2688
				28.80	61200	2165		
	106:38	4712	**	28.70	69510	2458	2427	2912
				28.68	67730	2395		
	129:12	5650	***	28.82	63680	2252	2334	3126
				28.64	68320	2416		
	674:06	28091	****	28.68	102830	3637	3630	4655
				28.98	102430	3623		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-49. I-75 Verification 10 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	26:25	54:18	81:12	105:15	128:57	673:43
Maturity (°C·Hrs)	1260	2464	3625	4655	5639	28091
Reading 1	19	25	22	25	28	28
Reading 2	22	22	24	26	26	29
Reading 3	18	20	22	25	28	28
Reading 4	20	22	22	24	24	32
Reading 5	18	22	25	24	24	33
Reading 6	20	21	22	26	26	30
Reading 7	23	24	24	28	26	28
Reading 8	22	24	23	29	31	34
Reading 9	24	23	24	31	29	30
Reading 10	21	21	23	28	25	32
Average Reading	20.7	22.4	23.1	26.6	26.7	30.4
Measured Strength (psi)	2293	2653	2804	3584	3607	4479
Predicted Strength (psi)	1577	2339	2664	2899	3124	4655

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-50. I-75 Verification 11 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	105:55	4784	**	8.15	34190	2721	2805	2928
				8.43	36300	2889		
	673:25	28265	****	8.27	46470	3698	3954	4659
				8.27	52910	4210		
6x12 Field- Cured Cylinders	81:13	3717	*	28.85	74100	2621	2722	2685
				28.88	79820	2823		
	105:06	4749	**	28.87	82970	2934	2955	2920
				28.73	84110	2975		
	129:03	5768	***	28.47	90160	3189	3136	3153
				28.78	87150	3082		
	673:13	28256	****	28.91	116190	4109	4091	4659
				28.53	115170	4073		
6x12 Lab- Cured Cylinders	83:04	3812	*	29.36	72180	2553	2504	2706
				29.08	69410	2455		
	106:18	4807	**	29.40	80190	2836	2871	2934
				29.20	82170	2906		
	128:44	5745	***	29.14	84440	2986	2906	3148
				29.00	79890	2826		
	673:35	28275	****	29.26	114890	4063	4077	4660
				29.08	115680	4091		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-51. I-75 Verification 11 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	26:01	53:48	80:48	104:49	128:26	673:43
Maturity (°C·Hrs)	1280	2511	3705	4738	5733	28275
Reading 1	22	22	30	26	32	34
Reading 2	23	22	22	26	27	34
Reading 3	24	24	26	26	29	28
Reading 4	20	21	24	29	26	29
Reading 5	23	20	24	28	24	30
Reading 6	22	20	26	24	28	30
Reading 7	23	23	24	22	28	30
Reading 8	20	26	23	28	28	30
Reading 9	24	22	24	28	28	32
Reading 10	20	21	22	24	28	30
Average Reading	22.1	22.1	24.5	26.1	27.8	30.7
Measured Strength (psi)	2589	2589	3111	3470	3861	4552
Predicted Strength (psi)	1592	2361	2682	2918	3145	4660

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity

Table D-52. I-75 Verification 12 Compressive Strength & Maturity Logger Data

Samples	Elapsed Time (Hr:Min)	Maturity (°C·Hrs)		Weight (lbs)	Load (lbs)	Strength (psi)	Measured Strength (psi)	Predicted Strength (psi)
4x8 Cores	104:15	4772	**	8.08	36260	2885	2874	2926
				8.25	35970	2862		
	671:43	28436	****	8.23	37530	2987	3214	4664
				8.07	43250	3442		
6x12 Field- Cured Cylinders	79:35	3703	*	28.32	71560	2531	2308	2681
				28.43	58950	2085		
	103:30	4738	**	28.38	73850	2612	2616	2918
				28.07	74080	2620		
	127:27	5754	***	27.82	81850	2895	2617	3150
				28.33	66150	2340		
	671:36	28436	****	28.52	91350	3231	3416	4664
				28.28	101820	3601		
6x12 Lab- Cured Cylinders	81:29	3783	*	28.72	64760	2290	2256	2700
				29.02	62790	2221		
	104:40	4783	**	29.04	67630	2392	2423	2928
				28.78	69410	2455		
	126:55	5731	***	28.78	73470	2598	2621	3145
				28.88	74750	2644		
	672:12	28456	****	29.28	107380	3798	3693	4664
				29.12	101440	3588		

* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 125% Target Maturity
**** 28-Day

Table D-53. I-75 Verification 12 Rebound Hammer & Maturity Logger Data

Day	1	2	3*	4**	5***	28
Elapsed Time (Hr:Min)	24:35	52:18	78:32	102:56	126:39	671:55
Maturity (°C·Hrs)	1232	2488	3655	4704	5720	28446
Reading 1	21	22	24	26	27	30
Reading 2	20	24	26	26	24	30
Reading 3	20	24	26	28	26	28
Reading 4	22	21	24	24	26	24
Reading 5	20	22	25	28	28	30
Reading 6	24	21	24	28	26	32
Reading 7	21	21	26	26	28	30
Reading 8	28	26	27	28	24	28
Reading 9	20	24	24	27	25	31
Reading 10	22	20	24	24	25	34
Average Reading	21.8	22.5	25.0	26.5	25.9	29.7
Measured Strength (psi)	2525	2674	3222	3561	3425	4310
Predicted Strength (psi)	1556	2350	2670	2910	3142	4664

--- Not Available
* Approximately 75% Target Maturity
** Approximately 100% Target Maturity
*** Approximately 100% Target Maturity

Table D-54. Temperature Data for Verification Location 2

Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)
0	28	66	31	288	31
2	31	68	31	300	36
4	34	70	30	312	30
6	39	72	30	324	35
8	40	76	34	336	29
10	40	80	37	348	36
12	39	84	35	360	31
14	38	88	32	372	35
16	36	92	30	384	31
18	35	96	29	396	36
20	34	100	34	408	31
22	34	104	38	420	35
24	34	108	35	432	30
26	36	112	32	444	34
28	37	116	30	456	28
30	39	120	29	468	35
32	40	124	34	480	29
34	40	128	37	492	35
36	38	132	35	504	29
38	37	136	32	516	35
40	36	140	30	528	30
42	35	144	29	540	36
44	34	156	34	552	30
46	34	168	29	564	31
48	34	180	31	576	27
50	35	192	27	588	33
52	35	204	30	600	29
54	33	216	27	612	34
56	34	228	32	624	29
58	34	240	28	636	31
60	33	252	35	648	29
62	32	264	30	660	34
64	32	276	35	672	29

Table D-55. Temperature Data for Verification Location 7

Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)
0	34	66	31	288	32
2	32	68	31	300	34
4	35	70	31	312	32
6	38	72	32	324	34
8	41	76	36	336	31
10	40	80	37	348	34
12	38	84	34	360	32
14	37	88	32	372	34
16	36	92	30	384	32
18	35	96	31	396	34
20	34	100	35	408	32
22	34	104	36	420	33
24	36	108	34	432	31
26	37	112	32	444	33
28	39	116	30	456	29
30	40	120	31	468	34
32	40	124	35	480	31
34	39	128	35	492	33
36	38	132	34	504	31
38	37	136	32	516	34
40	35	140	30	528	31
42	35	144	31	540	34
44	34	156	33	552	32
46	34	168	30	564	31
48	35	180	30	576	29
50	35	192	29	588	32
52	34	204	30	600	30
54	34	216	28	612	32
56	34	228	30	624	30
58	34	240	29	636	31
60	33	252	33	648	30
62	32	264	31	660	32
64	32	276	34	672	30

Table D-56. Temperature Data for Verification Location 11

Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)	Age (Hours)	Temperature (°C)
0	30	66	32	288	30
2	31	68	31	300	35
4	34	70	30	312	29
6	40	72	30	324	35
8	45	76	34	336	30
10	46	80	38	348	35
12	44	84	36	360	30
14	43	88	33	372	36
16	41	92	31	384	30
18	40	96	29	396	35
20	38	100	33	408	29
22	38	104	36	420	35
24	37	108	35	432	27
26	38	112	32	444	35
28	39	116	31	456	29
30	37	120	29	468	35
32	35	124	33	480	29
34	35	128	36	492	35
36	35	132	35	504	29
38	34	136	32	516	36
40	34	140	30	528	29
42	33	144	29	540	31
44	32	156	31	552	27
46	32	168	26	564	34
48	31	180	31	576	28
50	32	192	26	588	33
52	34	204	32	600	29
54	37	216	28	612	31
56	39	228	35	624	28
58	38	240	29	636	34
60	37	252	35	648	29
62	35	264	30	660	34
64	34	276	36	672	28

APPENDIX E

MODIFIED AASHTO SPECIFICATIONS

Standard Test Method for Estimating the Strength of Concrete in Transportation Construction by Maturity Tests

AASHTO Designation: TP52-95[1,2]
Modified for Use by the Tennessee Department of Transportation

1. Scope

1.1 This standard provides procedures for estimating concrete strength in roads, bridges and other transportation structures through the use of a maturity index.

1.2 This standard requires determination of the strength-maturity relationship of the approved concrete job mix in the laboratory, and determination of the temperature history subsequent to placement in the field.

1.3 This method may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Reference d Documents

2.1 AASHTO Standards:

R9	Acceptance Sampling Plans for Highway Construction
R18	Establishing and Implementing A Quality System for Construction Materials Testing Laboratories
T276	Developing Early Age Compression Test Values and Projecting Later Age Strengths

2.2 ASTM Standards:

C1074	Estimating Concrete Strength by the Maturity Method
D3665	Random Sampling of Construction Materials
E105	Probability Sampling of Materials
E122	Choice of Sample Size to Estimate the Average Quality of a Lot or Process
E141	Acceptance of Evidence Based on the Results of Probability Sampling

[1] This standard is based on SHRP product 2022.
[2] Approved in December 1995, this provisional standard was first published in June 1996.

3. Terminology

3.1 Maturity – the extent of development of concrete properties that are dependent on cement hydration and pozzolanic reactions.

3.2 Maturity function – a mathematical expression that converts the temperature history of concrete to an index which indicates its maturity.

3.3 Maturity index – an index, calculated by using a maturity function, which can be used as an indicator of strength development in concrete.

3.4 Strength-maturity relationship – an empirical relationship between concrete strength and its maturity index, usually determined by comparing the strength of concrete cylinders, made from a specific concrete mix, to their maturity index at time of strength testing.

4. Significance and Use

4.1 This standard can be used to estimate the strength of concrete placed in pavements and structures. These estimates provide guidance useful in making decisions concerning opening to traffic, form removal, post tensioning, termination of curing procedures, and initiation of strength test on the in-place concrete such as coring and pullout tests.

4.2 The most critical limitations of the procedures presented are 1) batching or placement errors are not detected, 2) curing errors other than those that affect temperature are not detected and 3) the actual strength of the concrete is not measured.

> Note 1 – Concrete must be cured in a condition that supports cement hydration/pozzolanic reactions.

4.3 This standard provides technical personnel with a coordinated procedure for 1) developing a strength-maturity relationship for the approved concrete job mix in the laboratory, 2) determining the temperature history of the in-place concrete, 3) determining the maturity index of the in-place concrete and, 4) using the strength-maturity relationship and the maturity index to estimate the strength of the in-place concrete.

5. Apparatus

5.1 Laboratory Requirements

5.1.1 Personal safety equipment required by the Laboratory and/or OSHA for work in the laboratory concrete mixing and testing areas.

5.1.2 Maturity loggers suitable for embedment in the center of cylindrical concrete test specimens and a maturity reader.

5.1.3 A computer terminal for input of laboratory test data or a supply of concrete test reports.

5.2 Field Requirements

5.2.1 Personal safety equipment required by the Laboratory/field organization and/or OSHA for work in the field concrete placement areas.

5.2.2 Maturity loggers suitable for embedment in the concrete placement

5.2.3 A maturity reader suitable for monitoring and recording the temperature of the concrete. The maturity reader is a device that automatically reads the maturity logger signals and digitally displays the data on demand.

6. Hazards – Observe the safety procedures required by the Laboratory and/or Field Agency and/or OSHA for each laboratory and field operation as applicable.

7. Field Sampling

7.1 Select the temperature sampling sites for installing maturity loggers by determining the quantity of concrete that is to be evaluated and dividing the concrete placement into lots that approximate the quantities indicated in Table 1. For the purposes of this standard, the quantity of pavement shall be estimated in square yards and the quantity of structural concrete shall be estimated in cubic yards

7.2 Select temperature sampling alternates in the following manner:

7.2.1 When the maturity of all lots is to be determined, use a stratified random selection procedure in determining where to place the temperature proves/sensors in each concrete lot to be evaluated, as indicated in Table 1.

7.2.2 When the maturity of only a fraction of the total lots is to be measured, determine the number of lots in accordance with Equation 1.

$$L_l = FT - L_L \qquad (1)$$

Where:

L_l = lots to be randomly chosen,
F = fraction of lots to be sampled for maturity testing,
T = total number of lots, and
L_L = last lot placed.

7.2.2.1 Round L_l to the next higher whole number. Then randomly select the number of lots, L_l, from the available lots, excluding the last lot placed, L_L. Add L_L to the list of randomly chosen lots scheduled for maturity testing. Finally, use a stratified random selection procedure to determine where to place each of the temperature probes/sensors, as indicated in Table 1, in each concrete lot scheduled for evaluation.

Note 3 -- Example: if T = 10, and F= 1/8, then L_l = 0.25. Rounding to the next higher whole number, L_l = 1. Then, excluding the last lot placed, there are (10- L_L) = 9 lots from which L_l is randomly selected. Assume that lot number 4 is the randomly selected lot, and that lot number 10 is L_L, the last lot placed. Then lots numbered 4 and 10 are scheduled for maturity testing. The purpose for excluding L_L from the random selection of lost scheduled for testing and then specifically including L_L in the list of lots scheduled for testing is to assure that the lot containing the last concrete placed is one of those evaluated in the maturity testing process. If all other factors are equal, L_L will be the weakest lot at the times likely to be of interest during the construction process. A similar approach should be followed with regard to a lot(s) that will be exposed to significantly more adverse curing conditions than other lots under evaluation.

Note 4 – ASTM D3665 contains a table of random numbers, including instructions for use. AASHTO R9 and ASTM E105, E122, and E141 contain additional information concerning sampling practices.

8. Preparations

8.1 Laboratory Operations – Prior to the initiation of the laboratory concrete placement operation, check to ensure that an adequate supply of maturity loggers is available for the scheduled work and a maturity reader is available for activation of the maturity loggers immediately after they are embedded in the concrete cylinders.

8.2 Field Operations – Prior to the initiation of the field concrete placement operation 1) select which sampling alternate is toe be used, 2) check to ensure that an adequate supply of maturity loggers is available for the scheduled concrete placement, 3) determine the locations at which the maturity loggers will be installed, and 4) ensure that a maturity reader is available for activation of the maturity loggers immediately after placement of the concrete lot.

9. Standardization – Verify the calibration of systems used for monitoring the maturity of concrete on a periodic basis.

> Note 5 – System verification can be accomplished by placing the temperature probe/sensor in a controlled temperature water bath and recording whether the indicated result agrees with the known temperature of the bath. Use at least 3 different temperature points (e.g. 5, 25, and 45°C).

10. Procedure

10.1 Develop the strength – maturity relationship for the approved concrete job mix in accordance with the manufacturer's recommendations (or the AASHTO T 276 Modified for TDOT Use).

10.2 Determine the temperature history of concrete after placement in the field as follows:

10.2.1 Insert the maturity logger in the fresh concrete at the predetermined location(s). If the maturity logger is installed prior to placement of the concrete, tie the logger wire to reinforcement to prevent displacement during the placement of the concrete. Maturity loggers can be inserted through an open surface of the concrete or through very small holes in forms.

10.2.2 Generally, maturity loggers should be placed 2 to 4 inches from any surface of the concrete placement. In a pavement overlay, place maturity loggers at mid-depth.

10.2.3 Protect wire connections to the maturity loggers from construction operations. In critical locations, use duplicate maturity loggers with separated wiring runs.

> Note 6 – SHRP research indicated that if a concrete surface is protected from a high rate of heat loss, the difference in maturity indexes between the center and surface of pavements, bridge decks, and structures 12 inches or less thick is negligible.

10.2.4 Make reader connections with the maturity loggers immediately after concrete placement and activate the maturity logger.

10.3 After placement of the concrete in the field, determine the maturity index at each maturity logger location periodically using the maturity reader.

10.4 Estimate the in-place strength of concrete in the field using the strength-maturity relationship and the maturity index.

10.4.1 Compare the maturity index determined in Section 10.3 to the strength-maturity relationship determined in section 10.1. The concrete strength value of the strength-maturity relationship which corresponds to the measured maturity index from a particular maturity logger location is the estimated concrete strength at that location.

10.4.2 Determine the estimated strength of a concrete lot using Equation 2.

$$S_{L(est)} = (\text{sum from } i = 1 \text{ to } i = n \text{ of } X_i)/n$$

Where:

$S_{L(est)}$ = estimated strength of the concrete lot,
X_i = estimated strength of concrete at a specific maturity logger location,
i = individual maturity logger, and
n = number of maturity loggers in the concrete lot.

11. Report

11.1 Laboratory Report – Include the following information in the final laboratory report:

11.1.1 Identification of the laboratory and date of testing;

11.1.2 Identification of the concrete job mix used for laboratory tests;

11.1.3 The strength of each test specimen and the average strength of test specimens at each test age;

11.1.4 The maturity index for each instrumented test specimen and the average maturity index for the instrumented specimens at each test age;

11.1.5 A graph of the average compressive strength versus the average value of the maturity index as described in the manufacturer's recommendations (or the AASHTO T 276 Modified for TDOT Use); and

11.1.6 Any other information required by the laboratory organization.

11.2 Field Report – Include the following information in the field report:

11.2.1 Project and route number;

11.2.2 A list, for each concrete lot evaluated, identifying the concrete job mix used and showing the station numbers, offset, item number, quantity of concrete, the number (how many) and location of each maturity logger installed, the maturity index determined for each maturity logger location, the estimated strength determined for each maturity logger location, and the estimated average strength for each concrete lot.

11.2.3 (OPTIONAL) Any additional data required by the laboratory/field organization responsible for the estimating the concrete strength by means of the maturity method.

12. Precision and Bias – The research required to determine the precision and bias of this standard has not been performed.

13. Keywords – concrete, maturity, maturity index, estimating concrete strength, strength-maturity relationship

Table 1. Minimum Number of Maturity Loggers Required for Concrete Lot

Structural Component	Quantity of Concrete in Lot	Number of Probes/Sensors
Slabs, beams, and abutment walls	100 yd^3	5
Columns	2-10 yd^3	1
Columns	More than 10 yd^3	2
Pavement, pavement overlays	1000 yd^2	2
Pavement repairs	Per repair or per 750 yd^2 (whichever is smaller)	2

Standard Method of Test, Modified for Use by the Tennessee Department of Transportation, for Developing Early-Age Compression Test Values and Projecting Later-Age Strengths

AASHTO Designation: T 276-97 (2001)
ASTM Designation: C 918-93

1. SCOPE

1.1 This test method covers a procedure for making, curing, and testing specimens of concrete stored under conditions intended to measure the maturity as it relates to strength gain in the concrete.

1.2 This test method also covers a procedure for using the maturity measurements and compressive-strength values to project potential strength of field concrete.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 *ASSHTO Standards:*

- M 205, Molds for Forming Concrete Test Cylinders Vertically
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 126, Making and Curing Concrete Test Specimens in the Laboratory
- T 141, Sampling Freshly Mixed Concrete
- T 231, Capping Cylindrical Concrete Specimens

3. TERMINOLOGY

3.1. *Descriptions of Terms Specific to This Standard*:

3.1.1. *degree-hours* – the age of a concrete cylinder in hours multiplied by the weighted average ambient temperature of that specimen. Degree-hours are obtained by dividing the age into suitable time intervals and the average ambient temperature during that interval.

3.1.2. *Maturity* – A measure to describe and to account for the combined effects of age and temperature on the strength of concrete. Maturity is expressed in degree-hours.

3.1.3. Prediction Plot – The plot composed of the lines of prediction that is used to predict the potential strength of Portland –cement concrete from tests on the compressive strength specimens at an early age.

4. SUMMARY OF TEST OF METHOD

4.1. This test method utilizes conventional curing with testing at not less than 20 hours. Storage during curing is as required by T 23 or T 126 with a maturity logger added to at least two (2) cylinders to monitor the maturity of the PCC specimens.

5. SIGNIFICANCE AND USE

5.1. This test method provides a procedure for constructing a mixture specific compressive strength-maturity relationship. It also provides information on using the correlation to allow new PCC pavements to traffic.

6. APPARATUS

6.1. *Equipment and Small Tools* – for fabricating specimens and measuring plastic concrete characteristics shall conform to the applicable requirements of T 23 or T126.

6.2. *Molds* – for specimens, shall conform to the requirements for cylinder molds in M 205.

6.3. *Maturity Logger* – to record accurately within ± 1.8°F (1°C) the temperature of the specimens during curing.

6.4. *Maturity Reader* – to download maturity logger data and upload the data to a computer.

7. SAMPLING

7.1. Sample and test the concrete in accordance with T 23, T 126, or T 141.

8. EARLY-AGE STRENGTH PROCEDURE

8.1. Mold and cure the specimens in accordance with T 23 or T 126. Continue curing for at least 20 hours.

8.2. Maintain a record of the maturity of the specimens during curing.

8.3 Testing – After 20-22 hours, remove the specimens from the molds as soon as practical. Test the cylinder for strength in accordance with T 22 at the age of 24 hours or more. Note the exact maturity at the time of the test.

9. PROCEDURE FOR DEVELOPING STRENGTH – MATURITY RELATIONSHIP

9.1. Develop compressive strength data for different ages of tests, and the corresponding maturity values in the laboratory or field to establish the prediction plot for each mixture to be used. These data shall include tests at age 24 hours, and 2, 3, 4, 7, 10, 14, 28 and 56 days. Compressive strength at each age shall be determined by averaging the strength obtained from a minimum of two cylinders.

9.2. Plot each of the strength values as developed in Section 9.1 versus the maturity for each age of the test. Do not draw a best-fitting straight line simply connect the points with line segments.

9.3. Target maturity is found by determining the abscissa of the point on the compressive strength-maturity correlation plot whose ordinate is the specified compressive strength.

10. FIELD APPLICATION

10.1 To accept the material as conforming to specifications requirements for opening to traffic use the following:

$S_M > (LL + K)$

where:

S_M = predicted strength at target maturity;
LL = specified lower compressive strength limit;
K = $1.645\ (\Sigma(S_M - S_{MTM})^2/2n)^{0.5}$;
1.645 = confidence coefficient for a five percent probability of accepting material with a strength below LL;
S_{MTM} = measured 28-day strength; and
n = number of paired (S_M and S_{MTM}) values used in the analysis.

10.2 The first twelve times a maturity logger is placed in the field, a pair of 6x12 cylinders will be fabricated and field-cured in close proximity to the maturity logger location. The pair of cylinders will be tested at 100 to 110% of target maturity. The average compressive strength of the pair will be used to verify the compressive strength-maturity correlation and also to establish the K value for the mixture.

10.3 At the discretion of the engineer, additional pairs of field-cured 6x12 cylinders may be required to refine K. Limited experience has shown that K ≥ 800-psi indicate high variability and need further refinement / investigation.

10.4 At the discretion of the engineer, a new compressive strength-maturity correlation plot may be required. A new compressive strength-maturity correlation plot should be considered when $S_M > 1.10(S_{MTM})$.

11. REPORT

11.1. The laboratory report shall include the following:

11.1.1. Identification number of test cylinder.

11.1.2. Diameter (and length, if not standard) of test cylinder, in inches or millimeters.

11.1.3. Cross-sectional area of test cylinder, in square inches or square centimeters.

11.1.4. Maximum load in pounds-force or newtons.

11.1.5. Compressive strength calculated to the nearest 10 psi (0.1 MPa).

11.1.6. Type of fracture, if other than the usual cone.

11.1.7 Age of specimens at the time of test.

11.1.8. Initial mix temperature to the nearest 2°F or 1°C.

11.1.9. Temperature records, and

11.1.10. Method of transportation used for shipping the specimens to the laboratory.

11.1.11. Compressive strength-maturity correlation plot.

11.1.12. Target maturity.

11. PRECISION AND BIAS

12.1. *Precision* – yet to be determined

12.2. *Bias* – This test method has no determinable bias as the values obtained can only be defined in terms of this test method.