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16. Abstract

Over the years, the Center for Transportation Research at The University of Texas at Austin, under the support of the Texas Department of Transportation (TxDOT), has conducted various research projects on materials, design, construction and analysis of portland cement concrete (PCC) pavement, more specifically continuously reinforced concrete pavement (CRCP), to improve its performance. One of the significant findings is that the concrete temperature at early ages has a significant effect on long-term performance of CRCP. Under research study 0-1700, a concrete temperature prediction model, PavePro, was developed and its accuracy validated using field temperature data. One of the primary objectives of this study was to evaluate the viability for limiting concrete maximum temperature during setting process, not the concrete temperature as delivered, which is the current specifications requirement. In this study, the shadow specifications were implemented in three construction projects: two projects in the Austin District and one in the Houston District. In accordance with shadow specifications, concrete temperatures at three different depths were predicted from PavePro using anticipated ambient temperatures and the properties of materials to be used. Based on the predicted concrete temperatures, a decision was made regarding the times and locations of temperature sensor installations. The temperature sensors used in this study are called I-buttons. At least 24 hours after the concrete placement, temperature data was retrieved from the embedded sensors and the actual temperature values were checked against the limit values allowed in the specifications. It is concluded that the implementation of shadow specifications is feasible. The equipment cost involved with the implementation will be minimal. The maximum concrete temperatures predicted by PavePro were within a range of 6.9 degrees, when compared to the actual values. The difference between predicted and actual temperature differentials between the top and the bottom of the slab was less than 3.6 F. This indicates the reasonableness of the PavePro predictions.

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Implementation of Shadow Specifications for Temperature Control in PCC Pavement

Dong-Ho Kim
Moon Won

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Report Date:	March 2006
Project:	5-1700-03
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Products

This report documents Product 2: Recommendations for changes to PCCP construction specifications.

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1. Introduction

1.1 Background

Over the years, the Center for Transportation Research at The University of Texas at Austin, under the support of The Texas Department of Transportation (TxDOT) has conducted various research projects on materials, design, construction and analysis of portland cement concrete (PCC) pavement, more specifically continuously reinforced concrete pavement (CRCP), to improve its performance. These research projects investigated mechanistic behavior of pavement systems and evaluated the primary factors responsible for pavement performance. The studies identified four factors that have significant effects on the performance of CRC pavement, and they are as follows: 1) aggregate type, 2) construction season, 3) concrete placement temperature, and 4) evaporation rate. Based on the findings, McCullough et al recommended that performance-based specifications be developed and implemented to improve the overall PCC pavement performance in Texas (McCullough et al., 1998).

One of the objectives of the long-term research project 5-1700-03-1 was to identify the effect concrete temperature has on long-term CRCP performance and to develop specifications to mitigate the detrimental effects of high concrete temperature on CRCP performance. The hypothesis that concrete temperature during concrete placement has significant effects on the long-term performance of CRCP is based on the assumption that crack widths and resulting load transfer efficiency at transverse cracks depend on the concrete placement temperature. It is further assumed that the number of punchouts is a function of transverse crack spacing, on which placement temperature has a significant effect. The implementation project 5-1700-03 is to develop shadow specifications and apply them to the actual construction project to evaluate the feasibility of implementing the specifications.

1.2 Objectives

The objective of this implementation study was to evaluate the applicability of the shadow specifications developed in this study to the actual construction project. In order to achieve this objective, the following tasks were conducted: 1) development of shadow specifications, 2) selection of three test sections, 3) field application of shadow specifications, and 4) evaluation of the shadow specifications.

1.3 Scope

The scope of this report is limited to the evaluation of the applicability of shadow specifications to the actual TxDOT construction project and the identification of any issues that need to be addressed for full implementation of the shadow specifications. This study consisted of the following: (1) the development of shadow specifications, (2) implementation of the shadow specifications in TxDOT construction projects, and (3) evaluation of the results.

2. Shadow Specifications and Pilot Projects

This chapter presents shadow specifications developed from this project, introduction of PavePro, and the general description of the activities conducted in this study.

2.1 Shadow Specifications

The provision below shows the shadow specifications developed in this project. The shadow specifications require the use of temperature measuring devices capable of capturing measurements for at least 48 hours and concrete temperature prediction models. Concrete temperatures for 2 days after placement are predicted with available weather information. Based on the predicted concrete temperatures, the locations of temperature measuring device installations are determined. At each location, three temperature measuring devices are installed: one in. from the top, at the middle, and one in. from the bottom of the slab. Figure 2.1 shows a flow chart for the shadow specifications.

ITEM 360

SHADOW SPECIAL PROVISION

360.3. Equipment shall be supplemented by the following:

K. Temperature Measuring Devices and Prediction Model. Provide temperature measuring devices capable of measuring and recording the in situ concrete temperature for a total of 2,048 readings or more. Obtain concrete temperature prediction model that has been shown to be accurate and reliable such as PavePro.

360.4. G. Concrete Placement 4. Temperature Restrictions shall be supplemented by the following:

4. **Temperature Restrictions.** Place a set of three temperature measuring devices at each location: 1 in. from the top, at the middle, and 1 in. from the bottom of the concrete slab. Insert these temperature measuring devices to fresh concrete every hour of construction for morning placement and every two hours for placement after 12 p.m. If the predicted maximum placement temperatures for the first 24 hours are lower than 120° F and the predicted maximum temperature difference between the top and bottom of the slab for the first 48 hours is less than 25° F, place only two sets of temperature measuring devices at the predicted time of maximum concrete temperature and temperature difference.

   The maximum concrete temperature for the first 24 hours after concrete placement shall not exceed 120° F, and the concrete temperature difference between the top and the bottom of the slab for the first 48 hours after concrete placement shall be less than 25° F.

The selection of 120° F and 25° F for the maximum concrete temperature and temperature differential, respectively, was made by Dr. Frank McCullough based on his many years' of extensive experience with temperature effects on CRCP performance in Texas. Further evaluation will be needed to validate these limits.

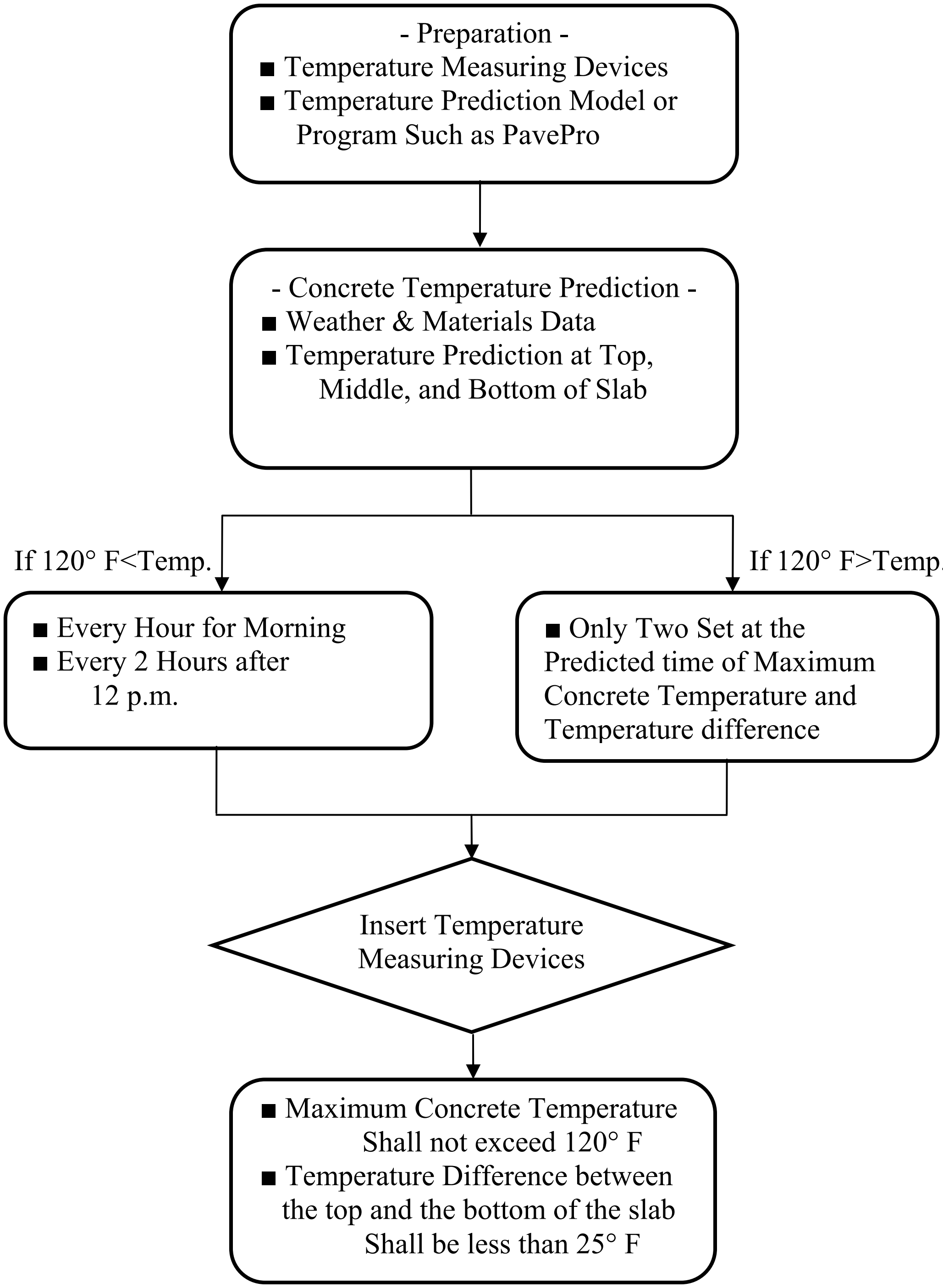

Figure 2.1 Flow Chart for Shadow Specification

2.2 PavePro

This section will briefly describe the PavePro program and introduce the input variables.

2.2.1 Description of the Program

PavePro computer program was developed by the Center for Transportation Research of The University of Texas at Austin under research project 0-1700 (Schindler, et al, 2002). The primary input variables required in this program include predicted weather information and material properties such as the mixture proportion of concrete, chemical composition and hydration properties of cement, CaO content of fly ash, activation energy, and adiabatic constants. For example, Figure 2.2 shows the degree of hydration versus the concrete equivalent age that is required in this program.

In addition, the program requires input variables such as pavement structure, fresh concrete temperature, base temperature, curing method, and environmental data such as ambient temperature, relative humidity, wind speed, and percentage of cloud cover. With these inputs, the program predicts concrete temperatures at locations of 1 in. from the surface, mid-depth, and 1 in. from the bottom of the concrete slab, as well as ambient temperatures. It also provides zero-stress temperature, final setting time, and temperature gradient for up to 36 hours with 3-hour intervals.

The next section will provide the details of the input variables.

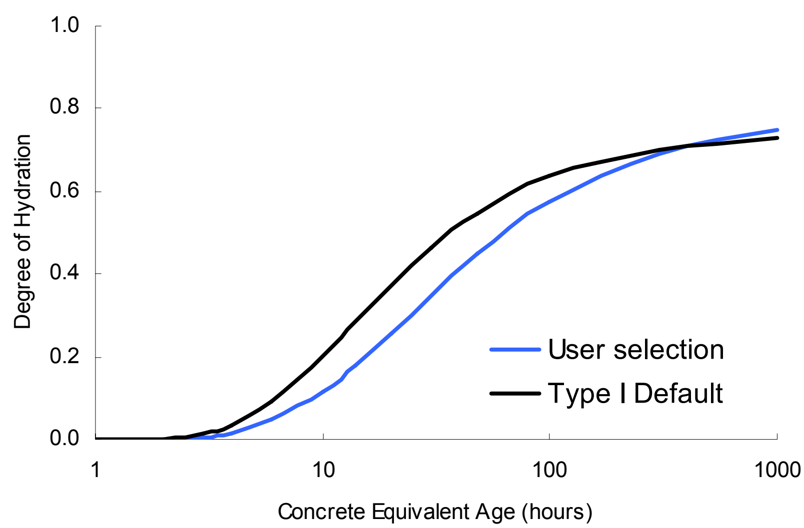

Figure 2.2 Hydration-Maturity Functions

2.2.2 Input Variables

Input variables of the PavePro program are divided into the following groups: general, mix proportion, material, environmental, and construction inputs. Detailed information on the input variables is described elsewhere (Schindler, 2002), and a brief description is provided here.

➢ ***General inputs***

Variables in this category include pavement slab and sub-base thicknesses and type (asphalt concrete, cement stabilized, asphalt stabilized, granular, and existing PCCP), prediction reliability level(50, 75, 90, 95%), geographical location in Texas, construction date, and time of placement.

➢ ***Mixture proportion inputs***

Information available in normal concrete mix design is required. They include mixture proportions such as w/c ratio, the amount of cementitious materials, aggregates, and chemical admixtures.

➢ ***Material inputs***

Listed below are the material properties required for PavePro:

- cement and other supplementary cementing materials (SCM): type, chemical composition, fineness, surface area, CaO content for fly ash
- coarse aggregate: type of coarse aggregate, thermal coefficient of concrete
- cementitious materials: activation energy, adiabatic constants (α_u, τ, β).

The most significant input variable is the hydration properties defined by the activation energy and the hydration parameters of cement used. These values are determined from the semi-adiabatic testing. In this program, the following exponential function has been employed to represent the degree of hydration development:

$$\alpha(t_e) = \alpha_u \cdot \exp\left(-\left[\frac{\tau}{t_e}\right]^{\beta}\right)$$

Where, the hydration time parameter (τ) corresponds to the time at which 37% of the degree of hydration has progressed. Higher values of τ are anticipated for more reactive cementitious materials such as Type3 cements, whereas, lower τ values are expected for cements that contain fly ash or slag. The hydration slope parameter, β, predominantly changes the slope of the hydration curve. An increase in β is associated with more reactive cementitious materials; however, because the hydration time is simultaneously delayed, a coinciding change in the τ parameter is also required. The ultimate degree of hydration parameter, α_u is factor affecting the magnitude of the degree of hydration. The higher α_u, the higher the final degree of hydration will become, and additional total heat will become available for the hydration process (Schindler 2002).

➢ ***Environmental inputs***

There are two options available for environment inputs. In the first option, a user provides the geographical location of the project and the program generates environmental data needed for the analysis. The data generated is based on the 30-year weather information from the National Oceanic & Atmospheric Administration (NOAA) database. The other option is to obtain local weather information for the next 3 days from the day of concrete paving and input that into the program. Between the two options, it is found that the results generated by the latter one are closer to the actual environmental conditions than those generated by the former one. It should be noted that the environmental input values have significant effect on the accuracy of the predicted concrete temperatures, and efforts should be made to obtain accurate information on the environmental conditions during concrete paving. Figure 2.3 shows the forecast weather information used in this project. It shows that the data was updated at 4:00 p.m. on November 10, 2005 and provides predicted environmental conditions for the next 3 days (72 hours). The following link is the source of the weather data shown in Figure 2.3.

<http://www.srh.noaa.gov/ifps/MapClick.php?FcstType=digital&textField1=30.3153839111328&textField2=-97.7663345336914&site=ewx>

- ***Construction inputs***

Finally, construction inputs include fresh concrete temperature, base temperature, and curing method. There are three different ways to calculate the fresh concrete temperature and they are as follows: calculating from environmental conditions, defining by user, or calculating from raw material temperatures. There are two options with regard to the base temperature: calculating from environmental conditions and defining the temperature at surface by user. Information on curing methods includes time of curing compound application, number of curing applications such as single coat or double coat, application rate defined by square feet per gallon, and color of curing compound.

www.srh.noaa.gov

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Tabular Forecast for 30.32N -97.77W

Last Update: 4:00 pm CST November 10, 2005

Locations within 5 miles of this gridpoint include...Austin TX...Lost Creek TX...Rollingwood TX...West Lake Hills TX

Digital Forecast

☑ Temperature ☑ Wind Chill ☑ Rel.Humidity ☑ Rain ☑ Snow ☑ Pcpn.Probability Submit

☑ Dewpoint ☑ Wind ☑ Sky Cover ☑ Thunder ☐ Freezing Rain

Date	11/10							11/11																
Hour	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Temp	75	73	70	67	65	64	62	61	61	60	60	59	58	58	59	61	65	69	72	76	77	79	80	79
Dewp	49	49	49	49	49	50	50	50	51	52	52	53	54	54	55	58	59	60	62	63	63	63	63	63
RH(%)	40	43	47	52	56	60	65	67	70	75	75	80	87	87	87	90	81	73	71	64	62	58	56	58
WdChl																								
PoP	5	5	5	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10	10	10	10
Sky (%)	19	21	23	24	25	25	25	15	15	15	50	50	50	100	100	100	100	100	100	85	85	85	85	85
WDir	WNW	W	WSW	SW	SW	SSW	SSE	SE	SSE	SSW	SW	SSW	SSE	SE	SE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE
WSpd	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	6	7	8	9	10	10
GSpd																								
Rain	--	--	--	--	--	--	--	--	--	--	--	--	--	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc
Tstm	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Snow	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Date								11/12																
Hour	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Temp	78	77	75	74	72	71	71	70	70	69	69	69	68	68	69	70	72	75	77	79	80	81	82	81
Dewp	64	64	65	66	66	66	67	67	67	68	68	68	68	68	69	69	69	69	69	69	69	69	69	69
RH(%)	62	64	71	76	81	84	87	90	90	97	97	97	100	100	100	97	90	82	76	72	69	67	65	67
WdChl																								
PoP	10	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	20	20	20	20	20	20	20
Sky (%)	85	85	85	85	75	75	75	100	100	100	100	100	100	100	100	100	90	90	90	80	80	80	97	97
WDir	SSE	SE	SE	SE	SE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	S	S	S	S	S	S	S	S	S
WSpd	9	8	8	9	9	9	9	9	9	8	8	8	7	7	7	8	9	9	10	10	11	13	13	11
GSpd																								
Rain	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc
Tstm	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	SChc	SChc	SChc	SChc	SChc
Snow	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Date								11/13																
Hour	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Temp	80	78	77	75	73	73	72	71	71	70	70	70	69	69	70	71	73	75	78	79	80	81	82	81
Dewp	68	68	68	69	69	69	70	70	70	70	70	70	69	69	70	69	69	68	68	67	67	66	65	65
RH(%)	67	71	74	82	87	87	93	97	97	100	100	100	100	100	100	93	87	79	71	67	65	60	57	58
WdChl																								
PoP	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Sky (%)	97	60	60	60	60	60	60	75	75	75	75	75	75	90	90	90	67	67	67	67	67	67	67	67
WDir	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	SSE	S	S	S	SSW	SSW	S	S	SSE	SE
WSpd	9	8	7	7	8	8	8	8	7	6	5	3	3	2	2	2	3	3	5	5	5	5	6	6
GSpd																								
Rain	SChc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc
Tstm	SChc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc	Chc
Snow	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Radar and Satellite Images

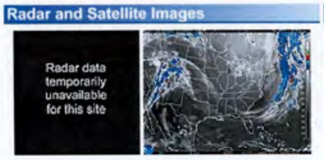

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Figure 2.3 Weather Information Collected from Website

2.3 Test Sections

Three sections were selected for this study. Detailed information on the test sections, including the location, pavement structure, concrete mix design, and environmental conditions during construction, is described below. Information on pavement structure and concrete mix proportions for each test section is presented in Figure 2.7 and Table 2.1, respectively.

2.3.1 Austin Test Section (US 183)

This section was located on US 183 between IH-35 and US 290. The placement of concrete began at 7 a.m. and was completed at 3:30 p.m. on November 11, 2005. The slab thickness of the US 183 test section is 13 in., while the width is about 25 ft. The location of this test section is shown in Figure 2.4.

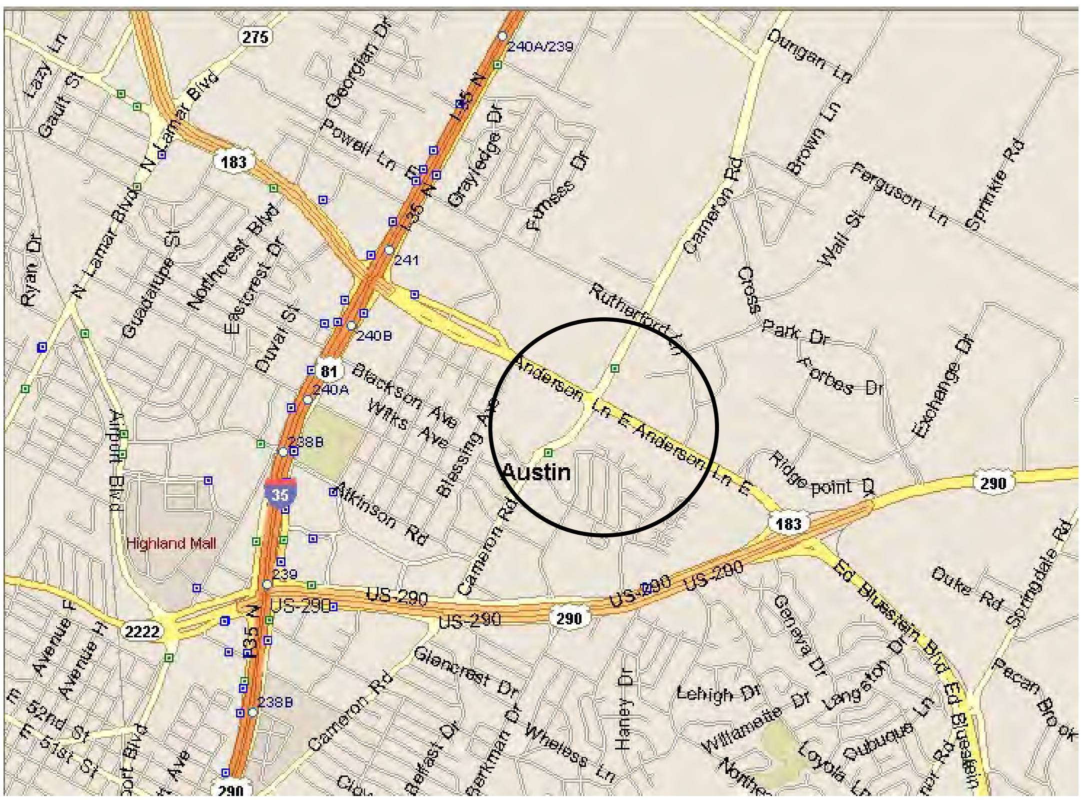

Figure 2.4 Location of Austin Test Section (US 183)

2.3.2 Austin Test Section (US 290)

This test section was located on Ben White Blvd. just west of IH-35. The placement of concrete began at 7:30 a.m. and was completed at about 3:30 p.m. on October 25, 2004. The thickness of the concrete slab was 13 in. and the width was about 15 ft (188 inches). Concrete slump values were 3.5 inches in the morning and 2.5 inches in the afternoon, respectively. Figure 2.5 shows the location of the test section.

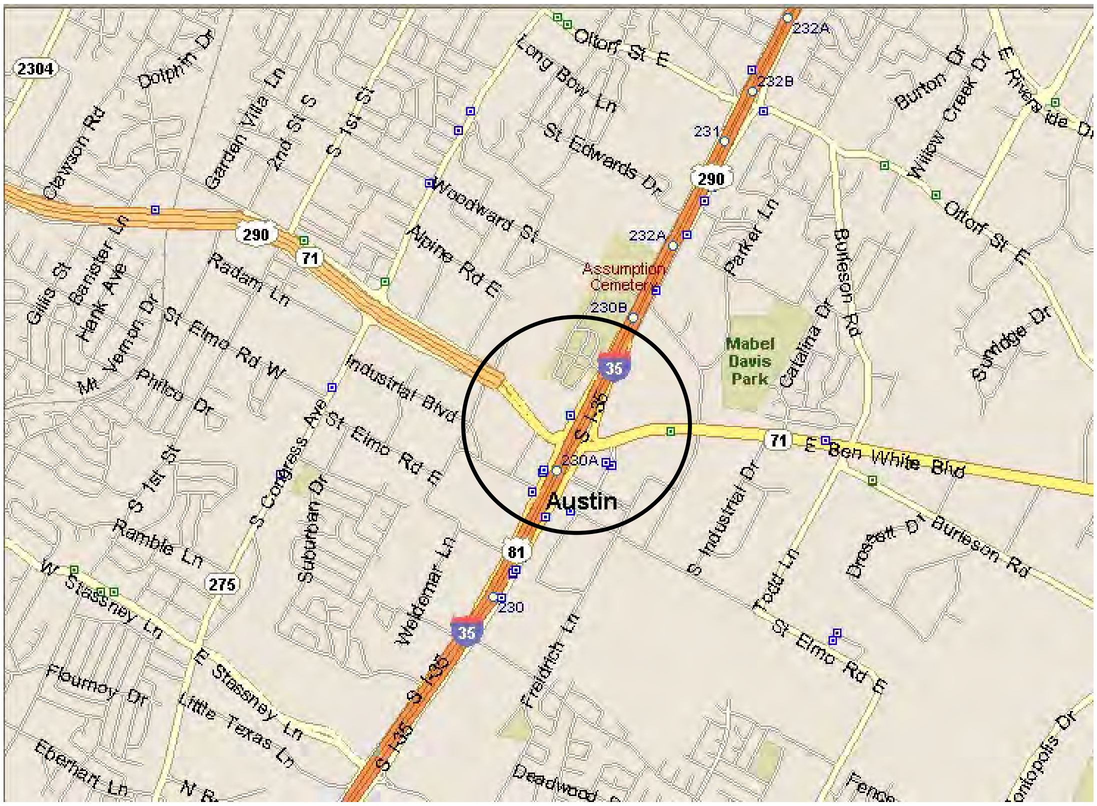

Figure 2.5   Location of Austin Test Section (US 290)

2.3.3 Houston Test Section (US 59)

Houston test section was located on US 59 in Cleveland. Figure 2.6 shows the location of the test section.

Figure 2.6   Location of Houston Test Section (US 59)

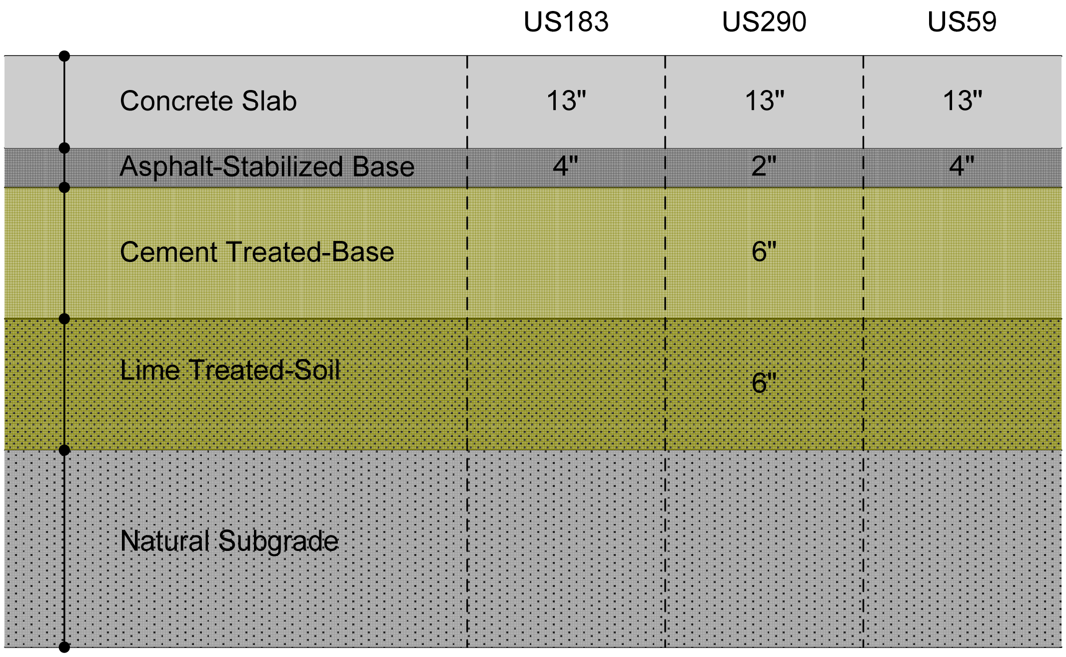

Figure 2.7 Pavement Structure of Test Sections

Table 2.1 Concrete Mix Designs used on Each Test Sections

Test Section	Unit	US-183	US-290	US-59
W/C ratio	-	0.52	0.59	0.44
Cement Factor	Sk./cy	5.0	-	5.5
Coarse Aggregate	-	0.685	-	0.740
Factor			-	
Max. Aggregate Size	inch	1.0	-	Grade 2
Water	lbs/cy	229	291	215
Cement	lbs/cy	358	336	362
Coarse Aggregate	lbs/cy	1916	1816	1848
Fine Aggregate	lbs/cy	1368	1287	1265
Fly Ash	lbs/cy	100	152	131
Air Entraining	oz	2.64	-	0.83
Reducer Retarding	oz	10.58	-	4.14

3. Implementation of Shadow Specifications

Shadow specifications were implemented to three projects as described in the previous chapter. Pavement temperatures were predicted from the computer program PavePro using appropriate input values. Table 3.1 presents the input values used for each project. For accurate predictions of pavement temperatures, the hydration-related properties of cementitious materials need to be properly quantified. However, in actual construction projects, it is not expected that those tests will be conducted for the purpose of accurate temperature predictions. Rather, default values will be used. In this project, default values provided in the PavePro program were utilized.

3.1 I-Button Assembly and Temperature Measurements

The devices used for concrete temperature measurements were i-buttons manufactured by Dallas Semiconductor. I-buttons, which are of the size of a dime with a diameter of 17mm (5.3/8 in.) and thickness of 5.5mm (1.7/8 in.), contain a memory chip, network interface, storage, a battery, and a temperature sensor. These devices can be programmed to record the temperature at any desired time interval. They can also internally store up to 2048 readings of temperatures; for instance, they can hold temperature readings of about 28 days at an interval of 20 minutes, or about 170 days at an interval of 2 hours. The built-in battery of the i-button is claimed to last more than a few years. The data can be downloaded into a computer using software provided by the manufacturer. These buttons meet the requirements of the shadow specifications. Because the i-buttons are inexpensive and simple to use, they are effective tools to measure concrete temperatures.

To meet the requirements of shadow specifications, three i-buttons were assembled to measure temperatures at three different depths of a concrete slab. In this report, three depths are defined as top (1-in. from the slab surface), middle (at the mid-depth) and bottom (1-in. from the bottom of the slab). The three i-buttons were secured by Plexiglass. First, holes slightly larger than i-buttons were made at the proper depths of the assembly. I-buttons were then inserted into the holes and each hole was filled with epoxies emulsion after leading wires were connected and welded. These i-buttons assemblies were installed at desired locations in the concrete pavement per Shadow Specifications. Figure 3.1 shows an assembly of an i-button before being inserted in concrete pavement. Figures 3.2 , 3.3, and 3.4 exhibit the installation of an i-button assembly into the actual pavement, the pavement surface with lead wires, and the data downloading process, respectively.

Table 3.1 Input Values Used for Each Project

Input Values	US-183	US-290	US-59
1. General			
Pavement Structure	Figure 2.7	Figure 2.7	Figure 2.7
Prediction Reliability Level	50%	50%	50%
2. Mixture Proportion			
Mixture Proportions	Table 2.1	Table 2.1	Table 2.1
Effect of Chemical Admixtures on Hydration	0	0	0
3. Material			
Cement Type	Type	Type	Type
Chemical Composition	Default	Default	Default
Surface Area	Default	Default	Default
Fly Ash CaO Content	Default	Default	Default
Activation Energy	37,506	Default	37,940
Adiabatic Constants: τ	33.50	Default	16.70
β, α_u	0.696, 0.846	Default	0.846, 0.757
Aggregate Type	Limestone	Limestone	Limestone
CoTE	Default	Default	Default
4. Environment			
Ambient Temperature	58/80, 68/82, 69/82	67/88, 63/86, 73/85	75/93, 74/94, 76/91
Relative Humidity	56/87, 65/100, 57/100	55/97, 65/100, 70/97	43/91, 51/91, 66/94
Wind Speed	10/2, 13/7, 6/2	13/3, 14/0, 10/5	10/0, 13/0, 9/0
Percent Cloud Cover	100/15, 100/60, 67/90	50/100,50/70,100/100	44/100,44/75,75/19
5. Construction			
Fresh Concrete Temperature	Calculate From Environmental Conditions	Calculate From Environmental Conditions	Calculate From Environmental Conditions
Base Temperature	Default	Default	Default
Curing Method			
- PCC Age at Application	0.5	0.5	0.5
- PCC Age at Removal	72	72	72
- Type	Double Coat	Double Coat	Double Coat
- Application Rate	180	180	180
- Color	White	White	White

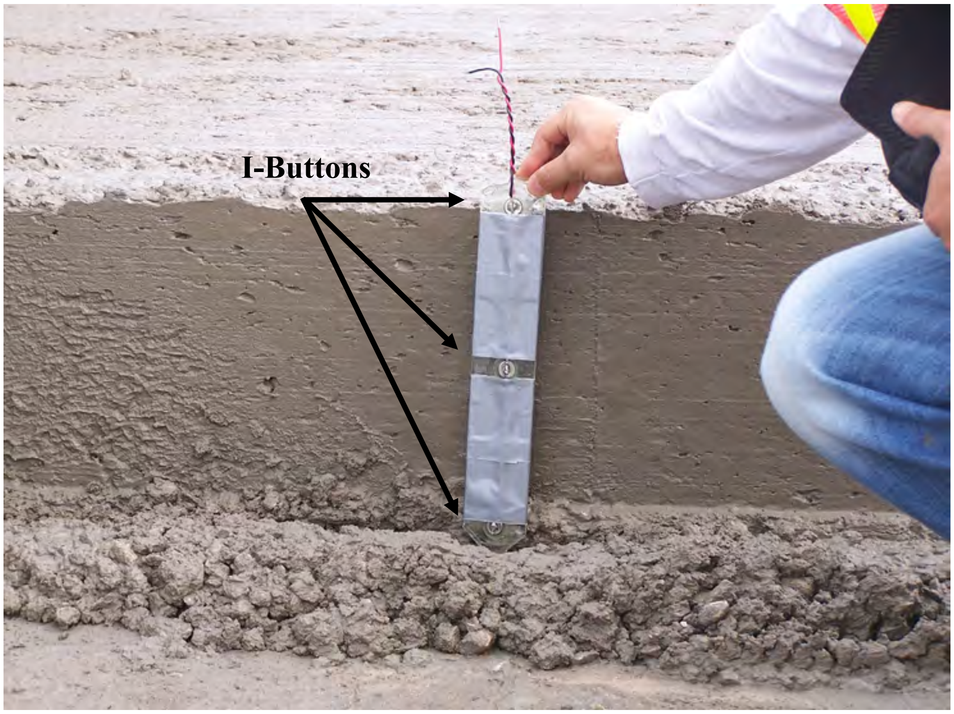

Figure 3.1 I-button Assembly

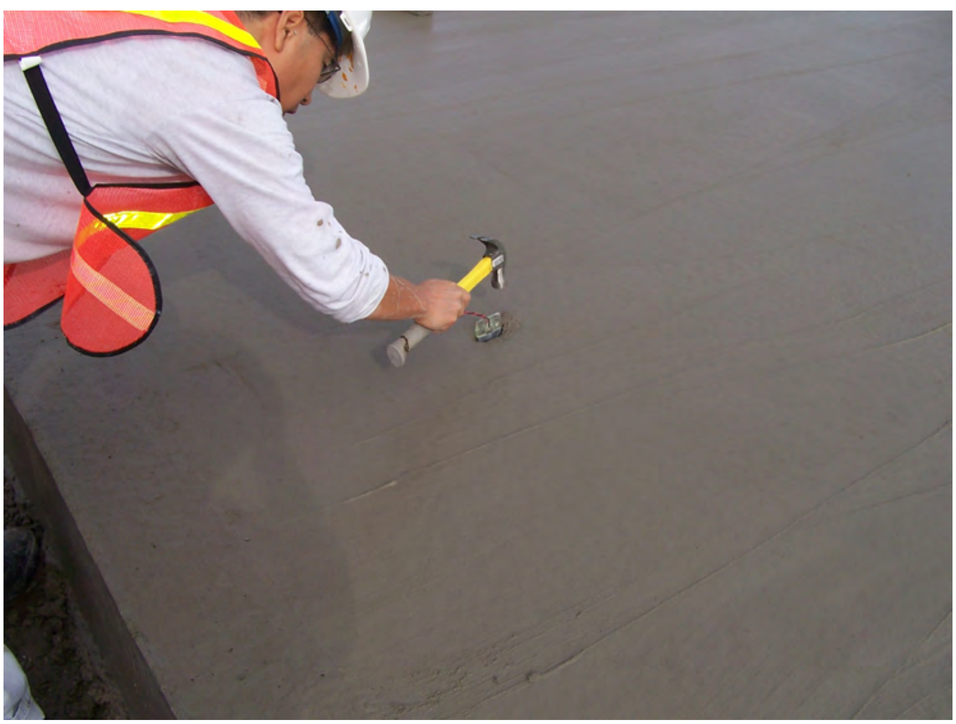

Figure 3.2 Installation of I-button Assembly into Concrete Pavement

Figure 3.3 Wires from Installed I-Button Assembly

Figure 3.4 Data Acquisition

3.2 Application of Shadow Specifications

The first step in the application of shadow specifications is to estimate concrete temperatures at three depths for 24 hours after concrete placement. As described earlier, the computer program PavePro was used to estimate concrete temperatures at different depths to determine when and at which locations the i-button assemblies needed to be installed.

3.2.1 Austin Test Section (US 183)

Figure 3.5 presents three different graphs showing predicted concrete temperatures at different depths of the slab and air temperatures. Investigation of the Figures 3.5-(a), (b), and (c) indicates that the maximum temperature of 89° F will occur at 4 p.m. at the mid-depth for the concrete placed at 4 p.m. on the previous day (24 hours after concrete placement).

The predicted maximum temperature differential between the top and bottom of the slab within the first 24 hours was 7.2° F, which occurred at 3 a.m. in the concrete placed at 11 a.m. on the previous day (16 hours after placement).

Table 3.2 and Table 3.3 summarize the results for the maximum temperatures and the maximum temperature differentials predicted by PavePro and actual for each project.

As discussed earlier, this section was placed on November 11, 2005. Because the predicted maximum temperature and the maximum temperature differential did not exceed the limits in the shadow specifications, only two sets of the temperature measuring devices would be installed at the placement time and the locations of predicted maximum temperature and temperature differential. The predicted maximum temperature and temperature differential from PavePro were at 4 p.m. placement and 11 a.m. placement, respectively. Therefore, two sets of i-button assemblies were installed, one at 11 a.m. placement and the other at 3 p.m. placement. The concrete placement was completed at about 3:30 p.m., and the second i-button assembly was installed at 3 p.m. instead of 4 p.m.

Figure 3.6 shows the comparison between predicted and actual temperature history at the mid-depth of the slab for 3 p.m. placement. It is noted that there is a discrepancy between the predicted and actual temperatures, especially within 12 hours after concrete placement. Figure 3.7(a) through (f) presents the actual temperature differential between the top and the bottom of the slab for the first 48 hours at each concrete placement hours. The maximum differential temperature of 10.8° F occurred after 26, 23, and 9 hours of concrete placed at 8 a.m., 11 a.m., and 3 p.m. The value is 3.6° F higher than the differential value predicted by PavePro.

3.2.2 Austin Test Section (US 290)

Figure 3.8 presents three different graphs showing predicted concrete temperatures at different depths of the slab and air temperatures. Investigation of the Figures 3.8-(a), (b), and (c) indicates that the maximum temperature of 102° F will occur at 10 p.m. at the mid-depth for the concrete placed at noon in the same day (10 hours after concrete placement).

The predicted maximum temperature differential between the top and bottom of the slab within the first 24 hours was 11.9° F, which occurred at 10 a.m. in the concrete placed at 2 p.m. in the previous day (18 hours after placement).

As discussed earlier, this section was placed on October 25, 2004. Because the predicted maximum temperature and the maximum temperature differential did not exceed the limits in the shadow specifications, only two sets of the temperature measuring devices would be installed at the placement time and the locations of predicted maximum temperature and temperature differential. Two sets of i-button assemblies were installed, one at noon placement and the other at 2 p.m. placement.

Figure 3.9 shows the comparison between predicted and actual temperature history at the mid-depth of the slab for the concrete placed at noon. It is noted that actual concrete pavement temperatures were much lower than the predicted values. The exact cause for the large discrepancy is not known. Figure 3.10(a) through (g) presents the predicted and actual temperature differential between the top and the bottom of the slab for the first 48 hours at each concrete placement hours. The maximum differential temperature of 13.5° F occurred after 20 and 14 hours of concrete placed at 10 a.m. and 3:30 p.m. The value is 1.6° F higher than the differential value predicted by PavePro.

3.2.3 Houston Test Section (US 59)

Figure 3.11 presents three different graphs showing predicted concrete temperatures at different depths of the slab and air temperatures. Investigation of the Figures 3.11-(a), (b), and (c) indicates that the maximum temperature of 119.3° F will occur at 2 a.m. at the bottom of the slab for the concrete placed at 2 p.m. in the previous day (12 hours after concrete placement).

The predicted maximum temperature differential between the top and bottom of the slab within the first 24 hours was 16.5° F, which occurred at 8 a.m. in the concrete placed at 2 p.m. in the previous day (18 hours after placement). It is noted that PavePro predicts that the maximum temperature as well as differential occur in the concrete placed at 2 p.m.

As discussed earlier, this section was placed on July 20, 2004. Since the predicted maximum temperature and the maximum temperature differential did not exceed the limits in the shadow specifications, only two sets of the temperature measuring devices would be installed at the placement time and the locations of predicted maximum temperature and temperature differential. Since the concrete placed at 2 p.m. produced both maximum temperature and maximum differential, only one set of i-button assemblies was installed at 2 p.m. placement.

Figure 3.12 shows the comparison between predicted and actual temperature history at the bottom of the slab for the concrete placed at 2 p.m. It is noted that actual concrete pavement temperatures were much lower than the predicted values. The exact cause for the large discrepancy is not known. Figure 3.13(a) through (f) presents the actual temperature differential between the top and the bottom of the slab for the first 48 hours at each concrete placement hours. The maximum differential temperature of 16.2°F occurred after 14 and 12 hours of concrete placed at 12 noon and 2 p.m. This value is close to the differential value predicted by PavePro, which is 16.5°F.

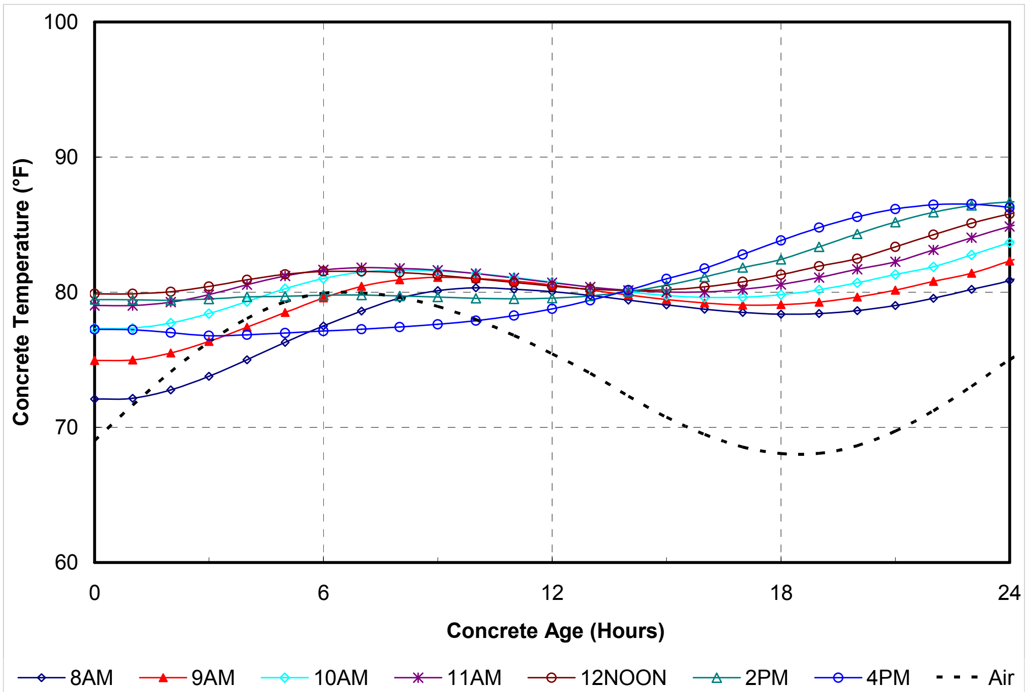

Figure 3.5(a) Top

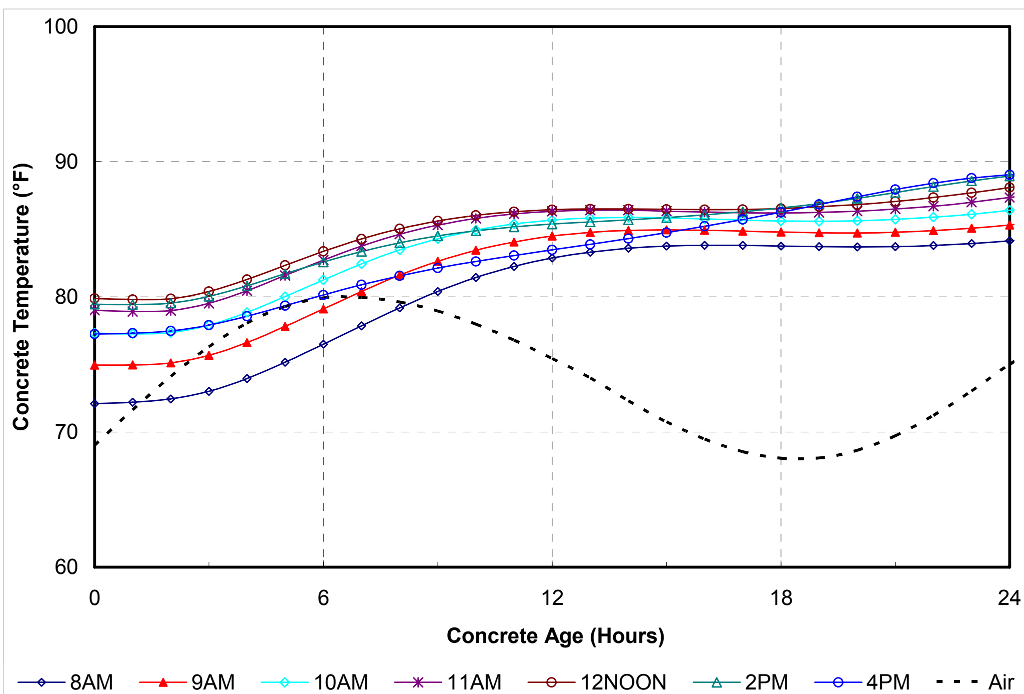

Figure 3.5(b) Middle

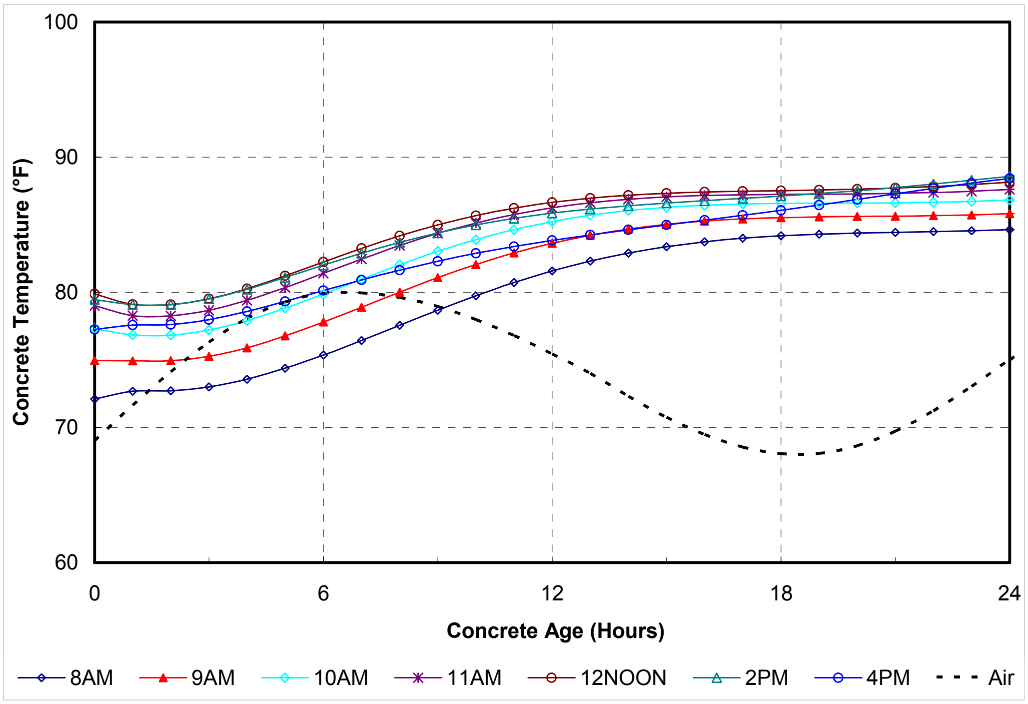

Figure 3.5(c) Bottom

Figure 3.5 Air & Slab Temperatures at Each Depths Predicted by PavePro (US 183)

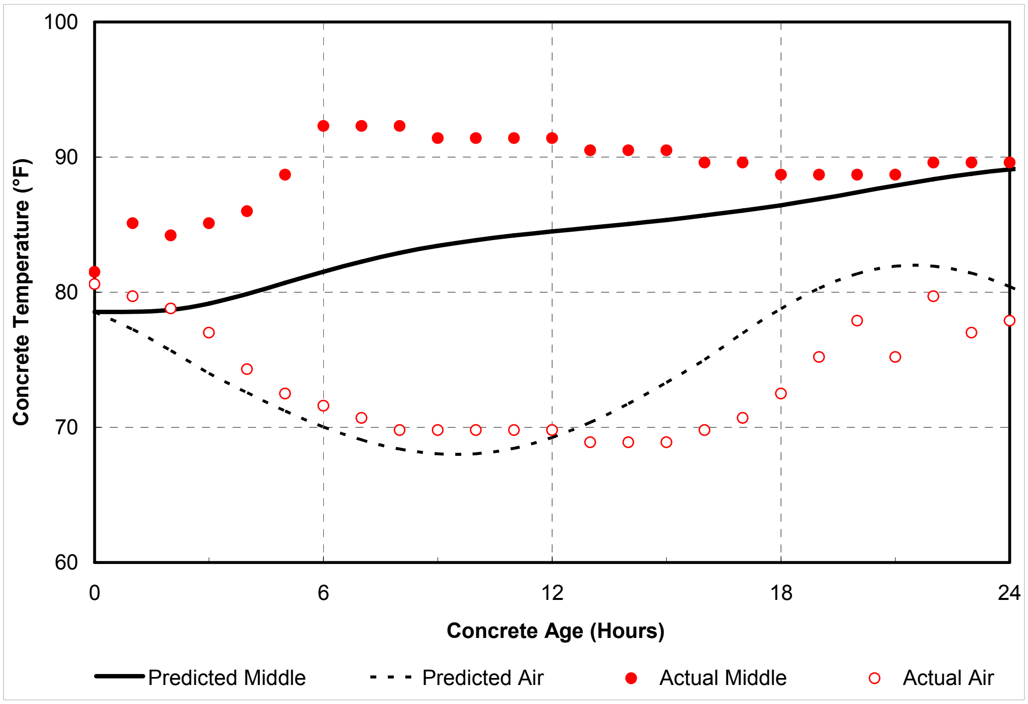

Figure 3.6 Predicted and Actual Air & Concrete Temperatures Placed at 3 p.m. (US 183 Austin Test Section)

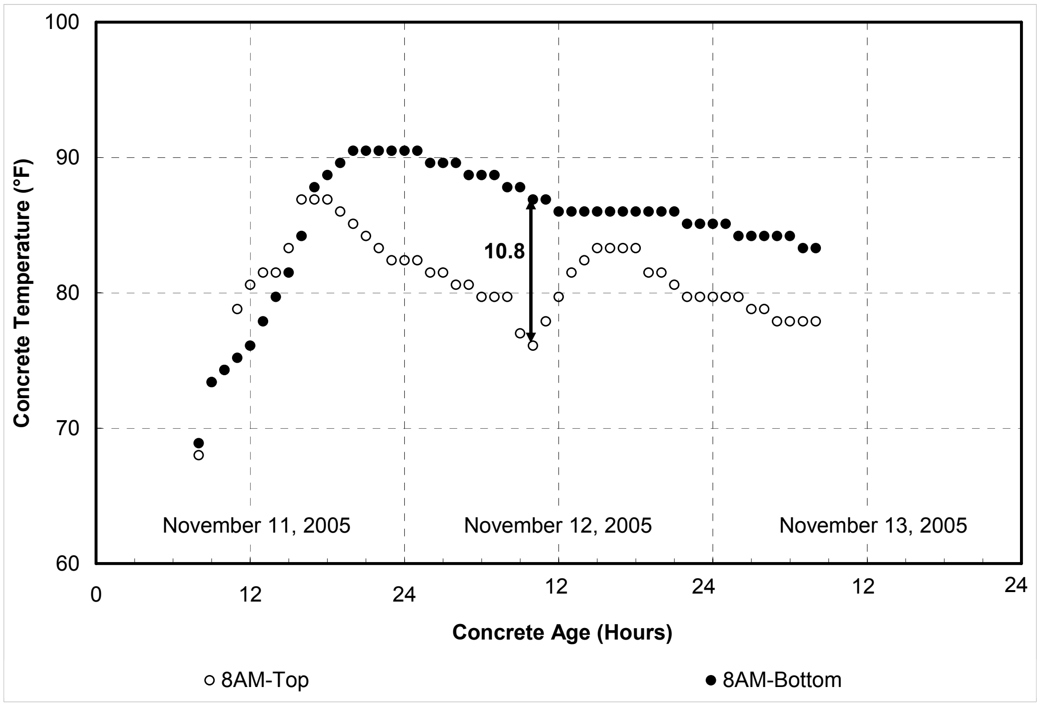

Figure 3.7(a) 8a.m

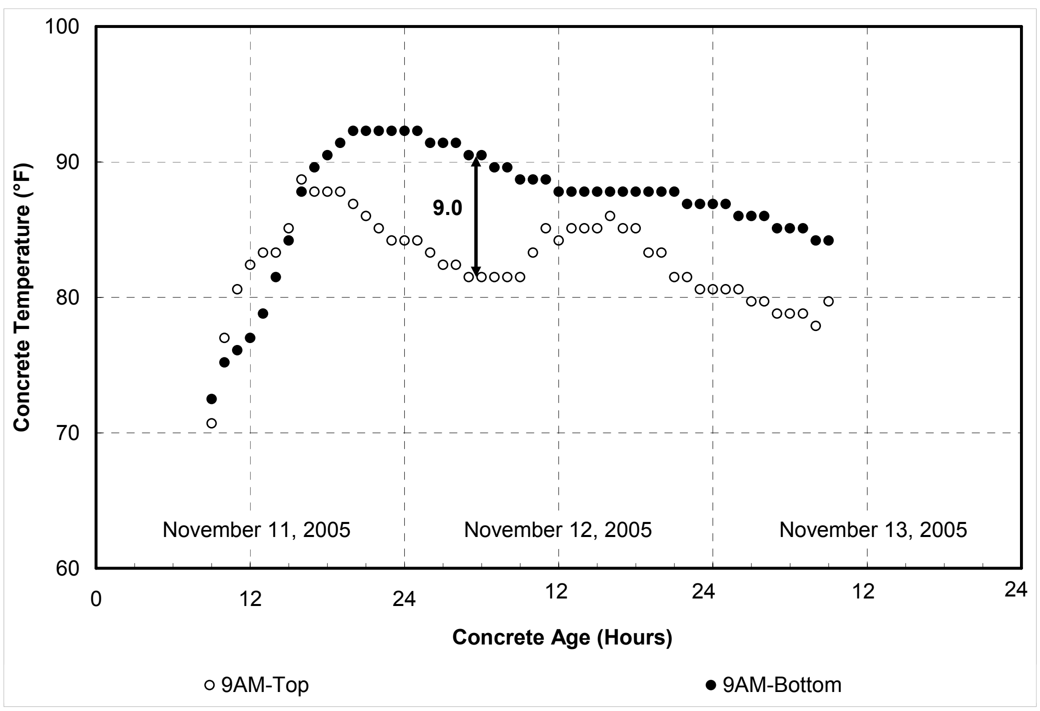

Figure 3.7(b) 9a.m

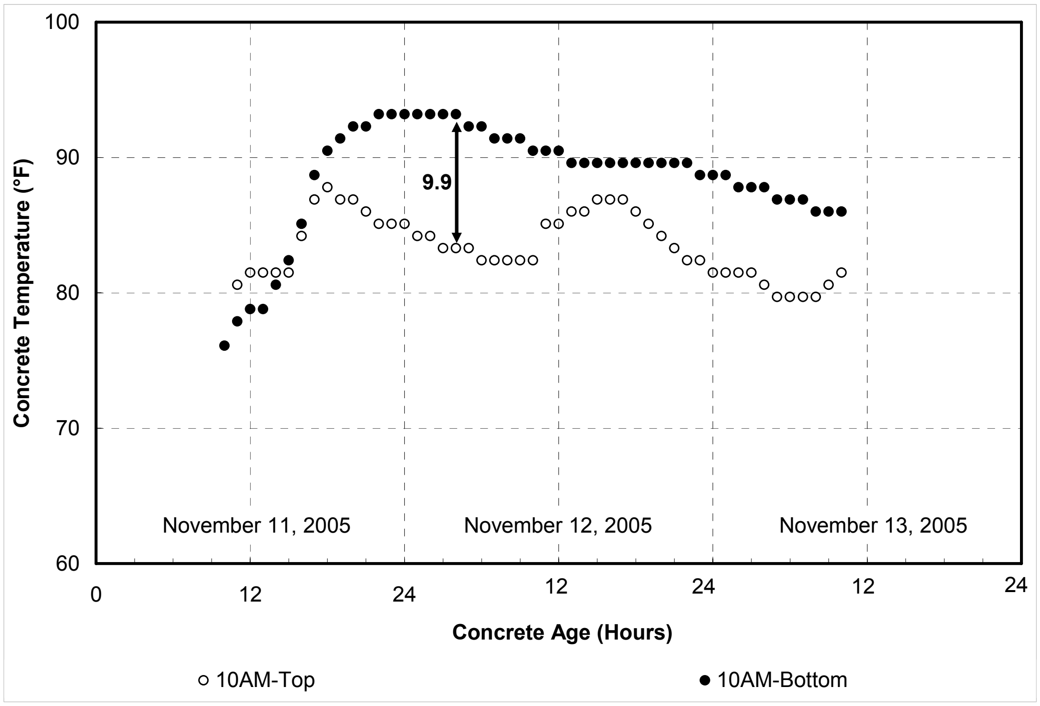

Figure 3.7(c) 10a.m

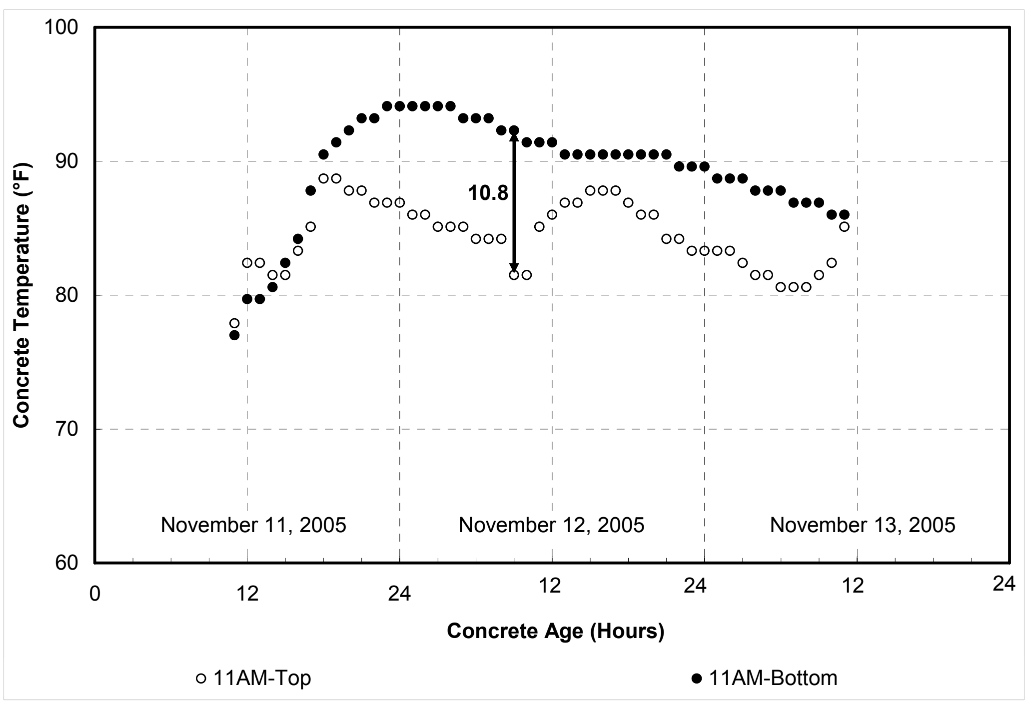

Figure 3.7(d) 11a.m

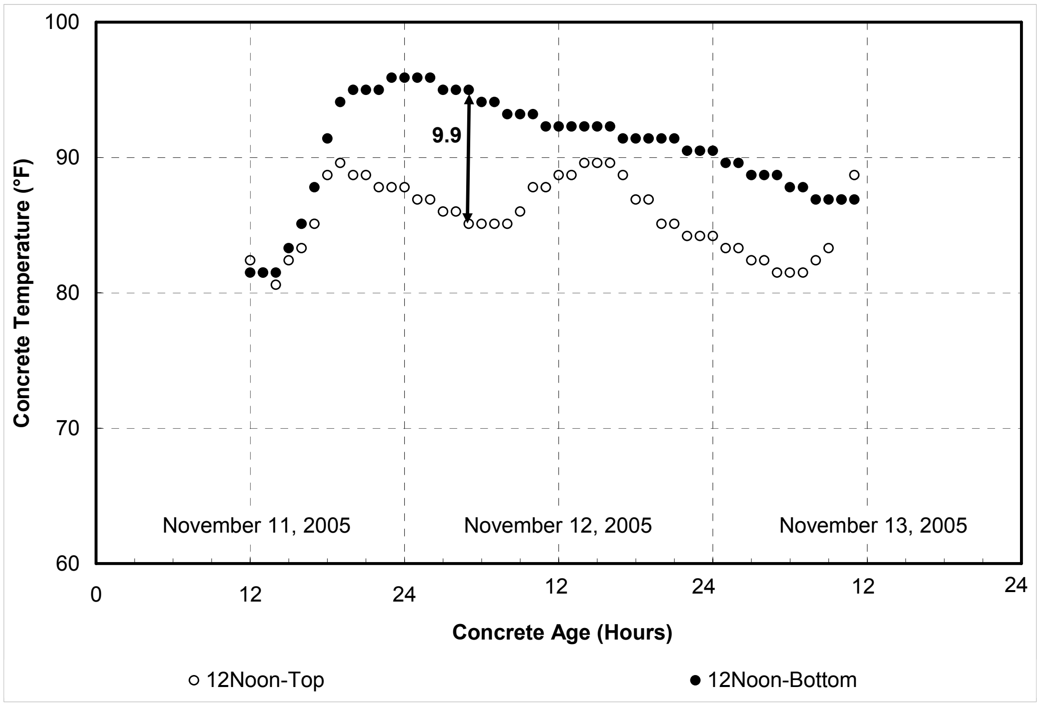

Figure 3.7(e) 12Noon

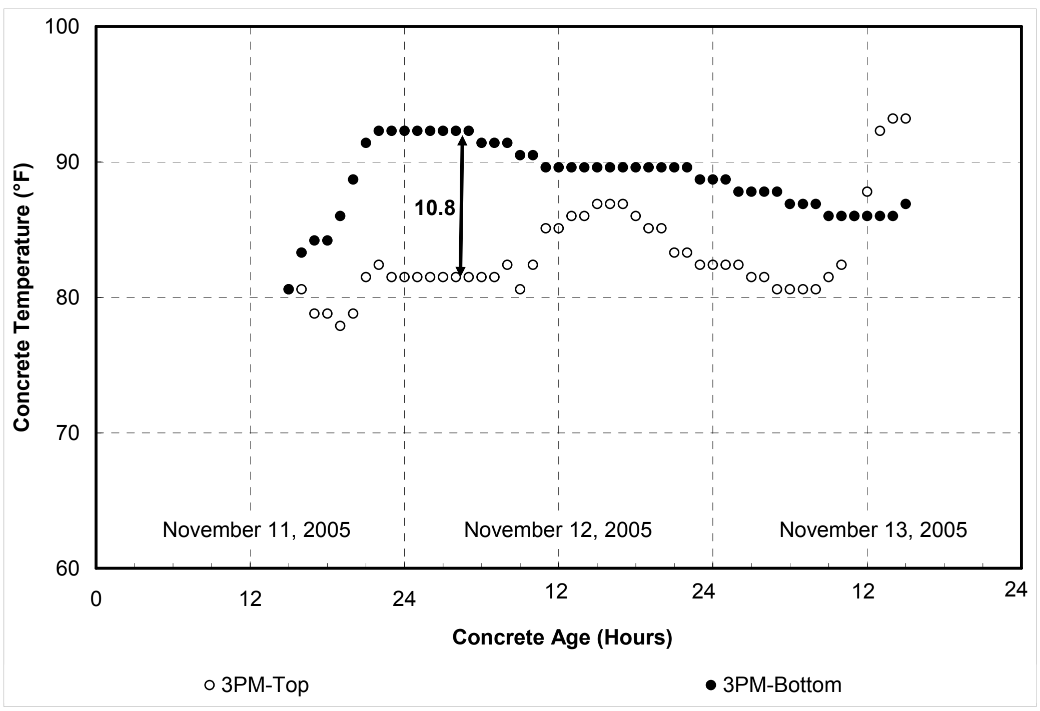

Figure 3.7(f) 3p.m

Figure 3.7 Temperature Differential between the Top and the Bottom of the Slab Placed at Each Hours of US 183 Austin Test Section

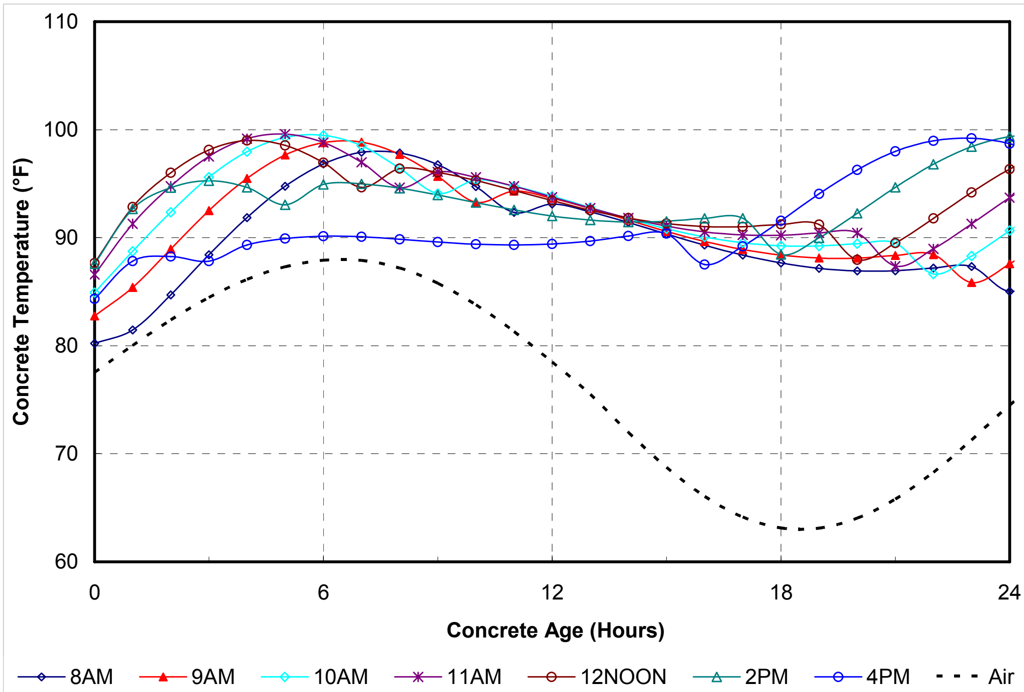

Figure 3.8(a) Top

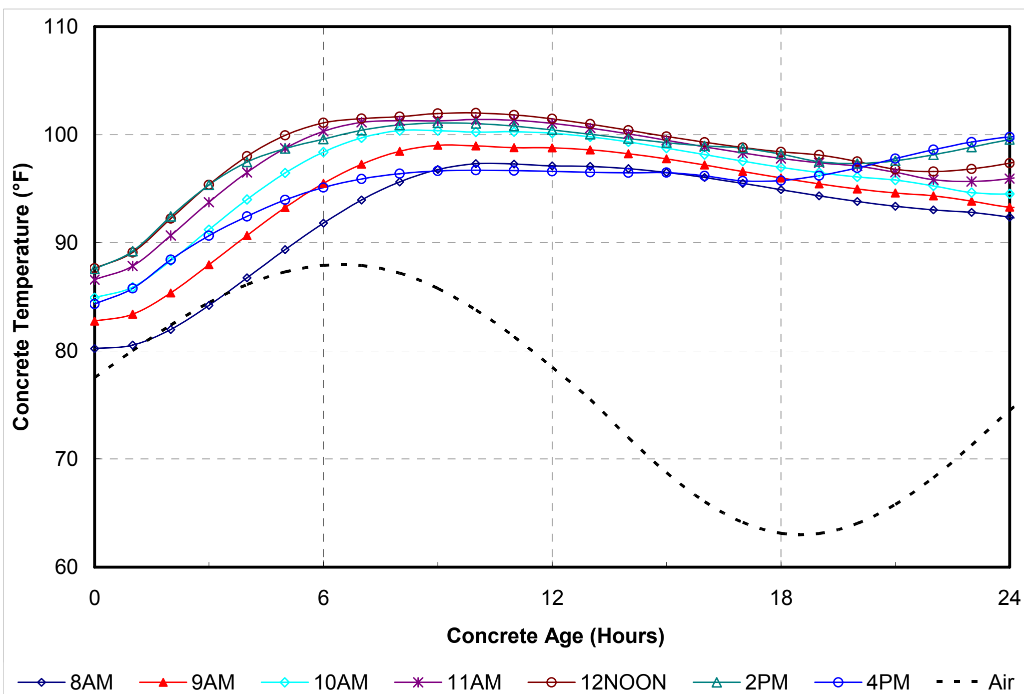

Figure 3.8(b) Middle

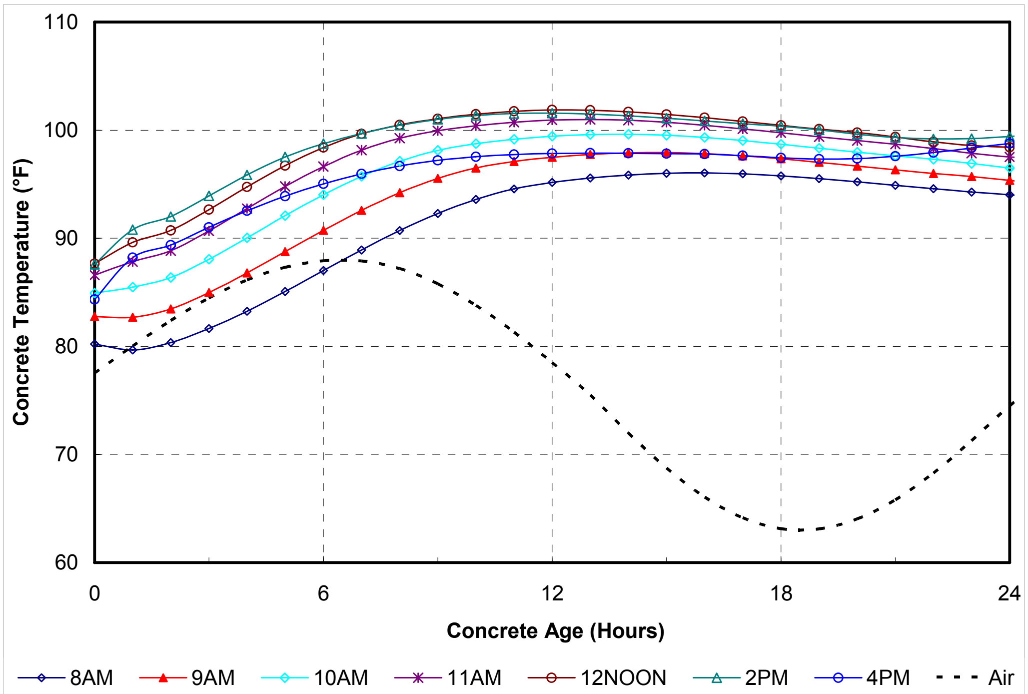

Figure 3.8(c) Bottom

Figure 3.8 Air & Slab Temperatures at Each Depths Predicted by PavePro (US 290)

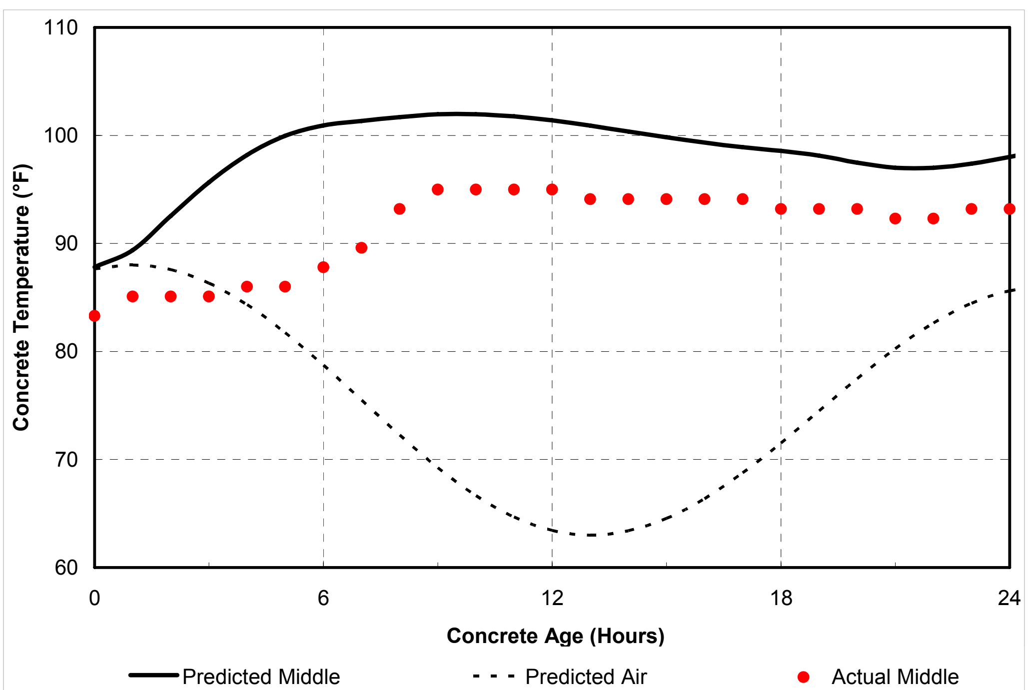

Figure 3.9 Predicted and Actual Air & Concrete Temperatures Placed at 3 p.m. (US 290 Austin Test Section)

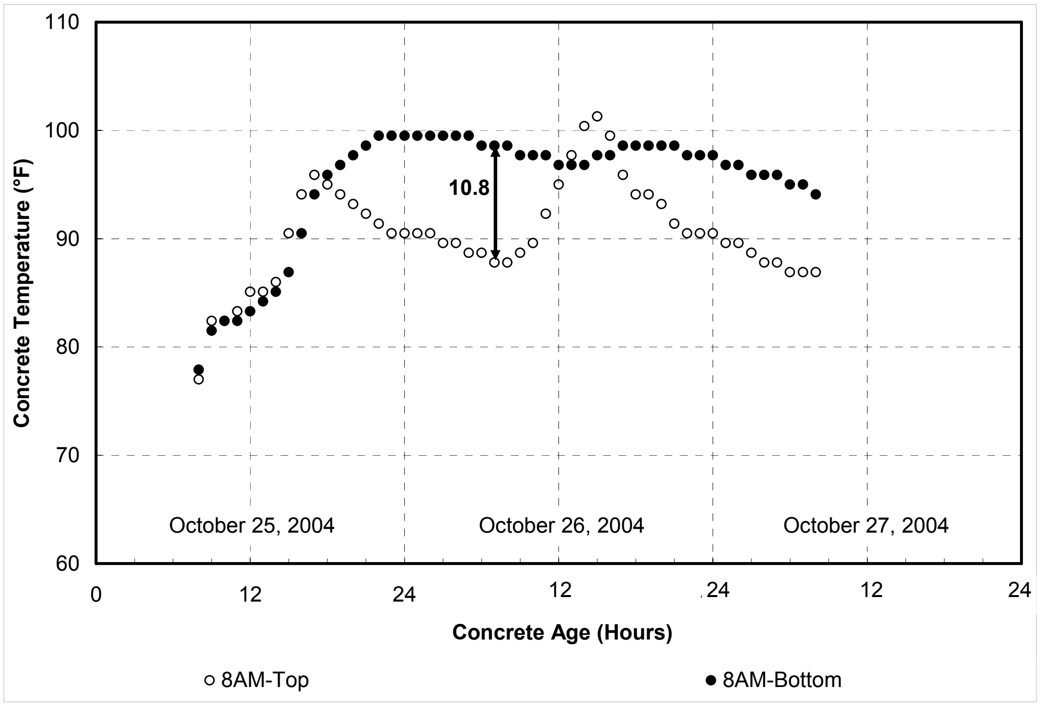

Figure 3.10(a) 8a.m

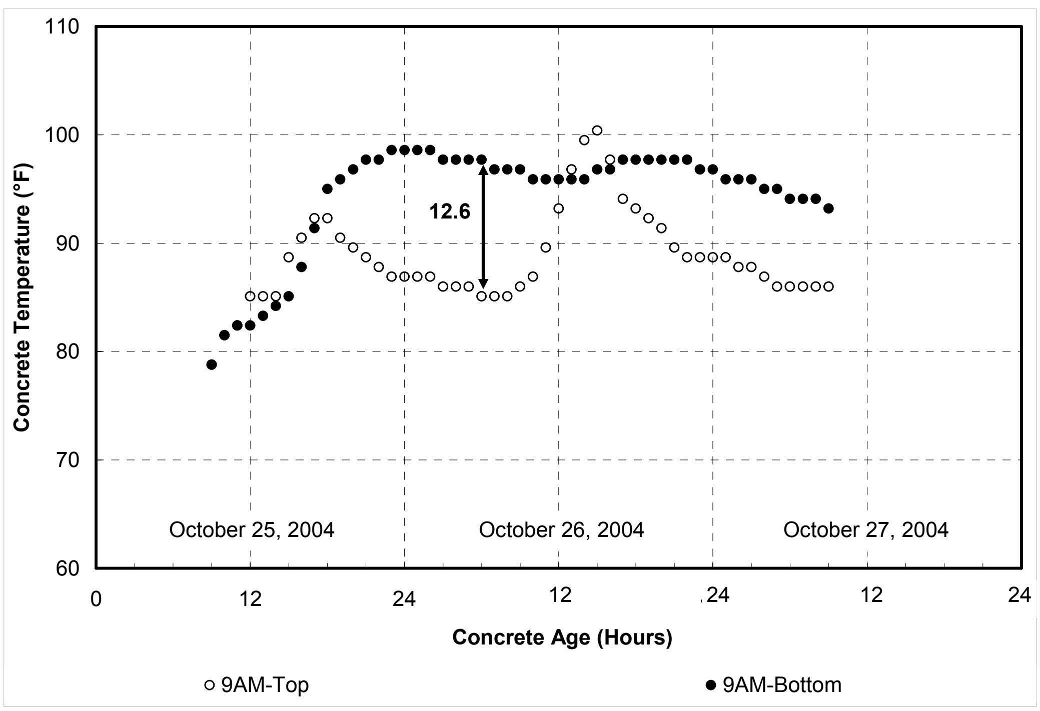

Figure 3.10(b) 9a.m

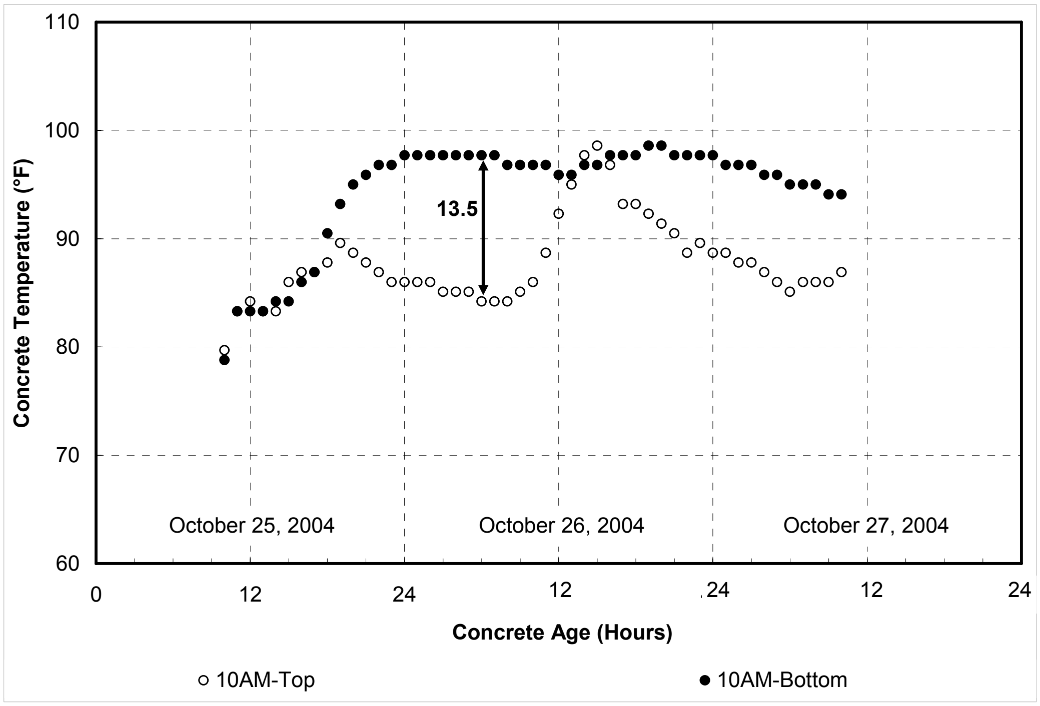

Figure 3.10(c) 10a.m

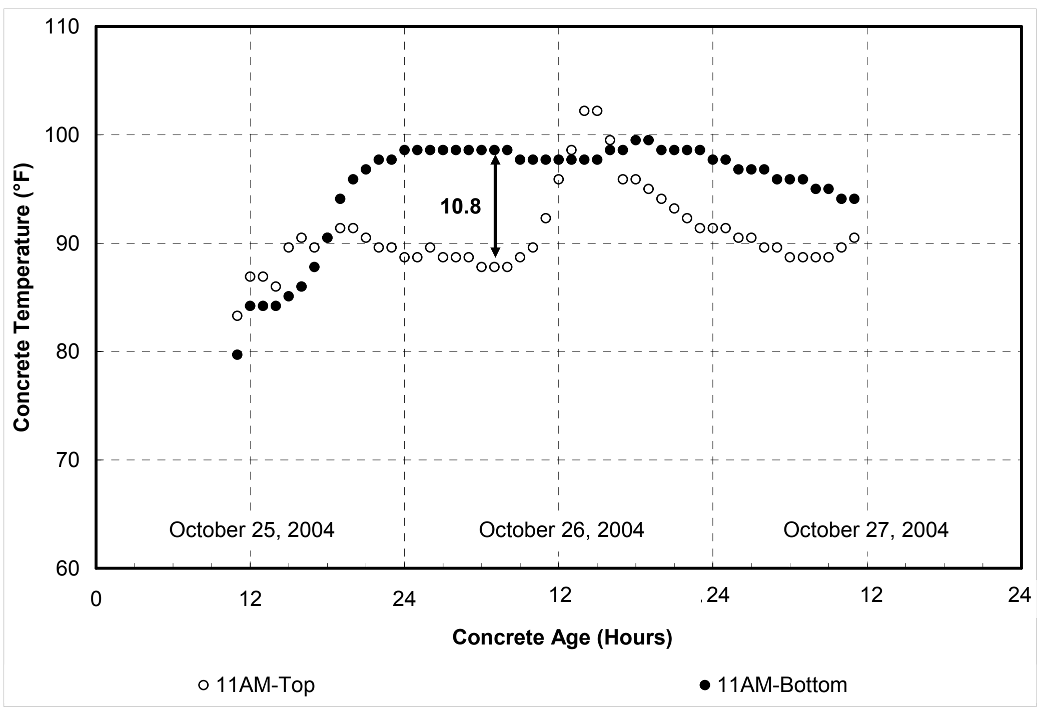

Figure 3.10(d) 11a.m

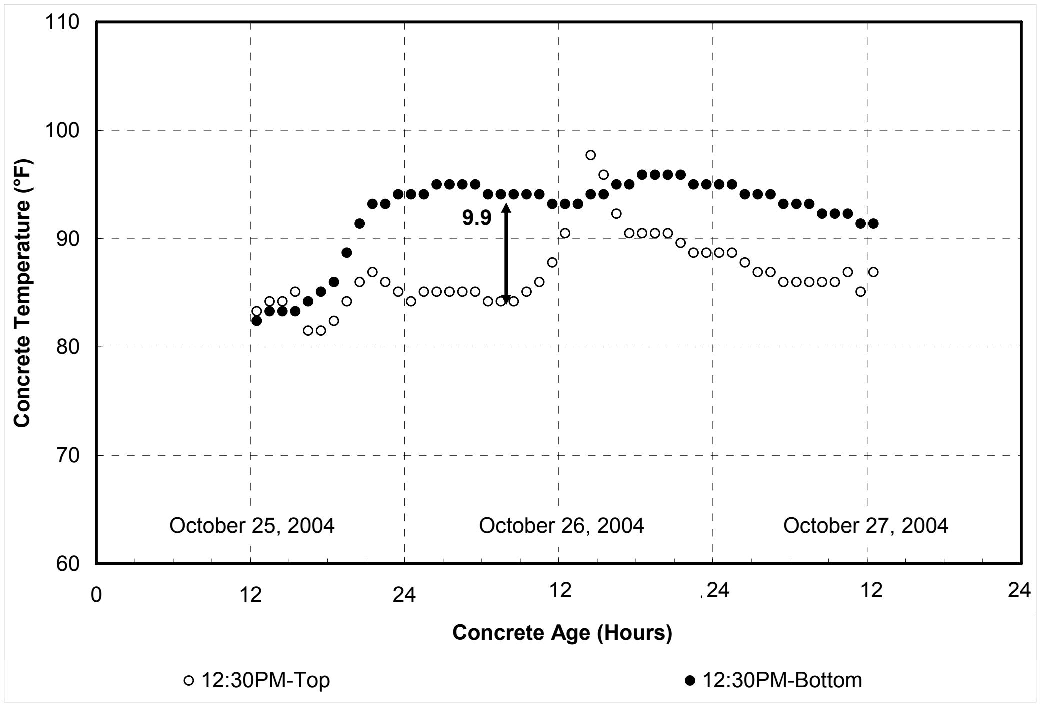

Figure 3.10(e) 12:30p.m

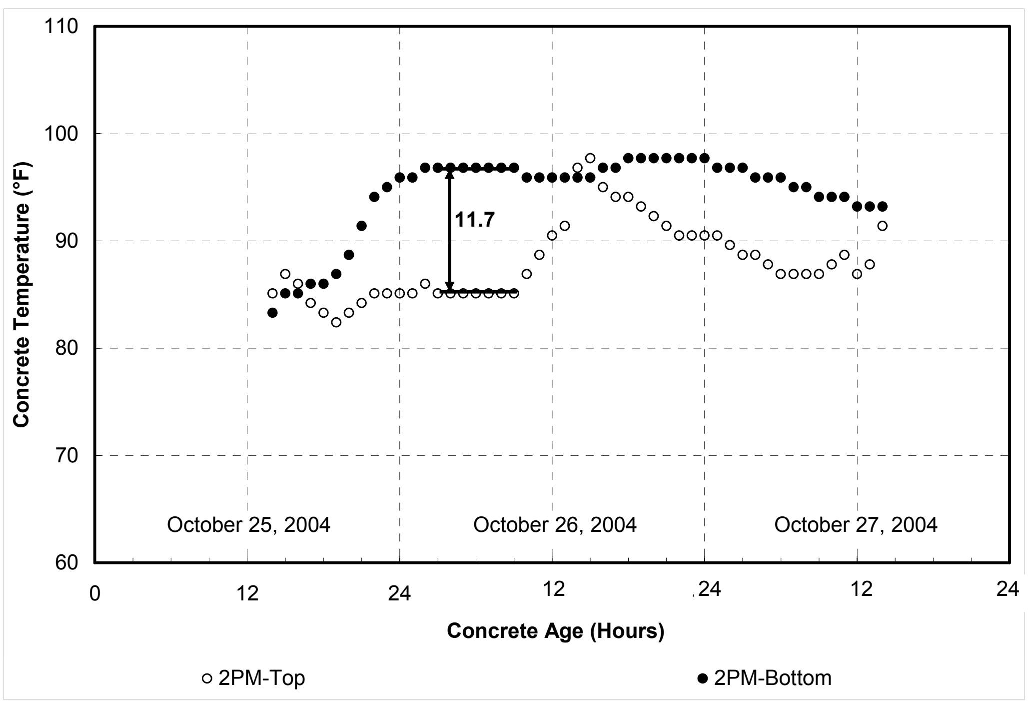

Figure 3.10(f) 2p.m

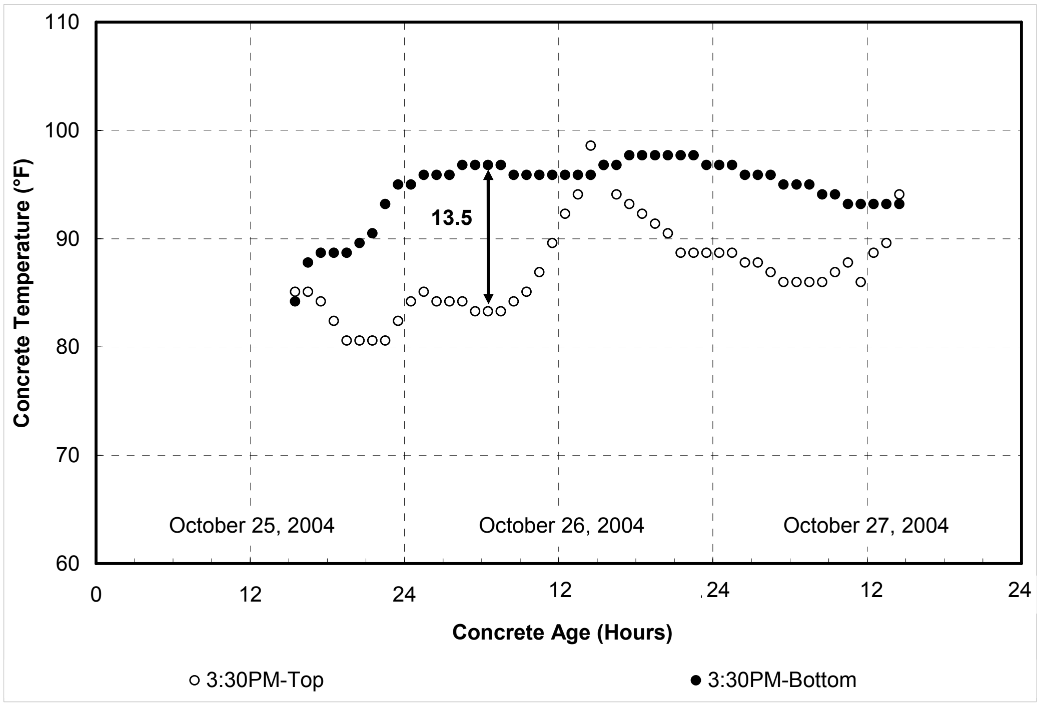

Figure 3.10(g) 3:30p.m

Figure 3.10 Temperature Differential between the Top and the Bottom of the Slab Placed at Each Hours (US 290 Austin Test Section)

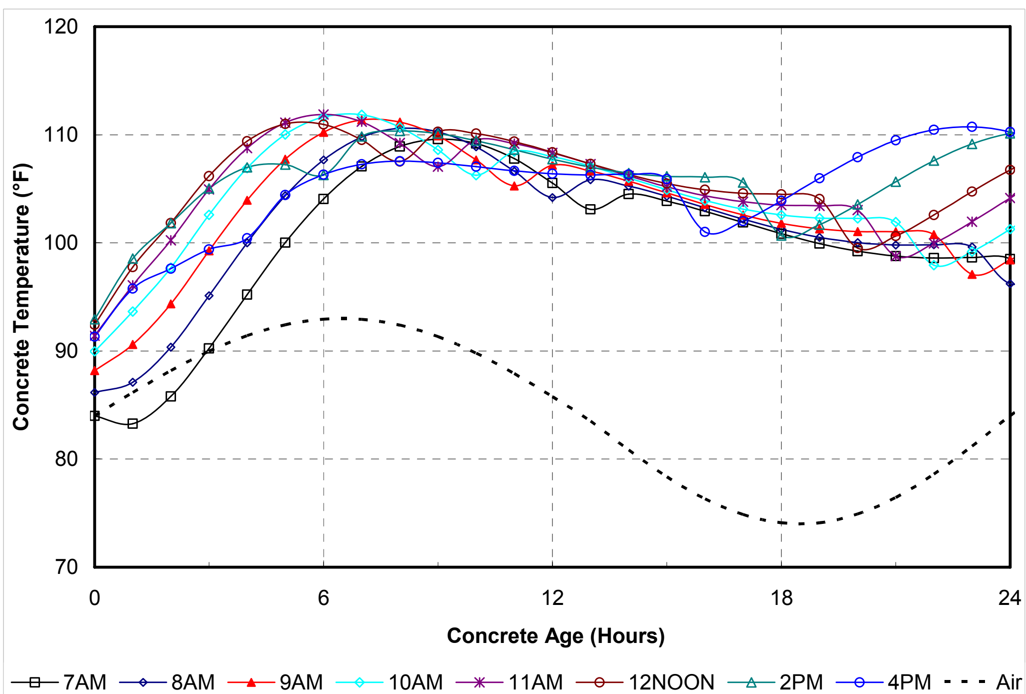

Figure 3.11(a) Top

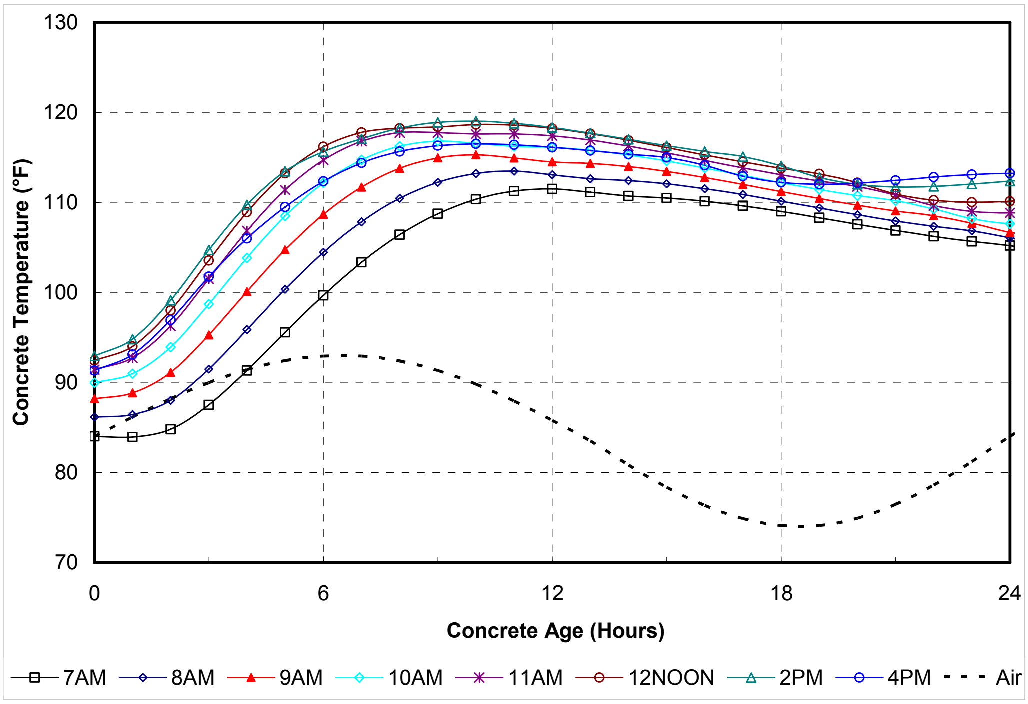

Figure 3.11(b) Middle

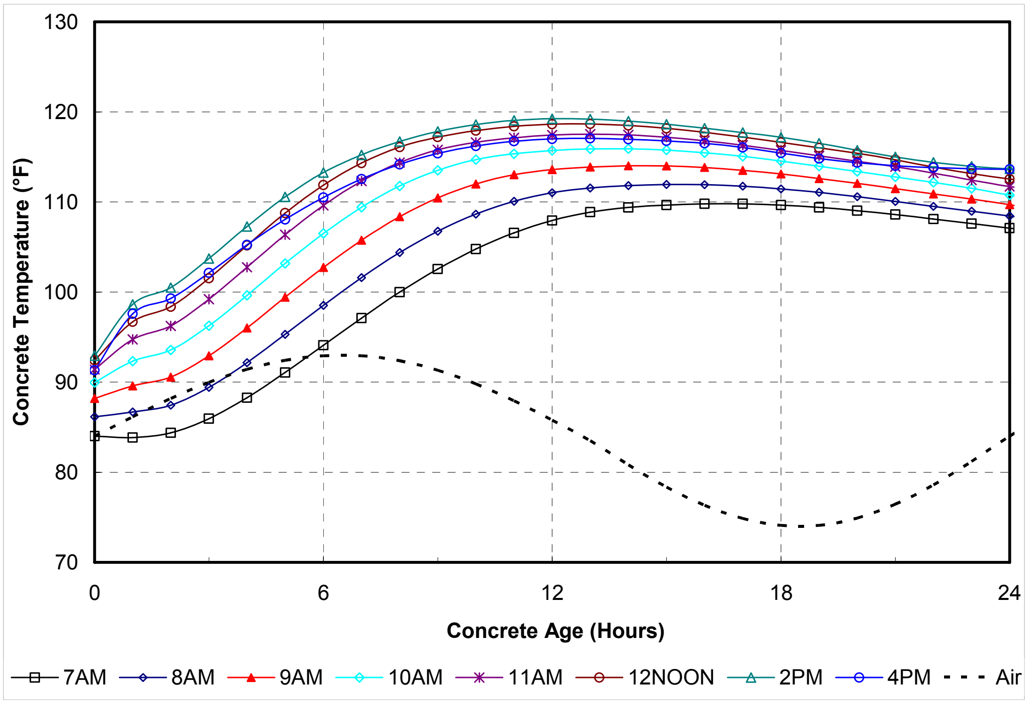

Figure 3.11(c) Bottom

Figure 3.11 Air & Slab Temperatures at Each Depths Predicted by PavePro (US 59)

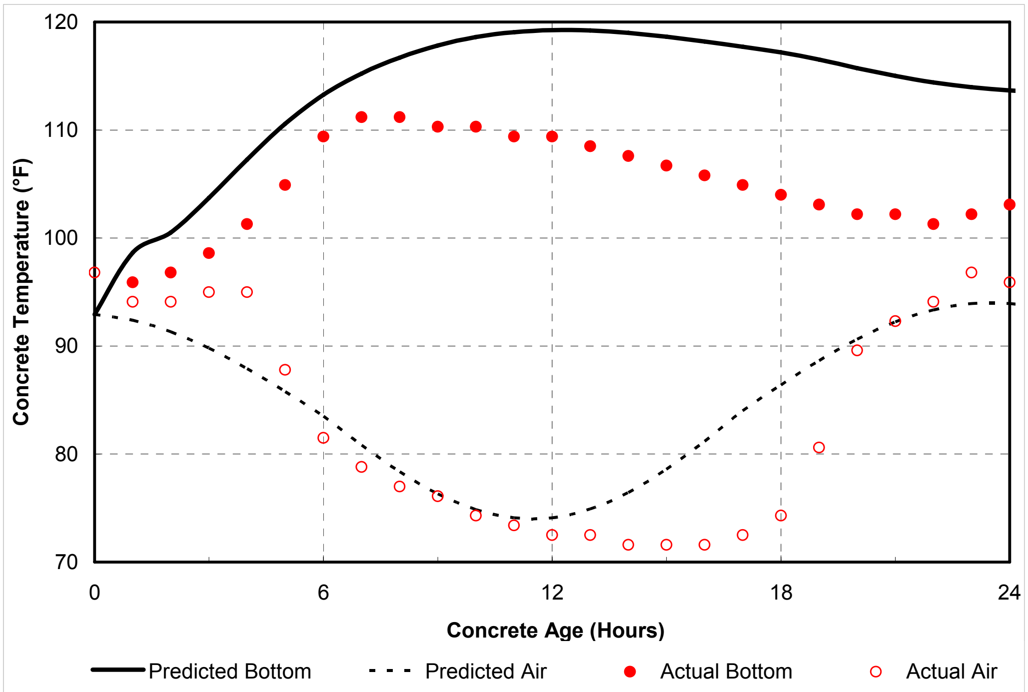

Figure 3.12 Predicted and Actual Air & Concrete Temperatures Placed at 3 p.m. (US 59 Cleveland Test Section)

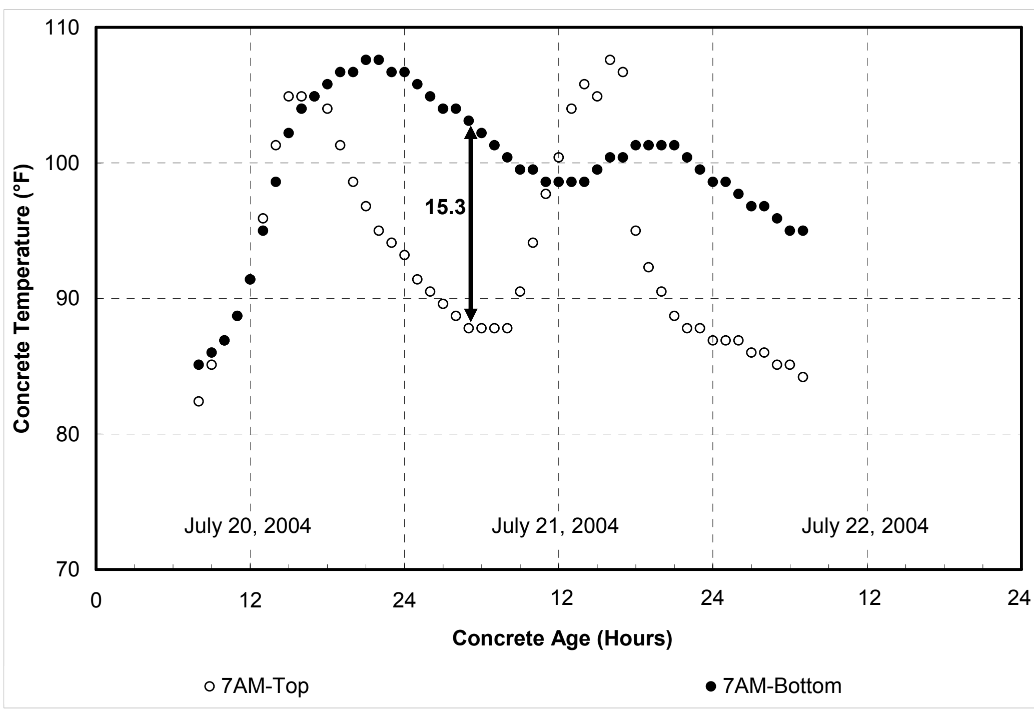

Figure 3.13(a) 7a.m

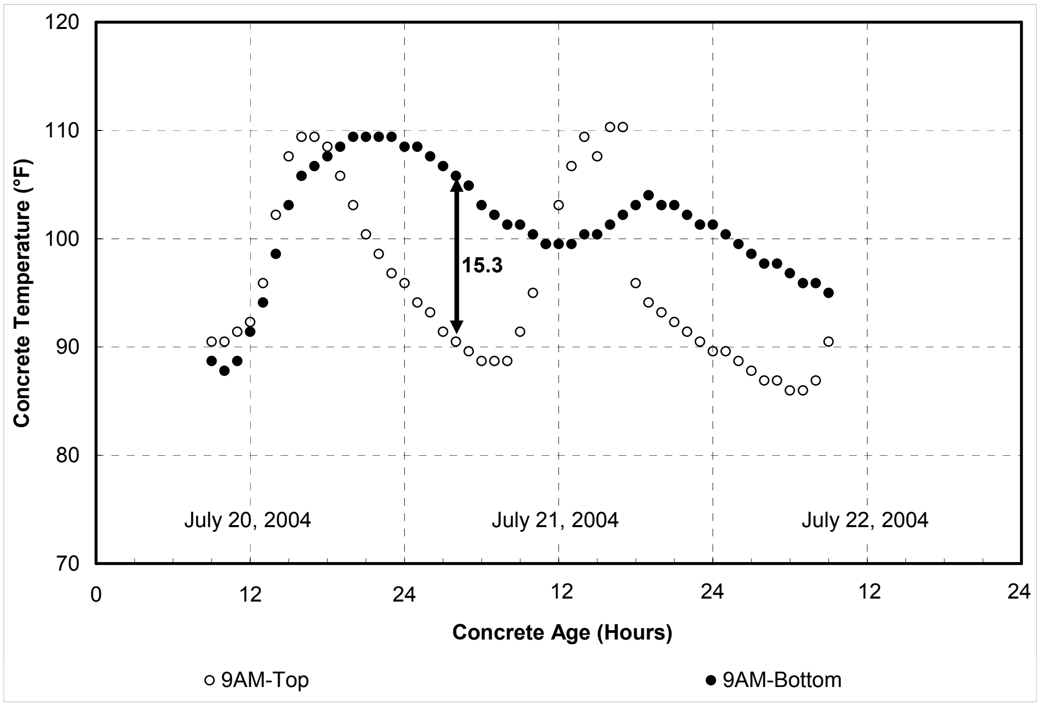

Figure 3.13(b) 9a.m

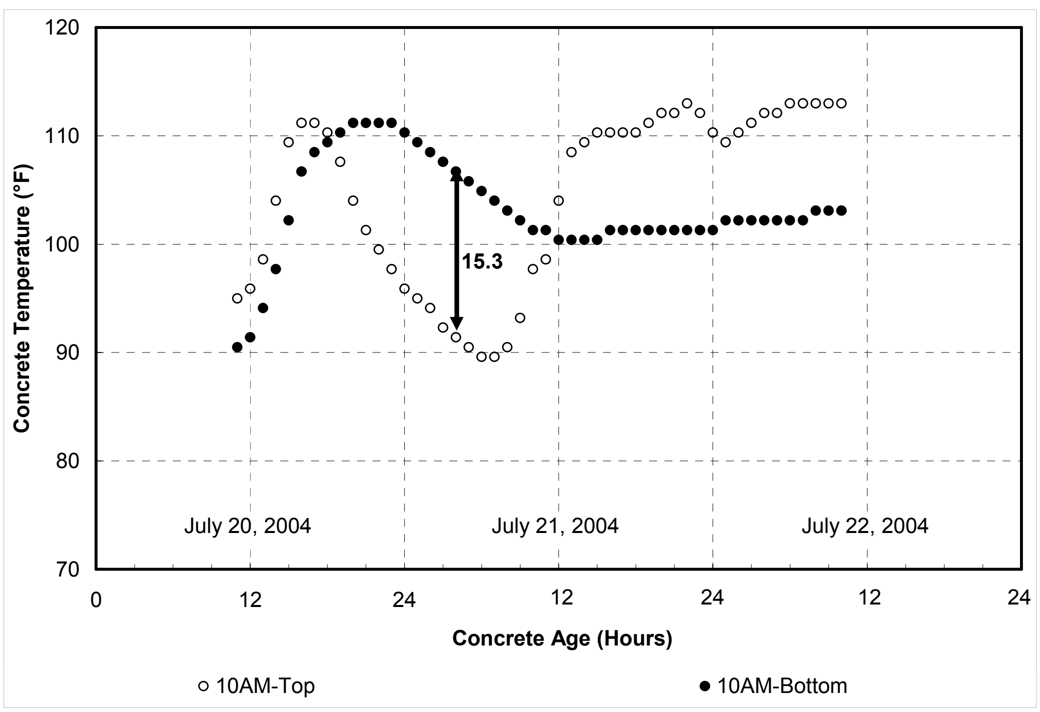

Figure 3.13(c) 10a.m

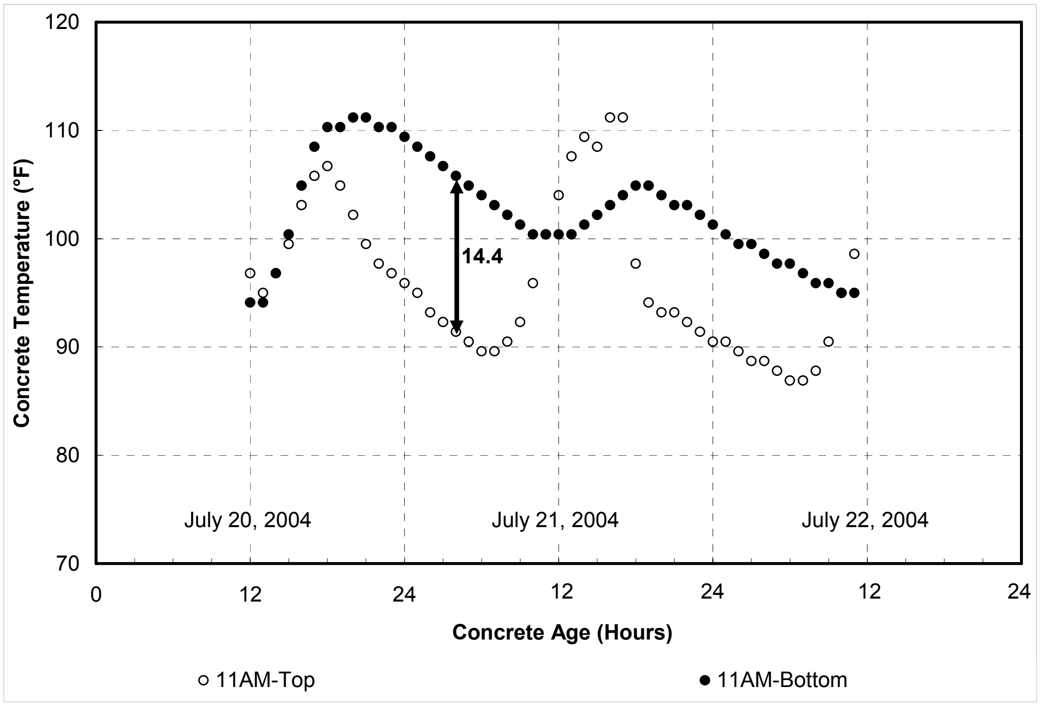

Figure 3.13(d) 11a.m

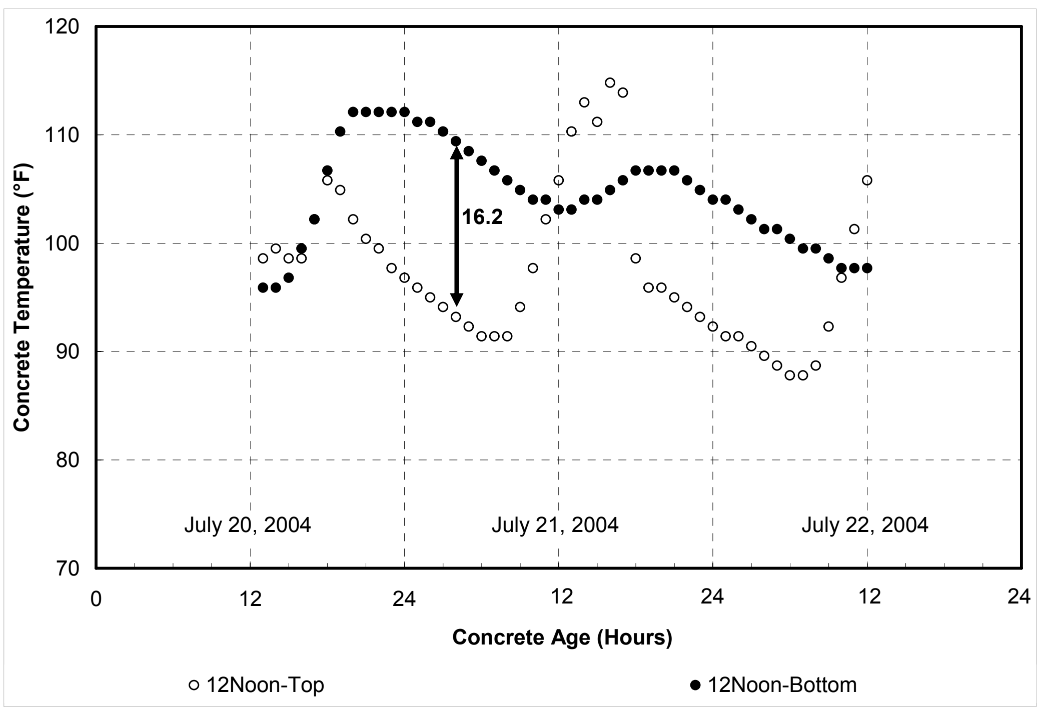

Figure 3.13(e) 12noon

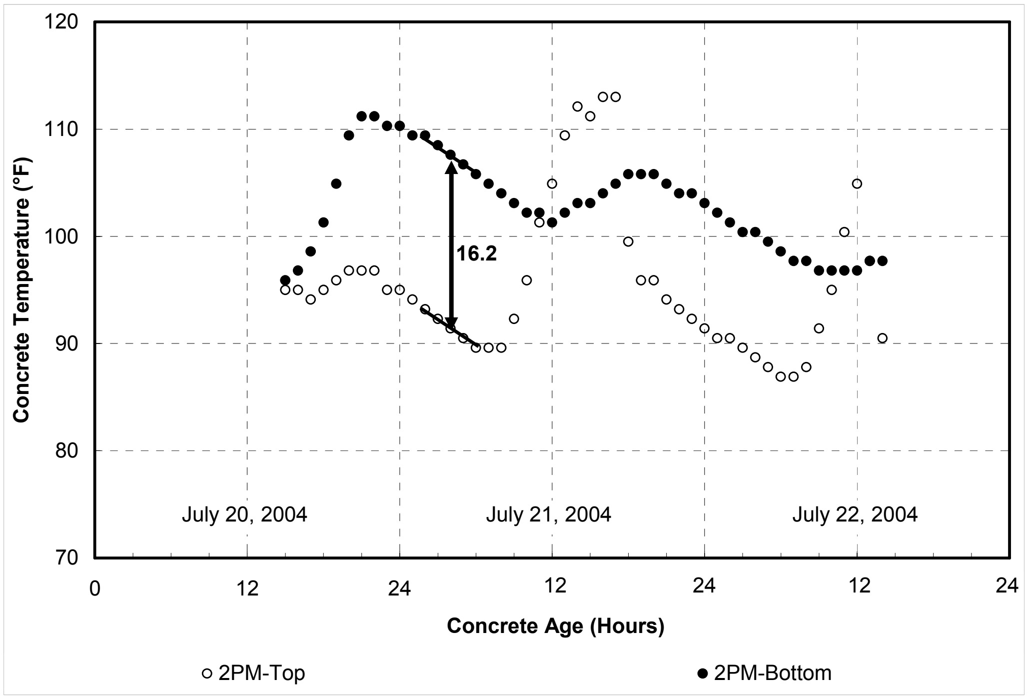

Figure 3.13(f) 2p.m

Figure 3.13 Temperature Differential between the Top and the Bottom of the Slab Placed at 2 p.m. (US 59 Cleveland Test Section)

Table 3.2 Results for the Predicted Maximum Temperatures by PavePro

Test Sections	Placement Time	Top		Middle		Bottom	
		Maximum Temperatures	Elapsed Hours	Maximum Temperature	Elapsed Hours	Maximum Temperature	Elapsed Hours
US 183	8 AM	80.9	24	84.2	24	84.6	24
	9 AM	82.3	24	85.3	24	85.8	24
	10 AM	83.7	24	86.4	24	86.8	24
	11 AM	84.9	24	87.3	24	87.6	24
	12 NOON	85.8	24	88.1	24	88.2	24
	2 PM	86.7	24	88.9	24	88.6	24
	4 PM	86.5	23	***89.0***	24	88.4	24
	The predicted maximum temperature difference = 7.2° F 80.0° F at top, 87.2° F at bottom with 16 hours at concrete placed at 11 a.m.						
US 290	8 AM	97.9	7	97.3	10	96.0	16
	9 AM	98.8	7	99.0	9	97.9	15
	10 AM	99.5	6	100.4	8	99.6	14
	11 AM	99.6	5	101.4	10	101.0	13
	12 NOON	99.0	4	***102.0***	10	101.9	12
	2 PM	99.4	24	101.1	9	101.6	12
	4 PM	99.2	23	99.8	24	98.8	24
	The predicted maximum temperature difference = 11.9° F 88.5° F at top, 100.4° F at bottom with 18 hours at concrete placed at 2 p.m.						
US 59	7AM	109.6	9	111.5	12	109.8	16
	8 AM	110.6	8	113.5	11	111.9	15
	9 AM	111.4	7	115.3	10	114.0	14
	10 AM	111.8	7	116.8	9	115.9	14
	11 AM	111.9	6	117.7	9	117.5	13
	12 NOON	111.0	5	118.6	10	118.7	13
	2 PM	110.3	8	119.0	10	***119.3***	12
	4PM	110.7	23	116.5	10	117.1	13
	The predicted maximum temperature difference = 16.5° F 100.7° F at top, 117.2° F at bottom with 18 hours at concrete placed at 2 p.m.						

Table 3.3 Results for the Actual Maximum Temperatures

Test Sections	Placement Time	Top		Middle		Bottom	
		Maximum Temperature	Elapsed Hours	Maximum Temperature	Elapsed Hours	Maximum Temperature	Elapsed Hours
US 183	8 AM	86.9	8—10	92.3	10—12	90.5	12—17
	9 AM	88.7	7	93.2	8—13	92.3	11—16
	10 AM	87.8	8	94.1	9—13	93.2	12—18
	11 AM	88.7	7—8	94.1	8—14	94.1	12—17
	12 NOON	89.6	8	***95.9***	8—13	***95.9***	12—15
	3 PM	86.9	24	92.3	7—8	92.3	7—14
	The actual maximum temperature difference = 10.8° F 81.5° F at top, 92.3° F at bottom with 22 hours at concrete placed at 11 a.m.						
US 290	8 AM	95.9	9	**100.4**	11—14	99.5	14—21
	9 AM	92.3	8—9	98.6	10—13	98.6	14—17
	10 AM	89.6	9	97.7	11—13	97.7	14—21
	11 AM	92.3	24	98.6	9—15	98.6	13—21
	12:30 PM	90.5	24	95.0	9—12	95.0	14—17
	2 PM	96.8	24	96.8	24	96.8	12—19
	3:30 PM	98.6	23	97.7	24	96.8	24
	The actual maximum temperature difference = 13.5° F 83.3° F at top, 96.8° F at bottom with 14—16 hours at concrete placed at 3:30 p.m.						
US 59	7 AM	104.9	8—10	109.4	10—12	107.6	14—15
	9 AM	109.4	7—8	113.0	9—10	109.4	11—14
	10 AM	111.2	6—7	***114.8***	8—9	111.2	10—13
	11 AM	106.7	7	112.1	7—9	111.2	9—10
	12 NOON	105.8	6	***114.8***	7—9	112.1	8—12
	2 PM	112.1	24	110.3	7	111.2	7—8
	The actual maximum temperature difference = 16.2° F 93.2° F at top, 109.4° F at bottom with 12—16 hours at concrete placed at 2 p.m.						

3.3 Evaluation of Shadow Specification Applications

In the previous sections, concrete temperatures predicted by PavePro and actual concrete temperatures for three projects were compared. It shows that, even though PavePro does a reasonable job in estimating maximum concrete temperature at early ages, there is quite a difference in the time of maximum temperature occurrence. Table 3.4 summarizes the results. It shows a maximum difference of 6.9° F between the predicted and actual maximum concrete temperatures in three projects. Also, the difference between predicted and actual temperature differentials is less than 3.6° F. As described earlier, the hydration properties of cementitious materials used in the three projects were not measured. Instead, default and approximate values in the PavePro were used. The reason why these values were used was that, if the specification is implemented, it will be most probable that chemical and hydrating-property analysis of cementitious materials may not be done. Considering the minimum effort exerted in obtaining input values, the PavePro program did a reasonable job in predicting concrete temperatures.

Over the years, CTR collected extensive data from a number of paving projects on concrete temperature increase due to heat of hydration. Based on the data, it is quite feasible to achieve the temperature requirements in the shadow specifications with minimum effort.

Table 3.4 Summary for the results of the predicted and actual

		US 183		US 290		US 59	
		Predicted	Actual	Predicted	Actual	Predicted	Actual
Maximum Temperature	Location	Middle	Middle Bottom	Middle	Middle	Bottom	Middle Middle
	Placement Time	4 p.m.	Noon Noon	Noon	8 a.m.	2p.m.	10 a.m. Noon
	Elapsed Time (hrs)	24	8—13 12—15	10	11—14	12	8—9 7—9
	Value	89.0	95.9	102.0	100.4	119.3	114.8
Maximum Temperature Difference	Placement Time	11 a.m.	11 a.m.	2 p.m.	2 p.m.	2 p.m.	2 p.m.
	Elapsed Time (hrs)	16	22	18	13—19	18	12—16
	Value	7.2	10.8	11.9	11.7	16.5	16.2

4. Conclusions and Recommendations

Previous research studies, including NCHRP 1-37A, indicated that the concrete temperature during placement, more precisely zero-stress temperature, has a substantial effect on the long-term performance of CRCP. To address this issue more efficiently from a materials and construction standpoint, in TxDOT project 0-1700, a temperature prediction model, called PavePro, was developed. Initial laboratory and field evaluations indicate that the predictions from the program compare well with the actual temperature values. In order to evaluate the feasibility of using this program in the specification to control concrete temperatures, this implementation project was initiated. In the project, shadow specifications were developed and implemented in three TxDOT projects. The findings from the three projects can be summarized as follows:

- The implementation of shadow specifications is feasible. The equipment cost involved with the implementation will be minimal. However, contractors will need to have a person familiar with PC operations.
- The maximum concrete temperatures predicted by PavePro were within a range of 6.9° F, when compared to the actual values. The difference between predicted and actual temperature differentials between the top and the bottom of the slab was less than 3.6° F. This indicates the reasonableness of the PavePro predictions. However, the predicted concrete placement times and elapsed times before maximum concrete temperatures and differentials take place, and the depths of maximum temperature are quite different from those observed in the actual pavement.

It would be ideal if temperature prediction models were more accurate so that testing frequency could be substantially reduced. In this scenario, the field testing would be not quality control or job control testing; rather, it would be verification testing. It is recommended that further efforts be made to improve the accuracy of the temperature prediction models. Until such accuracy is achieved through further study, it is recommended that pilot projects be selected, and the shadow specifications developed and evaluated in this research be implemented as special specifications. It is expected that the implementation will result in improved long-term performance of CRCP.

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Schindler, A. K., T. Dossey, and B. F. McCullough, "Temperature Control During Construction To Improve The Long Term Performance Of Portland Cement Concrete Pavements," Center for Transportation Research, The University of Texas at Austin, Research Report 0-1700-2, May 2002.

Suh, Y. C., K. Hankins, and B. F. McCullough, "Early-Age Behavior of Continuously Reinforced Concrete Pavement and Calibration of the Failure Prediction Model in the CRCP-7 Program," Center for Transportation Research, The University of Texas at Austin, Research Report 1244-3, March 1992.

Appendix A: Comparison of the Predicted with the Actual Temperatures During the First 48 Hours

US 183 Test Section in Austin

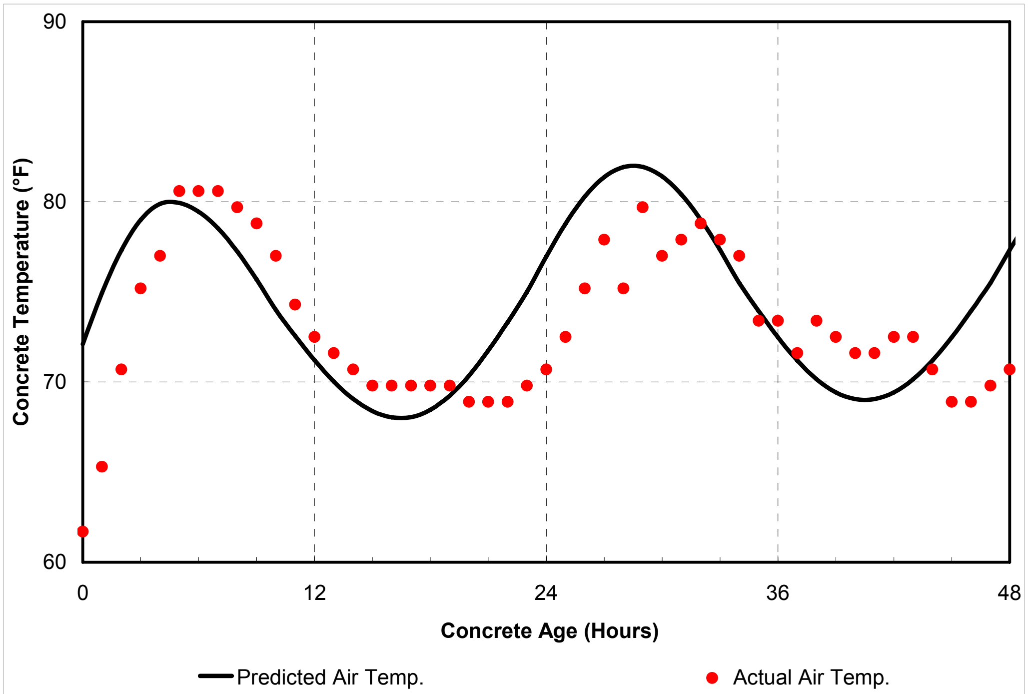
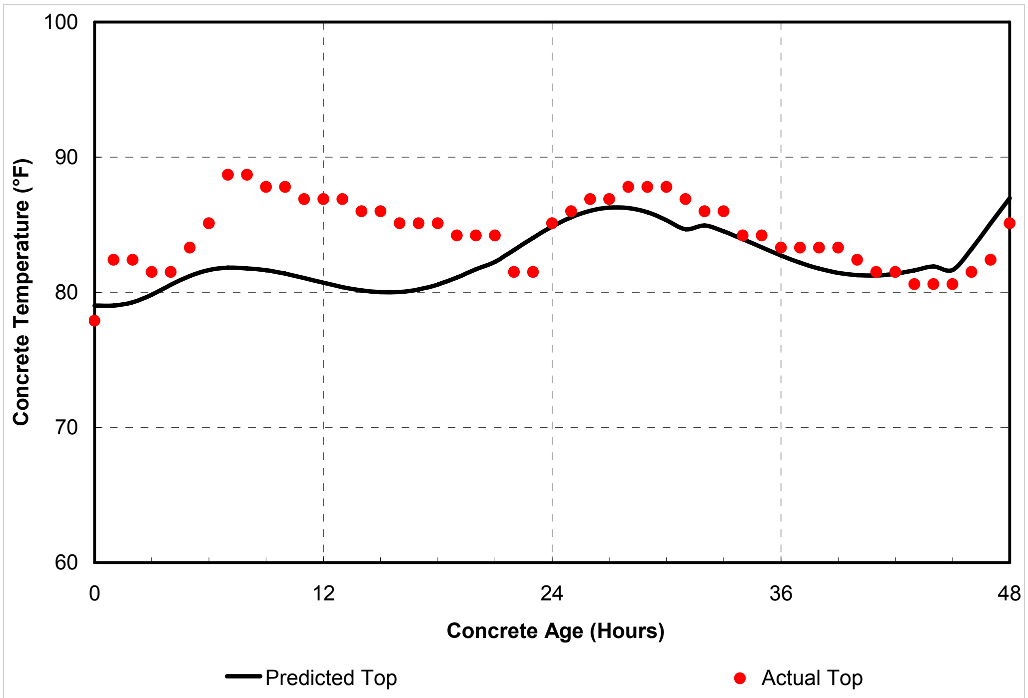
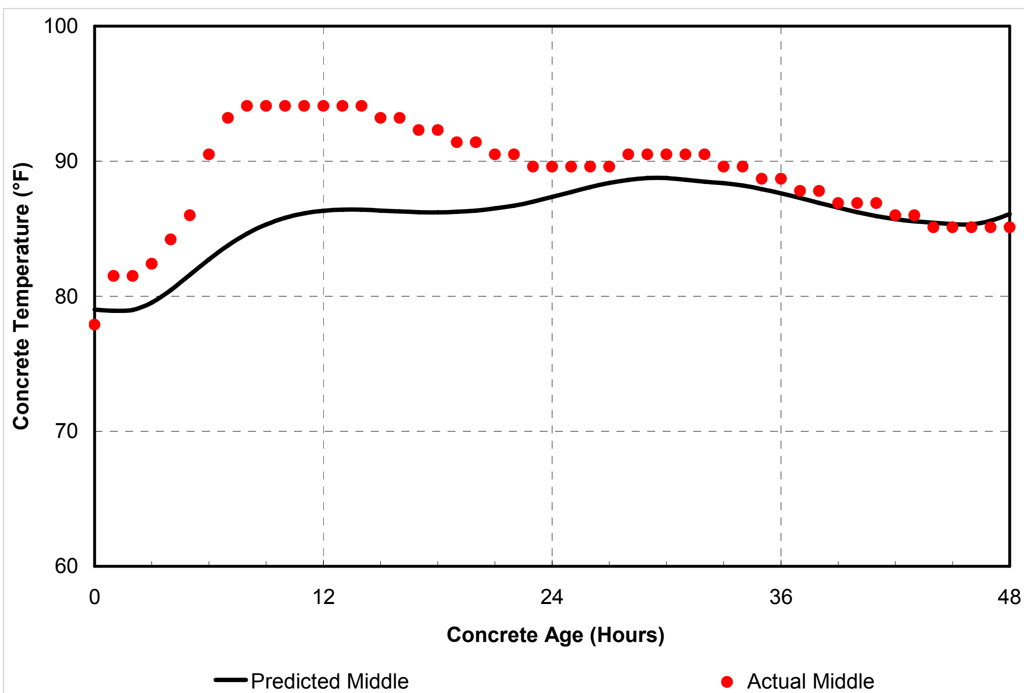


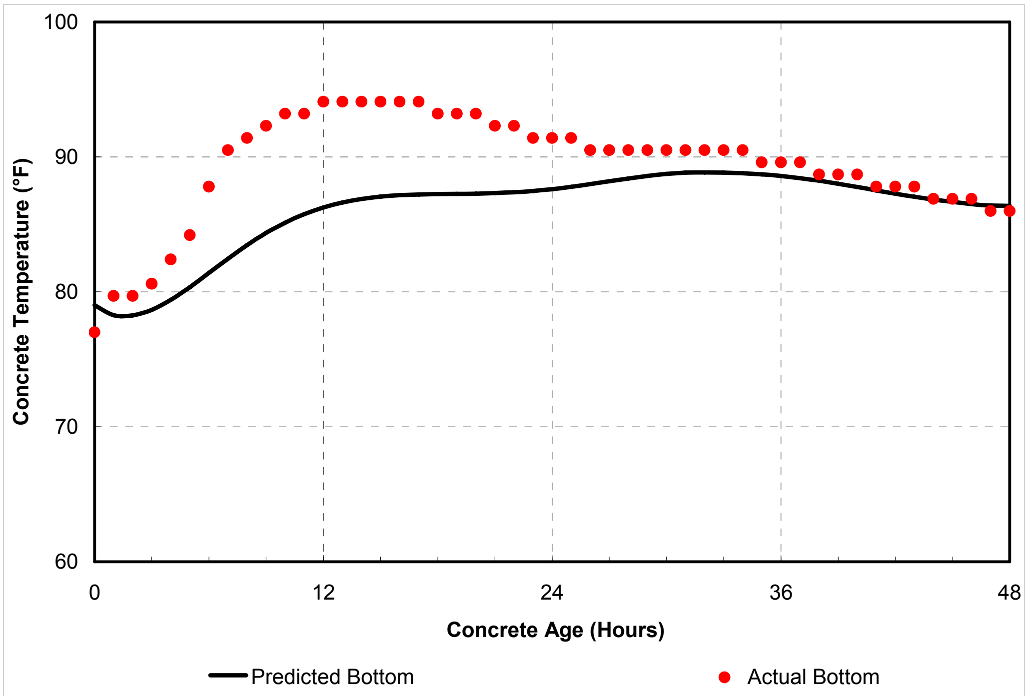
Figure A.1 Comparison of the Predicted with the Actual Air Temperatures (US 183)



(a) Top

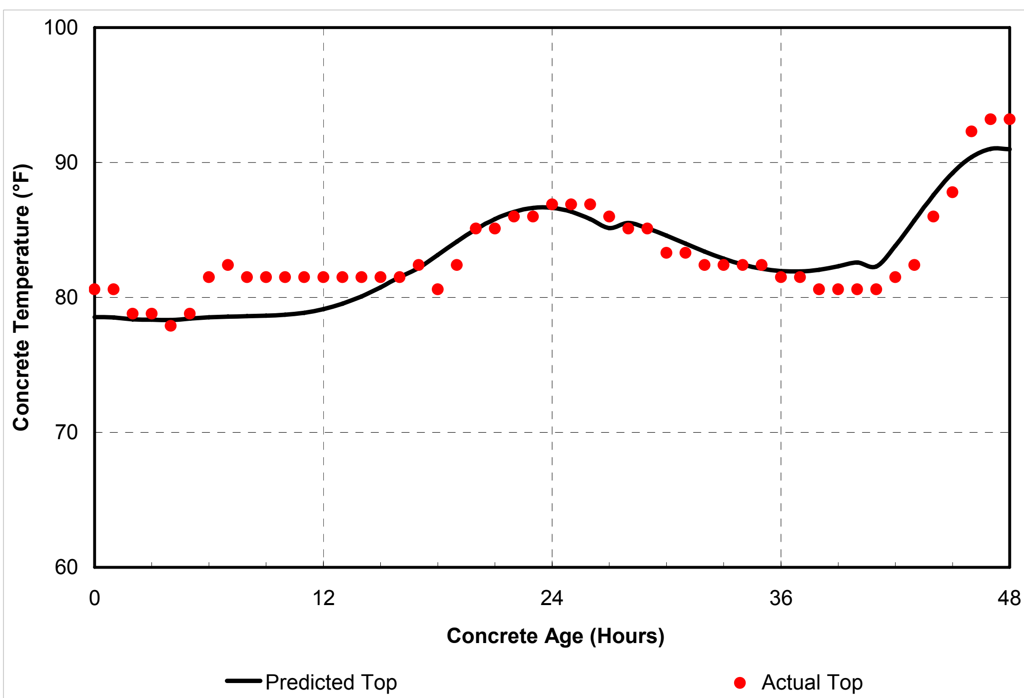


(b) Middle

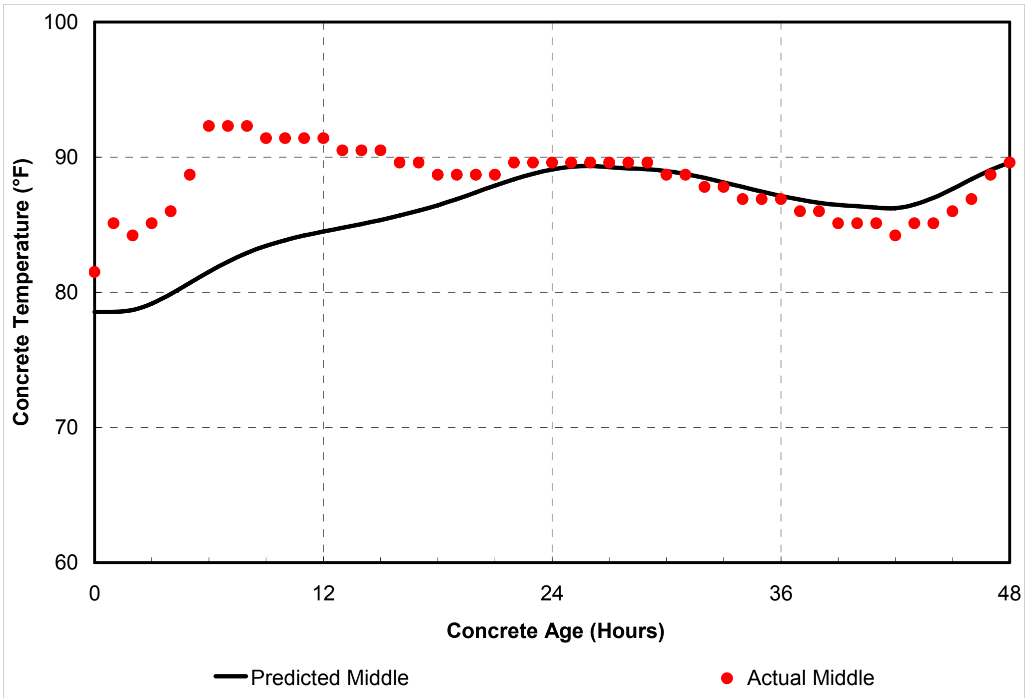


(c) Bottom

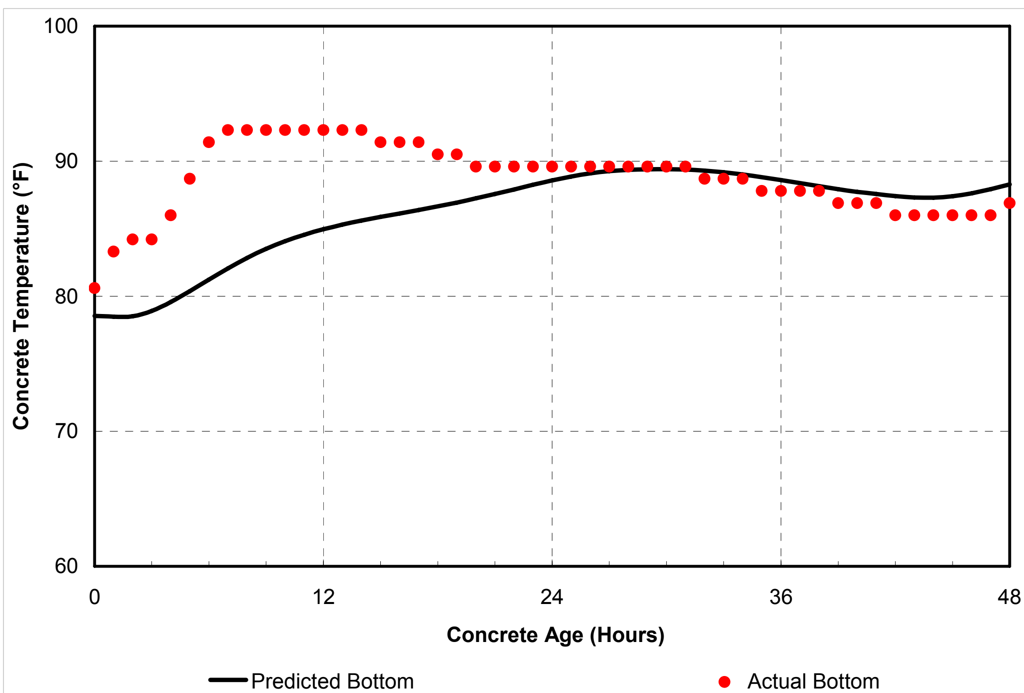
Figure A.2 (a), (b), (c). 11 AM



(a) Top



(b) Middle



(c) Bottom

Figure A.3 (a), (b), (c). 3 PM

US 290 Test Section in Austin

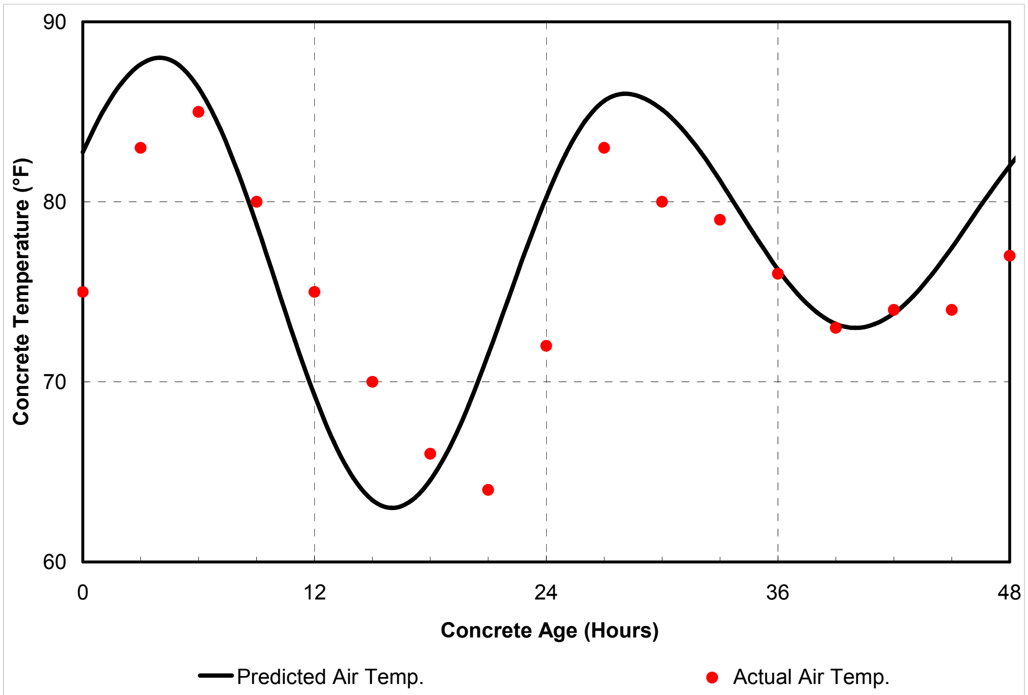
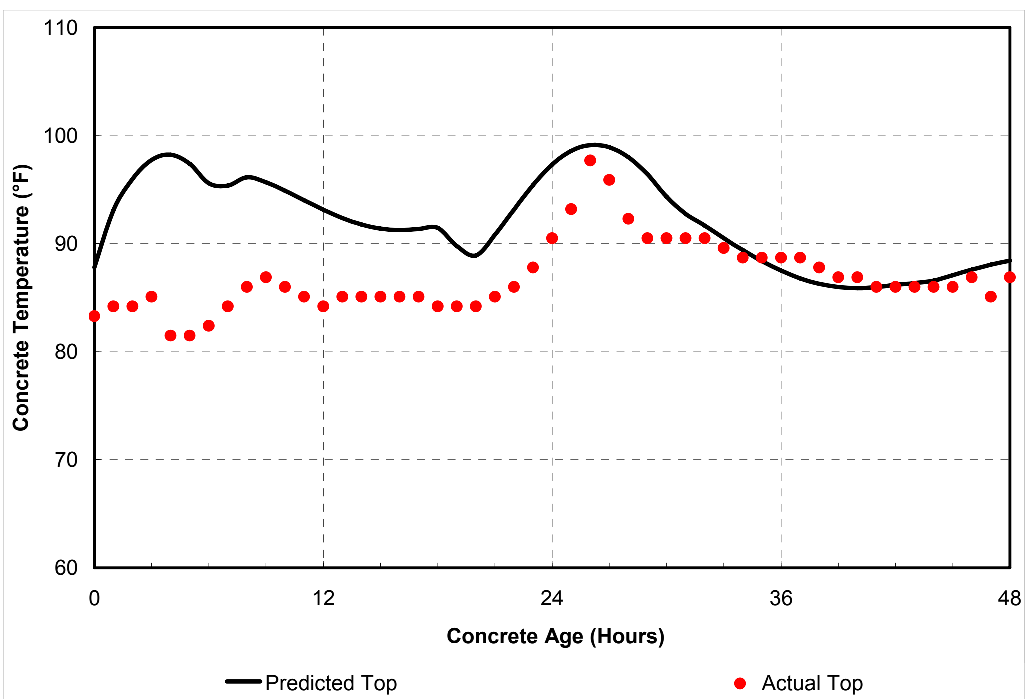
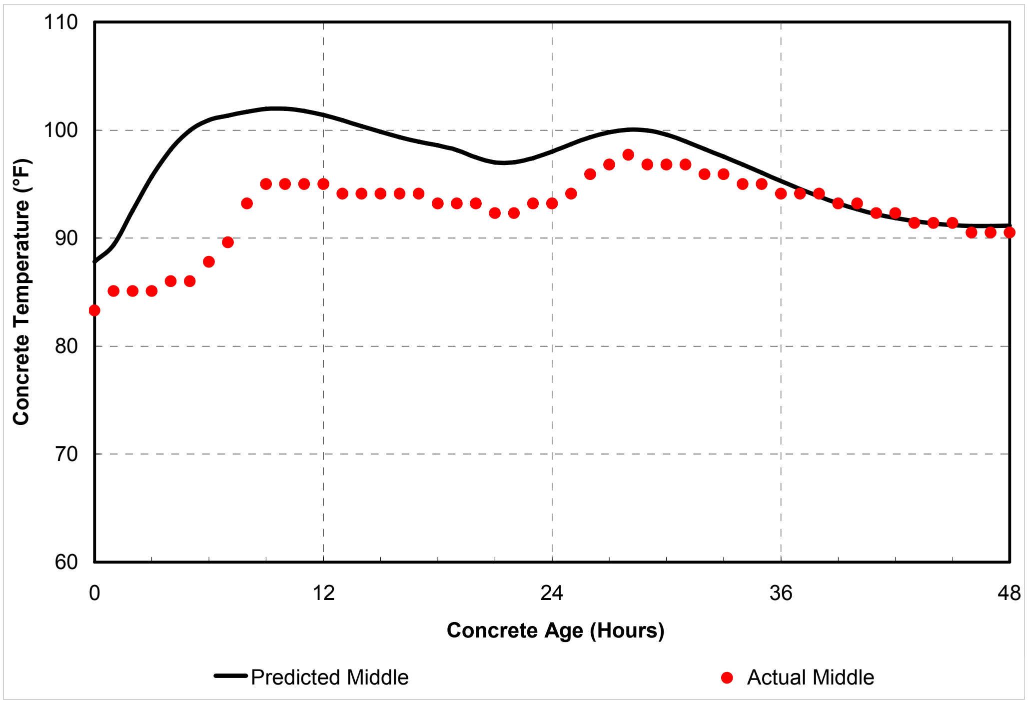


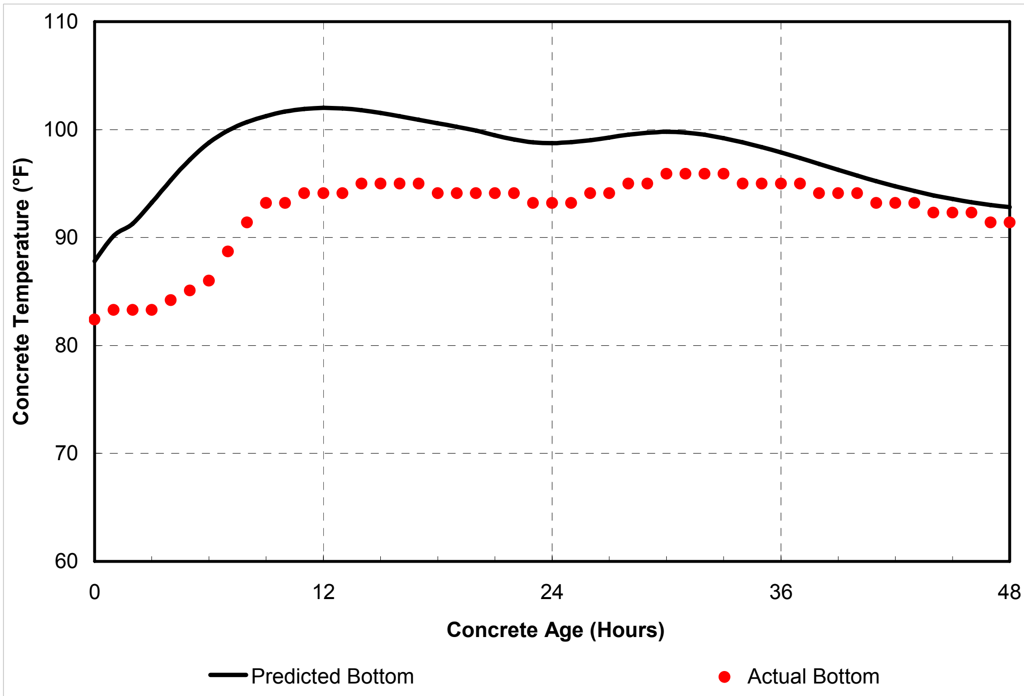
Figure A.4 Comparison the Predicted with the Actual Air Temperatures (US 290)



(a) Top

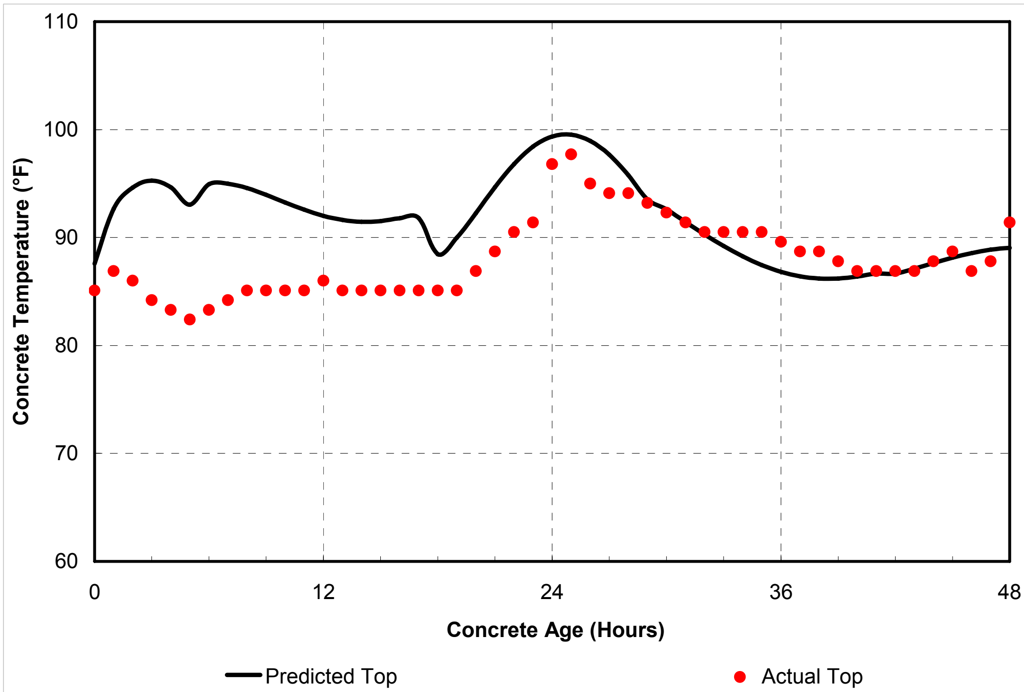


(b) Middle

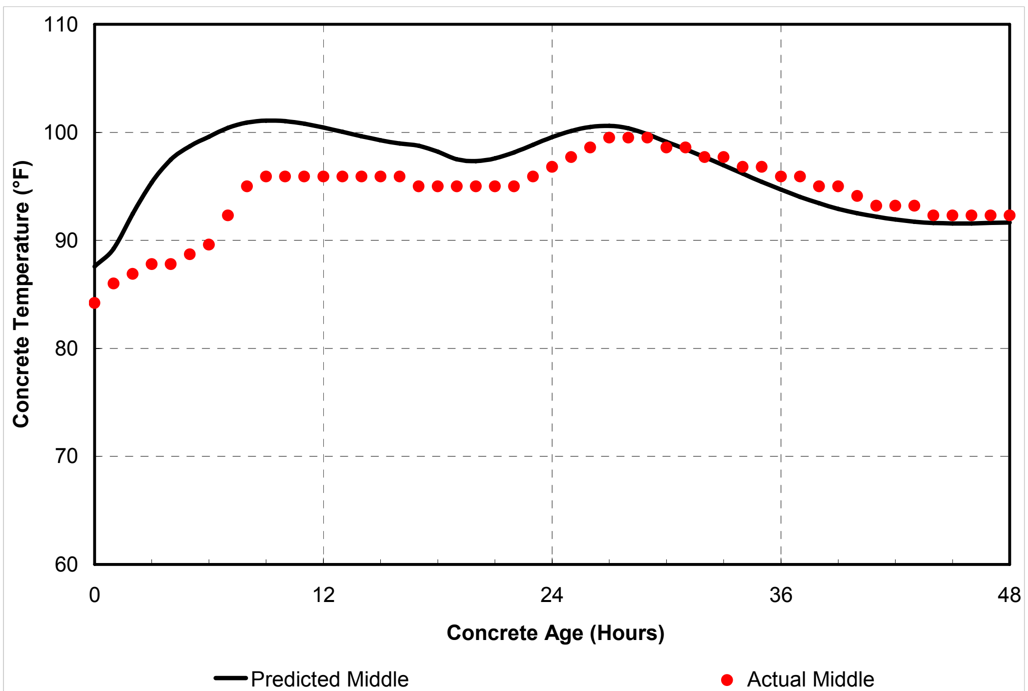


(c) Bottom

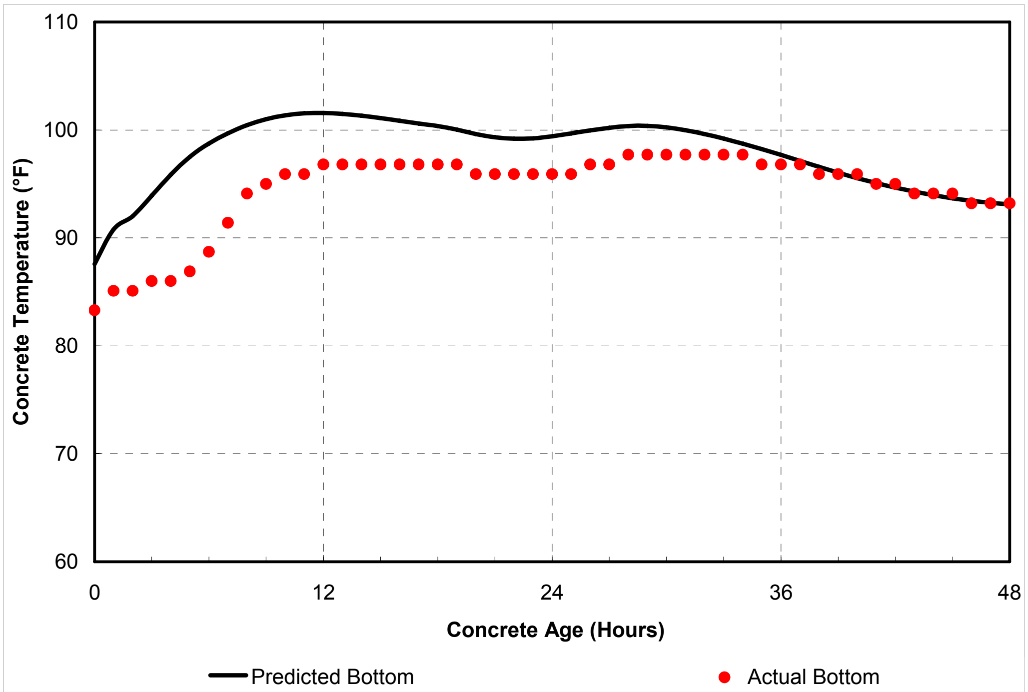
Figure A.5 (a), (b), (c). 12:30 PM



(a) Top



(b) Middle



(c) Bottom

Figure A.6 (a), (b), (c). 2 PM

US 59 Test Section in Houston

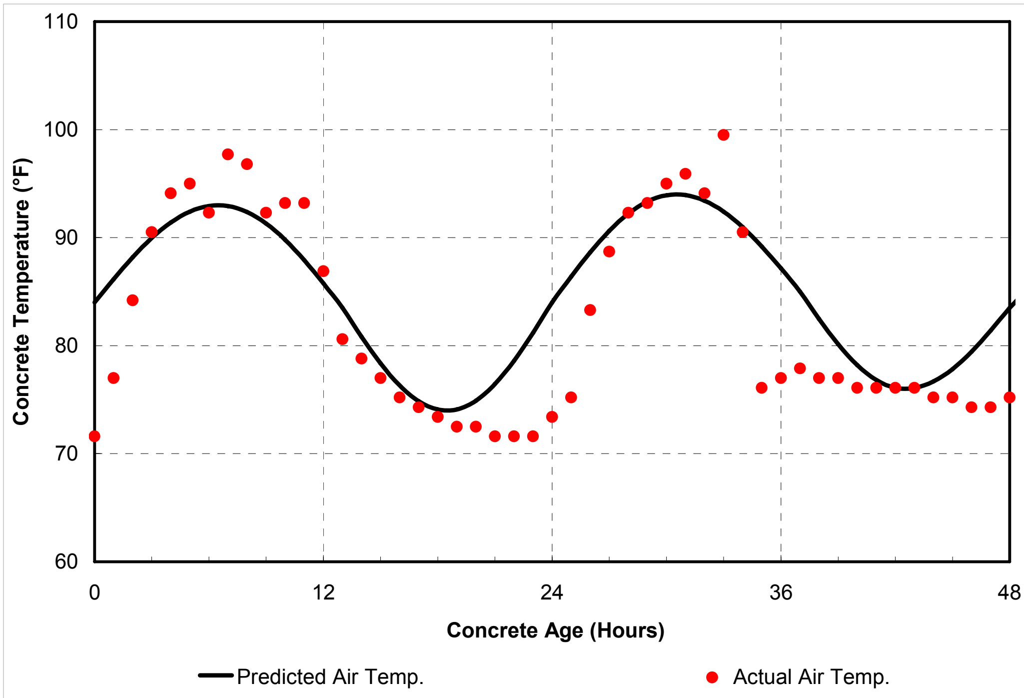
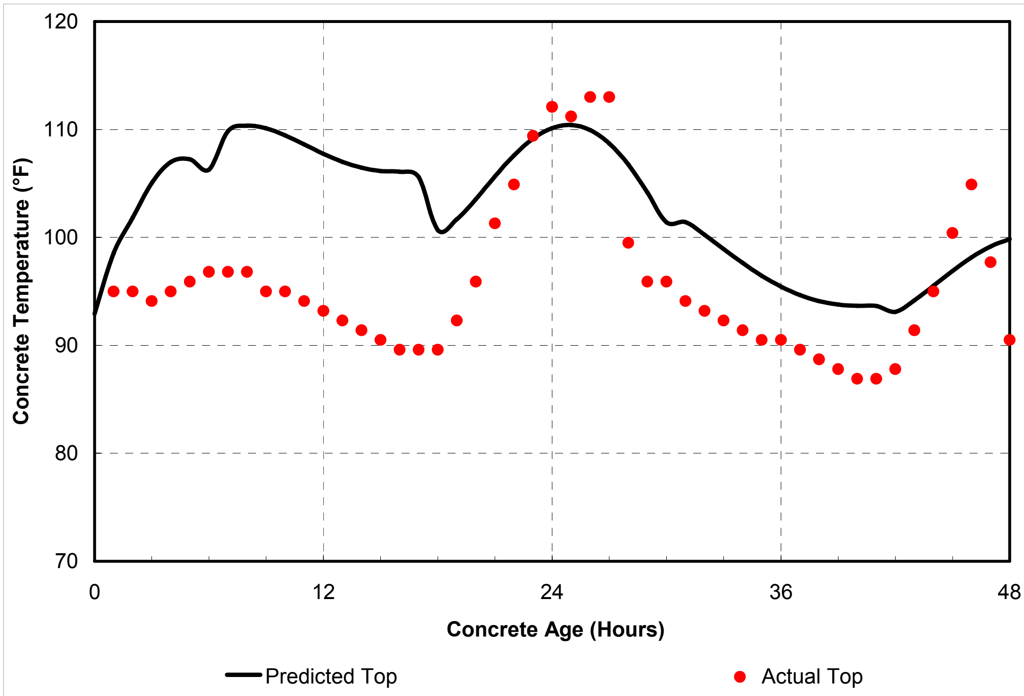
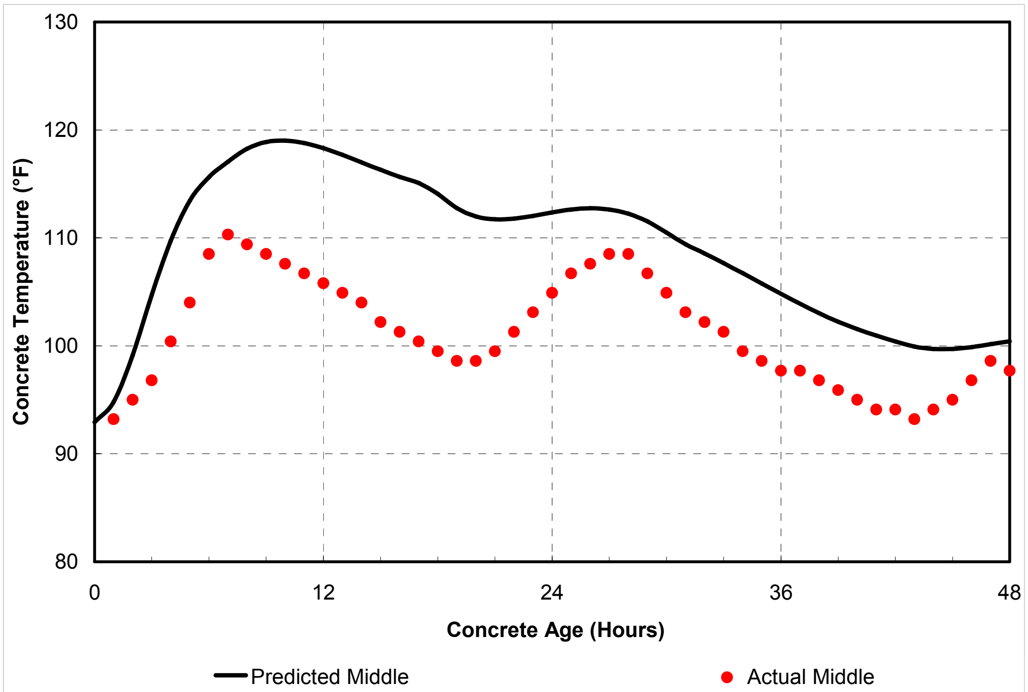


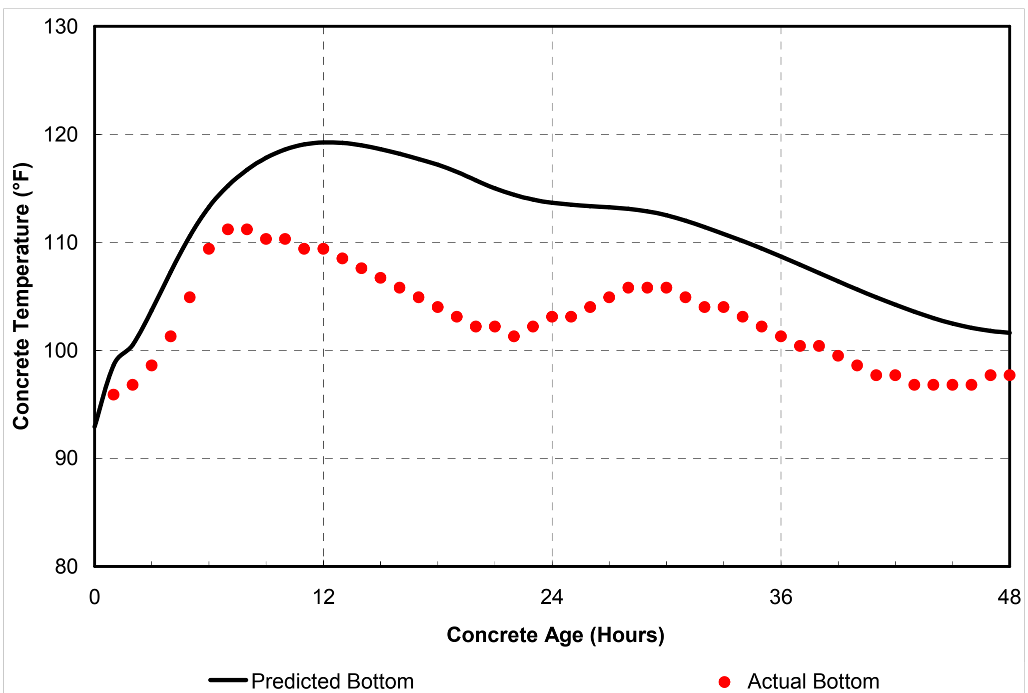
Figure A.7 Comparison the Predicted with the Actual Air Temperature (US 59)



(a) Top



(b) Middle



(c) Bottom

Figure A.8 (a), (b), (c). 2 PM

Appendix B: Actual Temperature Data

Table B.1 US 183 Test Section

Hours	Date	Air	11:00AM			3:00PM		
			Top	Middle	Bottom	Top	Middle	Bottom
0	11/11/2005 8:00	61.7	77.9	77.9	77.0	80.6	81.5	80.6
1	11/11/2005 9:00	65.3	82.4	81.5	79.7	80.6	85.1	83.3
2	11/11/2005 10:00	70.7	82.4	81.5	79.7	78.8	84.2	84.2
3	11/11/2005 11:00	75.2	81.5	82.4	80.6	78.8	85.1	84.2
4	11/11/2005 12:00	77.0	81.5	84.2	82.4	77.9	86.0	86.0
5	11/11/2005 13:00	80.6	83.3	86.0	84.2	78.8	88.7	88.7
6	11/11/2005 14:00	80.6	85.1	90.5	87.8	81.5	92.3	91.4
7	11/11/2005 15:00	80.6	88.7	93.2	90.5	82.4	92.3	92.3
8	11/11/2005 16:00	79.7	88.7	94.1	91.4	81.5	92.3	92.3
9	11/11/2005 17:00	78.8	87.8	94.1	92.3	81.5	91.4	92.3
10	11/11/2005 18:00	77.0	87.8	94.1	93.2	81.5	91.4	92.3
11	11/11/2005 19:00	74.3	86.9	94.1	93.2	81.5	91.4	92.3
12	11/11/2005 20:00	72.5	86.9	94.1	94.1	81.5	91.4	92.3
13	11/11/2005 21:00	71.6	86.9	94.1	94.1	81.5	90.5	92.3
14	11/11/2005 22:00	70.7	86.0	94.1	94.1	81.5	90.5	92.3
15	11/11/2005 23:00	69.8	86.0	93.2	94.1	81.5	90.5	91.4
16	11/12/2005 0:00	69.8	85.1	93.2	94.1	81.5	89.6	91.4
17	11/12/2005 1:00	69.8	85.1	92.3	94.1	82.4	89.6	91.4
18	11/12/2005 2:00	69.8	85.1	92.3	93.2	80.6	88.7	90.5
19	11/12/2005 3:00	69.8	84.2	91.4	93.2	82.4	88.7	90.5
20	11/12/2005 4:00	68.9	84.2	91.4	93.2	85.1	88.7	89.6
21	11/12/2005 5:00	68.9	84.2	90.5	92.3	85.1	88.7	89.6
22	11/12/2005 6:00	68.9	81.5	90.5	92.3	86.0	89.6	89.6
23	11/12/2005 7:00	69.8	81.5	89.6	91.4	86.0	89.6	89.6
24	11/12/2005 8:00	70.7	85.1	89.6	91.4	86.9	89.6	89.6
25	11/12/2005 9:00	72.5	86.0	89.6	91.4	86.9	89.6	89.6
26	11/12/2005 10:00	75.2	86.9	89.6	90.5	86.9	89.6	89.6
27	11/12/2005 11:00	77.9	86.9	89.6	90.5	86.0	89.6	89.6
28	11/12/2005 12:00	75.2	87.8	90.5	90.5	85.1	89.6	89.6
29	11/12/2005 13:00	79.7	87.8	90.5	90.5	85.1	89.6	89.6
30	11/12/2005 14:00	77.0	87.8	90.5	90.5	83.3	88.7	89.6
31	11/12/2005 15:00	77.9	86.9	90.5	90.5	83.3	88.7	89.6
32	11/12/2005 16:00	78.8	86.0	90.5	90.5	82.4	87.8	88.7
33	11/12/2005 17:00	77.9	86.0	89.6	90.5	82.4	87.8	88.7
34	11/12/2005 18:00	77.0	84.2	89.6	90.5	82.4	86.9	88.7
35	11/12/2005 19:00	73.4	84.2	88.7	89.6	82.4	86.9	87.8
36	11/12/2005 20:00	73.4	83.3	88.7	89.6	81.5	86.9	87.8
37	11/12/2005 21:00	71.6	83.3	87.8	89.6	81.5	86.0	87.8
38	11/12/2005 22:00	73.4	83.3	87.8	88.7	80.6	86.0	87.8
39	11/12/2005 23:00	72.5	83.3	86.9	88.7	80.6	85.1	86.9
40	11/13/2005 0:00	71.6	82.4	86.9	88.7	80.6	85.1	86.9
41	11/13/2005 1:00	71.6	81.5	86.9	87.8	80.6	85.1	86.9
42	11/13/2005 2:00	72.5	81.5	86.0	87.8	81.5	84.2	86.0
43	11/13/2005 3:00	72.5	80.6	86.0	87.8	82.4	85.1	86.0
44	11/13/2005 4:00	70.7	80.6	85.1	86.9	86.0	85.1	86.0
45	11/13/2005 5:00	68.9	80.6	85.1	86.9	87.8	86.0	86.0
46	11/13/2005 6:00	68.9	81.5	85.1	86.9	92.3	86.9	86.0
47	11/13/2005 7:00	69.8	82.4	85.1	86.0	93.2	88.7	86.0
48	11/13/2005 8:00	70.7	85.1	85.1	86.0	93.2	89.6	86.9

Table B.2 US 290 Test Section

Hours	Date	12:30PM			2:00PM		
		Top	Middle	Bottom	Top	Middle	Bottom
0	10/25/2004 8:12	83.3	83.3	82.4	85.1	84.2	83.3
1	10/25/2004 9:02	84.2	85.1	83.3	86.9	86.0	85.1
2	10/25/2004 10:02	84.2	85.1	83.3	86.0	86.9	85.1
3	10/25/2004 11:02	85.1	85.1	83.3	84.2	87.8	86.0
4	10/25/2004 12:02	81.5	86.0	84.2	83.3	87.8	86.0
5	10/25/2004 13:02	81.5	86.0	85.1	82.4	88.7	86.9
6	10/25/2004 14:02	82.4	87.8	86.0	83.3	89.6	88.7
7	10/25/2004 15:02	84.2	89.6	88.7	84.2	92.3	91.4
8	10/25/2004 16:02	86.0	93.2	91.4	85.1	95.0	94.1
9	10/25/2004 17:02	86.9	95.0	93.2	85.1	95.9	95.0
10	10/25/2004 18:02	86.0	95.0	93.2	85.1	95.9	95.9
11	10/25/2004 19:02	85.1	95.0	94.1	85.1	95.9	95.9
12	10/25/2004 20:02	84.2	95.0	94.1	86.0	95.9	96.8
13	10/25/2004 21:02	85.1	94.1	94.1	85.1	95.9	96.8
14	10/25/2004 22:02	85.1	94.1	95.0	85.1	95.9	96.8
15	10/25/2004 23:02	85.1	94.1	95.0	85.1	95.9	96.8
16	10/26/2004 0:02	85.1	94.1	95.0	85.1	95.9	96.8
17	10/26/2004 1:02	85.1	94.1	95.0	85.1	95.0	96.8
18	10/26/2004 2:02	84.2	93.2	94.1	85.1	95.0	96.8
19	10/26/2004 3:02	84.2	93.2	94.1	85.1	95.0	96.8
20	10/26/2004 4:02	84.2	93.2	94.1	86.9	95.0	95.9
21	10/26/2004 5:02	85.1	92.3	94.1	88.7	95.0	95.9
22	10/26/2004 6:02	86.0	92.3	94.1	90.5	95.0	95.9
23	10/26/2004 7:02	87.8	93.2	93.2	91.4	95.9	95.9
24	10/26/2004 8:02	90.5	93.2	93.2	96.8	96.8	95.9
25	10/26/2004 9:02	93.2	94.1	93.2	97.7	97.7	95.9
26	10/26/2004 10:02	97.7	95.9	94.1	95.0	98.6	96.8
27	10/26/2004 11:02	95.9	96.8	94.1	94.1	99.5	96.8
28	10/26/2004 12:02	92.3	97.7	95.0	94.1	99.5	97.7
29	10/26/2004 13:02	90.5	96.8	95.0	93.2	99.5	97.7
30	10/26/2004 14:02	90.5	96.8	95.9	92.3	98.6	97.7
31	10/26/2004 15:02	90.5	96.8	95.9	91.4	98.6	97.7
32	10/26/2004 16:02	90.5	95.9	95.9	90.5	97.7	97.7
33	10/26/2004 17:02	89.6	95.9	95.9	90.5	97.7	97.7
34	10/26/2004 18:02	88.7	95.0	95.0	90.5	96.8	97.7
35	10/26/2004 19:02	88.7	95.0	95.0	90.5	96.8	96.8
36	10/26/2004 20:02	88.7	94.1	95.0	89.6	95.9	96.8
37	10/26/2004 21:02	88.7	94.1	95.0	88.7	95.9	96.8
38	10/26/2004 22:02	87.8	94.1	94.1	88.7	95.0	95.9
39	10/26/2004 23:02	86.9	93.2	94.1	87.8	95.0	95.9
40	10/27/2004 0:02	86.9	93.2	94.1	86.9	94.1	95.9
41	10/27/2004 1:02	86.0	92.3	93.2	86.9	93.2	95.0
42	10/27/2004 2:02	86.0	92.3	93.2	86.9	93.2	95.0
43	10/27/2004 3:02	86.0	91.4	93.2	86.9	93.2	94.1
44	10/27/2004 4:02	86.0	91.4	92.3	87.8	92.3	94.1
45	10/27/2004 5:02	86.0	91.4	92.3	88.7	92.3	94.1
46	10/27/2004 6:02	86.9	90.5	92.3	86.9	92.3	93.2
47	10/27/2004 7:02	85.1	90.5	91.4	87.8	92.3	93.2
48	10/27/2004 8:02	86.9	90.5	91.4	91.4	92.3	93.2

Table B.3 US 59 Test Section

Hours	Date	Air	2:00PM		
			Top	Middle	Bottom
0	7/20/2004 7:00	71.6	-	-	-
1	7/20/2004 8:00	77.0	95.0	93.2	95.9
2	7/20/2004 9:00	84.2	95.0	95.0	96.8
3	7/20/2004 10:00	90.5	94.1	96.8	98.6
4	7/20/2004 11:00	94.1	95.0	100.4	101.3
5	7/20/2004 12:00	95.0	95.9	104.0	104.9
6	7/20/2004 13:00	92.3	96.8	108.5	109.4
7	7/20/2004 14:00	97.7	96.8	110.3	111.2
8	7/20/2004 15:00	96.8	96.8	109.4	111.2
9	7/20/2004 16:00	92.3	95.0	108.5	110.3
10	7/20/2004 17:00	93.2	95.0	107.6	110.3
11	7/20/2004 18:00	93.2	94.1	106.7	109.4
12	7/20/2004 19:00	86.9	93.2	105.8	109.4
13	7/20/2004 20:00	80.6	92.3	104.9	108.5
14	7/20/2004 21:00	78.8	91.4	104.0	107.6
15	7/20/2004 22:00	77.0	90.5	102.2	106.7
16	7/20/2004 23:00	75.2	89.6	101.3	105.8
17	7/20/2004 24:00	74.3	89.6	100.4	104.9
18	7/21/2004 1:00	73.4	89.6	99.5	104.0
19	7/21/2004 2:00	72.5	92.3	98.6	103.1
20	7/21/2004 3:00	72.5	95.9	98.6	102.2
21	7/21/2004 4:00	71.6	101.3	99.5	102.2
22	7/21/2004 5:00	71.6	104.9	101.3	101.3
23	7/21/2004 6:00	71.6	109.4	103.1	102.2
24	7/21/2004 7:00	73.4	112.1	104.9	103.1
25	7/21/2004 8:00	75.2	111.2	106.7	103.1
26	7/21/2004 9:00	83.3	113.0	107.6	104.0
27	7/21/2004 10:00	88.7	113.0	108.5	104.9
28	7/21/2004 11:00	92.3	99.5	108.5	105.8
29	7/21/2004 12:00	93.2	95.9	106.7	105.8
30	7/21/2004 13:00	95.0	95.9	104.9	105.8
31	7/21/2004 14:00	95.9	94.1	103.1	104.9
32	7/21/2004 15:00	94.1	93.2	102.2	104.0
33	7/21/2004 16:00	99.5	92.3	101.3	104.0
34	7/21/2004 17:00	90.5	91.4	99.5	103.1
35	7/21/2004 18:00	76.1	90.5	98.6	102.2
36	7/21/2004 19:00	77.0	90.5	97.7	101.3
37	7/21/2004 20:00	77.9	89.6	97.7	100.4
38	7/21/2004 21:00	77.0	88.7	96.8	100.4
39	7/21/2004 22:00	77.0	87.8	95.9	99.5
40	7/21/2004 23:00	76.1	86.9	95.0	98.6
41	7/21/2004 24:00	76.1	86.9	94.1	97.7
42	7/22/2004 1:00	76.1	87.8	94.1	97.7
43	7/22/2004 2:00	76.1	91.4	93.2	96.8
44	7/22/2004 3:00	75.2	95.0	94.1	96.8
45	7/22/2004 4:00	75.2	100.4	95.0	96.8
46	7/22/2004 5:00	74.3	104.9	96.8	96.8
47	7/22/2004 6:00	74.3	97.7	98.6	97.7
48	7/22/2004 7:00	75.2	90.5	97.7	97.7