TEMPERATURE VARIATION IN DRILLED SHAFT CONCRETE AND ITS EFFECT ON SLUMP LOSS

Final Report

Submitted to:

Florida Department of Transportation (FDOT)

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Under
Contract No. BC836

February 2003

ACKNOWLEDGMENTS

The authors acknowledge the support and expertise of the following individuals in conducting this research study:

Dr. Sastry Putcha, P.E.
State Construction Geotechnical Engineer, Florida Department of Transportation, Tallahassee

Mr. Ken Blanchard, P.E.
Contract Administration Engineer, Florida Department of Transportation, Tallahassee

Mr. Leigh Markert
Districts 4 and 6 Concrete Engineer, Florida Department of Transportation, Broward

Mr. Michael Bergin, P.E.
State Structural/Materials Engineer, Florida Department of Transportation, Gainesville

Ms. Robbin Dano
Districts 4 and 6 Concrete Engineer, Florida Department of Transportation, Broward

Mr. Jerry Haught, P.E.
Director of Technical Services, CSR Rinker, West Palm Beach

Mr. Dan Turner, *P.E.*
Mr. Travis Richards, E.I.
Mr. Peter G. Read, P.E.
Universal Engineering Sciences

The authors would like to thank *Mr. Ivan Canino*, Graduate Student at the Department of Civil and Environmental Engineering, Florida International University, Miami for helping out during experiments.

EXECUTIVE SUMMARY

Drilled shaft refers to a deep foundation system where a single large diameter pier is used to replace a whole group of piles. Florida Department of Transportation (FDOT) specification 346-3.2 requires that the concrete used for the construction of drilled shaft should have a slump between 7 and 9 inch (180 and 230 mm) when placed and should maintain a slump of 4 inch (25 mm) or more throughout the concrete placement time. Furthermore, it requires that the mix for the slump loss test should be prepared at a temperature consistent with the highest ambient or initial concrete temperature (whichever is greater) expected during actual concrete placement.

There is a prevalent feeling among many FDOT contractors that this requirement is not realistic and is too stringent. They feel that the temperature of concrete inside the drilled shaft is likely to be lower than the ambient or initial concrete temperature and hence slump loss would be less than the loss determined at the highest ambient or initial concrete temperature.

Based on the above premise, this research study was conducted with the objective to establish profiles of concrete temperature in time from placement to hardening along depth as well as width within the shaft. For this purpose, three 4 ft (1.22 m) diameter and 25 ft (7.62 m) deep drilled-shafts were constructed. Temperature probes connected with automatic data recorders were used to record the temperature of concrete inside the drilled shaft. Based on the gathered data, it was found that the temperature of concrete inside the drilled shaft was same as initial concrete temperature before placing at all locations. This finding leads to the conclusion that concrete temperature inside drilled shaft is not affected by ambient temperature and/or underground temperature conditions. Hence it is recommended that that the initial concrete temperature should be used for the slump loss test and the corresponding FDOT specifications should be revised accordingly.

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Chapter 1

INTRODUCTION

1.1 General

The terms *drilled shaft*, *caisson*, or *drilled pier* are often used interchangeably in foundation engineering, all refer to a *cast-in-place* pile generally having a diameter of about 2.5 ft (750 mm) or more, with or without steel reinforcement and with or without an enlarged bottom. A drilled shaft may be more cost-effective than driven piles in bridge piers at river crossings, retrofit operations, high-mast lighting, earth retaining structures, single column piers and similar applications (Das, 1998). The use of drilled shaft foundations has several advantages such as:

1. A single drilled shaft may be used instead of a group of piles and the pile cap.
2. Because the base of a drilled shaft can be enlarged, it provides a great resistance to the uplifting load.
3. The surface over which the base of the drilled shaft is constructed can be visually inspected.
4. Construction of drilled shafts generally utilizes mobile equipment, which, under proper soil conditions, may prove to be more economical than methods of constructing pile foundations.
5. Drilled shafts have higher resistance to lateral loads.

Most drilled shafts are excavated using *open helix augers*. The auger is inserted and withdrawn repeatedly while rotating, to drill a hole to the required depth (Figure 1.1a). Then the drilled hole is filled with concrete, usually with steel reinforcement so that the drilled shaft will be capable of resisting bending moments and uplift as well as compressive loads. The rebar cage is lowered into a drilled hole before the concrete is placed to form the drilled shaft. The rebar cage is usually so flexible that it needs to be stabilized with cross bars to ensure that it will keep its circular shape (Figure 1.1b).

Concrete is placed in the drilled hole using a tremie pipe to prevent segregation of the concrete, erosion of the sides of the drilled hole, and damage to the rebar that would occur if the concrete was allowed to free fall to the bottom of the shaft (Figure 1.1c). Bentonite slurry is often used to prevent collapse of the sides of the hole, which has been drilled in unstable ground. When the concrete flows out of the tremie pipe at the bottom of the shaft, it displaces the slurry, which is lighter (Figure 1.1d). As the slurry is displaced upward, overflowing the hole, it is pumped to a storage tank for cleaning and re-use on another shaft.

Figure 1.1a: Drilling of drilled shaft hole using open helix auger

Figure 1.1b: Lowering of steel cage

Figure 1.1c: Placing of concrete via tremie pipe

Figure 1.1d: Flow of bentonite slurry during placing of concrete

Figure 1.1: Different Construction Stages of Drilled Shaft Foundation

High slump self-compacting concrete is used in drilled shafts due to its high fluidity and less proneness to segregation. The placement of concrete in the drilled shaft must be completed within 30-45 minutes otherwise the concrete starts to lose its consistency and becomes stiffer, making pumping process harder. This loss of consistency in fresh concrete with elapsed time is called the *slump loss*. Slump loss occurs when the free water from a concrete mixture is removed by hydration reactions, by adsorption on the surfaces of hydration products, and by evaporation. Under normal conditions, the volume of hydration products during the first half-hour after the addition of water to cement is small and the slump loss is negligible. Thereafter, concrete starts losing slump at a higher rate depending on the ambient temperature, cement composition and the admixtures present (Mehta and Monteiro, 1993).

1.2 Research Objectives and Scope

Florida Department of Transportation (FDOT) specification 346-3.2 requires that drilled shaft concrete should have a slump between 7 and 9 inch (180 and 230 mm) when placed and should maintain a slump of 4 inch (25 mm) or more throughout the concrete placement time (*3*). Furthermore, it requires that the concrete mix for the slump loss test should be conducted at a temperature consistent with the highest ambient or initial concrete temperature (whichever is greater), expected during actual concrete placement.

There is a prevalent feeling among many FDOT contractors that this requirement is not realistic and is too stringent. They feel this requirement can be and should be relaxed in light of the fact that temperature inside the drilled shaft is likely to be lower than the ambient temperature or initial concrete temperature. If this is the case, then setting time would be longer and the magnitude of slump loss would be less than the loss determined at either ambient temperature or concrete temperature.

Based on the above premise, this research study was undertaken with the objective of determining temperature profiles of concrete in time from placement to hardening. For this purpose, three 4 ft (1.22 m) diameter 25 ft (7.62 m) deep drilled shafts were constructed. Temperature probes connected with automatic data recorders were used to record the concrete temperature inside the drilled shaft. Based on the collected data, temperature profiles are plotted and analyzed.

The research was conducted in two phases between February 2001 and March 2002. The objective of the first phase was to investigate the ground temperature variation along depth. The purpose of the second phase was to determine temperature variation in concrete with time. The temperature data were collected across the width (along the cross section) as well as along the depth of the drilled shafts.

1.3 Research Significance

It is important to note that no published or unpublished research work on the topic of the temperature variation in drilled shaft concrete is found and hence this research could be considered as pioneering in this area.

A clear answer as to whether the absolute temperature in the drilled shaft is lower than the ambient or initial concrete temperature was provided by this investigation. It also provides a reliable set of data in terms of the temperature profiles obtained. These data can serve as a basis for any future investigation.

1.4 Organization of the Report

This report is organized as follows: It begins with a simple introduction, with brief mentions of the advantages and construction methods of drilled shaft foundation system. The introduction also includes the research objectives, a description of the scope and significance (Chapter 1). In Chapter 2, the methodology employed to carry out the investigations is elaborated along with the related experimental details. Results and analysis of the findings are reported and discussed in Chapter 3. In Chapter 4, the conclusions and recommendations made on the basis of the experimental findings are presented. The important experimental data are included in the appendices.

Chapter 2

METHODOLOGY AND EXPERIMENTAL DETAILS

2.1 Methodology

A two phase methodology, as described in the following, was developed by the investigators to carry out this research study.

2.1.1 Phase I: Exploratory tests to determine underground temperature variation along depth

The purpose of this phase was to determine the underground temperature variation along depth in order to make a decision about the depth to be used in test shafts of Phase II with the stipulation that if there is no significant variation in temperature along depth, the test shafts do not have to be excessively deep.

2.1.2 Phase II: Field testing to determine temperature variation in freshly placed drilled shaft concrete

Field testing involved the recording of temperature variation across the width (cross section) and along the depth of the drilled shafts. Three experimental drilled shafts, each 4 ft diameter 25 ft length were constructed. No casing was used. Steel cages with minimum reinforcement were used. Their basic purpose was to hold the temperature probes at the specified locations. The temperature in each probe was recorded through an automatic data recorder for 125 hours until the concrete temperature started to stabilize.

2.2 Experimental Details

Experimental details of both of these phases and the data collected are explained in this section. All testing were carried out in the SE corner of the Engineering and Applied Sciences Building of Florida International University at 10555 West Flagler Street in Miami, Florida.

2.2.1 Phase I: Exploratory testing

In this phase, three 4-in. diameter holes were drilled up to 50+ ft depth and encased with plastic tubes as shown in Figure 2.1. The temperature data were recorded on February 26, 2001 (afternoon) and then again on March 01, 2001 (morning). The following observations were recorded.

- Temperature (of air or ground water) inside each hole at an interval of 2 ft up to a depth of 10 ft and then at an interval of 5 ft up to the full length of about 50 ft. Each reading was recorded when the temperature stabilized at that depth, using a temperature probe attached with a string and connected to a digital thermometer. The temperature data was recorded in both downward and upward directions (by lowering the temperature probe from the surface to the full depth and then lifting it up to the surface) to reduce variations due to handling of the apparatus as shown in Figure 2.2.
- Ambient temperature at the test site.
- Ambient temperature in the city using hourly weather data available from the Internet.

The purpose of recording the ambient temperature data was to compare them with the underground temperature data. The data helped to establish a temperature profile from the surface up to the full depth of the drilled shaft.

Figure 2.1: Drilling of Hole to Determine Ground Temperature Variation

Figure 2.2: Recording of Temperature Inside Hole

2.2.2 Phase II: Field testing

In this phase, three 4 ft diameter 25 ft long circular shafts were drilled and then filled with concrete. The dimensions for the drilled shafts were selected to facilitate attaching the temperature probes so that enough data can be collected both across the width and along the depth of the shafts. The depth of 25 ft was used as the Phase I results suggested that temperature remains practically constant underground and does not vary along depth. The site plan of the test drilled shafts construction is illustrated in Figure 2.3.

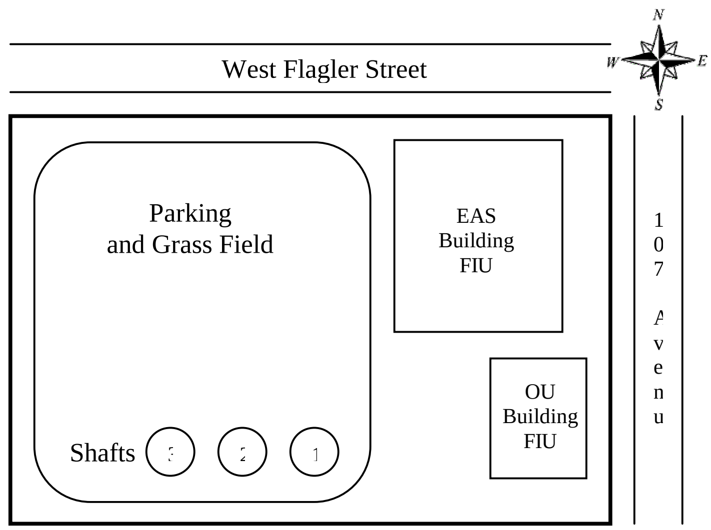

Figure 2.3: Location Plan of the Drilled Shafts

<u>Excavation/Drilling</u>

The water table was found to be at about 6-7 ft below the ground level during Phase I, so the Wet Construction method was used for excavation using the auger cast drilling technique as shown in Figure 2.4. The wet construction method is recommended for all sites where it is impractical to carry out a dry excavation for placement of the shaft concrete (FDOT specifications, 2002). The wet construction method consists of drilling the shaft excavation below the water table and keeping the shaft filled with fluid (mineral slurry, natural slurry or water) till the concrete is placed via tremie pipe that displaces the water or slurry. Excavation procedures as explained in FDOT specification 455-15.3 were followed (FDOT Standard Specifications, 2002). For this project, use of slurry was not needed as the ground consisted of hard limestone. No casing was used in any of the shafts. The actual depth of the holes varied between 27 ft to 30 ft.

Figure 2.4: Drilling of Shaft using Auger Cast Drilling Technique

Steel Reinforcement

Twenty five ft long square steel cages with cross-sectional dimension of 2.5 ft each way, as shown in Figure 2.5 were placed in the drilled shaft holes. The cage was used to attach the temperature probes. The steel cages consisted of 4-#4 main or longitudinal steel bars at each corner and #3 ties or loops at intervals of 1 ft along the length. In addition, every fifth tie (at 5 ft intervals) consisted of a diagonal #3 bar as shown in Figure 2.5. This diagonal bar was used to attach the temperature probes across the width of the shafts.

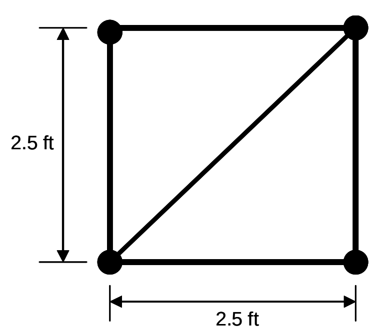

Figure 2:5: Cross Section of a Steel Cage

In Figure 2.6, photographs of the cages lying on the ground and lowering them in the shafts are shown.

Figure 2.6: Lowering and Placement of Steel Cages used for Drilled Shafts

<u>Installation of Temperature Probes and Recorders</u>

The locations of the temperature probes on each cage is shown in Figure 2.7. Twelve temperature probes were installed on each cage as shown. The vertical distance between the probes was 5 ft. The temperature probes were connected to the automatic temperature recorder (Digi-Sense 12 Channel Scanning Thermometer with a range of -418°-752°F), with an accuracy of 0.8°F (Figures 2.8-2.10). The recording interval was set at 3 minutes for the first 48 hours and then at 8 minutes for the remainder of the data collection period.

The total time of recording was approximately 125 hours. The temperature recorder has a built-in real-time clock, nonvolatile memory and data ports to facilitate the transfer of data from the recorder to the computer at the end of the experiment.

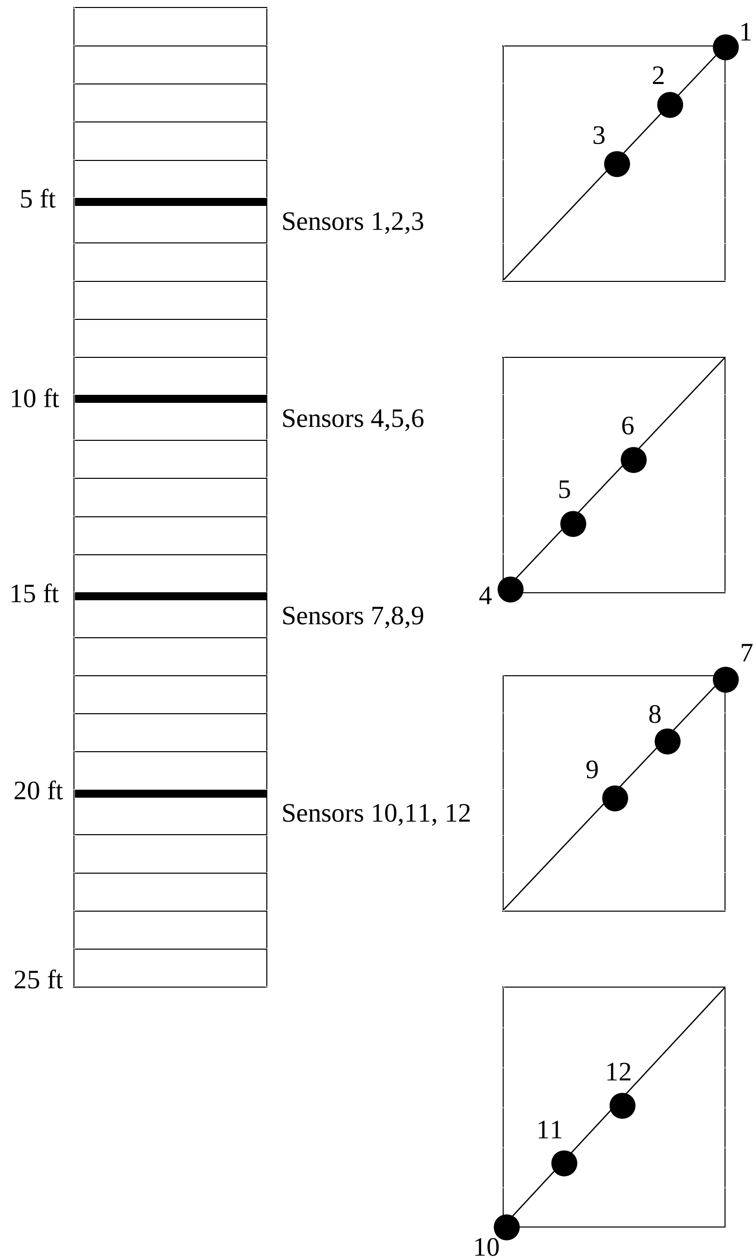

Figure 2.7: Locations of Temperature Probes as Attached to the Reinforcement of Each Shaft

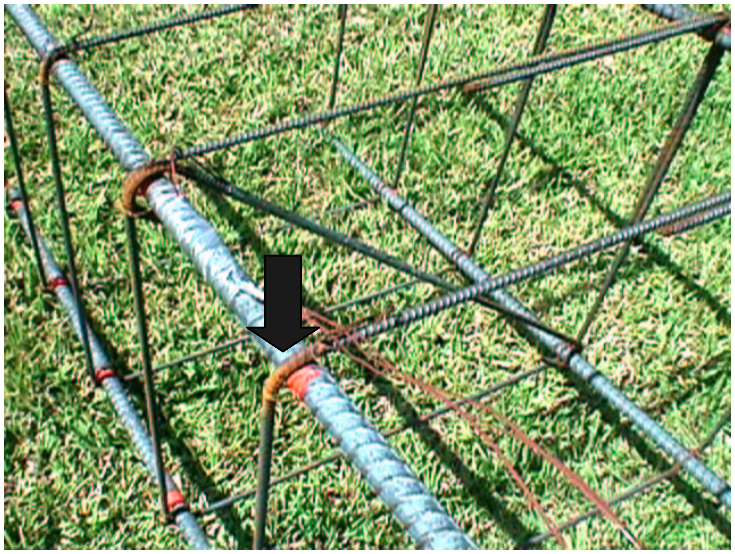

Figure 2.8: Installment of Temperature Probes on the Cage

Figure 2.9: A Closer Look at One of the Installed Probes

Figure 2.10: Digi-Sense 12 Channel Scanning Thermometer

Figure 2.11: Recording of Temperature Data

Concrete Mix Design

FDOT standard mix design for drilled shafts (Class 4: #06-0281) was used for this investigation (FDOT Standard Specifications, 2002). The targeted concrete strength was 4000 psi with a slump between 7-9 inches. The mix proportions are shown in Table 2.1.

Table 2.1 Mix Proportions of Drilled Shaft Concrete

CONCRETE SUPPLIER: RINKER MATERIALS CORP.	
ADDRESS: 1501 BELVEDERE ROAD	WEST PALM BEACH, FL 33405
PLANT LOCATION: LEJEUNE	TELEPHONE NO; 561/833-5555
FDOT ASSIGNED PLANT NO. : 87-085	PROJECT NO: 87000-5601
DATE: 10/22/98	
CLASS CONCRETE: IV DRILL SHAFT 4000PSI	
SOURCE OF MATERIAL	

COARSE AGGREGATE	: RINKER MATERIALS	GRADE :	57 S.G. (SSD): 2.460
FINE AGGREGATE	: E. R. JAHNA	F.M	: 2.40 S.G. (SSD): 2.630
PIT NO. (COARSE)	: 87-090	TYPE	: CRUSHED LIMESTONE
PIT NO. (FINE)	: 05-045	TYPS	: SILICA SAND
CEMENT	: RINKER PORTLAND	SPEC	: AASHTO M-85 TYPE II
AIR ENTR ADMIX	: DAREX AEA W. R. GRACE	SPEC	: AASHTO M-154
1ST ADMIX	: WRDA 64 W. R. GRACE	SPEC	: AASHTO M-194 TYPE D
2ND ADMIX	: N/A	SPEC	: N/A
3RD ADMIX	: N/A	SPEC	: N/A
FLY ASH	: $ RPCC SLAG RINKER	SPEC	: ASTM C-989

HOT WEATHER DESIGN MIX

$ BLAST FURNACE SLAG

CEMENT (Kg) LBS	: 298	SLUMP RANGE	: 7.00 TO 9.00 (mm) IN
COARSE AGG (Kg) lbs	: 1667	AIR CONTENT	: 2.4 % TO 5.6 %
FINE AGG (Kg) LBS	: 1053	UNIT WEIGHT (wet)	: 139.7 (Kg/M3) PCF
AIR ENT ADMIX (ml) 02	: 7.5	W/C RAT10 (plant)	: 0.41 (Kg/Kg) LBS/LB
1ST ADMIXTURE (ml) oz	: 23.8	W/C PATIO (field)	: 0.41 (Kg/Kg) LBS/LB
2ND ADMIX (ml) OZ	: 0	THEO YIELD	: 27.00 (M3) CU FT
3PD ADMIX (ml) OZ	: 0		
WATER (ml) GAL	: 37	PRODUCER TEST DATA	
WATER (Kg) LBS	: 308	CHLORIDE CONT	: 0.1 (Kg/M3) LB/CY
FLY ASH (Kg) LBS	: 447	SLUMP	: 7.5 (MM) IN
		AIR CONTEXT	: 3.6 %
		TEMPERATURE	: 97 DEG (C) F
		COMPRESSIVE STRENGHT (MPA) PSI	
		28- DAY	: 7740 PSI

Theoretically, a little over 9 cu yd concrete (1 truck load) was needed per shaft, but due to spillage and voids in the ground, (and due to the fact that the shafts were about a foot or two deeper than 25 ft.) approximately 12 cu yd of concrete (1½ truck) per shaft was needed. In total 5 concrete trucks were utilized. The slump and initial temperature data of the concrete in those trucks is shown in Table 2.2.

Table 2.2: Slump and Initial Temperature Data of the Concrete

Truck	Slump at Plant (inch)	Slump at the Site (inch)	Initial Concrete Temperature (°F)	Ambient Temperature at Placing of Concrete (°F)	Drilled Shafts Placed
1	7.00	6.50	86	87	1
2	8.50	7.00	87	88	1 and 2
3	7.00	7.50	87	90	2
4	N.A.	8.00	86	91	2 and 3
5	N.A.	8.25	88	92	3

Placing of Concrete

A 5 inch diameter pump was used to place concrete from the truck mixer to the drilled shafts using a tremie pipe as shown in Figures 2.12-2.15. Concreting was carried out in accordance with FDOT specification 455 (FDOT Standard Specifications, 2002). Pumping of the concrete was continuous over the three shafts (back to back). Approximately 30-40 minutes were spent to place each shaft with concrete.

An uplifting of the cages occurred during the placing of concrete due to the upward push of concrete on the cages. Manual pressure was applied to keep the cages at their designated depths (Figure 2.12). However, the cage of shaft 3 (placed first) couldn’t be brought back to its original position and remained 2 ft above the ground level after concreting.

Figure 2.12: Transfer of Concrete from the Truck Mixer to the Concrete Pump

Figure 2.13: Pumping of Concrete into the Tremie Pipe

Figure 2.14: Keeping the Cages at their Positions

Figure 2.15: A View of Completed Shafts

Chapter 3

RESULTS AND DISCUSSIONS

3.1 General

Results of both phases of the project are included in this chapter. For easy understanding, some typical results are presented graphically. All data are included in the appendices.

3.2 Phase I: Exploratory Testing

The results of exploratory testing are shown graphically in Figure 3.1. Detailed data can be seen in Appendix A. The data clearly indicates that the ground temperature stabilizes at about 1-2 feet below the ground water table, which was found to be at around 6.5 ft under the ground surface. The average temperature stabilizing depth was found to be 10 ft below ground surface and the average temperature below ground water table was between 75°and 77°F.

The test was performed on two different days at different timings (one in the morning and the other was around noon). Between the two days the difference in ambient temperature was around 6°-10°F. However, consistent temperature (75°-77°F) was recorded in the test holes under the ground water table. This indicates that the temperature variations within the hole are not dependent on the atmospheric conditions.

The test results further indicate that variations in slump loss of concrete would not be dependent on the depth of the drilled shaft. Hence, it was decided to reduce the depth of test shafts in Phase II to 25 ft. from the originally proposed 50 ft.

Ambient Temperature Readings from Internet

Februaury 26, 2001		*March 01, 2001*	
11:00 AM	79.5F	9:00 AM	70.9F
12:00PM	80.9F	10:00 AM	75.0F
01:00PM	82.0F	11:00PM	75.6F

From Thermometer at Site = 75.9F at 11:45 AM

From Thermometer at Site = 74F at 8:30 AM

From Thermometer at Site = 81F at 9:14 AM

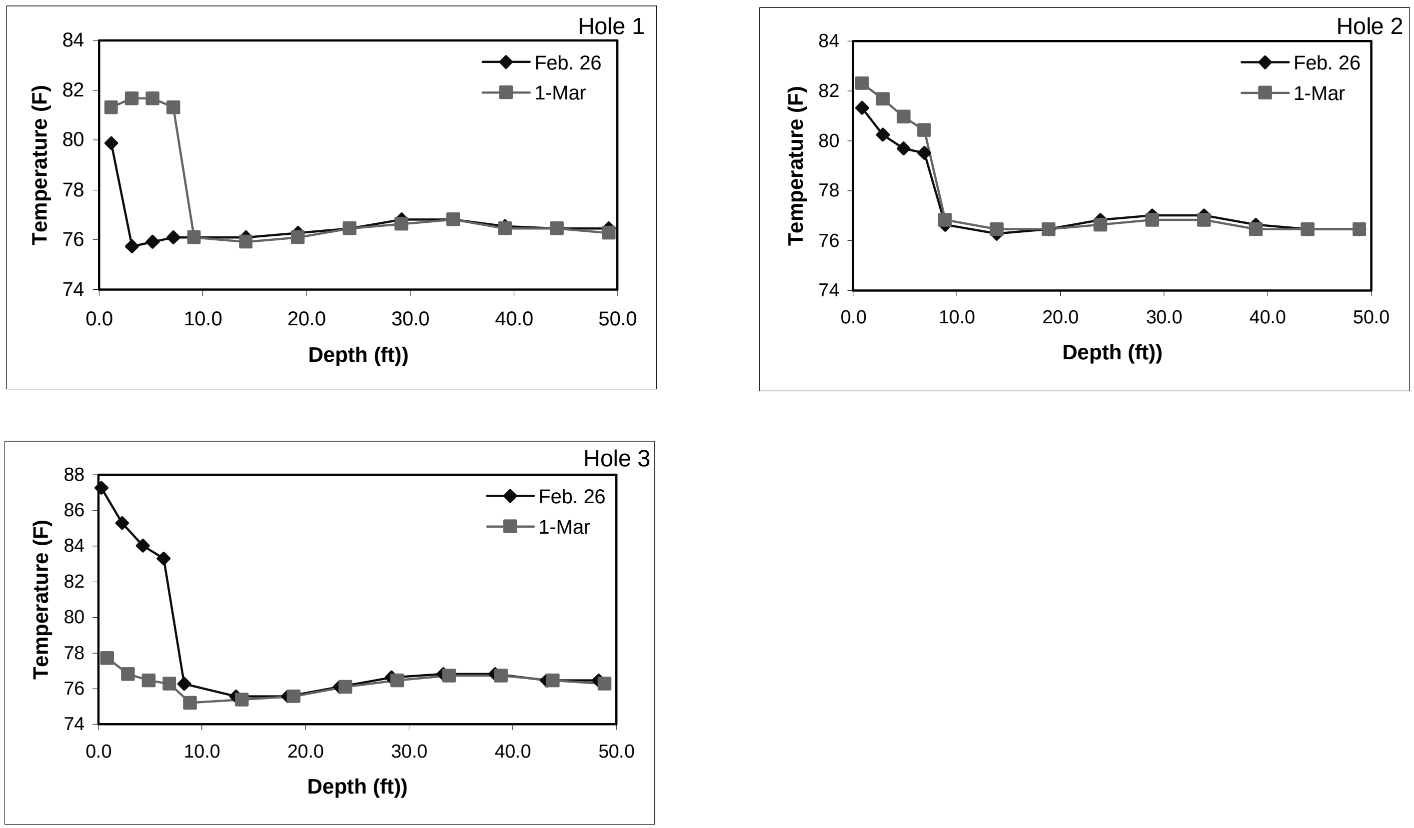

Figure 3.1: Temperature Variation along Depth (Phase I)

3.3 Phase II: Field Testing

In this phase, three 4 ft diameter 25 ft long drilled shafts were placed with high slump concrete and temperature data were recorded across the width and along the depth of the shafts. Very consistent results were obtained from the three shafts. For the sake of simplicity only Shaft 1 results are presented and discussed in this chapter. All test results including Shafts 2 and 3 are given in Appendices B and C.

3.3.1 Initial and final setting of concrete in the drilled shaft

Temperature variations in concrete along the depth of the drilled shaft during the first four hours is shown in Figure 3.2. The *initial set* marks the point in time when the concrete becomes unworkable and its placement, compaction and finishing becomes very difficult. Hydration results in an exothermic reaction and a certain amount of heat is generated making the temperature of concrete go up.

Before concrete was placed, average temperature in the shaft was around 76°F, which is about the same as found in Phase I. However, after placing of concrete, temperature within the shaft suddenly rose, which is indicated by a near vertical line in the profiles (see Figure 3.2) for each temperature probe. This magnitude of rise in temperature was about 12°F, that increased the average temperature in the shaft to about 88°F. It can be verified from Table 2.2 that the temperature within the shaft concrete just after placing was almost the same as the initial concrete temperature (before placing). Since two trucks were used to place this shaft (approximately 10 minutes were spent to move the first truck out and bring the second truck in position), the upper (probe numbers 3 and 6, Figure 2.7) and lower (probe numbers 9 and 12, Figure 2.7) temperature probes indicate different timings for temperature rise in the shaft.

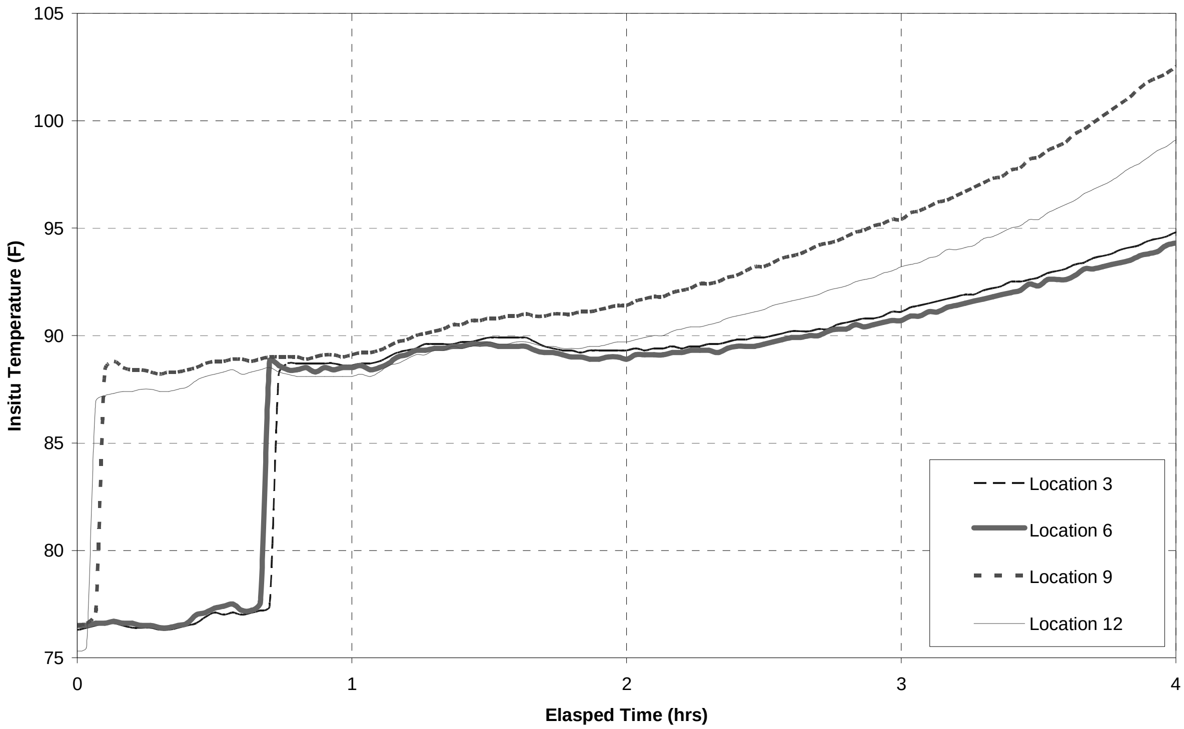

Figure 3.2: Temperature Variations with Time in Shaft 1 at Different Probe Locations (during initial setting of concrete)

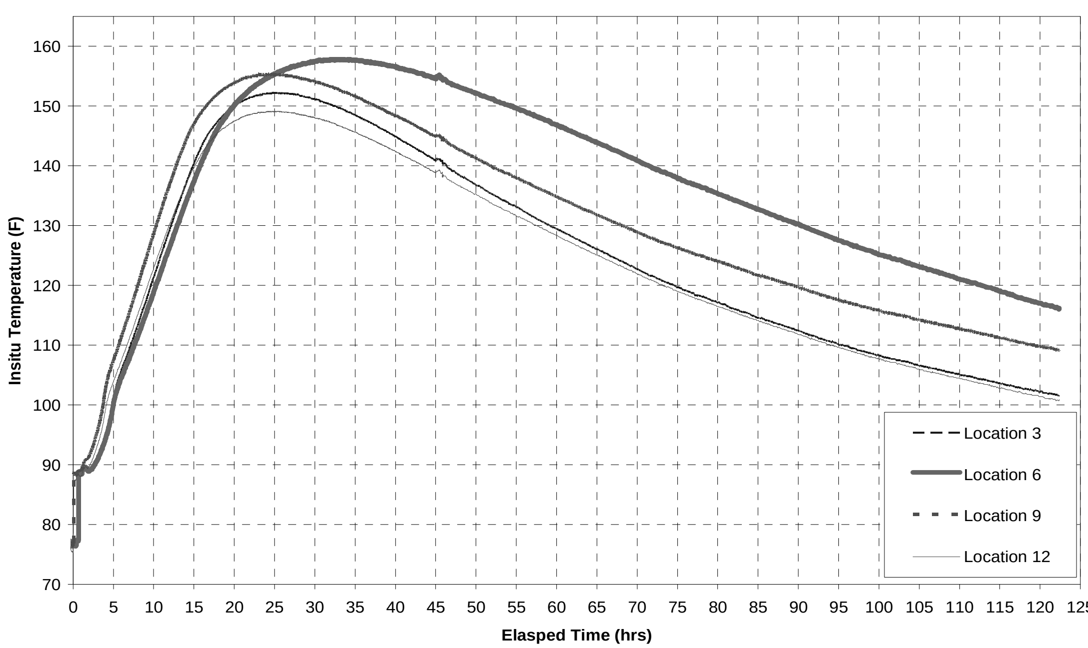

Figure 3.3: Temperature Variations with Time in Shaft 1 at Different Probe Locations (till final setting of concrete)

After the initial temperature rise, there was very little increase in temperature (around 2°-4°F) during the first two hours of concrete placement. Subsequently, the temperature began to rise at a higher rate, reaching its peak of about 155°F in approximately 30 hours and then beginning to decrease at a near constant rate (linear) as shown in Figure 3.3.

These results indicate that the first increase in temperature was due to the placement of concrete in the drilled shaft. Initially, the temperature in the drilled shaft was lower as found in the first phase of the project. When the concrete was placed inside the drilled shaft, the temperature increased and became equal to the internal concrete temperature. The setting of concrete began approximately after 2 hours as indicated by the sharp rise in the slope of temperature curve (when the hydration in concrete began). This fact is further supported by Figure 3.4 indicating the typical initial and final setting times of concrete with and without retarders.

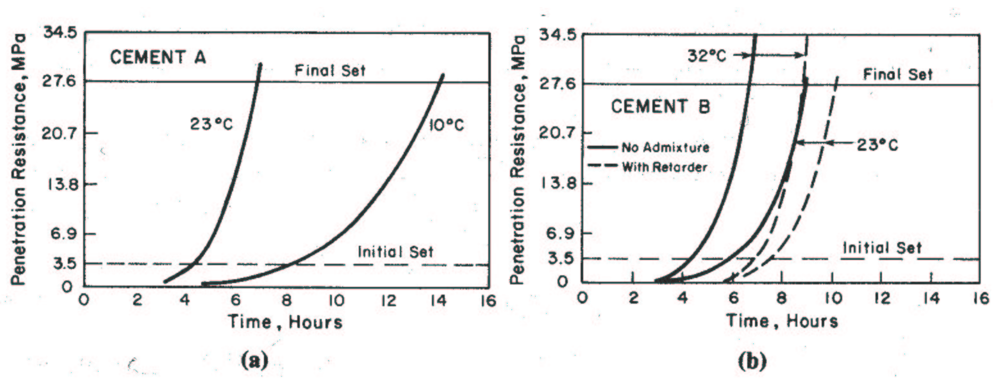

Figure 3.4: Effect of Temperature and Retarding Admixture on the Initial and Final Setting Times of Concrete a) ASTM Type I Cement, b) ASTM Type II Cement (Source: Mehta and Monteiro, 1993)

Figure 3.5 shows a typical graph indicating the relation between the temperature of concrete, elapsed time and the member thinness. For a 40 inch thick wall, the temperature of concrete reached its peak in approximately 35-40 hours and then decreased at a constant rate.

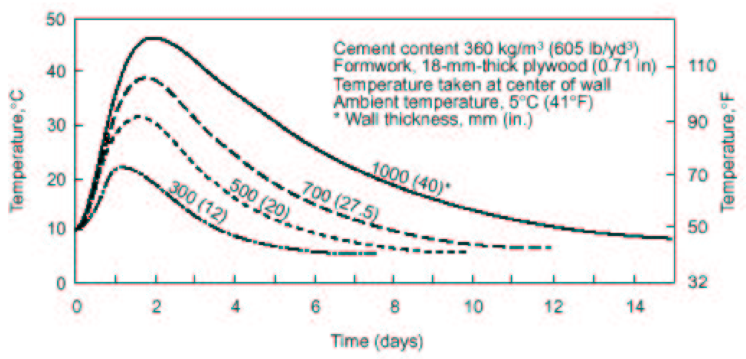

Figure 3.5: Effect of Member Thickness on Temperature of Concrete

(Source: Concrete Technology Today, 1997)

Figures 3.4 and 3.5 show typical behavior of concrete at the ground surface. Since a very similar pattern was evidenced in the drilled shaft concrete at various depths, it can be concluded that the internal shaft conditions or temperature did not have a great effect on the setting of concrete. However, it is recommended to investigate the setting times of this particular mix used for drilled shafts at the ground surface, as the setting times may be affected by the composition of the individual concrete mix.

Since the placing of concrete in each drilled shaft was completed within 30-45 minutes, no slump loss test was performed. As shown by Mehta and Monterio (1993), the slump loss becomes significant after 45 minutes when the hydration of cement starts. Since the placing of concrete in this study was completed within 30-45 minutes, it can be reasonably assumed that the slump of concrete within the shafts was more than 4 inches at all times during the placement of concrete, as required by the FDOT specifications.

3.3.2 Variation of temperature along the depth of the drilled shafts

Temperature variations in concrete with time along the depth of the drilled shafts are shown in Figures 3.6 through 3.9 for all probes and then separately for side probes ,middle probes and the center probes respectively. The data used in these graphs are from Shaft 1 only. Shafts 2 and 3, which are very similar to 1, are included in the Appendices B and C.

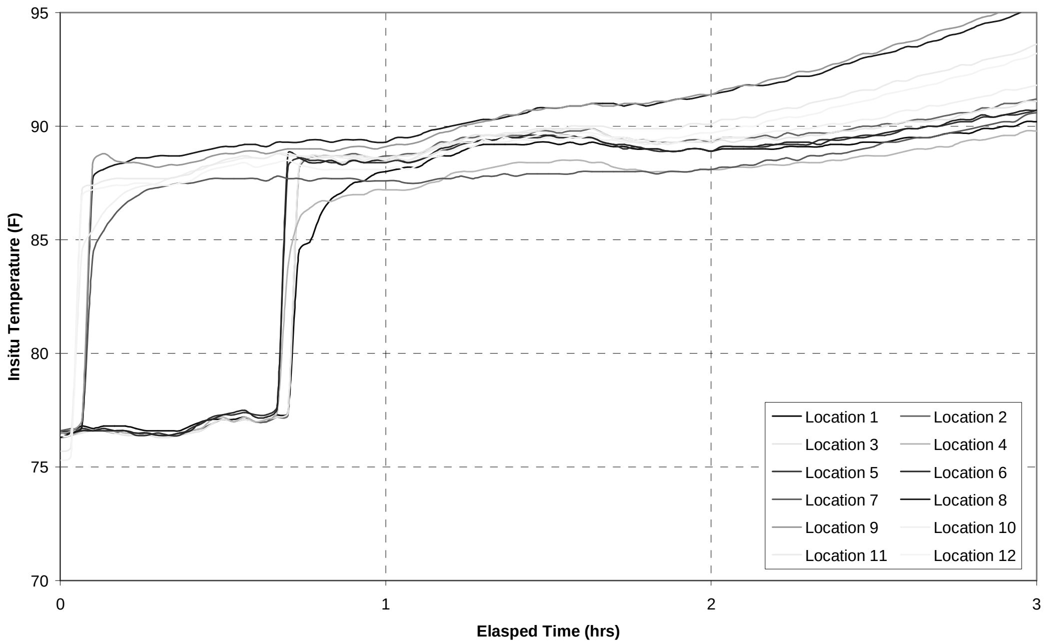

Figure 3.6: Temperature Variations with Time in Shaft 1 at all Probe Locations (Initial Set)

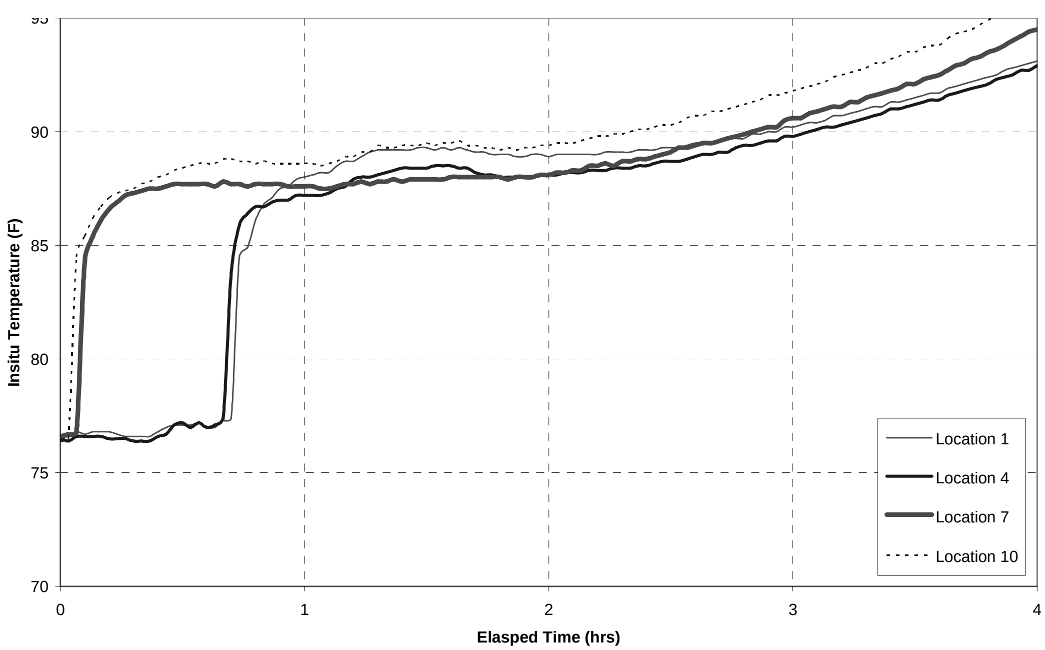

Figure 3.7: Temperature Variations with Time in Shaft 1 at Side Probe Locations (Initial Set)

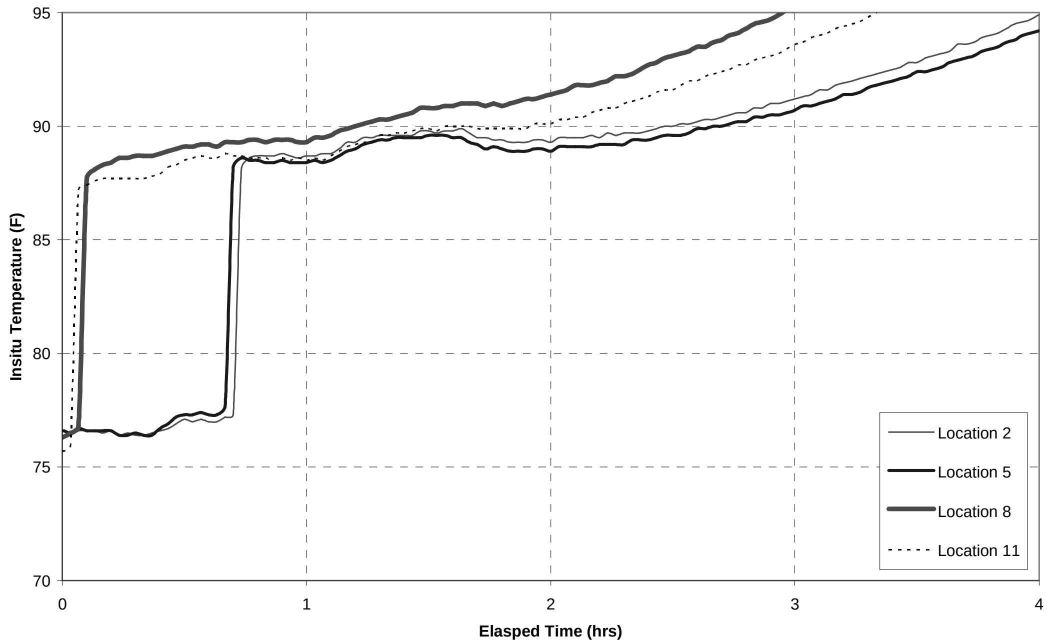

Figure 3.8: Temperature Variations with Time in Shaft 1 at Middle Probe Locations (Initial Set)

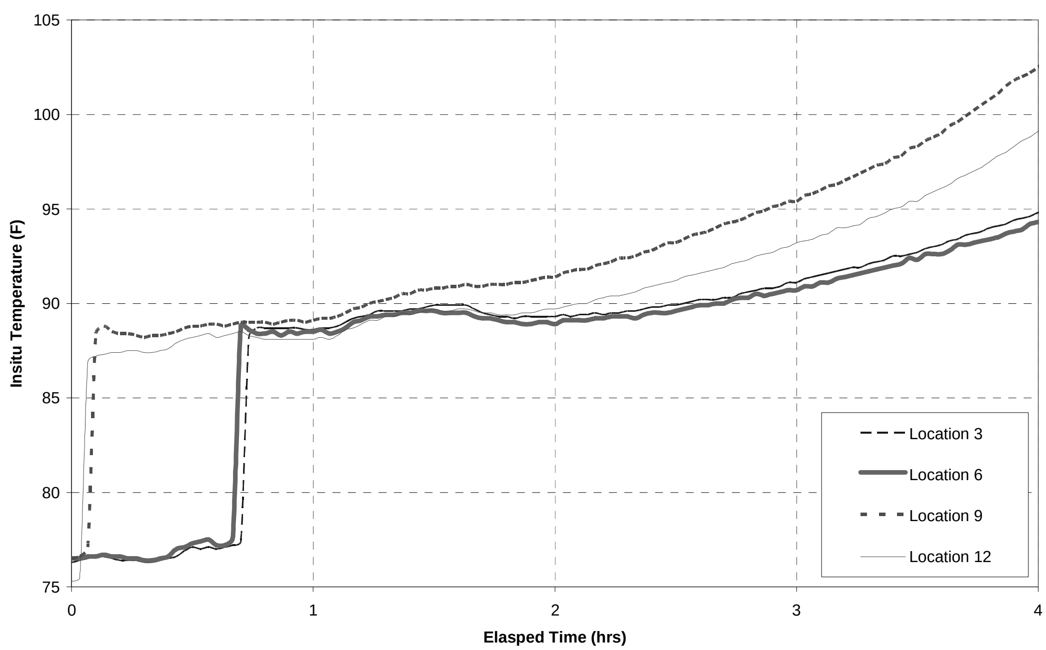

Figure 3.9: Temperature Variations with Time in Shaft 1 at Central Probe Locations (Initial Set)

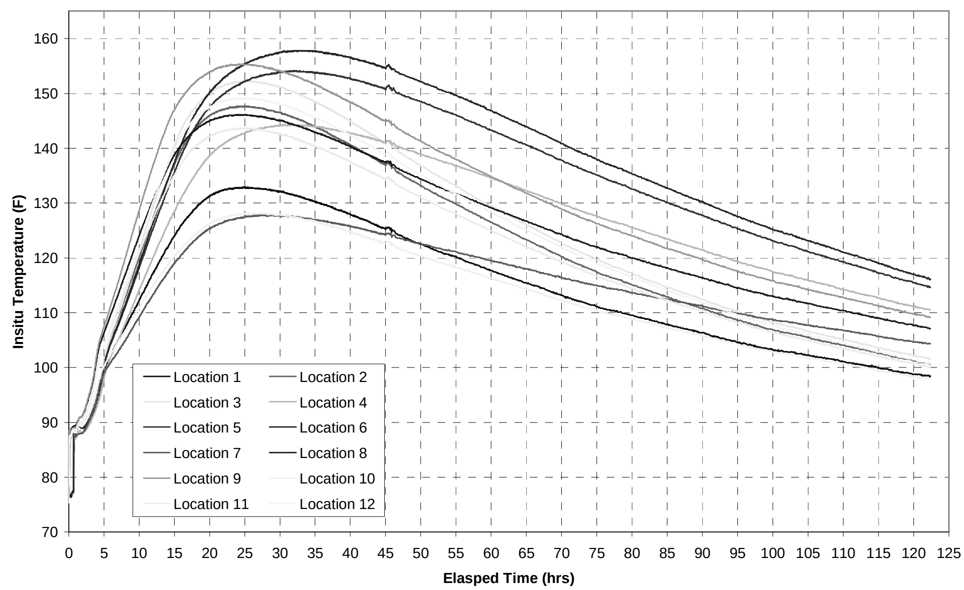

Figure 3.10: Temperature Variations with Time in Shaft 1 at Different Probe Locations (till final setting of concrete)

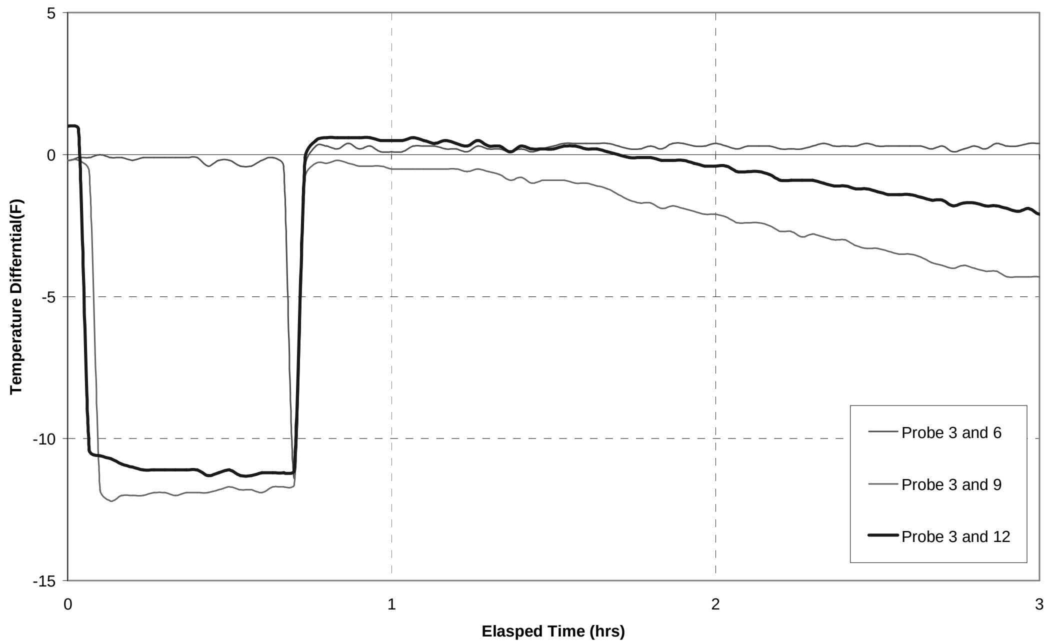

Figure 3.11: Temperature Differential with Time in the Shaft between Probe Locations at Different Depths (initial set)

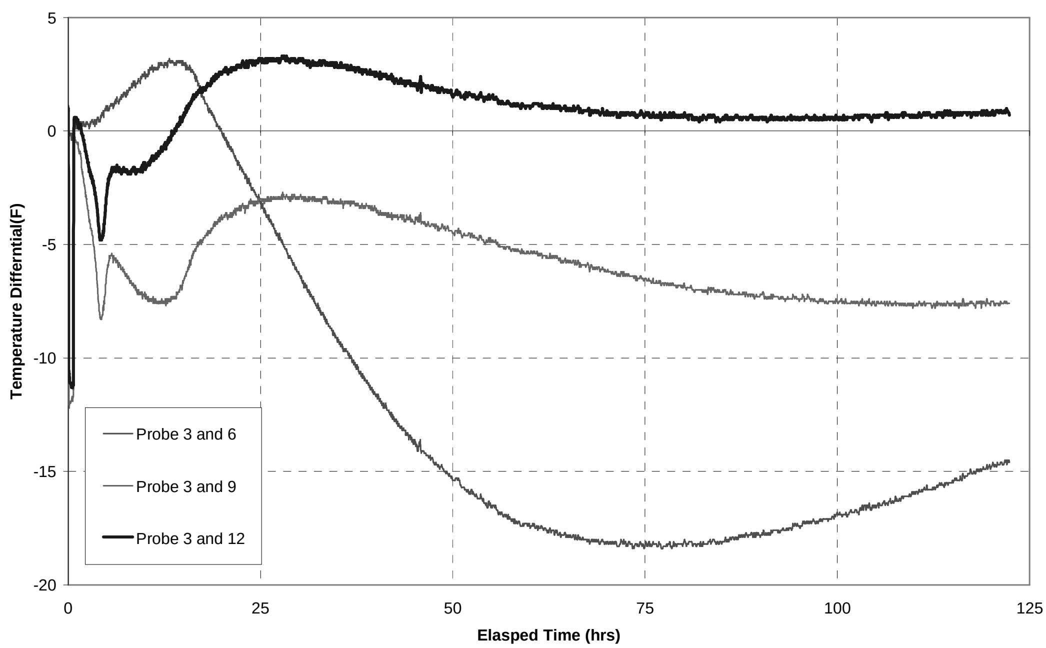

Figure 3.12: Temperature Differential with Time in the Shaft between Probe Locations at Different Depths (final set)

It can be seen from Figure 3.11 that during the time between the placement of concrete and the initial set, the maximum temperature differential exists between the probes numbered 3 and 9 which were at 5 ft and 15 ft depths respectively. The temperature of concrete at 15 ft depth is only 4°F lower than the temperature at 5 ft depth. Although temperature of concrete was not recorded at the surface with elapsed time but it can be reasonably assumed that it would be very close to the temperature at a depth of 5 ft (particularly since the water table was found at about a depth of 5 ft. 6 in.).

Thus the temperature in concrete can be assumed to be constant within the drilled shaft, i.e. no significant temperature differential exists between the surface and the bottom of the shaft. However, temperature differential started to rise after about 2 hours when the hydration began as indicated in Figure 3.9.

Based on the above observations, it can be concluded that the concrete temperature inside the drilled shafts right after placing would be identical to the initial concrete temperature and hence the slump loss test should be conducted at this temperature.

3.3.3 Variation of temperature across the width of the drilled shafts

In Figures 3.13 through 3.16, variations in concrete temperature with time across the width of the drilled shafts at various depths are shown. These figures show that the concrete temperature is maximum at the center of the shaft and decreases gradually towards the sides of the shafts.

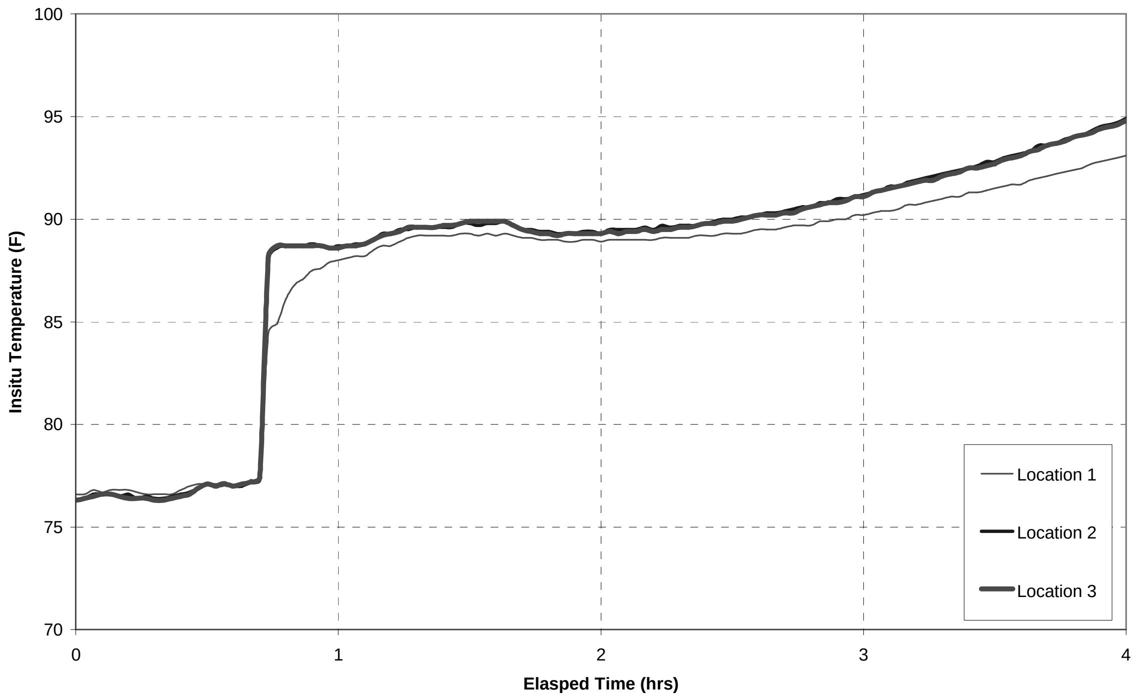

Figure 3.13: Variation of Temperature with Time across Width of the Shaft at 5 ft depth

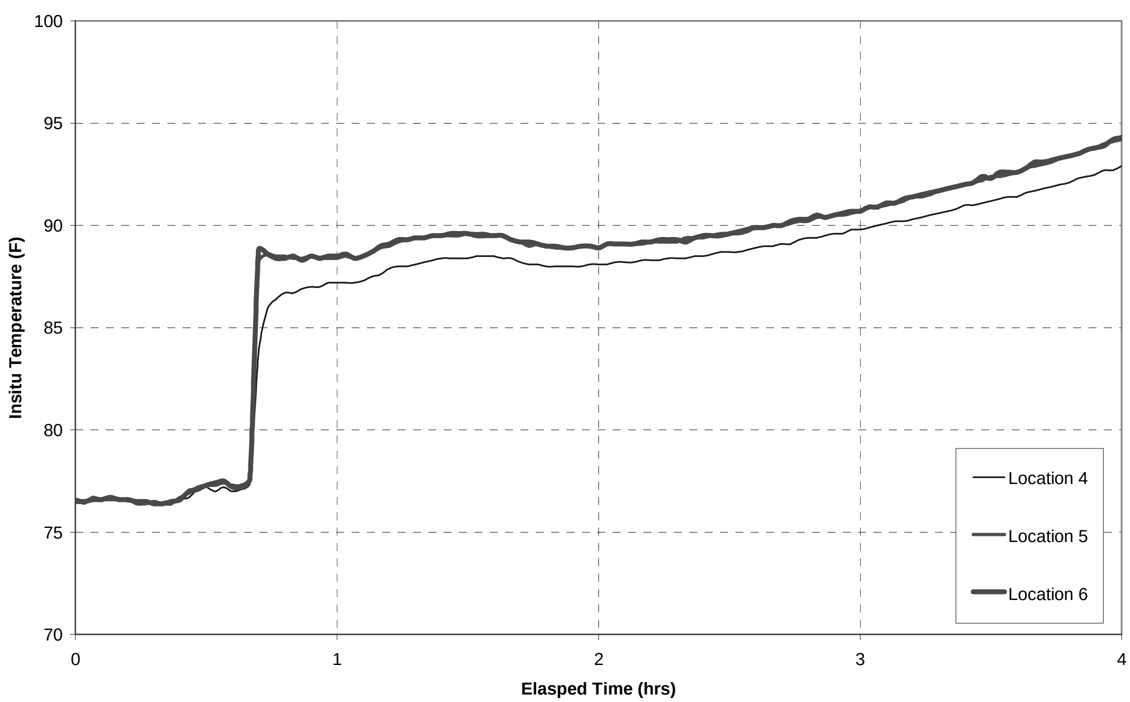

Figure 3.14: Variation of Temperature with Time across Width of the Shaft at 5 ft depth

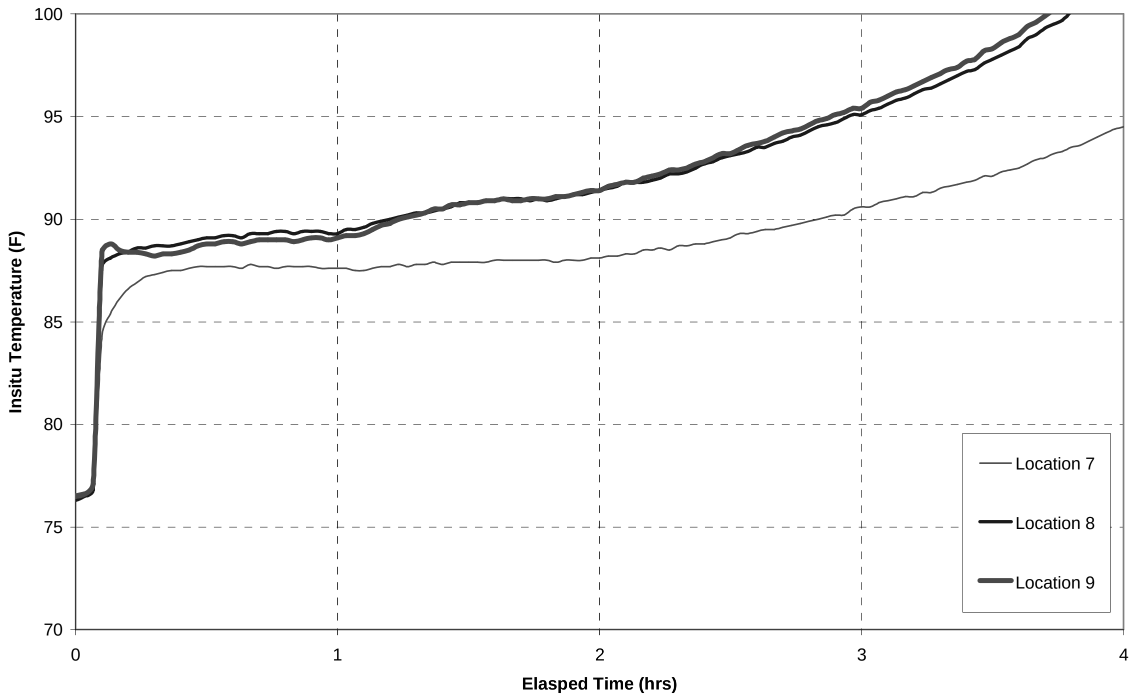

Figure 3.15: Variation of Temperature with Time across Width of the Shaft at 5 ft depth

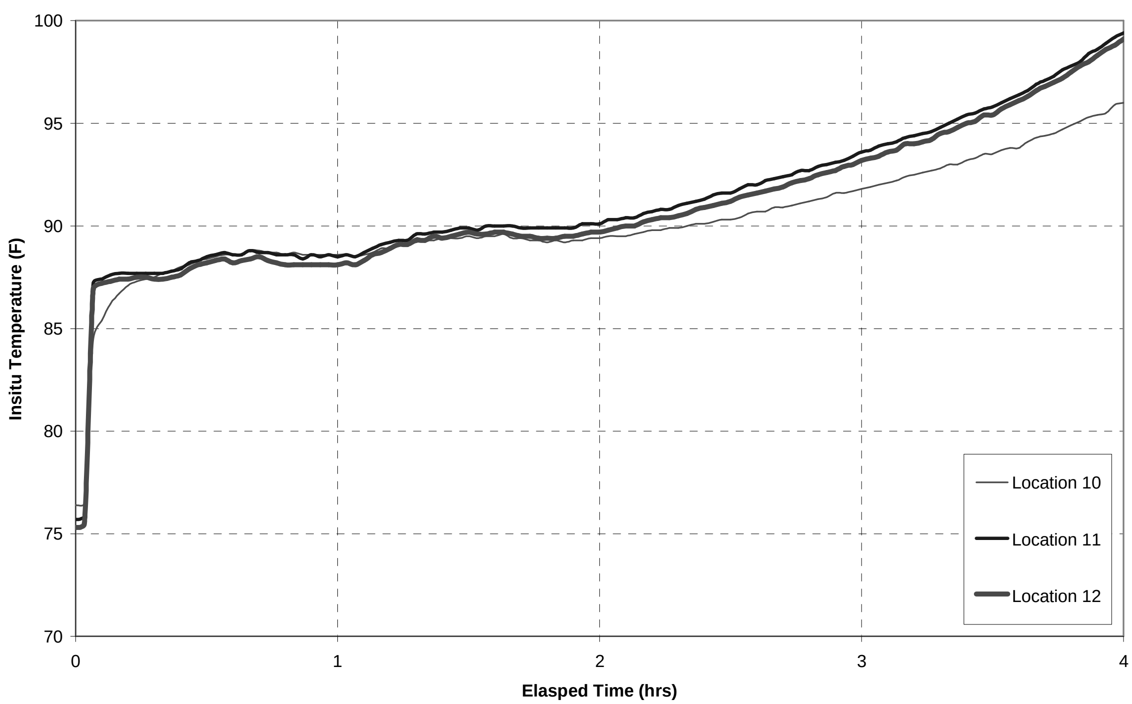

Figure 3.16: Variation of Temperature with Time across Width of the Shaft at 5 ft depth

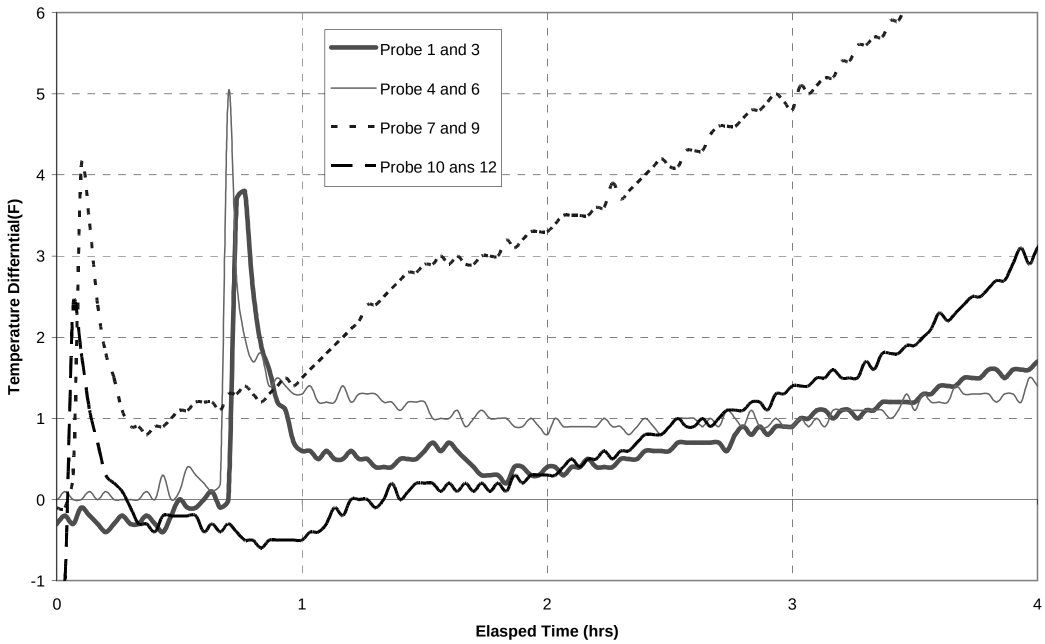

Figure 3.17: Temperature Differential with Time between Probe Locations across the Width of the Shaft (initial set)

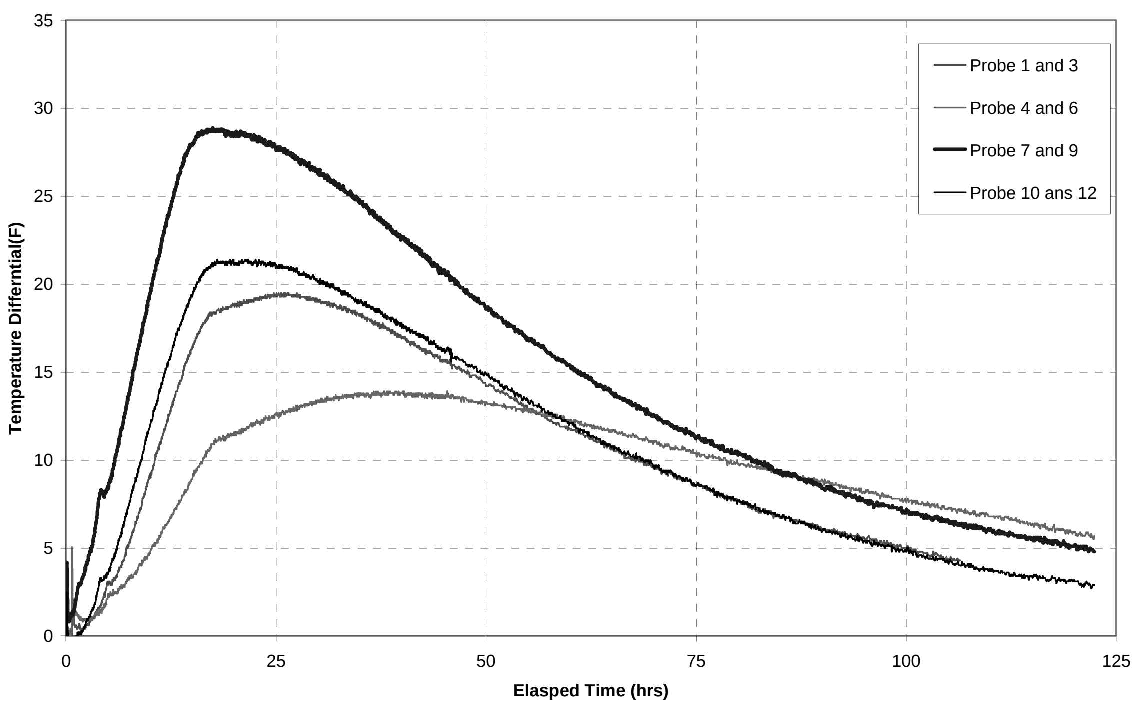

Figure 3.18: Temperature Differential with Time between Probe Locations across the Width of the Shaft (final set)

Figures 3.17 and 3.18 illustrate the temperature differentials with time across the width of the drilled shaft. It is clear from the figures that during the first 2 hours, the difference in temperature between center and side probes is only about 3-5°F, an insignificant amount for all practical purposes. The maximum temperature differential of approximately 28°F is found to exist after about 30 hours when the temperature in concrete reaches its peak.

3.4 Summary

The test results have revealed the following points.

1. The temperature differential along the depth and across the width of the shaft during the initial setting of concrete was approximately 3°-5°F and can be considered insignificant.
2. The initial setting of concrete (for this particular mix) occurs approximately 2 hours after placing of concrete while the concrete temperature reaches its peak after about 30 hours of placement in the drilled shafts.
3. The concrete temperature inside the drilled shafts was almost the same as the initial temperature of concrete before placing of concrete.

Chapter 4
CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Based on the results of this study, the following conclusions can be drawn.

1. The ground temperature stabilizes 1-2 ft below the water table and is independent of the atmospheric conditions. In this study conducted in Miami, the average temperature below the water table was found to be 75-77°F. Hence it is concluded that the slump loss in concrete would be same at all depths below the water table.
2. The temperature within the drilled shaft is same as the initial concrete temperature at the time of concrete placement despite the fact that prior to concrete placement, the temperature within the drilled shaft was lower than the ambient temperature. There was no indication for concrete temperature within the drilled shaft being lower than the initial concrete temperature due to the presence of ground water.
3. There is no significant increase in concrete temperature within the first 2 hours of placement. Hence it may be concluded that the slump loss would be minimal if the placement of concrete is completed within 2 hour from the start of operation.
4. No significant temperature differential exists along the depth and across the width of the drilled shaft during the initial setting of concrete. Hence the slump loss in drilled shaft concrete would be same at all locations.
5. Since the initial concrete temperature inside the drilled shaft was the same as the initial concrete temperature before placing, the rate and amount of slump loss inside the shaft would be same as on the ground surface.

4.2 Recommendations and Future Studies

1. The authors recommend that the FDOT specification 346-3.2 should be amended as follows in light of new findings:

Original specification:

> “The concrete mix for the slump loss test shall be prepared at a temperature consistent with the highest ambient or concrete temperature expected during actual concrete placement”.

Our recommendation is:

> “The concrete mix for the slump loss test shall be prepared at a temperature consistent with the highest initial concrete temperature expected during actual concrete placement”.

This revision in the FDOT specifications will be beneficial during hot weather concreting (common in Florida during the most months of the year) when the ambient temperature is much higher than the actual initial concrete temperature. This will allow more time to place the concrete in the drilled shafts before the slump is dropped to a minimum level of 4 inches.

2. Since no concrete temperature data was recorded on the ground surface without the presence of any ground water, it is recommended that a series of experiments be performed in order to record the concrete temperature above ground at the same ambient temperature conditions. To be able to compare with the temperature data of Phase II, this temperature should be same as the ambient temperature present on the day of experiment in Phase II. This may only be assured in a lab setting where the room temperature can be controlled. For this purpose, concrete cubes (it will be easier to prepare molds for concrete cubes than cylinders) of 4 ft dimension (to match the 4 ft diameter of drilled shafts) can be prepared. This will allow a realistic comparison between the temperature data above and below ground surface.

3. Slump loss test at the highest (in the three sample shafts, as recorded) initial concrete temperature (91°F) should be conducted to gather data on the amount of slump loss for the concrete mix used in this investigation. This will provide the investigators with further information about the rate of slump loss in this particular mix at the initial temperature.
4. The effect of varying retarder dose on slump loss can be investigated. W.R. Grace Inc. may be involved in this investigation.

References

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Florida Department of Transportation (FDOT), Standard Specifications for Road Bridge Construction. June 09, 2002. http://www11.myflorida.com/specificationsoffice/. Accessed July 28, 2002.

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Appendix A

Phase I: Exploratory Testing Results

Date: February 26, 2001

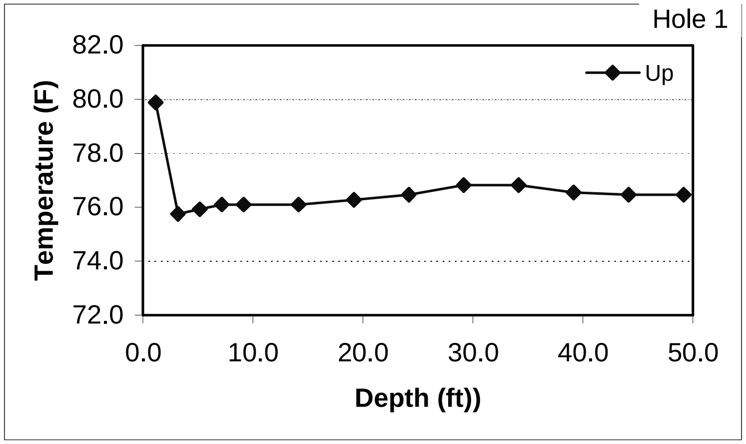
Hole 1 (11:30AM - 11:46AM)				**Hole 2 (11:51AM-12:20PM)**				**Hole 3 (12:54PM-1:24PM)**			
Depth	Temp (^oF)		Remarks	Depth	Temp (^oF)		Remarks	Depth	Temp (^oF)		Remrks
(ft)	Down	Up		(ft)	Down	Up		(ft)	Down	Up	
1.2	--	79.9		0.9	81.3			0.3	87.3		
3.2	--	75.7		2.9	80.2	76.5		2.3	85.3	75.7	
5.2	--	75.9		4.9	79.7	76.6		4.3	84.0	75.7	
7.2	--	76.1	WT = 6.37’	6.9	79.5	76.8	WT=6.42’	6.3	83.3	75.7	WT=6.38’
9.2	--	76.1		8.9	76.6	76.8		8.3	76.3	75.9	
14.2	--	76.1		13.9	76.3			13.3	75.6		
19.2	--	76.3		18.9	76.5	76.5		18.3	75.6	75.7	
24.2	--	76.5		23.9	76.8			23.3	76.1		
29.2	--	76.8		28.9	77.0	77.0		28.3	76.6	76.6	
34.2	--	76.8		33.9	77.0			33.3	76.8		
39.2	--	76.6		38.9	76.6	76.6		38.3	76.8	76.8	
44.2	--	76.5		43.9	76.5			43.3	76.5		
49.2	--	76.5		48.9	76.5	76.5		48.3	76.5	76.5	

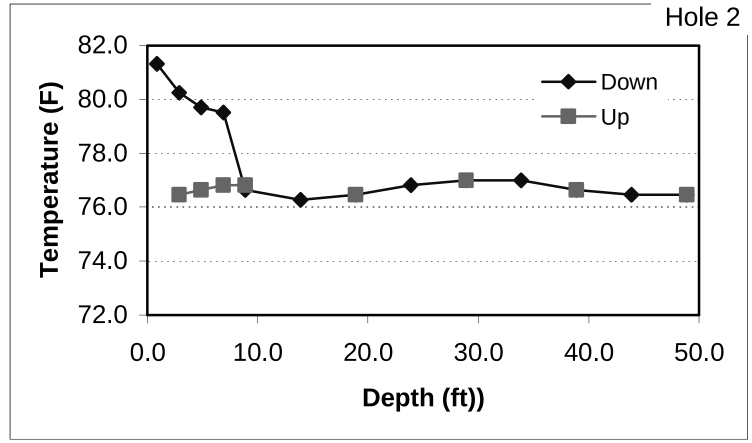
Ambient Temperature Readings from Internet

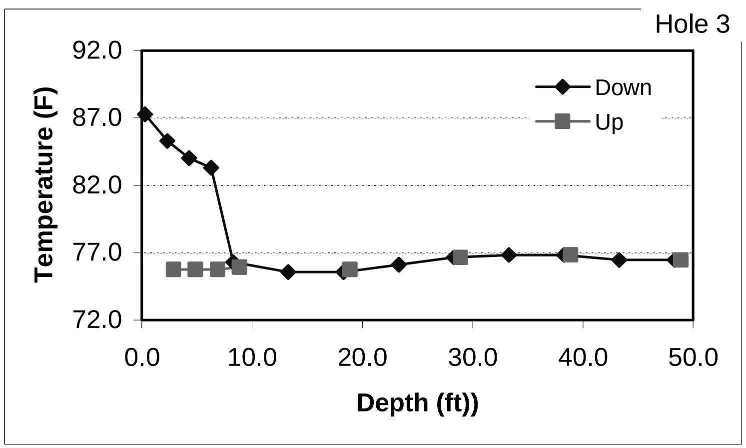
10:00 AM	77F
11:00 AM	79.5F
12:00PM	80.9F
01:00PM	82.0F
02:00PM	80.9F

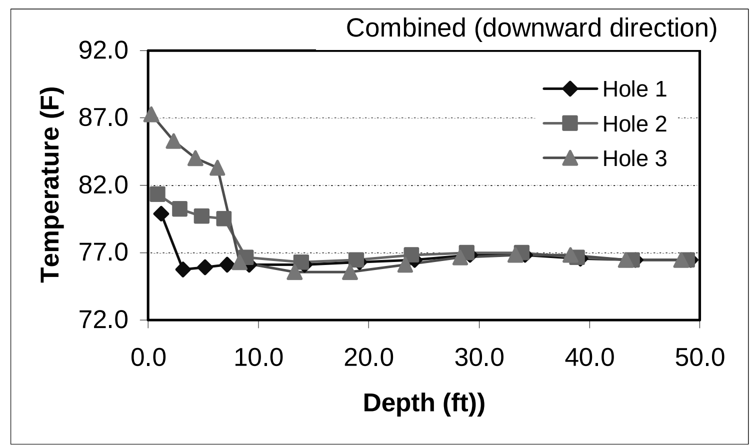
From Thermometer at Site = 75.9F at 11:45 AM

Date: February 26, 2001









Date: March 01, 2001

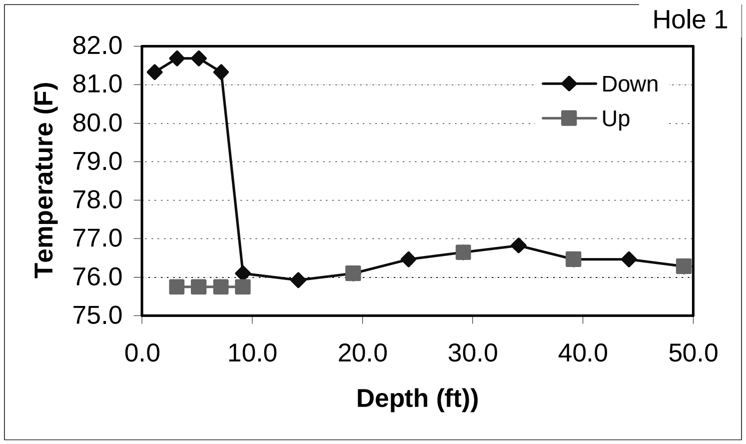
Hole 1 (08:38AM-09:11AM)				**Hole 2 (09:30AM-09:51AM)**				**Hole 3 (10:00AM-10:20AM)**			
Depth	Temp (^{o}F)		Remarks	Depth	Temp (^{o}F)		Remarks	Depth	Temp (^{o}F)		Remarks
(ft)	Down	Up		(ft)	Down	Up		(ft)	Down	Up	
1.2	81.3			0.9	82.3			0.3	77.7		
3.2	81.7	75.7		2.9	81.7	76.1		2.3	76.8	75.4	
5.2	81.7	75.7		4.9	81.0	76.1		4.3	76.5	75.4	
7.2	81.3	75.7	WT = 6.44'	6.9	80.4	76.3	WT=6.44'	6.3	76.3	75.4	WT=6.40'
9.2	76.1	75.7		8.9	76.8	76.3		8.3	75.2	75.4	
14.2	75.9			13.9	76.5			13.3	75.4		
19.2	76.1	76.1		18.9	76.5	76.5		18.3	75.6	75.7	
24.2	76.5			23.9	76.6			23.3	76.1		
29.2	76.6	76.6		28.9	76.8	76.8		28.3	76.5	76.6	
34.2	76.8			33.9	76.8			33.3	76.7		
39.2	76.5	76.5		38.9	76.5	76.5		38.3	76.7	76.6	
44.2	76.5			43.9	76.5			43.3	76.5		
49.2	76.3	76.3		48.9	76.5	76.5		48.3	76.3	76.3	

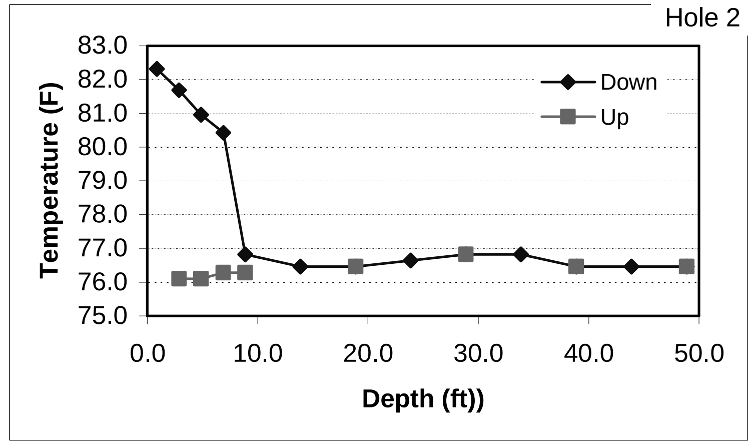
Ambient Temperature Readings from Internet

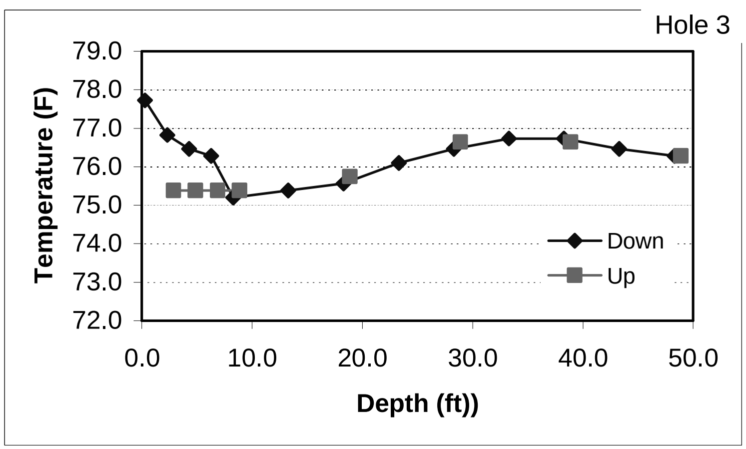
9:00 AM	70.9F
10:00 AM	75.0F
11:00PM	75.6F

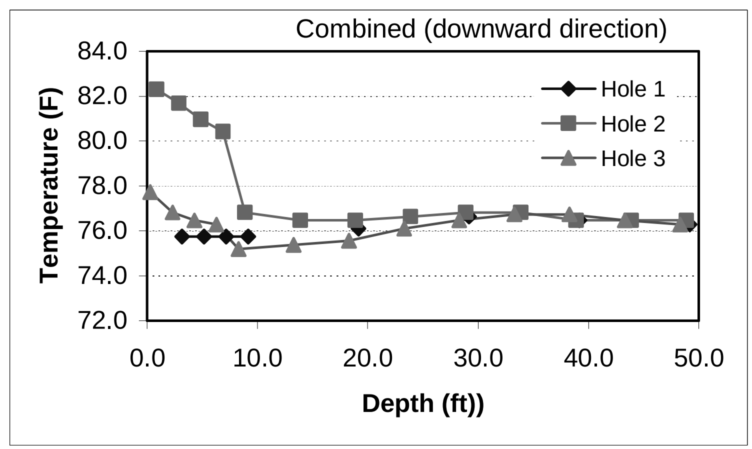
From Thermometer at Site = 74F at 8:30 AM
From Thermometer at Site = 81F at 9:14 AM

Date: March 01, 2001





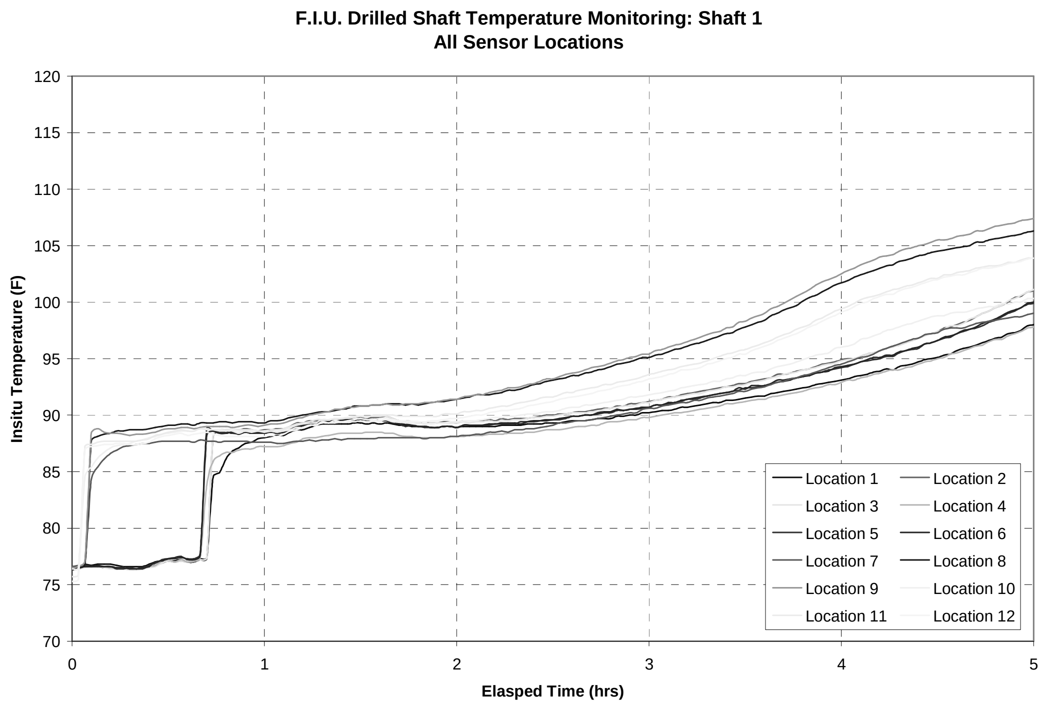


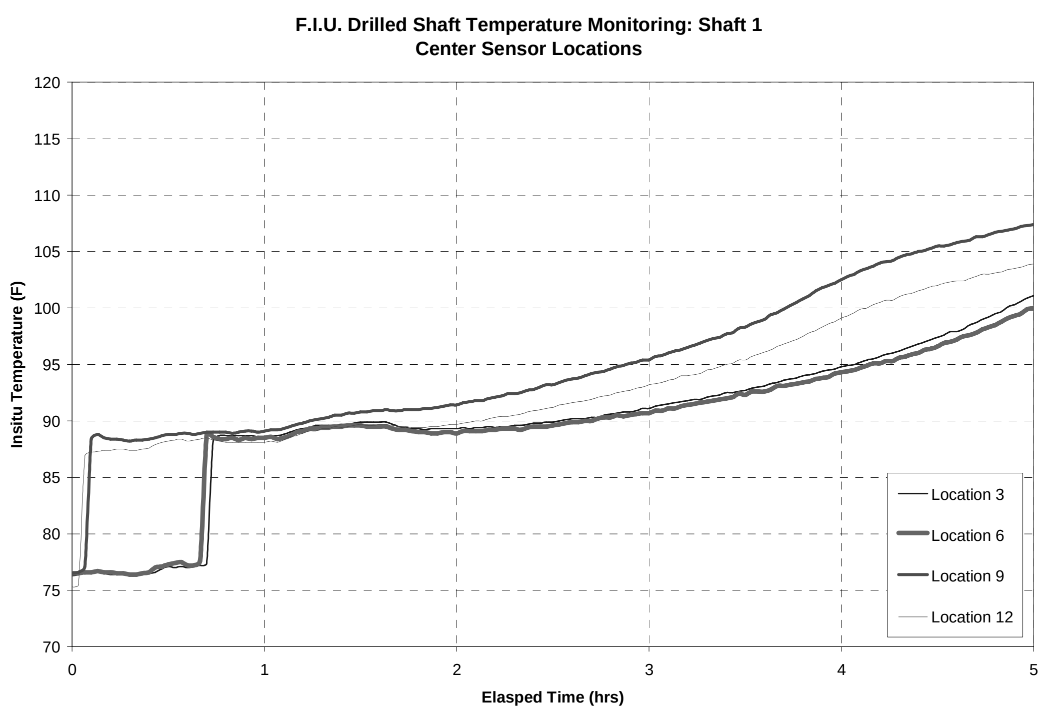


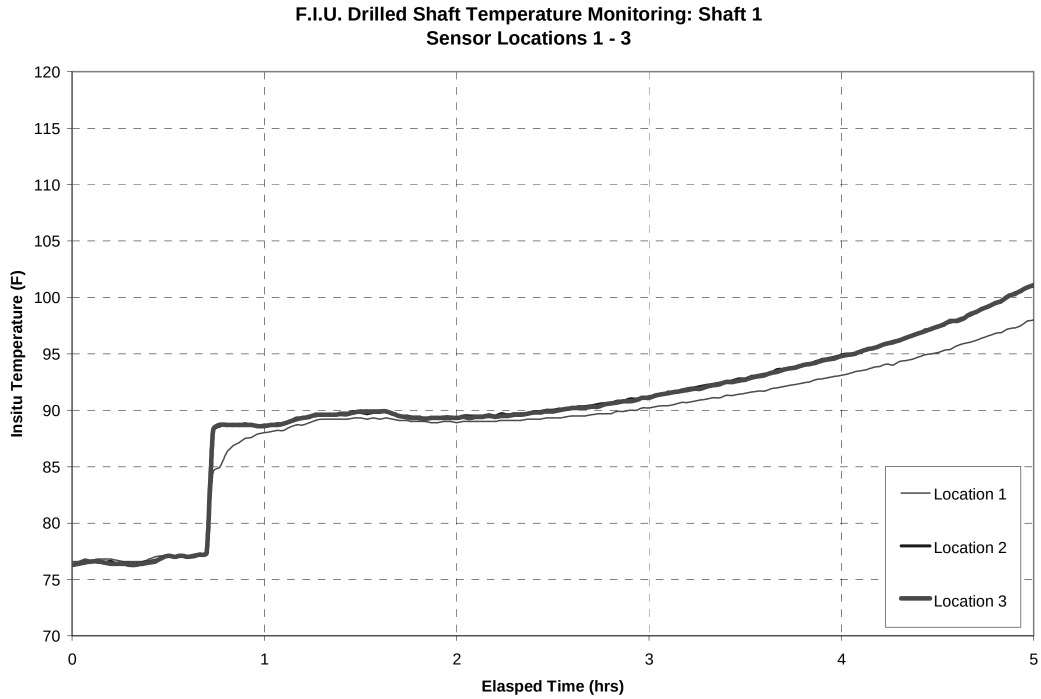
Appendix B

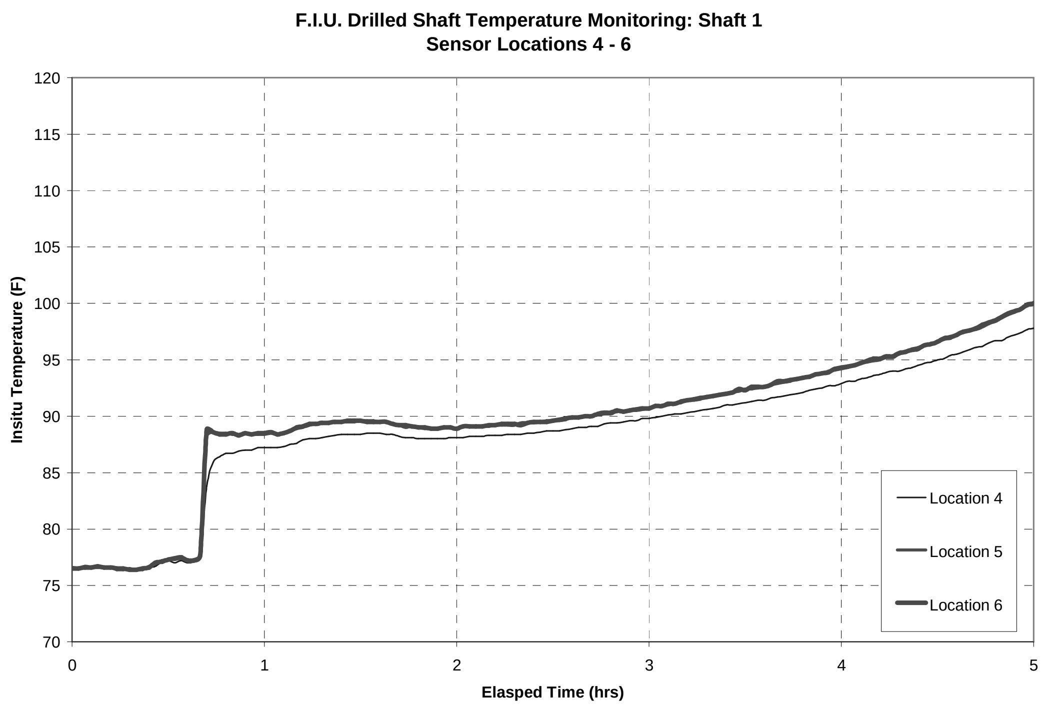
Phase II: Field Testing Results (Initial Setting)

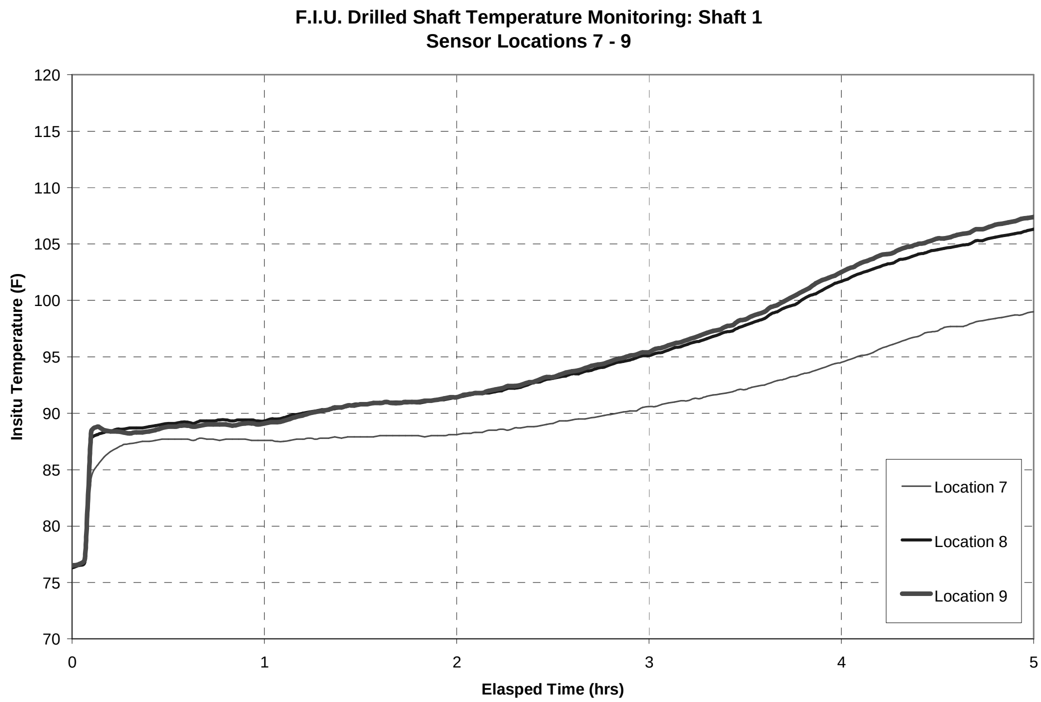
Drilled Shaft 1

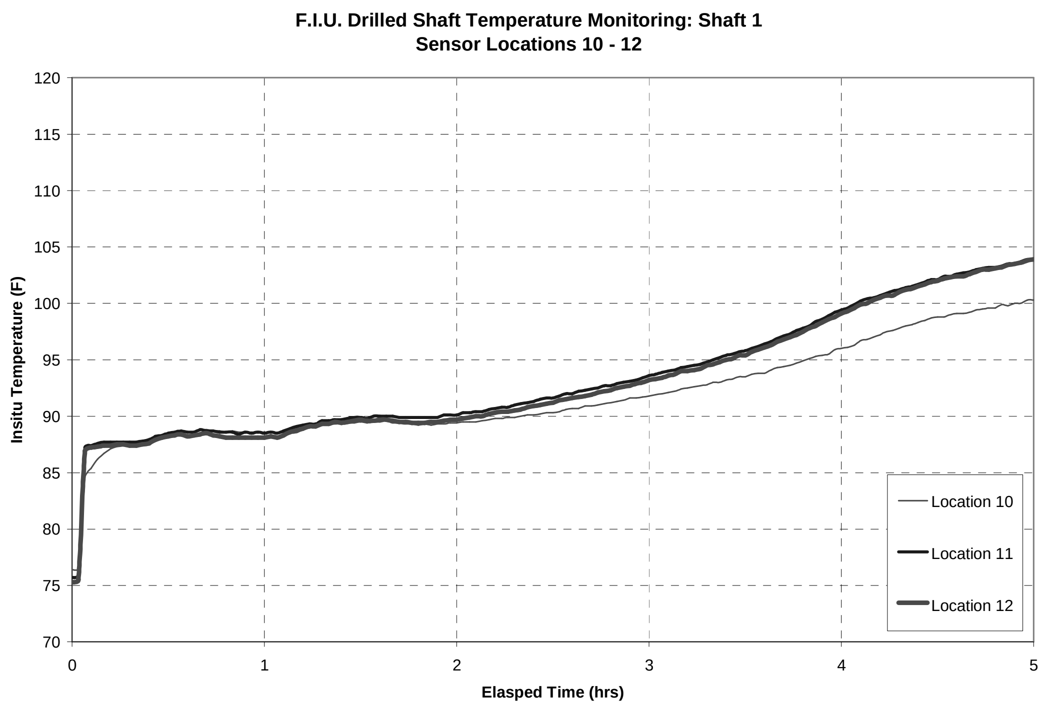




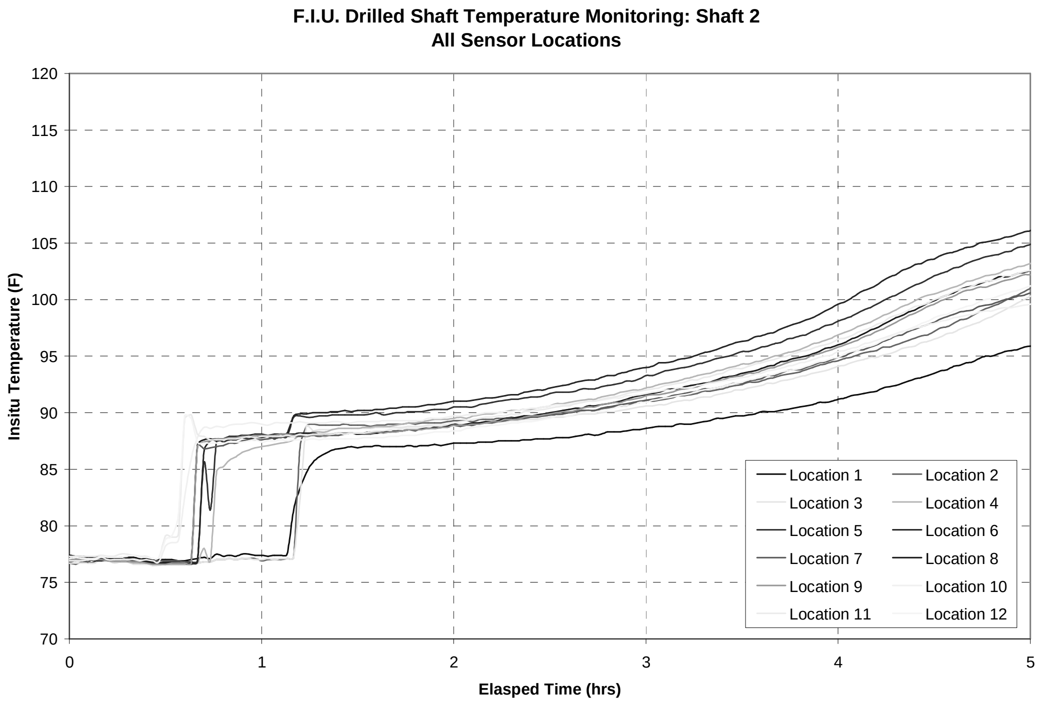

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 1 - 3
Insitu Temperature (F)
Elasped Time (hrs)
Location 1
Location 2
Location 3

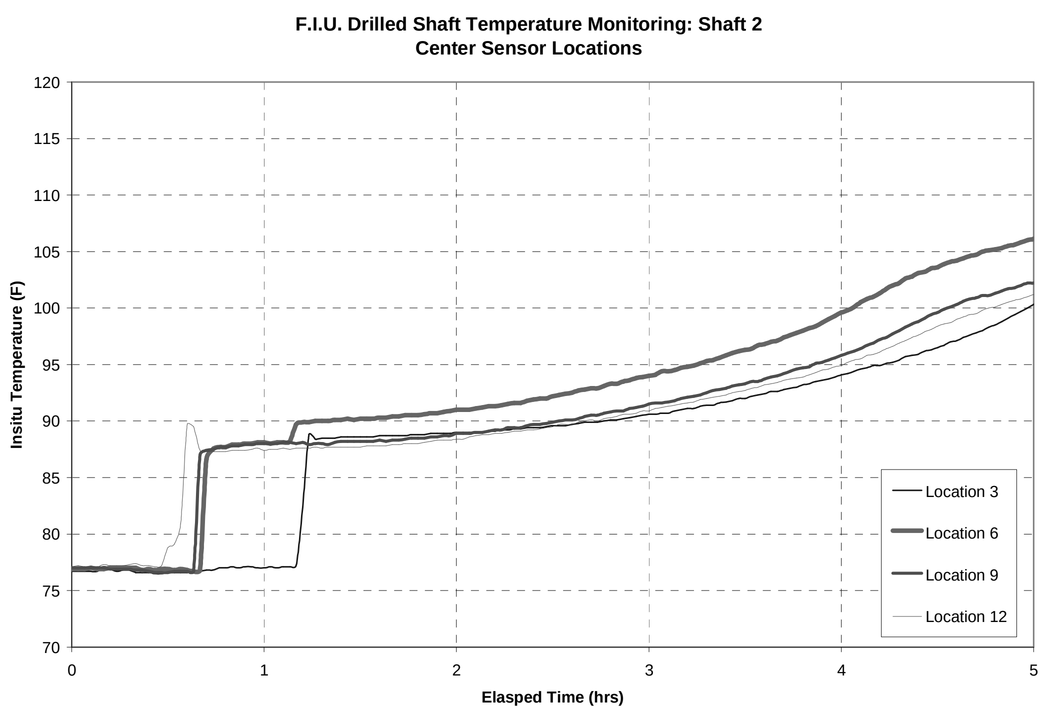

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 4 - 6
Insitu Temperature (F)
Elasped Time (hrs)
Location 4
Location 5
Location 6

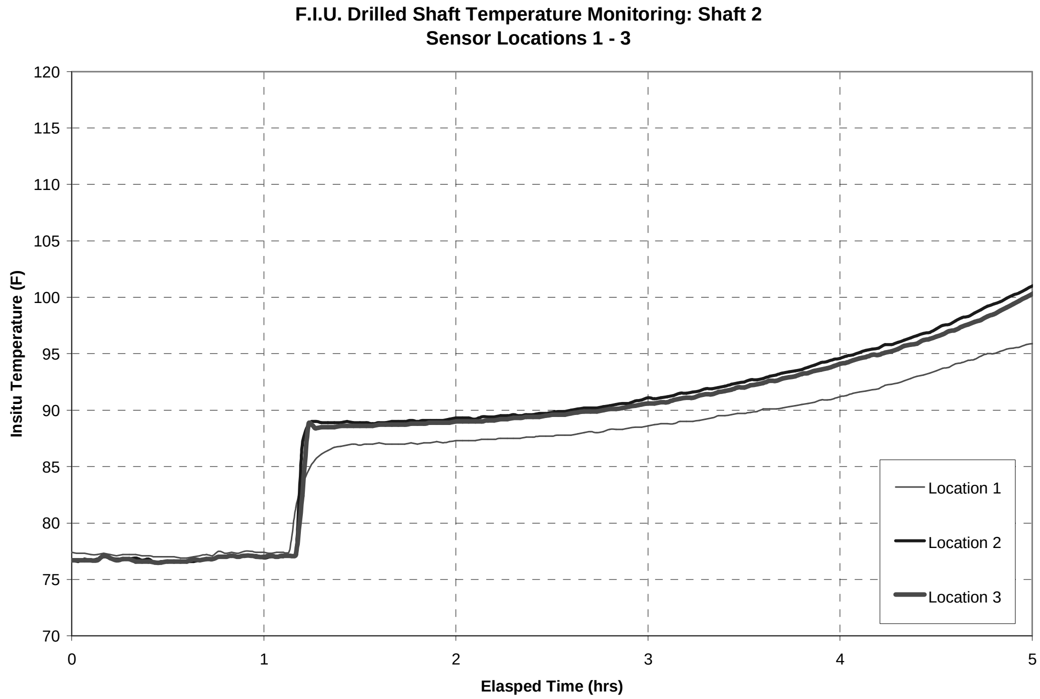

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 7 - 9
Insitu Temperature (F)
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 7
Location 8
Location 9

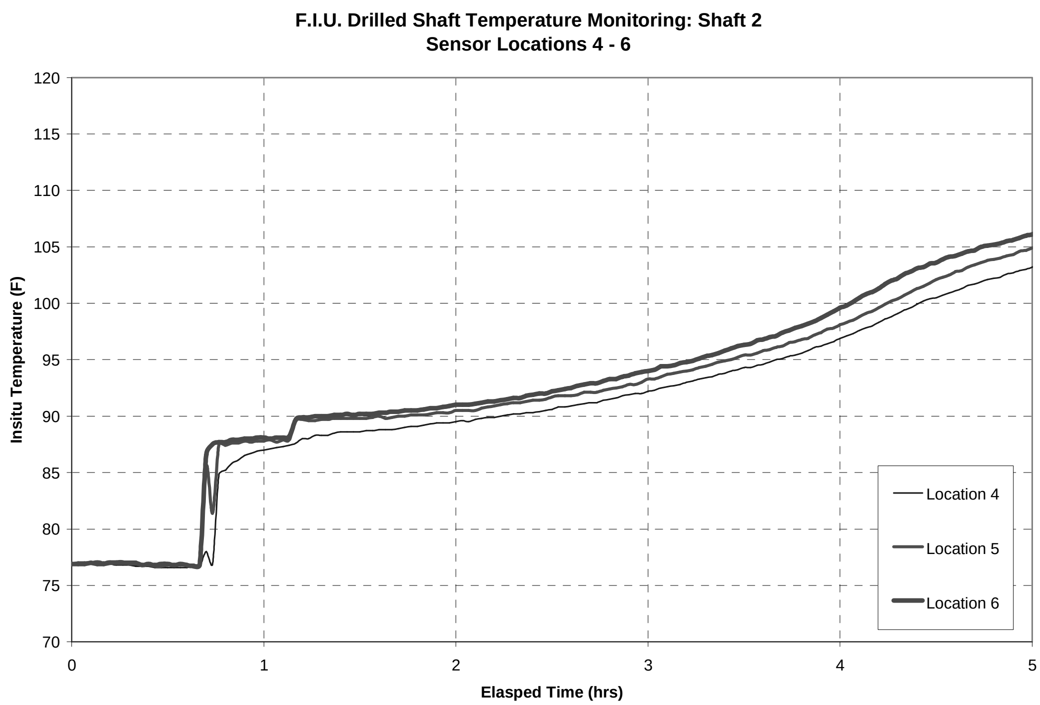

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 10 - 12
Insitu Temperature (F)
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 10
Location 11
Location 12

Drilled Shaft 2






F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 1 - 3
Insitu Temperature (F)
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 1
Location 2
Location 3


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 4 - 6
Insitu Temperature (F)
120
115
110
105
100
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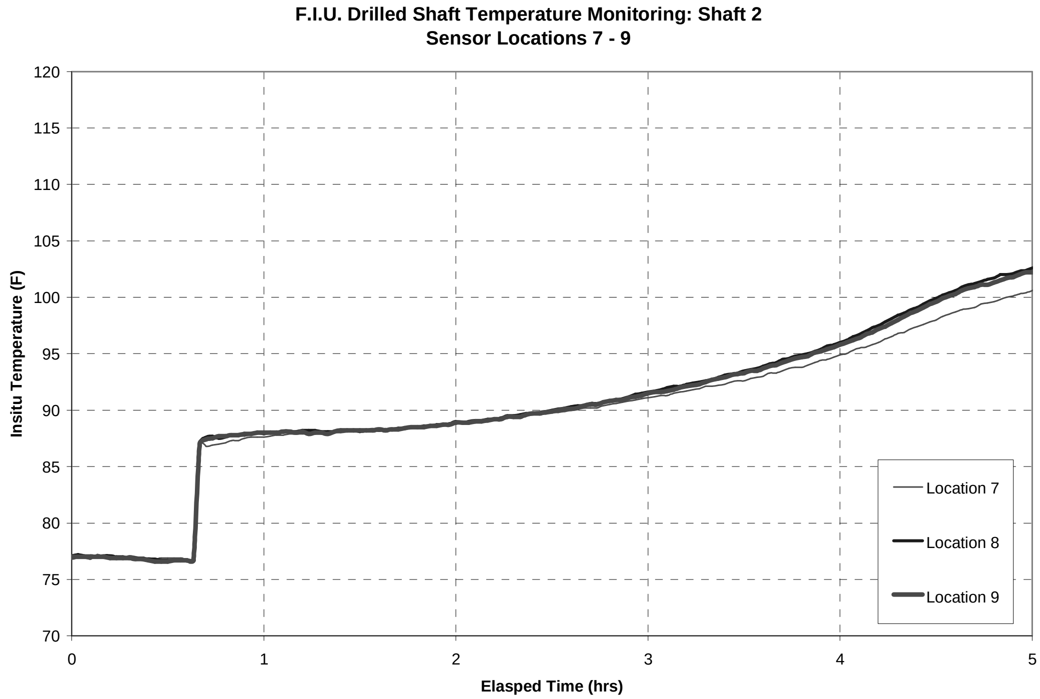
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 4
Location 5
Location 6


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 7 - 9
Insitu Temperature (F)
120
115
110
105
100
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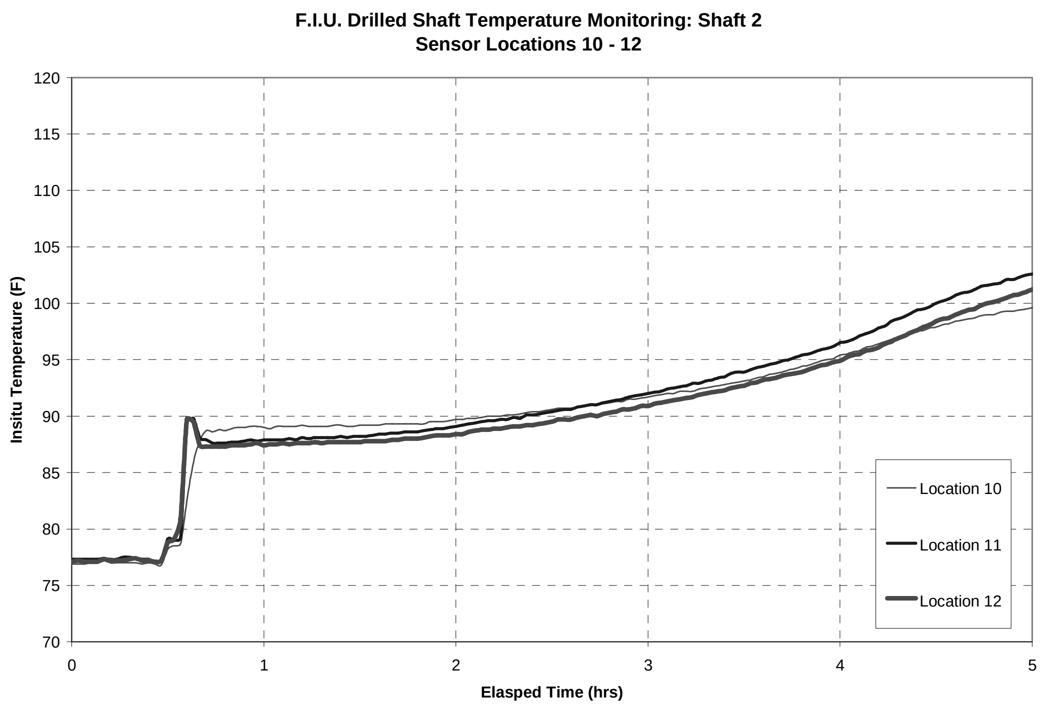
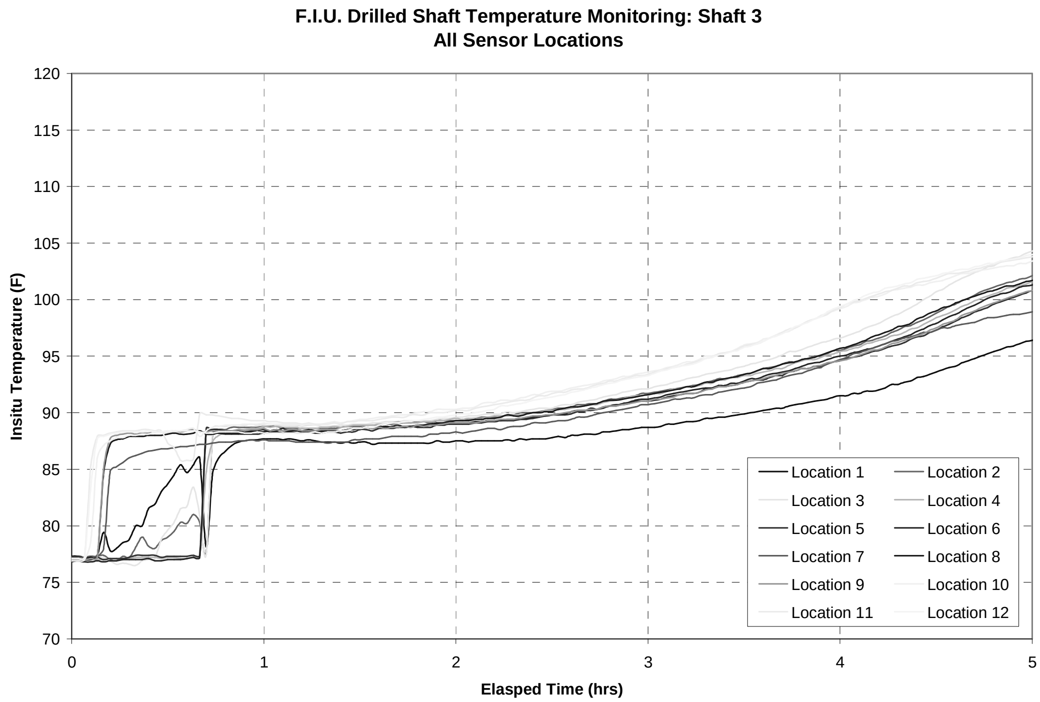
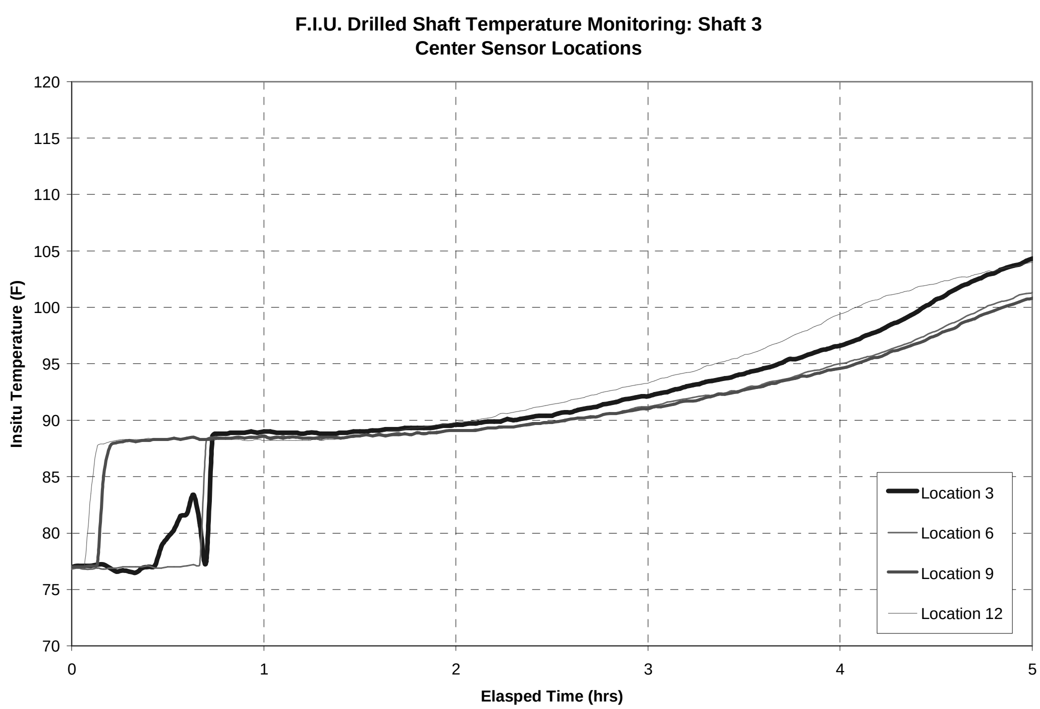
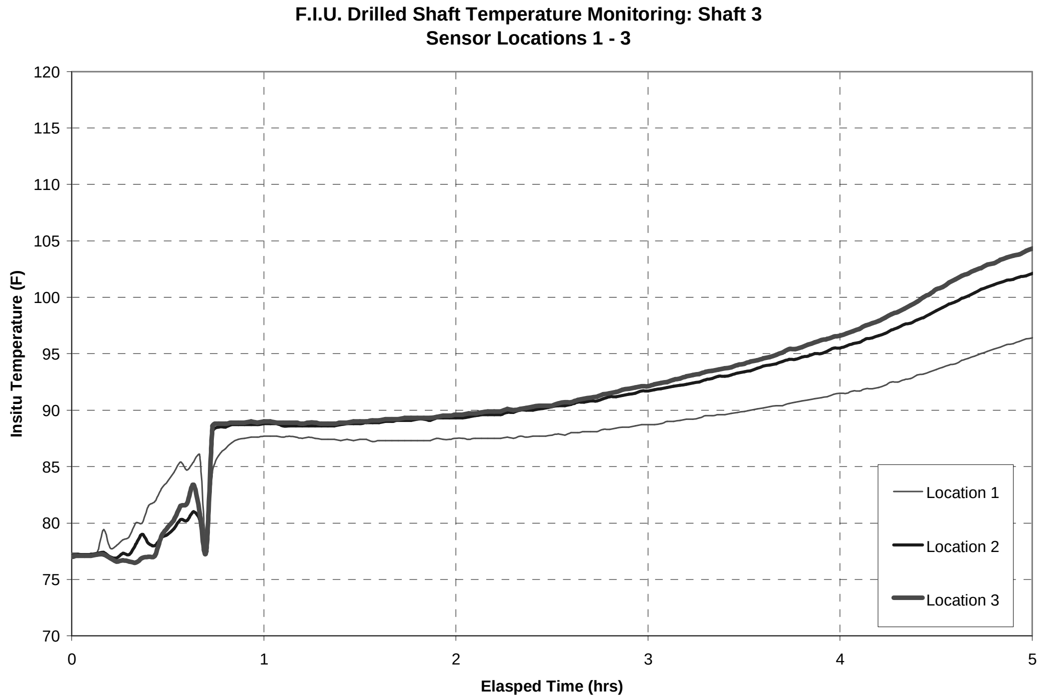
1
2
3
4
5
Elasped Time (hrs)
Location 7
Location 8
Location 9

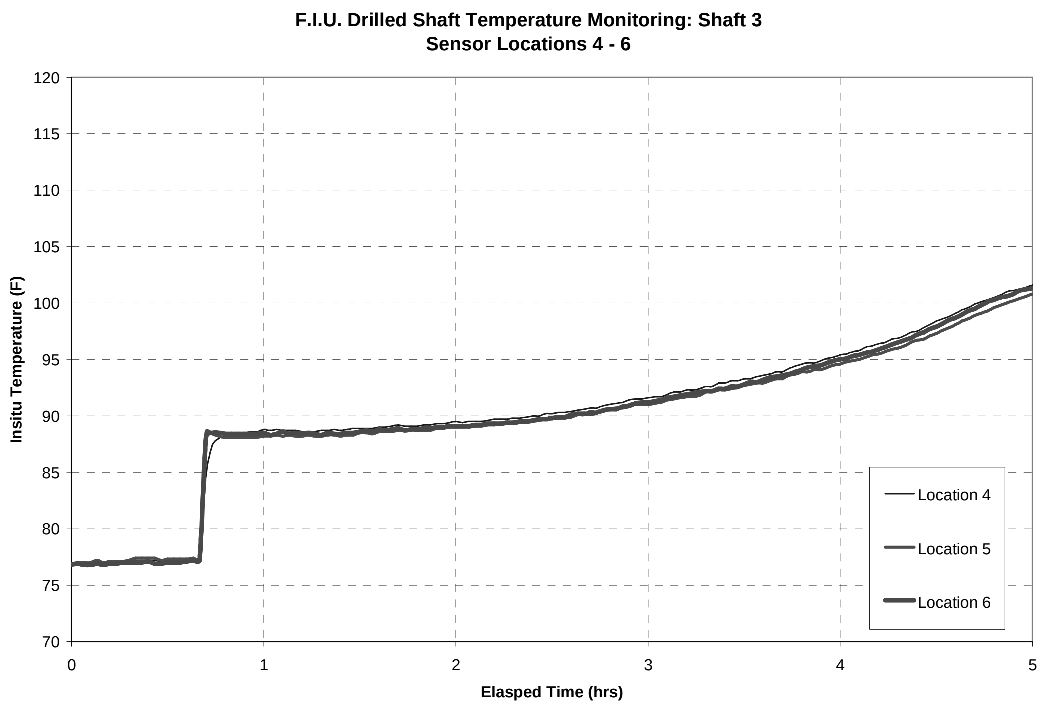

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 10 - 12
Insitu Temperature (F)
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 10
Location 11
Location 12

Drilled Shaft 3






F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 1 - 3
Insitu Temperature (F)
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
Elasped Time (hrs)
Location 1
Location 2
Location 3


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 4 - 6
Insitu Temperature (F)
120
115
110
105
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75
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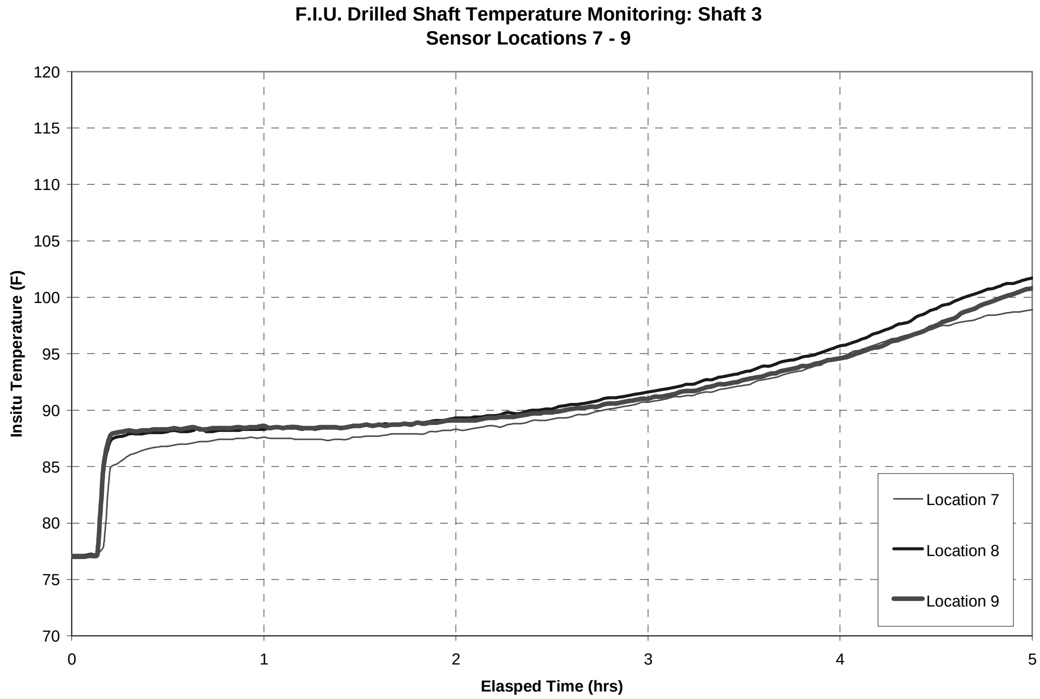
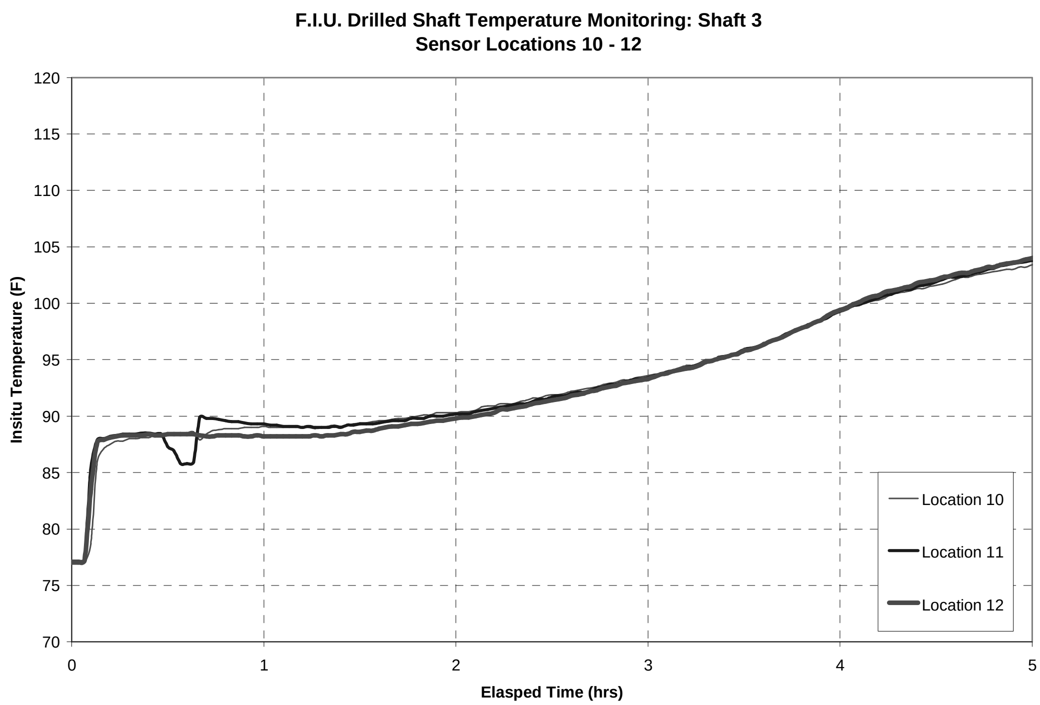
0
1
2
3
4
5
Elasped Time (hrs)
Location 4
Location 5
Location 6

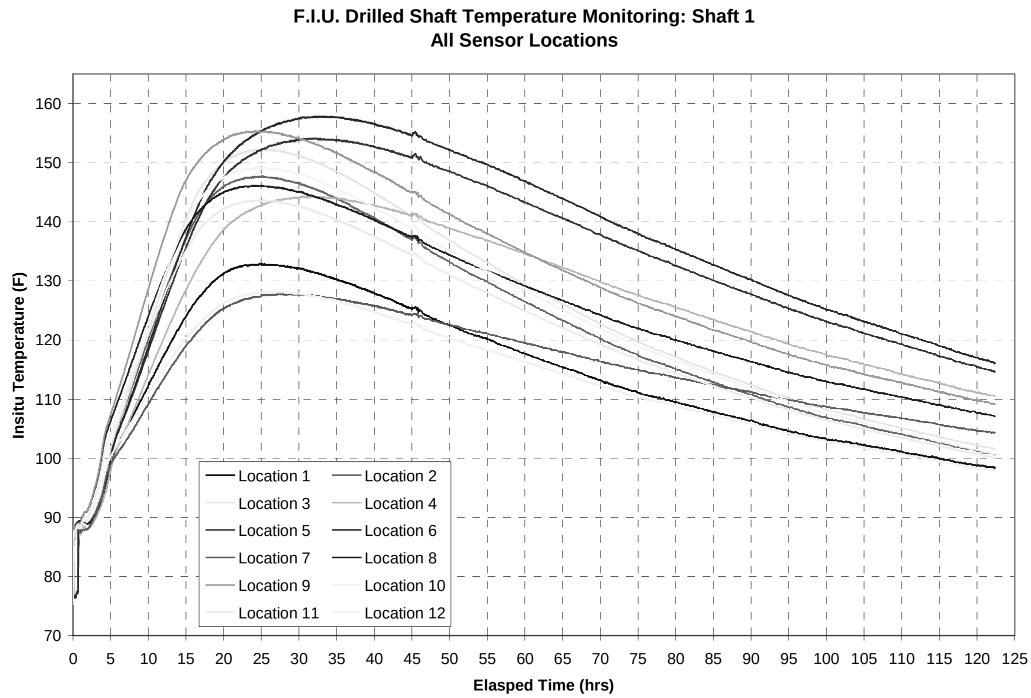

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 7 - 9
Insitu Temperature (F)
Elasped Time (hrs)
Location 7
Location 8
Location 9

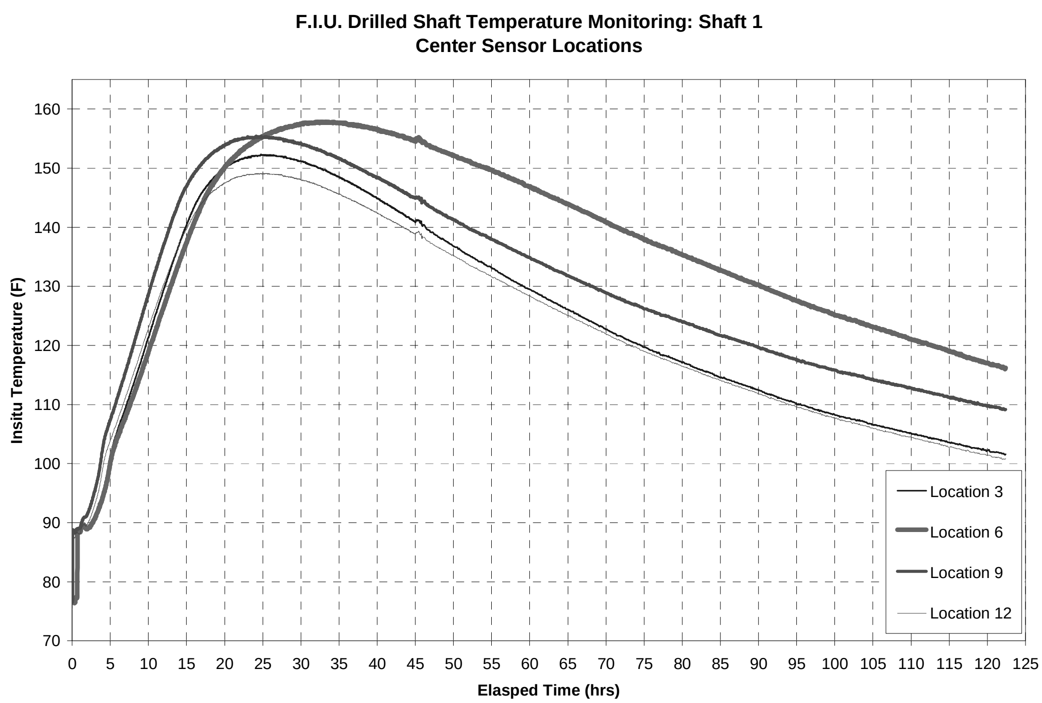

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 10 - 12
Insitu Temperature (F)
Elasped Time (hrs)
Location 10
Location 11
Location 12

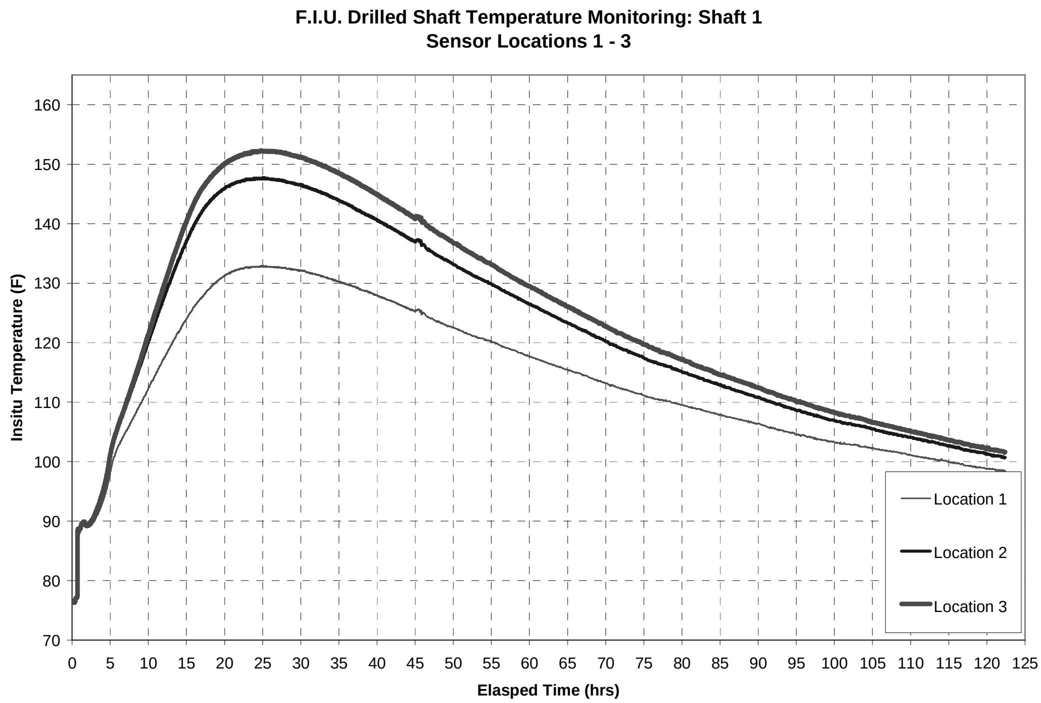
Appendix C

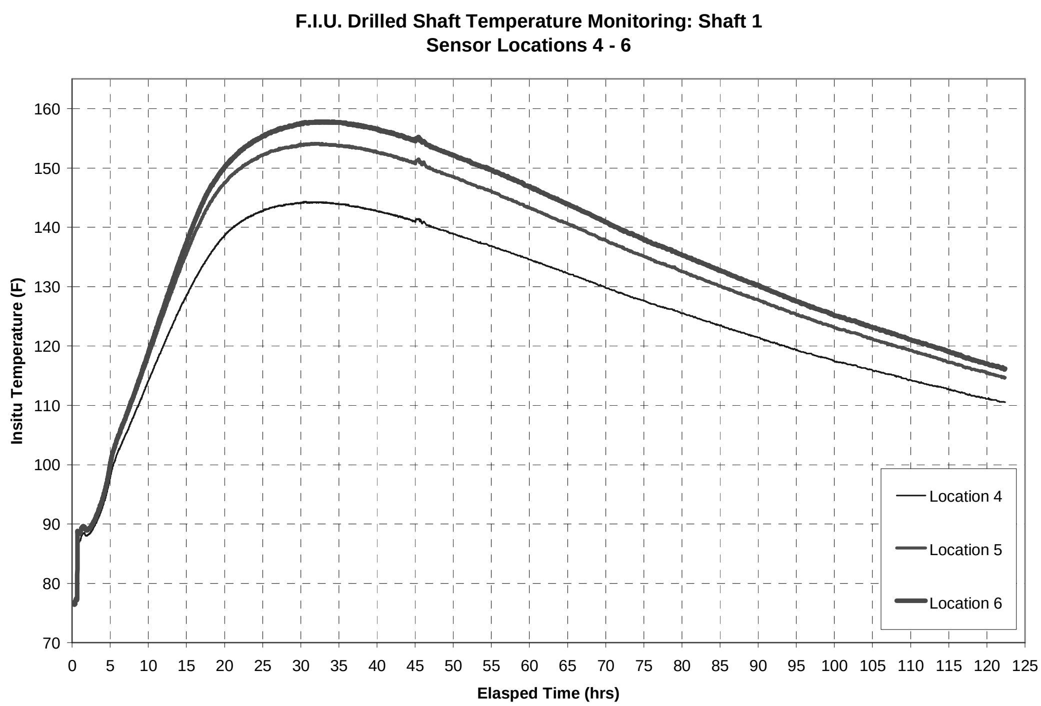
Phase II: Field Testing Results
(Final Setting and Hardening)

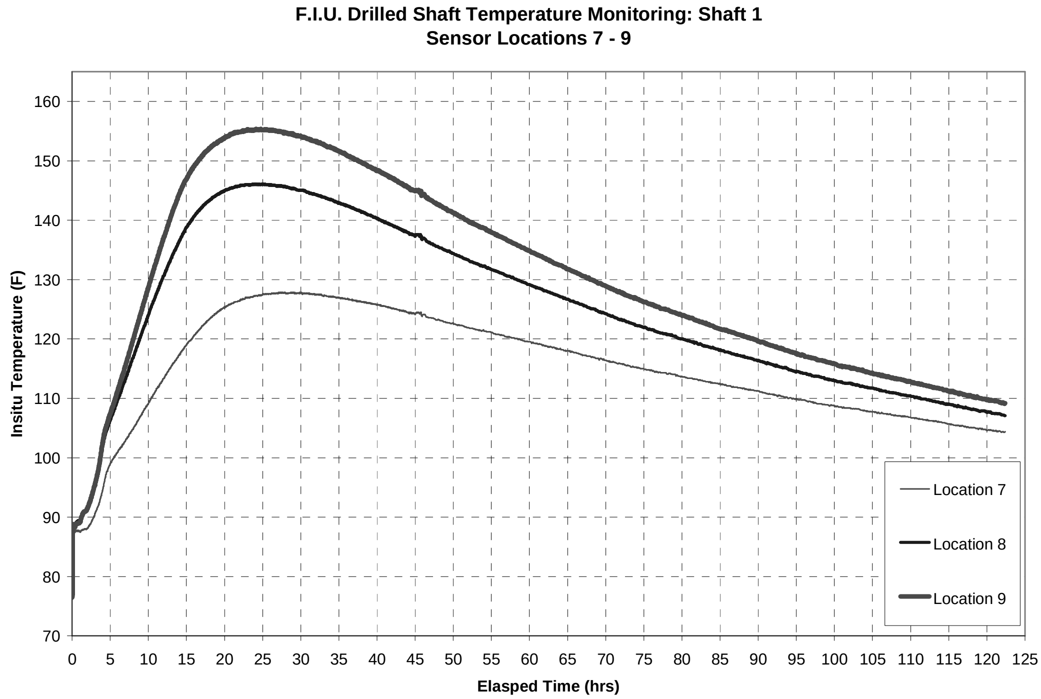
Drilled Shaft I

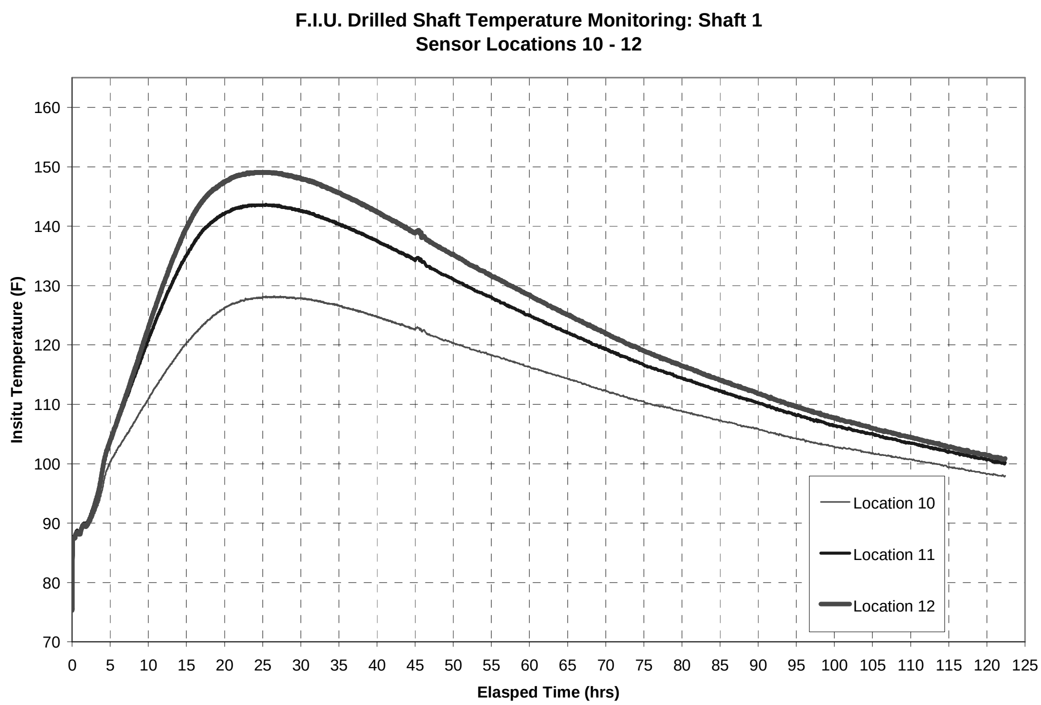




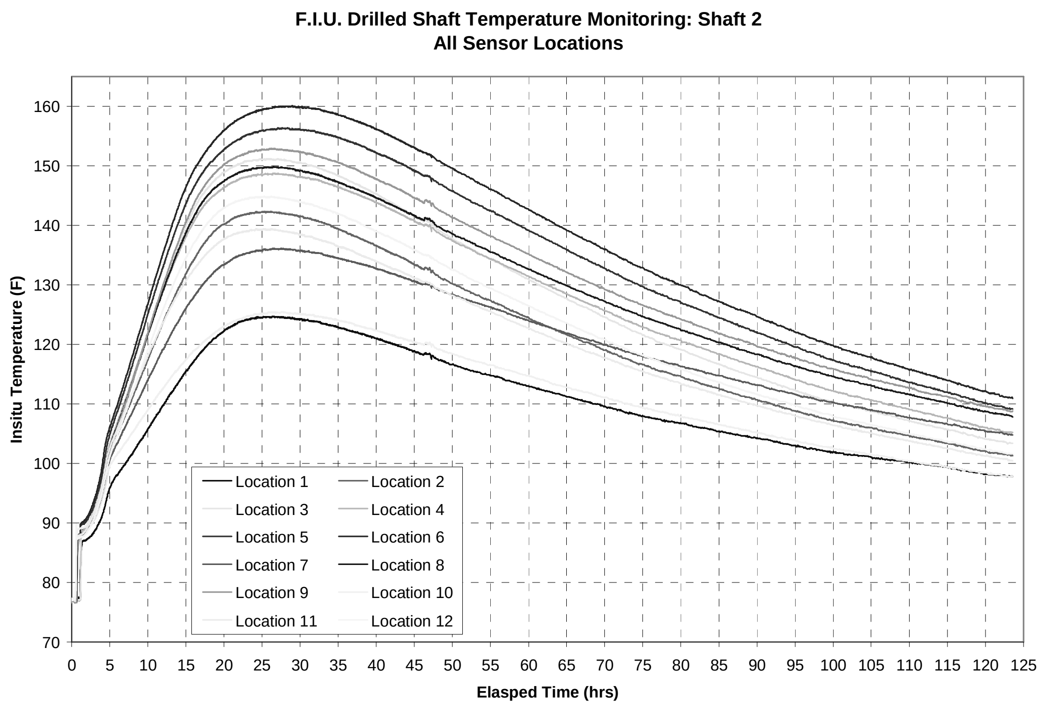

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 1 - 3
Insitu Temperature (F)
Elasped Time (hrs)
Location 1
Location 2
Location 3
70
80
90
100
110
120
130
140
150
160
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125

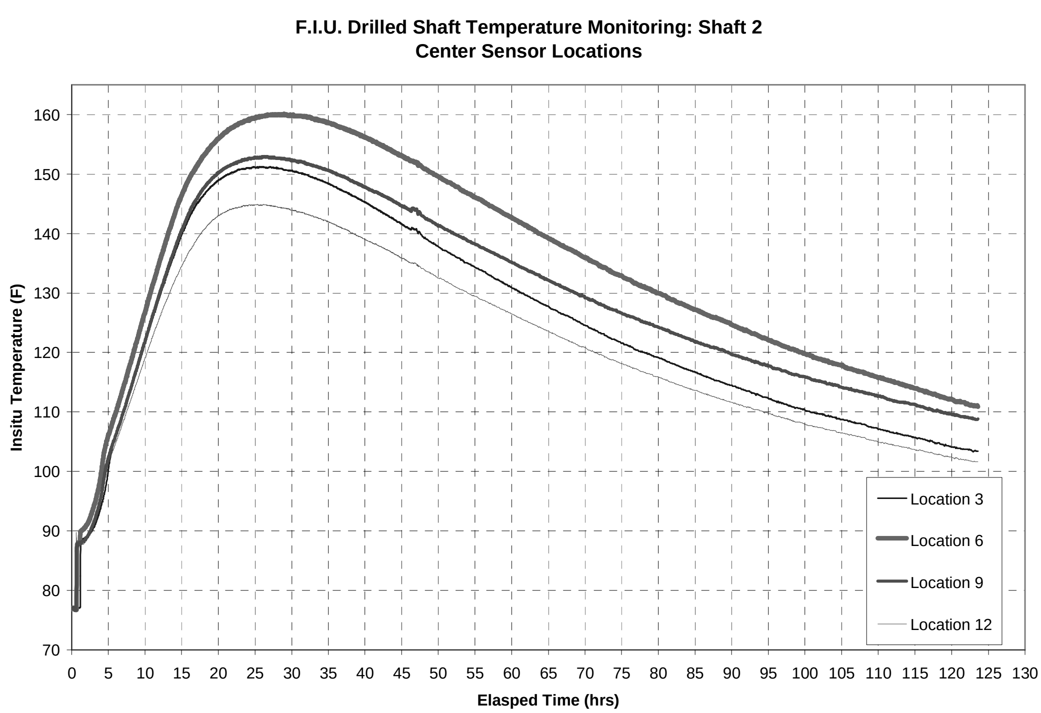

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 4 - 6
Insitu Temperature (F)
Elasped Time (hrs)
Location 4
Location 5
Location 6
70
80
90
100
110
120
130
140
150
160
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125

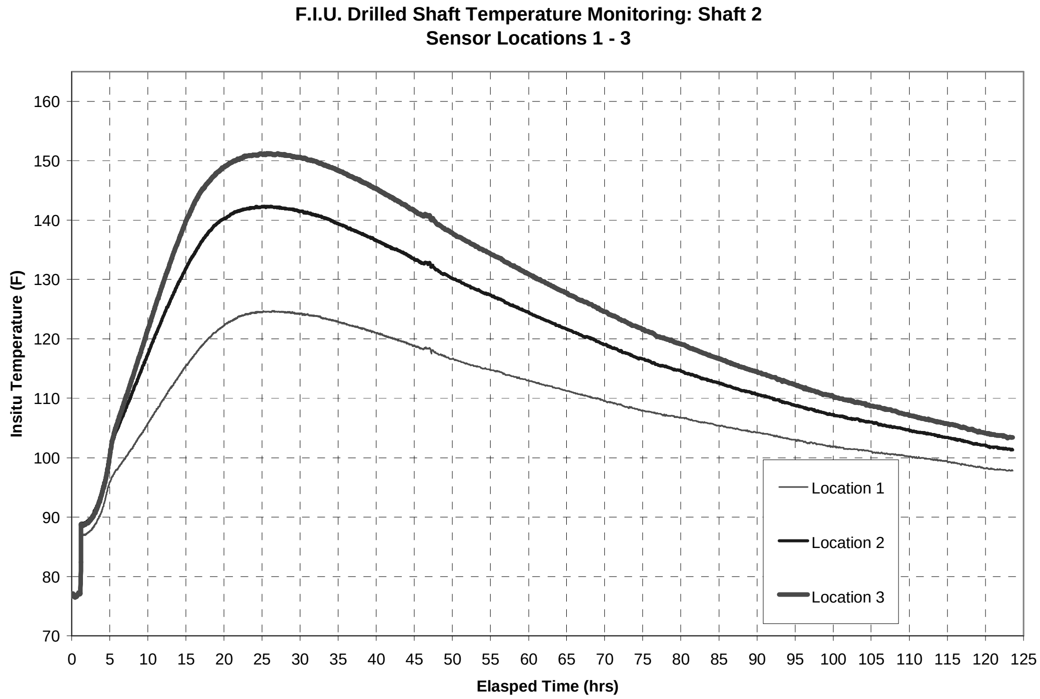

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 7 - 9
Insitu Temperature (F)
160
150
140
130
120
110
100
90
80
70
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
Elasped Time (hrs)
Location 7
Location 8
Location 9

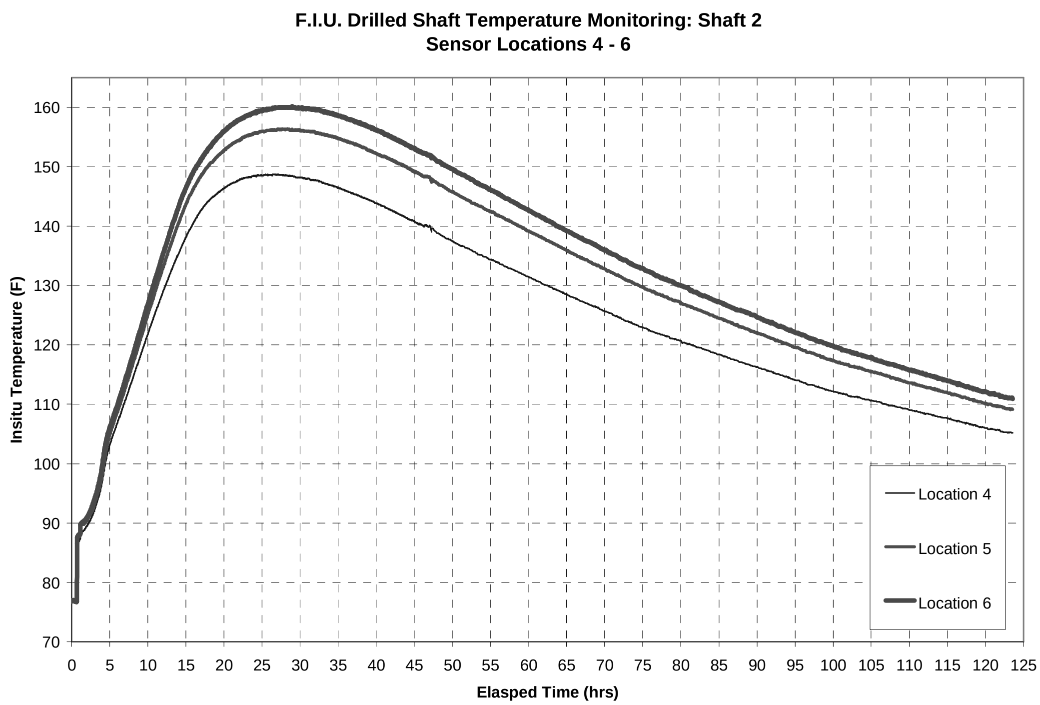

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 1
Sensor Locations 10 - 12
Insitu Temperature (F)
160
150
140
130
120
110
100
90
80
70
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
Elasped Time (hrs)
Location 10
Location 11
Location 12

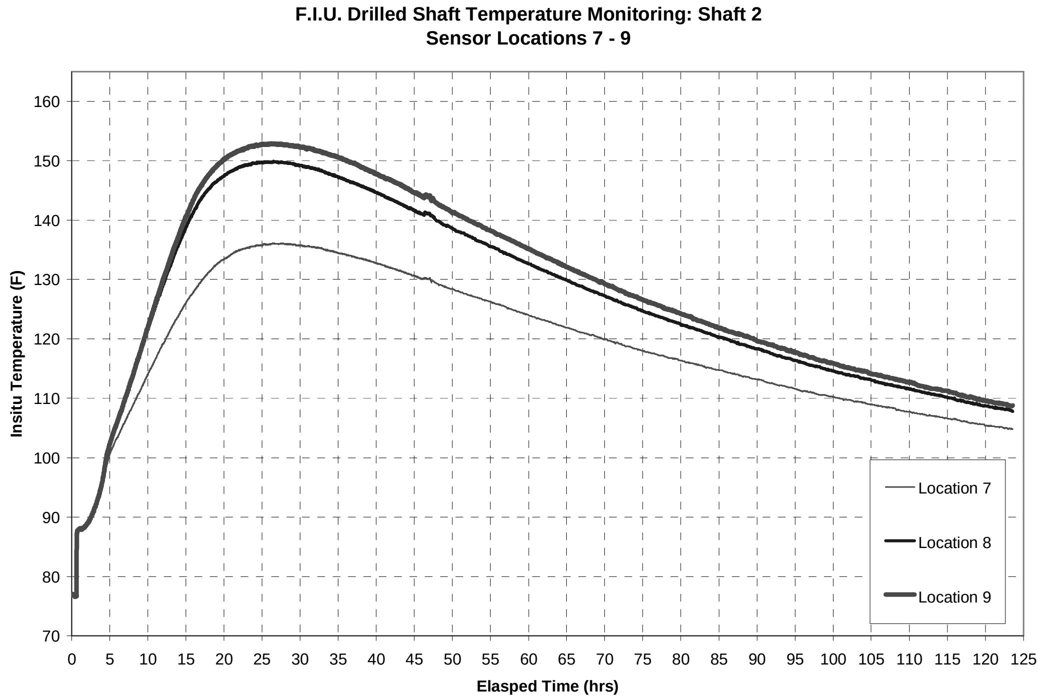
Drilled Shaft 2

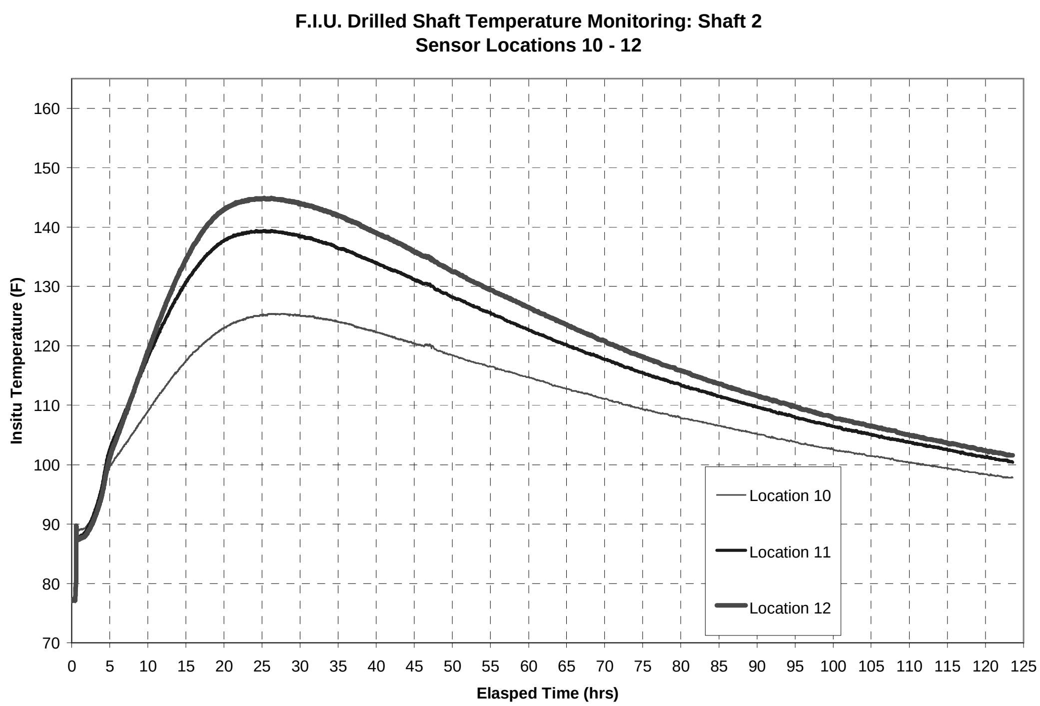




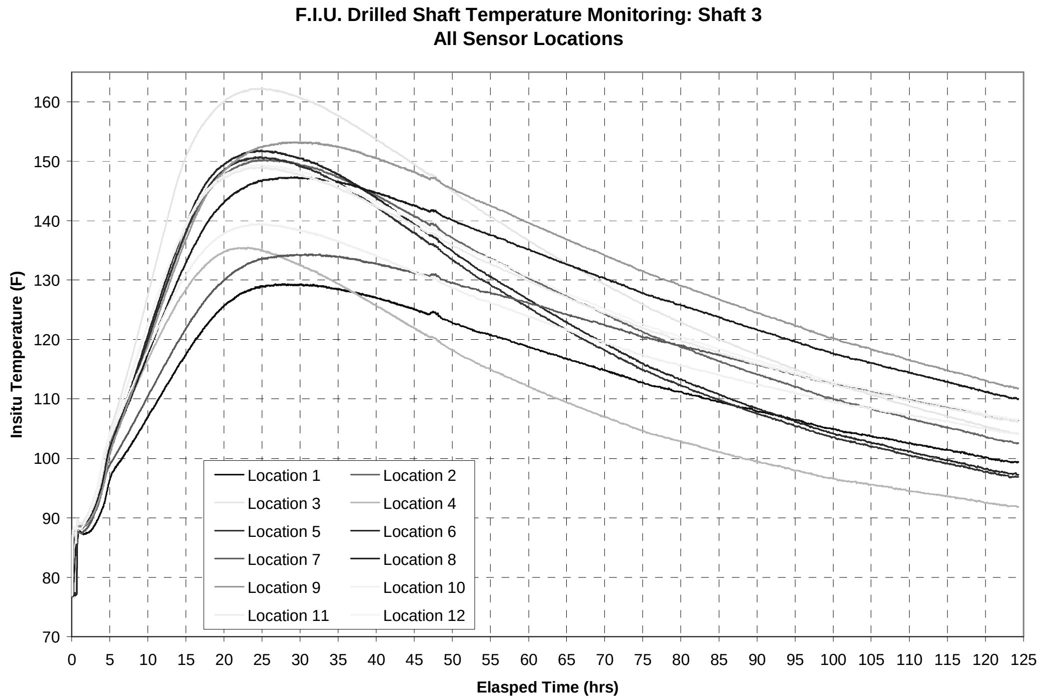

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 1 - 3
Insitu Temperature (F)
Elasped Time (hrs)
Location 1
Location 2
Location 3

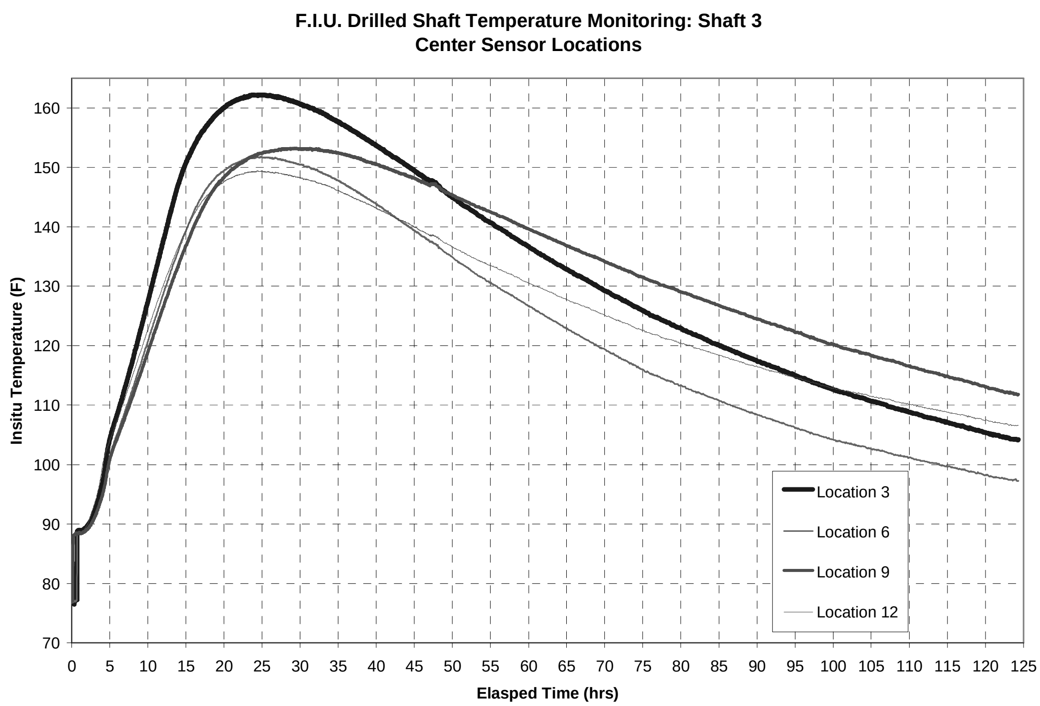

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 4 - 6
Insitu Temperature (F)
Elasped Time (hrs)
Location 4
Location 5
Location 6

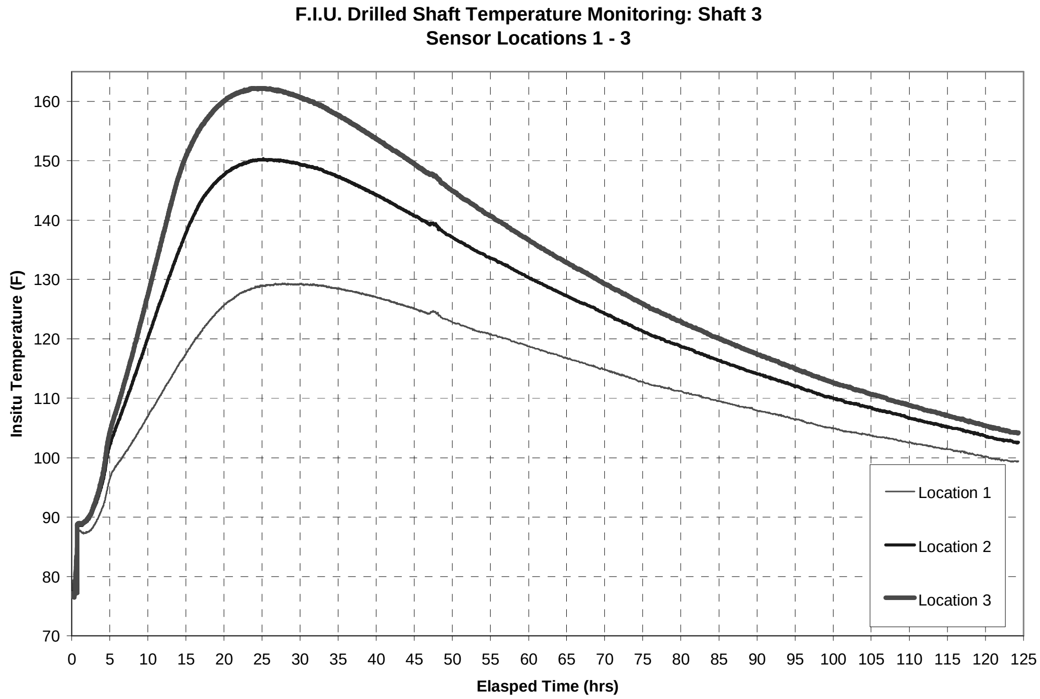

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 7 - 9
Insitu Temperature (F)
70
80
90
100
110
120
130
140
150
160
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
Elasped Time (hrs)
Location 7
Location 8
Location 9

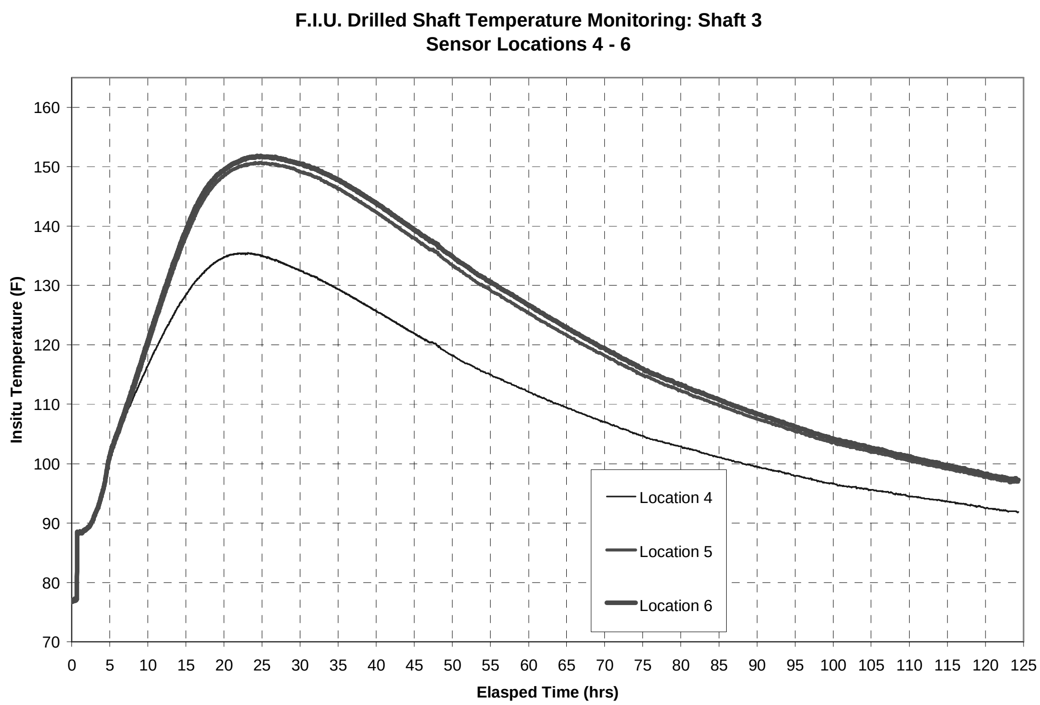

F.I.U. Drilled Shaft Temperature Monitoring: Shaft 2
Sensor Locations 10 - 12
Insitu Temperature (F)
70
80
90
100
110
120
130
140
150
160
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
Elasped Time (hrs)
Location 10
Location 11
Location 12

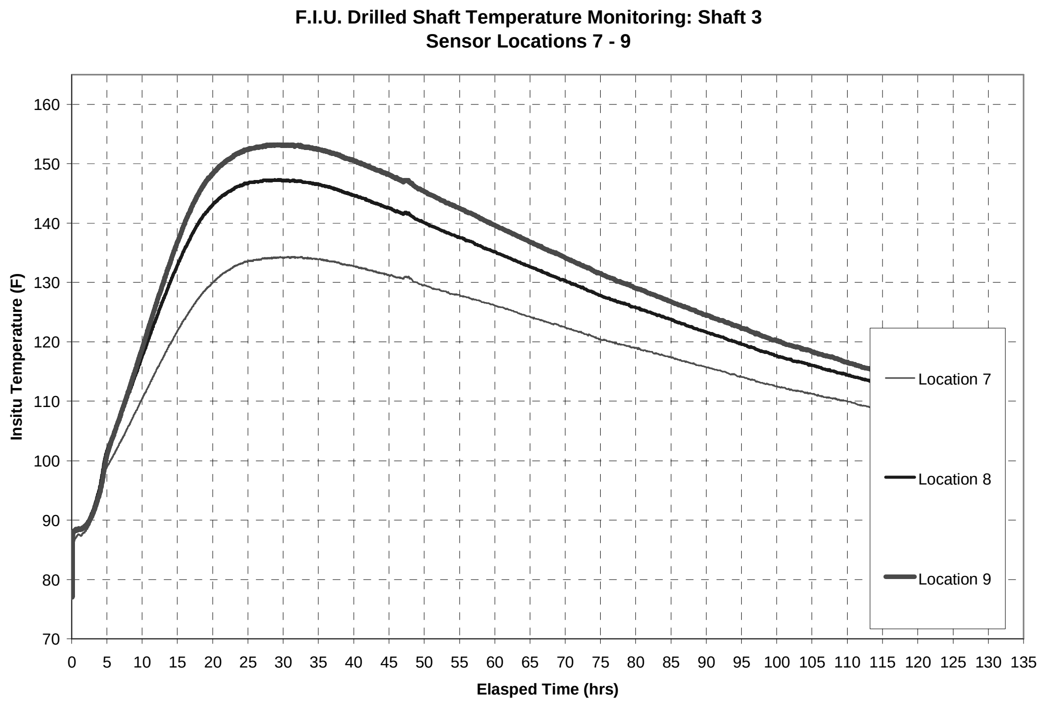
Drilled Shaft 3

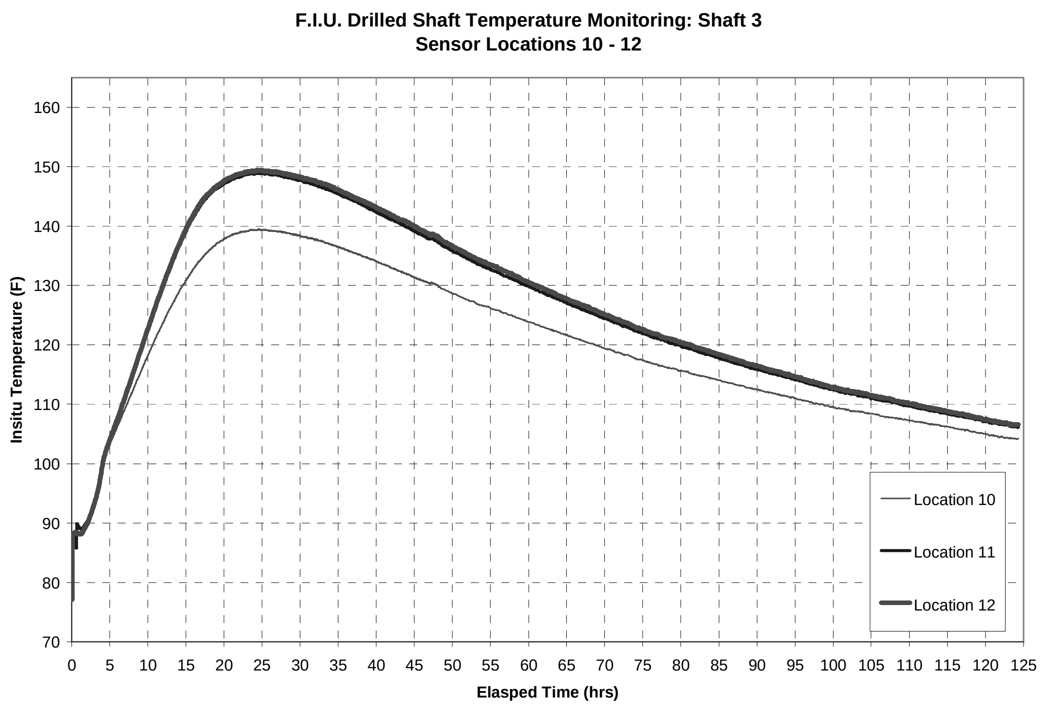





F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 1 - 3
Insitu Temperature (F)
Elasped Time (hrs)
Location 1
Location 2
Location 3


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 4 - 6
Insitu Temperature (F)
Elasped Time (hrs)
Location 4
Location 5
Location 6


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 7 - 9
Insitu Temperature (F)
Elasped Time (hrs)
Location 7
Location 8
Location 9


F.I.U. Drilled Shaft Temperature Monitoring: Shaft 3
Sensor Locations 10 - 12
Insitu Temperature (F)
Elasped Time (hrs)
Location 10
Location 11
Location 12