HEAT DISSIPATION AND CRACK CONTROL IN MASSIVE CONCRETE AT THE BURLINGTON BRIDGE

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Johnson Brothers, Inc.

8. ABSTRACT

The large concrete placements at the Burlington Bridge were expected to cause great temperature differentials within the individual placements. In an attempt to reduce cracking due to the large temperature differentials, the Iowa Department of Transportation required that contractors continuously monitor the temperatures and temperature differentials in the concrete placement to assure that the differentials did not exceed 35°F. It was felt that if temperature differentials remained below 35°F, cracking would be minimized. The following is a summary of the background of the project, and what occurred during individual concrete placements.

The following conclusions were drawn:

1) Side temperatures are cooler and more greatly affected by ambient air temperatures.
2) When the 35°F limit was exceeded, it was almost exclusively the center to side differential.
3) The top temperature increases substantially when a new pour is placed.
4) The use of ice and different cement types did seem to affect the overall temperature gain and the amount of time taken for any one placement to reach a peak, but did not necessarily prevent the differentials from exceeding the 35°F limit, nor prevent cracking in any placement.
5) Larger placements have a greater tendency to exceed the differential limit.

9. KEY WORDS
Concrete
Heat of hydration
Temperature differential

10. NO. OF PAGES

199

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DISCLAIMER

The contents of this report reflect the views of the author and do not necessarily reflect the official views of the Iowa Department of Transportation. This report does not constitute any standard, specification or regulation.

INTRODUCTION:

It is well-known and has been demonstrated that massive concrete placements can generate substantial temperature differentials that can be detrimental and even destructive to a structure. The concrete tends to expand outward early in its life due to a major temperature rise at the center, which in turn causes the center core of the concrete to be warmer than the exposed surfaces. Thus, as the outer surface cools and contracts, and the inner volume is still expanding, tensile stresses in the outer surfaces increase. When these tensile stresses become greater than the tensile strength of the concrete, cracking occurs. It would be helpful to have methods that would be able to:

1) Predict the internal temperature conditions of the placement, and

2) Minimize and mitigate the detrimental effects of the mass temperature differentials.

In this study, an effort was made to:

a) Record the temperature changes of the concrete at specified locations within the individual placements and note differentials between locations,

b) Relate that temperature differential to individual components and combined components (e.g., type of cement used, addition of ice, ambient temperatures, etc.),

c) Relate that temperature change to:
   i. Absolute concrete temperatures,
   ii. Temperature differentials, and
   iii. Size (both mass and dimension) of the unit placed, and

d) Relate maximum differential temperatures (especially those over the specified limit) to cracking experienced.

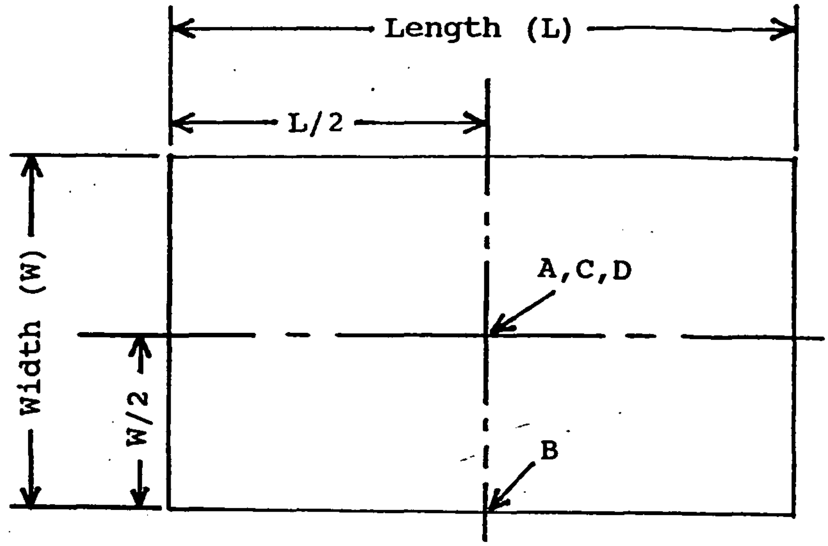
PROCEDURE:

I. Placement of Temperature Sensors

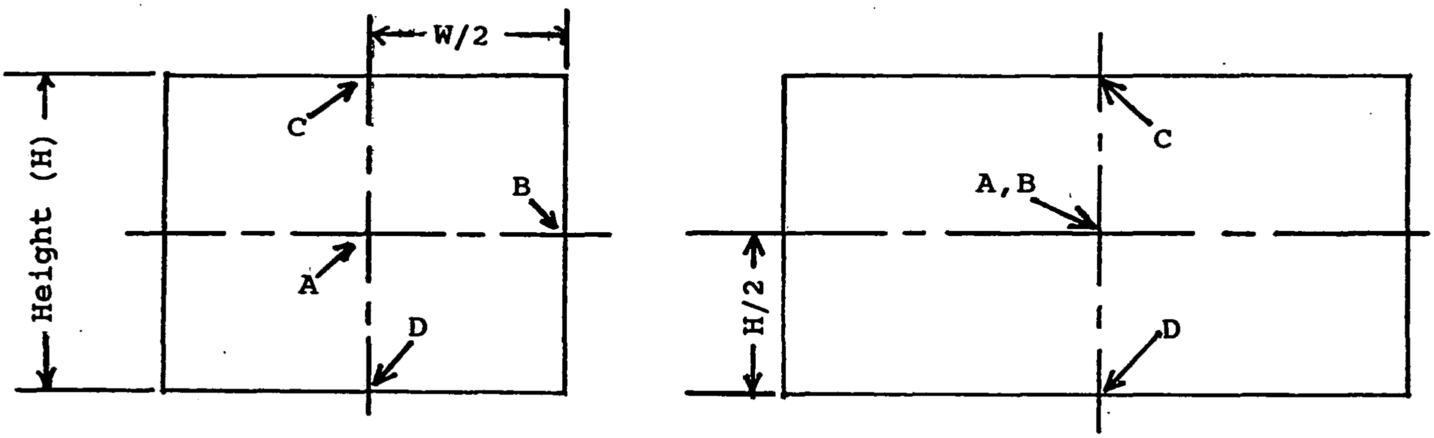
In order to continuously record the internal temperatures of the concrete placements, it was decided that temperature sensors would be placed as shown in the attached sketch (Figure 1). A sensor (A) was placed as near as possible to the center of the placement, with another backup sensor placed within one foot of A. To measure the outside surface temperatures, two sensors (B and C) would be placed on the outside edge (usually on the west side), and on top of the placement, respectively. Sensor B would be placed between the reinforcing steel and the outside surface of the placement. Another sensor (D) would be placed at the bottom of the placement, for monitoring information only. (Note: The sensor placed on the top of the previous placement was used as the "bottom" of the next placement.) The outside sensors were placed 1" ± ½" from the outside surface (exact locations are not available). The contractor for the substructure used the Metrosonic DL-714 Analog Data Logger with an eight channel capacity to record continuous temperature readings, and the contractor responsible for the pylons used the Metrosonics DL-716 Model. Problems with the data loggers arose due to: 1) moisture from flooding or precipitation shorting out the data loggers;
2) becoming disconnected; or 3) inaccurate readings possibly due to stray voltages.

The specification limited the temperature differential at preselected locations in the placement to 35°F, and placements where the temperature differential exceeded 35° would be inspected for cracks. The temperature differentials were calculated as

Sketch of a Typical Placement Section Showing the Location of Temperature Sensors



Plan View



End View

Side View

Key:

A = sensor at center of placement section

B = sensor at outside surface (Side)

C = sensor at outside surface (Top)

D = sensor at outside surface (Bottom)

Notes:

1) Two sensors required at each of A and B locations (one is back-up).
2) Sensor at location D is only required when this surface is on top of a cofferdam seal.

Figure 1

"center temperature minus top temperature" and "center minus edge temperature" for analysis purposes. If the temperature at the top or edge was higher than the center temperature, this constituted a "negative differential," since the center temperature was used as the base for comparison. The Iowa Department of Transportation (Iowa DOT) required that the temperature of the concrete be controlled and monitored until the temperature at the center was within 35°F of the average outside air temperature of the previous week. In addition, the concrete temperature would be monitored by a continuous recording device for at least one week. After one week, the temperature could be checked once daily with a nonrecording device until the criteria stipulated above was met. Also, during any period of form removal or insulation adjustment, the temperature differential would be monitored two to three times per day or more if necessary to insure that it did not exceed the 35°F limit. (Readings were to be taken daily from backup sensors to verify the accuracy of the primary sensors.)

The original objective of the Iowa DOT was to continuously monitor and control temperature differentials from both center to side and center to top until curing of the placement was complete. The contractor (Johnson Brothers), however, contracted with Braun Engineering Testing Incorporated to have a thermal analysis of the mass concrete in pier MS-2 done, and this study predicted that curing time on placements as big as the footing of pier MS-2 could last up to three months (see Appendix D). Due to the longer cooling time necessary for the mass placements and the necessity of completing the project in reasonable time, a compromise was agreed upon between the Iowa DOT and Johnson Brothers. This agreement stated that a new placement could be placed on top of uncured concrete, and once this was done, the center to top differential of the underlying placement was no longer required to be in compliance, that is, it could exceed the specified limit without the contractor being penalized.

The preceding temperature sensing plan was adhered to, except when flooding occurred and prevented use of the data loggers, or if the succeeding placement would be a controlling factor.

II. Insulation Plan

Each contractor (Johnson Brothers - substructure, E. Kraemer & Sons - superstructure) was required to submit a detailed insulation plan to prevent cracking in the massive concrete placements to the resident engineer before construction. Plans from the two contractors were quite similar. Johnson Brothers, who built the substructure, used insulated forms during the placement of the concrete, and when the forms were raised for placement of the next lift, usually after one week, sheets of styrofoam were used to cover the outside exposed surfaces as soon as possible. These 3 inch sheets of styrofoam (providing an R-15 value) were held in place by 2 x 6's bolted to the form ties in order to re-insulate the placements. In addition to the insulated forms, Johnson Brothers decided to cool the mix by adding ice (at their discretion, when they considered the mix temperature to be too high) and pre-wetting the aggregate in the summer. Johnson Brothers also agreed to experiment with Type II cement (in piers MS-2 and MS-4) to try to reduce the heat of hydration.

The contractor responsible for the pylons (Kraemer & Sons, Inc.) used steel forms in the construction. For the base placement, the forms were insulated between the ribs with 6 inches of fiberglass (providing an R-19 value), and insulated blankets were placed over the forms and over the top of the placement. In addition, the forms were left in place during curing. For pylon placements that had curing requirements, either blankets were hung after the forms were moved, or styrofoam was placed over the exposed concrete to try to maintain the temperature differential at 35°F or less. Kraemer also decided to add ice to the mix when the mix temperature exceeded 70°F.

In certain cases, problems arose due to how the insulation was used on the placements, cracking of the placements, and the temperature differentials exceeding the 35°F limit. When the temperature differentials did exceed the limit, the contractors were sent a non-compliance notice, and then had to decide how to solve the problem. These issues will be further explained, and their solutions examined in more detail, as each placement is analyzed. (For a complete listing of the placements which exceeded the limit and/or necessitated corrective action, see Appendix B.)

III. Sequence of Placement

The individual piers were constructed over a two-year period, in the following order of construction:

Structure	Start Construction	Completion	No. of Placements
MS-2(Subst.)	June 1, 1990	Aug. 23, 1990	4
MS-4	Aug. 21, 1990	March 5, 1991	7
MS-3	Nov. 15, 1990	Feb. 12, 1991	6
MS-1	March 7, 1991	Oct. 2, 1991	7
MS-2(Pylons)	April 2, 1991	Feb. 13, 1992	19

Both contractors experimented with Class D and C concrete in the placements since Class D concrete has a higher cement factor than Class C and was known to cause plastic shrinkage cracking. Type I and Type II cement were used in different placements, as well, because Type II cement is a lower heat-generating cement. Also, varying amounts of ice and super-plasticizer (if any) were added in different instances. Various problems occurred, as well, during placement of the concrete. The actual problems and the solutions used will be explained in detail as they occurred. In the following analysis, if serious cracking occurred, it is noted. If no cracking is mentioned in a placement description, it was either not significant, or not documented by field personnel.

IV. Individual Piers

A. MS-1

LaFarge Type I cement was used for all placements of pier MS-1. The mix number for all seven placements was C-3WR-C.

MS-1F:

Location: Footing of pier MS-1

Placement Date:	3/7/91	Mix Temperature:	59.3°F
Dimensions:	87'x35'x7'	Peak Temperature:	140.8°F
Ambient Temp.:	38.8°F	Temperature Gain:	81.5°F
Volume (cy):	846.0	Day Peak Reached:	Second
Ice(#/cy):	None	HRWR (oz/100# cement):	None

Prior to the next placement being placed, the top and side temperatures and differentials (when compared with the center) follow one another very closely. The center temperature was always the highest and the differentials increased as the top and side cooled more quickly than the center. When the next placement was placed on top of MS-1F on the thirteenth day of curing (March 20), however, the top temperature increased, the side continued to cool as it had done previously, and the center temperature continued to cool for a few days, but then increased again. These fluctuations caused the differential between the center and top to decrease and even become negative, as the top temperature rose with the addition of the new placement. Meanwhile, the differential between the center and the side increased, almost exceeding the 35°F specification, since the side cooled faster than the center due to the low ambient air temperatures. It is interesting to note that as the ambient air temperature rose, stagnated, and fell again, the concrete temperature (in all three locations) fell, and rose again at the end, with the top temperature increasing the most (Figures 2 and 3). This behavior would suggest that the insulation had been removed for some time, and that all the internal temperatures are affected by the ambient temperature after a certain amount of time (in this case it was twenty days).

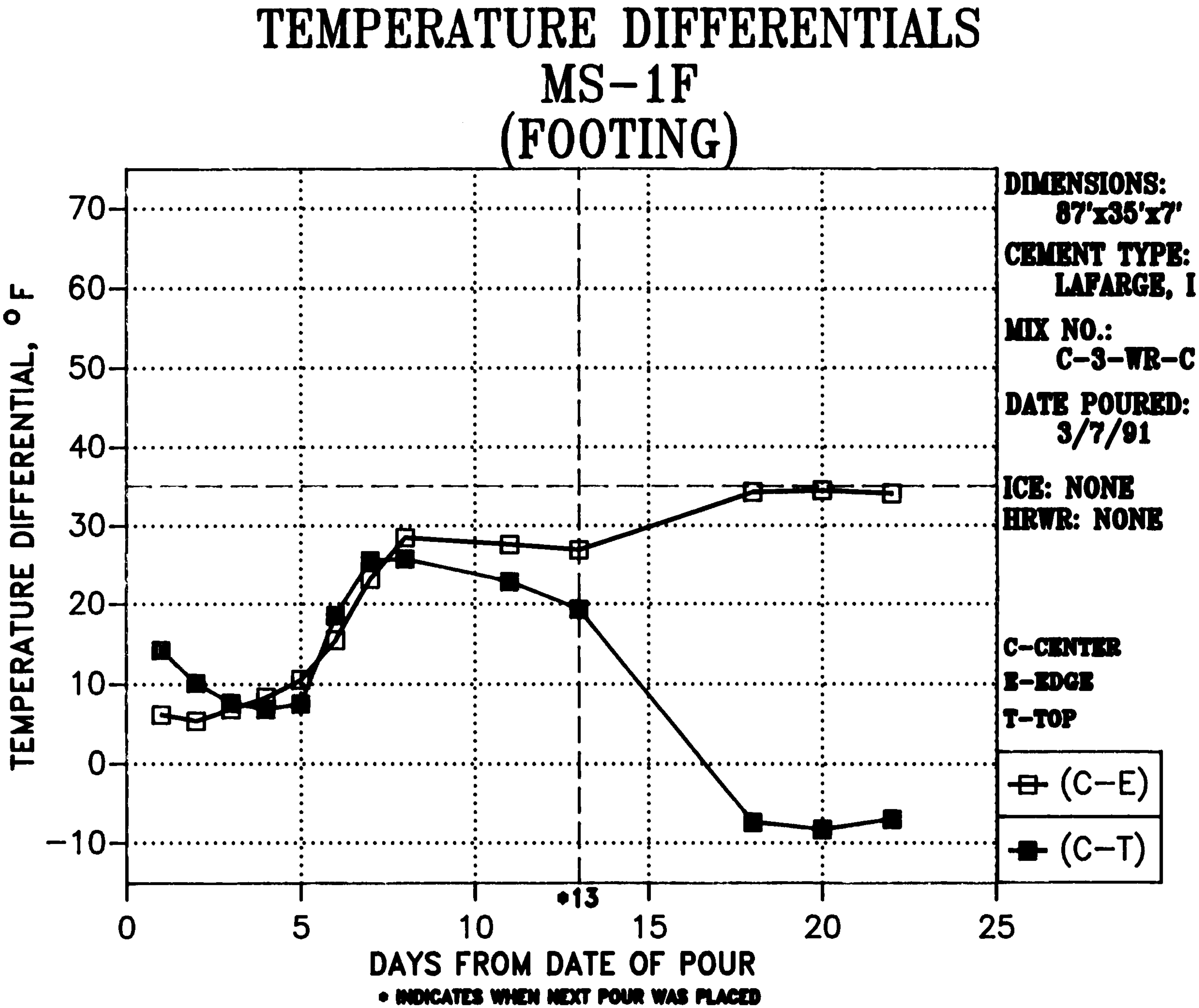
MS-1-1:

Location: First lift of pier MS-1

Placement Date:	3/20/91	Mix Temperature:	63.3°F
Dimensions:	75'x12'x15'	Peak Temperature:	158.0°F
Ambient Temp.:	58.7°F	Temperature Gain:	94.7°F
Volume (cy):	463.0	Day Peak Reached:	Fourth
Ice(#/cy):	None	HRWR (oz/100# cement):	None

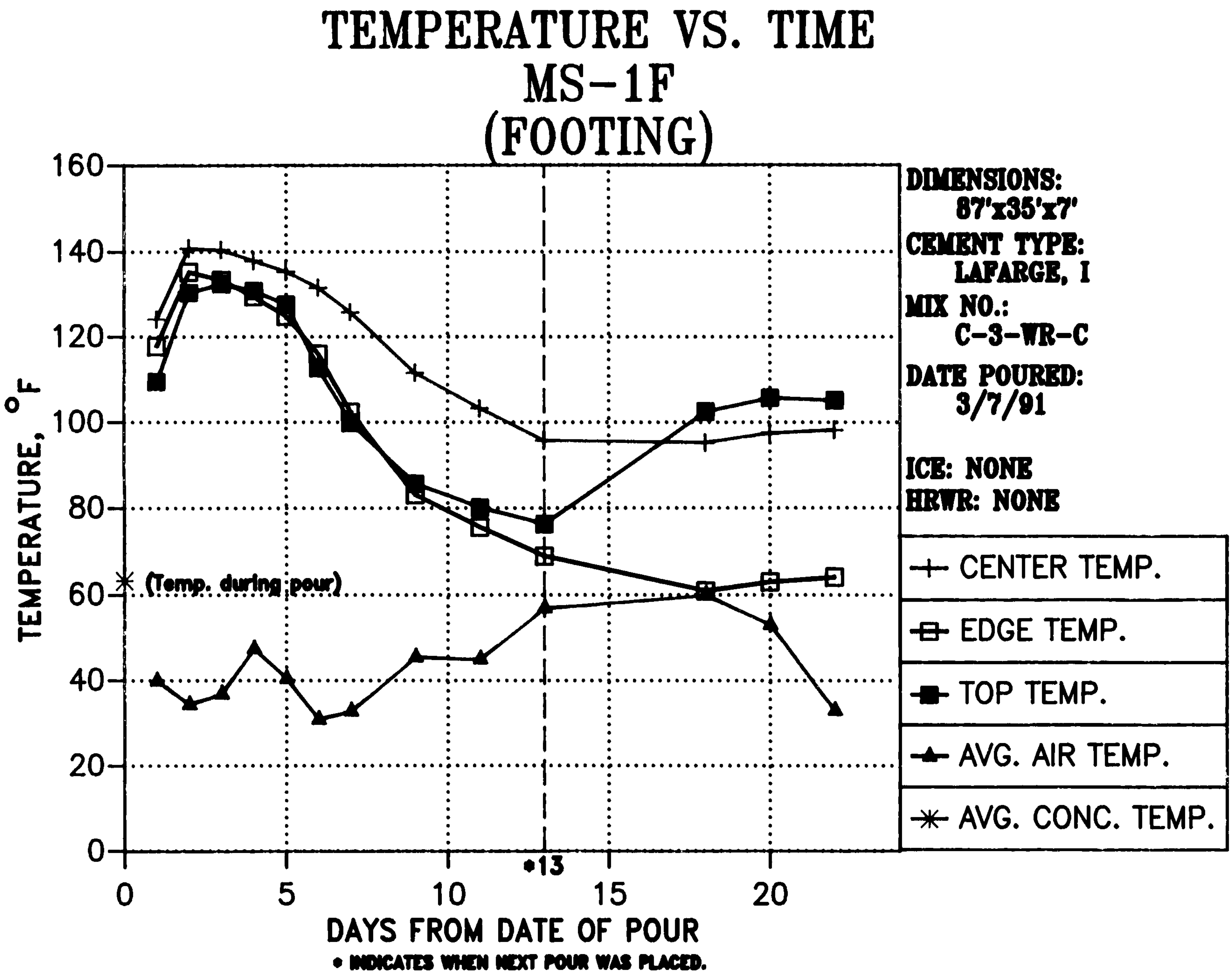
The temperature differentials between the center and side and center and top continued to increase during monitoring. While the ambient air temperature hovered around 55°F, the concrete temperatures cooled gradually, with the side and top cooling much

Figure 2



TEMPERATURE DIFFERENTIALS
MS-1F
(FOOTING)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
*13
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED
DIMENSIONS: 87'x35'x7'
CEMENT TYPE: LAFARGE, I
MIX NO.: C-3-WR-C
DATE POURED: 3/7/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 3


TEMPERATURE VS. TIME
MS-1F
(FOOTING)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
*13
(Temp. during pour)
DIMENSIONS:
87'x35'x7'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
3/7/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

faster than the center. During the time the placement was being monitored, the temperature differentials never exceeded the 35°F specification; it is, however, difficult to tell whether they would have, since the differentials were still rising when monitoring ceased on the ninth day after the date of placement (Figures 4 and 5).

MS-1-2:

Location: Second lift of pier MS-1

Placement Date:	7/12/91	Mix Temperature:	81.8°F
Dimensions:	75'x12'x15'	Peak Temperature:	170.5°F
Ambient Temp.:	86.2°F	Temperature Gain:	88.7°F
Volume (cy):	425.0	Day Peak Reached:	Fourth
Ice (#/cy):	55.7	HRWR (oz/100# cement):	None

From Figures 6 and 7, the center to top differential exceeded the 35°F specification by a great deal (up to 15°F) for twelve days. The differential between center and side increased as well, but did not exceed the specification. Up to the fourteenth day after the day of placement, all three areas cooled at similar rates, with the center being the warmest, followed by the side, and finally the top. On the fourteenth day, however, when the next placement was placed, the center and side continued to cool at a similar rate, and even began to approach the same temperature, unaffected by the new placement. Due to the heat of the new placement, however, the top temperature jumped almost 23°F in two days, exceeding the center temperature. This warmer placement placed on top of MS-1-2 caused the center to top differential to decrease a great deal (to within the specification limits), even becoming negative as the top temperature became greater than the center temperature.

Figure 4

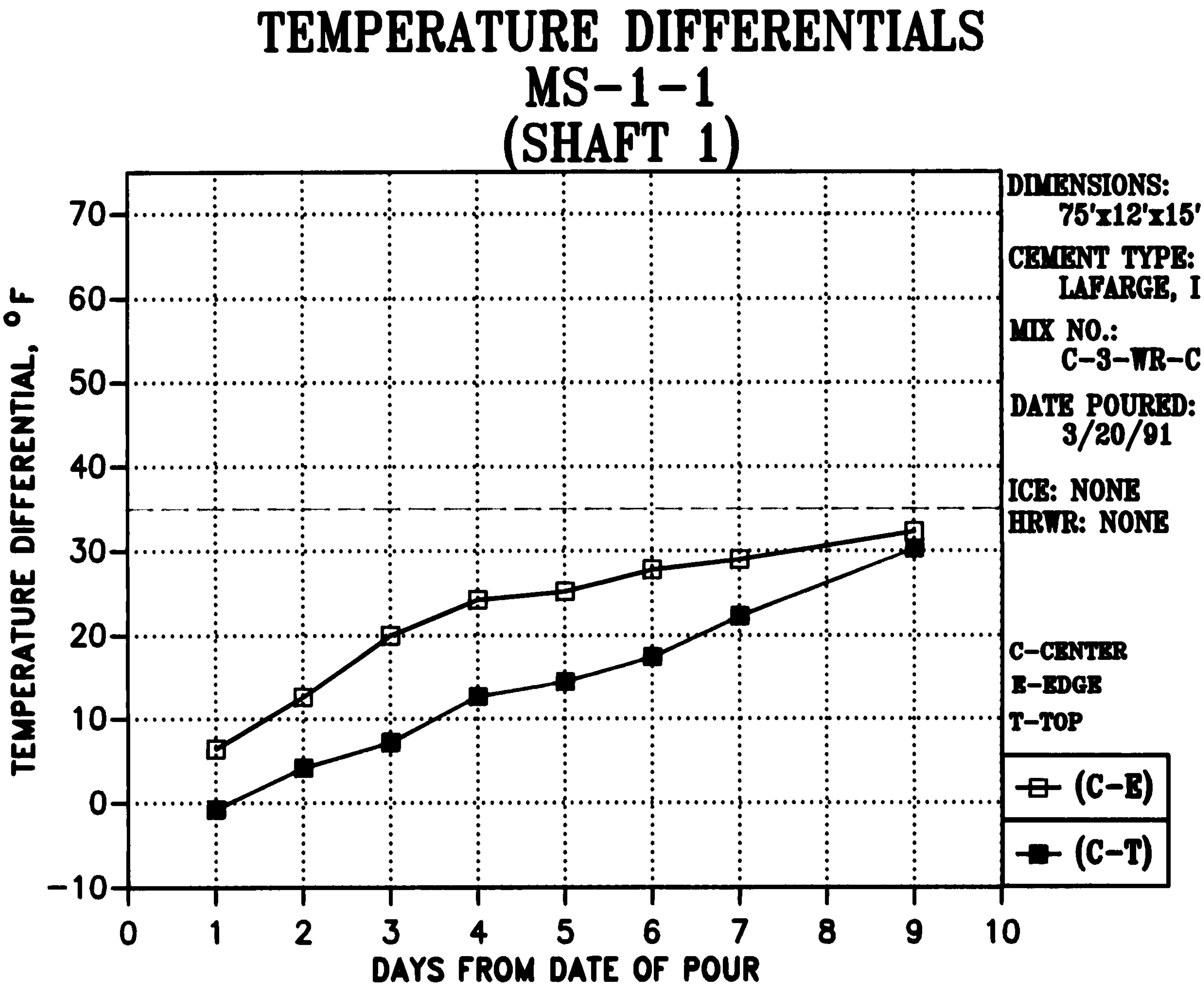

TEMPERATURE DIFFERENTIALS
MS-1-1
(SHAFT 1)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
10
DAYS FROM DATE OF POUR
DIMENSIONS:
75'x12'x15'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
3/20/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 5

TEMPERATURE VS. TIME
MS-1-1
(SHAFT 1)

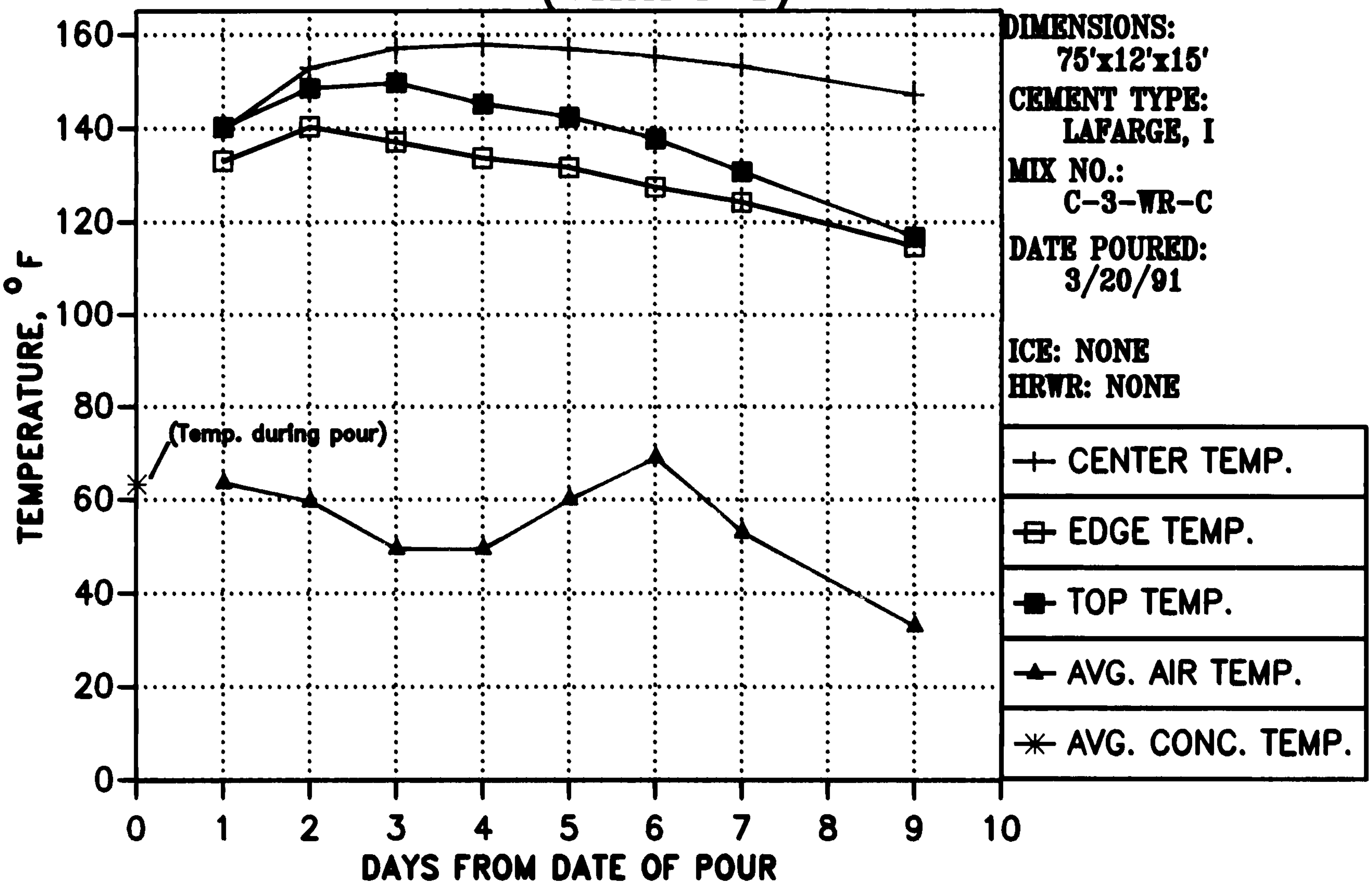
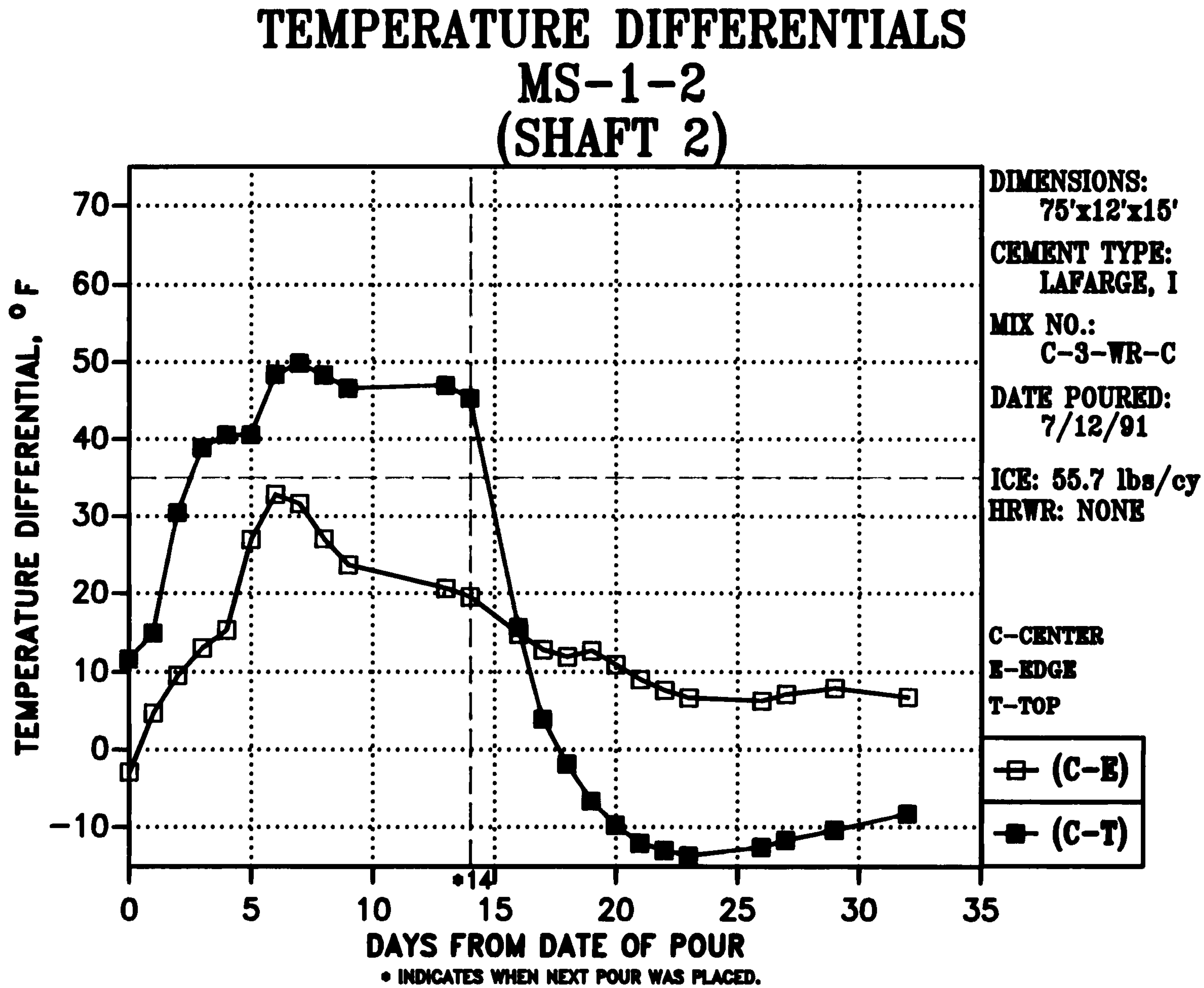
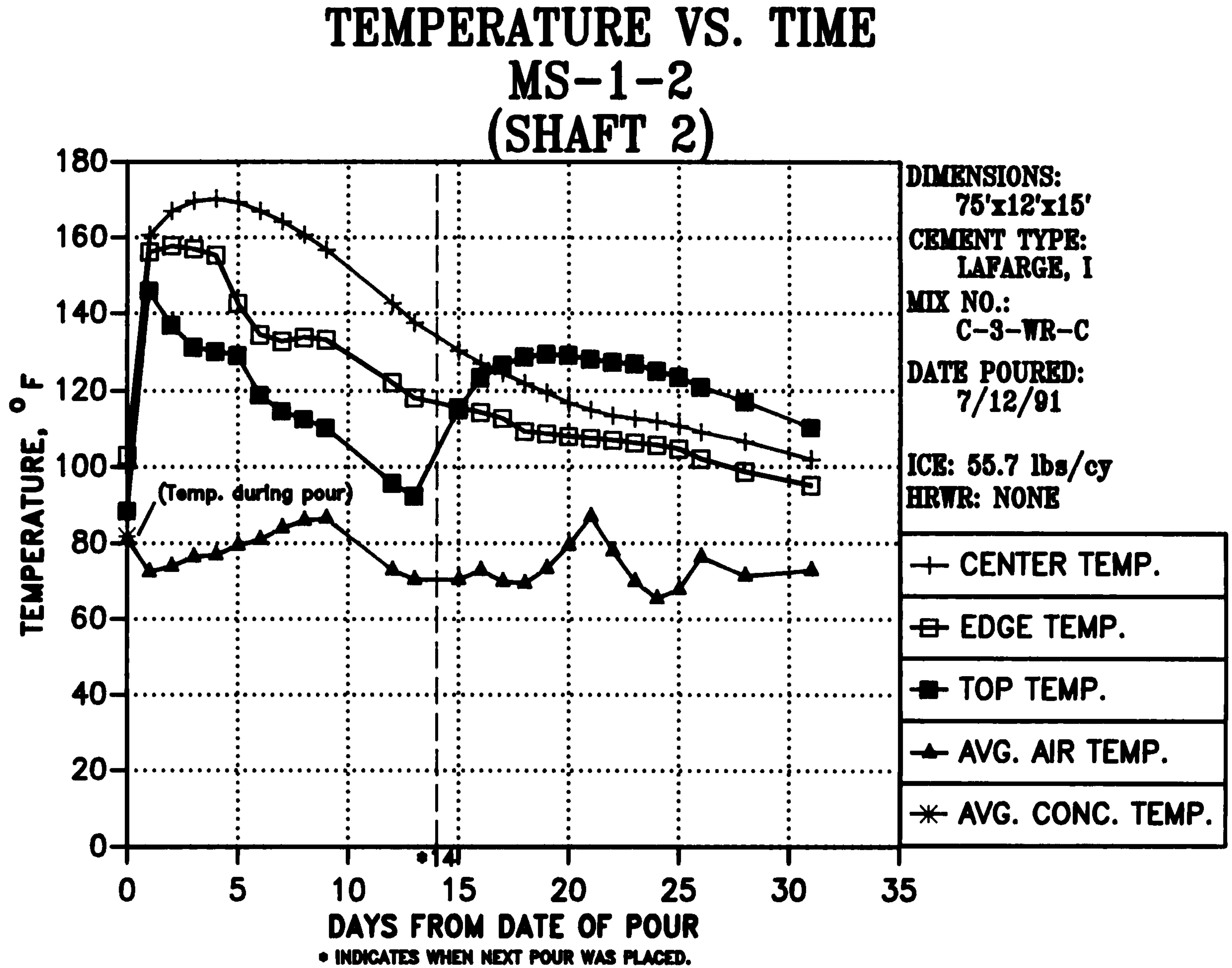


Figure 6



TEMPERATURE DIFFERENTIALS
MS-1-2
(SHAFT 2)
DIMENSIONS:
75'x12'x15'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
7/12/91
ICE: 55.7 lbs/cy
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
−10
*14
0
5
10
15
20
25
30
35
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 7



TEMPERATURE VS. TIME
MS-1-2
(SHAFT 2)
DIMENSIONS:
75'x12'x15'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
7/12/91
ICE: 55.7 lbs/cy
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
*14
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

MS-1-3:

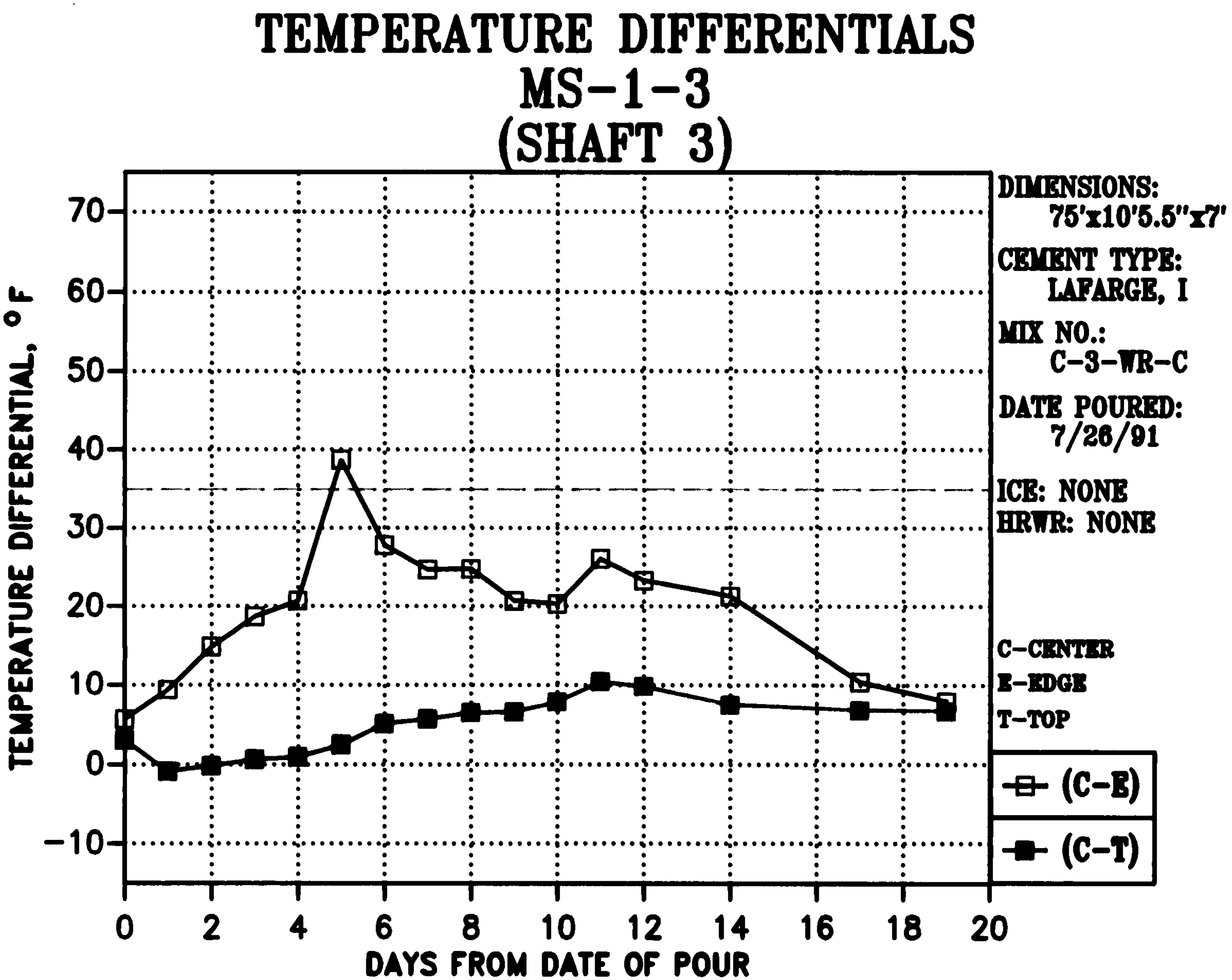
Location: Third lift of pier MS-1			
Placement Date:	7/26/91	Mix Temperature:	82.8°F
Dimensions:	75'x10'5.5"x7'	Peak Temperature:	167.3°F
Ambient Temp.:	75.5°F	Temperature Gain:	84.5°F
Volume (cy):	193.0	Day Peak Reached:	Fourth
Ice (#/cy):	None	HRWR (oz/100# cement):	None

The center to top differential was essentially the same and stayed constant during monitoring. It never exceeded the 35°F specification limit. The center to side differential increased during the monitoring period, and exceeded 35°F on day five when the side temperature dropped 22°F in a twenty-four hour period. It is not known why the side temperature suddenly dropped: the ambient temperature was increasing at that time, and the other areas were cooling at the same rate. Perhaps the insulation became dislodged, or other climatic conditions encouraged rapid cooling, such as a pump failure causing temporary flooding of the cofferdam. The next day, however, the side temperature increased and resumed its previous cooling course, and the center to side differential decreased a great deal, approaching the center to top differential. Another placement was placed on the twentieth day, but its effects cannot be determined, since monitoring was stopped before then (Figures 8 and 9).

MS-1-4:

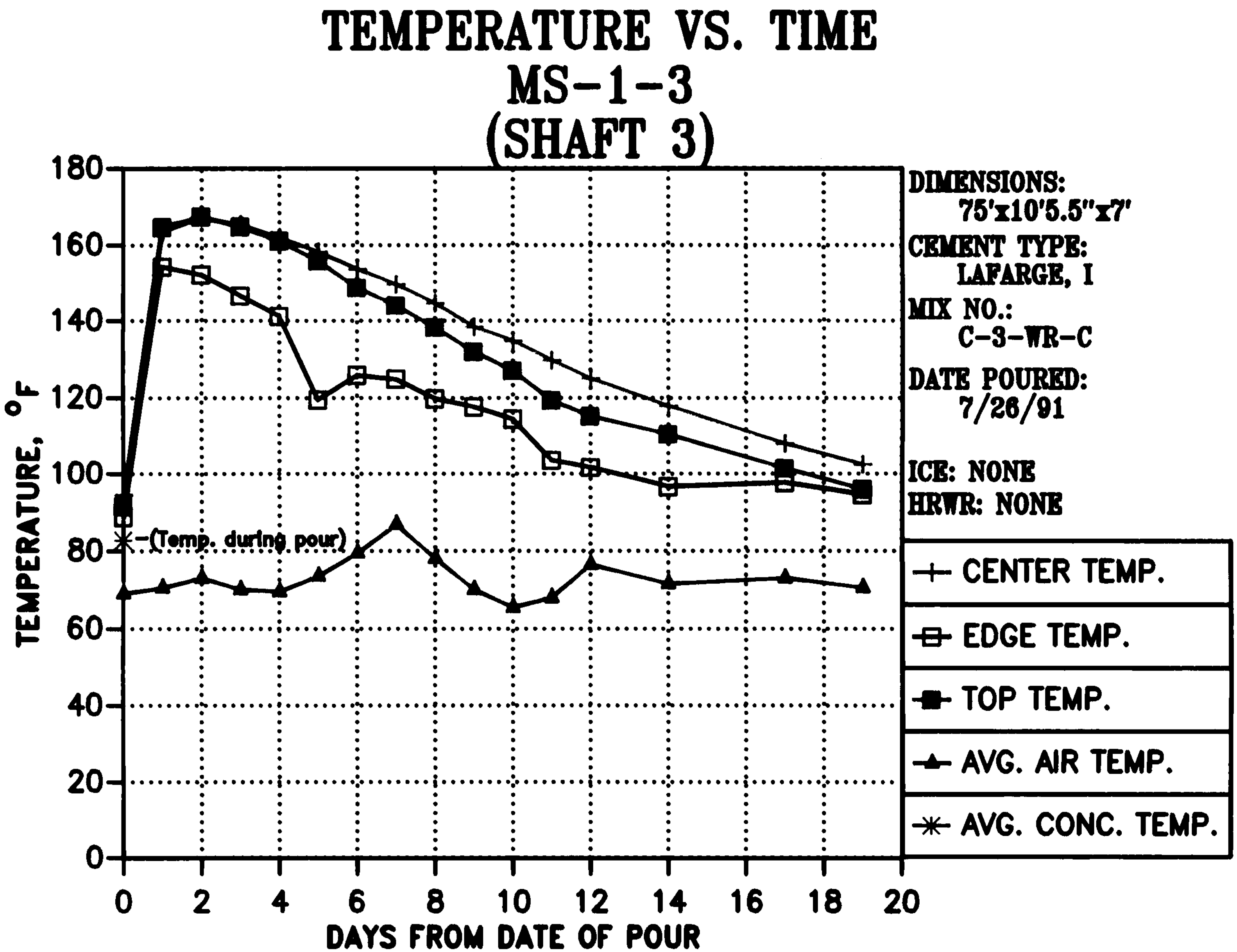
Location: South column of pier MS-1			
Placement Date:	8/15/91	Mix Temperature:	61.0°F
Dimensions:	16'9.5"x10'x22'11"	Peak Temperature:	166.6°F
Ambient Temp.:	74.5°F	Temperature Gain:	105.6°F
Volume (cy):	127.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	None

Figure 8


TEMPERATURE DIFFERENTIALS
MS-1-3
(SHAFT 3)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16
18
20
DAYS FROM DATE OF POUR
DIMENSIONS:
75'x10'5.5"x7'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
7/26/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

17

Figure 9


TEMPERATURE VS. TIME
MS-1-3
(SHAFT 3)
TEMPERATURE, °F
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
DAYS FROM DATE OF POUR
—(Temp. during pour)
DIMENSIONS:
75'x10'5.5"x7'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
7/26/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

While all three areas cooled at the same rate, the side was always the coolest and the center the warmest. After day eleven, the cooling rate for the side slowed slightly, so its temperature approached the top temperature, and therefore, the differentials approached one another. On the ninth day, another placement was placed 39 feet away from MS-1-4, but it did not appear to have any effects on the concrete temperature. On the eighteenth day, the next placement was placed on top of MS-1-4, which caused a slight temperature increase in all three areas (Figures 10 and 11). The specified limit was never exceeded.

MS-1-5:

Location: North column of pier MS-1

Placement Date:	8/24/91	Mix Temperature:	84.0°F
Dimensions:	16'9"x10'x22'11"	Peak Temperature:	173.1°F
Ambient Temp.:	87.0°F	Temperature Gain:	89.1°F
Volume (cy):	127.0	Day Peak Reached:	Fifth
Ice (#/cy):	None	HRWR (oz/100# cement):	None

Some problems did occur during this placement due to the temperature sensors. On the sixth day, the wire to the center malfunctioned and gave invalid readings. By the tenth day, though, the problem was resolved and the sensor produced accurate readings.

All three sensors indicated about the same temperatures for the first four days, and then the concrete began to cool, with the side cooling at the fastest rate, followed by the top, and then the center. The faster cooling rates of the side and top caused these differentials to increase substantially after the fourth day. After the next placement was placed on the ninth day, the temperatures continued to decrease at a steady rate, but slower than previously (1.2°F per day compared to 5.8°F per day). This next placement did not have much effect on the concrete temperatures, except to cause the temperatures and the cooling rates to essentially stagnate for four days. By the end of the monitoring period, the side and top temperatures neared one another again, practically coinciding (Figures 12 and 13). The specified limit was never exceeded.

MS-1C:

Location: Cap of pier MS-1

Placement Date:	10/2/91	Mix Temperature:	76.5°F
Dimensions:	93'x9'6"x9'	Peak Temperature:	184.2°F
Ambient Temp.:	76.5°F	Temperature Gain:	107.7°F
Volume (cy):	304.5	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	None

The peak reached on the second day was a large jump for the center, but the other two areas did not follow the same pattern. This sudden increase caused the differentials to increase substantially, from around 2°F on day one to around 25°F on day two. After the third day, the center and side cooled at the same rate, but the top cooled much more quickly. This occurred because the contractors were installing bearing pedestals during the day in order to meet construction deadlines, and the insulation was (most likely) not correctly replaced at night, so that the ambient temperatures (around 50°F) influenced the concrete on the top surface to a greater degree. The faster cooling rate of the top caused the differential between it and the center to increase dramatically, though it never exceeded the specified limit. When the ambient temperature increased slightly (after day six), the top's cooling rate slowed again, and the differential decreased (Figures 14 and 15).

Figure 10

TEMPERATURE DIFFERENTIALS MS-1-4 (SOUTH COLUMN)

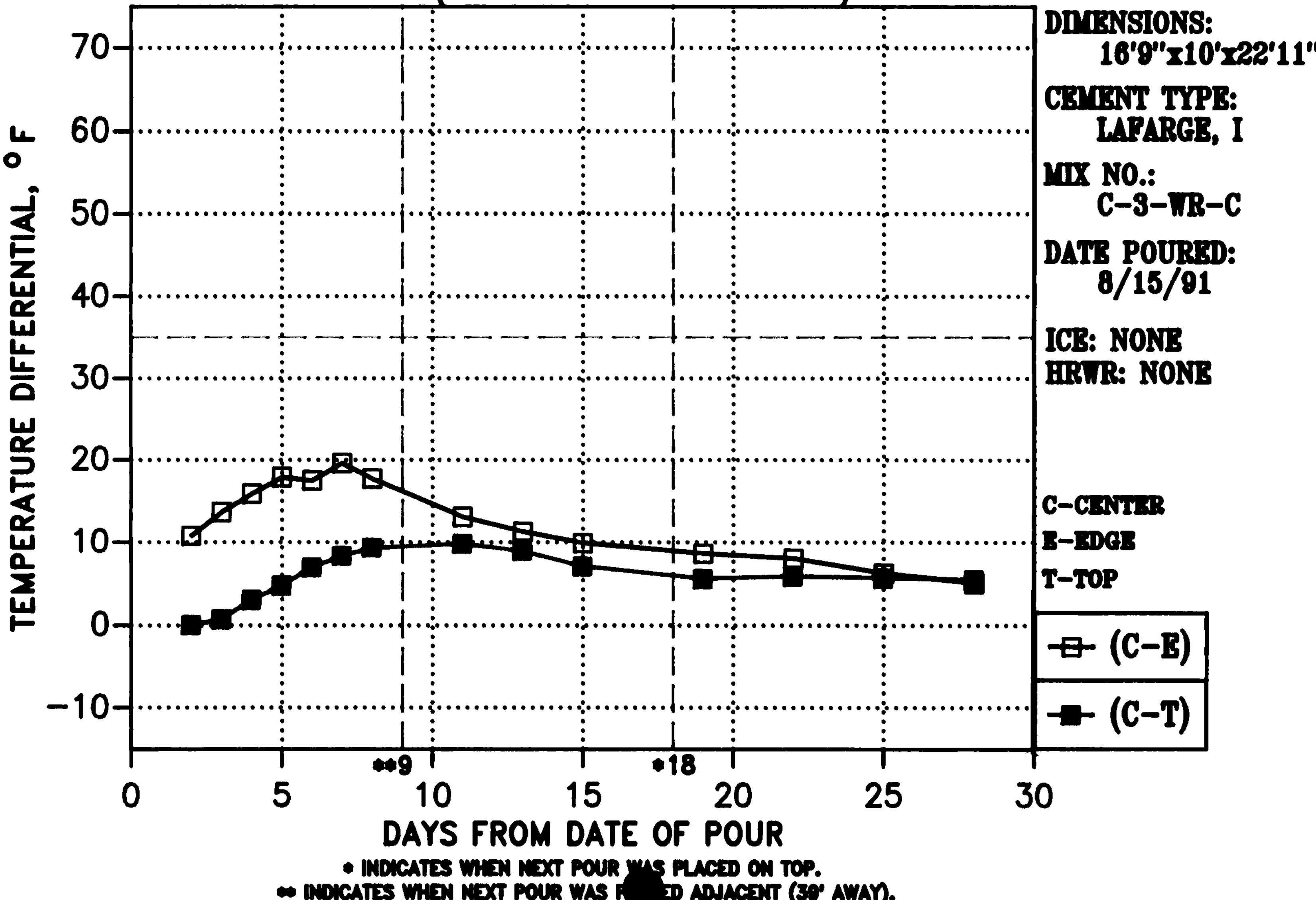


Figure 11

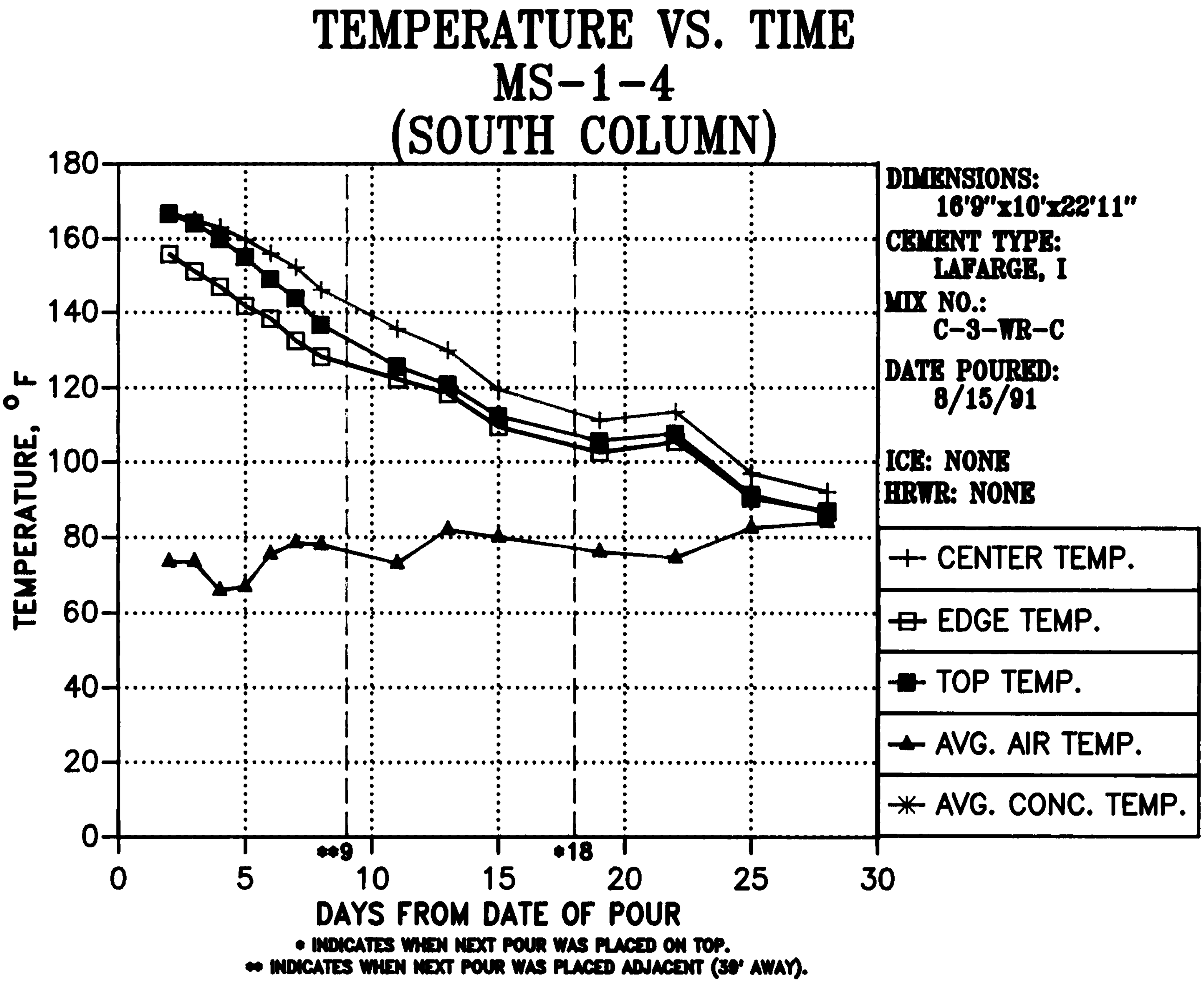
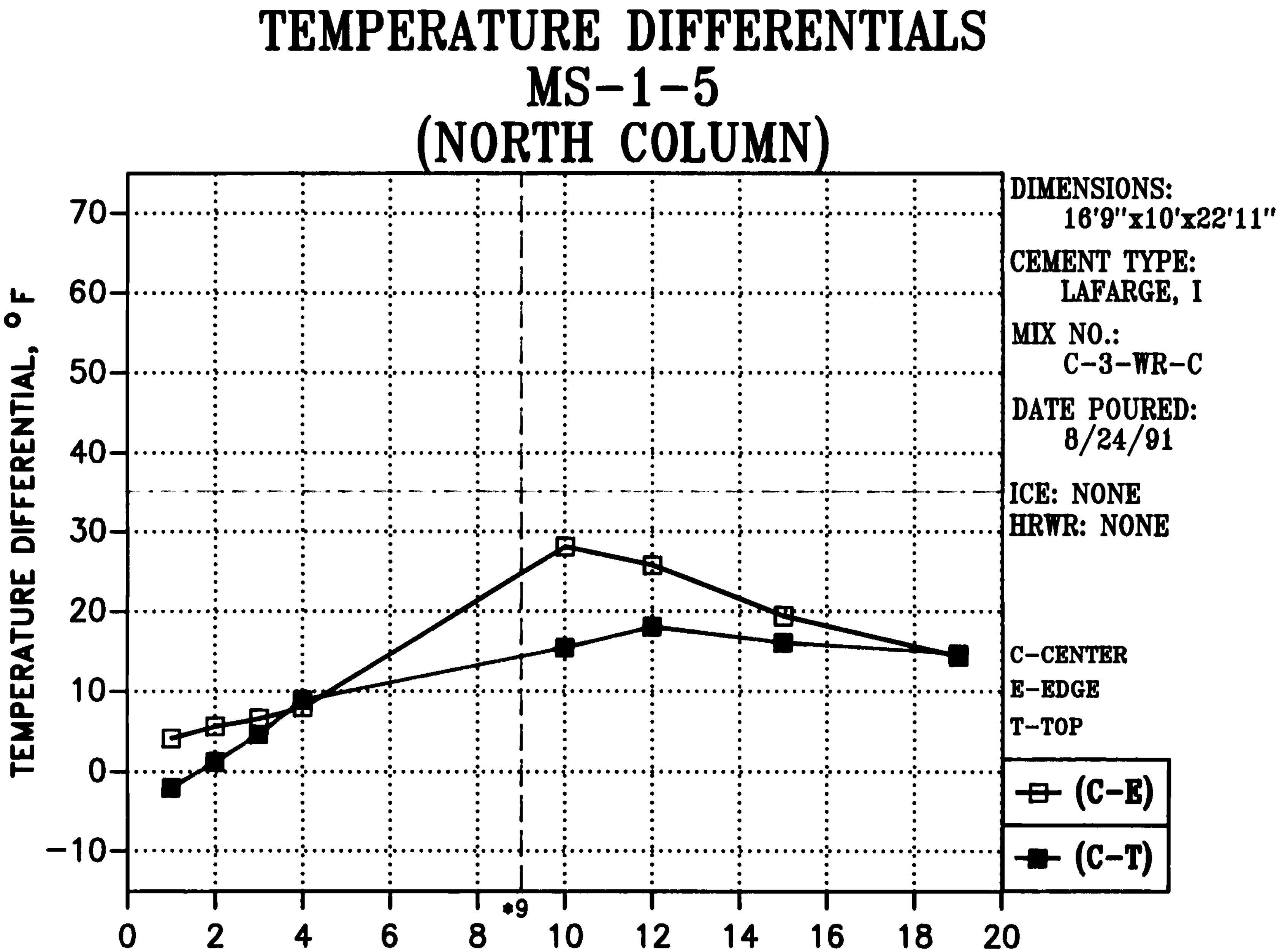
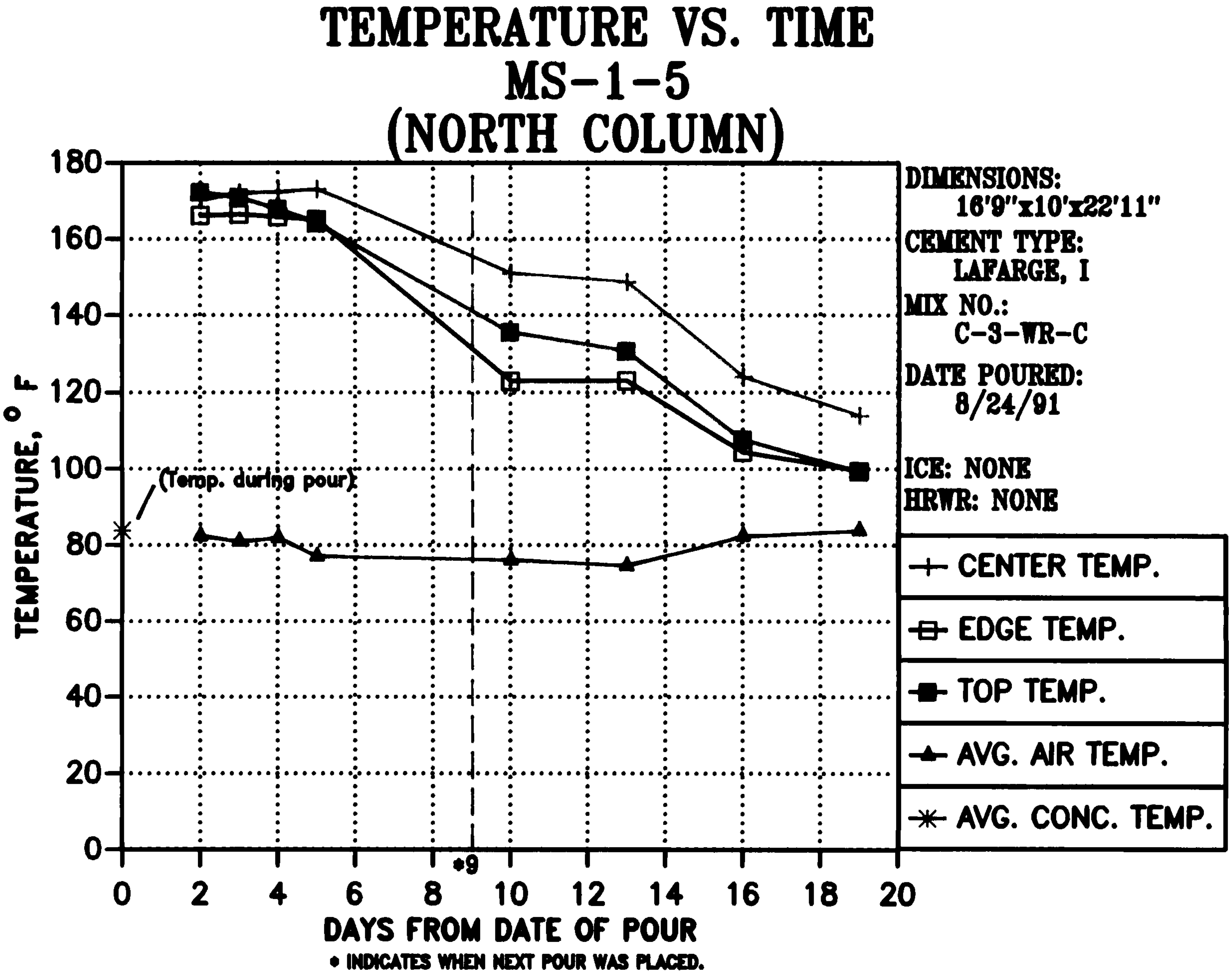

TEMPERATURE VS. TIME
MS-1-4
(SOUTH COLUMN)
TEMPERATURE, °F
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
**9
*18
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED ON TOP.
** INDICATES WHEN NEXT POUR WAS PLACED ADJACENT (30' AWAY).
DIMENSIONS:
16'9"x10'x22'11"
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
8/15/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

Figure 12



* INDICATES WHEN NEXT POU' 'AS PLACED.

Figure 13



TEMPERATURE VS. TIME
MS-1-5
(NORTH COLUMN)
180
160
140
120
100
80
60
40
20
0
TEMPERATURE, °F
(Temp. during pour)
0
2
4
6
8
*9
10
12
14
16
18
20
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
16'9"x10'x22'11"
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
8/24/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

Figure 14

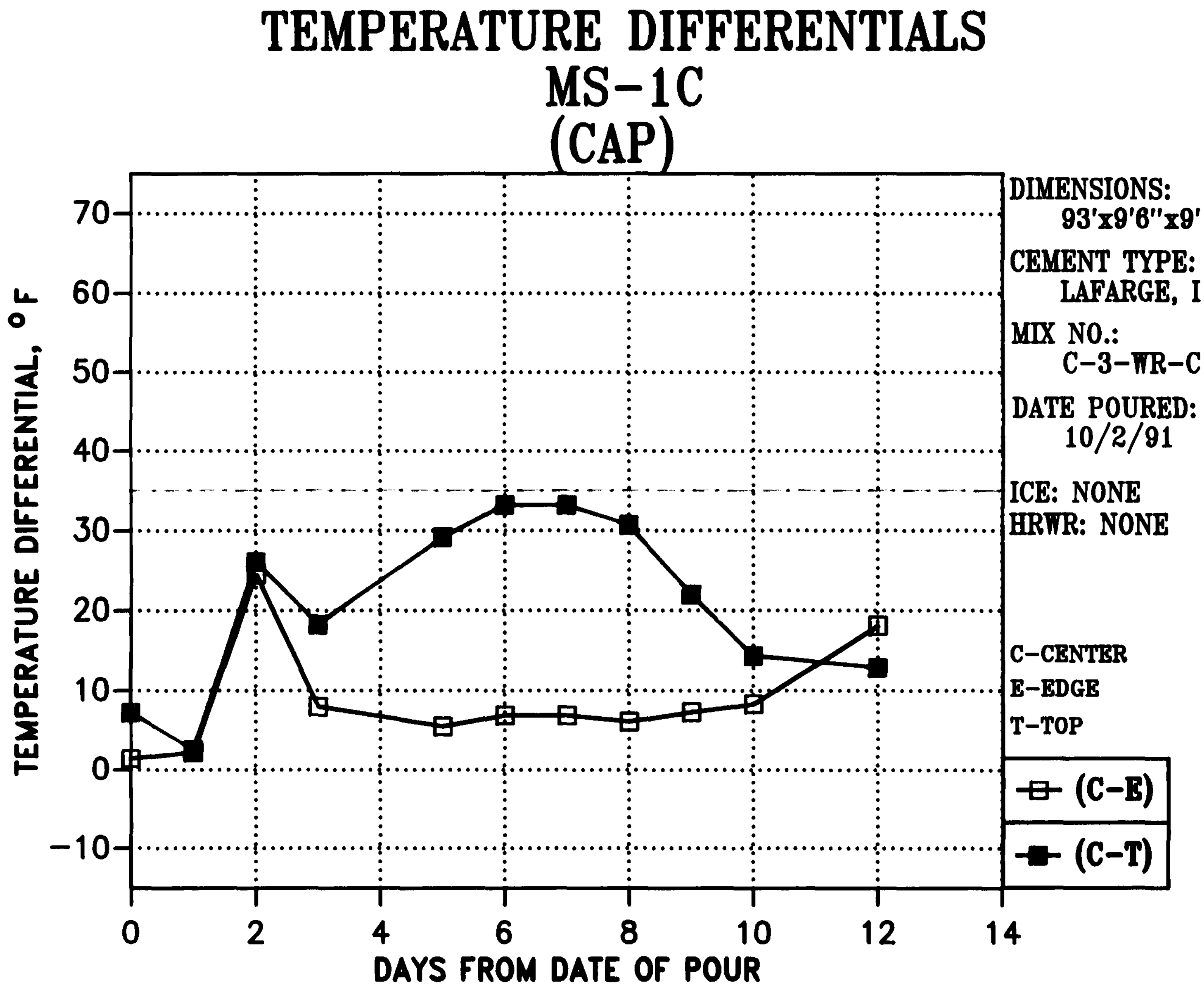
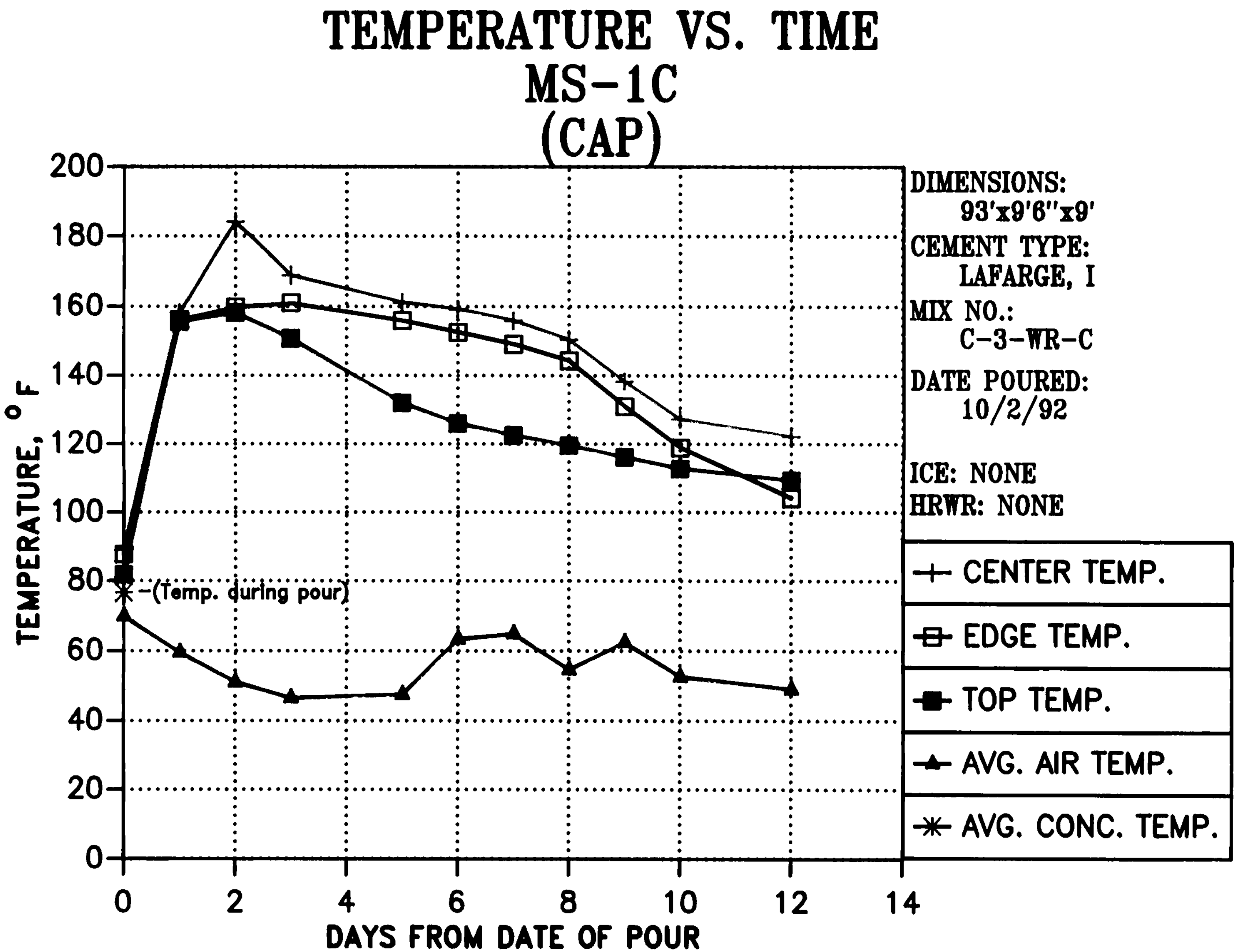

TEMPERATURE DIFFERENTIALS
MS-1C
(CAP)
DIMENSIONS: 93'x9'6"x9'
CEMENT TYPE: LAFARGE, I
MIX NO.: C-3-WR-C
DATE POURED: 10/2/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
DAYS FROM DATE OF POUR
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14

Figure 15


TEMPERATURE VS. TIME
MS-1C
(CAP)
200
180
160
140
120
100
80
60
40
20
0
TEMPERATURE, °F
-(Temp. during pour)
0
2
4
6
8
10
12
14
DAYS FROM DATE OF POUR
DIMENSIONS:
93'x9'6"x9'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
10/2/92
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

B. MS-2

MS-2 was the largest pier constructed on the bridge, requiring two contractors and 23 different placements to complete the substructure and the two towers. Many problems arose during the construction of MS-2, including: flooding, cracking, and sensor failures. In addition, different mix numbers, cement types, and amounts of ice and super-plasticizer were used in the twenty-three different placements. Numerous faults were found in the substructure of pier MS-2 (i.e., pours MS-2F through MS-2-3), ranging from hairline cracks to cracks that extended the full length of a shaft pour, to honeycombing and cold joints. Sketches and photos of the cracks and honeycombing found in the substructure may be found in Appendix E. Since the pylons constructed were hollow, the heat of hydration did not pose as much as a threat, and cracking was reduced. Several cracks were found in the struts and in the pylons of the superstructure, but they were all hairline, ranging in width from 0.001 inch to 0.01 inch.

MS-2F:

Location: Footing of pier MS-2

Placement Date:	6/1/90	Mix Temperature:	77.6°F
Dimensions:	155'x43'6"x7'6"	Peak Temperature:	156.5°F
Ambient Temp.:	79.6°F	Temperature Gain:	78.9°F
Volume (cy):	2002.0	Day Peak Reached:	Third
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	LaFarge Type I	Concrete Mix:	C-3WR-C

Sensor readings were taken continuously for the first ten days after the initial placement, and then a forty-four day gap occurred where no temperature readings were taken. For these first ten days of monitoring, the concrete temperatures were disparate and fluctuated quite a bit. Since the center remained at a much higher temperature than the other two areas, the differentials for this period of time were rather large, and exceeded the 35°F specification for the center to side. The center to top differential exceeded the specified limit for the first three days, but as the top temperature increased and reached its peak, and the center cooled, this differential decreased a great deal, and dropped below the 35°F specification. The center to side differential remained above the specified limit from approximately day three through day twenty.

Many problems occurred during this placement: the cofferdam was flooded temporarily on June 9 (day 8) when a pump failed, and substantial cracking occurred. On June 10, two pumps were found not operating, probably due to a short which tripped the circuit breaker. Also, the loss of temperature data may have been caused by premature battery failure in the data logger. The water temperature when the pump failed was 66°F, with an interior concrete temperature of 136°F, and a surface concrete temperature of 101°F. After the cofferdam was dewatered, the temperatures were 130°F and 88°F, respectively, on June 11 (day 10). It is possible that the great heat loss on the outside surface (13°F) compared to the interior of the concrete (6°F) caused the cracking, due to the large thermal gradient that existed. The cracks in the footing ranged in width from about 1/16" to about ⅛" and did extend down the sides at least 2 feet (the rest of the footing was not visible). Most cracks occurred on the edges and extended into the footing anywhere from 2 to 8 feet. Only one crack was positioned near the center of the footing, and it was not very long. These cracks in the footing proved to be wider than those that occurred in subsequent pours.

On the fifty-second day after the initial placement, the next placement was placed on top of MS-2F, and sensor readings resumed on day fifty-five. By this time, the center and side had cooled significantly, with the side following the ambient air temperature closely, and the center showing the most dramatic drop in temperature. The top temperature, however, increased slightly, and even exceeded the center temperature, due to the warmer placement being placed there. After the placement had been placed, all three temperatures increased to varying degrees. The side rose very slightly, the center increased by almost 20°F, and the top rose about 10°F; subsequently, they cooled again over the last four days. This change in temperatures in turn caused the temperature differentials to decrease. The center to side differential dropped to about 10°F, but then increased again. The center to top differential decreased a great deal, since the top had a higher temperature, and the center's temperature decreased so dramatically; but by the end of monitoring the differential had increased again (still remaining negative) (Figures 16 and 17).

MS-2-1:

Location: First lift of pier MS-2

Placement Date:	7/23-24/90	Mix Temperature:	70.0°F
Dimensions:	148'x24'x15'	Peak Temperature:	150.0°F
Ambient Temp.:	81.0°F	Temperature Gain:	80.0°F
Volume (cy):	1623.0	Day Peak Reached:	Seventh
Ice (#/cy):	114	HRWR (oz/100# cement):	None
Cement:	Lone Star Cape Girardeau, Type II		
Concrete Mix:	C-3WR-C		

Figure 16

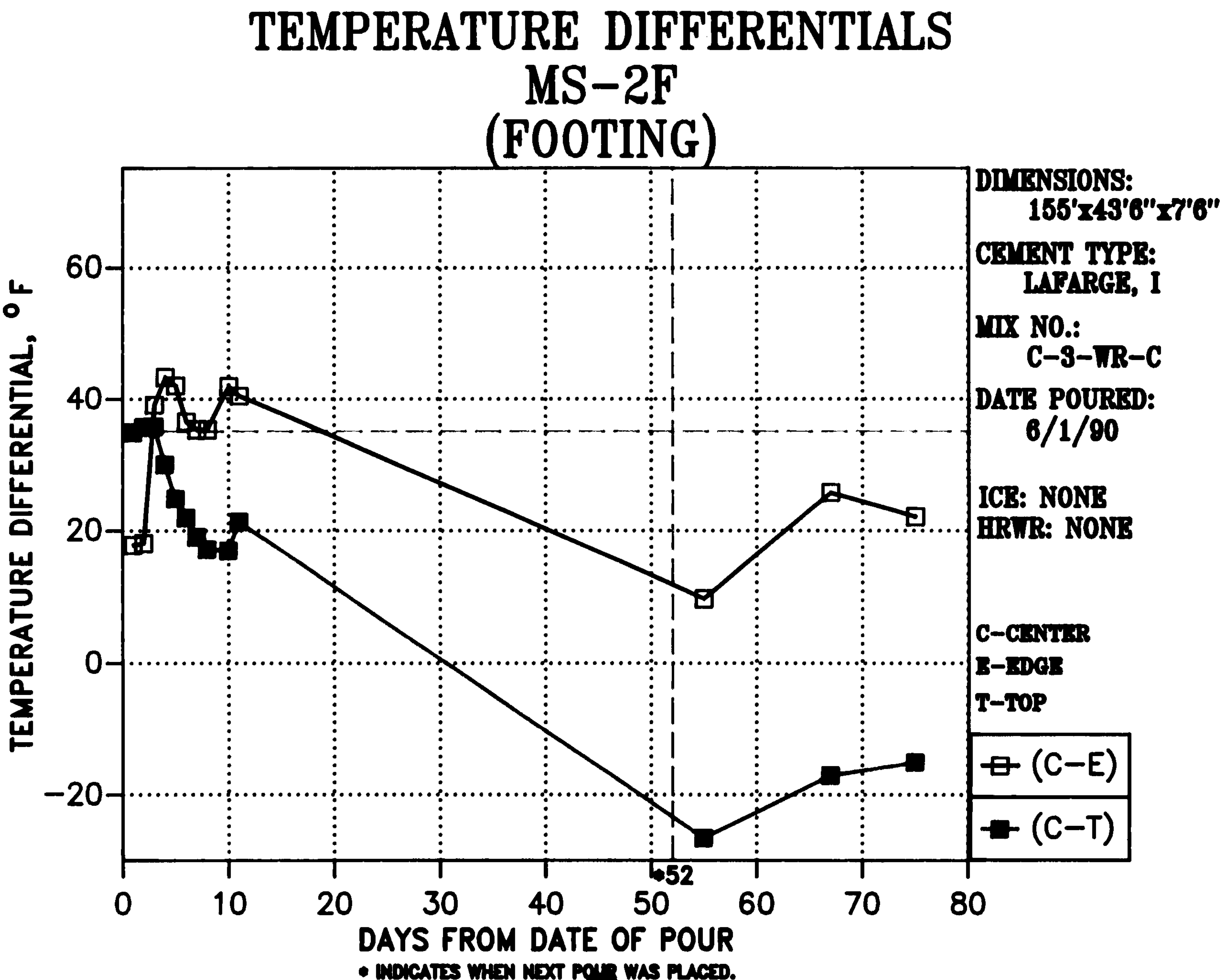
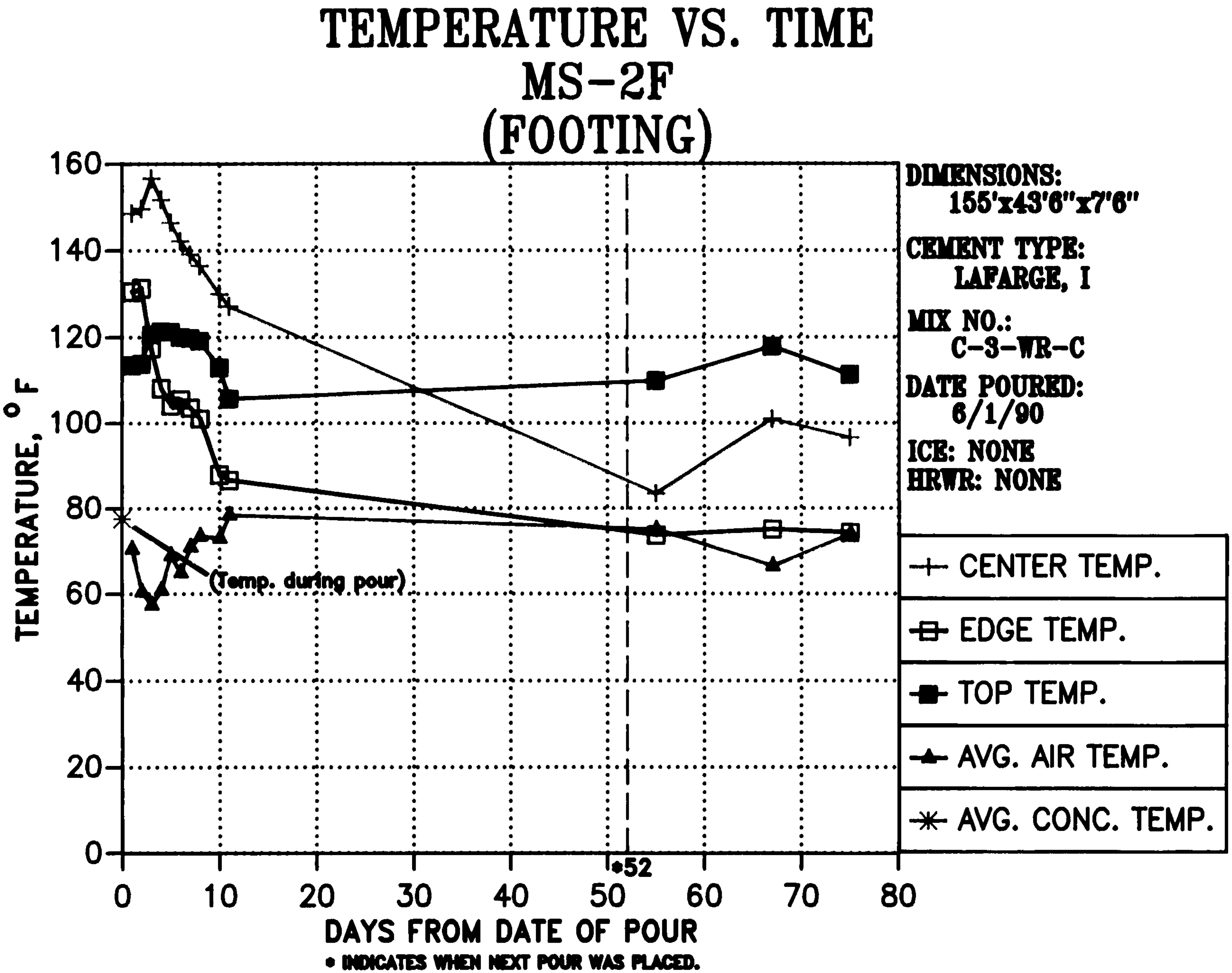

TEMPERATURE DIFFERENTIALS
MS-2F
(FOOTING)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
0
10
20
30
40
50
60
70
80
•52
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
155'x43'6"x7'6"
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
6/1/90
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 17

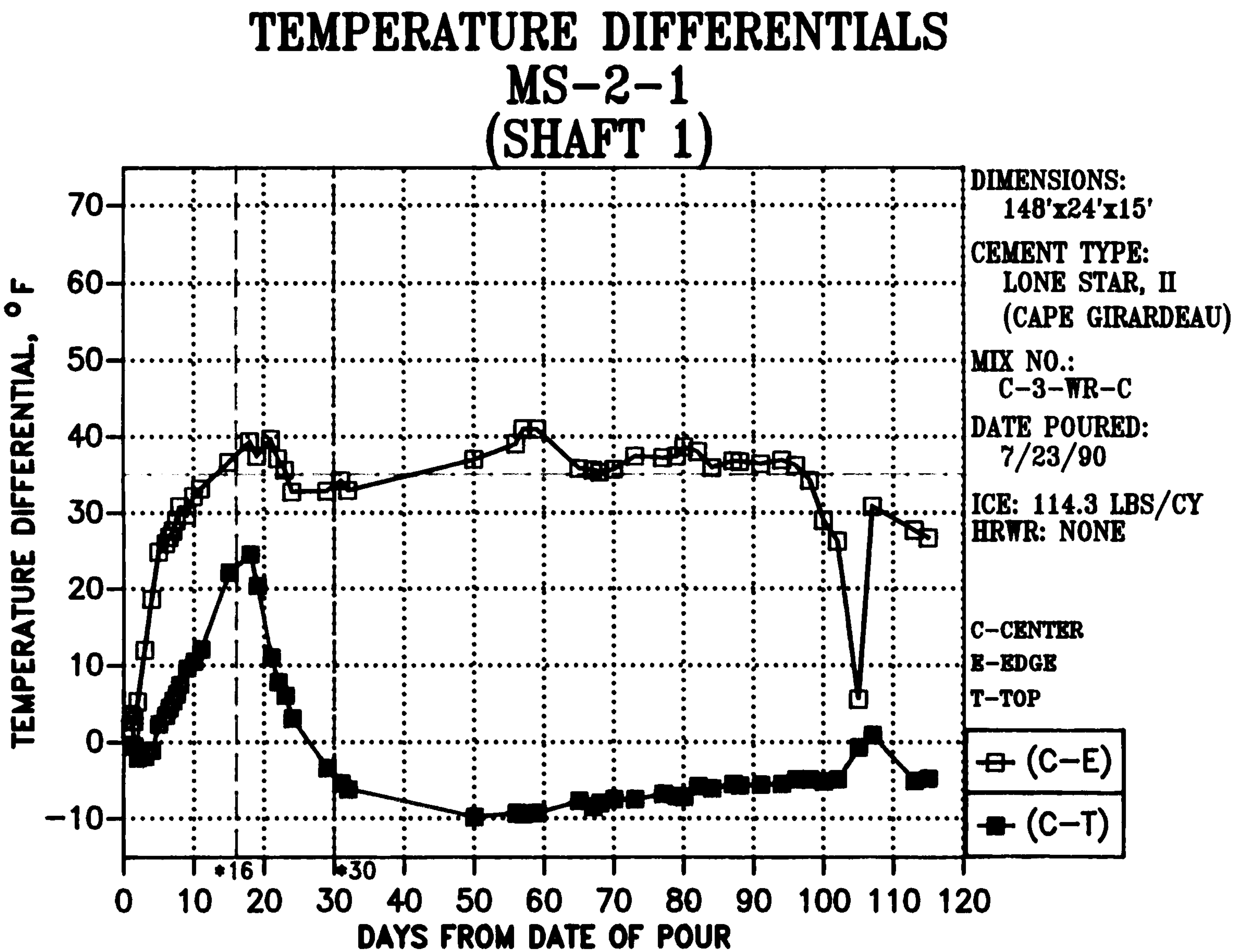

TEMPERATURE VS. TIME
MS-2F
(FOOTING)
160
140
120
100
80
60
40
20
0
TEMPERATURE, °F
0
10
20
30
40
50
60
70
80
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT POUR WAS PLACED.
•52
(Temp. during pour)
DIMENSIONS:
155'x43'6"x7'6"
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
6/1/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

The indicated temperatures in this placement were different than expected, and fluctuated quite a bit. While the top and center temperatures both increased dramatically and stayed close together, the side temperature did not. It seemed to be influenced by the ambient air temperatures, especially at the end of monitoring, when the ambient temperature shot up suddenly, and then, a few days later, the side temperature increased in the same manner. The low side temperatures caused the center to side differential to exceed the 35°F specification for almost the whole monitoring period, with a few exceptions at the very beginning and at the end. On the sixteenth day after the initial placement date, the next placement was placed on top of MS-2-1. While it had little effect on the side temperature, it did cause the center to cool more slowly (0.9°F per day before the placement, compared to 0.4°F per day after), and the top to increase almost twenty degrees. These temperature fluctuations caused the differentials to change also: the center to side dropped below the 35°F limit for a short while, and the center to top differential dropped dramatically, going from 25°F to below zero. Towards the end of the monitoring period, the center to side differential decreased sharply as the side temperature increased to approach the ambient air temperature. Afterwards, the center to side differential remained below the specification limit. Another placement was placed on day thirty, but it had little effect on any of the temperatures, except to increase the top temperature slightly.

It is important to note that the cofferdam was flooded from August 28 to September 6 (days 34-43); the water temperature at that time was 78°F. During this period, the center to side differential increased, and the center to top differential decreased. Since flooding would have the greatest cooling effect on the side temperature and less on the center or top temperatures (especially since the next two placements had been placed by this time), one can conclude that the center to side differential increased because the insulation was lost on the sides of the placement, and that the center to top differential decreased because the top was being heated by the subsequent placements. The center continued to cool at an unaffected rate. The Figures (18 and 19) support this theory: the center lost 10.7°F, the side lost 14.8°F, and the top lost 7.1°F. This accounted for an 8.3% loss in the center temperature, a 15.4% loss in the side temperature, and a mere 5.2% loss in the top temperature. Another reason why the side temperature was so influenced by the ambient temperature is that the insulation was not replaced on the side after the flooding.

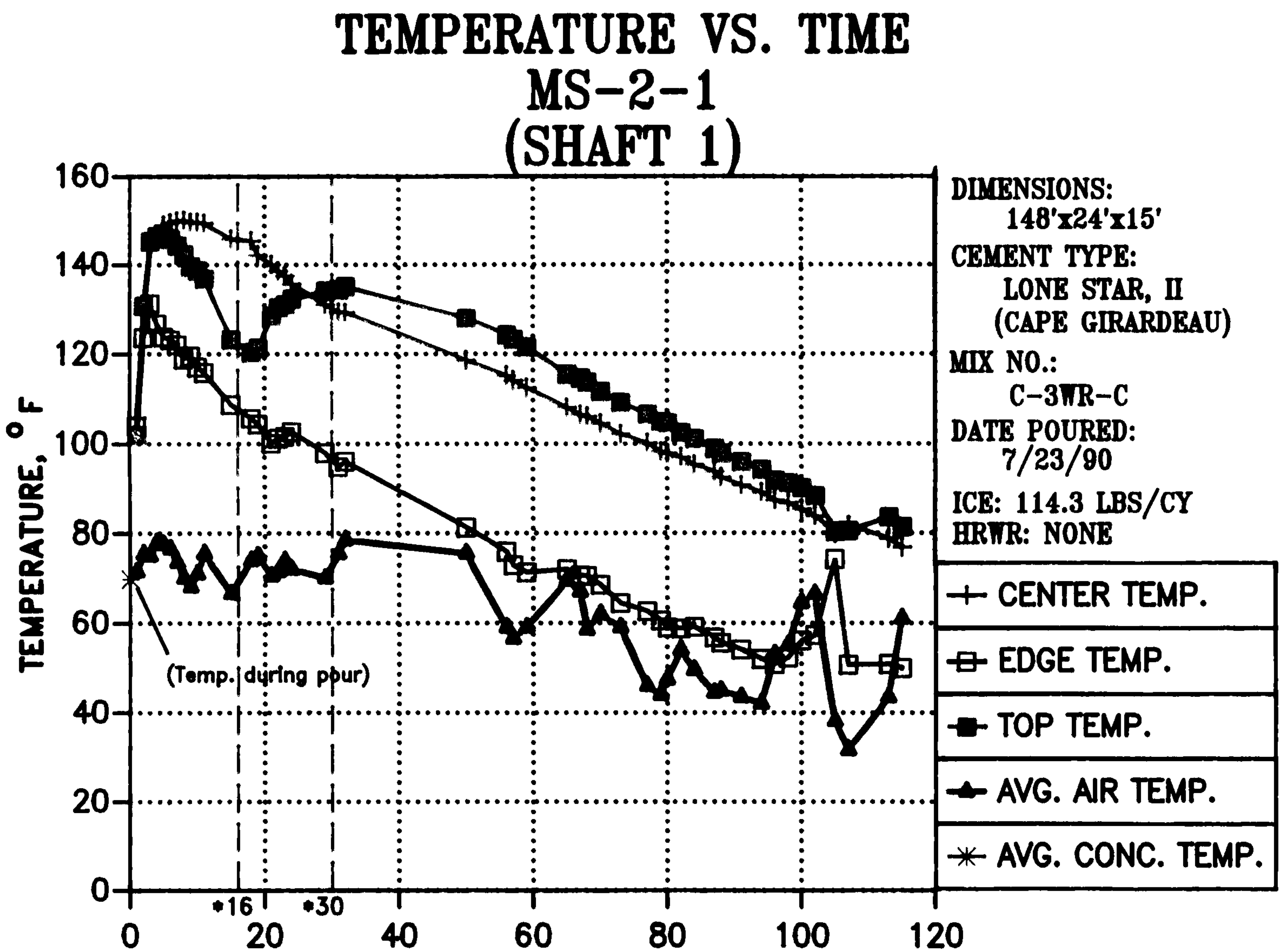
Cracking was also a problem in this placement. In general, the cracks were vertical and extended from the top to the bottom of the individual lifts. They were narrow and did not, except for a few instances, line up from one lift to the other. It was estimated that about six to ten cracks were visible on each side of the lift. Prior to the flooding on August 28, project personnel did observe about ten cracks on each side of the lift above

Figure 18



* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: Cofferdam flooded 8/28 - 9/6 (Days 34-43)

Figure 19



* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: Cofferdam flooded 8/28 – 9/6 (Days 34–43)

elevation 496±. The contractor did not place the insulating styrofoam sheets between the bottom of the forms (elev. 499) and this elevation, so that this 3 foot area was exposed to the elements. It is possible that cooling of this uninsulated area could have caused the cracks in MS-2-1. It is unknown whether the other cracks existed prior to the flooding of the cofferdam, and it is possible that they were indeed caused by the flooding. There were differences of opinion regarding whether the insulation should be put back in place. Some thought that if too large a thermal difference occurred between the first and second lifts, additional cracks (or widening of those that already existed) might occur in MS-2-1 due to the restraint provided by the higher temperature of the next placement. Others thought that reinsulation would raise the temperature of the exterior surfaces and reduce the overall rate of cooling of the mass, causing cooling to extend well into the winter. If so, and another pump failure occurred with 32°F water, the consequences could be worse. It was finally decided not to replace the insulation on this shaft, since the general opinion held that the concrete had already cracked and was to be sealed, so there was no need for more insulation.

In addition to the cracking, honeycombing and cold joints were noticed in MS-2-1. These were believed to be caused by inadequate vibration of the concrete during the placement and a low rate of concrete placement. It seems that the contractor had a tendency not to vibrate the leading side or toe of the individual layers (so the concrete would not "run"). The low placement rate necessitated having to build-up the concrete on one end of the lift before depositing any on the other end. The placement was essentially in a "hopscotch" pattern, jumping back and forth in order to prevent a cold joint. To try to reduce the honeycombing and cold joints, the contractor tried smaller lifts. To repair the honeycombing and cold joints that were larger than 3/4 inch, the contractor had to remove the bad spots and fill the holes with a 50/50 sand-cement grout.

MS-2-2:

Location: Second lift of pier MS-2

Placement Date:	8/8-9/90	Mix Temperature:	66.0°F
Dimensions:	148'x24'x15'	Peak Temperature:	149.3°F
Ambient Temp.:	57.3°F	Temperature Gain:	83.3°F
Volume (cy):	1568.0	Day Peak Reached:	Sixth
Ice (#/cy):	Yes	HRWR (oz/100# cement):	None
Cement:	Lone Star Cape Girardeau, Type II		
Concrete Mix:	C-3WR-C		

Two special events occurred during this placement which had a drastic effect on the concrete temperature: 1) the cofferdam flooded from August 28 to September 6 with 78°F water; and 2) another placement was placed on top of MS-2-2 on day 14. For the first 15 days after the placement, the temperatures were as expected: the center was much warmer than the side or top, and the temperature differentials kept increasing as the side and top cooled faster than the center. The center to top differential exceeded the 35°F limit slightly on the fourteenth day, with a 35.3°F differential. The next placement was placed on day fourteen, and the cofferdam flooded on day eighteen. These separate circumstances caused the top temperature to rise, and even surpass the center, and caused the side temperature to drop as the water surrounded it. After the cofferdam was dewatered, the center temperature had decreased by 10.2°F (7.1%), the top temperature had increased by 20.6°F (by 17.3%) (surpassing the center temperature), and the side had cooled by 32.3°F (28.9%). When the cofferdam was flooded, the insulation was completely washed away on the sides of the placement and never replaced, so that the side temperature followed the ambient temperature fluctuations very closely. The top temperature remained above the center temperature for the rest of the monitoring period. These temperatures caused the center to top differential to decrease dramatically, remaining below zero for the remainder of monitoring, and the center to side differential to increase sharply. In fact, the center to side differential exceeded the 35°F differential limit for a period of about forty-eight days, reaching a maximum of about 55°F (Figures 20 and 21).

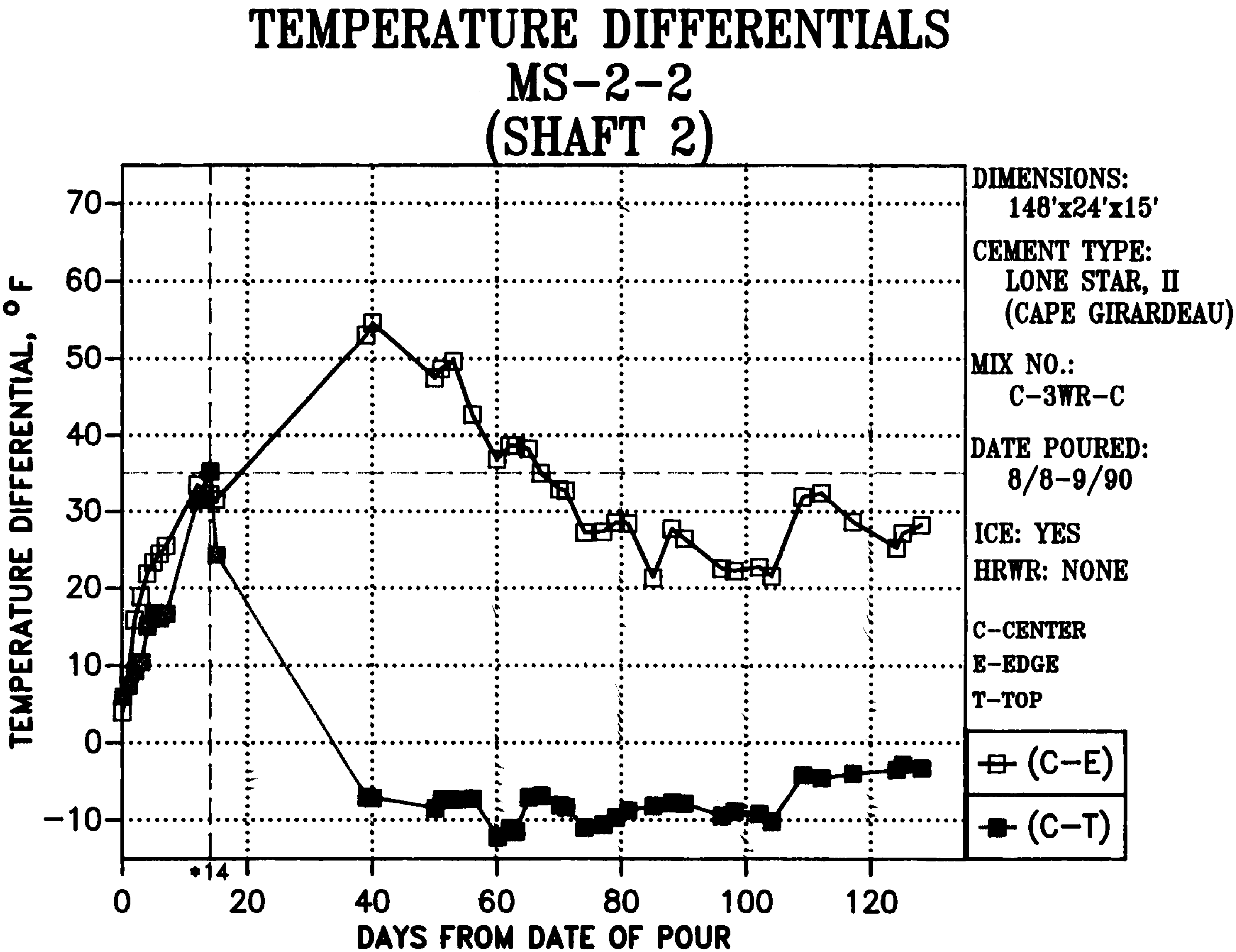
Cracking, cold joints, and honeycombing again constituted problems in this placement, for the same reasons as those mentioned previously for placement MS-2-1. (The same types of cracking were found.)

MS-2-3:

Location:	Third lift of pier MS-2		
Placement Date:	8/22-23/90	Mix Temperature:	65.0°F
Dimensions:	148'x24'x16'	Peak Temperature:	155.5°F
Ambient Temp.:	75.0°F	Temperature Gain:	90.5°F
Volume (cy):	1687.0	Day Peak Reached:	Fourth
Ice (#/cy):	114	HRWR (oz/100# cement):	None
Cement:	Lone Star Cape Girardeau, Type II		
Concrete Mix:	C-3WR-C		

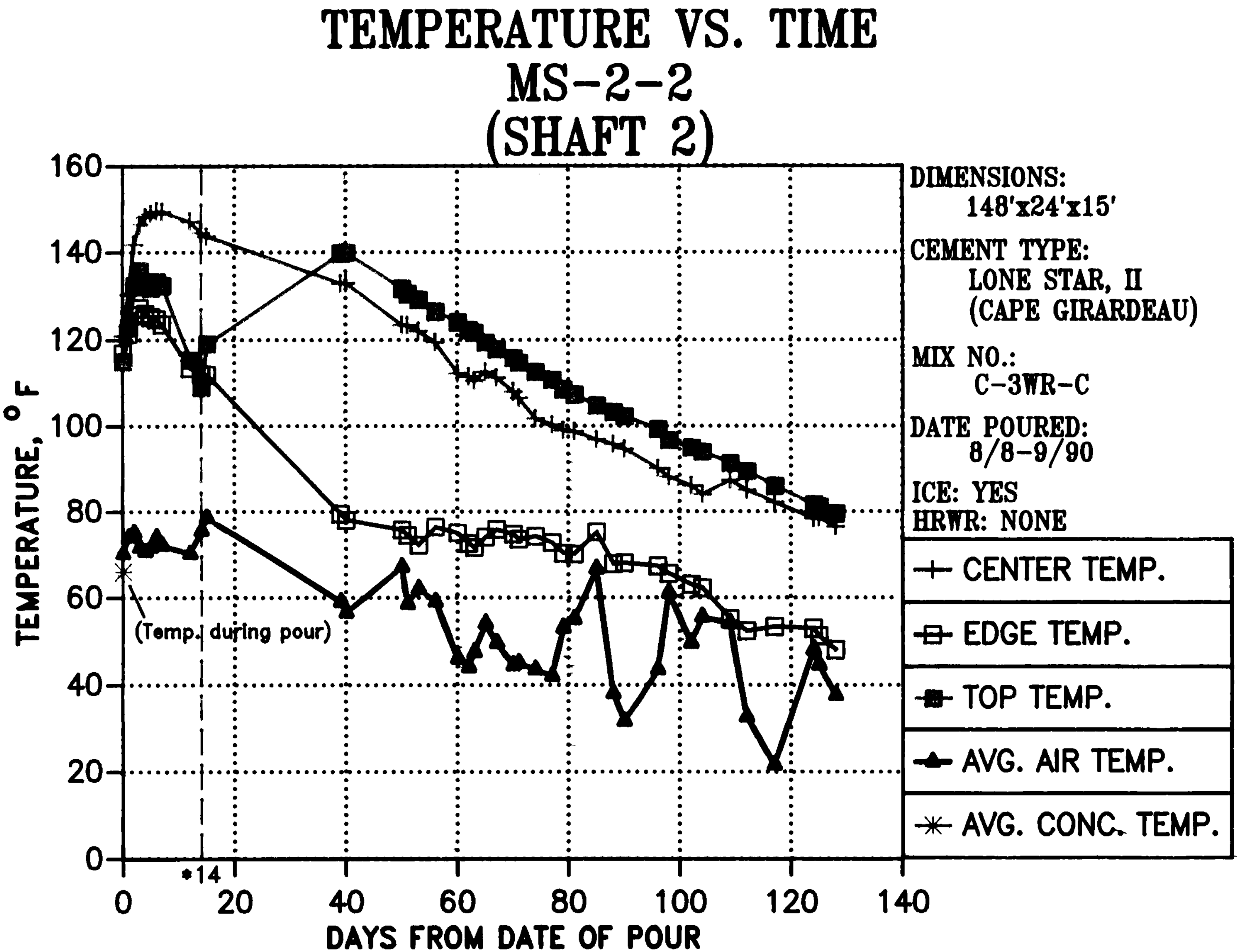
As was previously stated, the cofferdam was flooded from August 28 to September 6, and the insulation was completely washed away from the concrete. This flooding caused the side temperature

Figure 20



* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: Cofferdam flooded 8/28-9/6 (Day 21-30)(Insulation not replaced)

Figure 21



* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: Cofferdam flooded 8/28–9/6 (Day 21–30)(Insulation not replaced).

to drop dramatically (by 22%, or 30.8°F), whereas the top temperature only decreased slightly (by 6%, or 8.4°F); the center temperature actually increased by 1°F. Both temperature differentials exceeded the 35°F specification for a short time. The center to side differential shot up when the flooding occurred, and continued to exceed the specification limit for approximately twenty days, reaching a high differential of 47.5°F. The center to top differential surpassed the limit when, between days twenty-six and twenty-eight, the top dropped 17.8°F over a two-day period. This drop could have been caused by a large ambient temperature drop that was experienced over these two days. From that point on, the side and top temperatures were nearly identical, and since the center temperature was consistently about 20°F greater than the other two, the temperature differentials were nearly identical as well. All three temperature sensors recorded cooling at about the same rate, even with highly fluctuating ambient temperatures (Figures 22 and 23).

Cracking was noticed in this placement as well, with the same causes and effects as aforementioned.

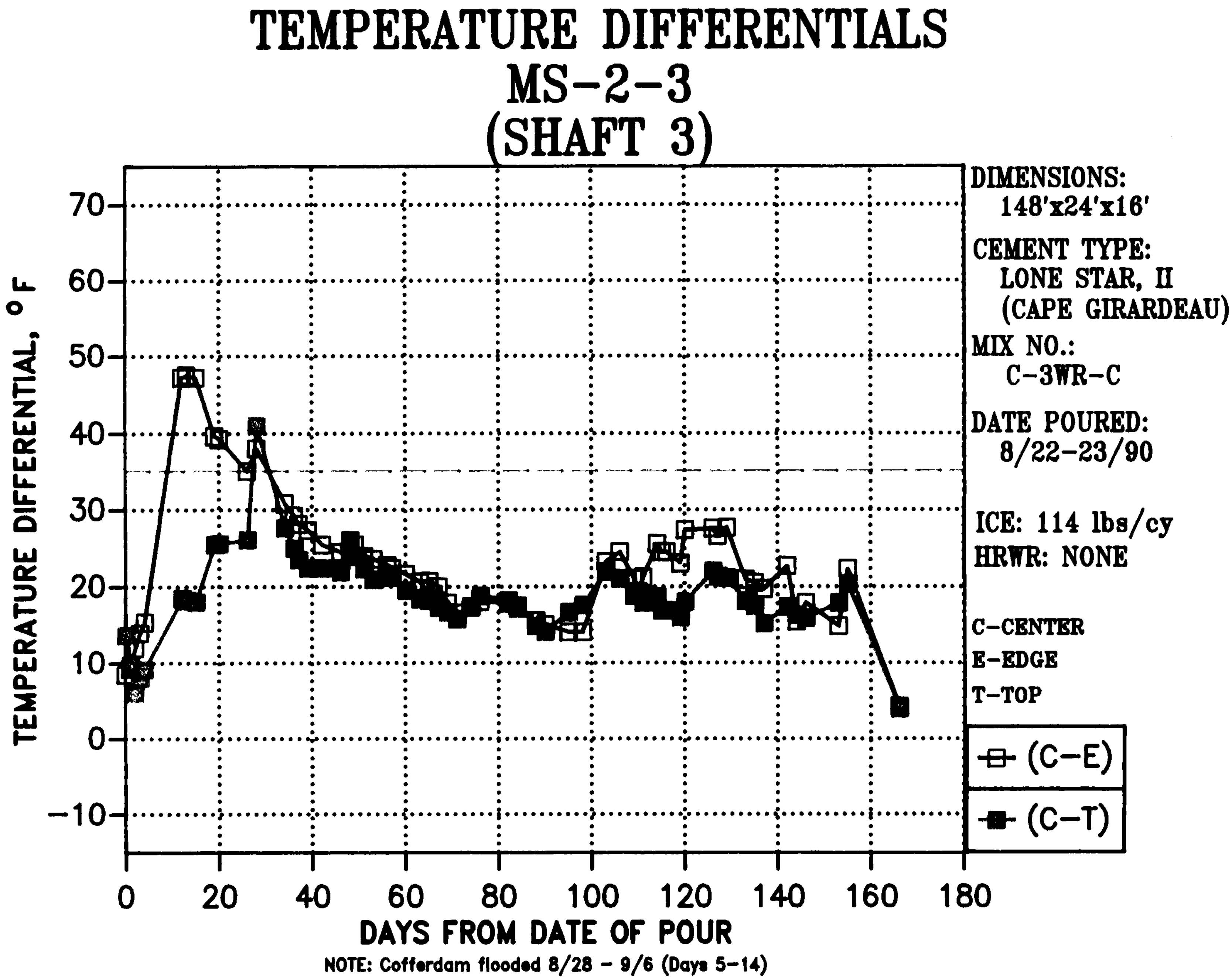
MS-2-4:

Location: South end placement of half of next placement in pier MS-2

Placement Date:	4/2/91	Mix Temperature:	62.3°F
Dimensions:	74'x24'x10'	Peak Temperature:	162.2°F
Ambient Temp.:	54.9°F	Temperature Gain:	99.9°F
Volume (cy):	586.0	Day Peak Reached:	Fourth
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	Lafarge Type I	Concrete Mix:	D-57-C

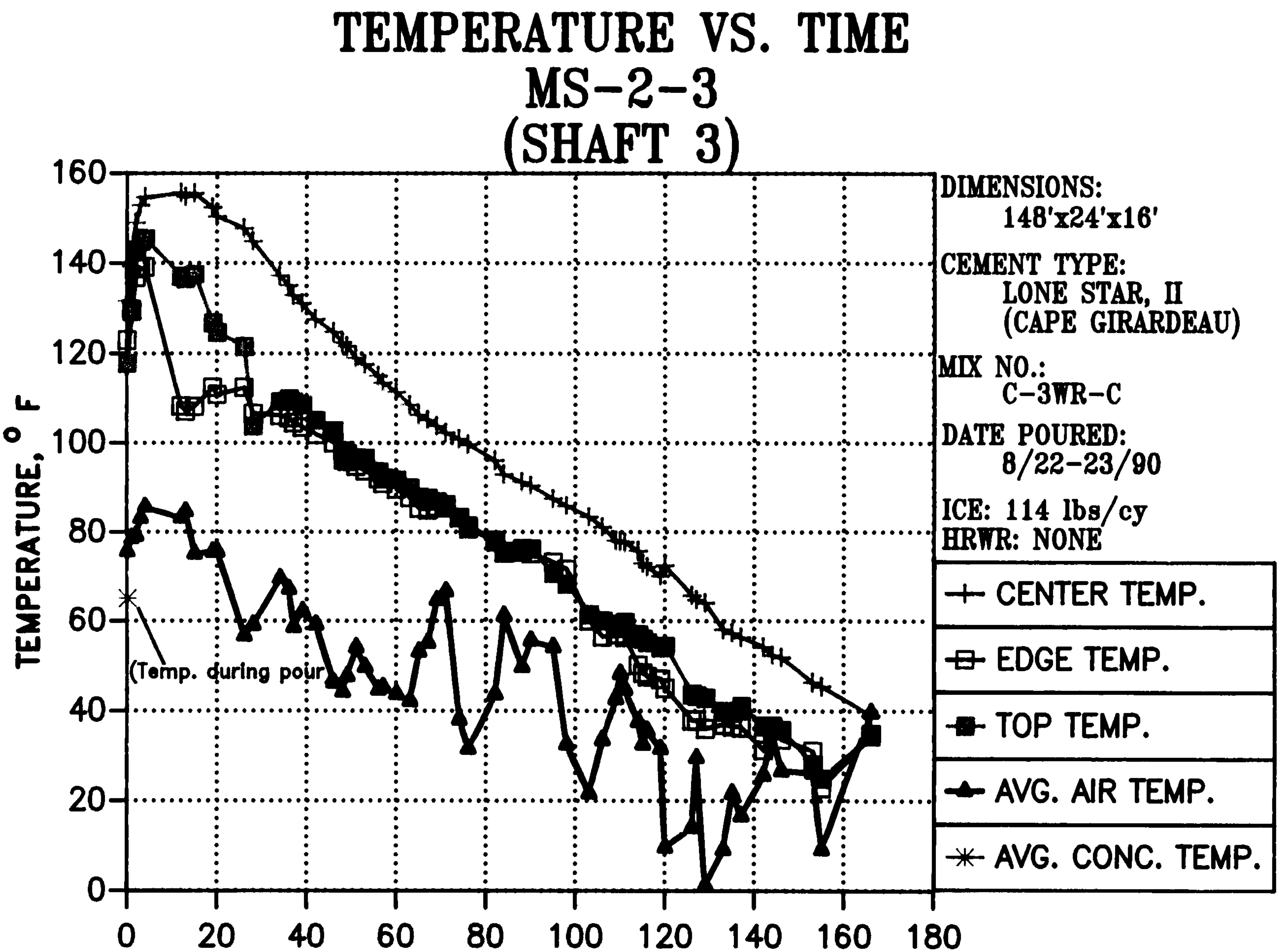
The three areas cooled at about the same rate, but the center temperature was always higher than the other two, so the temperature differentials were also high. The center to side

Figure 22



TEMPERATURE DIFFERENTIALS
MS-2-3
(SHAFT 3)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
160
180
DAYS FROM DATE OF POUR
NOTE: Cofferdam flooded 8/28 - 9/6 (Days 5-14)
DIMENSIONS:
148'x24'x16'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3WR-C
DATE POURED:
8/22-23/90
ICE: 114 lbs/cy
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 23



NOTE: Cofferdam flooded 8/28 – 9/6 (Days 5–14).

differential exceeded the 35°F specification for a period of about twenty days, with a maximum of 48.3°F, but it is unknown why it exceeded the limit for so long. The center to top differential was also rather high, and did also exceed the specification limit for one day, when the top temperature dropped 20°F overnight (Figures 24 and 25). To try to remedy the situation, the contractors placed double blankets on the top surface after the fourth day to try to control the differentials, and then later removed the top blankets to let the heat escape, but this did not work. They then doubled a blanket over the top of the outside forms and down the outside, which worked to some degree, but the outside temperature fell 3°F per day while the center fell only 1°F per day. When the blankets were loosened due to high winds, they were tightened up on the outside forms. The contractor believed the biggest factor causing the large temperature differentials was the high winds during a cold front which lasted for about two weeks. The winds made putting anything on the outside of the steel forms a non-effective solution because the winds were consistently at 25 to 30 mph.

MS-2-5:

Location: Second (north) half of previous placement, MS-2

Placement Date:	4/4/91	Mix Temperature:	64.2°F
Dimensions:	74'x24'x10'	Peak Temperature:	166.9°F
Ambient Temp.:	57.7°F	Temperature Gain:	102.7°F
Volume (cy):	585.0	Day Peak Reached:	Third
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	Lafarge Type I	Concrete Mix:	D-57-C

The three temperatures essentially followed the same cooling pattern, but since the center temperature was so much higher than the other two (especially the side), the center to side differential exceeded the limit for a period of about twenty-two

Figure 24

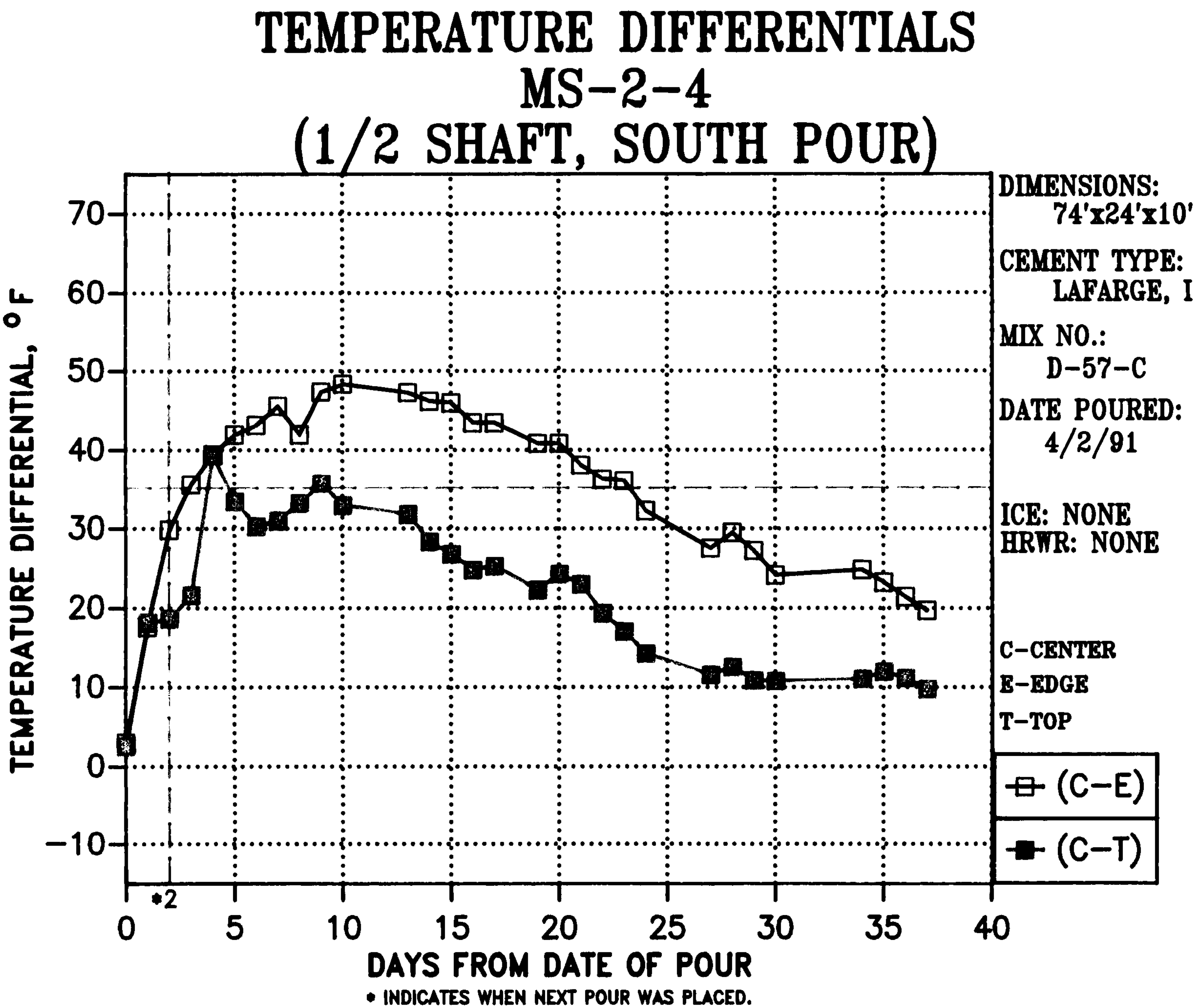
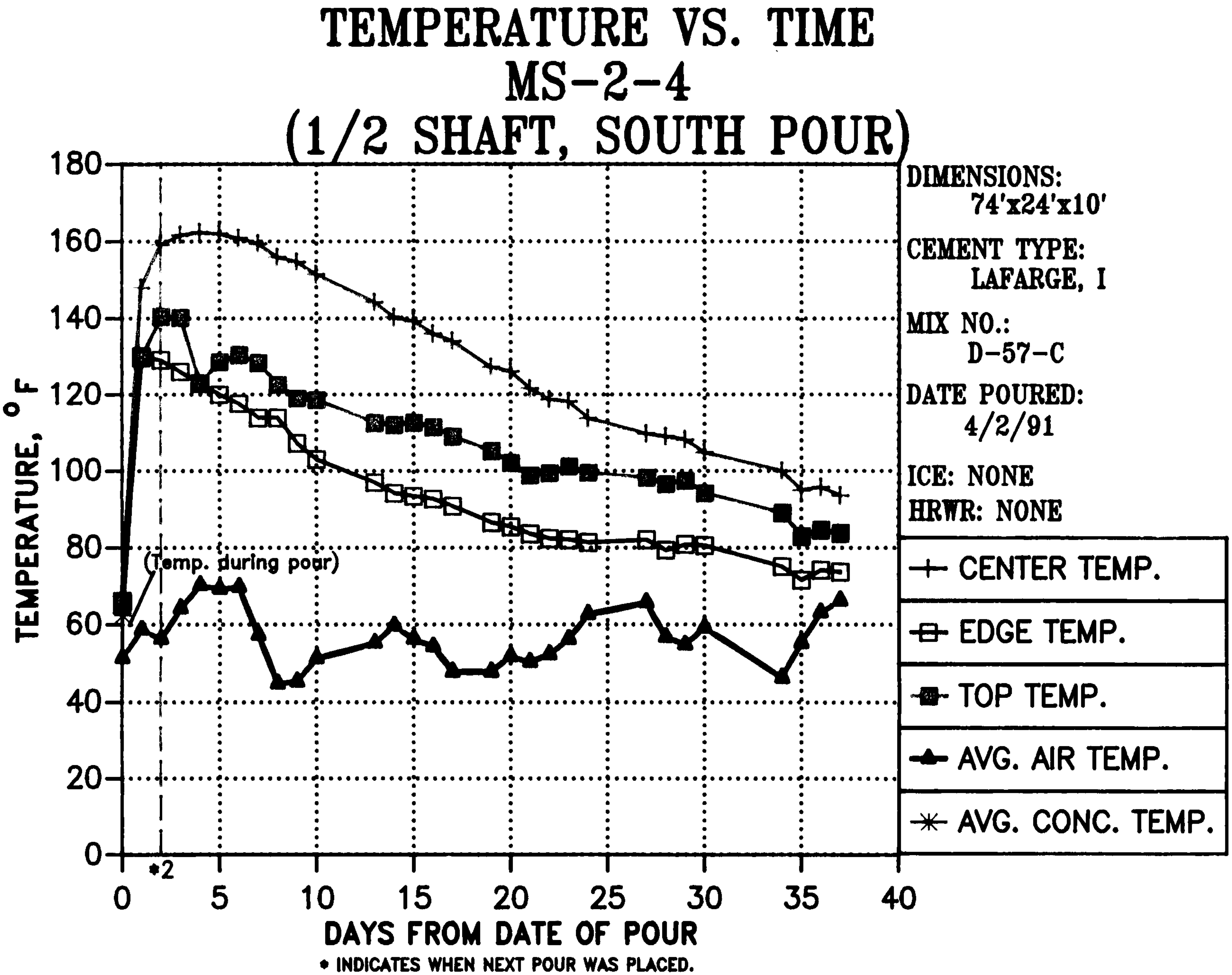

TEMPERATURE DIFFERENTIALS
MS-2-4
(1/2 SHAFT, SOUTH POUR)
DIMENSIONS:
74'x24'x10'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/2/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
*2
0
5
10
15
20
25
30
35
40
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 25



TEMPERATURE VS. TIME
MS-2-4
(1/2 SHAFT, SOUTH POUR)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
(Temp. during pour)
*2
DIMENSIONS:
74'x24'x10'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/2/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

days, with a maximum of 55.8°F at one point. The center to top differential also exceeded the limit at one time, when the top temperature dropped 17.5°F over a three-day period, and the center only dropped 7°F over that time. It is interesting to note that four days previously, the ambient temperature also experienced a similar temperature drop over a three-day period. From Figures 26 and 27, it appears that the top temperatures closely followed the ambient temperatures, even more than the side temperatures. It is possible that the insulation was not well placed on the top of this placement, or that it was completely removed at this time to prepare for the new placement. On the thirteenth day after placement, another placement (MS-2-6) was placed on top of MS-2-5. This new placement, however, did not appear to have an effect on the three temperatures. The large temperature differentials (greater than 20°F) continued until the thirty-fifth day, and finally on the thirty-ninth day, they had decreased substantially. The contractor used the same plan for this placement as was used for MS-2-4 to attempt to control the temperature differentials; again, the solution did not have the necessary effect.

MS-2-6:

Location: First placement on the north tower

Placement Date:	4/17/91	Mix Temperature:	68.4°F
Dimensions:	23'2.5"'x22'x8'	Peak Temperature:	157.7°F
Ambient Temp.:	68.8°F	Temperature Gain:	89.3°F
Volume (cy):	59.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	Lafarge Type I	Concrete Mix:	D-57-C

All three areas of the placement cooled at about the same rate, and the differentials never exceeded the 35°F limit. The center was always the warmest, followed by the side, and then the top. From day five to day eight, the center to top differential

Figure 26

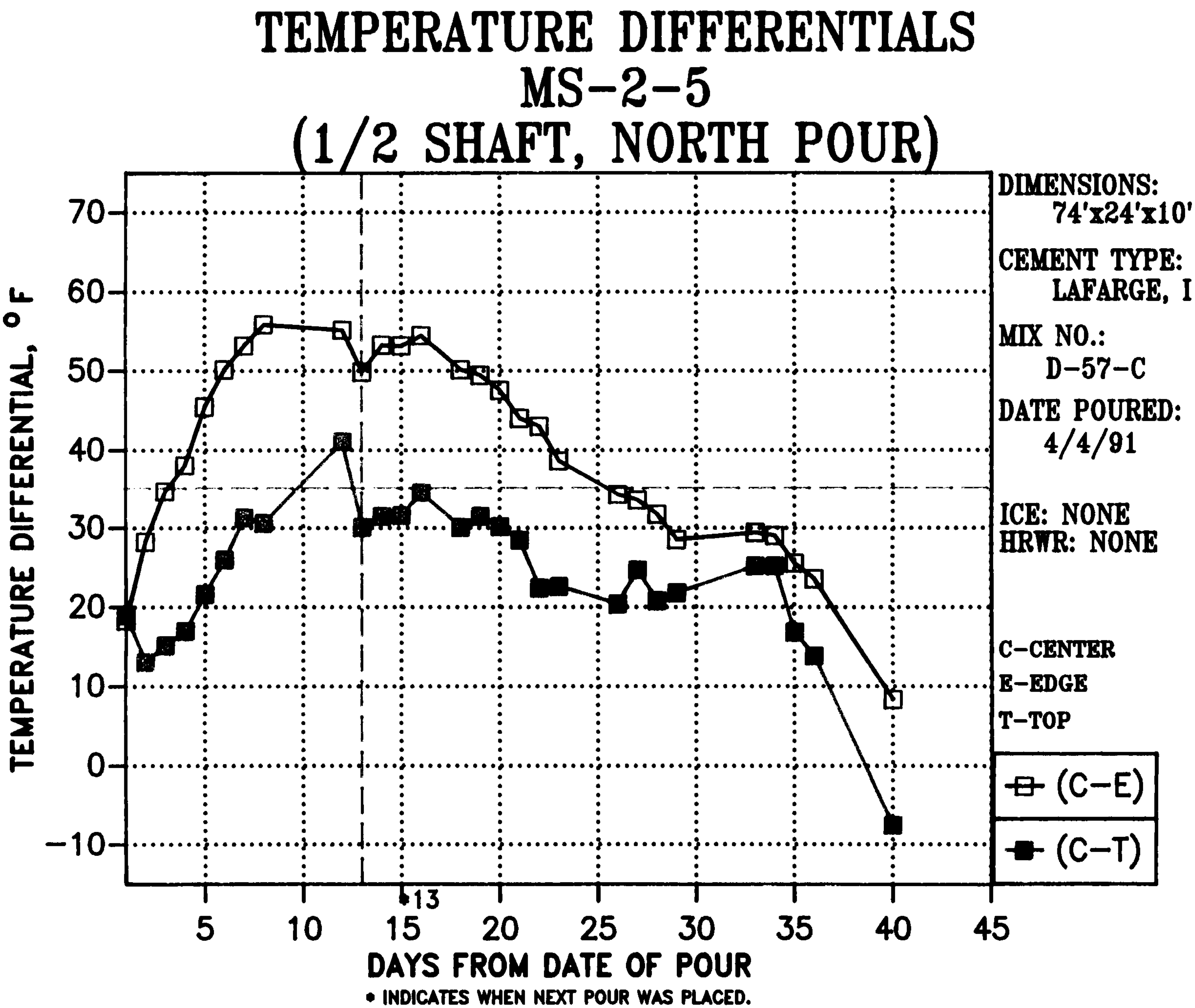
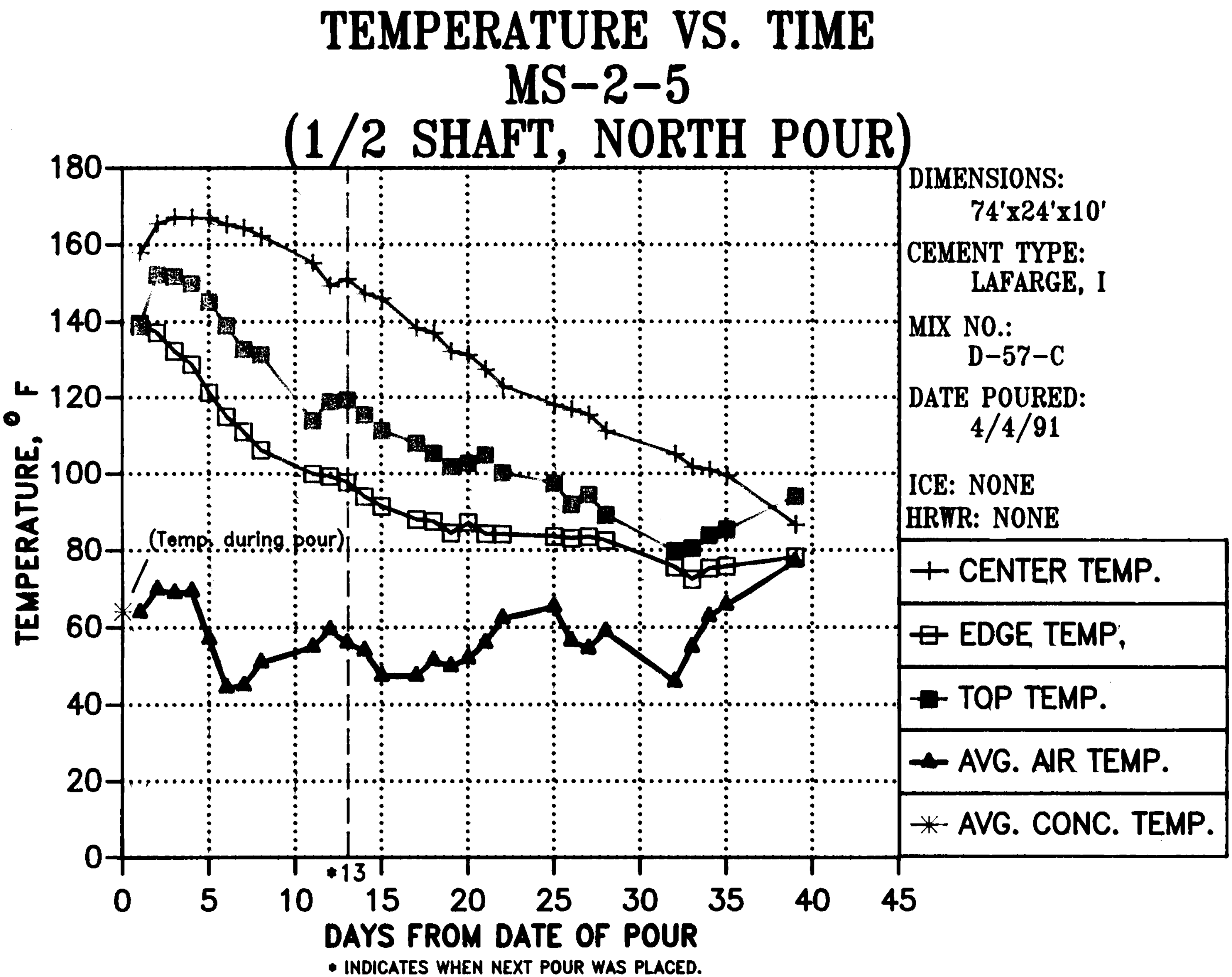

TEMPERATURE DIFFERENTIALS
MS-2-5
(1/2 SHAFT, NORTH POUR)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
5
10
15
20
25
30
35
40
45
•13
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
74'x24'x10'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/4/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 27



TEMPERATURE VS. TIME
MS-2-5
(1/2 SHAFT, NORTH POUR)
TEMPERATURE, ° F
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
*13
(Temp. during pour)
DIMENSIONS: 74'x24'x10'
CEMENT TYPE: LAFARGE, I
MIX NO.: D-57-C
DATE POURED: 4/4/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

did rise substantially more than the center to side differential, because the top was cooling faster than the other two areas. This change may be due to the ambient temperatures, which dipped a few days prior to the top's heat loss. It is interesting to note that on the nineteenth and twentieth days after the placement, the side temperature dipped lower than the top, causing the line plots of the differentials to "cross" one another. That phenomena was odd because of the side's sudden drop at that late date, possibly due to ambient temperature fluctuations (Figures 28 and 29).

MS-2-7:

Location: Pylon B of the north tower

Placement Date:	5/17/91	Mix Temperature:	78.7°F
Dimensions:	29'2.5"x22'x30'*	Peak Temperature:	172.9°F
Ambient Temp.:	79.6°F	Temperature Gain:	94.2°F
Volume (cy):	247.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	PSP-N2
Concrete Mix:	D-57-C		

* Indicates that pylon is hollow here.

For this and subsequent placements (above the 725' elevation) on both towers, it was decided to place temperature sensors in four areas instead of three, since the pylons have a hollow center. These areas differ from placement to placement, but always record a center and side temperature from two different directions. For example, in MS-2-8, the recorded temperatures were from the east center, the east side, the west center, and the west side. No top temperatures were recorded on any further placements, so the differentials are center to side in two different directions.

The center's peak temperature was very high when compared to the other two areas, a factor which caused the first day's differentials to exceed the 35°F limit. After the first day, the center began to cool, as did the top, and the edge temperature increased slightly. The center to top differential exceeded the specified limit for at least twelve days (the entire monitoring period), and a non-compliance notice was sent to the contractor to remedy the situation, and also requesting corrective action for the next placement to be placed (see MS-2-15). The contractor felt that rain and colder overnight temperatures caused the top temperature to drop faster than the other two areas, resulting in the non-compliance. The center to side differential exceeded the limit on only the first day (Figures 30 and 31).

MS-2-8:

Location: North tower, elevation 725'-737', pier MS-2

Placement Date:	9/28/91	Mix Temperature:	71.7°F
Dimensions:	9'3"x22'x12'*	Peak Temperature:	156.0°F
Ambient Temp.:	55.8°F	Temperature Gain:	84.3°F
Volume (cy):	68.5	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	PSP-N2
Concrete Mix:	D-57-C		

* Indicates that pylon is hollow here.

For the first three days of monitoring, the side temperatures were nearly identical, and followed the same cooling pattern, as did the top temperatures. On the fourth day, all of the temperature sensors recorded an increase in temperature, between ten and twenty degrees for each area, but the west side temperature jumped the most, approximately 30°F in one day, and assumed a temperature and cooling rate very close to the center's. The next day, the east center temperature dropped approximately 30°F. These fluctuations caused the east center to side differential to increase, but not to exceed the 35°F specification limit, and the west center to side differential to decrease, and remain below 10°F until the end of monitoring. No other placements were placed on MS-2-8 during monitoring, so their possible effects are unknown (Figures 32 and 33).

Figure 28

TEMPERATURE DIFFERENTIALS MS-2-6 (NORTH TOWER)

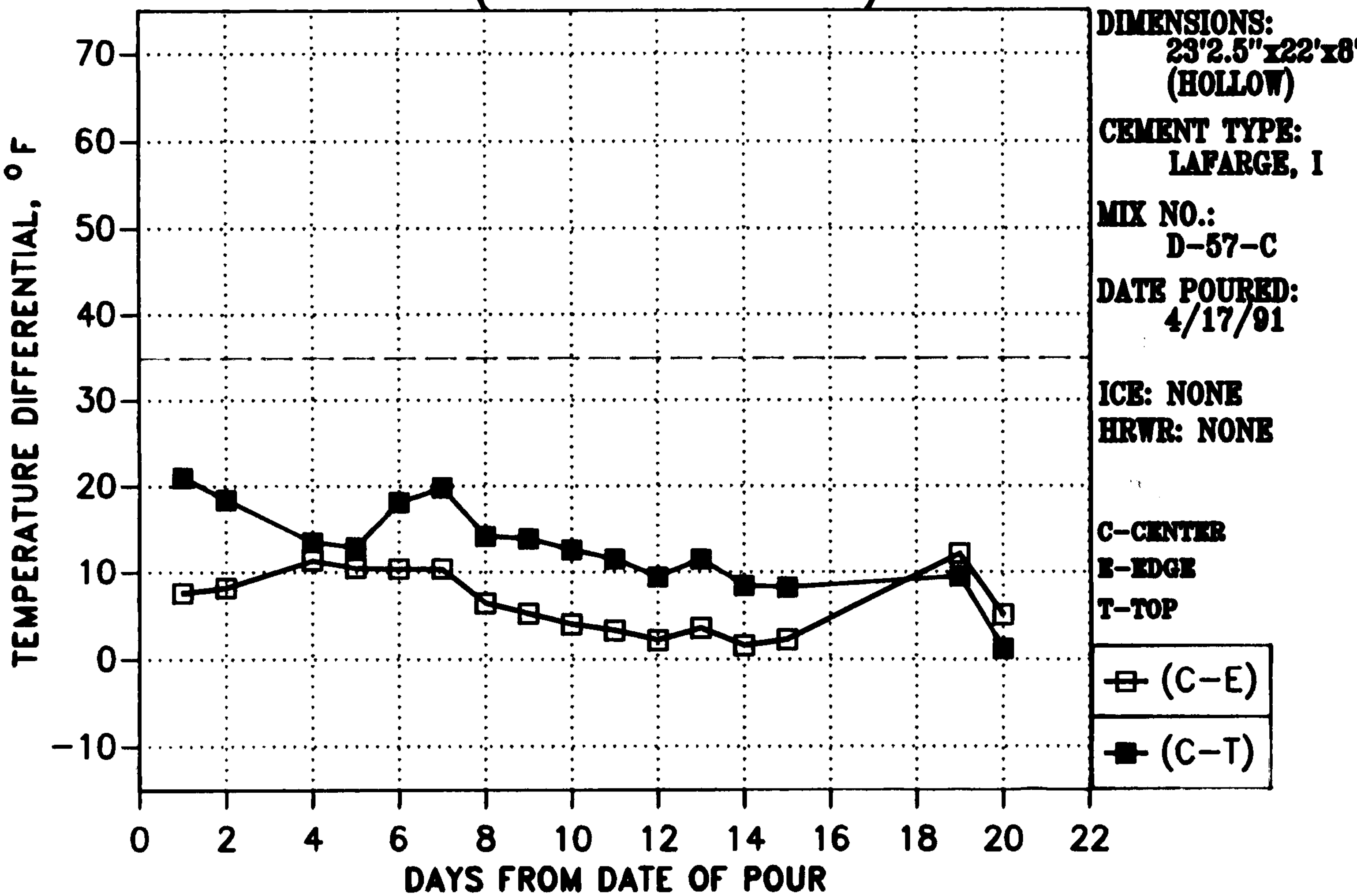


Figure 29

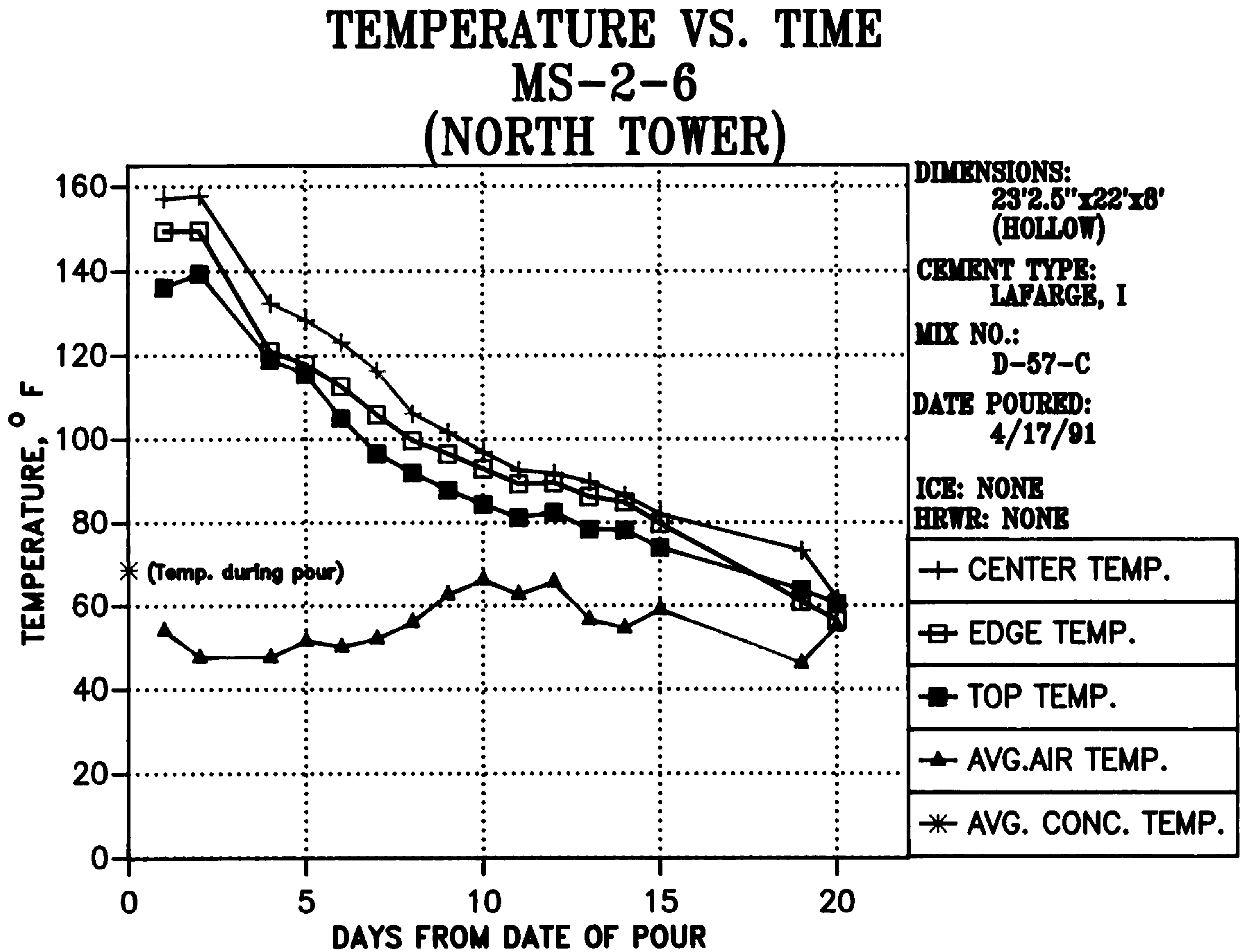
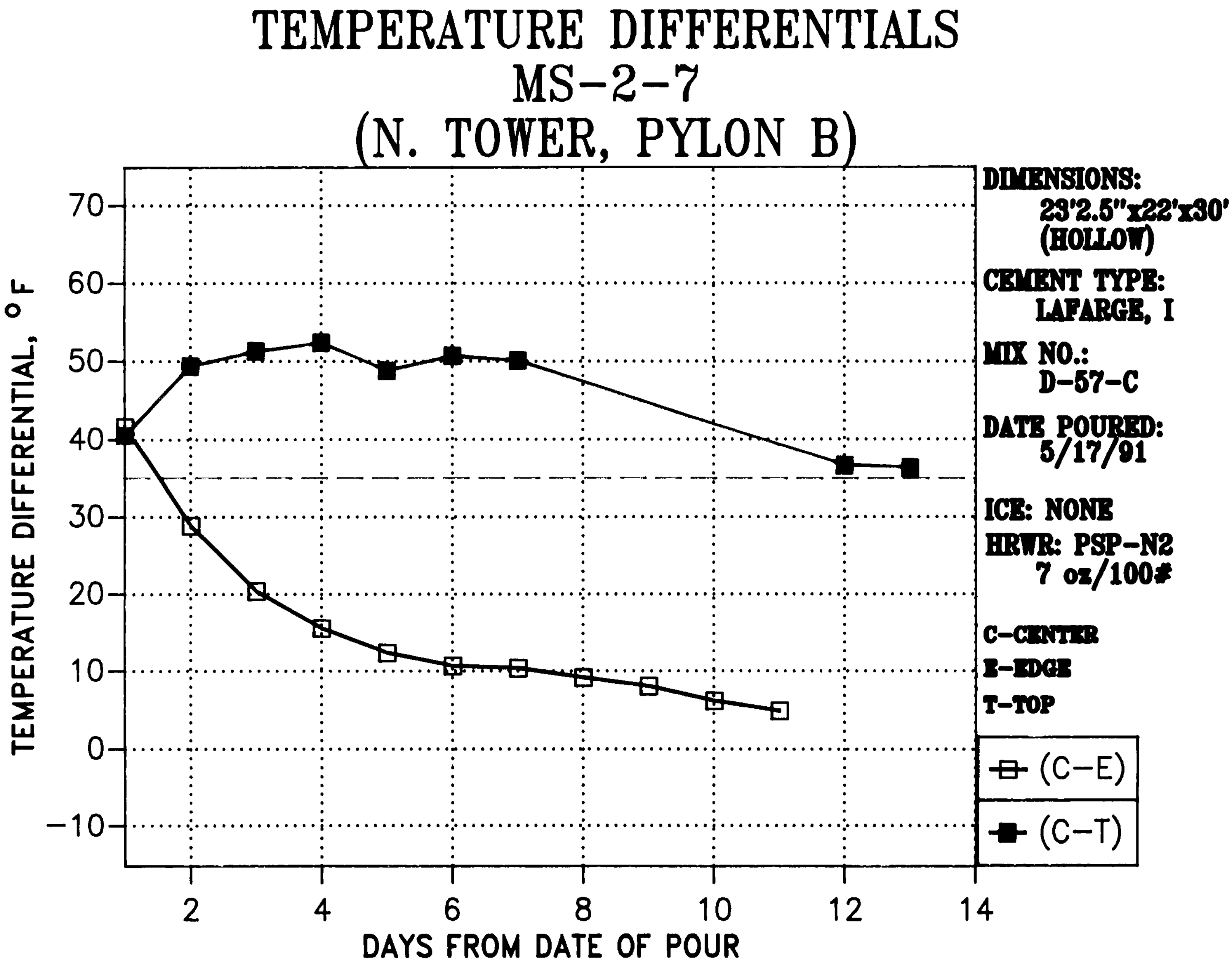
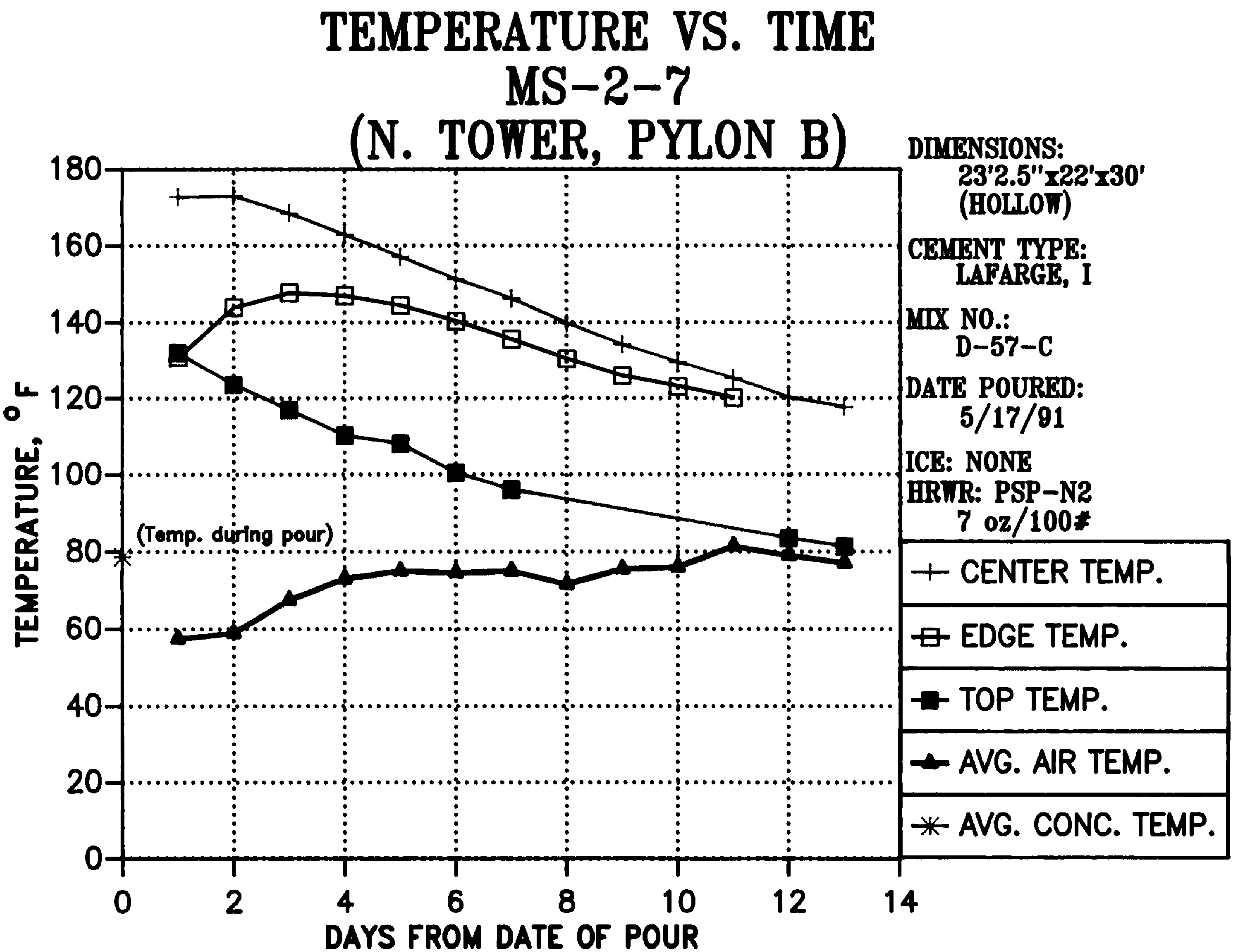

TEMPERATURE VS. TIME
MS-2-6
(NORTH TOWER)
TEMPERATURE, ° F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
5
10
15
20
(Temp. during pour)
DIMENSIONS:
23'2.5"x22'x8'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/17/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG.AIR TEMP.
AVG. CONC. TEMP.

Figure 30



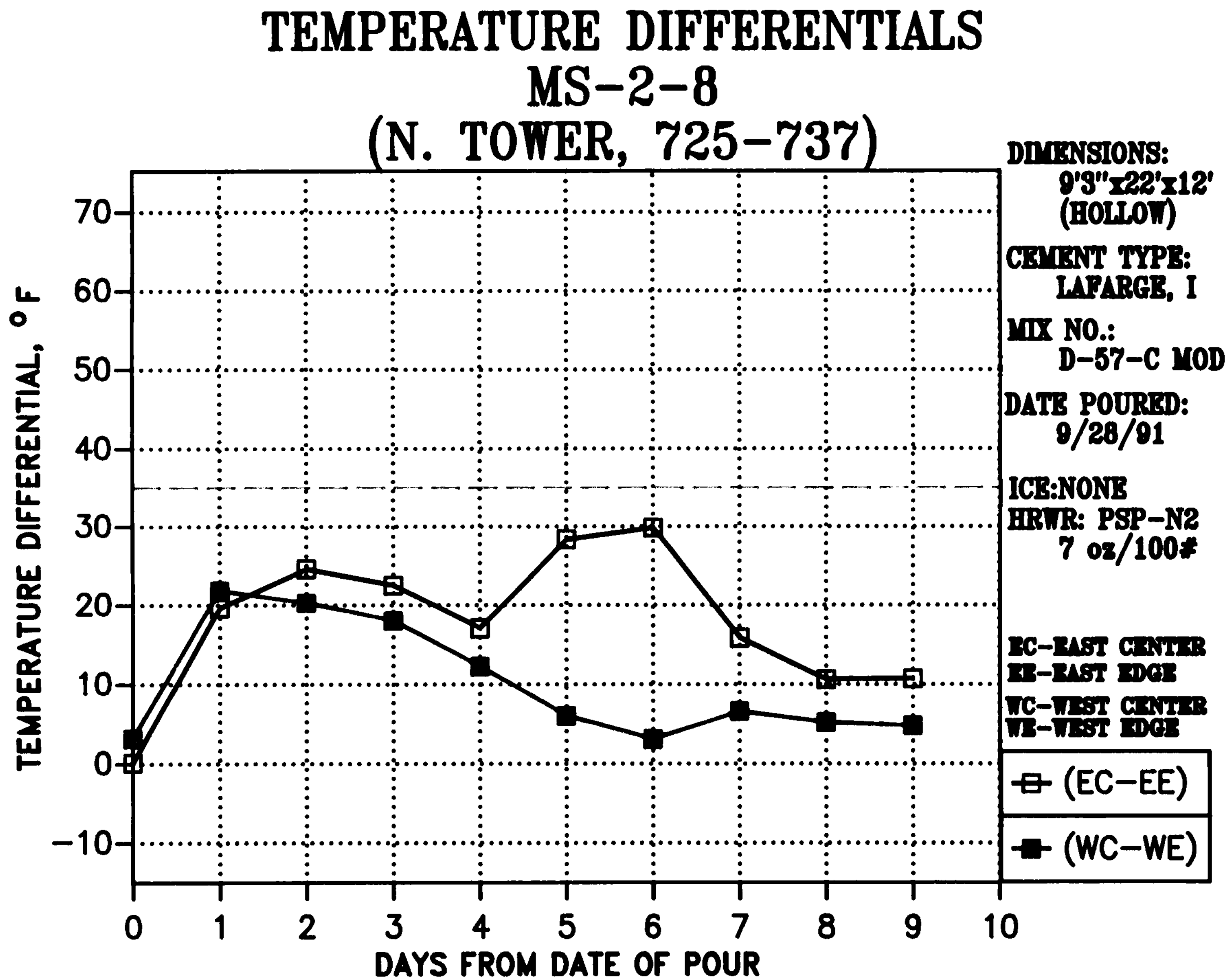
TEMPERATURE DIFFERENTIALS
MS-2-7
(N. TOWER, PYLON B)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
2
4
6
8
10
12
14
DAYS FROM DATE OF POUR
DIMENSIONS:
23'2.5"x22'x30'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
5/17/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 31


TEMPERATURE VS. TIME
MS-2-7
(N. TOWER, PYLON B)
DIMENSIONS:
23'2.5"x22'x30'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
5/17/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
180
0
2
4
6
8
10
12
14

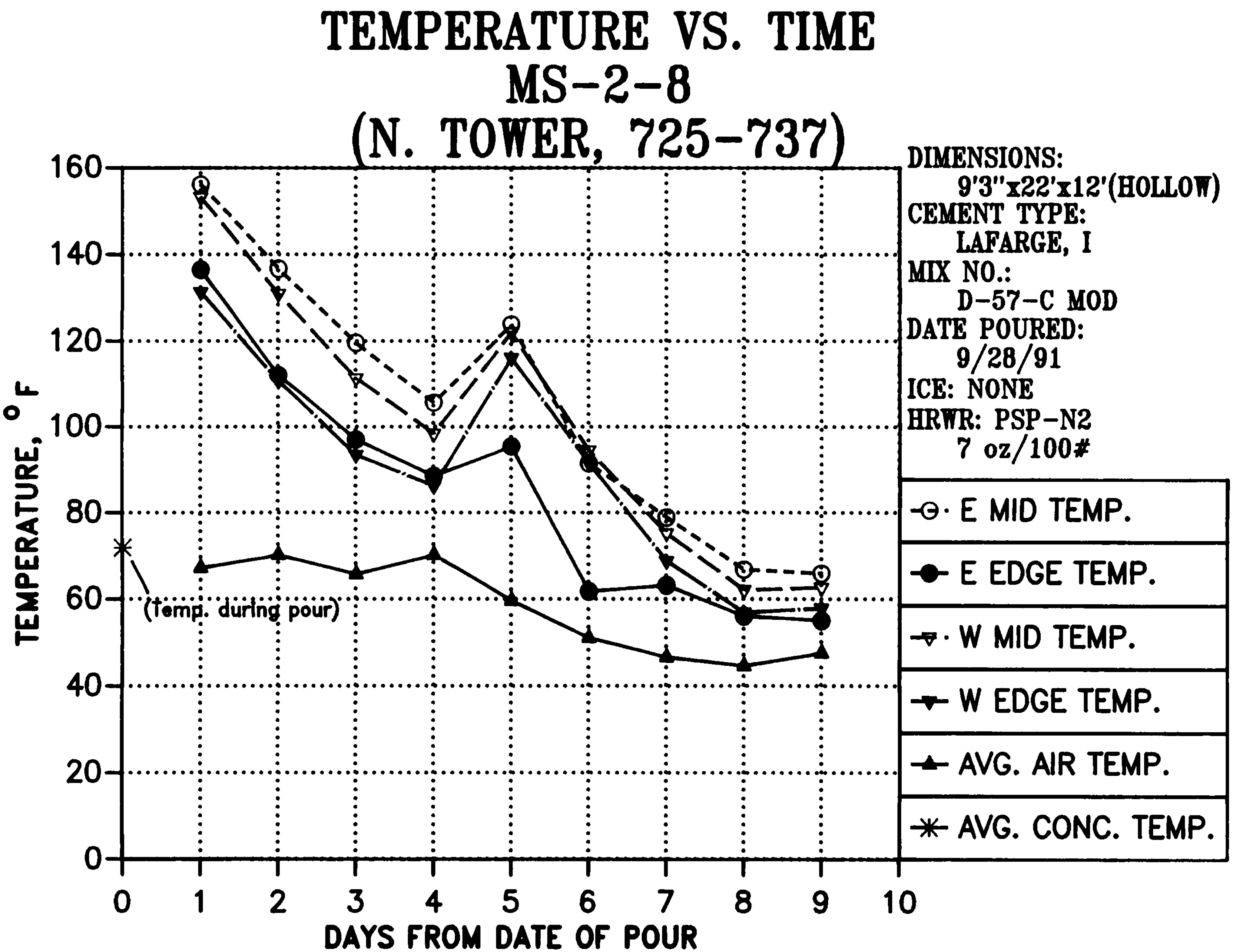
55

Figure 32



TEMPERATURE DIFFERENTIALS
MS-2-8
(N. TOWER, 725-737)
DIMENSIONS: 9'3"x22'x12' (HOLLOW)
CEMENT TYPE: LAFARGE, I
MIX NO.: D-57-C MOD
DATE POURED: 9/28/91
ICE:NONE
HRWR: PSP-N2 7 oz/100#
EC-EAST CENTER
EE-EAST EDGE
WC-WEST CENTER
WE-WEST EDGE
(EC-EE)
(WC-WE)
TEMPERATURE DIFFERENTIAL, °F
DAYS FROM DATE OF POUR

Figure 33


TEMPERATURE VS. TIME
MS-2-8
(N. TOWER, 725-737)
DIMENSIONS:
9'3"x22'x12'(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
9/28/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
E MID TEMP.
E EDGE TEMP.
W MID TEMP.
W EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(temp. during pour)
TEMPERATURE, °F
0
20
40
60
80
100
120
140
160
DAYS FROM DATE OF POUR
0
1
2
3
4
5
6
7
8
9
10

57

MS-2-9:

Location: North tower, elevation 737′-748′, pier MS-2

Placement Date:	10/8/91	Mix Temperature:	69.5°F
Dimensions:	9′3"x22′x12′*	Peak Temperature:	162.9°F
Ambient Temp.:	74.5°F	Temperature Gain:	93.4°F
Volume (cy):	69.5	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	PSP-N2
Concrete Mix:	D-57-C		

* Indicates that pylon is hollow here.

Four temperature sensors were placed in this placement: at the east center, east side, west center, and west side. Once again, the differentials were center to edge.

For the entire monitoring period, the sides were cooler than the centers, but all four areas did have the same cooling rate. For the first three days, the temperature differentials increased, but as the centers cooled down faster, the differentials decreased, ending up (after thirteen days) near zero (Figures 34 and 35). The 35°F limit was never exceeded.

MS-2-10:

Location: North tower, elevation 748′-768′, pier MS-2

Placement Date:	11/10/91	Mix Temperature:	61.5°F
Dimensions:	9′3"x22′x20′*	Peak Temperature:	147.2°F
Ambient Temp.:	48.5°F	Temperature Gain:	85.7°F
Volume (cy):	93.0	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	Daracem 100
Concrete Mix:	D-57-C, modified with ⅜" chips		

* Indicates that pylon is hollow here.

The temperature sensors were again placed at the east and west centers and sides for this placement.

After the first day after the placement date, the center and side temperatures in each side were very close, and followed the same cooling rate. The western side cooled much faster, though, and was always cooler than the eastern side. The temperature was only monitored for eight days, but for the last four days, the differentials were essentially zero, and they never exceeded the specified limit (Figures 36 and 37).

MS-2-11:

Location: North tower, elevation 768′-780′, pier MS-2

Placement Date:	12/30/91	Mix Temperature:	65.0°F
Dimensions:	9′3"x22′x20′*	Peak Temperature:	149.4°F
Ambient Temp.:	32.5°F	Temperature Gain:	84.4°F
Volume (cy):	58.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

Temperature sensors were placed on the eastern and western sides of the placement.

After the temperatures peaked, the concrete began to cool, but the center to side differential remained below 10°F. On the fourth day after the placement, the west side temperature dropped suddenly, cooling at a much faster rate. This in turn caused the differential to increase, but it decreased again as the center assumed the side's cooling rate (Figures 38 and 39). It is unknown why only the western side would drop so suddenly, unless the insulation was lost (which was possible). No other placements were placed on top of MS-2-11 during monitoring, and the differentials never exceeded 35°F.

MS-2-12:

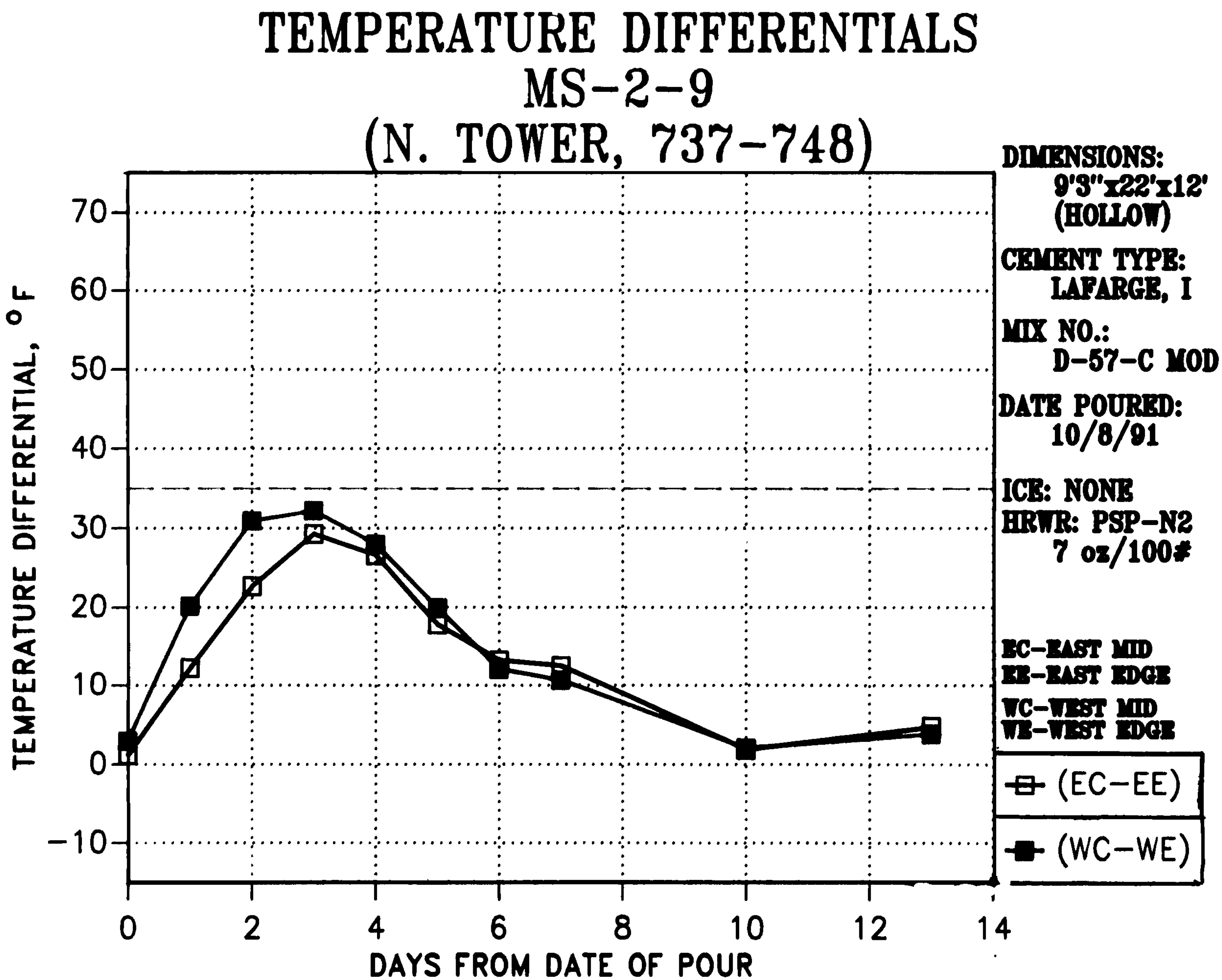
Location: North tower, elevation 780′-800′, pier MS-2

Placement Date:	1/21/92	Mix Temperature:	63.5°F
Dimensions:	9′3"x22′x20′*	Peak Temperature:	143.8°F
Ambient Temp.:	46.0°F	Temperature Gain:	80.3°F
Volume (cy):	97.0	Day Peak Reached:	Third
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

Figure 34



TEMPERATURE DIFFERENTIALS
MS-2-9
(N. TOWER, 737-748)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
10/8/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
EC-EAST MID
EE-EAST EDGE
WC-WEST MID
WE-WEST EDGE
(EC-EE)
(WC-WE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
DAYS FROM DATE OF POUR

Figure 35

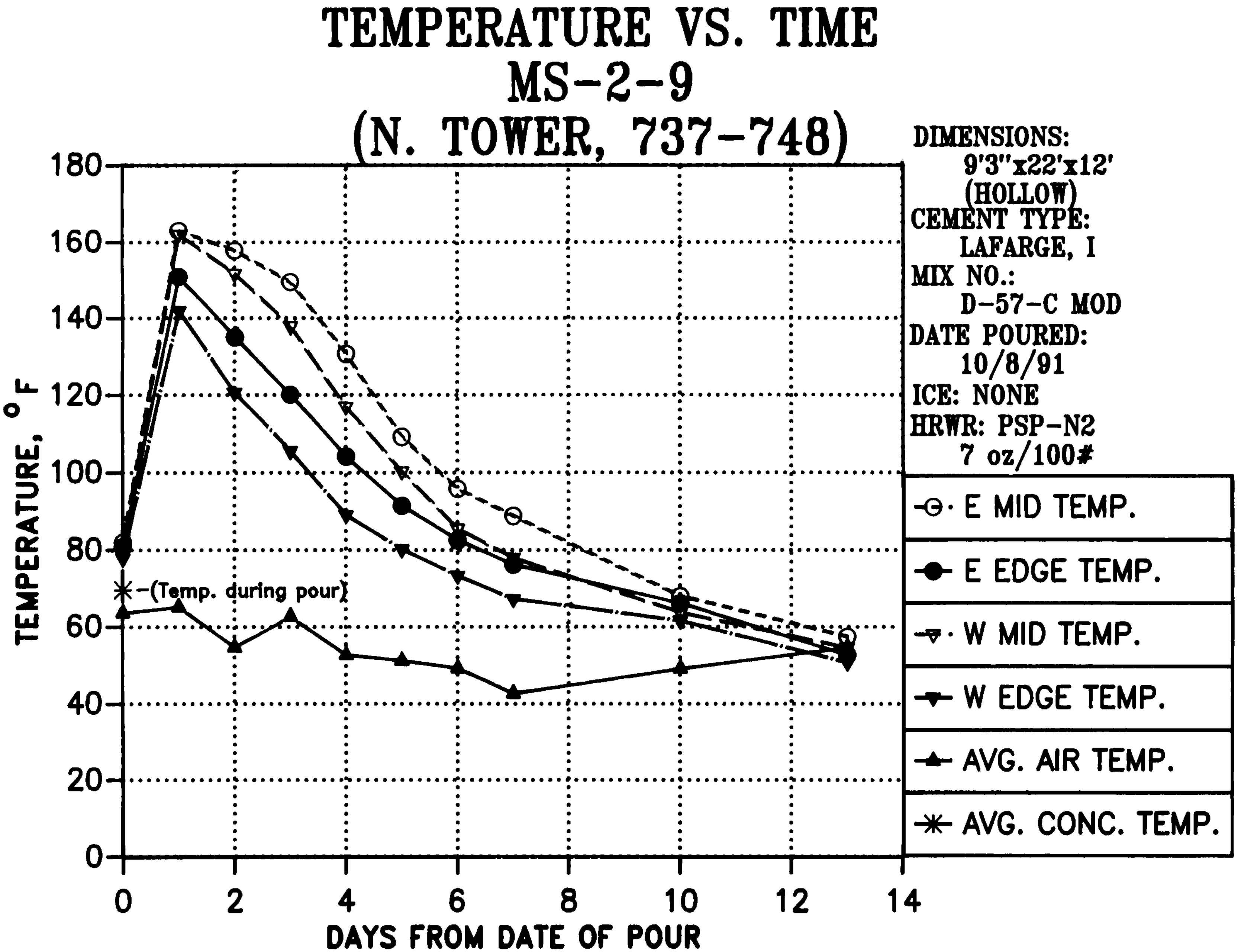

TEMPERATURE VS. TIME
MS-2-9
(N. TOWER, 737-748)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
10/8/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
E MID TEMP.
E EDGE TEMP.
W MID TEMP.
W EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
-(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
180
0
2
4
6
8
10
12
14

Figure 36

TEMPERATURE DIFFERENTIALS MS-2-10 (N. TOWER, 748-768)

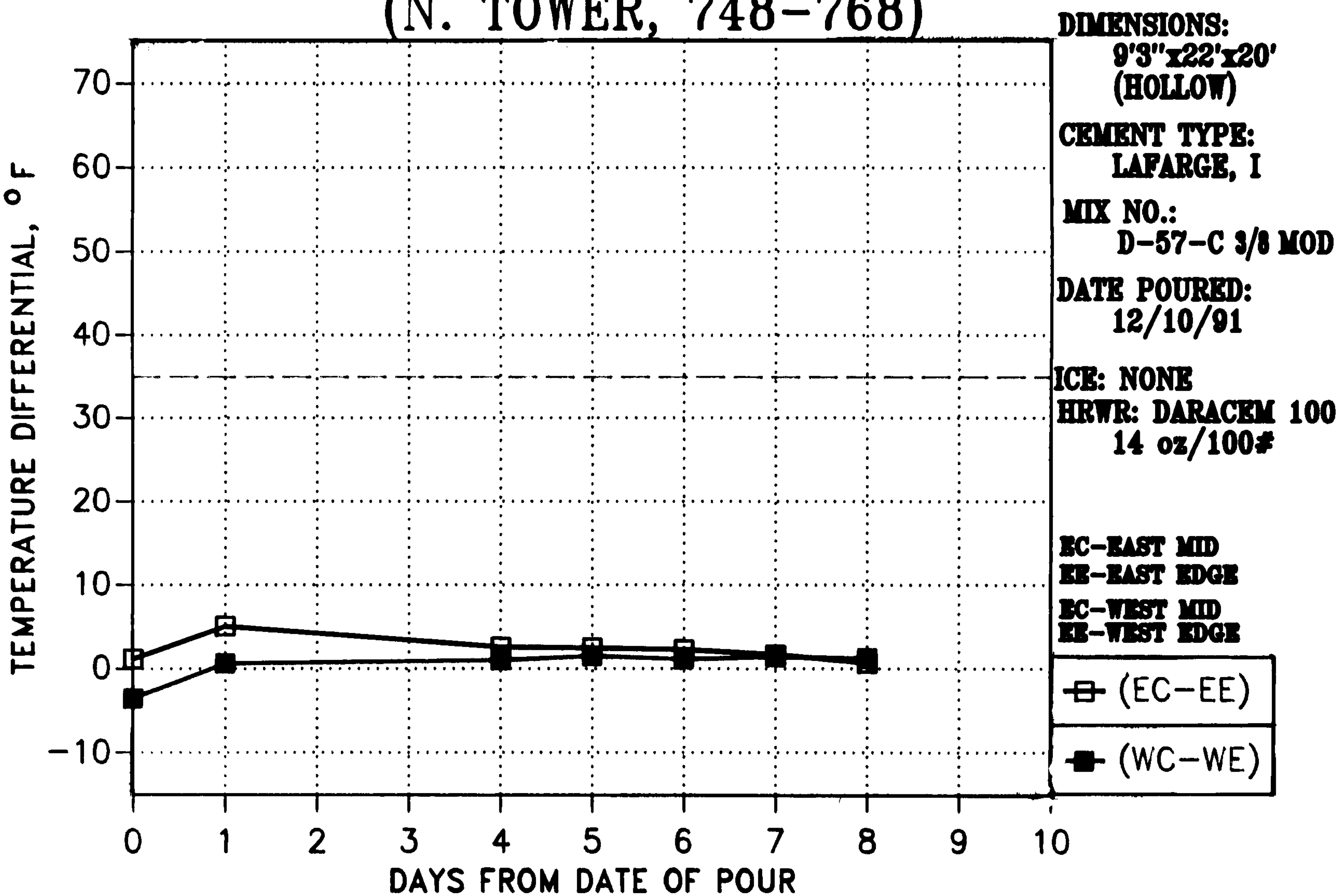
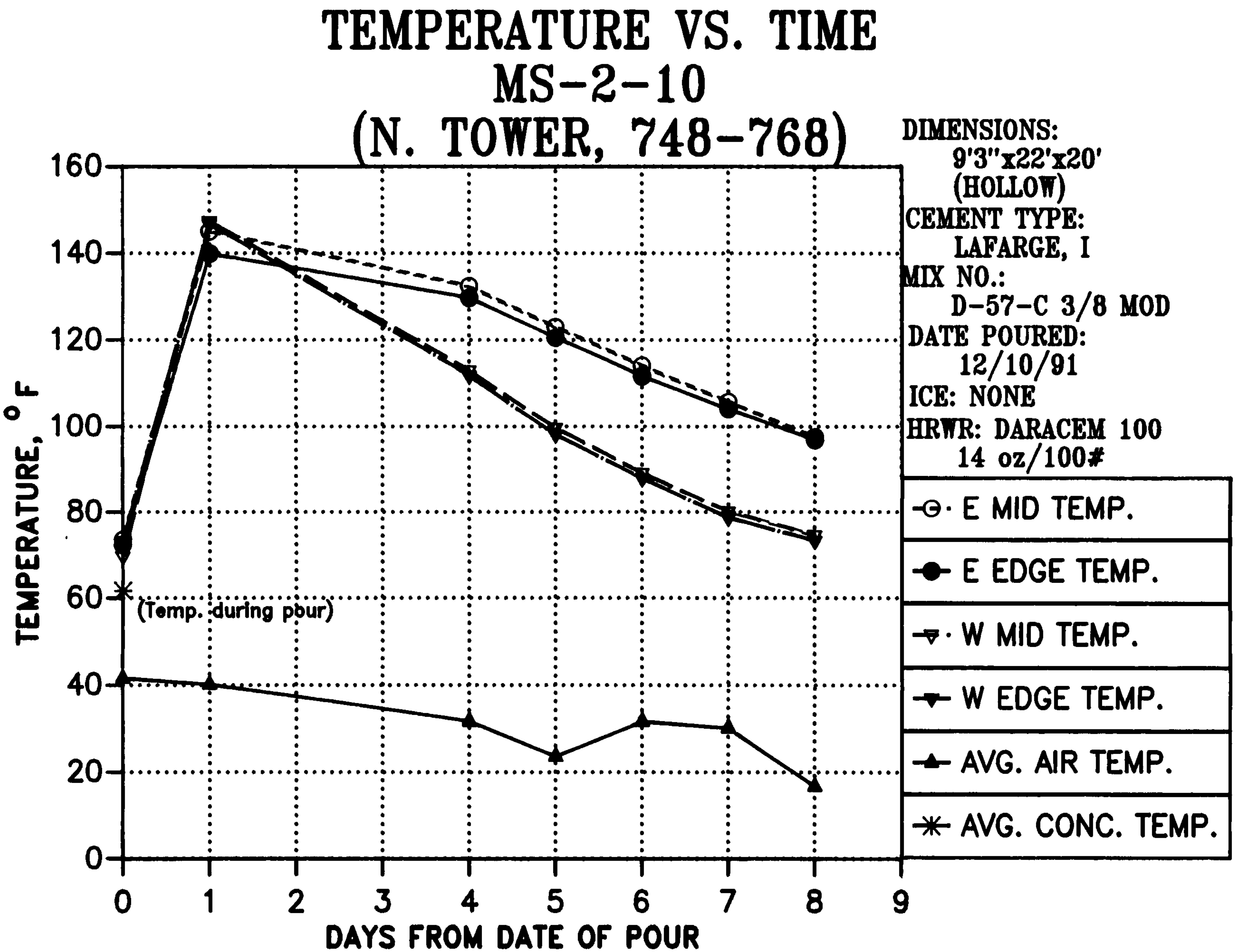


Figure 37



TEMPERATURE VS. TIME
MS-2-10
(N. TOWER, 748-768)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
12/10/91
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
W MID TEMP.
W EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
7
8
9

Figure 38

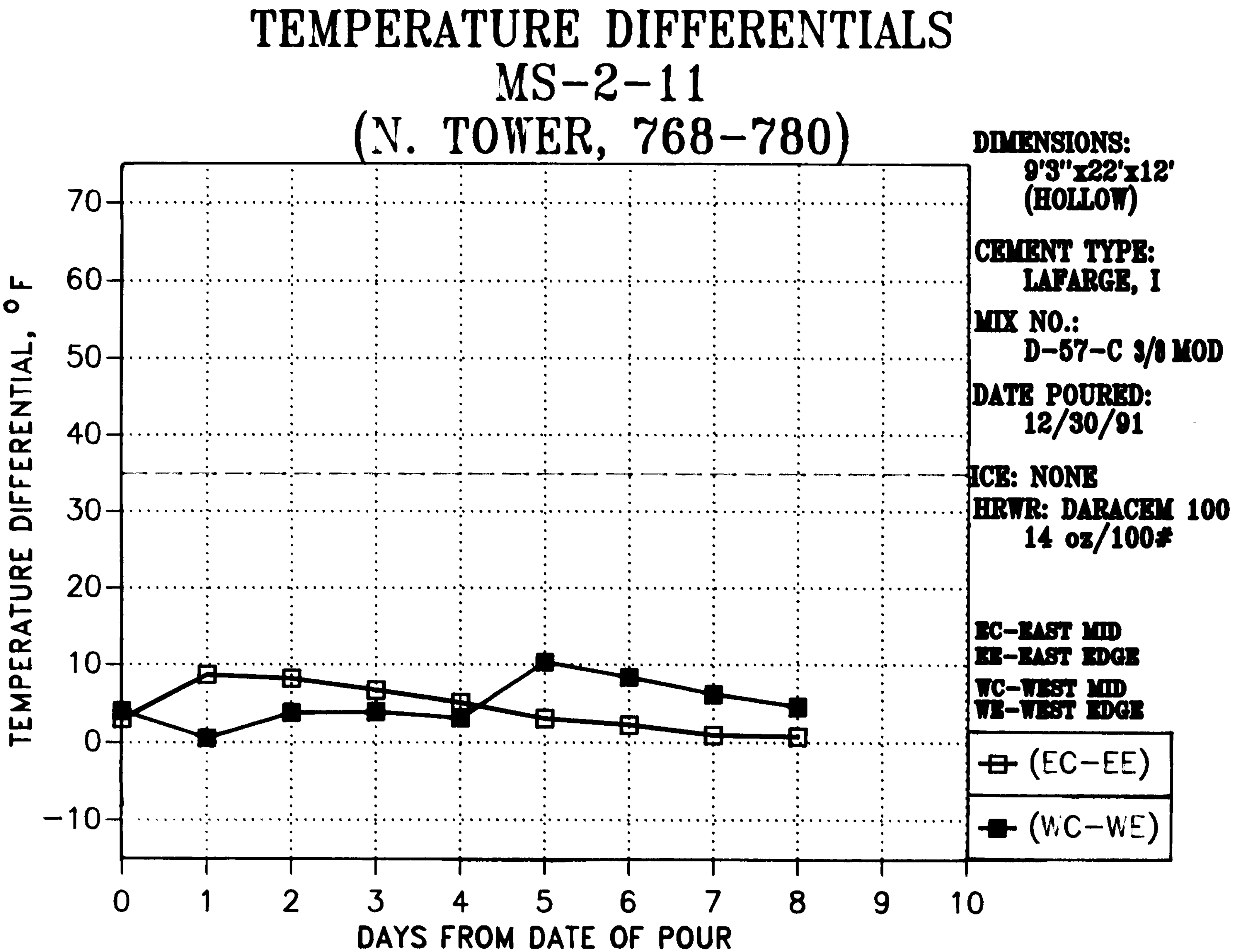
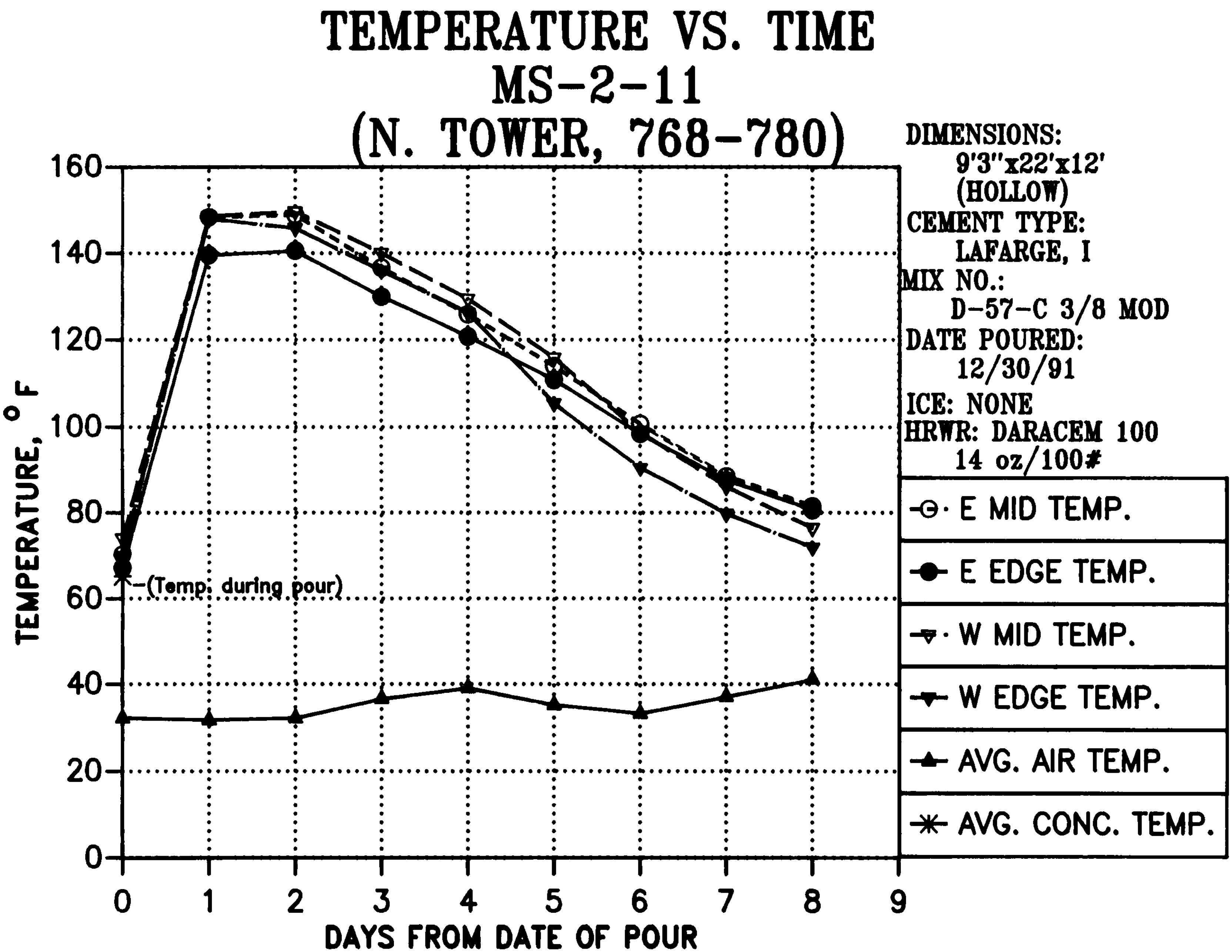

TEMPERATURE DIFFERENTIALS
MS-2-11
(N. TOWER, 768-780)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
12/30/91
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
EC-EAST MID
EE-EAST EDGE
WC-WEST MID
WE-WEST EDGE
(EC-EE)
(WC-WE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
10
DAYS FROM DATE OF POUR

Figure 39



TEMPERATURE VS. TIME
MS-2-11
(N. TOWER, 768-780)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
12/30/91
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
W MID TEMP.
W EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9

The temperature sensors were placed in the north and east sides of this placement.

After the initial peaks, the concrete temperatures were essentially constant for the next two days, and then began to cool, the north cooling much faster than the east. The temperature differentials were very low during the entire monitoring period. At the very beginning the north side was warmer than the center, but the center became warmer afterwards. The east temperatures were consistently higher than the northern temperatures, possibly due to sun exposure (Figures 40 and 41).

MS-2-13:

Location: North tower, elevation 800′-818′, pier MS-2

Placement Date:	2/6/92	Mix Temperature:	61.5°F
Dimensions:	9′3"x22′x18′*	Peak Temperature:	142.9°F
Ambient Temp.:	38.4°F	Temperature Gain:	81.4°F
Volume (cy):	87.5	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

The temperature sensors were placed at the eastern and southern sides of the placement.

During monitoring, the east was consistently cooler than the south, and the east also cooled faster than the southern side. While the eastern side was warmer than the center for the first day, afterwards the temperature differentials were quite close and low (less than 10°F) (Figures 42 and 43).

MS-2-14:

Location: North tower, elevation 818′-835′, pier MS-2

Placement Date:	2/21/92	Mix Temperature:	59.5°F
Dimensions:	9′3"x22′x17′*	Peak Temperature:	139.9°F
Ambient Temp.:	35.5°F	Temperature Gain:	80.4°F
Volume (cy):	84.5	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

Figure 40

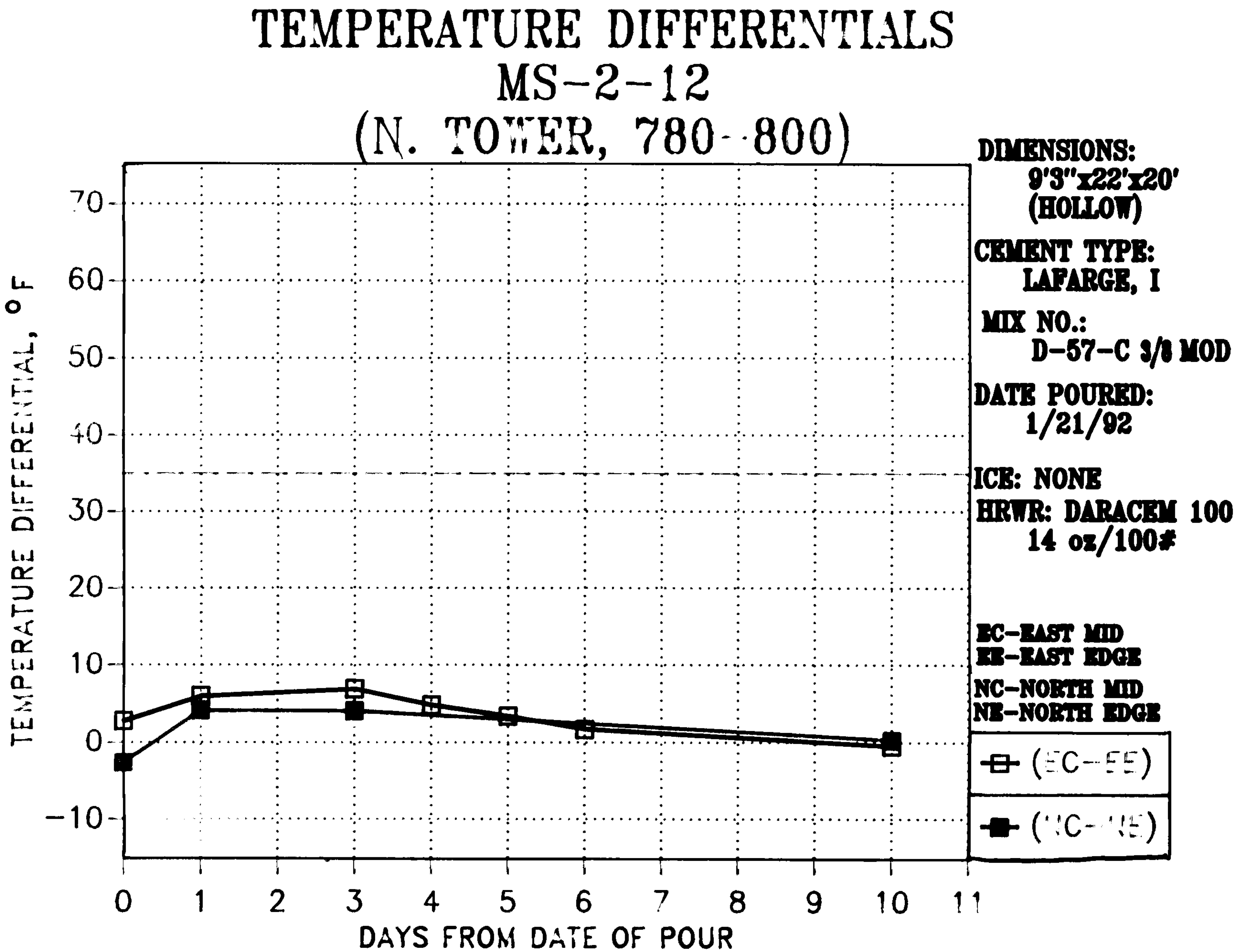

TEMPERATURE DIFFERENTIALS
MS-2-12
(N. TOWER, 780--800)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
10
11
DAYS FROM DATE OF POUR
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/21/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
EC-EAST MID
EE-EAST EDGE
NC-NORTH MID
NE-NORTH EDGE
(EC-EE)
(NC-NE)

Figure 41

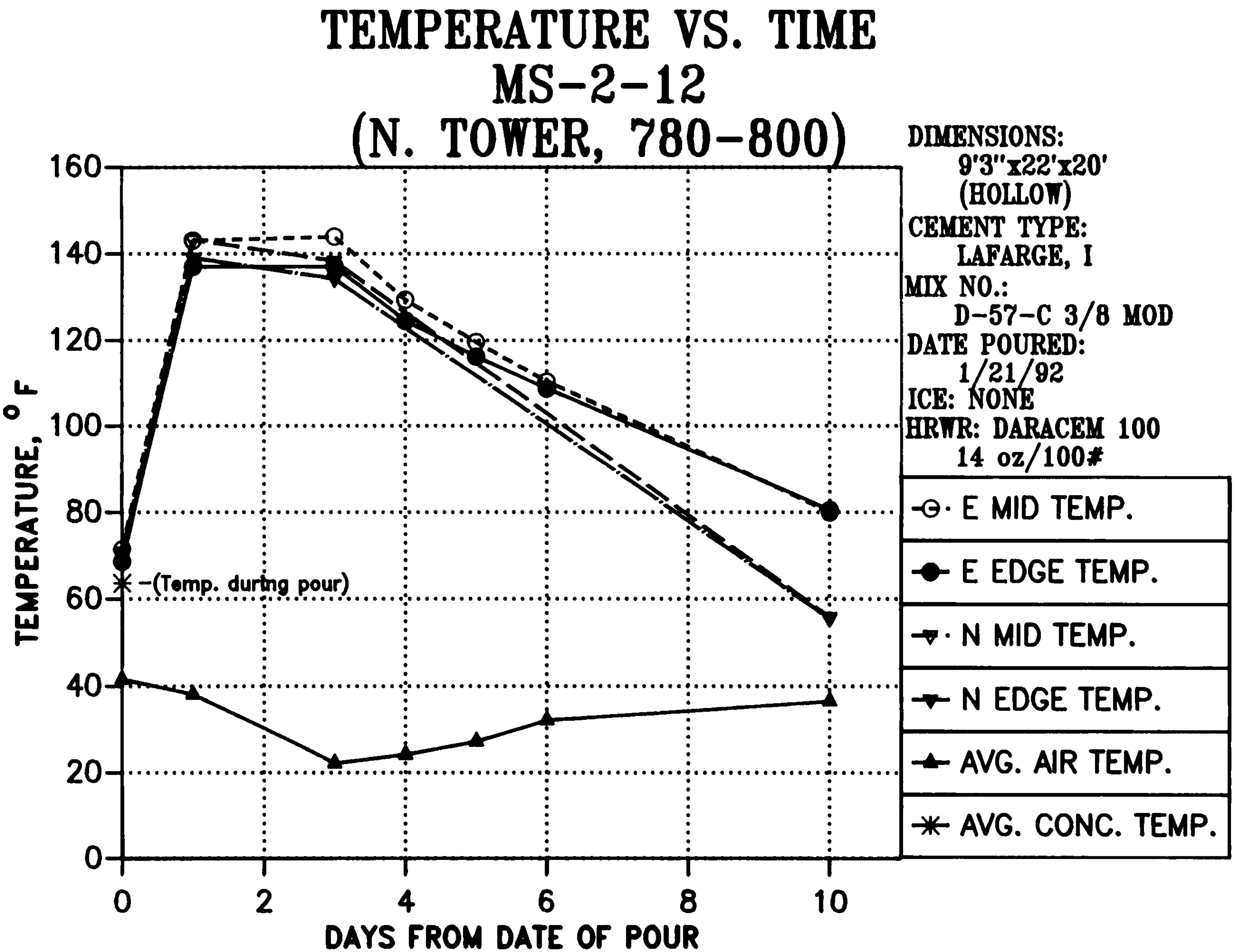

TEMPERATURE VS. TIME
MS-2-12
(N. TOWER, 780-800)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/21/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
N MID TEMP.
N EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
-(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10

Figure 42

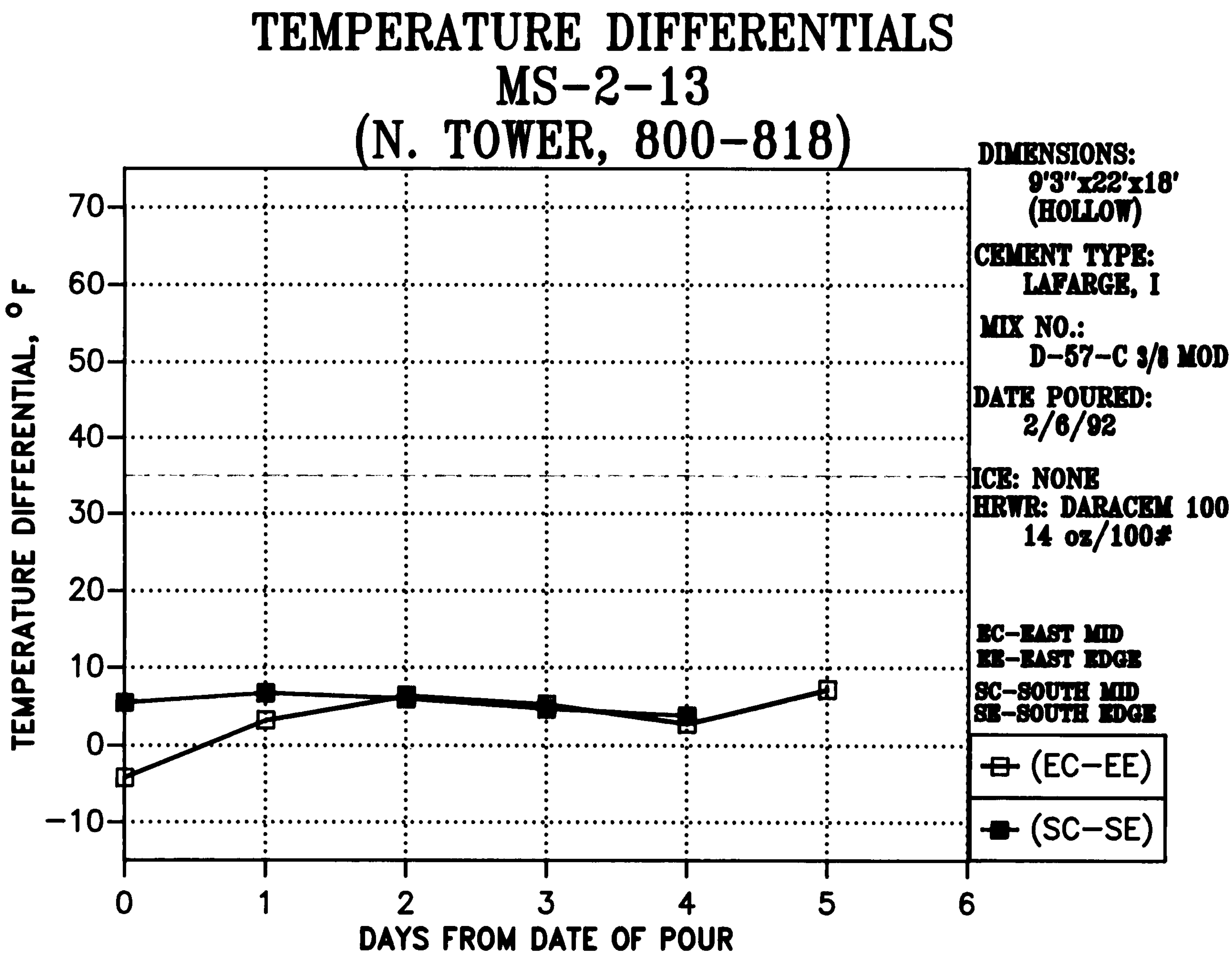
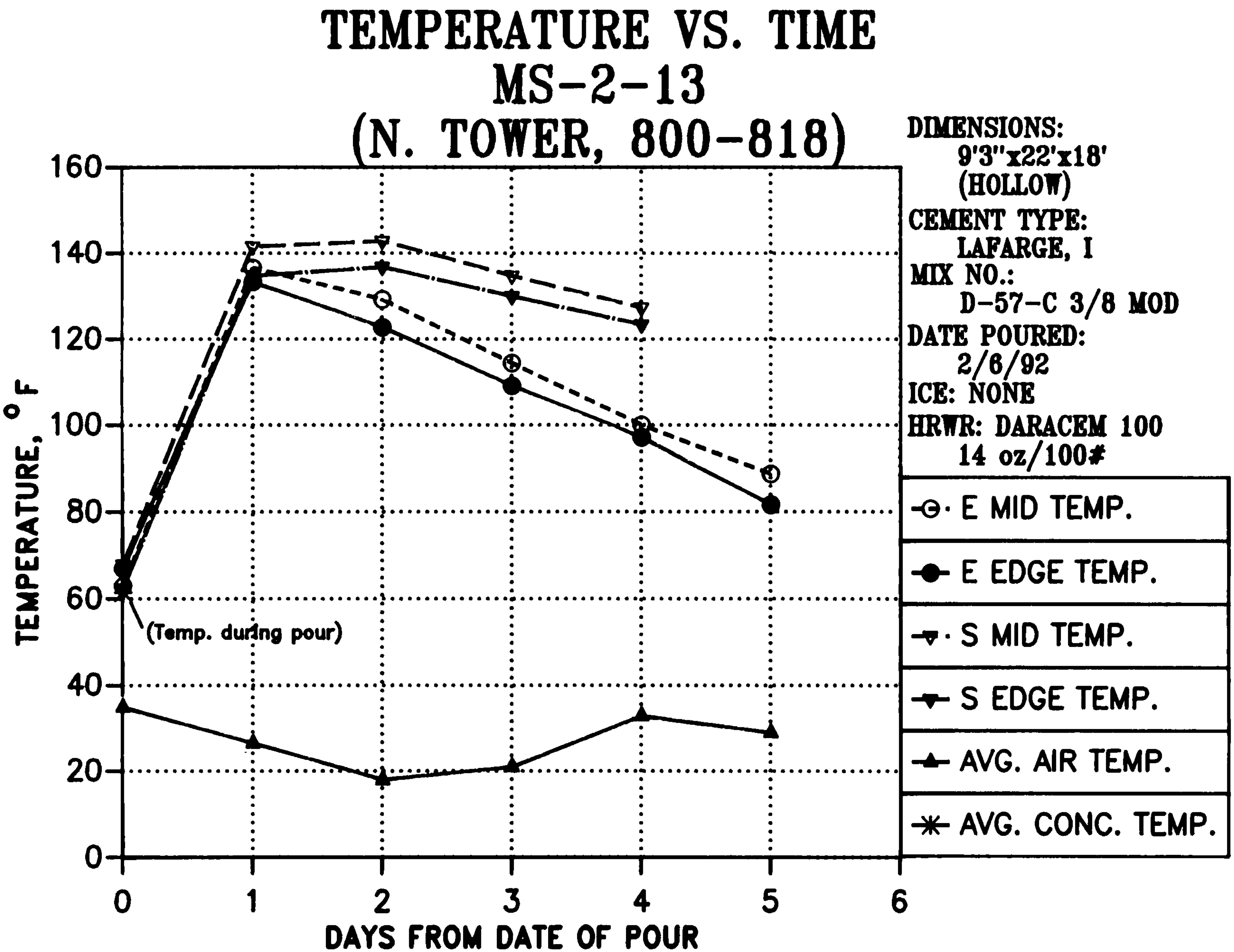

TEMPERATURE DIFFERENTIALS
MS-2-13
(N. TOWER, 800-818)
DIMENSIONS:
9'3"x22'x18'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/6/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
EC-EAST MID
EE-EAST EDGE
SC-SOUTH MID
SE-SOUTH EDGE
(EC-EE)
(SC-SE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
DAYS FROM DATE OF POUR

Figure 43



TEMPERATURE VS. TIME
MS-2-13
(N. TOWER, 800-818)
DIMENSIONS:
9'3"x22'x18'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/6/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
S MID TEMP.
S EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6

The temperature sensors were placed on the eastern and southern sides of the tower.

The temperature sensor on the eastern center was disconnected after placement due to a machine malfunction, so no other data is available on that area. While the southern temperature behaved normally, i.e., starting near the mix temperature and warming to a peak temperature in one day, the eastern side temperature oddly reached its peak temperature on the day of the placement, which was assumed to be a machine error. Afterwards, the three remaining areas cooled at about the same rate, with the southern side staying warmer than the eastern. The southern differential stayed below 20°F for the entire monitoring period (Figures 44 and 45).

MS-2-15:

Location: First placement of the south tower, pier MS-2

Placement Date:	4/22/91	Mix Temperature:	68.5°F
Dimensions:	23'2.5"x22'x8'*	Peak Temperature:	159.4°F
Ambient Temp.:	69.4°F	Temperature Gain:	90.9°F
Volume (cy):	60.0	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	Lafarge Type I	Concrete Mix:	D-57-C

* Indicates that pylon is hollow here.

The three sensor areas (center, side, and top) cooled at the same rate, with the center being the warmest, followed by the top, and finally, the side. Since the side did not attain as high a peak temperature as the other two areas, the center to side differential was substantially higher than the center to top differential. As the center cooled, the center to side differential decreased and followed the same pattern as the center to top differential (Figures 46 and 47). No other placements were placed on top of MS-2-15 during monitoring, and it did not exceed the 35° limit.

Figure 44

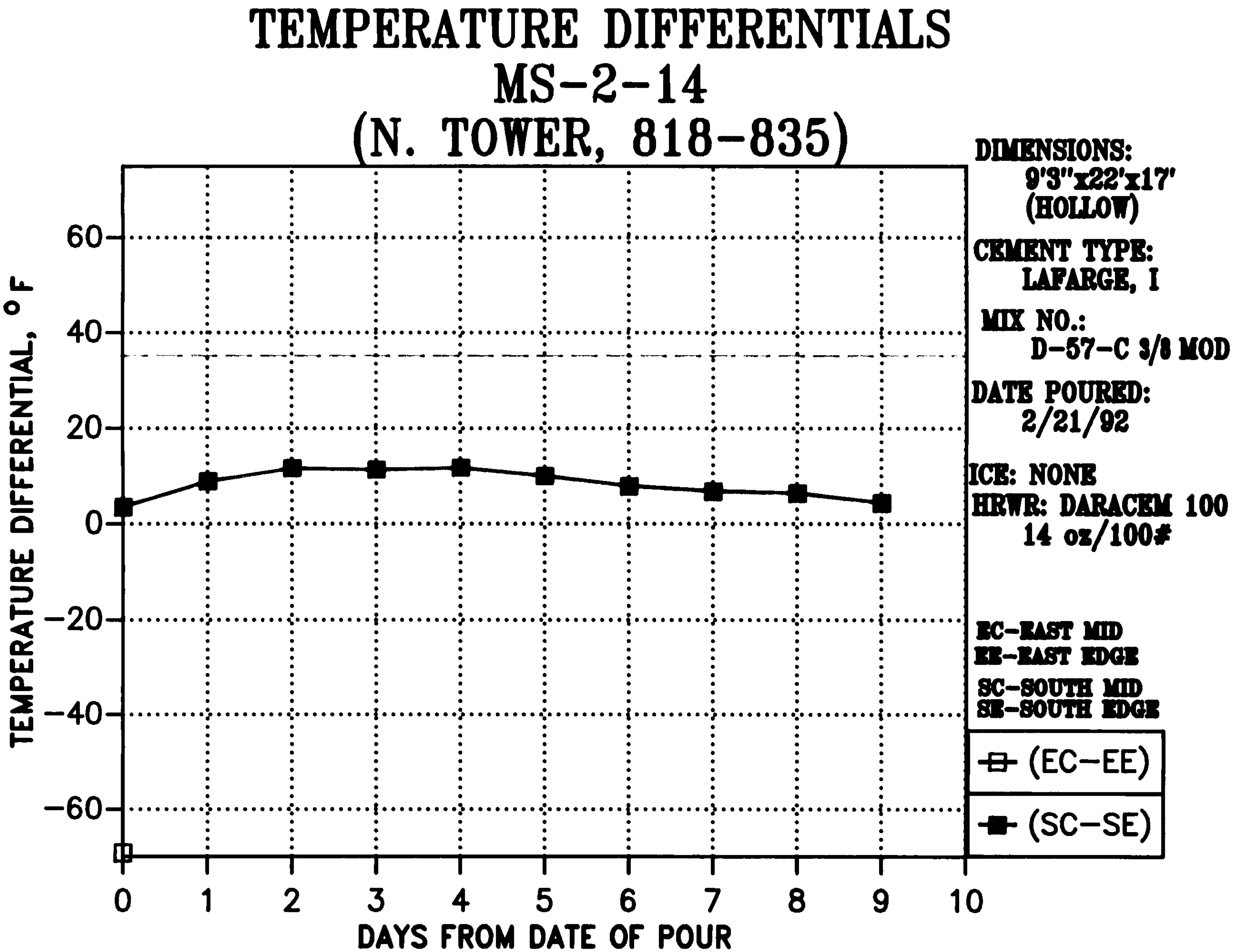
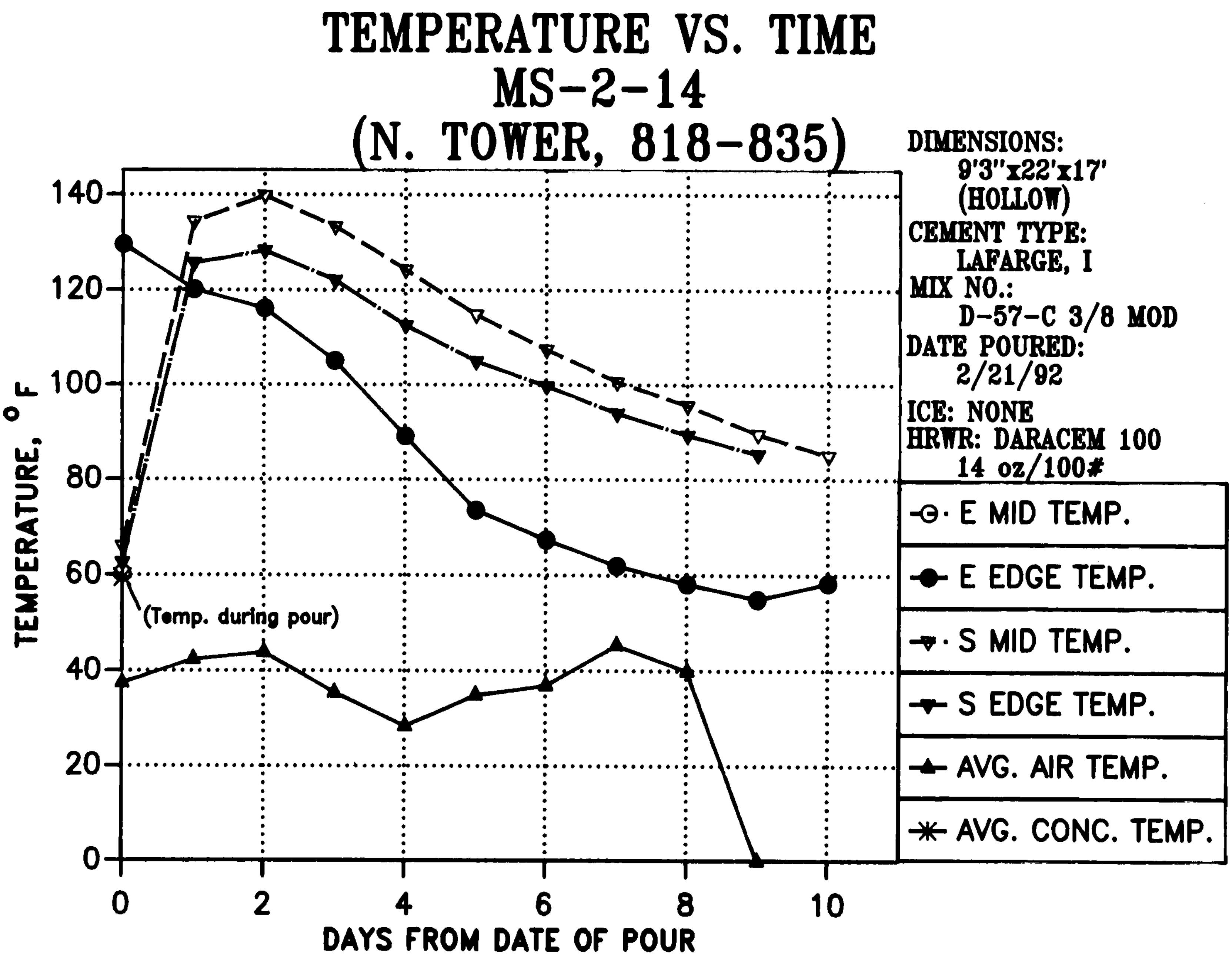

TEMPERATURE DIFFERENTIALS
MS-2-14
(N. TOWER, 818-835)
DIMENSIONS:
9'3"x22'x17'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/21/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
EC-EAST MID
EE-EAST EDGE
SC-SOUTH MID
SE-SOUTH EDGE
(EC-EE)
(SC-SE)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6
7
8
9
10
DAYS FROM DATE OF POUR

Figure 45



TEMPERATURE VS. TIME
MS-2-14
(N. TOWER, 818-835)
DIMENSIONS:
9'3"x22'x17'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/21/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
S MID TEMP.
S EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
2
4
6
8
10
20
40
60
80
100
120
140

Figure 46

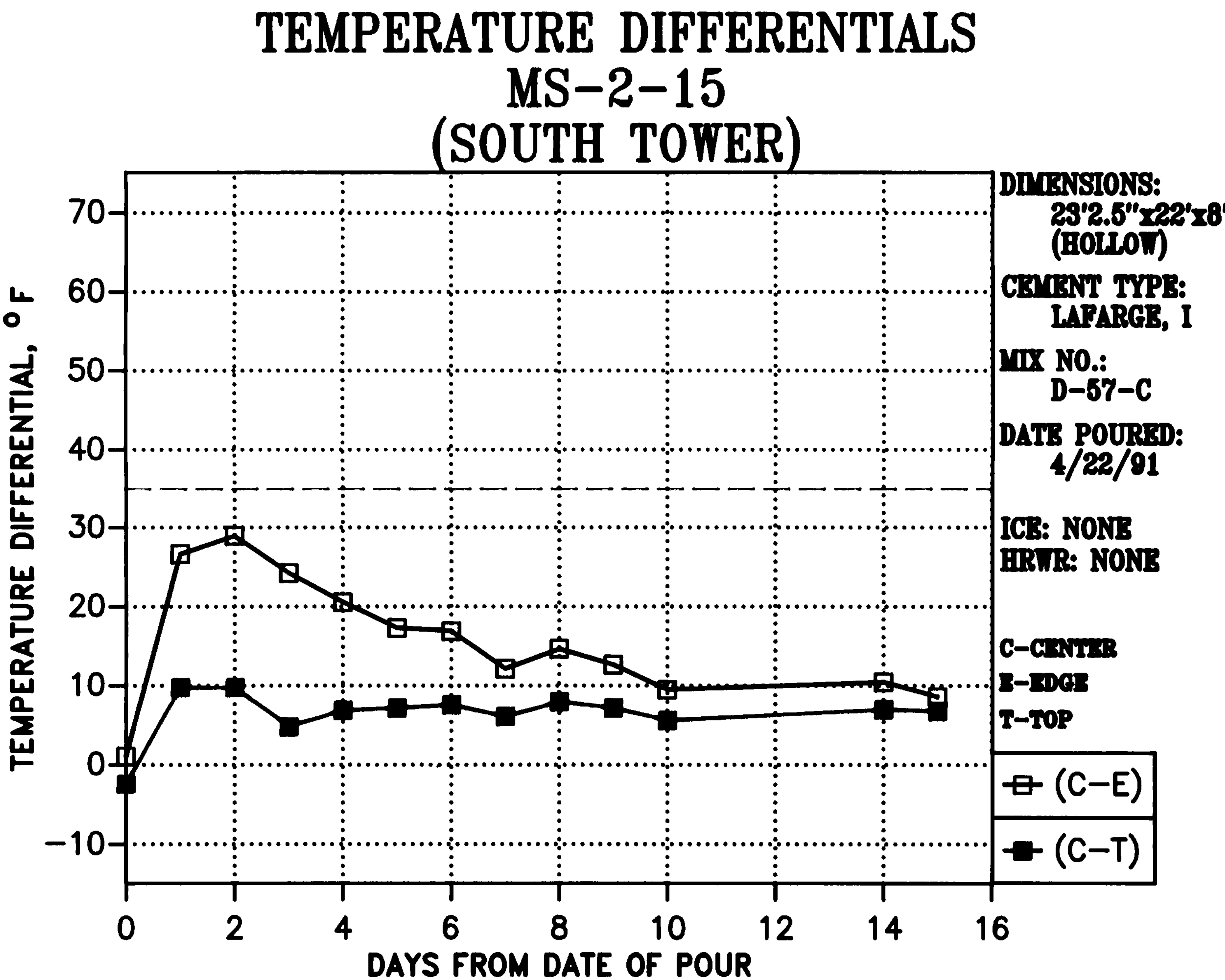
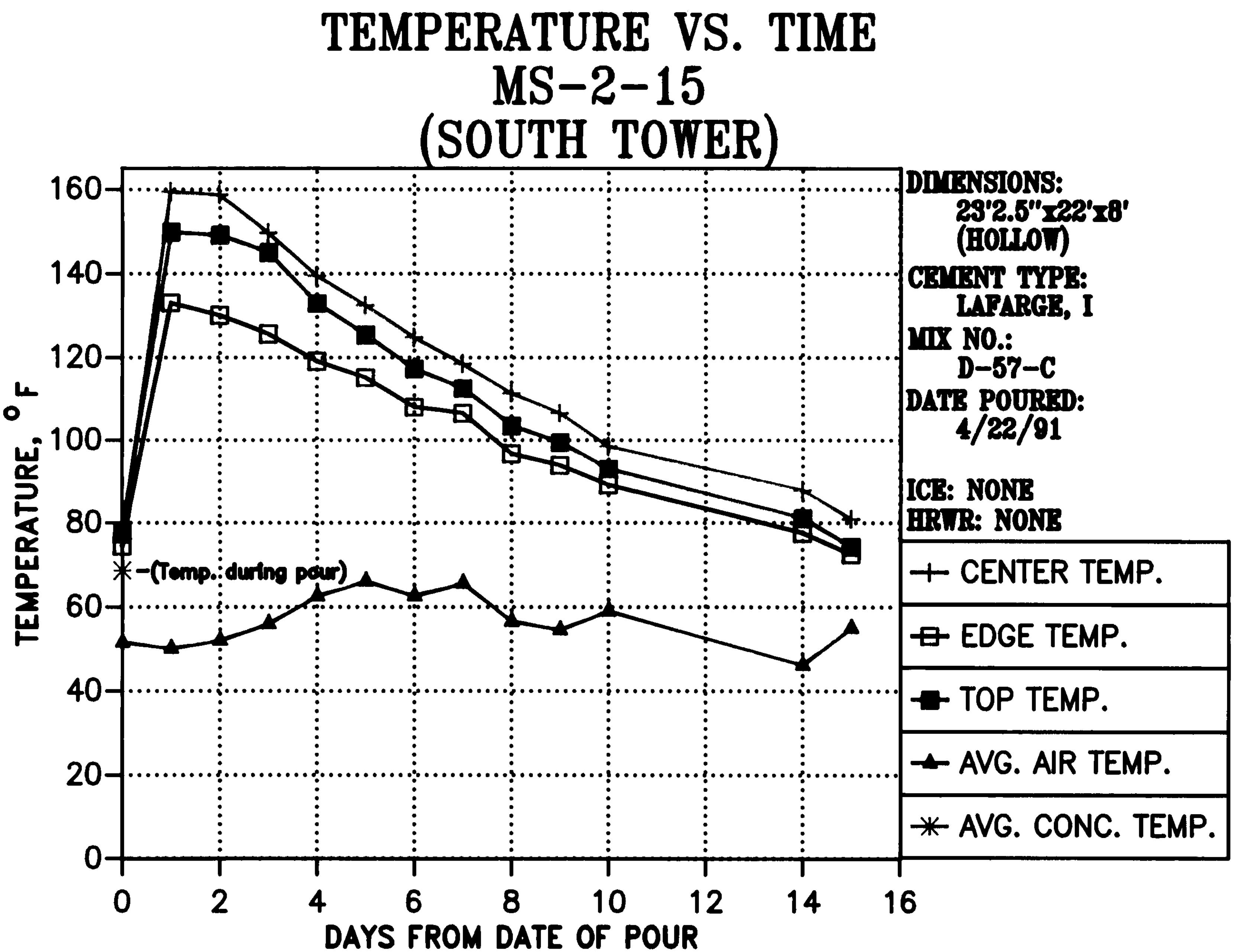

TEMPERATURE DIFFERENTIALS
MS-2-15
(SOUTH TOWER)
DIMENSIONS:
23'2.5"x22'x8'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/22/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
DAYS FROM DATE OF POUR
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16

Figure 47


TEMPERATURE VS. TIME
MS-2-15
(SOUTH TOWER)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14
16
-(Temp. during pour)
DIMENSIONS:
23'2.5"x22'x8'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
4/22/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

MS-2-16:

Location: Pylon B of the south tower, pier MS-2			
Placement Date:	5/28/91	Mix Temperature:	73.5°F
Dimensions:	23'2.5"x22'x30'*	Peak Temperature:	144.7°F
Ambient Temp.:	84.5°F	Temperature Gain:	71.2°F
Volume (cy):	239.25	Day Peak Reached:	First
Ice (#/cy):	123	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	PSP-N2
Concrete Mix:	D-57-C		

* Indicates that pylon is hollow here.

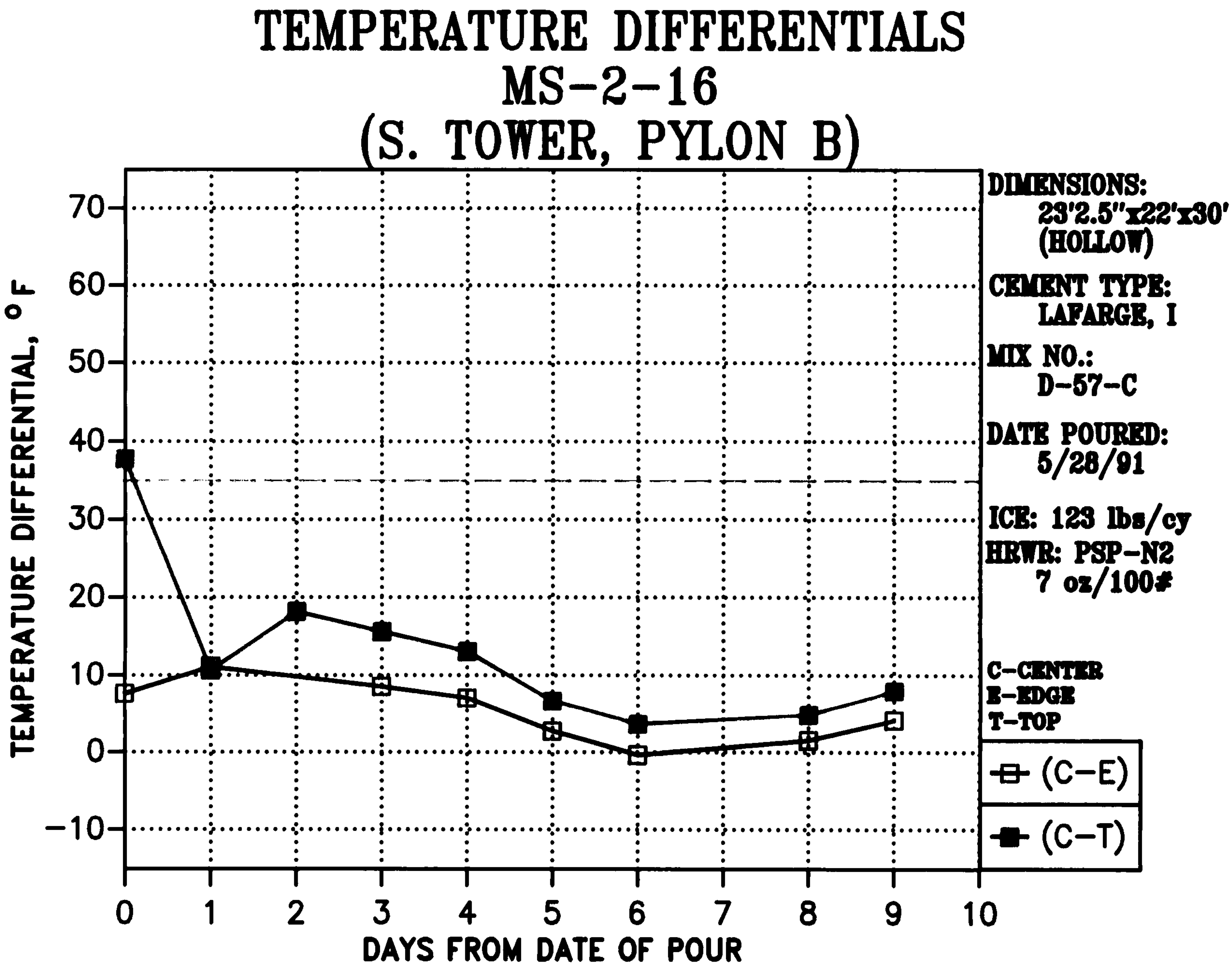
After the day of the placement, the differentials dropped substantially. On the day of the placement, however, the top temperature was so low that the center to top differential exceeded the 35°F specification limit. It is possible that the insulation was not placed soon enough on the top, so it assumed the ambient temperature. The contractor was required to take corrective action on this placement due to the non-complying temperatures which occurred on Pylon B of the north tower (placement MS-2-7). To try to prevent non-complying temperatures on this placement, the contractor placed blankets on the forms and also added ice since the ambient temperatures were still relatively high. On subsequent days, the three sensor areas cooled at about the same rate, with the center being the warmest, then the side, and finally the top. The differentials after the fifth day remained below 10°F, and no other placements were placed on top of MS-2-16 during monitoring (Figures 48 and 49).

MS-2-17:

Location: South tower, elevation 725'-737', pier MS-2			
Placement Date:	10/11/91	Mix Temperature:	71.7°F
Dimensions:	9'3"x22'x12'*	Peak Temperature:	155.4°F
Ambient Temp.:	68.5°F	Temperature Gain:	83.7°F
Volume (cy):	70.0	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	None
Cement:	Lafarge Type I		
Concrete Mix:	D-57-C, modified		

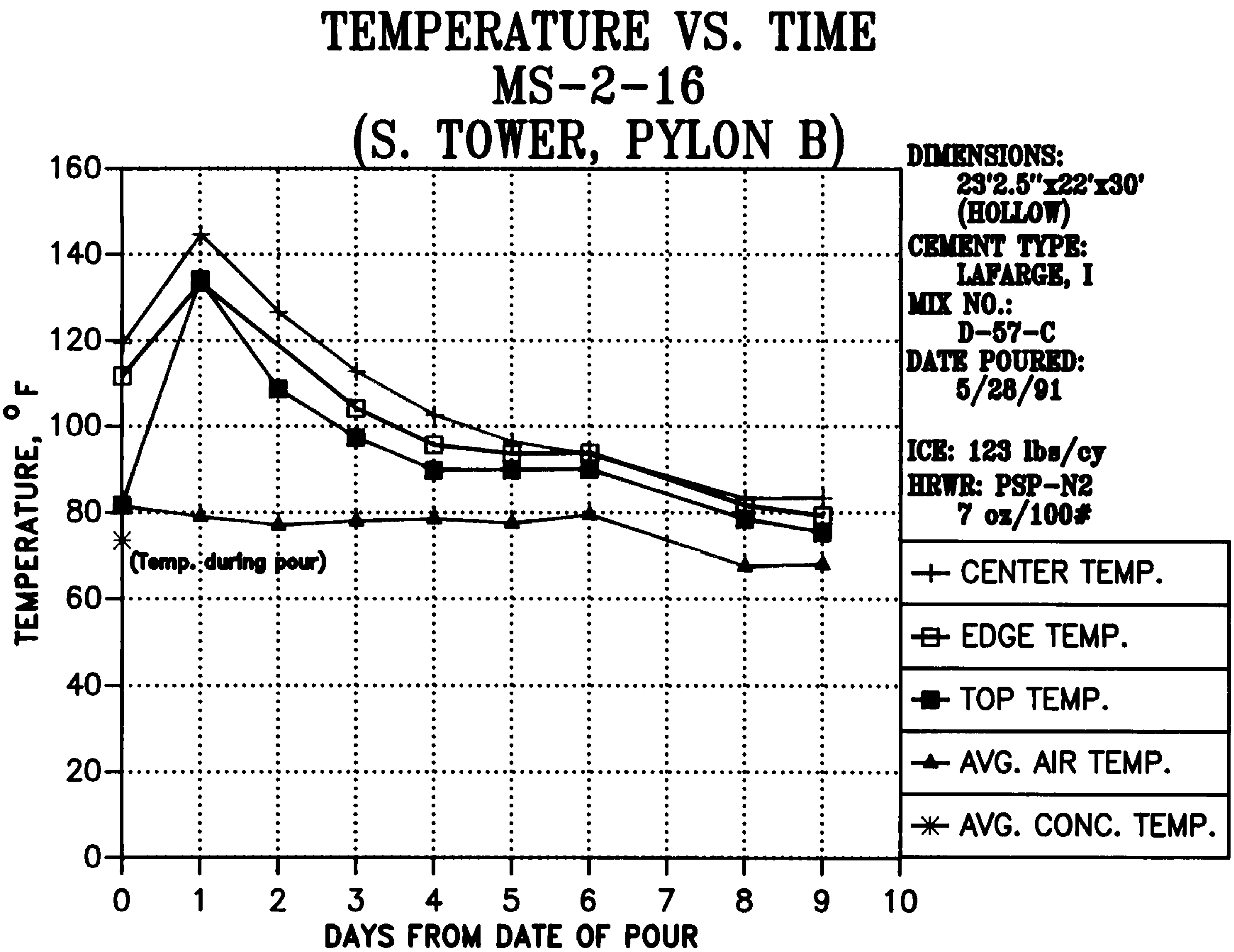
* Indicates that pylon is hollow here.

Figure 48



TEMPERATURE DIFFERENTIALS
MS-2-16
(S. TOWER, PYLON B)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
10
DAYS FROM DATE OF POUR
DIMENSIONS:
23'2.5"x22'x30'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
5/28/91
ICE: 123 lbs/cy
HRWR: PSP-N2
7 oz/100#
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 49



TEMPERATURE VS. TIME
MS-2-16
(S. TOWER, PYLON B)
160
140
120
100
80
60
40
20
0
TEMPERATURE, °F
0
1
2
3
4
5
6
7
8
9
10
DAYS FROM DATE OF POUR
(Temp. during pour)
DIMENSIONS:
23'2.5"x22'x30'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
5/28/91
ICE: 123 lbs/cy
HRWR: PSP-N2
7 oz/100#
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

The temperature sensors were placed at the eastern and western sides of the placement.

After the initial peaks on the first day, the four areas continued to cool at about the same rate, with the side temperatures appearing to be more affected by the ambient temperature than the center temperatures. Since the western center did not reach as high a peak as the other three areas, the west center to side differential did exceed the specified limit for days one and two after the placement date. After that, the side continued to cool at the same rate, but the center cooled much faster. During the entire monitoring period, the eastern and western center temperatures were practically the same, and the side temperatures differed only by an average of about 10°F. On the fourth day after the date of placement, the next placement was placed on top of MS-2-17. While all four temperature sensors did record an increase to some degree or a slower cooling rate, it is difficult to say whether this was caused by the new placement, or by the ambient temperature increase of 20°F over two days (Figures 50 and 51). One could conclude that the center temperatures were more affected by the new placement than the side temperatures, and that the side temperatures increased because of the ambient temperature increase.

MS-2-18:

Location: South tower, elevation 737'-748', pier MS-2

Placement Date:	10/15/91	Mix Temperature:	63.8°F
Dimensions:	9'3"x22'x11'*	Peak Temperature:	160.5°F
Ambient Temp.:	57.1°F	Temperature Gain:	96.7°F
Volume (cy):	68.25	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	07
Cement:	Lafarge Type I	Brand:	PSP-N2
Concrete Mix:	D-57-C, modified		

* Indicates that pylon is hollow here.

Figure 50

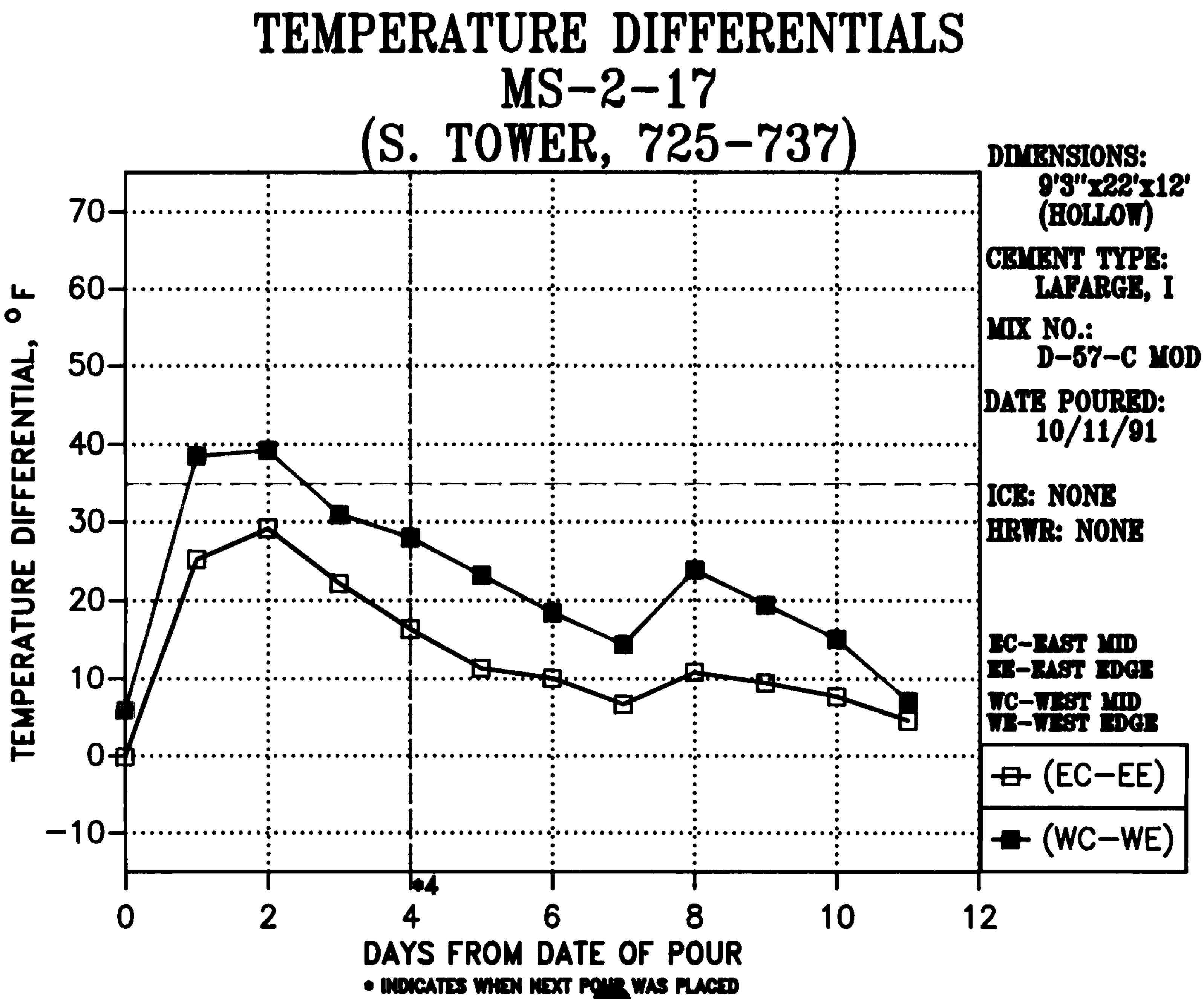
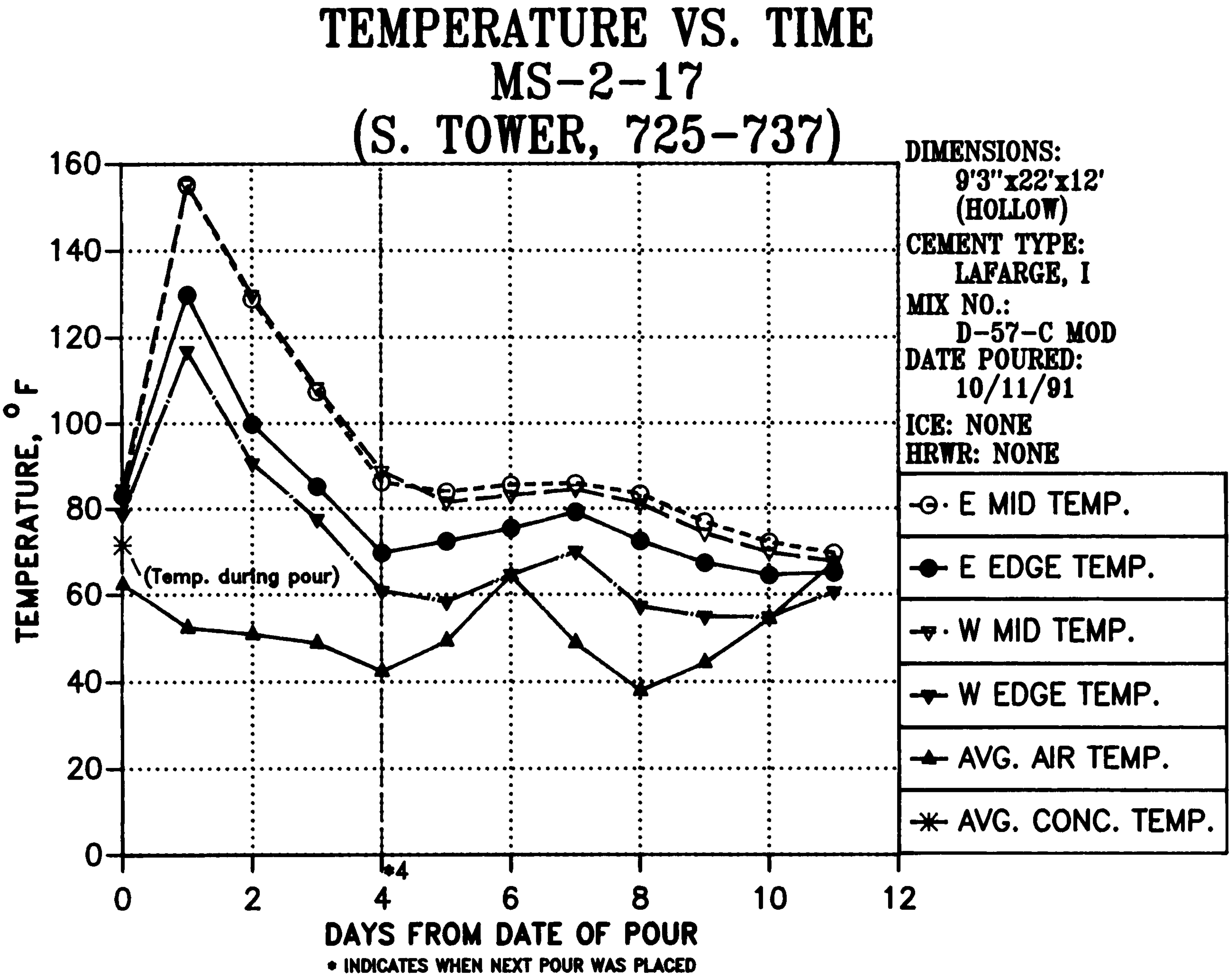

TEMPERATURE DIFFERENTIALS
MS-2-17
(S. TOWER, 725-737)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
10/11/91
ICE: NONE
HRWR: NONE
EC-EAST MID
EE-EAST EDGE
WC-WEST MID
WE-WEST EDGE
(EC-EE)
(WC-WE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
*4
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED

Figure 51


TEMPERATURE VS. TIME
MS-2-17
(S. TOWER, 725-737)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
10/11/91
ICE: NONE
HRWR: NONE
E MID TEMP.
E EDGE TEMP.
W MID TEMP.
W EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
*4
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED

Temperature sensors were placed at the eastern and western walls of the placement.

After the initial peak on the first day after pouring, the center temperatures stagnated for a day and then dropped, but the sides began cooling right away. The center temperatures remained within a few degrees of one another, as did the side temperatures. As the cooling became normalized (the sides' cooling rate slowed, and the centers' cooling rate stayed the same), the temperature differentials decreased, and never exceeded the 35°F limit (Figures 52 and 53). No other placements were placed during monitoring of MS-2-18.

MS-2-19:

Location: South tower, elevation 748'-768', pier MS-2

Placement Date:	11/9/91	Mix Temperature:	62.0°F
Dimensions:	9'3"x22'x20'*	Peak Temperature:	141.0°F
Ambient Temp.:	31.0°F	Temperature Gain:	79.0°F
Volume (cy):	96.5	Day Peak Reached:	First
Ice (#/cy):	None	HRWR (oz/100# cement):	16
Cement:	Lafarge Type I	Brand:	Daracem 100
Concrete Mix:	D-57-C, modified with ¾" chips		

* Indicates that pylon is hollow here.

The sensors were placed in the western and northern sides of the tower.

All four areas peaked on the first day at about the same temperature, but afterwards cooled at different rates. The western side of the tower cooled much more slowly than the northern side, and its differentials were much lower, very close to zero. The northern differentials were higher because the northern side and center cooled much more rapidly than the western side, and because the northern side cooled faster than the center. Still, the differentials for both sides stayed within 10°F of zero (Figures 54 and 55). No other placements were placed during monitoring.

MS-2-20:

Location: South tower, elevation 768'-780', pier MS-2

Placement Date:	12/18/91	Mix Temperature:	60.5°F
Dimensions:	9'3"x22'x12'*	Peak Temperature:	156.1°F
Ambient Temp.:	24.0°F	Temperature Gain:	95.6°F
Volume (cy):	58.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

The temperature sensors were placed at the western and southern sides of the tower.

The western side reached the highest peak, almost 20°F more than the other three areas. After the fourth day after the placement date, the western side to center differential decreased a great deal and approached zero. The southern differential began to approach zero as early as the second day after the placement date. The southern temperatures cooled much, much more rapidly than the western temperatures, and were always much lower than the western temperatures, as well (Figures 56 and 57). This could have been due to sun exposure and shading effects from the other tower. No other placements were placed during this monitoring period.

MS-2-21:

Location: South tower, elevation 780'-800', pier MS-2

Placement Date:	1/7/92	Mix Temperature:	62.5°F
Dimensions:	9'3"x22'x20'*	Peak Temperature:	150.5°F
Ambient Temp.:	41.0°F	Temperature Gain:	88.0°F
Volume (cy):	97.25	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

Figure 52

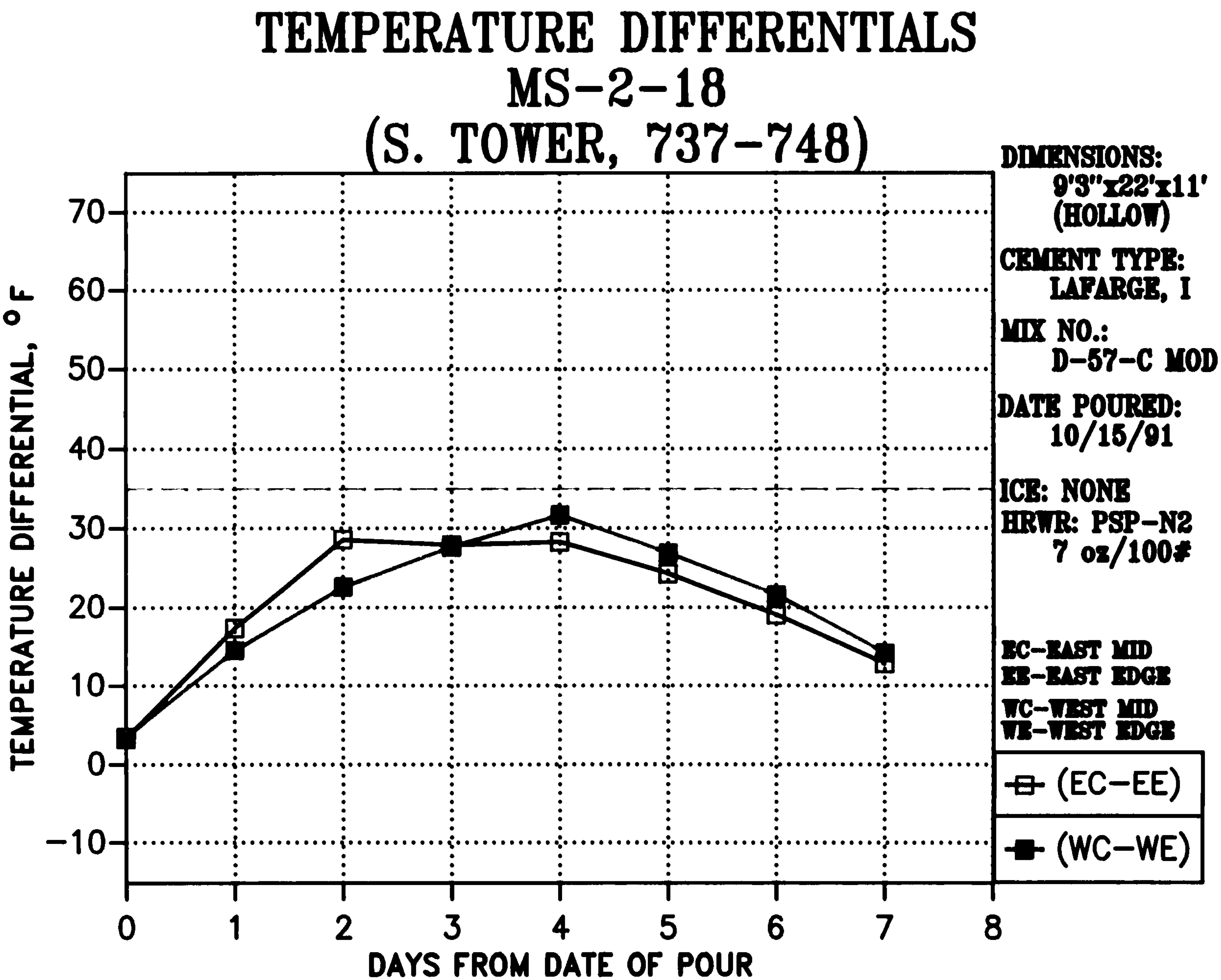

TEMPERATURE DIFFERENTIALS
MS-2-18
(S. TOWER, 737-748)
DIMENSIONS:
9'3"x22'x11'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C MOD
DATE POURED:
10/15/91
ICE: NONE
HRWR: PSP-N2
7 oz/100#
EC-EAST MID
EE-EAST EDGE
WC-WEST MID
WE-WEST EDGE
(EC-EE)
(WC-WE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
DAYS FROM DATE OF POUR

Figure 53

TEMPERATURE VS. TIME
MS-2-18
(S. TOWER, 737-748)

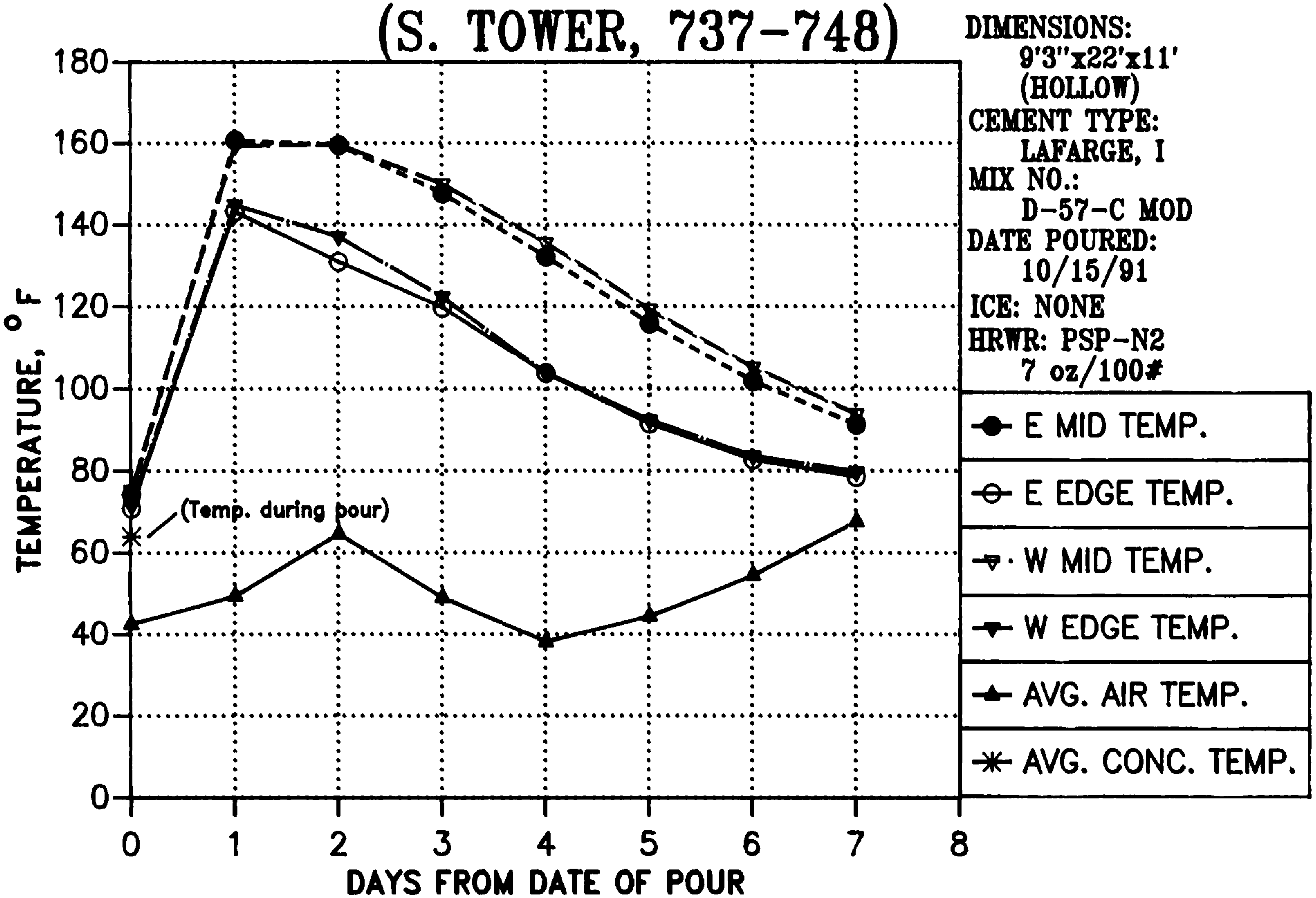


Figure 54

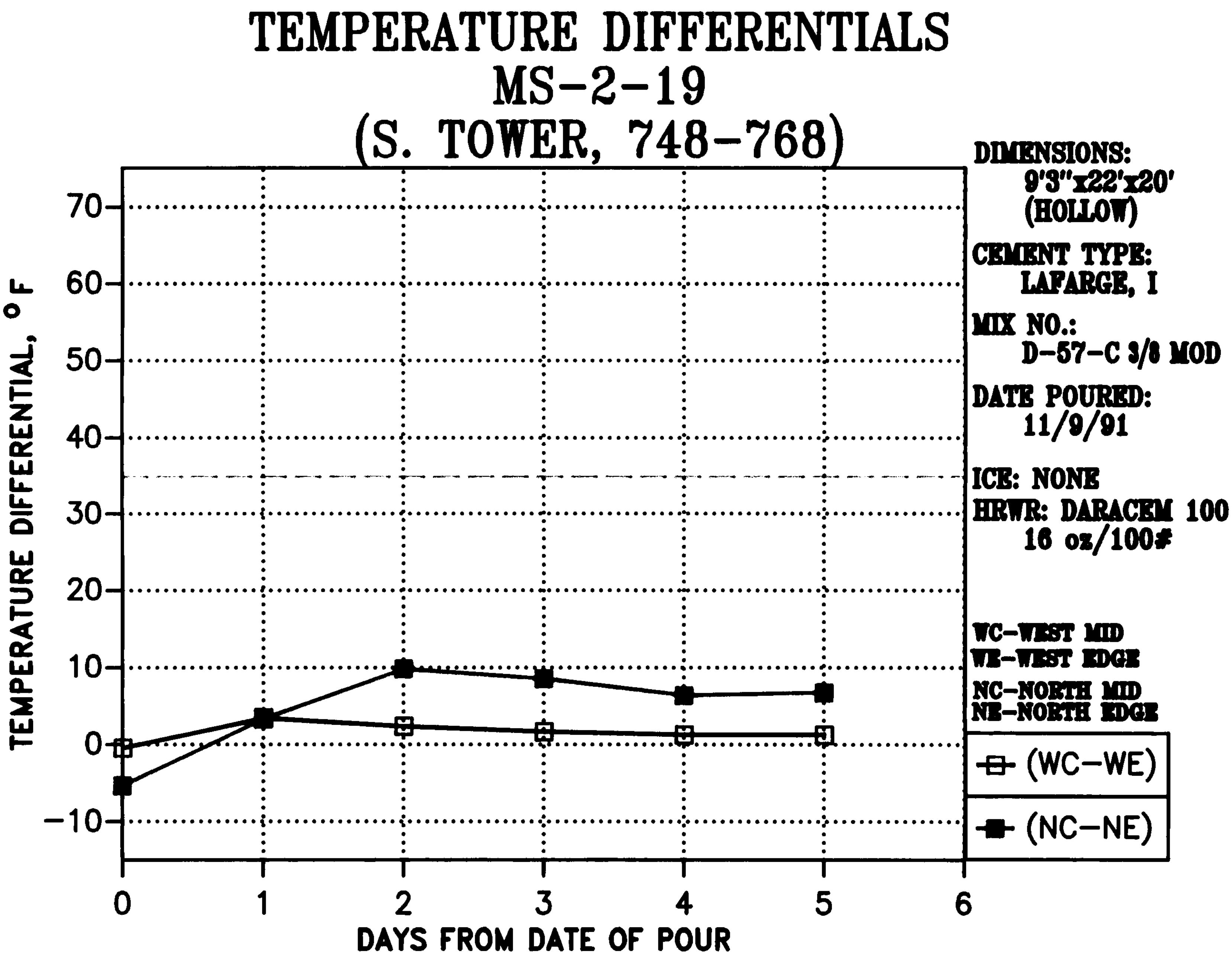
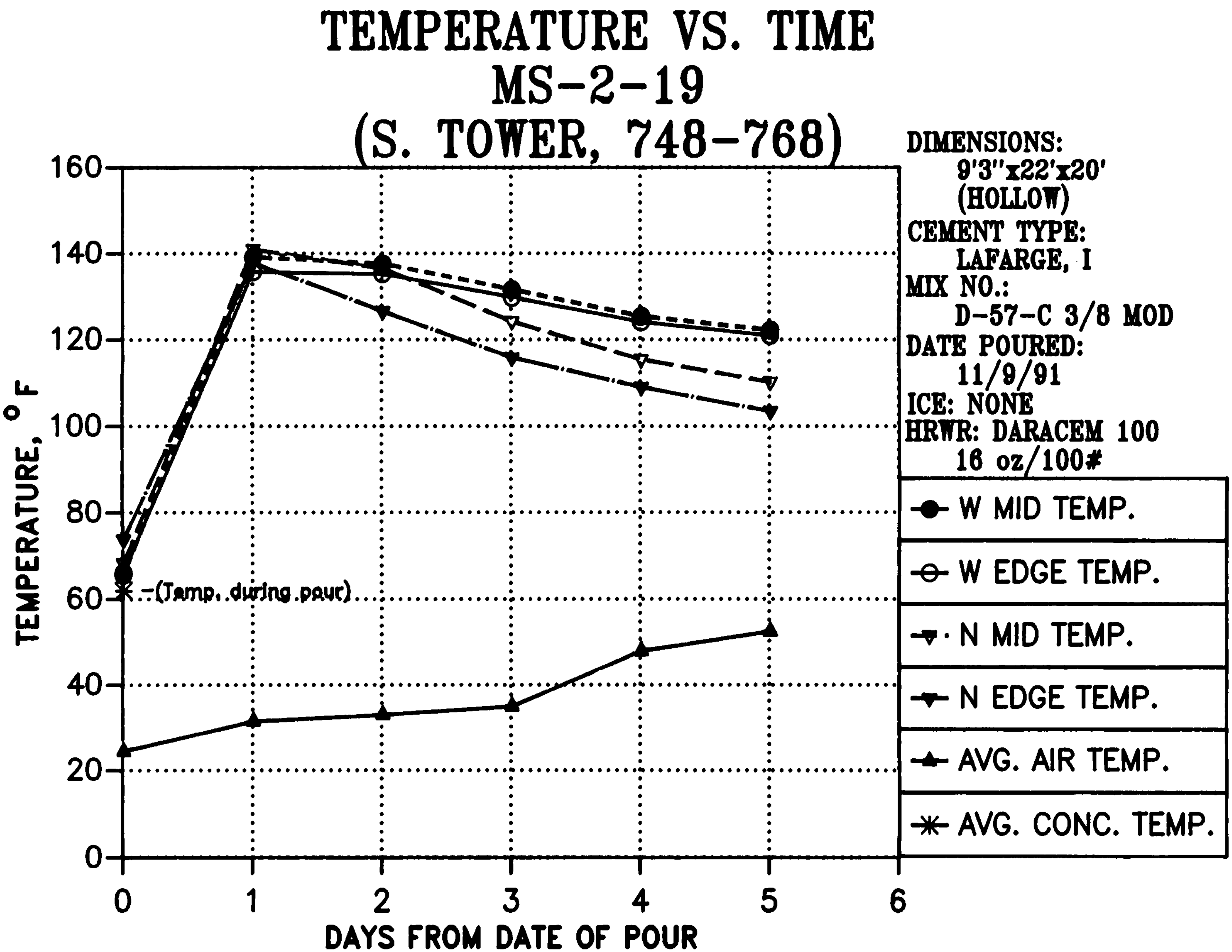
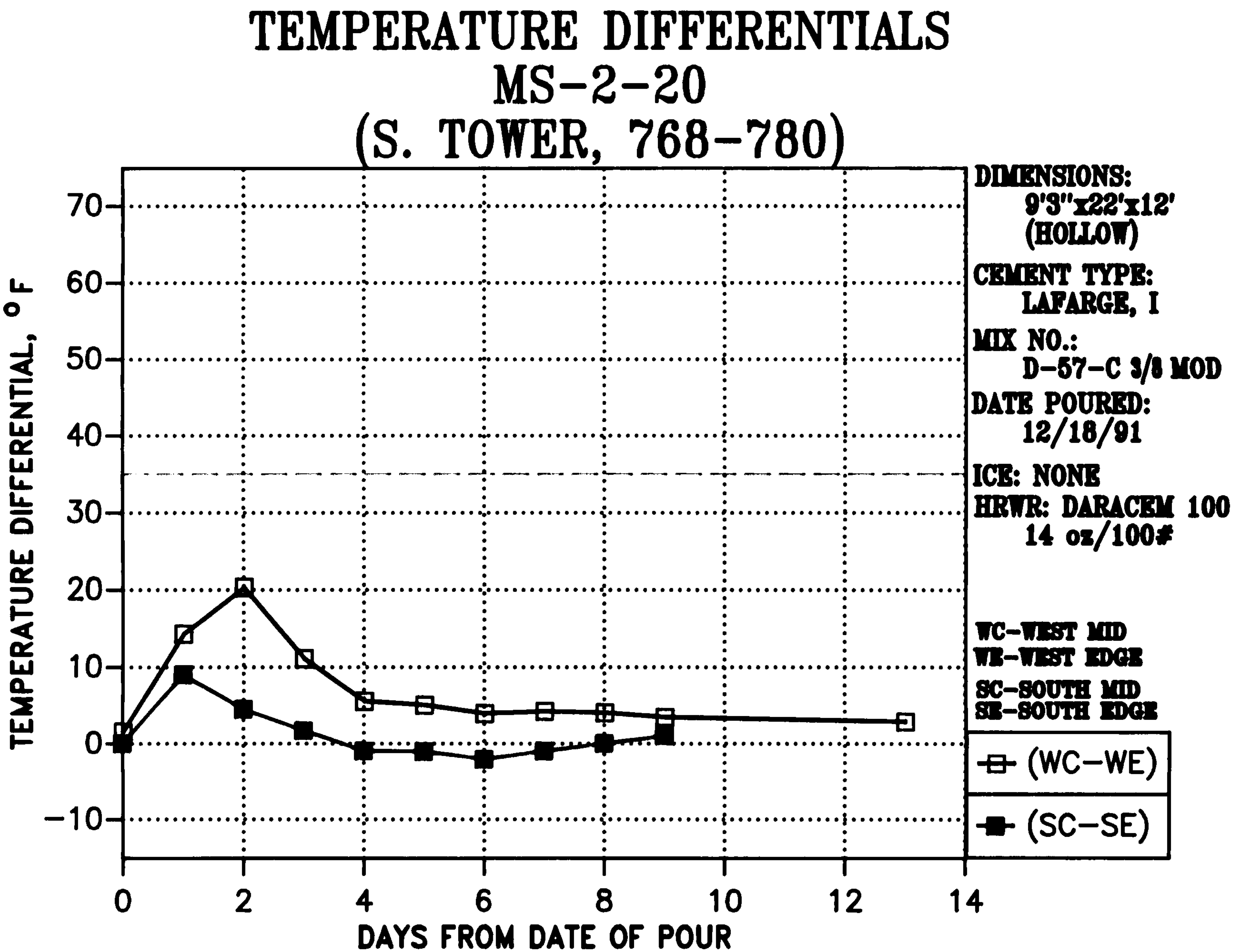

TEMPERATURE DIFFERENTIALS
MS-2-19
(S. TOWER, 748-768)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
11/9/91
ICE: NONE
HRWR: DARACEM 100
16 oz/100#
WC-WEST MID
WE-WEST EDGE
NC-NORTH MID
NE-NORTH EDGE
(WC-WE)
(NC-NE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
DAYS FROM DATE OF POUR

Figure 55



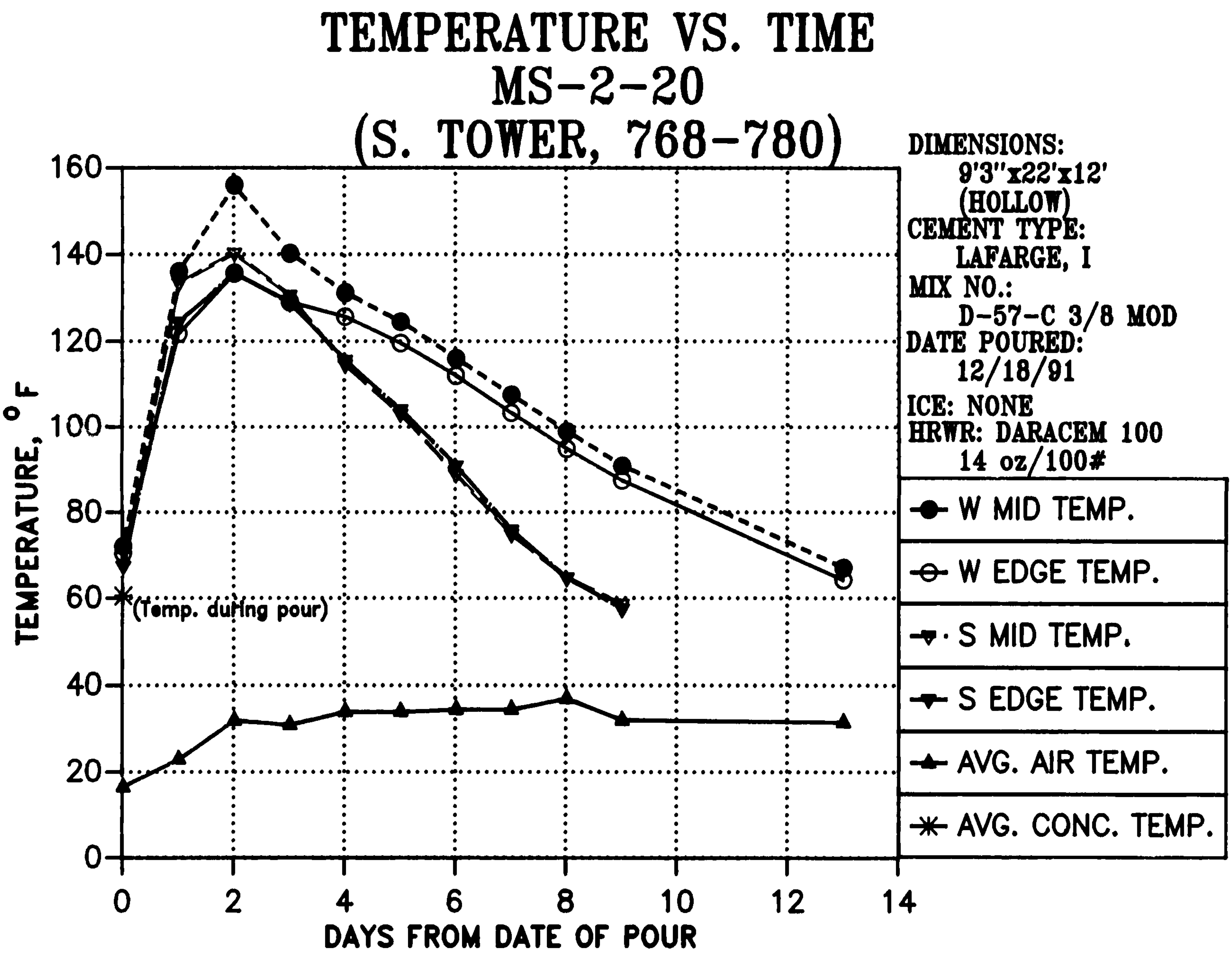
TEMPERATURE VS. TIME
MS-2-19
(S. TOWER, 748-768)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
-(Temp. during pour)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
11/9/91
ICE: NONE
HRWR: DARACEM 100
16 oz/100#
W MID TEMP.
W EDGE TEMP.
N MID TEMP.
N EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

Figure 56



TEMPERATURE DIFFERENTIALS
MS-2-20
(S. TOWER, 768-780)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
DAYS FROM DATE OF POUR
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
12/18/91
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
WC-WEST MID
WE-WEST EDGE
SC-SOUTH MID
SE-SOUTH EDGE
(WC-WE)
(SC-SE)

Figure 57


TEMPERATURE VS. TIME
MS-2-20
(S. TOWER, 768-780)
DIMENSIONS:
9'3"x22'x12'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
12/18/91
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
W MID TEMP.
W EDGE TEMP.
S MID TEMP.
S EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14

The temperature sensors were again placed on the western and southern sides of the tower.

Once again, the peaks were all very close, with the western center peak being only about 10°F higher than the other three peaks. After the concrete temperatures peaked, the western center and side temperatures gradually approached one another, until at the end of monitoring the differential was essentially zero. The southern differential started out positive, and suddenly became negative on the third day, because the center had a drastic cool-down, while the side followed a cooling pattern similar to that of the western center and side. The southern differential also approached zero by the end of monitoring, but it was negative (the side was warmer than the center, which is odd). The western side was always much warmer than the southern side (Figures 58 and 59). No other placements were placed during monitoring of MS-2-21.

MS-2-22:

Location: South tower, elevation 800'-818', pier MS-2

Placement Date:	1/30/92	Mix Temperature:	62.5°F
Dimensions:	9'3"x22'x18'*	Peak Temperature:	146.1°F
Ambient Temp.:	39.0°F	Temperature Gain:	83.6°F
Volume (cy):	87.5	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ⅜" chips

* Indicates that pylon is hollow here.

The temperature sensors were again placed in the western and southern sides of the tower.

After the first day, the temperature sensors in the southern side of the tower were disconnected, or no longer used. The western side and center cooled at about the same rate, and the temperature differential for the west was low, remaining below 10°F during the monitoring period (Figures 60 and 61). No other placements were placed during monitoring of MS-2-22.

MS-2-23:

Location: South tower, elevation 818′-835′, pier MS-2

Placement Date:	2/13/92	Mix Temperature:	57.5°F
Dimensions:	9′3″x22′x17′*	Peak Temperature:	142.8°F
Ambient Temp.:	33.0°F	Temperature Gain:	85.3°F
Volume (cy):	83.0	Day Peak Reached:	Second
Ice (#/cy):	None	HRWR (oz/100# cement):	14
Cement:	Lafarge Type I	Brand:	Daracem 100

Concrete Mix: D-57-C, modified with ¾" chips

* Indicates that pylon is hollow here.

The sensors were placed at the eastern and northern sides of the tower to monitor MS-2-23.

Once again, after the initial peak temperatures, the eastern center and side were very close, as were the northern center and side. Also, the north side was cooler and cooled much faster than the eastern side. For the entire monitoring period, the temperature differentials in both the east and north sides of the tower remained below 10°F (Figures 62 and 63). No other placements were placed on this placement.

C. <u>MS-3</u>

Pier MS-3 is composed of six different placements, including the footing. It was completed in approximately four months, from mid-November of 1990 through the middle of February 1991. All concrete mixes had LaFarge Type I cement in them, and no ice or super-plasticizer was added to any mixes in the pier. Sketches of the cracks found on the sides of pier MS-3 can be found in Appendix E.

Figure 58

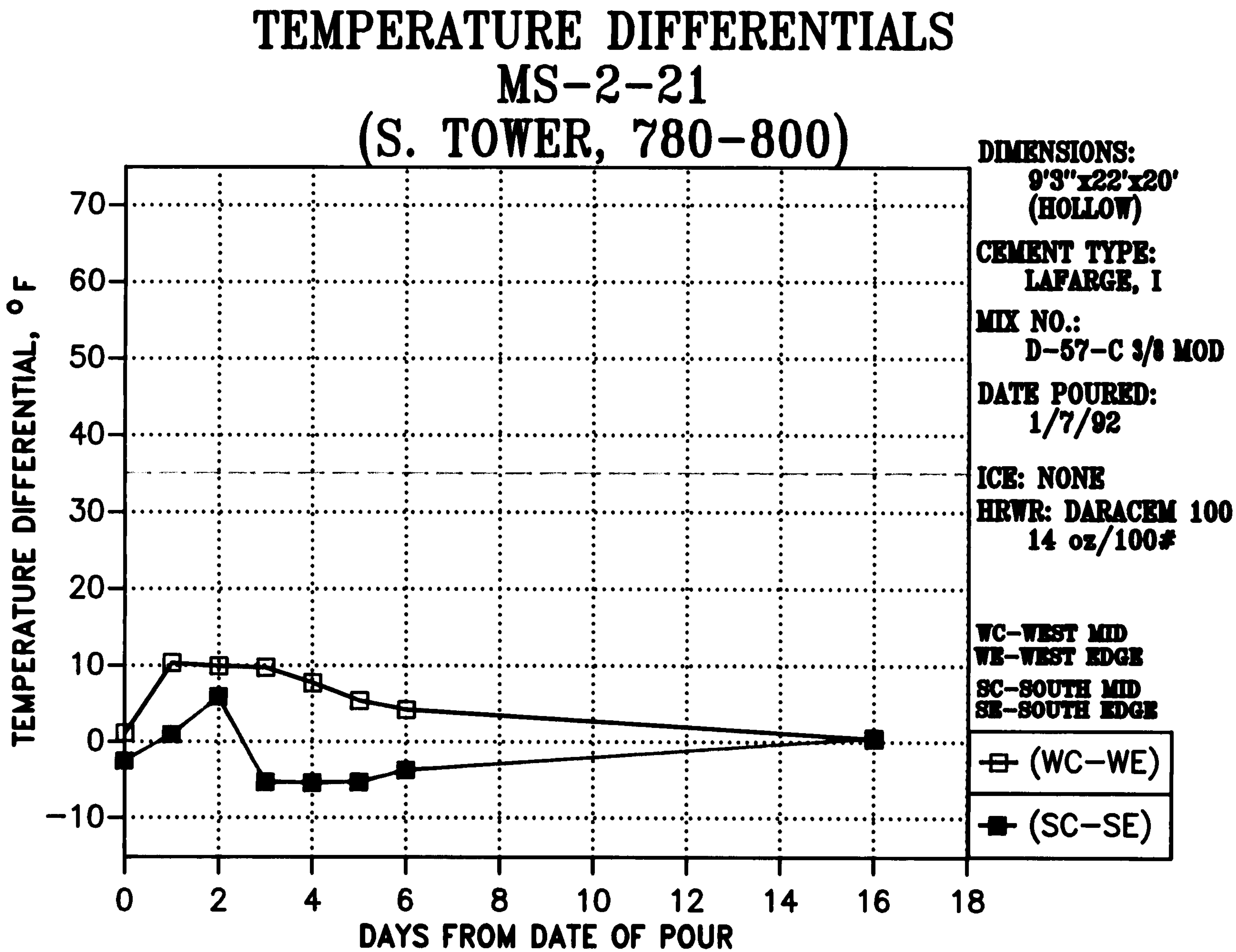
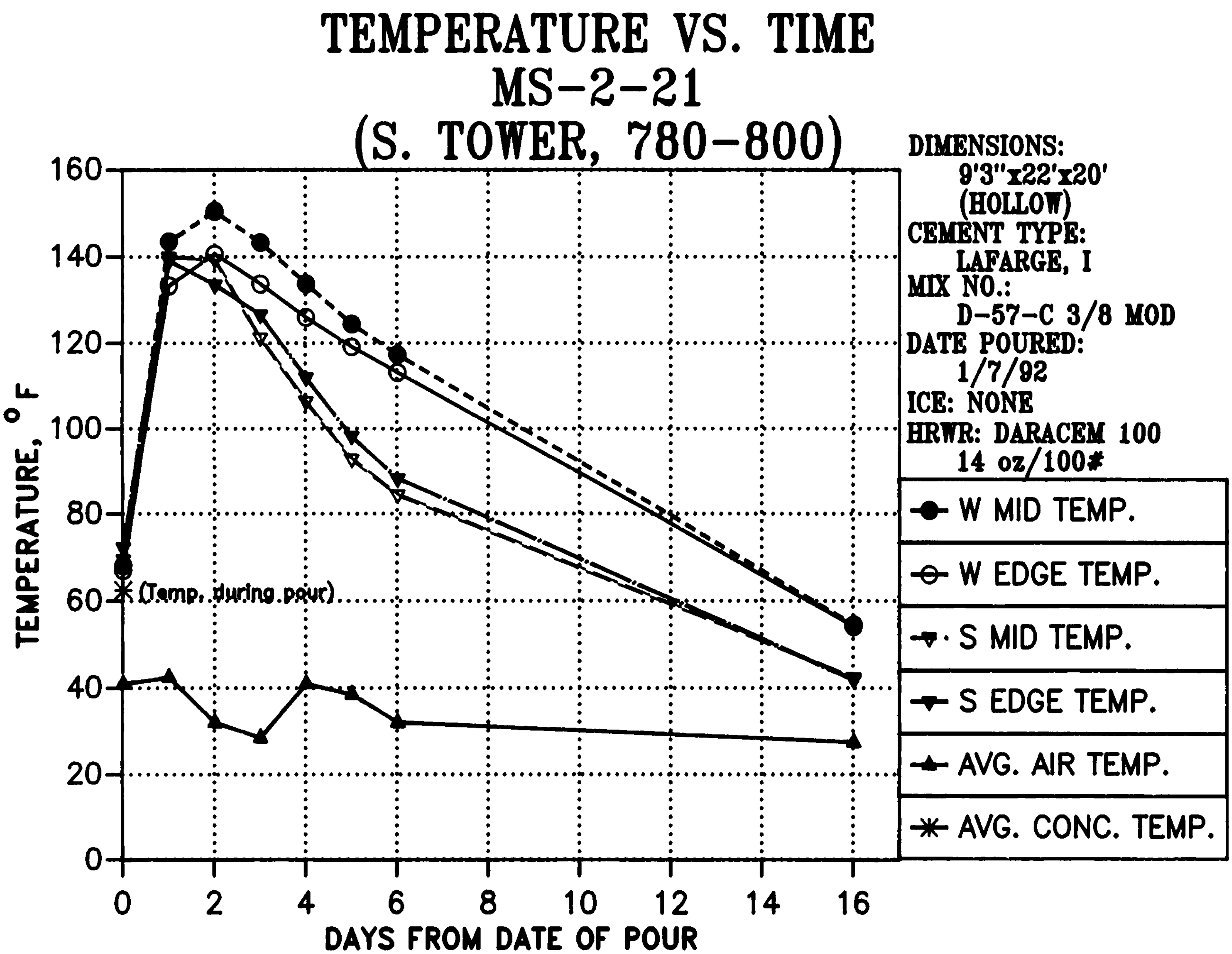

TEMPERATURE DIFFERENTIALS
MS-2-21
(S. TOWER, 780-800)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/7/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
WC-WEST MID
WE-WEST EDGE
SC-SOUTH MID
SE-SOUTH EDGE
(WC-WE)
(SC-SE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16
18
DAYS FROM DATE OF POUR

Figure 59



TEMPERATURE VS. TIME
MS-2-21
(S. TOWER, 780-800)
DIMENSIONS:
9'3"x22'x20'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/7/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
W MID TEMP.
W EDGE TEMP.
S MID TEMP.
S EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14
16

Figure 60

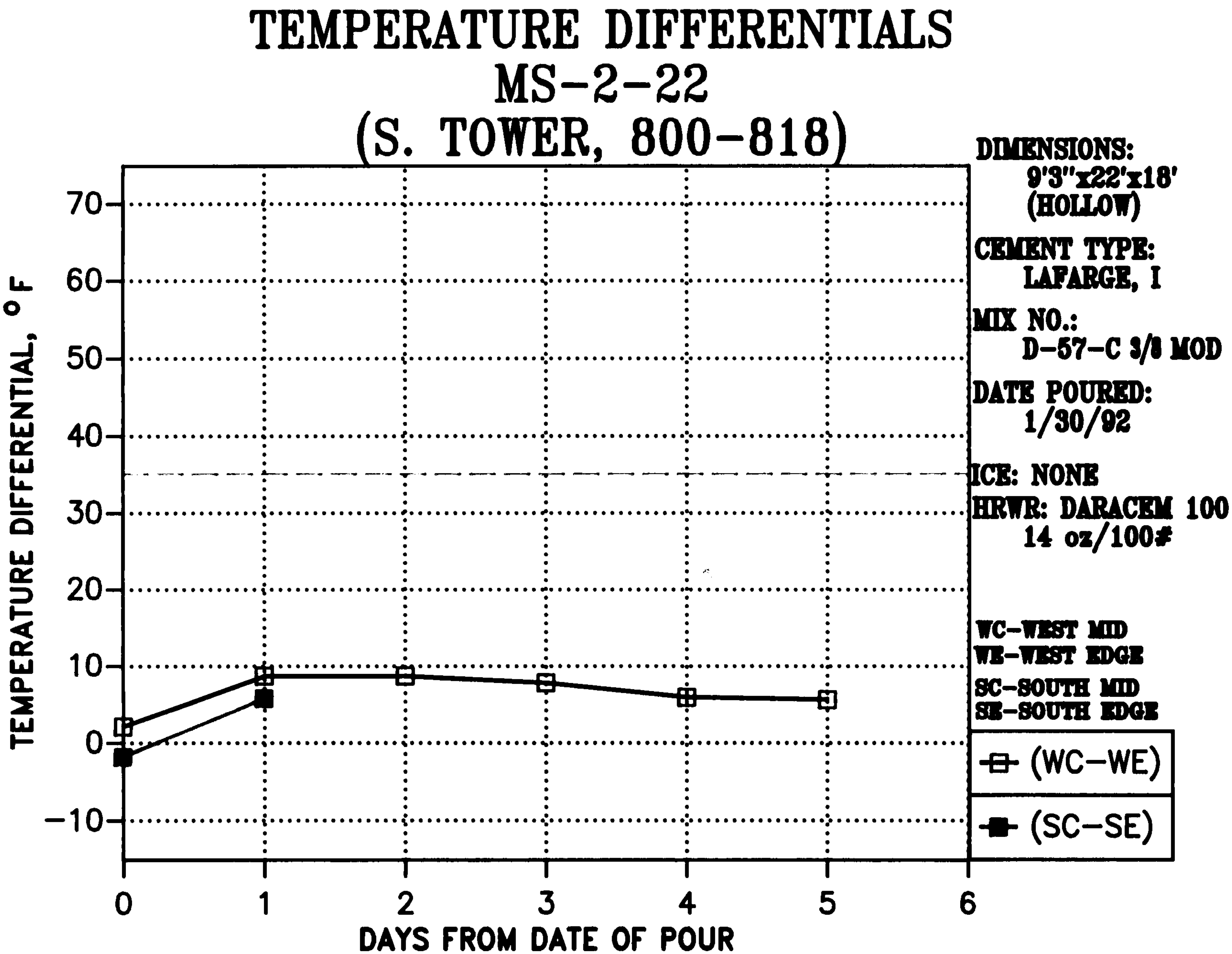
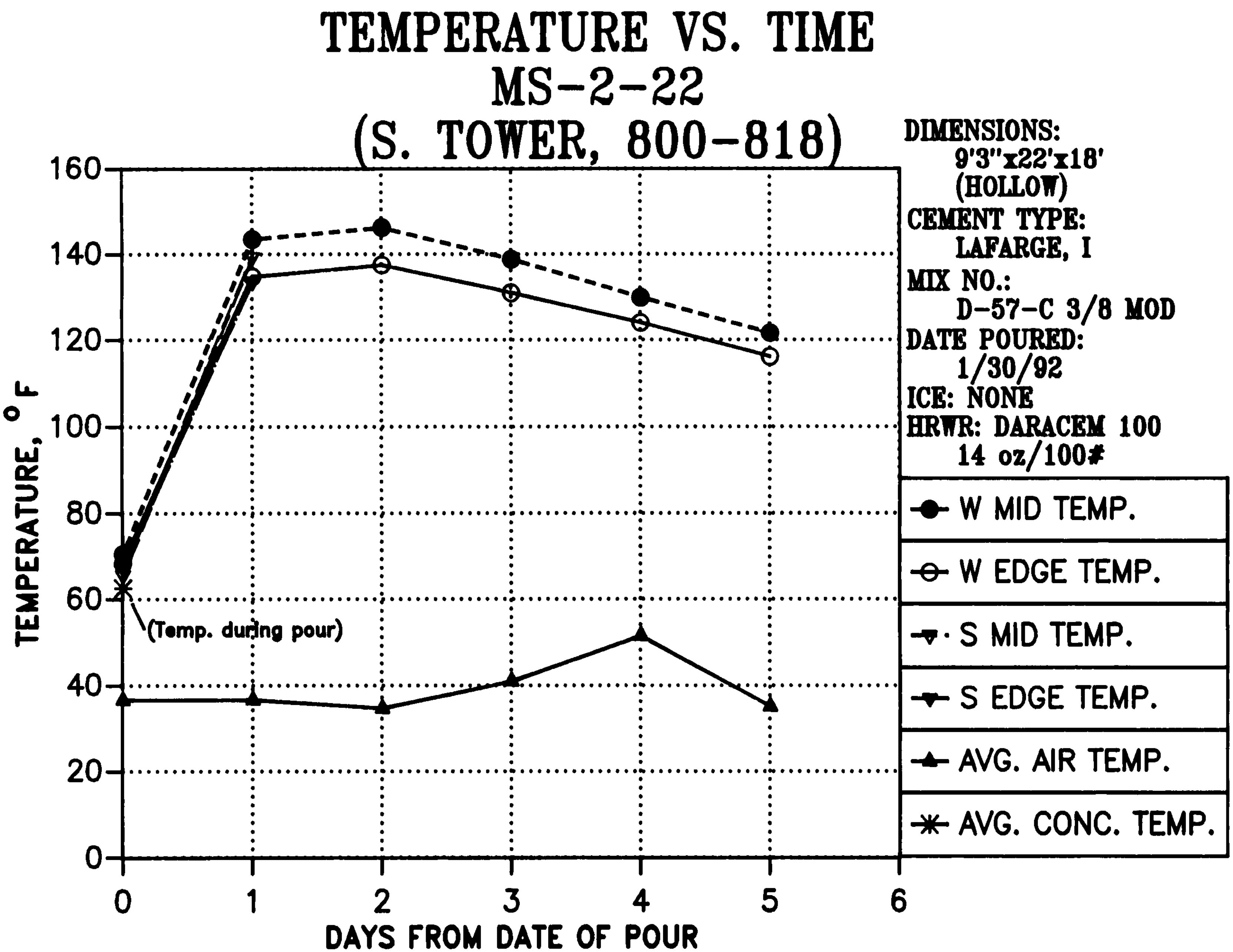
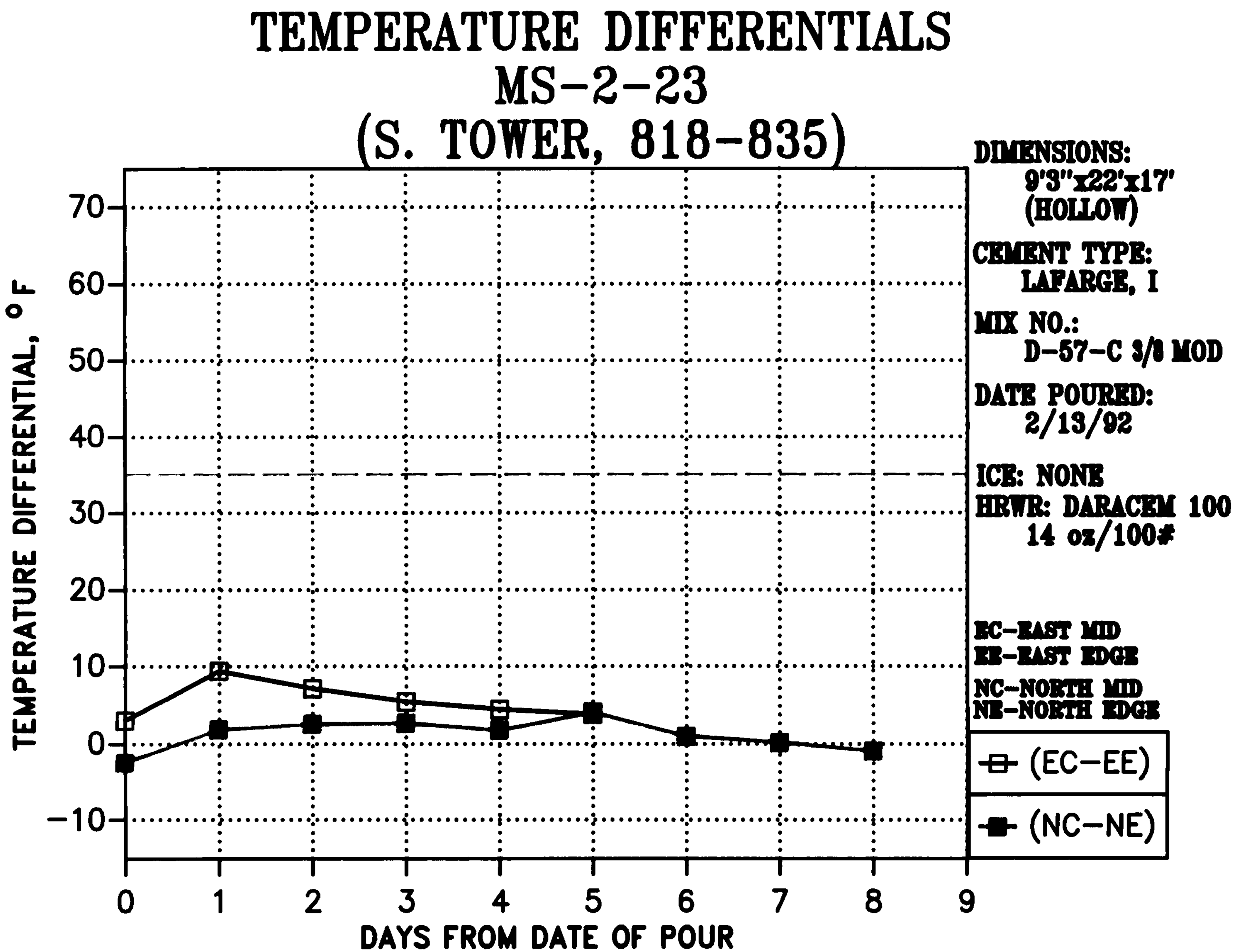

TEMPERATURE DIFFERENTIALS
MS-2-22
(S. TOWER, 800-818)
DIMENSIONS:
9'3"x22'x18'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/30/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
WC-WEST MID
WE-WEST EDGE
SC-SOUTH MID
SE-SOUTH EDGE
(WC-WE)
(SC-SE)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
DAYS FROM DATE OF POUR

Figure 61



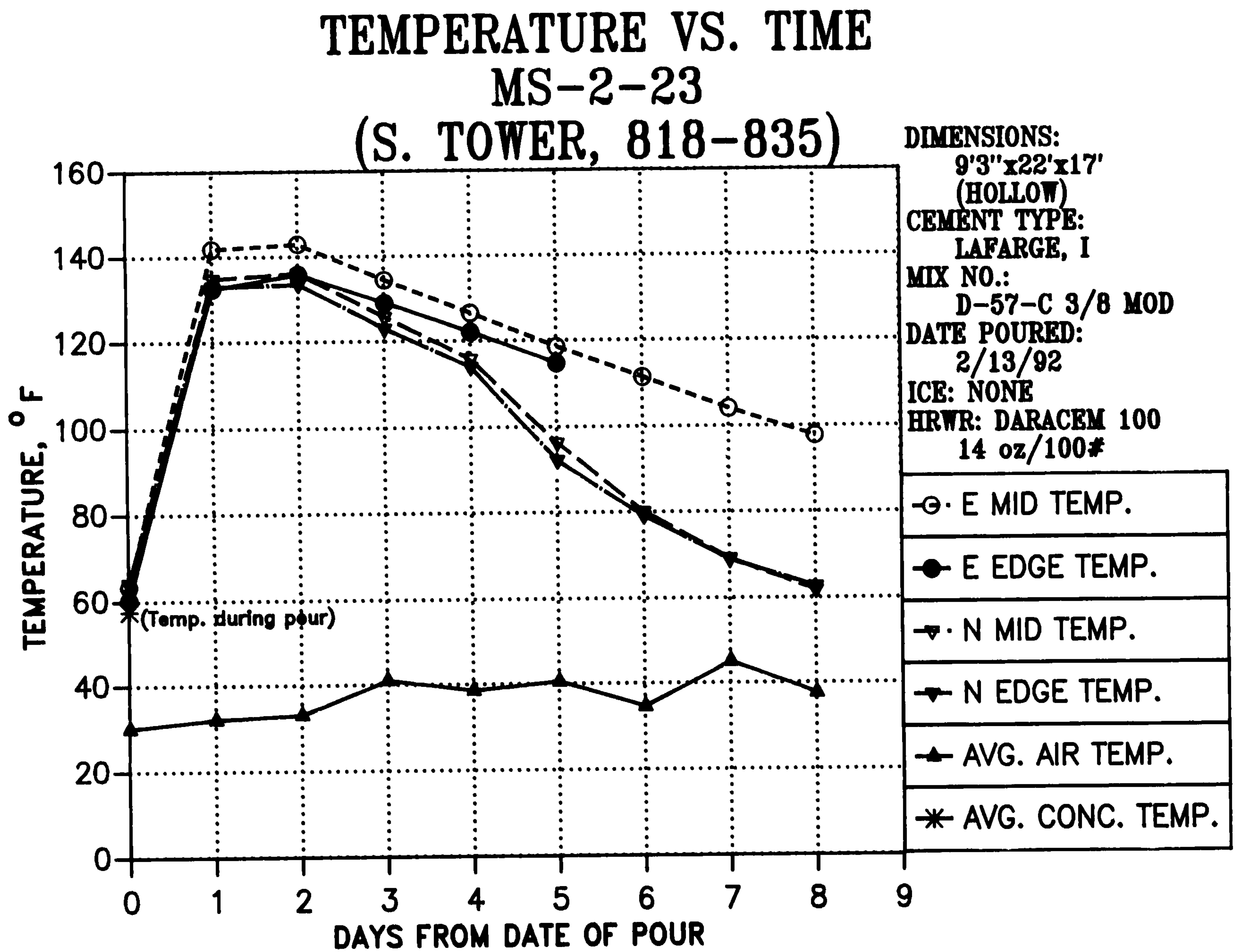
TEMPERATURE VS. TIME
MS-2-22
(S. TOWER, 800-818)
DIMENSIONS:
9'3"x22'x18'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
1/30/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
W MID TEMP.
W EDGE TEMP.
S MID TEMP.
S EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6

Figure 62



TEMPERATURE DIFFERENTIALS
MS-2-23
(S. TOWER, 818-835)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8
9
DAYS FROM DATE OF POUR
DIMENSIONS:
9'3"x22'x17'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/13/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
EC-EAST MID
EE-EAST EDGE
NC-NORTH MID
NE-NORTH EDGE
(EC-EE)
(NC-NE)

Figure 63



TEMPERATURE VS. TIME
MS-2-23
(S. TOWER, 818-835)
DIMENSIONS:
9'3"x22'x17'
(HOLLOW)
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C 3/8 MOD
DATE POURED:
2/13/92
ICE: NONE
HRWR: DARACEM 100
14 oz/100#
E MID TEMP.
E EDGE TEMP.
N MID TEMP.
N EDGE TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
1
2
3
4
5
6
7
8
9

MS-3F:

Location:	Footing of pier MS-3		
Placement Date:	11/15/90	Mix Temperature:	64.4°F
Dimensions:	53'2"x36'x8'	Peak Temperature:	133.7°F
Ambient Temp.:	61.5°F	Temperature Gain:	69.3°F
Volume (cy):	553.0	Day Peak Reached:	Eleven
Concrete Mix:	C-3WR-C		

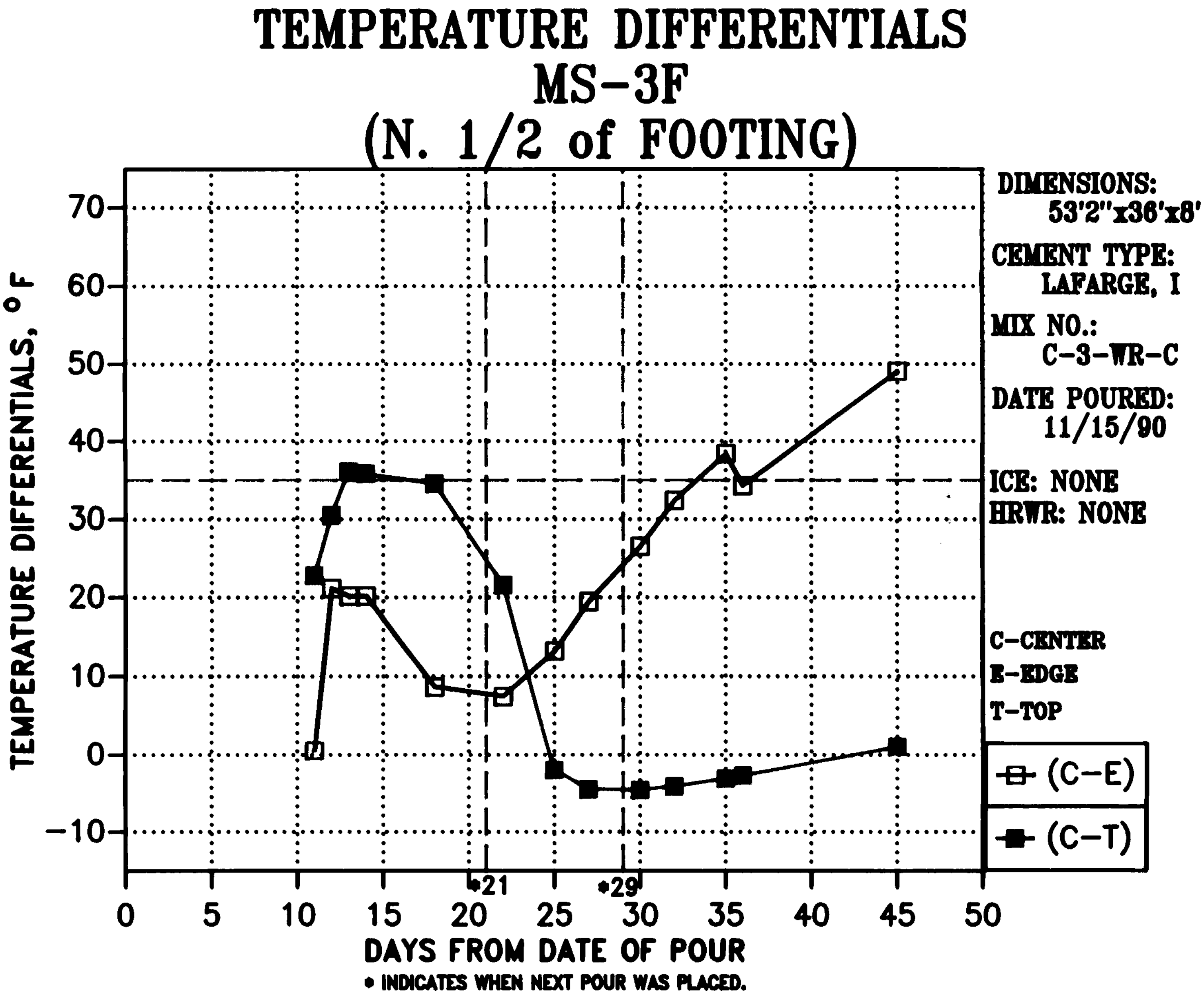
This peak temperature is probably not the actual peak of the concrete, since monitoring did not begin until the eleventh day after the date of placement, and since the peaks normally occur on the first or second day after the placement date. It is reasonable to assume that the peak was much higher than that, probably somewhere around 150°F. The temperature sensors were placed in the north half of the footing. The temperatures were not recorded until so late because the footing experienced temporary flooding on three occasions due to power (pump) failures. Due to the flooding, the monitoring recorder was damaged, and therefore, continuous temperature logging was not available.

The temperature differentials did exceed the specified limit on a few occasions. From day eleven through day twenty-one, the three areas cooled, but not at the same rate. The side cooled very quickly on the eleventh day, dropping 23.8°F overnight; and on the fourteenth day, the top and the center, when compared with the side, cooled rather quickly over a period of four days. During these four days the side dropped only 11.3°F, while the top dropped 21.5°F, and the center 22.8°F. It is obvious that the center and top temperatures correlate more closely to one another (i.e., in their cooling rates) than does the center to the side, even though the center temperature is closer to the side temperature than to the top. The center to top differential exceeded the specified limit on days thirteen and fourteen, because the top did not reach as high a peak as the center or the side. For these first twenty-one days, the center was the warmest, followed by the side, and then the top.

On day twenty-one, the next placement was placed on top of MS-3F, which had a significant effect on the temperature differentials. While the side continued to cool at the same rate throughout the monitoring period (it was unaffected by the new placement), the top temperature increased dramatically (over 25°F) in just three days. The center temperature also gradually increased as the heat generated by the new placement dissipated into this cooler area. For the remainder of the monitoring period, the top temperature was higher than the center, and the side was the lowest. On day twenty-nine, another placement was placed, and it may have had an effect on the center and top temperatures of MS-3F, since they did continue to rise afterwards, although it was not as dramatic as with the previous placement.

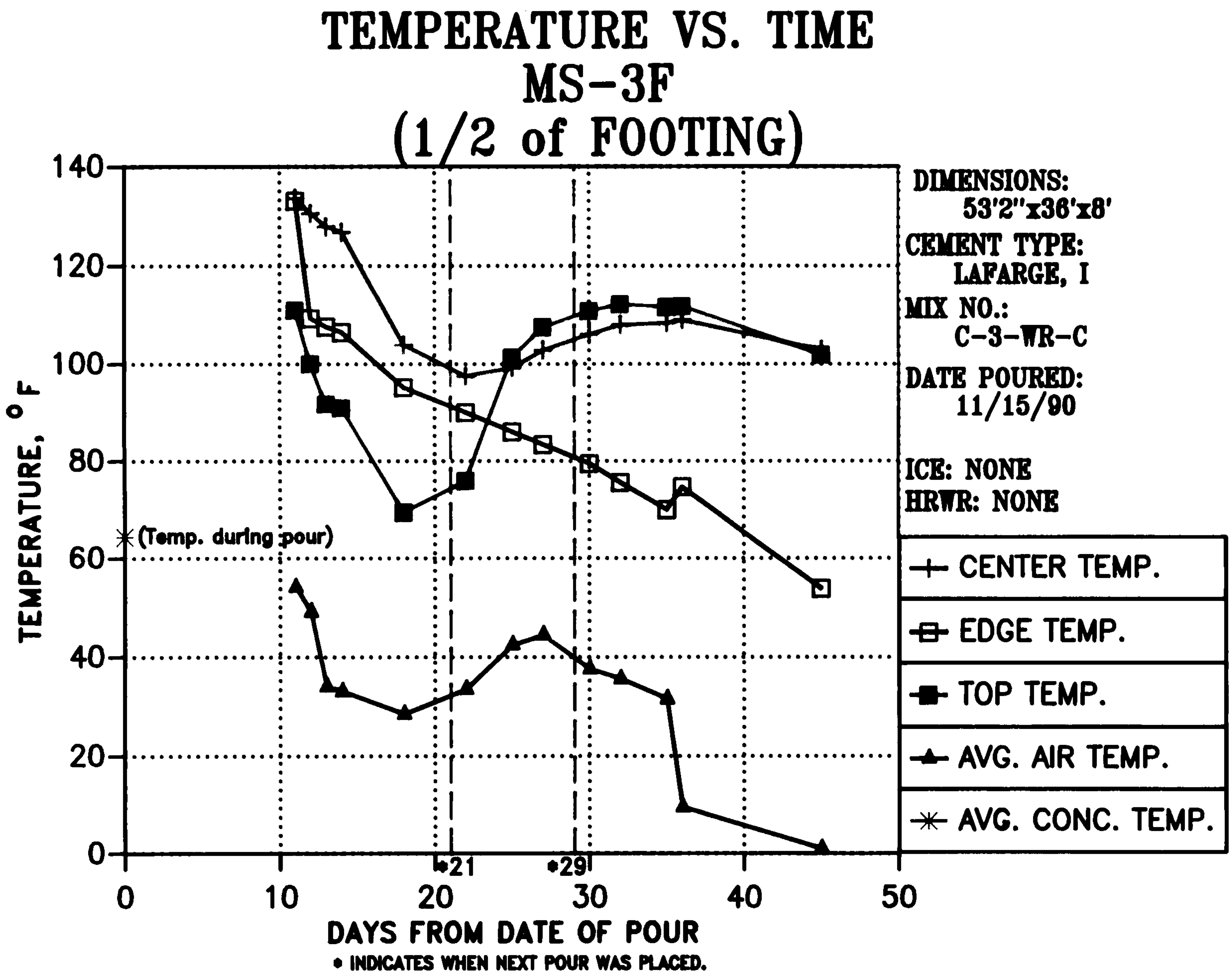
Since the top and center temperatures continued to rise and the side continued to cool as before, the differentials were substantially changed after the placement on day twenty-one. The center to top differential dropped significantly and stayed negative and very low until monitoring ceased. The center to side differential increased steadily until, at the end of monitoring, it greatly exceeded the specified limit (Figures 64 and 65). It is unfortunate that the sensors were inadvertently disconnected at this moment, since the 35°F limit was exceeded; action needed to be taken, and even if it was, the results are not known. Perhaps the differential would have decreased in a few more days, since the

Figure 64



TEMPERATURE DIFFERENTIALS
MS-3F
(N. 1/2 of FOOTING)
TEMPERATURE DIFFERENTIALS, °F
70
60
50
40
30
20
10
0
-10
*21
*29
0
5
10
15
20
25
30
35
40
45
50
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
53'2"x36'x8'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
11/15/90
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 65


TEMPERATURE VS. TIME
MS-3F
(1/2 of FOOTING)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT POUR WAS PLACED.
(Temp. during pour)
•21
•29
0
20
40
60
80
100
120
140
0
10
20
30
40
50
DIMENSIONS:
53'2"x36'x8'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
11/15/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

center temperature was beginning to decrease. Also, on the last few days of monitoring, the side temperature dropped drastically, probably due to a rapidly-dropping ambient temperature.

MS-3-1:

Location: First lift of pier MS-3

Placement Date:	12/6/90	Mix Temperature:	52.5°F
Dimensions:	104'11"x12'x12'	Peak Temperature:	142.8°F
Ambient Temp.:	35.5°F	Temperature Gain:	90.3°F
Volume (cy):	551.0	Day Peak Reached:	Fourth
Concrete Mix:	C-3WR-C		

As usual, the center reached the highest peak, followed by the top, and finally the side. The side and center cooled at about the same rate, and the side appeared to be more affected by the ambient temperature than the other two areas. Prior to the next placement being placed, the top temperature plunged 30°F, probably due to the removal of the insulation in preparation for the next placement. On the eighth day after the placement date, the next lift was placed on top of MS-3-1. Directly after this event, the top temperature increased by 20.9°F, while the center's and side's cooling rate slowed only slightly. This caused the center to top differential to decrease dramatically, while the center to side differential remained rather high (but below the 35°F limit). On day thirty-five, the side and top temperatures both dropped dramatically, but only for that one day, which is rather odd. Two days later, it was as if nothing had happened, and both temperatures resumed their previous cooling courses again. It is most likely that this large plunge was caused by a machine malfunction. On day thirty-seven, the next lift was placed on MS-3, but it had no effect on the temperatures of MS-3-1. The center to top differential remained near zero until the end of monitoring, and the center to side differential varied as the side temperature followed the ambient temperatures (Figure 66 and 67).

MS-3-2:

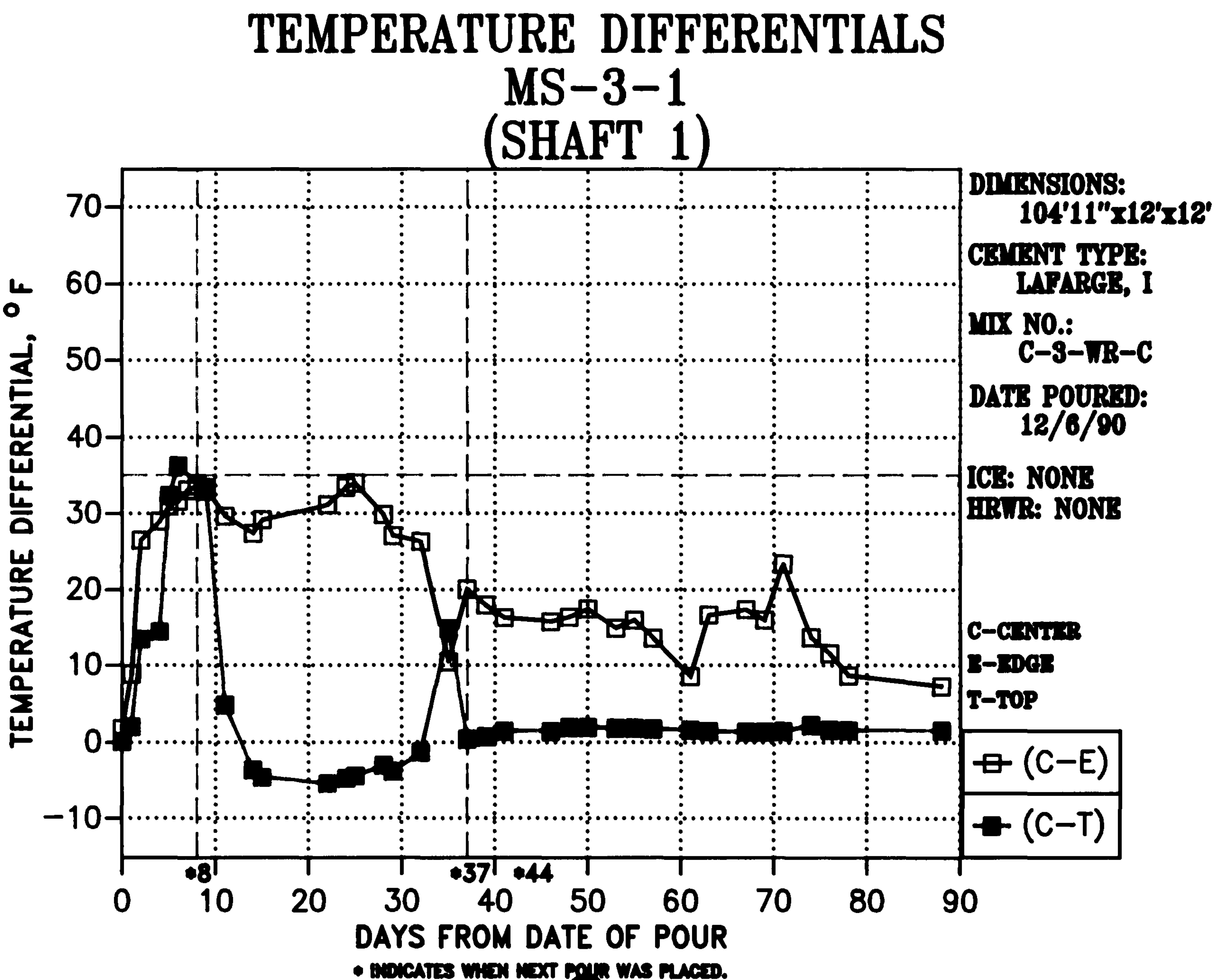
Location: Second lift of pier MS-3

Placement Date:	12/14/90	Mix Temperature:	64.3°F
Dimensions:	106'4"x12'x12'	Peak Temperature:	150.5°F
Ambient Temp.:	33.6°F	Temperature Gain:	86.2°F
Volume (cy):	538.5	Day Peak Reached:	Third
Concrete Mix:	C-3WR-C		

After the initial peaks, the concrete in all three areas cooled at about the same rate. From days seven to fourteen, temperatures were not recorded continuously, and during that week all the temperatures dropped significantly, but the top temperature dropped the most. It lost about 53°F, while the center and side lost 33.8°F and 30.6°F, respectively. This huge drop caused the center to top differential to increase dramatically and surpass the 35°F limit for about five days, until the top acquired a cooling rate similar to the others. The large drop in temperature could have been due to a large ambient temperature drop on the preceding days and poor insulation on the top (or none). As the ambient temperature increased again, the top resumed a cooling course parallel to that of the center and side.

On the twenty-fifth day after the placement date, the next lift was placed on top of MS-3-2. Immediately after, the top temperature rose 32.4°F in three days, and the center rose 4.2°F in that same time. This in turn caused the center to top differential to decrease sharply, and the center to side differential to increase. (The new placement did not affect the side temperature.) Then, just seven days later, on day thirty-two, another placement was placed. Once again, the top temperature increased, but the center and side were not affected.

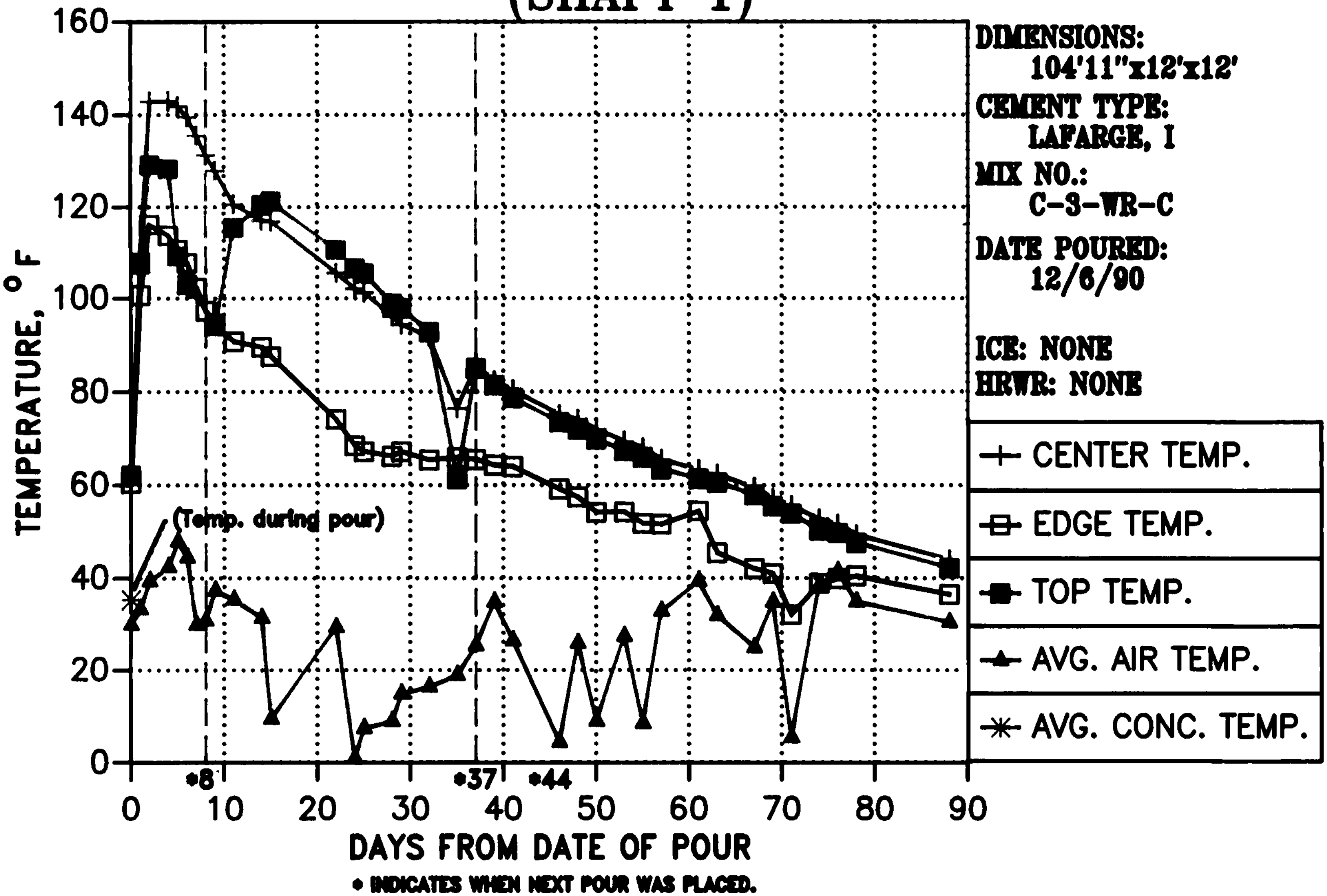
Figure 66



TEMPERATURE DIFFERENTIALS
MS-3-1
(SHAFT 1)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
*8
*37
*44
0
10
20
30
40
50
60
70
80
90
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
104'11"x12'x12'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
12/6/90
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 67

TEMPERATURE VS. TIME
MS-3-1
(SHAFT 1)



For the final monitoring days, the top was the warmest, followed by the center, and then the side. The center to top differential continued to approach zero, and the center to side differential fluctuated because the side temperature wavered due to lack of insulation. After the first placement was placed, the insulation was taken off of MS-3-2, and the side temperature behaved similarly to the ambient temperature. Another placement was placed on day sixty, but it did not have an effect on any of the temperatures (Figures 68 and 69).

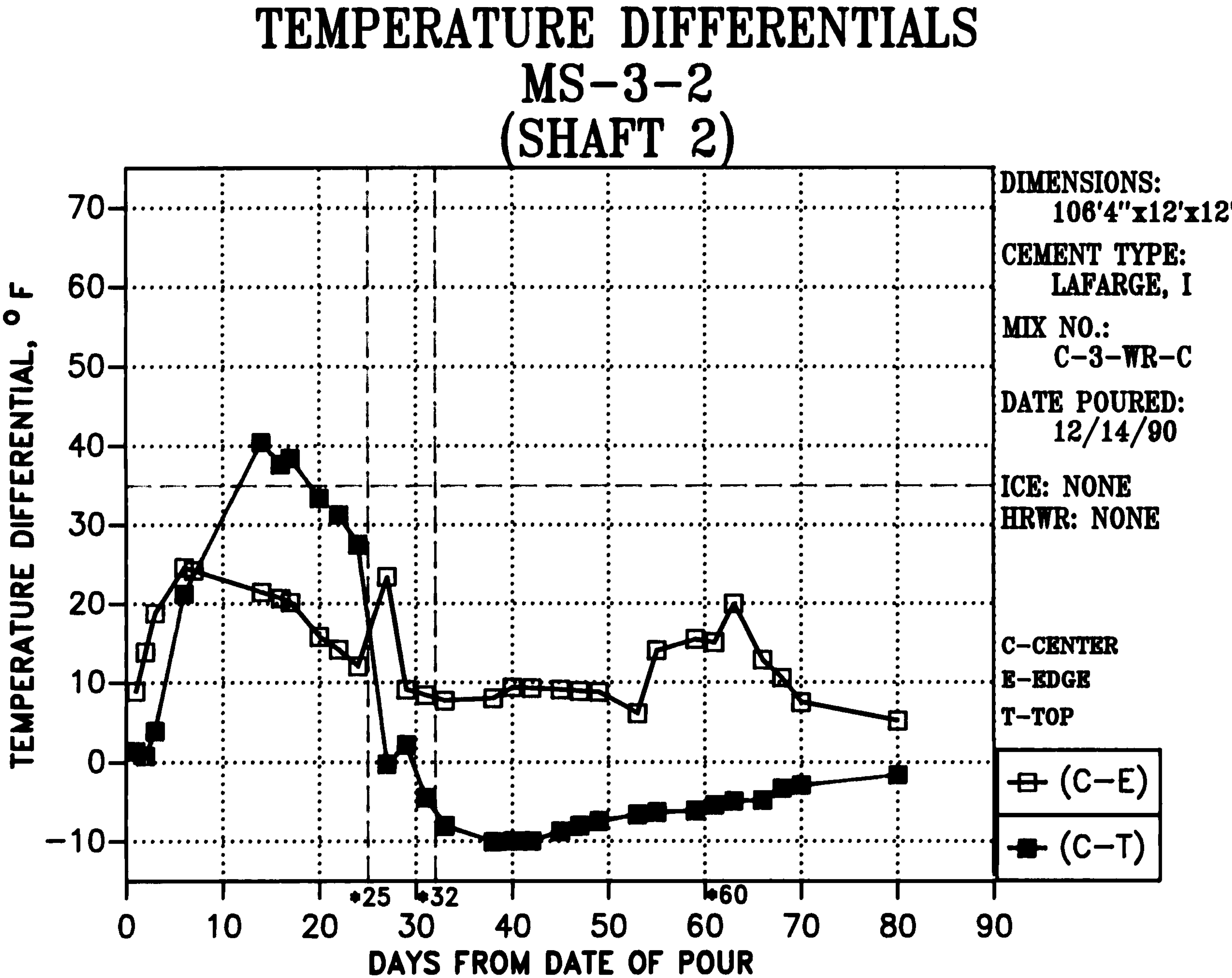
MS-3-3:

Location: Third lift of pier MS-3

Placement Date:	1/8/91	Mix Temperature:	55.3°F
Dimensions:	106'4"x12'x12'	Peak Temperature:	137.5°F
Ambient Temp.:	32.8°F	Temperature Gain:	82.2°F
Volume (cy):	525.0	Day Peak Reached:	First
Concrete Mix:	C-3WR-C		

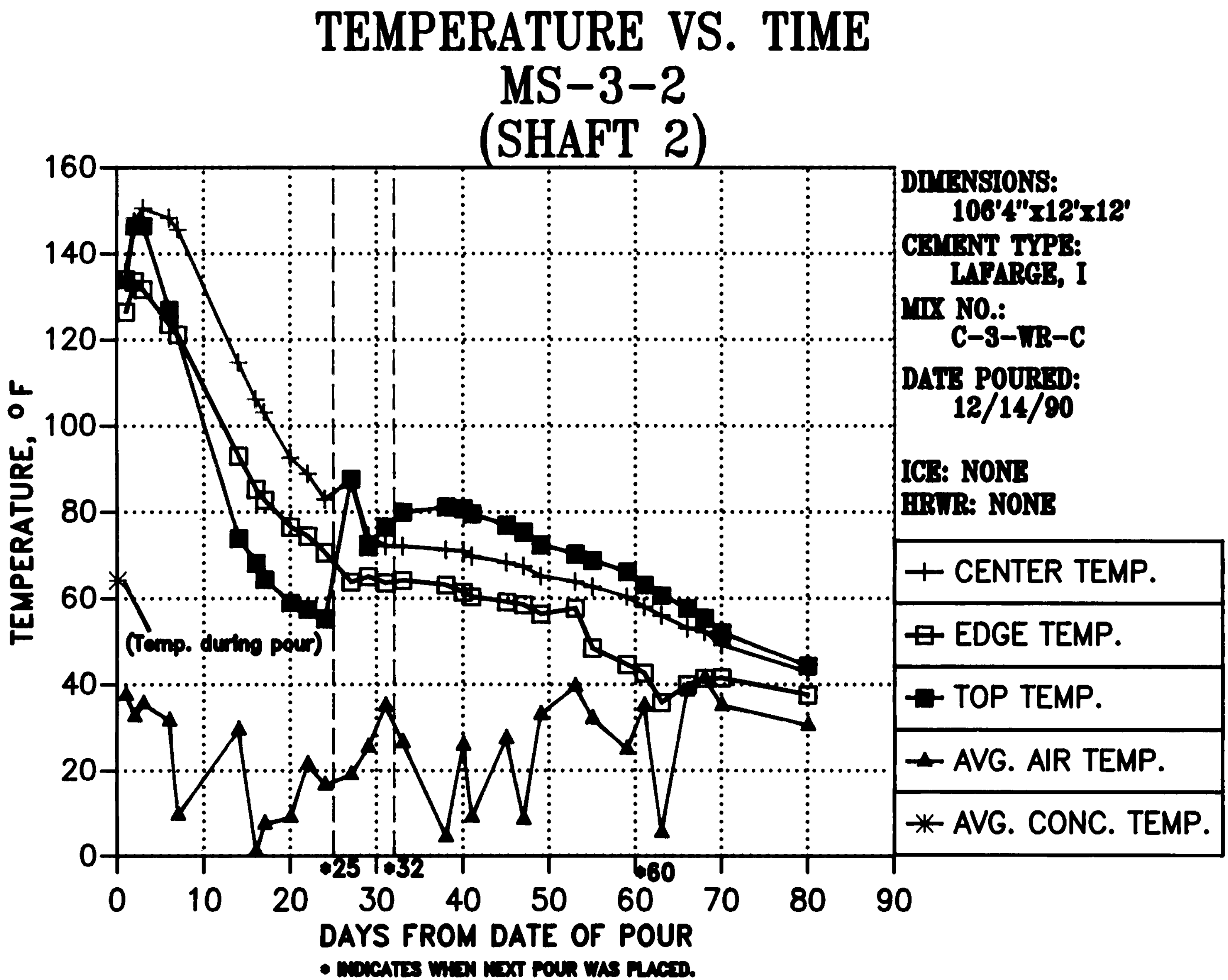
Although the center peaked on the first day, the side did not peak until the second day, and the top until the third day. (The center's peak temperature was the highest overall, however.) On the seventh day after the initial placement date, the next placement was placed on top of MS-3-3. The side and center continued to cool as before, but the top temperature actually increased after the placement of the next placement. This caused the center to side differential to become negative since the top temperature was higher than the center. It appears that the side cooled much more quickly than the center after day thirteen; the center to side differential increased for a while after that. On day thirty, the side temperature dropped about 20°F in four days, causing the differential to increase substantially. This large heat loss could be due to lack of insulation on the outer side,

Figure 68



* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 69


TEMPERATURE VS. TIME
MS-3-2
(SHAFT 2)
DIMENSIONS:
106'4"x12'x12'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
12/14/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
TEMPERATURE, °F
0
20
40
60
80
100
120
140
160
(Temp. during pour)
*25
*32
*60
0
10
20
30
40
50
60
70
80
90
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

since the insulation was moved up for the next placement. That would cause the side temperature to behave like the ambient temperature, as it does in fact appear to do. Another placement was placed on top of the previous one on day thirty-five, and six days later, the top temperature was again higher than the center temperature (it had been less than the center since day twenty-four). Towards the end of the monitoring period, both differentials were approaching zero (Figures 70 and 71).

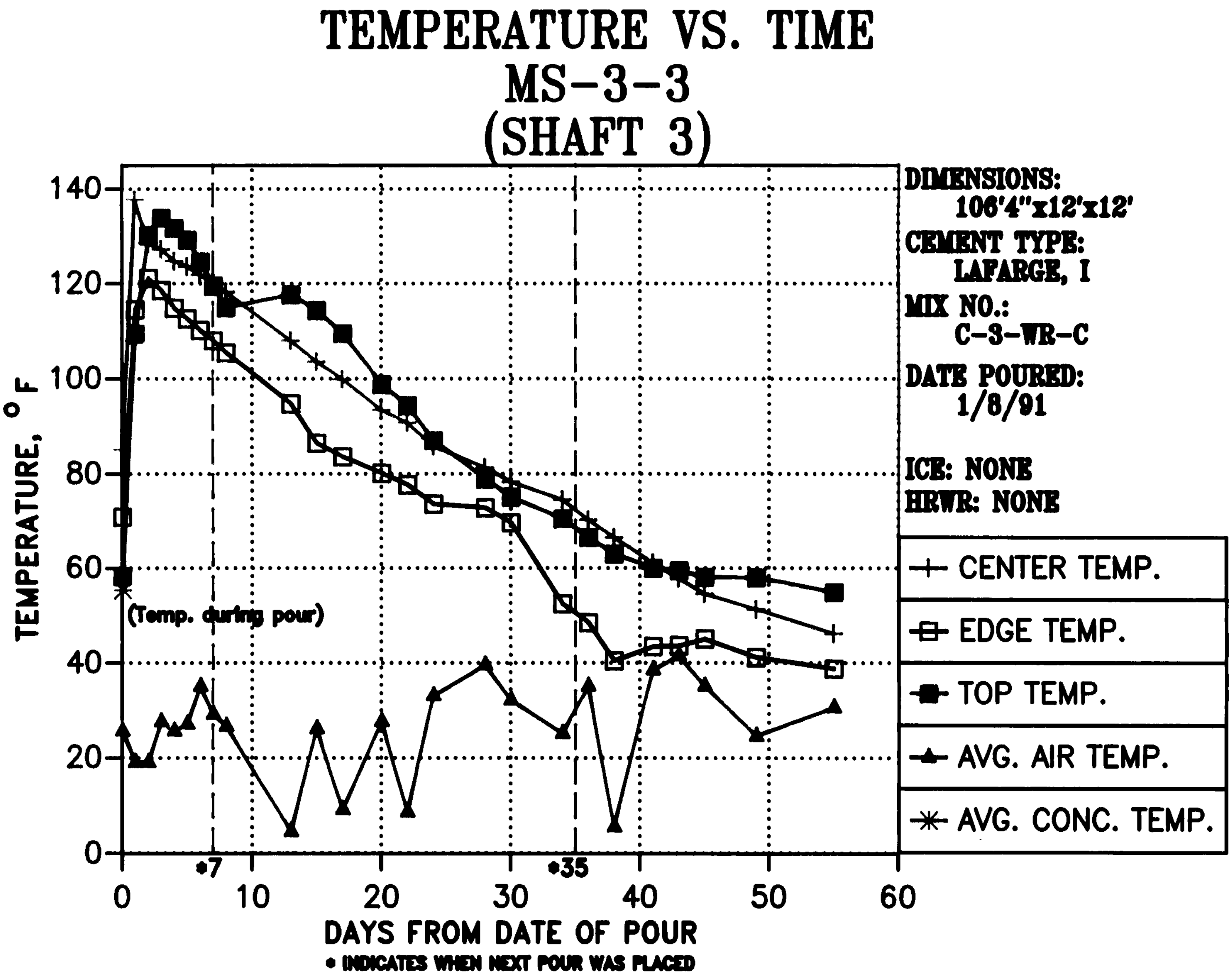
MS-3-4:

Location: First half of fourth lift of pier MS-3

Placement Date:	1/15/91	Mix Temperature:	61.6°F
Dimensions:	106'4"x12'x4'	Peak Temperature:	139.2°F
Ambient Temp.:	29.8°F	Temperature Gain:	77.6°F
Volume (cy):	145.0	Day Peak Reached:	First
Concrete Mix:	D-57		

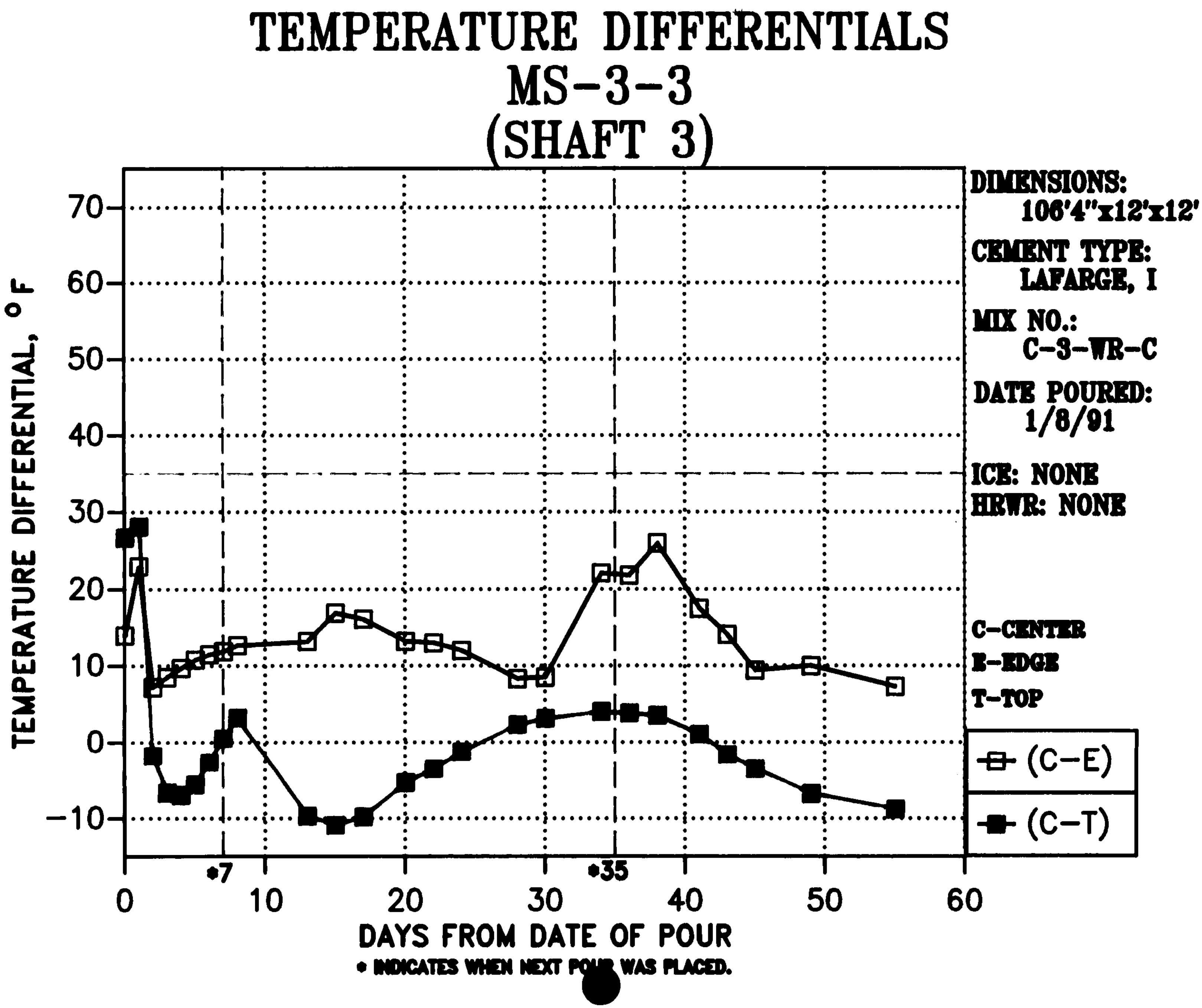
The top temperature peak was much higher than the center's or side's. After the first day, however, the center was warmer than the top, which, in turn, was warmer than the side. The temperature differentials increased for the first ten days, and then began to decrease as the concrete began to cool at the same rate all over. On day twenty-one, the side and top both increased slightly, at the same time that the ambient temperature did. It appears that the top and side were more affected by the outside temperature than was the center, because while the outside temperatures were very low, the side and top cooled faster than the center. Also, they showed the same fluctuations that the ambient temperature did. On day twenty-eight, another placement was placed on top of MS-3-4; this caused all three areas to increase in temperature. The top peaked again at around 90°F, the center at 70°F, and the side at about 65°F. The side temperature got much closer to the center's, and

Figure 71



TEMPERATURE VS. TIME
MS-3-3
(SHAFT 3)
TEMPERATURE, °F
140
120
100
80
60
40
20
0
(Temp. during pour)
*7
*35
0
10
20
30
40
50
60
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED
DIMENSIONS:
106'4"x12'x12'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
1/8/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

Figure 70



TEMPERATURE DIFFERENTIALS
MS-3-3
(SHAFT 3)
DIMENSIONS:
106'4"x12'x12'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
1/8/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
DAYS FROM DATE OF POUR
*7
*35
* INDICATES WHEN NEXT POUR WAS PLACED.

this caused the center to side differential to decrease for a time; but as the side temperature began to behave like the ambient temperature again, the differential began to oscillate. The center to top differential became negative since the top was warmer than the center; as they began to cool, the differential approached zero (Figures 72 and 73).

MS-3-5:

Location: Second half of fourth lift of pier MS-3

Placement Date:	2/12/91	Mix Temperature:	61.5°F
Dimensions:	106'4"x12'x14'	Peak Temperature:	165.3°F
Ambient Temp.:	32.4°F	Temperature Gain:	103.8°F
Cubic Yards:	603.0	Day Peak Reached:	Sixth
Concrete Mix:	D-57		

After the initial peaks, the top cooled very rapidly from days three through six (losing 2.9°F per day), while the side lost only 1.4°F per day, and the top temperature actually increased. This rapid cooling caused the center to top differential to exceed the 35°F limit for a period of about five days. Perhaps the insulation on the top was not placed well enough, or not at all; also, the insulation may have been removed to work on the bearing pedestals (as in the case of MS-1C). After the tenth day, the side and top temperatures were almost identical, crossing one another a few times until the end of monitoring. The temperature differentials fluctuated also, approaching zero towards the last days of the monitoring period (Figures 74 and 75). No other placements were placed on this pour during monitoring, and the differential limit was not exceeded again.

D. <u>MS-4</u>

MS-4 was completed over a period of eight months, from August 1990 to March 5, 1991. Mix number C-3WR-C was used for all seven placements. No super-plasticizer was added to any mixes. Type II Lone Star Cape Girardeau cement was used for placements MS-4-1 through MS-4-6, and the cap consists of LaFarge Type I cement.

MS-4-1:

Location: First lift of pier MS-4

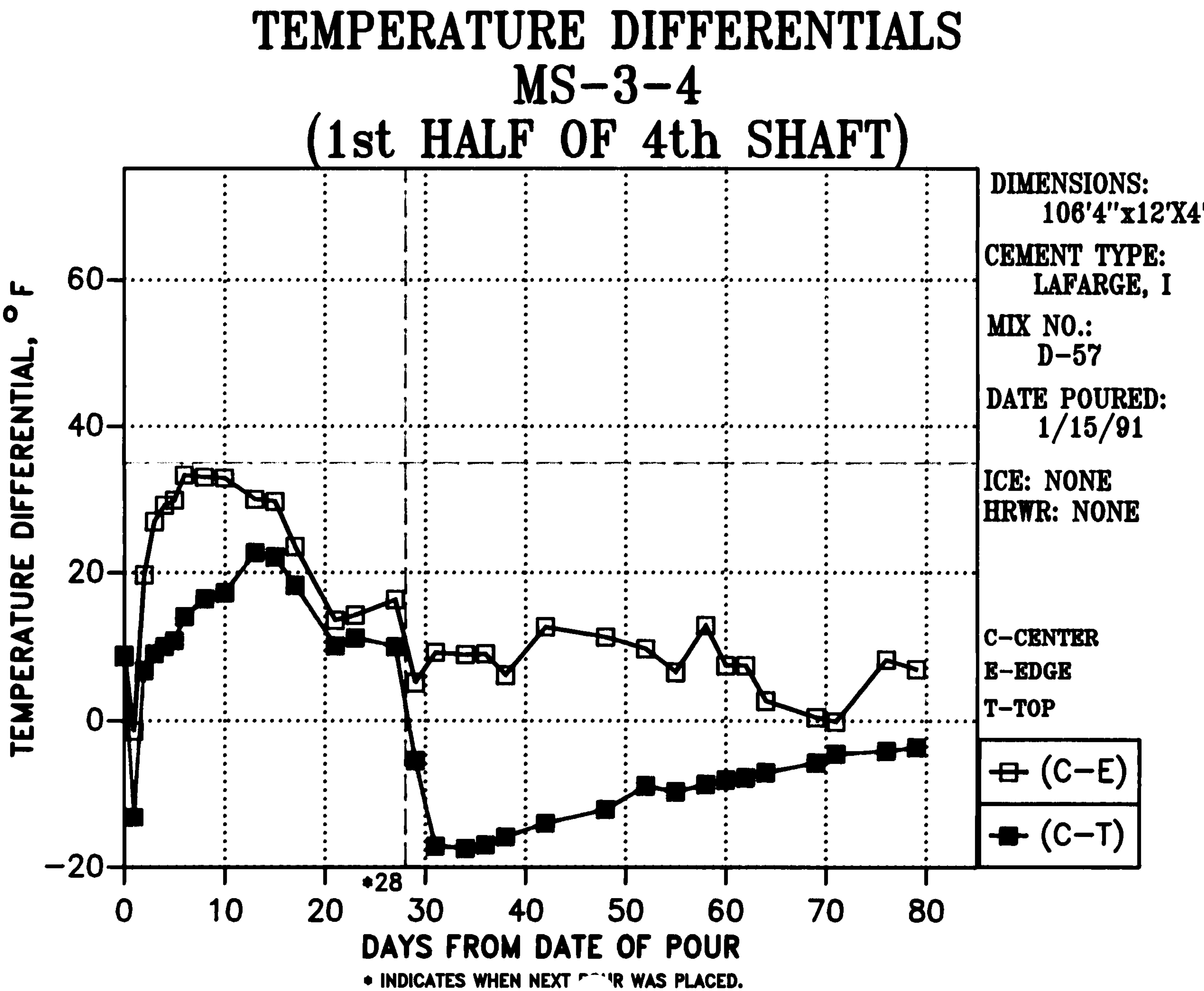
Placement Date:	8/21/90	Mix Temperature:	67.0°F
Dimensions:	63'7"x10'7"x15'	Peak Temperature:	155.5°F
Ambient Temp.:	74.0°F	Temperature Gain:	88.5°F
Volume (cy):	350+	Day Peak Reached:	Fourth

Ice (#/cy): Yes, amount unknown

Once again, the center temperature was much higher than the other two areas for the first week. The actual cooling rates of this placement cannot be examined, because the cofferdam was flooded from August 28 to September 5 (days seven through fifteen) with 78°F water, causing monitoring to be interrupted. Over this period, the side and top cooled much faster than the center: while the center lost 37.9°F, the top lost 42.5°F, and the side 58.1°F. Obviously, the surface temperatures were more affected by the flooding than the internal temperature. After the cofferdam was dewatered, the next placement was placed on top of MS-4-1 on day seventeen. This caused the top temperature to increase dramatically, and slightly slowed the cooling of the center and side.

The temperature differentials increased from the outset and almost reached the 35°F limit, but after the next placement was placed, the differentials decreased (especially the center to top, which became negative). Both differentials, however, were within twenty degrees of zero (Figures 76 and 77).

Figure 72



TEMPERATURE DIFFERENTIALS
MS-3-4
(1st HALF OF 4th SHAFT)
DIMENSIONS:
106'4"x12'X4'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57
DATE POURED:
1/15/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
*28
0
10
20
30
40
50
60
70
80
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT P..R WAS PLACED.

Figure 73

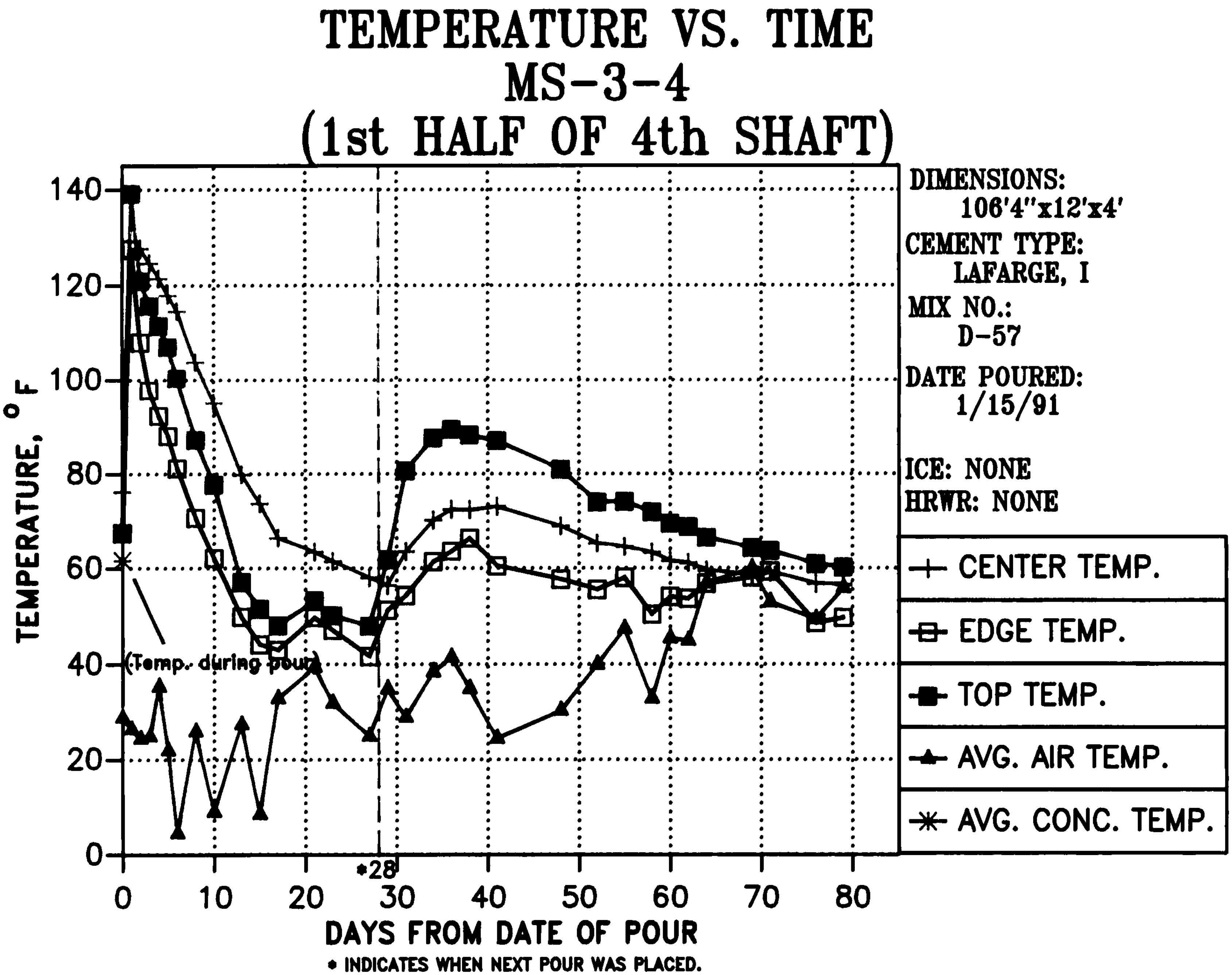

TEMPERATURE VS. TIME
MS-3-4
(1st HALF OF 4th SHAFT)
TEMPERATURE, °F
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
*28
(Temp. during pour)
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
106'4"x12'x4'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57
DATE POURED:
1/15/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

Figure 74

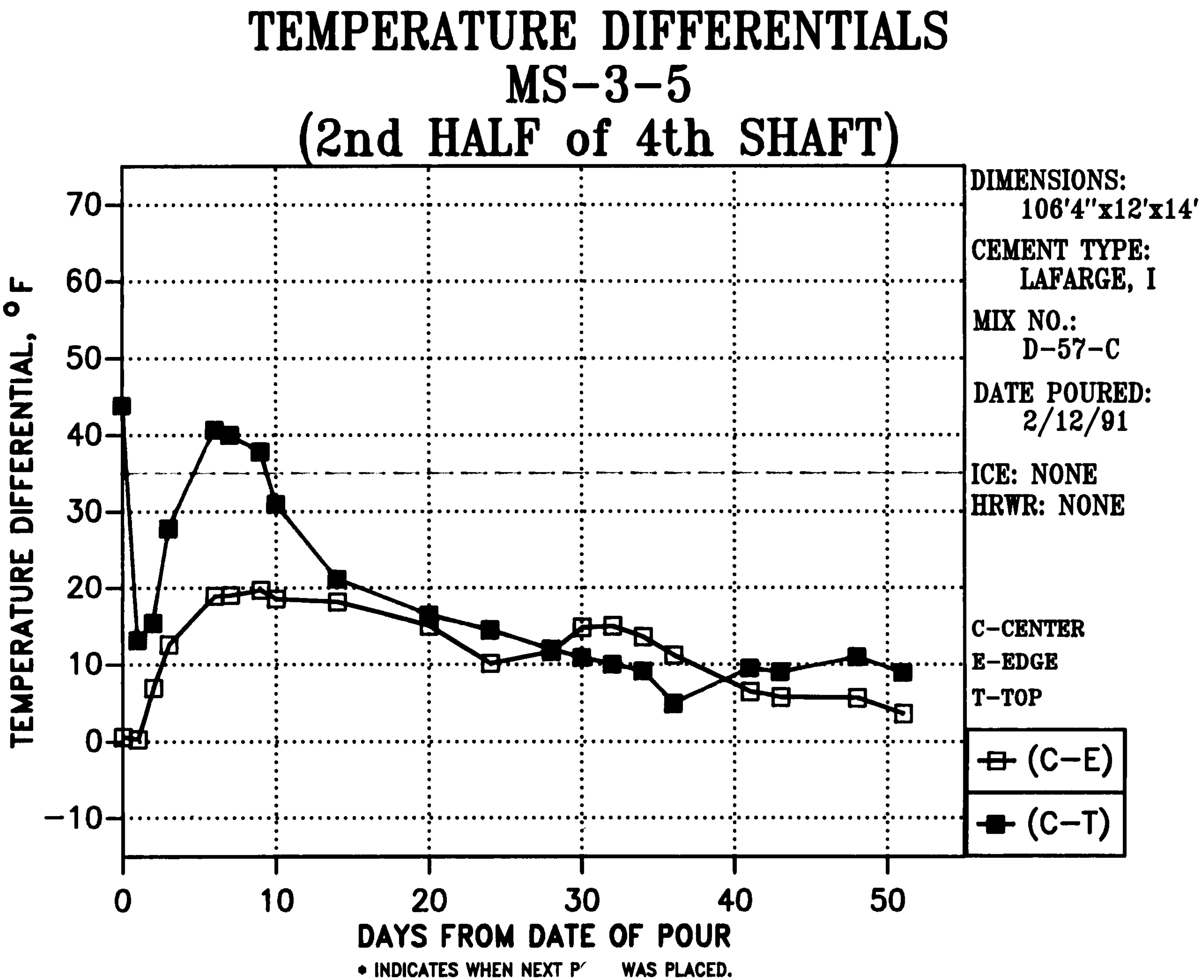
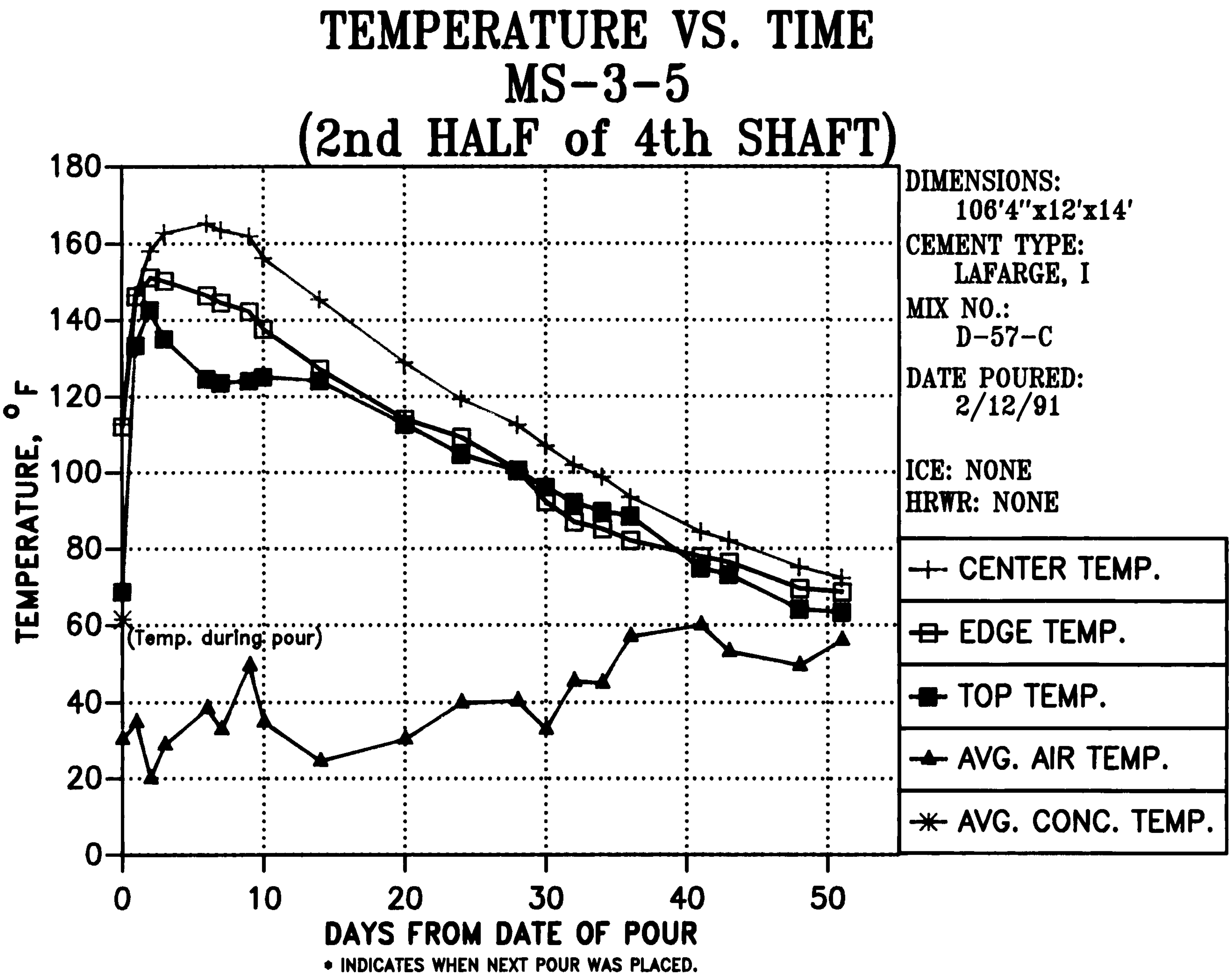
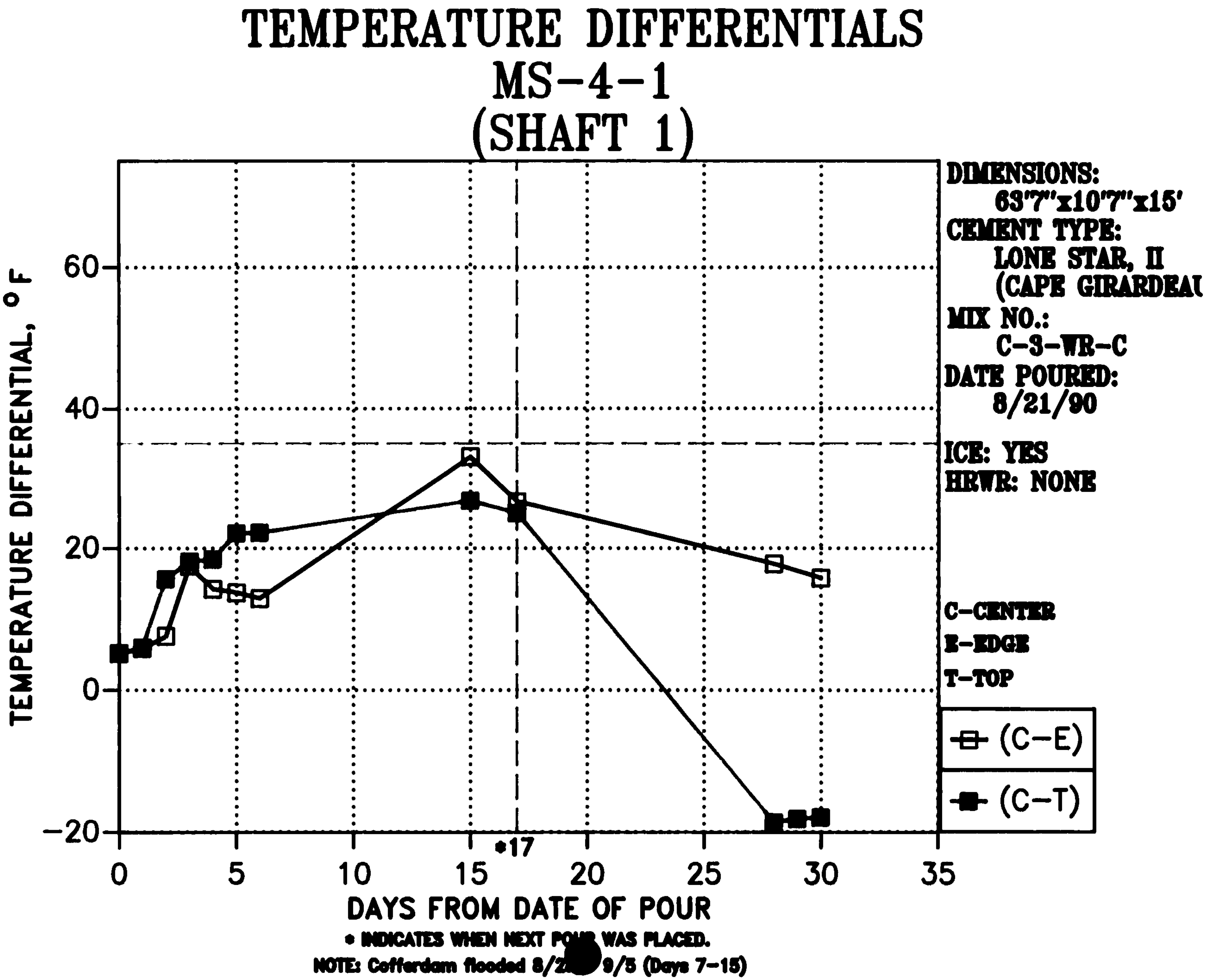

TEMPERATURE DIFFERENTIALS
MS-3-5
(2nd HALF of 4th SHAFT)
DIMENSIONS:
106'4"x12'x14'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
2/12/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT P'   WAS PLACED.

Figure 75



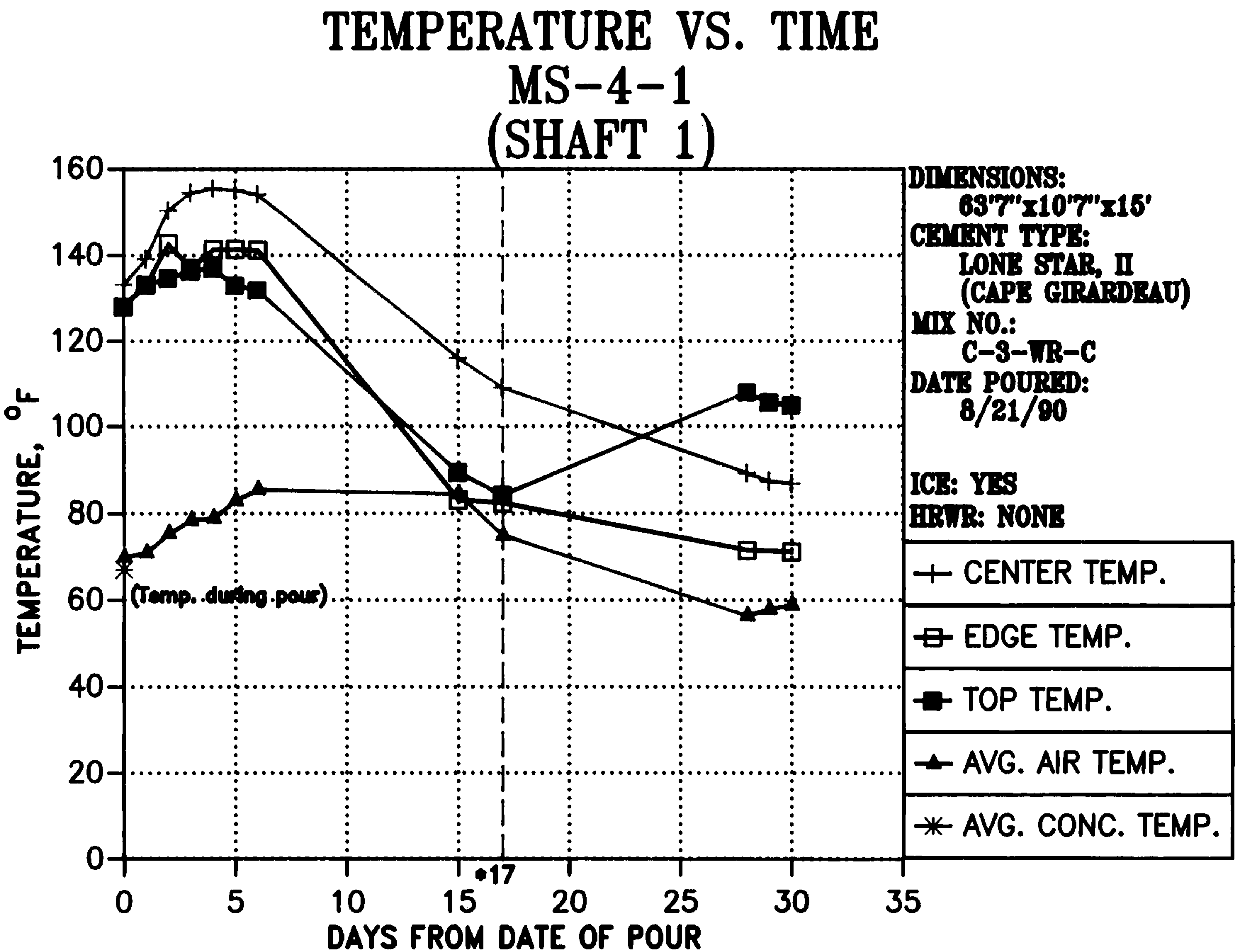
TEMPERATURE VS. TIME
MS-3-5
(2nd HALF of 4th SHAFT)
DIMENSIONS:
106'4"x12'x14'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
D-57-C
DATE POURED:
2/12/91
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 76



TEMPERATURE DIFFERENTIALS
MS-4-1
(SHAFT 1)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
0
5
10
15
20
25
30
35
*17
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: Cofferdam flooded 8/2 9/5 (Days 7-15)
DIMENSIONS:
63'7"x10'7"x15'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU
MIX NO.:
C-3-WR-C
DATE POURED:
8/21/90
ICE: YES
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 77



* INDICATES WHEN NEXT POUR WAS PLACED.
NOTE: COFFERDAM FLOODED 8/28 – 9/5 (Days 7–15)

MS-4-2:

Location: Second lift of pier MS-4

Placement Date:	9/7/90	Mix Temperature:	72.0°F
Dimensions:	63'7"x10'x15'	Peak Temperature:	155.4°F
Ambient Temp.:	75.0°F	Temperature Gain:	83.4°F
Volume (cy):	330+	Day Peak Reached:	Fourth
Ice (#/cy):	114		

While the center was once again the highest temperature, the top and side were very close in temperature until day thirteen. On that day, the top temperature suddenly dropped very sharply. One possible reason for this drop could be that the top insulation was removed to prepare for the next placement, leaving it exposed to much lower ambient temperatures. When temperature monitoring was resumed on day nineteen, the top temperature had again increased and eventually surpassed the center temperature. The placements on days fourteen and twenty-one did not appear to have any effect on the center and side temperatures, but did increase the top temperature (the placement on day fourteen having the greater effect). After day twenty-one, all three areas cooled uniformly, except for one inconsistency in the side temperature. On day thirty-five, the side temperature suddenly jumped up a few degrees. This could have been caused by a new placement placed on day thirty-three at the south end, by an ambient temperature increase at the same time, or by a machine malfunction. Another placement was placed on day forty-five, but it did not have an effect on any of the areas.

The temperature differentials were about the same until the top started to cool, then the center to top differential increased and exceeded the 35°F limit on day thirteen when the insulation was probably removed. After the next placement was placed, the center to top differential dropped again, and remained near zero until the end of monitoring. The center to side differential was essentially constant (except for the glitch at day thirty-five) until monitoring ceased (Figures 78 and 79).

MS-4-3:

Location: Third lift of pier MS-4

Placement Date:	9/21/90	Mix Temperature:	71.0°F
Dimensions:	63'7"x8'10.5"x11'	Peak Temperature:	139.3°F
Ambient Temp.:	66.0°F	Temperature Gain:	68.3°F
Volume (cy):	223.0	Day Peak Reached:	Fifth
Ice (#/cy):	56		

The center temperature was consistently the highest, followed by the side, and finally the top. New placements were placed on days seven, nineteen, and thirty-one, but they were not all placed directly on top of MS-4-3. They were, in order, the center column of the pier, the southern column, and finally the northern column. The first and last placements obviously had no effect on the concrete temperature in any area. While it appears that the placement on day nineteen caused the top temperature to rise (which is possible), it is more likely that the top was influenced by the ambient temperature fluctuations; this type of behavior was also evidenced later during monitoring. All three areas cooled at the same rate, and also were all affected by ambient temperatures. The center to side differential was constant during monitoring, but it is interesting to note that the center to top differential increased when the placements on days seven and nineteen were placed. It appears that the top temperature was more affected by ambient temperatures than the other two, because at the same time as the placements were placed, the top temperature decreased instead of increasing, and the ambient temperature dropped. After

Figure 78

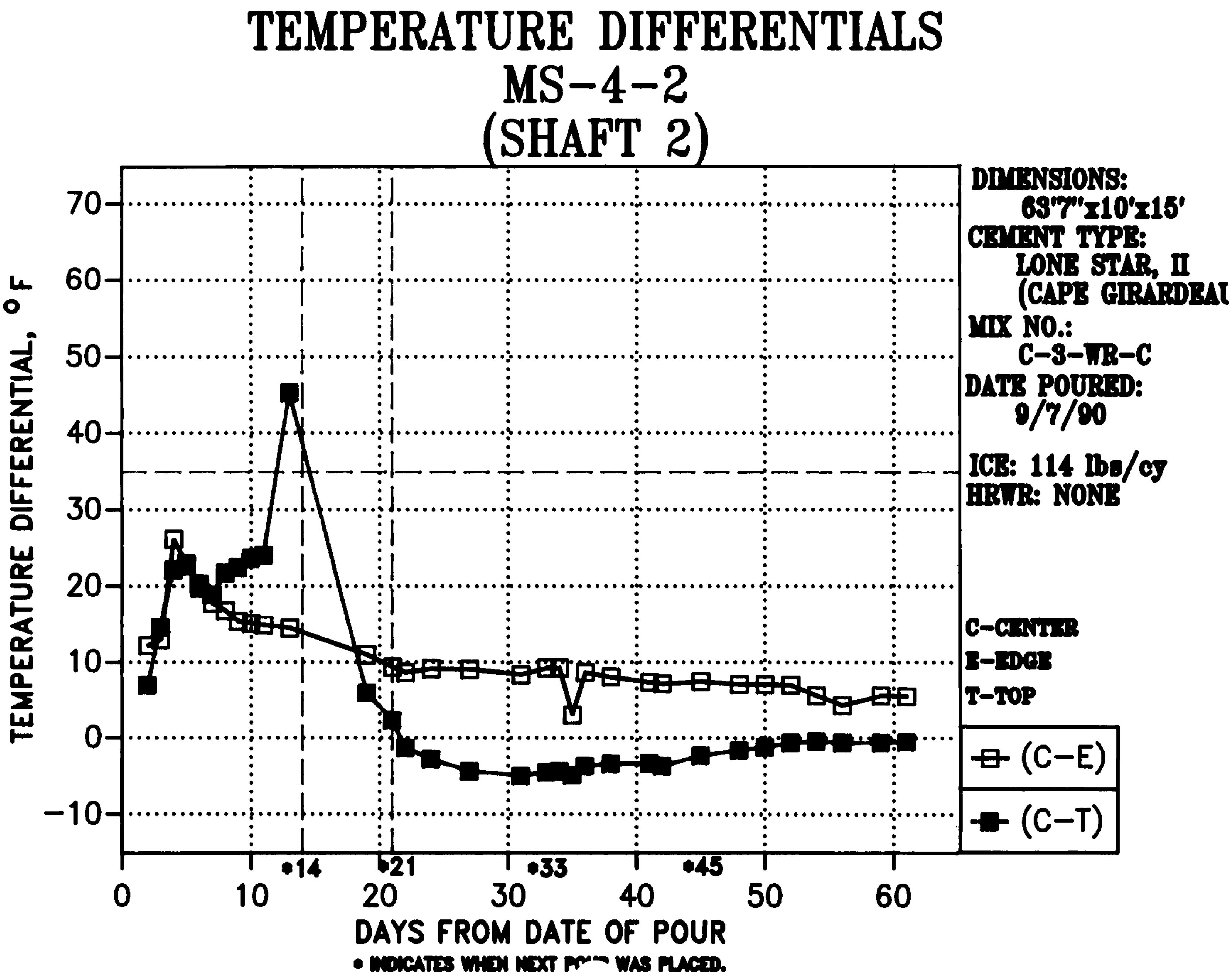
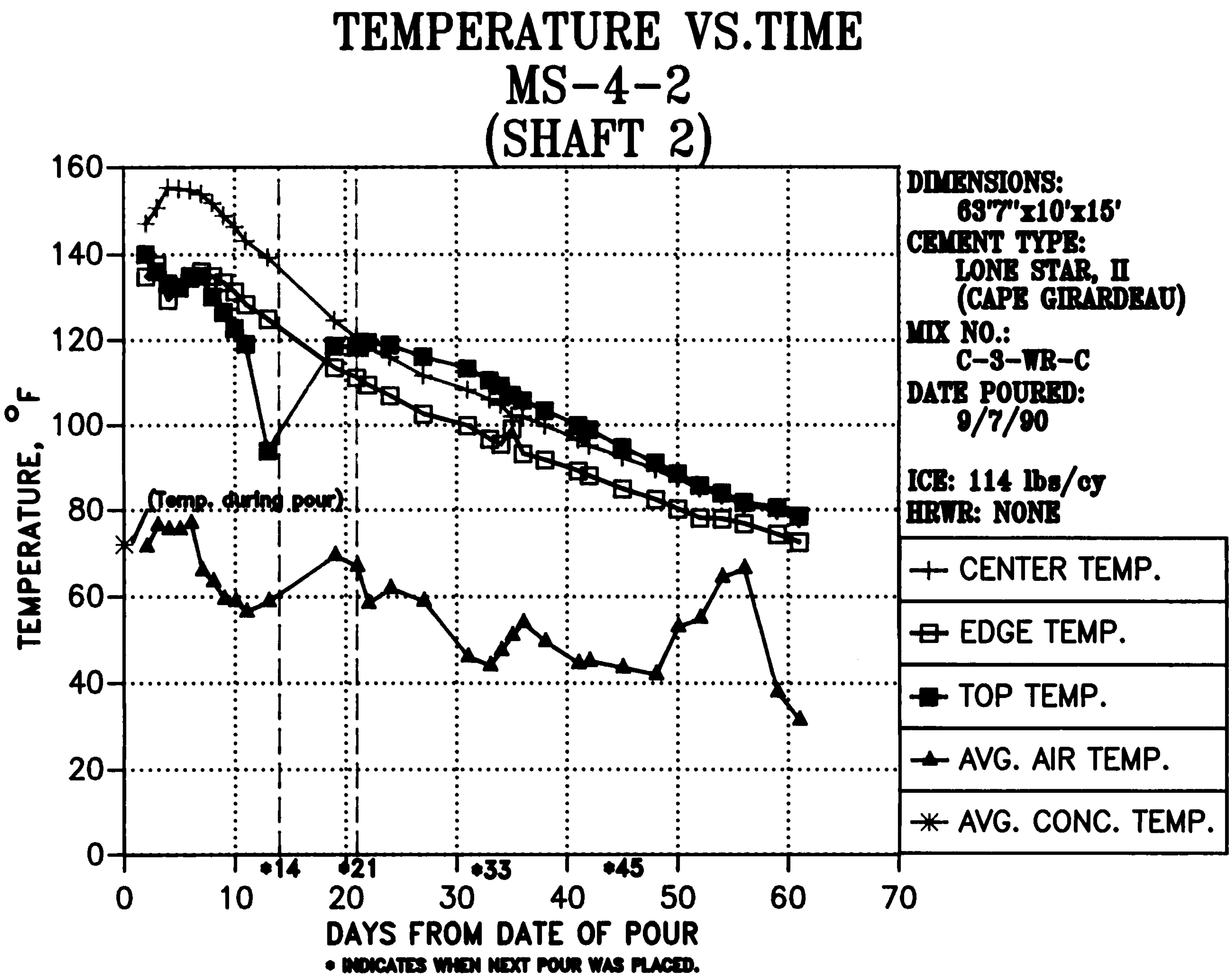

TEMPERATURE DIFFERENTIALS
MS-4-2
(SHAFT 2)
DIMENSIONS:
63'7"x10'x15'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU
MIX NO.:
C-3-WR-C
DATE POURED:
9/7/90
ICE: 114 lbs/cy
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
*14
*21
*33
*45
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 79


TEMPERATURE VS.TIME
MS-4-2
(SHAFT 2)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
(Temp. during pour)
*14
*21
*33
*45
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
DIMENSIONS:
63'7"x10'x15'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
9/7/90
ICE: 114 lbs/cy
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

day nineteen, the center to top differential dropped and was very close to the center to side differential (Figures 80 and 81).

MS-4-4:

Location: Center column of pier MS-4			
Placement Date:	9/28/90	Mix Temperature:	75.0°F
Dimensions:	11'x8'5"x22'11"	Peak Temperature:	152.7°F
Ambient Temp.:	67.0°F	Temperature Gain:	77.7°F
Volume (cy):	84.5	Day Peak Reached:	Third
Ice (#/cy):	None		

Temperature monitoring of the top ceased after day two, so the effects of new placements (on days twelve and twenty-four) on the top temperature are unknown, but since the new placements were columns placed adjacent to MS-4-4, it is unlikely that they would have any effect on any of the concrete temperatures. The center and side cooled at about the same rate, and no major fluctuations in the temperatures or the temperature differentials occurred during monitoring. The center and side temperatures decreased and approached one another. On the last day of monitoring, the center, side, and ambient temperatures were all within 3°F of one another (Figures 82 and 83).

MS-4-5:

Location: South column of pier MS-4			
Placement Date:	10/10/90	Mix Temperature:	59.0°F
Dimensions:	14'11.5"x8'5"x22'11"	Peak Temperature:	134.7°F
Ambient Temp.:	41.0°F	Temperature Gain:	75.7°F
Volume (cy):	93.6	Day Peak Reached:	Fifth
Ice (#/cy):	None		

For the most part during monitoring, the center was the warmest, followed by the side, and then the top. For a few days at the beginning of monitoring, the side was cooler than the top, but for only two days. The temperature differentials never exceeded the specified limit, and generally remained below 20°F. On day twenty-six, the center and side dropped suddenly, probably due to

Figure 80

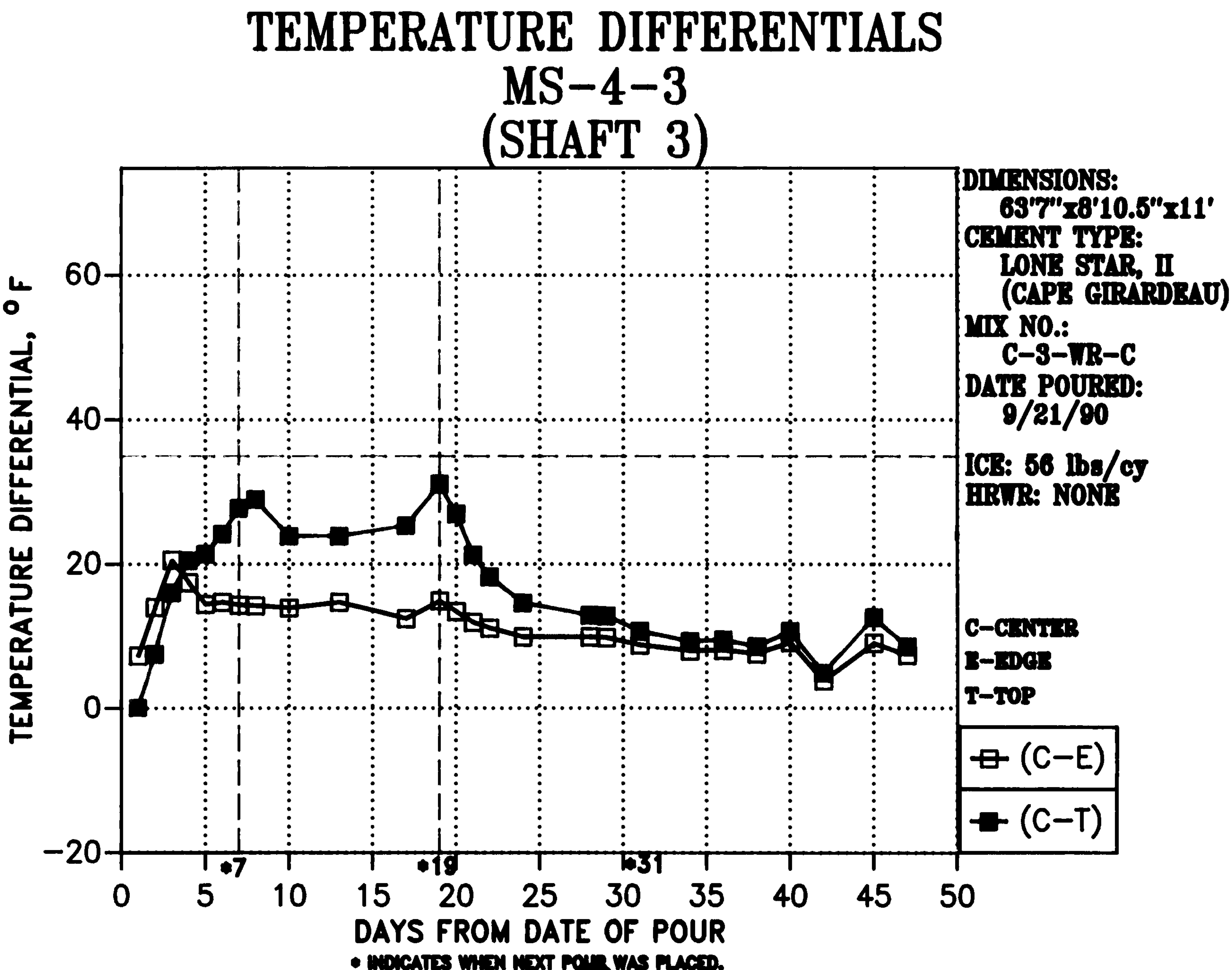
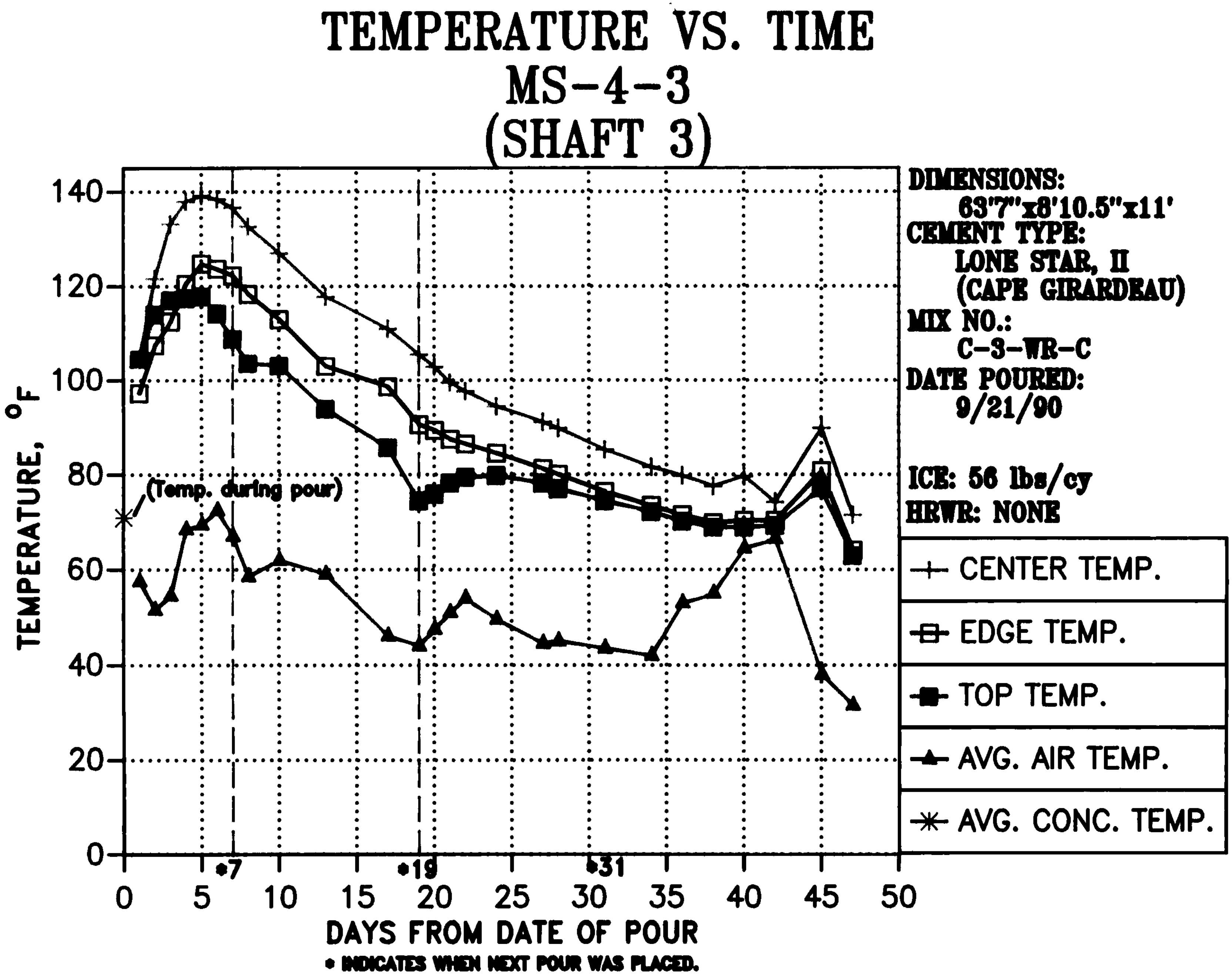
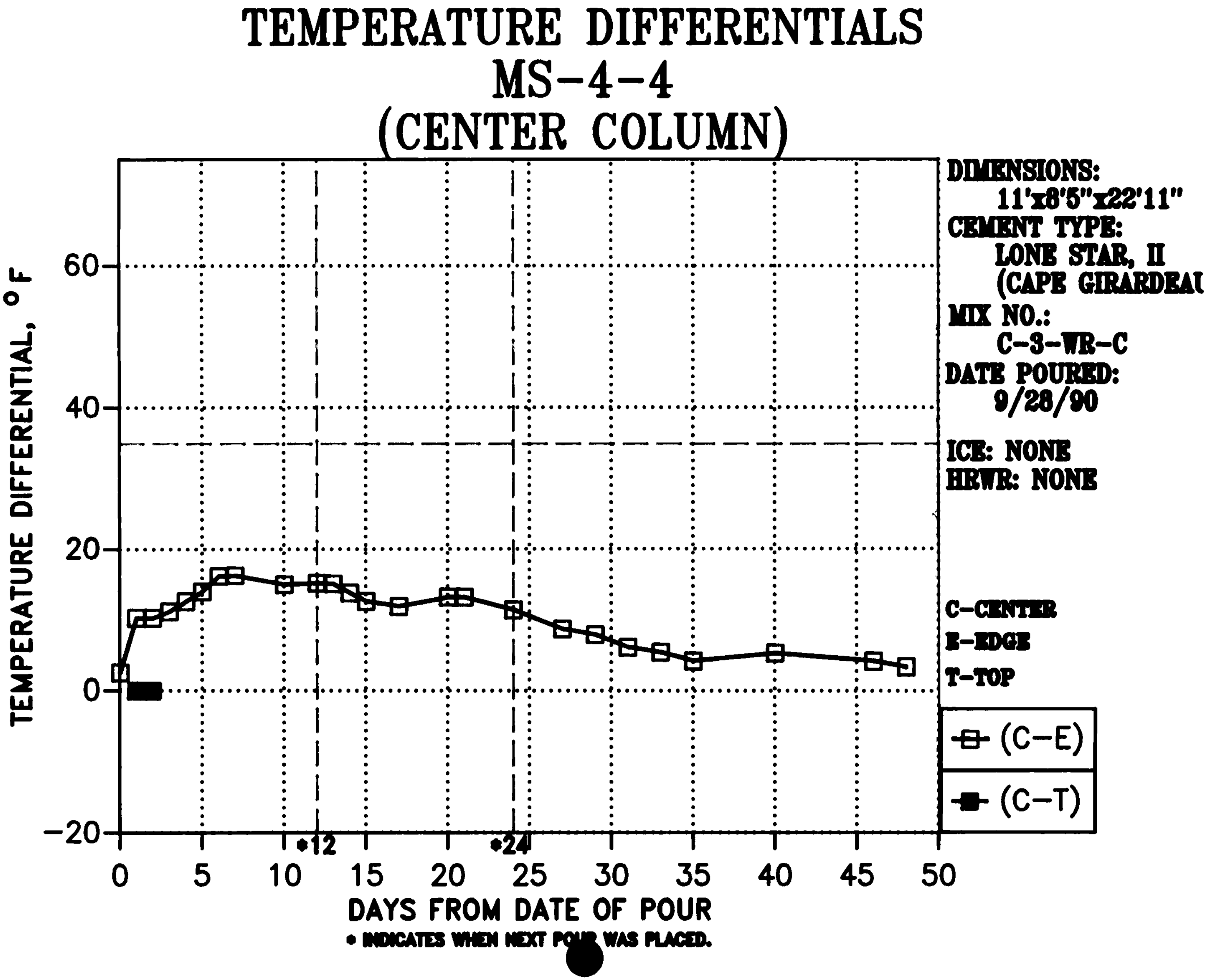

TEMPERATURE DIFFERENTIALS
MS-4-3
(SHAFT 3)
DIMENSIONS:
63'7"x8'10.5"x11'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
9/21/90
ICE: 56 lbs/cy
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
*7
*19
*31
0
5
10
15
20
25
30
35
40
45
50
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 81



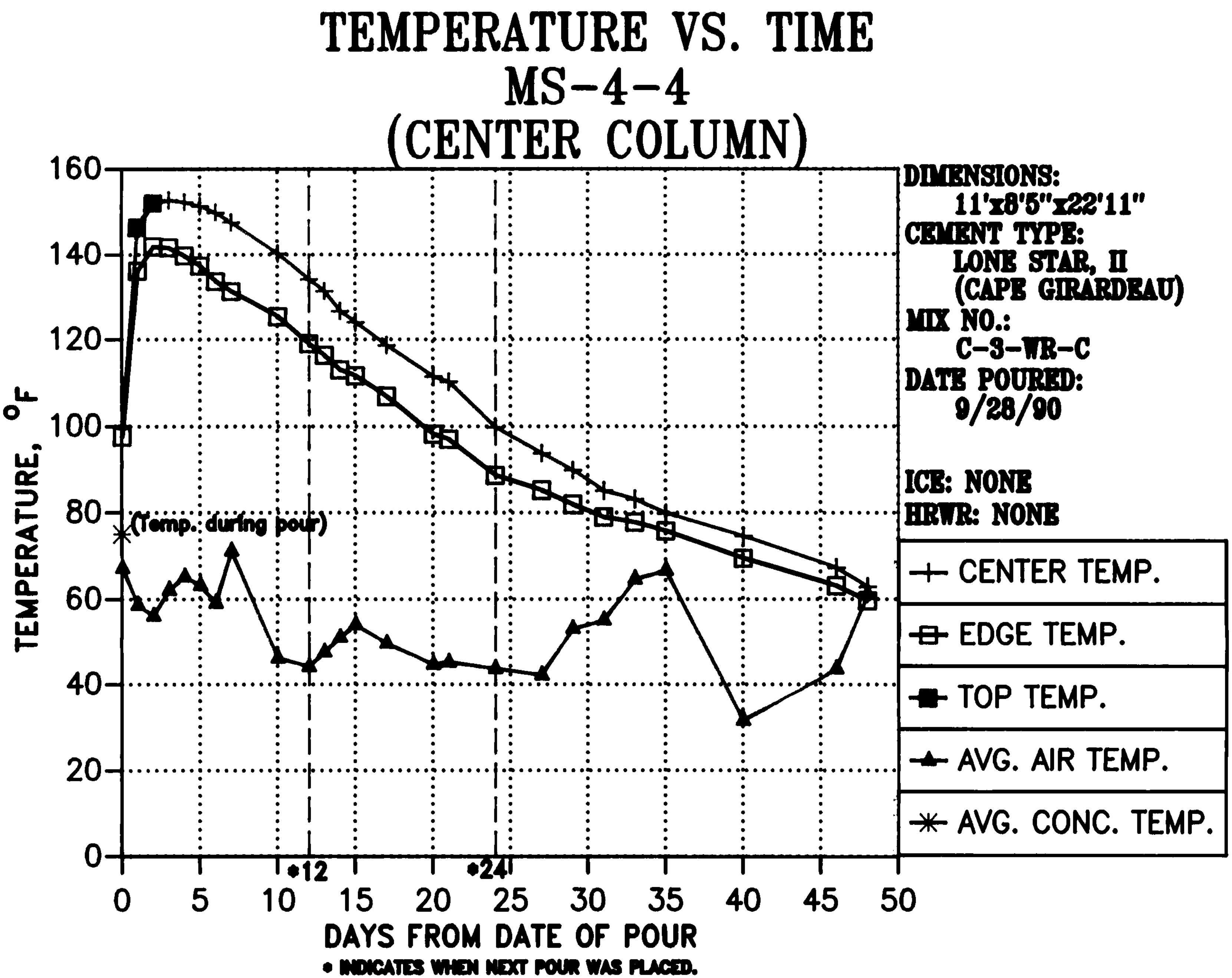
TEMPERATURE VS. TIME
MS-4-3
(SHAFT 3)
DIMENSIONS:
63'7"x8'10.5"x11'
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
9/21/90
ICE: 56 lbs/cy
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
*7
*19
*31

Figure 82



TEMPERATURE DIFFERENTIALS
MS-4-4
(CENTER COLUMN)
TEMPERATURE DIFFERENTIAL, °F
60
40
20
0
-20
0
5
10
15
20
25
30
35
40
45
50
*12
*24
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
11'x8'5"x22'11"
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU
MIX NO.:
C-3-WR-C
DATE POURED:
9/28/90
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)

Figure 83


TEMPERATURE VS. TIME
MS-4-4
(CENTER COLUMN)
TEMPERATURE, °F
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
*12
*24
(Temp. during pour)
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.
DIMENSIONS:
11'x8'5"x22'11"
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
9/28/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.

an ambient temperature drop at that time. Another placement was placed on day twelve, but it was not placed on top of MS-4-5; rather, it was the north column, placed 78 feet away from MS-4-5; it had no effect on the temperatures (Figures 84 and 85).

MS-4-6:

Location: North column of pier MS-4

Placement Date:	10/22/90	Mix Temperature:	61.7°F
Dimensions:	14'11.5"x8'5"x22'11"	Peak Temperature:	136.3°F
Ambient Temp.:	53.0°F	Temperature Gain:	74.6°F
Volume (cy):	93.6	Day Peak Reached:	Third
Ice (#/cy):	None		

At the beginning of monitoring (for the first six days), the temperatures in all three placements wavered a bit as they reached their respective peaks and then began to cool. Over days fourteen to sixteen, the center dropped 16°, while the side and top only dropped 5° and 8°, respectively. During this same time period, the ambient temperature also dropped significantly, but it is unlikely that it would have affected the center so drastically, but not the side or top. This sudden drop, of course, caused a sudden drop in temperature differentials as well, but afterwards they resumed their previous courses. (Figures 86 and 87.)

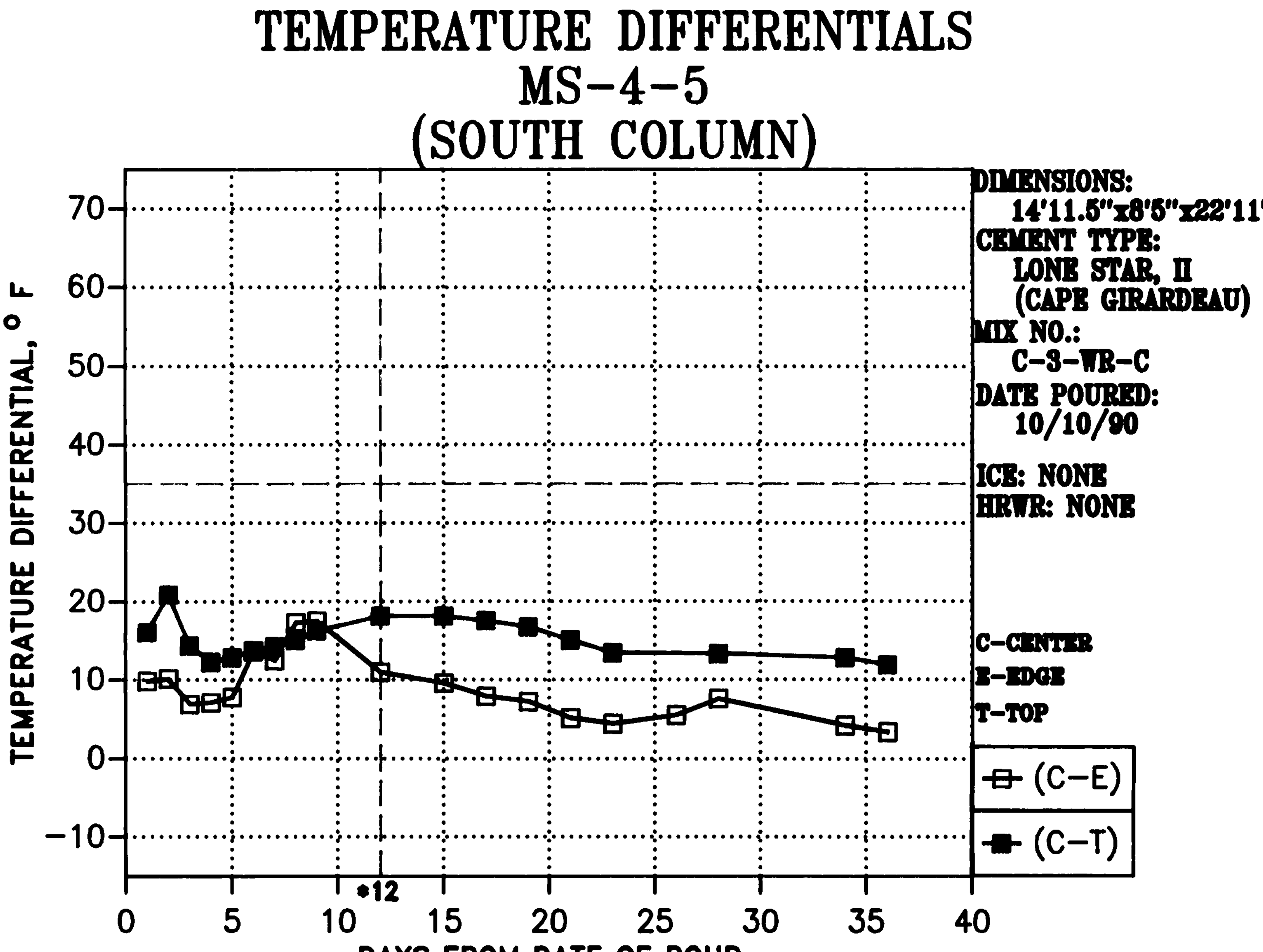
MS-4C:

Location: Cap of pier MS-4

Placement Date:	3/5/91	Mix Temperature:	67.7°F
Dimensions:	82'x7'6.75"x10'	Peak Temperature:	149.7°F
Ambient Temp.:	50.1°F	Temperature Gain:	82.0°F
Volume (cy):	228.0	Day Peak Reached:	Third
Ice (#/cy):	None		

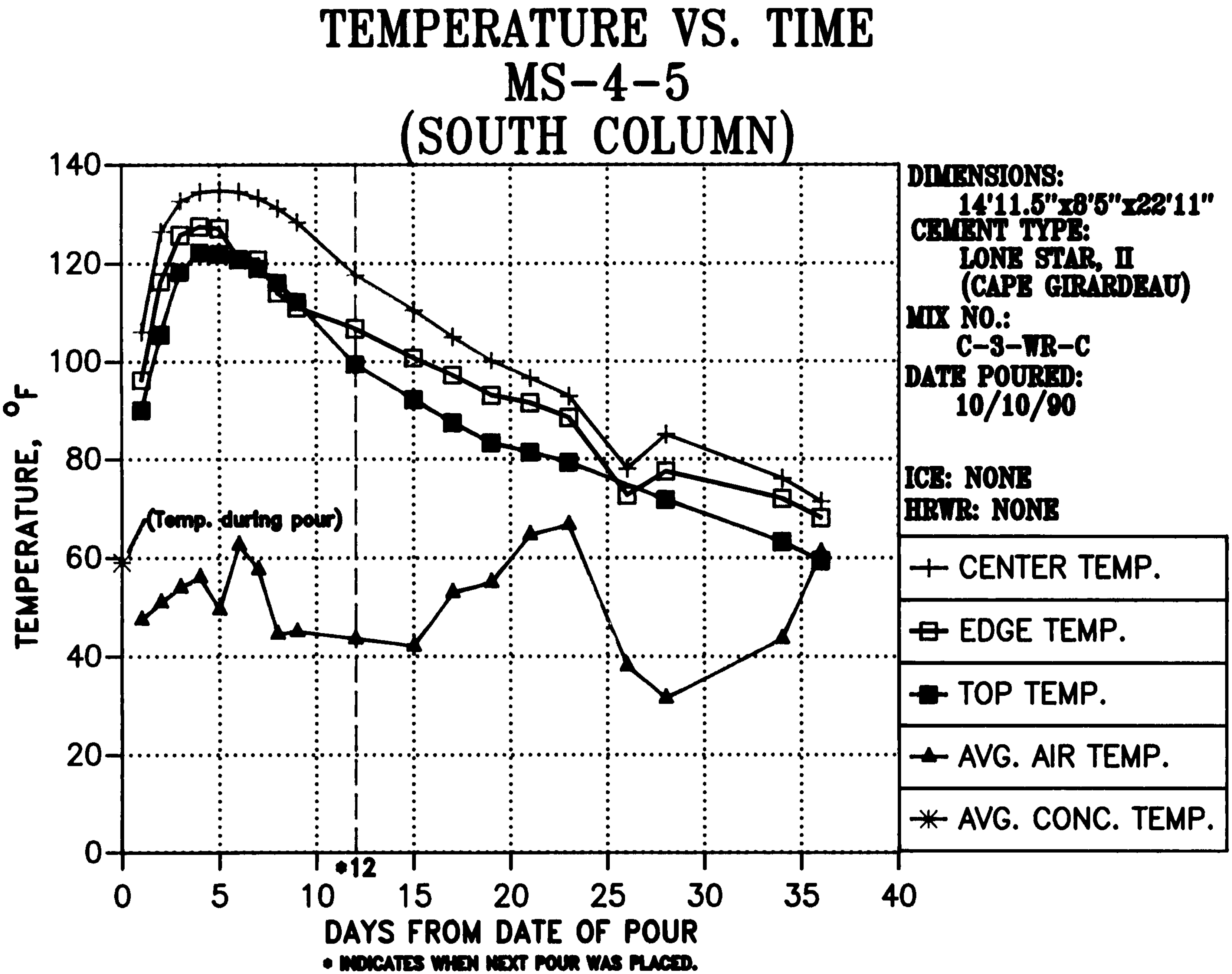
For the entire monitoring period, the center had the highest temperature, followed by the side, and then the top. The center to top differential exceeded the specified limit slightly for a few days before day ten. After the three areas began to cool at the

Figure 84



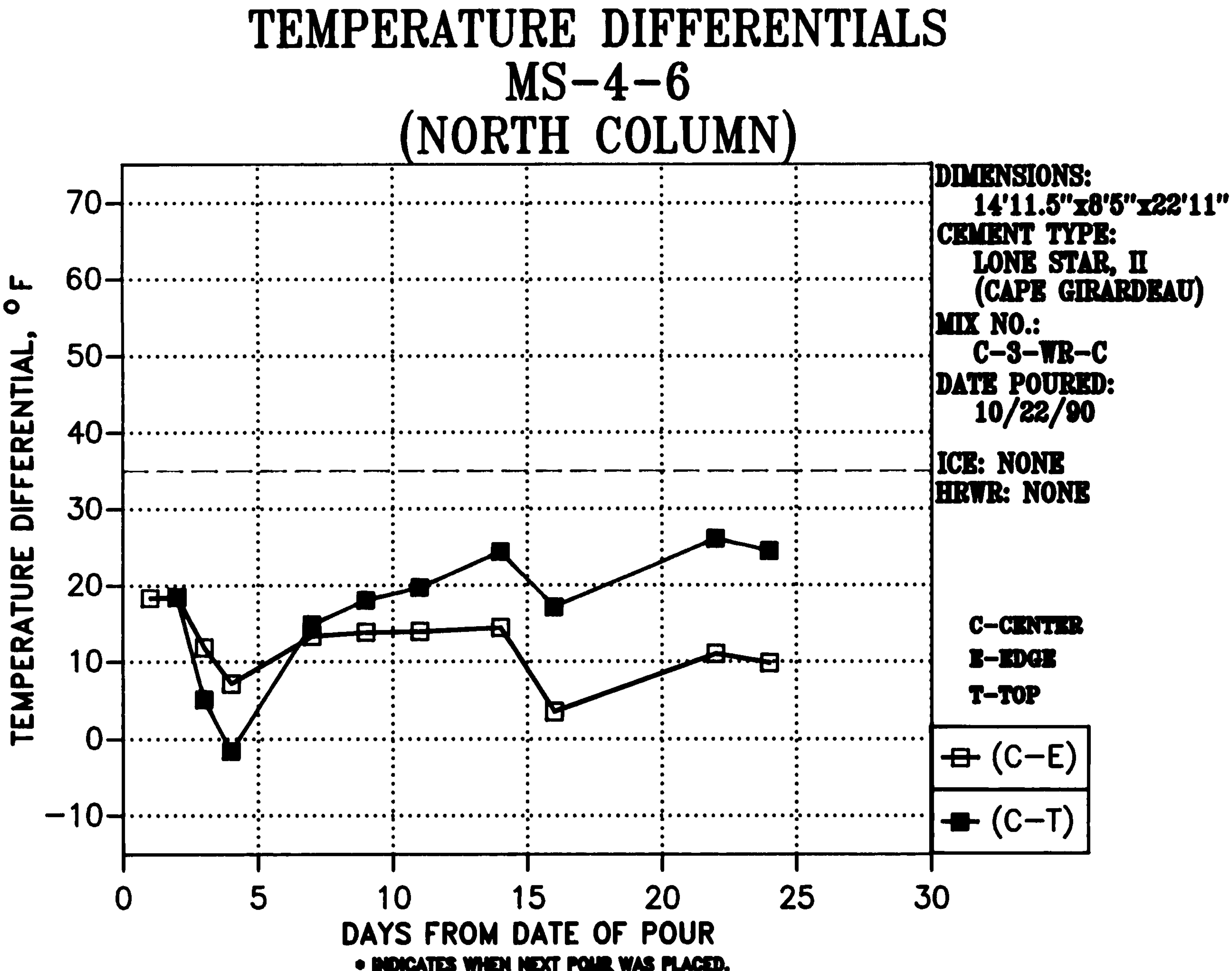
* INDICATES WHEN NEXT P... WAS PLACED.

Figure 85



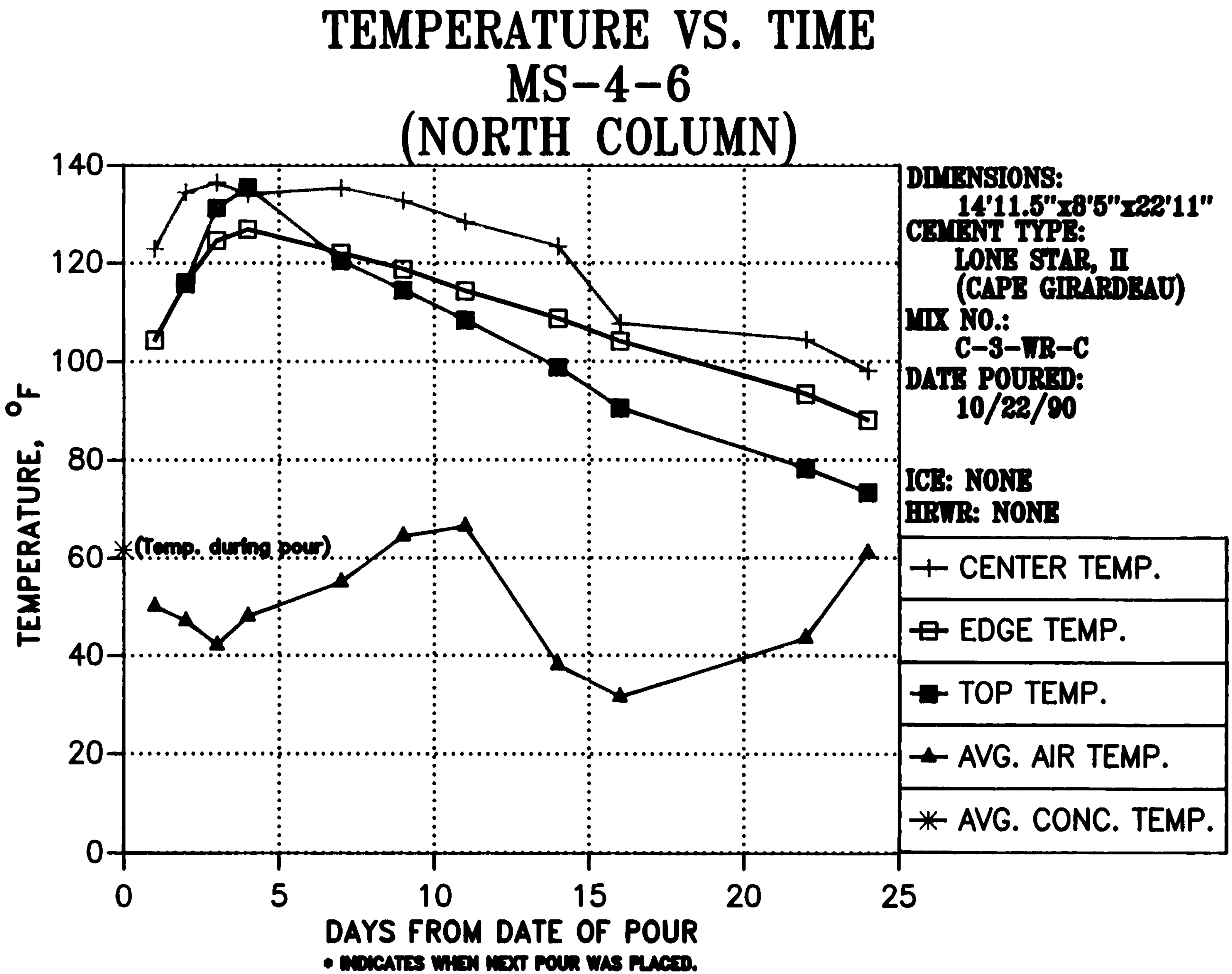
TEMPERATURE VS. TIME
MS-4-5
(SOUTH COLUMN)
DIMENSIONS:
14'11.5"x8'5"x22'11"
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
10/10/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
35
40
*12
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

Figure 86



TEMPERATURE DIFFERENTIALS
MS-4-6
(NORTH COLUMN)
DIMENSIONS:
14'11.5"x8'5"x22'11"
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
10/22/90
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
70
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
DAYS FROM DATE OF POUR
• INDICATES WHEN NEXT POUR WAS PLACED.

Figure 87


TEMPERATURE VS. TIME
MS-4-6
(NORTH COLUMN)
DIMENSIONS:
14'11.5"x8'5"x22'11"
CEMENT TYPE:
LONE STAR, II
(CAPE GIRARDEAU)
MIX NO.:
C-3-WR-C
DATE POURED:
10/22/90
ICE: NONE
HRWR: NONE
CENTER TEMP.
EDGE TEMP.
TOP TEMP.
AVG. AIR TEMP.
AVG. CONC. TEMP.
(Temp. during pour)
TEMPERATURE, °F
140
120
100
80
60
40
20
0
0
5
10
15
20
25
DAYS FROM DATE OF POUR
* INDICATES WHEN NEXT POUR WAS PLACED.

same rate (about day fifteen), the differentials began to decrease, and followed parallel patterns. On day twenty-three, the side and top started to cool a bit faster (about 4°F per day compared to 2°F per day previously), while the center was cooling slower (2°F per day compared to 3°F per day). These two combined circumstances caused both temperature differentials to increase slightly, but by the end of monitoring they had decreased again (Figures 88 and 89).

ANALYSIS:

I. Effects of Ice

During the construction of the main span's four piers, eight placements had ice added to the mix in order to delay the rate of temperature climb and to spread the temperature gain out over several days, in the hopes of lessening the stresses created by large, quick temperature changes (the cause of significant cracking). Of these eight different placements, some used Type I cement, while others used Type II cement. The mix temperatures and peak temperatures varied, as did the sizes of the placements and the amount of ice added to each placement. The relationship between the mix temperature and the average ambient temperature varied; most often, the mix temperature was between 10°F to 20°F greater than the air temperature, but in one instance the mix temperature was actually less than the air temperature. The eight placements that did include ice in the mix are: MS-1-2, MS-2-1, MS-2-2, MS-2-3, MS-2-16, MS-4-1, MS-4-2, and MS-4-3. In the determination of the effects of the addition of ice to a concrete mix, certain factors, such as the size of the placement, the cement type, and the ambient temperature, must be considered. The only

Figure 88

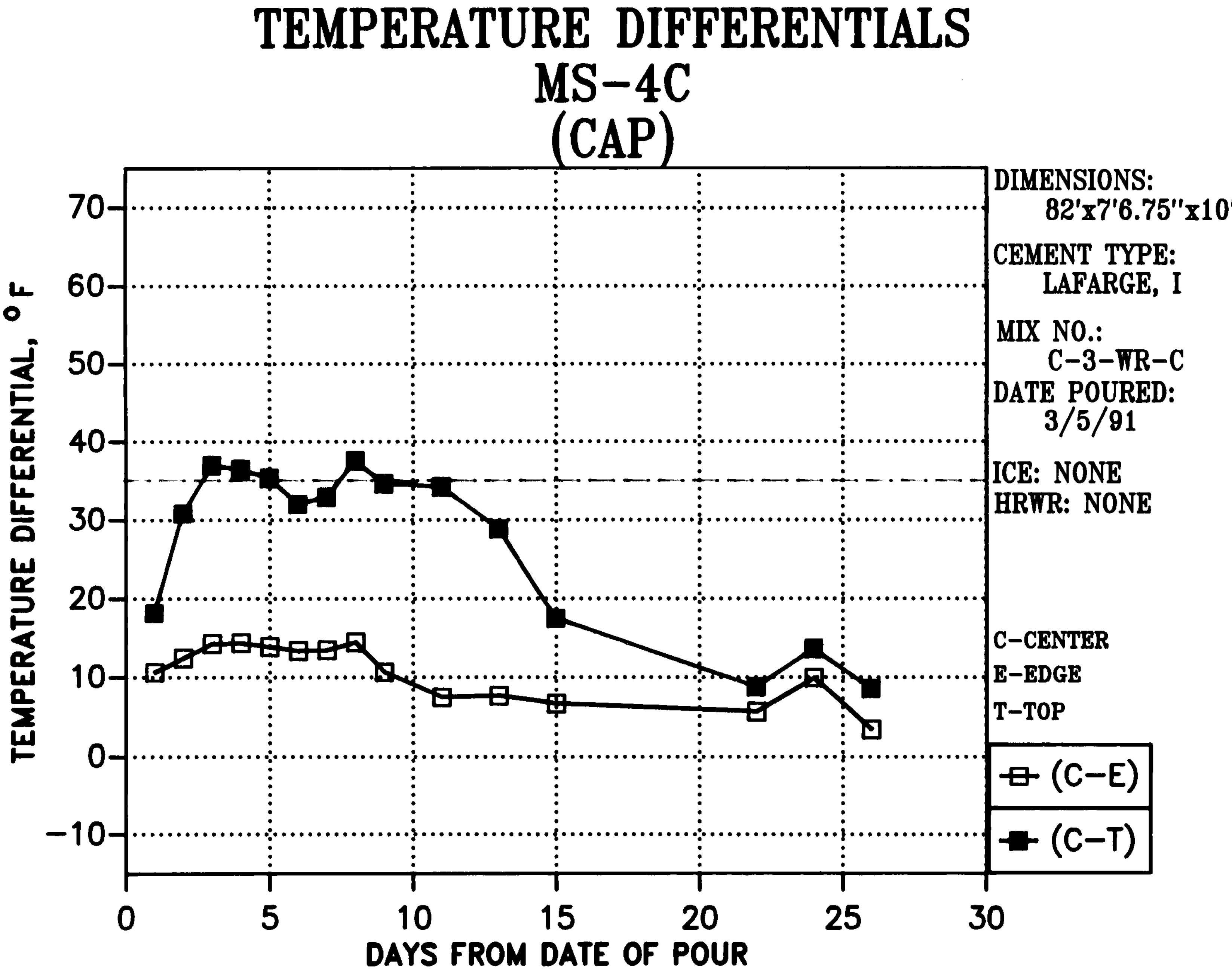
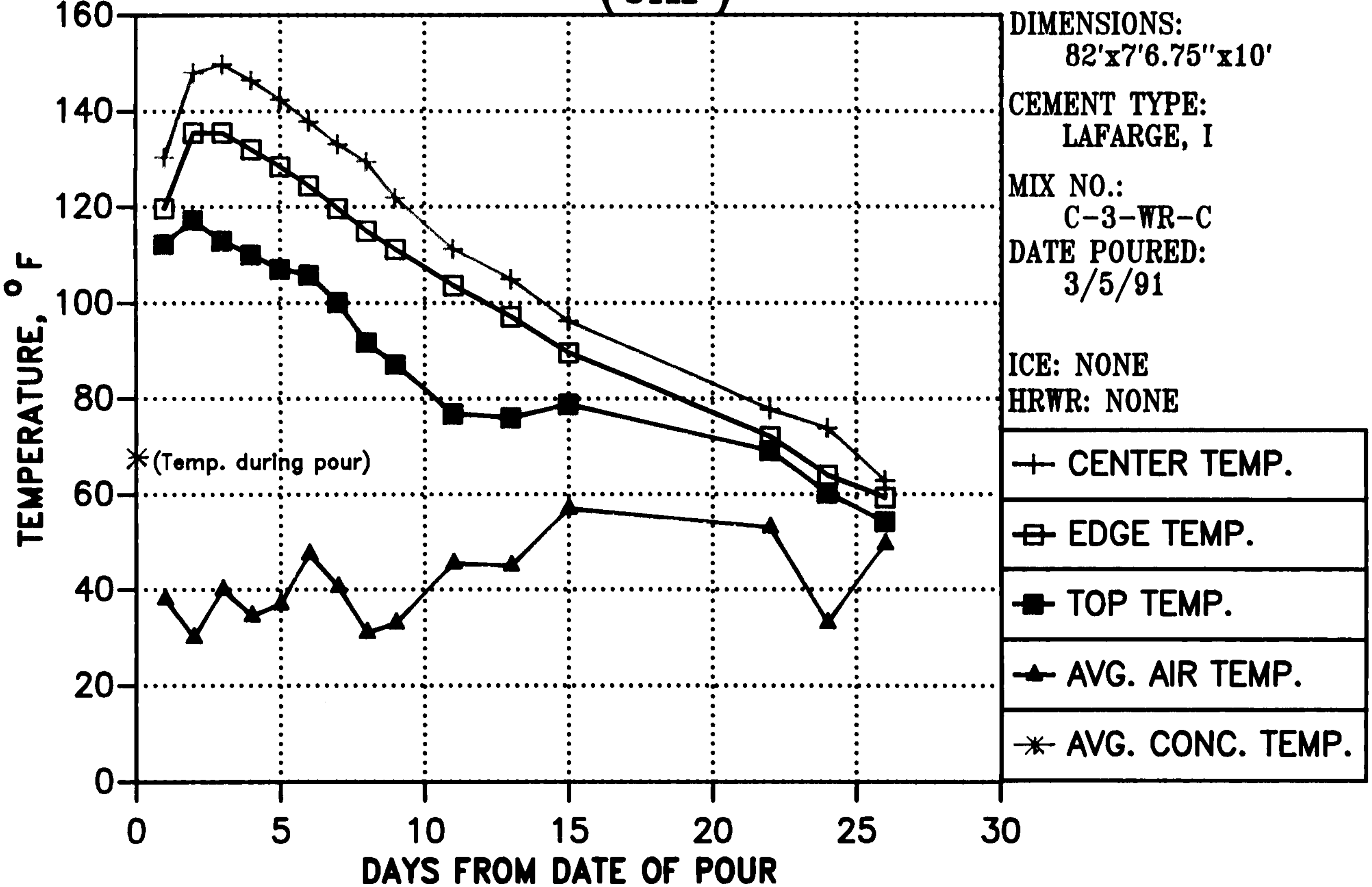

TEMPERATURE DIFFERENTIALS
MS-4C
(CAP)
DIMENSIONS:
82'x7'6.75"x10'
CEMENT TYPE:
LAFARGE, I
MIX NO.:
C-3-WR-C
DATE POURED:
3/5/91
ICE: NONE
HRWR: NONE
C-CENTER
E-EDGE
T-TOP
(C-E)
(C-T)
TEMPERATURE DIFFERENTIAL, °F
DAYS FROM DATE OF POUR
70
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30

Figure 89

TEMPERATURE VS. TIME
MS-4C
(CAP)



placements that could be matched for comparison purposes to similar placements according to these elements are MS-1-2 and MS-2-16.

It has been a general opinion that the addition of ice to a concrete mix would only have an effect on:

a) the initial mix temperature, and

b) the peak temperature of the concrete, but

c) not on the subsequent cooling of the concrete.

General conclusions can be drawn about the addition of ice by comparing the eight placements that did contain ice to other placements which had similar ambient temperatures on the day of the placement, as follows:

1) Those with ice took an average of five days to reach the peak,

2) Those without ice needed an average of two and a half days to reach a peak;

3) Also, in placements with ice, the difference between the peak temperature and the mix temperature was smaller, on average;

4) Placements that contained ice increased an average of 81.7°F, while

5) Placements without ice (but with similar ambient temperatures on the day of placement, i.e., above 55°F) increased an average of 90.2°F over the initial mix temperature. (Placements with ambient temperatures less than 55°F increased an average of 84.9°F.)

6) Individual placements had certain events that override the cooling effects of ice, and so they might vary from the averages found here.

MS-1-2 (the second lift of the first pier) can be compared to MS-2-5 or to MS-1-3, using the center temperatures as an indicator. If it is compared to MS-2-5, one can see that MS-1-2 had a smaller increase to reach its peak; the placement with ice increased by 88.75°F, while the placement without ice increased by 102.7°F. In addition, the temperature gain of placement MS-1-2 was further delayed by the addition of ice, since it required four days to reach a peak, while the placement without ice peaked in only three days. Also, during the curing of MS-1-2, the average ambient temperature was higher than for the curing of MS-2-5, a factor which should have caused it to have a greater increase to its peak. This, however, was not true, which leads one to conclude that the addition of ice was the determining factor. While the ice was an attempt to decrease the possibility of the concrete temperature differentials exceeding the established limit, both placements exceeded the 35°F limit for a short time.

Different results are obtained, however, when comparing MS-1-2 to MS-1-3. MS-1-3, without ice, had a lower temperature increase than MS-1-2; it only gained 74.3°F, compared to 89°F. The average ambient air temperature for the two placements were about the same, and they both reached peaked on the fourth day. Also, while MS-1-3 only exceeded the specification limit at one point, MS-1-2 exceeded 35°F for twelve days. It must be noted, though, that MS-1-3 is only half as deep as MS-1-2, a factor which could greatly change the temperature gain of the concrete.

MS-2-16 (pylon B of the south tower) can be compared to MS-2-7, pylon B of the north tower: both were placed at about the same time, and both are hollow. The results from this comparison are not as expected. The mix with ice had a greater temperature gain than the mix without ice: 71.2°F with ice, versus 67°F without ice. In addition, the placement with ice reached its peak in only one day, while the placement without ice peaked on the second day. Since the placements were poured only a few days apart, the average ambient temperatures for the two placements were practically identical, so it would not be a controlling factor in this case. Finally, only the placement with ice did exceed the differential limit, and that only on the day of the placement.

If only the overall averages are considered, it appears that the addition of ice does have an effect on lowering the peak temperatures and on spreading the temperature gain out over a longer period of time. Unfortunately, there are so many factors which must be considered and which make it difficult to determine which had the greatest effects on the temperature gain and possible cracking of the mass concrete. (Of the placements with ice, MS-1-2, MS-2-2, and MS-2-3 were the only placements to show significant cracking, but it is unknown if the addition of ice played a role.)

II. <u>Type I vs. Type II Cements</u>

All placements in pier MS-4 (except the cap) used Type II cement, and since this pier is similar in size to MS-1, which used Type I exclusively, the two piers can be compared to relate the difference in temperature changes of the individual placements due to the different cement types.

To compare the effects of high-heat vs. low-heat cement, graphs were made of the center temperatures of the individual placements of both piers (MS-1 and MS-4)(see Figures 90 through 95). In all instances, the Type I cement reached a higher peak temperature than the placement with the Type II cement. Also, the placements with Type I cement peaked at the same time or sooner than those with Type II. The overall average temperature increase

Figure 90

TYPE I VS. TYPE II CEMENTS (MS-1-1 vs. MS-4-1)

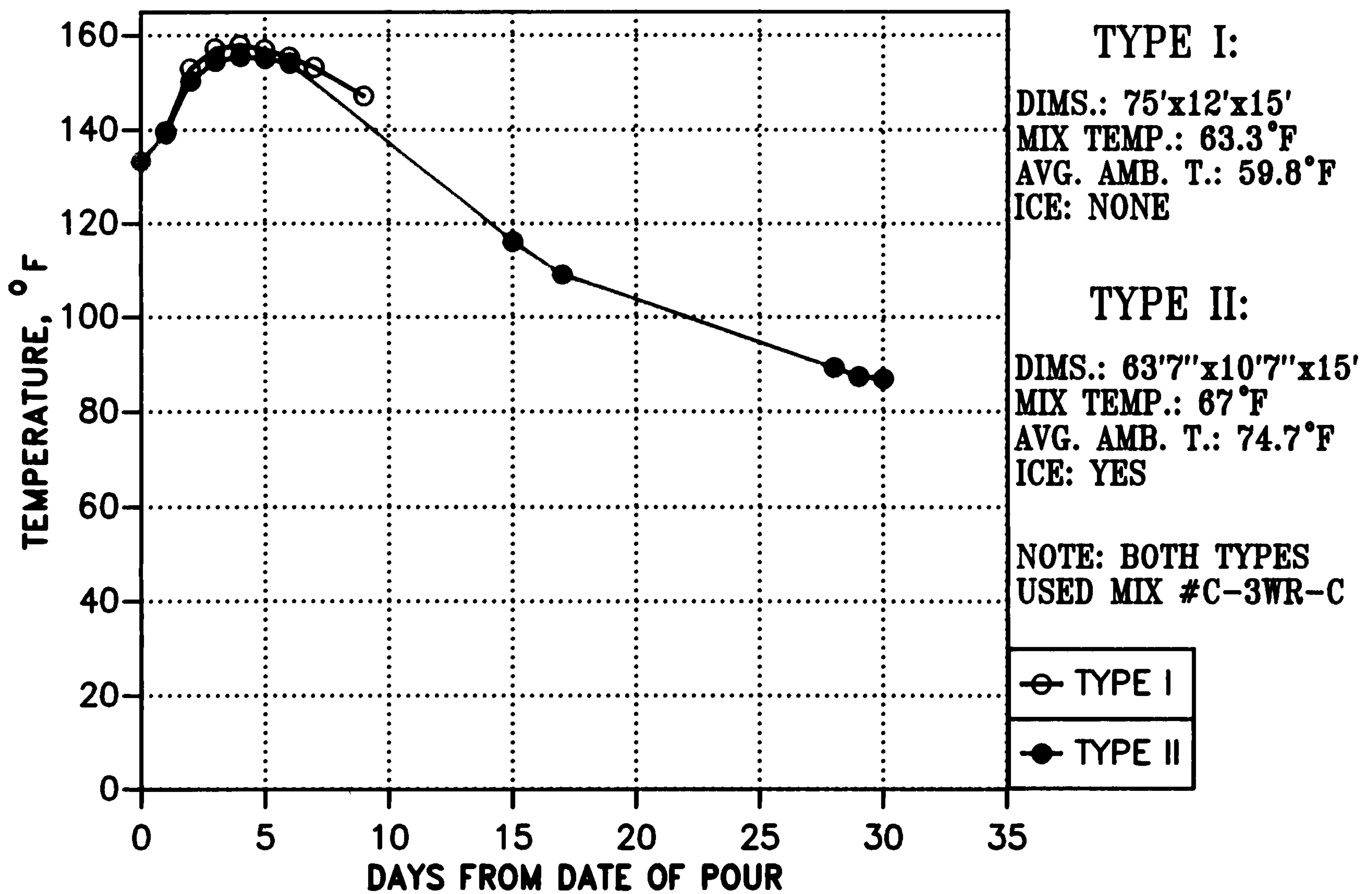


Figure 91

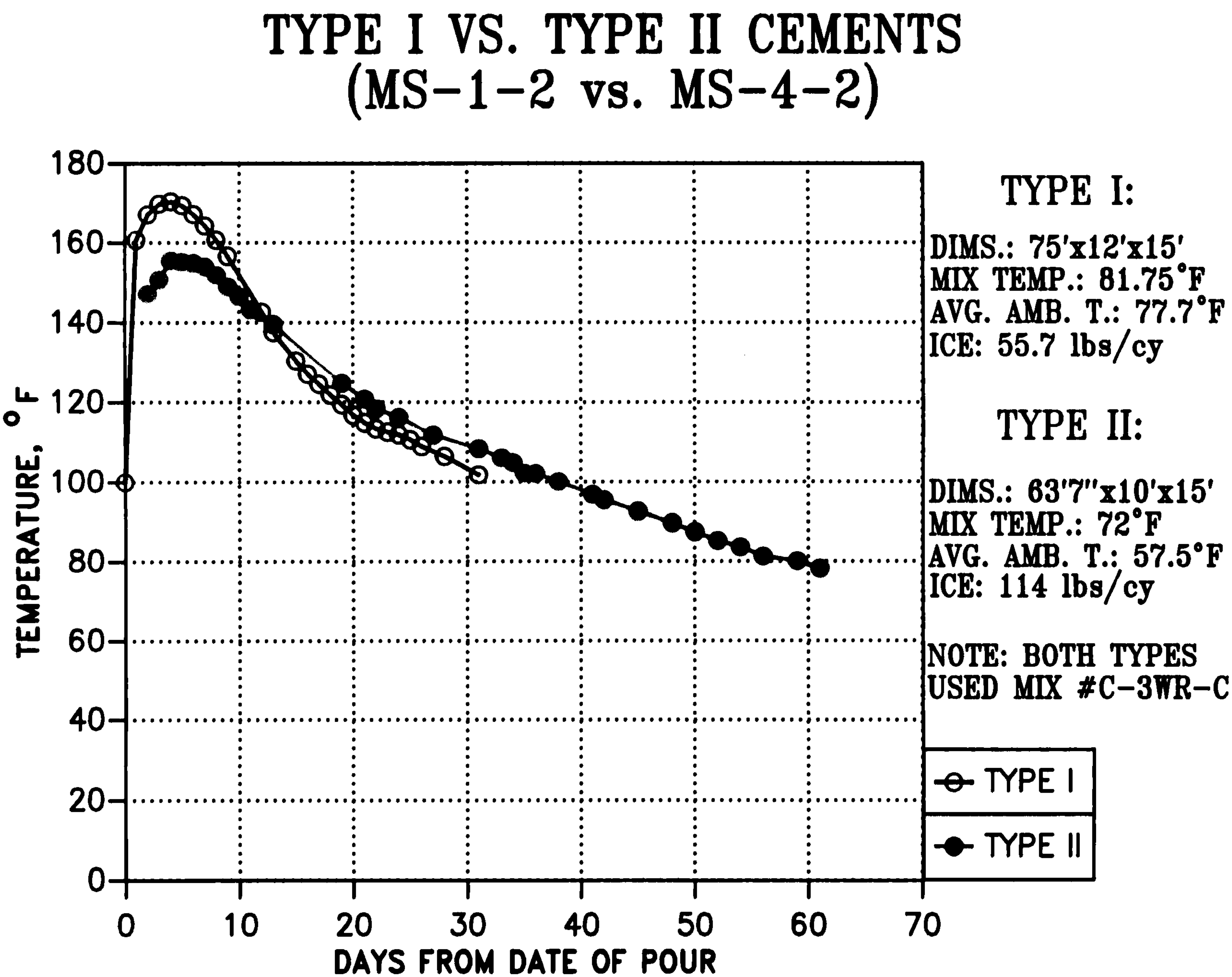

TYPE I VS. TYPE II CEMENTS
(MS-1-2 vs. MS-4-2)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
70
TYPE I:
DIMS.: 75'x12'x15'
MIX TEMP.: 81.75°F
AVG. AMB. T.: 77.7°F
ICE: 55.7 lbs/cy
TYPE II:
DIMS.: 63'7"x10'x15'
MIX TEMP.: 72°F
AVG. AMB. T.: 57.5°F
ICE: 114 lbs/cy
NOTE: BOTH TYPES
USED MIX #C-3WR-C
TYPE I
TYPE II

Figure 92

TYPE I VS. TYPE II CEMENTS (MS-1-3 vs. MS-4-3)

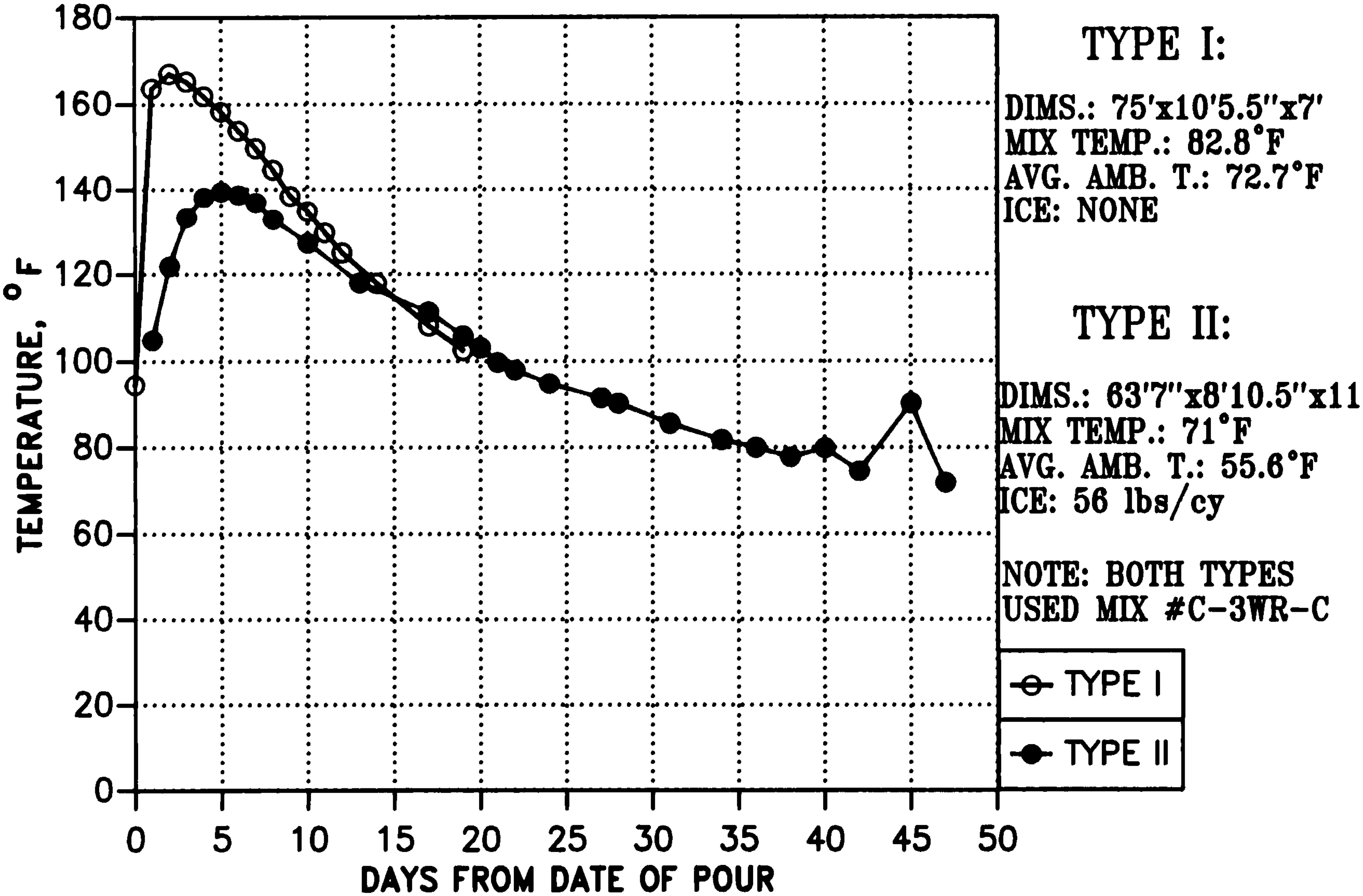


Figure 93

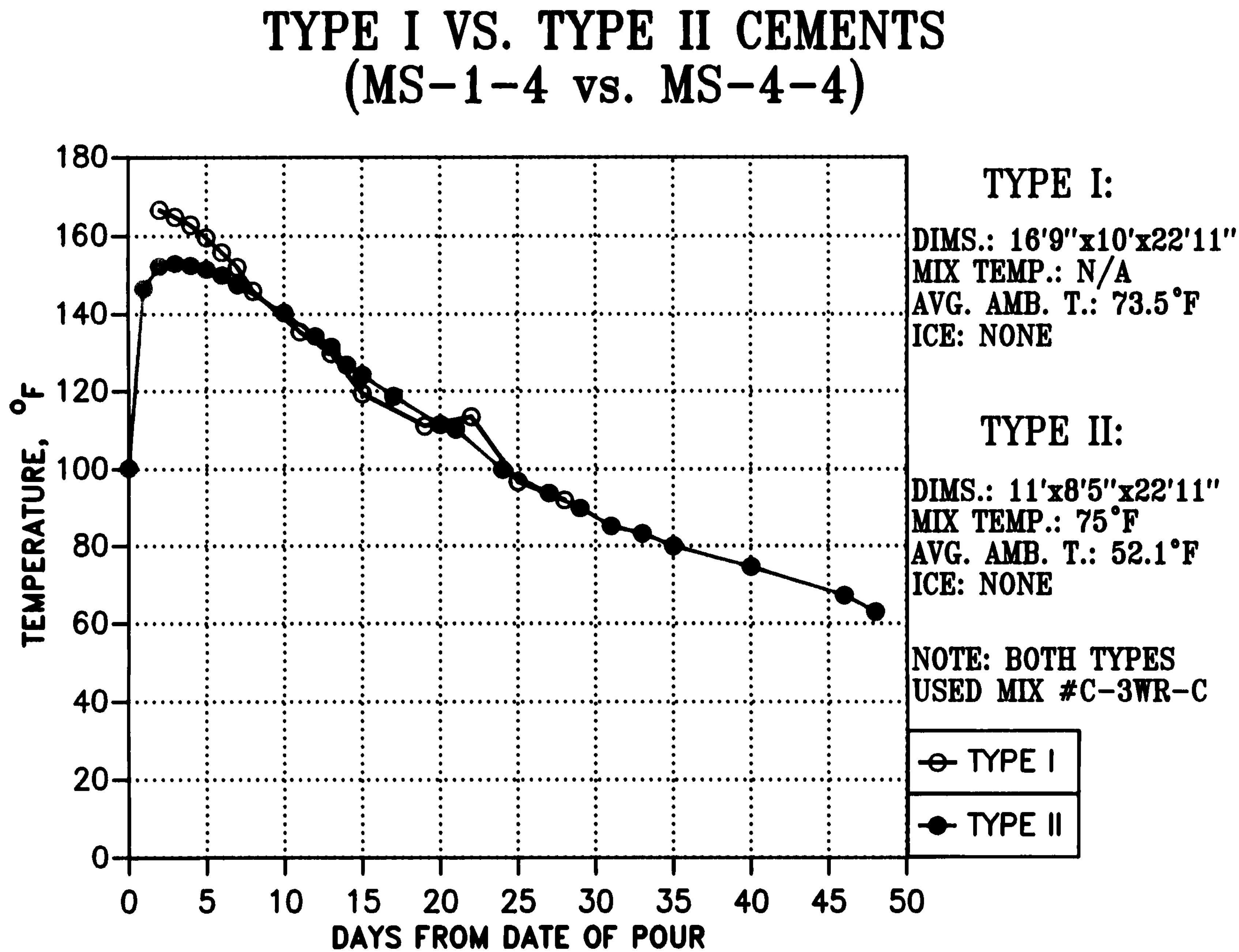

TYPE I VS. TYPE II CEMENTS
(MS-1-4 vs. MS-4-4)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40
45
50
TYPE I:
DIMS.: 16'9"x10'x22'11"
MIX TEMP.: N/A
AVG. AMB. T.: 73.5°F
ICE: NONE
TYPE II:
DIMS.: 11'x8'5"x22'11"
MIX TEMP.: 75°F
AVG. AMB. T.: 52.1°F
ICE: NONE
NOTE: BOTH TYPES USED MIX #C-3WR-C
TYPE I
TYPE II

Figure 94

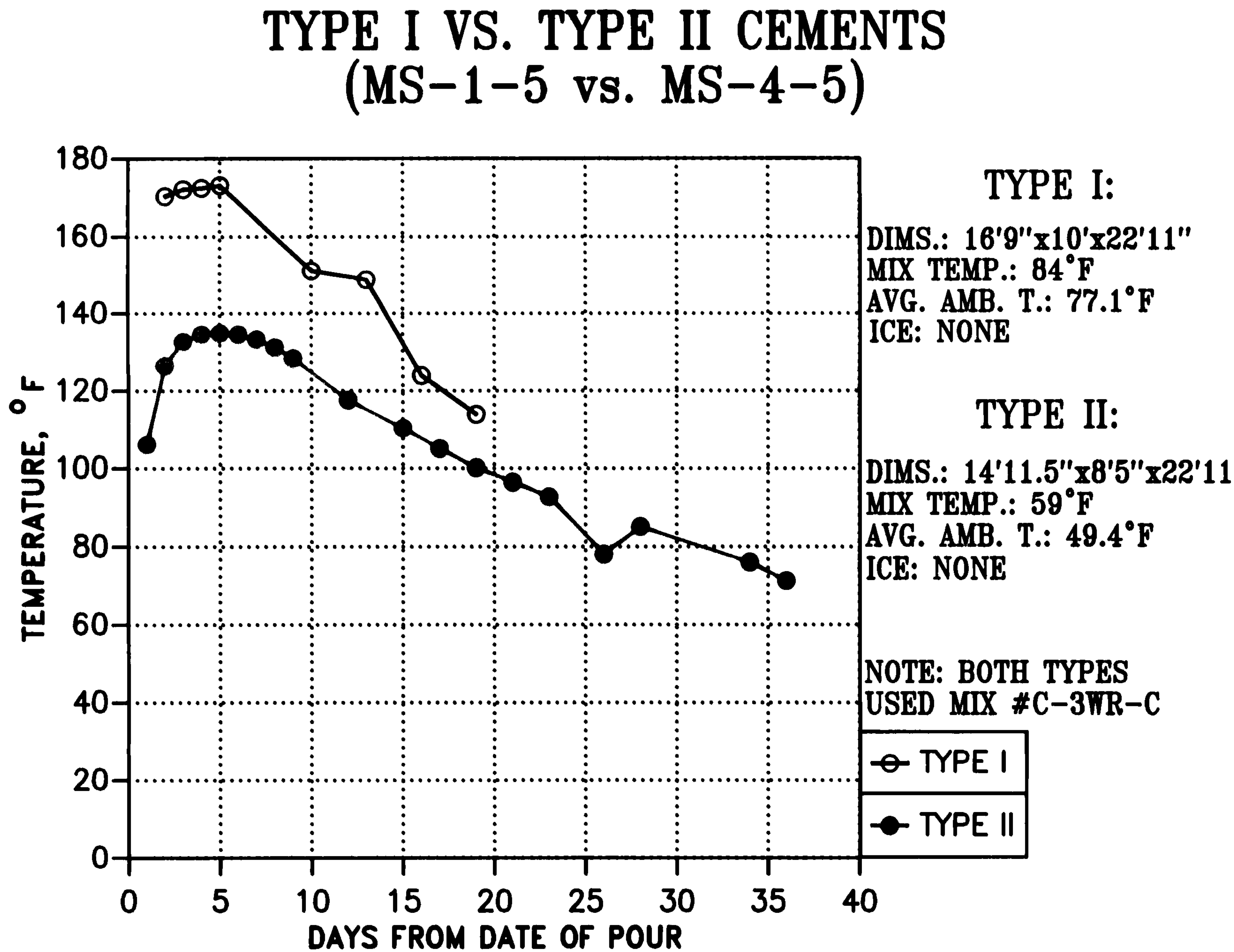
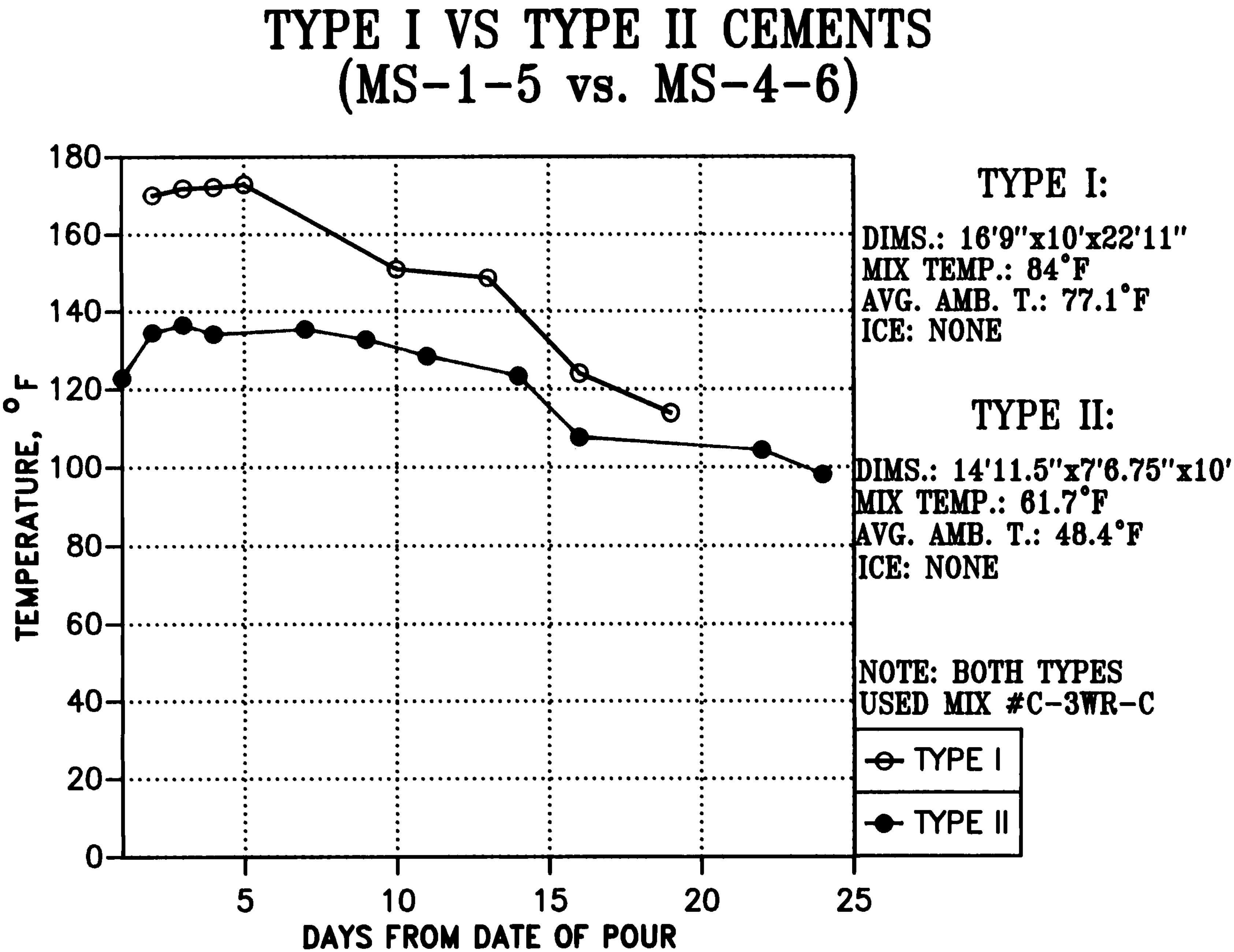

TYPE I VS. TYPE II CEMENTS
(MS-1-5 vs. MS-4-5)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40
TYPE I:
DIMS.: 16'9"x10'x22'11"
MIX TEMP.: 84°F
AVG. AMB. T.: 77.1°F
ICE: NONE
TYPE II:
DIMS.: 14'11.5"x8'5"x22'11'
MIX TEMP.: 59°F
AVG. AMB. T.: 49.4°F
ICE: NONE
NOTE: BOTH TYPES
USED MIX #C-3WR-C
TYPE I
TYPE II

Figure 95



TYPE I VS TYPE II CEMENTS
(MS-1-5 vs. MS-4-6)
TEMPERATURE, °F
DAYS FROM DATE OF POUR
180
160
140
120
100
80
60
40
20
0
5
10
15
20
25
TYPE I:
DIMS.: 16'9"x10'x22'11"
MIX TEMP.: 84°F
AVG. AMB. T.: 77.1°F
ICE: NONE
TYPE II:
DIMS.: 14'11.5"x7'6.75"x10'
MIX TEMP.: 61.7°F
AVG. AMB. T.: 48.4°F
ICE: NONE
NOTE: BOTH TYPES
USED MIX #C-3WR-C
TYPE I
TYPE II

for Type I cements in MS-1 was 92.5°F (average calculated by using temperature for MS-1-5 twice), while in MS-4 it was only 78.0°F. The difference in peak temperatures of similar placements varied, ranging from 2.5°F up to 38°F; the peaks of Type I cement placements were consistently higher then those of Type II placements.

While these results are as expected according to cement types, other factors need to be weighed as well, including: the average ambient temperature, the mix temperature, and the presence or absence of ice. It is obvious that the average ambient temperature at the time of the placement does, in fact, have an effect on the peak temperature that the concrete reaches; if the air temperature is low, the mix temperature is lowered, and, therefore, the concrete cannot reach as high a peak as if it had started with a higher mix temperature. In all instances comparing MS-1 to MS-4 except the first, the mix temperature of MS-1 is about 20°F higher than that of MS-4, so it would have a natural propensity to reach a higher peak temperature. Overall though, it does seem that the use of Type II cement does reduce the overall temperature gain and seem to spread it out more evenly over several days.

RESULTS AND CONCLUSIONS:

From this study the following conclusions can be made:

1) Side temperatures are generally cooler and more affected by the ambient temperatures than the others, indicating a need for tighter insulation on the sides of the placements.

2) When the differentials exceeded the 35°F limit, it was almost exclusively the center to side differential.

3) The top temperature increases substantially whenever a new placement is placed; to insure that a large temperature differential does not occur (increasing the chance of cracking), good insulation on the sides of the placements should be maintained until temperatures return to normal.

4) The use of ice and different cement types did seem to affect the overall temperature gain and the amount of time it took any one placement to reach a peak, but did not necessarily prevent the differentials from exceeding the specification limit, nor prevent cracking in any placements, even those that were within the 35°F limit.

5) Larger placements (such as in pier MS-2) have a greater tendency to exceed the differential limit.

In examining the results of this study, those who were greatly involved offered some suggestions to improve this type of project. These include the following:

1) Include a 35°F temperature differential limit on future projects involving massive concrete placements.

2) If one is to have a similar temperature limit specification, it is recommended that it be spelled out in the contract, so that the contractors may know their full responsibility, be able to make temperature control a part of the design, and include it in their bid.

3) Temperature sensors should be placed to collect continuous data in all conditions, and should not be affected by inconveniences such as flooding.

4) The controlling agency must be attentive to the specification being enforced, and have a specific plan of action to take if a non-compliance occurs.

5) Try more reinforcement in smaller placements to prevent cracking.

6) Determine the definition of <u>massive</u> concrete; is four feet actually "massive"? Should it be eight feet? Ten?

7) Specify other methods of cooling to be considered and included in the designs and planning, such as liquid nitrogen or internal water cooling.

In retrospect, the 35°F limit seems reasonable and seemed to accomplish the goal it was intended for. Cracking, however, did occur in each placement to some degree, regardless of cement type, insulation placement, or exceeding the specified limit. It is believed, however, that the cracking would have been worse had it not been for the attempt to limit the temperature differential with insulation and experimentation with different cement types and ice.

APPENDICES

Appendix A

Summary of Data for Individual Pours

LOCATION	DESCRIPTION	DATE PLACED	DIMENSIONS (L x W x D)	VOLUME (c.y.)	CEMENT BRAND	TYPE	CEMENT MIX NO.
MS–1F	Footing	03/07/91	87'x35'x7'	846.00	LaFarge	I	C–3WR–C
MS–1–1	First lift	03/20/91	75'x12'x15'	463.00	LaFarge	I	C–3WR–C
MS–1–2	Second lift	07/12/91	75'x12'x15'	425.00	LaFarge	I	C–3WR–C
MS–1–3	Third lift	07/26/91	75'x10'5.5"x7'	193.00	LaFarge	I	C–3WR–C
MS–1–4	South column	08/15/91	16'9.5"x10'x22'11"	127.00	LaFarge	I	C–3WR–C
MS–1–5	North column	08/24/91	16'9"x10'x22'11"	127.00	LaFarge	I	C–3WR–C
MS–1C	Cap	10/02/91	93'x9'6"x9'	304.50	LaFarge	I	C–3WR–C
MS–2F	Footing	06/01/90	155'x43'6"x7'6"	2002.00	LaFarge	I	C–3WR–C
MS–2–1	First lift	07/24/90	148'x24'x15'	1623.00	Lone Star Cape Girardeau	II	C–3WR–C
MS–2–2	Second lift	08/09/90	148'x24'x15'	1568.00	Lone Star Cape Girardeau	II	C–3WR–C
MS–2–3	Third lift	08/23/90	148'x24'x16'	1687.00	Lone Star Cape Girardeau	II	C–3WR–C
MS–2–4	South end pour of next lift	04/02/91	74'x24'x10'	586.00	LaFarge	I	D–57–C
MS–2–5	North half of previous pour	04/04/91	74'x24'x10'	585.00	LaFarge	I	D–57–C
MS–2–6	First pour, north tower	04/17/91	23'2.5"x22'x8'	59.00	LaFarge	I	D–57–C
MS–2–7	Pylon B, north tower	05/17/91	29'2.5"x22'x30'	247.00	LaFarge	I	D–57–C
MS–2–8	N. tower, elev. 725'–737'	09/28/91	9'3"x22'x12'	68.50	LaFarge	I	D–57–C
MS–2–9	N. tower, elev. 737'–748'	10/08/91	9'3"x22'x12'	69.50	LaFarge	I	D–57–C
MS–2–10	N. tower, elev. 748'–768'	11/10/91	9'3"x22'x20'	93.00	LaFarge	I	D–57–C, mod
MS–2–11	N. tower, elev. 768'–780'	12/30/91	9'3"x22'x20'	58.00	LaFarge	I	D–57–C, mod
MS–2–12	N. tower, elev. 780'–800'	1/21/92	9'3"x22'x20'	97.00	LaFarge	I	D–57–C, mod
MS–2–13	N. tower, elev. 800'–818'	02/06/92	9'3"x22'x18'	87.50	LaFarge	I	D–57–C, mod
MS–2–14	N. tower, elev. 818'–835'	02/21/92	9'3"x22'x17'	84.50	LaFarge	I	D–57–C, mod
MS–2–15	First pour, south tower	04/22/91	23'2.5"x22'x8'	60.00	LaFarge	I	D–57–C
MS–2–16	Pylon B, south tower	05/28/91	23'2.5"x22'x30'	239.25	LaFarge	I	D–57–C
MS–2–17	S. tower, elev. 725'–737'	10/11/91	9'3"x22'x12'	70.00	LaFarge	I	D–57–C, mod
MS–2–18	S. tower, elev. 737'–748'	10/15/91	9'3"x22'x11'	68.25	LaFarge	I	D–57–C, mod
MS–2–19	S. tower, elev. 748'–768'	11/09/91	9'3"x22'x20'	96.50	LaFarge	I	D–57–C, mod
MS–2–20	S. tower, elev. 768'–780'	12/18/91	9'3"x22'x12'	58.00	LaFarge	I	D–57–C, mod
MS–2–21	S. tower, elev. 780'–800'	01/07/92	9'3"x22'x20'	97.25	LaFarge	I	D–57–C, mod
MS–2–22	S. tower, elev. 800'–818'	01/30/92	9'3"x22'x18'	87.50	LaFarge	I	D–57–C, mod
MS–2–23	S. tower, elev. 818'–835'	02/13/92	9'3"x22'x17'	83.00	LaFarge	I	D–57–C, mod

LOCATION	DESCRIPTION	DATE PLACED	DIMENSIONS (L x W x D)	VOLUME (C.Y.)	CEMENT BRAND	TYPE	CEMENT MIX NO.
MS−3F	Footing	11/15/90	53'2"x36'x8'	553.00	LaFarge	I	C−3WR−C
MS−3−1	First lift	12/06/90	104'11"x12'x12'	551.00	LaFarge	I	C−3WR−C
MS−3−2	Second lift	12/14/90	106'4"x12'x12'	538.50	LaFarge	I	C−3WR−C
MS−3−3	Third lift	01/08/91	106'4"x12'x12'	525.00	LaFarge	I	C−3WR−C
MS−3−4	First half of fourth lift	01/15/91	106'4"x12'x4'	145.00	LaFarge	I	D−57
MS−3−5	Second half of fourth lift	02/12/91	106'4"x12'x14'	603.00	LaFarge	I	D−57
MS−4−1	First lift	08/21/90	63'7"x10'7"x15'	350.00	Lone Star Cape Girardeau	II	C−3WR−C
MS−4−2	Second lift	09/07/90	63'7"x10'x15'	330.00	Lone Star Cape Girardeau	II	C−3WR−C
MS−4−3	Third lift	09/21/90	63'7"x8'10.5"x11'	223.00	Lone Star Cape Girardeau	II	C−3WR−C
MS−4−4	Center column	09/28/90	11'x8'5"x22'11"	84.50	Lone Star Cape Girardeau	II	C−3WR−C
MS−4−5	South column	10/10/90	14'11.5"x8'5"x22'11"	93.60	Lone Star Cape Girardeau	II	C−3WR−C
MS−4−6	North column	10/22/90	14'11.5"x8'5"x22'11"	93.60	Lone Star Cape Girardeau	II	C−3WR−C
MS−4C	Cap	03/05/91	82'x7'6.75"x10'	228.00	LaFarge	I	C−3WR−C

LOCATION	AMBIENT TEMP.	MIX TEMP.	PEAK TEMP.	TEMP. GAIN	ICE (#/c.y.)	HRWR, Brand (oz/100#cement)
MS−1F	38.80	59.30	140.80	81.50	None	None
MS−1−1	58.70	63.30	158.00	81.50	None	None
MS−1−2	86.20	81.80	170.50	88.00	55.70	None
MS−1−3	75.50	82.80	167.30	84.50	None	None
MS−1−4	74.50	−−−−	166.60	−−−−	None	None
MS−1−5	87.00	84.00	173.10	89.10	None	None
MS−1C	76.50	76.50	184.20	107.70	None	None
MS−2F	79.60	77.60	156.50	78.90	None	None
MS−2−1	81.00	70.00	150.00	80.00	114.00	None
MS−2−2	57.30	66.00	149.30	83.30	Yes	None
MS−2−3	75.00	65.00	155.50	90.50	114.00	None
MS−2−4	54.90	62.30	162.20	99.90	None	None
MS−2−5	57.70	64.20	166.90	102.70	None	None
MS−2−6	68.80	68.40	157.70	89.30	None	None
MS−2−7	79.60	78.70	145.70	67.00	None	7, PSP−N2
MS−2−8	55.80	71.70	156.00	84.30	None	7, PSP−N2
MS−2−9	74.50	69.50	162.90	93.40	None	7, PSP−N2
MS−2−10	48.50	61.50	147.20	85.70	None	7, Daracem100
MS−2−11	32.50	65.00	149.40	84.40	None	14, Daracem100
MS−2−12	46.00	63.50	143.80	80.30	None	14, Daracem100
MS−2−13	38.40	61.50	142.90	81.40	None	14, Daracem100
MS−2−14	35.50	59.50	139.90	80.40	None	14, Daracem100
MS−2−15	69.40	68.50	159.40	90.90	None	None
MS−2−16	84.50	73.50	144.70	71.20	123.00	7, PSP−N2
MS−2−17	68.50	71.70	155.40	83.70	None	None
MS−2−18	57.10	63.80	160.50	96.70	None	7, PSP−N2
MS−2−19	31.00	62.00	141.00	79.00	None	16, Daracem100
MS−2−20	24.00	60.50	156.10	95.60	None	14, Daracem100
MS−2−21	41.00	62.50	150.50	88.00	None	14, Daracem100
MS−2−22	39.00	62.50	146.10	83.60	None	14, Daracem100
MS−2−23	33.00	57.50	142.80	85.30	None	14, Daracem100

LOCATION	AMBIENT TEMP.	MIX TEMP.	PEAK TEMP.	TEMP. GAIN	ICE (#/CY)	HRWR (oz/100#cement)
MS−3F	61.50	64.40	133.70	69.30	None	None
MS−3−1	35.50	35.50	142.80	107.30	None	None
MS−3−2	33.60	64.30	150.50	86.20	None	None
MS−3−3	32.80	55.30	137.50	82.20	None	None
MS−3−4	29.80	61.60	139.20	77.60	None	None
MS−3−5	32.40	61.50	165.30	103.80	None	None
MS−4−1	74.00	67.00	155.50	88.50	Yes	None
MS−4−2	75.00	72.00	155.40	83.40	114.00	None
MS−4−3	66.00	71.00	139.30	68.30	56.00	None
MS−4−4	67.00	75.00	152.70	77.70	None	None
MS−4−5	41.00	59.00	134.70	75.70	None	None
MS−4−6	53.00	61.70	136.30	74.60	None	None
MS−4C	50.10	67.70	149.70	82.00	None	None

Appendix B

Listing of Placements Necessitating Action

Placements where action was taken to fix cracking and honeycombing:

MS-2F:	Epoxy Grouted
MS-2-1:	Epoxy Grouted, Filled with sand-cement grout
MS-2-2:	Epoxy Grouted, Filled with sand-cement grout
MS-2-3:	Epoxy Grouted, Filled with sand-cement grout

Placements where other action was taken:

MS-2-4:	Doubled insulating blankets on top and sides
MS-2-5:	Doubled insulating blankets on top and sides
MS-2-7:	Non-compliance notice was sent requesting corrective action on next placement
MS-2-16:	(Placement following MS-2-7) Insulating blankets placed on forms and ice added

Placements where temperature sensors did not function properly:

MS-1-5:	Center wire shorted out
MS-2F:	Cofferdam flooded temporarily
MS-2-14:	Machine malfunction
MS-3-1:	Machine malfunction
MS-4-4:	Top wire disconnected accidentally

Placements where insulation placement was a problem:

MS-1C:	Removed on top to place bearing pedestals
MS-2-1:	Washed away during flooding, and not replaced
MS-2-2:	Washed away during flooding, and not replaced
MS-2-3:	Washed away during flooding, and not replaced
MS-2-5:	Possibly removed on top
MS-3-2:	Possibly poor or no insulation on top for a short time
MS-3-3:	Removed too early on side
MS-4-2:	Removed on top to prepare for next placement

Placements where flooding occurred:

MS-2F
MS-2-1
MS-2-2
MS-2-3
MS-4-1

Appendix C
Iowa Department of Transportation
Concrete Mix Designs and Nomenclature

Concrete Mix No.: C-3WR-C

Basic absolute volumes of materials per unit volume of concrete:

Cement Minimum:	0.092
Fly Ash:	0.019
Water:	0.146
Entrained Air:	0.06
Fine Aggregate:	0.308
Coarse Aggregate:	0.375

Approximate quantity of dry materials per cubic yard of concrete:

Cement, Pounds:	487
Fly Ash, Pounds:	86
Fine Aggregate, Tons:	0.688
Coarse Aggregate, Tons:	0.837
W/C + FA	
Basic:	0.430
Maximum:	0.489

Concrete Mix No.: D-57-C

Basic absolute volumes of materials per unit volume of concrete:

Cement Minimum:	0.114
Fly Ash:	0.023
Water:	0.178
Entrained Air:	0.06
Fine Aggregate:	0.313
Coarse Aggregate:	0.312

Approximate quantity of dry materials per cubic yard of concrete:

Cement, Pounds:	603
Fly Ash, Pounds:	104
Fine Aggregate, Tons:	0.699
Coarse Aggregate, Tons:	0.696
W/C + FA	
Basic:	0.423
Maximum:	0.450

Concrete Mix No.: D-57

Basic absolute volumes of materials per unit volume of concrete:

Cement Minimum:	0.134
Water:	0.178
Entrained Air:	0.06
Fine Aggregate:	0.314
Coarse Aggregate:	0.314

Approximate quantity of dry materials per cubic yard of concrete:

Cement, Pounds:	709
Fine Aggregate, Tons:	0.701
Coarse Aggregate, Tons:	0.701
W/C	
Basic:	0.423
Maximum:	0.450

Explanation of Mix Nomenclature:

Example: Mix No. C-3WR-C

C:	Class "C" Aggregate
C-3:	Mix No. C-3
WR:	Addition of Water-Reducer
C:	Addition of class "C" fly ash

Example: Mix No. D-57-C

D:	Class "D" Aggregate
D-57:	Mix no. D-57
WR:	Addition of Water-Reducer
C:	Addition of class "C" fly ash

Appendix D
Research Report from Braun Engineering
Completed for Johnson Brothers, Inc.
Reprinted with Authorization of Johnson Brothers, Inc.

FROM (WED) 02.14.'90 11:02 NO.5 PAGE 1

161

F-6 90-2-14 BE-TJ JB-JS THERMAL ANALYSIS OF MAT CONCRETE

1-CLRC, 2B-ATT, HEAT, CONCRETE (45)

BRAUN ENGINEERING TESTING Incorporated

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DATE: 2/14/90 TIME: 9:15 AM PM

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Tarif Jaber

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P.O. Box 35108
Mpls, MN 55435
(612) 941-5600
FAX #941-4151

February 14, 1990

Johnson Brothers Corporation
Attn: Mr. Jack Sehlin
P.O. Box 1002
Litchfield, MN 55355-1002

RE: 89-555 THERMAL ANALYSIS OF MASS CONCRETE
Mississippi River Bridge
Burlington, Iowa

Dear Mr. Sehlin:

We have completed the laboratory testing of Mix #C-3WR-C and the thermal analysis of the footing and the shaft on pier MS 2.

<u>LABORATORY TESTING</u>:

The laboratory testing included:

1. <u>Concrete Batching</u>: One batch of concrete mix, Iowa DOT designation C-3WR-C, was prepared according to the following proportions.

Cement, lbs.	487
Fly Ash, lbs.	86
Rock, lbs.	1700
Sand, lbs.	1380
Maximum Slump, inch	3
Water reducer	= 3 oz. per 100 lbs. of cement and ash.
Air Entraining Agent	= 6 oz. per cubic yard.

The mix was air entrained to 6% ± 1.
The weights are for one cubic yard (Dry Batch Weights).

The concrete mix design proportions were provided to us by Ideal Ready Mix. Water and air content were adjusted to meet the Iowa DOT requirements for Mix #C-3WR-C.

2. Compressive Strength: At the end of the batching process, ten 6" x 12" concrete cylinders were cast for further testing according to ASTM C 39. This testing was performed to evaluate the compressive strength of the concrete mix.

3. Adiabatic Heat Measurement: We performed tests to measure the heat of hydration of the concrete mix. Two measurements were conducted using calorimeters which measure the adiabatic heat rise of the concrete. The average of the two measurements was then computed. A curve showing the average adiabatic heat generation of the mix with time has been developed and is provided in Appendix A, Figure 1. Also provided in Appendix A, Figure 2, are curves showing the temperature rise and the maturity value with time for the two measurements.

LABORATORY TEST RESULTS:

1. Test results of the plastic properties of the concrete mix are provided in Appendix A. Also included are the final mix proportions and the actual plastic properties.

2. Results of the compressive strength of the concrete at the ages of 3, 7, and 14 days are also provided in Appendix A. Results of the 28 day compressive strength testing will follow in a separate report.

3. The thermal properties of mix #C-3WR-C are provided in the Heat Development report in Appendix A, Figure 2. The heat generation in mix #C-3WR-C is modeled to be a function of the maturity M and is assumed to follow the following equation:

Heat Generation $Q = Q\infty \exp(-(\mathrm{Tau} \div M)^{\mathrm{Alpha}})$.

For mix #C-3WR-C $Q = 145.86 \exp(-15.5)/M)^{0.92}$

where

$Q\infty$ = in BTU/lb. units
Tau = in hrs units
Alpha = No units

An estimate of the total heat generation of Mix #C-3WR-C is:

Total heat = 145.86 x 566.6 = 82,644 BTU.

The total heat represents the heat generated by that mix in the adiabatic state. The adiabatic state of the heat is expected to represent the mass concrete performance.

THERMAL ANALYSIS AND SIMULATIONS

The thermal analysis of the mass concrete is based on a finite difference analysis of the concrete element and its boundaries. Technical background of the heat dissipation concept and the analysis is provided in Appendix C.

The analyses in this report are provided for the foundation and the shaft on pier MS2. The following are the general conditions for these analyses:

- The analyses take into account the interaction and heat transfer between the concrete element (subject of the study) and its boundaries.

- The analyses are provided for the section that is more susceptible to heat loss and dissipation, and where maximum temperature differentials are likely to be crucial.

- The heat dissipation and simulation studies are analyzed for a curing period of 10 weeks (1680 hours).

- Two simulations are provided for each analysis. One simulates the heat dissipation for a 20 day curing period, while the other continues on for a 10 week curing period.

- We used concrete mix design #C-3WR-C as requested by you.

- Concrete was modeled to be continually placed with no interruptions.

o For ambient temperature considerations, we used Iowa Weather Bureau reports on temperatures for Burlington, Iowa provided to us as follows:

<u>Average Annual Temperature For The Last 30 Years</u>

<u>Burlington, Iowa</u>

	Jan	Feb	Mar	Apr	May	Jun	Jul
Max	32	36	47	62	73	82	86
Min	14	18	27	41	51	61	65

Ambient temperature changes are assumed to follow a sine wave with the maximum temperature occurring at 2:00 p.m. and the minimum temperature occurring at 2:00 a.m.

Four analyses are provided in this report:

1. <u>Concrete Footing (7 1/2 feet)</u>: The analysis is presented in Appendix B, Figure 1.a. and Figure 1.b. and it considers the following:

   A. The concrete foundation will be placed against the existing concrete seal. We assumed that the existing concrete seal will have a temperature of 75° when placing the concrete foundation.

   B. Concrete placement will commence at 5 a.m. on March 15 and is assumed to take approximately 24 hours. This reflects a placement rate of approximately 78 cubic yards per hour.

   C. Concrete surfaces in contact with the outside air (ambient temperature) is modeled to be insulated with an insulation material of R = 15. The insulation will be installed four hours after placement completion and remain throughout the curing procedure.

Three analyses are provided for the concrete shaft. All analyses are performed assuming the concrete shaft will be placed against the existing footing. The placement will commence when the average temperature of the top concrete surface and the thermal center of the footing is approximately 100°F.

2. Concrete shaft (9 foot section): The analysis is presented in Appendix B, Figure 2.a and Figure 2.b, and considers the following:

   A. Concrete placement will commence at 5:00 a.m. on April 1 and is assumed to take approximately 12 hours. This reflects a placement rate of approximately 79 cubic yards per hour.

   B. Concrete surfaces in contact with the outside air (ambient temperature) is modeled to be insulated with an insulation material of R = 15. The insulation is modeled to be installed four hours after placement completion and remain throughout the curing procedure.

3. Concrete Shaft (15 foot section): The analysis is presented in Appendix B, Figure 3.a and Figure 3.b, and considers the following:

   A. Concrete placement will commence at 5:00 a.m. on April 1 and is assumed to take approximately 24 hours. This reflects a placement rate of approximately 66 cubic yards per hour.

   B. Concrete surfaces in contact with the outside air has been modeled to be insulated with a material of R = 15. The insulation is modeled to be installed four hours after placement completion and remain throughout the curing process.

4. Concrete Shaft (2 foot section): This analysis is presented in Appendix B, Figure 4.a and Figure 4.b. The analysis is provided to closely study the affect of placing a warmer shaft concrete against the footing. This is recommended to avoid thermal shock of the existing concrete.

   Two simulations were made for two concrete placement temperatures of 70° and 80°.

   All other parameters are consistent with the previous analyses 2 and 3.

THERMAL ANALYSIS RESULTS:

Thermal analyses and simulation studies are provided in Appendix B. Each simulation report provides the following:

Rate of Placement:

This information is listed in the upper left corner of the data section of the report. The simulation divides the placement into four time steps:

- o Time step: is the length of each of the four time steps.
- o Cast step: is the time allocated for each cast (within time step).
- o Cast time: The time required to finish placement in each step (within cast step).
- o Cast height: The concrete height finished in each of the four steps.

Also listed are the temperature, density, specific heat and thermal conductivity of the existing concrete and the placed concrete.

Temperature Curves:

For each simulation analysis we provide five curves (center of the report). They represent the following (from top to bottom):

a. Maximum temperature occurring at any location inside the concrete section.

b. Temperature of the concrete surface next to the outside air (insulated surface).

c. Temperature of the concrete surface in contact with existing concrete (base).

d. The minimum maturity achieved in the concrete surface adjacent to the ambient air.

e. The temperature differential between the maximum and the minimum occurring in the simulated section.

Temperature Profiles:

Shown at the bottom of the simulation report are the temperature profiles in the concrete section at regular intervals during the simulation. Each profile shows the heat gradient in the simulated cross-section at the time indicated by the marks shown on the maximum heat generation curve (a). Also shown next to the top of the temperature profiles are the transmittance coefficient factors for the insulated surface at each designated hour.

CONCLUSIONS

Based on the analysis above and our previous experience we provide the following:

- Maximum Temperature Differential (MTD): The special provision of the MTD can be relaxed during concrete placement. Concrete in the plastic state cannot develop any cracking associated with stresses from volume changes.

- Concrete placed against existing concrete should not be more than 20° to 25° colder for the first 12 to 24 inches.

- The top of the footing should be continually insulated and can be exposed only immediately before the placement of the shaft concrete.

- Placement of new concrete should commence only when the existing concrete temperature (average of the maximum and interface) is about 100°.

- This procedure assumed that the insulation from the shaft walls and the foundation walls will be kept in place throughout the temperature monitoring.

- The procedure provided here is for the footing, and the first section of the shaft and the footing. This procedure can be used for the other subsequent shaft sections. However, extended time for heat dissipation will be expected.

This procedure is provided for your review. We appreciate the opportunity to provide these analyses for you. If you have any questions or need further information please call us.

Very truly yours,

BRAUN ENGINEERING TESTING, INC.

Professional Certification:

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

Tarif M. Jaber, P.E.
Senior Materials Engineer
Registration #: 19872
(612) 942-4834

William M. Weyrauch, P.E.
Director - Materials Testing
Registration #: 15663
(612) 942-4832

TMJ/WMW:prg\F:\WP\RPT\89-555-1

Attachments: Laboratory Testing, Appendix A
Thermal Analyses, Appendix B
Technical Background, Appendix C

APPENDIX A
LABORATORY TESTING

Mix C-3WR-C

- Lab Batch
- Compressive Strength
- Heat Development
- Temperature and Maturity

REPORT OF CONCRETE BATCH
FOR MIX DESIGN

P.O. Box 35108
Mpls., MN 55435
(612) 941-5600

DATE: February 13, 1990

PROJECT #: 89-555

CLIENT: Johnson Brothers
Mr. A.A. Sehlin
P.O. Box 1002
Litchfield, MN 55355-1002

PROJECT DESCRIPTION: Mississippi River Bridge
Burlington, IA

Material	Design Dry Weight lbs./yd.	Design Wet Wt. lbs/yd.	Trial Batch Wt. Lbs./ 3 cu. ft.	Actual Batch Wt. Lbs./ 3 cu. ft.	Final Prop. Wt. lbs/yd.
Cement	487	487.0	54.1	54.1	487.0
Fly Ash	86	86.0	9.6	9.6	86.0
Coarse Agg.	1700	1705.0	189.4	189.4	1702.9
Fine Agg.	1380	1400.0	155.6	155.6	1386.5
Water	280 max.	280 max.	30.6 max.	25.2	219.4
Prokrete Air Entrain	8.0 oz.	8.0 oz.	16.4 ml	16.5 ml	5.0 oz.
Prokrete #3 Water Reducer	17.2 oz.	17.2 oz.	56.5 ml	56.5 ml	17.2 oz.

COMMENTS:

Temp. Computer File = Mix C-3WR-C
Logfile MRBIOWA2
Haybox 11 cylinder wt. = 27.898
Haybox 12 cylinder wt. = 27.906

	Moisture Content	Absorption	Free Water
Coarse Aggregate	0.1	0.6	-8.5
Fine Aggregate	1.0	0.9	1.4

Aggregate contribution of water: -7.1 lbs.

CALCULATED		ACTUAL	
W/C:		W/C:	.38
# of specimens:	12	Age at Test(Min.):	8
Slump (in):	3	Slump (in):	3 1/2
Air Content (%):	6	Air Content (%):	7.6
Air Temp. (F):	70°	Conc. Temp.(F):	71°
		Unit Weight (pcf):	139.1

Appearance: good X sandy ______ rocky ______ other ______
Workability: good X fair ______ poor ______ other ______

BRAUN ENGINEERING TESTING, INC.

Peter A. Rauch TMJ
Peter A. Rauch

COMPRESSIVE TEST OF CONCRETE CYLINDER
Test Method: ASTM C39, 6"X12" Cylinder

P.O. Box 35108
Minneapolis, MN 55435
(612) 941-5600

DATE : February 5, 1990

PROJECT ID : 89-555
PROJECT DESCRIPTION :
Thermal Analysis of Mass Co
at the Miss. River Bridge
Burlington, IA

CLIENT :
Johnson Brothers Corporation
Attn: Mr. A. Sehlin
P.O. Box 1002
Litchfield, MN 55355-1002

FIELD DATA :
Set Number : 4
Date Cast : 1/19/90
Time Cast : 10:00 AM
Measured Slump : 3-1/2 in.
Measured Air : 7.6 %
Concrete Temperature: 72 °
Air Temperature : 70 °
Cylinder Cast By : Braun/PAR
Liquid Added at Site: none
Sample Location : BRAUN Laboratory

DESIGN DATA :
Mix Design : C-3WR-C
Supplier : Ideal
Specified Air : 6 +/- 1 %
Specified Strength : Not Given
Truck or Ticket # : Not Given
Cylinders per Set : 10

Sample No.	Date Recvd	Test Date	Field Cure	Lab Cure	Test Age	Max Load (pounds)	Cyl Area (sq in)	Compressive Strength, psi	Remar Code(
4A	1/20	1/22	1	2	3	95440	28.09	3400	A
4B	1/20	1/22	1	2	3	99110	28.09	3530	A
4C	1/20	1/26	1	6	7	122300	28.09	4350	A
4D	1/20	1/26	1	6	7	120410	28.09	4290	A
4E	1/20	2/02	1	13	14	136270	28.02	4860	A
4F	1/20	2/02	1	13	14	136980	28.02	4890	A

Specified Strength at 28 Days (psi) : Not Given

REMARKS :
A :These test results are for informational purposes only.

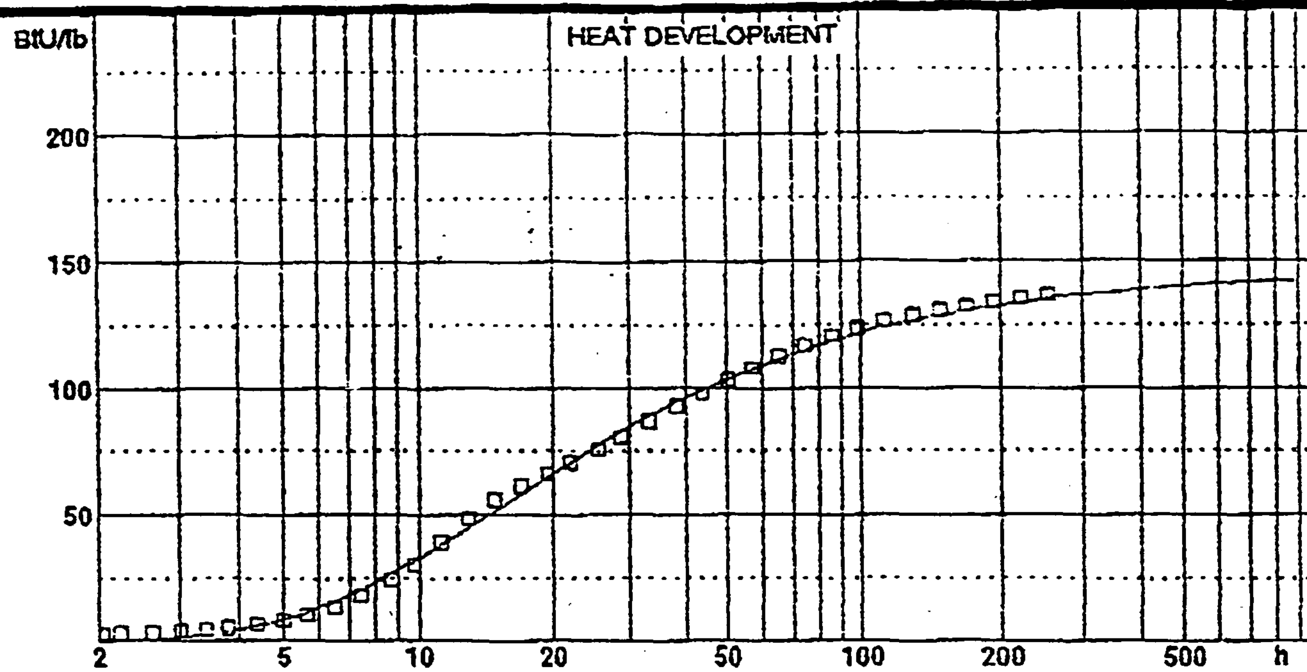
cc :

Reviewed by :

Tarif M. Jaber, P.E.
Senior Materials Engineer

Braun Engineering Testing, Inc. Minneapolis, MN 55435	HEAT DEVELOPMENT Documentation sheet

Client: JOHNSON BROTHERS CORP. Number: 89 – 555 Initials: TMJ
Name: MISS. RIVER BRIDGE, IOWA Date: 02 – 02 – 90



CONCRETE: C – 3WR – C Cement + min. additives Specific heat: 0.245 BtU/lb/dF

LINEAR MODEL
Qo = 49.37 BtU/lb To = 5.23 h

EXPONENTIAL MODEL
Qinf = 145.86 BtU/lb Te – 15.50 h Alpha = 0.82

MIX MATERIALS	type	density lb/ft3	weight lb/yd3	volume yd3/yd3	comment
Water	TAP WATER	62.4	217.0	0.129	
Cement	DAVENPORT	196.6	481.6	0.091	
Mineral additive	IOWA – ASH	168.5	85.0	0.019	
Aggregate	IOWA – ROCKS	166.8	1684.0	0.374	
	IOWA – SAND	163.4	1371.1	0.311	
Chemical Admixture	PROTEX WR	70.5	1.3	0.001	
	PROKRETE AEA	64.9	0.2	0.000	
Air				0.078	

CONCRETE PROPERTIES

density measured lb/ft3	density calculated lb/ft3	w/c – ratio lb/lb	air content %
139.1	142.2	0.38	7.6

COMMENTS: Average of two tests.

FIG -1-

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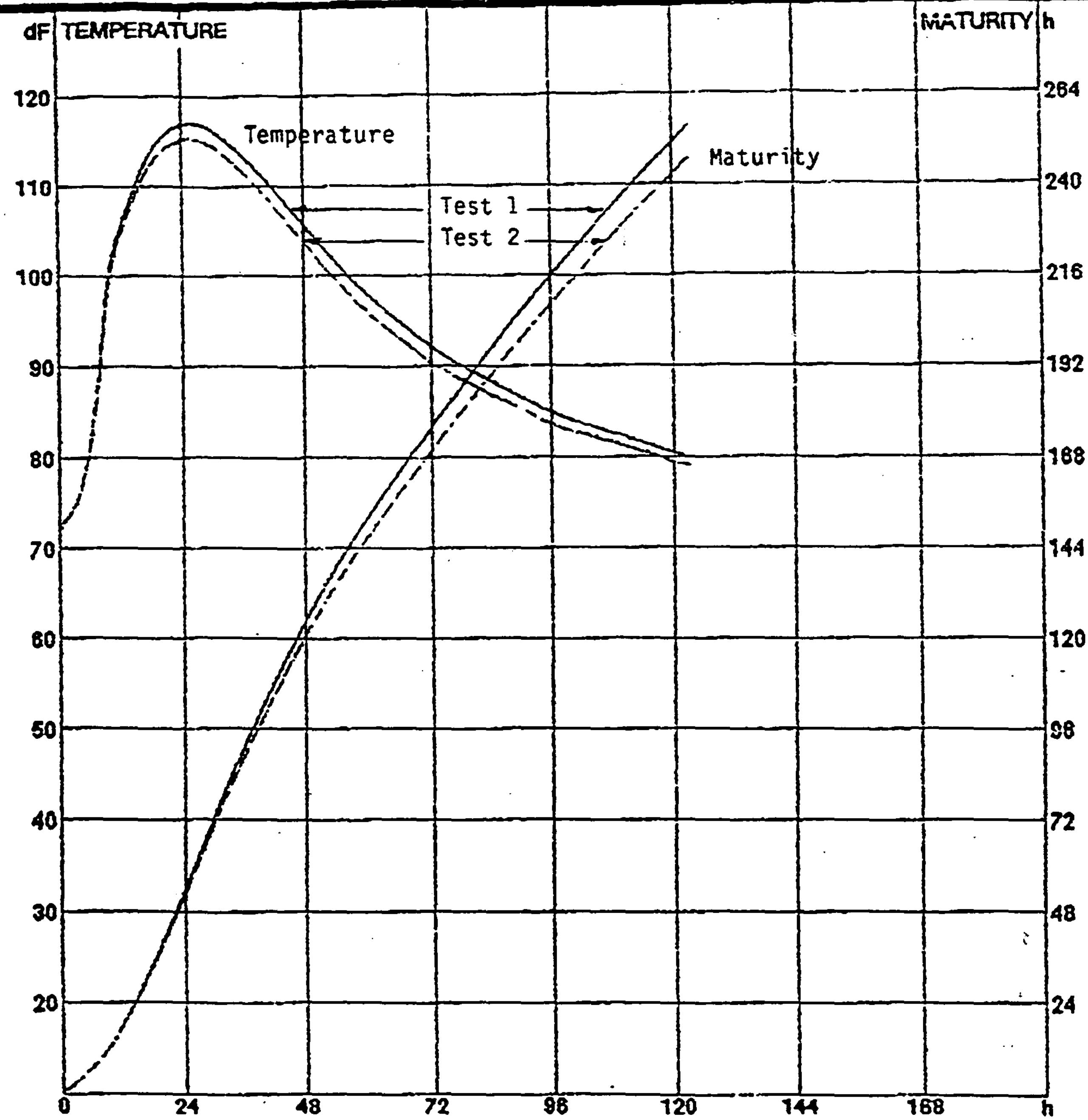
Braun Engineering Testing, Inc.
Minneapolis, MN 55435

LOG FILE DATA
Documentation sheet

Client:	JOHNSON BROTHERS CORP.	Number: 89 – 555	Initials: TMJ
Name:	MISS. RIVER BRIDGE, IOWA	Date: 01 – 25 – 90	



Log file	MRBIOWA2.LOG	6H ———	HB – 11 HAYBOX #1 C – 3WR – C
Start date	01 – 18 – 90	6H – – – –	HB – 12 HAYBOX #2 C – 3WR – C
Start time	09:52:00		
Scan interval	10 minutes		
Device type	CR10		
Program file	CR10XREF.DLP		

FIG -2-

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APPENDIX B

THERMAL ANALYSES AND SIMULATION STUDIES

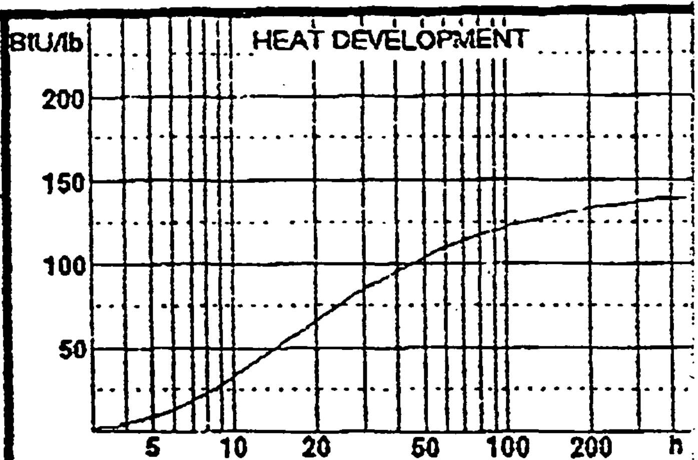
Braun Engineering Testing, Inc.
Minneapolis, MN 55435

FOUNDATION
Documentation sheet

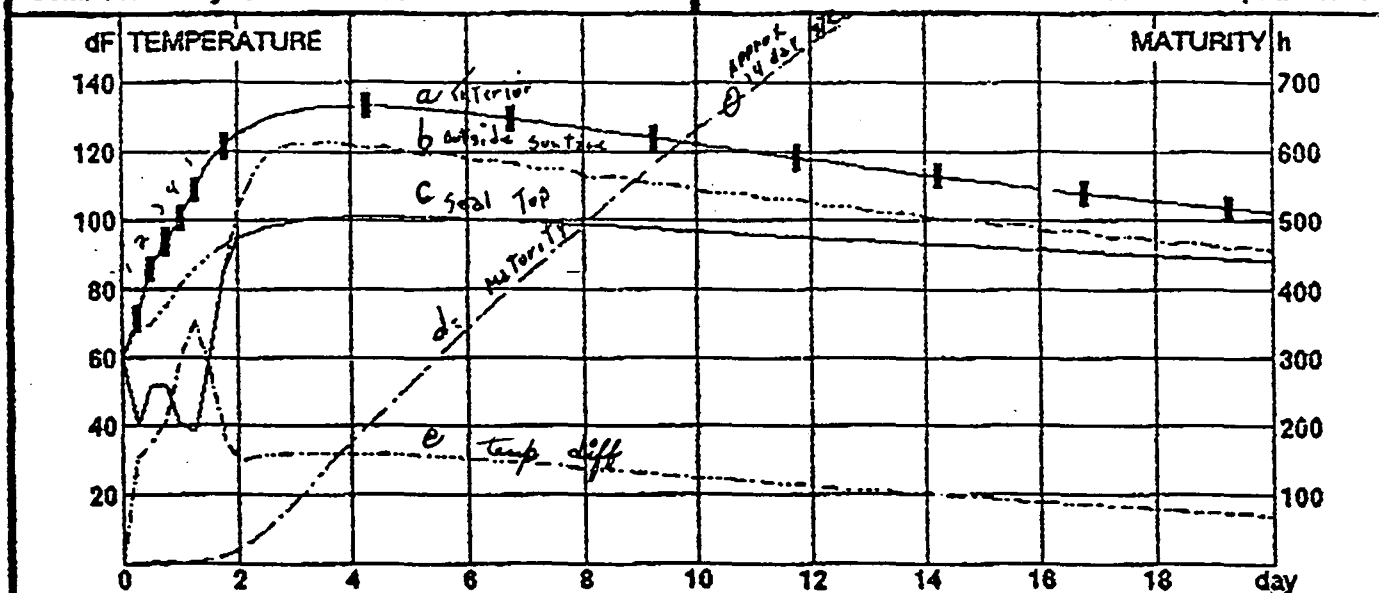
Client	JOHNSON BROTHERS CORP.	Number: 89 – 556	Initials: TMJ
Name:	MISS. RIVER BRIDGE, IOWA	Date: 02 – 02 – 90	

Time step	6.0	h
Cast step	6.0	h
Cast time	6.0	h
Cast height	22.5	inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	60.0	75.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.82



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 6.0/min = 24.0/max = 47.0

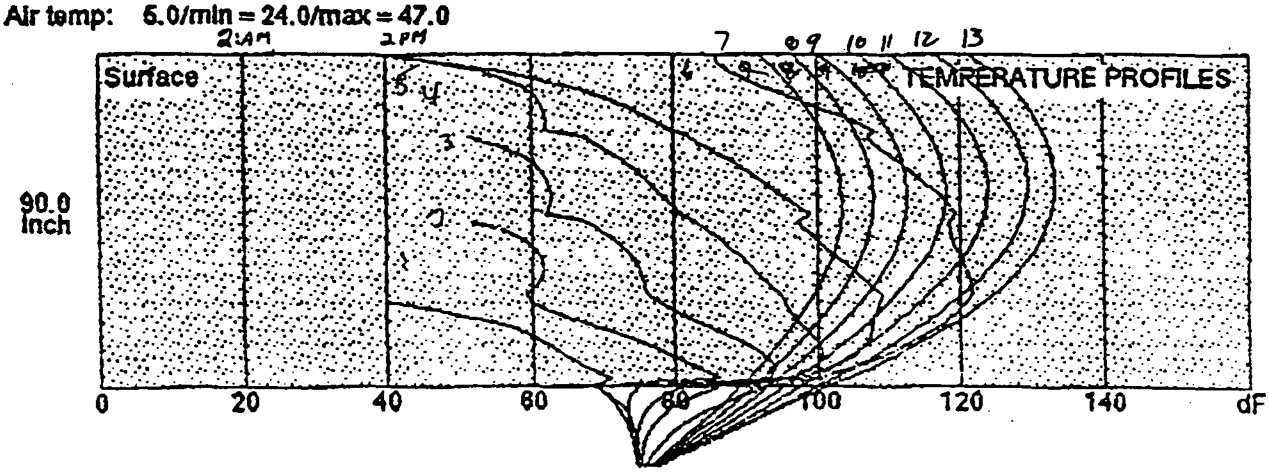


FIG -1.a-

Braun Engineering Testing, Inc.
Minneapolis, MN 55435

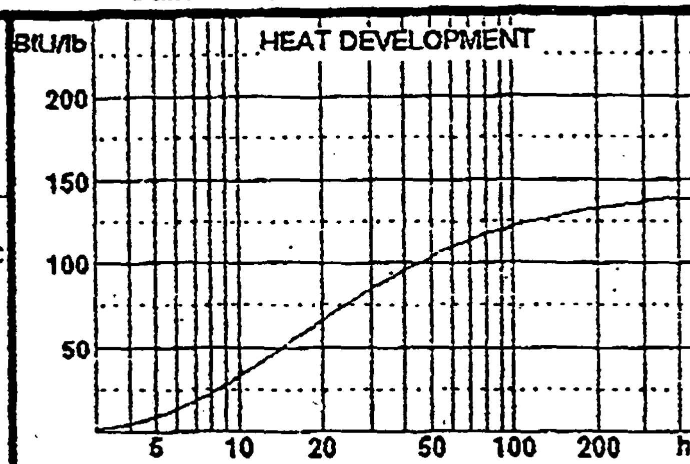
FOUNDATION
Documentation sheet

Client: JOHNSON BROTHERS CORP.
Name: MISS. RIVER BRIDGE, IOWA

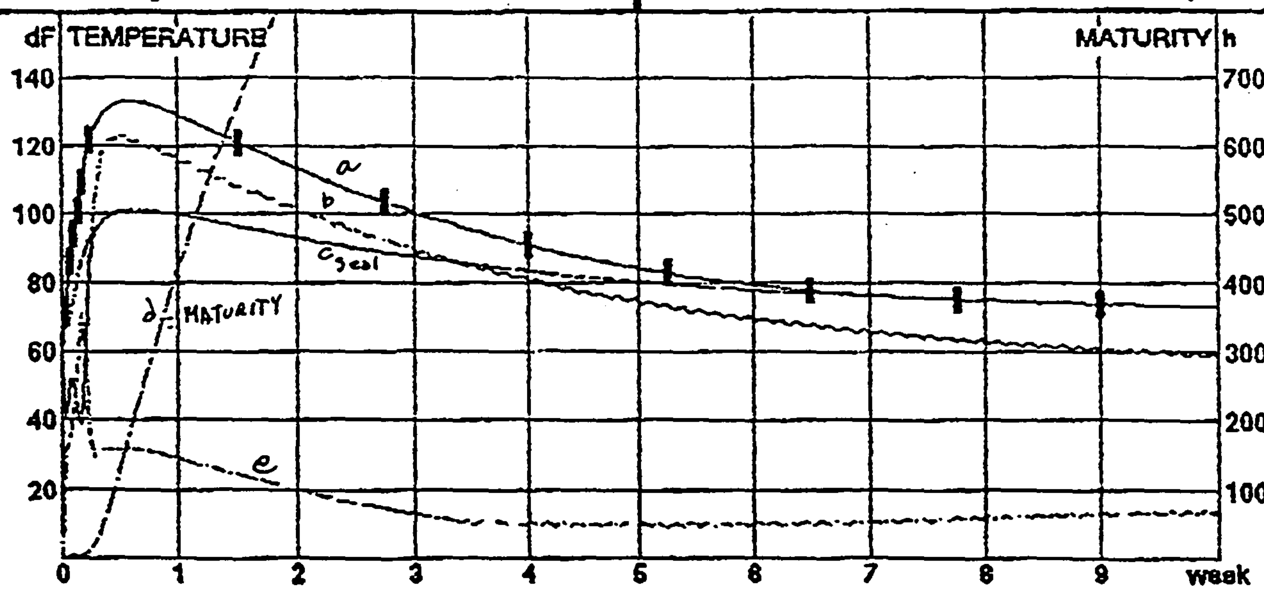
Number: 89 – 555   Initials: TMJ
Date: 02 – 02 – 90

Time step	6.0 h
Cast step	6.0 h
Cast time	6.0 h
Cast height	22.5 inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	80.0	75.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 5.0/min = 24.0/max = 47.0

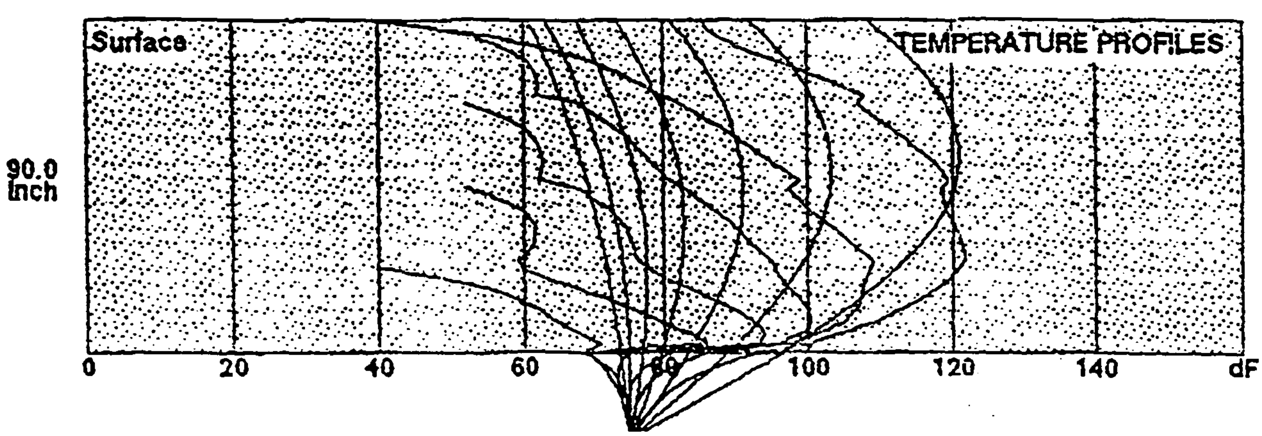


FIG -1.b-

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Minneapolis, MN 55435

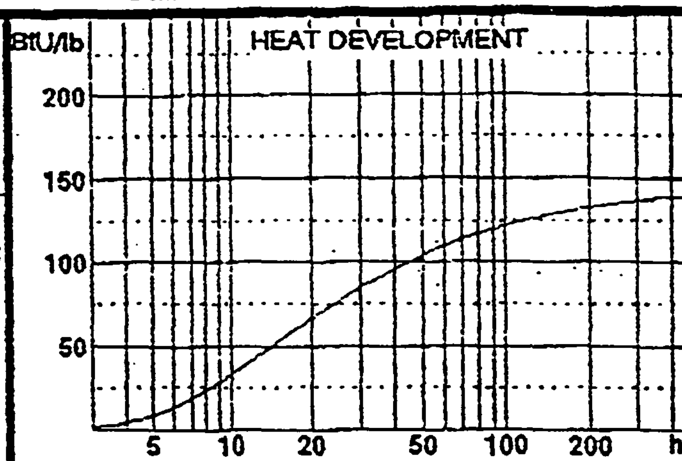
FOUNDATION
Documentation sheet

Client: JOHNSON BROTHERS CORP.	Number: 89 – 555	Initials: TMJ
Name: MISS. RIVER BRIDGE, IOWA	Date: 02 – 02 – 90	

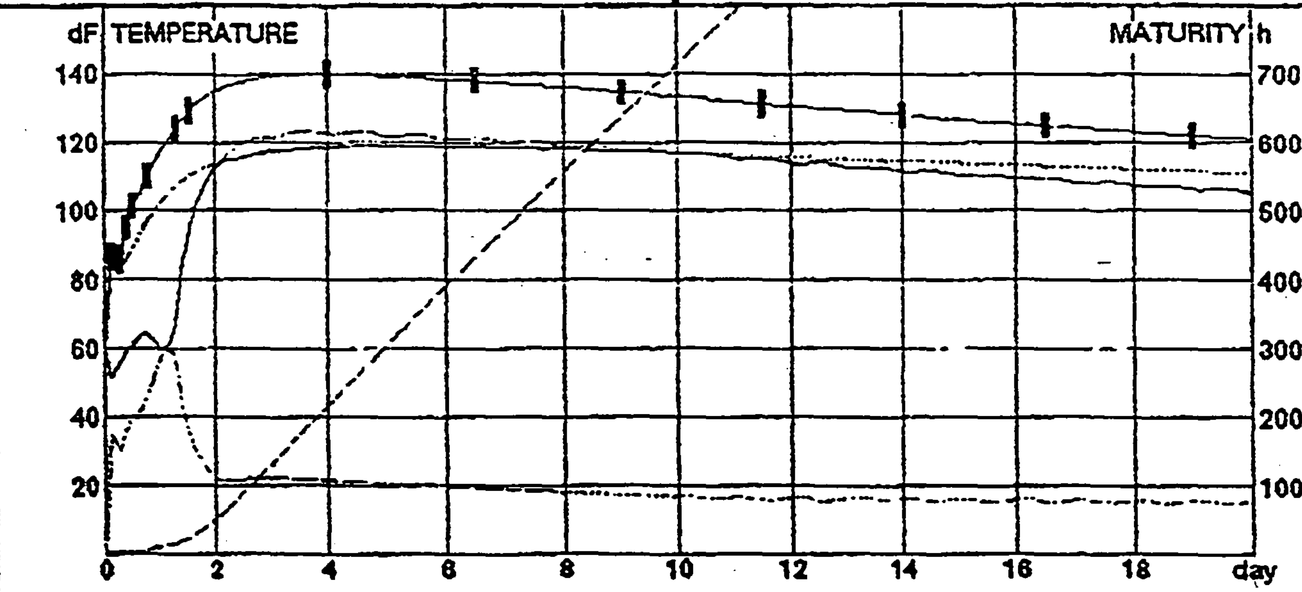
Time step	3.0	h
Cast step	3.0	h
Cast time	3.0	h
Cast height	27.0	inch

3 stage 3 hr = 9 hr pour

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	60.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 5.0/min = 41.0/max = 62.0

Pour ht No.2

108.0 inch

9'

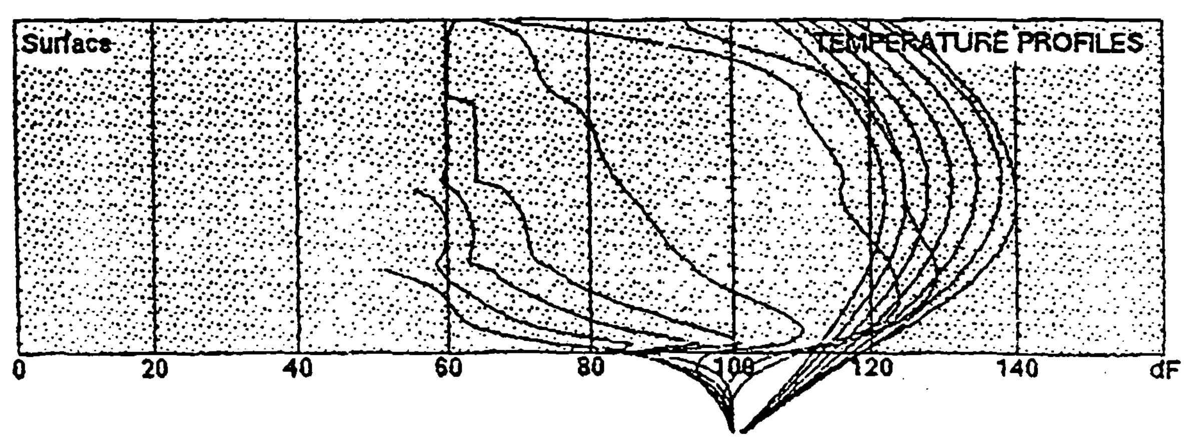


FIG -2.a-

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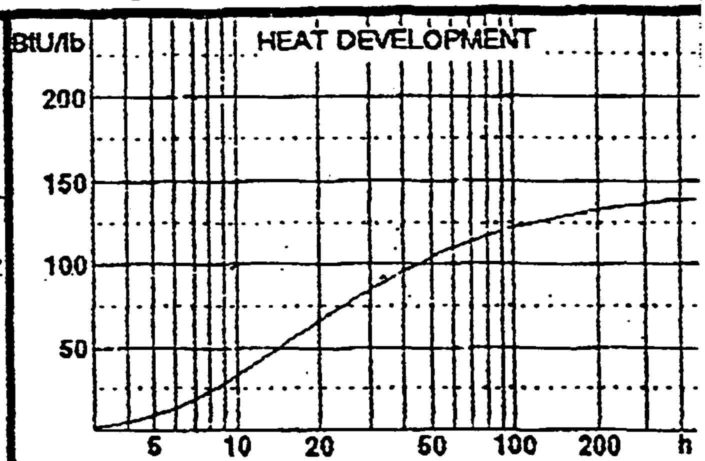
Minneapolis, MN 55435

FOUNDATION
Documentation sheet

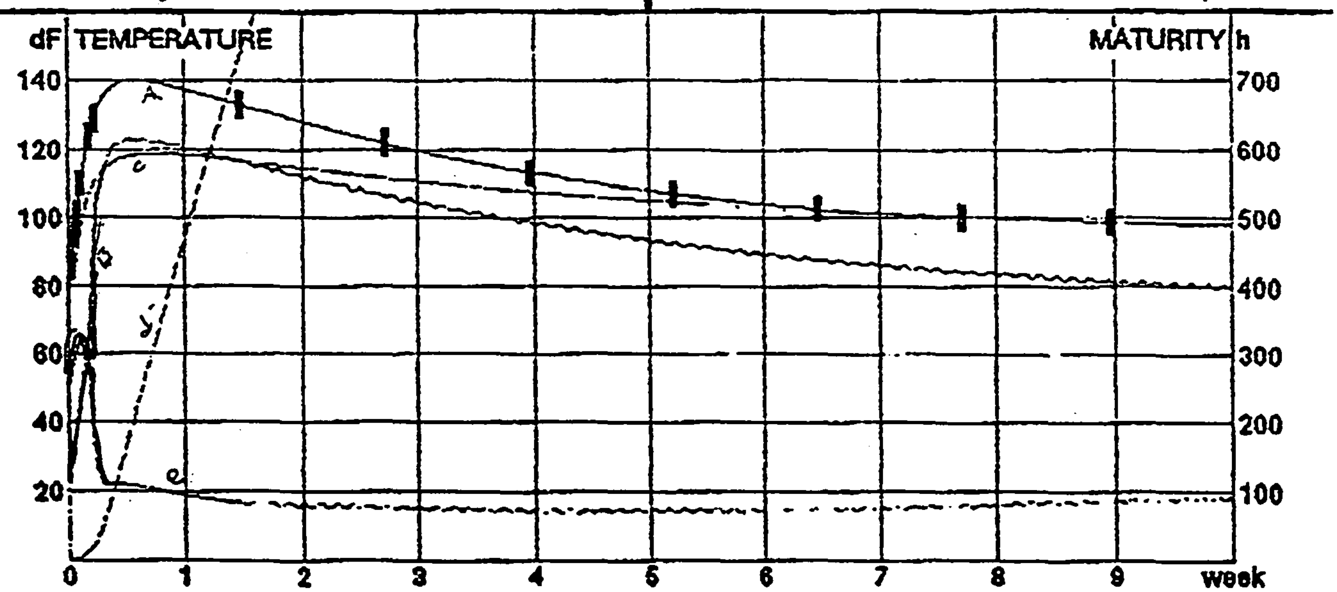
Client:	JOHNSON BROTHERS CORP.	Number: 89 – 555	Initials: TMJ
Name:	MISS. RIVER BRIDGE, IOWA	Date: 02 – 02 – 90	

Time step	3.0	h
Cast step	3.0	h
Cast time	3.0	h
Cast height	27.0	inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	60.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.266
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	586.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 6.0/min = 41.0/max = 62.0

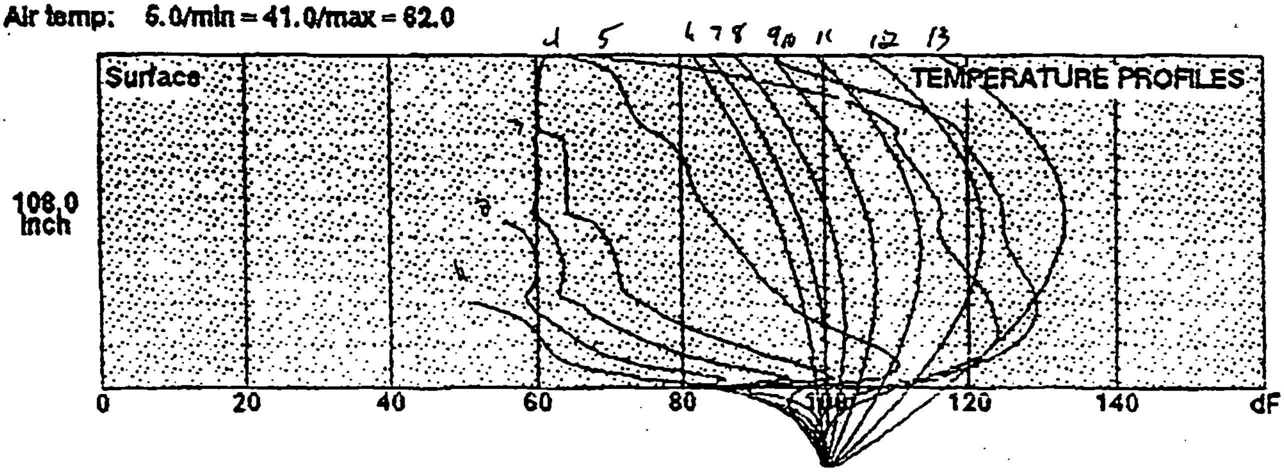


FIG -2.b-

Braun Engineering Testing, Inc.
Minneapolis, MN 55435

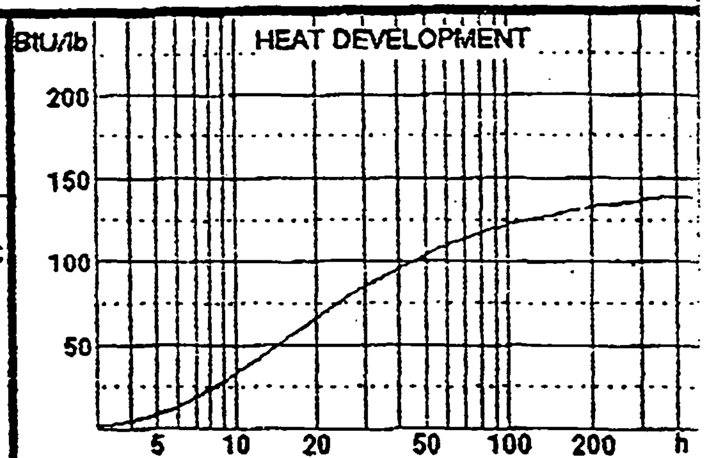
FOUNDATION
Documentation sheet

Client:	JOHNSON BROTHERS CORP.	Number: 89 – 555	Initials: TMJ
Name:	MISS. RIVER BRIDGE, IOWA	Date: 02 – 02 – 90	

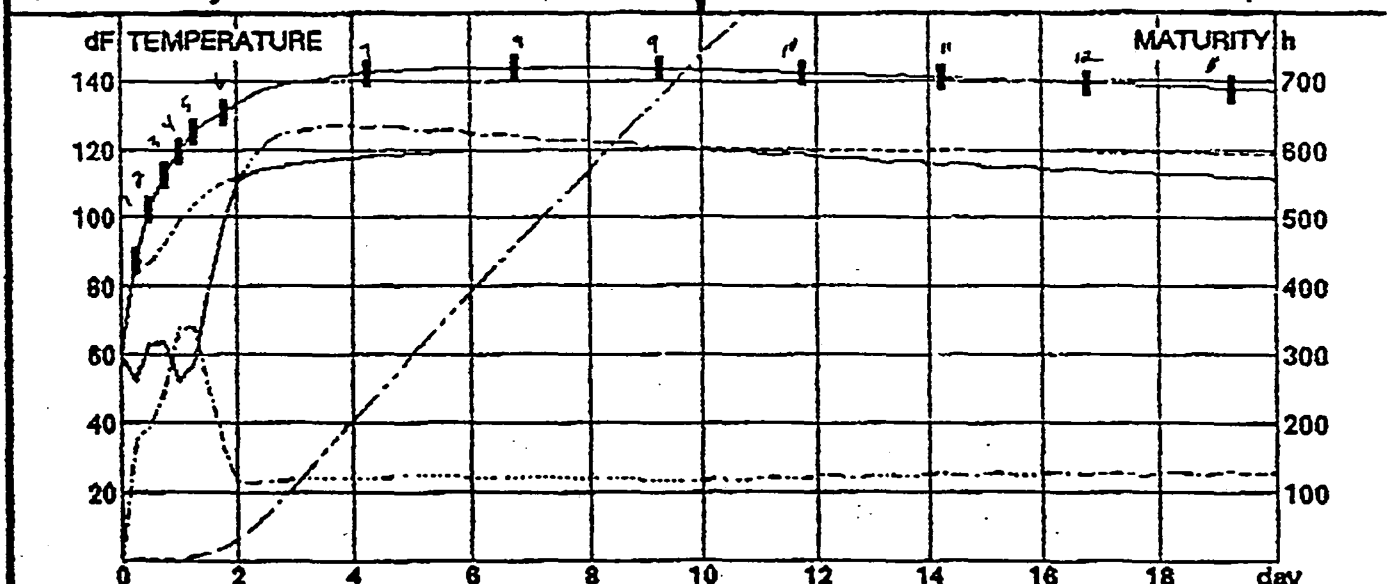
Time step	6.0	h
Cast step	6.0	h
Cast time	6.0	h
Cast height	45.0	Inch

24 hr placement
4 steps @ 6 hr

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	60.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.16 2400.0/0.16
Air temp: 5.0/min = 41.0/max = 62.0

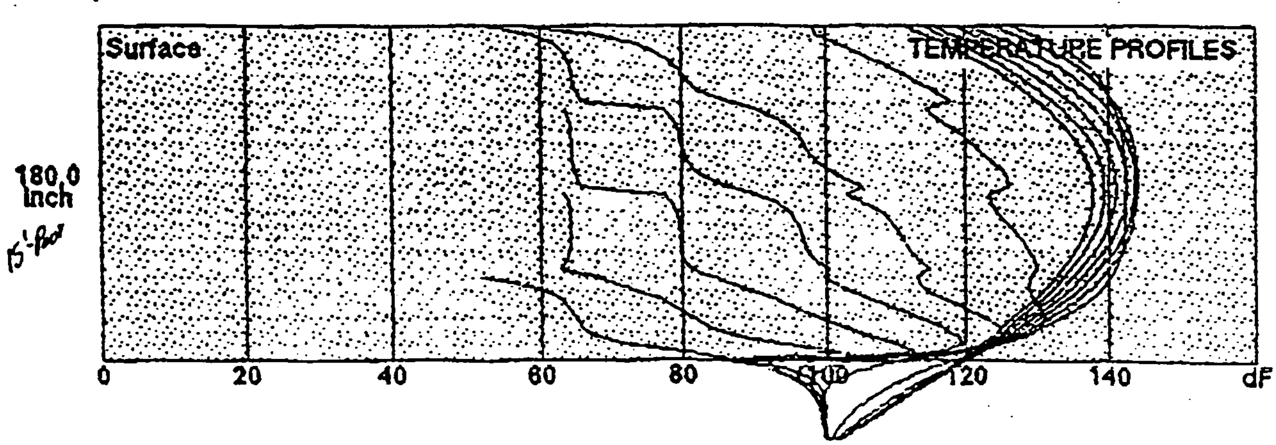


FIG -3.a-

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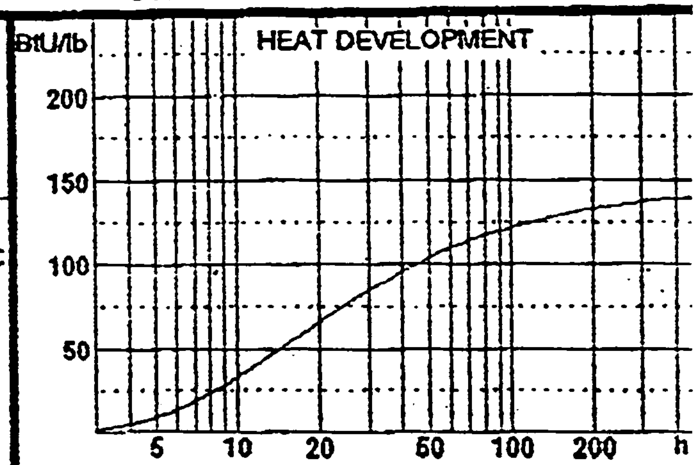
Braun Engineering Testing, Inc.
Minneapolis, MN 55435

FOUNDATION
Documentation sheet

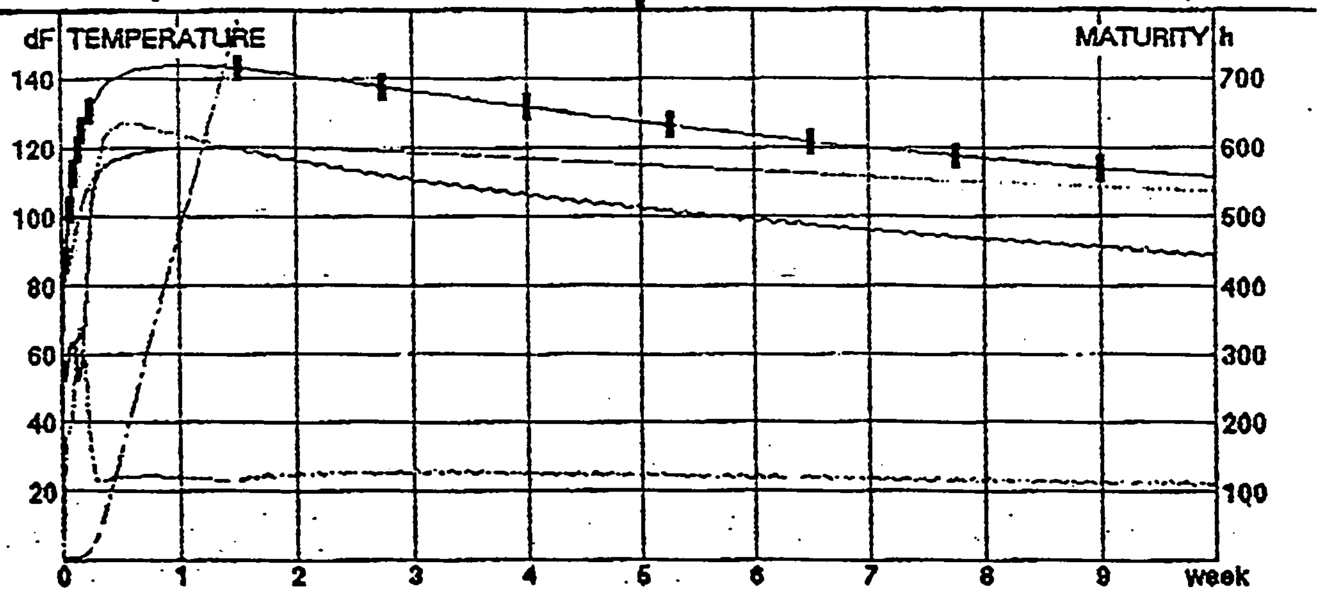
Client:	JOHNSON BROTHERS CORP.	Number: 89 – 555	Initials: TMJ
Name:	MISS. RIVER BRIDGE, IOWA	Date: 02 – 02 – 90	

Time step	6.0	h
Cast step	6.0	h
Cast time	6.0	h
Cast height	45.0	inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	60.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 6.0/min = 41.0/max = 62.0

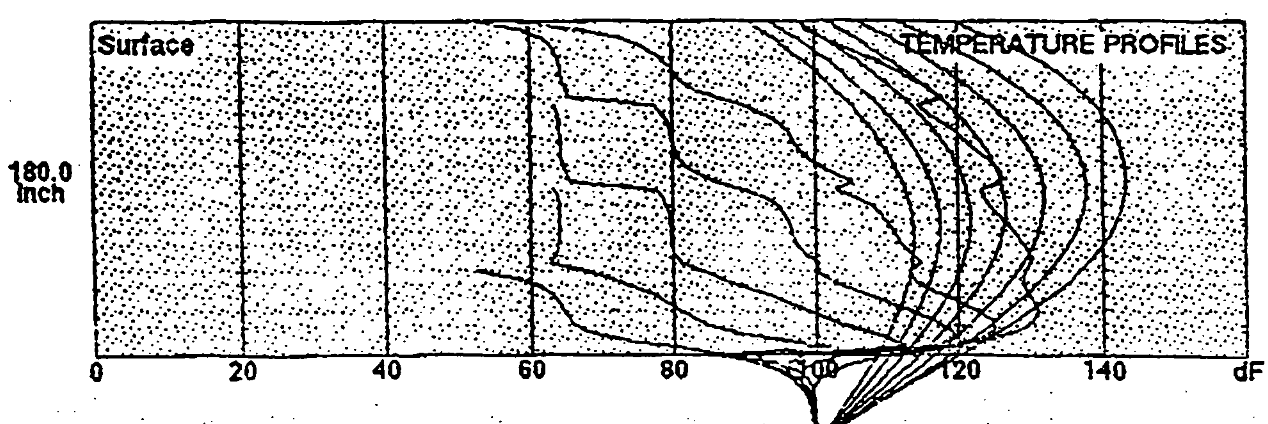


FIG -3.b-

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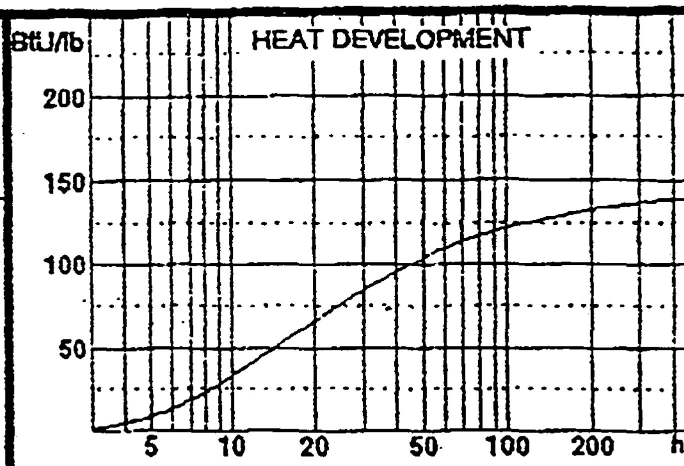
Braun Engineering Testing, Inc.
Minneapolis, MN 55435

FOUNDATION
Documentation sheet

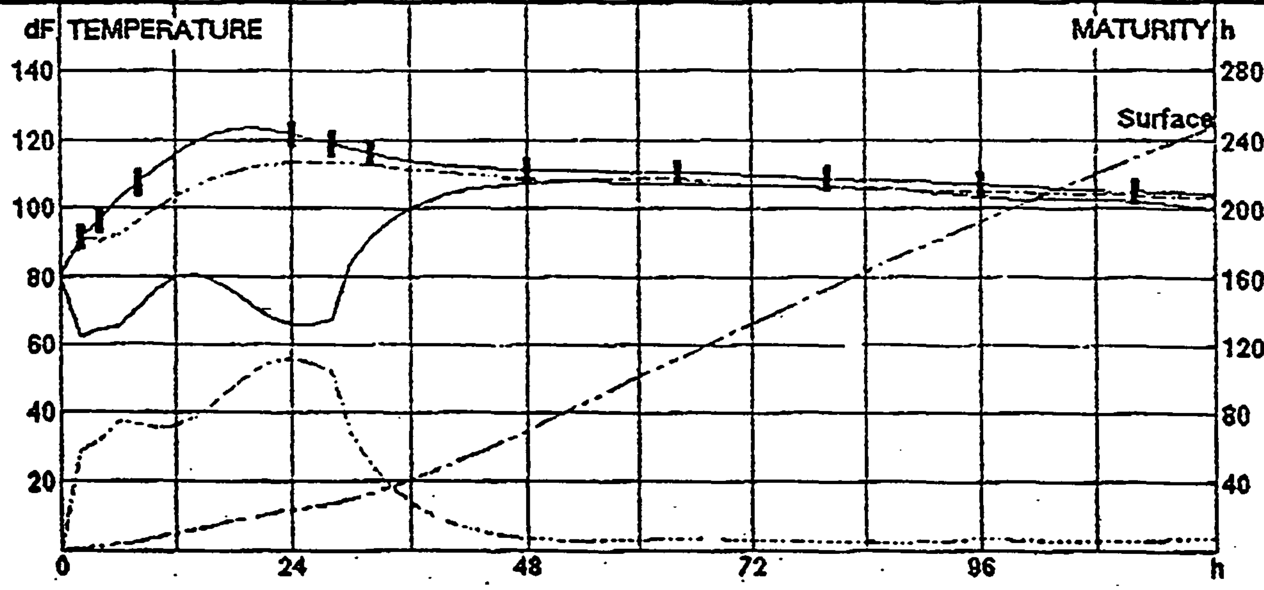
Client: JOHNSON BROTHERS CORP. Number: 89 – 555 Initials: TMJ
Name: MISS. RIVER BRIDGE, IOWA Date: 02 – 02 – 90

Time step	2.0 h
Cast step	2.0 h
Cast time	2.0 h
Cast height	12.0 inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	80.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.245	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 5.0/min = 41.0/max = 62.0

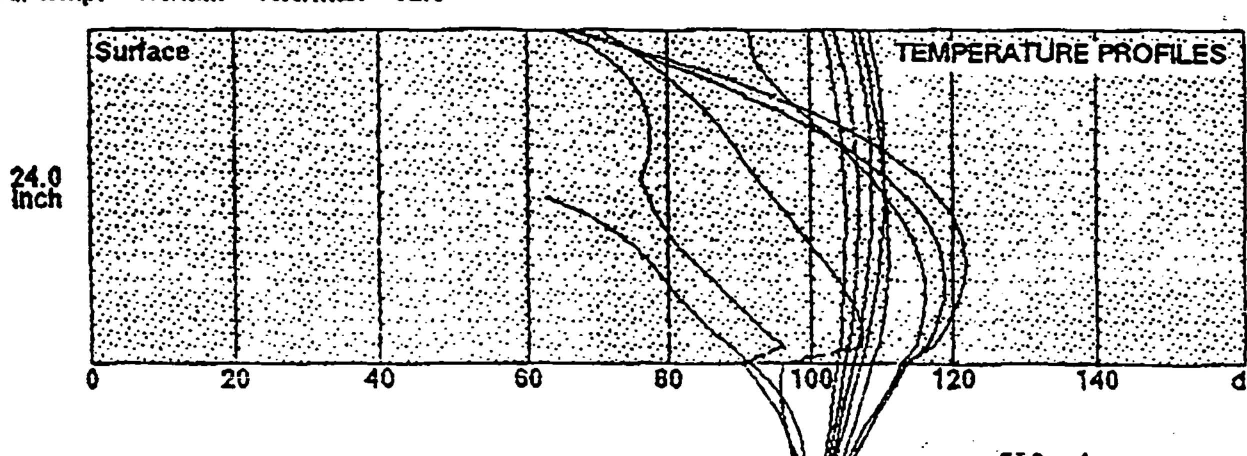


FIG -4.a-

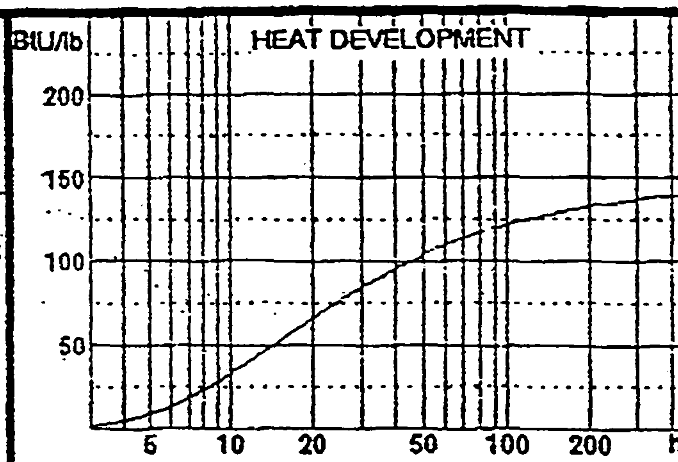
Braun Engineering Testing, Inc.
Minneapolis, MN 55435

FOUNDATION
Documentation sheet

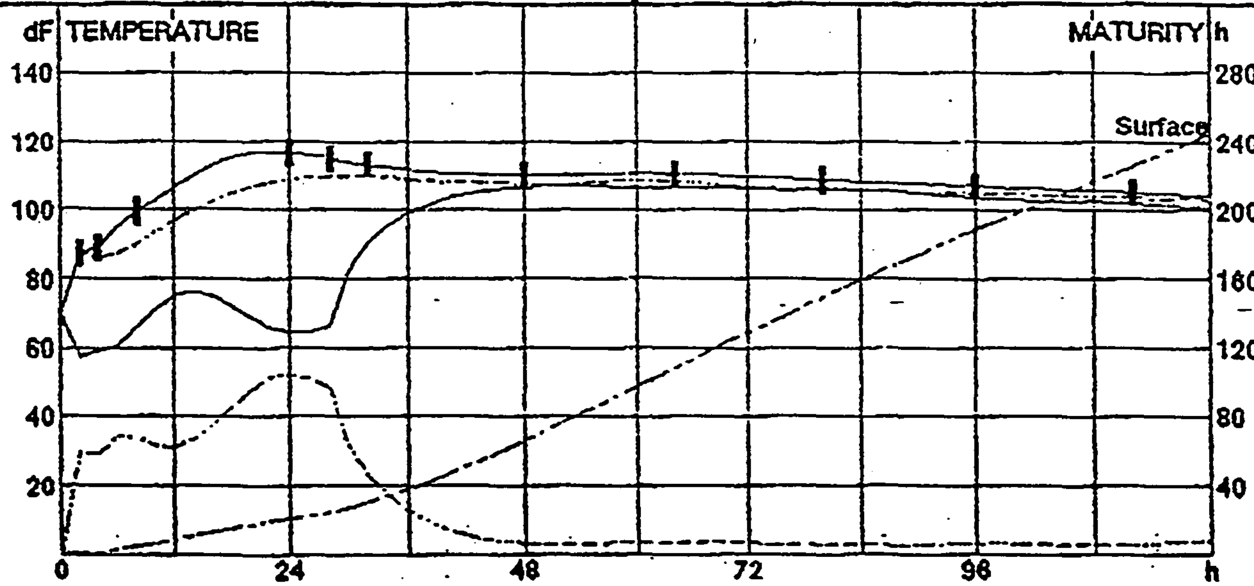
Client: JOHNSON BROTHERS CORP. Number: 89 – 555 Initials: TMJ
Name: MISS. RIVER BRIDGE, IOWA Date: 02 – 02 – 90

Time step	2.0 h
Cast step	2.0 h
Cast time	2.0 h
Cast height	12.0 inch

		CONCRETE	SOIL/BASE
Type		C – 3WR – C	EXIST. CONC
Temp.	dF	70.0	100.0
Density	lb/ft3	142.2	145.0
Sp. heat	BtU/lb/dF	0.246	0.256
Th. cond.	BtU/ft/h/dF	1.30	1.29
Cem. type		DAVENPORT	
Cem. cont.	lb/yd3	566.6	



Qinf = 145.86 BtU/lb Te = 15.50 h Alpha = 0.92



Tr. coef: 0.0/5.00 28.0/0.15 2400.0/0.15
Air temp: 5.0/min = 41.0/max = 62.0

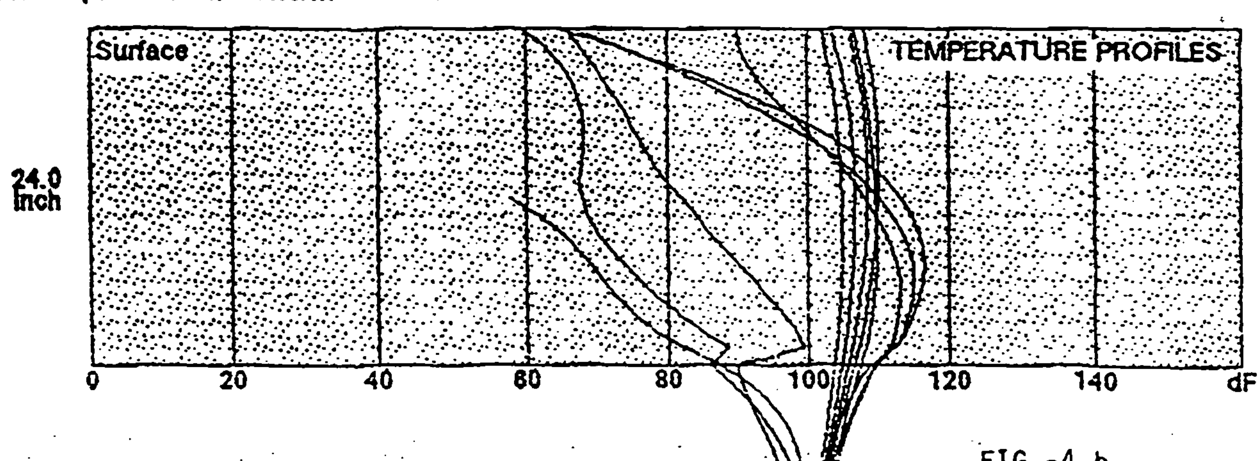


FIG -4.b-

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APPENDIX C

TECHNICAL BACKGROUND

(Not included in preliminary report issued to Iowa DOT.)

Appendix E
Sketches and Photos of Cracking and Honeycombing

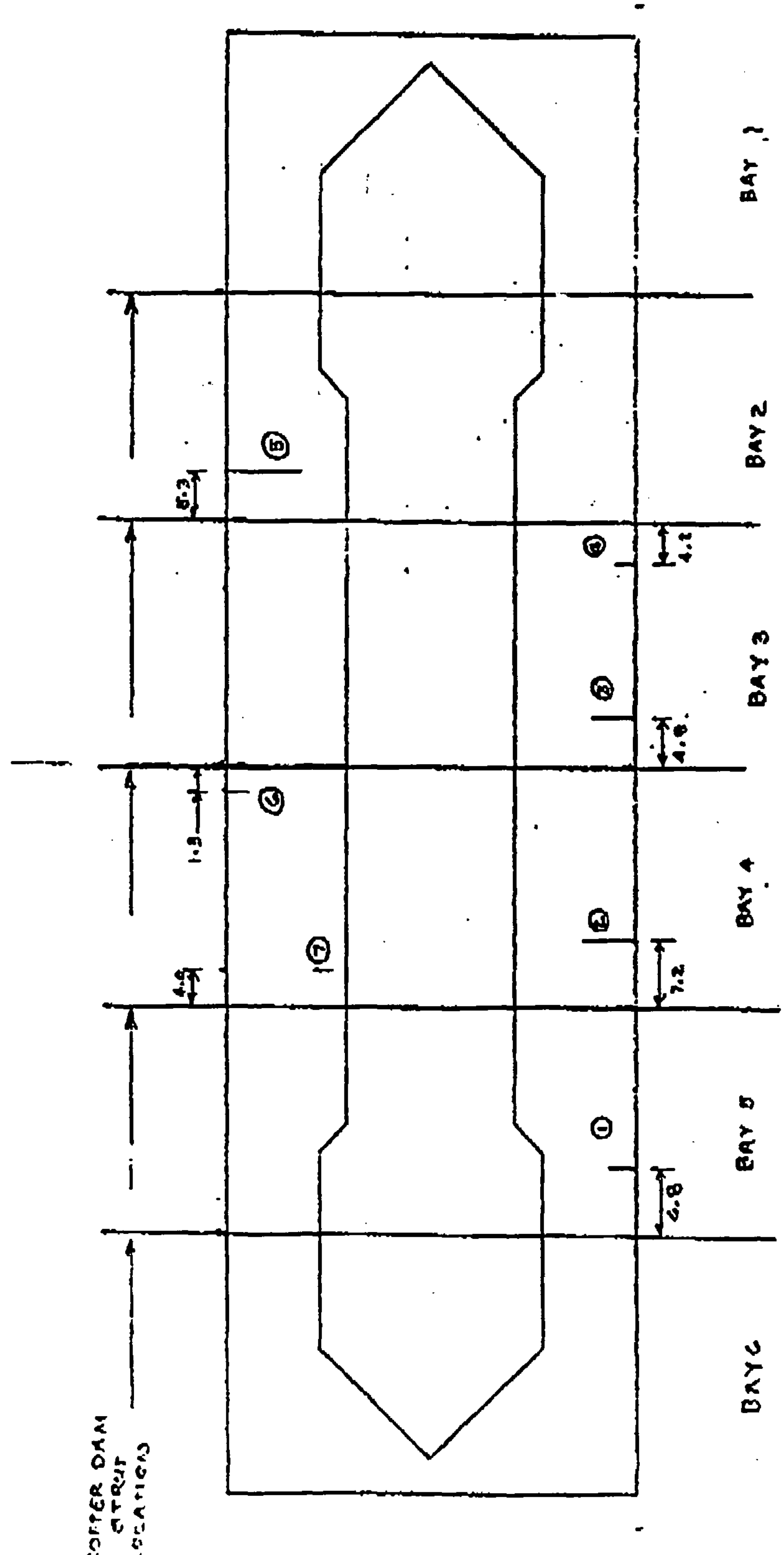
Post-It™ brand fax transmittal memo 7671 | # of pages ▸ 1

To Roy Kuhn	From L Sollanesne
Co.	Co. Dist 5
Dept. Construction	Phone # 472-4171
Fax # 515-232-0808	Fax # 472-3622

Roy Copy

8-7-90

LOCATION OF CRACKS IN FOOTING
26 JUL 90
(MS-2F)



Talked to Tom Mc...
7-31-90

Cracks do run down sides. Can only see a foot or so.
Could not find any under the Shell area.
No 7 is the only one in the center part

CRACK	LENGTH	WIDTH
1	3.2'	1/16"
2	5.5'	1/8"
3	4.7'	1/8"
4	1.8'	1/16"
5	8.0'	1/8"
6	1.6'	1/8"
7	1.1'	-

BRF-34-9(49)
MISSISSIPPI R. BRIDGE
DES MOINES COUNTY
PIER MS-2

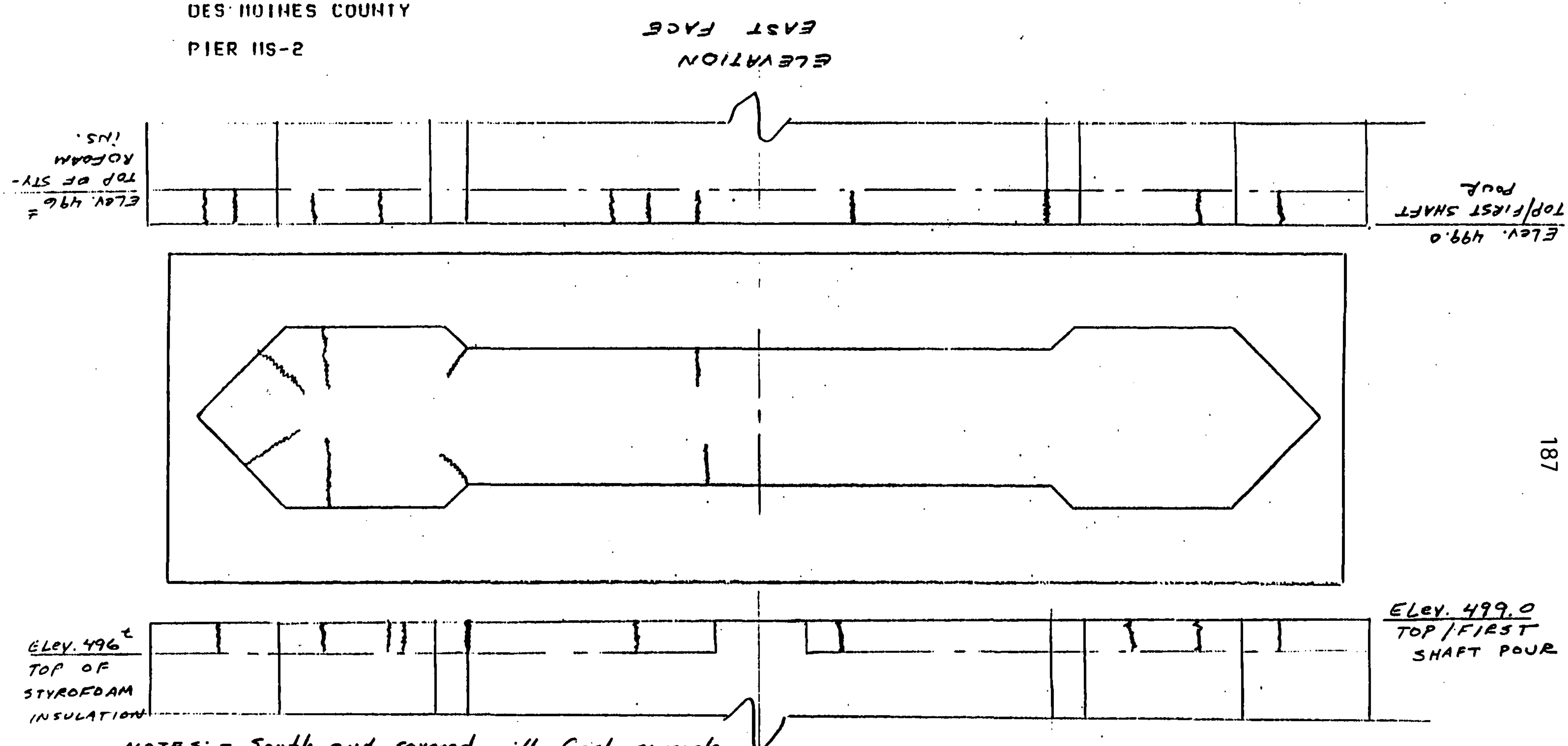
TLM

N

LOCATION OF CRACKS
FIRST SHAFT POUR
(MS-2-1)

BRF-34-9(45)
MISSISSIPPI R. BRIDGE
DES MOINES COUNTY

PIER MS-2



NOTES: - South end covered with fresh concrete. Unable to determine if cracks exist.
- Cracks vary in width.
- Widest cracks are 1/16" at top of concrete tapering down to hairline or disappearing at insulation.
- Some are completely hairline.
- All cracks on top of concrete are hairline.

ELEVATION
WEST FACE

SCALE: 1" = 20'

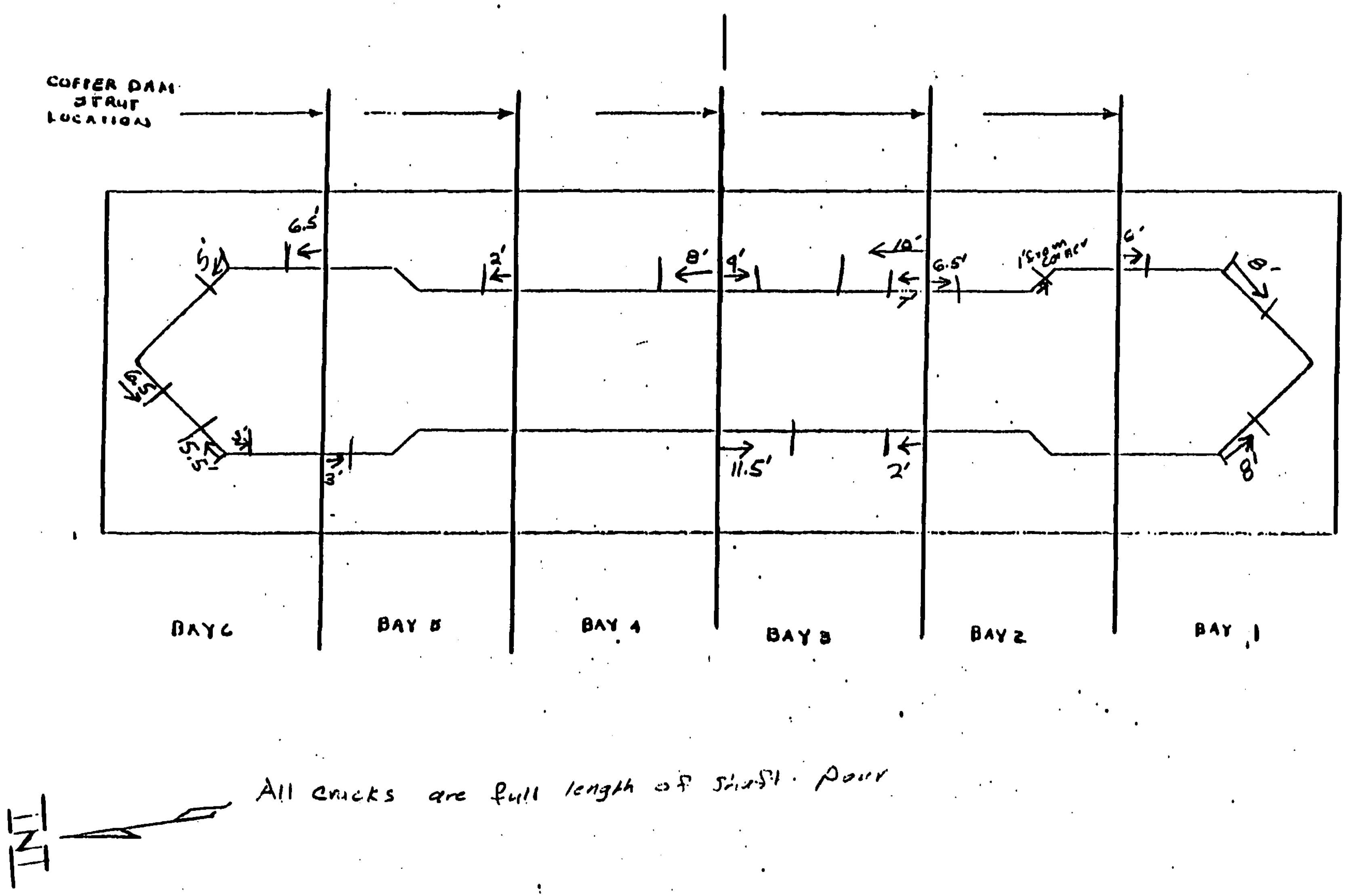
SK 8-8-90
DKR

1-DEW, MS-2, CRACKS (AS) LOCATION CRACKS IN 2ND SHAFT POUR

90-8-8 DOT DOT

BRF-34-8(45)
MISSISSIPPI R. BRIDGE
DES MOINES COUNTY
PIER MS-2

LOCATION OF CRACKS IN ~~FOOTING~~ Second Shaft pour
(MS-2-2)
18 CRACKS



All cracks are full length of shaft pour

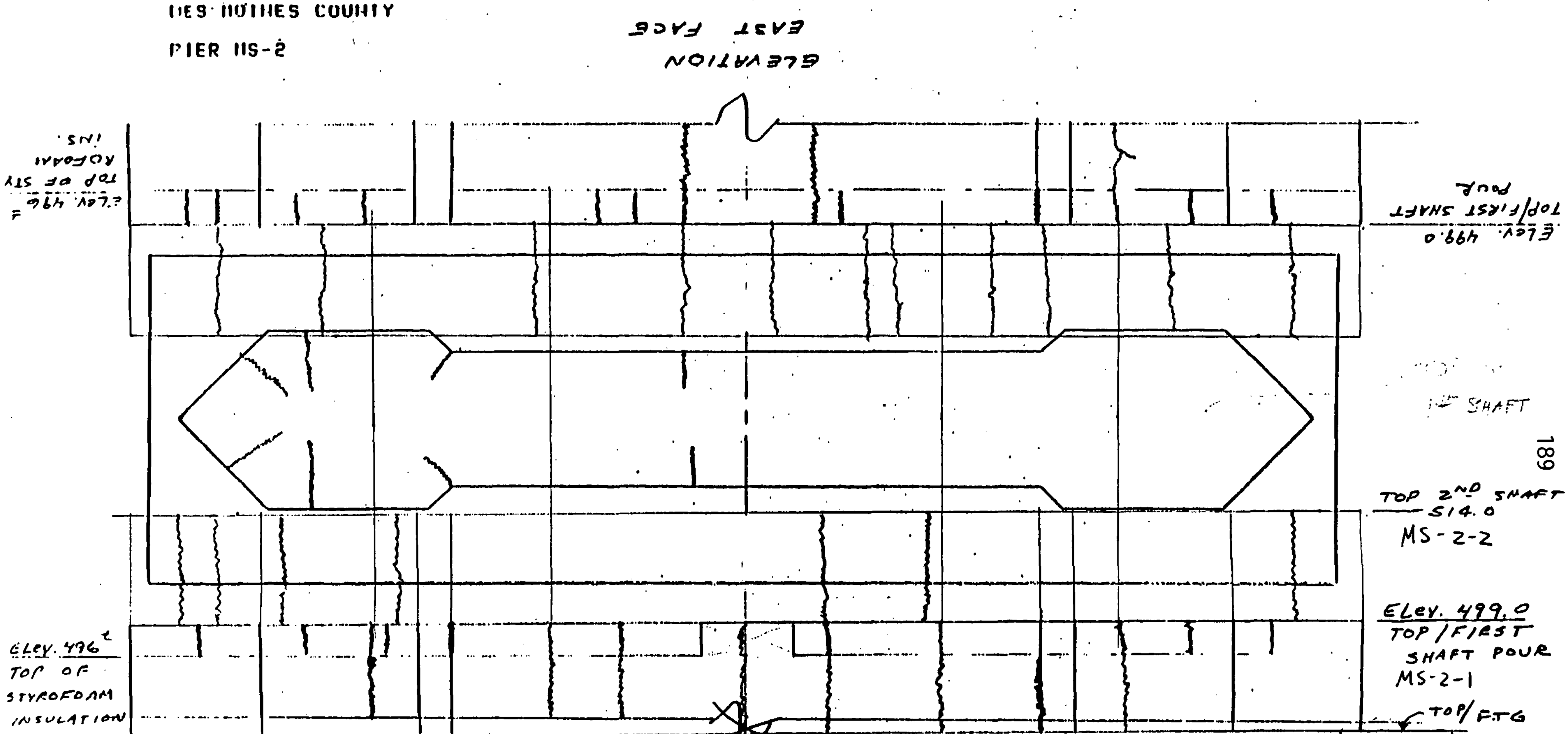
LOCATION OF CRACKS

FIRST SHAFT POUR

MS-2-1 AND MS-2-2

BRF-34-9(45)
MISSISSIPPI R. BRIDGE
DES MOINES COUNTY

PIER MS-2



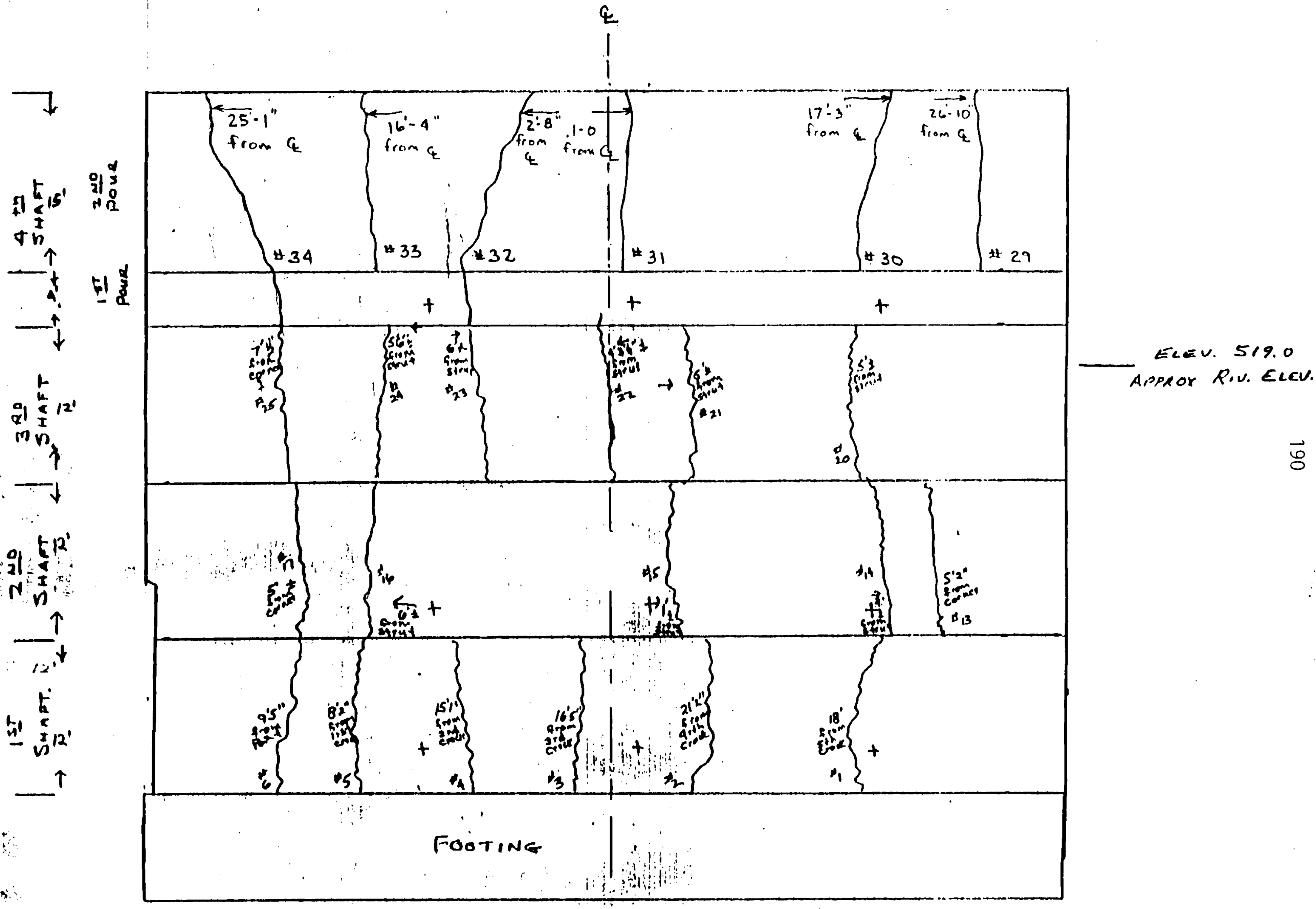
NOTES: - South end covered with fresh concrete. Unable to determine if cracks exist.
- Cracks vary in width.
- Widest cracks are 1/16" at top of concrete tapering down to hairline or disappearing at insulation.
- Some are completely hairline.
- All cracks on top of concrete are hairline.

ELEVATION
WEST FACE
SCALE: 1" = 20'

SK 8-8-90
DKR

189

CRACK LOCATION

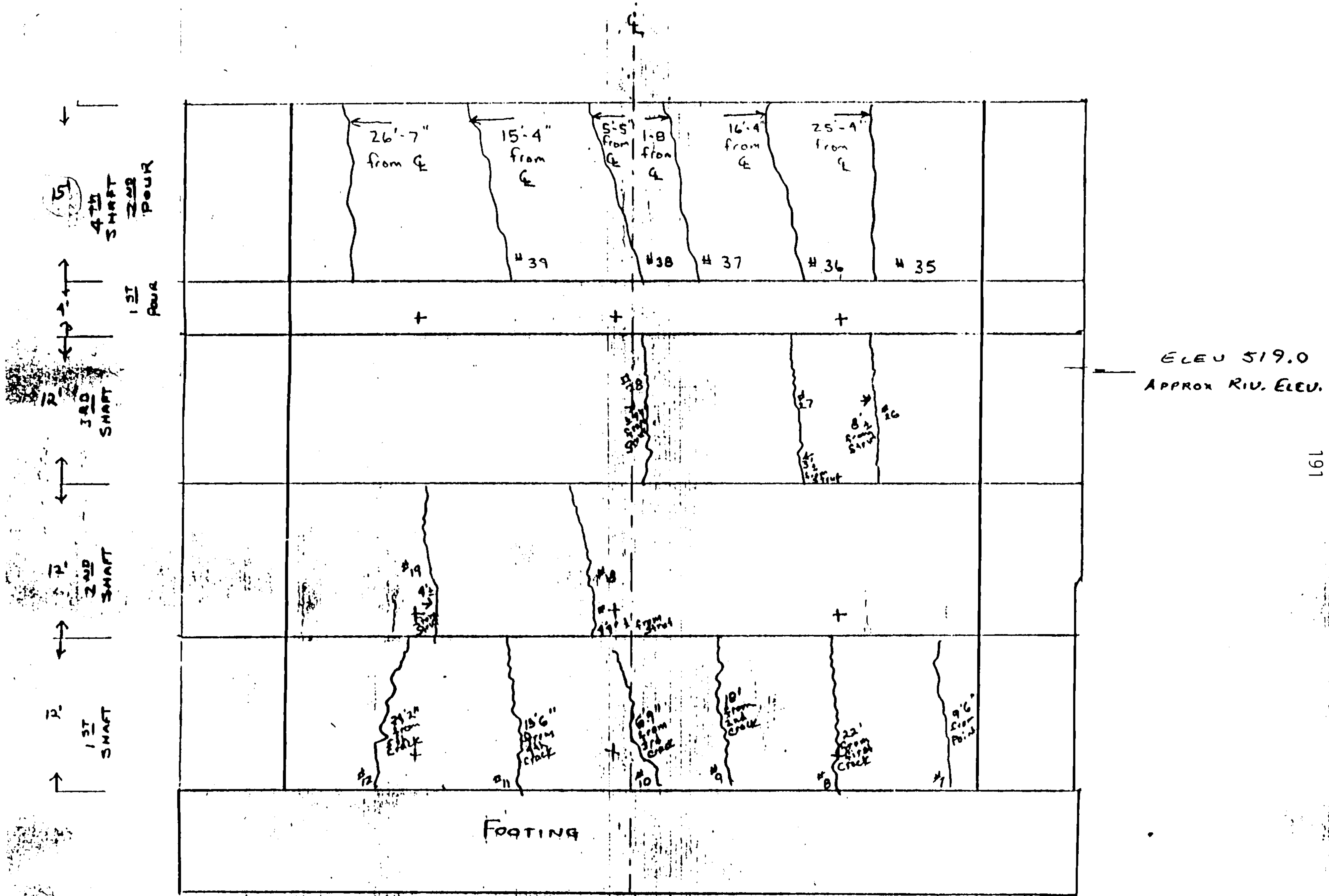


PIER MS-3 - EAST SIDE III

+ ~ APPROX. STRUT LOCATION.

190

CRACK LOCATION



PIER MS-3 – WEST SIDE IA

+ ~ APPROX. STRUT LOCATION.

NOT TO SCALE

191

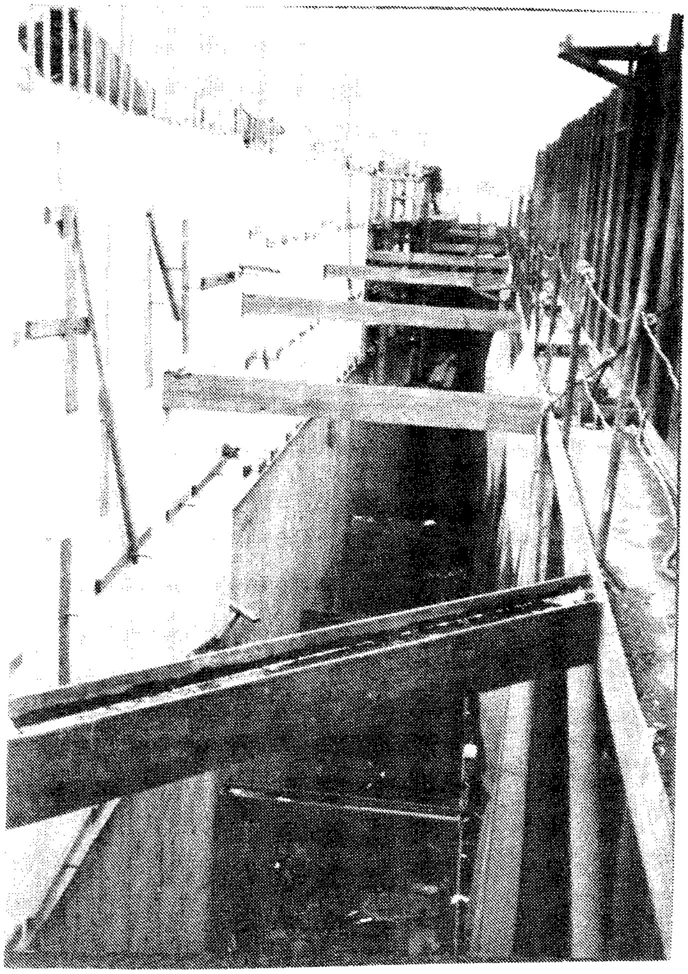


Photo 1 - Styrofoam sheets in place on third lift of pier MS-2 (pour MS-2-3)

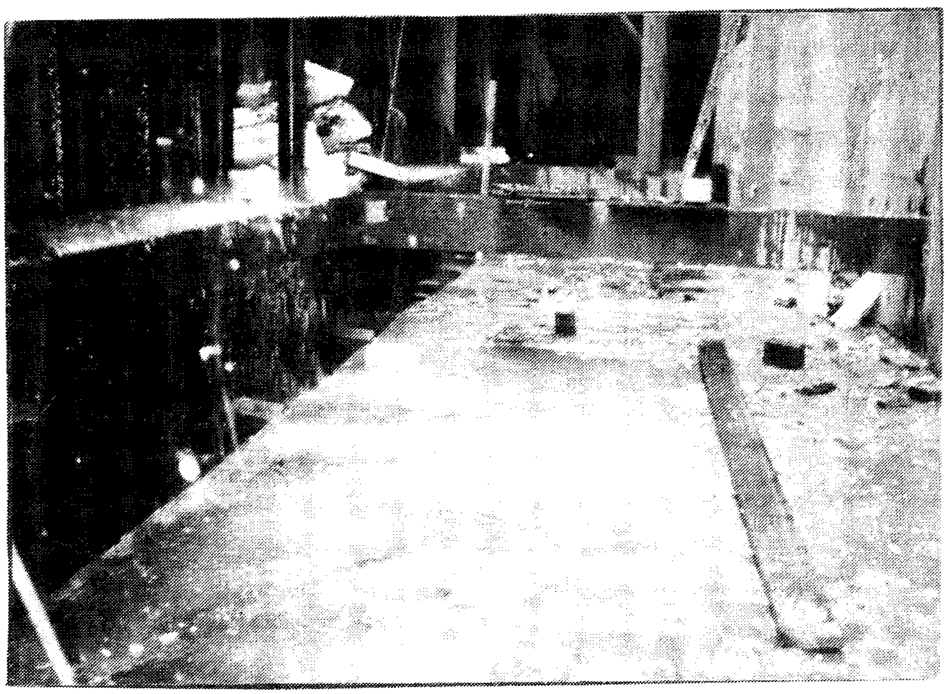
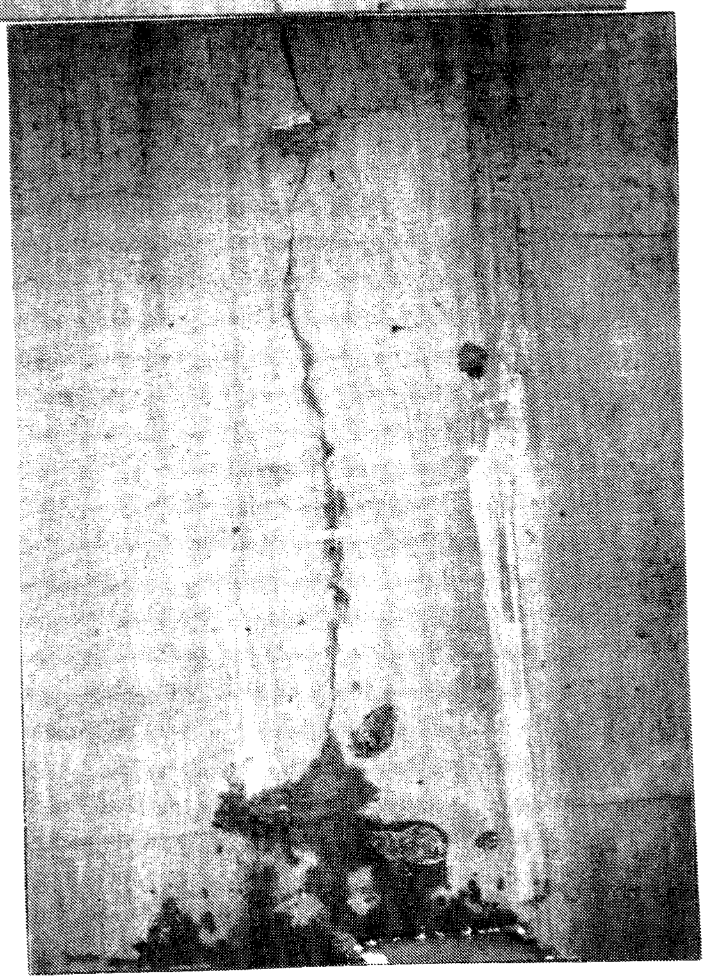


Photo 2 - Insulated forms in place on third lift of pier MS-2 (i.e., pour MS-2-3)



Photos 3 & 4

A longitudinal crack and honey-combing (at top of photos near strut) in sub-structure of pier MS-2. There are about 6 to 8 cracks in each side of each lift and they were relatively narrow. Cores were drilled to a depth of 4", and the cracks were present to that depth. All cracks were observed below elevation 514' (top of second lift). Norrmal pool elevation is 519.4'.

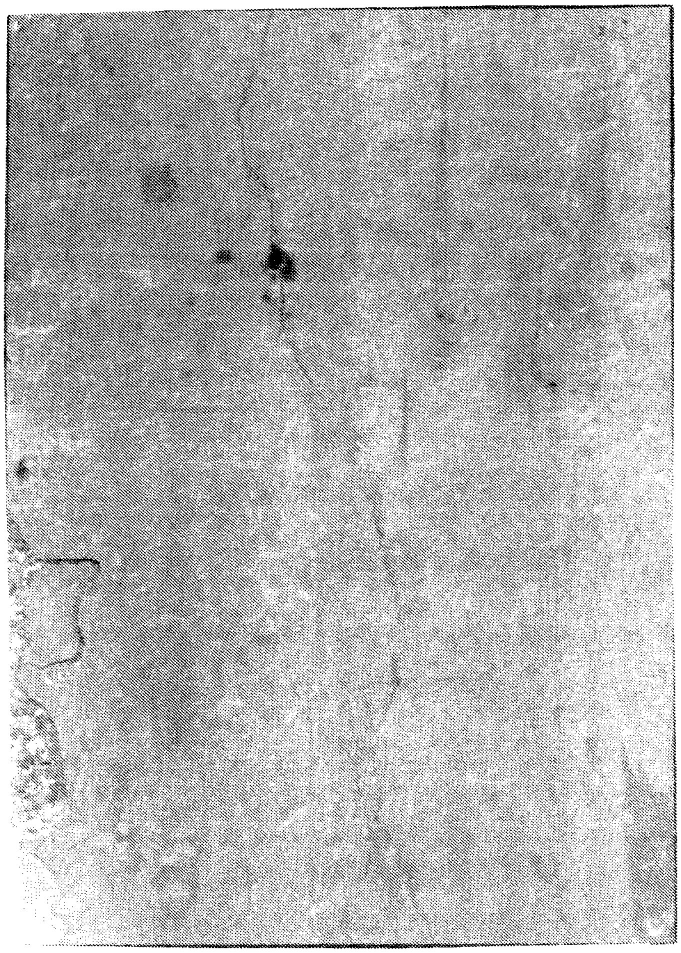


Photo 5 - A longitudinal crack in the substructure of pier MS-2

Photo 6 - Drilling cores in pier MS-2

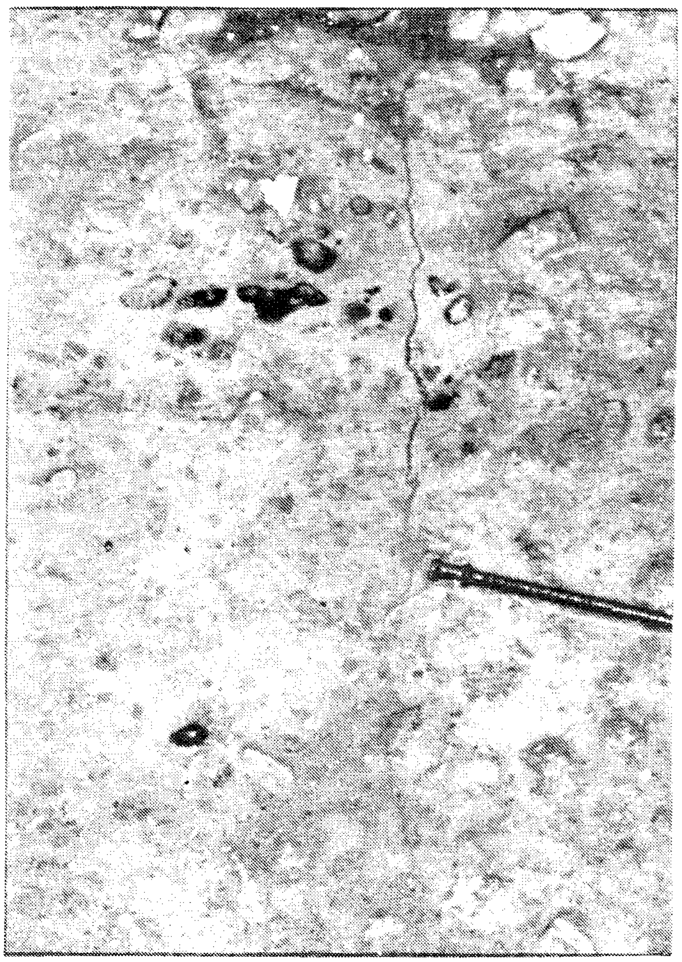
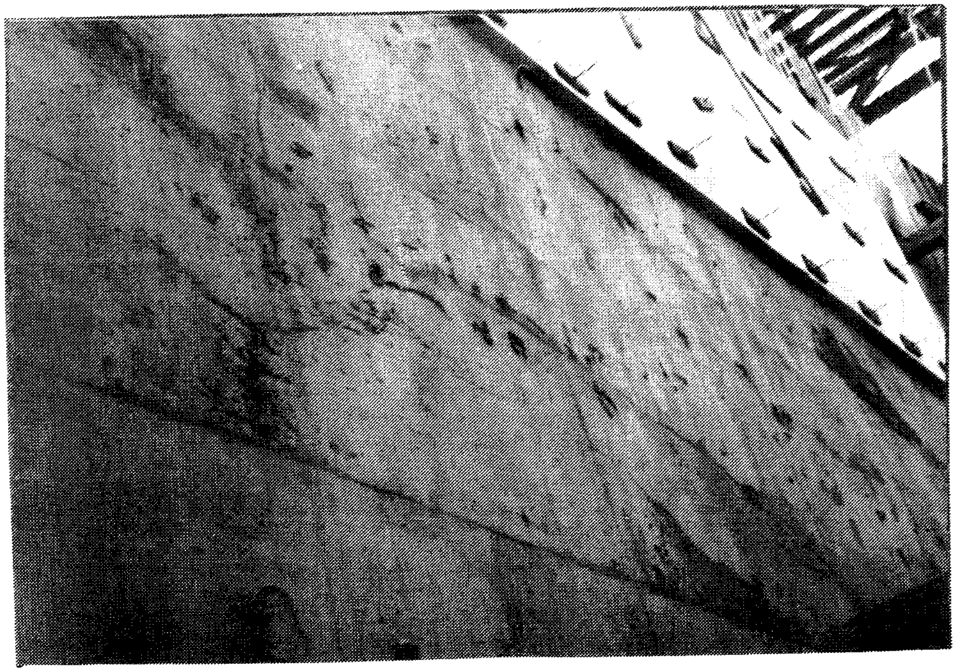
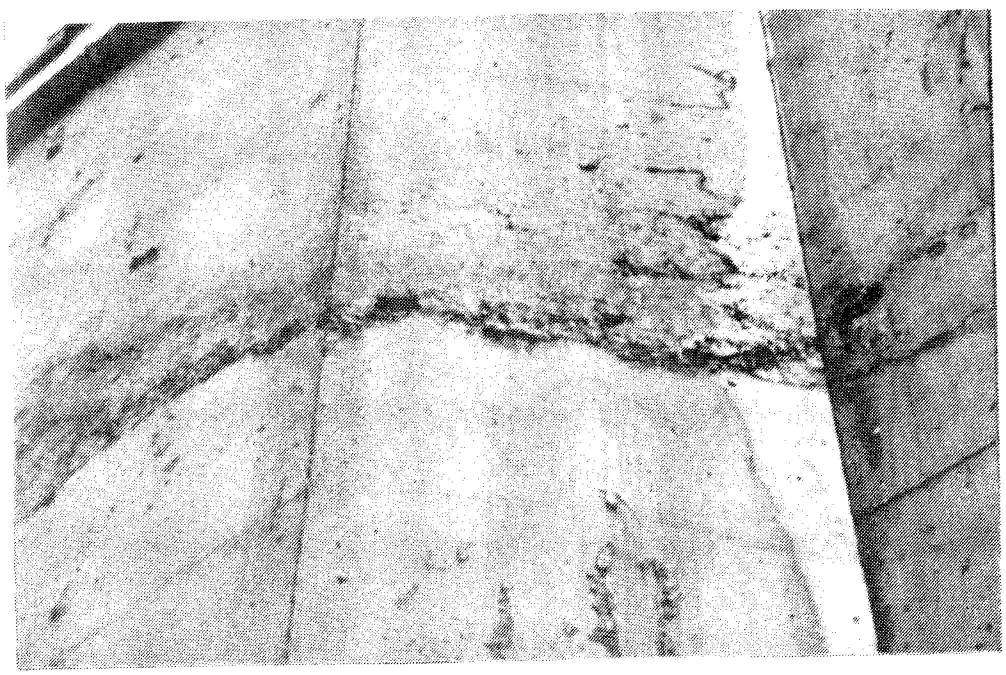


Photo 7
A crack in the footing of pier MS-2



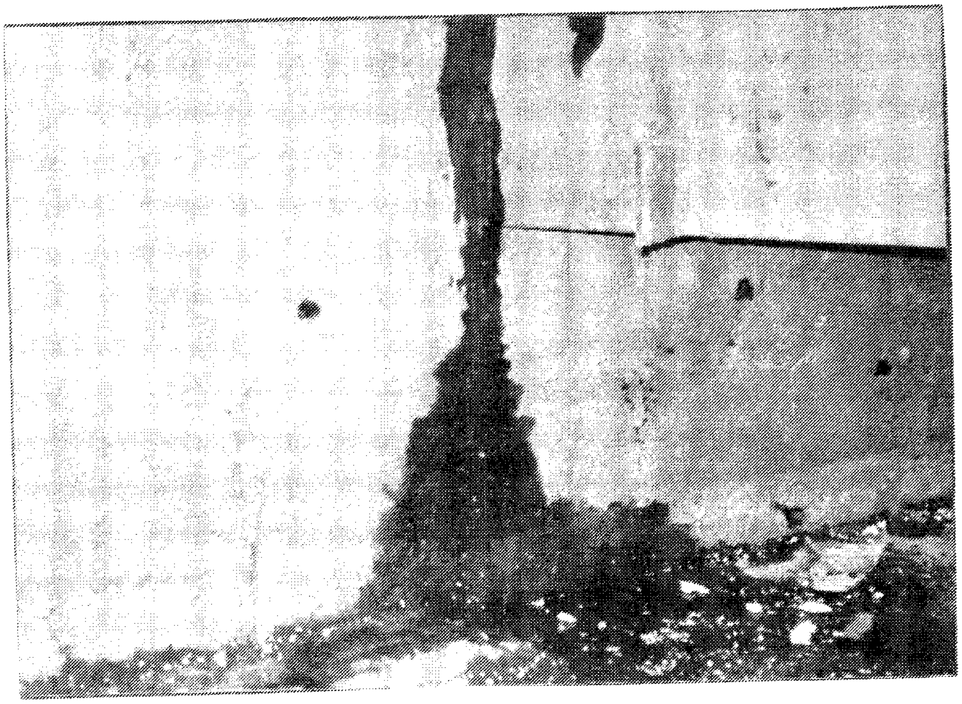
Photos 8, 9, 10

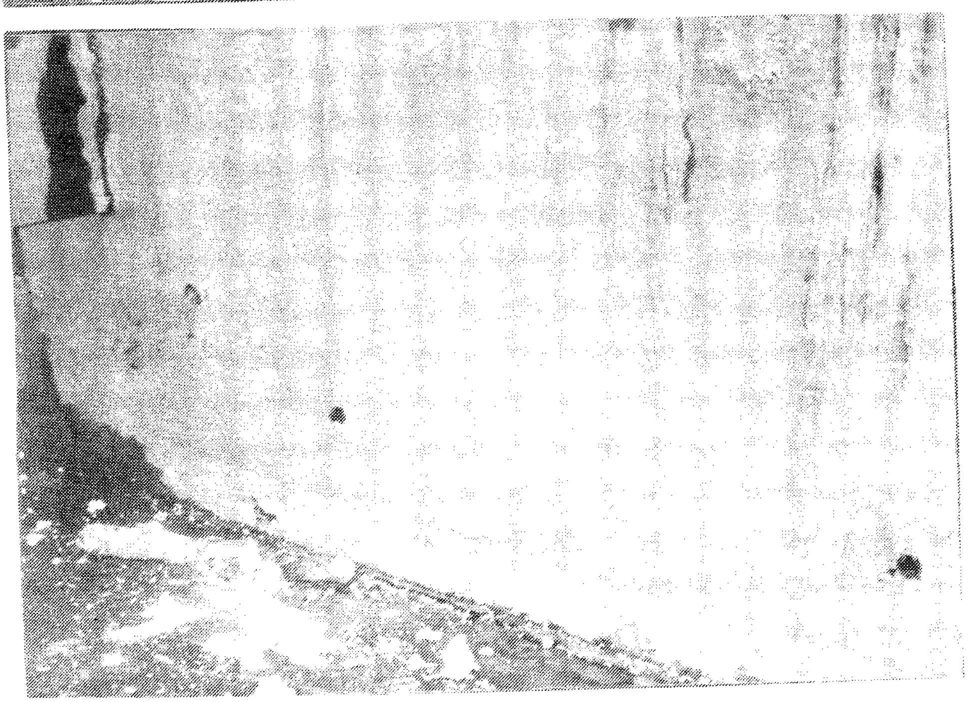
Honeycombing in the substructure of pier MS-2 (pours MS-2-1 and MS-2-2). Probably to inadequate vibration and low rate of placement.



Photos 11, 12 and 13

Honeycombing in pier MS-2 (pours MS-2-1 and MS-2-2-)





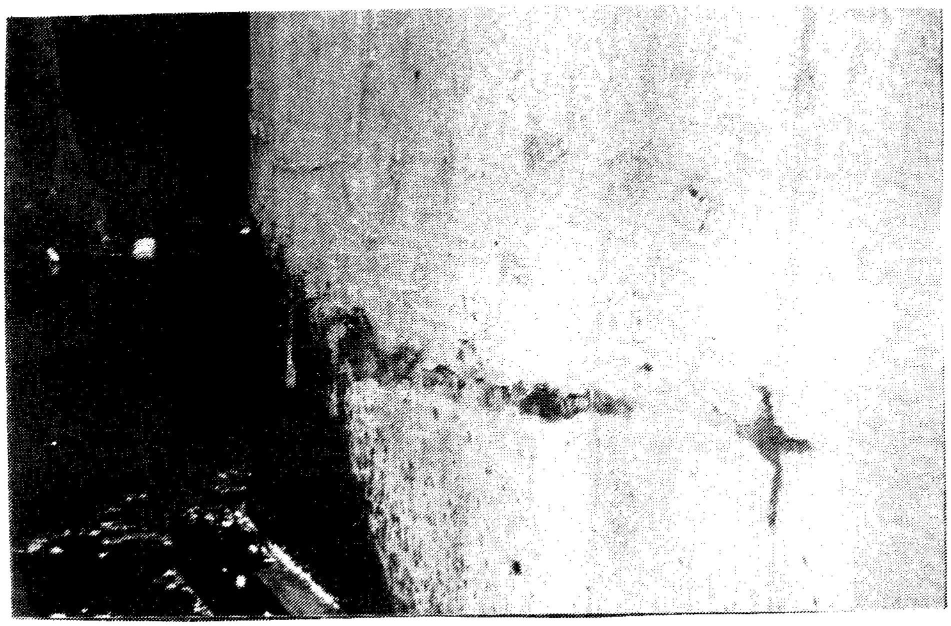
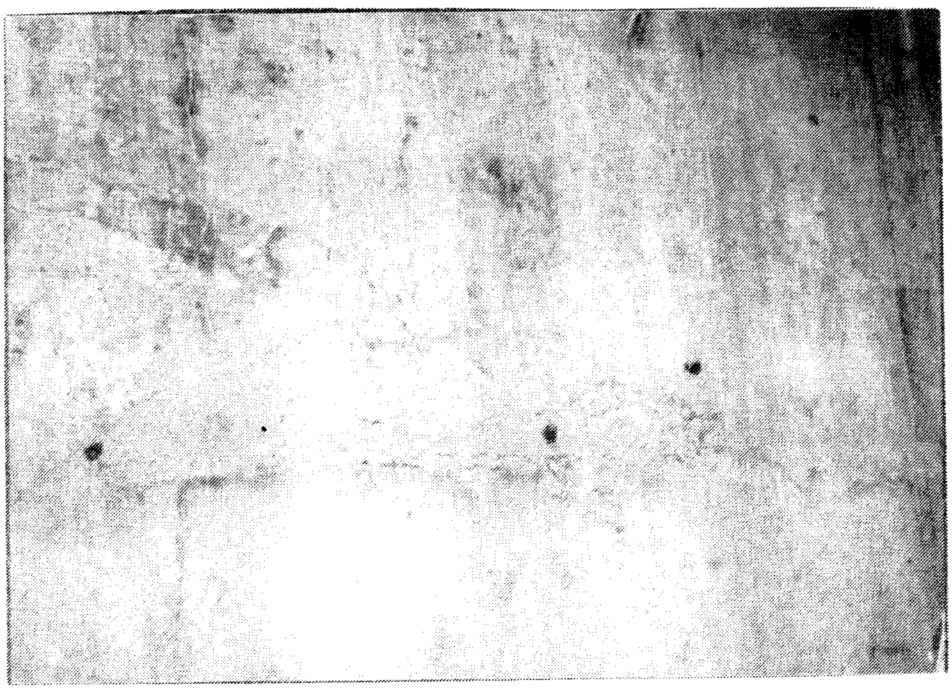


Photo 14, 15 and 16

Honeycombing



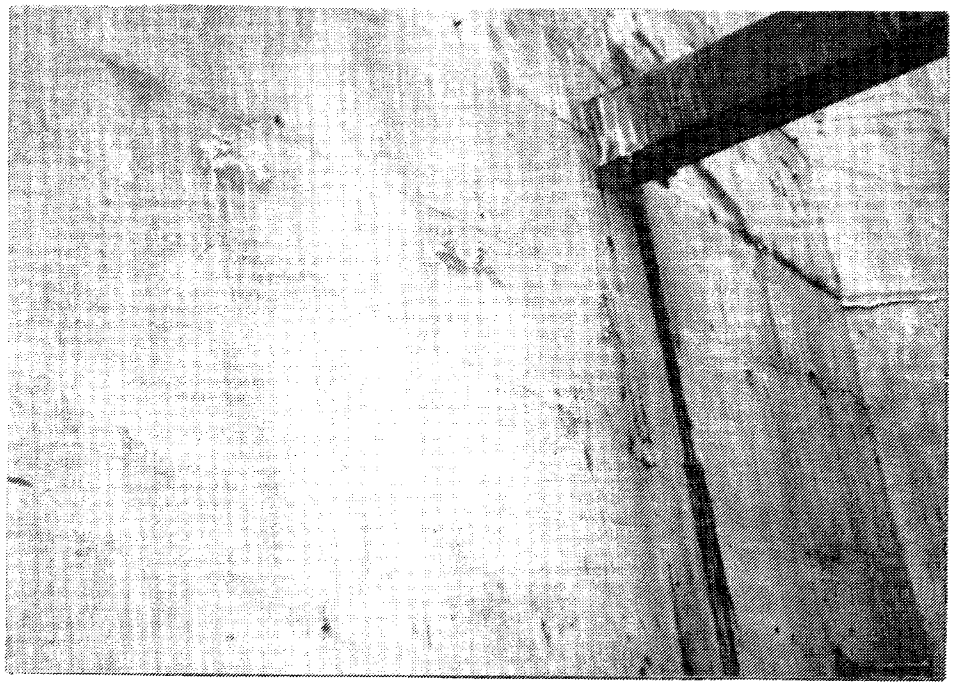


Photo 17 - Honeycombing

Photo 18 - Honeycombing

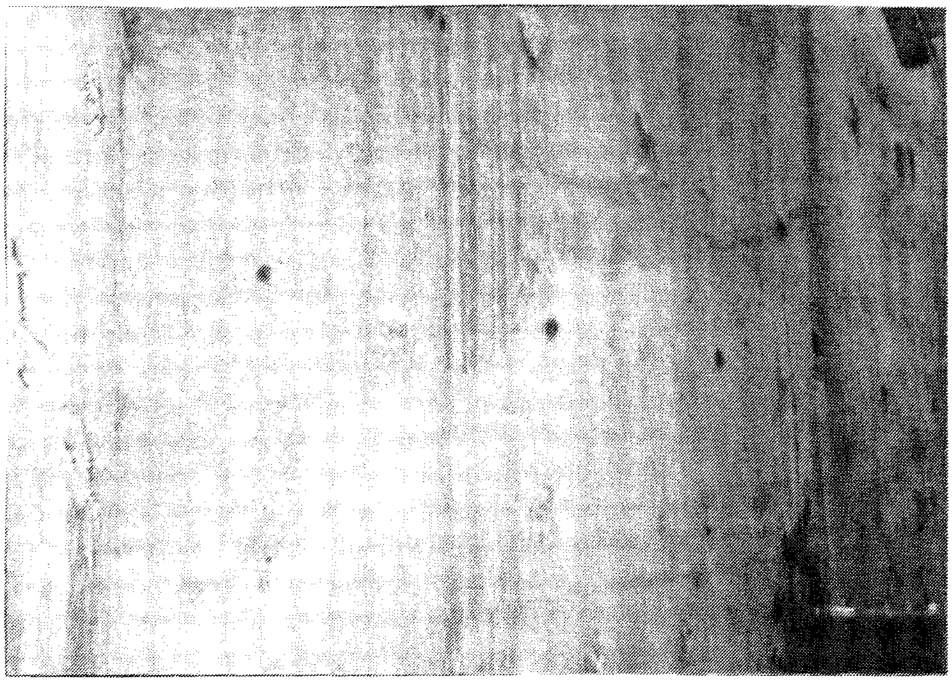


Photo 19 - Honeycombing

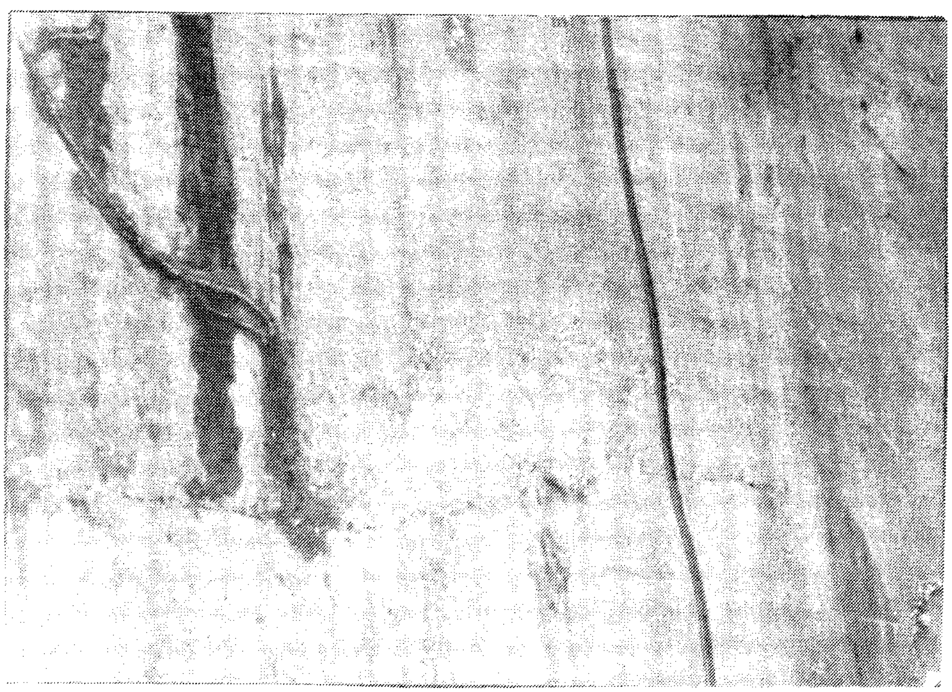


Photo 20 - Honeycombing