Iowa Highway Research Board

Project HR-87

SUBGRADE INSULATION TO PREVENT SOIL FREEZING

Final Report
December 1965

Research Department

Iowa State Highway Commission

IOWA STATE HIGHWAY COMMISSION
Ames, Iowa

December 21, 1965

To: All Concerned

From: Research Department

Subject: Subgrade Insulation to Prevent Soil Freezing

The report noted above is final for research project HR-87. The automatic temperature recording equipment has been removed from the test site. Observations of the pavement will continue to be made periodically; you will be informed of any significant changes.

The basic purpose of this study was to determine if insulating board composed of expanded polystyrene can be used under highway pavement to prevent freezing of the subgrade soil.

The insulating board was furnished without cost by the manufacturer. The thickness, one and one-half inches, was that recommended by the manufacturer. The board was placed on the subgrade composed of a frost-susceptible soil; a nine-inch Portland Cement Concrete slab was placed on top of the board.

The temperature of the air, the concrete, and of the soil was obtained from thermocouples. This was recorded automatically every two hours. The report contains graphs and illustrations showing temperature distributions for two years.

The insulation under a P.C. concrete slab and under the shoulders, as used in this experimental project, appears to have adequately protected the subgrade from freezing temperatures and prevented frost heave.

The concrete slab above the insulation, in comparison with the uninsulated control slab, experienced more cycles of freezing and thawing. It also appeared to have a more uniform temperature throughout its thickness.

The conclusions contained in this report do not constitute a recommendation for any particular brand nor type of thermal insulation. It may be that many suitable materials now exist or will subsequently be developed. While the basic requirement is low thermal conductivity, there are also other properties which should be exhibited by the insulating material. It should absorb little or no moisture, should be unaffected by chemicals and bacteria commonly found in soil and paving materials, and should have structural strength adequate for the intended application.

This report concerns the use of thermal insulation under rigid pavement. It is recognized that the desirability of preventing soil freezing applies equally to the supporting subgrade for flexible pavement. The exact placement of the insulation under either type of pavement will depend upon individual job requirements and the ingenuity of the designer. It should be kept in mind that the installation method and its compatibility with standard construction procedures is an important factor in the cost of the project. If the installation method is complicated, it will likewise be costly. In this event, the use of thermal insulation may not prove economical in comparison with the conventional practice of replacing the frost-susceptible subgrade soil with granular material.

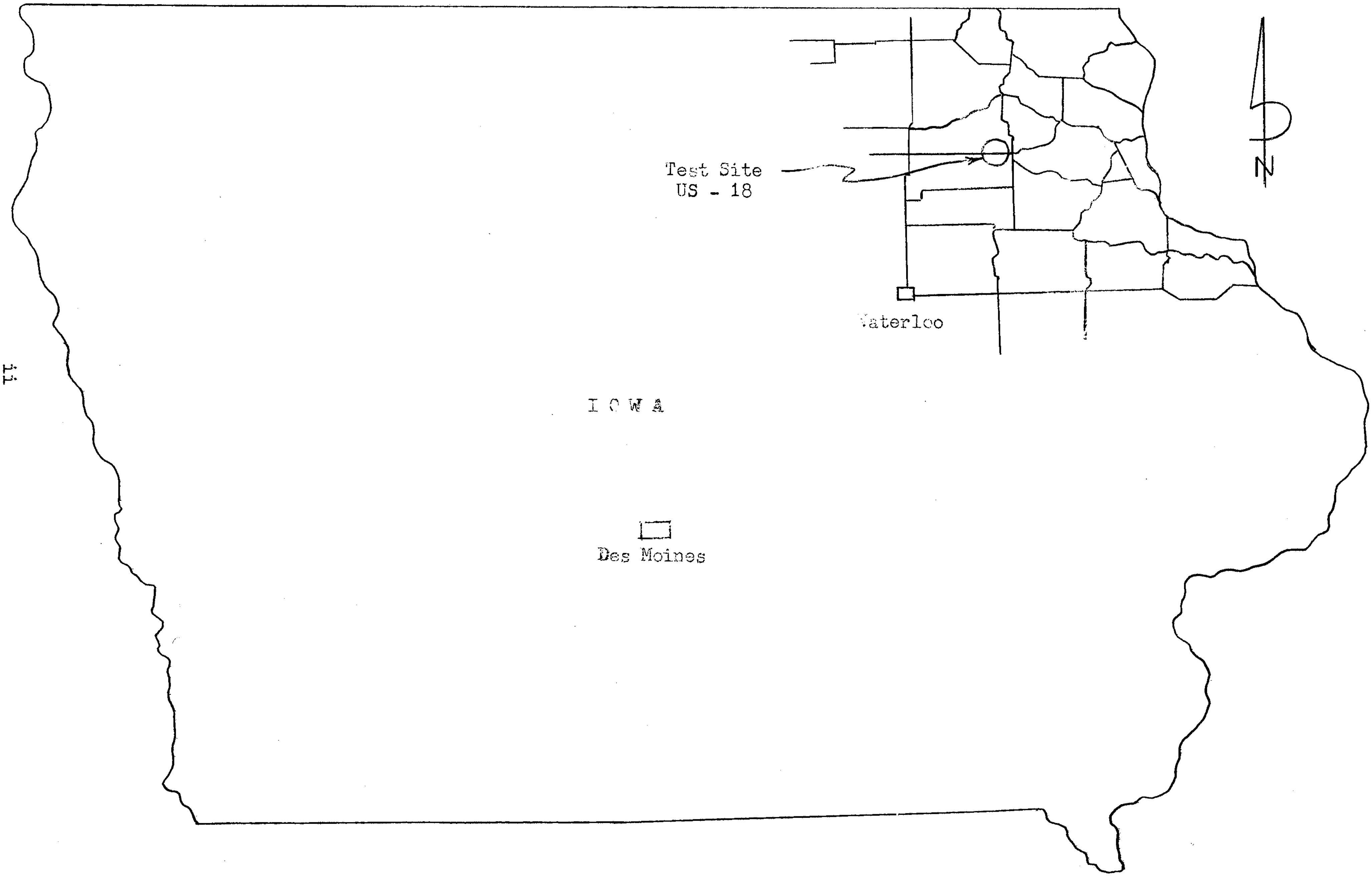

Figure 1: Project Map

ACKNOWLEDGEMENTS

The experimental work described in this report was accomplished through the cooperation of all concerned with the design and construction of the pavement. The temperature recording equipment was installed by personnel from the Materials Department Laboratory. Regular inspection of the installation and profile measurements of the pavement were provided by personnel from the Resident Engineer's Office at New Hampton.

We desire to also acknowledge the excellent cooperation of the paving contractor, Fred Carlson, and of the Dow Chemical Company, which furnished technical assistance as well as the Styrofoam insulation.

ABSTRACT

The basic purpose of this study was to determine if an expanded polystyrene insulating board could prevent subgrade freezing and thereby reduce frost heave.

The insulating board was placed between a nine inch P. C. concrete slab and a frost-susceptible subgrade. In one section at the test site, selected backfill material was placed under the pavement. The P. C. pavement was later covered by asphalt surfacing. Thermocouples were installed for obtaining temperature recordings at various locations in the surfacing, concrete slab, subgrade and shoulders.

This report contains graphs and illustrations showing temperature distributions for two years, as well as profile elevations and the results of moisture tests.

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INTRODUCTION

Frost heave is a ground-freezing phenomenon which has always been a problem for highway engineers. When severe enough, localized areas develop what are commonly called "frost boils." There is considerable vertical movement of the road surface during winter freeze and spring thaw. Finally, over a period of years, cracking of the slab and uneven settlement develop giving the pavement very poor riding qualities. In extreme conditions complete disintegration of the surface can occur.

In order for frost heaving or frost boils to develop, three basic conditions must exist. These are: (1) freezing temperatures in the soil; (2) a reservoir of ground water sufficiently close to the frost line to feed the growing ice layers; (3) soil material having favorable characteristics for rapid movement of capillary water upward from the water table. Since the temperature cannot be controlled, frost heave areas have generally been corrected by removing the undesirable material and replacing it with a granular backfill or by lowering the water table.

The conclusions contained in this report do not constitute a recommendation for any particular brand nor type of thermal insulation. It may be that many completely adequate materials now exist or will subsequently be developed. While the basic requirement is low thermal conductivity, there are also other properties which should be exhibited by the insulating material. It should absorb little or no moisture, should be unaffected by chemicals and bacteria commonly found in soil and paving materials, and should have structural strength adequate for the intended application.

This report concerns the use of thermal insulation under rigid pavement. It is recognized that the value of preventing soil freezing applies equally to the supporting subgrade for flexible pavement. The exact placement of the insulation under either type of pavement will depend upon individual job requirements and the ingenuity of the designer. It should be kept in mind that the installation method and its compatibility with standard construction procedures is an important factor in the cost of the project. If the installation method is complicated, it will likewise be costly. In this event, the use of thermal insulation will seldom prove economical in comparison with the conventional practice of replacing the frost-susceptible subgrade soil with granular material.

RESEARCH OBJECTIVE

During the fall of 1963, the Iowa State Highway Commission constructed a short section of highway where an insulating material was placed directly below the slab. The objective of this test was to determine if an insulating material will prevent the subgrade from freezing, thereby reducing the frost heave. If successful, this could eliminate the need to remove and replace the poor soil with granular material.

The insulating material for this test was furnished without cost by the manufacturer, Dow Chemical Company of Midland, Michigan. Therefore, no attempt was made to compare the cost of insulation with that of granular backfill.

MATERIAL

The insulating material used is an expanded polystyrene with the trade name of Styrofoam. The physical properties of the type of Styrofoam used in this test are shown in Table 1. Its mechanical properties decrease slightly as the temperature is raised. At 160°F to 170°F the cellular structure collapses. The material is not affected adversely at sub-zero temperatures.

Polystyrene, the base plastic, absorbs a negligible amount of moisture and the closed cell structure of Styrofoam almost completely prevents the entrance of water.

CONSTRUCTION

The Iowa test section is located on US 18 about two miles west of West Union. It is in a 450 foot section of pavement having a history of frost heaving.

The original plans were to core out three feet of the subgrade and backfill with selected granular material. The excavation and backfilling was eliminated on the east 250 feet of the section. Instead, one and one-half inches of Styrofoam was placed directly below the pavement on the subgrade and in the shoulders at a 2:1 slope.

The 250 foot test area was divided into three sections. In the east section, 75 feet in length, one layer of Styrofoam one and one-half inches thick was placed. In the middle section, 100 feet in length, two layers of Styrofoam, each three-fourths inch thick, were placed. In the west section, 75 feet in length, one layer of Styrofoam one and one-half inches thick was placed. In this section the Styrofoam was covered with a sheet of four mil polyethelene. A layout of the test area is shown in Figure 2.

The test sections were instrumented to measure the temperatures at various locations in the slab, subgrade and shoulders.

As soon as the pavement forms were in place and the subgrade cut and compacted, the first group of thermocouples was installed at various depths in the subgrade. This was followed by the placing of the Styrofoam between the forms. The Styrofoam was in the form of boards, 2 foot by 8 foot. Very little trouble was encountered in placing them, however, they were very light and could easily be blown away by the wind. They were fastened to the subgrade by wooden pegs.

Nine inches of Portland cement concrete pavement was then placed directly on the Styrofoam (or polyethelene). The thermocouples used to measure the temperature of the concrete pavement were held in position by frames during placing of the concrete.

The next day, after the paving forms had been removed, the 2:1 slope was cut on the shoulders. Styrofoam was then placed along the slope and the shoulder was constructed. Thermocouples were placed in the shoulder at various depths in the soil below and above the Styrofoam.

About June 15, 1964, three inches of asphaltic concrete were placed upon the nine-inch concrete slab. On May 7, 1965, thermocouples were placed at various positions in the resurfacing.

TESTING

The thermocouple wires terminated in a 5 foot by 5 foot by 6 foot building located near the right of way line. This building was well insulated and a temperature above $50^{\circ}F$ was easily maintained during the winter months by use of two electric heaters.

The temperatures obtained by the thermocouples were indicated by an automatic recording potentiometer which was capable of recording, in sequence, the temperatures in 24 separate locations. It was timed so that the temperatures at the 24 locations were recorded once every two hours. The recorder contained two instrument boards consisting of 24 terminals each. Either board could be connected, making it possible to obtain temperatures from 24 alternate locations if desired. The layout of the thermocouples at Station 602+00 and at Station 604+50 is shown in Figures 3 and 4.

Figures 5 and 6 show the thermocouple locations at the same stations after the asphaltic concrete resurfacing had been completed. The remaining thermocouples were placed in the concrete and subgrade at Station 603+50 but were not installed in the resurfacing at that particular location.

RESULTS

Graphs and illustrations of the temperatures at various locations are shown in Figures 7 through 24.

Figures 7 and 8 show the average daily air temperatures during the freezing seasons of 1963-1964 and 1964-1965.

Figures 9 and 10 compare the temperatures above and below the Styrofoam insulation. Figure 9 shows these comparative temperatures for the 1963-1964 freezing season (before resurfacing) and Figure 10 shows them for the 1964-1965 freezing season (after resurfacing).

Figures 11 and 12 compare minimum temperatures in the concrete one inch above the bottom of the slab, as affected by insulation below the slab. These graphs are included primarily to show that while the Styrofoam insulates the subgrade from freezing temperatures, it also prevents the concrete from receiving heat from the subgrade. Figures 13 and 14 show maximum temperatures at the same locations during the warmest summer months. In this case the Styrofoam reduces the amount of cooling from the subgrade. The temperatures shown in Figure 11 are those before the asphaltic concrete was applied and those in Figures12, 13, and 14 are after the three inch resurfacing.

Figures 15, 16, 17, and 18 show minimum and maximum temperatures at various depths below the surface with and without the Styrofoam insulation. It should be noted that during the winter of 1963-1964 the minimum temperature one inch above the Styrofoam was $-15^{\circ}F$ while the minimum temperature one inch below the styrofoam was 34°F. During the winter of 1964-1965, however, the minimum temperature one inch above the Styrofoam was -8°F and the minimum temperature one inch below the styrofoam dropped to 30°F. During the 1964-1965 winter the subgrade temperature five inches below the styrofoam dropped below 32°F for a period of five days.

DISCUSSION

In order to accurately evaluate the results obtained on a field installation such as this, it becomes necessary to determine whether or not the installation was put to a severe enough test.

A commonly accepted method for determining the severity of cold weather is to calculate the freezing index for the winter or winters in question.

Definitions:

Average daily temperature - The average of the maximum and minimum temperatures for one day or the average of several temperature readings taken at equal time intervals during one day.

Mean daily temperature - The average of the average daily temperatures for a given day for several years.

Degree-days - The degree-days for any one day equals the difference between the average daily air temperature and 32°F. The degree-days are minus when the average daily temperature is below 32°F (freezing degree-days) and plus when above 32°F (thawing degree-days).

Freezing index - The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is a measure of the combined duration and magnitude of below freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 feet above the ground is commonly designated as the air freezing index, and that determined for temperatures immediately below a surface is known as the surface freezing index.

Design freezing index - The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years are not available, the air freezing index for the coldest winter in the latest 10 year period may be used.

Mean Freezing Index - The freezing index determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years (preferably 30) and should be the latest available.

Figure 19 shows the freezing index to be 1463 degree-days for the 1963-1964 freezing season. Figure 20 shows the freezing index for the 1964-1965 freezing season has a value of 2035 degree-days. The mean freezing index for this part of the state as determined by the U.S. Army Corps of Engineers is 1100 degree-days over a 105 day period and the design freezing index is 1700 degree-days. From these figures it can be seen that the 1963-1964 winter was somewhat colder than average for this area, and the 1964-1965 winter was very severe. Mr. Paul J. Waite, Weather Bureau State Climatologist, speaking of the

1964-1965 winter says it was "the coldest winter (December through March) since 1935-1936. Subnormal temperatures occurred throughout all four months."

Figures 21 through 24 show the depth of frost penetration down to and including 46 inches below the top of the P.C. concrete in the section containing the granular backfill material.

Profile elevations of the roadway were taken at various times during the course of the investigation to determine the amount of frost heave. Table 2 shows that elevation changes in the styrofoam sections were much less than those either in the special backfill section or outside the test sections.

Moisture samples of the subgrade and shoulder were taken in April, 1964 and May, 1965. These values are listed in Table 3 and appear to have little significance. The subgrade in the control section consists of 3 feet of granular backfill which normally has a much lower moisture content than the fine grained soil under the Styrofoam.

CONCLUSIONS

The Styrofoam insulation under a P.C. concrete slab and under the shoulders, as used in this experimental project, appears to have adequately protected the subgrade from freezing temperatures and prevented frost heave.

Because of an insulating layer under the concrete slab it is known that the slab undergoes more freeze-thaw cycles than it would if such an insulating layer were not present. Whether or not this is detrimental remains to be seen.

The concrete slab above the Styrofoam appears to maintain a more uniform temperature throughout its depth than does a slab resting on the subgrade. The advantages gained from this due to a reduction in curling of the slab is beyond the scope of this report.

Photo 1: Installing the first thermocouple wires.

Photo 2: Placing 1½" Styrofoam on the Subgrade.

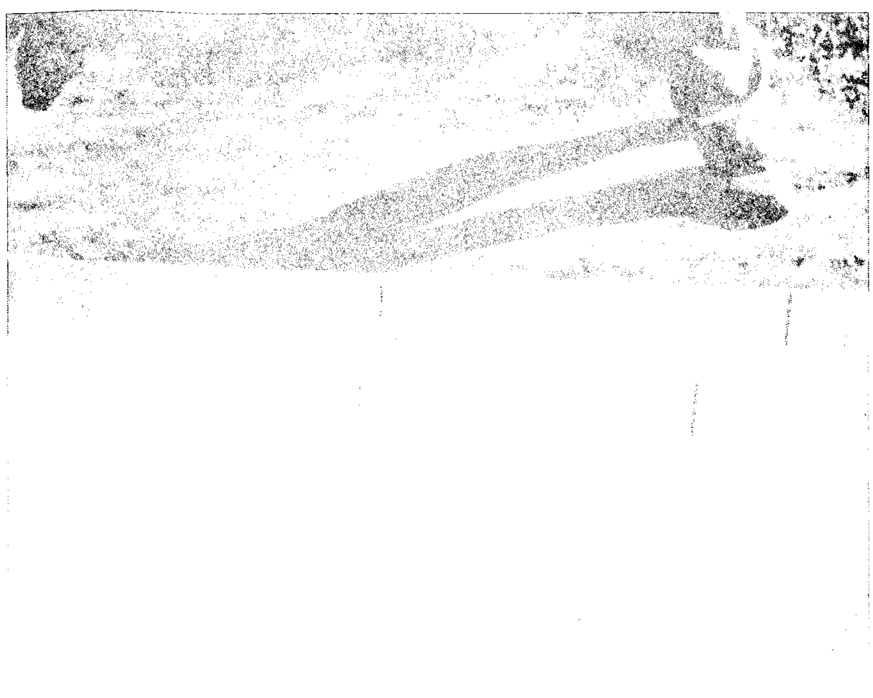


Photo 3: Wooden pegs used to fasten the Styrofoam to the Subgrade.

Photo 4: Two layers of 3/4" Styrofoam on the subgrade.

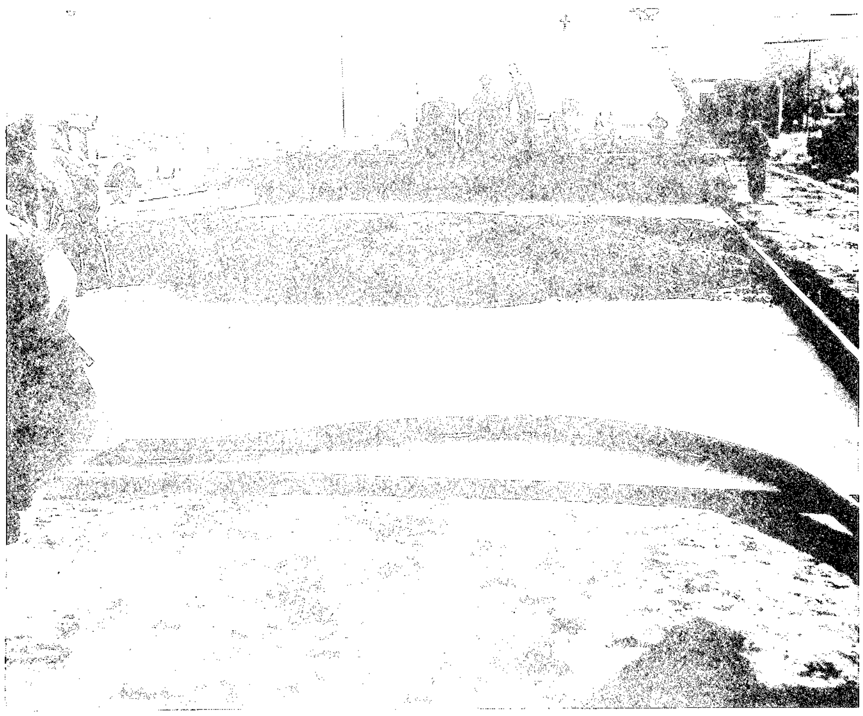


Photo 5: Concrete being placed on the Styrofoam.

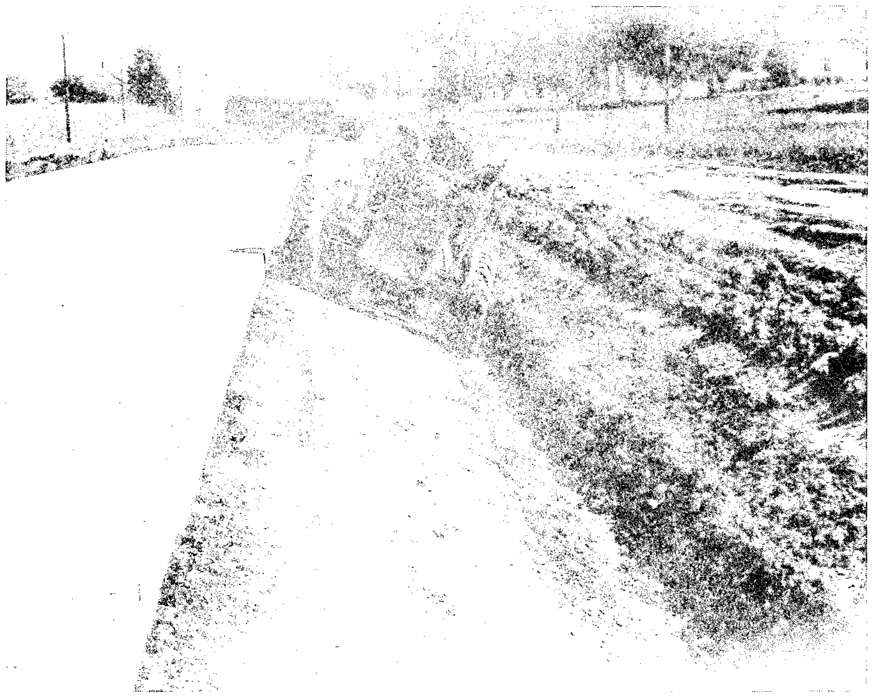


Photo 6: Cutting the 2:1 Shoulder Slope for the Styrofoam.

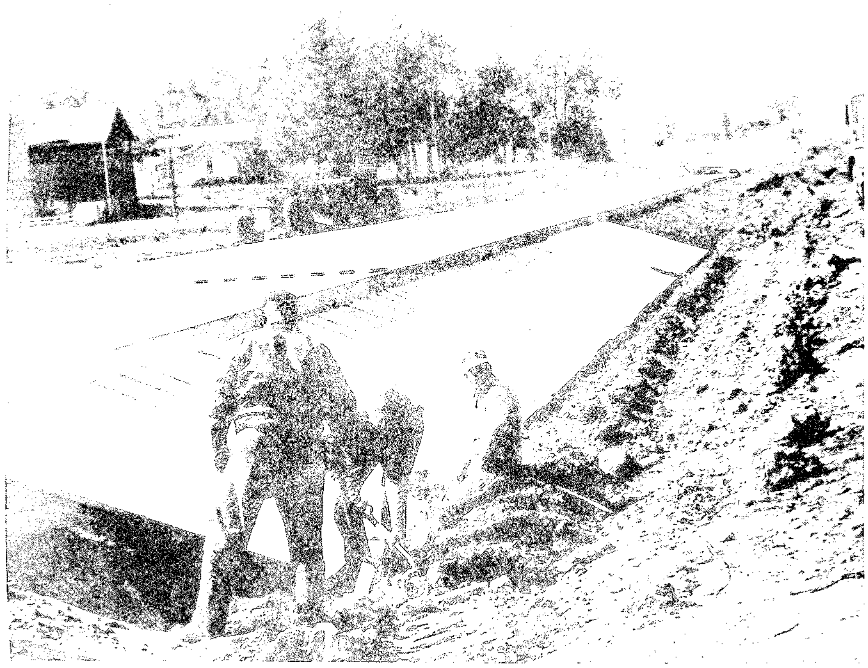


Photo 7: Styrofoam being placed on the 2:1 Slope in the Shoulder.

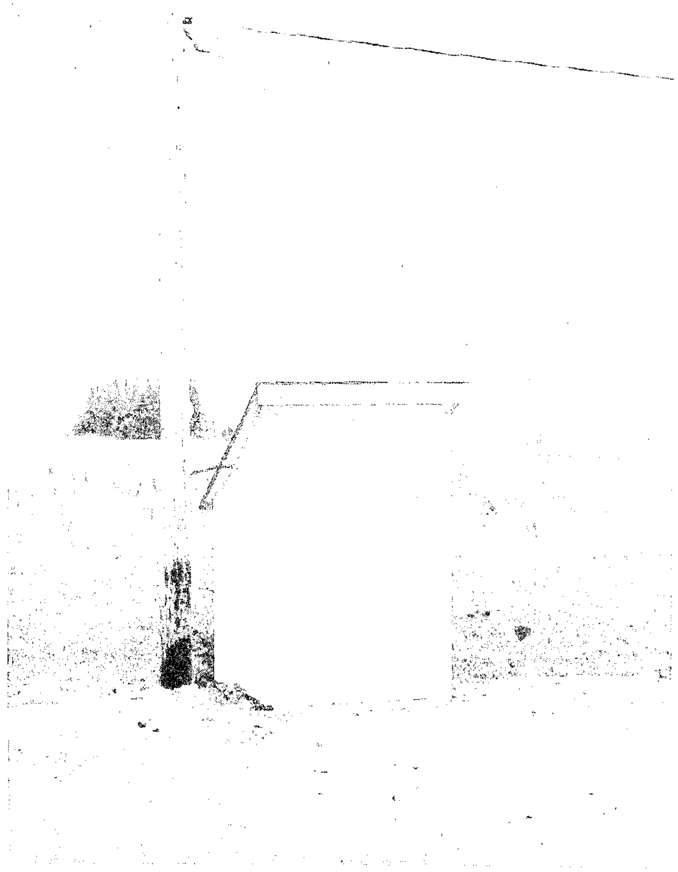


Photo 8: Housing for the temperature recording device.

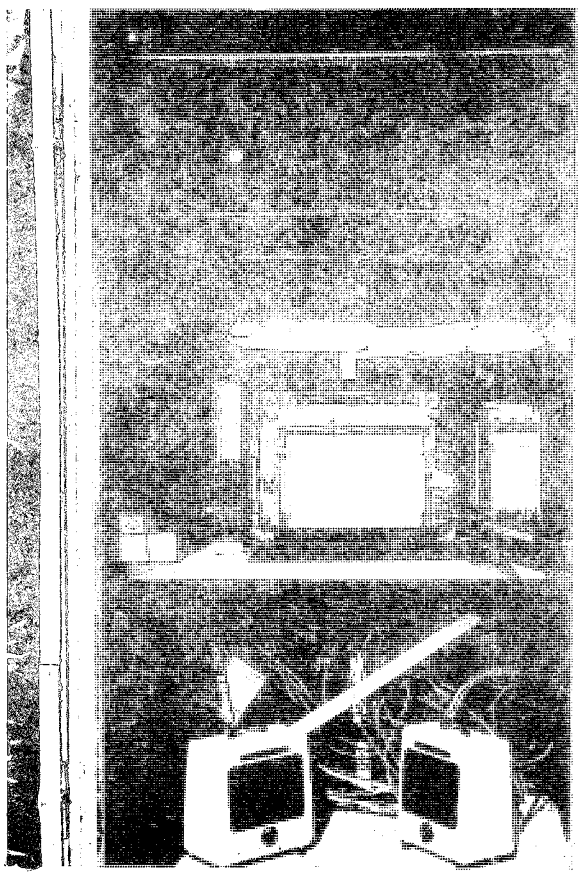


Photo 9: Interior of temperature recording installation. Recording potentiometer above, two electrical heaters below.

Table 1

Physical Properties of Styrofoam Scorbord SM

	ASTM Test Method	1" Thick	2" Thick
Density, #/ft. 3		2.7	2.3
Tensile Strength, psi.	D1623-59T	56	52
Ultimate Elongation, %	D1623-59T	2.3	2.5
Tensile Modulus, psi.	D1623-59T	2490	1990
Compressive Strength at 5% Deformation, psi.	D 621-59T	31	48
Compressive Modulus, psi.	D1621-59T	876	1900
Flexural Strength, psi.	C203-58	96	114
Deflection at Break, in.	C203-58	0.57	0.62
Flexural Modulus, psi.	C203-58	3830	2750
Shear Strangth, psi.	C273-53	42	25
Shear Modulus, psi.	C273-53	--	652

1. Tensile properties were obtained at a crosshead speed of 0.05"/min. for 1" specimens and at 0.1"/min. for 2" specimens, using respectively 1" and 2" jaw span.

2. Compressive properties were obtained at a crosshead speed of 0.1"/min./ 1" of specimen thickness.

3. Flexural properties obtained at a crosshead speed of 0.5"/min. for 1" specimens and 1.0"/min. for 2" specimens using a 10" span.

4. Shear properties obtained at 0.05"/min. crosshead speed.

TABLE 2

CENTERLINE PROFILE ELEVATION

Sta.	Before Resurfacing			After Resurfacing		
	Dec. '63	Feb. '64	May '64	Dec. '64	Apr. '65	May '65
600+00	99.87	99.93	99.83	100.08	100.15	100.07
+33	Begin	Granular	Backfill			
+40	99.99	100.05	99.97	100.21	100.32	100.23
+60	100.15	100.17	100.12	100.36	100.43	100.38
+80	100.32	100.35	100.31	100.55	100.60	100.57
601+00	100.49	100.51	100.48	100.71	100.76	100.73
+20	100.63	100.64	100.62	100.88	100.90	100.88
+40	100.79	100.80	100.78	101.02	101.06	101.03
+60	100.93	100.95	100.92	101.18	101.21	101.27
+80	101.09	101.13	101.08	101.34	101.36	101.33
602+00	101.23	101.27	101.24	101.50	101.51	101.48
+20	101.36	101.39	101.36	101.62	101.64	101.62
+33	End Granular - Begin Styrofoam					
+40	101.47	101.48	101.47	101.75	101.75	101.73
+60	101.62	101.64	101.62	101.90	101.90	101.88
+80	101.76	101.78	101.77	102.04	102.04	102.03
603+00	101.92	101.95	101.93	102.22	102.21	102.21
+20	102.12	102.14	102.11	102.38	102.40	102.38
+40	102.28	102.30	102.28	102.54	102.56	102.55
+60	102.44	102.46	102.44	102.70	102.72	102.71
+80	102.58	102.60	102.58	102.85	102.87	102.85

(Table Continued On Next Page)

TABLE 2 (Continued)

CENTERLINE PROFILE ELEVATION

Sta.	Before Resurfacing			After Resurfacing		
	Dec. '63	Feb. '64	May '64	Dec '64	Apr. '65	May '65
604+00	102.73	102.74	102.73	102.98	103.02	102.99
+20	102.85	102.87	102.86	103.12	103.15	103.11
+40	103.00	103.02	103.00	103.25	103.30	103.26
+60	103.16	103.18	103.17	103.41	103.45	103.42
+80	103.34	103.37	103.34	103.60	103.65	103.63
+85	End	Styrof	oam			
605+00	103.56	103.66	103.55	103.80	103.88	103.80
+20	103.73	103.83	103.72	103.99	104.06	103.99
+40	103.92	103.99	103.90	104.18	104.24	104.18
606+00	104.50	104.58	104.49	104.76	104.81	104.78

Average Change Per Section

Section	Dec. '63 to Feb. '64	Feb. '64 to May '64	Dec '64 to Apr '65	Apr. '65 to May '65
Granular	+0.028'	-0.038'	+0.030'	-0.029'
Styrofoam	+0.020'	-0.018'	+0.019'	-0.018'
Outside Test Section	+0.082'	-0.096'	+0.065'	-0.059'

TABLE 3

SUBGRADE MOISTURE CONTENT

Depth Inches	6 Ft. Lt. of CL Under Slab % Moisture Apr. '64	6 Ft. Lt. of CL Under Slab % Moisture May '65	6 Ft. Rt. of CL Under Slab % Moisture Apr. '64	6 Ft. Rt. of CL Under Slab % Moisture May '65	14 Ft. Rt. of CL In Shoulder % Moisture Apr. '64	14 Ft. Rt. of CL In Shoulder % Moisture May '65
Station 601+00 (No Styrofoam)						
0- 6	5.7	6.9	4.7	7.0	21.0	17.7
6-12	4.6	4.1	5.1	5.8	10.0	13.4
12-18	4.5	3.5	4.2	4.2	6.0	5.9
18-24	5.1	4.9	---	4.8	5.9	5.3
24-30	---	---	---	---	6.7	6.6
30-36	---	---	---	---	7.9	7.6
Station 602+00 (No Styrofoam)						
0- 6	5.7	6.2	5.8	5.9	14.0	12.6
6-12	5.7	5.4	5.9	5.6	8.0	11.2
12-18	4.9	4.7	5.4	5.4	5.6	10.9
18-24	4.9	4.7	---	5.6	5.3	5.2
24-30	---	---	---	---	5.6	13.9
30-36	---	---	---	---	7.1	9.4
36-42	---	---	---	---	11.2	6.6
Station 603+50 (Styrofoam Only)						
0- 6	---	---	10.0	13.5	17.3	17.7
6-12	---	---	15.0	14.7	18.5	20.5
12-19	---	---	16.2	15.0	11.9	15.5

(Table Continued On Next Page)

TABLE 3 (Continued)

SUBGRADE MOISTURE CONTENT

Station 603+50 (Styrofoam Only) (Cont.)						
Depth	6 Ft. Lt. of CL Under Slab		6 Ft. Rt. of CL Under Slab		14 Ft. Rt. of CL In Shoulder	
	% Moisture		% Moisture		% Moisture	
Inches	Apr. '64	May '65	Apr. '64	May '65	Apr. '64	May '65
19-25	---	---	---	---	14.1	19.0
25-31	---	---	---	---	17.1	24.0
31-37	---	---	---	---	20.4	21.9
37-43	---	---	---	---	18.5	19.3
Station 604+50 (Styrofoam Only)						
Depth			6 Ft. Rt. of CL Under Styrofoam		14 Ft. Rt. of CL In Shoulder	
			% Moisture		% Moisture	
Inches			Apr. '64	May '65	Apr. '64	May '65
0- 6			12.9	18.9	19.2	17.7
6-12			17.9	17.8	16.9	17.5
12-18			19.5	17.6	16.9	17.3
18-24			17.3	---	15.0	16.8
24-30			---	---	13.6	13.9
30-36			---	---	13.4	13.2
Station 602+50 (Styrofoam and 4 mil polyethylene)						
0- 6			10.4	14.4	---	---
6-12			14.4	14.4	---	---
12-18			15.2	14.7	---	---

(Table Continued On Next Page)

TABLE 3 (Continued)

SUBGRADE MOISTURE CONTENT

Depth Inches		6 Ft. Rt. of CL Under Styrofoam % Moisture Apr. '64	6 Ft. Rt. of CL Under Styrofoam % Moisture May '65	14 Ft. Rt. of CL In Shoulder % Moisture Apr. '64	14 Ft. Rt. of CL In Shoulder % Moisture May '65
Station 602+90 (Styrofoam and 4 mil polyethylene)					
0- 6		14.6	15.0	---	---
6-12		16.7	16.2	---	---
12-18		16.4	15.0	---	---
Station 603+90 (Styrofoam Only)					
0- 6		14.6	15.5	---	---
6-12		17.2	16.3	---	---
12-18		15.7	14.7	---	---
Station 604+20 (Styrofoam Only)					
0- 6		14.8	19.2	---	---
6-12		19.2	17.5	---	---
12-18		18.7	19.9	---	---

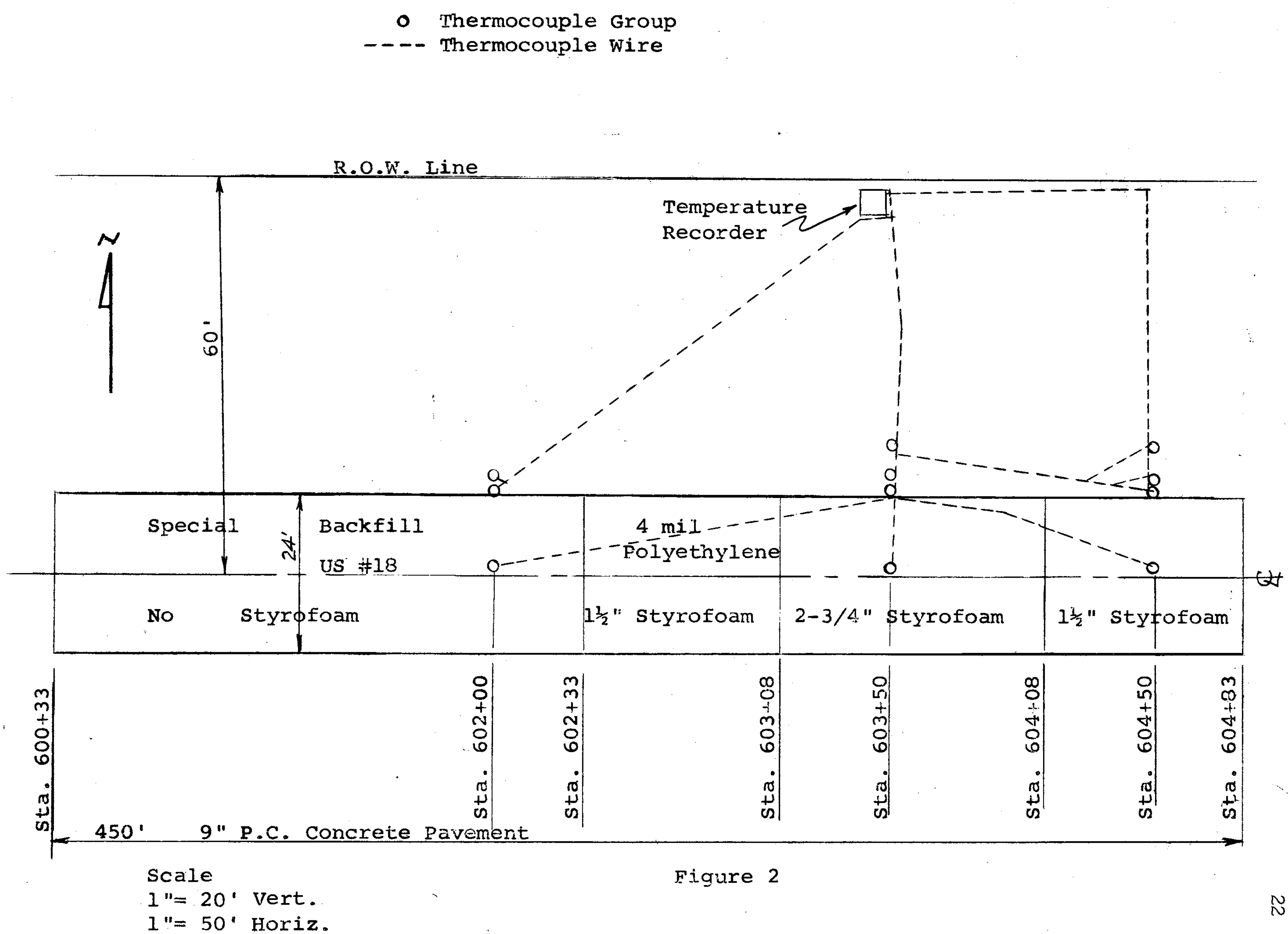
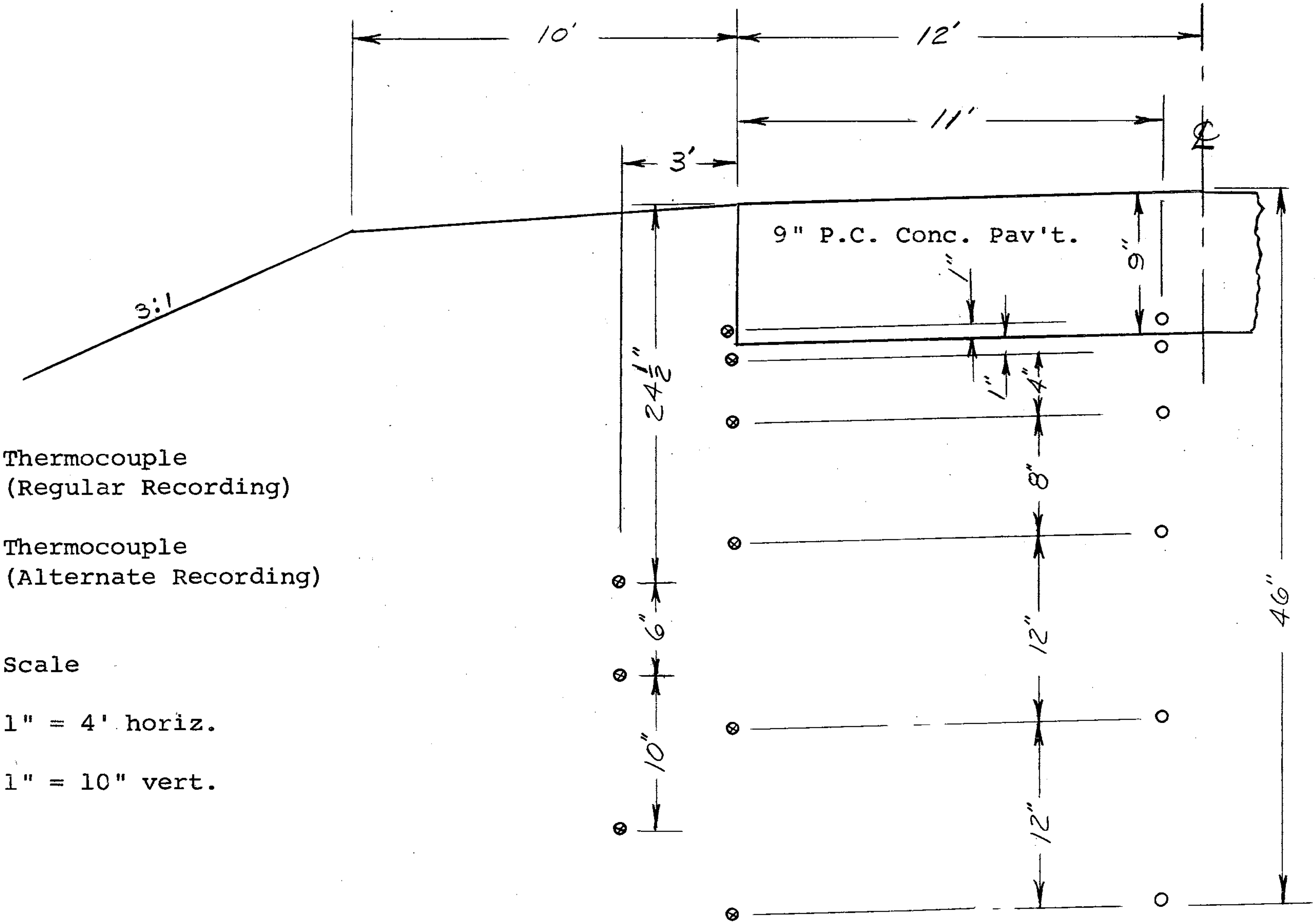

Thermocouple Group
Thermocouple Wire
R.O.W. Line
Temperature
Recorder
60'
Special Backfill
US #18
24'
4 mil
Polyethylene
No Styrofoam
1½" Styrofoam
2-3/4" Styrofoam
1½" Styrofoam
Sta. 600+33
Sta. 602+00
Sta. 602+33
Sta. 603+08
Sta. 603+50
Sta. 604+08
Sta. 604+50
Sta. 604+83
450' 9" P.C. Concrete Pavement
Scale
1"= 20' Vert.
1"= 50' Horiz.

Figure 2



o Thermocouple (Regular Recording)

⊗ Thermocouple (Alternate Recording)

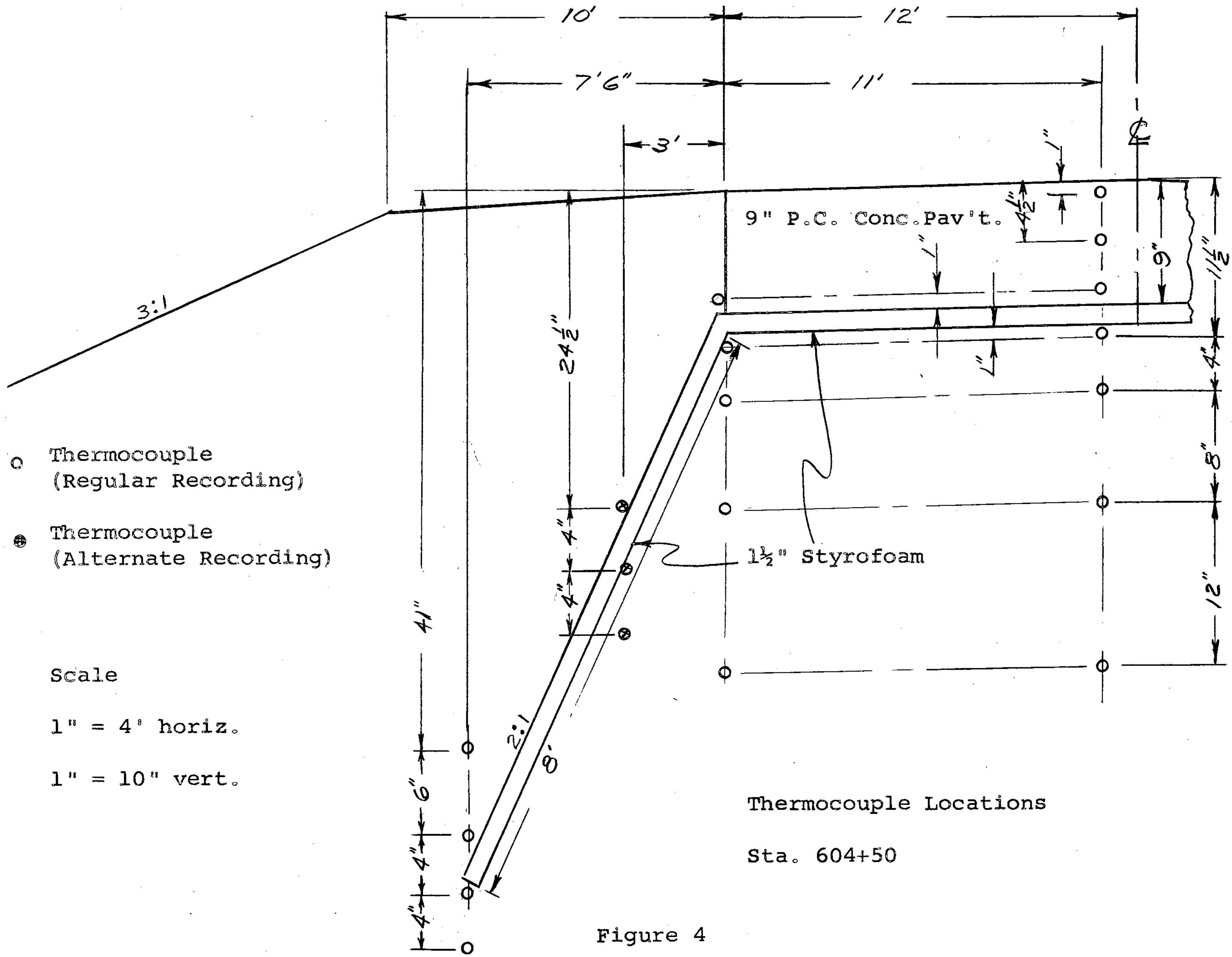
Scale

1" = 4' horiz.

1" = 10" vert.

Thermocouple Locations

Sta. 602+00 Figure 3



○ Thermocouple (Regular Recording)

⊗ Thermocouple (Alternate Recording)

Scale

1" = 4' horiz.

1" = 10" vert.

Thermocouple Locations

Sta. 604+50

Figure 4

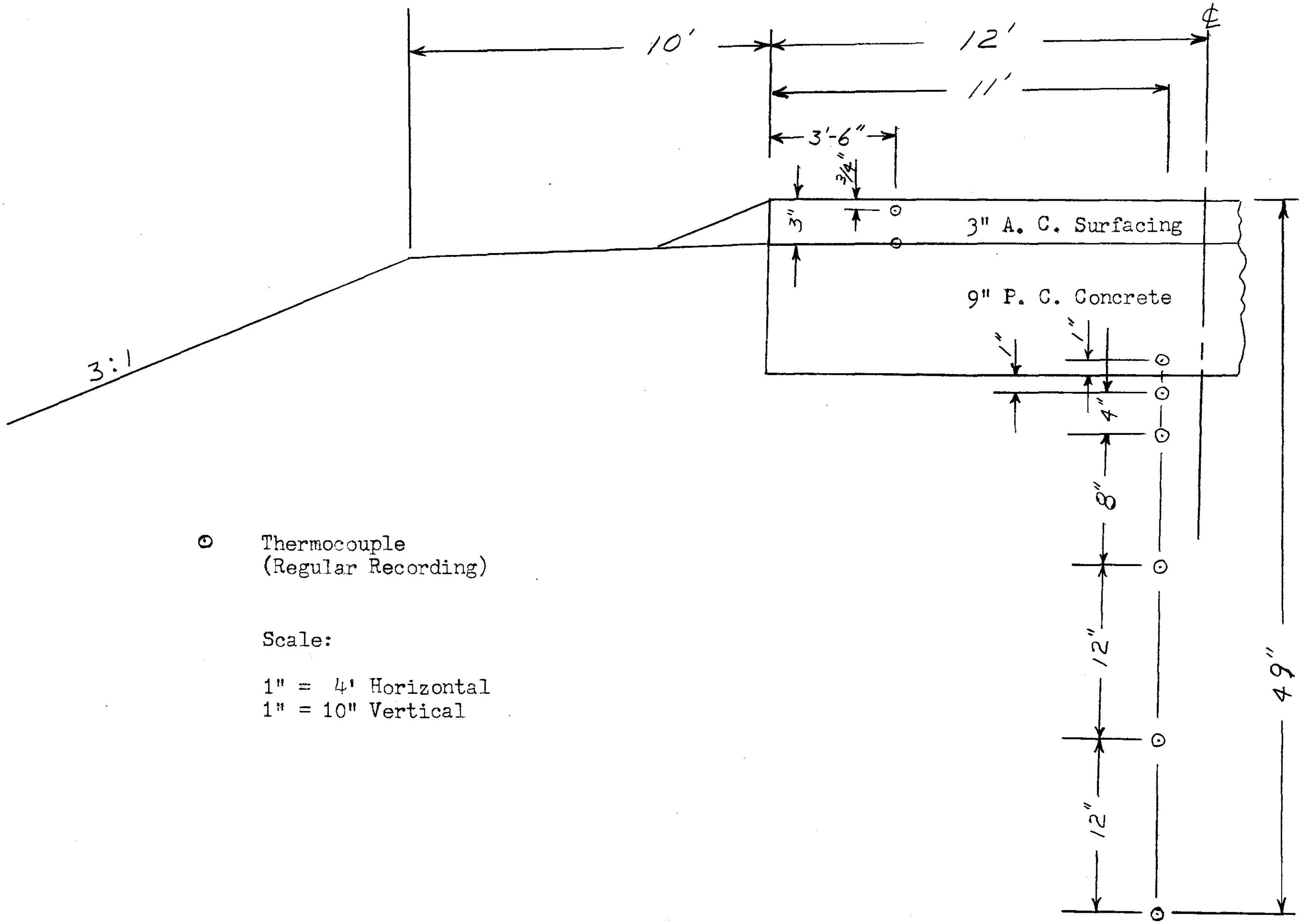


Figure 5: Thermocouple Locations Sta. 602 + 00 - Effective 5-7-65

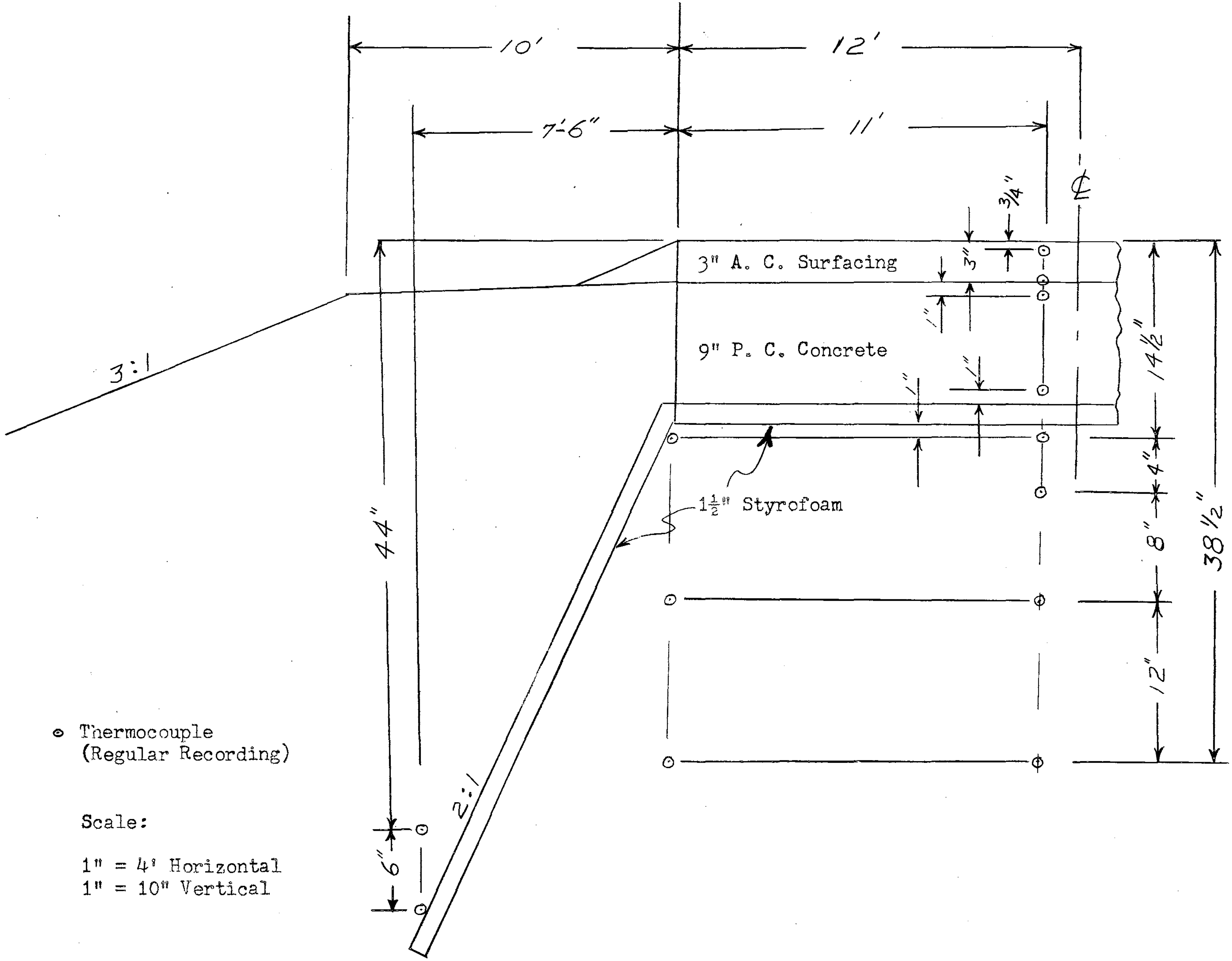


Figure 6: Thermocouple Locations Sta. 604 + 50 - Effective 5-7-65

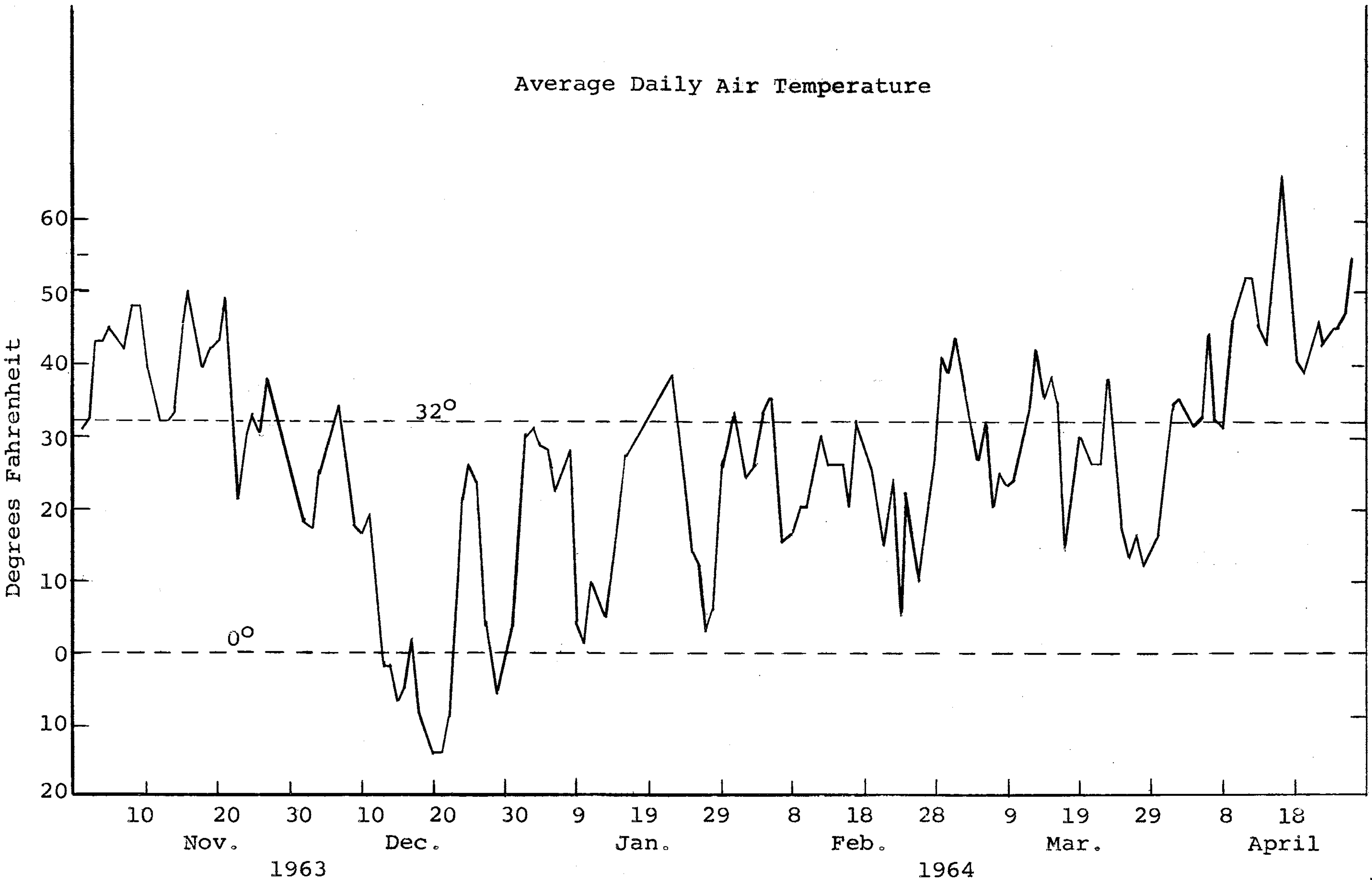
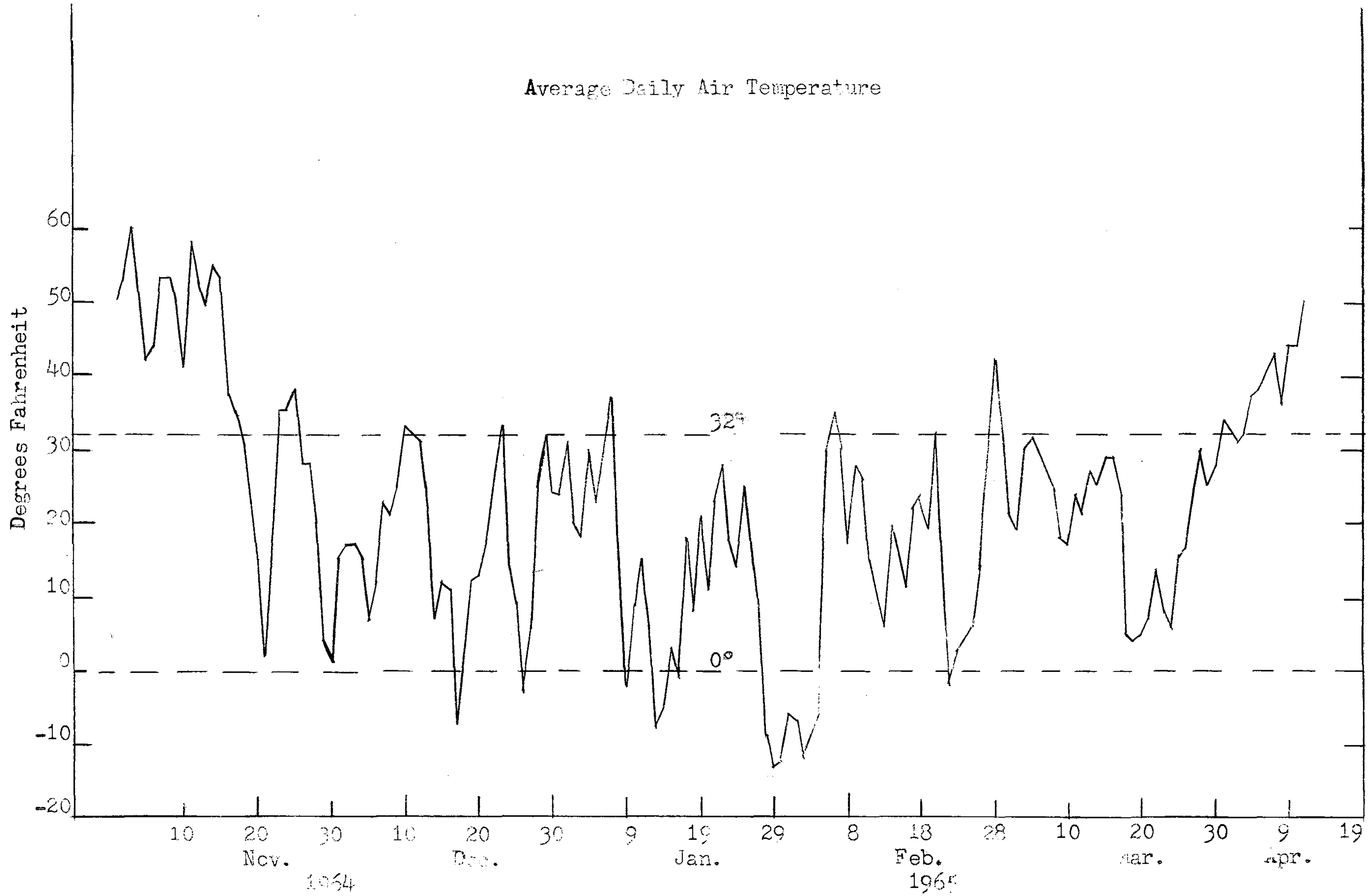
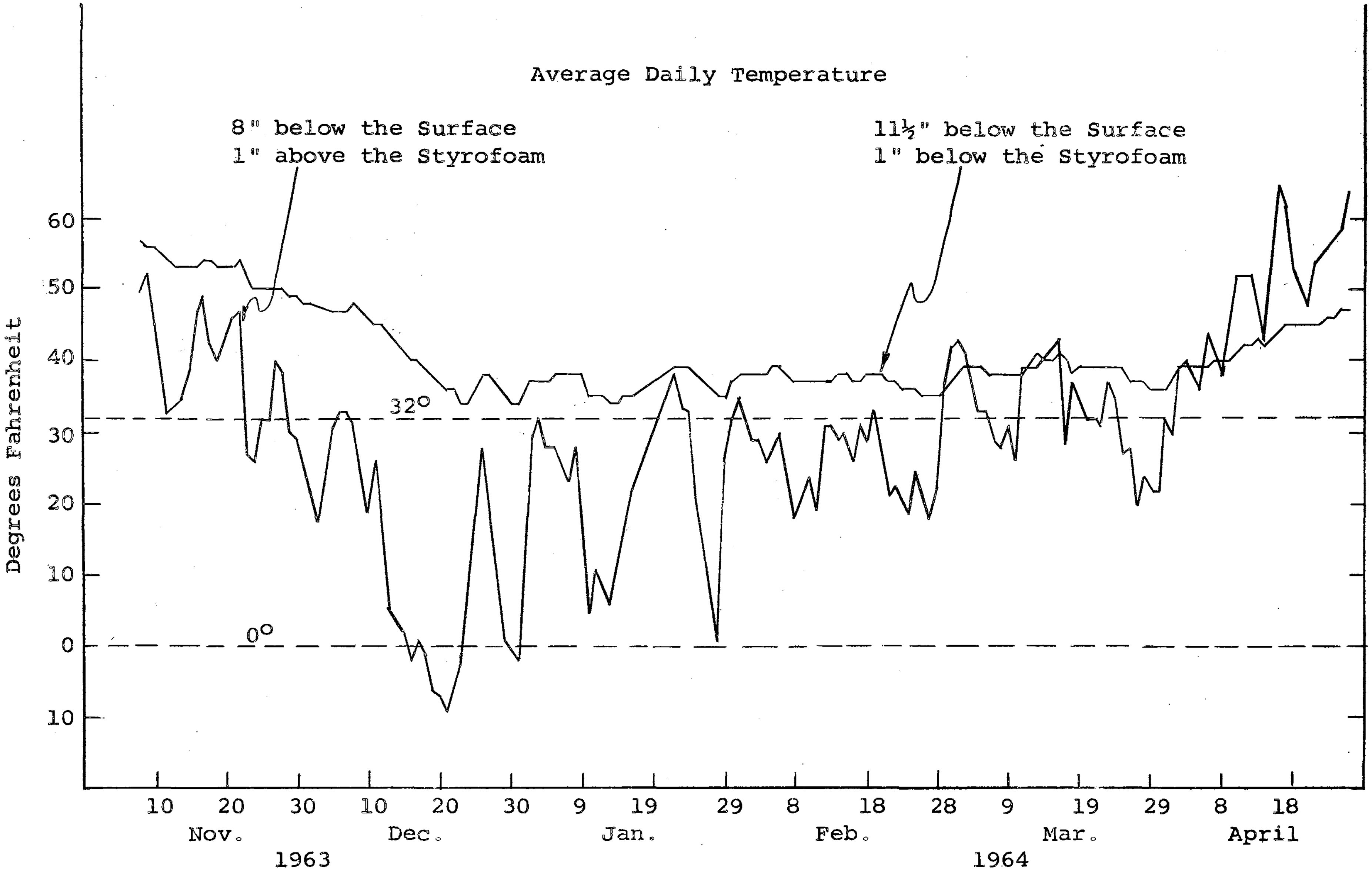

Average Daily Air Temperature
Degrees Fahrenheit
60
50
40
30
20
10
0
10
20
32°
0°
10
20
30
10
20
30
9
19
29
8
18
28
9
19
29
8
18
Nov.
Dec.
Jan.
Feb.
Mar.
April
1963
1964

Figure 7



Average Daily Air Temperature
Degrees Fahrenheit
60
50
40
30
20
10
0
-10
-20
32°
0°
10
20
30
10
20
30
9
19
29
8
18
28
10
20
30
9
19
Nov.
Jan.
Feb.
1965

Figure [illegible]



Average Daily Temperature
8" below the Surface
1" above the Styrofoam
1½" below the Surface
1" below the Styrofoam
60
50
40
30
20
10
0
10
32°
0°
Degrees Fahrenheit
10
20
30
10
20
30
9
19
29
8
18
28
9
19
29
8
18
Nov.
Dec.
Jan.
Feb.
Mar.
April
1963
1964

Figure 9

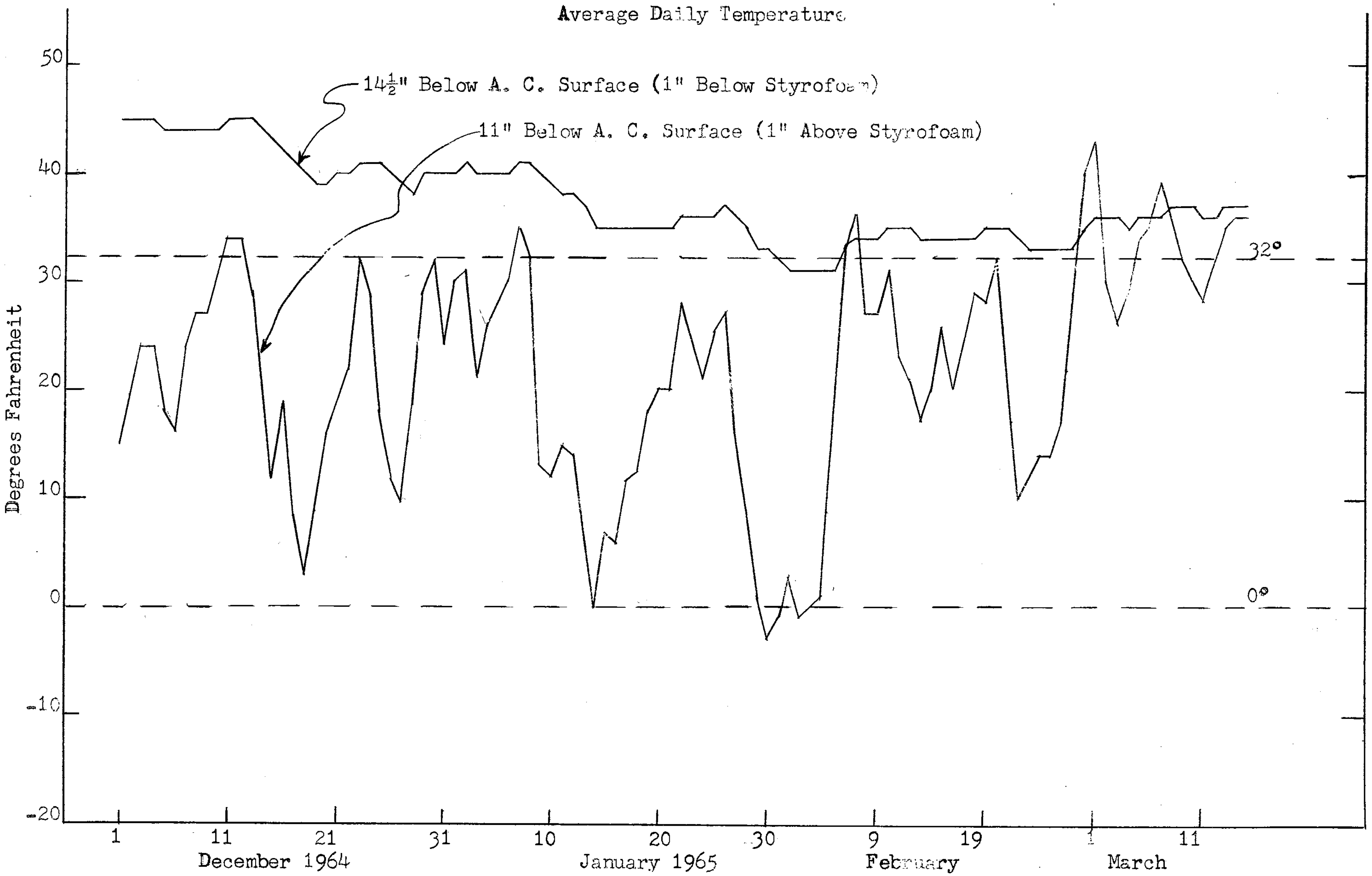

Average Daily Temperature
14½" Below A. C. Surface (1" Below Styrofoam)
11" Below A. C. Surface (1" Above Styrofoam)
Degrees Fahrenheit
50
40
30
20
10
0
-10
-20
32°
0°
1
11
21
31
10
20
30
9
19
1
11
December 1964
January 1965
February
March

Figure 10

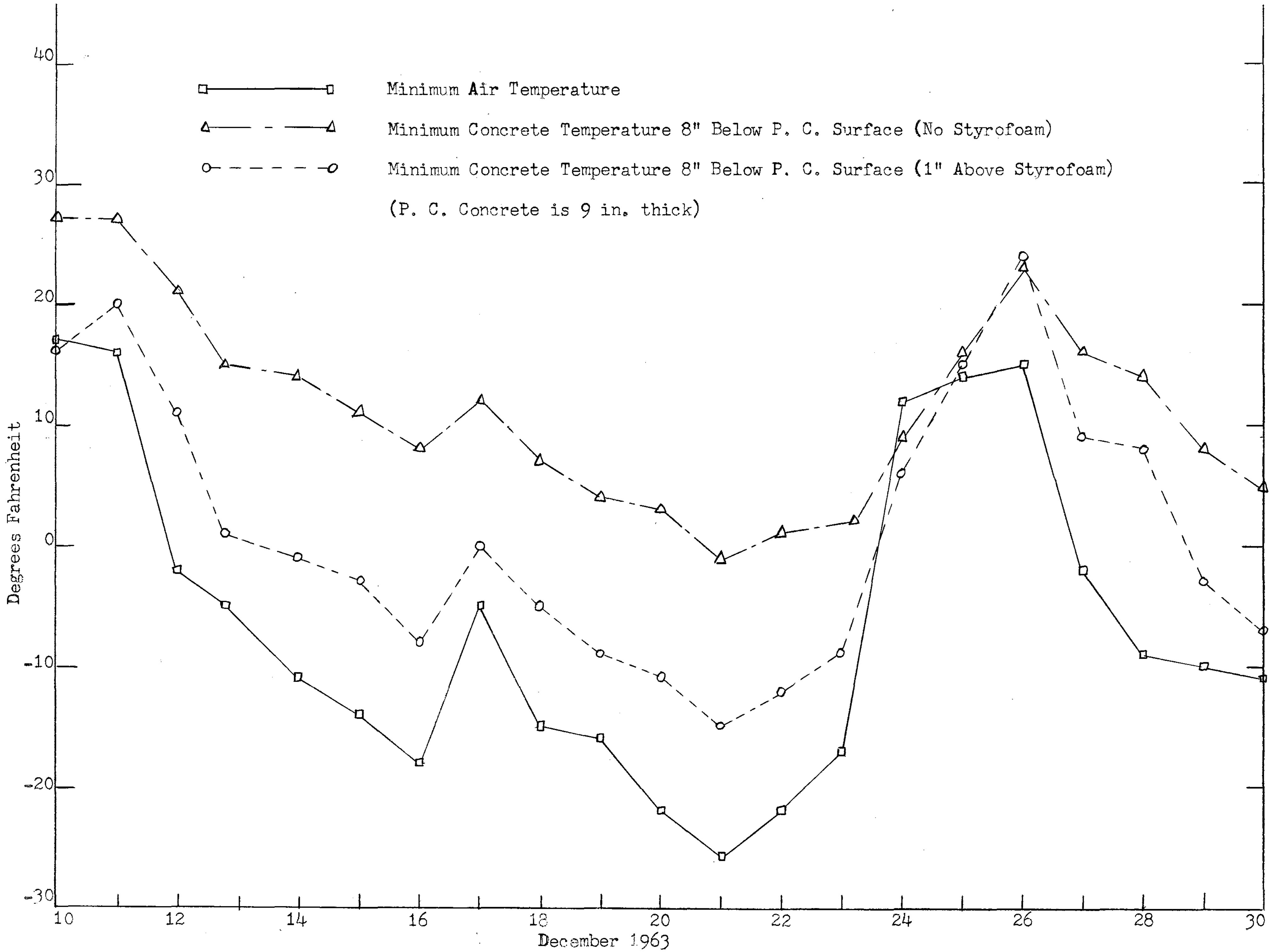


Figure 11: Concrete temperatures as affected by insulation - Winter 1963 - 1964

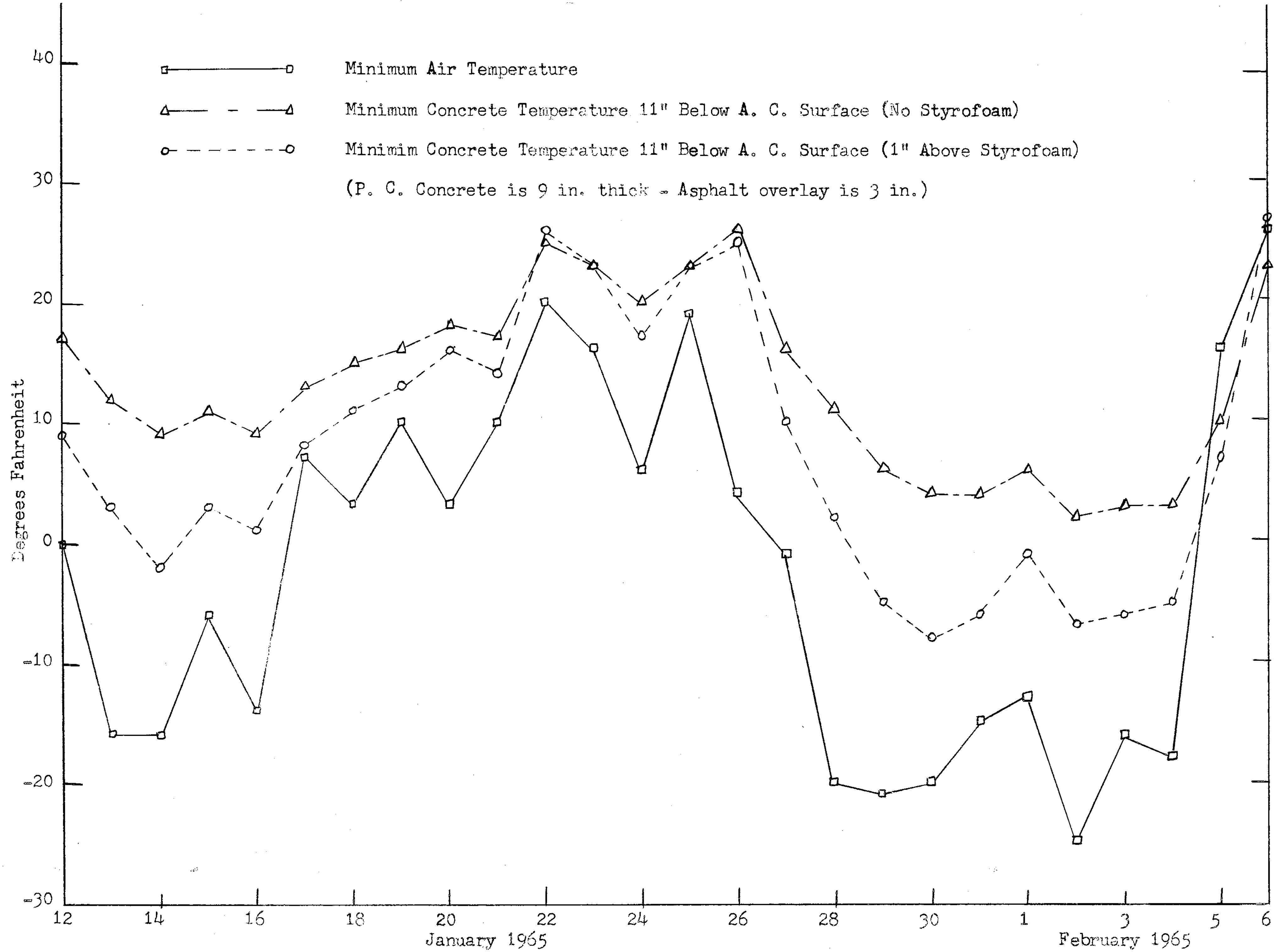


Figure 12: Concrete temperatures as affected by insulation - Winter 1964 - 1965

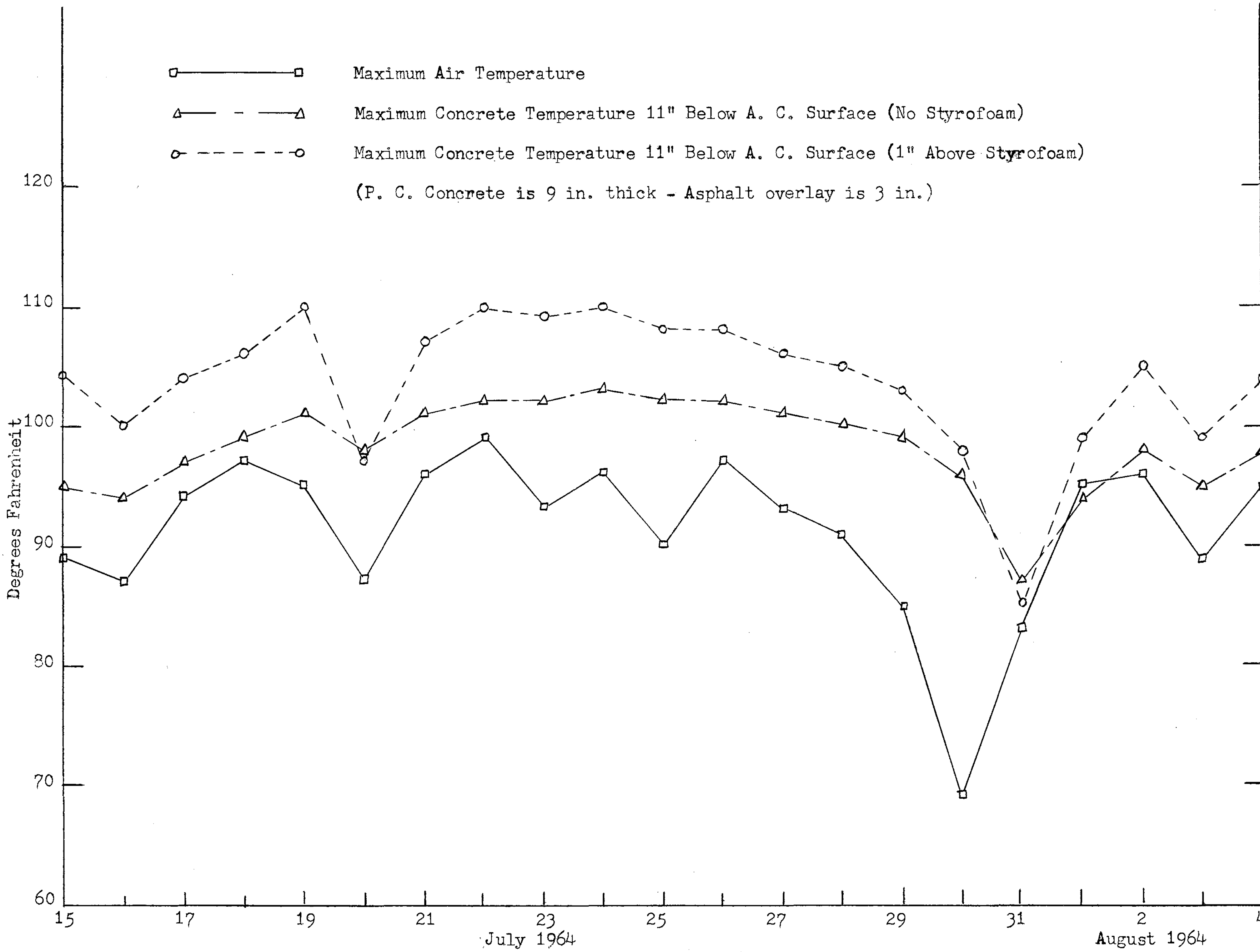


Figure 13: Concrete temperatures as affected by insulation - Summer 1964

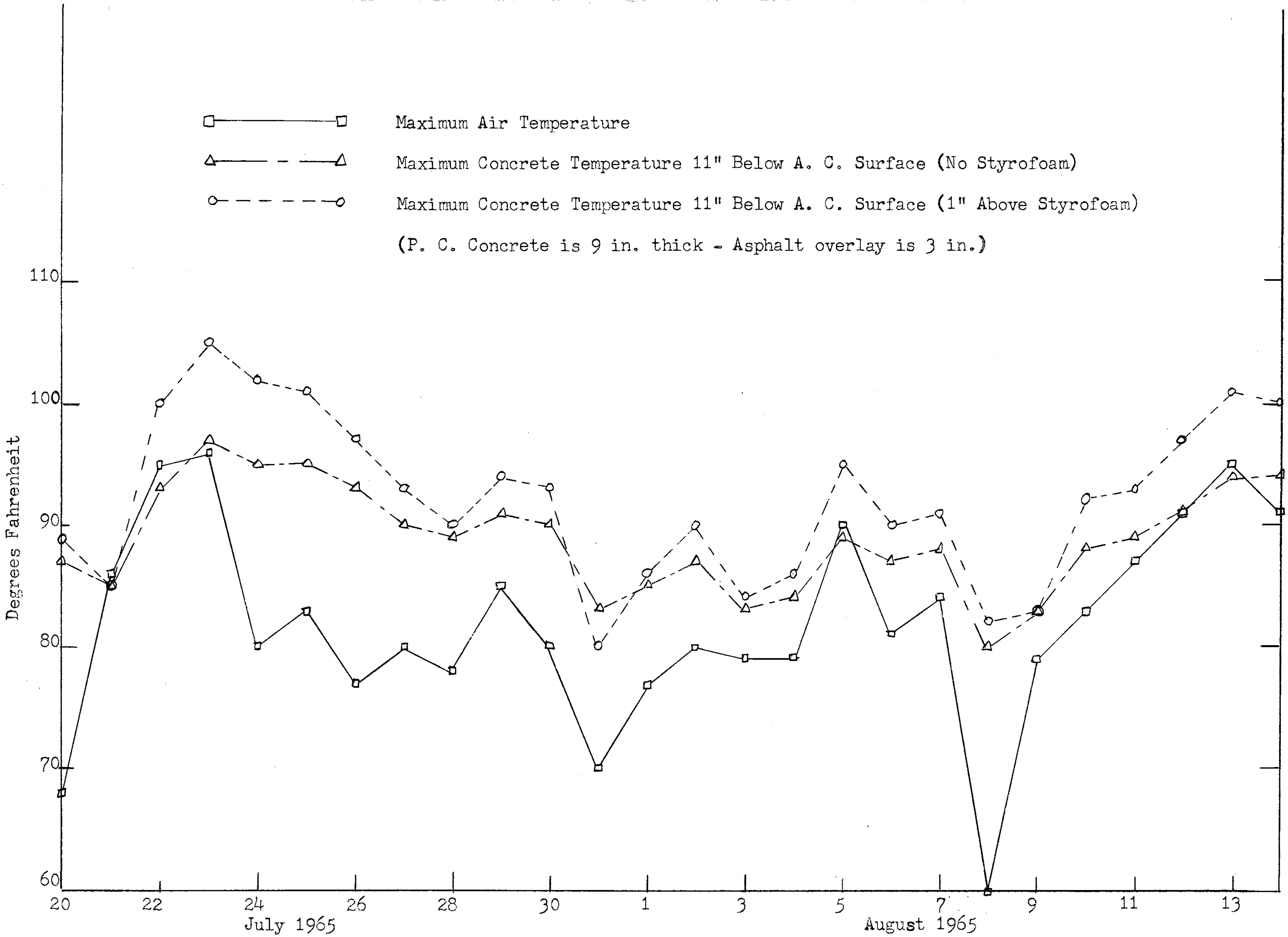


Figure 14: Concrete temperatures as affected by insulation - Summer 1965

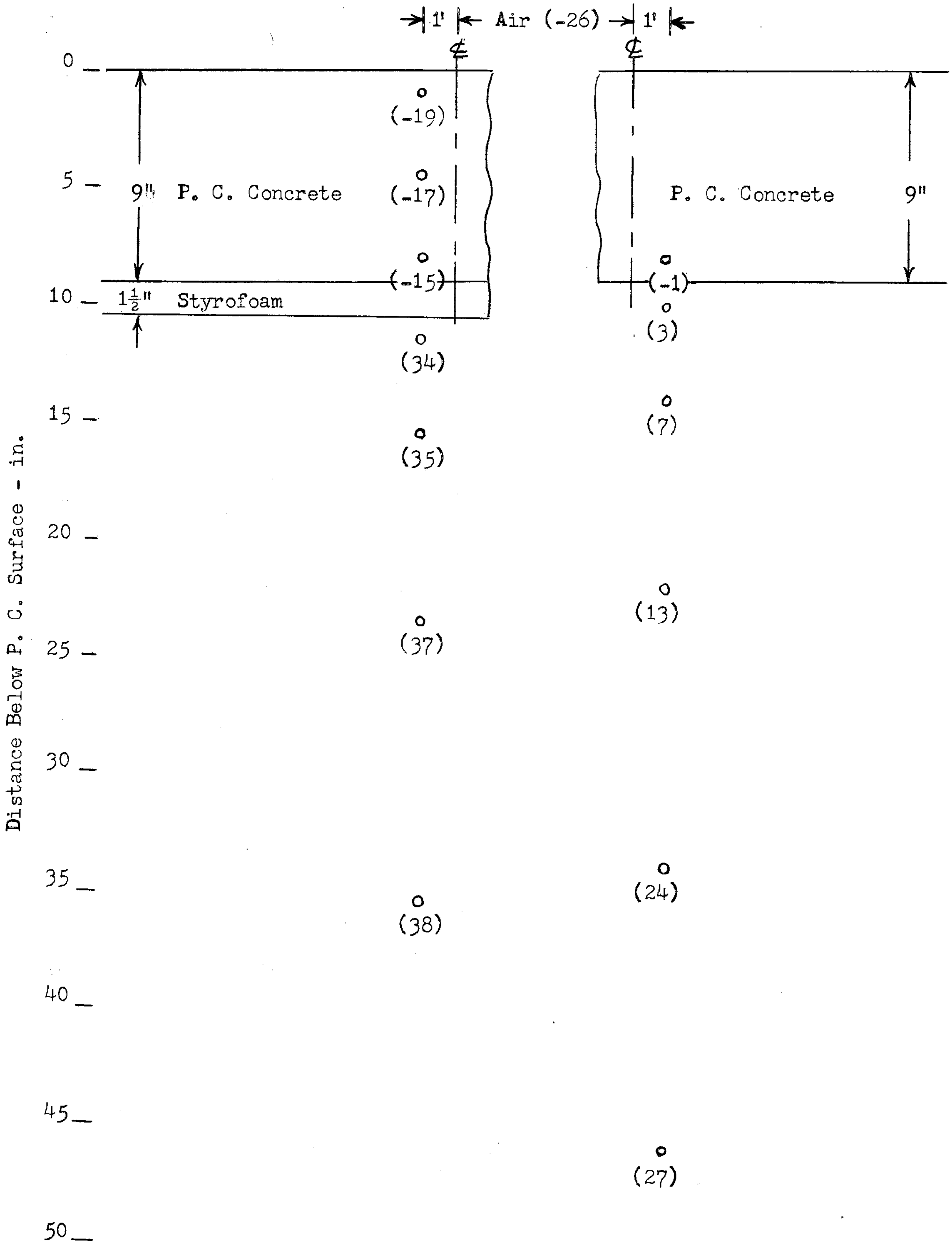


Figure 15: Minimum Temperatures °F - November 1963 - June 1964

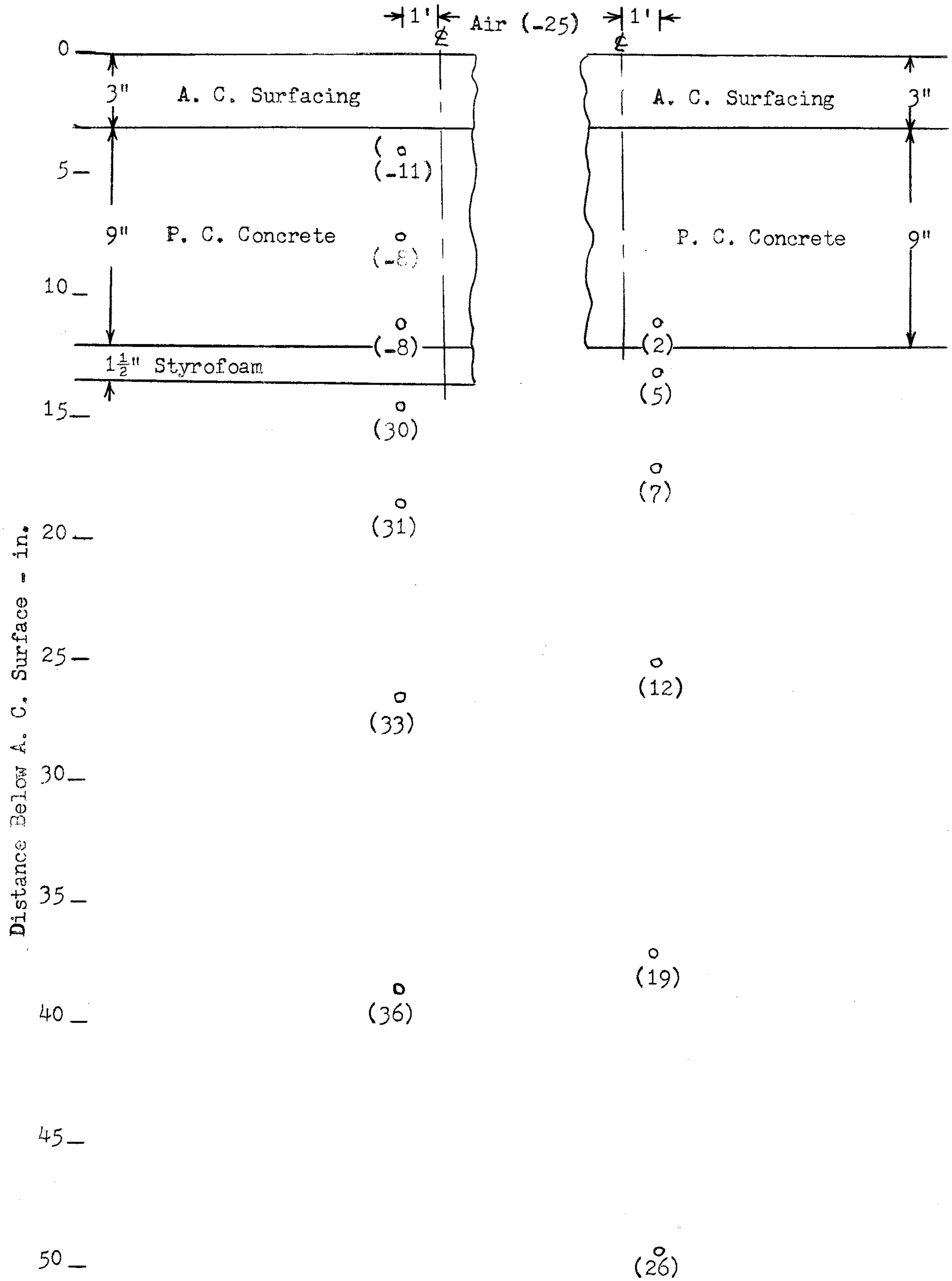


Figure 16: Minimum Temperatures °F November 1964 - May 1965

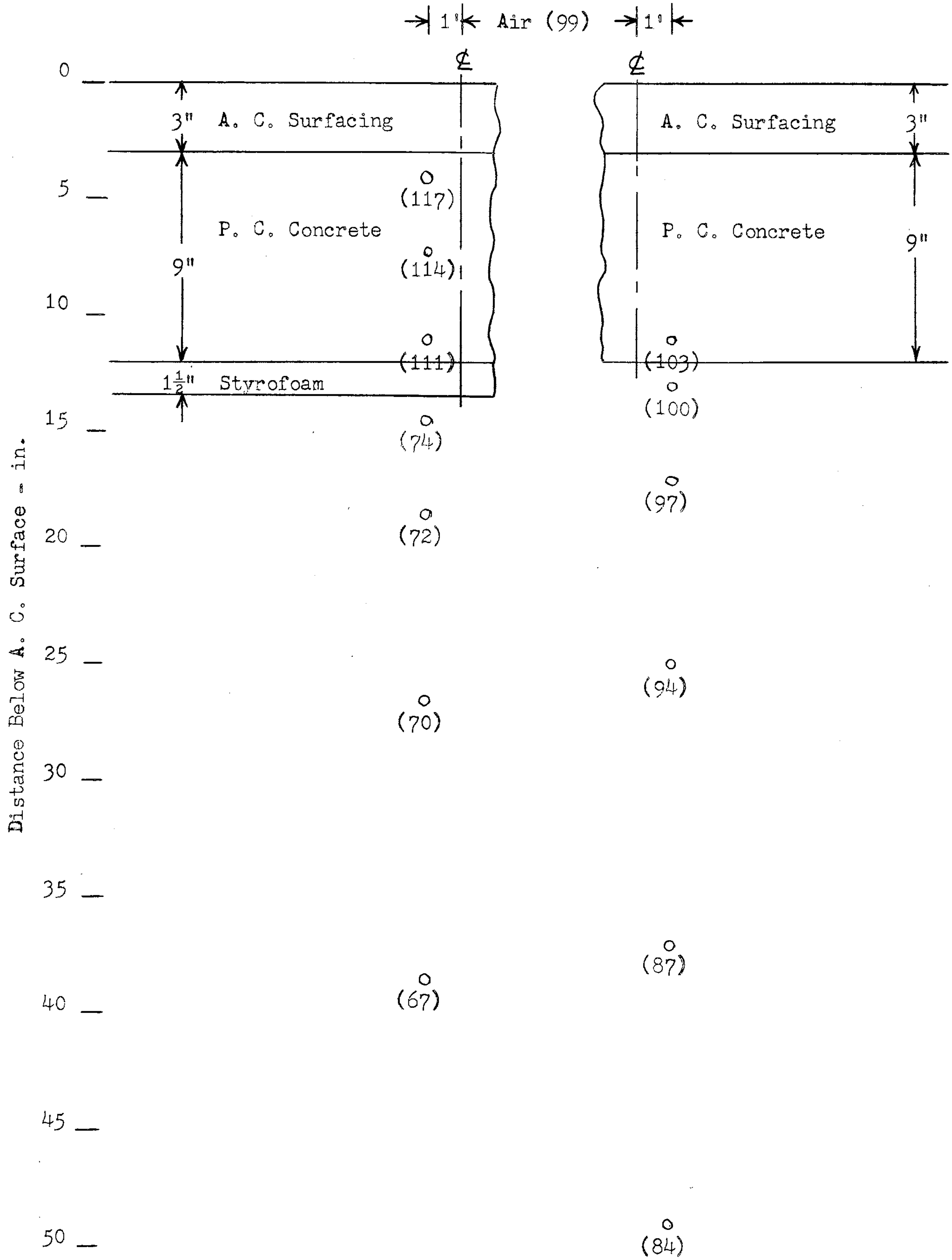


Figure 17: Maximum Temperatures °F - June 1964 - November 1964

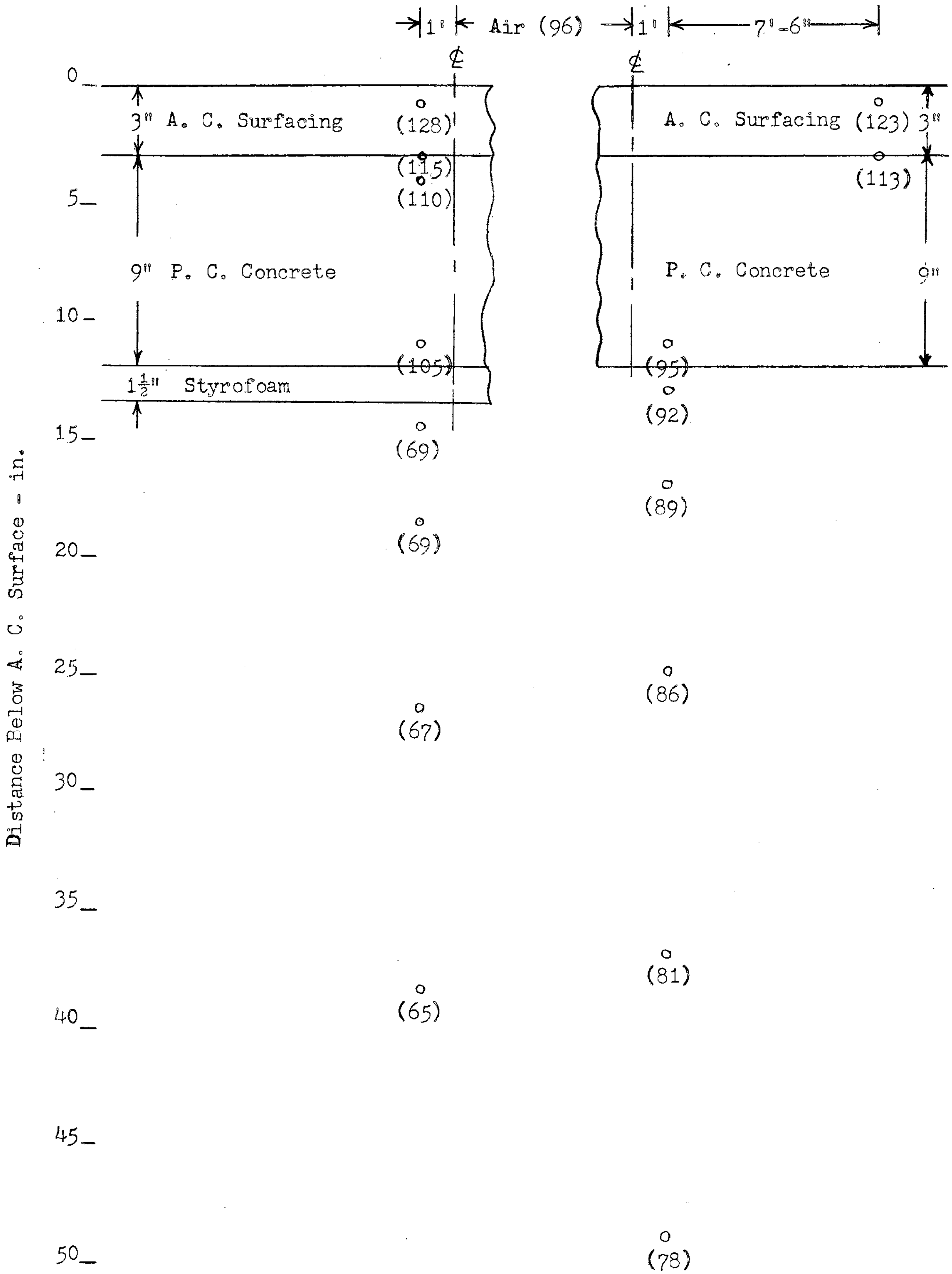


Figure 18: Maximum Temperatures °F - May 1965 - August 1965

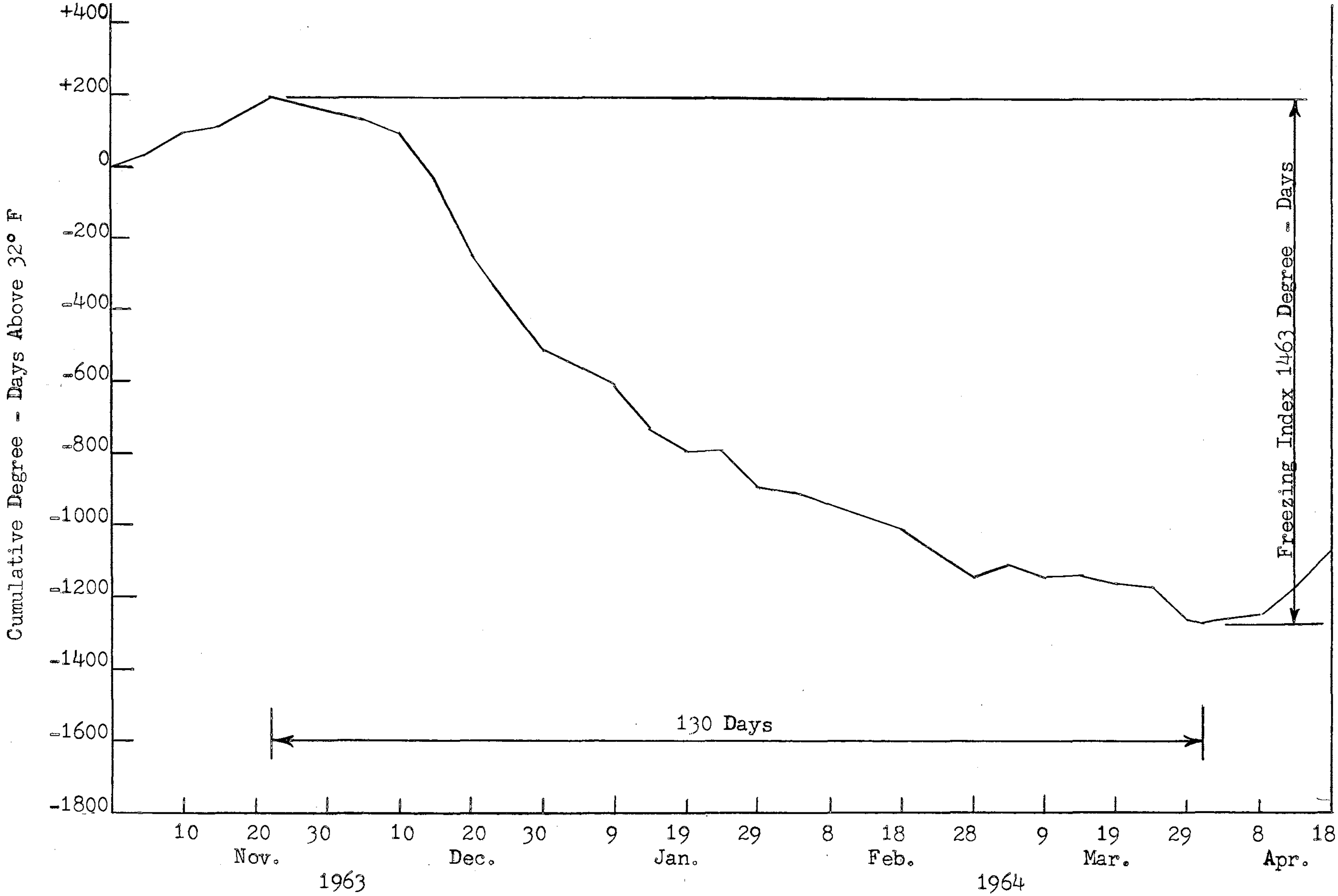


Figure 19: Determination of Freezing Index

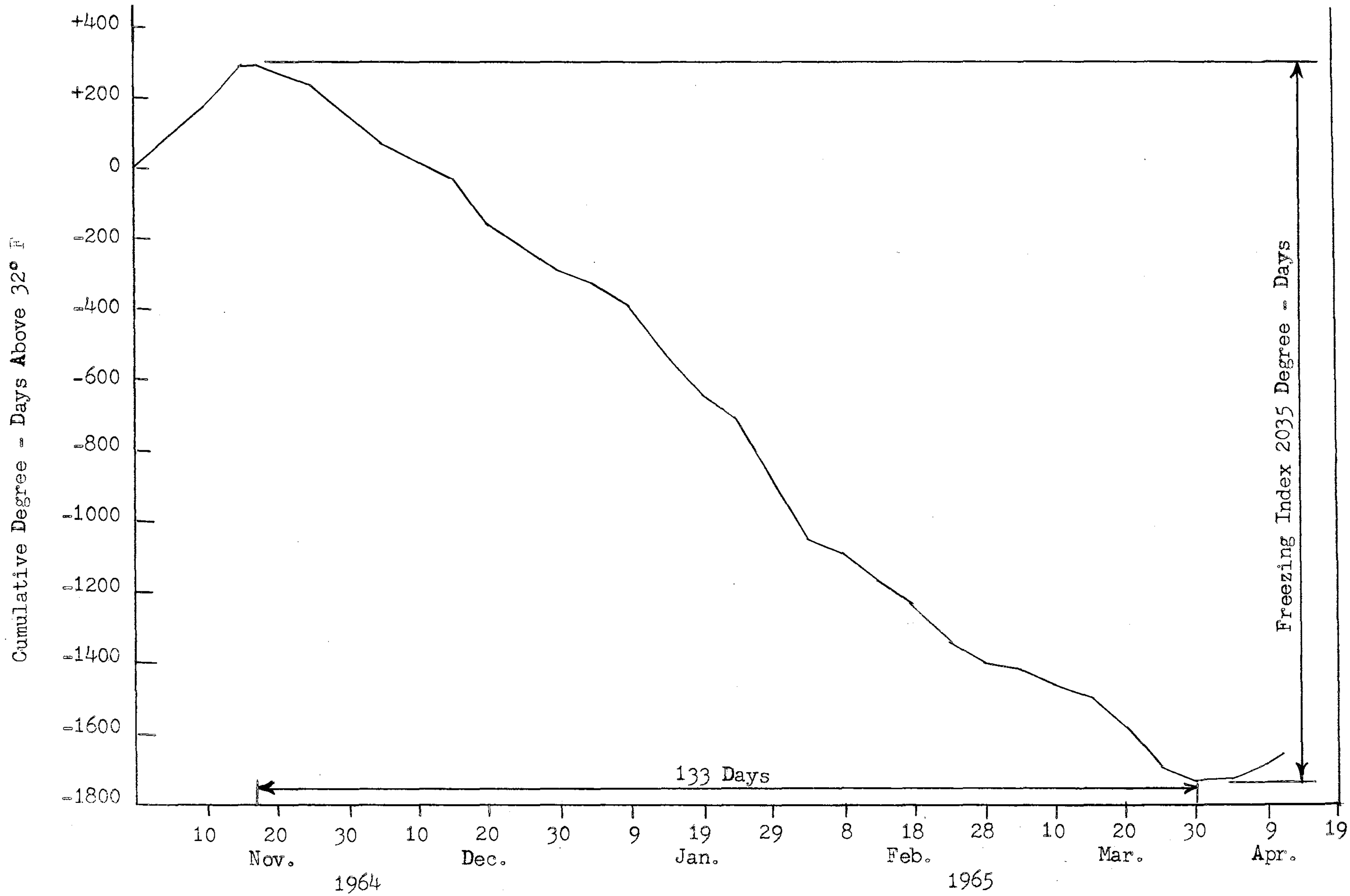


Figure 20: Determination of Freezing Index

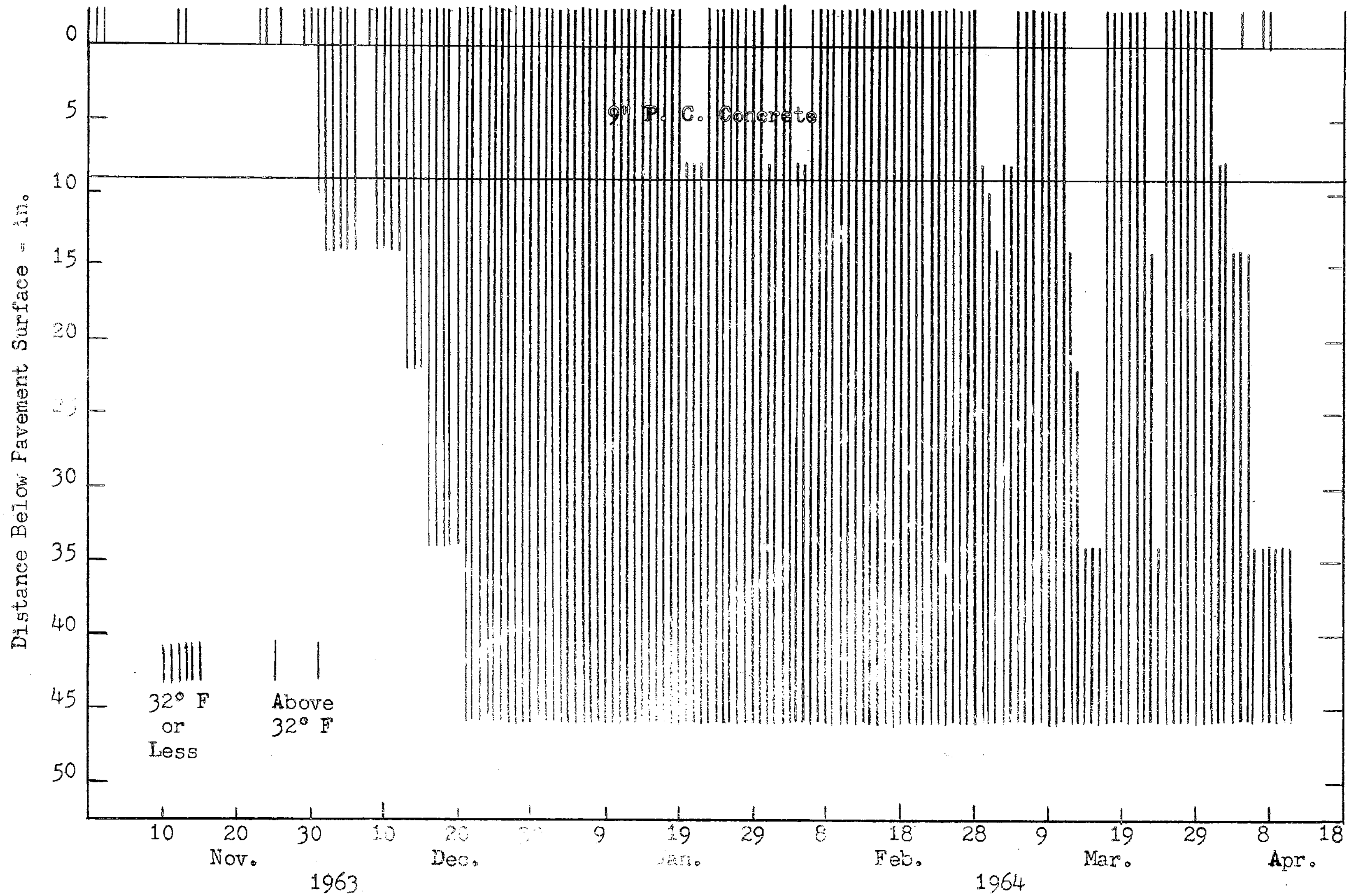


Figure 21: Depth at which average temperatures of 32° F or less were recorded

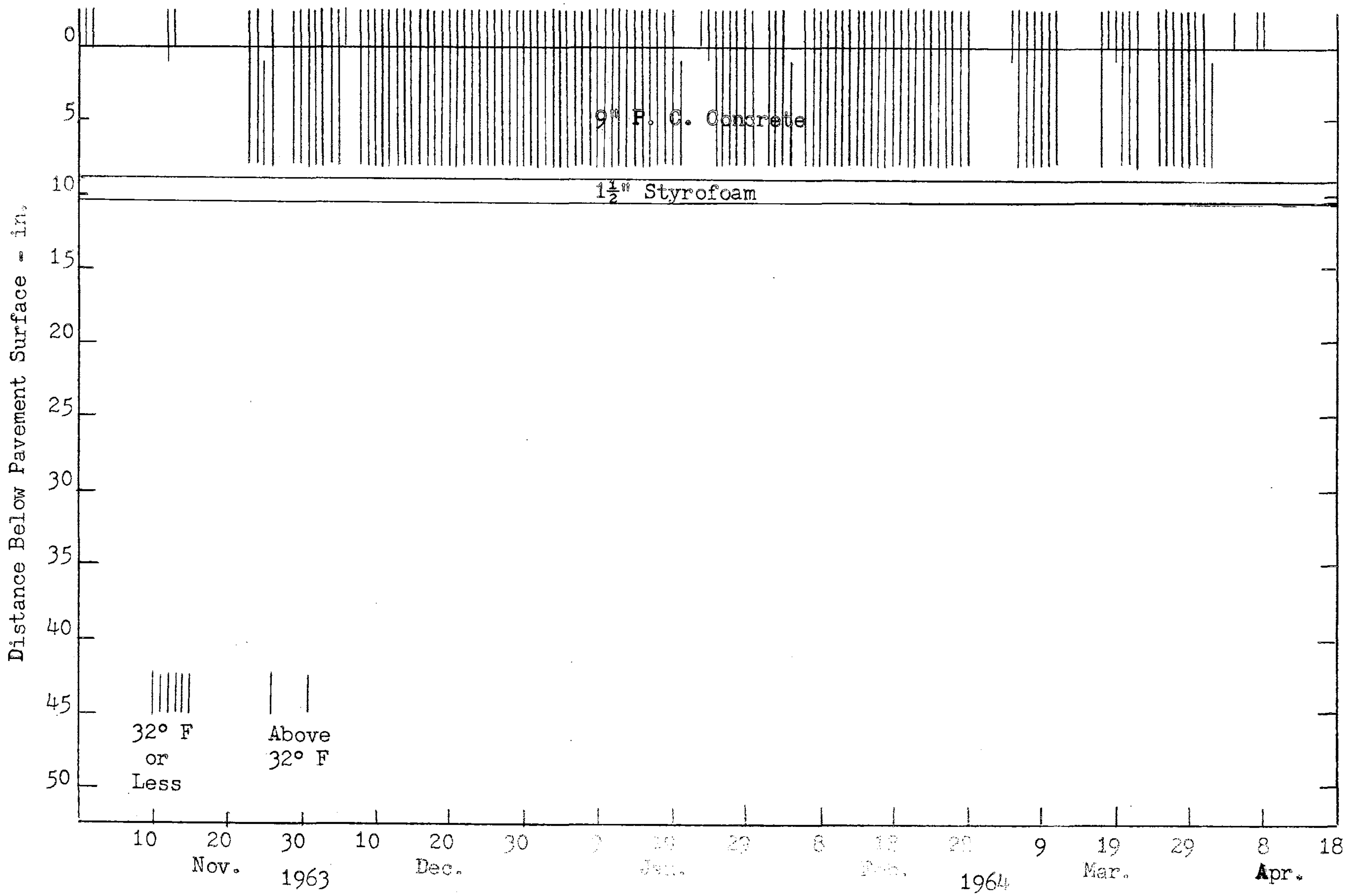


Figure 22: Depth at which average temperatures of 32° F or less were recorded

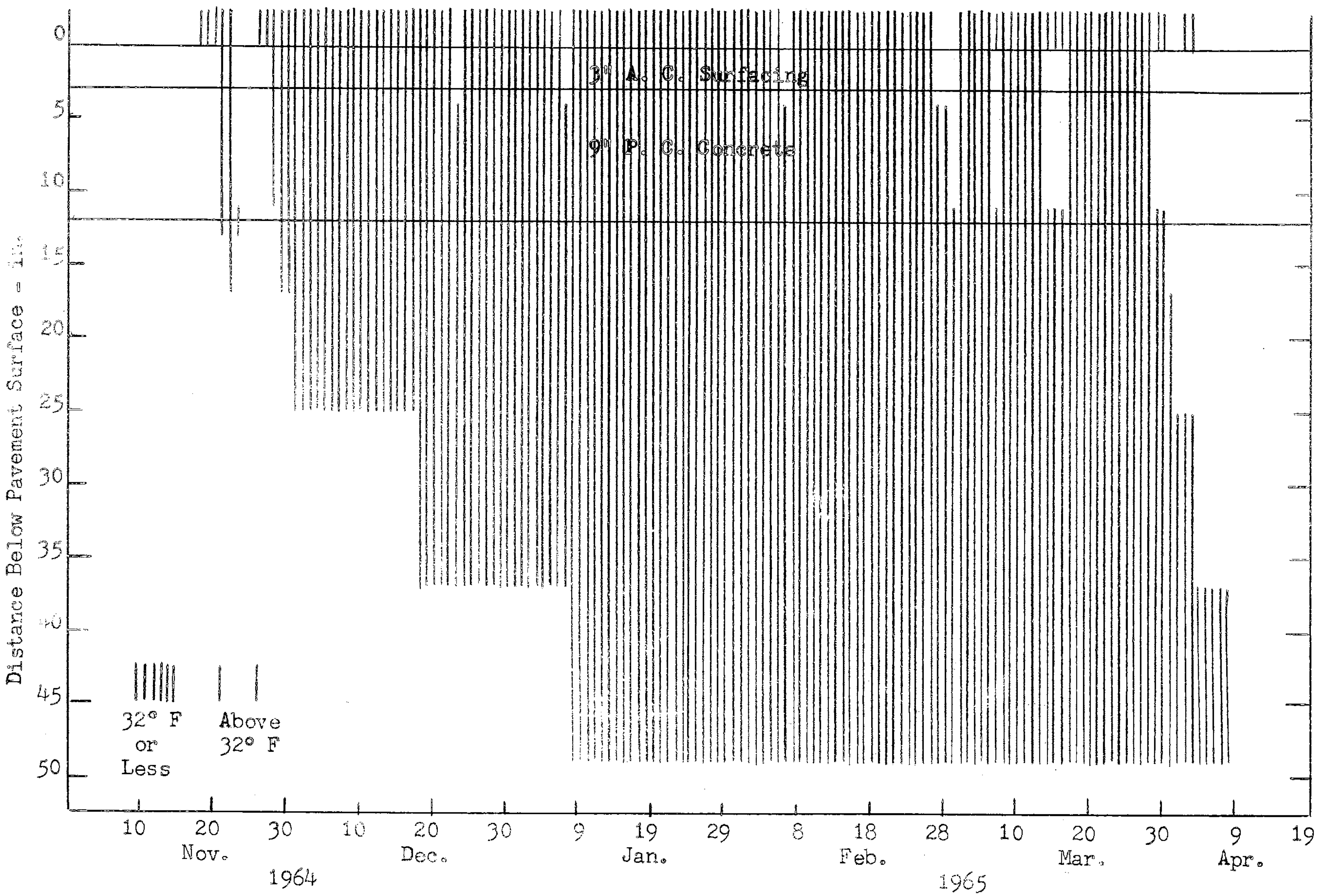


Figure 23: Depth at which average temperatures of 32° F or less were recorded

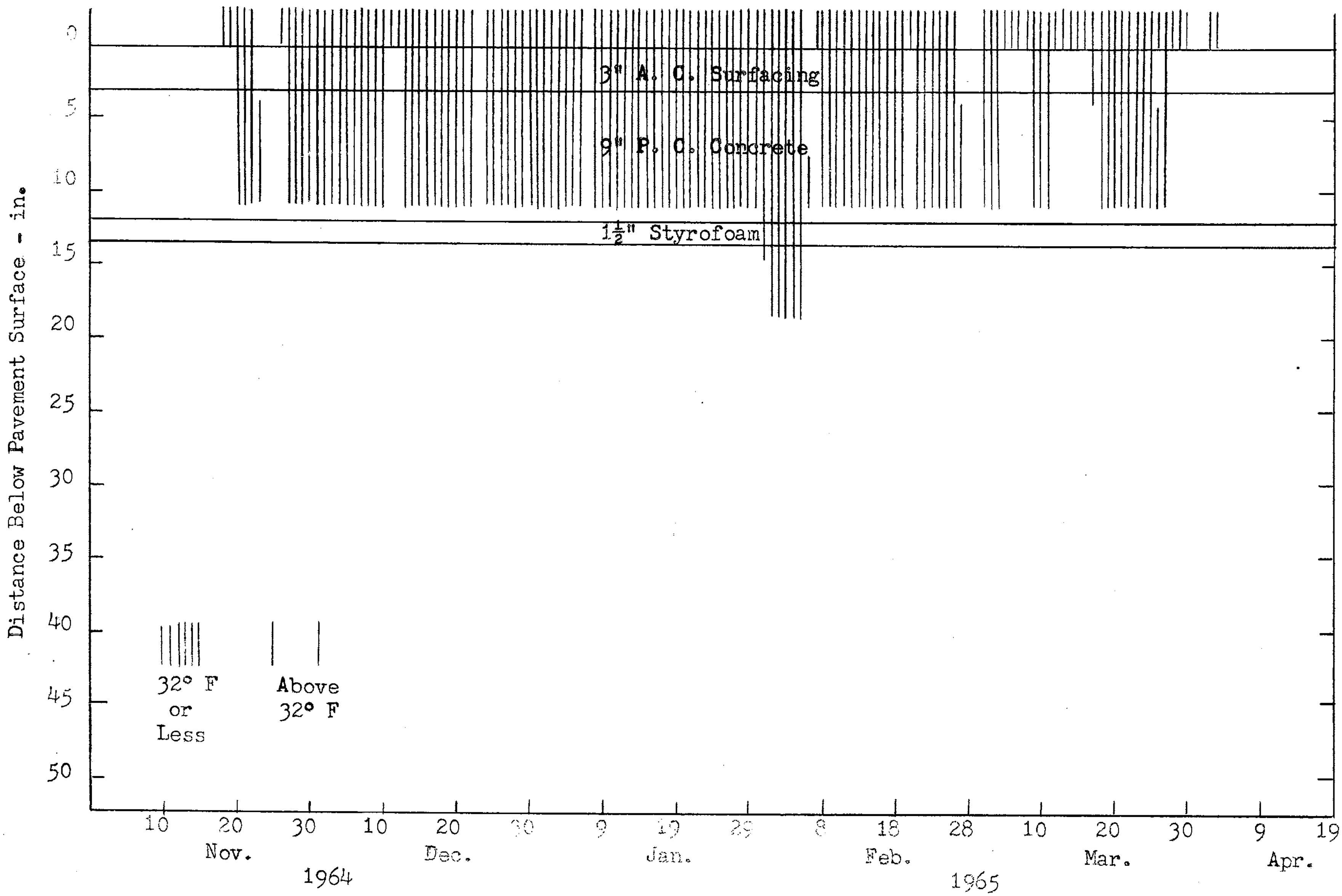


Figure 24: Depth at which average temperatures of 32° F or less were recorded