Iowa Highway Research Board
Project HR-87

Subgrade Insulation To Prevent Soil Freezing

August 1964

Research Department
Iowa State Highway Commission

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Project Map

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Fayette County

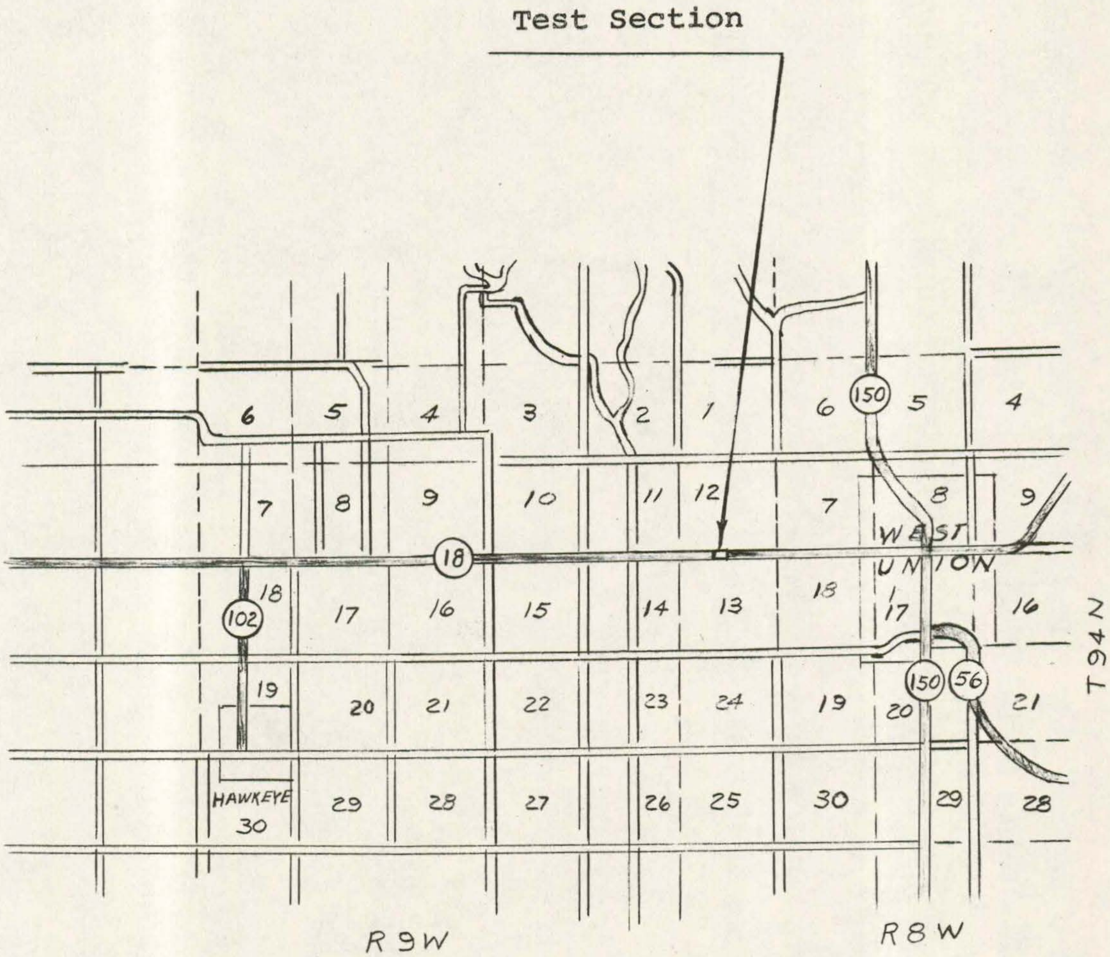

Figure 1

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.

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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 is 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 could not 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.

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 is to determine if an insulating material will prevent the subgrade

*From "Soil Engineering" by M. G. Spangler.

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. However, 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.

PREVIOUS TESTING

Styrofoam has been previously tested by Dow Chemical Company under an asphalt road at their plant in Midland, Michigan. The State of Minnesota also placed some under an asphalt road.

CONSTRUCTION

The Iowa test section is located on US 18 about two miles west of West Union. It is in a 450 ft. reconstruction area that has a history of frost heaving.

The original plans call for coring out three feet of the subgrade and backfilling with selected granular material. The excavation and backfilling was eliminated on the east 250 ft. of the reconstruction 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 remaining 200 ft. was not changed and serves as a control section.

The 250 ft. test area was divided into three sections. In the east section, 75 ft. in length, one layer of Styrofoam one and one-half inches thick was placed. In the middle section, 100 ft. in length, two layers of Styrofoam, each three-fourths inch thick, were placed. In the west section, 75 ft. in length, one layer of Styrofoam one and one-half inches thick was placed. In this section the Styrofoam was covered with 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 ft. by 8 ft. 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. 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.

TESTING

The thermocouple wires terminate in a 5 ft. by 5 ft. by 6 ft. building located near the right of way line. This building is well insulated and a temperature above 50° F can easily be maintained during the winter months by use of two electric heaters.

The temperatures obtained by the thermocouples are indicated by an automatic recording potentiometer which is capable of recording, in sequence, the temperatures in 24 separate locations. It is timed so that the temperatures at the 24 locations are recorded once every two hours. The recorder contains two instrument boards consisting of 24 terminals each. Either board can 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. The rest of the thermocouples are installed in a similar manner at Station 603+50.

Graphs of the temperatures at various locations are shown by Figures 5, 6, 7 and 8. Figure 5 gives the average daily air temperature. Figure 6 compares the temperature above and below the Styrofoam. Figures 7 and 8 give the temperatures at the corresponding locations in the control section. Figure 9 gives the freeze-thaw cycles in both the Styrofoam section and the control section. One cycle was counted when the temperature of the slab or subgrade dropped from 33° F to 31° F or lower and returned to at least 33° F.

A profile of the slab was taken in December 1963, February 1964 and May 1964. This is tabulated in Table 2. Moisture samples of the subgrade and shoulder were taken in April 1964. The results are tabulated in Table 3. These results have very little significance. The subgrade in the control section consists of 3 ft. of granular backfill which normally has a much lower moisture content than the subgrade under the Styrofoam.

CONCLUSIONS

This past winter was fairly mild for Iowa. There were no extended periods of sub-zero temperatures except for a ten-day period in

December 1963. However, it is quite evident that Styrofoam or a similar insulating material is very effective in protecting the subgrade from freezing temperatures.

During the December cold period when the air temperature reached -26° F, the temperature one inch above the Styrofoam was -15° F and one inch below the Styrofoam was 34° F. Temperatures in the corresponding locations in the control section were -1° F and 3° F. The insulation did increase the number of freeze-thaw cycles by 80 percent. Whether this is detrimental or not remains to be seen.

Because of the dry fall and winter very little frost heave occurred. However, the profile indicates that the movement was four times as great in the area outside the test section compared with the Styrofoam area. Even the movement in the granular backfill section was slightly greater than in the Styrofoam section.

FUTURE TESTING

The recording of temperatures will continue throughout the summer and winter until next spring (1965). It is hoped the coming winter will provide a more severe test than was experienced in the past winter.

Photo 1: Installing the first thermocouple wires.

Photo 2: Placing 1½" Styrofoam on the Subgrade.

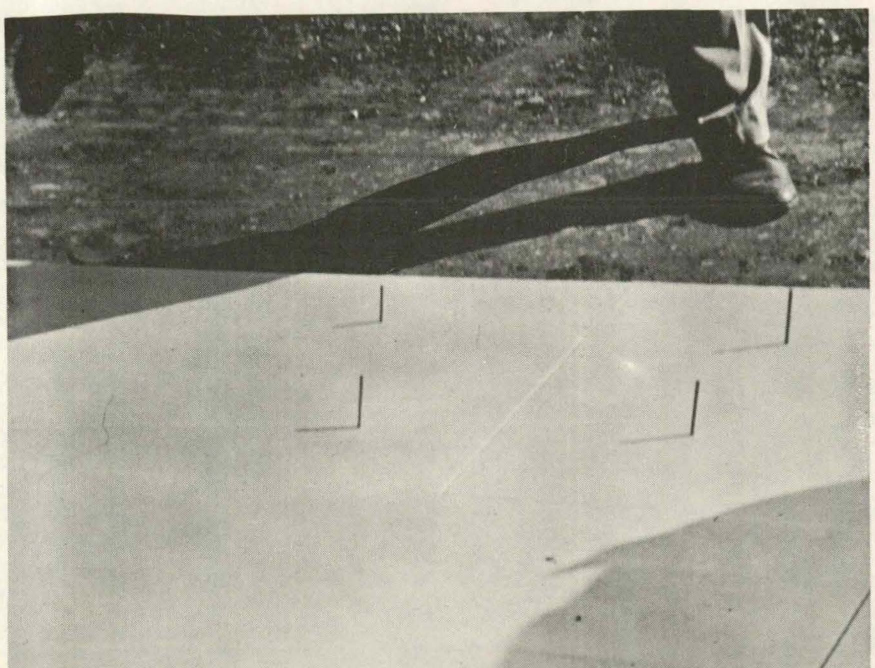


Photo 3: Wooden pegs used to fasten the
Styrofoam to the Subgrade.

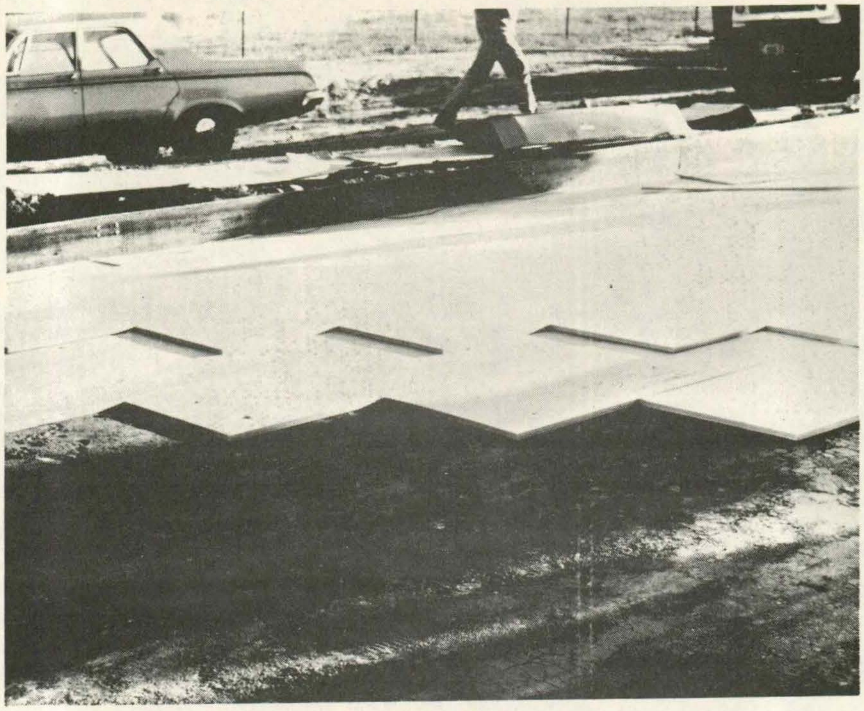


Photo 4: Two layers of 3/4" Styrofoam on the subgrade.

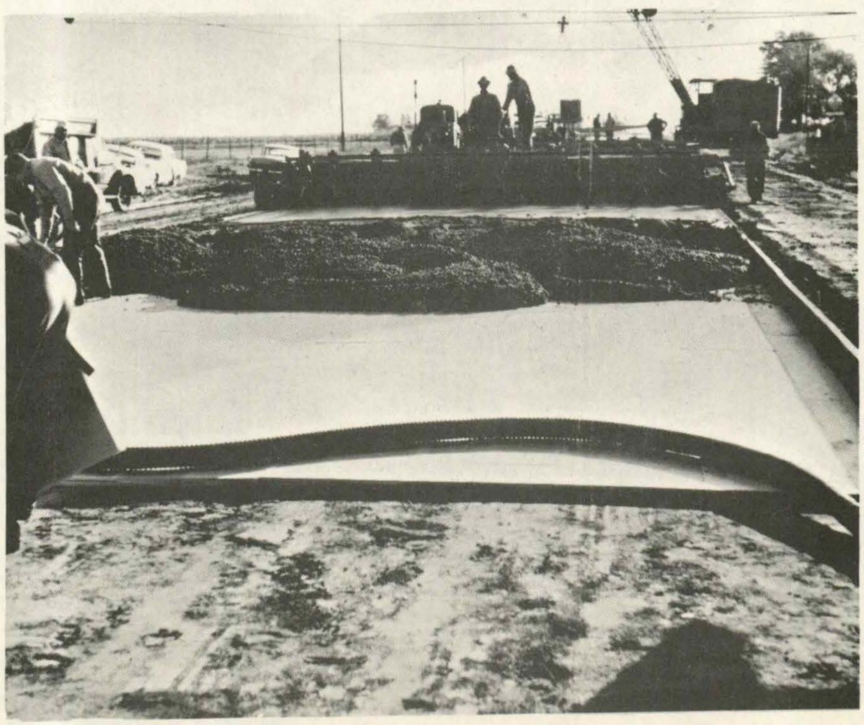


Photo 5: Concrete being placed on the Styrofoam.

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

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

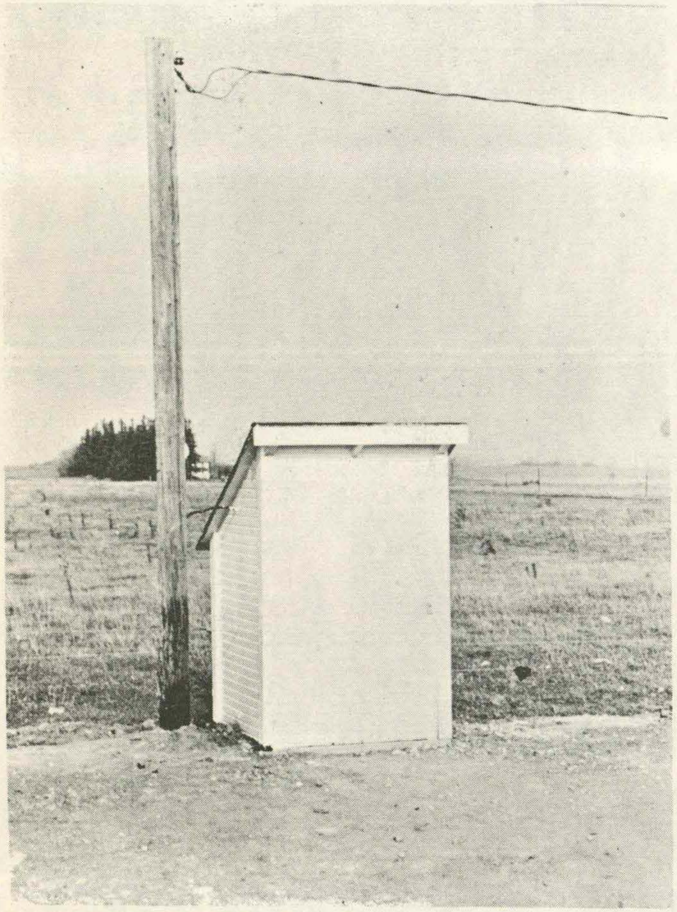


Photo 8: Housing for the temperature recording device.

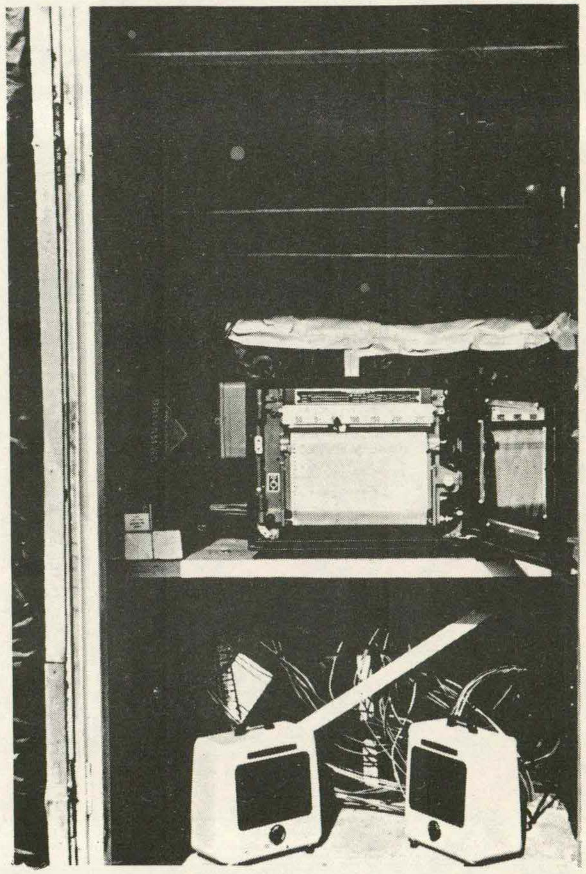


Photo 9: Interior of temperature recording installation. Recording potentiometer above, two electrical heaters below.

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.	Dec. 1963	Feb. 1964	May 1964	Sta.	Dec. 1963	Feb. 1964	May 1964
600+00	99.87	99.93	99.83	603+00	01.92	01.95	01.93
	Begin Granular						
+33	Backfill			+20	02.12	02.14	02.11
+40	99.99	00.05	99.97	+40	02.28	02.30	02.28
+60	00.15	00.17	00.12	+60	02.44	02.46	02.44
+80	00.32	00.35	00.31	+80	02.58	02.60	02.58
601+00	00.49	00.51	00.48	604+00	02.73	02.74	02.73
+20	00.63	00.64	00.62	+20	02.85	02.87	02.86
+40	00.79	00.80	00.78	+40	03.00	03.02	03.00
+60	00.93	00.95	00.92	+60	03.16	03.18	03.17
+80	01.09	01.13	01.08	+80	03.34	03.37	03.34
602+00	01.23	01.27	01.24	+85	End Styrofoam		
+20	01.36	01.39	01.36	605+00	03.56	03.66	03.55
+33	End Granular			+20	03.73	03.83	03.72
	Begin Styrofoam						
+40	01.47	01.48	01.47	+40	03.92	03.99	03.90
+60	01.62	01.64	01.62	606+00	04.50	04.58	04.49
+80	01.76	01.78	01.77				

Average Change per Section

Section	Dec. to Feb.	Feb. to May
Granular Backfill	+0.028'	-0.038'
Styrofoam	+0.020'	-0.018'
Outside Test Section	+0.082'	-0.096'

Table 3

SUBGRADE MOISTURE CONTENT

US 18 F-172(4) Fayette County

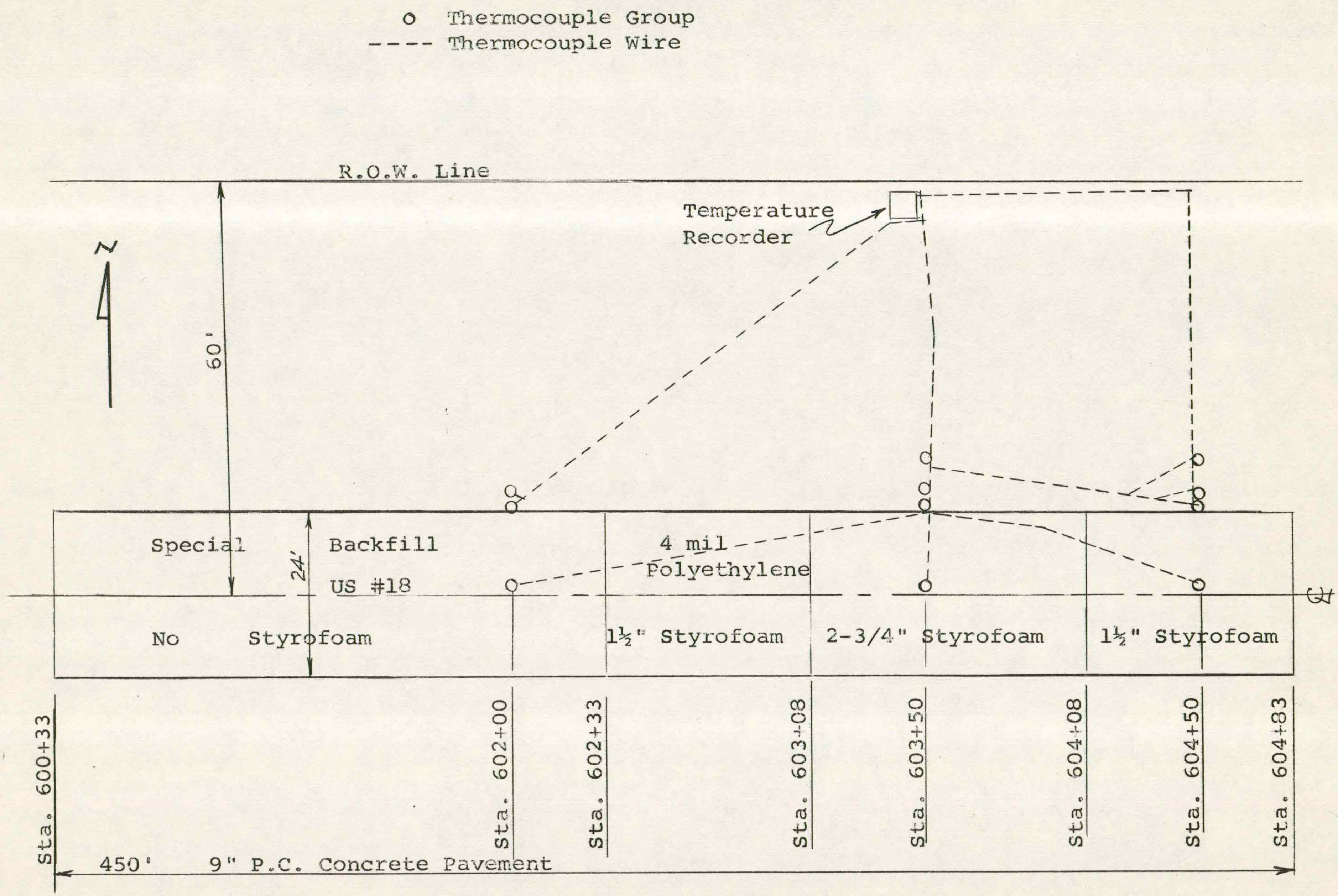
HR-87 April 1964

6 ft. Lt. of CL Under Slab		6 ft. Rt. of CL Under Slab		14 ft. Rt. of CL In Shoulder	
Depth (In.)	% Moisture	Depth (In.)	% Moisture	Depth (In.)	% Moisture
Sta. 601+00 (No Styrofoam)					
0- 6	5.7	0-6	4.7	0- 6	21.0
6-12	4.6	6-12	5.1	6-12	10.0*
12-18	4.5	12-18	4.2	12-18	6.0
18-21½	5.1			18-21	5.7
				21-27	6.1
(*)1-3/4" Silty Clay - 4¼" Gravel				27-33	7.3
				33-35	8.5
Sta. 602+00 (No Styrofoam)					
0- 6	5.7	0- 6	5.8	0- 6	14.0
6-12	5.7	6-12	5.9	6-12	8.0
12-18	4.9	12-18	5.4	12-18	5.6
18-24	4.9			18-22	5.3
				22-28	5.3
				28-34	5.9
				34-40	8.5
				40-43	13.9

6 ft. Rt. of CL (Under Styrofoam)		14 ft. Rt. of CL (In Shoulder)	
Depth (Inches)	% Moisture	Depth (Inches)	% Moisture
Sta. 603+50 (Styrofoam only)			
0- 6	10.0	0- 6	17.3
6-12	15.0	6-12	18.5
12-18	16.2	12-18	11.9
		18-19	10.4
		19-25	14.1
		25-31	17.1
		31-37	20.4
		37-41	18.5
Sta. 604+50 (Styrofoam only)			
0- 6	12.9	0- 6	19.2
6-12	17.9	6-12	16.9
12-18	19.5	12-16	17.4
18-20½	17.3	16-22	16.4
		22-28	13.7
		28-34	13.6
		34-37	13.2

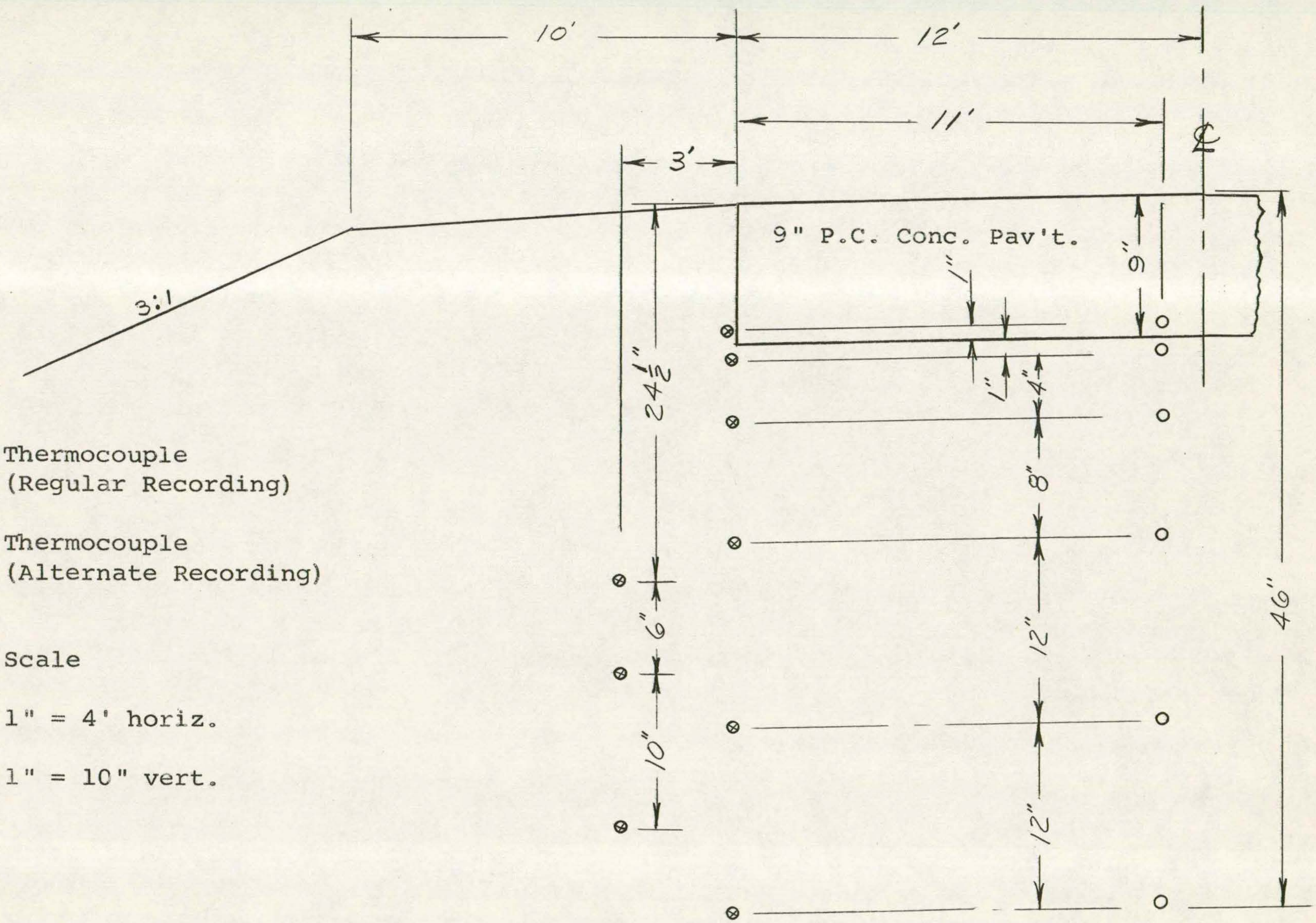
Table 3 (cont'd.)

Sta. 602+50 (Styrofoam and 4 mil polyethylene)	
6 ft. Rt. of CL (Under Styrofoam)	
Depth (Inches)	% Moisture
0- 6	10.4
6-12	14.4
12-18	15.2
Sta. 602+90 (Styrofoam and 4 mil polyethylene)	
0- 6	14.6
6-12	16.7
12-18	16.4
18-20.4	14.2
Sta. 603+90 (Styrofoam only)	
0- 6	14.6
6-12	17.2
12-18	15.7
Sta. 604+20 (Styrofoam only)	
0- 6	14.8
6-12	19.2
12-18	18.7



Scale
1"= 20' Vert.
1"= 50' Horiz.

Figure 2



○ Thermocouple
(Regular Recording)

⊗ Thermocouple
(Alternate Recording)

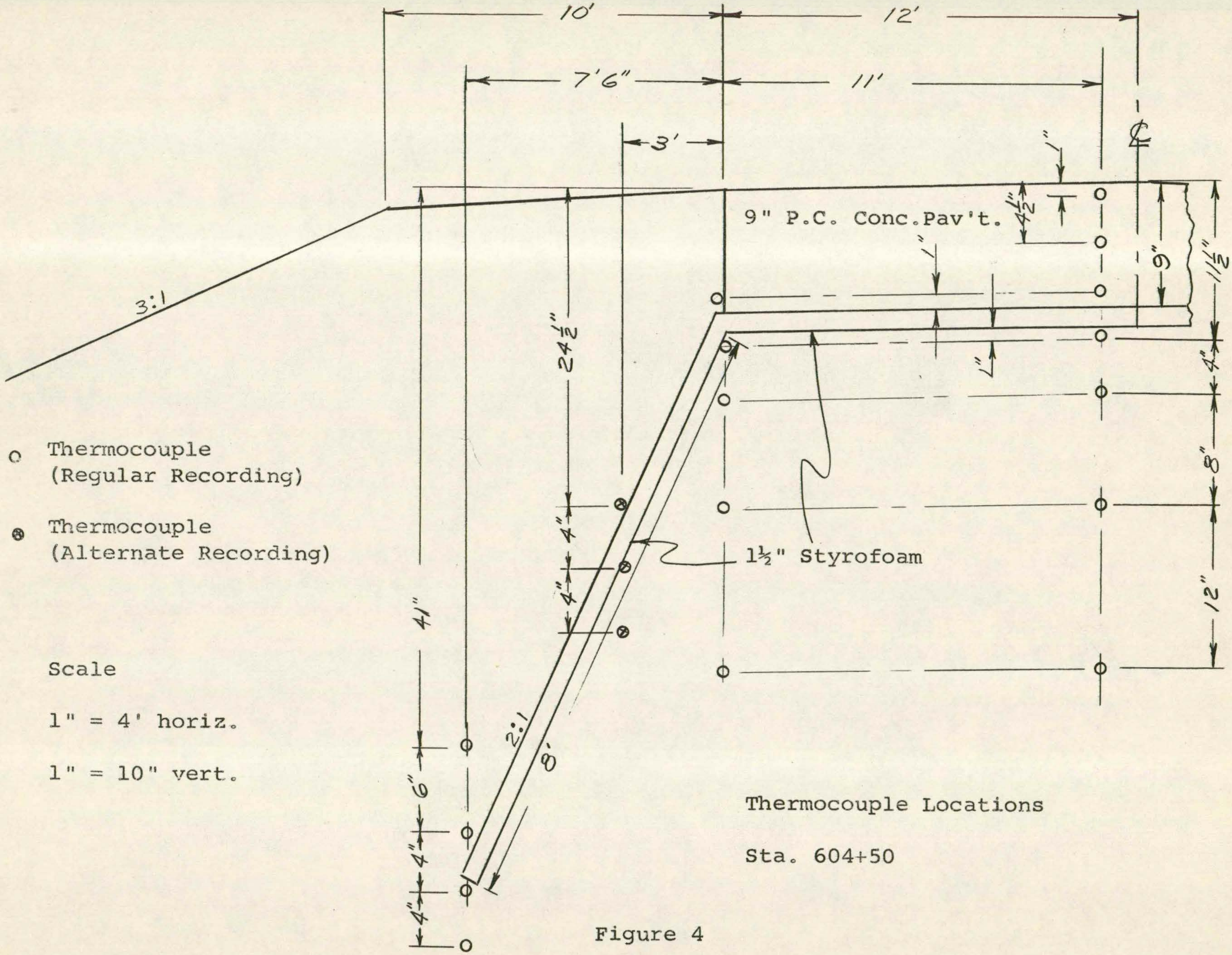
Scale

1" = 4' horiz.

1" = 10" vert.

Thermocouple Locations

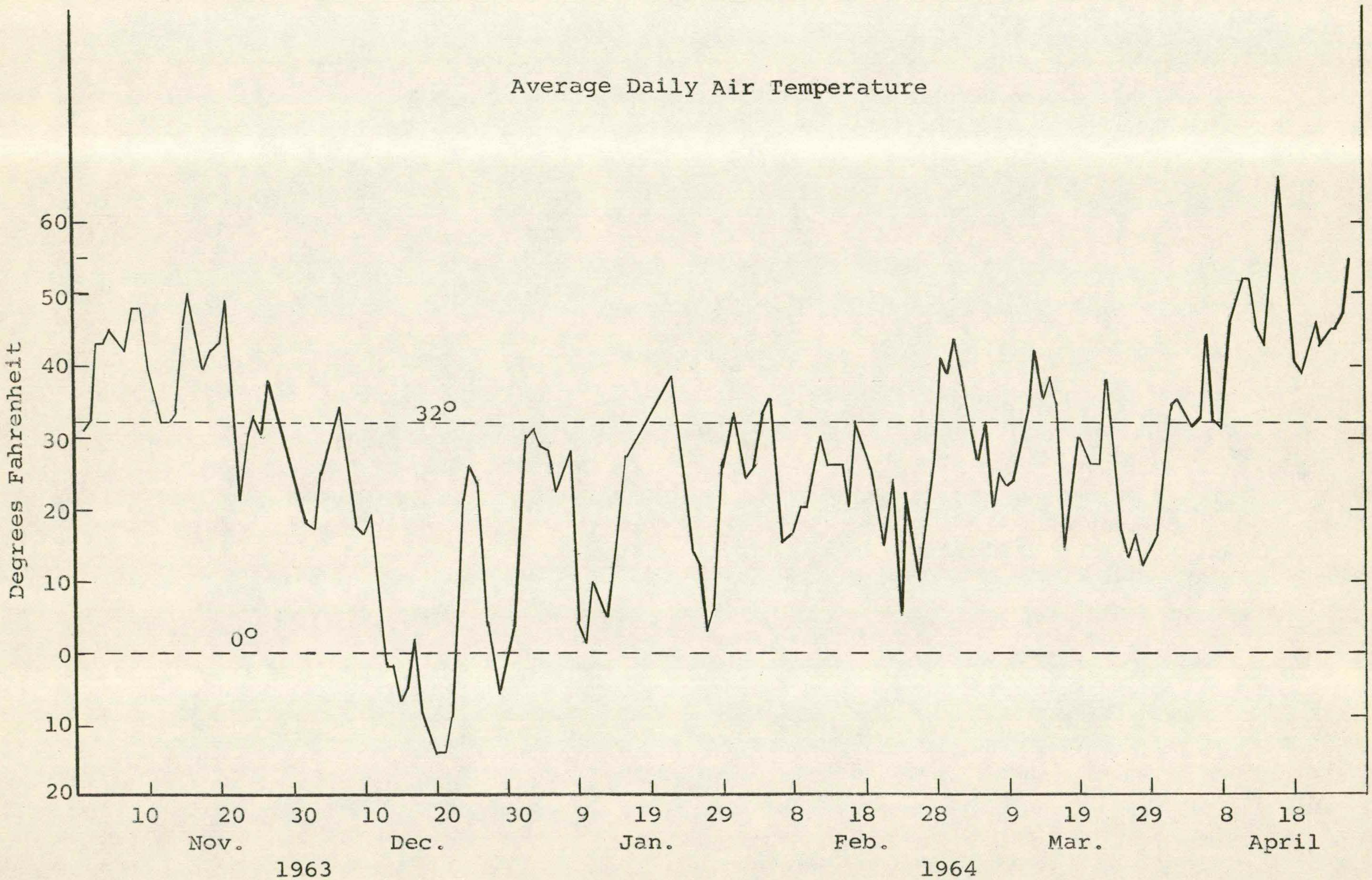
Sta. 602+00 Figure 3



Thermocouple Locations

Sta. 604+50

Figure 4



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 5

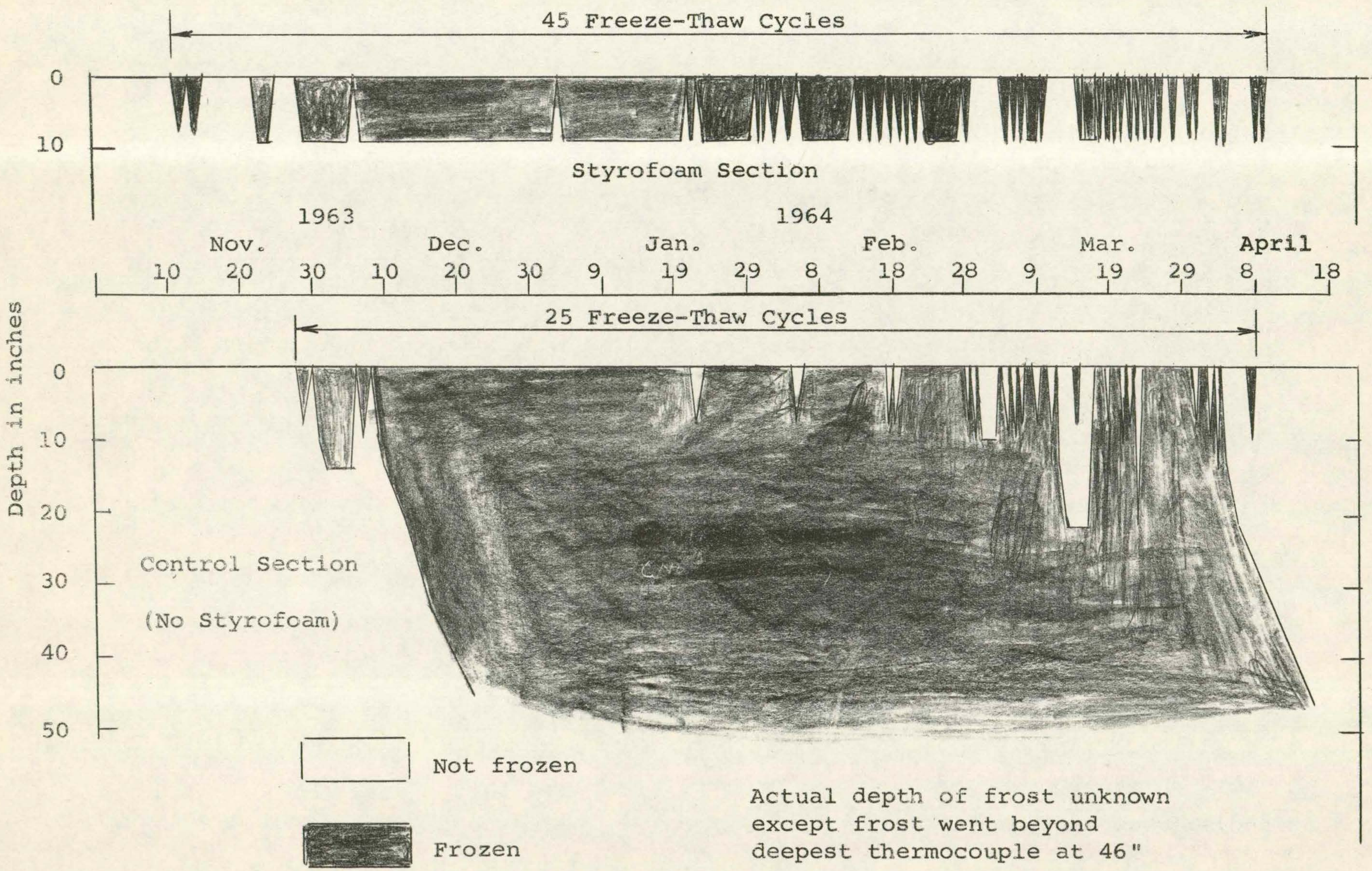

45 Freeze-Thaw Cycles
0
10
Styrofoam Section
1963
1964
Nov.
Dec.
Jan.
Feb.
Mar.
April
10 20 30 10 20 30 9 19 29 8 18 28 9 19 29 8 18
25 Freeze-Thaw Cycles
Depth in inches
0
10
20
30
40
50
Control Section
(No Styrofoam)
Not frozen
Frozen
Actual depth of frost unknown
except frost went beyond
deepest thermocouple at 46"

Figure 9

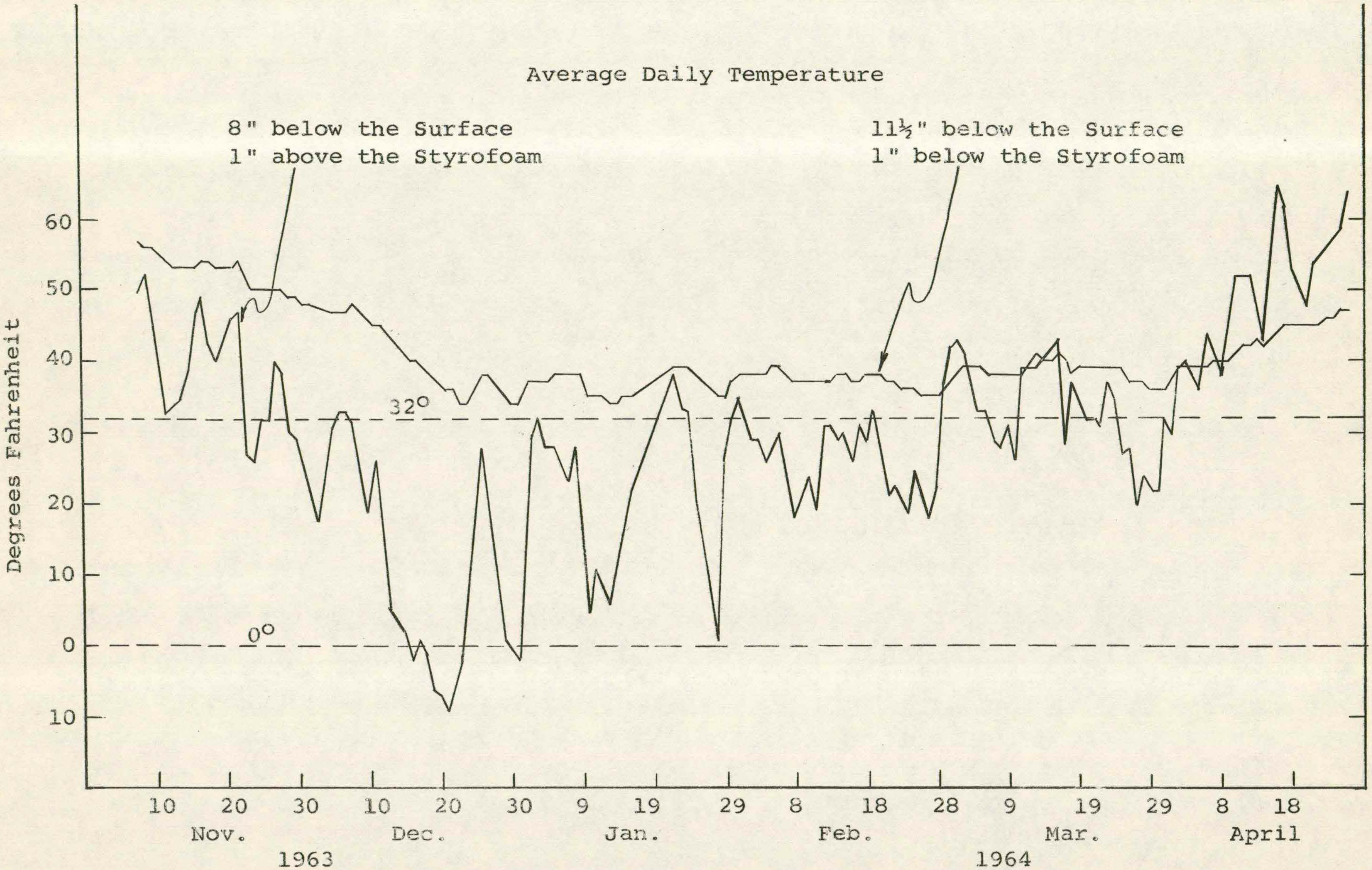

Average Daily Temperature
8" below the Surface
1" above the Styrofoam
11½" below the Surface
1" below the Styrofoam
Degrees Fahrenheit
60
50
40
30
20
10
0
10
32°
0°
10
20
30
10
20
30
9
19
29
8
18
28
9
19
29
8
18
Nov.
Dec.
Jan.
Feb.
Mar.
April
1963
1964

Figure 6

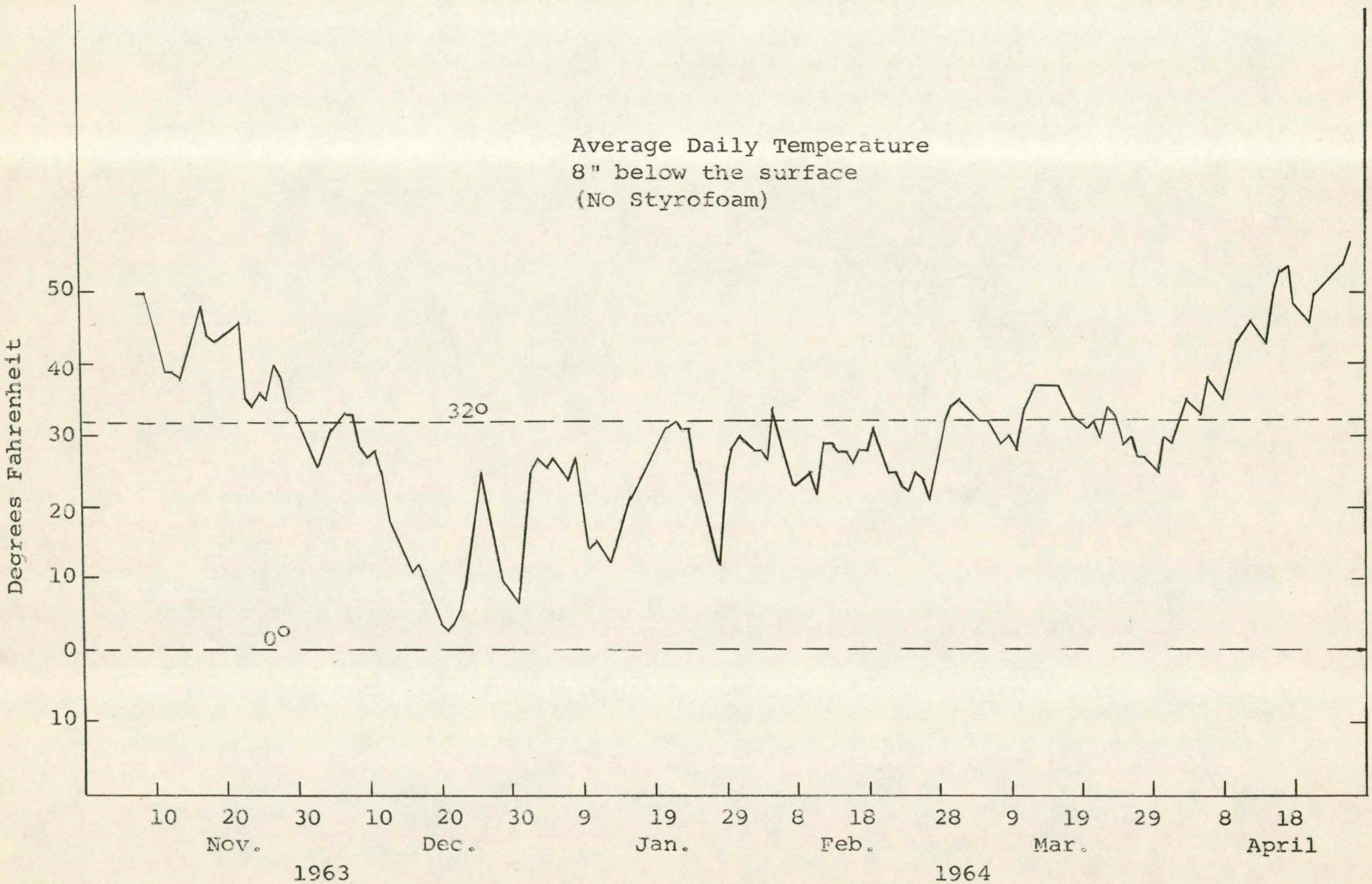

Average Daily Temperature
8" below the surface
(No Styrofoam)
Degrees Fahrenheit
50
40
30
20
10
0
10
32°
0°
10 20 30 10 20 30 9 19 29 8 18 28 9 19 29 8 18
Nov.
Dec.
Jan.
Feb.
Mar.
April
1963
1964

Figure 7

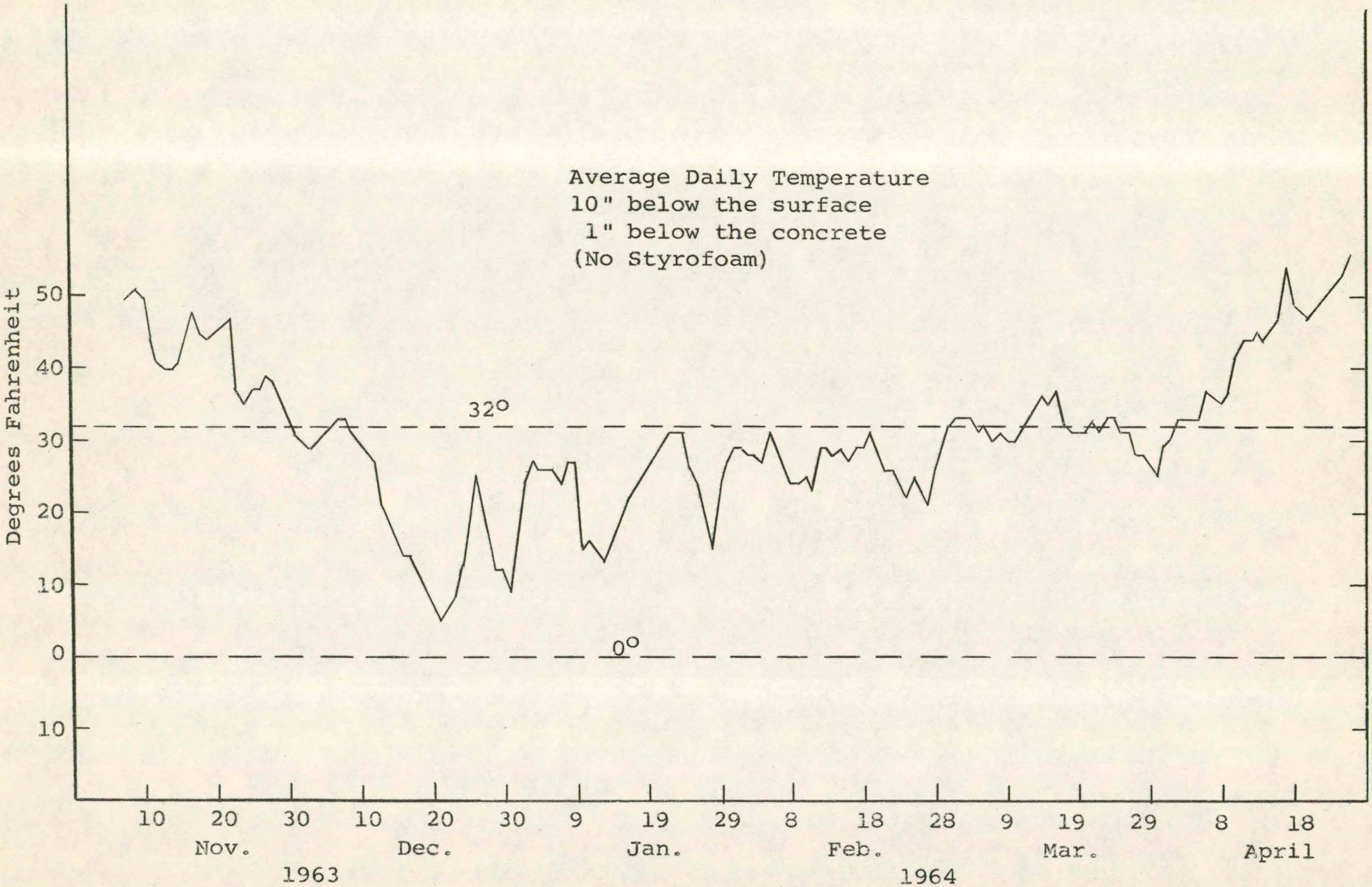

Average Daily Temperature
10" below the surface
1" below the concrete
(No Styrofoam)
Degrees Fahrenheit
50
40
30
20
10
0
10
32°
0°
10 20 30 10 20 30 9 19 29 8 18 28 9 19 29 8 18
Nov.
Dec.
Jan.
Feb.
Mar.
April
1963
1964

Figure 8