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THERMAL INFLUENCE OF STEEL POSTS ON THE GROUND TEMPERATURE REGIME DURING THE WINTER - A FIELD EXPERIMENT

by

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PREFACE

Frost heaving around footings of transmission towers is thought to be aggravated by excessive heat withdrawal from the soil by the steel superstructures. The study described in this report is a first attempt to assess the severity of the problem under relatively simple conditions and was undertaken in response to inquiries by designers.

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Ottawa
January 1970

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Director.

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Footings of unheated structures are normally placed below the depth of maximum seasonal frost penetration as a method of preventing frost heaving. When the thermal properties of the structure are different from those of the soil, it is possible that there may be an influence on the ground thermal regime during the winter because the superstructure is in a colder environment than the foundation. This possibility exists in the case of self-supporting steel transmission line towers where the steel members of the superstructure extend into the ground and are attached rigidly to footings at some depth. Excessive heaving has occurred in the case of tower foundations of transmission lines and it has been suggested that the steel tower legs may be partly responsible for the severe frost penetration and heave problem. How much of this can be attributed to the influence of the steel posts on the ground thermal regime is not known.

An analytical assessment of the additional heat loss from the soil induced by the structure under field conditions cannot readily be carried out for many reasons. Factors which contribute in combination to the complexity of the problem are the variability of the daily air temperature, the changes in thermal conduction when the soil freezes, movement of water to the freezing plane which increases the insitu water content of the frozen zone, the variable snow cover depth, the thermal properties of the complex organic cover in northern regions, and many others. It has not been possible to extend the results of the model studies carried out by Brown (1) in a meaningful way to the conditions described above. A simple field experiment was undertaken, therefore, to evaluate the influence of steel tower legs on the environment in the surrounding soil under one particular set of conditions. This note describes the experiment and gives an assessment of the influence based on one winter's results.

METHODS AND MATERIALS

Site and Soil Conditions

The site of the experiment is in the eastern outskirts of Ottawa on the National Research Council's Montreal Road property. The soil is a postglacial marine deposit with a natural grass cover. It has an autumn moisture content of about 44 per cent and consists of approximately 70 per cent clay size particles and 30 per cent silt. The average apparent density is 1.76 gm/cm^3 (110 lb/ft^3).

Design of Experiment and Installation

The steel posts that were used to simulate the tower legs consisted of four 12-ft lengths of steel angles $3\frac{1}{2}$ x 3/8 in. bolted together in the arrangement shown in Figure 1 a. The posts were driven into 6-in. augered holes to a depth of 6 ft and backfilled as closely as possible to the original density. The length of post exposed to the atmosphere was also 6 ft.

To measure the temperatures along the steel post, 20-gauge copper constantan thermocouples were located at 1-ft intervals along the 12-ft length and were positioned as shown in Figure 1 b. The thermal voltages were recorded daily at 0815 hr with a millivolt data acquisition system. Air temperatures were obtained from the Division's meteorological station located a few hundred yards from the site.

Two such steel posts were installed 20 ft apart (Figure 1 c). Thermocouples were used to measure soil temperatures to a depth of 6 ft and at various distances from the posts. These thermocouples were placed on 1-in. diameter wooden dowels with an 18-in. length of the thermocouple wrapped around the dowel at each level to avoid heat conduction errors in the measurements. The centre string (SP 6, Figure 1 c), located halfway between the steel posts, was considered to be a control not influenced by the thermal effects of the steel posts. Natural snow cover was allowed to accumulate and the area was left undisturbed throughout the winter period. Snow depth gauges were located above SP 4 and SP 8 (Figure 1 c) 4 ft from each steel post.

RESULTS

Based on thermal considerations the portion of the posts above the ground surface was sufficiently long to simulate tower legs which are normally much longer than those used in this experiment. This was substantiated by the experimental results that showed, that the top 4 ft of all the posts were essentially at the same temperature. Figure 2 shows the temperature distribution along the steel posts; this is representative of the usual condition, although some anomalies did occur during abrupt air temperature changes or in short periods of bright sunlight.

Figure 3 a shows the daily air temperatures at the DBR meteorological site located a few hundred yards from the experimental site. Figure 3 b shows the daily ground temperatures of the control string (SP 6) located halfway between the steel posts. It should be noted that no freezing took place in the ground at this site under the undisturbed snow cover during the 1968-69 winter.

Figures 4 and 5 give the temperature differences between the control string and the below-ground portion of the steel posts at intermediate locations at the various depths. Temperature differences plotted above the base lines indicate the temperatures of these locations were colder than the control string; this is attributed to the influence of the steel posts. A thermal end effect is noted on the steel posts. This is thought to be because of the different heat flow patterns at the ends of the posts as compared to the sides of the posts where only lateral heat flow took place.

Table 1 gives the average temperature of each location at all depths between 23 November 1968 and 31 March 1969, based on daily 0815 hr readings. This Table also gives average temperature differences between the control and the other locations. These results have been plotted in Figure 6 to display clearly the pattern of influence the steel posts had on the ground thermal regime. The thermal behaviour of the two steel posts was similar but there were some differences resulting largely from the uneven snow cover.

Figure 7 is a series of plots which gives the position of the 0°C isotherm at various distances from both steel posts as a function of time. The depth of snow cover for the entire period is given in the same figure. Near the steel post, SP 1 position A, the snow cover reached a depth of 28 in.; at Position B, 23 in.; hence, some differences in the thermal regime at the two sites might be expected. SP 6, the control thermocouple string, had a snow depth cover somewhere in between these two extremes.

It should be mentioned also that there was a funnel-shaped cavity in the snow cover at each post due to wind action. The funnel was about 18 in. in diameter at the top and gradually narrowed down to the size of the posts near the ground surface. These funnels were not interfered with because they were a natural phenomenon that would probably occur around any similar structure exposed to the same field conditions in the winter.

DISCUSSION

It can be seen from Figure 7 that 6 in. from the posts the frostline (based on the 0°C isotherm) penetrated 1.2 to 1.4 ft. One ft from the posts it penetrated 0.8 to 1.0 ft. No frost penetration occurred 2 ft from the posts (Position A), but at Position B it penetrated to a depth of 0.6 ft, and 4 ft from the posts, to 0.2 ft.

The temperature of the steel posts dropped to 0°C at depths of 1.6 to 1.8 ft from the ground surface. Thus the freezing plane 6 in. from the posts was 0.4 ft higher in the profile than on the steel posts and 0.8 ft higher at a 12-in. distance. Figure 8 shows, in section, the dimensions of the cone of soil frozen at each steel post. As mentioned previously the slightly larger cone at Position B is probably a result of the shallower snow depth at that location. In the area halfway between the steel posts and not influenced by them, there was no frost penetration into the ground.

All the freezing in the soil as shown in Figure 8 was induced by the steel posts and hence the direction of the heat flow involved in the freezing process was toward the posts. The forces developed in ice lens growth are parallel to the direction of heat flow. Based on this, the direction of heave would not be in a vertical direction but rather would follow the lines of heat flow. Observations during the latter part of the winter showed that the posts had, in fact, not moved. The amount of frost heaving associated with vertical penetration of the frost line in these soils is in excess of 1 in. per foot of frost penetration hence at least $1\frac{1}{2}$ in. of heave should have been anticipated in the present case.

CONCLUSION

The results indicate that steel posts installed with both above- and below-ground portions have a substantial thermal influence on the ground in a region of seasonal frost. The results from one winter when no natural frost penetration occurred due to snow cover showed that 6 in. from the post the frostline penetrated to a depth of from 1.2 to 1.4 ft, and 12 in. from the post it penetrated 0.8 to 1 ft. At the surface of the ground induced soil freezing extended 2 ft laterally in one case and beyond that in the other.

It may be tentatively concluded from one winter's results that the heat flow pattern induced was not conducive to vertical heaving of the posts. Thermal measurements will be continued at this site for at least one more year to obtain results for different winters. It is hoped that such results will be helpful for predicting the thermal influence by steel posts of different dimensions and configuration for other regions in Canada where both climate and soil conditions are different.

REFERENCE

(1) Brown, W.G. Thermal model tests for probe conduction errors in ground-temperature measurement. Géotechnique, Vol. XIII, No. 3, September 1963, p. 241-249.

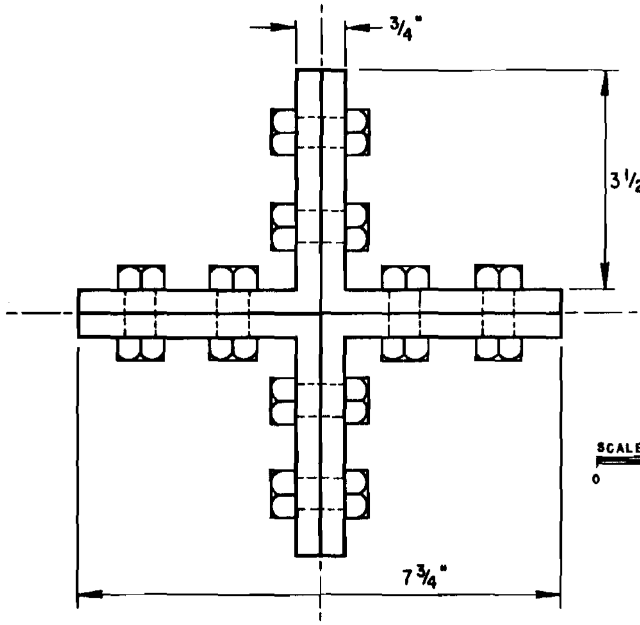
Table 1

AVERAGE TEMP FOR WINTER SEASON AND TEMPERATURE DIFFERENCES BETWEEN CONTROL AND VARIOUS LOCATIONS, NOVEMBER 23, 1968--MARCH 31, 1969

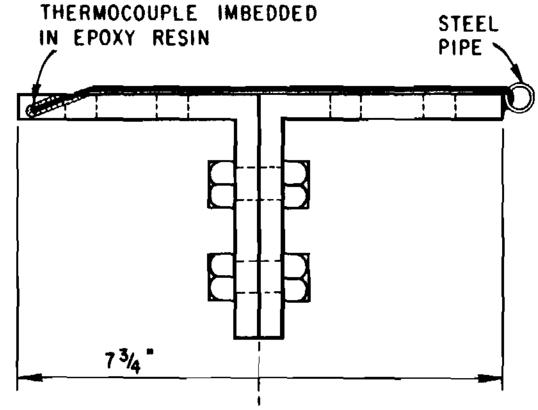
				HORIZONTAL DIS. TO STEEL POST SP 1								HORIZONTAL DIS. TO STEEL POST SP 11									
	CONTROL	STEEL POST		1/2"		1'		2'		4'		4'		2'		1'		1/2"		STEEL POST	
	SP 6	SP 1		SP 2		SP 3		SP 4		SP 5		SP 7		SP 8		SP 9		SP 10		SP 11	
DEPTH	T*	T	ΔT**	T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT
0	0.26	-2.41	2.67	-0.84	1.10	-0.39	0.65	0.34	0.08	0.30	0.04	0.14	0.12	-0.16	0.42	-0.76	1.02	-1.75	2.01	-2.84	3.10
1'	1.36	0.16	1.20	0.56	0.80	0.79	0.57	1.12	0.24	1.41	0.05	1.12	0.24	0.85	0.51	0.56	0.80	0.18	1.18	-0.10	1.46
2'	2.80	1.84	0.94	2.16	0.64	2.25	0.55	2.43	0.37	2.67	0.13	2.47	0.33	2.00	0.80	1.91	0.88	1.76	1.04	1.76	1.04
3'	4.06	3.43	0.63	3.58	0.48	3.67	0.39	3.79	0.27	4.00	0.06	3.78	0.28	3.47	0.59	3.41	0.65	3.29	0.77	3.26	0.80
4'	5.25	4.63	0.62	4.85	0.40	4.91	0.34	5.01	0.24	5.22	0.03	5.00	0.25	4.72	0.54	4.68	0.57	4.58	0.68	4.54	0.69
5'	6.25	5.59	0.66	5.87	0.38	5.93	0.32	6.10	0.15	6.26	0.01	6.05	0.20	5.84	0.41	5.75	0.50	5.64	0.60	5.50	0.75
6'	7.13	6.15	0.98	6.78	0.35	6.85	0.28	6.98	0.15	7.14	0.01	6.96	0.17	6.81	0.32	6.78	0.40	6.60	0.53	7.10	1.03

* (T), TEMP. °C

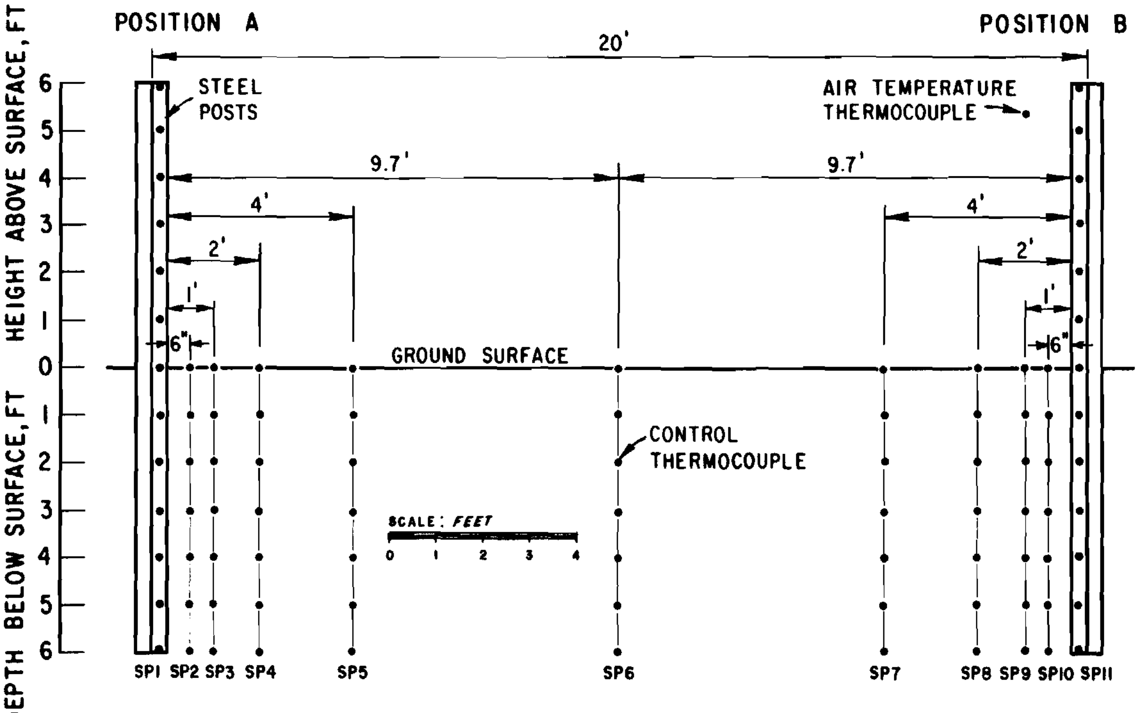
** (ΔT), DIFFERENCE IN TEMPERATURE BETWEEN THIS LOCATION AND THE CONTROL SP 6, WHICH WAS LOCATED HALFWAY BETWEEN STEEL POSTS - IN CENTIGRADE DEGREES.



(a) ARRANGEMENT OF STEEL ANGLES IN SECTION



(b) POSITIONING OF THERMOCOUPLES AT 1 FT INTERVALS ON STEEL POSTS IN SECTION



(c) EXPERIMENTAL LAYOUT OF THERMOCOUPLES

FIGURE 1
DESIGN OF STEEL POST AND EXPERIMENTAL LAYOUT

BR 4479-1

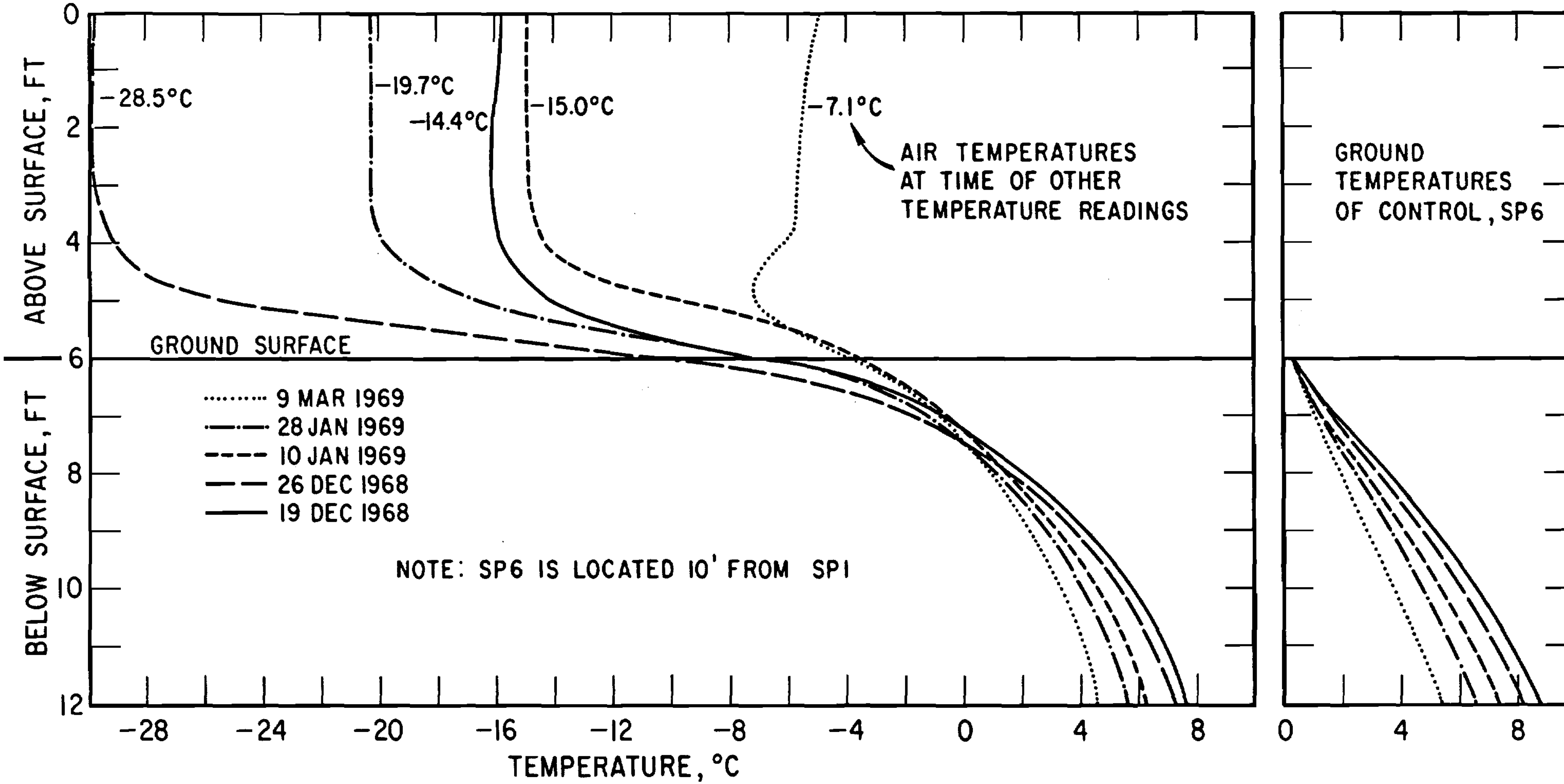


FIGURE 2

TEMPERATURE DISTRIBUTION ON STEEL POST (SP1), AIR TEMPERATURES, AND GROUND TEMPERATURES CONTROL (SP6) ON THE DAYS GIVEN AT 0815 HR

BR 4479-2

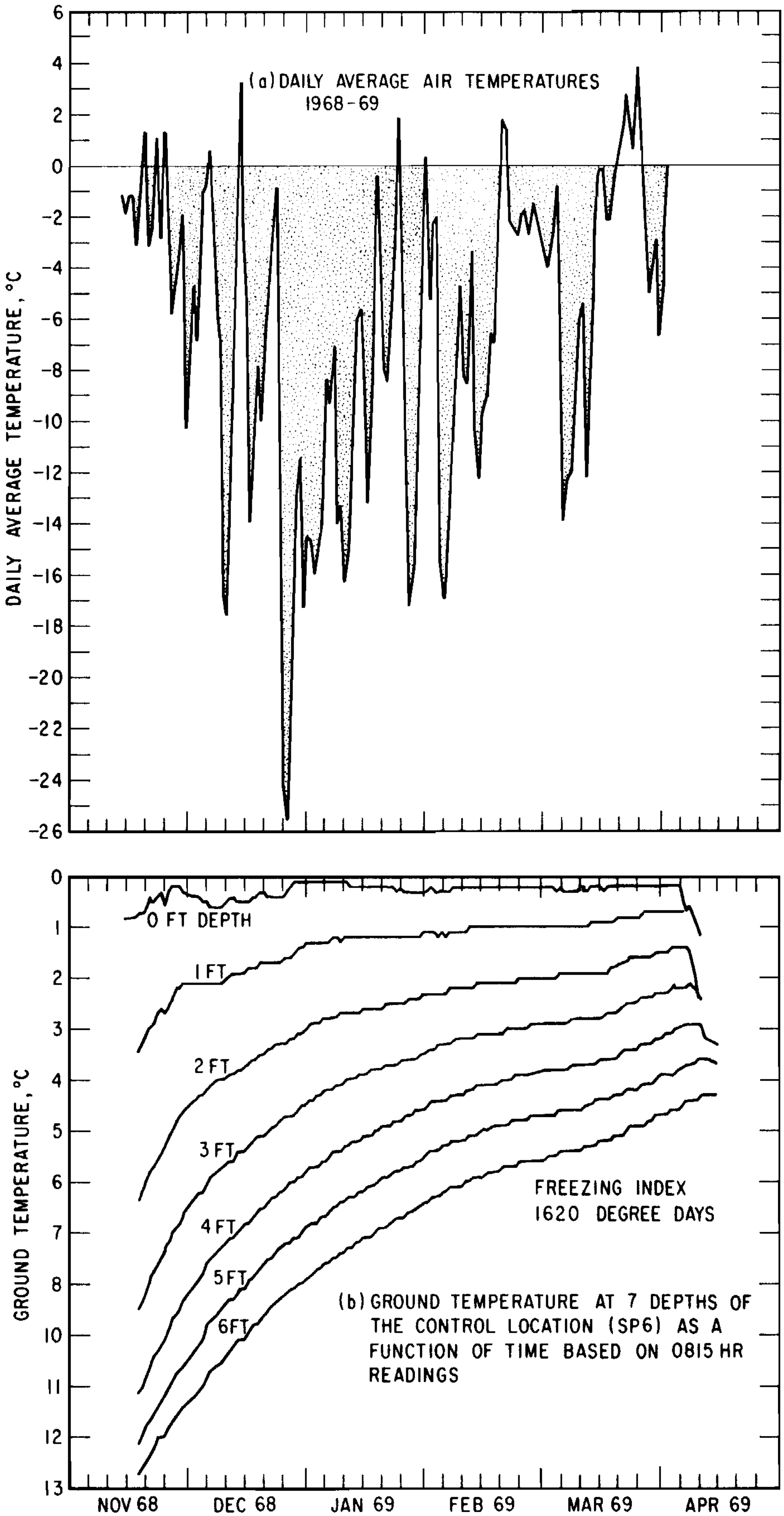


FIGURE 3
AIR AND GROUND TEMPERATURES 1968-69

BR 4479-3

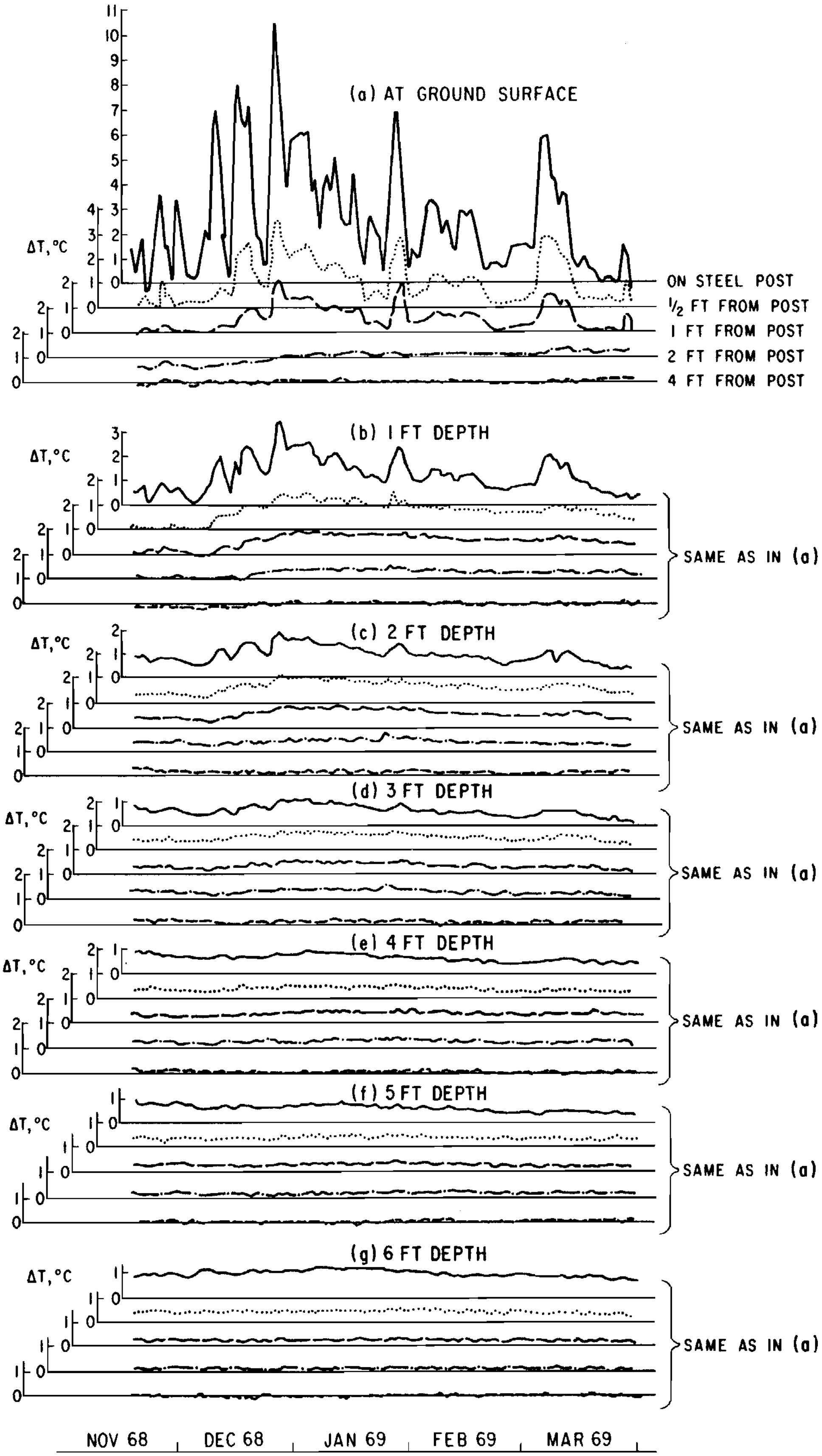


FIGURE 4

TEMPERATURE DIFFERENCES BETWEEN CONTROL, SP6, AND STEEL POST, SP1, AND VARIOUS DISTANCES FROM SP1

BR 4479-4

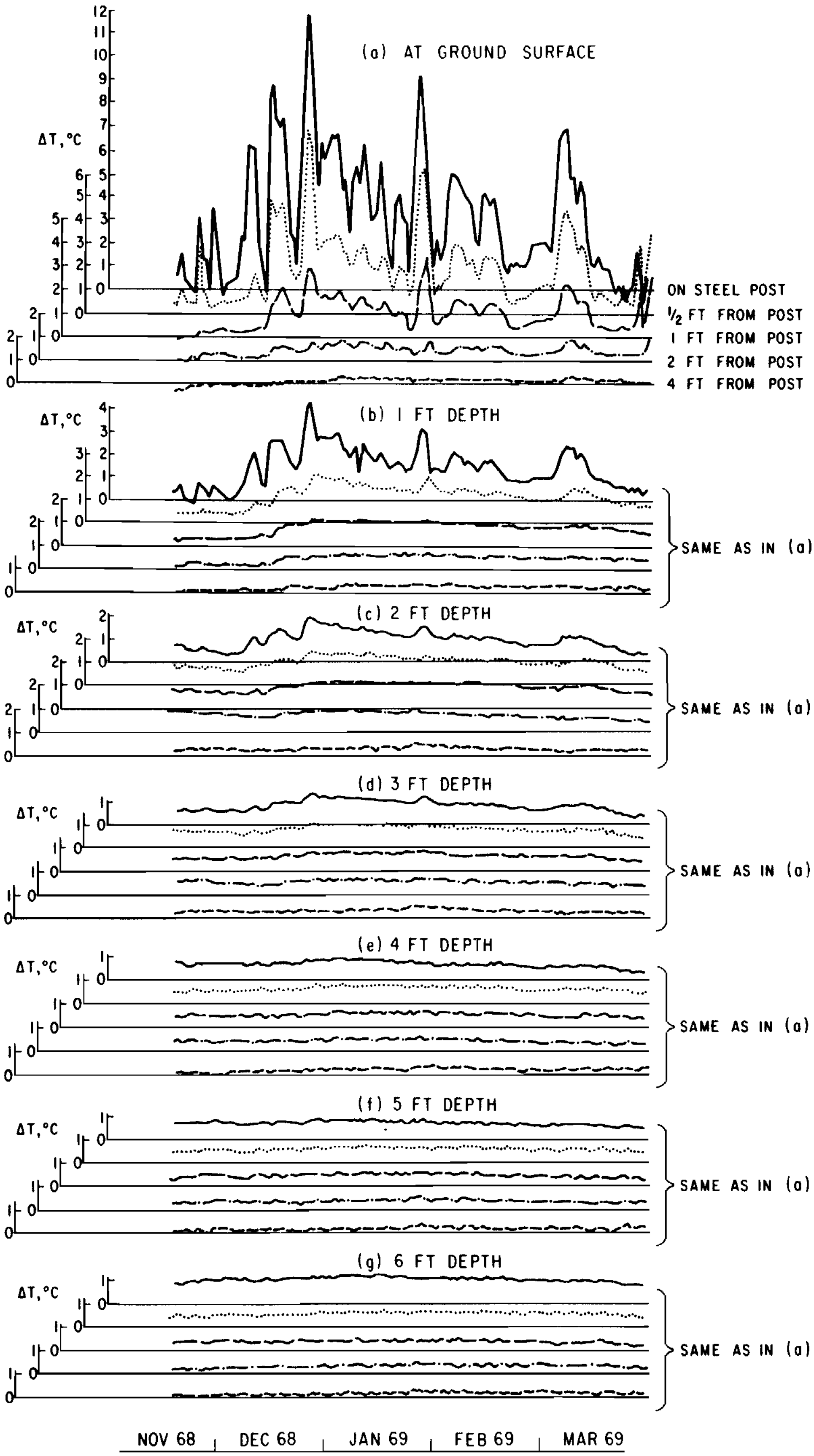


FIGURE 5

TEMPERATURE DIFFERENCES BETWEEN CONTROL, SP6, AND STEEL POST, SP11, AND VARIOUS DISTANCES FROM SP11

BR 4479-5

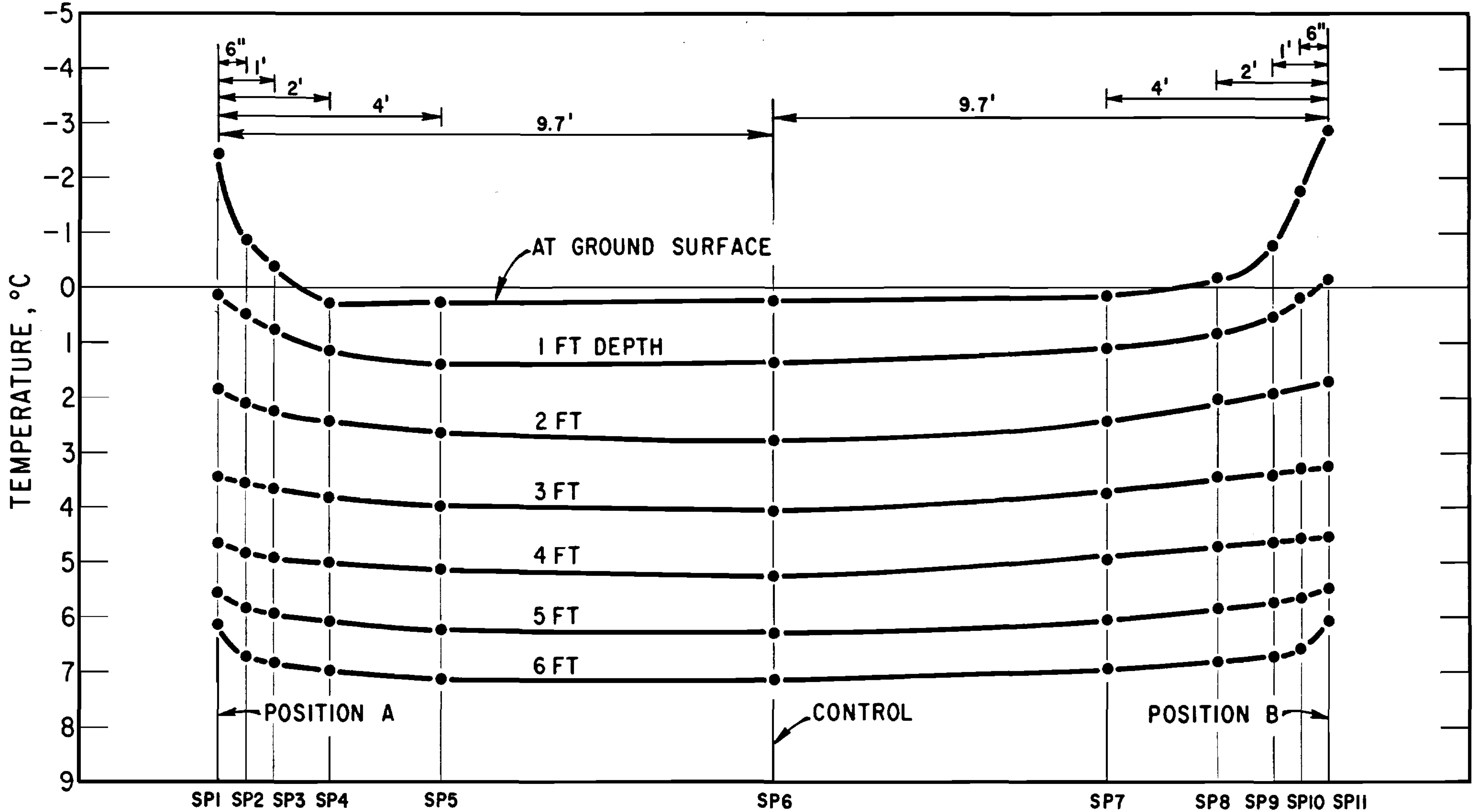


FIGURE 6

AVERAGE TEMPERATURE DISTRIBUTION BASED ON DAILY MEANS FOR WINTER PERIOD (18 NOV 1968 – 31 MAR 1969) AT VARIOUS DEPTH AND DISTANCES FROM STEEL POSTS

BR 4479 – 6

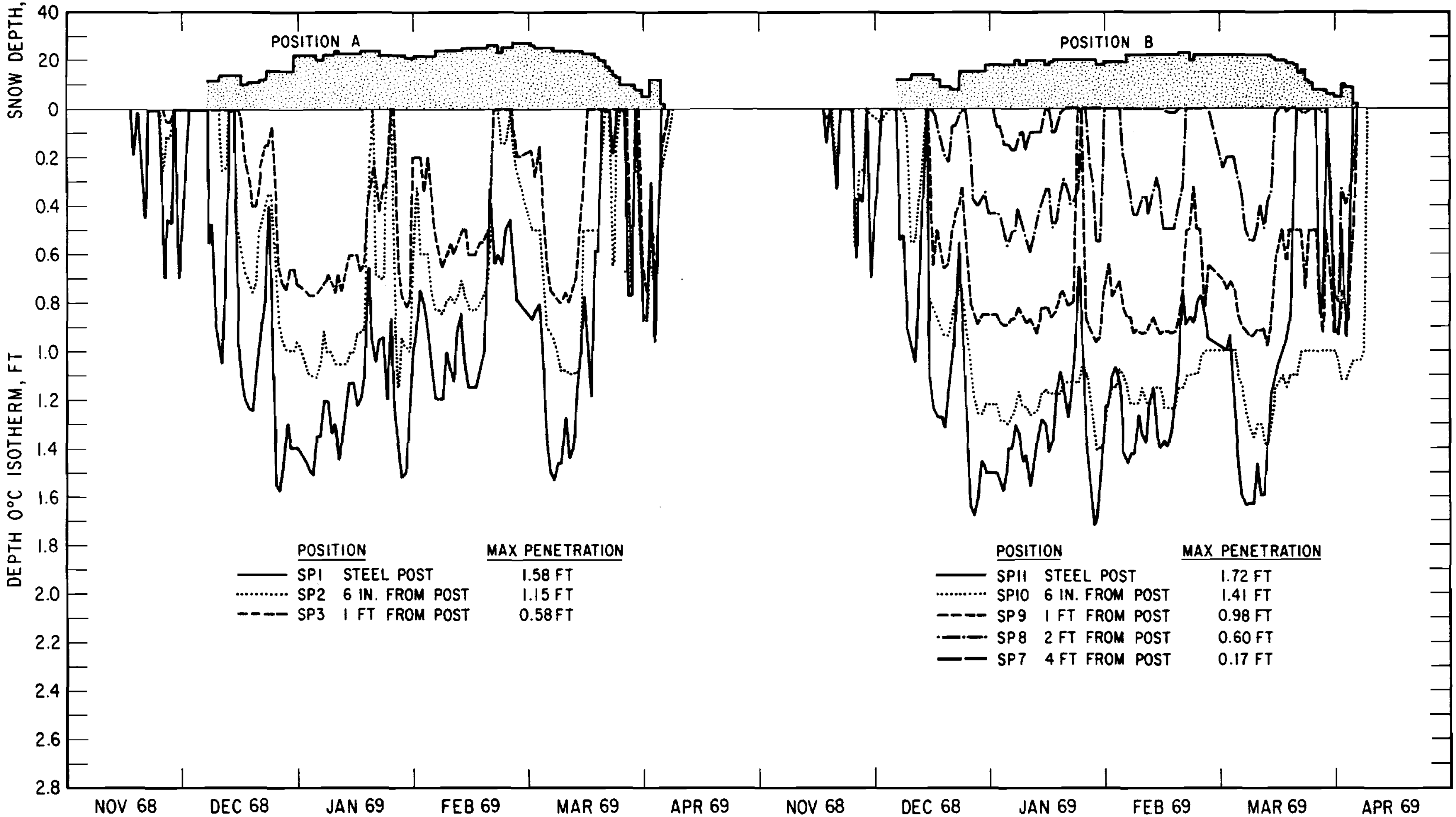


FIGURE 7

POSITION OF 0°C ISOTHERM ON STEEL POSTS AND IN THE GROUND AT VARIOUS LATERAL DISTANCES FROM POSTS

BR 4479-7

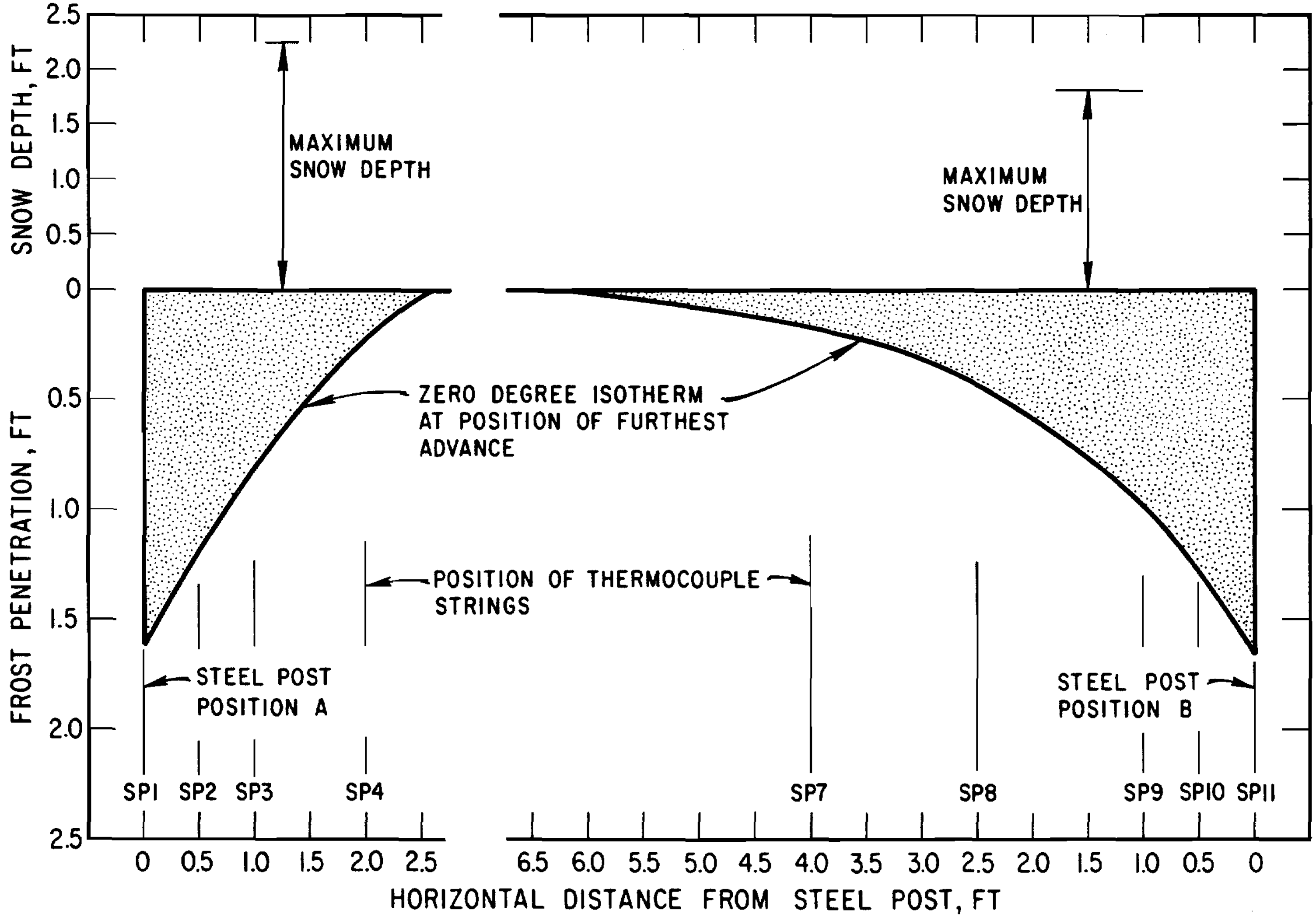


FIGURE 8
SECTION VIEW OF MAXIMUM FROST PENETRATION AROUND STEEL POSTS BASED ON ZERO DEGREE ISOTHERM

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