AD750270

Technical Note N-1248

BUILDING FOUNDATION STUDY AT MCMURDO STATION, ANTARCTICA

By

R. A. Paige

September 1972

Approved for public release; distribution unlimited.

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California 93043

22

BUILDING FOUNDATION STUDY AT MCMURDO STATION, ANTARCTICA

Technical Note N-1248

YF 38.536.001.01.006

by

R. A. Paige

ABSTRACT

The Naval Civil Engineering Laboratory (NCEL) investigated problems concerning subsurface temperatures, snow accumulation, and potential frost heaving beneath buildings at McMurdo Station, Antarctica. Two buildings were selected for a comparative study of their effects upon earth-fill foundation and underlying permafrost. One building has an open blow space beneath it for air circulation and the other is completely enclosed.

Snow drifting and accumulation beneath buildings with an open blow space is detrimental because it engulfs utility pipes and renders them inaccessible for maintenance. It is also a source of melt water which could cause fill erosion or frost heaving. It is concluded that any building can be enclosed as necessary because: (1) permafrost consists predominantly of solid rock; there are no zones of high-ice-content silty soils typical of the Arctic; (2) the buildings protect the frozen ground from solar and atmospheric heat and tend to prevent thawing; (3) the enclosed building has shown no detrimental foundation effects since its completion in 1964. The earth-fill pad is frozen solid and the area beneath the building is clean and dry.

Approved for public release; distribution unlimited.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Civil Engineering Laboratory Port Hueneme, California 93043	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP
3. REPORT TITLE BUILDING FOUNDATION STUDY AT MCMURDO STATION, ANTARCTICA	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) October 1970 to May 1972	
5. AUTHOR(S) (First name, middle initial, last name) Russell A. Paige	
6. REPORT DATE September 1972	7a. TOTAL NO OF PAGES: 18 — 7b. NO OF REFS: 1
8a. CONTRACT OR GRANT NO b. PROJECT NO YF 38.536.001.01.006 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TN-1248 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Facilities Engineering Cmd.

13. ABSTRACT

The Naval Civil Engineering Laboratory (NCEL) investigated problems concerning subsurface temperatures, snow accumulation, and potential frost heaving beneath buildings at McMurdo Station, Antarctica. Two buildings were selected for a comparative study of their effects upon earth-fill foundation and underlying permafrost. One building has an open blow space beneath it for air circulation and the other is completely enclosed.

Snow drifting and accumulation beneath buildings with an open blow space is detrimental because it engulfs utility pipes and renders them inaccessible for maintenance. It is also a source of melt water which could cause fill erosion or frost heaving. It is concluded that any building can be enclosed as necessary because: (1) permafrost consists predominantly of solid rock; there are no zones of high-ice-content silty soils typical of the Arctic; (2) the buildings protect the frozen ground from solar and atmospheric heat and tend to prevent thawing; (3) the enclosed building has shown no detrimental foundation effects since its completion in 1964. The earth-fill pad is frozen solid and the area beneath the building is clean and dry.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Foundations						
Buildings						
Investigations						
Antarctic regions						

INTRODUCTION

During the Deep Freeze 71 and 72 field seasons in Antarctica, the Naval Civil Engineering Laboratory (NCEL) investigated problems concerning subsurface temperatures, snow accumulation, melt water drainage, and potential frost heave beneath permanent buildings at McMurdo Station. All of the new buildings were examined, and two were selected to study the effects of heat loss upon the frozen fill beneath the buildings. Thermometers and thermocouples were used to obtain air and fill temperatures throughout the summer. Ground temperatures from beneath the buildings were compared with natural ground temperatures measured at two different sites during previous field seasons. Representative samples of natural frozen ground and frozen fill were collected for grain size and moisture content measurements to determine frost susceptibility.

This report discusses the results of the investigation and describes existing permafrost conditions at McMurdo Station. Recommendations are made for correcting the current problems and preventing potential future problems.

LOCATION AND PHYSICAL SETTING

McMurdo Station is located on the southern tip of Hut Point Peninsula, a prominent land feature extending 11 miles south from the main mass of Ross Island (Figure 1). Ross Island is of volcanic origin and is dominated by Mt. Erebus, an active volcano over 13,000 feet high. Land not covered by ice and snow amounts to only a few percent of the total area of Ross Island and occurs mostly at Cape Royds, Cape Evans, and on Hut Point Peninsula. About two square miles of land are exposed in the vicinity of McMurdo Station of which less than 0.5 square miles is utilized for the station facilities.

McMurdo Station is situated on the slopes of a cirque-like basin surrounded on three sides by hills 400 to 900 feet high (Figure 2). Most of the ice-free area is covered with thin surficial deposits of unweathered, angular rock fragments of all sizes. The windswept surface has been deflated of soil fines and generally consists of a mantle of larger rocks underlain by rocky, non-organic soil high in silt and sand-sized particles. Permafrost is one of the most important characteristics of the terrain and underlies all of the land area around McMurdo Station.

Permafrost refers to any naturally occurring earth material that is continuously below 32^{o}F for more than one year. Permafrost can be supersaturated silt or clay, solid rock, or dry sand and gravel.

Generally, only the fine-grained silt or clay soils having a high ice content are considered detrimental for foundations if thawing is permitted. The soil zone that seasonally freezes and thaws is defined as the active layer. The thickness of the active layer depends upon many factors, the most important of which are soil texture, moisture content, and vegetation cover. Frost heaving often occurs in the active layer if the soil has a high silt or clay content and if enough water is available. Frost heaving under natural conditions is rare at McMurdo Station because sufficient water is usually not available.

BUILDING FOUNDATION STUDY

Building foundations at McMurdo Station are basically the same and consist of an earth-fill pad two to more than ten feet thick depending upon the topography of the building site. The fill is leveled and compacted before placing timber footings that support either steel joists or columns of steel and/or timber. Most of the buildings are elevated from two to about six feet above the fill surface to provide an open blow space for air circulation beneath the building. This design prevents or retards thawing of the frozen ground that could be caused by heat loss through the floor of the structure.

Foundation Problems

The basic problem associated with an open blow space beneath buildings at McMurdo Station is one of snow accumulation during storms. The best example of this occurs beneath Building 155. As the snow accumulates, it engulfs utility pipes and renders them inaccessible for inspection or maintenance (Figures 3 and 4). This accumulation problem is especially severe in a climate where the winter snowfall tends to remain throughout most of the summer.

Secondary problems may occur when some of the snow melts during the summer. If this melt water accumulates and begins to flow over the sides of the earth-fill pad, serious erosion could result. Melt water can also form large puddles beneath a building (Figure 5) and soak the underlying fill. This could cause either differential footing settlement resulting from non-uniform fill compaction or frost heave damage during spring and fall freeze-thaw cycles. Although damage resulting from either one or both of the above causes is possible, it is considered somewhat unlikely because of the low permeability of the fill and the brief melting period.

Buildings Selected for Study

Of the new buildings examined, two were selected to compare the effects of an enclosed versus open space beneath the buildings. These buildings are the new Personnel Building (No. 155) featuring an open blow space, and the Dispensary (No. 142) which has the blow space completely enclosed by continuous skirting extending from floor level to the fill surface. As would be expected for polar buildings, the floors are extremely well insulated.

FOUNDATION STUDY RESULTS

Both of the buildings studied were instrumented with thermometers and thermocouples to determine temperatures both in the air space and in the fill beneath the buildings. Dial thermometers were placed directly on the bottom surface of the floor, in the intervening air space, and at shallow depths in the fill directly beneath the floor thermometers. Thermocouples were placed in holes drilled to depths of three to four feet in the fill. One string of thermocouples was placed to a depth of twelve feet in road-fill to obtain temperature profiles under natural atmospheric conditions. These data are compared with temperatures from beneath the buildings. All temperature sensors were placed beneath maximum heat sources in the buildings and far enough inward from the outside walls to avoid edge effects.

Samples of fill and undisturbed frozen ground were collected to determine particle size distribution and moisture content by standard methods. Data from ground temperature observations and subsurface investigations taken during previous field seasons are used as appropriate to provide additional comparative and descriptive information.

Sieve Analyses

The material used as fill at McMurdo consists of hard, angular, unweathered rock particles ranging from boulder to silt sizes with the grain size distribution depending partly upon location and bedrock geology. Sieve analyses of six representative samples indicates that 15 to 20 percent of the soil passes the No. 80 screen and from 10 to as much as 21 percent passes the No. 100 screen (Figure 6). A fine-grained soil fraction exceeding 3 percent silt or clay is considered to be potentially frost susceptible (Haley, 1953, p. 2)*. The basic conditions required for frost heaving are fine-grained soil in the silt to clay sizes, abundant water, and freeze-thaw cycles. Footing displacement due to frost heaving is a possibility because of soil fines and frequent freeze-thaw cycles. However, frost heaving can be prevented by proper drainage so that the required water cannot saturate the fill.

---

*Haley, J. F., 1953. Cold Room Studies of Frost Action in Soils, A Progress Report in Soil Temperatures and Ground Freezing. Highway Research Board Bulletin 71, pp. 1-18.

Moisture Content

Moisture content determinations of the soil fraction passing the No. 80 screen show a low of 2 percent and a high of 21 percent water by dry weight. Most of the samples were within 4 to 8 percent moisture content with an average of 5.3 percent. Moisture content of the frozen surficial deposits is low except in gulleys or other drainage areas; it can also depend upon topography and the time of year the fill is utilized.

The compactability of the soil at McMurdo is very good if larger rock fragments are removed. If the moisture content is below 8 to 10 percent, then water should be added for maximum compaction. The angle of repose is 35 to 45 degrees and any fill thicker than 2 or 3 feet becomes frozen solid and quite strong after the first winter, especially at a moisture content of 20 percent or more.

Natural Ground Temperatures

Ground temperature data provides a comparative basis for observing the effects of a building upon the natural temperature regime. One set of data is from Station A which consisted of thermocouples placed to a depth of 12 feet in a road-fill prism of dry, rocky soil about 8 feet thick (Figure 7). The unusually high temperatures of February 1972 probably result from intense solar heat penetrating the top and sides of the road-fill prism. The second set of data is from Station B (Figure 8) which had thermocouples placed to a depth of 10 feet in jointed rock covered with about 2 feet of fill. The data from Station B are probably more representative of natural ground temperatures than that from Station A. Time-temperature curves from Station B show summer temperatures at different depths (Figure 9). These curves illustrate how effective only 2 or 3 feet of soil is in attenuating daily or weekly temperature fluctuations.

Temperatures Beneath Buildings

Temperature data from beneath the instrumented buildings include both air and fill temperatures to a maximum depth of 42 inches. Figure 10 shows early season temperature profiles from beneath the Dispensary (Building 142, enclosed), the Personnel Building (Building 155, open blow space) and the road-fill at Station A. The curves in Figure 11 are plotted from measurements taken about a month later from the same sensors. The protective, or shading effect, of the buildings is obvious in both of the figures. A small but negligible heat loss through the floor is indicated by the slightly higher temperature under Building 142 (Figure 10).

The time-temperature curves in Figure 12 show the trend of temperature fluctuations at a specific depth beneath the instrumented buildings as compared with temperatures from the road-fill prism at

Station A. Again, the effectiveness of an enclosed building in protecting the frozen fill from high summer temperatures is well illustrated.

DISCUSSION

Of the new buildings having an open blow space, only the Personnel Building (No. 155) has enough snow accumulated beneath it to cause a problem. Accumulation beneath the other buildings has either been minor or non-existent; however, an unusual storm could occur at any time to completely alter the situation. The best method of preventing snow accumulation would be to completely enclose the blow space.

One objection to enclosing the open blow space concerns the possibility of heat loss that may thaw the underlying permafrost and cause footing settlement. This would be true for many areas in the Arctic where permafrost consists of high-ice-content silt and clay soils that become strengthless upon thawing. Under these conditions it would be necessary to provide air circulation, insulation, or other protection to prevent thawing beneath a heated structure.

Permafrost at McMurdo Station consists predominantly of solid rock with small amounts of ice in joints or other voids within the upper few feet of the surface. Even if this material thaws, overall settlement would be minor because of the interlocking nature of the jointed rock fragments. Settlement may be significant where an unusually large mass of ice occurs but it would probably be highly localized. In the McMurdo Station area, there are no known occurrences of high-ice-content silty soils typically found in the Arctic.

In a few small drainage areas such as the gulley between the diesel power plant and the USARP warehouse, a small area of permafrost consisting of angular gravel to boulder-size rocks in a matrix of ice is found. This material has been called ice-rock conglomerate and is potentially troublesome for foundations because, if thawed, the voids formed by melting ice may cause differential settlement. If foundation exploration discloses this kind of material, a compacted earth-fill pad more than 3 feet thick provides enough insulation to prevent thawing.

The soil in the active layer often undergoes numerous freeze-thaw cycles and can be responsible for damage to foundation elements by causing frost heaving. The intensity or amount of frost heaving depends upon soil texture, availability of water, and the frequency or intensity of freezing. Frost heaving can be prevented by removing or altering one or more of the required factors. This could include drainage to remove water, preventing the accumulation of water, or excavation to replace fine-grained soils with non-frost susceptible coarse-grained soils. The easiest method is usually to prevent the accumulation of water.

CONCLUSION

Of all the possible methods of preventing snow accumulation beneath elevated buildings at McMurdo Station, the easiest and probably the least expensive would be to completely enclose the open blow space provided the floor system of the building had the insulation quality typical of the two buildings studied. This would have no detrimental effect upon the underlying fill and permafrost for the following reasons:

1. Temperature profiles from beneath the buildings compared with natural ground temperatures show that the buildings tend to protect the frozen ground from solar and atmospheric heat and tend to prevent thawing rather than to promote it.

2. The earth-fill foundation pads are usually of low moisture content and tend to insulate the underlying permafrost, especially where the fill is more than three feet thick. Even during freeze-thaw cycles, there is no frost heaving if the moisture content is low.

3. The Dispensary has been skirted (enclosed) since its completion in 1964 with no detrimental results. The earth-fill pad is frozen solid and the area beneath the building is clean and dry.

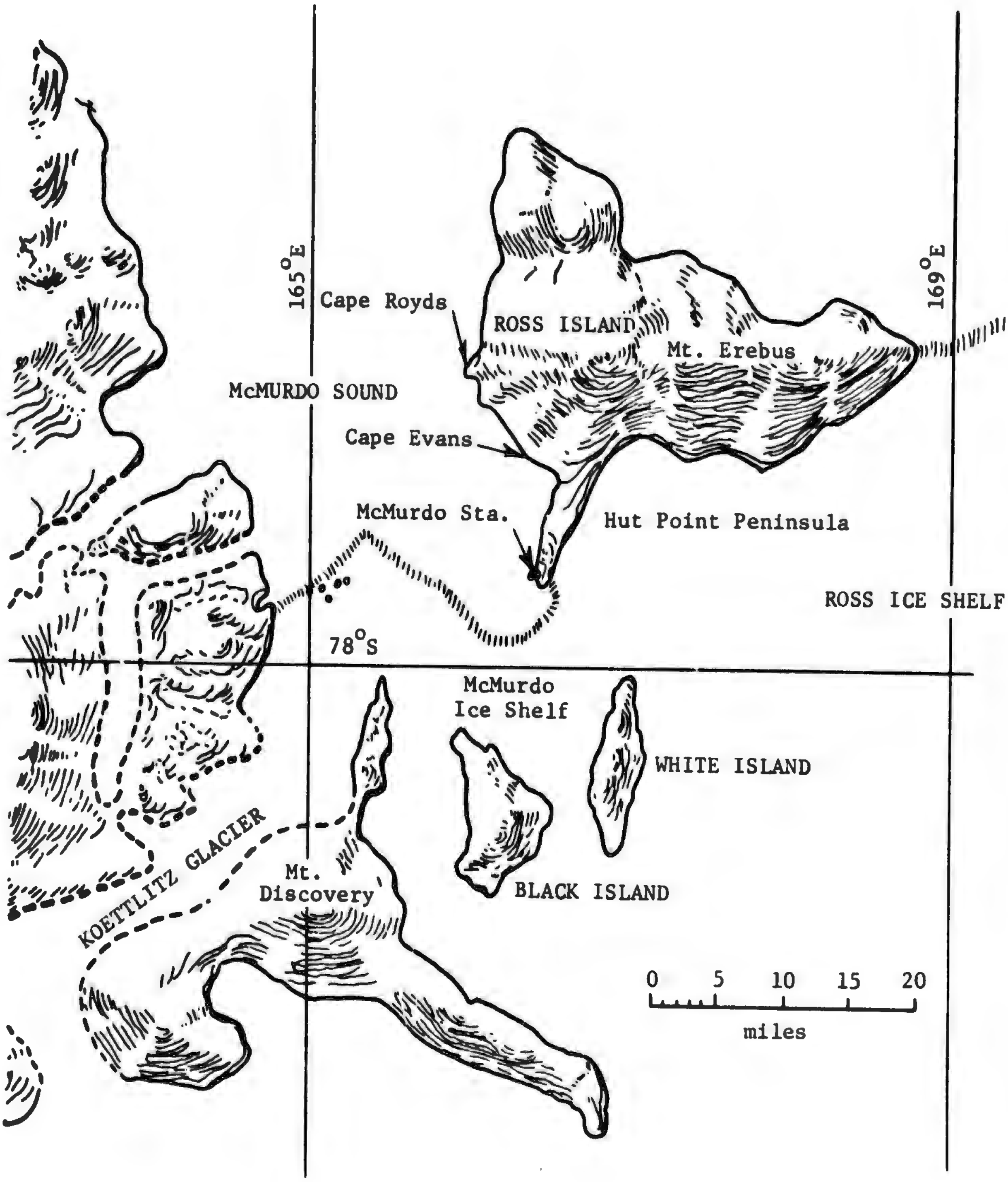

Figure 1. Index map of the McMurdo Sound region, Antarctica

Figure 2. View of McMurdo Station showing most of the new permanent buildings.

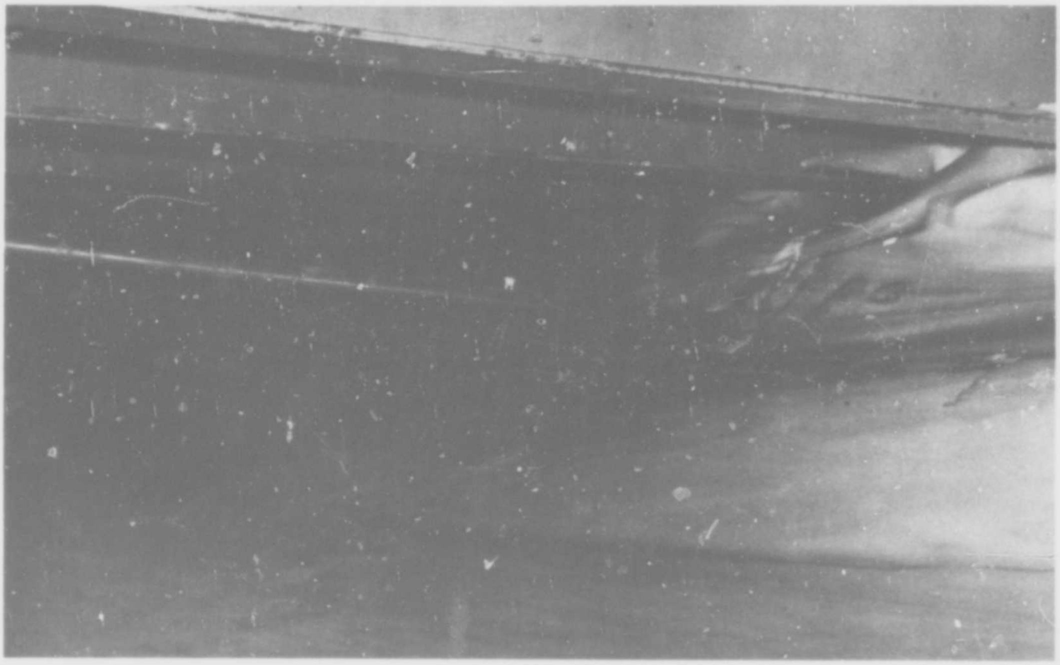

Figure 3. Utility pipes beneath Building 155 becoming engulfed in drifted snow.

Figure 4. Utility pipes beneath Building 155 that required extensive digging to provide access for repair.

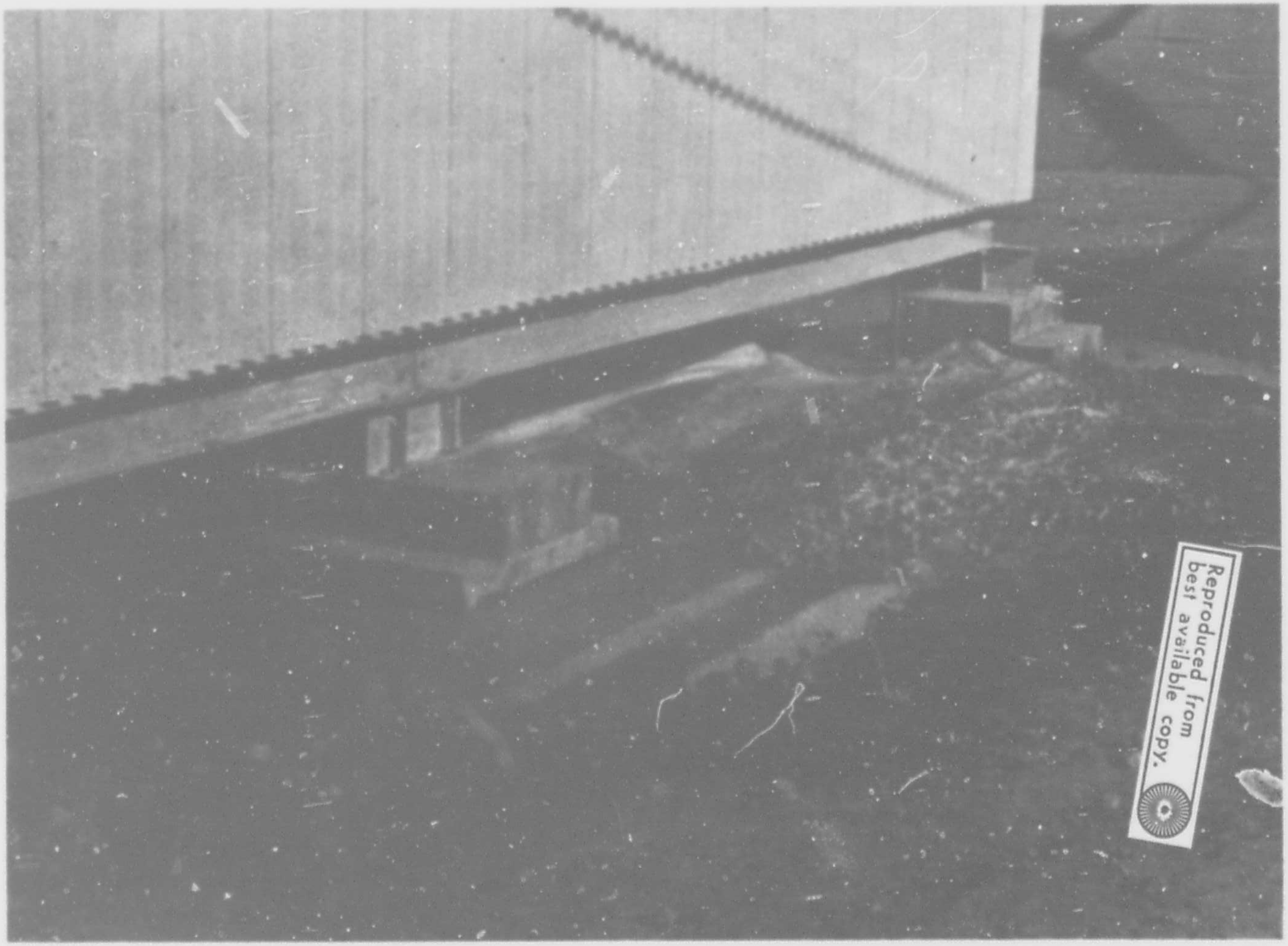

Figure 5. Melt water around footings of Building 155.

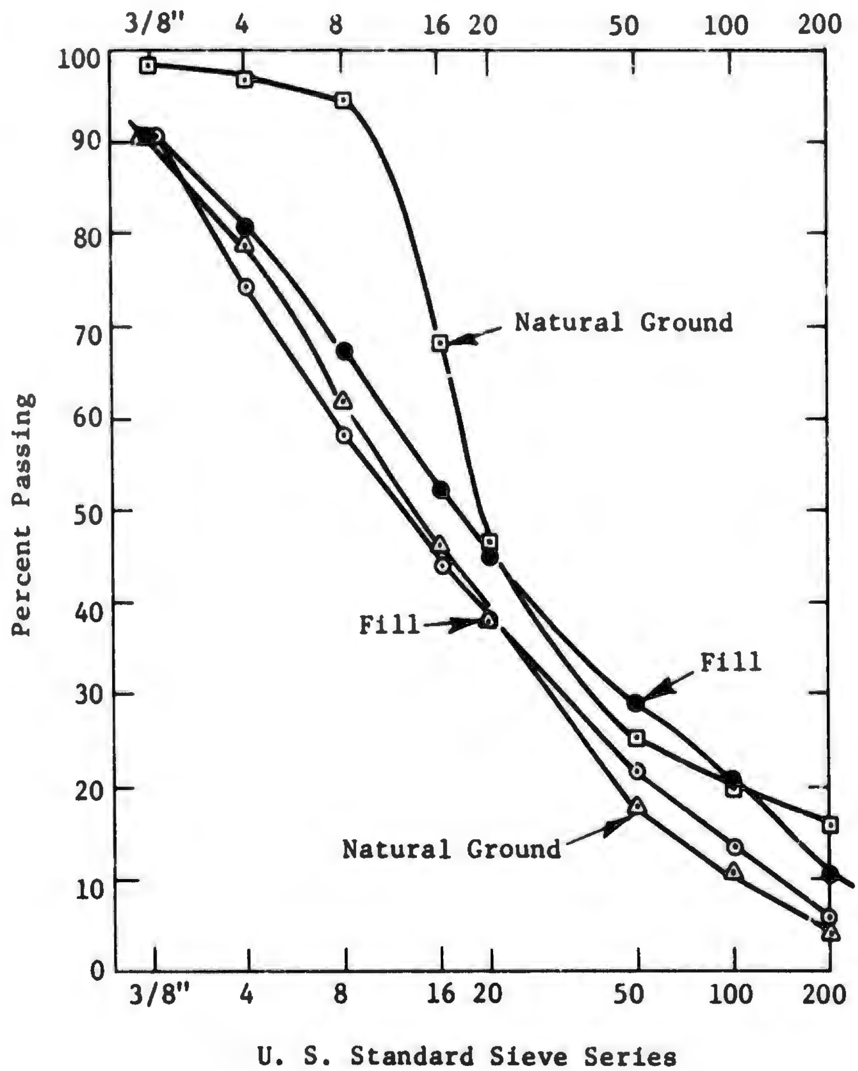

Figure 6. Sieve analyses of two fill and two natural ground samples at McMurdo Station, Antarctica. Particles larger than one inch were removed by hand.

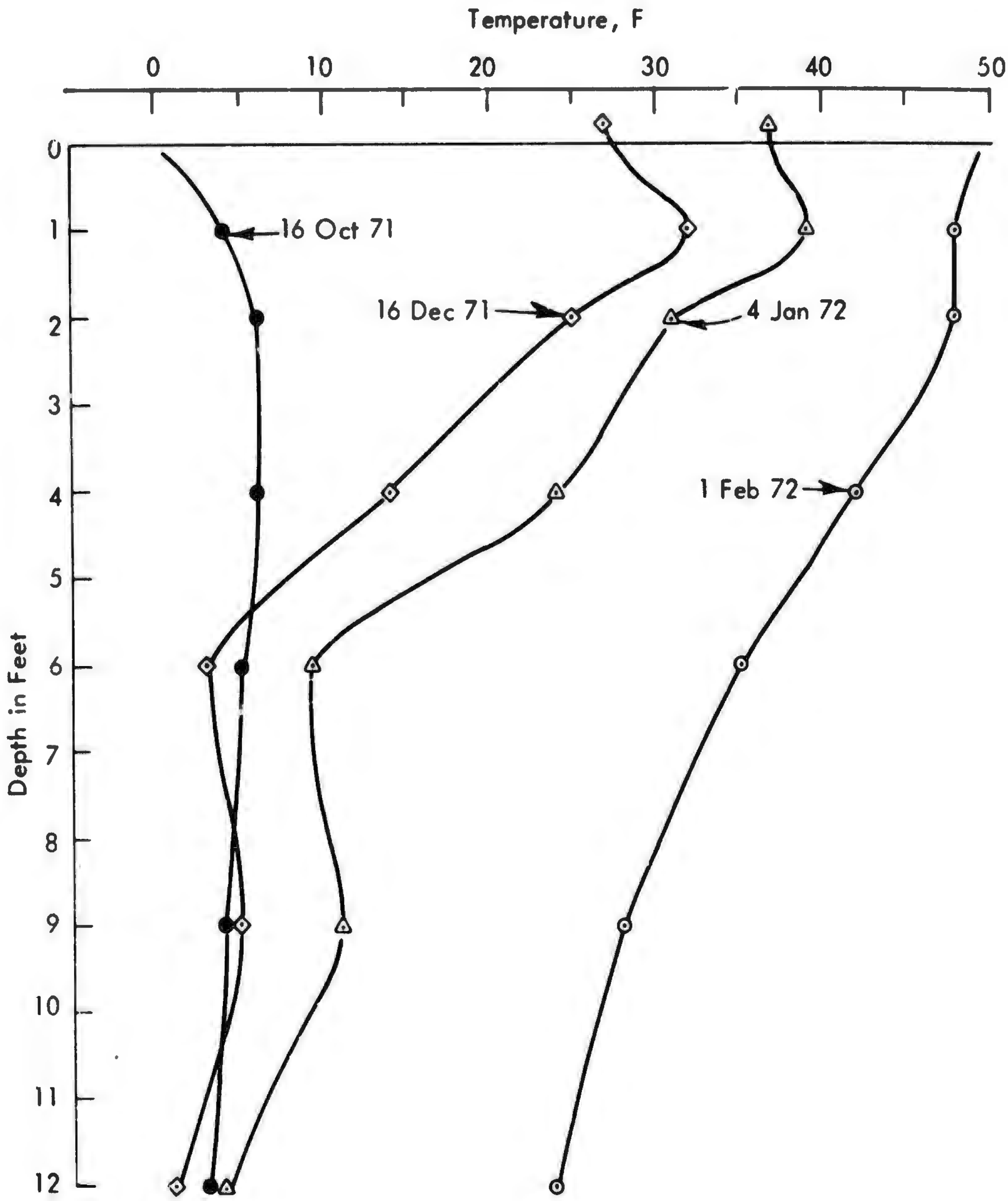

Figure 7. Representative ground temperatures at McMurdo Station, Antarctica. From Station A, Deep Freeze 72.

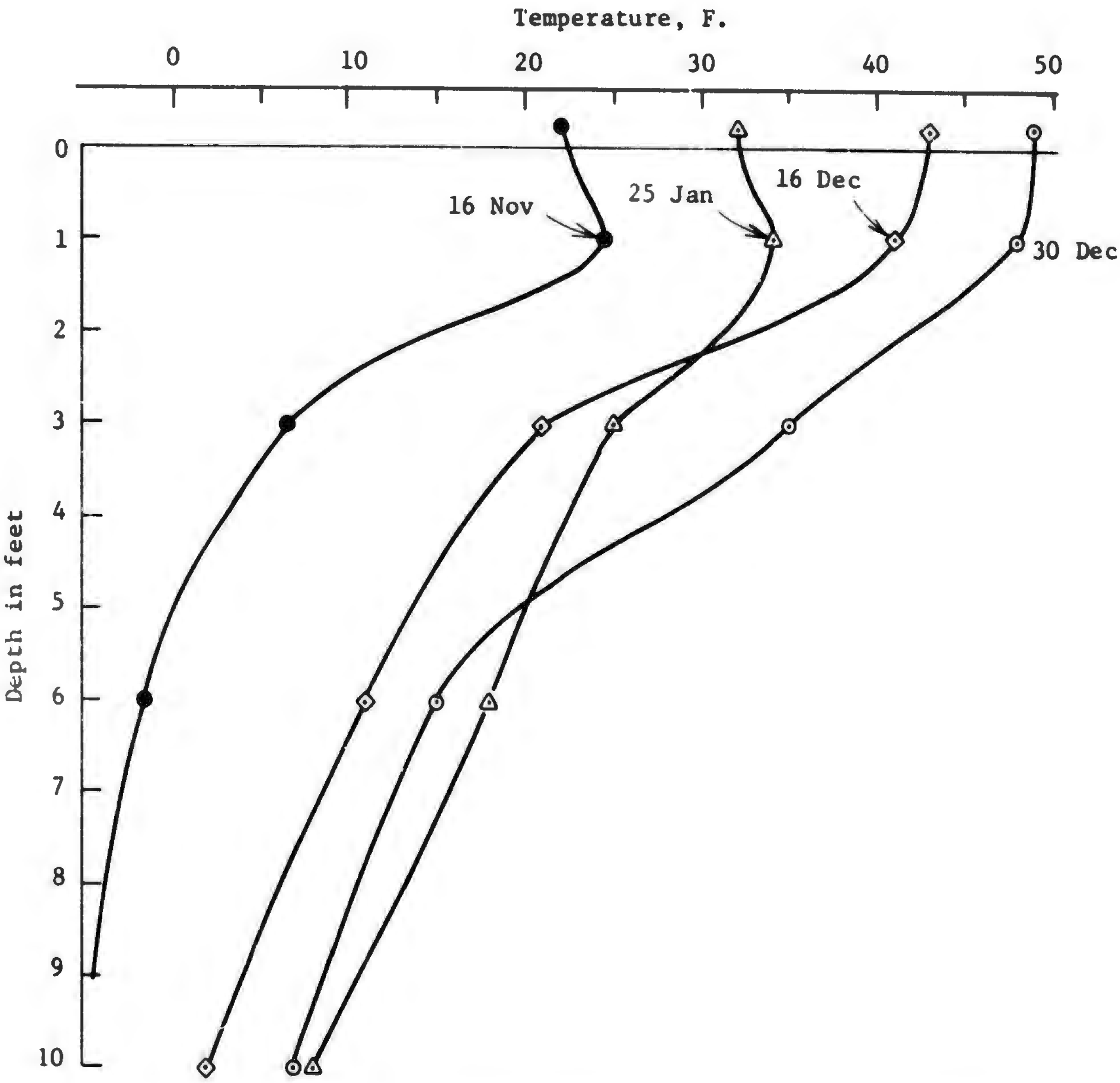

Figure 8. Representative ground temperatures at McMurdo Station, Antarctica. From Station B, Deep Freeze 68

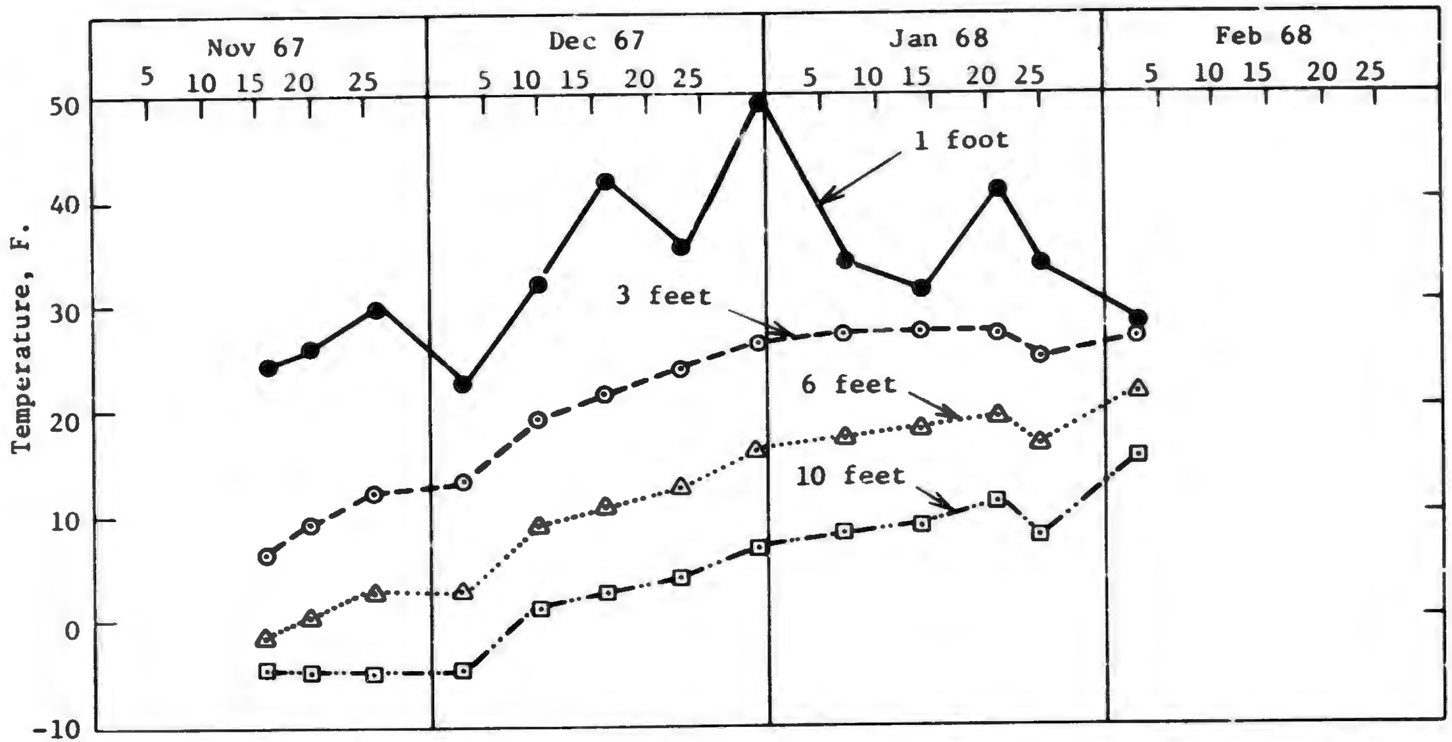

Figure 9. Summer ground temperatures at McMurdo Station, Antarctica.

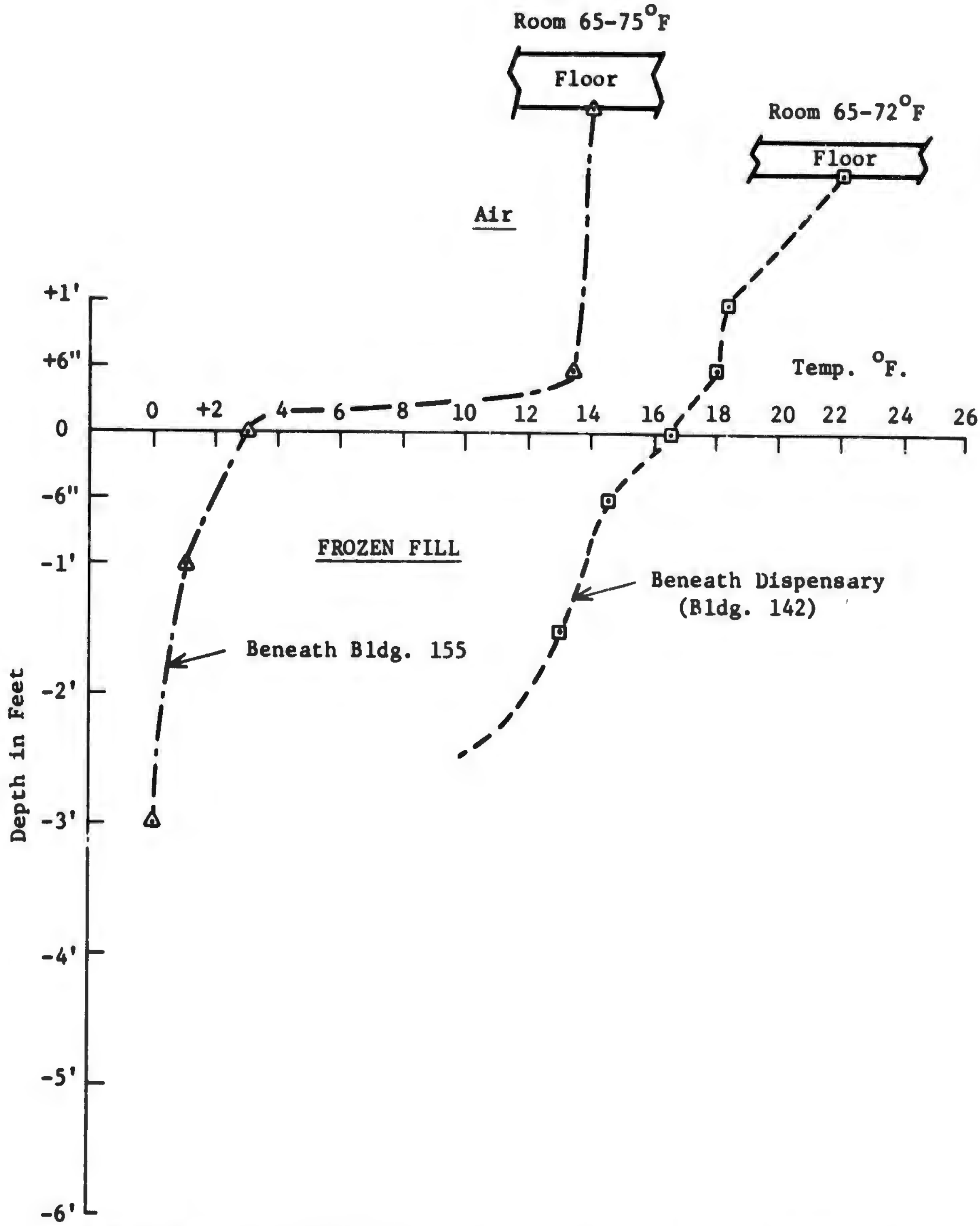

Figure 10. Temperature profiles for natural ground, frozen fill beneath the Dispensary and beneath the Personnel Building. 14 November 1970

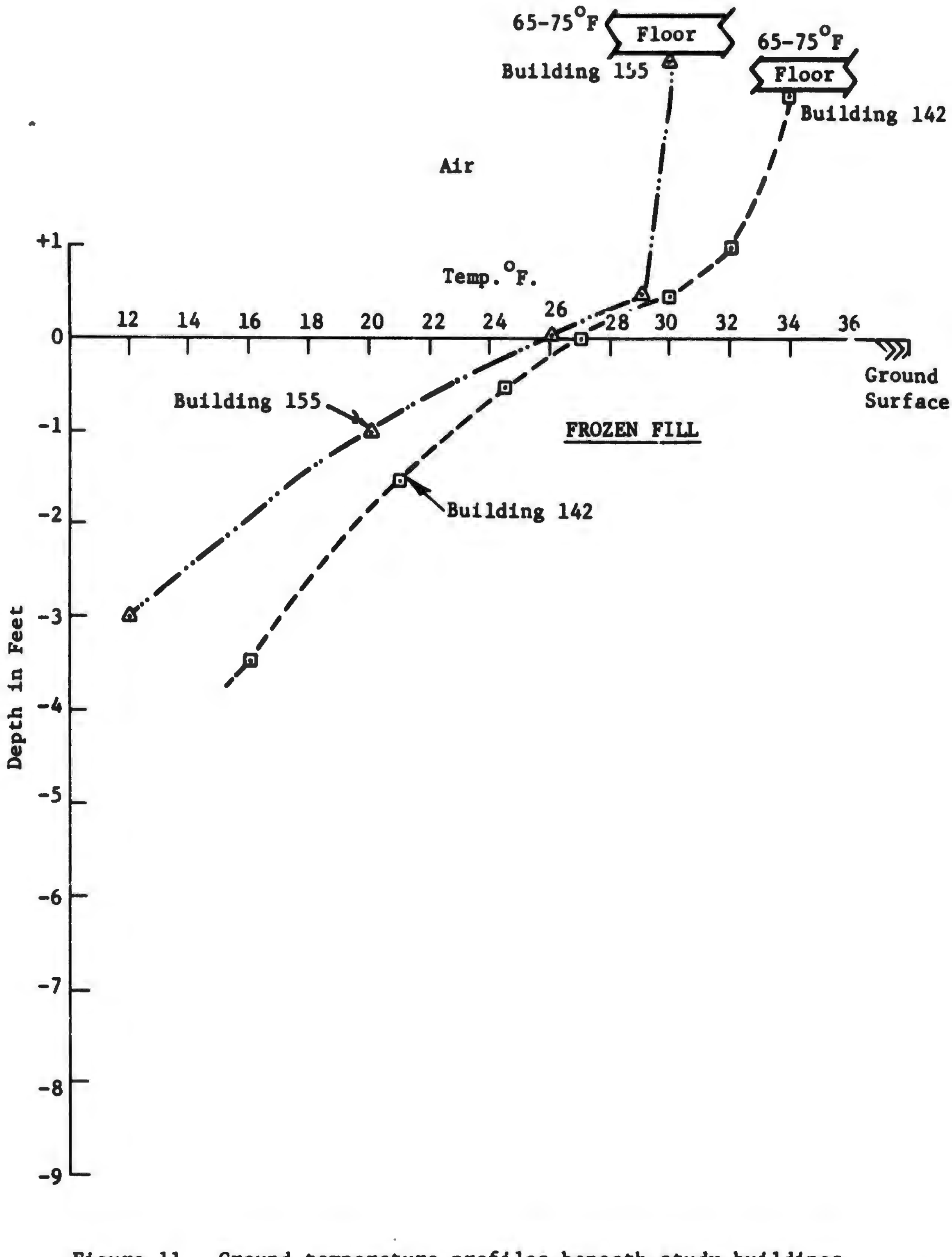

Figure 11. Ground temperature profiles beneath study buildings compared with ground temperature profiles of unprotected area on 12 December 1970, Deep Freeze 71.

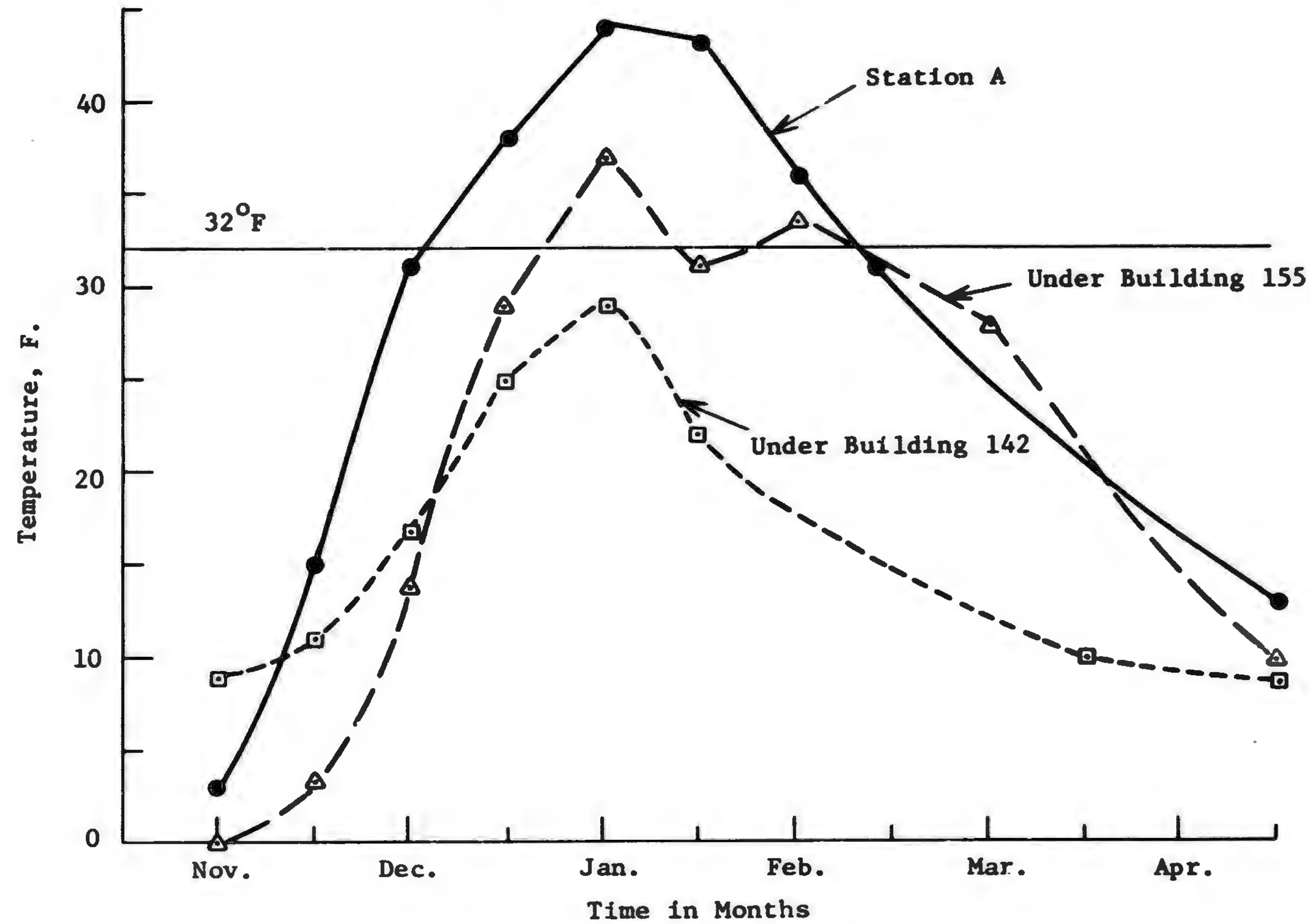

Figure 12. Trend of temperature changes at a depth of three feet beneath Buildings 155 and 142 compared with natural ground temperature.

DISTRIBUTION LIST

SNDL Code	No. of Activities	Total Copies	
--	1	12	Defense Documentation Center
FKAIC	1	10	Naval Facilities Engineering Command
FKNI	6	6	NAVFAC Engineering Field Divisions
FKN5	9	9	Public Works Centers
FA25	1	1	Public Works Centers
--	9	9	RDT&E Liaison Officers at NAVFAC Engineering Field Divisions and Construction Battalion Centers
--	180	180	NCEL Special Distribution List No. 7 for persons and activities interested in reports on Polar Engineering