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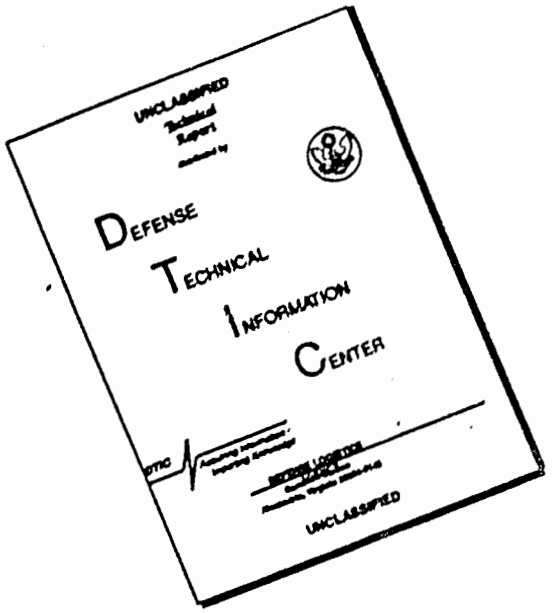

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ENGINEERING MANUAL

FOR

MCMURDO STATION

AD-A135 104

Sponsored by

U.S. NAVAL SUPPORT FORCE, ANTARCTICA

Prepared by

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with contributions from

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CIVIL ENGINEERING LABORATORY
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1974

Revised 1979

Approved for public release; distribution unlimited.

FOREWORD

This document presents engineering methods and operational procedures that have proved successful in working with the terrain and environmental features in the vicinity of McMurdo Station, Antarctica. Experience, as well as directly applied research in the McMurdo area, has provided the basis for the manual. The information could have application to other areas having the characteristics discussed in this manual; however, the manual pertains specifically to McMurdo Station.

The manual is organized into chapters, each of which covers a particular problem encountered at McMurdo. The subjects are listed in the Table of Contents; each chapter also has its own list of contents.

Original publication was made in 1974 with the thought that updating would occur when needed. These updates, as envisioned, could be as simple as pen-and-ink changes, or they could entail large additions of new material or extensive revisions of existing material. These updates would be made as further information on the area became available. Such information often is published in technical documents in other formats. Additions considered a permanent part of the manual are incorporated (in their original format) into the basic text of a chapter by including them after the figures and tables in that chapter (see Chapter 1, page 1-25 for an example). Other additions, often considered temporary, are included as appendixes at the end of the chapter.

A listing of the appendixes follows the last page of each chapter's basic material, just preceding the appendixes (see Chapter 4, page 4-25 for an example), even for those chapters having no appendix material at this time. Appendixes to be added at later dates will be listed on this page by the recipient to keep the manual up-to-date.

It should also be noted that any replacement or new pages in the basic text will be appropriately identified at the bottom left of the page as revisions or additions, respectively, along with the year of the change. A special note should be made concerning Chapter 8, which has been completely rewritten for the 1979 edition of the manual.

Addition – 1979

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Revised – 1979

INTRODUCTION

This manual describes the terrain and environmental features in the vicinity of McMurdo Station, Antarctica, and presents engineering methods and operational procedures for working within these natural constraints. The information contained has been developed from experience as well as from direct applied research.

The manual deals specifically with McMurdo Station and is not intended to apply to other areas even though it undoubtedly could have broader application. No information is contained on operation of the Williams Field air facility since this is intended to be the subject of a supplemental manual when that facility is relocated in 1975 or 1976.

It is intended that the manual will serve to maintain a record of successful operating methods and provide sufficient background to prevent duplication of previously tried ineffective methods. Considerable technical data are contained which should be of value in the solution of problems on-site.

BACKGROUND

The participation of the Navy in antarctic exploration began in 1839 when LT Charles Wilkes explored the coastal waters east of Palmer Peninsula. This was at a time when the actual existence of the antarctic continent was in dispute.

Establishment of McMurdo Station

The current Navy operation in Antarctica began in the austral summer of 1954-55 when the ice breaker *USS Atka* was sent to Antarctica to look for sites for bases to be established as part of the International Geophysical Year (IGY) scientific effort. One of the sites investigated was Kainan Bay, 30 miles east of the Bay of Whales (Figure 1). It was decided that a tractor train could be sent overland from this point to establish a station at 80°S, 120°W (Byrd Station). However, it was quickly apparent to the Navy that neither the equipment nor the personnel were available to establish or support a station at the geographic South Pole from Kainan Bay. Instead it was proposed to establish an air logistics station on Ross Island in McMurdo Sound. The site for this station was finally selected at Hut Point because Frank Debenham, a veteran of the second Scott expedition, was able to assure U.S. planners that the bay ice would support heavy cargo aircraft [1].*

Construction of the Naval Air Facility, McMurdo Sound, renamed McMurdo Station in 1961, began in the autumn of 1955 in order to be ready for the IGY which began in July 1957. On 20 Dec 1955, four Navy aircraft (two standard C-54's and two ski-equipped P2V Neptunes flew from Christchurch, New Zealand to McMurdo Sound in 14-1/2 hours, the first large cargo aircraft to take off from a distant land mass and set down in the Antarctic.

[1] Encyclopaedia Britannica, vol. 2, 1971 ed., Chicago, Ill., p. 17.

* For the remainder of the Manual, references will be listed at the end of each chapter.

The IGY was scheduled to end on 31 Dec 1958. Originally, it was expected that the United States would withdraw early in 1959 but the success of the IGY scientific program resulted in a decision to continue the program for an indefinite period. The principal impact on McMurdo Station was the change in status from a temporary camp to a permanent station and the inauguration of a long-term redevelopment program to improve or replace the temporary station facilities.

NCEL Participation in Antarctica

Participation of the Naval Civil Engineering Laboratory in Navy antarctic operations began in 1955 with the site-selection expedition of the ice breaker *USS Atka* and in 1956 with a performance study of mechanical equipment specially built or modified by NCEL for antarctic operation.

Though not active in Antarctica during the IGY, NCEL resumed participation in Deep Freeze (DF) operations in the austral summer of 1959-1960 (Deep Freeze 60) and each year since has had representatives in McMurdo during the summer construction seasons. This work was primarily a research and development effort to improve Navy operational capabilities in polar regions. Funding for this work was provided by the Naval Facilities Engineering Command which was previously known as the Naval Bureau of Yards and Docks. The largest participation by NCEL occurred in 1964 when a self-sufficient camp for 24 people was established near the edge of the McMurdo Ice Shelf 2.5 miles from Pram Point. During this season, a 5,000-foot runway of compacted snow was constructed which successfully supported fully loaded C-130 aircraft on wheeled take-off and landings.

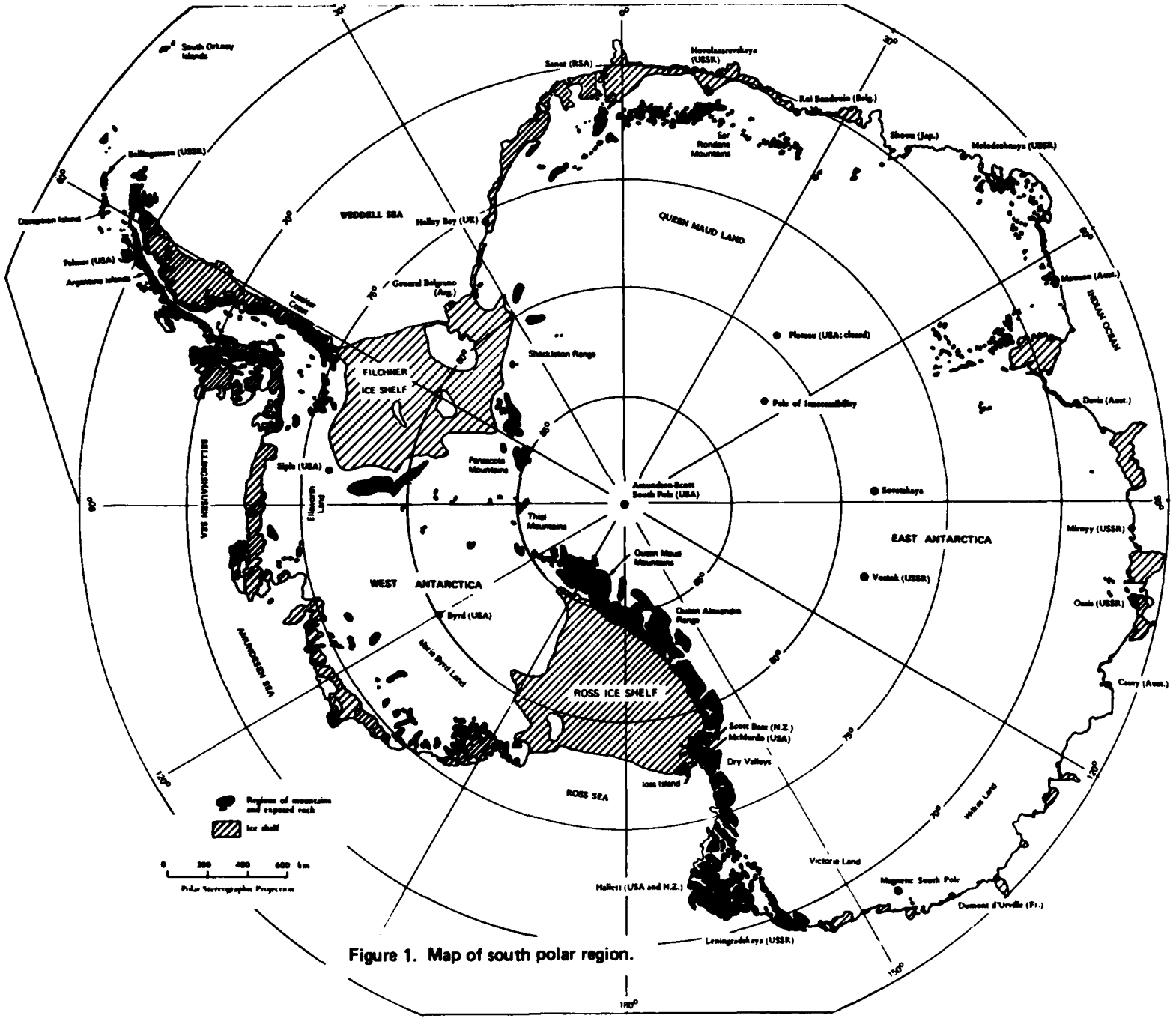

Figure 1. Map of south polar region.

Chapter 1

PHYSIOGRAPHY OF THE MCMURDO AREA

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Revised – 1979

Chapter 1

PHYSIOGRAPHY OF THE MCMURDO AREA

INTRODUCTION

The dominant physiographic features in the McMurdo Station area include part of the Ross Ice Shelf, the annual sea ice on McMurdo Sound and the bare, volcanic rock hills of Hut Point Peninsula. Experience has emphasized the need for a knowledge and understanding of these areas. This was illustrated in DF-61 and again in DF-64 when unstable ice conditions not previously recognized or known required an unscheduled and hurried dismantling and relocation of the Williams Field Air Facility when ice breakup engulfed the area.

GEOGRAPHY

The McMurdo Station complex is located on and adjacent to the southern end of Hut Point Peninsula, a prominent land feature extending 11 miles south from the main mass of Ross Island (Figure 1-1). The station complex consists of McMurdo Station on Hut Point Peninsula, the Williams Field Air Facility on the deep snow of the ice shelf, and the ice runway on the annual sea ice of the McMurdo embayment. This embayment is about 4 miles wide and 6 miles long in an east-west direction (Figure 1-2). Since it is covered with sea ice for about 10 months each year and used extensively for roads and runways, it should be considered as part of the McMurdo complex.

The map in Figure 1-3 shows the McMurdo area in greater detail and covers approximately 80 square miles. The Ross Ice Shelf and the ice covered embayment of McMurdo dominate the area in relation to the land mass. The ice shelf south and west of Hut Point Peninsula and east to a line connecting the northern tip of White Island with Cape MacKay is significantly different from the rest of the Ross Ice Shelf and has been called the McMurdo Ice Shelf [1]. (Maps in this manual do not show Cape MacKay and Cape Crosier.) A zone of pressure ridges 2 to 4 miles wide extends for about 30 miles southwest from Cape Crosier and represents a transition between the northward-moving Ross Ice Shelf and the westward-moving McMurdo Ice Shelf.

METEOROLOGY

The climate of the McMurdo Station is less severe than many areas of the Antarctic, being tempered by the proximity to the ocean and the near sea level elevation. The local climate has not been studied in detail but is known to vary significantly with changes in location of a few miles.

Temperature

The average monthly temperatures at McMurdo Station for a 13-year period are presented in Table 1-1. Averages for other

antarctic locations are also shown for comparison. As may be seen, the coldest temperatures occur in July and August with a mean monthly temperature of -15 and -19°F, respectively. The warmest temperatures occur in December and January with a mean temperature of 26°F for both months. The average mean temperature during the summer construction (November through February) is 20°F and the mean temperature for the entire year is 0°F.

Precipitation

All of the precipitation at McMurdo Station occurs as snow. The annual total as shown in Table 1-2 is equivalent to 6.84 inches of water. January, February, and June are the months of heaviest precipitation. The distribution of the annual snowfall is highly dependent on winds. Exposed land areas are essentially snow-free year-around and sheltered areas accumulate heavy drift.

Winds

Winds at McMurdo Station are strongest during the winter months and prevail from the east with storm winds from the south. The mean monthly wind velocities are presented in Table 1-3. The velocity of peak wind gusts for McMurdo and other antarctic stations is shown in Table 1-4. Winds often result in blowing surface snow which reduces visibility and increases the difficulty of outdoor work. In winter when surface snow is dry, blowing snow can be expected at wind velocities of about 10 knots and above. In summer, when the surface snow is warmer and more dense, higher wind velocities of 15 to 20 knots are required to produce a similar condition. Figure 1-4 shows the average number of days with blowing snow for the different months of the year.

Sunlight and Solar Radiation

With the extreme southern latitude, McMurdo Station is subject to seasonal periods of continuous daylight and continuous darkness. The sun first rises above the horizon on 19 August following a period of winter darkness and sets for the final time each fall on 12 April. The number of hours of sunlight and twilight each day can be determined from Figure 1-5.

Solar radiation during periods of sunlight has a significant warming effect on people and materials. Melting of ice and snow is common during periods of bright sunlight even when air temperatures are below 32°F. The average numbers of cloud-free hours and of bright sunlight, each day during the daylight period, are also shown in Figure 1-5. These data are available for only 2 years but show reasonably close agreement. Figure 1-6 shows the heating produced by short-wave solar radiation in the McMurdo Sound region during different months of the year and varied cloud cover.

Wind Chill

Wind chill is the cooling effect of moving air on a body, taking into account both temperature and wind speed. It is expressed as the amount of heat lost per unit area per unit of time. The effect of wind chill is most apparent in the increased rate of heat lost from the human body as wind velocities increase. Wind chill also affects heat loss rates from any warm body and causes, for example, the engine of a vehicle to cool more rapidly

when shut down or causes a pipeline carrying water to freeze at an air temperature where freezing had not occurred previously when the air was still. Wind chill does not change the reading on a thermometer nor change the characteristics of a material which is already at the air temperature, such as the impact strength of steel. Figure 1-7 shows the cooling rate on a warm body as a resultant effect of wind and temperature. Degrees of human discomfort are also indicated for an individual in a state of inactivity. Figure 1-8 presents the cooling power of wind expressed as equivalent chill temperature and is more convenient to use in assessing the protection required for human comfort and safety.

GEOLOGY AND GLACIOLOGY

Land not covered by ice and snow amounts to only a few percent of the total area of Ross Island. Most of the exposed land in the southern McMurdo Sound area occurs at Cape Royds, Cape Evans, the Dellbridge Islands, and on Hut Point Peninsula. Approximately 2 square miles of land is exposed in the vicinity of McMurdo Station, of which less than 0.5 square mile is utilized for the station complex. Figure 1-9 shows distribution of permanent snowfields and bare ground in this area.

Topography

McMurdo Station is constructed on the south-facing slope of a cirque-like basin surrounded on three sides by hills 400 to about 700 feet high (Figure 1-10). The topography is hilly, moderately rugged, and has high local relief. Observation Hill is one of the prominent and historically famous landmarks and rises from sea level to 747 feet within a horizontal distance of about 2,000 feet. The Arrival Heights area consists of a broad, north-south trending range of volcanic hills having elevations of 900 to almost 1,000 feet and descending southward to the low, elongated hill of Hut Point on the western side of Winter Quarters Bay. Crater Hill is about 1 mile north of Observation Hill and is also a prominent landmark having an elevation of 987 feet. The Pram Point basalt flow, upon which Scott Base is located, originated from the Crater Hill volcano during its active stage sometime in the prehistoric past.

Hut Point Peninsula consists entirely of volcanic rocks that are predominantly olivine basalts with smaller amounts of associated, less basic rocks such as trachite, tuffaceous agglomerate, phonolite, and kenyte. The basalt ranges from black, dense, microvesicular rocks through vesicular basalt. Scoriaceous and cindery masses are found on the surface and as irregular, interflow layers and lenses. The basalts occur as flows of varying thickness and extent, and as massive, but small, volcanic necks such as Crater Hill and Observation Hill.

Rock debris 6 inches thick or more covers most hill slopes and fills small valleys and other low areas. Most of the surface consists of wind-swept lag gravel that is underlain by varying amounts of dry silt and sand-sized particles. Perennially frozen ground (permafrost) is continuous and, during the middle-to-late summer season thaw, occurs at depths of 8 to about 12 inches depending upon location, slope angle, and slope orientation. All unconsolidated material is frozen from these depths down to solid rock. A description of the permafrost conditions at McMurdo Station is contained in Chapter 4.

Rock Quarry

The Fortress Rocks, about 3,000 feet north of the central McMurdo Station complex, is the most suitable source for large quantities of high quality concrete aggregate and fill material in the McMurdo area. This site consists of a small elliptical knoll about 1,000 feet long and 500 feet wide. The knoll rises 20 to 60 feet above the surrounding, south-sloping hillside and could provide 500,000 cubic yards or more of rock fill.

The rock is of local volcanic origin and consists predominantly of slightly to moderately vesicular olivine basalt. Most of the rock is dense, hard, solid basalt or hard, vesicular basalt with small amounts of cindery rock. The entire deposit is closely jointed and, with proper blasting, should be easy to quarry. The quarry has been thoroughly sampled and tested as a source for concrete aggregate [4]. Rock sample analyses are found on page 1-25.

Fast Ice

Fast ice is defined as sea ice more than 1 year old that has frozen to and accumulated along the shoreline. Fast ice can also form in protected embayments where the annual sea ice may remain for 1 or more years without breaking up and going to sea.

The amount of fast ice along the McMurdo shoreline has not been fully determined but it is believed to extend from the tip of Hut Point Peninsula around Winter Quarters Bay at least as far as Cape Armitage. The most satisfactory method of determining the presence of fast ice is by core drilling with the tube core bit described in Chapter 8.

The largest area of fast ice is that comprising the ice wharf used for cargo ship off-loading since DF-64. This section of ice, which is about 150 feet wide and 400 feet long, is described in detail in Chapter 6. Fast ice was found beneath the sewage outfall structure in DF-71 when wave action undercut the piling set into it causing separation from the land (Figure 1-11). Drilling has also shown the presence of fast ice on the shoreline at VXE-6 Hill Road, but the full extent has not been determined.

Snow-Drift Ice Slabs

These features form in areas where the annual accumulation of windblown snow exceeds the annual loss by sublimation or melting. A permanent snowfield results that usually consists not only of snow and firn (dense, old snow) but may grade downward into ice (density 0.81 gm/cm^3) if the deposit is thick enough. These snowfields are common in the McMurdo Sound region [5] and can occupy a shoreline position similar to fast ice. The two deposits may appear to be similar topographically but can easily be differentiated by differences in ice crystal composition, origin, and the fact that snow-drift ice slabs have an upper surface usually well above sea level. A good example of coastal slabs can be found along the shoreline of Cape Armitage.

Lakes

Three perennially frozen, freshwater lakes occur in the Arrival Heights area about 0.75 mile north of McMurdo Station. Two of the lakes are located within a small crater and the third, known as Star Lake, occupies a shallow depression north of the crater. During December and January, the greenhouse effect of intense solar radiation, low reflectivity of

the blue, bubbly ice, and dark colored dirt in the ice causes subsurface melting similar to that in the snow free area of the McMurdo Ice Shelf described in Chapter 2. By midsummer, the ice cover over Star Lake may thin to as little as 4 inches and water beneath the ice may be as much as 3 feet deep.

Star Lake has often been used as an extra source of freshwater for McMurdo Station, and during DF-67, was estimated to contain 70,000 gallons by late December. To promote subsurface melting and a maximum continuing summer water supply, the ice surface of the lake should be kept clear of any snow cover that may collect during the summer months.

OCEANOGRAPHY

The water depths in McMurdo Sound embayment south and east of McMurdo Station are shown in Figure 1-12. As may be seen, the depth increases rapidly from the shoreline, and the water is over 1,800 feet deep in the vicinity of the Williams Field 3 annual ice runway.

Tides in the McMurdo area are small ranging from less than half a foot above and below mean tide level to a maximum of 1.7 feet above and 2.0 feet below. The most current tide tables are available from the Naval Oceanographic Office, Oceanographic Analysis Division, Washington, D.C. 20390.

NATURAL HAZARDS

Various natural hazards exist in the vicinity of McMurdo Station that should be avoided by inexperienced personnel traveling on foot or in vehicles. These areas are described by the following letter designations and relate to the map in Figure 1-13.

A. The hillside area above the big curve in the compacted snow road is heavily crevassed both by visible and by hidden crevasses and should be avoided by vehicles or personnel on foot. A Trackmaster vehicle and a rescuing D-8 tractor each fell into separate crevasses in this area in DF-72. Crossed flags traditionally warn of crevasses and should be taken seriously at all times.

B. One large crevasse occurs along the compacted snow road between the road and the cliffs north of Scott Base. This crevasse is covered by wind-packed snow and has been filled and compacted in the road area. As a result, it is usually not visible even in late summer.

C. There are many crevasses in the pressure ridge zone near Scott Base. These crevasses are oriented both parallel with and perpendicular to the long axis of pressure ridges. Most of the crevasses are small and well hidden and can easily cause leg injuries to careless personnel on foot. Slush pools also occur in the swales between pressure ridges and can be dangerous during late summer (Figure 1-14). Slush zones are often bridged over with dry snow and are indistinguishable from the surrounding safe areas.

D. A narrow zone of intensely ridged and broken sea ice forms each season in the area between Scott Base and Cape Armitage (Figure 1-15). These pressure ridges, along with downwarped, flooded areas, usually occur at the sea ice-to-land contact and are easily avoided because of their prominence.

Slush zones also form in this area and are different from the slush pools associated with pressure ridges. Slush zones form in the area between Scott Base and Cape Armitage where the snow cover is often more than 1 foot thick. By midsummer, large areas of snow may become flooded with seawater to form strengthless slush. Flooding is usually caused by tide cracks or seal breathing holes. Slush zones can be several hundred square yards in extent and may not be visible because of an undisturbed crust of wind-packed snow. Vehicles can break through the crust and become stuck in the slush (Figure 1-16).

E. Areas "E" and "E_1" are zones of sea ice that become dangerously thin when the sea ice elsewhere in McMurdo Sound is still thick enough for safe travel. The most important, and dangerous, thin ice area is off Cape Armitage and covers about 90 acres (Figure 1-17). During DF-63 a driver and passenger in a D-8 tractor taking a shortcut from McMurdo to Williams Field broke through the ice in this area and sank in 35 feet of water. The driver and passenger survived through considerable luck and the tractor was recovered.

F. This small area of steep ice slopes should be avoided by the casual hiker. The sailor from Scott's crew commemorated by the cross on Arrival Heights was believed lost in this area.

G. Crevasses like cornices often form between the vertical face of the ice shelf and the wedge of drifted snow resting on the sea ice. These crevasses are seldom dangerous but could cause injury to personnel on foot. Figure 1-18 shows a vehicle immobilized in this hazard.

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APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

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5. R. L. Nichols. "Snowdrift ice slabs and historic Antarctic climatic warming," Journal of Glaciology, vol. 5, no. 39, 1964, pp. 345-351.

Table 1-1. Air Temperatures at Selected Antarctic

Stations	Lat	Long	Elevation (m)	Years of Record	January			February			
					Max	Mean	Min	Max	Mean	Min	Max
McMurdo (USA)	77°51'S	166°40'E	59	13	42	26	4	39	17	7	26
South Pole Station (USA)	90°00'S		9,186	12	6	-20	-42	7	-40	-69	-19
Byrd (USA)	80°01'S	119°32'W	4,959	12	31	5	-21	26	4	-38	16
Cape Hallett (US NZ)	72°19'S	170°13'E	16	9	47	30	9	40	27	15	31
[illegible] (USA)	75°15'S	77°06'W		3	34	14	-9	29	[illegible]	-27	28
[illegible] (USA)	77°43'S	41°08'W	[illegible]	6	33	17	0	27	3	-23	25
[illegible] (USA)	78°11'S	162°12'W	158	3	42	20	6	32	12	-36	29
[illegible] (USA)	79°15'S	40°30'E	11,890	3	-1	-30	-56	15	-49	-77	-33
[illegible] (USSR)	78°27'S	106°52'E	11,200	3	-8	-31	-57	13	-49	-83	-46
[illegible] (Australia)	68°35'S	77°58'E	40	7	45	32	17	42	27	3	37
[illegible] (Australia)	66°01'S	110°32'E	31	7	48	31	18	42	28	13	27
[illegible] (Argentine)	62°59'S	60°43'W	26	8	51	34	19	48	34	20	36
Dumont D'Urville (France)	66°40'S	140°01'E		8	41	30	16	40	22	5	37
Halley Bay (Base Z) United Kingdom	75°31'S	26°36'W		6	36	22	4	32	14	17	26

Stations	July			August			September			October		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
McMurdo (USA)	24	-15	-59	18	-19	-57	19	-13	-47	24	-4	-39
South Pole Station (USA)	-29	-75	-113	-27	-75	-108	-35	-75	-110	-21	-60	-89
Byrd (USA)	10	-33	-82	8	-34	-80	14	-35	-80	12	-24	-73
Cape Hallett (US NZ)	25	-16	-44	20	-16	-54	21	-12	-41	28	-1	-41
Lights (USA)	15	-29	-62	8	-36	-76	17	-30	-61	26	-20	-69
Ellsworth (USA)	10	-28	-61	20	-28	-61	20	-23	-60	25	-9	-70
Little America (USA)	23	-30	-70	22	-35	-78	21	-27	-73	29	-13	-53
Plateau (USA)	-47	-91	-123	-42	-96	-121	-36	-86	-120	-35	-75	-112
Vostok (USSR)	-47	-89	-117	-62	-96	-127	-48	-90	-116	-41	-75	-104
Davis (Australia)	30	1	-36	30	1	-34	29	1	-30	33	11	-18
Wilkes (Australia)	34	3	-35	31	5	-30	30	5	-30	30	11	-19
Deception (Argentine)	40	16	-13	41	17	-18	39	22	-10	45	27	2
Dumont D'Urville (France)	32	0	-28	31	1	-29	30	3	-34	32	9	-19
Halley Bay (Base Z) United Kingdom	23	-18	-60	24	-21	-58	23	-16	-58	29	-2	-50

r Temperatures at Selected Antarctic Stations (°F)

	February			March			April			May			June		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
	39	17	-7	26	0	-46	25	-7	-39	19	-12	-48	21	-11	-40
	-7	-40	-69	-19	-66	-95	-18	-73	-99	-30	-72	-100	-24	-71	-109
	26	-4	-38	16	-19	-64	19	-22	-70	20	-28	-79	13	-30	-75
	40	27	15	31	13	-12	29	0	-27	21	-9	-35	20	-10	-37
	29	-1	-27	28	-13	-43	20	-24	-52	15	-28	-57	15	-29	-59
	27	4	23	25	10	-40	25	-18	-58	36	-19	-66	13	-26	-59
	32	12	-36	29	-9	-52	30	-19	-58	30	-21	-63	25	-21	-60
	-13	-49	-77	-33	-72	-104	-45	-87	-108	-38	-88	-113	-27	-92	-116
	-13	-49	-83	-36	-67	-103	-46	-82	-100	-45	-83	-109	-53	-89	-114
	32	27	5	37	17	-16	32	10	-18	32	5	-26	31	4	-25
	42	28	10	37	20	-1	35	13	-24	39	7	-28	32	3	-25
	48	34	20	36	32	12	47	28	2	42	23	-6	39	19	-16
	40	23	5	37	17	-8	34	12	-13	32	5	-26	28	1	-28
	32	14	-17	26	2	-35	28	-7	-54	29	-11	-55	18	-19	-60

		October			November			December			Annual Mean	Record Temp	
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min		Max	Mean
	-47	24	-4	-39	37	16	-19	42	26	2	0	42	-59
	-110	-21	-60	-89	-2	-38	-66	-2	-19	-38	-57	6	-113
	-80	12	-24	-73	24	-7	-42	27	5	-22	-19	31	-82
	41	28	-1	-41	38	17	-14	44	28	8	4	47	-54
	-61	26	-20	-69	24	1	-24	36	11	-19	-15	36	-76
	60	25	9	-70	31	5	-40	32	18	-4	-9	36	-70
	73	29	-13	-53	30	6	-34	39	22	-2	-8	42	-78
	120	-35	-75	-112	-16	-49	-87	-5	-28	-54	-70	-1	-123
	-116	-41	-75	-104	-28	-49	-74	-6	-28	-54	-68	-6	-127
	-30	33	11	-18	38	23	5	49	31	14	13	49	-36
	30	30	11	-19	40	22	-6	42	30	6	15	48	-35
	-10	45	27	2	42	29	7	45	33	18	26	51	-18
	-34	32	9	-19	38	19	-8	43	28	13	12	43	-34
	59	29	-2	-50	30	11	-20	36	21	-6	-2	36	-60

2

Table 1 2. Precipitation Data for Antarctic Stations (Inches of Water)

Stations	Years of Record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total Annual
McMurdo (USA)	13	0.79	1.14	0.47	0.41	0.60	0.85	0.39	0.64	0.49	0.33	0.32	0.41	6.84
South Pole Station (USA)	12	0.02	0.03	0.01	T*	T	T	T	T	T	T	T	0.01	0.07
Byrd (USA)	12	0.25	0.22	0.13	0.14	0.20	0.21	0.31	0.29	0.14	0.30	0.11	0.23	2.53
Cape Hallett (US-NZ)	9	0.60	0.76	1.22	0.50	0.74	0.27	0.89	0.54	0.64	0.32	0.11	0.31	6.90
Eights	3	1.21	1.54	1.58	0.58	2.08	1.53	1.29	0.49	1.31	0.86	0.56	0.82	13.85
Ellsworth (USA)	6	0.25	0.15	0.25	0.55	0.19	0.24	0.20	0.20	0.27	0.39	0.47	0.20	3.36
Little America (USA)	3	0.41	1.33	1.63	0.78	1.07	0.84	0.66	0.48	0.92	0.83	0.48	0.95	10.38
Plateau	3	T*	T	T	T	T	T	T	T	T	T	T	T	T
Vostok (USSR)	2	0.02	0.04	0.28	0.17	0.33	0.49	0.23	0.21	0.19	0.07	0.02	0.03	2.08
Wilkes (Australia)	7	0.54	0.39	1.68	1.09	1.35	1.17	1.28	0.83	1.52	1.15	0.84	0.31	12.15
Decepcion (Argentine)	2	2.30	2.10	2.70	2.00	0.20	0.30	0.60	1.00	0.90	4.30	3.80	2.00	22.20

* T = Trace.

Table 1-4. Wind Data for Arctic and Antarctic [illegible]

Stations	Years of Record	Peak Gusts (mph and dir						
		Jan	Feb	Mar	Apr	May	Jun	[illegible]
McMurdo	13	62S	75S	81SE	79SE	95S	99S	11[illegible]E
South Pole Station (USA)	12	48NNW	45N	36NW	39N	54NNE	40N	4[illegible]
Byrd	12	47NE	60NNE	67N	71NNE	71NNE	87N	8[illegible]
Cape Hallett	9	72S	92S	89S	87S	120SSW	92SSW	92[illegible]
Eights	3	44S	44SE	58ENE	82NNE	71N	77NNE	75[illegible]
Ellsworth	4	35S	46S	47NE	65E	63NE	61ENE	81[illegible]
Little America	3	37SW	40NNE	48NNW	46NNE	77NNE	59NNE	75[illegible]
Plateau	2	20WNW	27N	35NE	40NE	35W	48NNE	30[illegible]
Vostok[a]								
Davis	5	67NE	96NE	101NE	116ENE	100ENE	99NE	96E[illegible]
Wilkes (Australia)	7	89ESE	113ESE	101E	134E	136E	131E	12[illegible]
Decepcion (Argentine)[b]								
Dumont D'urville (France)[c]								
Halley Bay	6	66	48	85	74	77	89	[illegible]

[a] Gust data not available, but estimates would place the peak at about 100 mph.

[b] Data not available.

[c] Gust data not available, but estimates would place the peak at about 130 mph.

Of Water)

Oct	Nov	Dec	Total Annual
0.33	0.32	0.41	6.84
T	T	0.01	0.07
0.30	0.11	0.23	2.53
0.32	0.11	0.31	6.90
0.86	0.56	0.82	13.85
0.39	0.47	0.20	3.36
0.83	0.48	0.95	10.38
T	T	T	T
0.07	0.02	0.03	2.08
1.15	0.84	0.31	12.15
4.30	3.80	2.00	22.20

Table 1-3. Average Mean Monthly Wind Direction and Velocities for McMurdo Station (Knots)

Month	Direction	Speed
Jan	E	9.7
Feb	E	12.1
Mar	E	14.8
Apr	E	12.7
May	E	12.4
Jun	E	13.5
Jul	E	12.6
Aug	E	12.9
Sep	E	12.6
Oct	E	11.5
Nov	E	10.6
Dec	SE	10.5

Wind Data for Arctic and Antarctic Stations

Peak Gusts (mph) and Direction									
Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
79SE	95S	99S	116SSE	100SE	106S	84SSE	76SSW	77SSE	116SSE
39N	54NNE	40N	43NNE	51N	52NNW	48N	38NNE	30NNW	54NNE
71NNE	71NNE	87N	83NW	82NE	89ENE	70N	62N	62NE	89ENE
87S	120SSW	92SSW	92S	99S	104S	114SSW	97S	67S	120SSW
82NNE	71N	77NNE	75NNE	75N	70NNE	70NNE	71N	39S	82NNE
65E	63NE	61ENE	81SW	81S	82NE	66NE	43NE	33S	82NE
46NNE	77NNE	59NNE	78NNE	80NNE	61NNE	67NNE	44NE	61NNE	80NNE
40NE	35W	48NNE	30N	33NNE	25NNE	29W	55NNE	28WNW	55NNE
116ENE	100ENE	99NE	96ENE	81ENE	98NE	111NE	88ENE	105NE	116ENE
134E	136E	131E	121E	128E	111E	138ESE	115E	76ESE	138ESE
74	77	89	86	91	77	94	68	84	94

100 mph

150 mph

2

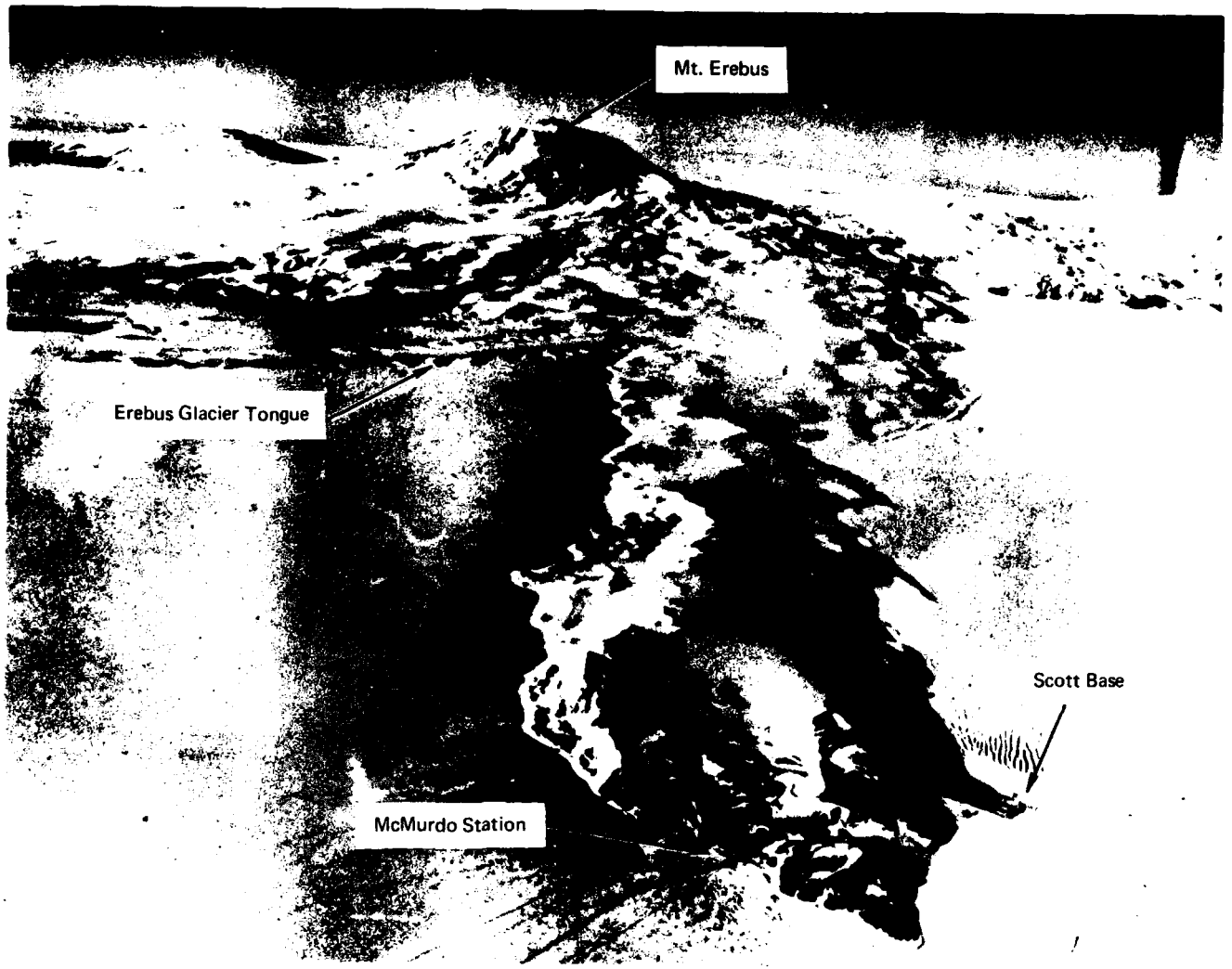


Figure 1-1. Hut Point Peninsula extending south from Ross Island.

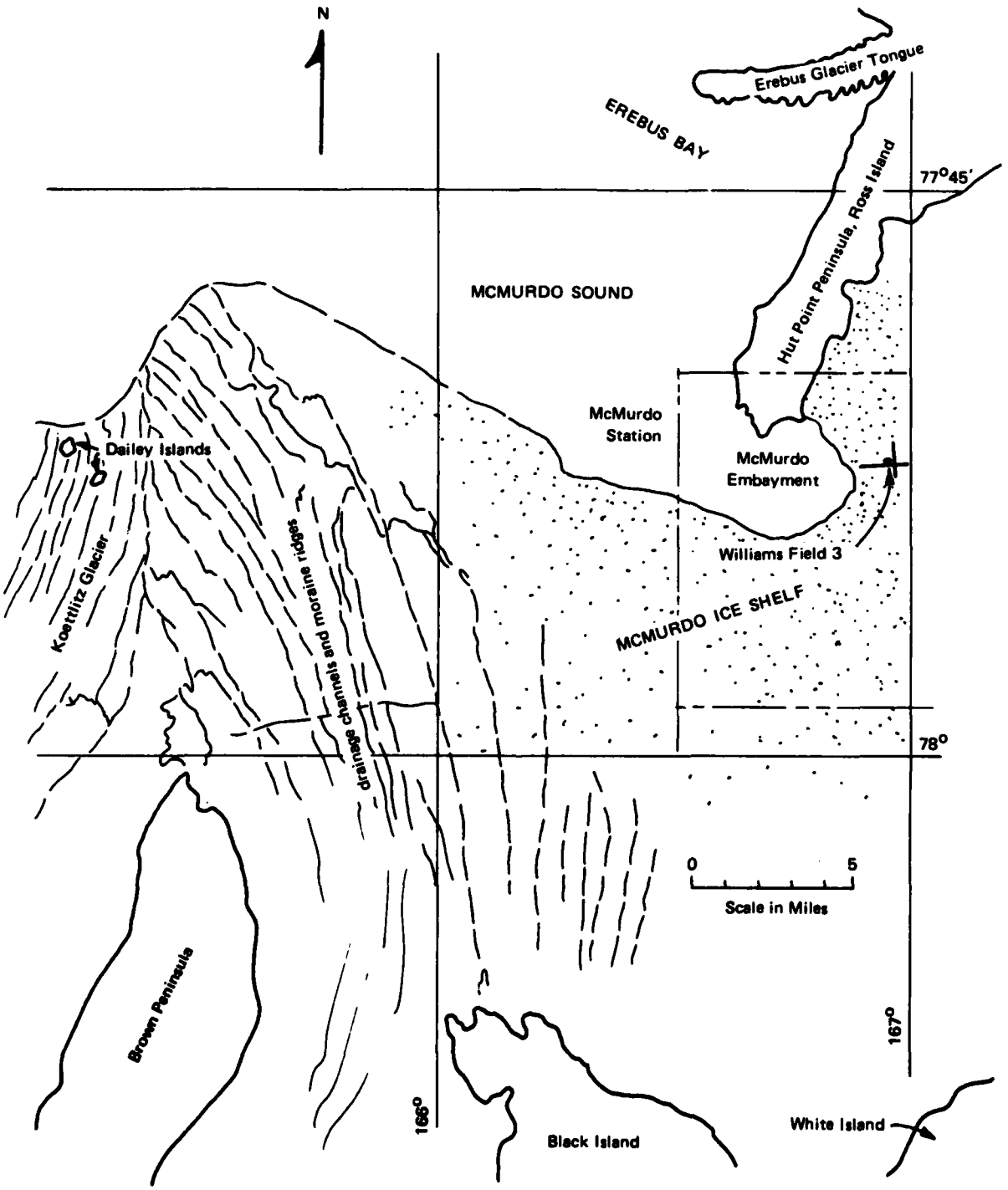


Figure 1-2. McMurdo Ice Shelf. See Figure 1-3 for details of inset outlined by the broken line.

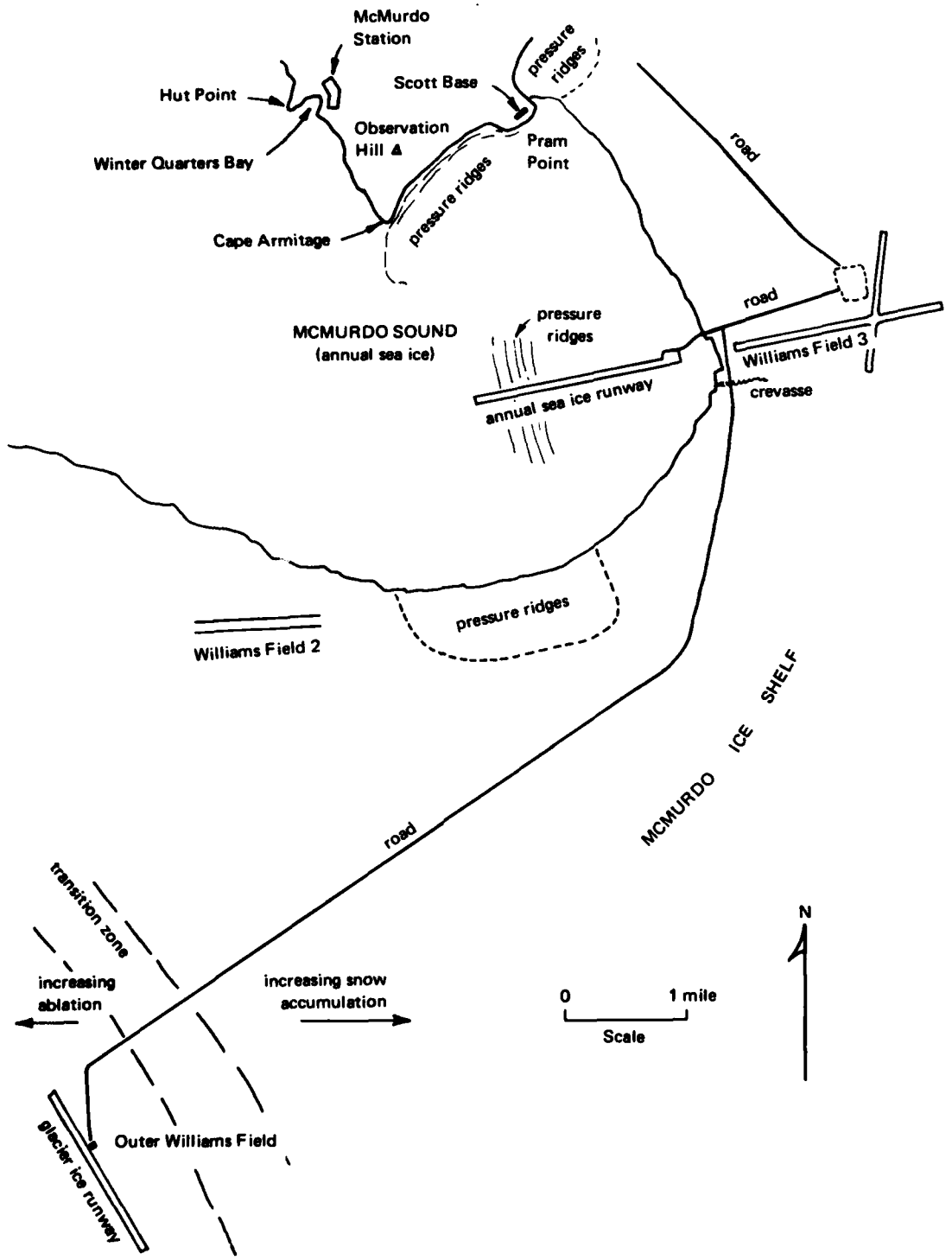


Figure 1-3. Facilities and features on the McMurdo Ice Shelf.

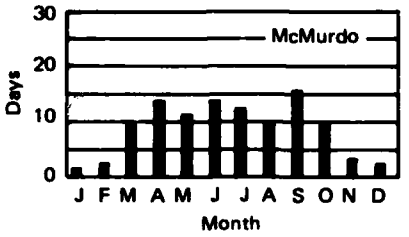


Figure I-4. Number of days with blowing snow (mean monthly values).

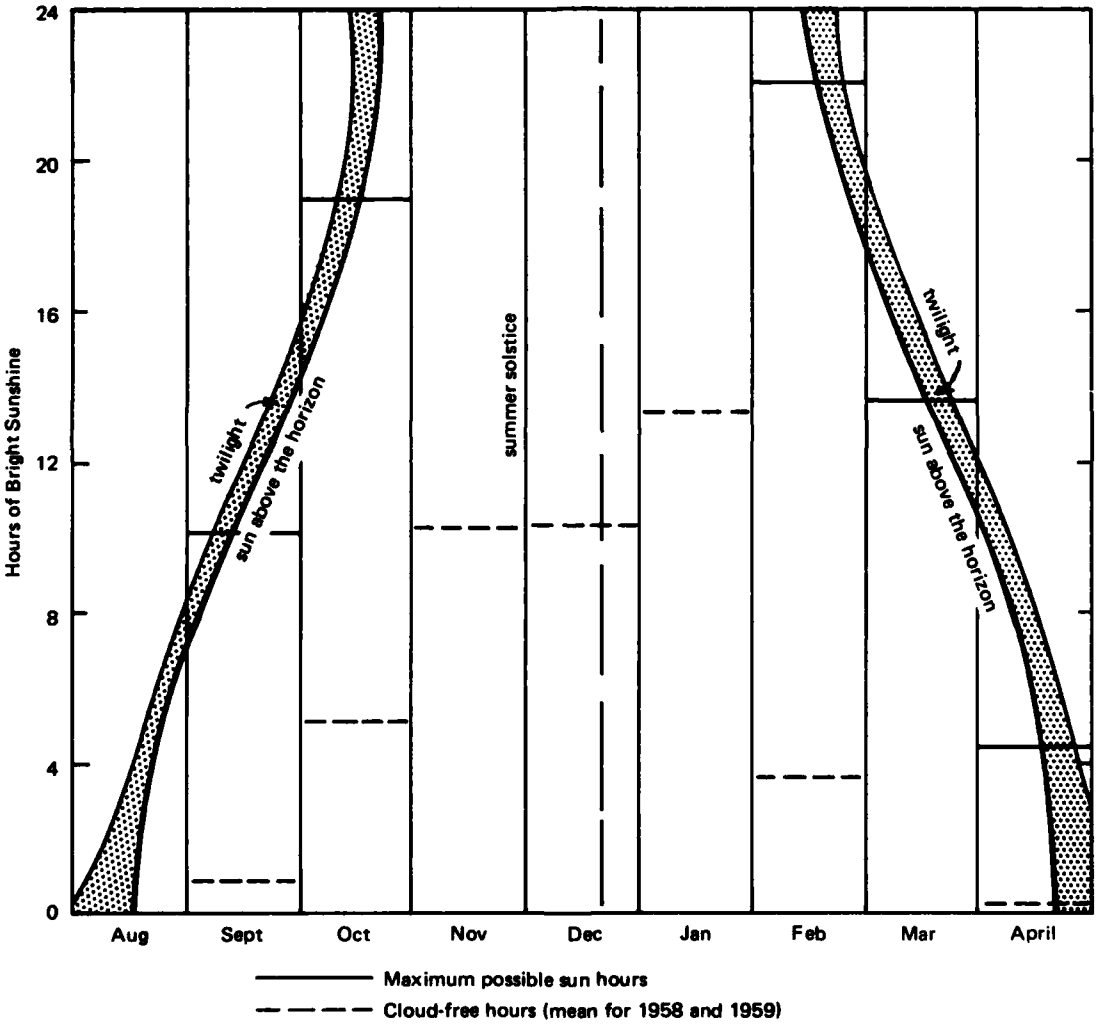


Figure 1-5. Average daily hours of bright sunshine for each month, March 1957 to February 1959, Scott Base. (After Reference 2.)

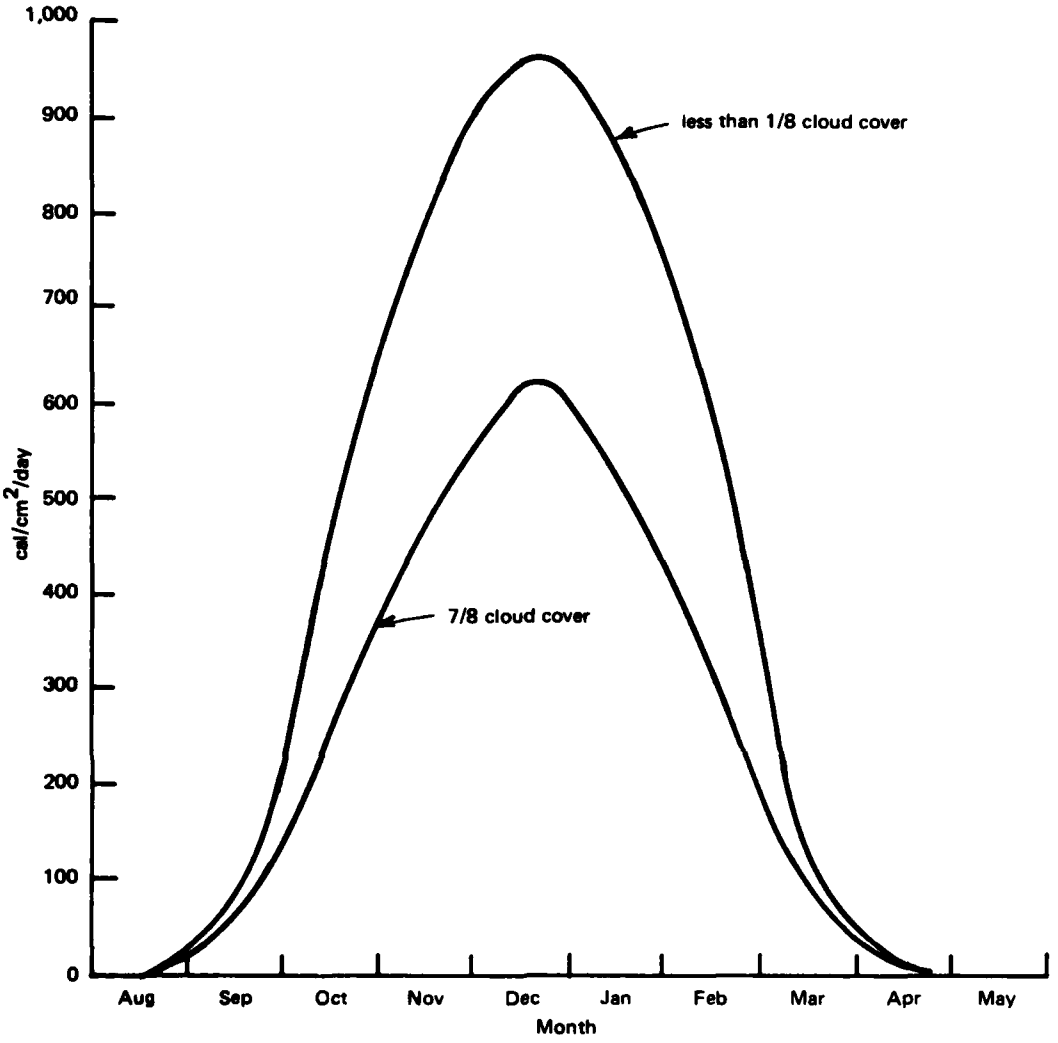
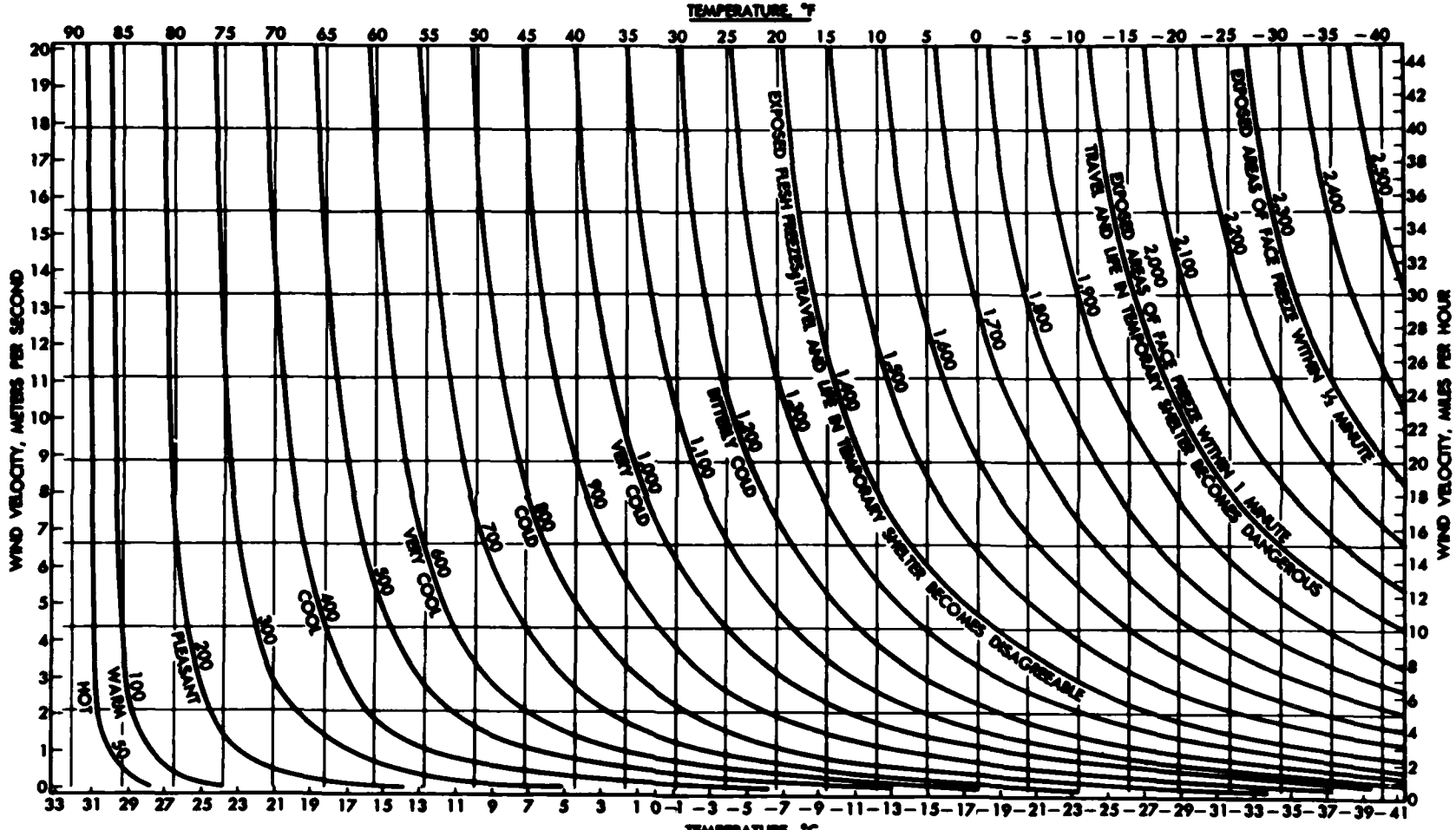


Figure 1-6. Daily totals of downward flux of short-wave solar radiation for the McMurdo Sound region. (After Reference 3.)



COOLING IS EXPRESSED IN KG-CAL/SQ M/HR FOR VARIOUS TEMPERATURES AND WIND VELOCITIES. THE COOLING RATE IS BASED UPON A BODY AT A NEUTRAL SKIN TEMPERATURE OF 33° C (91.4° F). WHEN DRY COOLING RATE IS LESS THAN THE RATE OF BODY HEAT PRODUCTION, EXCESS HEAT IS REMOVED BY VAPORIZATION. UNDER CONDITIONS OF BRIGHT SUNSHINE, COOLING IS REDUCED BY ABOUT 200 CALORIES. EXPRESSIONS OF RELATIVE COMFORT ARE BASED UPON AN INDIVIDUAL IN A STATE OF INACTIVITY.

Figure 1-7. Wind chill curves.

WIND SPEED		COOLING POWER OF WIND EXPRESSED AS "EQUIVALENT CHILL TEMPERATURE																				
KNOTS	MPH	TEMPERATURE (°F)																				
CALM	CALM	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-60
		EQUIVALENT CHILL TEMPERATURE																				
3-6	5	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-65	-70
7-10	10	30	25	15	10	5	0	-10	-15	-20	-25	-35	-40	-45	-50	-60	-65	-70				
11-15	15	25	15	10	0	-5	-10	-20	-25	-30	-40	-45	-50	-60	-65	-70						
16-19	20	20	10	5	0	-10	-15	-25	-30	-35	-45	-50	-60	-65								
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45	-50	-60	-65									
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50	-55	-65	-70									
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50	-60	-65										
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55	-60	-70										
WINDS ABOVE 40 HAVE LITTLE ADDITIONAL EFFECT		LITTLE DANGER					INCREASING DANGER (Flesh may freeze within 1 min.)															
DANGER OF FREEZING EXPOSED FLESH FOR PROPERLY CLOTHED PERSONS																						

INSTRUCTIONS

MEASURE LOCAL TEMPERATURE AND WIND SPEED IF POSSIBLE. IF NOT, ESTIMATE. ENTER TABLE AT CLOSEST 5°F INTERVAL ALONG THE TOP AND WITH APPROPRIATE WIND SPEED ALONG LEFT SIDE. INTERSECTION GIVES APPROXIMATE EQUIVALENT CHILL TEMPERATURE. THAT IS, THE TEMPERATURE THAT WOULD CAUSE THE SAME RATE OF COOLING UNDER CALM CONDITIONS.

NOTES

WIND

1. THIS TABLE WAS CONSTRUCTED USING MILES PER HOUR (MPH). HOWEVER, A SCALE GIVING THE EQUIVALENT RANGE IN KNOTS HAS BEEN INCLUDED ON THE CHART TO FACILITATE ITS USE WITH EITHER UNIT.
2. WIND MAY BE CALM BUT FREEZING DANGER GREAT IF PERSON IS EXPOSED IN MOVING VEHICLE, UNDER HELICOPTER ROTORS, IN PROPELLOR BLAST, ETC. IT IS THE RATE OF RELATIVE AIR MOVEMENT THAT COUNTS AND THE COOLING EFFECT IS THE SAME WHETHER YOU ARE MOVING THROUGH THE AIR OR IT IS BLOWING PAST YOU.
3. EFFECT OF WIND WILL BE LESS IF PERSON HAS EVEN SLIGHT PROTECTION FOR EXPOSED PARTS. LIGHT GLOVES ON HANDS, PARKA HOOD SHIELDING FACE, ETC.

ACTIVITY — DANGER IS LESS IF SUBJECT IS ACTIVE. A MAN PRODUCES ABOUT 100 WATTS (341 BTUs) OF HEAT STANDING STILL BUT UP TO 1000 WATTS (3413 BTUs) IN VIGOROUS ACTIVITY LIKE CROSS COUNTRY SKIING.

PROPER USE OF CLOTHING and ADEQUATE DIET are both important.

COMMON SENSE — THERE IS NO SUBSTITUTE FOR IT. THE TABLE SERVES ONLY AS A GUIDE TO THE COOLING EFFECT OF THE WIND ON BARE FLESH WHEN THE PERSON IS FIRST EXPOSED. GENERAL BODY COOLING AND MANY OTHER FACTORS AFFECT THE RISK OF FREEZING INJURY.

(REVISED FROM ARCTIC AEROMEDICAL LABORATORY TECHNICAL REPORT 64-28)

CONTRIBUTORS

ARCTIC AEROMEDICAL LABORATORY, FORT WAINWRIGHT, ALASKA
SCIENTIFIC SERVICES, 11th WEATHER SQDN, ELMENDORF AFB, ALASKA

Figure 1-8. Cooling power of wind expressed as equivalent chill temperature.

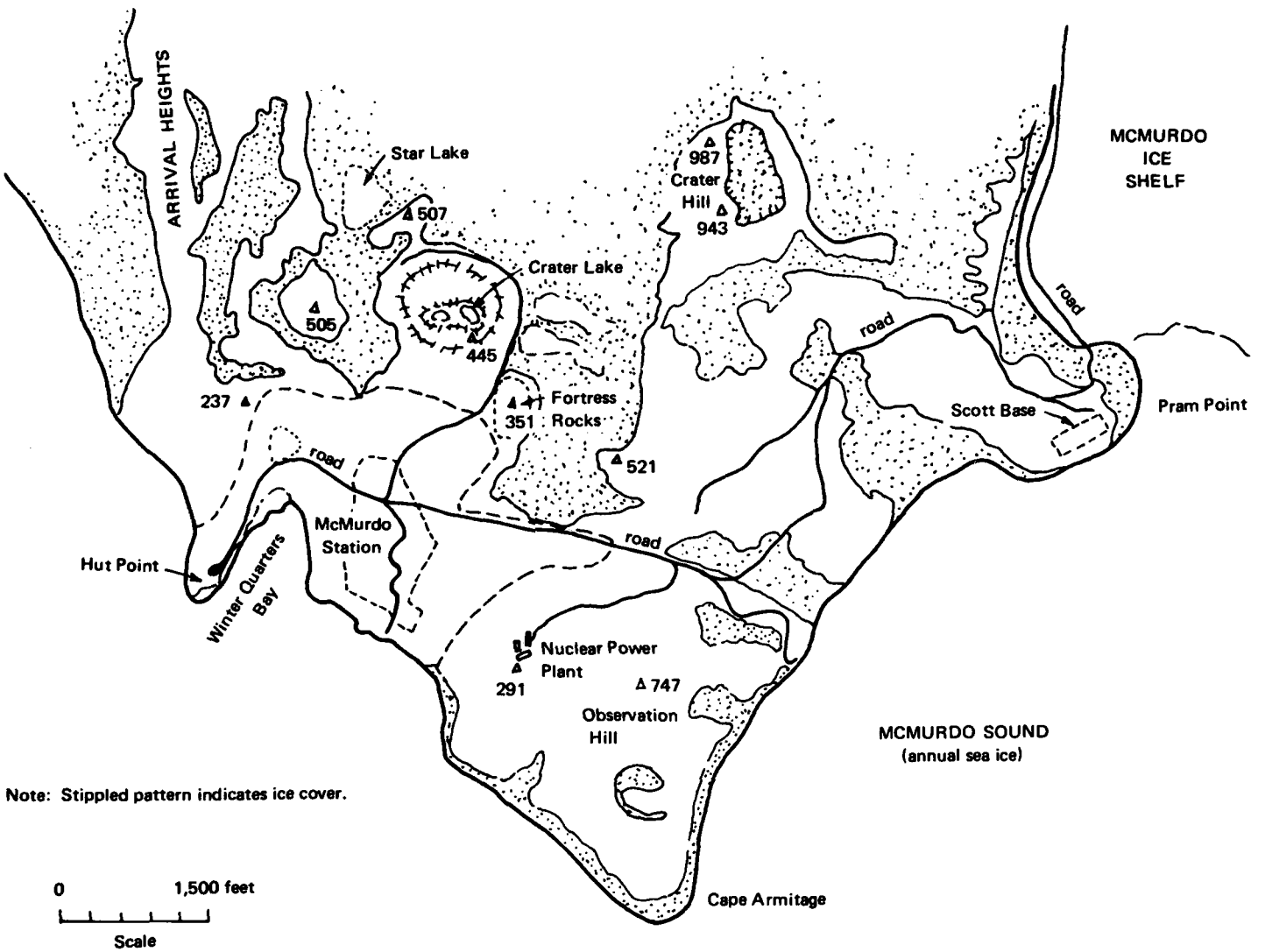


Figure 1-9. Distribution of permanent snowfields near McMurdo Station.

Figure 1-10. McMurdo Station, looking east.

Figure 1-11. Separation of undetected fast ice from shoreline beneath sewage outfall structure.

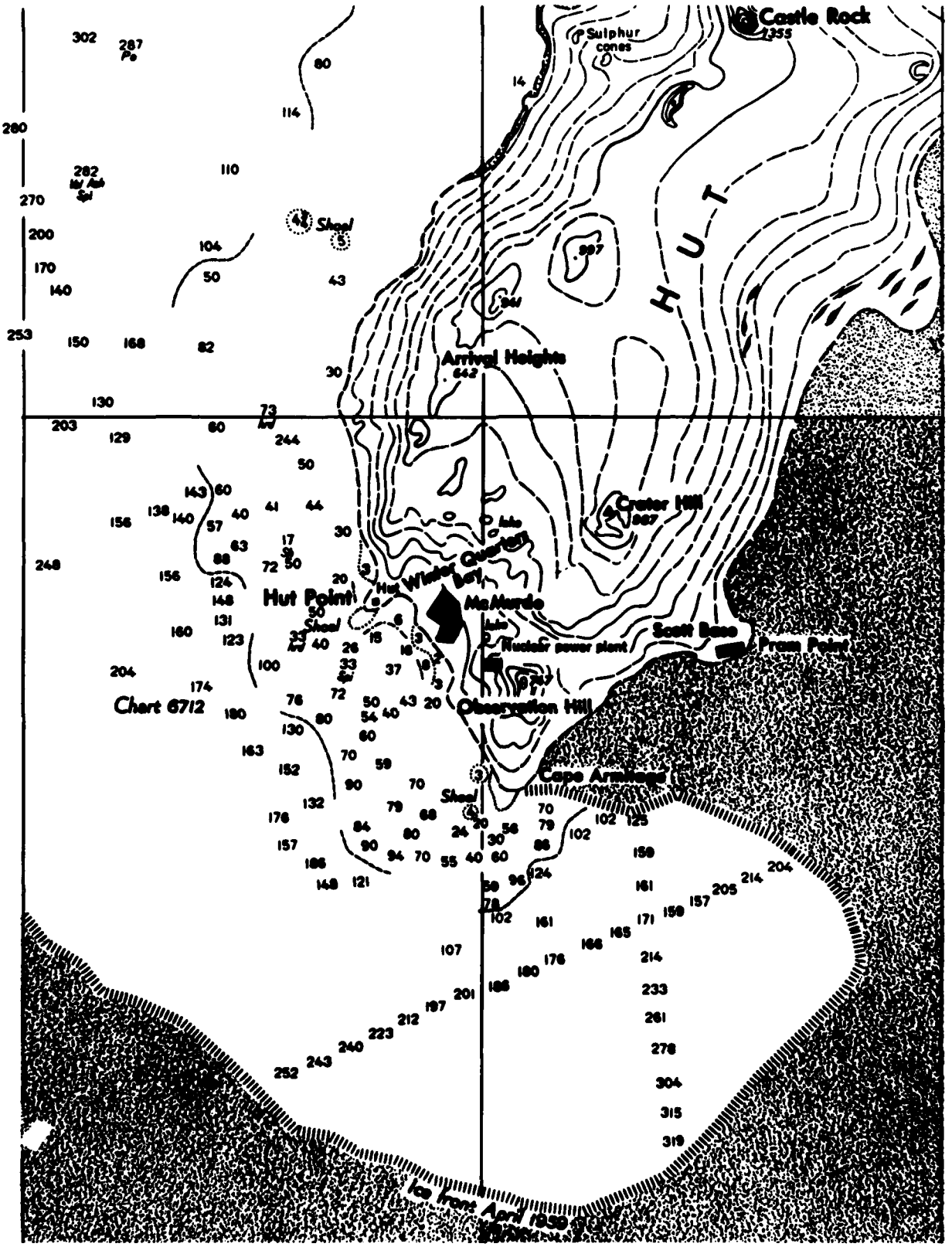


Figure 1-12. McMurdo Sound soundings in fathoms, height in feet. Scale 1:50,000.

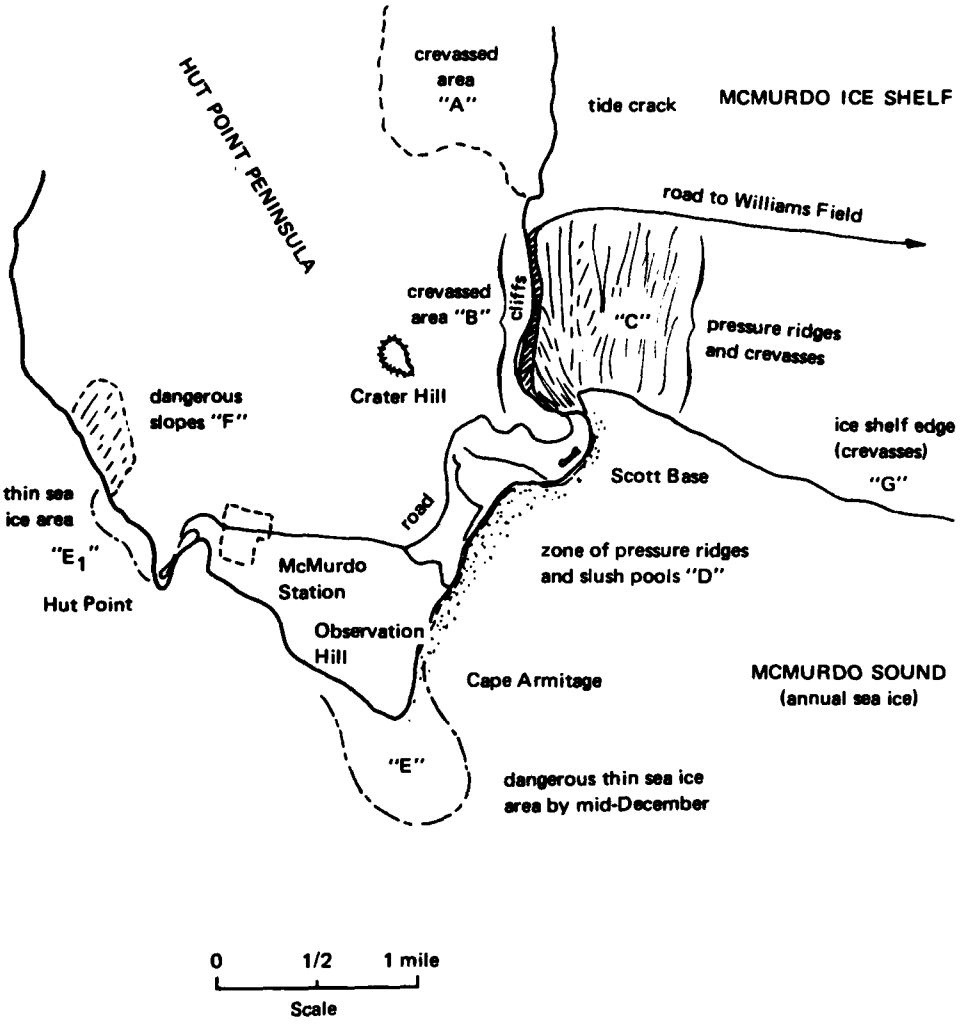


Figure 1-13. Hazard areas near McMurdo Station, Antarctica.

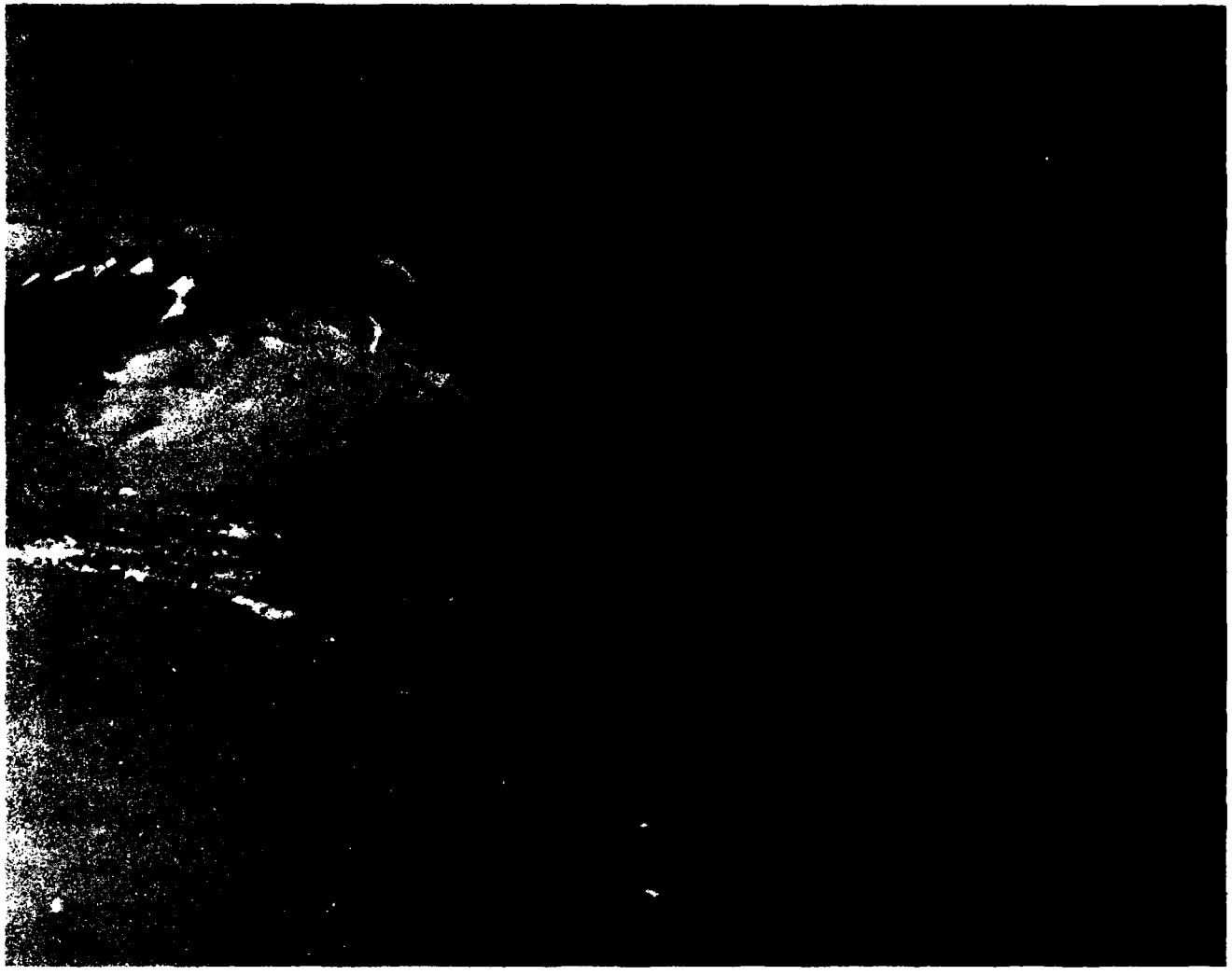


Figure 1-14. Hazardous slush pools in pressure ridge area near Pram Point.

Figure 1-15. Hazardous pressure ridge and slush pool between Scott Base and Cape Armitage.

Figure 1-16. LGP-D8 tractor immobilized in slush pool covered by dry snow on sea ice between Scott Base and Cape Armitage.

Figure 1-17. Sea ice melted away in-place off Cape Armitage.

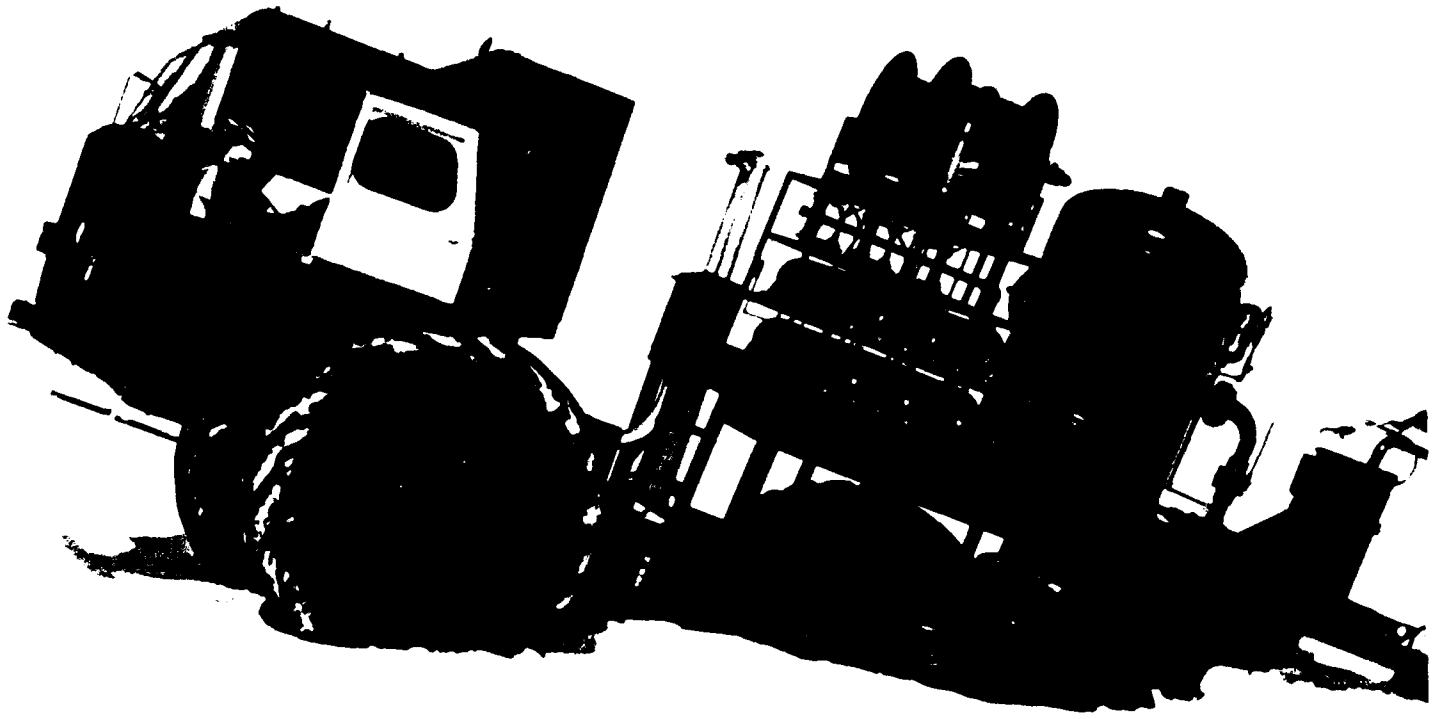


Figure 1-18. Water-Trotter immobilized in crevasse-like cornice of edge of McMurdo Ice Shelf.

FORTRESS QUARRY ROCKS

This material originally appeared as Appendixes A and B in Naval Civil Engineering Laboratory Technical Note N-1000: Concrete for Antarctica - Aggregate and Mix Design for McMurdo Area, by J. R. Keeton and N. S. Stehle, December 1968.

PETROGRAPHIC EXAMINATION OF ANTARCTIC ROCKS FOR NCEL

by

Corps of Engineers, USAE
Waterways Experiment Station
Jackson, Mississippi
18 January 1968

SAMPLES

Three sacks of broken rock from the Fortress Rocks Quarry in Antarctica, each weighing about 80 pounds, were received for testing on 27 December 1967. Pertinent data concerning the samples are given below.

CD Serial No.	Naval CE Lab Designation	Remarks
NAV-1 G-1	A	Considered best available rock
NAV-1 GS-2	B	Considered worst available rock
NAV-1 G-3	C	Considered average quality rock

TEST PROCEDURE

The three samples were examined visually and with a stereoscopic microscope as needed for classification. Thin sections of each sample were made and examined with a petrographic microscope. Grain immersion mounts of hand-picked mineral grains from crushed sample material were examined and identified. Samples for X-ray diffraction analysis were taken from each sample, ground to pass a No. 324 sieve, analyzed on an X-ray diffractometer, and their patterns compared with each other. The bulk specific gravity and absorption of representative portions of each sample were determined.

Addition – 1979

RESULTS

General Description

All three samples were composed of similar material - brownish black (5YR 2/1)* to dusty brown (5YR 2/2),* fairly dense to highly vesicular, very-fine-grained volcanic rock. The size of the vesicles in the more vesicular particles ranged from less than 1/16 to about 1/4 inch in diameter, most being between 1/16 and 1/8 inch. The vesicles in the more dense particles were generally much smaller, averaging less than 1/16 inch in diameter. None of the vesicles contained secondary mineral deposits. The more dense particles tended to be slightly porphyritic, containing many small (usually less than 1/8, but up to 1/4 inch) olivine and pyroxene phenocrysts in a very-fine-grained, partially glassy matrix. Phenocrysts in the vesicular particles were much smaller. The highly vesicular particles were more brownish colored than the dense particles, due to the oxidation of iron minerals in the matrix.

Sample A (NAV-1 G-1) was composed of dense-to-vesicular basaltic-rock particles as described above. There was a higher ratio of dense-to-vesicular particles in this sample as compared to the other two. The rock particles were fresh and were probably in slightly better physical condition than those in the other samples. Practically all of the particle surfaces were clean and free of secondary coatings. A very few particles contained small amounts of soft, white, powdery opaline material on one or more probably pre-existing surfaces. In most cases, however, the material could be washed off under a faucet.

Sample B (NAV-1 G-2) consisted of basaltic-rock particles similar to Sample A, except that highly vesicular, cindery particles outnumbered the more dense particles. Many of the surfaces of the particles were partially coated with soft, white, powdery opaline material, an indication that the rock in this sample came from a highly broken and fractured zone within the quarry. Rock particles in this sample were obviously in worse physical condition than those in either of the other two samples; however, most were still physically sound.

The rock particles in Sample C (NAV-1 G-3) were much more like those in Sample A than Sample B, being more dense than Sample B, but having many surfaces that contained the white secondary opaline material like Sample B. There was less variation in the amount of "vesicularity" of these particles; that is, the particles were more uniformly vesicular than those in either of the other two samples.

Mineralogy of Samples

X-ray diffraction analysis of selected dense and vesicular particles from Sample A, and composites from Samples B and C indicated that all three samples were mineralogically very similar, each being composed of pyroxene, olivine, plagioclase feldspar, magnetite and glass. Thin sections revealed that the rock was made up of euhedral to subhedral

*The Rock Color Chart Committee, National Research Council, Rock-Color Chart, Washington, D.C., 1963.

Addition – 1979

olivine and pyroxene phenocrysts in a hypocrystalline matrix composed of tiny lath-shaped plagioclase feldspar microlites, irregularly shaped magnetite and pyroxene crystals, and brown-to-black natural glass. There was no definite orientation or lineation of the feldspar laths. The amount and color (shade) of the glass varied from one thin section to another, ranging from yellowish and reddish-brown to almost black (opaque) in plane light. The thin sections of the vesicular-rock particles appeared to contain the most glass; however, the coloring of the glass followed no particular pattern. The feldspar laths measured from about 75 to 200 microns in length; index of refraction measurements indicated that it was labradorite. Magnetite and pyroxene crystallites in the matrix were usually less than five microns in diameter, although some of the pyroxene was much larger. As earlier stated, the pyroxene and olivine phenocrysts were up to 1/4 inch in diameter. Microscopical measurements on grain mounts of the pyroxene and olivine indicated that the pyroxene was a high-iron augite, and the olivine had a composition near the forsterite end of the solid solution series. There was little or no alteration of the olivine or augite. Based on the mineralogy and texture, the rock in all three samples was classified as olivine basalt.

Grain-immersion mounts of the white material present on some particle surfaces, particularly in Samples B and C, indicated that the material was amorphous opal, having an index of refraction near 1.460. Opal is a very common secondary mineral in basic volcanic rocks such as these.

Physical Test Results

Bulk specific gravity and absorption test results (Method CRD-C 108-60) are tabulated as follows:

Sample	Bulk Specific Gravity	Absorption (%)
NAV-1 G-1 (Sample A)	2.91	0.7
NAV-1 G-2 (Sample B)	2.52	4.0
NAV-1 G-3 (Sample C)	2.80	0.7

These results are in good agreement with other observations previously mentioned, namely, that Sample A was the best. Sample B was worst, and Sample C was more like Sample A than C. The low gravity-high absorption of Sample B was due to the large number of highly vesicular particles in the sample; however, due to the relatively large size of the vesicles and the fact that most of them are sealed off from adjoining vesicles, the aggregate's high absorption would not have as deleterious an effect on the durability of concrete if it were used as aggregate as would be the case if the pores were smaller and connected.

Addition – 1979

SUMMARY AND CONCLUSIONS

Petrographic examination of the three samples indicated that all three were composed of fairly dense to highly vesicular, somewhat glassy olivine basalt. Sample A contained the most dense rock, was the least weathered, and had the highest bulk specific gravity and lowest absorption. Sample B contained the most highly vesicular particles, had the lowest specific gravity and highest absorption, was physically the weakest and contained the most secondary material on particle surfaces. Sample C was of almost as high a quality material as Sample A.

It was concluded that durable concrete could be made from material represented by any of the three samples, especially if material represented by Sample B were blended with that represented by Samples A and C, and provided that other steps commensurate with good concrete construction practice such as low water-cement ratio, air entrainment, and adequate curing of the concrete before freezing were used.

The presence of natural glass in basaltic rocks such as these is of no consequence, since the glass is of lower silica content than that of lighter-colored extrusive rocks and is hence less likely to react with cement alkalies.*

*U.S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements, Test Method CRD-C 139-56, Vicksburg, Miss., 1949.

Addition – 1979

ASTM TESTS

by

California Testing Laboratories, Inc.
619 East Washington Boulevard
Los Angeles, California 90015
24 May 1968

GENERAL

In accordance with instructions, California Testing Laboratories, Inc., performed a series of ASTM tests on samples of crushed stone submitted by NCEL.

TESTS PERFORMED

ASTM C131-66 Resistance to Abrasion of Small-Size Coarse Aggregate by Use of the Los Angeles Machine
ASTM D1411-66T Water Soluble Chlorides
ASTM C123-66 Lightweight Pieces in Aggregate
ASTM C40-66 Organic Impurities
ASTM C289-66 Potential Reactivity of Aggregate
ASTM C-235-62T Scratch Hardness of Coarse Aggregate Particles
ASTM C-88-63 Soundness of Aggregates

TEST RESULTS

Resistance to Abrasion -

	Sample Grading "A"
L. A. Rattler	
Loss at 100 Rev:	4.7%
Loss at 500 Rev:	20.2%
Water Soluble Chlorides	
Percent alkali chlorides as sodium chloride	0.408
Lightweight Pieces in Aggregate	
(Material lighter than Sp. Gr. 2.00)	Negligible
Organic Impurities	
After 24-hour standing, the supernatant liquid was clear and much lighter than Standard	OK

Addition – 1979

Potential Reactivity of Aggregate

Soluble Silica Sc	84.36
Reduction in alkalinity -Rc	73.80
Reactivity value: Sc/Rc =	1.14

Chemical tests indicate the material to be slightly reactive.

Sieve Size (in.)	Scratch Hardness Percent Ret. Each Sieve (Grading)	Sample Weight (gr)	Weight Soft Particles	Loss (%)	Weight Average
1-1/2 to 2	13.0	3,000	0	0	0
1 to 1-1/2	18.1	2,000	0	0	0
3/4 to 1	13.4	1,200	0	0	0
1/2 to 3/4	16.0	600	0	0	0
3/8 to 1/2	8.4	200	0	0	0
					0

Soundness of Aggregate: Sodium Sulphate

Sieve Size Passing	Sieve Size Retained	Grading Orig. Sample*	Weight of Test Fraction Before Test (gr)	Passing Finer Sieve After Test (%)	Weighted Average
Coarse Aggregate:					
2-1/2	1-1/2	32.6	3228	2.4	0.78
1-1/2	3/4	31.5	1535	0	0
3/4	3/8	24.4	999	0	0
3/8	4	11.5	301	0	0
		100.0			0.78
Fine Aggregate:					
4	8	35.8	100	0	0
8	16	22.6	100	0	0
16	30	15.5	100	0	0
30	50	8.6	100	1.0	0.09
50	100	6.4	-	-	-
100		3.5	-	-	-
		100.0			0.09

*Material retained on 2-1/2 inches not used in test or grading.

Addition – 1979

LIST OF APPENDIXES

Chapter 1

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

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Chapter 2

MCMURDO ICE SHELF

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Chapter 2

MCMURDO ICE SHELF

INTRODUCTION

The McMurdo Ice Shelf extending south and east of Hut Point Peninsula is a key part of the McMurdo Station complex because of the Williams Field aircraft runways and camp which are located on the deep snow surface. In the history of McMurdo operations, this airfield has been located in three different areas on the shelf.

Williams Field 1

From the beginning of the IGY until DF-62 the Williams Field runways were located about 2.5 miles southwest of Hut Point on 30-foot thick ice covered with 12 to 30 inches of snow. The runways for wheeled aircraft were prepared by bulldozing the snow to the edge of the runways. The resulting berms accelerated accumulation of drift snow and by DF-62, these berms were over 20 feet high and tapered out 150 to 200 feet on each side of the two runways. The weight of this snow overburden depressed the surrounding ice and produced visible cracks in the runway surface and unseen cracks in the surrounding area. At the close of the DF-62 summer season, the ice on which the airfield was constructed calved off and went to sea.

Williams Field 2

In October, DF-63, Williams Field 2 was established on the ice shelf almost directly south of McMurdo Station (Figure 2-1). The ice in this area was buckled by pressure ridges up to 2 feet high and the entire area covered with snow 4 to 5 feet deep. To prepare the two runway complexes, snow was again dozed from the ice surface and distributed along the edge of the runway. Undulations were leveled by chipping down high areas with snow-processing pulvimixers and by flooding low areas with seawater which eventually froze. By DF-65 the snow berms along the runways were over 30 feet high in some areas and the runways resembled broad trenches with sloped sides. In February 1965, ice breakup again resulted in the loss of several thousand feet of the crosswind runway and threatened the remainder. In a period of three days, the facility was disassembled and moved to safety.

Williams Field 3

In DF-66, Williams Field was reestablished on the barrier about 3 miles southeast of Pram Point (Figure 2-1). The structure of the barrier at this location provided greater security from ice breakout but was not suitable for construction of runways for wheeled aircraft. As a result skiways were prepared on the barrier and a runway for wheeled aircraft constructed on the annual sea ice (Figure 2-1). This ice runway met most requirements for wheeled aircraft operation but could not be used after early January because of deterioration of the ice sheet. To accommodate wheeled aircraft after early January (primarily C-121 aircraft used for

redeployment) another runway was established 8.5 miles south of McMurdo Station as shown in Figure 2-1. This runway was designated Outer Williams Field and was built on snow-free glacier ice. Buildings at this location were minimal and housed only a maintenance crew. When use of C-121 aircraft was discontinued in DF-71, the operation of this outer runway was also discontinued.

CHARACTERISTICS

East and south from Hut Point Peninsula, the ice shelf appears to be a flat, featureless plain broken only by White Island and Black Island far to the south (Figure 2-2). To the west, the white snowfields gradually change to a mottled white, then blue, as glacier ice becomes exposed at the surface. Near Black Island, drainage channels and black streaks of rock debris appear as ridges trending north from Black Island and Brown Peninsula. Closer inspection reveals, however, that the ice shelf within the map area is not completely featureless. The vertical face of the ice shelf around the McMurdo Sound embayment gradually rises from a height of 8 feet near Pram Point to a maximum of about 22 feet near Williams Field (Figure 2-1). Continuing clockwise around the shelf, the edge then trends westward and the height diminishes to 3 feet about 4 miles west of Cape Armitage.

Two pressure ridge areas form the most prominent surface features on the ice shelf. One area is northeast of Pram Point and is caused by the ice shelf moving against Hut Point Peninsula. The other zone on the ice shelf is less obvious and is located across the annual ice about 3 miles south of Cape Armitage where ice shelf movement decreases.

The topography of the ice shelf is subdued and consists of broad, gentle undulations. The elevation at the present Williams Field (Williams Field 3) is about 33 feet and rises to the east at 8 to 10 feet per mile. To the southwest of Williams Field, the surface elevation rises almost imperceptibly for several miles then decreases to about 20 feet at the former Outer Williams Field site.

Movement

Studies of the ice shelf started in 1957 [1] near Scott Base and were expanded in 1963 [2] and 1967 [3] indicated that the ice shelf was moving westward at a rate of about 270 feet a year near Pram Point and increasing to 373 feet a year near the Williams Field 3 location. These surveys were accomplished by triangulation from a fixed baseline or by a resection from outlying observation stations.

In DF-66, the Naval Civil Engineering Laboratory (NCEL) established a series of movement markers near the edge of the ice shelf around the embayment south of Cape Armitage [4]. Angles and distances were measured by theodolite and electrotape twice each season during DF-66, 67, and 68. The object of this study was to determine movement and stability conditions around the margin of the ice shelf where travel routes and other installations are most often located. The location of these movement markers is shown in Figure 2-3 with the average movements observed.

From this it can be seen that rates of westward movement diminish from 347 feet/year at Station A to 54 feet/year at Station C' which is located 4.5 miles to the west. The greatest difference in movement occurs between Stations B-68 and C-68 where

the rate decreases from 350 feet/year to 124 feet/year over a 2-mile distance. This disparity of 226 feet per year is manifested in the pressure ridges between the two stations where compressive forces deform the ice shelf. As of DF-69, Williams Field 3 was moving westward at 350 feet/year.

In the area between D-68 and Outer Williams Field, movement decreases to less than 100 feet/year and attains a northwest component caused by ice moving northward from between Brown Peninsula and Black Island. The dominant movement direction is still westward as indicated by the westward deflected moraines and drainage channels north of Brown Peninsula (Figure 2-2).

Thickness

Thickness differences in the McMurdo ice shelf were first discussed in 1961 in describing equilibrium and westward movement of the ice shelf. In 1963 data collected from pits, bore holes and surface elevations showed the ice shelf to be wedge-shaped with drastic thinning in the direction towards Hut Point Peninsula. Accurate thickness data were obtained by NCEL in DF-71 and DF-72 when eight holes were drilled through the ice shelf for direct measurement at key locations.

The map in Figure 2-3, which shows thickness contours, was prepared from these measurements and from temperature, density, and salinity data from numerous core holes. Cross sectional elevations of the ice shelf were also prepared and are shown in Figures 2-4 and 2-5.

Cross section A–A′ located along an east-west flow line west of Williams Field provides valuable information on thinning, and stability at the ice shelf edge. Drill holes H3 and H4 gave thicknesses of 146 and 91 feet, respectively. The known movement rate for the Williams Field area is 350 feet per year and the annual net snow accumulation is about 11 inches. As a unit column of ice moves westward between these two points, the ice shelf thickness decreases by a net 55 feet (from 146 feet at H3 to 91 feet at H4). However, snow continues to accumulate on the surface during the 15.8 years required for the unit column of ice to move the 5,500 feet between H3 and H4. This accumulation is equivalent to 14.5 feet which, when added to the 55-foot net decreases in thickness, indicates that the total loss by bottom melting is 69.5 feet or 4.4 feet per year in this part of the ice shelf.

The data in cross section A–A′ also show that the ice shelf is in a state of negative budget: losing more mass by bottom melting and calving than is gained each year by flow and accumulation. Calving accounts for the greatest loss but is not a regular occurrence.

The process of bottom melting and calving apparently decreases westward and is replaced by bottom freezing of freshwater underflowing the ice shelf from the Koettlitz Glacier [5]. This accretion by bottom freezing may also be important beneath much of the ice shelf east of the Koettlitz Glacier. No calving has occurred along the ice shelf edge near Station D68 (Figure 2-3) since 1965, nor has there been any appreciable decrease in thickness. This suggests that much of the ice shelf in this area may be in equilibrium.

Stability

The calving of large, tabular icebergs is the only event that seasonally affects the marginal stability and safety of the ice shelf. This calving is controlled by various factors such as thickness, strength, internal structure

of the ice shelf, and the existence of the annual sea ice facing the ice shelf. The sea ice on the embayment south of Cape Armitage and portions of the adjacent ice shelf have gone to sea many times during the recorded history of this area. No two breakouts have occurred at precisely the same time of year nor has the extent of the breakout been the same [6]. Generally, breakouts occur in February and new sea ice begins to form in late March or during April. A detailed record of sea-ice and ice-shelf breakout has been reported for the years 1962 to 1966 [7].

The sea-ice breakout in 1965 was followed by extensive calving of the ice shelf from Pram Point around the embayment to the Williams Field 2 location (Figure 2-1). The DF-63-65 Williams Field camp area was damaged by active cracks during this breakout and had to be relocated. Calving occurred following sea-ice breakouts in DF-66, 67, and 68, but the total mass of ice lost was minor compared with the DF-65 breakout. After the DF-67 breakout, all of Pram Point was surrounded by open water. Old records indicate that only four previous breakouts of similar magnitude occurred; those were between 1901 and 1915 [6].

Calving cannot occur as long as the annual sea ice remains in the embayment south of Cape Armitage. If the restrictive effect of the sea ice sheet is removed, thickness and strength are then the most important factors controlling calving. The extensive calving that occurred between DF-63 and DF-68 involved ice-shelf thicknesses varying from about 35 feet at the seaward edge to about 80 feet at the DF-68 edge. This was determined by projecting the bottom slope, based on known thinning rates, to the known position of the DF-63 edge. Thickness measurements show that the 1968 edge was 50 feet thick near Pram Point, 90 feet thick west of Williams Field, 67 feet thick at DH C-1, 33 feet thick at C-68, and 37 feet thick at D-68. As previously stated, records indicate that the ice-shelf breakout has never extended eastward beyond the DF-68 edge. This suggests that the critical thickness beyond which calving does not occur is 80 to 90 feet for the area west of Williams Field [8].

Brine Penetration

The presence of brine 20 to 30 feet beneath the snow on the ice shelf was first observed during core and pit studies in 1963 [2]. In 1967 a comprehensive study and analysis was made of this brine layer from which it was shown conclusively that the brine originates by lateral infiltration from the face of the ice shelf rather than by upward infiltration as first considered [9]. Lateral penetration has been observed up to 9.9 miles eastward from the edge of the shelf [9].

Cross sections A–A′ and B–B′ (Figure 2-4), which are based on accurate thickness and elevation measurements, show that the upper surface of the brine layer is found at increasing depths below sea level as distance from the edge increases. The brine layer can be detected in three ways: visually, by determining salinity, and by a sudden increase in density as shown in Figure 2-6. By projecting density curves downwards, it can be shown that the impermeable density of 0.81 gm/cm^3 is reached at various levels above the bottom of the ice shelf. The density profiles and the increasing depth of the brine layer below sea level, as well as hydrostatic considerations support the belief that the brine layer flows inward from the seaward edge of the ice shelf.

One important effect of brine infiltration is in raising the temperature of the ice shelf and decreasing its strength. The subsurface temperature increase is greatest near the edge and decreases in magnitude farther from the edge as shown in Figure 2-7. The temperature of the upper surface of the brine layer decreases from about 28.8°F at the ice-shelf edge to 24°F about 5,000 feet back from the edge. Within the marginal 1,000 feet, the warming of the ice shelf is considerably more than that which would occur if the ice shelf were devoid of brine. Much of this heat comes from the latent heat of fusion released when salt-free ice forms from the seawater upon initially entering the cold ice shelf. The warming and weakening of the ice shelf is greatest at the seaward edge and at the bottom. Sagging along a newly formed edge soon after calving occurs has been observed during extensive breakout periods. This warming, weakening, and sagging probably initiates breaking and calving under marginal thickness conditions.

Surface Features

Several surface features appear on the McMurdo Ice Shelf, with which station personnel should be familiar. These features are crevasses, tide cracks, pressure ridges, and melt pools. The hazards of these and their location is outlined in Chapter 1.

Crevasses. Crevasses are generally rare in the marginal area of the McMurdo Ice Shelf south and east of Cape Armitage. Two large crevasses which are similar are known to exist at present near the current Williams Field 3 skiway and are located on the map in Figure 2-1. The crevasse south of the Williams Field Skiway is the older of the two and the changes in its dimensions from season to season are considered typical of crevasses in the area. In DF-64 this crevasse was about 3 feet wide (Figure 2-8). By DF-68 it had widened to 6 feet at the widest point and was found to extend about 1,000 feet east at right angles to the barrier face. Early in DF-69 it had begun to close and was only 2 to 4 feet wide. In cross section it was wider at the bottom and was floored with sea ice during most of the year. The snow bridge covering the crevasse varied in thickness from a few inches to 12 inches and often sagged downward during the summer, thus warning of its presence.

Tide Cracks. Only one prominent tide crack occurs where the ice shelf is in contact with Hut Point Peninsula. This crack has been traced at least 5 miles north along the eastern side of the peninsula. North of Pram Point for a distance of about 1 mile, the crack becomes a crevasse and intermittently widens to 6 or 8 feet but is almost always covered and is considered dangerous. In DF-67, a section of the snow roof collapsed and permitted entry for measurements (Figure 2-9). The walls were very erratic and the crack alternated between widths of 8 feet to only a few inches. The total depth was about 45 feet to unfrozen seawater.

Pressure Ridges. Pressure ridges occur in only two areas as shown on the map in Figure 2-1. The most prominent pressure ridges are adjacent to Hut Point Peninsula north of Pram Point, and trend roughly north-south, normal to the direction of maximum compression and about 30 degrees north of the direction of movement. The wavelength of the ridges varies between 180 and 300 feet with an average of about 260 feet. The

amplitude increases southward and attains a maximum of about 12 feet near Pram Point.

The second pressure ridge area is south of Cape Armitage and is about 9,000 feet wide parallel to the direction of movement. These ridges are smaller than those near Pram Point and have wavelengths of 80 to 120 feet with an amplitude not exceeding 6 feet. The major hazard in both pressure ridge areas consists of numerous cracks, or crevasses, in the crests. These cracks occur both parallel with, and perpendicular to, the axis of each ridge. They are usually only 8 to 12 inches wide and seldom more than 20 feet deep; however, they are hazardous to personnel on foot and can also cause trouble for vehicles.

Melt Pools. During DF-66, the Outer Williams Field alternate runway was located on glacier ice 8.5 miles south of McMurdo Station (Figure 2-1). The surface in this area has a mottled appearance caused by thin, patchy snowdrifts and low mounds of white bubbly ice distributed in a random pattern on clear, blue glacier ice. While building the runway and access road, subsurface melt pools were discovered that presented a serious hazard to aircraft traffic and a troublesome obstacle to road construction (Figure 2-10). Although this area is no longer used, the subsurface melting can occur anywhere clear blue ice is exposed and is, therefore, described in detail.

The melt pools found at Outer Williams Field vary widely in size and shape but are usually 3 to 4 feet deep and span circular or elliptical areas 40 to 70 feet in diameter. They occur only beneath blue ice and are caused by the greenhouse effect of intense solar radiation, low reflectivity of the surface, and heat absorption by dirt in the ice [10]. Subsurface melting begins in mid-December at a depth of 18 inches or more and progresses until late January when refreezing begins. The ice cover may decrease to as little as 3 inches in thickness during the warmest part of the summer. Subsurface melting can be prevented by maintaining a cover of snow or ice chips over surface to reflect solar radiation. To be effective the cover must be at least 2 inches thick.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCES

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7. Naval Civil Engineering Laboratory. Technical Note N-721: Sea ice studies on McMurdo Sound during Deep Freeze 65, by R. A. Paige and C. W. Lee. Port Hueneme, Calif., Oct. 1965.

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10. R. A. Paige. "Subsurface melt pools in the McMurdo Ice Shelf, Antarctica," Journal of Glaciology, vol. 7, no. 51, 1968, pp. 511-516.

Revised – 1979

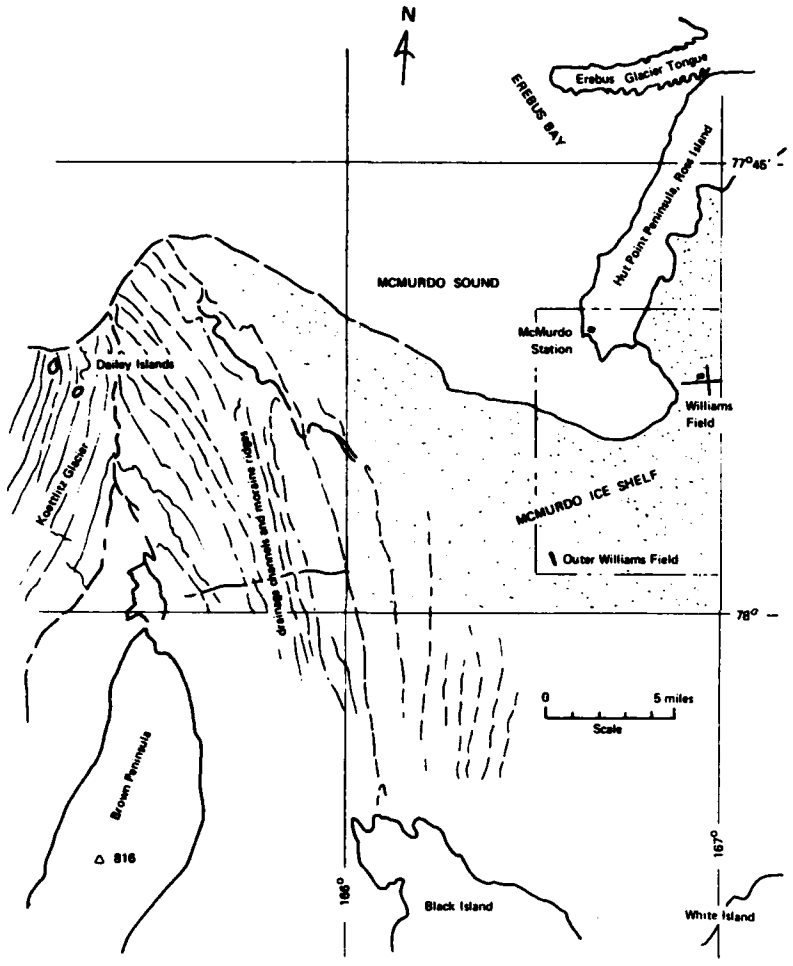

Figure 2-1. Overview of McMurdo Ice Shelf. See Figure 2-2 for details of inset outlined by broken line.

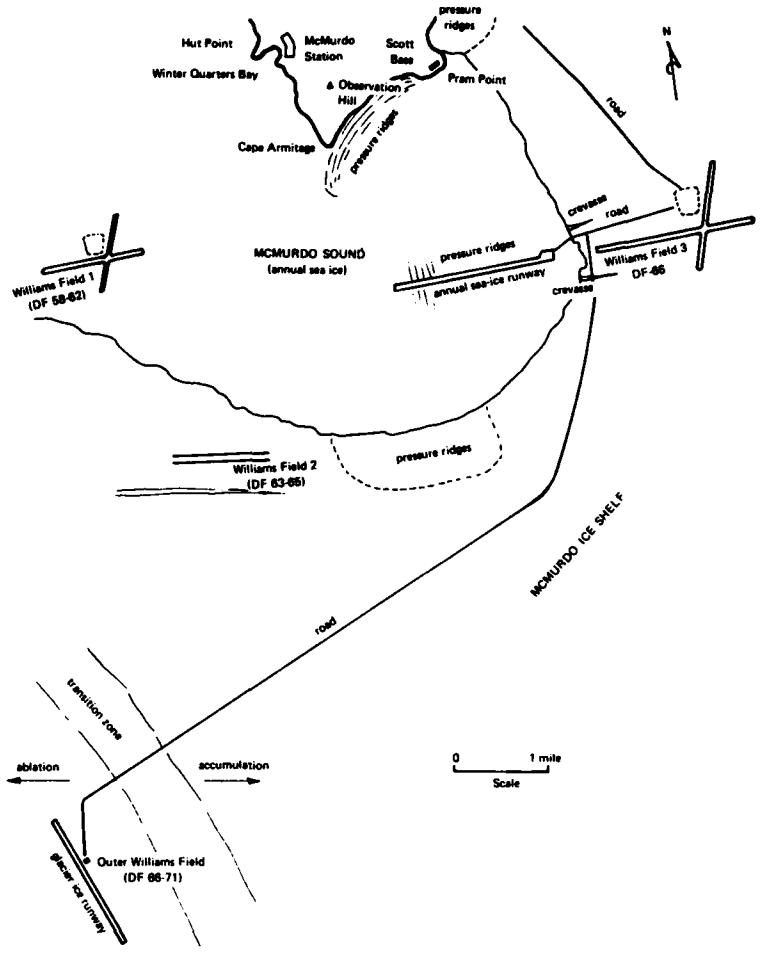

Figure 2-2. McMurdo Ice Shelf (inset from Figure 2-1) showing features and historical sites of the Williams Field air facilities.

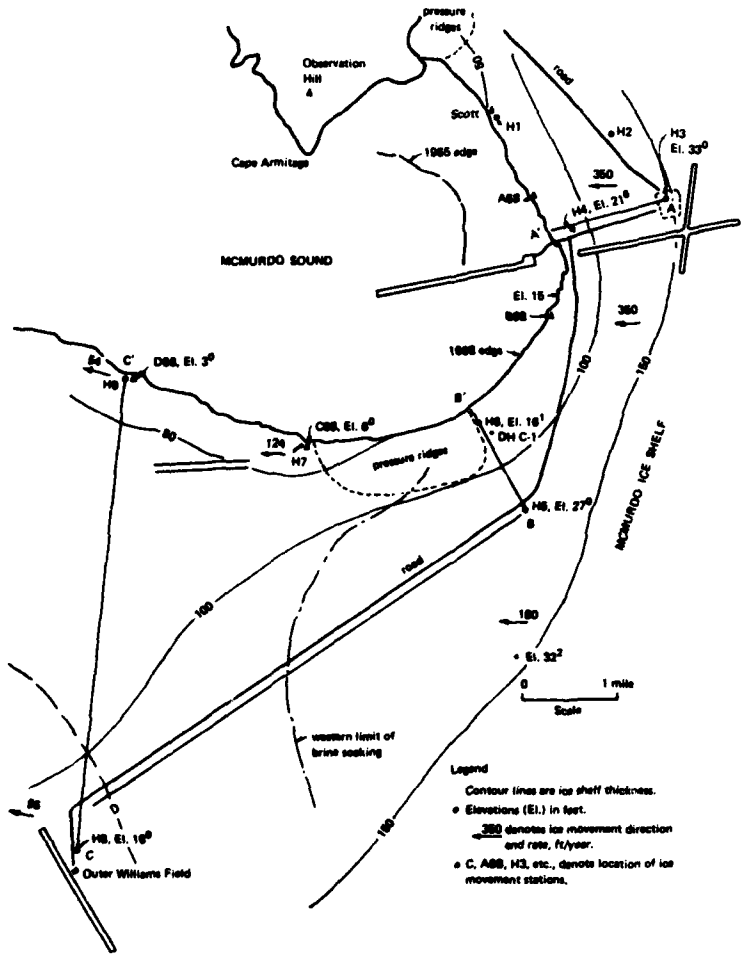

Figure 2-3. Movement and thickness of the McMurdo Ice Shelf.

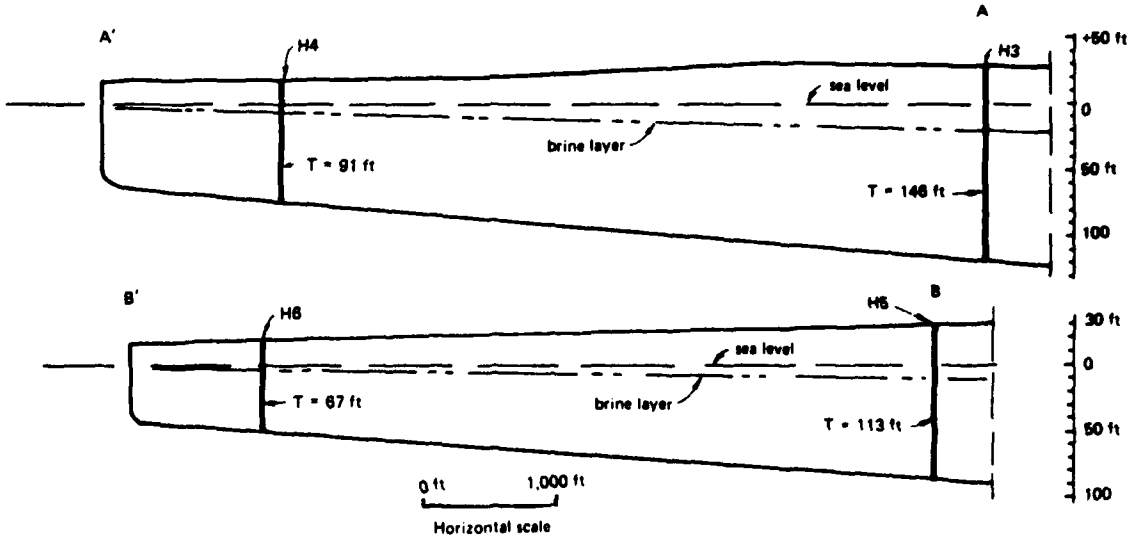

Figure 2-4. Cross sections of the McMurdo Ice Shelf along A–A' and B–B'.

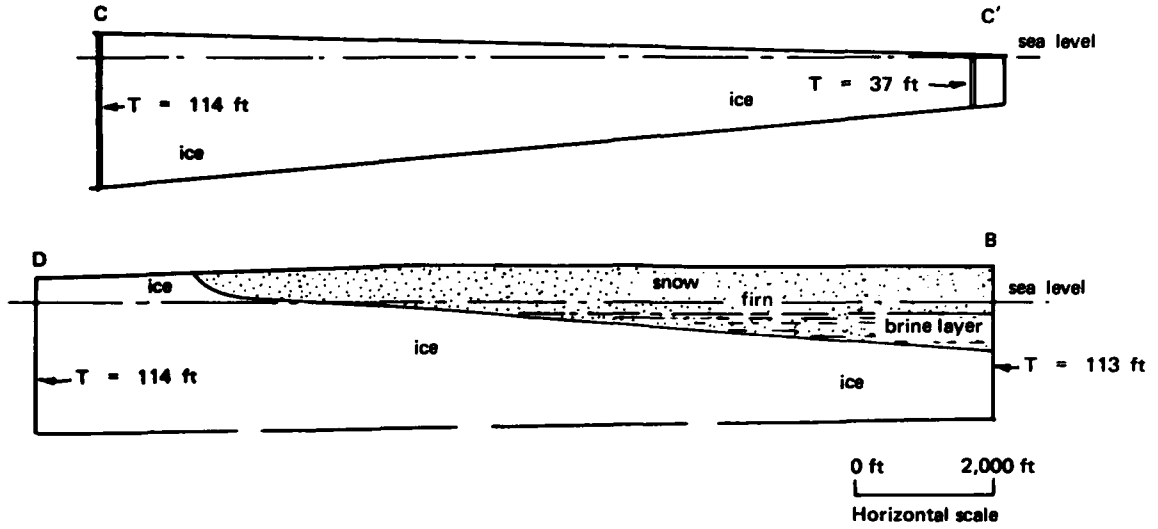

Figure 2-5. Cross sections of the McMurdo Ice Shelf along C–C′ and D–D′.

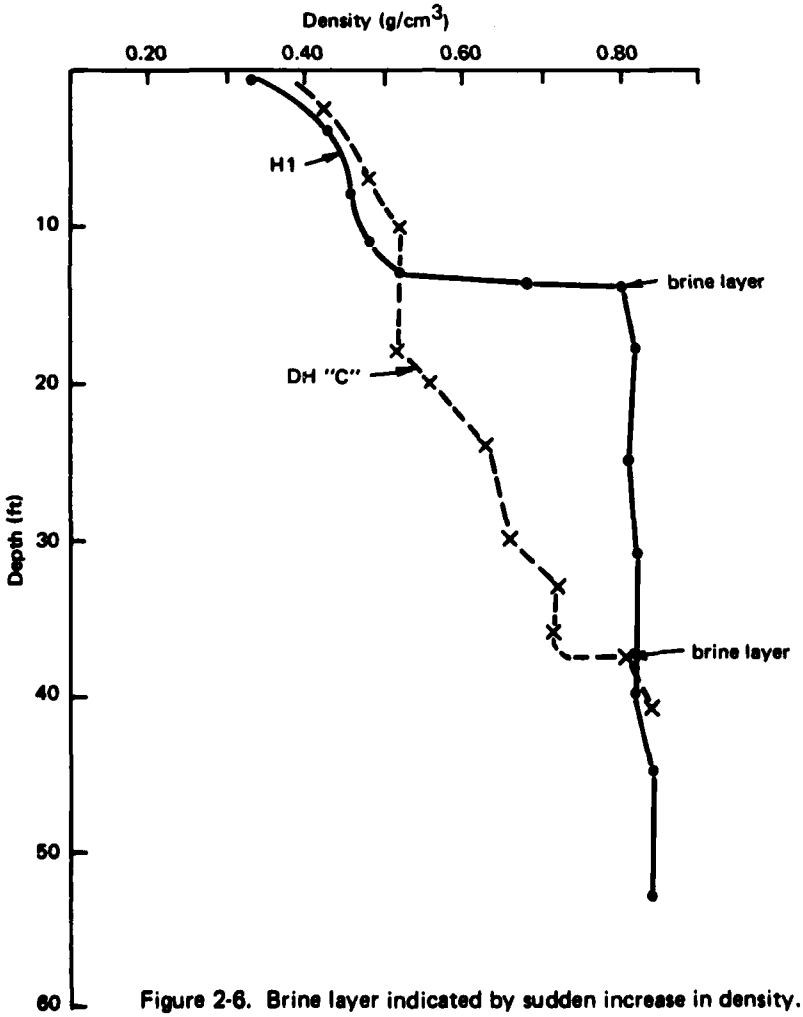

Figure 2-6. Brine layer indicated by sudden increase in density.

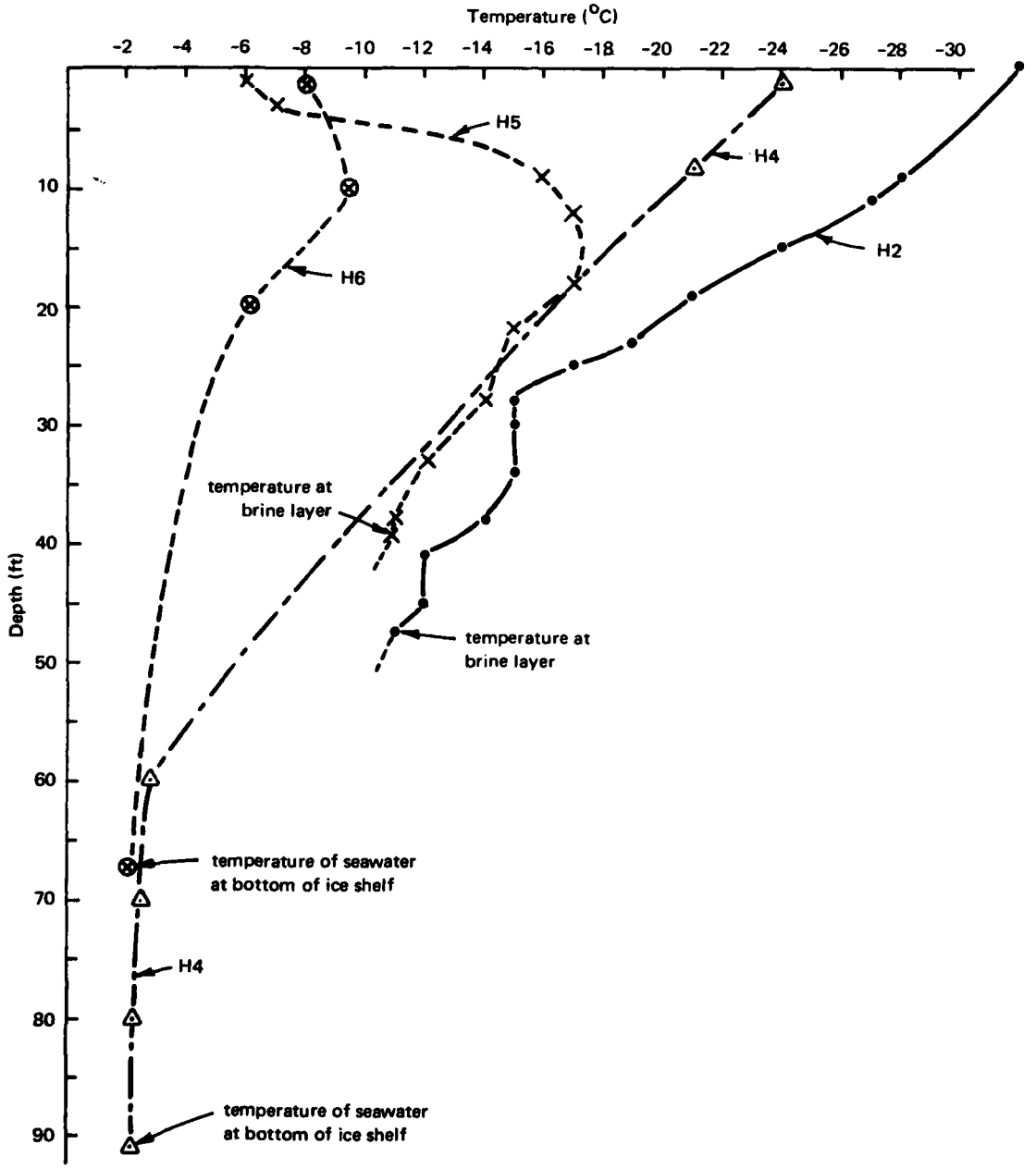

Figure 2-7. Effect of brine infiltration on temperature of McMurdo Ice Shelf.

Figure 2-8. Crevasse in McMurdo Ice Shelf south of skiway.

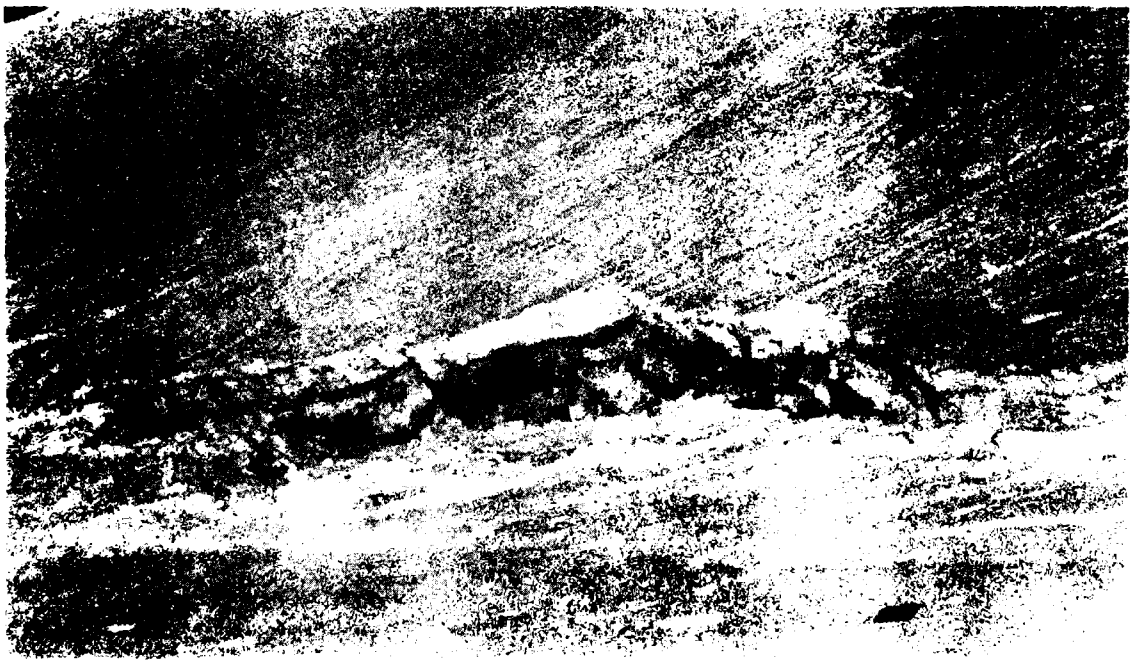

Figure 2-9. Hazardous tide crack between McMurdo Ice Shelf and Hut Point Peninsula.

Figure 2-10. Ice road crossing flooded downwarped area on 2-year-old sea ice near Williams Field 3 ice runway.

LIST OF APPENDIXES

Chapter 2

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Chapter 3

SEA-ICE SHEET

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Chapter 3

SEA-ICE SHEET

INTRODUCTION

The sea-ice sheet which covers the McMurdo embayment is used throughout the summer for travel, for freight hauling, and as a runway site for operation of heavy cargo aircraft. Continued safe utilization of the sea ice requires an understanding of the hazards, the history, and the basic properties of the sea ice such as thickness, strength and the effect of temperature variations. This chapter deals with the seasonal history and thickness of the ice sheet and describes the location and causes of common operational problems.

FEATURES AND SEASONAL VARIATION

The embayment south of McMurdo Station is covered by sea ice for about 10 months each year. This ice sheet generally appears as a flat, featureless surface with a 6 to 8-inch-deep snow cover and low, wind-carved drifts rarely more than 18 inches in total height. On rare occasions, pieces of 2-year-old ice or small bergs may be frozen into the annual ice sheet. By mid-December, the ice reaches a maximum thickness of 8 to 11 feet if less than 1 year old but begins to deteriorate internally and thin by bottom melting in late December. In February or early March, cracks generally appear and the ice begins to break up into individual floes and drift out to sea. By April, new sea ice has formed and grows at an average rate of 1 to 1.5 feet per month until November when the growth rate decreases [1]. Figure 3-1 shows the growth and thinning rate of the sea ice for 2 summer seasons.

To determine a complete and detailed history of the ice sheet, accurately located thickness measurements are needed over a large area for an extended time period. Measurements that meet these requirements are available only for a few summer months during DF-66 and DF-67 [1]. Because of this, continued reference will be made to these 2 years throughout this chapter. From these data, the general history of the sea-ice sheet can be described through its various stages of growth. These stages may be defined for the McMurdo area in the following manner:

1. *Young Ice.* The ice sheet is growing rapidly in thickness and extent. This period lasts from late March to late November.

2. *Mature Ice.* The ice sheet has attained its maximum thickness for the season and is in equilibrium with the environment. It is no longer growing and has not begun to deteriorate internally or to lose ice by bottom melting. This stage usually lasts only from late November to mid-December. At the peak of maturity, the ice sheet is nearly isothermal (Figure 3-2).

3. *Old-Age.* The ice sheet becomes warmer and thins rapidly by bottom melting. Internal deterioration of strength is also rapid and is expressed by accelerated brine drainage and the enlargement of brine channels and cavities. This stage lasts from late December until breakout or the coming of winter.

In DF-69, the sea ice did not break up but remained in the McMurdo embayment for a second season. When this occurs, the ice again grows in thickness during the winter and the stages of young and old ice are superimposed.

Thickness

The average thickness of the ice sheet at different locations at different times during the summer is shown in Figure 3-3. These variations in thickness with location are typical and result from variations in water depth and circulation beneath the ice, and by difference in exposure to wind and depth of snow cover on the ice surface. An unusually deep snow cover on young ice results in a thinner mature ice sheet with other factors being equal.

Thinning of the Ice Sheet

December and January are the midsummer months at McMurdo Station and are characterized by ambient temperatures as high as 42°F, intense solar radiation, and a general warming of the upper few feet of the land, ice, and snow surfaces. The annual sea ice in McMurdo Sound also becomes warmer and begins to decrease in thickness by bottom melting.

The DF-65 thickness-versus-time curves in Figure 3-4 illustrate the typical trend of thinning that occurs each season. The mature stage lasted throughout December in DF-65, but ended in mid-December during DF-64. The thickness, growth, and thinning rate varies from season to season and from place to place. For example, during DF-64, the ice over most of McMurdo Sound remained thick enough to support heavy vehicle traffic almost until breakout. However, by mid-January of DF-66, the sea ice in the entire central part of the embayment had thinned and deteriorated to a dangerous condition.

The start of deterioration for the annual sea ice is also the beginning of the most critical period for safety considerations. Surface melting is negligible in McMurdo Sound but melting at the bottom of the ice sheet is rapid and of considerable magnitude in certain locations. This rapid melting is attributed to increasing temperature of the sea water near the surface. Studies have shown that the seawater temperature to a depth of 5 meters (16 feet) below the surface has reached the melting point of sea ice by mid-December and that by early January the seawater temperature is warmer than that required to melt the overlying ice [2]. This temperature rise takes place while most of McMurdo Sound is still covered with sea ice.

Sea-Ice Breakout

The sea ice in the McMurdo embayment breaks out and goes to sea nearly every fall. No two breakouts have occurred at the same time or rate and are not readily predictable. In DF-65, breakout continued for 13 days before the embayment was clear of annual sea ice, but the following year most of the Sound was clear of ice in less than 30 hours. The slow progression of the DF-65 ice breakout is mapped in Figure 3-5. The history of annual-ice breakout is shown in Table 3-1.

Sufficient data are not available to predict breakout although various events may indicate that it is imminent. A decrease in the strength and thickness of sea ice, internal

deterioration, a temperature gradient near the melting point, and accelerated brine drainage are some of the intrinsic factors that precede breakout. The appearance and enlargement of numerous seal breathing holes, the formation of working cracks, and areas where the sea ice melts away in situ, have also preceded most recorded breakouts since DF-63. During the period of low ice strength, a storm cycle accompanied by high winds will also greatly increase the probability of ice sheet breakout.

Table 3-1. Record of Annual-Ice Breakout at McMurdo Station

Year	Breakout
DF-60–DF-62	Complete
DF-63	Partial to Cape Armitage
DF-64–DF-68	Complete
DF-69	Partial to Cape Armitage
DF-70–DF-72	Complete

Special Features

As outlined in Chapter 1, certain features occur each year on the sea ice that are hazardous or constitute an obstacle to travel. Some recur in the same area each year, and some have a random location. These features are pressure ridges, slush zones, anamolous thin areas, cracks, and seal-breathing holes.

Pressure Ridges. Pressure ridges are a common feature on the sea ice and result from horizontal stresses caused by the adjacent, westward-moving ice shelf. Their magnitude, size, and extent vary from year to year depending partly on the position and configuration of the ice shelf edge. Pressure ridges form every year along the sea ice-land contact between Pram Point and Cape Armitage and become a definite obstacle to travel by midsummer. Pressure ridges and downwarped areas are also common for about 3 miles along the ice shelf edge from Pram Point southward.

The surface of the ice in downwarped areas or in the swales of pressure ridges is usually below sea level. These areas collect snow that eventually becomes soaked with seawater to form a slush pool. Slush pools are common by late summer and are dangerous; however, they are usually easy to avoid because of their location in zones of obviously deformed ice.

Slush Zones. Slush zones are different from the slush pools that are associated with pressure ridges and usually form in areas where the snow cover is 1 foot deep or more. Flooding is a result of proximity to tide cracks, open cracks, or seal breathing holes. Slush zones may be several hundred square yards in extent and may not be visible because of an undisturbed crust of wind-packed snow. Vehicles can break through this crust and become immobilized in the slush (Figure 1-16). These zones usually form in middle or late summer and are common in the Pram Point to Cape Armitage area.

Thin-Ice Areas. Three known areas of thin ice occur on McMurdo Sound that are a serious danger to middle and late summer travel on the sea ice. These areas are anomalous because the ice becomes dangerously thin when the sea ice elsewhere near McMurdo Station is still thick enough for safe travel. The most important thin-ice area is off Cape Armitage. Less well known areas are the central part of the embayment south of Cape Armitage and a small area west of Arrival Heights (Figure 3-6).

The shoal-water area off Cape Armitage is about 90 acres in extent where the sea ice becomes dangerously thin by early January.

The amount and rate of thinning varies from season to season; however, a typical example is shown by the thickness-versus-time curves in Figure 3-7. In DF-73, the ice melted away in situ, leaving an area of open water in an otherwise continuous ice sheet. This thin ice was attributed to high surface water temperatures during the summer, an early thick snow cover that insulated the ice to retard growth, and to shoal-water currents as high as 3 or 4 knots [2].

Thickness measurements during DF-66 show that the sea ice in the central part of the embayment south of Cape Armitage can become dangerously thin late in the summer (Figure 3-8). Bottom melting started between 20 and 23 December 1965 and progressed rapidly until mid-January when the rate decreased. At the far end of the annual-sea-ice runway, the ice had deteriorated badly and had thinned to about 2 feet 10 inches by late January. At the same time, and even up to breakout on 3 February 1966, the sea ice along the margin of the ice shelf varied in thickness between 4 and 6 feet. DF-66 is the only known season in which this unusual thinning occurred; nevertheless, it is evident that late season thickness monitoring in this area is essential for safe operation. Techniques for thickness monitoring are described in Chapter 4.

Airphotos taken in DF-66 showed an area of open water west and north of Hut Point. The sea ice had melted away in-place, which indicates conditions similar to the Cape Armitage thin-ice area. Shoal water in this area is probably responsible for currents that are capable of eroding and melting the ice at an accelerated rate. This area is frequently traveled by scientists visiting the seal rookeries in Erebus Bay and should be flagged as dangerous.

Cracks. Cracks are a common feature in sea ice and occur in one or a combination of the following forms:

1. Tidal cracks which occur at sea ice-to-land and sea ice-to-ice shelf contacts.
2. Dry surficial cracks that are usually narrow and penetrate only a short distance into the ice.
3. Wet cracks that do not penetrate the ice sheet but that are partly filled with brine that has drained from the adjacent ice.
4. Wet, working cracks that completely penetrate the ice sheet with the ice on one side moving relative to the ice on the other side.

Tidal cracks occur completely around the periphery of the sea ice in the McMurdo Station area. They are crossed by numerous travel routes and can become troublesome when they tend to widen. Cracks up to 14 inches wide have been observed in the sea ice and were probably formed by a combination of thermal stresses and stresses caused by movement of the ice shelf. During the summer of DF-65, a wet, brine-filled crack 14 inches wide occurred on the crosswind annual-ice runway at Williams Field 2 but penetrated only 44 inches in sea ice 105 inches thick [3].

Seal Breathing Holes. Seal breathing holes are rare early in the summer around McMurdo Sound and occur only in pressure ridge areas, near tidal cracks, or in other areas of broken or disrupted ice. As the ice sheet progressively thins and weakens, seal holes appear in greater numbers in the thinnest areas but are still somewhat restricted to the area of thin ice off Cape Armitage, Hut Point, and the pressure ridge and tidal crack areas south and east of Pram Point. Seal holes are a

warning of thin ice and can become enlarged enough to be dangerous even to small vehicles.

Two-Year-Old Sea Ice. As mentioned earlier in this chapter, the annual sea ice did not break out of McMurdo Sound in DF-69. Figure 3-9 shows the thickness record for this 19-month-old ice. No direct measurements were made from February to September and the data shown for this period are based on a salinity profile and core study made in October of DF-70.

First consideration would indicate that preserving the sea ice for 2 years or longer would be desirable because it results in a thicker ice sheet and greater safety for aircraft and vehicle operations. The experience on the 2-year-old ice during DF-70 does not support this idea and indicates that the presence of the older ice may be detrimental. The pressure of the westward-moving ice shelf on the annual sea ice during DF-70 caused the formation of pressure ridges and both downward and upward warped sea ice over large areas.

About 1,000 feet of the west end of the sea-ice runway was closed early in DF-70 because of low pressure ridge formation. The 2-year accumulation of snow on the sea-ice runway is also a detrimental factor because repeated snow removal increases the height and weight of the snow berms along the edges of the annual-ice runway and around the parking area. The added weight of these berms caused additional local downwarping and flooding that increased in severity later in the DF-70 season. Longitudinal cracks along the centerline of the runway were also caused by edge loading and can become a traffic hazard. Figure 3-10 shows the Williams Field ice road crossing a flooded downwarped area and the high snow berms resulting from the 2-year snow accumulation.

Whether or not the 2-season DF-70 sea ice would have gone to sea under natural conditions is not known. However, in late February 1970, the Coast Guard icebreakers cleared the embayment south of Cape Armitage to assure the formation of new, undeformed sea ice for DF-71. The use of icebreakers to break up the annual ice in McMurdo Sound at the conclusion of each summer season is recommended.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Note N-849: Sea ice on McMurdo Sound, Antarctica, preliminary thickness and temperature studies, by R. A. Paige. Port Hueneme, Calif., Oct. 1966.

2. U.S. Navy Hydrographic Office. Technical Report TR-125: Seasonal oceanographic studies in McMurdo Sound, Antarctica, by W. L. Tressler and A. M. Ommundsen. Washington, D.C., 1962.

3. R. A. Paige and C. W. Lee. "Preliminary studies on sea ice in McMurdo Sound, Antarctica, during Deep Freeze 65," Journal of Glaciology, vol. 6, no. 46, 1967, pp. 515-529.

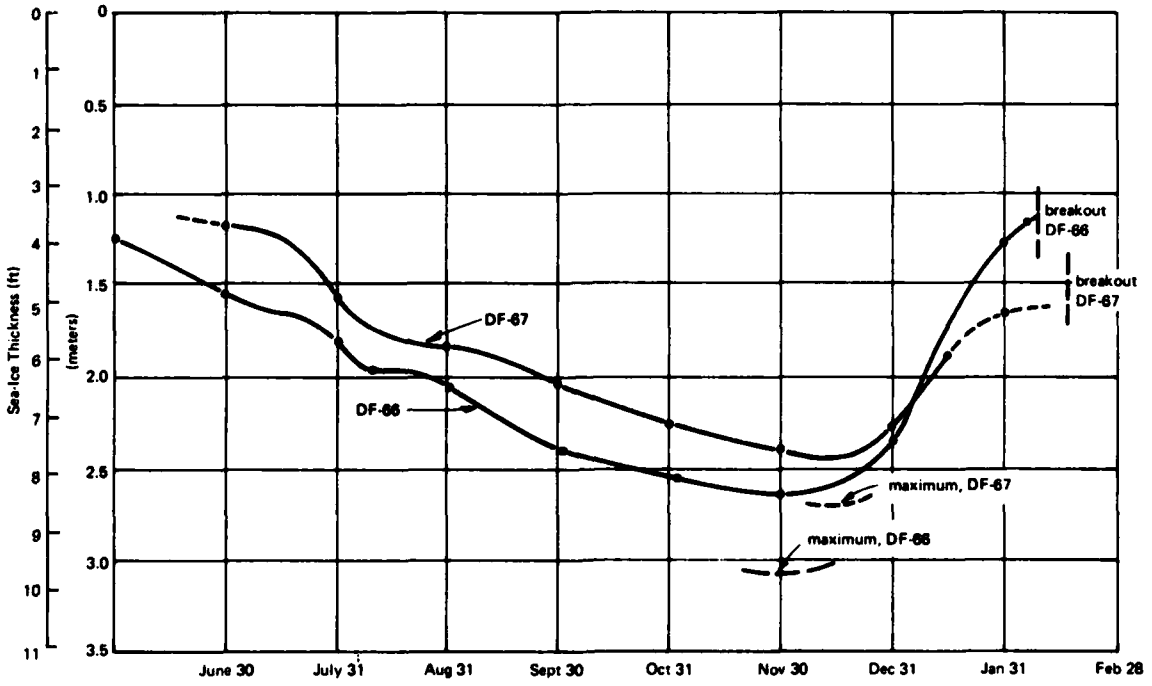

Figure 3-1. Growth and thinning of the annual sea ice in McMurdo Sound during Deep Freeze 66 and 67.

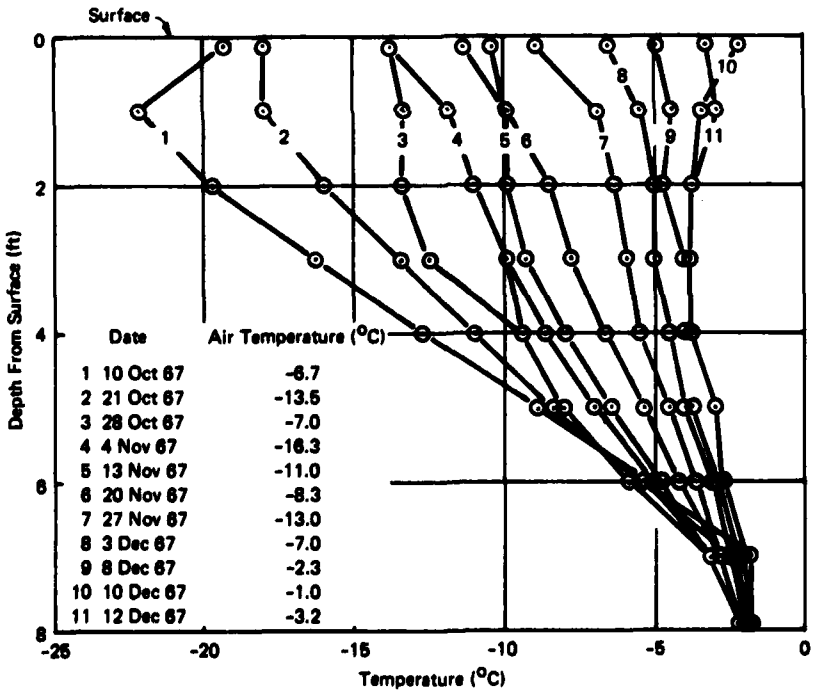

Figure 3-2. Temperature of annual sea-ice sheet, McMurdo (near shelf end of runway, no snow cover, DF-68).

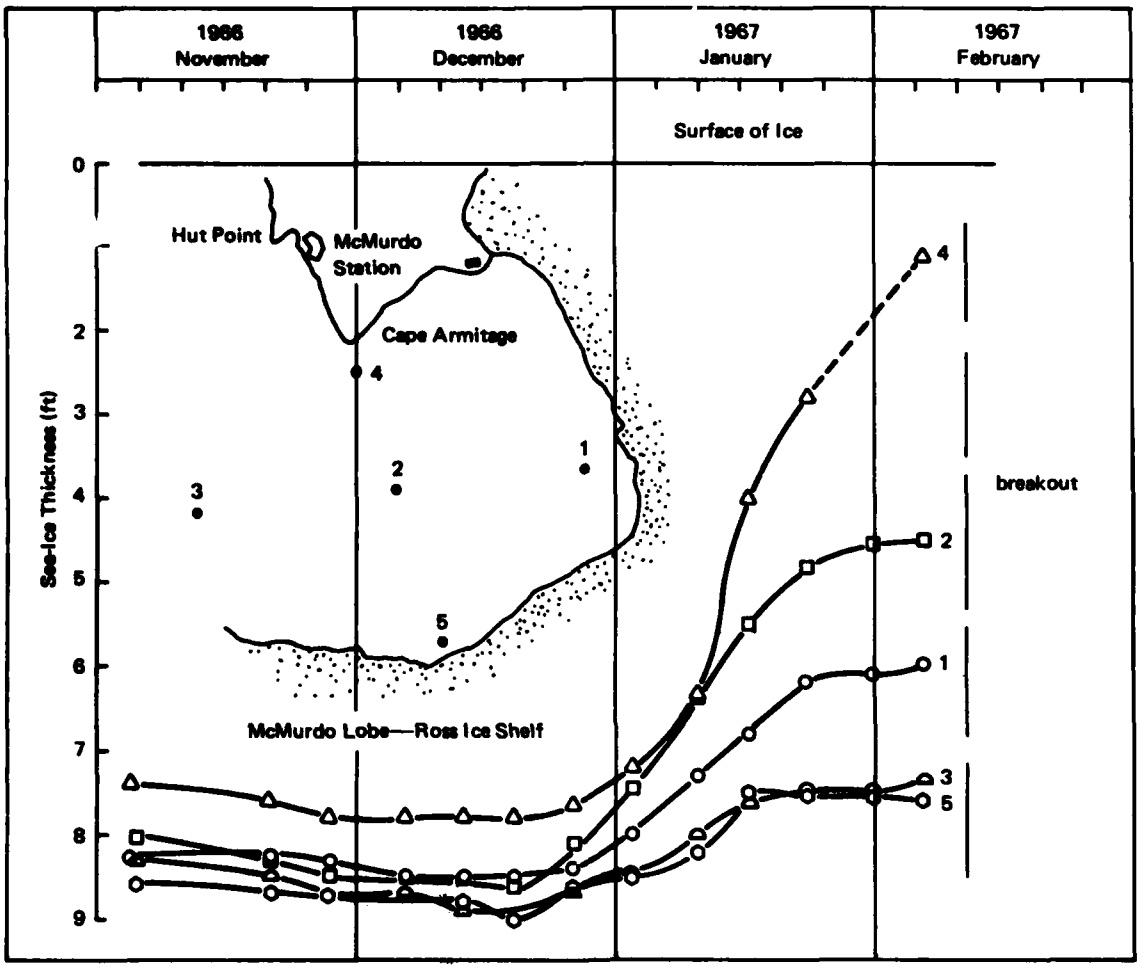

Figure 3-3. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 67.

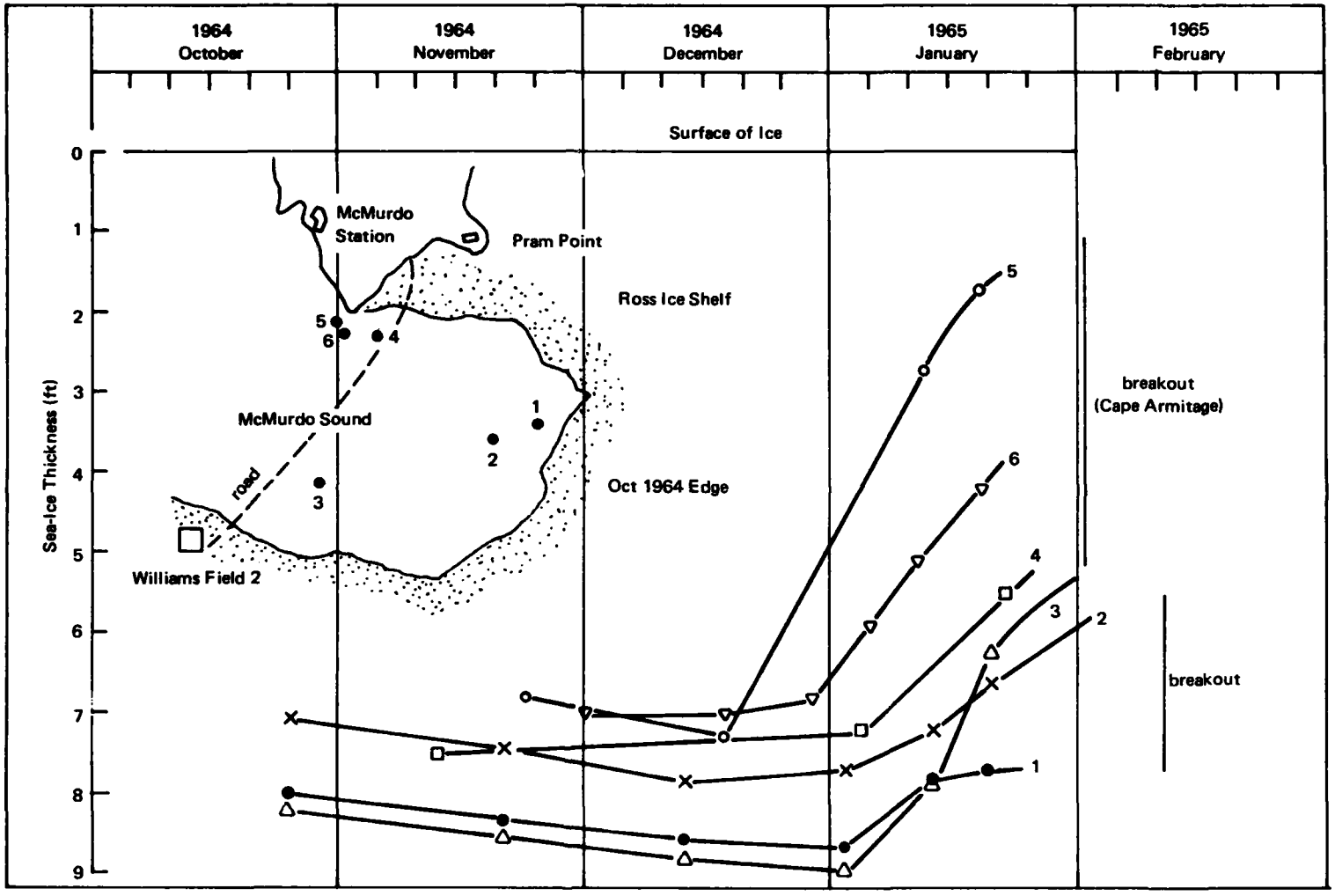

Figure 3-4. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 65.

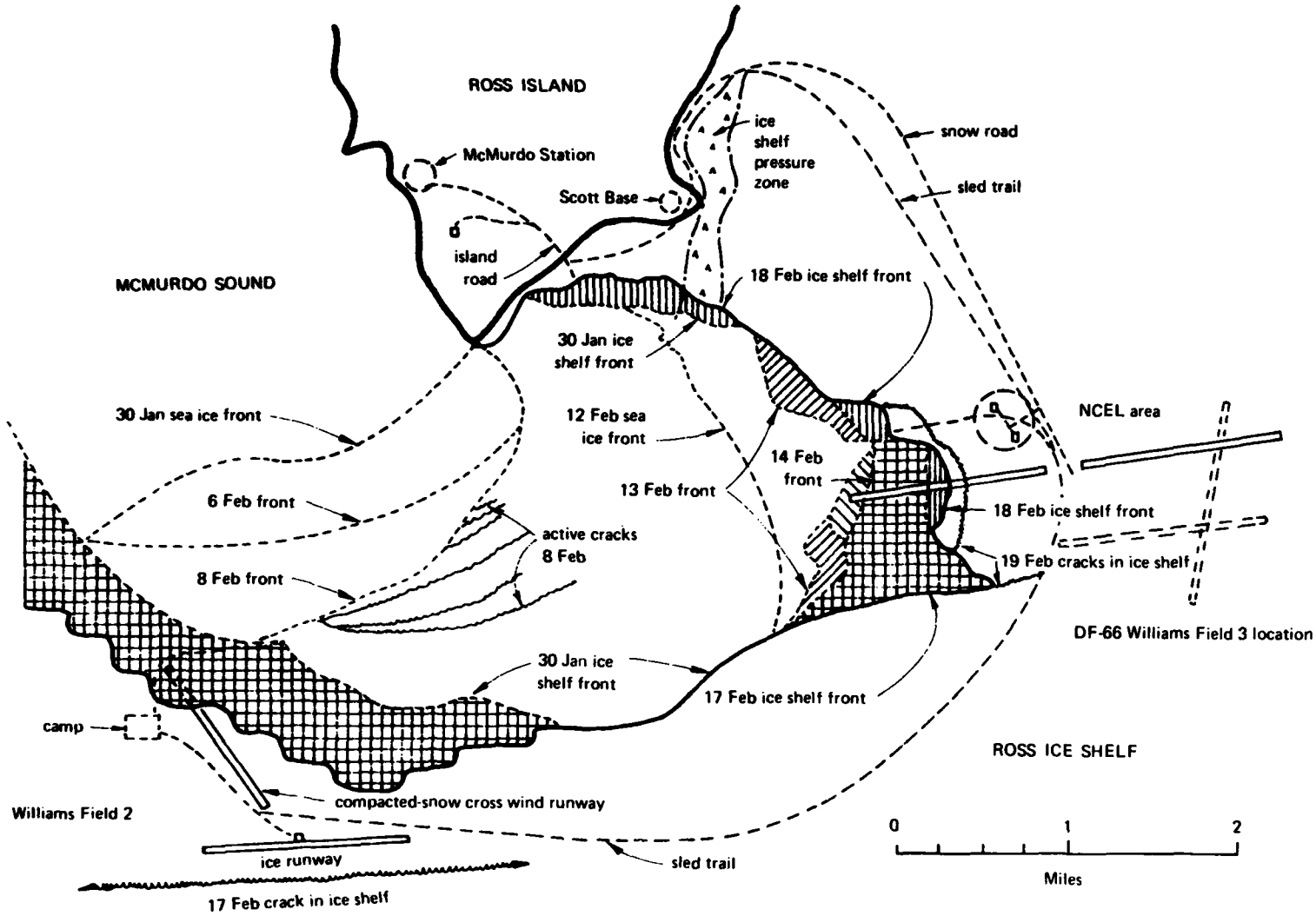

Figure 3-5. Progression of ice breakout at McMurdo Station during February 1965. Shaded areas are breakouts of ice shelf and fast ice.

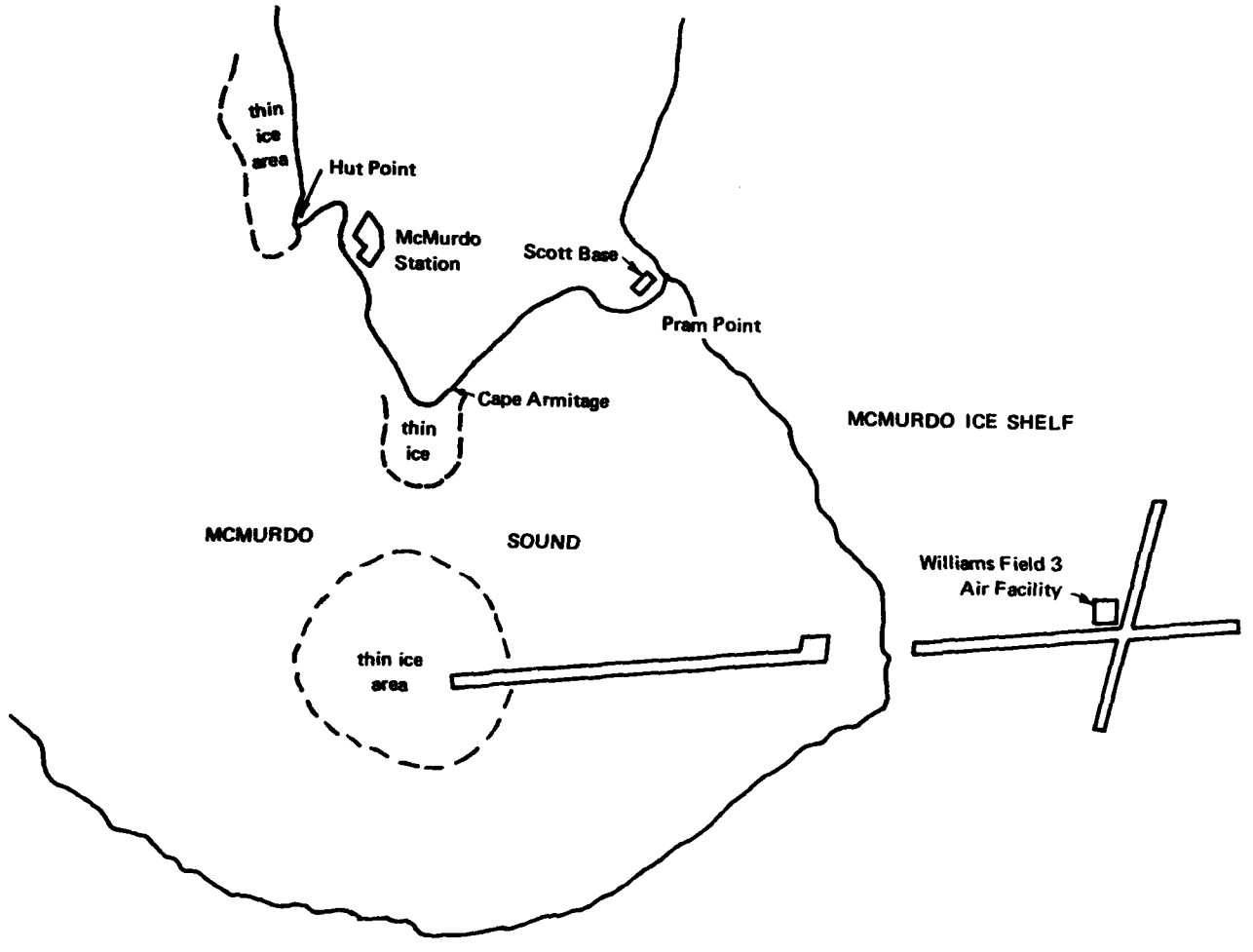

Figure 3-6. Map showing the location of anomalous thin sea-ice areas in McMurdo Sound.

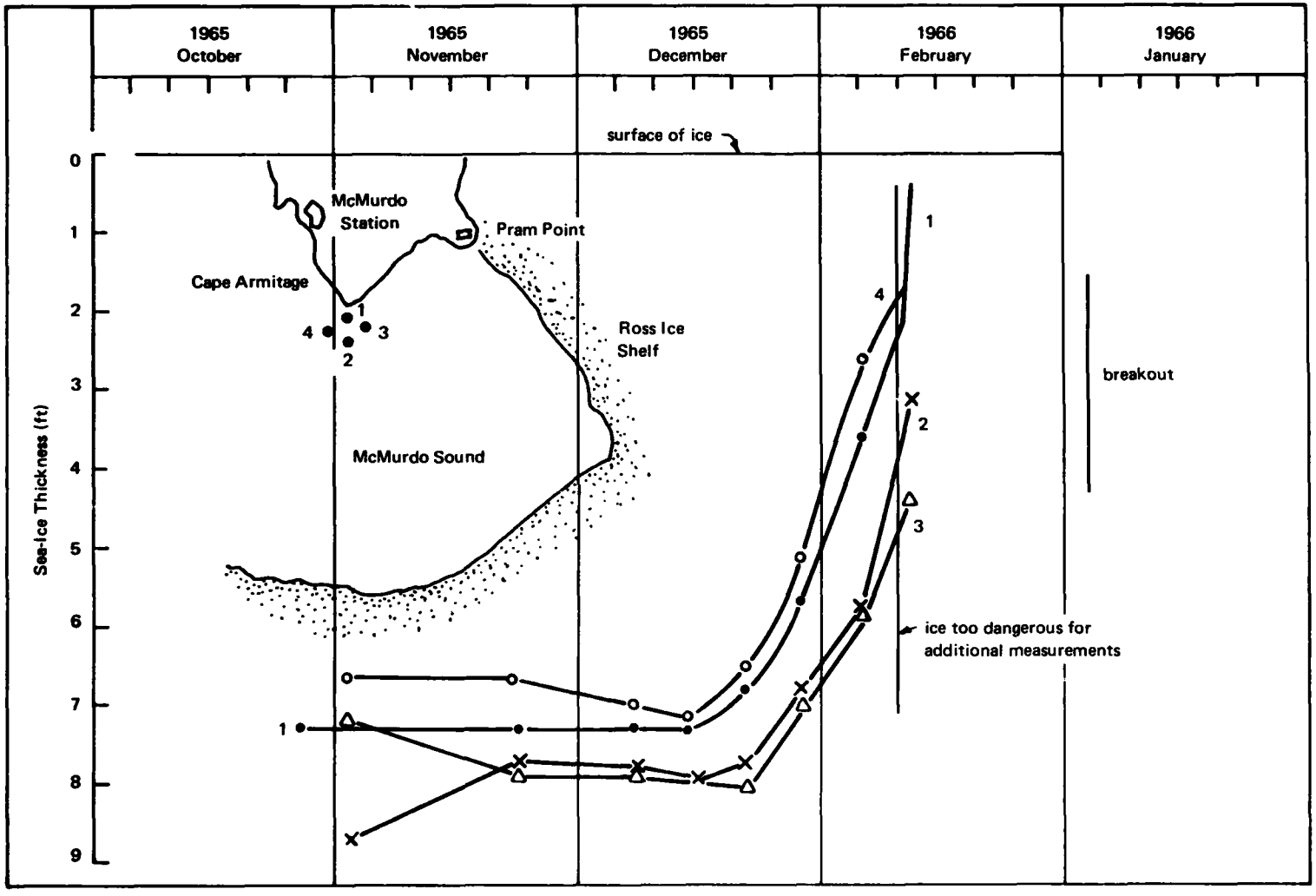

Figure 3-7. Sea-ice thickness versus time at Cape Armitage during Deep Freeze 66.

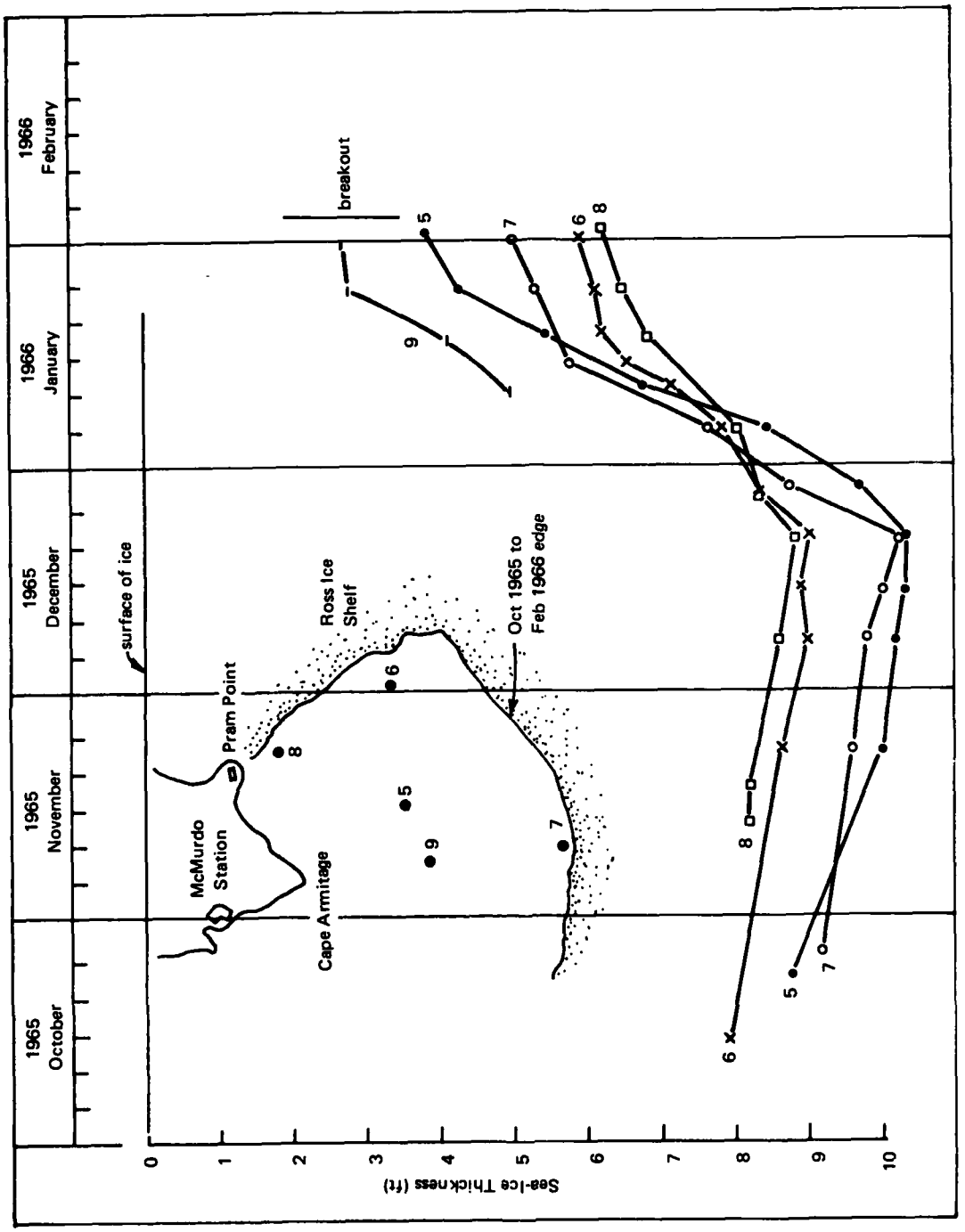

Figure 3-8. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 66.

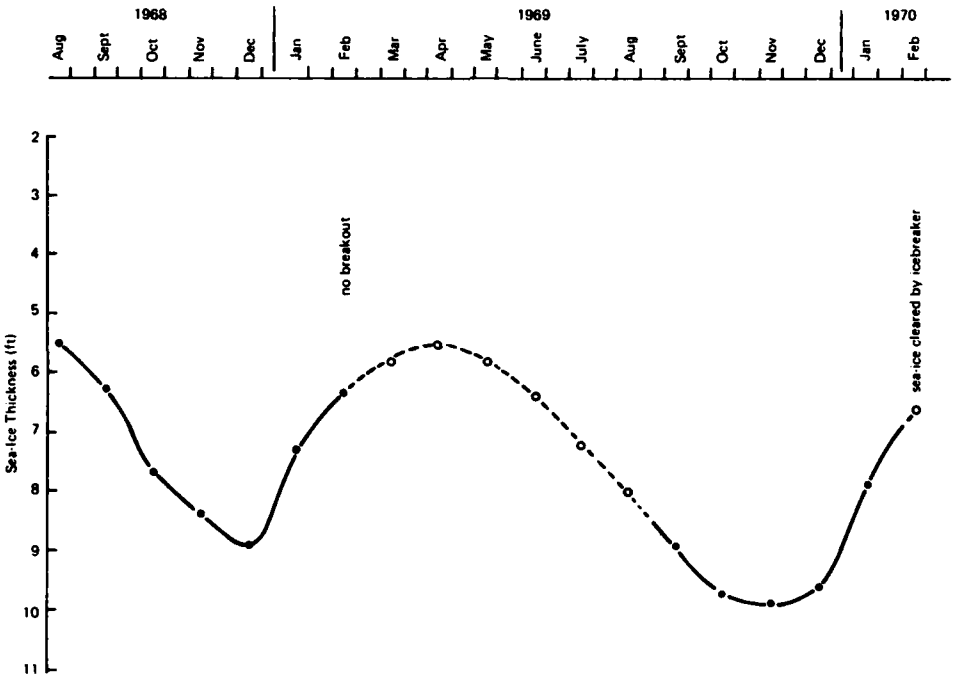

Figure 3-9. Average mid-month sea-ice thickness for 2-year-old sea ice in McMurdo Sound, Antarctica. Dashed part of curve is interpolated from a salinity profile.

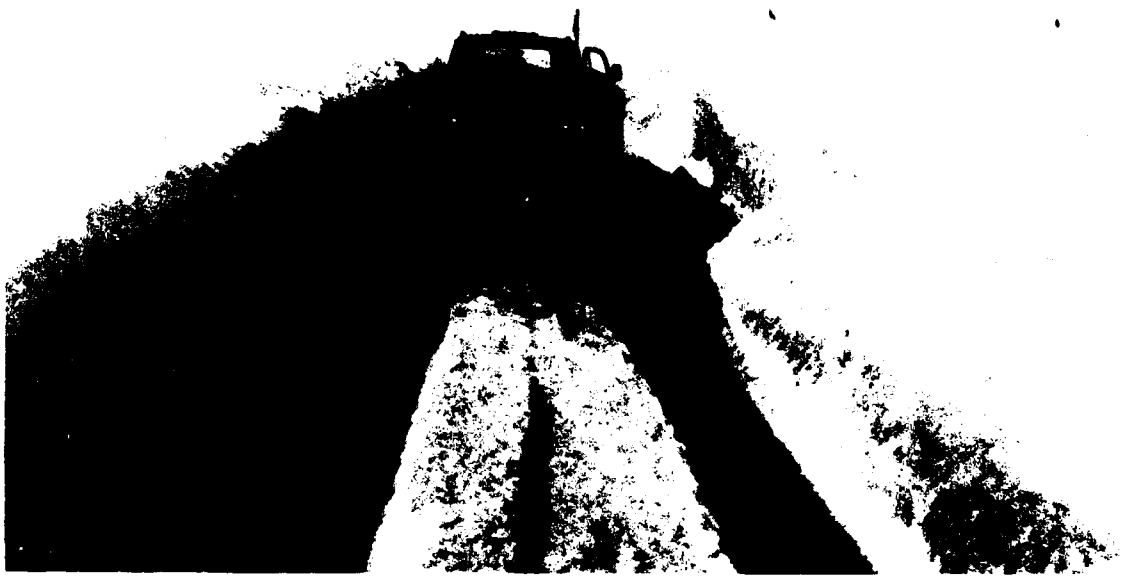

Figure 3-10. Ice road crossing flooded downwarped area on 2-year-old sea ice near Williams Field 3 ice runway.

LIST OF APPENDIXES

Chapter 3

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

3-A. _____

3-B. _____

3-C. _____

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Addition – 1979

Chapter 4

PROPERTIES OF SNOW, ICE, AND PERMAFROST

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Chapter 4

PROPERTIES OF SNOW, ICE, AND PERMAFROST

INTRODUCTION

This chapter presents a summary of the principal characteristics of snow, ice, and permafrost as apply to McMurdo Station. A more general discussion on this subject is presented in NAVFAC Design Manual DM-9.

SNOW PROPERTIES

The properties of natural snowfall are the result of a combination of many conditions, three of which are:

1. Meteorological environment at the time the snow was formed.

2. Degree of deformation of the snowflakes while falling.

3. Increased density of the snow cover caused by gravity, warming of the snow followed by subsequent freezing (recrystallization), and firnification and the mechanical effects of wind.

Density

The density of snow is one of its most important physical characteristics because all other properties relate directly to it. Snow density is often used as an index for its utilization with respect to construction and transportation.

The density of snow can vary from 0.01 to 0.80 gm/cm^3, depending upon many factors; however, if the density is greater than 0.80 gm/cm^3, the material is considered to be ice. A classification that describes snow cover in general terms according to its density is given in Table 4-1. All other factors being equal, the density of newly fallen snow increases with higher air temperature and wind velocity at the time it is deposited and with depth within the snow cover.

Table 4-1. Snow Cover Density Classification

Classification	Density	
	(gm/cm^3)	(lbs/ft^3)
Very loose	0.01 to 0.1	0.6 to 6
Loose	0.1 to 0.25	6 to 16
Medium	0.25 to 0.35	16 to 22
Dense	0.35 to 0.45	22 to 28
Very dense	Over 0.45	Over 28

Porosity and Permeability

Another important property of snow which can be calculated from its density is porosity. Absolute porosity is defined as the ratio of void volume to total volume and can be calculated from

$$n = \frac{d_i - d_s}{d_i}(100)$$

where n = the absolute porosity in percent

d_i = the density of solid ice (0.917 gm/cm^3 for most purposes)

d_s = the density of the snow

A condensed table for conversion of density to porosity is given in Table 4-2.

When the density of snow is less than 0.6 gm/cm^3, there is almost complete communication between the voids in snow and consequently, the snow is quite gas (air) permeable. At higher densities, the voids begin to separate from one another until at a density of about 0.8 gm/cm^3, the permeability to air becomes zero and snow becomes ice by definition. Air permeability is determined by drawing air through a sample and measuring the pressure drop across the sample. Figure 4-1 shows the relationship of permeability to density.

Table 4-2. Conversion of Density to Porosity

Density (gm/cm^3)	Porosity (%)	Density (gm/cm^3)	Porosity (%)
0.05	94.5	0.35	61.8
0.10	89.1	0.40	56.4
0.15	83.6	0.45	50.9
0.20	78.2	0.50	45.5
0.25	72.7	0.55	40.0
0.30	67.3	0.60	34.6

Mechanical Properties

Natural snow has poor strength characteristics. Vehicles with standard tires used on normal hard-surfaced roads become hopelessly mired, and tracked vehicles with ground pressure of only 3 to 5 psi may sink several inches into the snow.

It is difficult to associate the mechanical properties determined by experimentation with the real-time properties of a particular snowfield. Snow is in a continuous state of metamorphism. Its strength properties are greatly affected by combined influence of crystal size (particle size), density, age, and temperature. The surface temperature of the snow corresponds closely with the air temperature. For practical purposes, it can be assumed that little temperature change occurs at a depth below 25 feet where it is at a value close to the annual mean air temperature.

It has been concluded from experiments that maximum strengths are achieved at or near a critical density of 0.60 gm/cm^3, where the snow is permitted to achieve bond growth, or age hardening, at temperatures between $-7^{\circ}C$ and $-12^{\circ}C$. The critical density is considered to represent a limit beyond which grain packing is no longer effective as a mechanism for developing strength. Dense, well-bonded snow may be considered as a compressible viscoelastic material. However, for a very short time interval, it can respond elastically under moderate load with strains which are proportional to stress and which are recoverable on removal of the load. For sustained loads, the deformation that occurs is practically all irrecoverable after the load is removed.

If one considers the complex effect of the several variables that determine the mechanical properties of snow at particular stages in its metamorphic history, it is not surprising to find a wide variation in the definition of the mechanical behavior. A deterrent to a systematic study of snow has been the necessity of conducting most of the research in the field under variable and existing conditions as opposed to the controlled condition of the laboratory. Most published data define the strength properties as related to density whereas there are many other influencing parameters (e.g., sensitivity of the mechanical properties to temperature has not been adequately studied). In general, the information on the mechanical properties

of snow shown in the figures to follow have been obtained from a wide distribution of geographical locations.

Test results of the crushing strength of snow as a function of density are shown in Figure 4-2. Figure 4-3 provides the shear strength versus density relationship. The elastic modulus (Young's modulus) determined by dynamic techniques as related to density is shown in Figure 4-4. The dynamic modulus is measured by applying high frequency vibrations to a specimen of snow or to snow in situ using seismic methods. It has been found generally unsatisfactory to measure this property by static methods. The fact that snow has very little mechanical strength until the density becomes greater than 0.4 gm/cm^3 is a prominent feature in the three preceding figures. An indication of the temperature effect on the shear and elastic modulus property of snow is provided in Figures 4-5 and 4-6.

The snow processing technique for constructing roads on the McMurdo Ice Shelf is an attempt to densify the snow to a value near 0.6 gm/cm^3 for best strength development (Figure 4-7). Figure 4-7 also shows that little change in density occurred during the month of December due to aging or sintering for the two construction seasons. Figure 4-8 provides a record of the confined shear strength of the snow due to sintering for the same construction. It can be noted that the 1973 construction, though having a higher density, did not develop as much shear strength as the previous construction. Based on ideal conditions during the sintering period, the higher snow density for the 1973 construction should have developed the highest strength. The temperature of the snow during this period provides the obvious answer since it was above the -7^{o}C to -12^{o}C (+19^{o}F to 10^{o}F) range that has been determined to develop the best bond growth between snow particles. The experimental evidence in Figure 4-9 illustrates the detrimental effect of having too cold a temperature during the sintering stage for developing strength.

Hardness and Bearing Capacity

Hardness is defined as the resistance of a material to penetration by another material without undergoing permanent deformation. The hardness of snow is important as an indicator of its bearing capacity with respect to over-snow travel by various types of vehicles. The hardness of snow is affected by many variables, the principal of which are the density and the cohesive bond strength between the snow crystals. Snow hardness values for various types of snow are shown along with other descriptive data in Table 4-3.

The hardness of a snow cover is quite susceptible to alteration by compressional processing. The fact that the hardness of a snow cover tends to increase as the temperature drops is illustrated in Figure 4-10. Hardness also increases with increasing specific pressure; and, for a given temperature and pressure, the hardness of processed snow will increase with the number of processing passes, as is shown in Figure 4-11. The relationships between hardness and various types of mechanical processing treatments are discussed further in Chapter 6.

Friction

Experiments have shown that the coefficients of friction between snow and skis or runners depend upon the material involved,

Table 4-3. Description of Various Types of Snow

Type of Snow	Grain Size (mm) min-max	Specific Gravity (usual range)	Hardness–Usual Range	
			(gm/cm^2)	(psi)
Dry new snow	0.2-7	0.07-0.10	1-10	0.01-0.14
Dry settling snow	0.2-5	0.10-0.20	10-100	0.14-1.4
Wet settling snow	0.2-5	0.15-0.20	20-100	0.28-1.4
Dry settled snow	0.2-1	0.25-0.35	100-6,000	1.4-85
Loose granular snow	1-9	0.18-0.28	20-100	0.28-1.4
Dry old snow	1-8	0.25-0.45	100-20,000	1.4-284
Wet old snow	1-4	0.35-0.50	50-500	0.57-5.7

the temperature, load, snow type, and water content, and that the dynamic coefficient (sliding friction) varies with velocity.

The static coefficients of friction are as a rule greater than the dynamic coefficients of friction. On snow the difference may be even greater due to the adhesion, or "adfreezing," of snow to the runner, which occurs whenever the surface snow directly beneath the runner melts and subsequently refreezes. Static and dynamic coefficients of friction for various ski materials on snow are shown in Table 4-4.

Table 4-4. Static and Dynamic Coefficients of Friction for Various Ski Materials on Snow

Material of Ski Surface	Dynamic		Static	
	Min	Max	Min	Max
1/16-in.-thick beeswax	0.029	0.288	0.092	0.808
16 ga. brass	0.122	0.428	0.226	0.977
16 ga. monel metal	0.103	0.167	0.197	0.847
22 ga. stainless steel	0.128	0.322	0.056	0.992
Bakelite varnish	0.072	0.211	0.336	0.631
American White Ash treated with raw linseed oil	0.069	0.215	0.420	0.811
1/8-in.-thick bakelite Grade F14-2, fabric base	0.064	0.223	0.227	0.620
1/8-in.-thick bakelite Grade F15-1, fabric base with graphite incorporated in surface	0.068	0.162	0.145	0.605

Thermal and Radiation Characteristics

The specific heat and the latent heat of fusion of snow are generally assumed to be the same as for ice.

Snow is a good absorber of long-wavelength radiation (infrared). For wavelengths longer than 1.5 microns, snow acts like a blackbody (that is, the radiation is approximately 100% absorbed). For visible radiation, snow is a good reflector. The albedo (ratio of reflected to incident radiation) of a snow cover depends upon the character of the snow surface and varies with snow type, age, and the presence of impurities. Albedo values for many types of snow cover are given in Table 4-5.

The albedo of snow decreases with increasing snow compaction and age, with increasing size of the snow crystals on the surface, and with increasing water content or

Table 4-5. Albedo Values for Ice and Snow

Material	Albedo		
	Avg	Max	Min
South-Pole snow		0.92	0.84
Fresh snow—wind crust		0.88	0.81
Old, dry snow—sun crust		0.81	0.65
Wet snow		0.65	0.52
Ice		0.50	0.43
Snow or ice covered with impurities		0.45	0.30
Dry, bright-white, clean, freshly fallen snow	0.88	0.98	0.72
Wet, bright-white, freshly fallen snow	0.80	0.85	0.80
Dry, clean, loosely packed, freshly drifted snow	0.85	0.96	0.70
Moist, gray-white, freshly drifted snow	0.77	0.81	0.59
Dry, clean snow, fallen or drifted 2 to 5 days ago	0.80	0.86	0.75
Moist, gray-white snow, fallen or drifted 2 to 5 days ago	0.75	0.80	0.56
Dry, clean, dense snow	0.77	0.80	0.66
Wet, gray-white, dense snow	0.70	0.75	0.61
Dry, gray-white snow and ice	0.65	0.70	0.58
Wet, gray melting ice	0.60	0.70	0.40
Moist, dirty gray melting ice hummocks	0.55	0.65	0.36
Light green snow, saturated with water (snow during intense thawing)	0.35	—	0.28
Light blue-water melt puddles in last period of thawing	0.27	0.36	0.24
Green-water melt puddles, 30-100 cm deep	0.20	0.26	0.13
Blue-water melt puddles, 30-100 cm deep	0.22	0.28	0.18
Gray-green melt puddles covered with smooth ice	0.25	0.30	0.18
Smooth ice, covered with icy white hoar frost,over melt puddles	0.33	0.37	0.21

impurities at the surface. The albedo of a natural snow cover is generally independent of the angle of light incidence.

This summary on the characteristics and mechanical behavior of snow is based on information contained in References 1, 2, 3, and 4.

ICE

Ice found in the McMurdo Station area is nearly all formed from seawater. The only significant amount of freshwater ice is on Star Lake and in the fast ice in the McMurdo Ice Wharf which was formed by glaciation. A more detailed description of these areas can be found in Chapter 1 and Chapter 7.

Ice Formation and Growth

Freshwater freezes at, or slightly below, 32°F; seawater freezes at, or slightly below, 29°F. The rate at which the ice forms is dependent upon the air temperature, water temperature, wind velocity, and the presence of snow on the water (ice) surface. The typical growth rate with little snow or wind is shown in Figure 4-12. Snow cover and solar radiation decrease the growth rate, whereas wind and effective radiation increase it.

When ice begins to form, snow or rough water will promote the formation of small crystals, usually averaging less than 1 mm by 3 mm, at or near the surface; below these, the crystals grow larger with a long axis that is perpendicular to the ice surface and is often many times longer than the diameter of the crystal.

In freshwater ice, the strength of the ice during the melt season and its resistance to deterioration appear to have a strong relationship to the long axis (c-axis) orientation of the ice. Those areas in which the orientation is predominantly vertical are often stronger and deterioration is slower than ice areas in which the c-axes are predominantly horizontal. These differences are attributed to the fact that the albedo of ice with vertical c-axes is much higher than that of ice with horizontal c-axes. However, no similar resistance or susceptibility has been noticed in sea ice.

The temperature gradient through an ice sheet is nearly linear under basically steady state conditions since the temperature of the ice depends primarily upon the air and water temperatures. Temperatures are usually slightly below the freezing point at the ice-water interface and slightly above or below the air temperature at the ice-air interface. This temperature fluctuation at the surface is due to the lag of the ice in attaining an equilibrium temperature with the air; hence, if the air temperature is rising, the ice temperature will be lower and vice-versa.

The rise in ice temperature during the spring is caused mainly by solar radiation absorption. Snow cover reflects about 75% of this radiation, but an exposed ice surface reflects only 50%. Consequently, if the ice surface is exposed, melting proceeds at a faster rate; this is further accelerated as melt water accumulates on the surface, since water reflects only 8% of the incident solar radiation. In addition, any dark material on the ice such as mud or gravel absorbs a great deal of radiation, causing accelerated melting in that area.

Physical Properties of Ice

Density. The density of clear freshwater ice produced in a laboratory is 0.917 gm/cm^3 at 32^{o}F, increasing slightly as the temperature is lowered. Density values by field measurement generally range from 0.80 to 0.91 gm/cm^3 depending upon air content. Sea-ice density is also reduced by the presence of entrapped air but tends to be increased by entrapped brine. Field measurements of the density of sea ice range from 0.85 to 0.96 gm/cm^3. The difference between the theoretical and measured densities of sea ice is a measure of the air content of the ice. An increase in the density of sea ice as the melt season progresses has been noted as surface melt water fills the air cavities in the ice.

Salinity. Seawater normally has a salinity of 30 to 34 parts per thousand (ppt). When first formed, the sea ice has an average salinity of nearly 20 ppt, which decreases rapidly to less than 10 ppt in one week. After six months, the average salinity of sea ice is nearer 6 ppt. Sea ice that has lasted through a thaw season can have nearly no salts and can approach the purity of freshwater ice. The salts of sea ice are concentrated in brine cells that form between parallel platelets of pure ice. The dimensions and spacing of the brine cells are controlled by the ice crystal and vary in width from 0.39 to 0.5 mm as measured along the c-axis. As a result of gravity and the thermal gradient, the brine cells are longest in

the direction of ice growth and, tend to migrate in the direction of the warmer temperature and with gravity.

Heat of Fusion. The heat of fusion of freshwater air-free ice at $32^{o}F$ is 143.49 Btu/lb, and its specific heat at $32^{o}F$ is 0.487 Btu/^{o}F/lb. The specific heat of pure ice decreases with lower temperatures. The thermal conductivity of freshwater ice is 1.34 Btu/hr/ft^2/^{o}F/ft.

Because sea ice does not have a specific melting point, a change in the temperature of sea ice will involve melting or freezing and a change in the constituent salt phases. The heat required to completely melt and bring one gram of sea ice to $32^{o}F$ versus initial temperature is shown in Figure 4-13. The coefficient of expansion varies over several orders of magnitude and can be negative (expansion) or positive (contraction).

Electrical Resistivity. The electrical resistivity of sea ice is extremely variable and inconsistent, probably because the overall resistivity of sea ice is a combination of the resistivities of the ice, brine, and salt, as well as the ice crystal orientation. Values range from 3×10^3 ohm-cm ($10^{o}F$, parallel to c-axis) to 3×10^6 ohm-cm ($-12^{o}F$, perpendicular to c-axis). The dielectric constant of sea ice has been found to vary from 3.1 to 4.3, increasing as temperature and salinity increase.

The electrical resistivity of freshwater ice varies with the amount of impurities and the temperatures with values from 2,240 megohms/cm^3 ($10^{o}F$) to 284 megohms/cm^3 ($32^{o}F$). Specific conductivity of freshwater ice has been found to vary in a linear fashion with temperature from 0.6×10^7 ohm/sec ($32^{o}F$) to 21×10^7 ohm/sec ($-13^{o}F$). Small inclusions of sodium chloride result in a large increase of conductivity. The dielectric constant of freshwater ice has been determined to be 86.4.

Mechanical Properties of Saline Ice

At McMurdo Station, the sea ice in McMurdo Sound is used extensively for surface travel by vehicles and as a runway site for wheeled heavy-cargo aircraft. The load carrying capacity of the ice sheet is the combined effect of the unit strength (mechanical properties), thickness of the ice sheet, and type of loading. Heavy, long-term loads cause the ice to deform or creep. Under short-term loads, the ice behaves like most other materials, e.g., it returns to its original state once the load is removed. Extremely high rates of loading on very cold ice can result in failure typical of brittle materials.

Sea ice is a crystalline material with the long axis of the crystal growth in a generally vertical direction. Figure 4-14 shows the typical crystal structure of sea ice as it appears under polarized light. The mechanical properties of sea ice are influenced by temperature, salinity, crystal size and orientation, and previous thermal and strain history. Though much knowledge is still missing on how these variables affect the strength properties, there presently is sufficient understanding to make possible strength prediction by analytical methods. The discussion of the mechanical behavior of sea ice in this chapter will be limited to the elastic response of such fundamental strength properties as tensile strength, flexural strength, compressive strength, and elastic modulus (Young's modulus). Only the salinity and temperature effect on these strength properties will be presented leaving creep

behavior, effect of load rate, and effect of previous thermal and strain history to future discussion when more detailed knowledge has been obtained.

Exposure to cyclic temperatures ranging from near melting to very low over a period of time (generally at least a calendar year) can result in considerable expulsion of concentrated brine from the ice and a certain amount of recrystallization which tends to increase the strength properties as related to temperature. Essentially no effect of thermal cycling is observed in the annual sea ice during the spring-summer operating season at McMurdo. The general influence of temperature and salinity on the mechanical properties of ice are graphically depicted in Figure 4-15.

Seawater contains several salts in solution. These salts, during the freezing process, become a brine concentrate encapsulated in a highly dispensed fashion between the fresh ice plates that form the ice crystal (Figure 4-14). They are commonly referred to as brine pockets. The precipitation temperature of the two major salts, sodium sulfate and sodium chloride, has been found to have a definite association with the strength behavior. Figure 4-16 shows the temperature and salinity effect on the tensile strength as determined by the Naval Civil Engineering Laboratory tests. The curves in Figure 4-16 represent the tensile strength in the horizontal plane of an ice sheet. A much higher tensile strength is exhibited by the ice crystal in its vertical growth direction (Figure 4-17). An ice sheet, therefore, can resist a much higher tensile load in the vertical direction than it can under horizontal loading. Unfortunately, most load applications on an ice sheet such as aircraft, vehicles, etc., create forces that are resisted by the horizontal tensile strength.

Flexural strength is the measure of the ability of a material to resist bending whether it be a beam, a plate, or some other shape. The unit failure strength of a material under bending is technically known as rupture modulus. Since the compressive strength of ice is many times higher than its tensile strength, the bending failure will always occur on the tensile side of the ice plate or beam resisting the load. Figure 4-18 shows the temperature influence on the flexural strength of seawater ice as determined from beam tests made in both the laboratory and the field. Laboratory data were obtained from tests on small beams of 2 x 2-inch cross-sections while the majority of field data were from large in-situ tested beams cut from the natural ice sheet in McMurdo Sound (normal site of annual-sea-ice runway) and the Arctic Ocean off Barrow, Alaska. The annual-sea-ice sheet at McMurdo during the beam tests was between 7 and 8 feet thick while at Barrow it was approximately 5 feet thick. The data in Figure 4-18 show a strong linear strength-temperature trend for temperatures up to $-10^{o}C$. Beyond this, more data are needed to define the curve. The data for beams with a temperature gradient are plotted as strength versus average temperature of the beam. Such data, therefore, have to be considered as representing an effective strength due to the variable strength as related to the temperature gradient across the beam. Comparing the flexural strength property determined from beam tests (failure of tension area) with the horizontal tensile strength property determined from uniaxial tests, it was found that the flexural strength is greater by a ratio ranging from 1.3 to 1.7. This difference in strength values, however, is not uncommon to materials having different compressive and

tensile strengths, e.g., cast iron has a ratio of approximately 1.8, while for concrete the range is from 1.5 to 2.0.

The temperature effect on the compression strength of sea ice at the present time has not received as detailed a study as has the tensile strength property. A survey of the literature indicates the compressive strength will generally range from 400 to 800 psi. The lower strength values are associated with the higher ice temperatures and the higher strengths with the lower temperature.

Although the elastic modulus (Young's modulus) property of sea ice has received rather extensive study by various researchers, it is not as well defined as it should be for application with recently developed sophisticated methods for problem solution. The literature reveals that reported values for this property are influenced by the test method used for its determination. For example, values derived by seismic techniques are on the order of two to three times greater than those derived by less dynamic test methods. At present, the generally accepted values used for analytical purpose range from 250,000 to 800,000 psi. The lower value being associated with sea ice near its melting temperature while the higher value of 800,000 psi is associated for cold ice in the temperature range of -25°C to -30°C. Figure 4-19 shows the temperature effect on the elastic modulus property. The modulus values shown in this figure are considered apparent values for the property since they were determined from the stress-strain behavior of small beams tested in the laboratory, whereas the usual method for determining this property is from true tensile tests.

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Thickness Measurement

An area of the sea-ice sheet that is used for vehicle travel or for aircraft landings should be monitored for thickness throughout the period of use. For frequent monitoring, a network of permanent thickness-measuring stations is the most efficient method. Determining the thickness by using a permanently installed device is rapid and provides an accurate record of changing conditions since it is made at the same location each time. The thickness of an ice sheet sometimes varies over relatively short distances.

A simple, good method for establishing a permanent thickness station is to install the pipe device detailed in Figure 4-20. It consists of a length of galvanized pipe (3/8-to-1/2-inch diameter) fitted with a toggle bar at the bottom to catch the bottom of the ice sheet, and a cross-bar at the top end for manipulation. A short wooden post is generally placed between the cross-bar and ice sheet during nonuse periods to prevent loss by drifting snow. The galvanized coating on the iron pipe reacts with the seawater to form zinc hydroxide which prevents the ice from adhering to the pipe.

Bearing Capacity and Operation Safety

The bearing capacity and operation safety procedures for vehicle and aircraft operation on the annual sea ice are defined in the Official Operations Manuals used by the Naval Task Force. CAUTION: Any material contained in the Appendix section of this chapter concerning vehicle and aircraft operations on annual sea ice is intended as back-

ground information to assist with general planning. The Naval Task Force Operations Manuals are the official instructions guiding these critical operations.

This summary of the characteristics and mechanical behavior of ice is based on information contained in References 1, 5, 6, 7, and 8.

PERMAFROST

Permafrost refers to any earth material that is frozen continuously for more than one year. If water is present in the permafrost, a sufficiently high percentage of it will be frozen to cement the material together.

A temperature definition alone for permafrost is not considered sufficient because a geothermal condition could exist in which a frozen or cemented state has not been attained even though a temperature of the material has been well below 32°F. This may result from either the salinity of the water and soil, the pressure or stress conditions, the soil-water chemical and physical interactions, or the migratory potential [9]. A detailed discussion of various permafrost phenomena is contained in References 1 and 9. These are generally not applicable to McMurdo Station because of the different composition of the permafrost.

Permafrost at McMurdo

In perennially snow-covered areas of McMurdo Station, the permafrost will be found at the ground surface. The depth of the permafrost at McMurdo has not been determined but may extend to 1,000 feet or more. In snow-free areas, permafrost is generally encountered 6 to 18 inches below the surface. Most of the permafrost at McMurdo consists of rock with interstitial ice in joints and other voids within the upper few feet of the surface. Even if this material were to thaw, overall settlement would be minor except rarely where an unusually large mass of ice occurs, then settlement may be large but would probably be highly localized. In the McMurdo Station area, there are no known occurrences of high-ice-content silty fine-grained soils of the type typical to the arctic and sub-arctic regions which are considered detrimental for building foundations if thawing is permitted.

In a few small drainage areas, such as the gulley between the diesel power plant and the USARP warehouse, permafrost consists of angular gravel-to-boulder-size rocks in a matrix of ice. 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.

Other potential problem areas in McMurdo Station are the flat areas overlooking Winter Quarters Bay in front of the photographic laboratory (building 105) and the area in the vicinity of the proposed fuel fill stand behind buildings 110, 111, and 112. Both of these areas have been used as a repository for snow and dirt removed from the McMurdo streets and from between the buildings. Melting of the snow has concentrated the dirt content on the surface which, in turn, insulates the material below. Core drilling would indicate the ice content and the size of the area involved. Any structure in these areas which increased the heat input to the ground would undoubtedly result in severe settlement.

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Ground Temperatures

Ground temperatures have been measured to a depth of 10 feet at McMurdo Station during the summer months. Figure 4-21 shows a temperature profile with depth in jointed rock covered with 2 feet of earth fill near the U.S. Antarctic Research Program (USARP) warehouse. These data show ground thawing to a depth of at least 2 feet in this one area. Figure 4-22 utilizes the same data plotted to show change in ground temperature for specific depths with time. Observations in other areas of McMurdo Station, made when scraping fill material from the hillsides and when drilling construction holes, do not support this 2-foot depth of thaw and suggest it is 6 to 12 inches maximum. Until more data are available, each area should be considered individually.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

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2. M. Mellor. "Polar snow—a summary of engineering properties," in Ice and snow, edited by W. D. Kingery. Cambridge, Mass., M.I.T. Press, 1963, pp. 528-559.

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9. Cold Regions Research and Engineering Laboratory. Monograph CRSE I-A2: Cold regions science and engineering, pt. 1. Environment, Sect. A2: Permafrost (perennially frozen ground), by S. Stern. Hanover, N.H. Aug. 1966.

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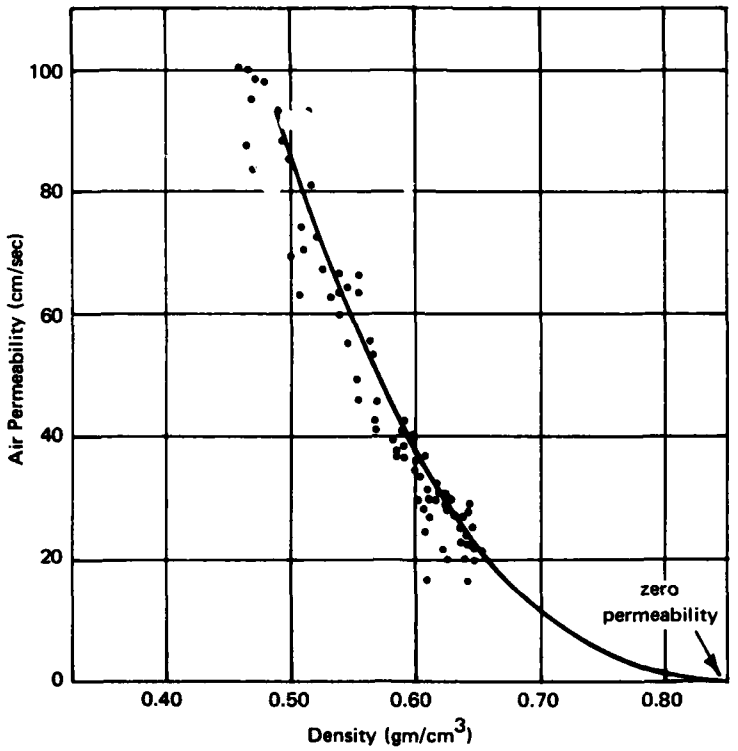


Figure 4-1. Decrease in air permeability of snow with increase in density.

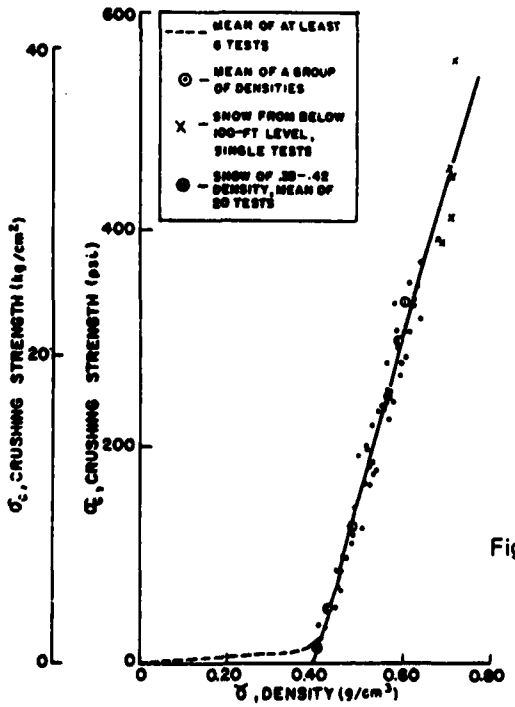


Figure 4-2. Unconfined crushing strength versus density for high-density snow. (Data adjusted to a common snow temperature of -10°C.)

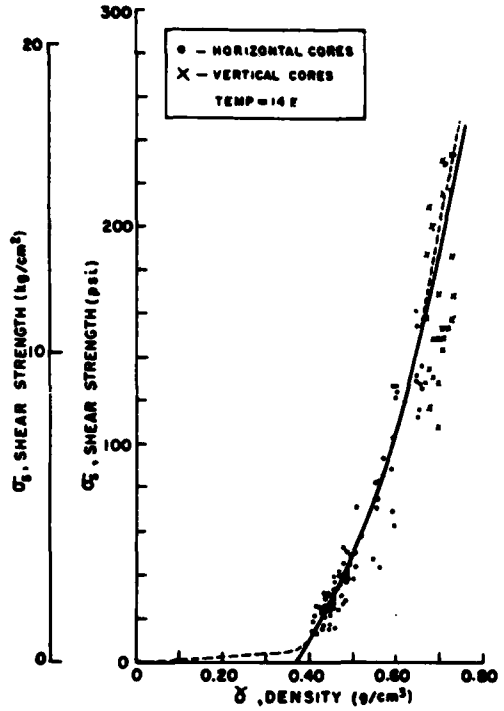


Figure 4-3. Unconfined double shear versus density for high-density snow. (Data adjusted to a common snow temperature of -10°C.)

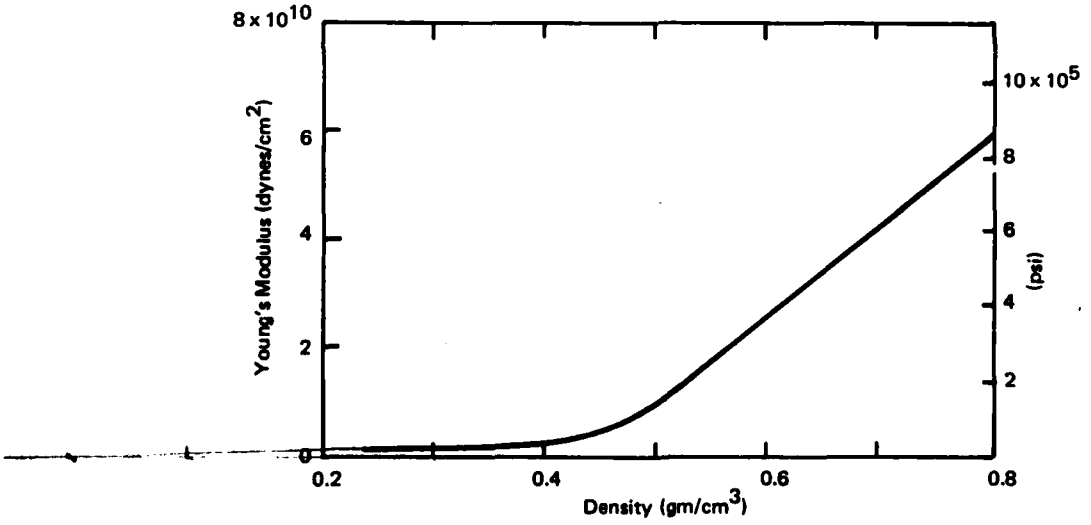


Figure 4-4. Relationship between the dynamic Young's modulus, as measured by the viscoelastic meter, and snow density for a range of Greenland snow type.

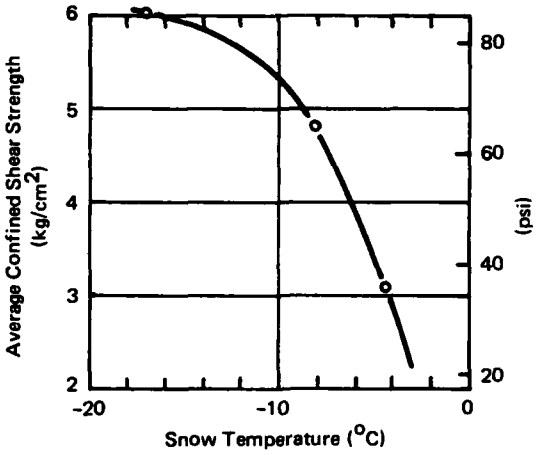


Figure 4-5. Strength versus temperature for compacted snow. (Density approximately 0.6 gm/cm^3.)

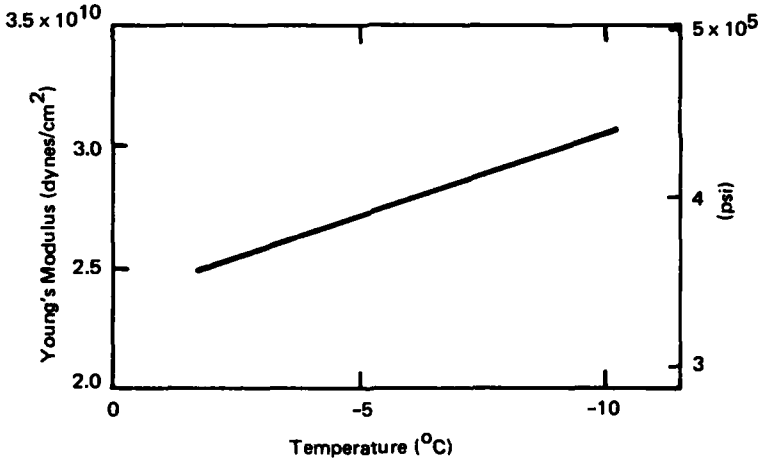


Figure 4-6. Relationship between the dynamic Young's modulus and temperature in the range -2°C to -10°C. (Density 0.63 gm/cm^3.)

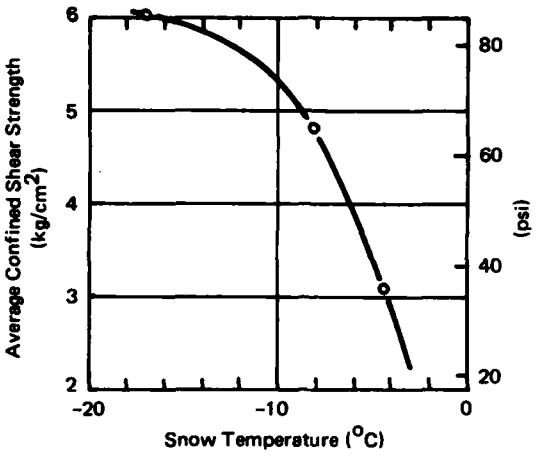


Figure 4-5. Strength versus temperature for compacted snow. (Density approximately 0.6 gm/cm^3.)

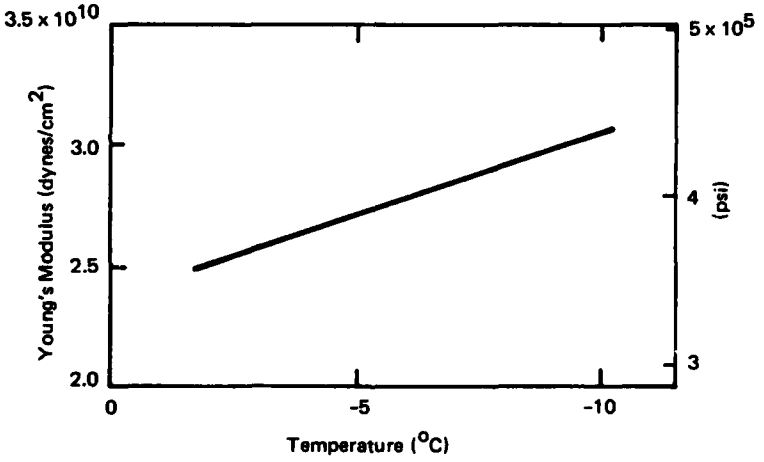


Figure 4-6. Relationship between the dynamic Young's modulus and temperature in the range -2°C to -10°C. (Density 0.63 gm/cm^3.)

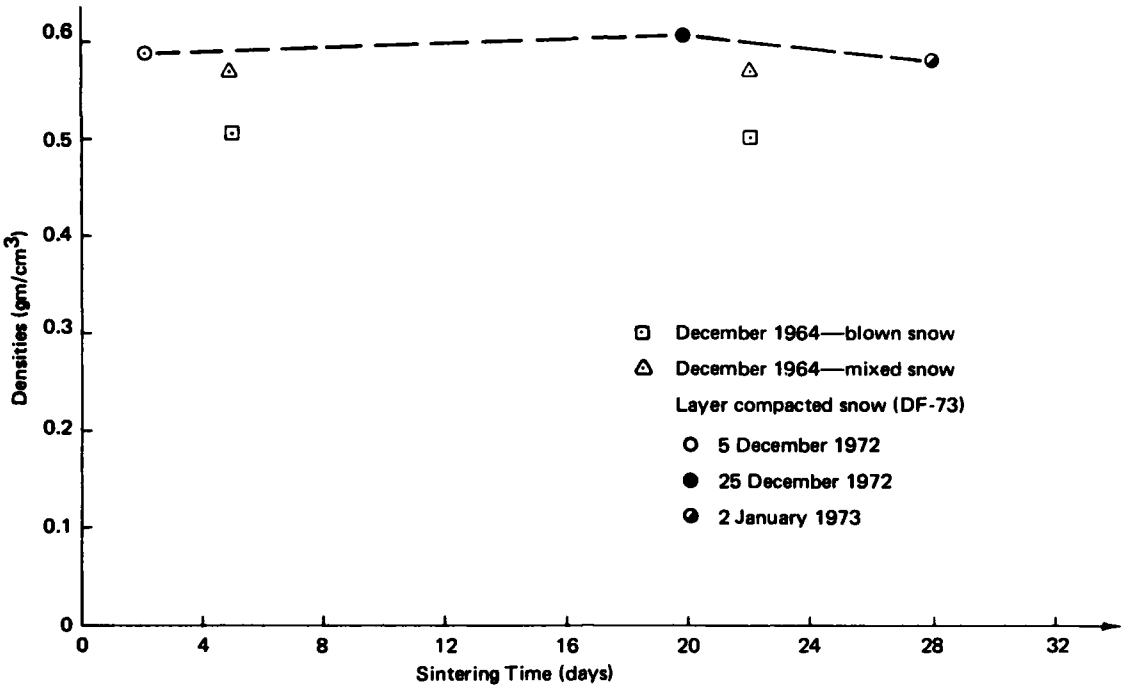


Figure 4-7. Sintering time versus average density for snowblown and pulvimixed roads.

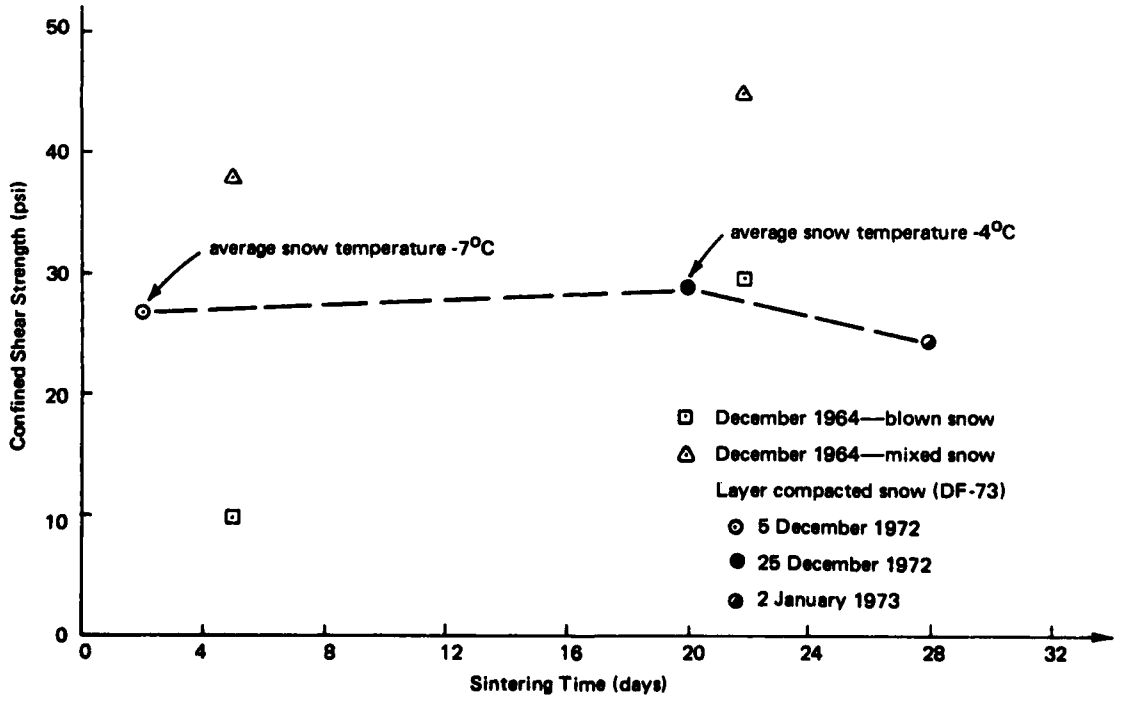


Figure 4-8. Sintering time versus average shear strength for snowblown and pulvimixed roads.

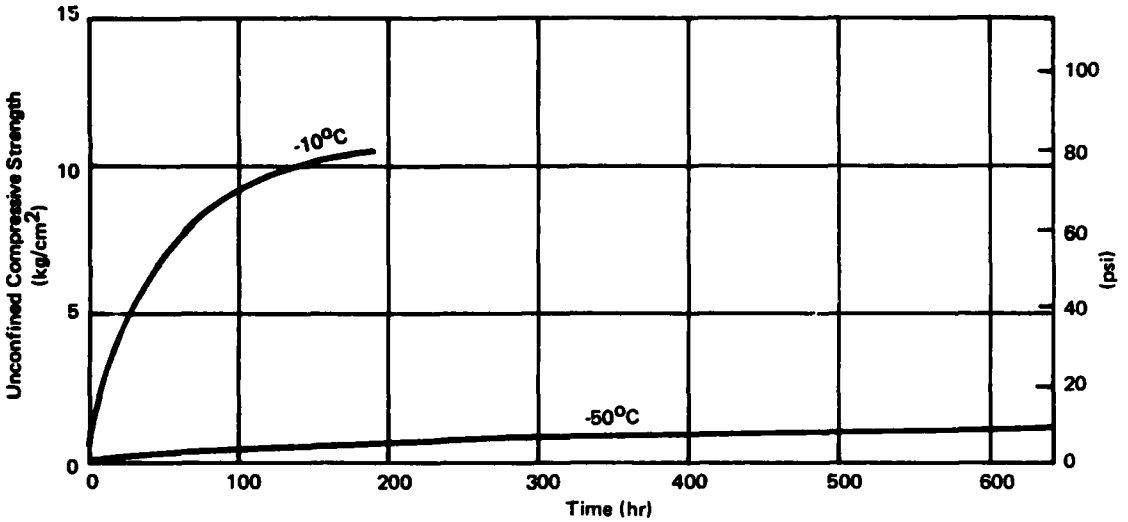


Figure 4-9. Age-hardening curves for artificially disaggregated snows setting up at temperatures of -10°C and -50°C.

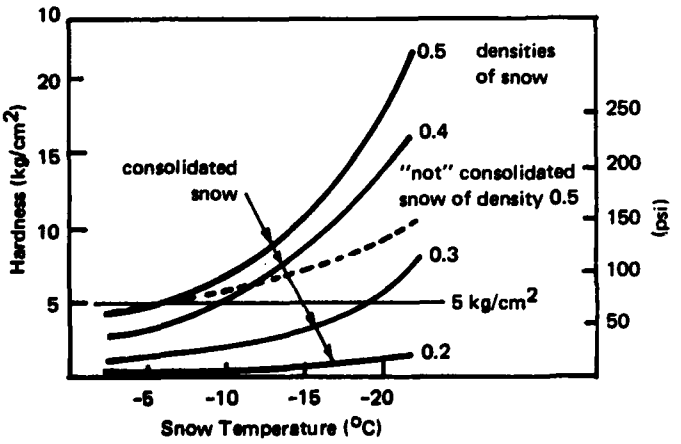


Figure 4-10. Relationship of hardness to temperature for depth-processed snow of various densities.

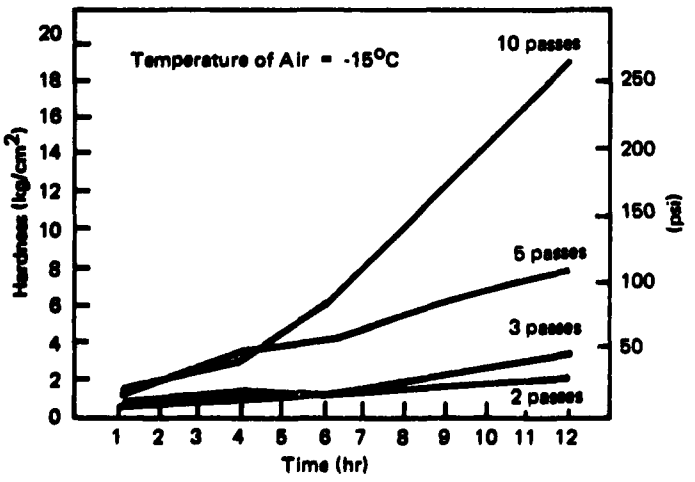


Figure 4-11. Hardening of snow after various sets of consecutive passes of 4.5-ton roller.

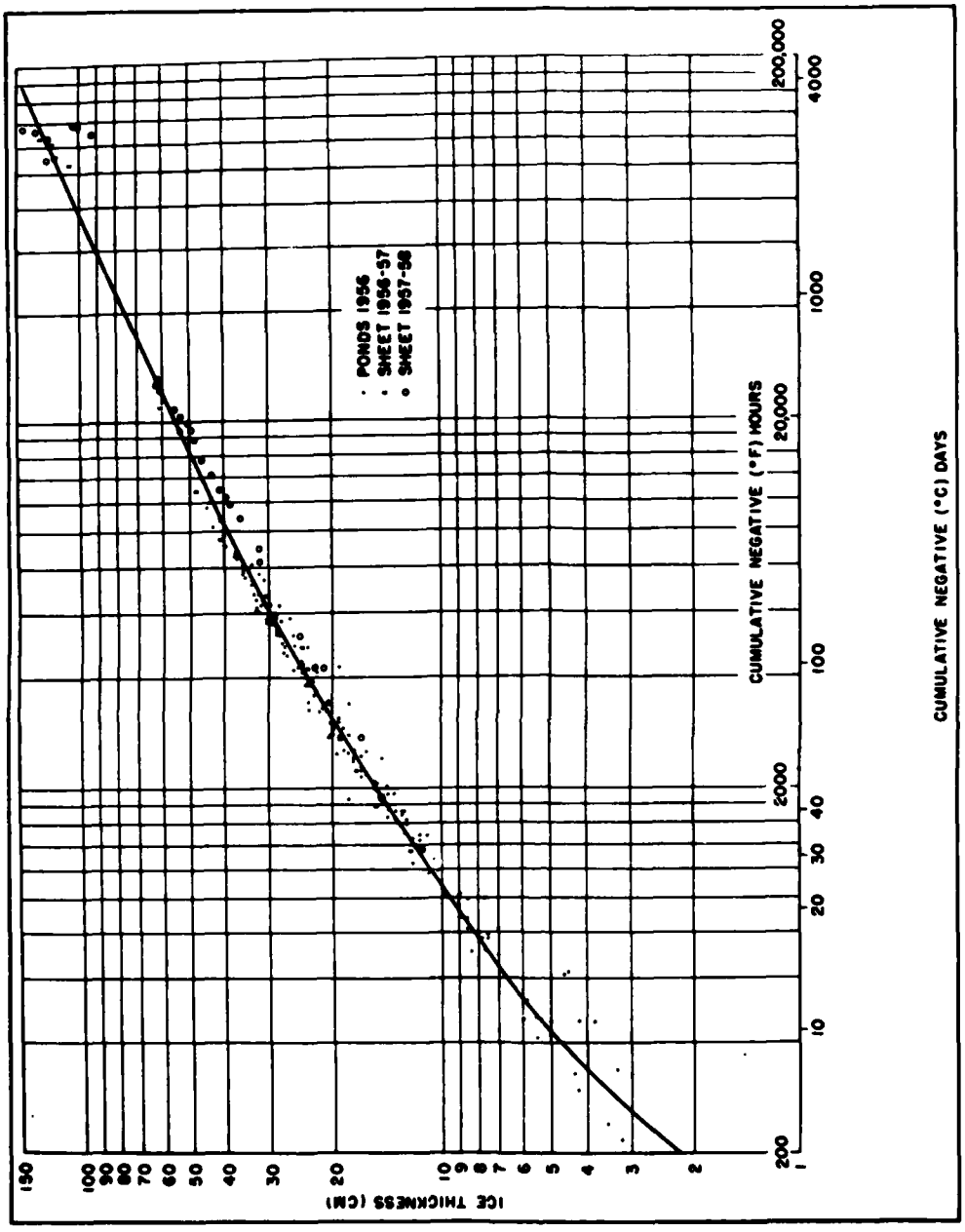


Figure 4-12. Typical growth rate of freshwater ice or sea ice.

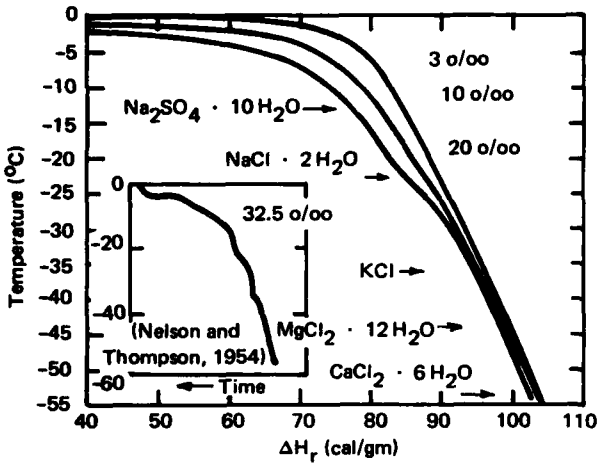


Figure 4-13. Heat required to completely melt and bring to 0°C one gram of sea ice versus initial temperature.

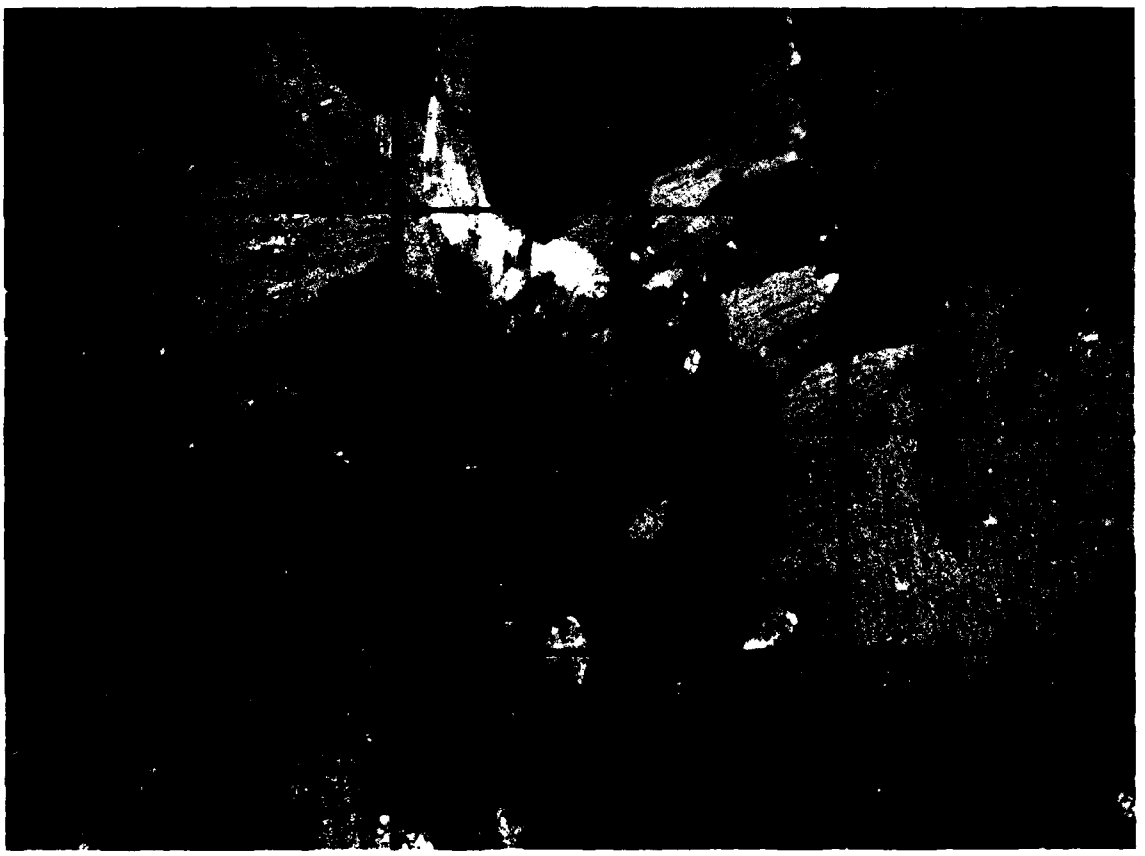
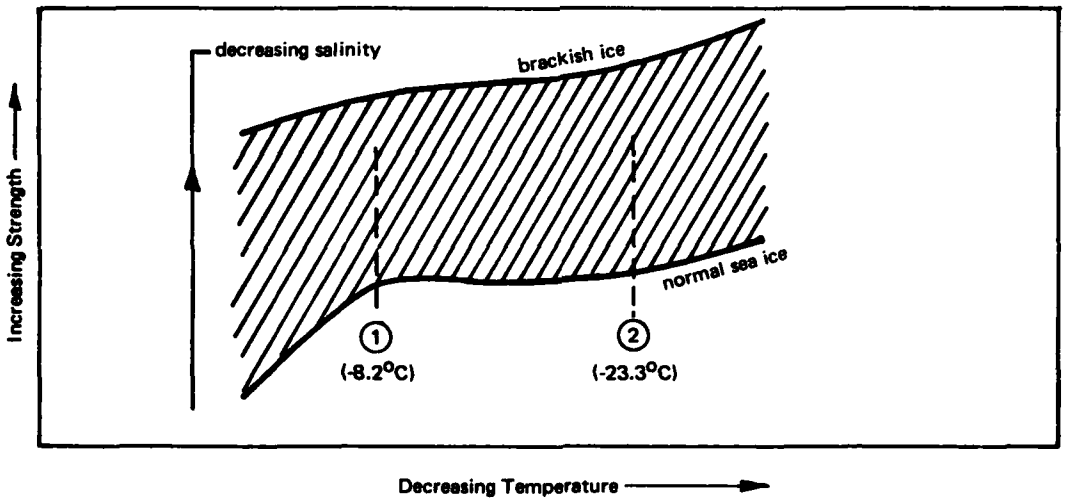


Figure 4-14. Horizontal thin section of natural seawater ice enlarged to show crystal and subcrystal structure. The grid is 1 cm on a side.



Salts in brine concentrate precipitate out of solution

(1) Sodium sulfate ($Na_2 \cdot SO_4 \cdot 10H_2O$)

(2) Sodium chloride ($NaCl \cdot 2H_2O$)

Figure 4-15. Strength envelope as function of temperature and salinity.

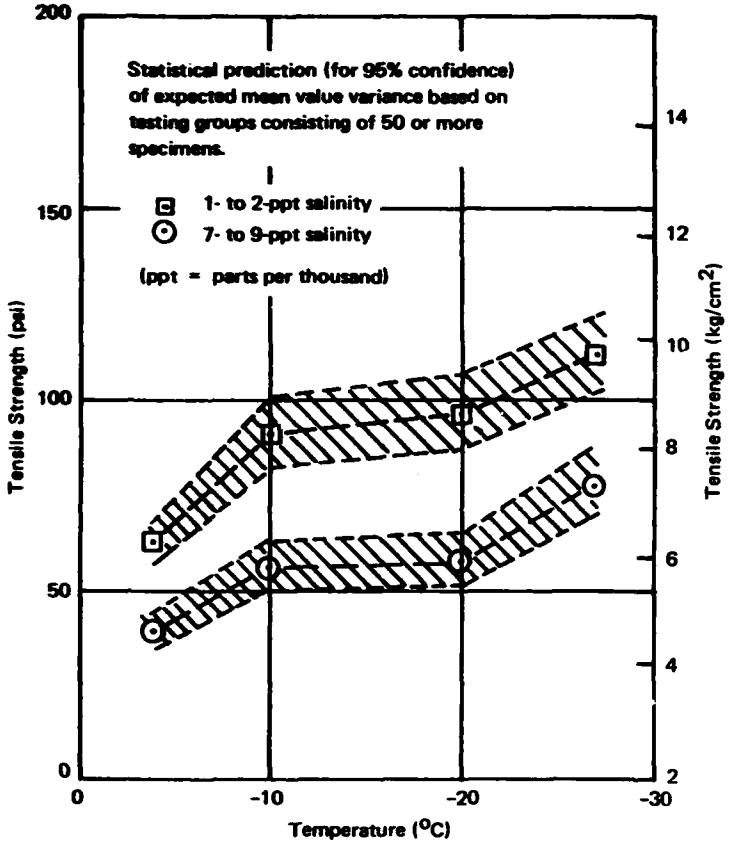


Figure 4-16. Average tensile strength of large horizontal specimen group versus temperature and salinity. (Test load rate 0.5 in./min.)

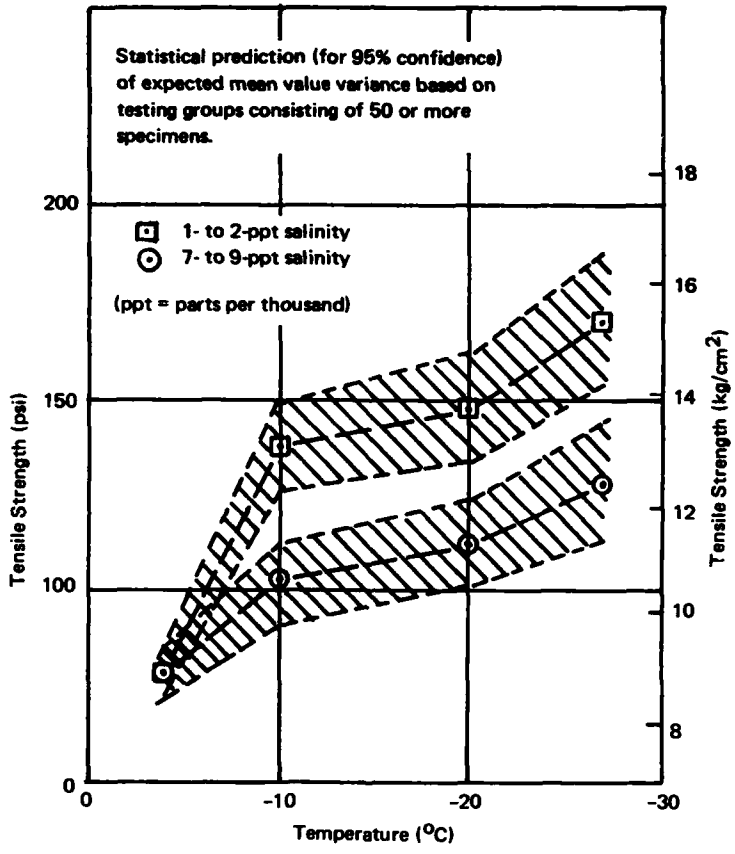


Figure 4-17. Average tensile strength of large vertical specimen group versus temperature and salinity. (Test load rate 0.5 in./min.)

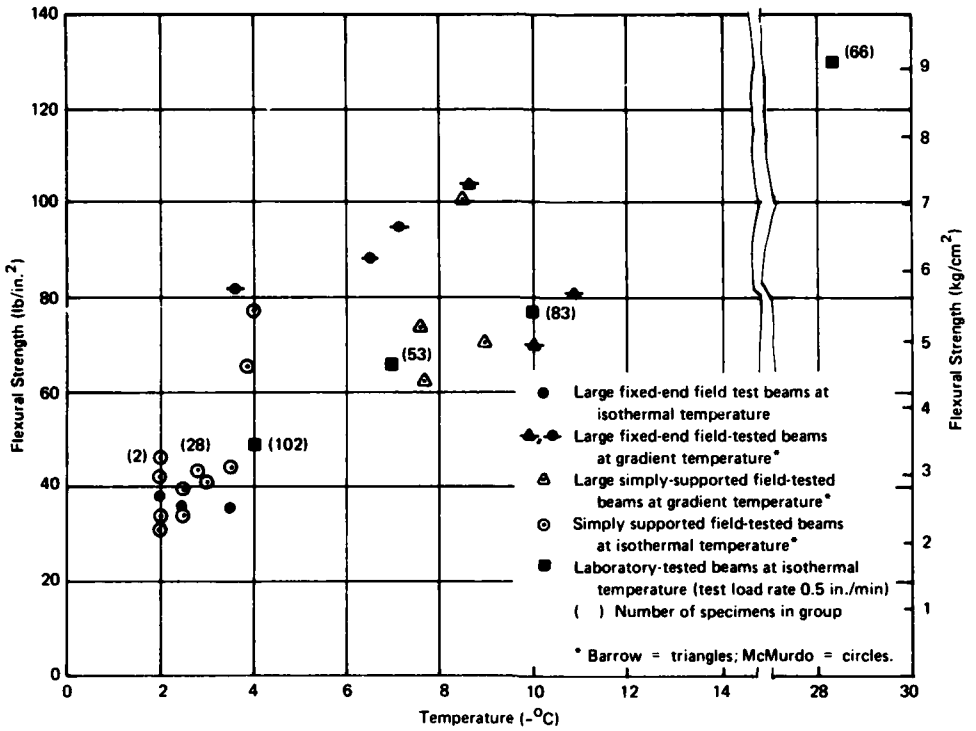


Figure 4-18. Flexural strength (rupture modulus) versus temperature.

1. Beams with temperature gradients are plotted at mean temperature of the beam.
2. Salinity range approximately 5 to 9 ppt.

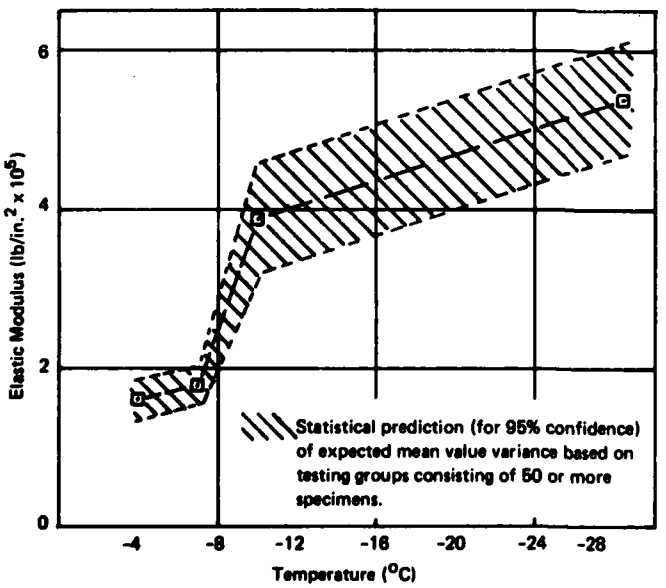


Figure 4-19. Average apparent elastic modulus of large specimen group versus temperature.

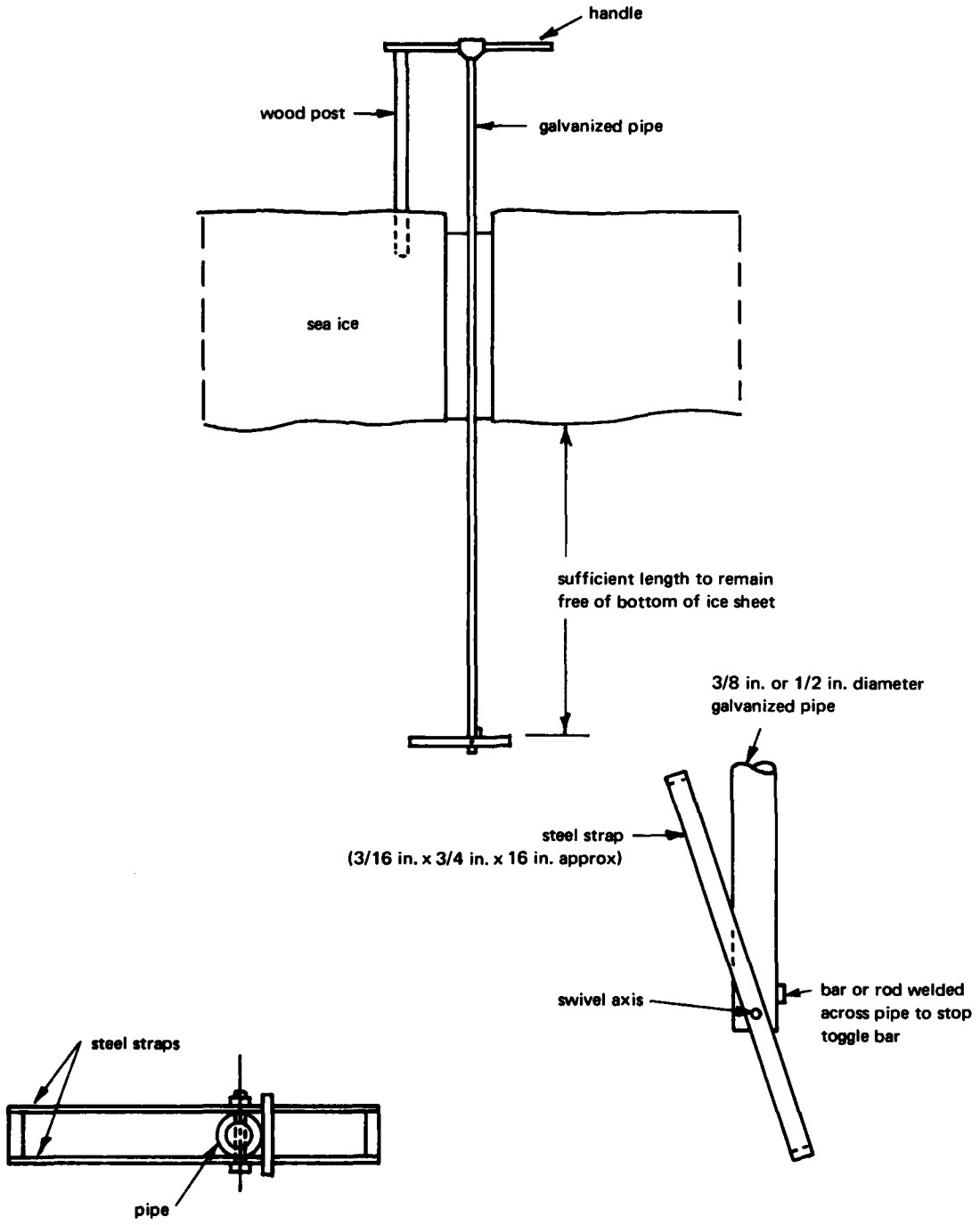


Figure 4-20. Detail of permanent sea-ice thickness station using galvanized iron pipe.

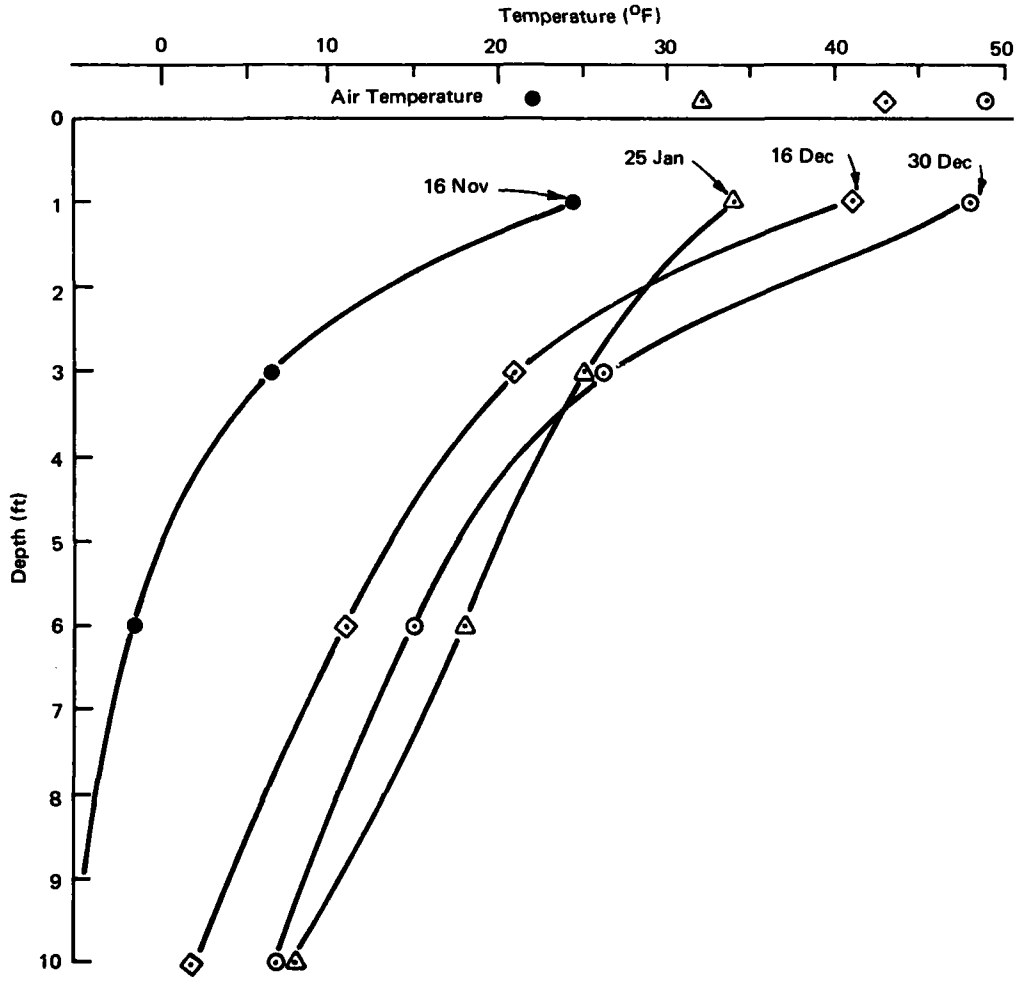


Figure 4-21. Ground temperatures in jointed rock covered with 2 feet of earth fill at McMurdo Station.

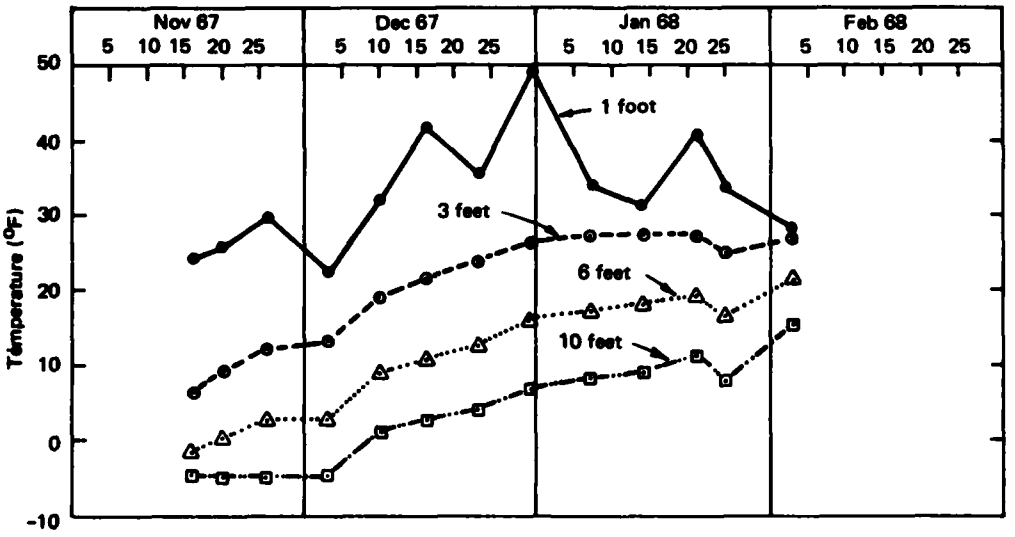


Figure 4-22. Summer ground temperatures in jointed rock covered with 2 feet of earth fill at McMurdo Station.

LIST OF APPENDIXES

Chapter 4

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

4-A. **Civil Engineering Laboratory. Technical Note N-1406: Earth science related environmental factors in polar region construction, by J. E. Cronin, Nov 1975.**

4-B. **-----. Technical Note N-1413: Revised aircraft load curves and vehicles ice-thickness tables for annual ice sheet operations near McMurdo, Antarctica, by K. D. Vaudry, Apr 1976.**

4-C. --- SEA ICE LOAD CURVES FOR 707-120 & 707-320B, C BOEING AIRCRAFT, BY J. E. DYKINS DDC 1979

4-D.

4-E.

4-F.

4-G.

4-H.

4-I.

4-J.

Addition – 1979

APPENDIX 4-A

Technical Note N-1406

EARTH SCIENCE RELATED ENVIRONMENTAL FACTORS IN POLAR REGION CONSTRUCTION

By

J. E. Cronin

November 1975

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

Approved for public release; distribution unlimited

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

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INTRODUCTION

Although man is a relative newcomer to the Antarctic, the history of his presence in the Arctic goes back much further. However, it has only been in the past 2 or 3 decades that numerous projects of high interest have spurred the construction of major encampments in the polar regions. With the development of these camps came the need for better understanding of the physical environment of these regions, so that structures could be properly engineered for a reasonable lifetime. It should be kept in mind that the polar regions, with regard to environmental factors, have no definite boundaries. For instance in the north discontinuous frozen ground, occurs as far south as 53 degrees north, latitude, and seasonally frozen ground occurs even further south.

The polar environment, basically one of conditions brought about by continued extremely low temperatures, affects men, materials, and equipment. With the upsurge in scientific and military work in polar regions, and now with industrial exploitation of the Alaskan and Canadian North, interactions of men, materials, and equipment with this environment are being studied. This present study examines what could be called the earth science or engineering geology problems of the polar regions. These problems are related to the founding of permanent or semipermanent structures on the ''earth materials'' of the polar regions - frozen ground, snow, and ice. The scope of this study is limited to only four major categories: foundations of structures, roadway construction, excavation in general, and utilities and pipelines.

The purpose of this study is not to provide a design manual for construction in polar regions; such a document already exists [1]. Rather, the purpose is to provide an overview of solutions already applied to selected earth science problems in polar engineering, with references for those who seek more detailed information on a given topic. Too often in the history of operations in the Arctic and Antarctic the completion of a given project has taken priority over research. Solutions to problems are sought which support this end; lessons learned have not necessarily been documented for assimilation by those who follow. This trend is now reversing, and applied research in polar engineering is being conducted not only by government agencies but by academic institutions and industrial concerns. The variety of work being performed in the field is beneficial but, at the same time, adds to the problem of assimilation.

Every attempt has been made in this study to incorporate recent research on and proposed solutions to problems, even though the solutions may not yet have been extensively employed in the field. The thus-assembled collection of information will hopefully serve as a data base

to those not familiar with the field and, by summarizing past experiences, current practice, and work in progress, should point to areas needing further research for improvment of operation standards in polar regions.

Except for a few installations, most construction in polar regions has taken place on frozen ground. Emphasis in polar applied research in recent years has likewise dwelt heavily on problems related to this material. Because of this greater amount of experience and research, a large portion of this report considers problems relating to construction on frozen ground, but snow and ice are also discussed to present a balanced picture of the polar environment to the reader.

FROZEN GROUND

Introduction and Physical Properties

In regions of high latitude (and hence cold climates) the effects of freezing temperatures upon the soil can significantly change its physical properties, creating additional difficulties for the engineer who must design facilities that will perform satisfactorily in these regions. At progressively higher latitudes soil conditions change from seasonally frozen ground to permanently frozen ground; in the intermediate latitudes the ground is discontinuously frozen.

The term permafrost is applied to permanently (or perennially) frozen ground. In this condition frozen pore water is usually present in sufficient quantity to cement the soil particles together. It is possible, however, to have ''dry-frozen'' ground where merely a ground temperature below $0^{\circ}C$, without the presence of ice bonding, defines a permafrost condition. It should be noted that consolidated rock as well as soils and unconsolidated sediments may be classified as permafrost. Although there are areas in the world where permafrost is currently being formed, such as alluvial deposits and mine tailings in the northern regions [2], most permafrost masses are thought to have been formed during the Pleistocene glacial epoch and are currently being thawed from below by terrestrial heat flow.

In permafrost regions,[a] the upper portion of the soil is subject to seasonal thawing and freezing; this soil is referred to as the ''active layer,'' which may be as thick as 20 feet but is generally less than 10 feet. At Barrow, AK, for instance, it is only about 2 feet thick. In a given season the entire depth of the active layer may not thaw or freeze back (both processes proceed primarily from the ground surface down), and a seasonally unfrozen or unthawed zone may exist at the top

[a] In areas not underlain by permafrost, such as the northern United States and southern Canada, the surficial soils may be subject to seasonal freezing; the underlying ground remains thawed year-round.

of the permafrost (the actual permanently frozen ground below the active layer).

The thickness of the permafrost itself depends on its original thickness, as modified by thermal conditions since that time. These conditions include present climate, insulating properties of the ground surface, presence or absence of groundwater (which tends to thaw permafrost), and the soil's thermal conductivity (dependent on soil type, density, and water content). In some areas permafrost has been found to extend to depths as great as 2,000 feet. The permafrost zone may contain discontinuous islands of thawed ground; likewise, islands of permafrost may occur below the main body of permafrost.

Of significant interest to engineers dealing with permafrost are bodies of segregated ice that frequently occur within the soil mass and may vary in size from small crystals and lenses to large wedges and masses with dimensions measured in feet. These vertically oriented, downward-tapering ice wedges are thought to result from the freezing of meltwater which infiltrates cracks resulting from contraction of the ground mass during freezing. The wedges commonly form a polygonal network, resulting in a characteristic appearance of the ground surface. Other forms of ground ice may result from segregation of water from the soil mass at the freezing point, or from the burial of preexistent ice masses by sedimentation.

Soil as a foundation medium has a variety of problems and peculiarities associated with it; permafrost adds its own set of problems to the situation. Permafrost itself is actually a reasonable foundation material with high compressive strength, although it does tend to creep under load; however, most of the problems with permafrost arise from the cyclic freezing and thawing of the active layer or from unnaturally induced thawing of the permafrost itself. Thawing of ice-rich soils, either in the active layer or the permafrost, can result in a near-liquefied condition, with a significant loss of soil strength. If the meltwater can migrate from the area of thawing, substantial loss of volume can occur through settlement caused by consolidation. It can be seen that thawing of ice-rich soils can result in major settlement of any structure supported upon them. The effect of the thawing of a large segregated mass of ground ice or an ice wedge can be disastrous.

Thaw-stable soils are those in which the water content is low enough and the grain size distribution and density are such that after thawing the water is contained in pores with no excess. Such soils will not exhibit significant consolidation or loss of strength upon thawing. In general, sandier soils will be thaw stable if not oversaturated with water.

The refreezing or seasonal freezing of soil can also cause problems in building. In fine-grained soils which support capillary action and have access to free water, water tends to be drawn through the partially frozen soil to the freezing front and develops ice segregations within the soil mass. The growth of these ice masses causes an increase in volume of the ground and a resultant heaving of the ground surface.

This process is termed ''frost heaving,'' and soils in which it takes place are designated ''frost susceptible.'' Pewe and Paige [3] present a good discussion of the process and factors relating to it.

Piles or columns passing through the active layer are gripped by the freezing soil and, if inadequately anchored will heave with the surrounding soil. The soil will usually subside to more or less its original elevation when the next thaw occurs, but generally the void created under the pile or column has been filled with ice, holding the structure in its elevated position. Continued seasonal heaving of this sort will result in the progressive jacking of the pile or column out of the ground; the process is termed ''frost jacking.''

Inhomogeneities in the soil (including segregated ice) and in heat-flow factors (especially after the ground surface has been disturbed or a structure built) can cause differential settlement or heave, which can cause serious problems, whereas uniform movement of the same magnitude might have been tolerable.

Rationale of Design

In rare cases, extensive investigation of a permafrost site may prove that thawing of the soil will not result in consolidation and settlement and that the active layer is not frost-susceptible and will not promote heaving. In such a case, structures could be designed more or less according to standards used in the temperate regions. However, the majority of sites in permafrost regions are underlain by soils which could potentially exhibit deleterious effects (settlement) if the natural environment is disturbed by construction. In such cases, the designer has two alternatives: to alter the site to make it stable or to acknowledge the situation and attempt to coexist with it.

Site Alteration. In terms of altering the site, a thin permafrost layer can be removed and replaced with thaw-stable and non-frost-susceptible (NFS) soil. Alternately, it may be possible to thaw and preconsolidate the frozen layer (a process known as ''thaw consolidation''). In true permafrost regions, the permafrost layer is usually too thick for complete removal or thaw consolidation, but in cases where a thaw-stable granular material is overlain by unacceptable material removal or preconsolidation of the upper zone may be possible. Treatment could also extend only to the anticipated depth of postconstruction thaw, although this becomes a risky guessing game.

Problems associated with removal and replacement of potentially unstable frozen ground are discussed in a later section on excavation. Thaw consolidation can be carried out by first thawing with steam, water, or electricity, and experiments have been made with gas burners. Less efficient methods include fires, various ground coverings, and solar thawing.

The most effective use of steam seems to be steam points which melt their way into the frozen ground [4,5], although steam can also be circulated through a system of coils laid on the frozen surface. Water

can be directly jetted into the ground like steam [4], warm water can be recirculated through well points, or water can be used to flood the ground surface. Gas burners or electric heaters inserted in drilled holes can provide rapid thawing [5]. The Russians have done considerable work with thawing by direct current flowing between electrodes inserted in the ground, followed by consolidation aided by electro-osmosis [6]. Each of the methods listed above has its own relative advantages and disadvantages, such as the need for predrilled holes, amount of excess water introduced to the site, and rate of thawing. However, the type and availability of the energy source also plays a major role in the method chosen.

The actual consolidation of the thawed material can be self-induced, aided by a surcharge load, effected by blasting [7], or performed with conventional construction equipment and techniques. It should be kept in mind that the surface-thawing techniques described above (flooding, steam coils, solar heating) require frequent stripping of the surface to expose unthawed material to the heat source. No case is known where vibroflotation [8] has been used for consolidation (after thawing), but if soil and water conditions were favorable this process might have some merit.

Coexistence with Frozenground. The most common construction practice at present is to protect the thermal regime by isolating the structure from the natural ground. However, economic or logistic considerations may dictate a design that allows continued thawing of the permafrost, even though resulting settlement may necessitate continued maintenance to provide a habitable structure. Temporary buildings, if light and flexible, can be supported directly at grade on frost-susceptible materials if one is willing to relevel the structure occasionally as differential settlement or heaving occur. In such a case, the natural surface of the ground should not be stripped and a 1-foot layer of sand or gravel applied to organic terrain as a leveling course, if available.

For more permanent buildings, measures must be taken to reduce heat transfer from the structure to the ground. In most situations the natural ground is covered with a pad of NFS material, or the structure is elevated to provide an insulating air space, or both. Alternate measures involve cooling the subgrade with air or a refrigerant medium.

Pads of NFS material are designed as replacements for the active layer. These pads freeze in winter and thaw in summer with little or no thawing of the underlying natural ground, despite any additional heat input from the structure. NFS material, by definition, is also not subject to heaving and helps minimize any frost-heaving effects of the natural ground as well as any differential settlement arising from thawing of the native material.

Sanger [9] details recommendations for NFS pads as follows: the most desirable NFS material appears to be the finer sands (rather than coarse sand or gravel), as they tend to hold more water and hence have a higher latent heat. Recommended practice with coarse NFS material is to

separate it from fine-grained subgrade soils with a 6-inch sand layer to prevent the upward migration of water or fine-grained soils into the gravel pad. The pad should extend at least 10 feet around the building at full thickness, which should be about 1-1/2 times the thickness of the undisturbed active zone for full protection.

A simple gravel pad alone will not necessarily eliminate permafrost degradation under a heated structure. Usually an air space on the order of 3 feet high is incorporated between the floor and the NFS pad to insulate the ground from the structure. Insulation must be incorporated into the floor to further stem the heat flow. The ground may be protected from solar heat input by sunshades around the perimeter of the structure, but these should not be allowed to restrict normal air circulation. Snow, if allowed to accumulate in the air space, will impede the winter freeze-back of the pad and lead to problems. Heat transfer down piles or columns must also be considered - both the heat transferred from the structure and the heat absorbed by the pile or column from solar radiation or the air. Less permanent structures (or those at some distance from a source of NFS soil) may depend solely on air space for isolation, with footings placed below the natural active zone to prevent heaving.

The nature of the structure (such as a garage or hangar) sometimes precludes the use of an elevated floor with an airspace. In these cases, air ducts must be included either in the floor slab or footings or in the pad itself. Such duct systems are generally designed to operate on natural, rather than forced, air flow because of inherent simplicity. Stacks are sometimes used to increase natural air flow, and the ducts are provided with dampers, opened in winter but closed in summer to exclude warm air. Accumulation of ice, snow, and silt can reduce air flow and lead to problems, so the system should be designed to be self-draining in summer of the previous winter's accumulation. Mechanical refrigeration is generally limited to special cases or for remedial purposes. The most reliable cooling system is one which is the least subject to machine malfunction or human error [10].

Other Factors. Even well-designed structures utilizing the measures outlined above can be subject to failure due to permafrost degradation caused by ''external'' factors. Poor drainage resulting in the ponding of water around a structure can cause thawing of the ground, and for this reason the surface of the natural ground or NFS pad should be sloped away from the structure and the runoff carried to a point where it will cause no harm. Leaks in utility lines can likewise cause degradation. The effect of blocked vents in duct-ventilated floors and pads has already been mentioned.

For critical structures a monitoring program to observe ground temperatures and settlement is a worthwhile and inexpensive insurance policy. Ground temperature increases will often indicate a potential problem before actual settlement has taken place, allowing corrective measures to be taken.

Foundations

Types of foundations used in permafrost regions do not vary significantly from those used in temperate regions, but the design and the decisions behind design are necessarily more detailed and complicated. Footings at or near grade are generally used only for temporary or noncritical structures; structures whose performance is critical are usually supported on piles. Sanger [9] provides useful data and references for actual design of both conventional and pile foundations.

Spread, continuous, and pad footings and raft or mat foundations have all been used successfully in permafrost. Determination of allowable bearing on frozen soils becomes an involved task because of dependence of strength not only on soil type and density, but also on temperature and degree of ice saturation. Strength generally increases with coarseness of soil, degree of ice saturation (without segregation), and decreasing temperature. However, the behavior of frozen soil under stress is one of creep deformation with time, and the allowable bearing based on tolerable creep with time is generally much lower than that determined by short-term loading and is the value used for design purposes. Methods of determining allowable bearing are sufficiently refined so as to result in reasonably stable foundations if sufficient and correct input data on site conditions are used in the calculations. Unexpected deterioration of thermal conditions under the foundations (as a result of heat flow from the structure), even without thawing, can change soil strengths sufficiently to cause failure; hence critical structures require careful monitoring of subsurface temperatures after construction to insure that design parameters remain valid.

Type and area of footings are determined by consideration of allowable bearing, distribution of loads and structural parameters and economics. Footing depth is determined by obtaining bearing on material that will not be subject to thawing or will be stable if thawed. Potential depth of thaw after construction must be considered rather than seasonal depth of thaw with the site in its natural state. In the case of a structure built on an NFS pad, footings may be supported at or slightly below the surface of the pad. Where no pad is used, the footings should bear on or slightly below the permafrost surface. Heave forces on the columns of such buried footings must be eliminated by backfilling around the column with NFS material or by isolating the column by methods similar to those employed for piles (discussed in a later section).

Although wood has been used in the past for groundsills, pads, and mats, and still has a place for temporary structures, concrete has become a more popular material for conventional footings. The technology of cold-weather concreting, though not without problems, has been developed and is discussed below. A more serious problem is the effect of heat of hydration of the concrete on the surrounding permafrost. For very large pours, artificial refrigeration may be required during curing to prevent thawing of the permafrost. Such a system can be kept operational for future use in controlling ground temperatures under the structure if the

need arises. The use of precast concrete shapes, set in a bed of damp sand to ensure good contact, is a viable alternative to the problems associated with heat of hydration, but the method has not been widely used.

The use of concrete at near-freezing temperatures becomes difficult because of the necessity to prevent freezing of the material during the curing period. If the concrete freezes before curing is complete, it may appear to have reached full strength but could fail if thawing occurs later under load.

Extensive studies have been made of cold-weather concreting. The Civil Engineering Laboratory (CEL) has made recommendations concerning concrete construction in Antarctica [11,12]. General recommendations for cold-weather concreting, as summarized by CEL, are as follows: Concrete should not be mixed if the prevailing air temperature is below 35°F. The temperature of concrete when cast should be in the range of 50°F to 70°F. Newly cast concrete must be kept from freezing for 3 days to obtain sufficient compressive strength and durability. Use of calcium chloride is recommended to stimulate early heat development and early strength gain. When placing a concrete slab on permafrost, a well-drained, compacted gravel blanket should be provided to insulate the permafrost from the warm concrete. For some installations, it may be necessary to heat the mixing water and the aggregate and to provide insulation and heat for the forms and the newly cast concrete.

Successful concreting in any region is, of course, dependent on proper mix. The nature of the sand and aggregate fractions will be different for different areas, and the suitability for use of these materials in concrete must be determined. In some polar regions, it may be difficult to find local sources of these materials. Design of the proper mix is discussed in the referenced CEL reports. Placement of the concrete is also outlined in Reference 13.

Pile Foundations

Pile foundations are generally employed where it is necessary to go to some depth to obtain adequate bearing to support large loads, or where such depth is necessary to provide adequate stability against movement associated with the freezing and thawing of the soil. In frozen soils the pile load is supported by adfreeze bond stress (the equivalent of skin friction in unfrozen soils); only rarely (in coarse granular soils) is end bearing used to carry the load. As in the case of conventional footings, the allowable bearing is determined by a creep value rather than a short-term value of bond stress. Failure to recognize this fact has led to the failure of pile foundations in the past. Also piles must be designed to resist the heaving forces of the active zone.

Adfreeze strength is dependent upon (1) the grain size, moisture content, and temperature of the ground, (2) the surface and shape of the pile, and (3) the rate of loading [3]. Adfreeze strength increases with decreasing grain size, reaching a peak with fine sands and then decreasing

with silts and clays. It also increases with increasing moisture content until the point of ice saturation is reached. Lower temperatures yield significantly higher strengths. Rougher pile surfaces develop a stronger adfreeze bond than smooth surfaces, but complex surfaces (such as H-beams) seem to develop less overall strength than a round pile of the same equivalent surface area. Rate of loading is important because creep of the frozen soil will yield a much lower allowable adfreeze strength under long-term loading than under short-term loading conditions.

Wood has been and remains a popular piling material for structures with light loads because of local availability in many areas of the Arctic. The preference in the United States at present seems to be for steel, either pipes or structural shapes. Precast reinforced concrete piles have been widely used in Russia [9]. Cast-in-place concrete piles are nearly impossible to use because of the interaction between permafrost temperatures and heat of hydration of the concrete - the concrete cannot cure properly and the ground thaws.

Pile Emplacement. The most common method of emplacement of piles is to freeze them into a predrilled, oversized hole with a slurry of silt and water. Such holes are generally drilled with an auger. Many piles have also been placed by conventional driving methods with success. In the past, driving has been employed following steaming to thaw the ground [14], but the high heat input of this method makes it undesirable. Experimentation with vibratory driving of piles shows promise under certain conditions [15]. This is also substantiated by later-referenced vibratory drilling in permafrost. Piles have also been emplaced by driving into an undersized predrilled hole. Besides the obvious difficulty of driving piles in rocky frozen ground, driven piles have the disadvantage that they usually must be open-ended; thus, very little end bearing is developed, which might otherwise be depended on as an additional safety factor.

Pre-augered pile holes should be backfilled by placing the slurry with a tremie[b] and vibrating to ensure complete filling of the annulus. The native soil may be used as backfill, but sandy materials will give a higher adfreeze strength for the same water content [3]. The slurry must be oversaturated to insure good placement, but excess water will slow the freezeback process. Time required for freezeback is highly variable but can be minimized by placing the piles in spring when the ground temperature is lowest, by imparting the least heat possible to the hole while drilling, and by prechilling the slurry. Monitoring the freezeback of a few selected piles with thermocouples is an advisable method of determining when the piles are ready to accept a load. Mechanical refrigeration can be utilized if rapid freezeback of the slurry is necessary; also, if unexpected thawing later occurs, the refrigeration system can be reactivated. Refrigerated piles can also be used to maintain warm permafrost in a continually frozen state at a lower temperature, thus delivering a high allowable bearing. Cold air circulation in hollow piles has been used to hasten freezeback, but this is a slower process than mechanical refrigeration.

[b] Funnel with hose.

Frost Heave Prevention. Perhaps the greatest problem associated with piles is designing to reduce the heaving forces applied to the pile during annual freeze-thaw cycling. Several approaches to this problem exist. The pile may simply be embedded in permanently frozen ground far enough to resist the heave forces with a factor of safety. The old rule of thumb was embedment to twice the thickness of the active layer, but Linell and Johnston [16] have suggested that this is unreliable and recommend a minimum of 10 feet. Mechanical anchoring against heave is difficult to utilize, and the increased creep rate of frozen soil at points of stress concentration must be considered. In the case of wooden piles, installation is often butt down in an attempt to utilize the taper of the pile to reduce heave.

Attempts have been made to mechanically isolate the pile through the active layer by casing the active layer and filling the annulus between the casing and pile with an oil-wax mixture to prevent water infiltration (and subsequent adfreezing). However, the casing will have a tendency to be progressively jacked out of the ground, and usually cannot be driven back in [17]. The exposed oil-wax mixture alone will provide some protection, but will eventually be penetrated by water and heaving forces will be applied to the pile. As an alternate to the casing system the augered hole can be directly backfilled with a soil, oil, and wax mixture through the active layer.

Various brush-applied coatings and film wrappings have been used through the active zone with questionable results. Along these lines of reducing heave forces, consideration should be given to the relative adfreeze bond strengths developed between a given soil type and various pile materials. Extensive data have not been compiled, but Pewe and Paige [3] present a useful summary of values.

Another method of combating heave forces is to increase the load on the individual piles by increasing pile spacing, but this requires adequate soil bearing. Another advantage of increased pile spacing is the reduction of heat input to the ground as a whole (as a result of pile emplacement), thus reducing the chances of permafrost thaw during construction and hastening the freezeback of the soil or slurry around the individual piles. However, increasing pile load should not imply increasing the size of the building. Larger buildings tend to cause deeper thaw, and, although they may be more efficient to heat, they may be less efficient to build.

If the site is covered with an NFS pad of a thickness great enough to prevent any thawing of the native frost-susceptible soils, heaving forces will be almost completely eliminated, depending on how truly non-frost-susceptible the soil in the pad is.

Reducing the availability of water to the active layer by restricting surface water infiltration can also reduce heave forces; lowering the water table may also be effective. Another effective procedure, though not known to be generally used, would be reduction of the surface area of the pile through the active layer. In all of the methods discussed for preventing frost heave in this section, it should be remembered that

the material chosen for the pile must have sufficient tensile strength to withstand the differential stresses to which it may be subjected.

Self-Refrigerated Piles. The mechanical isolation methods of reducing frost-heave forces, as described above, were until recently widely recommended, and the other methods had at least been experimented with. Current practice relies mainly on embedment to counteract heaving [18]. Mechanically refrigerated piles are functional but expensive and lack the simplicity of nonrefrigerated piles. The recent development of self-refrigerated piles is thus a considerable advancement. Two basic patented designs exist: the Long thermopile [19], utilizing a two-phase refrigerant (usually propane) system, and the Balch liquid-filled pile [20], a single-phase system. Both thermopiles act as unidirectional heat-transfer devices - extracting heat from the ground in winter, but not allowing a reverse flow in summer. Although a self-refrigerated pile does not prevent freeze-thaw cycling of the entire active layer, apparently the radial refreezing in winter reduces the adfreeze bond between the pile and the thawed (and refreezing) portion of the active layer. The substantial reduction in heave forces thus realized enables design with much less embedment, and it may be practical to design piles using end bearing rather than adfreeze bond. More recently, Long has suggested thermopiles with protruding ring or helical blades which would utilize the shear strength of the frozen soil rather than adfreeze bond [21]. He goes on to show that helical-bladed thermopiles with a higher bearing capacity are economically competitive with nonthermal wood piles for remote sites.

Other Factors. Although frost heaving is one of the major problems in pile design, other factors must also be considered and dealt with. The active layer is normally thought of in terms of heaving forces, but it must be remembered that when this material thaws in the summer it can produce a drag-down force that must be allowed for in calculating bearing. These conventional vertical loads on pile foundations are fairly well understood, but the effect of lateral and especially vibratory loads have not been widely studied and must be considered in design. Lateral pile load testing has been conducted in connection with arctic pipeline research [22].

Heat transfer down piles, both from solar input and conductive input from the structure, must be reduced to prevent thawing. Solar input can be reduced by reflective paint or sun shields; conductive input depends on structural details. Goff [18] describes concrete insulating pile caps used in high-load applications at Prudhoe Bay. He also presents a good case history of an application of pile foundations in permafrost. Another approach to the heat transfer problem is that being used on the trans-Alaska pipeline, where ''heat pipes'' (essentially 2-phase heat transfer devices) are buried with the support anchors for the above-ground sections of the pipeline [23]. During the winter these heat pipes will extract any heat input from the hot-oil pipeline, and should supercool the ground enough to prevent degradation during the summer.

The system is similar in function to a self-refrigerated pile, except that the load will be carried by a separate structural member.

Corrosion of piles must be considered for structures which are to be long-lived. Work cited by Linell and Johnston [16] states that corrosion is not a significant problem with steel piles (even within the active zone), but that wooden piles should be protected through the active zone. Very little deterioration of the wood occurs in the permanently frozen portion. Painting or coating of a steel pile should be avoided, except for the portion above ground that might require a reflective paint, because of possible reduction in adfreeze bond. Creosote treatment of wood likewise reduces the bond strength. For this reason it would be desirable to treat only that portion of a wooden pile above permafrost, but this is possible only by manually applying the creosote. The work cited has shown pressure creosoting to be superior to the brush-applied diffusion process, but at present no method exists for pressure creosoting only part of a pile, and so the reduced adfreeze bond must be tolerated and allowed for in design.

Anchors. Ground anchors, used to restrain guyed towers, pipelines, temporary equipment installations, etc., against lateral or uplift forces, are a special type of foundation, of which piles are only one configuration. A recent survey of anchors was conducted by Hironaka [24] in which he concluded that grouted rod anchors were the best permanent system for use in frozen ground. This anchor basically consists of a steel rod grouted into a predrilled hole extending into frozen ground or bedrock. Such a system is being used to support the above-ground portions of the trans-Alaska pipeline. Further research is still needed on expedient anchors for frozen ground.

Foundations Near Water

Foundations in or near bodies of water (rivers, lakes, oceans) require special attention because of the varying conditions found in the soil beneath them. Sufficiently large bodies of water which do not totally freeze in winter will generally be underlain by unfrozen soil. In the case of rivers and lakes in areas of deep permafrost, this ''thaw bowl'' of unfrozen soil is in turn underlain by permafrost. In the case of oceans, very limited data suggests that the immediate ocean floor sediments are unfrozen but are underlain by frozen ground for a few hundred feet off the shoreline [25]. It has also been noted that the occurrence of saline water in the soil in both the near onshore and offshore may cause erratic distribution of unfrozen soil at ground temperatures below $0^{\circ}C$. Brewer [25] also discusses the thermal regime under lakes in permafrost regions, and Pewe and Paige [3] discuss conditions adjacent to and below rivers in Alaska. The basic requirement is that great caution be used in designing foundations near bodies of water, with decisions based upon as much subsurface data as possible.

Roads

The thickness of the annual active layer in a given permafrost region generally remains quite constant from year to year, provided that there is no disturbance of the natural environment. Most areas have a cover of vegetation which serves as a very good natural insulator and effectively limits the summer depth of thaw penetration. If this surface layer is disturbed, which can occur by trafficking of anything but the lowest ground pressure vehicles, the underlying soil is exposed to greater thaw penetration. In soils of high ice content this thaw can result in settlement leading to ponding of water, further accelerating the thawing process. After several seasons, the area is transformed into a bog. In addition, if the land surface is other than flat, erosion can take place in the thawed areas where the soil is no longer anchored by vegetation.

The brief discussion above outlines the shortcomings of conventional at-grade, unpaved roadways using the native subgrade materials in permafrost regions. Application of asphaltic or concrete paving at-grade likewise increases the thawing of the permafrost, and such pavements soon become unserviceable. Another major problem in fine-grained soils with capillary access to water is frost heaving, which can seriously disrupt the surface of a roadway. Areas do exist in the permafrost regions where the soil is relatively ice free and non-frost-susceptible, but such areas are the exception.

Embankment Roadways. The design of a roadway in permafrost for year-round trafficking by conventional wheeled vehicles thus becomes a major engineering project. The two main objectives in such road design are (1) the prevention of settlement (especially differential settlement) by the limiting of thaw penetration and (2) the minimizing of frost heaving. Common practice in accomplishing both these objectives is to construct the roadway on a raised embankment of NFS soil, a method similar to that of using an NFS pad for buildings, discussed previously. As in that application, the embankment serves as a heat sink, freezing in winter and thawing in summer, and its thickness should prevent thaw penetration into the underlying natural ground, thus averting possible settlement from the thawing of high-ice-content soils. The use of NFS material in the embankment also prevents frost heaving and its associated problems.

The NFS embankment roadway is in theory a good solution to the problems of roadway construction over permafrost. However, in many areas NFS material is either not available or is not economically available. One possible solution to this problem would be to process some available material to separate the finer soil particles from the coarser particles thus manufacturing an NFS soil. However, from the standpoint of a ''heat sink'' embankment, NFS material (usually sand or gravel) is inferior to finer-grained materials which with their higher water content have a higher latent heat although also a tendency to promote frost heaving. So, if frost heaving could be controlled, almost any soil could be used for the embankment.

Limiting frost heaving basically involves interrupting moisture migration in the soil and can theoretically be accomplished either by physical or chemical means. If a limited amount of granular material is available and can be placed in a layer between the embankment and the natural ground, this reduces the capillary availability of water for heaving. However, surface water can still infiltrate the embankment material and somehow has to be excluded.

To find a more positive means of controlling water availability, experiments are being performed on the use of membranes to encapsulate frost-susceptible soils and prevent moisture migration [26]. The main concern with respect to this system is the mechanical integrity of the membrane after a period of time, but also of concern is the prevention of lateral migration of water within the encapsulated soil mass.

Lambe and Kaplar [27,28] have experimented with various chemical additives to modify the frost susceptibility of soils. These included void fillers, aggregants, waterproofers, and dispersants. They found that some aggregants and dispersants gave very promising results, and the authors are engaged in further field testing. The Japanese have also conducted tests on chemical additives with some promising results [29]. The main problem with chemical additives is their durability in moist environments, the possible detrimental environmental effects if the additives do leach out, and the difficulties in properly mixing them with the soil.

Insulated Embankment Roadways. Another approach to roadway embankment construction is to decrease the required thickness of embankment materials (either NFS or modified-frost-susceptible) by use of insulation in the embankment. Wherever possible, the original ground vegetation should be left in place undisturbed under the embankment because of its favorable insulating qualities. Trees have also been used as insulating material where available [30]. Another possible organic insulator is wood chips derived from brush-clearing operations. Bales of compressed peat have been tested as insulation but do not show great promise [31].

Petrochemical insulation has been tested and used in actual applications for subgrade insulation. Data is available on styrofoam panels [32,33,34] and polyurethane, both panels [35] and sprayed application [36]. To be effective, the insulation must be moisture resistant (moisture degrades the insulating properties) and mechanically durable to withstand the applied loads. Installation of the material is at present a major cost item, but the promising benefits may spur development of new application techniques.

Paved Roadways. Any one or a combination of the above methods could be employed in the construction of roadways over permafrost, depending on the logistics of materials and the desired performance of the roadway. A road which is to be surfaced with rigid or flexible pavement obviously requires a more rigorous design than a gravel road which can be periodically maintained (preferably by adding material to fill in depressions, not just by regrading). A good practice with paved

roads is to leave them unpaved for several seasons to allow some of the inevitable settlement to take place before paving. The performance of the paving material itself under freeze-thaw cycling must also be considered. In addition, heat absorption by dark-colored pavements can necessitate greater insulating potential in the embankment; if not allowed for, this absorption can cause serious permafrost degradation. Studies have shown that painting the pavement surface white can substantially cut down the amount of insulation necessary for adequate performance [31]. A traffic-durable paint is needed for this application.

Drainage Problems. The construction of roadways in permafrost creates additional problems besides the obvious need for control of thawing and heaving. Elevated roadways, so constructed as to prevent thawing of the underlying natural ground and also to prevent snow drifting on the roadway, block the surface drainage (and sometimes subsurface drainage because of the raising of the permafrost table under the embankment). A blanket of coarse granular material under the embankment can in theory act as a subdrain, but such a drain often remains solid with ice well after the spring thaw begins and the drain is needed. For this reason culverts are usually placed at strategic locations under the embankment, but these are also subject to freezing solid. Countermeasures involve either covering the ends of the culvert during winter to prevent freezing inside the culvert, or thawing in the spring by steam or other heat source. CRREL[c] has experimented with electric heating of culverts to control icing [37]. Preconstruction planning for icing prevention involves designs using oversize culverts on steep gradients as deep in the ground as possible [38].

Icings. Associated with groundwater drainage problems are general problems of ''icings'' formed adjacent to or on roadways (the above-mentioned culvert icings also belong to this category). By definition, icings are masses of surface ice formed by the freezing of successive sheets of water originating from the ground, a river, or a spring [38]. When such icings encroach on a road, very hazardous driving conditions are created, necessitating repeated maintenance. Prevention of icing in the design stage requires proper drainage in the vicinity of the roadway or grade differences to allow the icing to form without encroaching on the roadway. Fences of sack cloth[d] or subsurface ''freezing belts'' of artificially deepened permafrost[e] have been used as possible, but less desirable, solutions to existing problems.

Slope Stability. Roads in hillside terrain may be subject to stability problems. Solifluction (mass movement of soil downhill) or, in some cases, actual landslides can occur with the thawed active layer

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[c] U. S. Army, Cold Regions Research and Engineering Laboratory.
[d] Sack cloth freezes solid and forms a dam.
[e] Artificially deepened by removing ground cover and snow in winter and replacing ground cover in summer.

sliding on the permafrost. A more common occurrence is thermal ''erosion'' of cut slopes in permafrost, especially if large volumes of massive ground ice are present.

For the landslide problem, the depth of the active layer and the angle of the natural slope should be considered; evaluation can probably be made along the lines of conventional slope-stability analyses used in temperate regions. Drainage will often help alleviate this situation [2].

For cut slopes, Smith and Berg have suggested that high cuts in areas of high-ice-content ground be made nearly vertical with a wide ditch at the base of the cut for sloughing material [39]. Trees and brush (but not the vegetative mat are removed by hand from the top of the cut for a distance approximately equal to the height of the slope. Then, as thawing and sloughing occur (this tends to flatten the angle of the slope), the vegetative mat overhangs and gradually conforms to the now-flattening slope, providing insulation to prevent further thawing and sloughing. Keyes [30] suggests the possibility of employing insulation, a subdrain, and a retaining wall backfilled with granular material as an alternate method of cut protection, but the previously mentioned natural process seems to be acceptable according to the performance data supplied by Smith and Berg. Smith and Berg recommend avoiding north-facing slopes in the Arctic, which seem to have permafrost closer to the surface. However, the higher solar heat input to south-facing slopes and its effect on the finished cut should also be considered.

Dust Control. Dust is another problem with unpaved roads in permafrost areas. The dust tends to accumulate on the ground surface and vegetation adjacent to the roadway and can alter its albedo (reflectivity) sufficiently to cause deepened thaw from the additional solar heat input. Oiling the road, standard practice in temperate regions, generally is unacceptable, because of the solar heat input it would generate. The need thus exists for a reflective dust-control medium.

Excavation

The need for mass excavation in permafrost regions arises in several ways. Although many structures are supported on piles, removal and replacement of objectionable subgrade material is still performed on some jobs. Quarrying of NFS material also involves excavation, as does the construction of cut portions of roadways in hilly areas. The problems of trenching and drilling in permafrost will also be discussed in this section.

Earthwork. Excavation in permafrost presents a variety of problems not encountered in temperate regions. High-water-content frozen soils take on the strength properties of rock or lean concrete. On the other hand, when thawing occurs, these soils often have very low bearing capacity, and the melt water may transform the site into a bog. In addition, the low temperatures coincident with permafrost regions can tax and reduce the efficiency of both men and equipment. In areas of thin permafrost,

the site can be thawed (or insulated to prevent freezing), or work can be restricted to the summer season and earthwork can proceed almost as in temperate regions. However, in areas of deep permafrost, or where work must be performed in winter, the problems must be confronted and solved. Excavations in permafrost with steep sides that must remain exposed during periods of above-freezing temperatures may be subject to sloughing as the material thaws, and sloughing of the active layer may occur after very short exposure. In addition, care must be taken during any construction work to minimize disturbance of the adjacent terrain (especially any vegetative cover), or else undesirable permafrost degradation and erosion may follow.

Excavation in permafrost can either follow a ''brute-force'' method, dealing with the ground in its frozen state, or by conventional methods after thawing the ground. As discussed earlier, thawing may be done with water, steam, gas, electricity, fires, or solar energy. Thawing of only the surficial material can slow down the excavation process because of the daily ''thaw and scrape'' nature of the operation. Any excavation which involves the thawing of some or all of the permafrost can generate a very wet working environment because of the water released by thawing and by the steam or water used as the thawing medium. The relative disadvantages and limitations of the thaw-and-excavate method can be seen from the discussion above.

Larger excavations have commonly used explosives to disintegrate the frozen soil to facilitate excavation, but Yoakem [40] reports that the use of tractor-mounted rippers is a more efficient and economical method to break up frozen soils. Explosives have the disadvantage of generally requiring a drilled hole for placement, except shaped charges can be used to prepare the shot hole, as discussed by Mellor and Sellman [41]. Some explosives become more sensitive at low temperatures, but adequate explosives do exist. Another limitation of explosives is imposed where the work must be carried out close to other structures. The use of compressed gas blasting in frozen ground has also been investigated, and the process has shown promise [42,43].

Linell and Johnston cite reports that conclude that ripping and shearing are at present the most satisfactory methods for excavating frozen ground. Of several novel, experimental processes for disengaging frozen ground, high-velocity water jets seem to offer the most promise, although they are currently not at an adequate stage of development for this application.

Frozen soils of high moisture content may be subject to refreezing after excavation, depending on ambient temperatures, and so the work must be carefully scheduled. This freezing can also be a problem in the handling and transporting of excavated frozen soils, where the material may freeze to buckets, truck beds, etc. Drying the soils or heating the contact surfaces of the equipment can help alleviate this problem [16].

Although excavation may be carried out at subfreezing temperatures, the placement of fill is a different matter. Yoakem [40] has surveyed and summarized allowed practices for placement of fill in cold weather.

In general, frozen material should not be used to construct fills. Exceptions would be if the fill material is granular and of a low moisture content and if it is allowed to consolidate for at least one thaw season following construction. If earthwork is done in subfreezing temperatures, the material should be compacted as soon as possible after placing, and extreme care must be taken to exclude masses of frozen soil or ice or snow from the fill.

Trenching. Trenching in permafrost has received a great deal of attention in connection with the present work on the trans-Alaska pipeline system. Hironaka [44] has written a state-of-the-art survey of trenching, incorporating some of the recent pipeline research. He cites work that concludes that at present, ditching machines utilizing transverse rotation cutting are the most efficient for frozen fine-grained soils. For frozen gravels, ripping in low-moisture-content conditions or drilling and blasting in high-moisture-content gravels, followed by excavation with a backhoe, appear to be the most efficient methods.

Cutting-tooth wear on the various machines caused by the hardness of the frozen soils seems to be one of the major problems. Again, high-velocity water jets hold promise as a trench-cutting tool. Other methods including drop hammers and hydraulic/pneumatic breakers, have also been used successfully for trenching frozen ground.

Drilling. Much experience with drills and drilling techniques in permafrost, has been gained by soil sampling and other explorations, preparation of shot holes for blasting, or digging foundation holes for structures. Rotary drills employing tricone, drag, or fishtail bits must be used with air, water, or some other drilling fluid for removing the cuttings. For these and all other drills requiring fluid circulation, it is advantageous to chill the drilling fluid to prevent sloughing and caving of the hole, which might occur if the hole were thawed by an unchilled fluid. Rotary drills are capable of fairly rapid drilling in frozen ground [41]; however, the bit life of these drills is relatively short in frozen ground containing any quantity of hard rock.

Although they are slower [45], churn drills, which utilize a chopping motion to make a hole, have been successfully used in permafrost. They have the advantage of normally not requiring fluid circulation for drilling and, in addition, are readily adapted to driving casing or small piles.

Coring bits, with either carbide or diamond inserts, are generally used only when sample recovery is desired for soil investigations because of their slow penetration rates. Recovery of usable cores also generally requires the use of a refrigerated drilling fluid. Carbide bits can be used in fine-grained frozen soils, but diamond bits are normally required if rock is present. Short bit life is a problem with either type of bit, but it must be tolerated if the primary purpose of the hole is core recovery.

Pneumatic percussion drills, similar to those used for shot-hole drilling in rock in temperate zones, seem to provide very good service in permafrost, even if gravel is present [41]. Drilling rates are

comparable to rotary drilling, but because of the massive character of the percussion bit its life is much longer than a rotary bit. However, percussion drilling is usually limited to small hole diameters. In addition, fluid (usually air) must be circulated to remove the cuttings, and this fluid should be chilled.

The above discussions of drilling equipment have not considered the factors of weight, size, and availability, which often take precedence for choice of equipment for work in polar regions. Some drilling equipment itself is quite heavy, and the air compressors required if air is to be used as the drilling fluid are likewise large pieces of equipment.

The equipment discussed above is in general limited to drilling holes a foot or less in diameter. This size is adequate for soil investigations (though it will not allow down-hole inspection) and for holes for small piles. Most larger diameter holes have been drilled with augers. Auger bits with replaceable carbide teeth provide good service, fairly fast drilling rates, and can perform even in coarse gravel [9]. For pile installation, augering has the advantage of producing an even hole of a known size with minimum heat input to the ground.

A new approach to drilling in permafrost has been taken for drilling pile holes for the trans-Alaska pipeline [46]. For the drilling of several thousand 24-inch-diameter holes for vertical support members for the elevated sections of the pipeline, special ''vibropercussion rotary'' drilling rigs have been developed. These units can use ''vibration, percussion, pulldown, and conventional rotary action, or combinations of these actions to make holes...Soft formations will be drilled using milled-tooth, tricone rock bits with maximum rotation, minimum vibration, and minimum pulldown. Hard formations will be drilled with a tungsten carbide-insert, concave, mill-type bit using maximum pulldown, minimum rotation, and maximum percussion to fracture the rock ahead of the bit face.'' This drill rig marks a breakthrough in that by combining the various drilling functions in one machine, the optimum type of drilling action can be used, depending on conditions encountered.

Methods of making holes also exist that are not widely used but deserve mention. CRREL [41] has tested commercial vibratory drills that have given fairly fast drilling rates, and are of a small physical size. More primitive methods of making holes include jetting with water or steam; however, even though equipment is small, the holes can be quite irregular and an undesirable amount of heat is introduced into the ground. The use of shaped charges to make shot holes has been mentioned previously. Internal burners using fuel oil in a jet of compressed air have been tested for making holes in permafrost [47] and are capable of good penetration rates, but, again, the heat input to the ground may be a problem in many applications. Although it has been used in mining applications, the internal burner has not been widely used in permafrost.

Tunneling. Tunneling in permafrost has been successful in the past for mining purposes. Recent research has been directed toward improved methods of tunneling and also the use of underground rooms as

an alternative to above-ground shelters. Swinzow [48] describes techniques used for driving tunnels, basically a slightly modified version of the conventional hard-rock drill-blast-ventilate-muck cycle. The cold tunnel environment presented advantages, such as the use of a frozen soil slurry (given the name ''permacrete'') for foundations, supports, bulkheads, etc. Pettibone [49] made studies of the stability of an underground room in frozen gravel. He concluded that tunnels will stay open without support as long as temperatures in the mine are below freezing. Operation at above-freezing temperatures would require warm air removal or partial support. Mechanical mining machines have been used successfully in permafrost [50].

Utilities and Pipelines

Most installations require a variety of piping for various fluids (water, sewage, fuel, etc.), and in polar regions some means must be employed to prevent these fluids from freezing. Even if the systems need not remain operational during periods of freezing temperatures, if the fluid is water or water-based, protection must still be provided to prevent damage to the systems from expansion of the fluid upon freezing. An additional consideration in permafrost installations is the need for reduction of heat flow from the line to the soil; otherwise, thawing of the ground might be induced, resulting in settlement and possible related damage to the pipeline if the soils have a high ice content.

Freezing can often be prevented in pipelines if adequate flow is maintained. Such a system, however, requires extra piping to complete a circuit through all laterals, or pitorifices to provide circulation, and if demand is not high enough, forced circulation may be required. If the system is shut down due to a malfunction or emergency, it will freeze unless provision is made to drain it in time. In the case of sewers, holding tanks may be required to store the fluid until an adequate volume exists to insure rapid flow. The limitations and possible pitfalls of a utility system dependent on circulation to prevent freezeup should be obvious.

Insulation of pipelines is thus a far more reliable method of preventing freezeup. The insulating material must be waterproof; it rapidly loses its desirable properties if saturated either internally from pipeline leaks or externally from the environment. Closed-cell polyurethane foam is well-suited from this standpoint. External coverings over the insulation can aid in the waterproofing, as well as in protecting the material from accidental or intentional physical damage.

The required thickness of the insulation depends on the material used, the thermal and flow characteristics of the fluid in the pipeline, and the climatic factors; as a result, the insulation may become unwieldy. The thickness can be reduced by wrapping or tracing the pipeline with electrical heating cable. In this case, the insulation is only required to reduce heat loss from the cable to an acceptable level, rather than provide total protection for the pipeline. Thermostatic control of the

heating cable can be employed to insure efficient operation under variable flow and climatic conditions. Thermal properties of the pipeline insulation and the electric insulation should be such that damage will not occur if excessive temperatures are reached due to thermostat malfunction.

For ease of installation under less-than-ideal climatic situations, preassembled sections of pipe, incorporating a heating cable, insulation, and an outer protective jacket have been developed. CEL has tested and evaluated some of these systems in the laboratory and in the field [51].

Where several utility lines are to be run between two points, it is economically advantageous to run them together. In addition, if one of the lines is for hot water or steam, the lines can be enclosed in a common corridor, and heat lost from the hot line can be used to prevent freezeup of the others. This is the basic concept of the ''utilidor,'' which has become a common replacement for separate, heat-traced lines. The walls of the utilidor are usually covered with several inches of insulation; the pipes inside are not insulated, with the possible exception of the steam or hot-water pipe if it is desirable to limit its heat loss somewhat, concurrent with adequate performance of the system. Detailed thermal design for a given installation must include consideration of the number, size, and type of lines, physical configuration of the utilidor proper, climate, and other factors. CEL has surveyed various utilidor systems presently in use and designed and tested a system for Navy application [52]. In addition, CEL evaluated the cost-effectiveness of a utilidor over separate lines and concluded that utilidors are most cost effective for more than six lines and are almost the most cost-effective system for four to six lines.

In most cases, it is preferable to install utility lines above ground to avoid possible thawing of the ground as is the case with most systems presently in use in permafrost regions, although there are exceptions. The lines, either separately or in utilidors, are generally supported by piles. Sufficient restraint must be provided to resist lateral loads imposed by thermal expansion at bends in the pipe. Wind loading should also be considered, as should the possibility of heat transfer down the piles from the utilities.

The trans-Alaska pipeline, which will transport oil from production facilities at Prudhoe Bay to tanker facilities at the Port of Valdez, is an interesting case history of the interaction of engineering and environmental factors for design in permafrost. The oil is to be transported at 140°F, and it was concluded that insulation could not entirely prevent heat loss from the pipeline and, in turn, thawing of the permafrost. Use of natural convection heat-transfer systems for protection of the permafrost was considered but was apparently rejected, as was mechanical refrigeration [53]. After extensive studies, it was decided that the pipeline would be elevated where it traversed permafrost which would be unstable if thawed. The short sections of the pipeline placed underground in permafrost not thaw-stable would use refrigeration to preserve the thermal regime.

The insulation on the above-ground sections of the pipe is not so much to retain heat when the oil is flowing as it is to retain the heat

in the event of a shutdown. The insulation being used is 3-3/4 inches of glass fiber jacketed with galvanized sheet metal [54]. Polyurethane will be used to insulate the pipe supports. As mentioned earlier, heat pipes will be embedded with the support piles to extract any heat transferred down the piles from the pipeline.

In the case of the proposed Canadian gas pipeline, it has been tentatively decided to run the line underground but to chill the gas to below 32°F in permafrost areas to prevent thawing [55]. Chilling is not an option with oil because of its high viscosity at low temperatures. However, the chilling effects of the gas can conceivably alter the thermal regime and keep the ground frozen year-round. This can have a disruptive effect on groundwater flow, possibly resulting in ponding and thawing of the adjacent permafrost or in development of surface icings during the winter.

SNOW

Introduction and Physical Properties

Applied research in the use of snow as a foundation material has not been quite as extensive as for permafrost, principally because deep snowfields exist in a much more limited area. Moreover, there has not been the need for the development of extensive facilities in these regions. Greenland and the Antarctic are the primary areas where deep-snow construction has been performed and where most of the background related herein has been gained.

The type of snow found in most of Greenland and Antarctica is typically dry and forms a rather cohesionless mass of particles. Wet snow, more typical of the temperate regions, is quite cohesive and will form clods and clumps during excavation [56]. In deep polar snowfields, snow becomes denser with depth as a result of consolidation (''densification'') with time and overburden. If the area is subject to seasonal melting of the surface, discontinuous ice lenses may be found; the remainder of the snow will remain similar to dry snow.

Snow generally has sufficient tensile strength or cohesion to support drilled holes, shafts, or tunnels without collapsing. However, such cuts will gradually deform by viscoplastic flow, and also as a result of natural densification if near the snow-mass surface.

Fine particles of fresh snow tend to rapidly become bonded to each other by ice bonds; thus, new drifts or newly processed snow rapidly gain cohesion to form a hard mass. This process is known as sintering or ''age-hardening'' and is dependent primarily on time and temperature.

There are two major problems associated with construction on permanent snowfields. The first is the inevitable settlement resulting from ongoing densification of the snow; the second is snow accumulation, both by deposition and by drifting. Both of these problems must be attended to if the structure is to perform satisfactorily. Actual melting of the

snow and ensuing settlement do not present the major problems that thawing of the ground in permafrost terrain does because areas that support permanent snowfields tend to have quite cold climates. On the margins of these areas, however, warmer summertime temperatures may promote surficial melting, and more careful consideration must be given to the problem of melting.

Rationale of Design

Design of structures on polar snowfields is not so site-dependent as is design on frozen ground in permafrost regions. Snow is a much more uniform and consistent material from site to site, and climatic factors such as temperature, snowfall, and wind speed and direction become the major variables which must be considered. Of course, the size, purpose, and expected lifetime of the structure will also affect the design. It should be kept in mind that when speaking of deep snowfields there are no really permanent structures. The new South Pole Station, for instance, has a designed life of 15 years which is actually a fairly long life. This is due to the physical environment of snowfields, including such factors as the continued accumulation and densification of the snow. Because of such factors, design of structures for snowfields becomes a process of optimal compromise rather than perfection.

Construction on the surface of a snowfield encounters a major problem in snow accumulation. The combined effects of direct accumulation by precipitation and indirect accumulation by drifting can bury a camp within a few seasons. Although drifting can be controlled by proper orientation of camp buildings, as will be discussed later, there is nothing that can be done about precipitation. Loads imposed by snow accumulation can cause direct structural damage, as well as increased distress due to differential settlement of the structure from uneven loads. Accumulation of snow also makes access to outbuildings, equipment, and stores difficult.

One approach to the accumulation problem at temporary camps can be the use of buildings mounted on skis or sturdy runners. The buildings can be uncovered and moved as often as necessary to prevent complete burial. Aside from the obvious logistical problems of this system, further difficulties occur in that buildings often become frozen to the surface by the formation of ice and can become extremely difficult to move.

Also with surface construction densification of new surficial snow occurs at a fairly rapid rate, and the settlement thus caused will require continued shimming of the building supports. The frequency of maintenance can be reduced by placing the foundations at depth in snow which has already undergone initial densification and will exhibit slower settlement rates at the same bearing pressure. Alternately, the placing of footings on a pad of compacted processed snow will also lessen the settlement rate.

A unique solution to the problems associated with surface construction on snowfields was employed for the construction of DEW-line stations DYE-2 and DYE-3 on the Greenland ice cap. These heavily-loaded stations had to remain above the surface and free from drifting in order to fulfill their functions. In the final design each station was supported on eight pairs of columns bearing on mat footings 30 feet below the snow surface at the time of construction. Large hydraulic jacks were incorporated into the columns so that the structure could be jacked up occasionally, to compensate for settlement and snow accumulation, thus maintaining a 15- to 20-foot space between the snow surface and the underside of the building to minimize the buildup of snow drifts. The system worked well, despite the accumulation of almost 30 feet of snow during the stations' first 7 years of operation [57].

A more widely used approach to the problem of snow accumulation is the construction of undersnow camps. Although for some cases, such as for the DEW-line stations, this is not an acceptable approach, for other camps the method has the added advantage of camouflaging the camp. In addition, undersnow camps are completely isolated from the severe environment at the surface. Such camps usually consist of buildings placed in deep trenches cut into the surface of the snow. The trenches are then covered over with molded processed snow or covered with steel arches which are naturally covered over by drifting snow. The tunnel thus formed then serves not as a building per se, but as a corridor for year-round access around and between buildings placed in the tunnels. An additional advantage of placing the buildings in the tunnels is that their foundations are automatically placed on denser deep snow and less subject to settlement. The method is not without its disadvantages. Snow tunnels gradually undergo horizontal or vertical deformation (''closure'') as a result of viscoplastic creep, especially under increasing loads from snow accumulation, and will require ''trimming'' if specific clearances must be maintained. The rate of closure can be limited if the air temperature within the tunnels is kept low.

In the case of the new South Pole Station, the buildings are being constructed at the surface, but are being covered by a 164-foot-diameter by 50-foot-high geodesic dome and a series of semicircular arch sections. Although the camp layout was designed to minimize drifting, the station will eventually be buried by snow.

Another factor which must be considered when designing facilities for snowfields is the prevention of melting of the snow. This basically involves raising the building off the surface and providing adequate floor insulation as in the case of construction on frozen ground. Likewise, melting by wastewater, sewage, etc., must be avoided. Contamination of the snow surface with soot, dust or other material can change the albedo of the surface enough to cause melting, although this generally should be a problem only in warmer areas.

Foundations

Strip footings or longitudinal sills running parallel to the long dimension of the structure are probably the most commonly used footing on snow. They can be made from timbers and if the foundation members themselves are stiff enough, they provide an easy method of evenly distributing the load. The steel runners on buildings previously mentioned which are designed to be movable to prevent burial are essentially longitudinal sills. Transverse sills (running the width of the building) have occasionally been used; they cannot be used in undersnow tunnels, as will be discussed later.

Spread footings consisting of timber mats, with a grillage to distribute the load and a column running to the surface, are used to support heavy structures such as the DEW-line stations. Placing these footings at some depth below the snow surface enables the load to bear on denser, higher-strength snow. Enclosing the columns in wooden boxes prevents the adhesion of the adjacent snow, which would put an additional load on the column as the snow densifies and settles. In addition, removing the overburden snow around a group of deep spread footings increases the allowable bearing.

Raft footings can and have been used at the surface. but heated buildings must be adequately separated from the footing for ventilation to prevent melting of the snow.

Few pile foundations have been used in snow, and these have mostly been end bearing piles designed to transfer the load to denser snow at depth. The piles were emplaced either by driving or placing in augered holes. However, Mellor [58] reports that limited testing of friction piles shows that they may perform better than equally loaded end-bearing piles. The negative skin friction (''drag down'') forces generated by the settlement of the densifying surficial snow must be considered when calculating allowable bearing for either end-bearing or friction piles.

A good summary of theoretical detail on foundation design for snow can be found in Mellor's report [58], which also includes references to various studies made on the subject.

The testing of anchors in snow has mainly been limited to buried plate anchors [59,24]. These consist of a circular steel plate with steel tie rods which extend to the surface. The plates are placed in an augered hole, and the hole is backfilled with dry snow. A period of several days before applying the load is desirable to allow the backfill to gain strength from age hardening. The tests showed that these anchors are capable of holding large short-term loads, but the long-term loading capacity is substantially less because of creep.

Types of Construction

As mentioned previously, buildings can be constructed on the surface of a snowfield or in tunnels below the surface. In addition to standard building materials (usually wood), snow itself has been experimentally

used as a building material. This section will expand on some of the details of these various types of construction.

Surface Construction. The accumulation of snow from precipitation or drifting is the primary problem with surface construction. Little can be done about precipitation except to remove the snow or to periodically relocate the structure to the new surface of the snow.

Actual removal of the snow becomes unfeasible in areas where the annual accumulation rate is high. The accumulated snow makes access between buildings difficult, and structures are usually unable to withstand the loads imposed by large snow accumulations. Drifted snow preferentially accumulated against one side of a building can also promote differential settlement because of the additional load imposed on the snow surface. Accumulation of snow has necessitated the abandonment of polar facilities such as the original South Pole Station. Relocating of structures, on the other hand, is quite difficult because of the tendency for the buildings to freeze to the surface. A large amount of work is often necessary to free a building and this becomes a major undertaking for large camps.

Where annual snowfall is not so high, the control of drifting snow becomes a more important consideration. Snow drifting has been studied extensively by CEL in connection with Navy support operations in Antarctica, both with field observations and with scale model tests in a wind tunnel using powdered borax to simulate snow. In a summary report on snowdrift control [60], Brier concluded that ''snowdrift accumulation and camp maintenance costs can be reduced by elevating the camp on a snow platform, orienting the buildings 45 degrees to the snow-carrying wind, and placing the structures and utilities to permit easy snow removal.'' Such measures will not eliminate drifting but will reduce the amount of snow removal required or extend the life of the camp with respect to burial by accumulation of drifting snow.

The recommended snow platform for elevation of a camp to prevent drifting can serve a dual purpose. Tests by CEL in connection with construction of the new South Pole Station [61] showed that ''settlement of a footing into undisturbed snow is about nine times greater than that of an equally loaded footing of the same size into a compacted snow pad having a thickness at least 1.5 times the width of the footing.'' The pads for this study were constructed by compacting 6- to 8-inch-thick layers of snow with several passes of an LGP[f] D-8 tractor.

Another factor that must be considered for buildings on the snow surface or in tunnels is prevention of melting of the foundation snow by heat lost from the building. With wood construction and adequate floor insulation, a minimum air space of 18 inches between the building and the snow surface should be adequate to prevent melting [62]. The space should be enclosed to keep out drifting snow, thus providing free air circulation and facilitating releveling if differential settlement should occur.

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[f] Low ground pressure.

While snow accumulation must be considered, differential melting (ablation) of the snow around buildings must also be considered. The most common cause of ablation is discoloration of the snow by soot from engine exhaust or building heating systems or by dust. This increases the solar heat absorption, and, in regions where summertime temperatures are at or only slightly below freezing, melting of the snow will be accelerated. The melting will not occur where the snow surface is covered or shaded - by a building or stores or a piece of equipment, for instance. In extreme cases, melting can result in buildings perched on islands of snow above the surrounding surface, and the stability of the foundations becomes dubious. Even without surface contamination, ablation can occur on snowfields which, because of their climatic location, are subject to seasonal melting. The reflection of sunlight off the sides of a building could also contribute to differential melting.

Subsurface Construction. Construction of camps by placing buildings in interconnected tunnels beneath the snow surface is one obvious method for eliminating problems associated with snow accumulation. This method of construction has been successfully used for several operational stations, notably Camp Century on the Greenland ice cap and Byrd Station in Antarctica.

This method actually utilizes trenches in the snow rather than tunnels, the end product being a covered trench. The trenches are generally excavated with a rotary snowplow, the snow being blown out of the trench as it is excavated. Trenches can be made either with vertical walls or by undercutting the walls, the latter process requiring a narrower roof arch for the same width at the floor of the trench.

Most of the trenches are roofed with corrugated metal arches, although wooden arches or flat wooden roofs have also been used. The roof of the trench is then covered over with blown, milled snow. Small trenches have been roofed by blowing snow over arched roof forms, which were later removed when the snow had achieved sufficient strength, thus leaving a snow arched roof. Air-inflatable forms have also been used for this purpose. However, most operational stations rely on metal arches for roof support. Stations consisting of wooden buildings set inside metal cylinders set inside trenches have been built, but seem to have no real advantage over the standard wooden building in a trench.

The main problem with undersnow camps is ''closure'' of the trenches. Vertical closure occurs as a result of the natural densification of the snow forming the sides of the trench and supporting the roof arch. Horizontal closure also occurs, being most pronounced about midheight on the walls of the trench. Deeper trenches or those with wider roof spans tend to have greater horizontal closure rates. Wider trenches will also undergo ''hogging,'' or relative raising of the center of the trench floor. This apparently occurs because the center of the floor is settling at a slower rate than the sides of the floor, due to less overburden at the center.

Closure rate is dependent on the temperature within the trench, the amount of overburden and the initial dimensions of the trench. Even though the overburden is continually increasing with accumulation of snow, deformation rates should decrease with time since snow densification, the prime driving force for closure, tends asymptotically to a limit.

Initially, closure was regarded as a problem which required periodic maintenance, consisting of trimming the walls of the trenches or even of removing and relocating roof arches, to provide necessary clearances between buildings and the trench. To this end, much work was done developing equipment and techniques for performing this work. However, more recently the opinion [58] has been expressed that ''it seems desirable to design undersnow structures with sufficient clearances to accommodate all the deformation which will accumulate over a reasonable working life for the station...the so-called 'maintenance cutting' which has been found necessary at some stations is actually a salvage operation.''

Adequate clearances can be built into the trenches at the time of their construction. These clearances will be gradually lost through inevitable deformation, but the rate of deformation can be minimized if the temperature within the trench is kept low enough, ideally about $0^{\circ}F$. Lost heat from heated buildings and heat from machinery exhaust are the prime sources for heat buildup within the trenches. Adequate building insulation and external exhausts for stationary engines can reduce the heat buildup. Exhaust fans or, ideally, gravity vents can remove the remaining warm air. Intake of outside air at ambient temperatures, however, will not necessarily keep temperatures inside the trench low enough to insure a reasonably low deformation rate. When low enough temperatures could not be achieved in certain heat-producing tunnels at Byrd Station in Antarctica, a snow-plenum air-cooling system was installed. This system basically consists of a chamber excavated into the subsurface snow, in which is installed a fan which draws surface air through the porous snow and discharges the cooled air into the tunnels. Although the snow mass will gradually warm and lose its cooling efficiency during summer operation, winter operation should cool it back down for the following summer's use. Because the capacity of the initial excavated chamber did not prove adequate, 12-inch-diameter holes were augered horizontally from the plenum chamber to increase the mass of snow available for cooling the air. The final report on this project [63] concluded that snow plenums were effective in maintaining the desired tunnel temperatures if outside ambient temperatures were warmer than the desired tunnel temperatures. When outside temperatures were colder than the desired tunnel temperature, large diameter gravity ventilation shafts were recommended, and an omnidirectional snow-free vent cap was described for use on these shafts.

It should be noted that originally Byrd Station, and also Camp Century, attempted to use ''air wells'' in the snow for maintaining low temperatures. These consisted of holes about 12 inches in diameter drilled about 40 feet below the floor of a tunnel. The upper half of the holes was cased and fans installed to pull air out of the holes, the

idea being that warm tunnel air would be pulled down through the floor of the tunnel, be cooled as it passed through the snow, enter a well hole, and be discharged back into the tunnel. This recirculation system did not work well; leakage paths (actual open channels) developed between the tunnel floor and the wells, especially alongside the casing. In addition, the mass of snow involved was not as great as with snow plenums, and the system did not have the winter-recharge feature of snow plenums.

Foundations for buildings placed in undersnow trenches are generally more stable than foundations on the surface because they bear in denser snow. However, footings must be placed only along the walls of the trench - not running across the trench nor in the middle and along the walls. In the latter cases, hogging of the trench floor can cause differential movement of the footings of a magnitude great enough to damage the buildings.

A good overall discussion of the construction and performance of a cut-and-cover snow trench is given in a report by Tobiasson and Rissling [64] describing a facility adjacent to Camp Century in Greenland.

Snow as a Structural Medium. Though snow has not been used extensively as a structural material for operational camps (with the exception of cut-and-cover trenches), tests have been conducted on the use of snow blocks and cast snow for the construction of surface structures. The use of snow blocks for the construction of igloos is an obvious application for temporary or survival situations. Larger buildings with vertical snow block walls can be built for various temporary purposes, including aircraft hangars, as was done on one of the Byrd expeditions.

Cast pulverized snow is perhaps a more useful application. Access tunnels to undersnow trenches have been built with walls of pulverized snow cast between plywood forms. The snow rapidly gains strength by the formation of ice bonds, and the forms can be removed, leaving free-standing walls. The construction of arched covers for trenches from pulverized snow has already been discussed. Experiments with both unreinforced and reinforced beams of cast snow have shown that reinforced beams may have some value for use in small structures.

A more detailed summary of structural applications of snow is given by Mellor [56].

Roads

In the early days of polar exploration, tracked vehicles were almost completely relied upon for mechanized land transportation. With the advent of larger military and scientific stations in the polar regions, it became desirable to use conventional wheeled vehicles over snow. Although light vehicles equipped with low-ground-pressure balloon tires can traffic natural snowfields, actual processed roadways are necessary for heavily loaded vehicles. The processing required is basically compaction, increasing the density and shear strength of the snow and hence its allowable loading.

Initial tests using water and slush-ice to form snow-ice pavements over a disaggregated snow base course showed promise, but the scarcity of water in the polar regions made this process one of questionable feasibility [65]. Dry processing methods were then investigated, consisting of compacting disaggregated snow and allowing it to age-harden. CEL performed extensive research on methods of snow compaction in connection with the construction of roads in the Antarctic.

Initially, a piece of equipment known as a pulvimixer was used; this machinery is similar in operation to those used to process the base course for conventional paved roadways on soil [66]. In this process, an elevated roadway about 3 feet high was formed by placing blown snow with a rotary snowplow (optionally by bulldozing natural snow), making two passes over this snow with the pulvimixer, and then compacting the pulverized snow with a large drum roller. After several days of age hardening, a wearing surface was formed by further compaction with a wobbly-wheel roller.

This system had the disadvantage of requiring specially fabricated equipment (the pulvimixer) and was also critically sensitive to quality control during construction. For these reasons, the layered compaction method was developed [67]. In this method, successive 4-inch layers of snow are blown onto the roadway with a rotary snowplow, leveled, and compacted by track rolling with an LGP tractor. When a roadway height of 24 to 30 inches has been achieved in this manner, rollers are used to harden the surface as in the pulvimixer method. Such construction produces acceptable snow roads if enough layers are built to reach the specified thickness. Further background on the history of snow roads can be found in Reference 68.

If a snow road is not built with an adequate thickness, ''punch-through'' failures can occur, especially with heavily loaded vehicles or over-inflated tires. Thus, quality control during construction is needed, as is conscientiousness on the part of drivers.

Transitions between dirt roads and snow roads can be problem areas, especially in instances where the snow road is built on a floating ice sheet, as in the vicinity of McMurdo Station in the Antarctic. Tidal cracks at the shoreline can hinder transportation, and ramps are generally required to bridge these areas. Timber road extensions have also been used at snow/land transitions to catch dirt dropped from the undersides of vehicles; such dirt can cause melting and potholes if dropped on the snow road.

Ruts will form in a snow road during periods of relatively high temperatures and require prompt maintenance in the form of regrading or patching with ice chips and water. Likewise, any snow drifts which accumulate on the road should be removed before they harden. Control of drifting is the major reason that snow roads are elevated above the surrounding surface. In addition, siting of the road in a fairly level area free of drift-generating obstructions will lessen the extent of this problem.

Experiments have been made with compacted snow for constructing runways for use by wheeled aircraft in the polar regions. However, these have never been considered operational for large aircraft. Most landings on snow are by ski-configured aircraft on a leveled snow skiway. In the case of the Antarctic, wheeled aircraft are landed on an ice runway on the annual ice sea.

Excavation

Excavation in snow presents many fewer problems than excavation in frozen ground because of the lower strength properties. Surficial snow can generally be excavated with only a shovel; denser snow at depth, or snow with ice lenses, may require a pick and shovel. Chainsaws seem to be well suited for excavating blocks of this harder snow.

For larger excavations, almost any conventional construction equipment can be used, providing it has adequate mobility on the snow (which usually calls for an LGP track system). Because of their versatility, bulldozers or tracked loaders are probably the most common equipment used on snowfields. Draglines and clamshell buckets have been used for excavation of snow in Greenland, although their use may not be justifiable unless the services of a crane are also required at a site.

The only nonconventional piece of equipment used for excavation of snow is the rotary snowplow which serves a multiple purpose by disaggregating snow in the process of excavation. As explained previously, this snow can be formed or used for pavements, and will rapidly gain strength through the process of sintering. Snowplows are widely used for the excavation of trenches for undersnow camps, and are capable of producing trenches with very uniform walls.

Drilling in snow is generally easy, and augers are the most widely used drill type; fluid recirculation, as used for rotary drilling or coring, cannot be employed because of the highly permeable nature of near-surface snow. However, there is a problem with augers in that the fine cohesionless snow cuttings are difficult to convey out of the hole, especially with continuous flight augers. For this reason, short auger sections are generally used and hoisted clear of the hole for spoil dumping [69]. This limits auger drilling in snow to a depth equal to the length of the drill kelly (telescoping kellies can be used).

For small diameter holes a variety of electric ''hotpoint'' borers have been designed, which melt the snow and allow the meltwater to dissipate into the permeable snow around the hole. For small-diameter cores at shallow depth CRREL has developed a coring auger which consists of a core barrel wrapped with auger flight which carries the excess cuttings to the surface. CRREL has also developed thermal corers for use in snow and ice, and down-hole electromechanical drills for deep core drilling.

Tunneling in snow can be carried out relatively easily with hand tools or chain saws, with the spoil hauled out on sleds. Such tunnels will be subject to deformation much the same as cut-and-cover trenches,

depending on the depth of the tunnel. The use of tunneling machines for snow has been investigated by CRREL [56]; the primary problem has been spoil removal. Both pneumatic and helical conveyors have been used, with mixed success.

In contrast to frozen ground, there is little need for blasting in snow because of its low strength. In addition, the snow rapidly absorbs the energy from the blast, making this a relatively inefficient method of excavating [56].

ICE

Introduction and Physical Properties

If there has not been extensive development of facilities on snow, there have been even fewer facilities constructed on ice. These have consisted primarily of the research stations established on drifting pack ice in the Arctic and stations constructed on glacial ice fields or ice shelves. Such stations have generally been small and their lifetime has been dependent upon breakup of the ice or lack of usefulness for scientific purpose because of location. Stations such as the Williams Field complex on the Ross Ice Shelf in Antarctica have been built, but the surface material there is snow, just as most deep snowfields are underlain by glacial ice.

This discussion of ice will be limited to a few major problems relating to construction and transportation on ice, rather than following the general outline of the previous sections on frozen ground and snow. The ice most often dealt with is generally annual sea ice or river ice. As mentioned above, camps have been established on thicker pack ice or glacial ice, but no particularly unusual construction methods have been used for these temporary drifting stations [70].

Annual sea ice can be used for airfields, piers, causeways, or as islands for floating stations, and much the same is true for fresh water ice on large bodies of water, while river ice is often used for winter bridges. Ice has fairly low tensile strength and moderate compressive strength. These strengths are dependent on temperature, salinity, crystal orientation, and thickness. Of these factors, thickness is the only one over which man has significant control.

Because annual ice asymptotically reaches a maximum thickness each season and because it is at a usable thickness for a relatively short period of time, methods for artificially thickening ice have been studied extensively. These studies have concentrated first on surface-flooding techniques, and more recently on bottom-thickening processes.

Foundations on ice are basically the same as those used on snow, consisting of some sort of sill, pad, or raft footing. The surface densification problems associated with snow are not present, but melting or ablation as a result of the erection of a structure must be considered in the design process. Studies have been performed on anchors in ice and are discussed in a later section.

Ice Thickening Methods

Surface Flooding. Surface flooding can be used for thickening or leveling the surface of a natural ice sheet. Water for flooding is generally obtained from below the ice sheet by use of either a submersible or elevated pump freely discharging onto the ice surface (hoses or pipelines can also be used to distribute the water). The water is applied and allowed to freeze in about 3-inch layers, thus promoting rapid freezing.

Two methods of flooding exist: confined flooding and free-flooding [71]. With the former method, the water is confined by man-made dikes and is generally used on thicker natural ice where the primary purpose is to level or improve the nature of the ice surface or to construct a thickened or elevated surface of a given shape. On thinner natural ice this method produces severe deflection of the natural ice underneath the flooded area, resulting in cracking of the ice around the perimeter of the deflected area.

Free flooding, on the other hand, is useful in thickening large areas of relatively thin ice. In this method, the area flooded by a single pump is dependent on the temperature and rate of flooding (freezing of the perimeter creates a dam which limits the extent of the area flooded). The center of a free-flooded area will still deform under the additional weight, but a nearly level surface is maintained, and generally the cracking associated with confined flooding does not occur.

One major application of confined flooding has been the construction of an artificial ice wharf for ship unloading in Winter Quarters Bay, near McMurdo Station, Antarctica [72]. In one winter's operations, an approximately 600-foot-long and 170-foot-wide area of sea ice was thickened to a maximum of 29 feet. This wharf was secured to the shore by cables, because the tidal crack between the thickened ice and the fast ice[g] never refroze as expected. Trouble also arose in the process of breaking the annual ice from the face of the new wharf. It had been expected that separation of the annual ice from the wharf would occur naturally from downwarping caused by the flooding, but it did not. An icebreaker was used to clear the annual ice, and, despite a row of holes drilled along the face of the wharf to form a plane of weakness for separation, cracking of the wharf itself resulted. However, the pieces of the wharf were lashed together, and the wharf successfully handled cargo operations.

One major drawback to ice thickening by surface flooding is the length of time necessary to freeze the required number of successive layers. Deposition of nozzle-sprayed water which is cooled or frozen as the droplets travel through the air, has been suggested as a more rapid means of thickening ice in construction of ''ice islands'' for drilling platforms in the Arctic [73]. However, this method would appear to require further study as well as adequate quality control during construction

[g] Sea ice more than 1 year old.

to insure that the thickened ice is not just a porous aggregate of small crystals.

Another method used to strengthen ice is to combine reinforcement of some sort with surface flooding, thus obtaining equivalent bearing with a lesser overall thickness of ice and hence a shorter time for construction. The reinforcement material function similarly to steel reinforcement used in concrete. In view of the logistics problems of the polar regions and the expendable nature of the thickened ice in most cases (it is lost in the next spring breakup), local timber or brush is often used as reinforcement. This method has been used for some time in the Arctic and has been used to bridge the Yukon River in Alaska for transport of equipment in conjunction with oil activities on the North Slope [74].

Bottom Thickening. In a further attempt to investigate more rapid methods of ice thickening, CEL studied techniques for accelerating ice growth at the bottom of an ice sheet [75,76]. Techniques studied included (1) fluid circulation (to extract heat from the water beneath the ice sheet and promote freezing), (2) cold fluid injection beneath the ice sheet, and (3) injection of ice chips below the ice sheet. Circulation was chosen as the most promising method, and free-convection cells were chosen over mechanical circulation or refrigeration because of simplicity. In their simplest form, these cells are vertical pipes, capped top and bottom, with heat rejection fins above the ice surface, and protruding below the bottom of the ice to whatever length desired. They are, in fact, basically the same as the thermopiles previously described for use in maintaining a frozen state in the active zone of permafrost. Laboratory tests of a single-phase convection cell and ducted and unducted two-phase cells showed that the single-phase (liquid) convection cell produced the greatest quantity of ice at low temperatures. More recent work on convection cells has been directed toward field tests and quantification and optimization of the design [77]. Horizontal loop cells have been tested on a limited scale in the laboratory and show promise [76], and limited field tests have been run.

In field tests attempting to grow a grounded ice structure with convection cells, cracking at the surface occurred as a result of tidal action bending the ice sheet at the grounding point. Although it has not been reported, cracking might also be expected as a result of bouyant forces generated by the bottom thickening.

Pile Foundations

In conjunction with work on the McMurdo ice wharf, the holding strength of piles in ice was tested [78]. Metal and wooden piles were subjected to short- and long-term pullout tests. The piles were installed by inserting them in holes augered in the ice, backfilling with fresh water, seawater, or a fresh-water/sand slurry, and allowing the backfill to freeze. This, of course, is very similar to the method used for

installing piles in permafrost, and test results showed behavior very similar to the behavior of piles in permafrost. Tangential adfreezing is again the mechanism that anchors or supports the pile, and the piles will creep under long-term loads (creep values must be used to determine design loading). Adfreeze strength is dependent upon temperature, backfill material, and pile material, size, and shape. The report concluded that freshwater backfill was best for wooden piles and was almost as good as the sand slurry for other piles, but was also much easier to use than sand slurry backfill. Seawater yielded significantly lower adfreeze strengths than freshwater.

Excavation

Although annual sea ice is generally rather flat (except for some pressure ridges), perennial ice is often disrupted by pressure ridges, drainage channels, and hummocks. Preparation of roads, airstrips, or campsites generally requires leveling these topographic irregularities. Conventional grading equipment is somewhat effective in this application, but the desire for greater efficiency and versatility prompted development by CEL of an icedozer attachment for tracked tractors [79]. A rotating drum was fitted with sharp-pointed circular cross-sectioned teeth, and mounted on booms in front of the tractor (much the same as a blade would be), and powered by an auxiliary engine. In field trials the icedozer was effective for pioneering or rough-grading but had limited use in fine-grading or surfacing. The machine was also a useful source for ice chips for construction (such as repairing melt holes in compacted snow roads). The icedozer cutting drum has been incorporated into a rubber-tired grading machine for grading and leveling the ice runways used for aircraft operation at McMurdo. In addition, a small rotating ice-chipping drum has been developed and is being tested as an attachment for small backhoes.

For cutting large blocks of ice a chain saw is effective. A 12-foot chain saw has been used by CEL to cut beams out of sea ice for removal and testing. However, the need for trenching in ice exists, and so at present, tests are being performed on a commercial chain-type trencher equipped with cutting teeth similar to those used in the prototype icedozer. This device should also be useful for making wide cuts in sea ice that will not freeze back as rapidly as chain-saw cuts.

Conventional augers, can be used to drill in ice although wet sea ice produces slushy cuttings difficult to convey out of the hole (similar to the problems encountered in augering snow). Core bits and tricone rotary bits can be used in ice, with water as the circulating fluid. Air, unless chilled, cannot be used for this purpose because the cuttings are partially melted and may refreeze further up the hole, making removal of the drill bit difficult.

A large diameter, carbide-tipped, ''tube core'' drill, originally used by CEL for drilling frozen basalt in Antarctica, has also been successfully used for drilling ice [69]. CRREL, in addition to deep

coring of small diameter holes in ice, has studied augers and auger bits for optimizing man-portable drills [80,81].

DISCUSSION

Although the primary purpose of this study has been to provide an overview of earth-science problems in polar engineering, it seems pertinent to mention several broad areas in which continuing research is needed:

1. As design factors become more refined, a need exists for more rapid and accurate methods for determining subsurface conditions at a site. This will involve the development of versatile and lightweight exploration equipment and new test procedures and equipment.

2. In addition to determining conditions at a given site, techniques of site selection and evaluation are required. Application of newly developing remote sensing techniques promises to be helpful.

3. Continued basic research is needed to add to the understanding of the physical properties of snow, ice, and frozen ground, and of various processes occuring in these mediums.

4. Gravel has been widely used as an insulating pad over frozen ground, but is in short supply in many regions. Substitutes for gravel or the development of construction techniques not requiring use of an insulating pad would be beneficial.

5. Most equipment currently used in the polar regions for construction or exploration is the same as that used in temperate regions. More specialized equipment, such as the vibropercussion rotary drilling rigs being used on the trans-Alaska pipeline, needs to be developed, especially keeping in mind the portability necessary in polar work. Application of new technology, such as jet cutting, should also continue to be pursued.

6. Work should be continued on the artificial improvement and utilization of sea ice to facilitate various operations in the polar seas.

7. The results of research and performance of experimental systems should be made available for optimal technology transfer among the parties concerned.

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APPENDIX 4-B

Note: Dated material, refer to paragraph "Bearing Capacity and Operation Safety," page 4-9.

Technical Note N-1431

REVISED AIRCRAFT LOAD CURVES AND VEHICLE ICE-THICKNESS TABLES FOR ANNUAL ICE SHEET OPERATIONS NEAR MCMURDO, ANTARCTICA

By

K. D. Vaudrey

April 1976

Sponsored by NAVAL SUPPORT FORCE, ANTARCTICA

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CIVIL ENGINEERING LABORATORY
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INTRODUCTION

Existing floating sea ice sheets in the polar regions have been utilized to support surface and air operations. Adequate airfields and ice roads can be economically constructed and maintained on annual sea ice; for example, the sea ice near McMurdo Station, Antarctica, has been used each season since the International Geophysical Year (IGY). However, the operating criteria must be updated as research continues to provide an increased understanding of the overall behavior of an ice sheet.

This report presents a new series of allowable load versus ice-thickness curves for both C-130 and C-141 aircraft and updated tables of minimum allowable ice thicknesses for many different vehicles operating near McMurdo Station. Both curves and tables are intended to supersede those presented in CASAINST 3710.2G, Chapter 1, Section V, currently used as operational guidance criteria [1]. The aircraft load curves and the ice-thickness tables for vehicles presented in this report have replaced empirical and plate solution techniques used previously [2,3] by employing an elastic finite element method for predicting sea-ice sheet behavior. Results and experience from an extensive experimental program are incorporated into the finite element computer code and are the basis for establishing failure criteria and setting appropriate safety factors.

MATERIAL PROPERTIES OF SEA ICE

Temperature, salinity, and age each affect the bearing strength of an ice sheet. The combined effect of these parameters generally results in anisotropic behavior vertically through an ice sheet. Fortunately, for a short-term operation between October and February on the McMurdo annual sea ice, the only variable in strength analysis is temperature. During this short period there is no appreciable change in ice properties from salinity variation and aging. Salinity profiles of the ice sheet taken during the operational period are fairly constant. The salinity profile from year to year also varies little because the sea-ice runway and ice roads generally are located on annual ice.

Therefore, only temperature-dependent material properties of sea ice have to be defined. The ice temperature near the top surface specifies the thermal gradient in an ice sheet, since the temperature at the bottom approximates the freezing point of seawater (28.8°F). This gradient can be assumed to be linear for the purpose of practical application.

Division of the ice conditions during aircraft and vehicle operations into four thermal time periods logically reflects the effect of progressive warming and internal melting on the material properties and resulting lower strength of the ice sheet. In periods one and two (Figure 1), strength deterioration results from decreasing the temperature gradient or general warming of the ice sheet. During period four, strength deterioration is due to a stagnation at an isothermal condition (near-melting temperature). Both the later phase of general ice sheet warm-up and beginning phase of internal melting are included in period 3.

Prior to analyzing the ice-sheet behavior, both the flexural strength and modulus of elasticity properties of sea ice must be determined as a function of ice temperature. The following discussion presents a brief summary of a portion of the sea-ice experimental program undertaken by the Civil Engineering Laboratory (CEL).

Flexural Strength

Both laboratory and field experiments were performed to determine the flexural strength of sea-ice beams [4,5]. All laboratory and small field beams were simply supported and had nominal dimensions of 2 x 2 x 16 inches. On the other hand, large field specimens were tested in-situ as either cantilever or simply supported beams having a cross-sectional width of 35 to 40 inches, a depth of 60 to 95 inches, and a length of 35 to 90 feet. A summary of the results, representing a complete strength-temperature history for sea-ice beams appears in Figure 2. The data span a temperature range of $-2^{o}C$ to $-28^{o}C$. Each field strength datum point is plotted at the average temperature for beams having a thermal gradient, while the average of each isothermal laboratory group is shown with 95% confidence limits on the mean.

Modulus of Elasticity

In addition to the flexural strength, the single most important material property of sea ice is the modulus of elasticity. The easiest method for finding this modulus is to measure the strain corresponding to a given stress state in a right circular cylinder subjected to either pure compression or tension. Over 300 compression specimens with a length-to-diameter ratio of 2.0 were tested in the laboratory at four different ice temperatures and for both vertical and horizontal crystal orientation. Deflection measurements were recorded by extensometers, having a gage length of 2.375 inches, bonded directly to each specimen with freshwater ice. The tests were performed on specimens cored both perpendicular to (horizontal) and parallel to (vertical) the direction of crystal growth. The results of these modulus of elasticity tests are shown in Figure 3. The values for the modulus of elasticity are not only temperature-dependent but are considerably greater for ''vertical'' sea-ice specimens than for ''horizontal'' specimens.

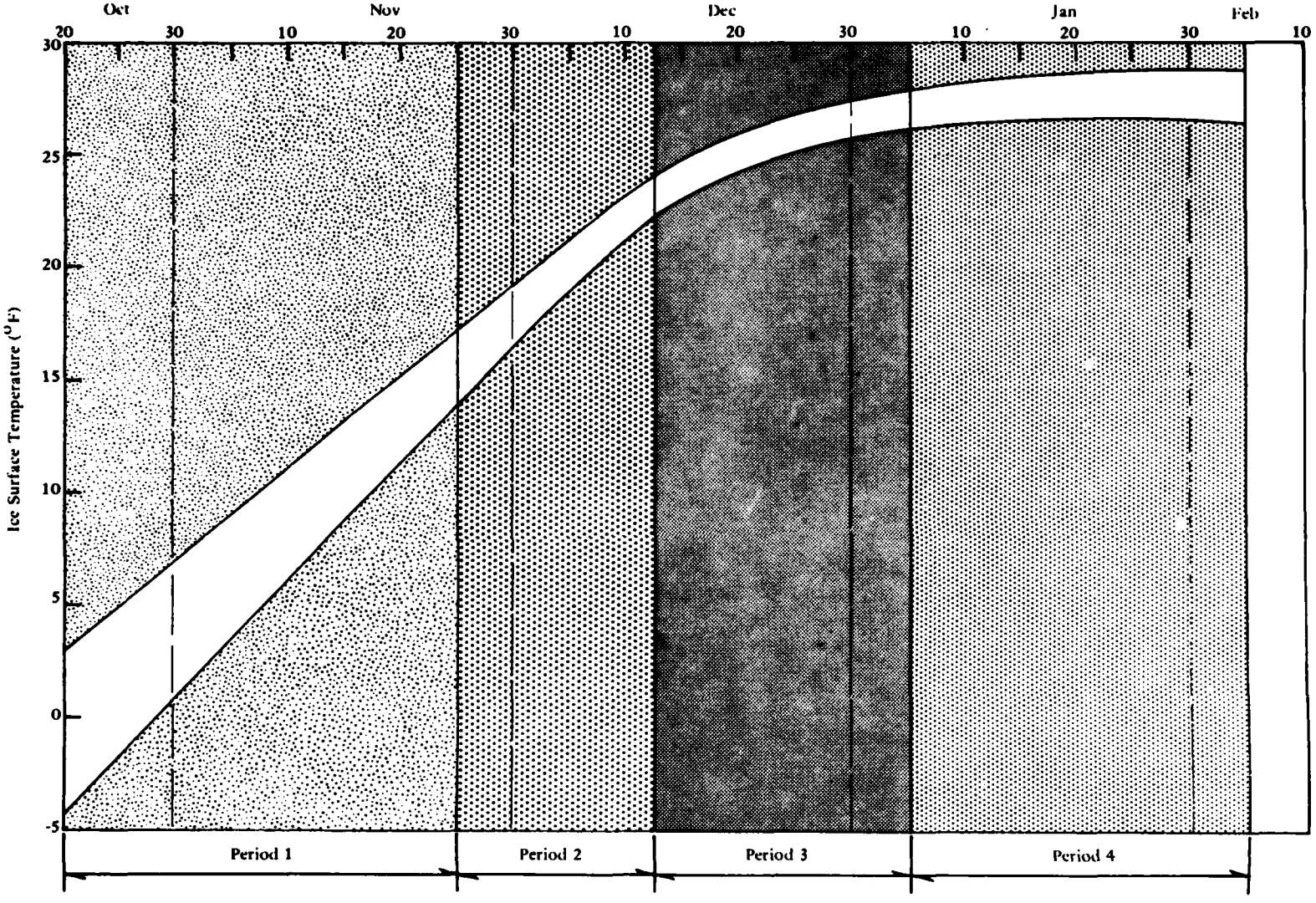

Figure 1. Near-surface temperature of McMurdo annual sea ice for normal operating season.

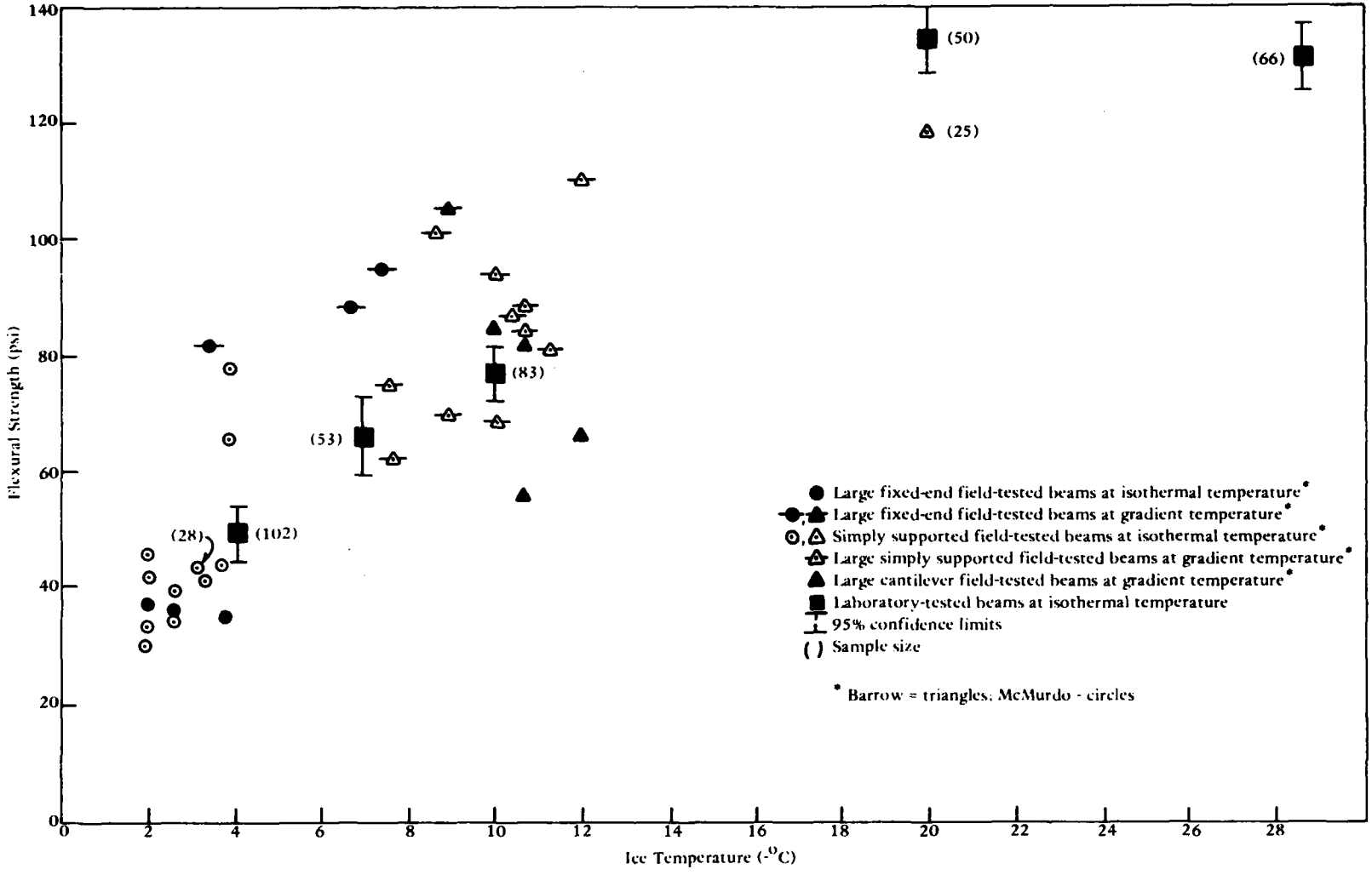

Figure 2. Flexural strength versus ice temperature

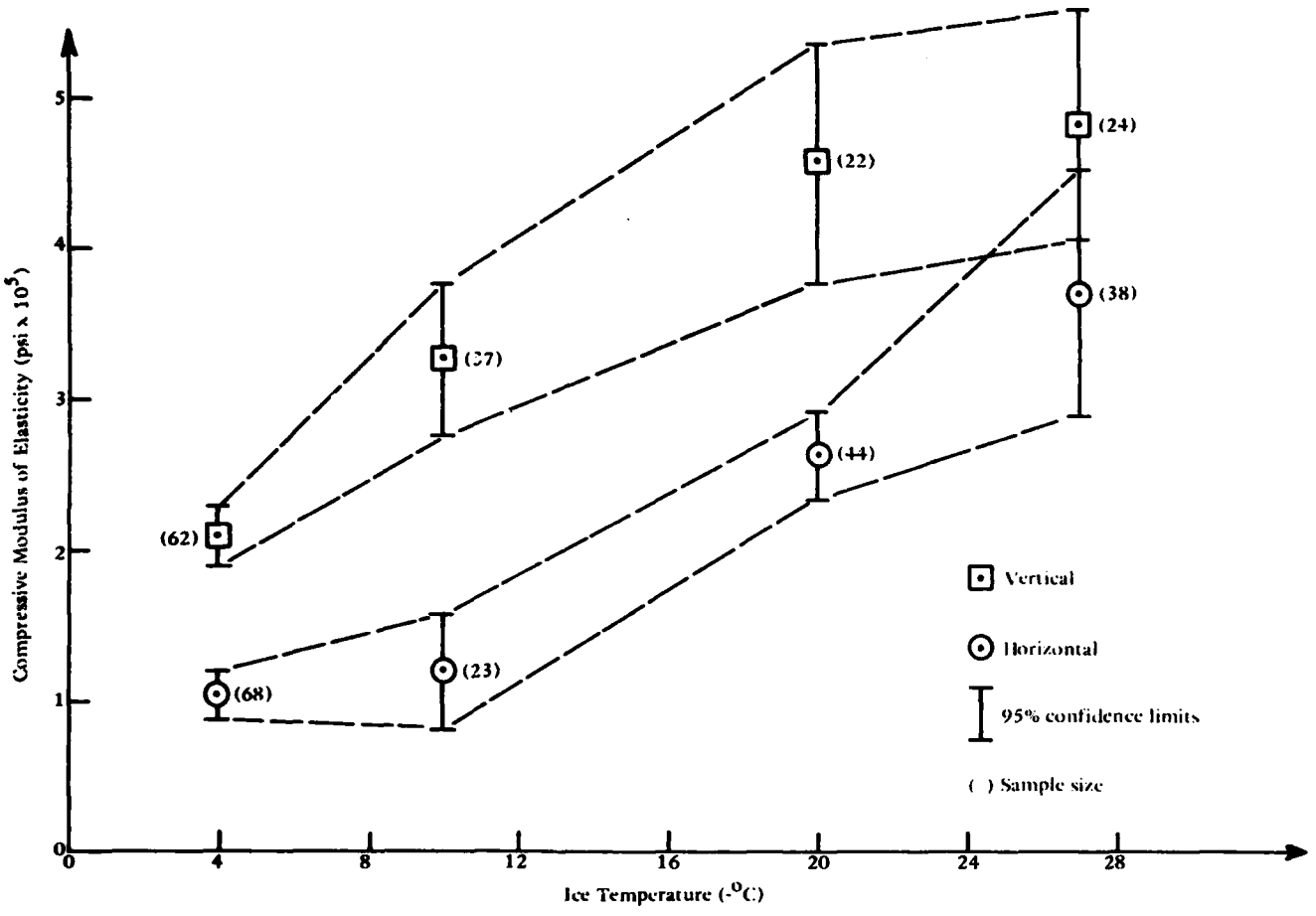

Figure 3. Compressive modulus of elasticity versus ice temperature.

Another method of determining the modulus of elasticity is to measure the strain at the location of the maximum fiber stress on sea-ice beams. These beams were the same ones tested for flexural strength. Bending deformations during laboratory tests were measured by an extensometer bonded to the underside of the beams, while in-the-field deflection was recorded by a linear voltage displacement transducer (LVDT) having a 6-inch stroke. Results from all modulus of elasticity beam testing are shown as a function of ice temperature in Figure 4.

Still another method for determining Young's modulus is a dynamic experimental method [6]. An ice specimen is vibrated by a transmitter, and either the velocity of the longitudinal waves or the fundamental transverse frequency is determined from the receiver output. The dynamic modulus of elasticity can be calculated from simple equations, if either the velocity or frequency is known. Dynamic modulus values are generally higher than those obtained by deflection measurement methods; therefore, average modulus of elasticity values for different temperature periods were selected as input to the finite element computer code.

There exists a modulus gradient across the ice sheet corresponding to the temperature gradient for each season. These modulus gradients, as well as their corresponding flexural strength values, are given in Table 1 for each seasonal period defined in Figure 1. These modulus gradient values can be assumed to vary linearly as a function of ice sheet thickness for practical application, with larger values corresponding to the top of the ice sheet. There is an apparent discrepancy between the moduli values shown in Table 1 and those plotted as a function of ice temperature in Figures 3 and 4. However, it must be remembered that Table 1 values represent averages obtained from both dynamic and deflection methods while Figures 3 and 4 depict results from two different deflection methods only. In addition to the flexural strength and modulus of elasticity properties listed in Table 1, Poisson's ratio (the ratio of transverse to longitudinal strain) is needed for determining the bearing capacity of an ice sheet. A constant value for Poisson's ratio of 0.33 was assigned on the basis of reported experiments indicating a range from 0.30 to 0.35.

Table 1. Material Properties of Sea-Ice

Seasonal Period	Ice Surface Temperature (^{o}F)	Modulus of Elasticity Gradient$_5$ (psi x 10^5)	Flexural Strength (psi)
1	-4 to 14	7.0 to 2.9	70.0
2	14 to 23	6.0 to 2.9	62.0
3	23 to 27	4.0 to 2.9	58.0
4	27 to 28.5	2.9*	40.0

* Isothermal condition.

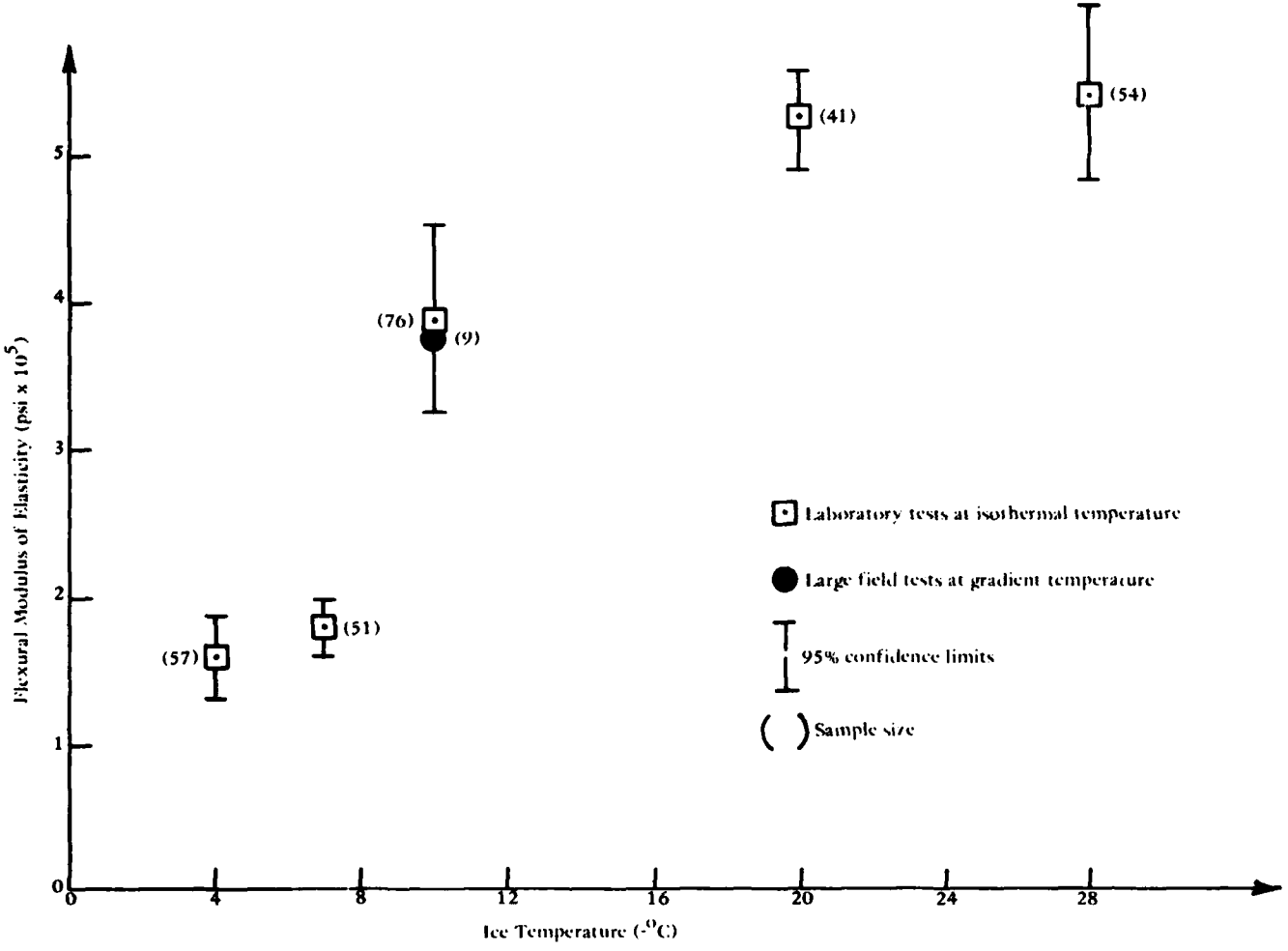

Figure 4. Flexural modulus of elasticity versus ice temperature.

ANALYTICAL METHOD

The main portion of the general axisymmetrical finite element computer code employed in this investigation was written by Wilson [7]. The formulation is based on the direct stiffness method with triangular or quadrilateral conical elements representing the axisymmetrical ice sheet. Generally, the ice sheet may have a complex configuration and can be considered as a layered medium. The constitutive relationships can be orthotropic, nonlinear, and temperature-dependent. External loading can be either structural or thermal in nature with an option to consider gravitational forces. In addition, subroutines are incorporated into the main computer deck to simulate a fluid foundation and to superimpose stresses from any combination of wheel or track configurations.

Fluid Foundation

Development of the simulated fluid foundation is achieved by calculating a vertical resistance proportional to the displaced volume and adding it to the global stiffness matrix of the solid for every node on the solid-fluid interface. In formulating the vertical resistance, compatibility of displacements requires off-diagonal terms as well as diagonal terms; all of these terms are determined by energy principles consistent with the finite element formulation.

Superposition

The superposition development determines the combined state of stress in an ice sheet resulting from an arbitrary configuration of circular loads. The principle of superposition has inherent limitations; first, the stress-strain relationships must be linear, and second, the ice sheet must be free of variations of material property and layer geometry with respect to any horizontal plane. Fortunately, typical ice sheets are composed of horizontal layers that have material property variations and temperature changes solely in the vertical direction. Moreover, the infinite extent of the ice sheet nullifies the effect of boundaries, confounding the superposition principle; hence, the only significant limitation is the restriction to linear stress-strain laws.

The process of determining the superimposed stress state begins by choosing a point in the ice sheet where the combined state of stress is to be calculated. Usually this point is located beneath a critical wheel or track on aircraft or vehicles. The chosen point is declared to be at the bottom of the ice sheet beneath the origin of an x-y rectangular coordinate system. Then, for each additional load from i^{th} other wheel or track circles, the load center is assigned the coordinates (x_i, y_i), and the local state of stress at (x_i, y_i) is transformed into an incremental stress contribution at the origin by using polar coordinates. This process is repeated until the stress contributions for each load are summed at the designated origin to yield the complete combined stress state. Finally, the principal stresses are calculated from this combined stress state.

Representation of an Infinite Boundary

For many applications an infinite expanse of ice is characteristic of the problem to be solved. In such cases defining an infinite expanse by an axisymmetrical solid of finite extent is justifiable only if the boundary radius is chosen large enough so that changes in the boundary condition do not appreciably alter the structural response. Preliminary investigations show that the structural response of typical ice sheets tends toward plate-theory behavior in the outer region, beginning several loading radii away from the load center. Consequently, the minimum boundary radius required may be determined in terms of the radius of relative stiffness, ℓ,

$$\ell = \sqrt[4]{\frac{E\,h^3}{12(1 - \upsilon^2)\gamma}} \qquad (1)$$

where E = Young's modulus
h = ice sheet thickness
υ = Poisson's ratio
γ = seawater density

In general, a boundary radius of 10ℓ with a fixed boundary condition will adequately represent an infinite ice sheet.

Input Parameters

The input requirements can be divided into two basic categories: (1) ice-sheet material properties, and (2) aircraft or vehicle loading conditions. In the first category the temperature is given for both the top and the bottom of the ice sheet, along with a corresponding modulus of elasticity and Poisson's ratio for each temperature. Also, the thickness must be estimated, as well as the density of the fluid foundation (in this case, seawater). For category 2 the number of circular loadings (e.g., wheels or tracks) and total load (weight of aircraft or vehicle) are required, along with such individual wheel or track circle characteristics as: (1) radius and pressure of load; (2) x-y coordinates (to locate each loading); and (3) fraction of total weight carried by an individual loading. An idealized ice sheet subjected to a circular load during seasonal period one is shown in Figure 5 where many of the input parameters are identified.

ICE-THICKNESS CURVES AND TABLES

After experiments to determine sea-ice material properties have been performed and a finite element model to predict sea-ice behavior has been developed, it is possible to calculate required ice thicknesses for aircraft and vehicular operations.

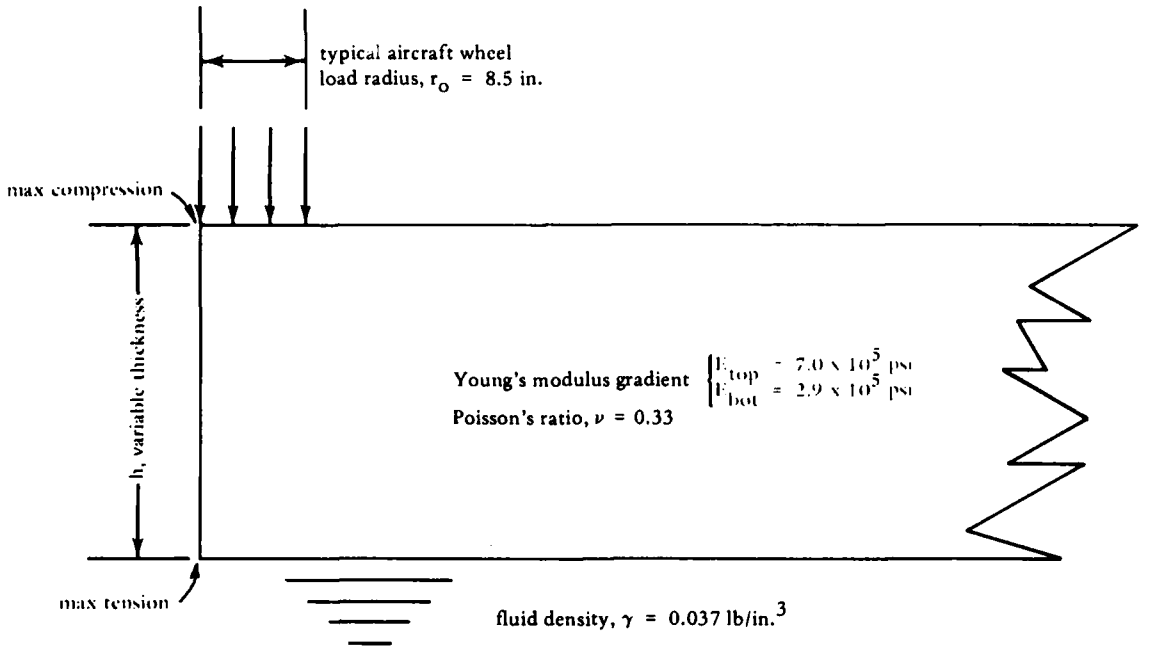

Figure 5. Idealized sea-ice sheet for seasonal period 1.

Updated aircraft load versus ice-thickness curves are presented in Figure 6. Previous curves from Reference 3 were calculated using classical plate theory and assuming no ice sheet temperature gradient. In Figure 6 curves for both C-130 and C-141 aircraft are shown for all four seasonal periods defined in Figure 1. Calculating these curves requires exercising the computer code in two series of repeated steps. Initially, the input parameters for a single seasonal period are selected from Table 1, and several ice-sheet thicknesses are assumed for this period. By performing computer iterations, tensile stresses are found at the bottom of the ice sheet for each specified thickness. This process formulates an aircraft load curve for a given seasonal period, and the entire cycle is repeated for the remaining periods. Period one curves for both aircraft are calculated from an allowable stress that is found by reducing the period one flexural strength by 30%, an effective safety factor of 1.20. All other curves reflect a reduction of 25% in their respective ultimate strengths, representing a safety factor of 1.15. Therefore, the allowable stress for period one is 70% of its ultimate flexural strength, while the allowable stresses for the other three periods become 75% of their respective ultimates.

Minimum ice-sheet thicknesses for vehicles and equipment combinations are given in Tables 2 and 3. Again, the iterative process is repeated for each seasonal period. However, for relatively constant loads (e.g., vehicles) the iterations converge to a single, tabular point rather than a curve

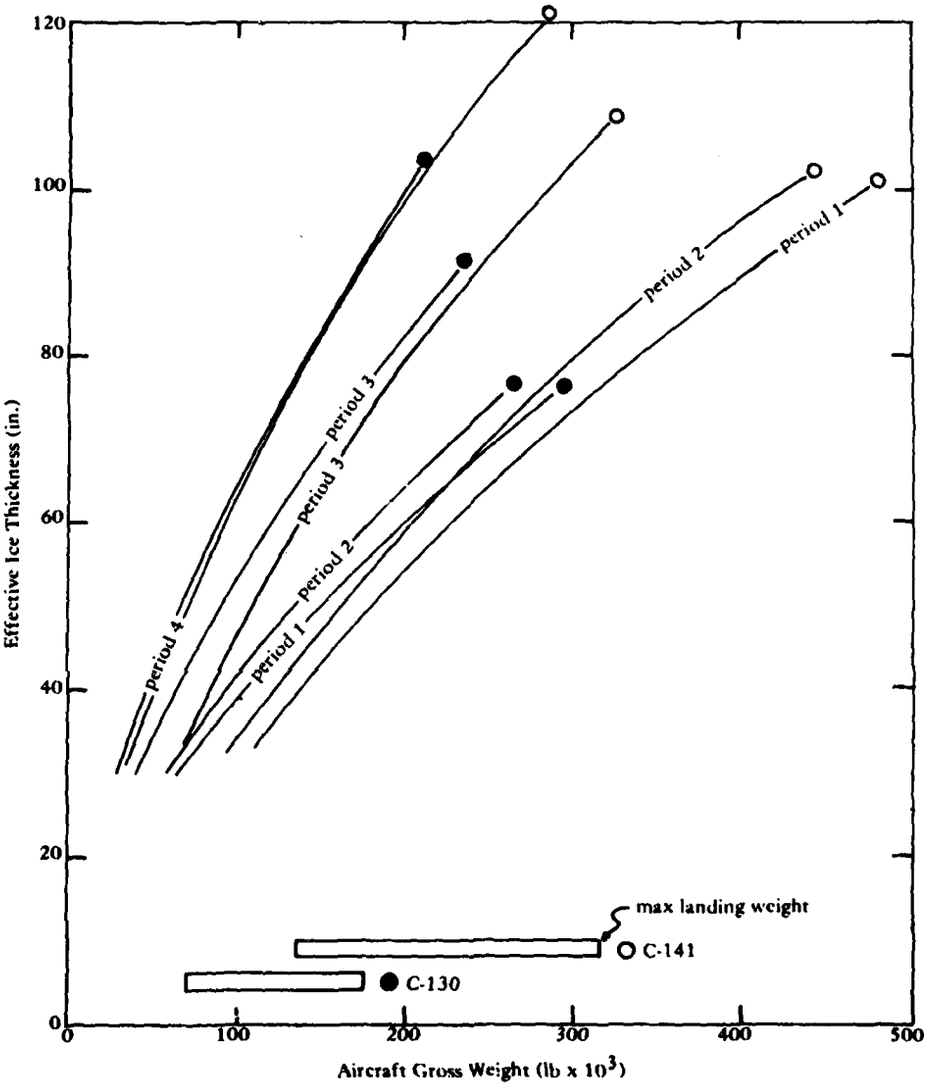

Figure 6. Load curves for both C-130 and C-141 aircraft over four seasonal periods.

in the case of aircraft, which have a wide range of load capacity. All vehicles and equipment combinations are grouped by function categories, and vehicle weights used for thickness calculations are given. Allowable stresses represent a sufficient reduction in failure strength to produce a safety factor of 1.50. These tables are meant to replace those in Reference 1 for tracked vehicles, sleds, and tractor-sled combinations.

OPERATIONAL FIELD PROCEDURE

Field procedure for aircraft and vehicle operation on the annual sea-ice sheet near McMurdo Station should include: (1) ice-thickness surveys; (2) ice-temperature stations; and (3) ice runway and road inspection and precautions.

Ice-Thickness Survey

The maintenance of complete, up-to-date ice-thickness surveys for all ice-sheet operating areas is necessary for safety.

1. At the start of the operating season (usually October), a detailed thickness survey should be made down each edge of the sea-ice runway, alongside the ice road, and around all other operating areas. Thickness stations on the runways should be at 1,000-foot intervals, with opposite stations staggered at midinterval.

2. During October and November, thickness measurements should be made at every station at 14-day intervals to provide thickness information. Field conditions may indicate a need for more frequency measurements.

3. Starting in December, the time interval between measurements should be decreased to 7 days, and by early January, daily measurements may be required if the ice conditions and aircraft operations warrant such surveillance.

4. Any soft, mush-ice skeletal layer at the bottom of the sheet should be subtracted from the measured thickness to obtain the effective thickness of the ice for the curves or tables. The thickness of this layer will vary considerably through the season. Until late December, this layer is normally new ice growth that has not completed solidification. By early January, the new growth should have disappeared; it may be replaced by a soft layer resulting from bottom deterioration. Because of this layer, the effective thickness of the ice is usually 2 to 6 inches less than the actual thickness. The thickness of the skeletal layer can only be determined by extracting cores from the ice with a 3-inch-diameter coring auger.

Table 2. Minimum Allowable Ice Thicknesses for Vehicles

Vehicle	Minimum Allowable Ice Thickness (in.)			
	Period 1[a]	Period 2[b]	Period 3[c]	Period 4[d]
Small cargo/personnel (wheeled)				
1. Pickup, 1T-Dodge W300 (GVW = 9,000 lb)	11	13	17	21
2. Jeep, Kaiser 1414 (4,000 lb)	10	11	14	17
3. Truck, ambulance-Kaiser M725 (8,400 lb)	14	16	20	24
4. Bus, 4 x 4 – Fabco (15,260 lb)	15	18	23	29
5. Cargo/personnel-Nodwell 45TT (15,000 lb)	16	18	23	28
6. Crash/rescue-Nodwell 100TT (25,000 lb)	21	24	30	36
Small cargo/personnel (tracked)				
1. Personnel carrier-Nodwell RN110 (GVW = 27,500 lb)	17	21	28	34
2. Personnel carrier-Nodwell RN110 (50% load – 21,500 lb)	15	18	24	30
3. Personnel carrier-Trackmaster 601 (7,540 lb)	10	12	16	20
Truck, tractor				
1. Tractor, 10T-MIL M123A1C (28,100 lb)	24	27	34	41
2. Tractor, 10T-Fabco CT850 (15,200 lb)	16	18	23	28
3. Tractor, 5T-M52A2 (18,700 lb)	17	20	25	31
Crawler tractor				
1. Caterpillar D-4 STD (17,250 lb)	20	24	31	38
2. Caterpillar D-4 LGP (27,160 lb)	26	30	38	46
3. Caterpillar D-8 STD (67,600 lb)	43	48	60	71
4. Caterpillar D-8 LGP (85,000 lb)	44	48	59	71

continued

Table 2. Continued

Vehicle	Minimum Allowable Ice Thickness (in.)			
	Period 1[a]	Period 2[b]	Period 3[c]	Period 4[d]
Load-handling equipment				
1. Caterpillar 950 (24,900 lb)	24	28	35	42
2. Caterpillar 966C (34,240 lb)	25	30	37	45
3. Caterpillar 955 STD (30,200 lb)	29	33	42	50
4. Caterpillar 955 LGP (33,500 lb)	23	26	33	41
Snow-removal equipment				
1. Snowblast R2200A (36,000 lb)	27	31	39	47
2. Cat 966 with snowblower attachment (43,470 lb)	31	35	44	52
3. Cat 950 with snowblower attachment (34,320 lb)	33	36	46	54
4. Road grader - Cat 12F (28,310 lb)	26	29	37	44
Special equipment				
1. Truck, wrecker – Fabco F800 (16,000 lb)	14	16	21	26
2. Crane, wheeled-Pettibone 70 (70,730 lb)	40	45	57	69
3. Drill, Trlr-Mtd-Mobile (14,800 lb)	17	19	25	30
Trailers				
1. Trailer, semi-12T Fruehauf (GVW = 25,500 lb)	26	30	37	45
2. Trailer, semi-20T Fabco (GVW = 29,770 lb)	27	31	39	47
3. Trailer, lowboy - 60T Military (GVW = 90,650 lb)	50	57	69	83
Sleds				
1. Sled, 10-ton-Otago (GVW = 29,000 lb)	19	22	29	35
2. Sled, 20-ton-Otago (GVW = 60,000 lb)	30	34	42	50

[a] Before October to late November.
[b] Late November to mid-December.
[c] Mid-December to early January.
[d] Early January to February.

Table 3. Minimum Allowable Ice Thicknesses for Equipment Combinations

Equipment Combinations	Minimum Allowable Ice Thickness (in.)			
	Period 1[a]	Period 2[b]	Period 3[c]	Period 4[d]
Tractor-trailer				
1. 5T tractor (military) + 12T trailer (Fruehauf) (GVW = 56,000 lb)	27	31	39	43
2. 5T tractor (military) + 12T trailer (Fruehauf) (50% load = 44,000 lb)	23	26	34	41
3. 10T tractor (Fabco) + 20T trailer (Fabco) (GVW = 65,000 lb)	29	33	42	51
4. 10T tractor (Fabco) + 20T trailer (Fabco) (50% load = 45,000 lb)	23	27	34	41
5. 5T tractor (military) + 20T trailer (Fabco) (GVW = 69,000 lb)	29	33	42	52
6. 5T tractor (military) + 20T trailer (Fabco) (50% load = 49,000 lb)	24	27	35	43
7. 10T tractor (military) + 60T lowboy (military) (GVW = 180,000 lb)	52	58	74	88
8. 10T tractor (military) + 60T lowboy (military) (50% load = 120,000 lb)	41	46	58	70
Towed drill rig				
1. Caterpillar D-4 STD + Mobile drill B40L12 (32,000 lb)	21	25	31	36
2. Nodwell RN 110 + Mobile drill B40L12 (GVW = 42,300 lb)	21	24	32	38
Tracked vehicle -- sled				
1. Caterpillar D-4 STD + 10T sled (GVW = 46,200 lb)	20	23	30	37
2. Caterpillar D-8 LGP + 20T sled (GVW = 145,000 lb)	45	51	61	72
3. Caterpillar D-8 LGP + two -- 20T sleds (GVW = 205,000 lb)	56	62	74	88
4. Caterpillar D-8 LGP + three -- 10T sleds (GVW = 172,000 lb)	49	55	66	78

[a] Before October to late November.
[b] Late November to Mid-December.
[c] Mid-December to early January.
[d] Early January to February.

Ice-Temperature Stations

The maintenance of a complete up-to-date temperature record of the ice sheet is necessary for a verification that the proper seasonal period is being used.

1. For ice-sheet thicknesses greater than 24 inches permanent stations to measure ice temperatures with thermocouples or thermistors should be established at five or more locations dispersed for general coverage of the entire operational area. Each permanent station should consist of two separate probes, one located 6 inches below the surface and the other, as a backup, 4 inches below the surface. At these depths daily fluctuating air temperatures should have little effect on obtaining consistent ice temperature data. These temperatures are compared with those given for the seasonal periods listed in Table 1. Temperature stations should be monitored two or three times a week during the operating season and preferably at the same time during the day.

2. For ice-sheet thicknesses less than 24 inches permanent stations need not be installed. No doubt such an ice thickness would represent an early season operational condition; therefore, governing tables for vehicular traffic probably would fall under period one. However, prior to operating on an ice sheet less than 2 feet thick, it is recommended that one take accurate thickness measurements as well as ice temperatures by inserting an accurate dial or mercury-bulb thermometer into the ice in a two- to three-inch drilled hole fitting thermometer stem. Snow or chipped ice should be packed around the thermometer to reduce air effects on ice temperatures. Measurements should be made as directed in the previous paragraph.

Ice Runway and Road Inspection

It is recommended that the ice runway and all roads be routinely inspected. If only the minimum ice thicknesses given in the curves and tables are measured, then the runway should be checked after every takeoff and landing, while the roads should receive daily reconnaissance. A log should be maintained of any cracks that occur and their condition, wet or dry. Development and spreading of cracks indicate the operations area has a near-capacity load, and further use should be suspended or continued only on an emergency basis at significantly reduced loads.

Ice creeps under sustained load; therefore, progressive deformation of the ice sheet can be expected beneath parked aircraft and vehicles, snow berms, and stored cargo. The limit of permissible deformation has not been defined as yet; however, it is recommended that any parked aircraft or vehicle be moved when the deflection has reached 8 to 10 percent of the ice sheet thickness. This limiting deflection represents the freeboard of an ice sheet, and flooding could occur if this value were exceeded. Any surface flooding over a loaded region could make

working difficult or impossible and workers unwilling to remain in the area. A level or transit should be available at all times to measure the deflection at the aircraft when questionable conditions are evident. To determine this deflection, the instrument should be located at least 300 feet from the aircraft, and measurements near the main wheel of the aircraft should be compared with those 600 feet from the aircraft.

When minimum ice thicknesses are encountered, no aircraft, whether landing, taxiing, taking off, or parked, should be closer than 500 feet from the edge of the ice sheet. No vehicle or equipment combination should be driven nearer than 300 feet from the edge of the ice sheet. Distances greater than these limits are preferred, if possible.

SUMMARY

This study represents an application of existing analytical techniques using current knowledge of sea-ice properties to redefine aircraft and vehicle operational criteria on the annual ice sheet at McMurdo Station, Antarctica. Mathematically modeling the ice sheet has been accomplished by a finite element computer code. The ice sheet was considered to be an axisymmetrical, elastic solid supported by a fluid foundation. The computer code has the capability of accounting for the ice-sheet temperature gradient, while calculating critical stresses for different multiple-load configurations. Since ice-sheet bearing strength is temperature-dependent, four seasonal periods, based on different ice-sheet temperature gradients, are defined by appropriate sea-ice material properties.

To calculate required ice thicknesses for aircraft and vehicle operations, stresses are determined for each wheel or load pattern, having assumed an ice-sheet thickness and temperature gradient. This process is repeated for other ice thicknesses; comparisons are made with allowable stresses, thus determining minimum required ice thicknesses. These minimum values generate curves for aircraft and single entries in the tables for vehicles and equipment combinations. The computation process is repeated again for each seasonal period.

Once the ice-thickness curves and tables are determined, proper field procedure is still necessary to operate safely on the ice sheet. Of course, both ice thicknesses and temperatures should be monitored; however, routine inspection of the ice-sheet surface should be made for the existence of cracks. These cracks should be recorded for length and location, and whether they are refrozen or ''working.''

Thus far, the analysis has been limited to elastic ice-sheet response; however, it is known that ice creeps under sustained loads. Although experimentation is currently underway to determine the viscoelastic response of sea ice, maximum allowable deformations have not been defined as yet. Therefore, it is imperative that long-term loads be monitored for excessive ice-sheet deflection.

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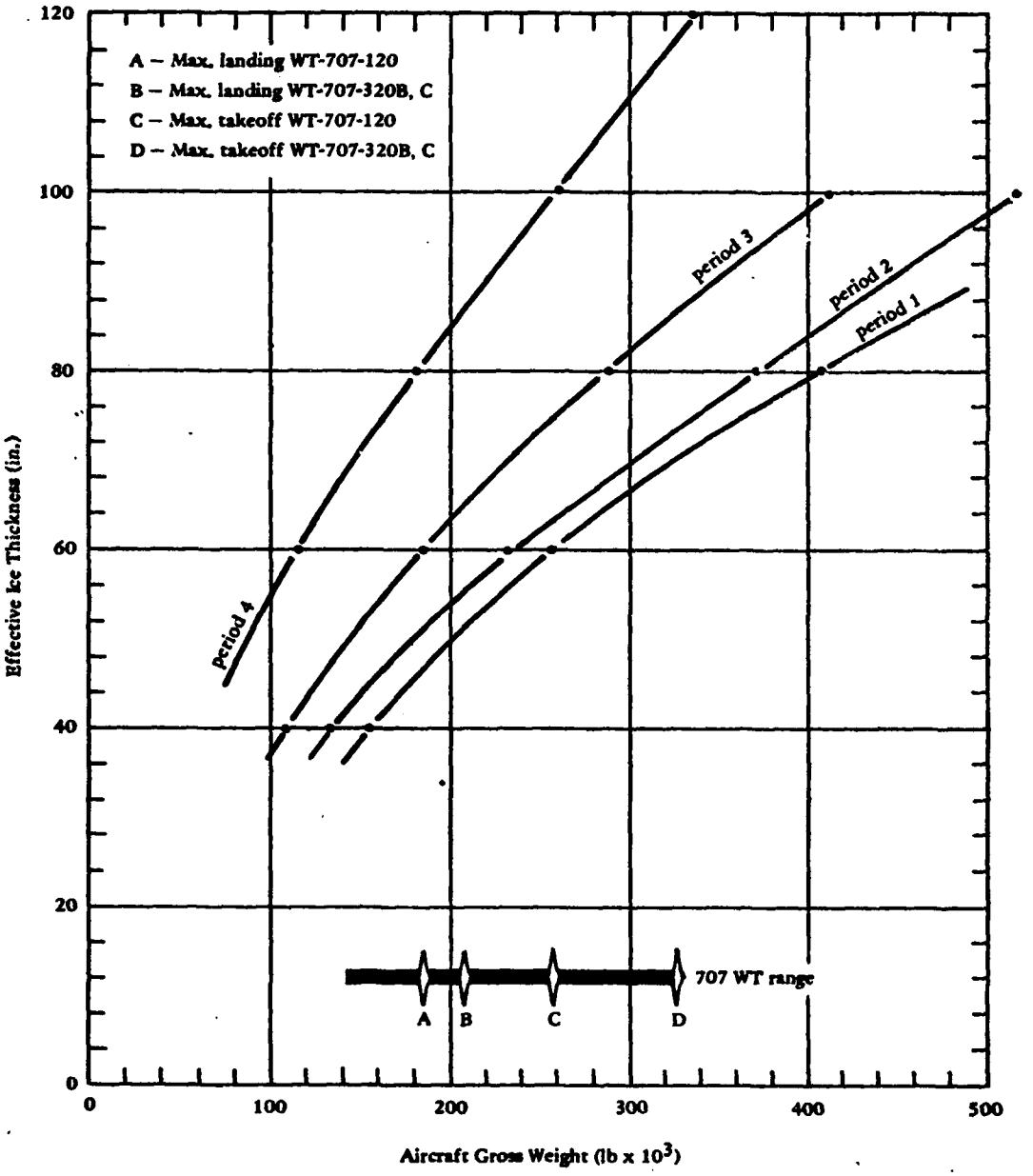

Load curve for both 707-120 and 707-320B, C Boeing aircraft over four seasonal periods. (Curves are based on ice temperatures, ice properties, and safety factors defined in Ref: CEL Technical Note, N-1431, Apr 1976.

CEL
Nov 1979

Chapter 5

BUILDING DESIGN AND MAINTENANCE

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Chapter 5

BUILDING DESIGN AND MAINTENANCE

INTRODUCTION

An extensive facilities redevelopment program began at McMurdo Station when it was determined that the antarctic science program would be continued beyond the International Geophysical Year. A major portion of the redevelopment was the replacement of the temporary Quonset and Jamesway huts and some T5 panelized buildings with permanent, more spacious structures. In addition, ventilation and heating systems were designed to improve personnel comfort.

BUILDINGS

One basic building system was selected for use in all the major structures including warehouses, shops, and living quarters. The building system chosen is the steel frame, panelized building produced by the H. H. Robertson Co., Pittsburgh, Penn. Four types of exterior panel are made by the company. The panel used at McMurdo Station is the H-Type Q-Panel which is insulated with 3 inches of fiberglas and contains no metal fasteners extending through the panel. A coated-steel vapor-barrier on the interior side prevents moisture penetration. The manufacturer states that at -50°F outside and 70°F inside, condensation should not form even with a relative humidity of 80%. Figure 5-1 shows the building panel in cross-section.

Only two replacement buildings at McMurdo are not of this type. Those are the public works garage and steel shop (building 143) and the USARP administration building (building 167). The public works garage erected in about DF-65 is a prefabricated aircraft hangar modified by shortening the sidewalls and changing the door arrangements. The USARP administration building is a prefabricated wood structure selected primarily for its more pleasing architectural style.

All of these new buildings were designed and fabricated for erection on a level building site. Also, all are elevated 4-feet or more above the ground surface with the exception of the public works garage which is at ground level.

FOUNDATIONS

The sloping terrain on which McMurdo is built generally requires quite extensive preparation of the building site. Because of the hazard of blasting the permafrost in the vicinity of existing buildings, sites for new buildings are generally prepared by placing compacted earthfill obtained elsewhere, rather than the common cut and fill methods found in more temperate climates. Consideration has also been given to use of poured concrete foundations.

Earth Fill

Unfrozen, unconsolidated fill material is rare around McMurdo Station and is usually scraped from the surrounding hillsides as it thaws. After the first few inches of unfrozen hillside material is removed, it is necessary to

wait a few weeks until a few more inches thaws before more fill can be obtained. This method is slow and inefficient and could be avoided by quarrying from a single source such as the Fortress Rocks Quarry described in Chapter 1. The fill material at McMurdo consists of hard, angular, unweathered rock particles ranging from boulder to silt sizes with the percent of various particle sizes depending upon location and bedrock geology. Usually material passing the 1/2-inch screen predominates. Sieve analysis of six typical fill samples has indicated that 15% to 20% of the soil passes the #80 screen. This indicates susceptibility to frost action providing abundant water is available to the soil and that several freeze-thaw cycles occur each season. Moisture content determinations of the same samples show a low of 2.0% and a high of 21.0% by dry weight with most samples falling within the 4%-to-8% range. Moisture content can vary widely depending upon local drainage conditions and the time of year the fill is utilized.

The compactability of this fill material is very good unless excess boulders exist. If the moisture content is below 8% or 10%, water should be added if possible. The angle of repose is 35 to 45 degrees and any fill thicker than 2 or 3 feet becomes frozen solid after the first winter and is quite strong especially if the moisture content is over 20%.

Concrete

Until DF-68 the use of Portland cement at McMurdo Station was considered unfeasible and impractical because of an apparent lack of suitable locally available aggregates, and construction contingencies associated with cold-weather concreting operations. In that year, NCEL conducted studies [1, 2] to determine if concrete of sufficient compressive strength (3,000 psi) could be produced from locally available aggregate and to develop mixing, placing, and curing methods for use at below-freezing temperatures. Test results were favorable and a "Field Guide for Portland Cement Concrete Construction in Antarctica" was prepared, a copy of which can be found on page 5-7.

Drainage

In laying out and grading the ground areas around buildings, care should be taken to prevent the collection and ponding of melt water around building footings and foundations. The presence of surface water increases the heat flow to the ground and promotes thawing to greater depths. If subsurface ice lenses are present, foundation settlement can occur. Also, the freezing of surface water around footings can cause uplifting or shifting of the foundation due to expansion as the ice forms.

Skirting of Crawl Spaces

With one exception, the permanent buildings at McMurdo Station are elevated 4 feet or more above the ground surface to prevent the heat that is lost through the building floor from thawing the permafrost beneath and causing possible settlement. It is generally considered important to allow free air circulation beneath the building so that accumulation of heated air does not, in turn, thaw the ground. At McMurdo Station this underbuilding crawl space often fills in with drifted snow to varying extents which makes

access to utility pipes difficult. As a result, a study was made to determine if ground thawing has occurred beneath the dispensary (building 142) which was skirted to enclose the crawl space at the time of construction. Also, existing ground temperatures were measured beneath the personnel building (building 155) and projections made to determine if skirting of this building would be detrimental. Although somewhat imcomplete the study showed that the ground surface temperature beneath the skirted dispensary remained below freezing throughout the summer season and no problems have resulted [3]. Ground temperatures above freezing were observed to a depth of 3 feet beneath the yet unskirted personnel building but no settlement was found, which is attributed to the dry snow-and-ice-free earth fill pad on which the building is built. In conclusion, the study found that any building at McMurdo Station completed to that date (DF-71) can be skirted to enclose the crawl space if the building is constructed on a well compacted snow-and-ice-free earth fill pad.

HEATING AND VENTILATION SYSTEMS

The heating and ventilation systems in the buildings at McMurdo Station are of several types depending on the age and function of the buildings. The smaller buildings which were part of the original station are heated by forced-air electrical wall heaters or by oil-fired forced-air furnaces. In several buildings, both systems are provided with the oil furnace serving as a standby. Generally no provision is made for introducing fresh air but vitiated air is often exhausted through wall-mounted exhaust fans. These systems are fairly satisfactory because of the small size of the buildings.

The permanent warehouses and unpartitioned shops also utilize forced-air heating without ventilation systems. The permanent buildings which are partitioned into small office and quarters spaces are provided with forced-circulation hot-water heating with one or more finned-tube baseboard convectors in each room. All of the hot water systems use a 56% ethylene glycol solution as the hydronic fluid so freezing will not occur if a system is shut down for an extended period.

Balancing of Heating System

When first completed, occupants of the new buildings had numerous complaints of too little or too much heat. In DF-71, a civilian consultant was hired to balance the hydronic system completed to that time. Balancing of a system consists of adjusting flow control valves, blower speeds, air dampers, etc., so that the quantity of air or hot water flowing in each branch circuit is as specified by the designer on the design drawings. Once a system is balanced, there should be no indiscriminate changing of equipment settings. This is particularly true of the system in the personnel building (building 155) which is more complex than most Navy utilitymen are trained to operate.

Temperature Control

In some of the heating systems at McMurdo Station, the correct method of adjusting room temperatures is not immediately obvious to the building occupants. For example, the USARP quarters,

building 166, is a two-zone forced-circulation hydronic system with each zone corresponding roughly to one floor of the two-story building. The temperature of the glycol circulated through the convectors in each zone is controlled by a wall thermostat in the hallways. Temperature control in the rooms is accomplished with hand valves within the cabinet of the wall-mounted convectors. Experience has shown that occupants of this building are often not aware of the control valves within their rooms but depended on the hall thermostat for room temperature adjustment.

Changes in setting of this thermostat affected every room within that zone to the discomfort of others. To correct the problem, instructions should be posted directing attention to the controls within the room and the true function of the hall thermostat. Also for more suitable operation, the hall thermostats should have been the tamper-proof type accessible only to maintenance personnel for seasonal adjustment. Similar procedures should be followed in other office and quarters buildings.

Humidification

When cold outside air is admitted to a building and heated to a comfortable temperature the total moisture content of that air is very low which is referred to as low humidity. The physical effects of this are the drying of building contents, the buildup of charges of static electricity and a drying of the respiratory tract of human occupants. On continued exposure humans adjust to this condition to some extent and initial discomforts of dryness become more acceptable. Other problems, however, continue to exist. Some of the quarters and office buildings at McMurdo are equipped with mechanical humidifiers which are moderately effective in increasing the humidity level. For practical considerations, the relative humidity should not be maintained above about 30%. As may be seen in the psychometric chart in Figure 5-2, condensation in a 70°F room at this humidity will occur on surfaces at 37°F and colder. If the humidity is increased to 50%, the dew-point temperature at which condensation will occur becomes 51°F. Temperatures in this range often occur behind furniture placed against outside walls, under rugs, and around window and door openings. This is damaging to the building in addition to making housekeeping difficult.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

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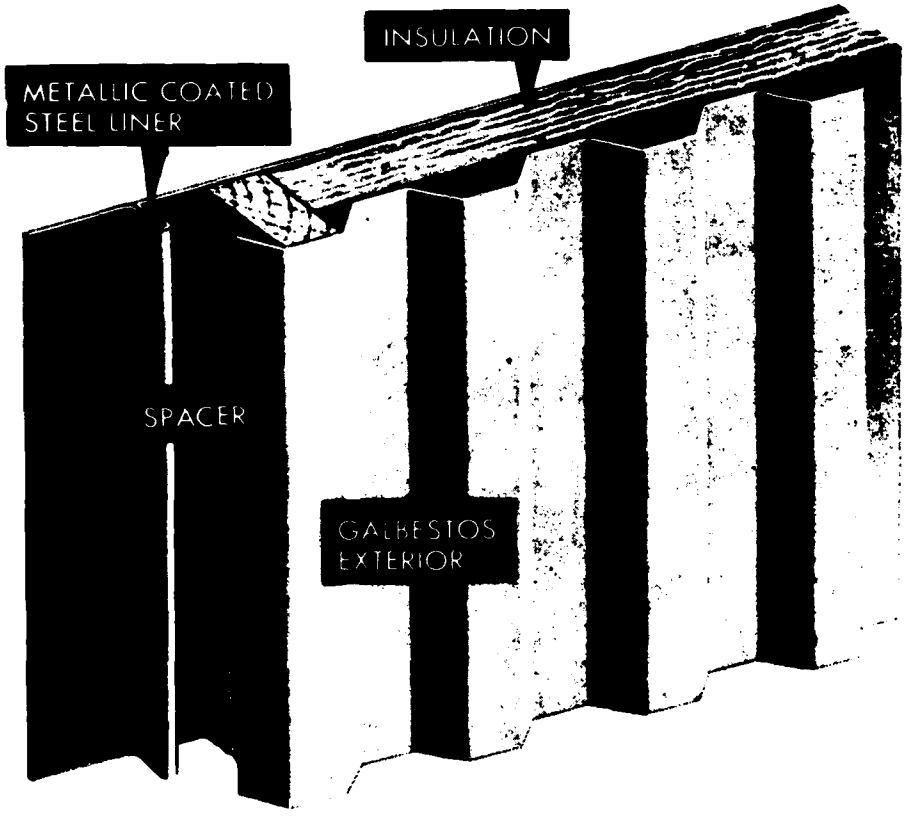


Figure 5-1. Typical building panel in permanent structures at McMurdo Station.

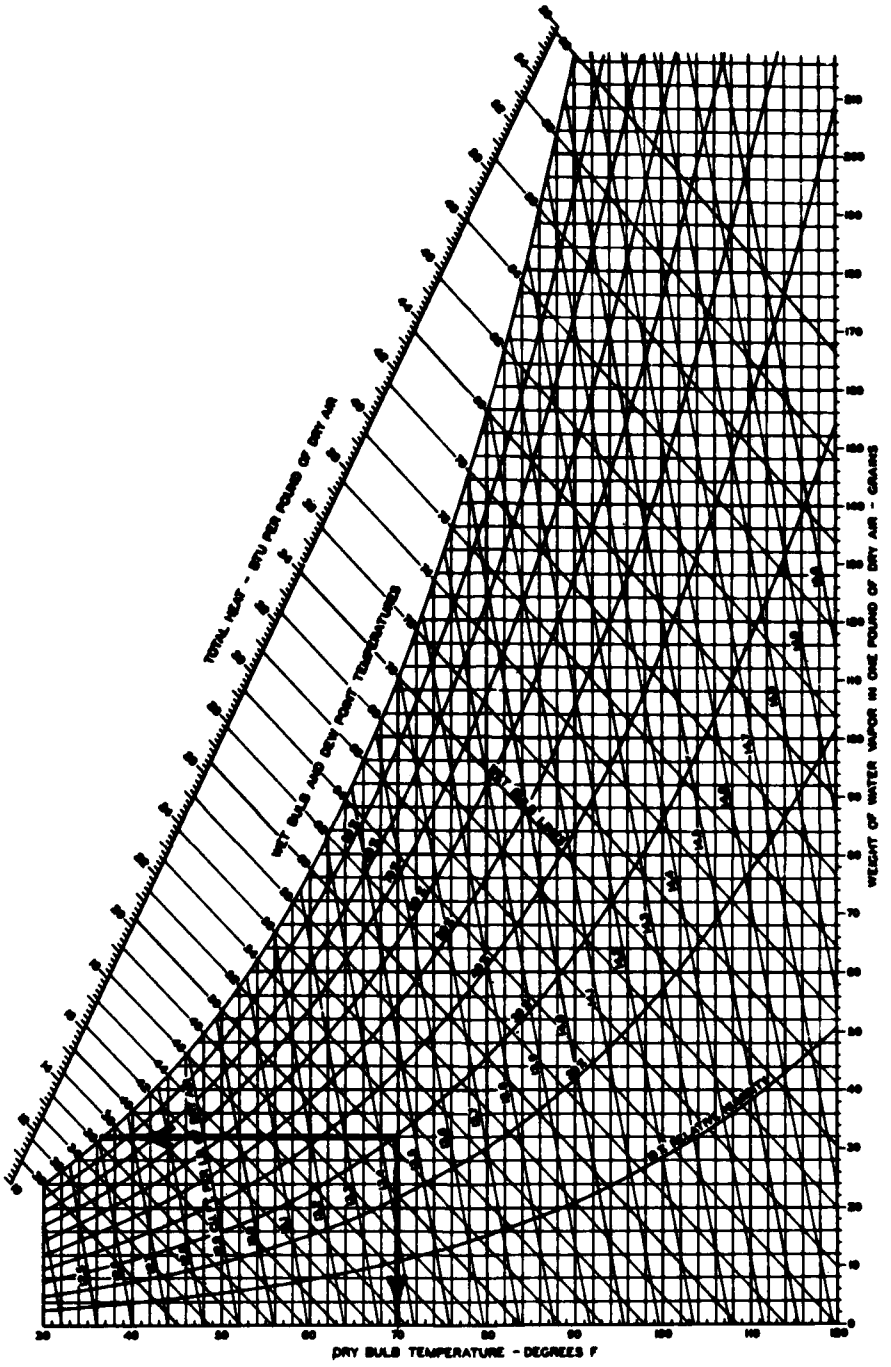


Figure 5-2. Psychometric properties of air at 29.92 inches of mercury absolute pressure. Dew point temperature of 70°F air at 30% relative humidity depicted.

Technical Note N-1060

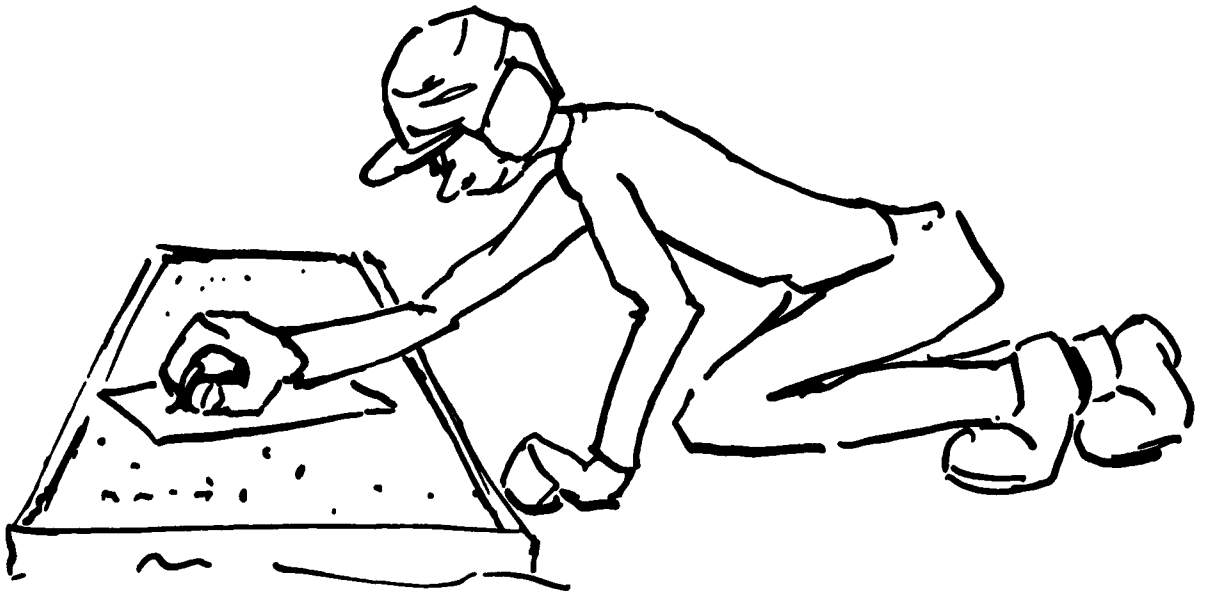
FIELD GUIDE FOR PORTLAND CEMENT CONCRETE CONSTRUCTION IN ANTARCTICA

October 1969

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

by John R. Keeton



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FIELD GUIDE FOR PORTLAND CEMENT CONCRETE CONSTRUCTION IN ANTARCTICA

Technical Note N-1060

YF 38.536.003.01.003

by

John R. Keeton

ABSTRACT

This technical note was prepared for field use by military crews in producing, placing and curing Portland cement concrete in Antarctica under summer temperatures down to 15°F. Since the principal factors are mix control and mix temperature during production and exposed surface temperature control for 3 days following placement, these steps are discussed in considerable detail. The technical information presented in this document is based on field experiments at McMurdo Station, Antarctica, during Deep Freeze 69, which are described in Naval Civil Engineering Laboratory Technical Report "Portland Cement Concrete for Antarctica." *

* This report will be published in FY-70.

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INTRODUCTION

This field guide outlines procedures for the production of Portland cement concrete in Antarctica. The procedures presented here are applicable to construction of footings below ground, formed or not formed, to construction of slabs at ground level, and to construction of pedestals and other castings above ground level. No provision is necessary for insulating the concrete from frozen ground as long as the procedures outlined herein are closely followed. Formwork actually serves as a natural insulator.

SUMMARY OF PROCEDURE FOR CASTING CONCRETE IN ANTARCTICA

1. Assemble equipment and materials.
2. Crush the rock and stockpile the aggregates at casting site.
3. Perform sieve analyses and obtain combined gradation.
4. Determine free moisture content of rock and sand.
5. Prepare mixing water and air entraining agent.
6. Prepare batch sheets similar to Table 5.
7. Weigh out rock, sand, cement, and calcium chloride for each batch.
8. Mix the butter batch and discard.
9. Mix the regular batches, measuring slump and air content for each one.
10. Place the concrete by vibration and finish the surface.
11. Begin curing procedure immediately after casting.

Men, materials, and equipment are much the same in Antarctica as elsewhere. It is the PROCEDURE that differs.

REMEMBER

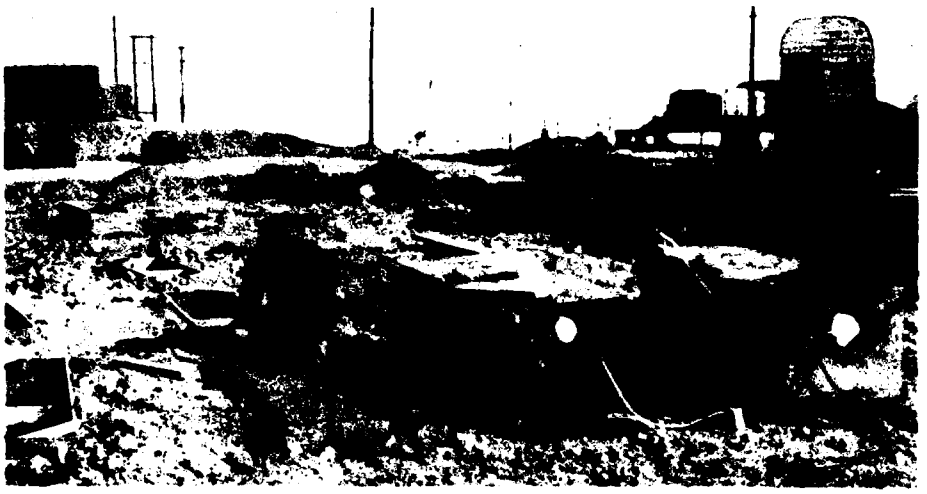
For producing concrete in Antarctica having a minimum compressive strength of 3,000 psi, 3 days after casting, you need:

1. Cement: Portland Type III, High Early Strength
2. Water–cement ratio: 5.5 gallons per bag of cement
3. Mixing water: 35 gal/yd^3
4. Maximum size aggregate: 1 inch
5. Entrained air content: 5% to 7%
6. Sand content (percentage of material passing the no. 4 sieve, in terms of total aggregate): 35% to 37%
7. Slump: 3 inches
8. Minimum temperature of concrete when placed: 50^{o}F to 60^{o}F

9. Minimum curing period: 3 days after casting

10. Curing temperature range: 50^{o}F to 70^{o}F (minimum to maximum)

11. Calcium chloride: 2% of weight of cement



Concrete cast at McMurdo Station, Antarctica, is heat cured by using wooden boxes in which an electric element supplies the heat and a fan circulates the air.

The basic concrete mix design used in Antarctica is shown in Table 1, with quantities of ingredients given for 1 ft^3 and for 1 yd^3. In preparing to cast a given batch of concrete, the quantity of mixing water and the individual weights of rock and sand **MUST** be determined by aggregate moisture content tests described later in these instructions.

Table 1. Basic Concrete Mix Design

Item	Quantity	
	1 Cubic Foot	1 Cubic Yard
Total aggregate (T. A.)	119 lb	3,210 lb
Cement (Portland Type III)	22 lb*	594 lb
Mixing water	10.8 lb†	292 lb†
Air entraining agent‡	to obtain 5%-7%	to obtain 5%-7%
Calcium chloride	0.44 lb§	11.9 lb§
Desired slump	3 inches	3 inches

* Cement quantity rounded to nearest pound.

† Quantity must be adjusted for free moisture in aggregates. Weight shown is rounded to the nearest 0.10 pound.

‡ A neutralized vinsol resin is recommended; the quantity used should be that recommended by the manufacturer to obtain 5%-7% entrained air.

§ Weight of calcium chloride is 2% of the weight of cement.

STEP 1: ASSEMBLE EQUIPMENT AND MATERIALS

Equipment

1. Rock crusher
2. Concrete mixer
3. Wheelbarrows, Georgia buggies, or concrete bucket and crane
4. Large platform scales with 1,000-pound capacity
5. Herman Nelson gas heater
6. Immersion burner or facility for heating water
7. Shovels, trowels, buckets, and assorted hand tools
8. Set of laboratory testing sieves and sieve shaker
9. Hot plate and pans for determining moisture content
10. Laboratory balance with a capacity of at least 20,000 grams
11. Pressure-type air content meter (ASTM C-231)
12. Slump cone and associated gear (ASTM C-143)
13. Stud vibrators, with vibrating stem 1 inch in diameter
14. Volumetric flask (250 ml) for dispensing air entraining agent
15. Three metal thermometers, range $0^{o}F$ to $220^{o}F$

Materials

1. Portland Cement, Type III, High Early Strength. The cement should be shipped to Antarctica in bags sealed in 55-gallon drums. Requirement is 594 pounds (6.33 bags) for each cubic yard of concrete to be cast.

2. Calcium Chloride in Flake or Powder Form. It should be shipped in sealed 55-gallon drums. Requirement is 12 pounds for each cubic yard of concrete to be cast. It must be kept dry until ready for use.

3. Neutralized Vinsol Resin Air Entraining Agent in Powder Form. It should be shipped in sealed 5-gallon cans. Two 5-gallon cans should be enough for a construction season. Prior to using, a certain portion of the powder is mixed with a certain volume of water as stated by the manufacturer. A small amount of the agent in liquid form is then added to a portion of the mixing water.

4. Concrete Curing Compound. Refer to directions by the manufacturer for quantity required per square foot of concrete to be coated.

Rock crusher in operation.

STEP 2: CRUSH THE ROCK AND STOCKPILE THE AGGREGATE AT YOUR CASTING SITE

Crusher Operation and Stockpiling

1. In the upper screen position, install a screen with 1-1/4-inch-square openings. This will provide a maximum rock size of about 1 inch. The rock may be collected directly in a dump truck or stockpiled for later removal to the jobsite.

2. In the lower screen position, install a screen with 3/8-inch-square openings. Material passing through the 3/8-inch screen constitutes the sand. The sand may be collected directly in a dump truck or stockpiled for later removal to the jobsite.

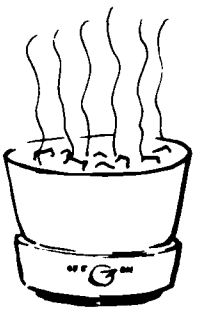
3. The rock and sand should be taken to the jobsite and placed in separate stockpiles.

STEP 3: PERFORM SIEVE ANALYSIS AND OBTAIN COMBINED GRADATION

Sieve Analysis

An example sieve analysis of rock is shown in Table 2. Remember that this is an example to illustrate the method; the actual sieve analysis of local crushed rock must be determined in the field (ASTM C-136).

1. Dry to constant weight (by hot plate, for example) about 10,000 grams of rock. Obtain the rock sample by combining samples taken from several places in the rock stockpile; split off about 10,000 grams.



2. Set up a nest of U. S. Standard Sieves (ASTM E-11) for the sieve shaker in the following order, beginning at the bottom: pan, no. 30, no. 16, no. 8, no. 4, 3/8 inch, 3/4 inch, 1 inch, and the top.

3. After it has cooled, weigh the dried sample (in grams) and shake it through the nested sieves. After about 5 minutes of shaking, obtain the weight of rock particles retained on each of the sieves and record as shown in Column 2 (Table 2) of the example sieve analysis. Column 3 of Table 2 shows the cumulative weights for each of the sizes. Cumulative % retained, computed from weights shown in Column 3, are listed in Column 4. Column 5, % passing, is obtained by subtracting from 100% the values shown in Column 4. To get a good average, repeat the sampling and sieve analysis procedure three times.

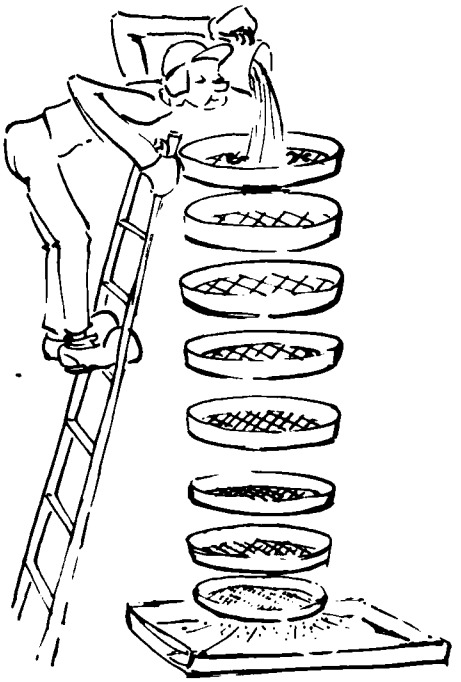


Table 2. Example Sieve Analysis of Rock

Sieve Size	Weight Retained (grams)	Cumulative Weight Retained (grams)	% Retained	% Passing
Column 1	Column 2	Column 3	Column 4	Column 5
1 in.	0	0	0	100
3/4 in.	3,820	3,820	40	60
3/8 in.	2,870	6,690	70	30
no. 4	2,670	9,360	98	2
no. 8	190	9,550	100	0
no. 16	0	0	0	0
no. 30	0	0	0	0
pan	0	0	0	–

An example sieve analysis of sand is shown in Table 3. Remember that this is an example to illustrate the method; the actual sieve analysis of local sand must be obtained in the field (ASTM C-136).

1. Dry to constant weight 800 to 1,000 grams of sand. Obtain the sand sample by combining samples taken from several places in the sand stockpile; split off 800 to 1,000 grams.

2. Set up a nest of U. S. Standard Sieves for the sieve shaker in the following order, beginning at the bottom: pan, no. 100, no. 50, no. 30, no. 16, no. 8, no. 4, 3/8 inch, and the top.

3. After it has cooled, weigh the dried sample (in grams) and shake it through the nested sieves. After about 10 minutes of shaking, obtain the weight retained on each of the sieves and record as shown in Column 2 (Table 3) of the example sieve analysis. Values shown in Columns 3, 4, and 5 of Table 3 are obtained in the same manner as for Table 2. To get a good average, repeat the sampling and sieve analysis procedure three times.

Table 3. Example Sieve Analysis of Sand

Sieve Size	Weight Retained (grams)	Cumulative Weight Retained (grams)	% Retained	% Passing
Column 1	Column 2	Column 3	Column 4	Column 5
3/8 in.	8	8	1	99
no. 4	33	41	5	95
no. 8	82	123	15	85
no. 16	164	287	35	65
no. 30	164	451	55	45
no. 50	206	657	80	20
no. 100	131	788	96	4
pan	33	821	100	–

Combined Gradation

Values of % passing (cumulative) for the example sieve analysis of rock and sand are repeated in Columns 2 and 3, respectively, of the example combined gradation shown in Table 4. The recommended range for % passing the no. 4 sieve in the combined gradation is 35% to 37%. To obtain this percentage range, multiply by 0.37 the value of 95% found in Column 3 for the no. 4 sieve (35/95). Similarly, values for all the sand sizes in Column 3 are multiplied by 0.37 and the results are listed in Column 5, which shows the % passing a given size when 37% of the combined gradation is taken from the sand stockpile. Thus, for this example 63% (100 minus 37) of the combined gradation must come from the rock stockpile. The results of multiplying the values in Column 2 by 0.63 are shown in Column 4. The example combined gradation, presented in Column 6, is obtained by adding the values in Column 4 to the values in Column 5 for each size.

If concrete were made with aggregates having a combined gradation as shown in Table 4, 37% of the total aggregate requirement would come from the sand stockpile and 63% would come from the rock stockpile.

Again it must be emphasized that the sieve analysis must be made on the rock and sand in the field, and the percentage of rock and the percentage of sand to use must be calculated to obtain 35% to 37% passing the no. 4 sieve, as shown in Table 4.

Table 4. Example Combined Gradation of Rock and Sand

(All values shown are percent passing the size shown.)

Sieve Size	Rock	Sand	Rock x 0.63	Sand x 0.37	Combined Gradation
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
1 in.	100	100	63.0	37.0	100.0
3/4 in.	60	100	37.8	37.0	74.8
3/8 in.	30	99	18.9	36.6	55.5
no. 4	2	95	1.3	35.0	36.3
no. 8	0	85	0	31.4	31.4
no. 16	0	65	0	24.0	24.0
no. 30	0	45	0	16.7	16.7
no. 50	0	20	0	7.4	7.4
no. 100	0	4	0	1.5	1.5

STEP 4: DETERMINE FREE MOISTURE CONTENT OF ROCK AND SAND

The free moisture content (M.C.) of the stockpiles of rock and sand should be obtained the day before mixing of the concrete. The procedure for determining the free moisture content is outlined below.

1. Obtain about 4,000 grams of the crushed rock and about 1,000 grams of sand. Moisture content should be determined separately of rock and of sand. Material should be taken from several areas of each stockpile (including the interior) and thoroughly mixed; the moisture content samples should be taken from the mixed materials and weighed to the nearest 0.5 gram.

2. Dry the sample to constant weight by heating on a hot plate or in an oven. Reweigh the dried sample to the nearest 0.5 gram.

3. Compute the total moisture content (M.C.) as follows:

$$\text{M.C. (\%)} = \frac{W - D}{D} \times 100$$

where W = wet weight (grams)

D = dry weight (grams)

4. The free moisture portion available as mixing water is obtained as follows:

Rock: M.C. minus 1.0% for absorption

Sand: M.C. minus 0.5% for absorption

Correction for free moisture in the aggregates is accomplished as follows, referring to weight of total aggregate shown in Table 1:

Assuming a free M.C. of 3% in the rock and assuming that the rock will be 63% of the weight of the total aggregate, the weight of rock for 1 ft^3 is

$$W_R = 119\ (0.63)(1.03) = 77 \text{ pounds}$$

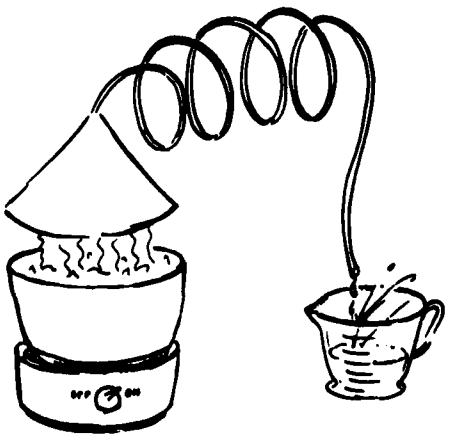
A corresponding adjustment is made for 1 yd^3. Assuming a free M.C. of 8% in the sand and assuming that the sand will be 37% of the total aggregate, the weight of sand for 1 ft^3 is

$$W_S = 119\ (0.37)(1.08) = 47 \text{ pounds}$$

STEP 5: PREPARE MIXING WATER AND AIR ENTRAINING AGENT

Mixing Water

Since the aggregates contain free water that is available for combining with the cement, the amount of mixing water must be decreased accordingly. Using the free M.C. values and rock and sand quantities given above for 1 ft^3, free water in the rock is 77 x 0.03 = 2.3 pounds and free water in the sand is 47 x 0.08 = 3.7 pounds, making a total of 6.0 pounds of water. The actual



mixing water added to the batch will then be 10.8 pounds (see Table 1) minus 6.0 pounds or 4.8 lb/ft^3. Final batch quantities for the combined gradation shown in Table 4 and for the M.C. values used above are shown in Table 5. Remember: the quantities of aggregates and mixing water shown in Table 5 are only appropriate for the example.

Air Entraining Agent

The air entraining agent, a neutralized vinsol resin in powder form, must be mixed with water as specified by the manufacturer; a one-gallon plastic container is a convenient quantity. The agent is then added in liquid form to a portion of the mixing water.

Table 5. Example Batch Quantities

Item	Batch Quantity	
	1 Cubic Foot	1 Cubic Yard
Total aggregate (T.A.)	119 lb	3,210 lb
Rock: T.A. x 0.63* x 1.03†	78 lb	2,120 lb
Sand: T.A. x 0.37* x 1.08†	46 lb	1,248 lb
Cement (Portland Type III)	22 lb	594 lb
Mixing water	4.8 lb‡	119 lb
Air entraining agent	20 ml§	540 ml
Calcium chloride	0.44 lb¶	11.9 lb

* Rock and sand proportions of the total aggregate used in the example in the text.

† Free moisture content corrections as given in the example.

‡ Desired mixing water minus free aggregate water (10.8 minus 2.3 minus 3.7).

§ Quantity used in Antarctica during Deep Freeze 69.

¶ Quantity equals 2% of the cement weight.

STEP 6: PREPARE BATCH SHEETS SIMILAR TO TABLE 5

Prior to batching, a batch sheet should be prepared similar to Table 5.

STEP 7: WEIGH OUT ROCK, SAND, CEMENT, AND CALCIUM CHLORIDE FOR EACH BATCH

Rock, sand, cement, and calcium chloride should be weighed out for each expected batch in advance of the casting date.

Remember: the relative portions of rock and sand must be determined from the combined gradation as outlined above and further adjusted for free moisture content.

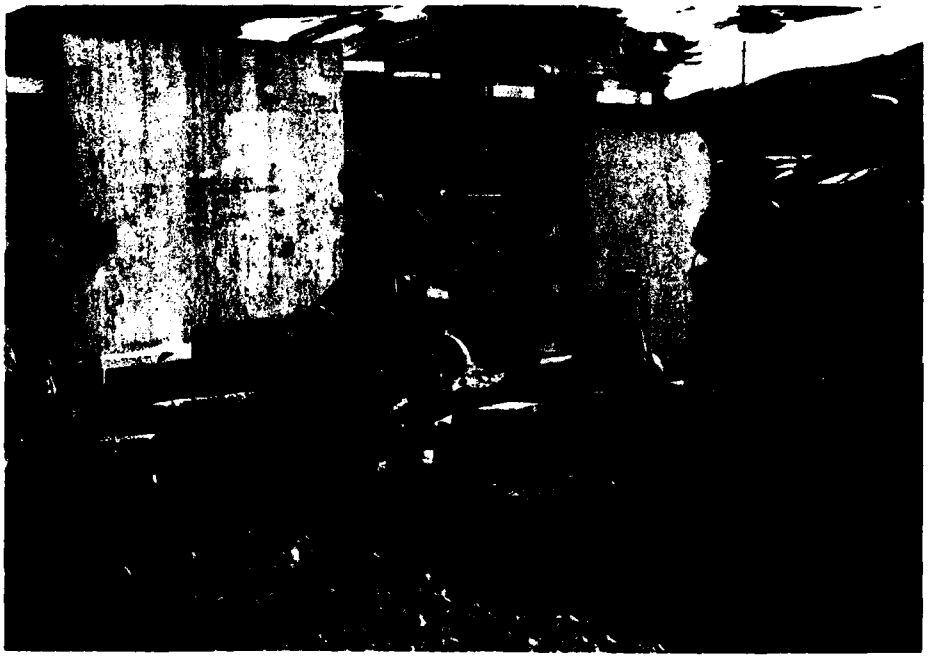
The ingredients can be stored in specially prepared bins or boxes.

Aggregates and cement **MAY** be batched by volume in containers which are known to contain certain weights of the ingredients when loosely filled. For example, a 1-ft^3 box can be loosely filled several times with rock and weighed and the weight of rock determined on an average basis. Thereafter, the container, filled with rock in the same manner, may be considered to contain the same weight of rock each time. The same procedure may be used to batch sand and cement. If desired, the rock and sand for a given batch may be stored mixed together and protected from direct precipitation; the cement should be stored separately and kept dry.

Batching rock by volume container (1 ft^3).

STEP 8: MIX THE BUTTER BATCH AND DISCARD

To coat the mixer and to assume uniform mixing in subsequent batches, an initial batch of concrete should be prepared amounting to about one-third to one-half of the quantity of the regular batches to be made. For example, if the regular batches are to be 8 ft^3 in volume, the butter batch should be about 4 ft^3. All regular ingredients, including air entraining agent and calcium chloride, should be included in the butter batch. After mixing for about 3 minutes, measure the air content (step 9, section 6) to check on the amount of air entraining agent used. The amount can be adjusted to obtain the proper air content of subsequent batches. Then discard the butter batch.



Mixing concrete at McMurdo Station during Deep Freeze 69.

STEP 9: MIX THE REGULAR BATCHES, MEASURING SLUMP AND AIR CONTENT FOR EACH

1. The rock and sand should be placed in the mixer first. The mixing water, heated to temperatures as shown in Table 6, is then added in two separate portions.

2. The air entraining agent should be mixed with one portion of the mixing water and placed in the mixer.

3. The calcium chloride should be dissolved in a second portion of the

mixing water and placed in the mixer. Do not place the calcium chloride in the portion of mix water containing the air entraining agent.

4. After mixing the aggregates, water, and admixtures for about 1 minute, add the cement and mix for about 3 minutes.

5. Make a slump test in accordance with the procedure shown below (taken from ASTM C-143).

a. Holding the slump cone firmly in place, fill the cone (larger end down) in three layers, each about one-third of the volume.

b. Rod each layer with 25 strokes of the tamping rod, uniformly distributing the strokes across the cross section of each layer.

c. Strike off the top surface and remove the cone from the concrete by raising it carefully in a vertical direction.

d. Determine the slump by measuring the difference between the height of the cone and the height over the original center of the base of the slumped cone of concrete.

e. If the slump is within 1/2 inch of the required 3 inches, the batch can be placed in the forms. If the slump is less than 2-1/2 inches, more water must be added to the batch. Water at the correct temperature should be added in small increments. Repeat the slump test after adding water and remixing for 2 minutes. If the original slump is 4 inches or more, the batch must be rejected.

Table 6. Mixing Water Temperatures

Prevailing Air Temperature (^{O}F)	Required Mixing Water Temperature (^{O}F)
15	180*
20	175
25	170
30	160
35	150
40	140

* Water temperature shown will provide a minimum temperature of 60^{O}F in the in-place concrete.

Measuring slump.

6. Measure the air content of the concrete. Follow the directions accompanying the pressure air meter. If the air content is less than 5% or over 7%, the batch must be rejected. The air content test and the slump measurement should be made at the same time.

Measuring air content by means of the pressure air meter (left foreground).

STEP 10: PLACE THE CONCRETE BY VIBRATION AND FINISH THE SURFACE

Transportation

The concrete can be transported from the mixer in a wheelbarrow or a concrete bucket to the place of casting.

Vibration of Concrete in Place

After the concrete is placed in the forms, it should be vibrated with a stud vibrator until consolidation seems complete.

Vibrating concrete immediately after placement.

Rough screeding follows immediately after vibrating. Note thermocouples inserted in the fresh concrete.

Leveling and Finishing

1. After vibrating, the concrete surface should be struck off to a level surface. No attempt should be made to trowel the surface at this time.

2. The concrete surface can be steel troweled a few hours after casting. As soon as troweling is completed, coat the concrete surface with curing compound. The heated enclosure or insulation (described below) can be removed long enough to accomplish the troweling but should be replaced promptly after the troweling and treatment with curing compound are completed.

STEP 11: BEGIN CURING PROCEDURE IMMEDIATELY AFTER CASTING

For adequate strengths under any reasonable prevailing air temperature encountered during the construction season, heat should be applied to the exposed concrete surface for a period of at least 3 days after casting. Heat can be applied by at least two methods, hot air blowers and electric blankets. On the other hand, under air temperatures above 30°F, curing can be accomplished by placing 2 inches of insulation over the newly cast concrete and retaining the insulation for at least 3 days.

Hot Air Blower

After the concrete surface has been screeded, place over it an enclosure into which heat can be introduced at temperatures shown in Table 7. Do not allow hot air to blow directly onto the concrete surface. The heat should be maintained for at least 3 days after casting, following which, the heat can be turned off, leaving the enclosure in place for about 8 hours. This will allow the concrete to cool slowly to the temperature of the outside air, thus avoiding thermal shock of the concrete.

Table 7. External Heat Requirements for Freshly Cast Concrete

Prevailing Air Temperature Range (^{O}F)	Required Temperature Range for Heated Air (^{O}F)
10 to 20	70 to 80
20 to 30	60 to 70
30 to 40	50 to 60
40 to 50	50
above 50	no external heat

Electric Blanket

If preferred, an electric blanket may be used to supply heat to the concrete surface. Other conditions should be the same as for a heated enclosure.

Curing With Insulation

When formwork is used and when the average air temperature is above 30^{O}F, curing can be accomplished by placing 2 inches of insulating material, such as fiberglass roof insulation, over the concrete surface immediately after screeding. The insulation should remain on the concrete until it is ready to be used; the concrete must cure for at least 3 days. If a smooth finish is desired, the insulation can be removed long enough for steel troweling.

ACKNOWLEDGMENTS

Aside from the author, this field guide is the result of the talents of R. C. Hamm, EOC, who contributed significantly to the clarification of the technical material for field use. Robert Easton organized the format and Rebecca Dunham prepared the sketches.

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LIST OF APPENDIXES

Chapter 5

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

5-A. **Civil Engineering Laboratory. Technical Memorandum M-61-77-2: A review of cold weather insulation materials, by J. L. Barthelemy, Mar 1977.**

5-B.

5-C.

5-D.

5-E.

5-F.

5-G.

5-H.

5-I.

5-J.

Addition – 1979

APPENDIX 5-A

TM no. M-61-77-2

TECHNICAL MEMORANDUM

title: A REVIEW OF CURRENT COLD WEATHER INSULATION MATERIALS

author: J. L. Barthelemy

date: March 1977

sponsor: NAVAL FACILITIES ENGINEERING COMMAND

program nos: YF52.555.001.01.003

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

Addition – 1979

A REVIEW OF CURRENT COLD WEATHER INSULATION MATERIALS

YF52.555.001.01.003

by
J. L. Barthelemy

March 1977
Sponsored by Naval Facilities Engineering Command

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INTRODUCTION

The very hostile environment encountered in the polar regions presents man with many hardships atypical to other parts of the world. Winter climatic conditions are severe, characterized by periods of total darkness, strong winds and extremely low temperatures. In addition, there are very few readily usable resources; supplies, equipment and construction materials must be transported at great expense by ship or airplane. As a result, construction by conventional means is at best difficult and most often costly as well. Mankind, however, has an uncanny ability to adapt to adverse environmental conditions by developing novel construction techniques, building materials and equipment.

Needless to say, proper thermal insulation is an essential ingredient in the design of any polar facility. Walls, doors and roofs must be insulated to minimize the consumption of fuel required for comfort within the living quarters. Flooring systems placed on the permafrost or snow must be insulated, not only for comfort, but for protection of the supporting ground as well. Excessive heat conducted to unstable ground can cause melting which will result in the eventual destruction of the facility by settling or heaving. Likewise, liquid distribution systems must also be protected from the cold so that freeze-up does not occur, resulting in interrupted service and possible structural damage. This Technical Memorandum presents the results of a survey which was conducted to compile technical data on state-of-the-art cold weather insulation materials. The literature/industrial search was a two-fold inquiry. It included: (1) a general inquiry of selected insulation manufacturers as to product line, material properties and price, and (2) a specific inquiry of cellular polyurethane plastic manufacturers to determine the availability and characteristics of materials for foam-in-place application under cold-weather conditions.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its contents outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

The Eskimos have managed to survive for centuries in the harsh polar climate with amazingly simple clothing made from animal skin. Early explorers assumed that the Eskimos had evolved a physiological adaptation to the cold. That belief has continued to the present, even though measurements do not support this conclusion. Scientists now believe that Eskimos are adapted all right, but not so much in physiology as in know-how. They have survived in the Arctic by keeping the cold at bay with simple clothing and housing that conserve metabolic heat. Europeans and Americans settling in the far north have not been willing to adopt the rudimentary life-style of the native population. Through an advanced technology and heretofore abundant supply of fuel, they have continued to create a comfortable 70-degree climate by heating their dwellings and by using large amounts of insulation--insulation

of themselves by clothing and insulation of their shelters by any means available. But the apparent effortlessness of achieving thermal comfort is often bought expensively and irresponsively. In this era of dwindling fuel reserves and rising costs, man is becoming increasingly more aware of the need to conserve. Without reverting to the extreme lifestyle of the Eskimo, man can, with a little attention to common sense, select optimum methods and materials for heating and insulating his cold-weather environment.

General Considerations

Insulation materials may be classified as "reflective insulators" which fight radiation heat loss and "mass insulators" which bar the conduction of heat. The most important type for polar application is the non-reflective mass insulation. There are two fundamental requirements for a non-reflective thermal insulating material: (1) it should contain a high proportion of air in a static state; and (2) the solid matter itself should have a low thermal conductivity. These two requirements are fulfilled to a greater or lesser extent by those naturally occurring materials used as thermal insulators, such as cork, wood and asbestos. These materials vary in the proportion of air held to solid content and thus their bulk densities will be different from material to material. Generally speaking, the higher the bulk density, the higher the thermal conductivity and therefore the lower the efficiency of the material as a thermal insulator. This relationship is usually true for the man-made foam-type insulations also. Unfortunately, structural strength of rigid foams is also related to density, but conversely, so that sometimes one has to decide whether to choose a good insulation which is weak or a poor insulation which is strong.

Artificially produced inorganic materials such as rock-wool and fiber glass have been developed with low thermal conductivities, but these materials are of different form than solid natural products and generally exist as blankets or resin-bonded mats. In general, they have a number of disadvantages that detract from their application in building. They absorb large quantities of water and their weight becomes greatly increased. The cellulosic materials under such conditions can grow molds and fungi and eventually rot. The fibrous products compress easily under load and thus lose efficiency as insulants, and they can also absorb and transmit large quantities of water. Nonetheless, for many types of construction in cold-weather regions, including wood-frame home construction and modular-built assemblies, fibrous glass insulation has been the thing to use. Why is this? Mainly because it uses only space available within the walls and joists, because it is far cheaper than other equivalent insulators, and because it is not smoky nor toxic when heated.

A few generalizations may be made regarding the types of insulation materials used in polar regions. Foam-type insulators made from glass, polystyrene or polyurethane are unsurpassed for certain jobs. For instance, there are no insulations so useful in contact with the ground as those made of polystyrene, none so resistant to chemical attack and high temperatures as foamed glass, and nothing comparable to polyurethane for foam-in-place

versatility. The thing to watch for in foams is their cost, their toxicity when burned, and their saturability.

The material properties and performance characteristics of foam-type insulations can vary considerably from manufacturer to manufacturer. Fibrous glass insulation, on the other hand, is more or less uniform among manufacturers and is installed in polar regions in the same manner as in more temperate areas. However, there are a few not-so-obvious differences in application. For instance, fibrous materials marketed stateside are often produced with a reflective foil backing on a thick, waterproof paper membrane. An Arctic builder is wise to avoid these. Such insulation is designed for use where the optimum thickness is smaller than the usual space within a frame wall. In the polar regions one does not need foil-backed insulation because there is no advantage to the foil. Foil needs to have a space to "reflect into," and the designer of cold-region dwellings will choose to completely fill the wall with insulation, since it is a better thermal barrier than air. Also, the vapor barrier inherent in foil-backed insulation is illusory and inadequate for long, cold winters. The practical thing to do is to use thick, friction-fit batts of insulation which do not need any fasteners other than components of the wall itself. Friction fit is cheaper to buy and cheaper to install.

ACCOMPLISHMENTS

Foam-type insulation materials may be defined as a combination of solid and gaseous materials of fine and uniform structure. The solid portion is a continuous phase; the gaseous portion may be discrete or continuous. When the gas is discrete, there is a closed-cell or unicellular foam. When the gas is continuous, the foam is an open-cell type. Foams used for thermal insulation applications are the closed-cell type and may exist in either rigid or flexible form.

The insulating qualities of foamed materials vary according to the formulation of the constituent components. Historically, there has been little information available in published literature about the particular characteristics of foamed materials other than that contained in the manufacturers' brochures. This is still pretty much the situation today. Therefore, the literature search was mainly a canvassing of industry to determine: (1) the types of foam insulation products; (2) the physical and thermal properties of these products; (3) comparative costs; and (in the case of foam-in-place polyurethane manufacturers)(4) the environmental conditions and restrictions under which component chemicals could be successfully combined.

For the most part, companies selected for this survey were taken from references (1) and (2). Appendix A presents a listing of solicited companies under the type of inquiry made--that is, the type of insulation about which information was desired. It would not be constructive to reproduce in this document all of the industrial information provided by industry. Instead, the DISCUSSION section of this memorandum considers each type of foamed insulation and highlights the material properties and application considerations that affect usage in cold-weather regions.

DISCUSSION

The types of insulation materials generally classified as foamed include foamed rubber, foamed glass and the cellular plastics. The cellular plastics include phenol formaldehyde (phenolic), urea formaldehyde and, more importantly, polystyrene and polyurethane.

Foamed Rubber

For purposes of insulation, foamed rubber is available in either a rigid form (boards) or a flexible form (sheets and molded shapes). Unlike some of the cellular plastics, it is strictly a prefoamed material and foam-in-place systems are not available. Both the flexible and rigid types are black in color with a smooth surface, and are exceptionally clean to handle. They have good resistance to both rot and vermin. Foamed rubber has a closed cellular structure that forms a vapor barrier in itself, so that no separately applied vapor barrier is required. As a material, foamed rubber is light in weight and a good thermal insulator, although compared to some of the cellular plastics, it is less than optimum. The average density of the flexible type is 5 pcf with a thermal conductivity of 0.26 Btu in/lb sq ft ^{o}F, while that for the rigid stock is 7 pcf at 0.28 Btu in/lb sq ft ^{o}F. Foamed rubber is often used to insulate piping for refrigeration systems; however, it is somewhat limited for cold weather application, since even the flexible type becomes hard at -20^{o}F and for temperatures below that will be increasingly brittle. Manufacturers do not recommend its usage for temperatures below -40^{o}F.

Foamed Glass

Foamed glass insulation is the only known material produced by expanding pure glass. It is essentially a rigid, completely closed cell foam, available in a variety of molded shapes. It cannot be foamed-in-place at a construction site. As an insulating material it has several favorable qualities. For instance, the sealed-glass cells are impermeable; thus, water and vapor cannot enter the material, and insulating efficiency and weight remain unaltered for the life of the insulation. When all joints are sealed on low-temperature lines, there is no need to provide additional vapor barriers. As a result, foamed glass is good for underground as well as aboveground construction. In addition, it has the widest range of temperature service, operating between -450^{o}F and +450^{o}F. Foamed glass insulation is impervious to common acid spillage, to corrosive atmospheres and to soil acids that can deteriorate other insulating materials. It cannot burn, nor will it act as a wick or generate toxic fumes if a fire occurs in the area where it is installed.

From the standpoint of cost, prices of foamed glass pipe coverings are comparable to those for urethane and styrofoam; however, foamed glass is not usually the best insulation to use in polar regions. Compared to both polystyrene and urethane, foamed glass has a higher density as well as a higher thermal conductivity. Thus, for equivalent values of insulation protection,

it takes not only a greater volume of foamed glass material, but an appreciably greater weight as well. The average density of foamed glass is 8.5 pcf with a thermal conductivity (at 50°F) of 0.36 Btu in./lb sq ft °F. Both polystyrene and polyurethane, on the other hand, have typical densities less than 3 pcf and thermal conductivities less than 0.25 Btu in./lb sq ft °F. In the polar regions, where most materials are flown in or transported by ship, both the cube and weight of cargo are important considerations.

Phenol Formaldehyde

Phenol formaldehyde is a cellular plastic used to a limited extent as an insulating material. It is supplied by manufacturers as either a resin for foaming in place or as prefoamed molded shapes. Phenol formaldehyde foams have a relatively large cell structure with a proportion of open cells. Water vapor permeability and water absorption are higher than those of the fully closed cell material. The product has an exceptionally high degree of fire and temperature resistance, and can be used in contact with most chemicals. The thermal conductivity at densities of 2 to 3 pcf is 0.25 Btu in./lb sq ft °F, which is comparable to polystyrene. However, their density is difficult to control; they are weak and brittle at low densities and are expensive compared to urethane and polystyrene. Special problems are posed with foam-in-place application. Care should be taken so that the foam does not have to travel too far to fill crevices or molds since the liquid phenol resin has a high-speed reaction when foam is produced.

Urea Formaldehyde

Although urea formaldehyde foam was first developed in Europe about thirty years ago, widespread interest in the material has developed only recently. Urea formaldehyde has been studied in detail in Scandinavia and Great Britain, and is of growing importance in the United States. During the past five years, numerous buildings in North America have been retrofitted with urea foam insulation. Urea formaldehyde foams are essentially open-cell materials and the plastic itself has a relatively high water absorption. The foamed product therefore has high water vapor permeability and water absorption. It also has very weak mechanical properties and therefore is not produced in board form but is invariably foamed in place. It is in this regard that the material may assume greater importance in cold-weather regions. Many existing buildings in cold regions are inadequately insulated by current standards. Some such buildings are being reinsulated by removing either the interior or exterior surfaces of the wall to expose the insides, and then filling the stud spaces with batts or rolls of glass fiber. This process is expensive and time consuming. More recently, the U.S. Army Cold Regions Research and Engineering Laboratory has reinsulated several stud-framed structures at Fort Greely, Alaska, by blowing urea formaldehyde foam into the stud space through small holes in the wall surface. To date, the material appears to be holding up quite well.

According to Tobiasson and Flanders, urea formaldehyde foam is a water-based resin combined with a foaming agent and catalyst. Compressed air froths these ingredients to the consistency of shaving cream at the applicator nozzle. The component ingredients must be maintained at 45°F or above, preferably at temperatures of at least 70°F. The foam requires the presence of water to occupy volume as the substance cures. If the water leaves before final strength is attained, the cellular structure contracts and causes shrinkage. From the standpoint of dimensional stability, water should be induced to leave slowly during cure. In the interest of dry insulation, it should leave rapidly after curing is complete. Thus manufacturers aim to achieve a balance between the two considerations by attempting to hold shrinkage to less than 2 or 3 percent. The dry foam has a typical density of about 0.7 pcf and thermal conductivity of 0.25 Btu in./lb sq ft °F.

Polystyrene

Cellular plastic polystyrene insulation has been especially useful in cold weather regions for applications that require contact with the ground, since polystyrene has an extremely low affinity for water. When in the expanded state, it has a closed cell structure and can be produced commercially at a bulk density of 1 pcf. At this density it has a relatively low water vapor transmission and negligible water absorption. Also it has a high strength-to-weight ratio and even boards of ½" thickness are sufficiently strong and rigid to be handled easily.

Polystyrene may be either rigid or flexible, both types having a closed-cell structure. It is available from manufacturers either as prefoamed, molded shapes or as free-flowing, expandable beads for foaming applications. The expandable beads, however, should not be classified as a foam-in-place insulation. Most users "foam" expandable beads by first placing them in selected molding equipment and then applying external heat or epoxy resins. Thus polystyrene insulation used in the polar regions is supplied as preformed slab stock or molded shapes.

Polystyrene is gaining an ever-increasing acceptance in the building industry as a whole. It is being used as a foundation and perimeter insulation, as a floor insulation for under-floor heating and in all types of roof insulation. It is also being used more and more as a sandwich material for modular panel construction.

As a result of the recent surge in development and construction in the far North, the usage of styrofoam there has increased even faster than stateside--especially in the area of ground protection. A number of plastic foam materials were tested during 1959 by Purdue University in an effort to find the best insulation to prevent frost action under highways. As a result of those tests, polystyrene-type insulation was determined as the best material suited for the job. It was light in weight, high in strength, and resistant to water penetration. Subsequent to that time, a number of

improved polystyrene insulations for cold weather ground work have been developed. Probably the product getting the most use is "styrofoam," which is actually a trademark of the Dow Chemical Company covering its product line of expanded polystyrene foams. There are a number of different types of styrofoams on the market today. Among these, styrofoam HI is produced especially as a soil insulation for airport runways and highways where insulation of the soil is needed to prevent thawing of the subsurface or frost heaving in the spring. It has a high compressive strength and a tough surface skin to withstand the heavy construction and soil loads to which it is subjected. Also, it has a higher resistance to water absorption than do the other styrofoams. As a result, its density of 2 to 3 pcf is somewhat higher than other polystyrenes which may be as low as 1 pcf, while its thermal conductivity of approximately 0.22 Btu in./lb sq ft ^{o}F is slightly higher.

With regard to permafrost experience, the airport at Kotzebue, Alaska, was rebuilt in 1969 using a 4-inch layer of styrofoam HI to protect the permafrost. The surface of the runway was paved with asphalt concrete the following year, and to date it has not shown any subsidence on the insulated portion. Also, that same year, the Alaska Highway Department installed an insulated roadway over permafrost near Chitina, Alaska. The insulated sections have shown no signs of settling while the noninsulated roadway has settled 3 to 6 inches. In the Canadian Arctic, styrofoam HI has been used under exploratory oil drilling rigs to prevent thermal degradation of the permafrost. A typical insulated drill pad consists of placing a 6- to 18-inch leveling course of gravel on the original ground, above which is placed a 2-inch layer of styrofoam boards. The framework which supports the drill rig platform is placed directly on the layer of insulation. The top and bottom surface of the insulating layer is protected from the chemical attack of fuel spills by a layer of polyethylene film. In most cases, up to 95 percent of the insulation can be reclaimed and reused after the exploratory has been dismantled.

The largest single project which has utilized styrofoam HI as an earth insulation is the Alyeska Trans-Alaska pipeline. In that project, over 100 miles of pipeline pad constructed north of the Brooks Range includes styrofoam HI as part of the embankment. Either 1½-inch or 3-inch layers were placed on the original frozen ground, which had first been bladed smooth and then a 2-foot fill of gravel placed over the foam.

Polyurethanes

The last major type of cellular plastic foam used for thermal insulation is polyurethane. Polyurethane foams are available as either foamable resin systems for foaming in place or as prefoamed molded shapes, both types having the same general insulating qualities. They can be foamed to produce a rigid or flexible material with either open- or closed-cell structure, the latter being the natural choice for insulation. Water vapor transmission is relatively low and water absorption reasonably low. Polyurethane may be foamed-in-place or molded at densities ranging from less than 1 pcf to a little over 4 pcf.

Probably the most important property of a thermal insulation material is its thermal conductivity or K-factor, a quality in which the urethanes have a definite advantage over other types of foamed plastics. Polyurethane foams which use carbon dioxide as a blowing agent have average thermal conductivity values around 0.21 Btu in./lb sq ft ^{o}F, while foams using fluorinated hydrocarbons such as freon for blowing agents have reduced average values or thermal conductivity as low as 0.13 Btu in./lb sq ft ^{o}F.

Like polystyrene products, polyurethane foams are gaining wider acceptance and usage in the construction industry. It is commonly used as a perimeter insulation to sharply reduce heat transfer along a building's concrete foundation, or as a roof insulation applied as either boardstock or foamed in place. Urethane, faced with felt or made in a composite with a fire-rated material, is used like fibrous board roof insulation. Sprayed urethane is solving the problem of insulating unusual shapes, including corrugated, arched and elliptical roofs. Using rigid urethane foam in masonry wall construction, a builder can insulate and install a plaster base in a labor-saving operation that can eliminate the need for furring and lathing.

As previously emphasized, the relative inaccessibility of most polar locations requires that goods be imported by plane or ship at great expense. Thus it is desirable to hold both the volume and weight of required construction materials to a minimum. Because of their low density, low K-factor characteristics, polyurethane foams are typically suited to many polar applications, since it takes less material to achieve equivalent insulation. Furthermore, the foam-in-place characteristics of polyurethane foams make them the most versatile of all plastic foams and certain candidates for polar application. Because the urethane foams are produced from liquid components occupying 1/30 the volume of the expanded material, substantial savings in shipping, inventory and material handling costs are guaranteed.

There are three methods of foaming polyurethane in place:

(1) Pouring. This is the method used to install a strong, seamless core of rigid urethane in wall cavities, around heated pipes or on roofs. The foam fills all angles and corners of any space or cavity, going under pipes, around corners and into crevices.

(2) Frothing. In this technique the urethane chemicals are dispensed in a partially expanded state. Because the froth expands only about three times in the cavity rather than 30 times, this process often reduces pressure on mold or cavity walls.

(3) Spraying. Large, open surfaces such as walls or roofs can be covered with sprayed-on layers of rigid urethane, using special gun-type apparatus. The chemical components are mixed and atomized as they are sprayed. To attain the desired thickness, thin layers are sprayed on successively, each adhering to the surface below, hardening, curing and sealing rapidly.

Although foam-in-place urethane insulation is certainly attractive for use in polar areas, it cannot always be applied effectively--especially on a large scale. Urethane foams are created through the combination of (most usually) two component chemicals. The quality of the end product is sensitive to and highly dependent on the initial temperature of the components, the temperature of the application surface and the ambient temperature of the surrounding air. Thus lower ambient temperatures can cause improper mixing, lengthen cure time, adversely affect final physical properties and reduce cubic-foot yields. In addition, water (condensation, excessive humidity, etc.) will chemically react with the raw materials, adversely affecting foam formation and resultant properties. Also, wind velocities greater than 10 to 15 miles per hour may result in excessive loss of exotherm, causing a degradation of density and thermal properties. Even though sometimes thermal conductivity itself may not increase appreciably, reduced yield means that some of the favorable economics of on-site application are lost.

Needless to say, environmental conditions in the Arctic and Antarctic are usually certainly less than ideal. The problem of foaming in place can partially be helped by pre-warming the component chemicals to an ideal pour temperature (usually above 70°F and often 110°F or above for self-contained high pressure equipment). With this in mind, the following questions were presented to the manufacturers of polyurethanes listed in Appendix A: Once such (pre-heated) chemicals are released to an unfavorable environment, can they nonetheless produce an insulation of satisfactory quality? Are there catalysts or special techniques available that encourage foam curing at depressed temperatures?

For the most part, responses to these questions were negative. Companies hesitate to make claims about their products, other than those stated in brochures, without knowing all the details of a proposed application. It is safe to say that there is no single additive or combination of additives that will guarantee proper foam mixing and curing over a range of low temperatures. On the other hand, most companies admit that they are developing or plan to develop special duty formulations for use in hostile environments. The Foam Systems Company of California, for instance, recommends the use of their special "Winter Grade" foams when temperatures fall below 50°F. Even this special mixture, however, is not recommended for foam-in-place application when air temperatures or surface temperatures fall below 20°F, something which happens constantly in the polar regions.

There is one foam-in-place urethane product that has already been widely used in the Arctic. Insta-Foam Froth-Pak urethane foam dispensing systems have been used at Prudhoe Bay, Alaska, to insulate building support piles and in numerous civil projects on the North Slope. Each Insta-Pak unit is a self-contained aerosol system, including all chemical components and dispensing equipment for on-location production of foam in formulated densities from ½-pound to 4½ pounds per cubic foot. Like other urethane systems, components should be dispensed at an ideal pour temperature, thus it is necessary to maintain the self-contained chemical tanks near 75°F. Also, under very cold weather conditions, the dispensing lines should be insulated and

heated so that reactants do not cool before arriving at the mixing-applicator gun. One unique feature of the Insta-Foam product is that it has been successfully foamed (at least in confined spaces) at ambient temperatures as low as -20°F. This product deserves further investigation.

CONCLUSIONS

The physical, thermal and performance characteristics of most thermal insulations are well established and available from literature. However, there is still a need for additional testing and development of foam-in-place type insulations--especially with regards to application under extreme environmental conditions as encountered in the polar regions. Foam-in-place insulations have been developed and used both historically and presently under temperature conditions typical of stateside, which usually implies 70°F or above. Perhaps with a little development of additives or special techniques, it may be possible someday to foam easily and reliably under much colder conditions. New products, as they become available from industry, should be tested and added as applicable to the inventory of cold-weather construction materials.

RECOMMENDATIONS AND FUTURE WORK

The current literature search is complete; however, an open contact with the chemical plastics industry should be maintained. New products acceptable for cold-weather foam-in-place applications should be tested as they become available. For the present work effort, two medium-sized (9.6 cu ft) Insta-Foam Froth-Pak kits have been purchased for field-test evaluation at Barrow, Alaska, and laboratory cold-chamber evaluation at CEL.

REFERENCES

1. U.S. Foamed Plastics Markets and Directory: 1974. Westport, CT. Technomic Publishing Co., Inc., 1974.

2. Thomas Register of American Manufacturers: 1976. New York, NY. Thomas Publishing Co., 1976.

APPENDIX A

The following companies were contacted by letter to obtain the industrial background information and product literature used in this report.

Polyurethanes

Witco Chemical Corporation
Isocyanate Products Division
900 Wilmington Road
New Castle, DE 19720

Mobay Chemical Company
Division of Baychem Corporation
Penn Lincoln Parkway West
Pittsburgh, PA 15205

The Upjohn Company
CPR Division
555 North Alaska Avenue
Torrance, CA 90503

API Systems
13618 Vaughn Street
Pacoima, CA 91331

Hightemp Resins, Inc.
225 Greenwich Avenue
Stamford, CT 06902

Quik-Foam Insulation Company
9449 South Central Expressway
Dallas, TX 75216

Pelron Corporation
7847 West 47th Street
Lyons, IL 60534

Dow Chemical Company
Urethane Chemicals
2040 Dow Center
Midland, MI 48640

Glo-Brite Products, Inc.
6415 North California Avenue
Chicago, IL 60645

The Flintkote Company
Sealzit Division
3640 Chicago Avenue
Riverside, CA 92507

PPG Industries
Number 1 Gateway Center
Pittsburgh, PA 15222

Sherwin-Williams Company
11541 South Champlain Avenue
Chicago, IL 60628

Mr. Theodore M. Komen
President
Foam Fabricators, Inc.
316 South 16th Street
St. Louis, MO 63103

Atlas Insulation Company
6 Willows Road
Ayer, MA 01432

Hastings Plastics Company
1704 Colorado Avenue
Santa Monica, CA 90404

Flexible Products Company
1007 Industrial Park Drive, N.E.
P.O. Box 996
Marietta, GA 30060

DeBell & Richardson, Inc.
Hazardville Station
Enfield, CT 06032

Zero-Foam Products
Division of Zero Manufacturing Company
4540 Brazil Street
Los Angeles, CA 90039

BASF Wyandotte Corporation
Industrial Chemical Group
Alkali Square
Wyandotte, MI 48192

GSF Corporation
44-T Lowell Junction Road
Andover, MA 01810

Polystyrene

Mr. D. D. Albers
President
Amxco, Inc.
850 Avenue H East
Arlington, TX 76010

Durelite Corporation
P.O. Box 947
63 David Street
New Bedford, MA 02741

Mr. C. Allen
President
Falcon Manufacturing, Inc.
P.O. Box 83
Wichita, KS 67201

Mr. K. L. McLaren
Sales Manager
Morval-Durofoam, Ltd.
156 Birch Avenue
Kitchener, Ontario, Canada

Mr. Harold P. Stern
Sales Manager
Rector Insulations
9 West Prospect Avenue
P.O. Box 427
Mt. Vernon, NY 10551

Mr. W. J. McGarrity
Toyad Corporation
P.O. Box 30
Latrobe, PA 15660

Thermacon Industries, Inc.
Number 1 Thermacon Building
Rockhill Road
Cherry Hill, NJ 08034

Mr. I. H. Leach
President
AMFLO
3406 Solano Avenue
Napa, CA 94558

Mr. E. Oftedahl
President
Expanda-Foam, Inc.
966 Anita
Antioch, IL 60002

Mobil Foam Products
Mobil Chemical
Plastics Division
Macedon, NY 14502

Mr. B. Chosnek
President
Poly Molding Corporation
Fourth Avenue
Haskell, NJ 07420

Mr. N. J. Huber
President
Standard Molding Corporation
1501 Webster Street
Dayton, OH 05404

Mr. Robert W. Schock
President
Tufflite Plastic, Inc.
19 Low Street
Ballston Spa, NY 12019

Urea Formaldehyde

Borden Chemicals
180 E. Broad St.
Columbus, OH 43215

U. F. Chemical
37-20 58th St.
Woodside, NY 11377

Phenol Formaldehyde

Isochem Resins Co.
221 Cook St.
Lincoln, RI 02865

Smithers-Oasis
919 Marvin Ave.
P.O. Box 118
Kent, OH 44240

Foamed Glass

Pittsburgh Corning Corp.
800 Presque Isle Drive
Pittsburgh, PA 15239

Foamed Rubber

Armstrong Cork Company
Lancaster, PA 17604

In addition, letters were sent to the following companies regarding the availability, cost and use of pre-insulated piping systems for cole-weather application.

Accessible Products Co.
1350 E. 8th
Tempe, AZ 85281

Cosmodyne Division
2920 Columbia Street
Torrance, CA 90503

Widwesco-Enterprise, Inc.
1650 North Elston Avenue
Chicago, IL 60690

Triangle Pipe and Tube Co.
6900 Jersey Avenue
New Brunswick, NJ 08903

Ric-Wil, Inc.
10101 Brecksville Road
Brecksville, OH 44141

Thermacor Process, Inc.
500 N.E. 23rd Street
Fort Worth, TX 76106

Cemco Products Inc.
Building 228-T
Snohomish County Airport
Everett, WA 98204

Chapter 6

UTILITY DISTRIBUTION SYSTEMS

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Chapter 6

UTILITY DISTRIBUTION SYSTEMS

INTRODUCTION

The objective of this chapter is to document experience gained in the installation and maintenance of utility systems at McMurdo Station. The discussion of utilities might include the telephone and fuel distribution systems; however, few problems peculiar to the Antarctic have been experienced with either. As a result, the information following is concerned with the water distribution and sewage collection systems and to some extent to the electrical distribution system.

WATER AND SEWAGE SYSTEM

Installation of the water distribution and sewage collection piping at McMurdo Station began in Deep Freeze 64 and included approximately 6,000 feet of 2-, 4-, and 5-inch waterline and 1,500 feet of 6-inch sewerline. All piping was placed above ground on wood cribbing and was electrically heat-traced, insulated, and jacketed to prevent freezing (Figure 6-1). In DF-66 and DF-67 an automatic alarm and drain valve system was installed to prevent freezing should the pipe-heating system fail. The enunciators for this system are located in the diesel power plant building. In the period that followed the initial installation, numerous failures occurred in the water and sewer systems that required innovative on-site repairs. Additions were also made which resulted in a conglomerate system using materials from many manufacturers. Portions of the system were also built up using on-site materials when preassembled piping was not available. A description of the preassembled and on-site assembled pipe materials follows, with the details of construction listed in Table 6-1.

Corrugated-Steel-Jacketed Piping

The first waterlines and sewerlines at McMurdo consisted of prefabricated electrically heat-traced and insulated pipe material with corrugated-steel outer jackets (Figure 6-2). Both waterlines and sewerlines were of similar construction, consisting of type K copper tubing with resistance-wire heating elements, polyurethane insulation from 2-3/4 to 4 inches thick, and 10-gage galvanized-steel outer jacketing. Connections for joining the 20-foot-long prefabricated sections were 150-pound tube-shoulder flanges, silver-soldered to the copper tube. Joints in the outer casing were covered with 10-gage steel bands drawn together with metal wedge clips.

During initial operation of the system, several of the resistance wire heat-tracing elements burned out and were destroyed. Investigation showed that the thermoplastic insulated elements, which had a maximum operating temperature of approximately 180°F, had overheated for a variety of reasons—element in poor contact against the copper tube, elements crossed over each other causing heat buildup, and failure of temperature controls.

Repairs consisted of replacing all of the original heating elements with 24-watt-per-

Table 6-1. Types of Heat-Traced, Insulated, and Jacketed Piping at McMurdo Station

Identifying Feature	Piping Material	Heat-Tracing Type	Insulation Type	Estimated Percent of Total Piping
Corrugated-Steel outer jacket	Type K Copper, flanged joints	24 watt/ft, thermostatic control	Mixed Types	5
Flat Aluminum jacket	Type K Copper, flanged joints	24 watt/ft, thermostatic control	Formed fiberglass half sections	45
Wood box enclosure	Type K Copper, soldered couplings	24 watt/ft, thermostatic control	Wrapped fiber-glass batts	10
Corrugated-Aluminum jacket (Sea water intake)	Epoxy and Fiberglass, flanged connection	8 watt/ft, thermostatic control	Foamed-in-place polyurethane	20
Plastic outer jacket	Type K Copper	8 watt/ft, thermostatic control	Foamed-in-place polyurethane	On-site but not installed
Corrugated-Aluminum jacket	Epoxy and Fiberglass, flanged connection	Self-regulating Auto-Trace	Foamed-in-place polyurethane	20

foot Electro-Wrap heating tape (described later) manufactured by the Electro-Trace Corporation, Danbury, CT. This replacement required complete disassembly of the installed piping and removal of the heavy steel jacket and insulation from the individual pipe sections. During the latter operation a considerable amount of the urethane insulation was damaged and was replaced with fiberglass and other available substitutes.

By DF-74 most of this original corrugated-steel-jacketed piping had been replaced and only small sections of this material are still in use.

Flat-Aluminum-Jacketed Piping

In reworking the corrugated-steel-jacket system, much of the flanged copper pipe was salvaged for re-use by applying new fiberglass insulation with heavy gage flat-aluminum-foil/kraft-paper jacketing over the electrically heat-traced pipe (Figure 6-3). Joints in the 3-foot-long sections of insulation were taped with 4-inch-wide polyethylene pressure-sensitive tape made by the 3M Co., St. Paul, MN. Tapes from other manufacturers have also been tried. None have been found that remain entirely serviceable and undamaged by weather for more than a year (Figure 6-4).

For thermal insulation the pipe flanges were wrapped with batts of fiberglass and taped over entirely with the polyethylene tape. This method of construction is not entirely satisfactory because splits developed in the tape within a year, exposing the insulation (Figure 6-5). The splits in the tape form as a result of weathering and from stretching the tape excessively during application.

Plywood-Jacketed Piping

A shortage of more suitable materials in DF-68 resulted in several hundred feet of 6-inch sewerlines and 4-inch waterlines being insulated with fiberglass batts and jacketed from the weather in a plywood box (Figure 6-6). This installation has been reasonably satisfactory but requires an excessive amount of labor to install and is not as weathertight as the metal-jacketed piping. Shortly after construction, a sewerline leak saturated and made unusable more than 100 feet of the piping because of the permeability of the fiberglass.

Corrugated-Aluminum-Jacketed Piping

In DF-72 large numbers of leaks began to develop in the saltwater-intake pipeline to the distillation plant. Investigation showed that pinholes were developing along the bottom of the pipe. This was found to be typical erosion-corrosion caused by turbulent flow of the seawater on the copper surface. Three materials were considered for complete replacement of the line: 90-10 copper-nickel pipe, Poly(Vinyl Chloride) (PVC) pipe, and filament-wound fiberglass-epoxy pipe. Selection of the latter material over the others was based on its cost and on its impact resistance at low temperatures.

The fiberglass-epoxy pipe was obtained from CEMCO Products Co., Everett, WA, in an electrically heat-traced, insulated, and jacketed assembly with flanged pipe connections. The insulation was 3-inch-thick polyurethane, foamed in-place between the pipe and the jacket of corrugated aluminum to form a rigid unitized assembly. This type of construction is light in weight, requires less labor for installation, and is impervious to moisture should a leak develop in the piping. Also, because the insulation is foamed in place, there is no movement of the pipe in the jacket. This facilitates anchoring of the pipe which is important on the hillside installation.

Plastic-Jacketed Piping

The fifth type of insulated and heat-traced piping in the McMurdo water and sewer system is similar to the piping just described but utilizes a PVC plastic outer jacket over the foamed-in-place urethane insulation. The piping is type K copper and is electrically heat-traced with Electro-Wrap heating element, as in the other jacketed and insulated piping assemblies. This material designated as X-50 piping is manufactured by Triangle-Price Co., New Brunswick, NJ. Extensive study of this material was made at NCEL in 1970 and 1971 and is described in detail in Reference 1. At the date of this writing, the X-50 piping had not yet been installed.

Brine-Return-Line Piping

In DF-74 the brine-return line from the distillation plant on Observation Hill was replaced because of pinhole corrosion of the copper. The material used was preassembled

fiberglass-reinforced epoxy pipe, heat-traced, insulated, and jacketed in corrugated aluminum. This material was also made by Triangle Price Co., New Brunswick, NJ, and resembled the saltwater-intake line in construction. A new self-limiting electric heat-tracing element that does not require thermostatic temperature control was used in this assembly. This element was made by Electro-trace Corp. and is described later in this chapter.

Cribbing and Pipe Supports

All of the liquid distribution systems at McMurdo Station are constructed above ground and supported on wood cribbing from a few inches to about 12 feet above the ground. These differences are necessary to maintain the grade and provide gravity flow in the sewerline. Much of this cribbing consists of well-braced four-legged structures set directly on the ground surface (Figure 6-7). Supports are not set into the ground because of the difficulty of digging into the frozen, rocky terrain. This method of pipe support has been reasonably satisfactory but is time-consuming to construct. Also, thawing of the ground surface often results in the subsidence beneath the timbers, leaving them unsupported (Figure 6-8). This condition is effectively corrected by dumping earth fill around the leg of the pipe support.

Pipeline Freeze Protection

The sewerlines and waterlines for both saltwater and freshwater are protected from freezing by applying an electric heating element against the outside of the pipe under the insulation and protective outer jacket. Three slightly different heating elements, all manufactured by Chemelex Co., Redwood City, CA, are used as shown in Table 6-1. The construction of these elements is unique in that they can be cut to any desired length without destroying the heating element or changing the voltage on which they operate. The 24-watt-per-foot and 8-watt-per-foot elements provide a fixed heat output and require a thermostat attached to the pipeline for temperature regulation. Figure 6-9 shows the construction of the Electro-Wrap heat-tracing element.

The Auto-Trace, Chemelex Co., element is a newer product and resembles the Electro-Wrap in arrangement of the conductors and resistance element but is self-regulating and does not require a thermostat for temperature control. This is possible because the resistance of the conductive element increases as the temperature increases and decreases with temperature decreases, thereby automatically controlling the current and heat output. The nominal rating of the Auto-Trace element is 3 watts per foot at 50°F. Greater heat input can be obtained by spiraling the element around the pipe or by applying two or more elements.

Electrical power is brought to the terminal of the heating elements through rubber-insulated cables laid alongside the pipes. The thermostats for the older-style heating elements are located in raintight, electrical panel boxes along the pipeline. Many of these panel boxes still contain the 88-volt stepdown transformers used to reduce the electrical load and heat output of the 24-watt-per-foot heating element when first installed. None of these small transformers were in use following DF-72. One problem often encountered with the electrical panel boxes is that of packing with snow (Figure 6-10). When the snow

melts, electrical problems are common. About DF-67, canvas bags resembling duffel bags were placed over the boxes, very effectively excluding wind-borne snow. By DF-74, nearly all of these had been lost or had deteriorated, however; and the problem had returned.

Insulation for Pipeline

As indicated in Table 6-1, several types of thermal insulation are used to retard heat loss from the waterlines and sewerlines. From in-service observations, it is believed that the foamed-in-place polyurethane provides the greatest service and results in the lowest heat loss. The advantages are:

1. The outer jacket and inner pipe are rigidly fixed into a single unit which facilitates anchoring the pipe on the hillside runs.

2. The urethane forms a more rigid structure with the pipe and outer jacket, thereby reducing the number of pipe supports required.

3. Urethane is lighter in weight than other pipe insulations of comparable insulating value.

4. Urethane insulation is essentially impermeable to water, and leaks at pipe connections cause little damage.

The principal disadvantages are:

1. The rarely occurring failure of a heating element would require complete replacement of the pipe section.

2. The composite structure makes cutting of a section of pipe more difficult.

Since the disadvantages are seldom encountered, they are believed to be more than offset by the advantages.

ELECTRICAL SYSTEM

The electrical distribution system at McMurdo consists of a 1,460-volt primary and a 208-volt secondary. Power is carried overhead through insulated conductors on 30-foot wooden poles spaced more closely than is common at facilities in more temperate areas. Both the insulated-wire and short-wire spans are used to reduce the possibility of electrical shorting during periods of high winds, which have been recorded with gusts of 116 mph. This shorting problem was eliminated on the main powerlines from the nuclear power plant on Observation Hill by installing them in four rigid steel conduits elevated a few feet above the ground. The conduits were supported on a T-shaped pipe and channel iron bracket. The pipe leg was set into holes drilled into the hillside with a pneumatic wagon drill. This produced an exceptionally neat and trouble-free installation.

Pole Setting and Guying

Emplacement of the power poles and guying continues to be difficult because of the frozen and fragmented rock terrain. Holes can be hand-dug with jack hammers but are more easily drilled with the tube core drill and rotary drill rig described in Chapter 10. In some cases, however, the steep hillsides or close proximity to buildings prevent its use. Guy-wire anchors for power poles or other needs can be provided by drilling a 2-inch or larger hole with the wagon drill and implanting a steel rod. The hole is then backfilled with water and fine dirt and allowed to freeze. Care should be taken to see that the entire hole is filled with liquid if full holding strength is to be achieved. If such anchors are carefully placed in solid terrain, tangential adfreeze strength over 200 psi of surface area is obtained [2].

Corrosion and Insulator Cleaning

For most of the year, McMurdo is not thought of as a coastal station because it is icebound for up to 9 months of the year. During the remaining period, however, open water is generally present in the vicinity; and winds carry the salt moisture ashore. Since there is no rainfall at McMurdo, accumulations of these electrically conductive salts build up on switch gear and insulators, causing corrosion and electrical breakdown. To overcome this problem, some preventive maintenance is required. Through DF-73 this had consisted of periodic rebuilding of corroded elements and a routine washing of transformer insulators. Since no mechanized insulator spray washers are available at McMurdo, the procedure has been to remove the insulators and clean them in the galley dishwater.

Moisture-displacing chemical sprays of the types recommended for drying electric motors and automotive ignition systems have been tried as a preventive maintenance aid on insulators, but these were found to be of little value.

Electrical Insulation

When procuring electrical wire and cable, care should be taken in specifying the insulation, or a material may be obtained which will crack and flake at low temperatures. Two types of plastic insulations have been found satisfactory at temperatures to -50°F. These are polyethylene (PE) and fluorinated ethylene propylene (FEP). Rubber compounds for electrical insulation vary widely, depending on individual formulations by the various manufacturers: some neoprene rubbers have been satisfactory, while others crack and flake badly in the cold. The most reliable method of obtaining a usable product is to subject actual manufacturers' samples to cold-chamber tests.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Report R-733: Single-line, heat-traced piping system, by C. R. Hoffman. Port Hueneme, CA, June 1971.

2. ——. Technical Report R-700: Holding strength of piles in ice, by N. S. Stehle. Port Hueneme, CA, Oct 1970.

Revised – 1979

Figure 6-1. Freshwater line as seen from Observation Hill.

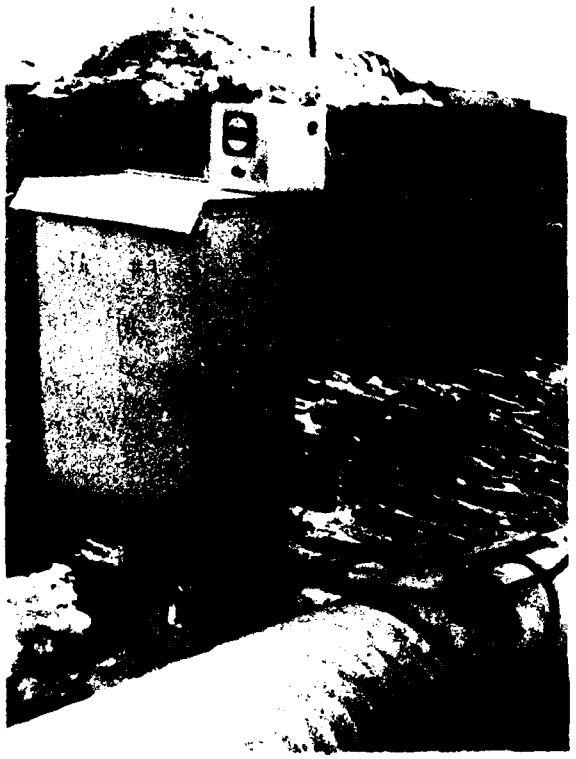

Figure 6-2. Typical corrugated-steel-jacketed piping used in first liquid distribution system.

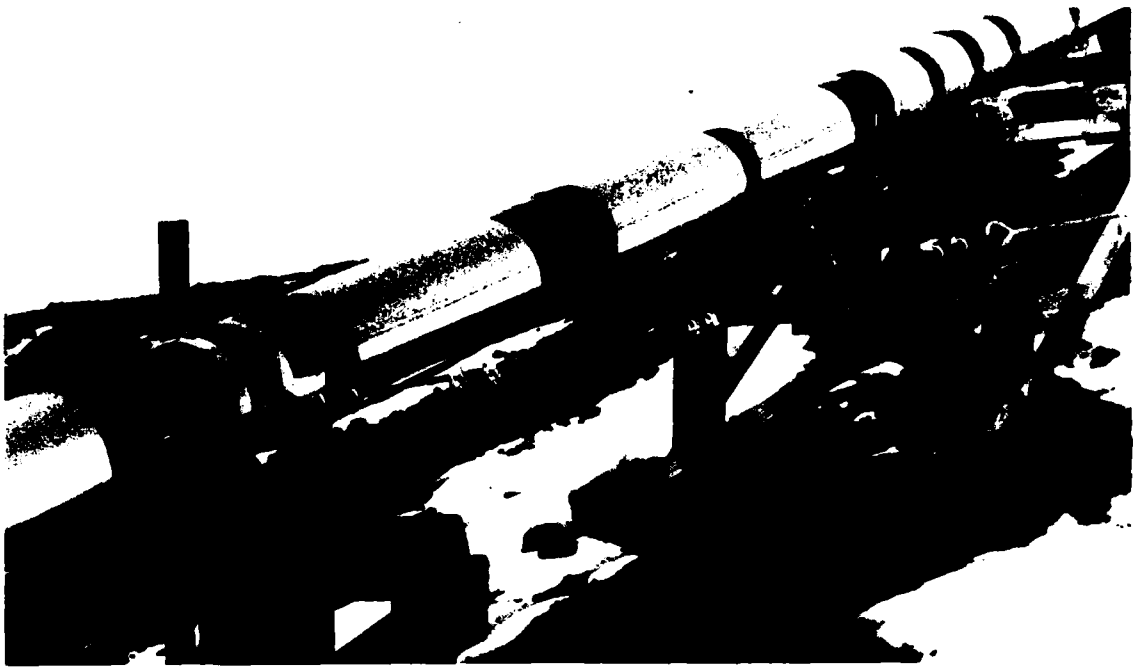

Figure 6-3. Waterline with 3-inch fiberglass insulation and heavy aluminum foil and kraft-paper jacketing.

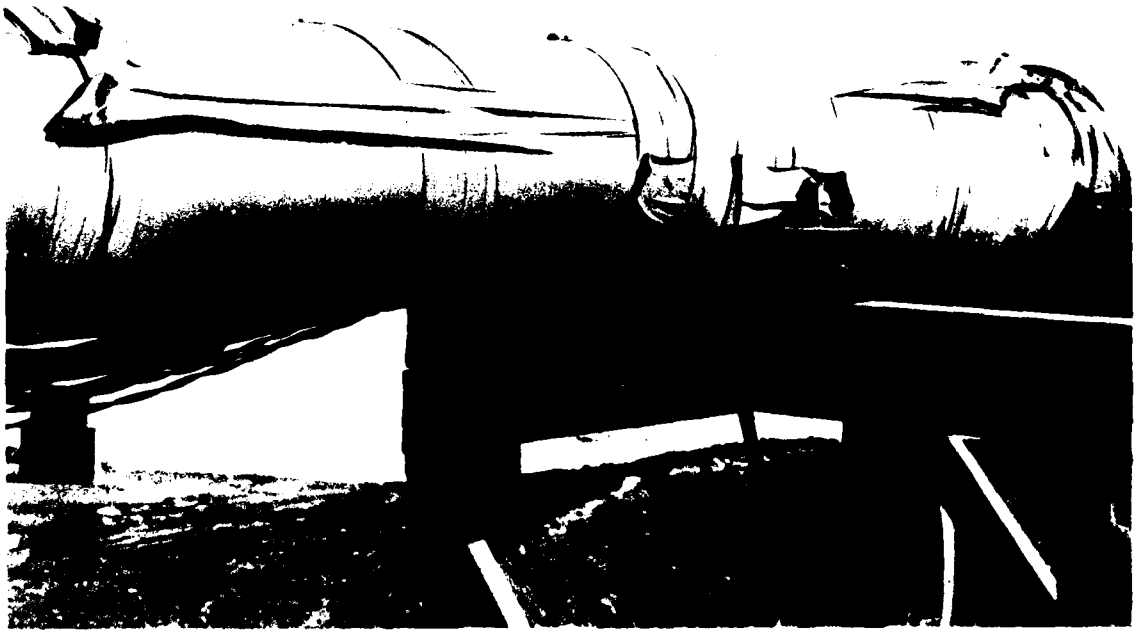

Figure 6-4. Polyethylene tape peeling from aluminum-jacketed sewerline after 1 year.

Figure 6-5. Weathering and splitting of polyethylene tape over pipe flange insulation after 1 year of service.

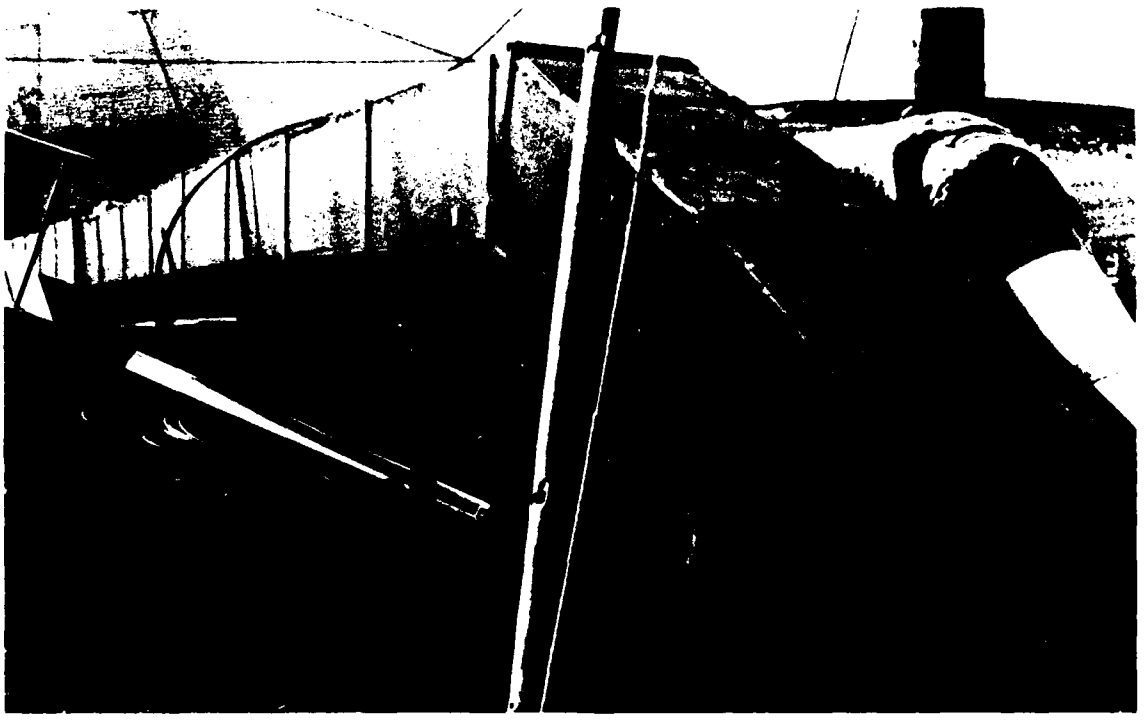

Figure 6-6. Plywood enclosure for fiberglass-insulated sewerline.

Figure 6-7. Typical wooden cribbing supporting piping system. Piping is original saltwater and brine-return lines.

Figure 6-8. Loss of pipeline foundation support caused by ablation of ice beneath dirt.

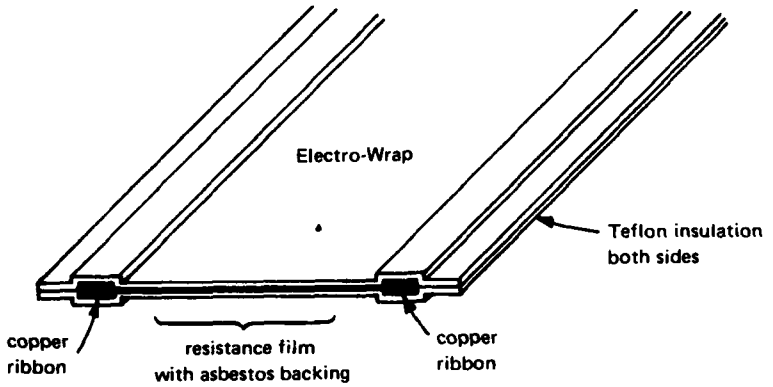

Figure 6-9. Construction of 8- and 24-watt-per-foot Electro-Wrap heat-tracing tape.

Figure 6-10. Wind-driven snow accumulation inside electrical distribution panel for waterline and sewerline heat tracing.

LIST OF APPENDIXES

Chapter 6

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

6-A. **Civil Engineering Laboratory. Technical Memorandum M-61-77-8: Recent advances in cold-regions liquid-distribution systems, by J. L. Barthelemy, Aug 1977.**

6-B. **-----. Technical Memorandum M-61-78-7: Conservation concepts related to the production, distribution and consumption of potable water at Antarctic stations, by J. L. Barthelemy, Jun 1978.**

6-C.

6-D.

6-E.

6-F.

6-G.

6-H.

6-I.

6-J.

Addition – 1979

TM no. M-61-77-8

TECHNICAL MEMORANDUM

title: RECENT ADVANCES IN COLD-REGIONS LIQUID-DISTRIBUTION SYSTEMS

author: J. L. Barthelemy

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RECENT ADVANCES IN COLD-REGIONS LIQUID-DISTRIBUTION SYSTEMS

YF52.555.001.01.006

by
J. L. Barthelemy

August 1977
Sponsored by Naval Facilities Engineering Command

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INTRODUCTION

The hostile environment encountered in the polar regions presents man with many problems atypical to other parts of the world. Winter climatic conditions are severe, characterized by periods of total darkness, low temperatures and strong winds. The predominant soil structure often consists of high-ice-content permafrost, ground that is very difficult to excavate, both in the frozen and thawed states. Permafrost is also very sensitive to thermal disturbances. Any structure placed on or in frost-susceptible soils that interferes with the natural heat-exchange process is in danger of settling during the thaw season and possibly heaving during the winter refreeze.

Outside work is accomplished under extreme winter conditions only through great effort and hardship. Very few readily usable resources are available--supplies, equipment and construction materials are ordinarily transported at great expense by ship or airplane. Thus construction by conventional means is often impossible. Special considerations must be provided to counteract cold-weather conditions. For instance, maintaining water in a liquid state throughout a distribution system is the major problem confronting the water-supply engineer in the Arctic and Antarctic. Although many schemes have been developed to this end, there are actually only two variations. Either enough heat is added to the water to prevent it from freezing, or the system is designed such that the liquid can be removed from the piping prior to freezeup. This Technical Memorandum considers some of the state-of-the-art advances in the design and construction of water and waste-water distribution systems in the polar regions.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

The delivery of utility services, such as supplying water to and removing waste-water from individual buildings in permafrost regions, is technically difficult and usually very expensive. During the past twenty years, a great variety of systems have been used to provide these services. Techniques such as above and below ground utilidors, various amounts and types of insulation around pipe, alternative means of heating and supporting the piping systems, and the use of centralized facilities, have all been studied. In 1965, the Civil Engineering Laboratory (CEL) began investigating systems for the distribution of freezable liquids in polar regions. The initial effort was directed toward a single, preassembled, insulated, electrically heat-traced piping system. In March 1967, the Northwest Division of the Naval Facilities Engineering Command (NORWESTDIVNAVFAC) requested CEL to investigate composite utilidor distribution systems to determine the most suitable and least costly above-ground design for naval polar facilities. The request was based on the need for about 2300 feet

of multiline piping carrying water, sewage and medium-temperature hot water to future facilities at the Naval Arctic Research Laboratory, Point Barrow, Alaska. The investigation was undertaken in June 1968; the results are published in a Technical Report (1) issued in 1971.

In the past few years especially, the Arctic has become a focal point for research and development. The recent discovery and exploitation of petroleum reserves has resulted in a dramatic surge in cold-weather technology. Many problems have been solved while others are being studied in greater detail than ever before. Accompanying the industrial development has been an increased awareness and desire on the part of the public sector to share in the "luxuries" of the South. More now than ever, the goal of most northern communities is to have year-around, piped water and wastewater utilities similar to their southern counterparts. Some argue that utility systems in the polar regions are still in their infancy--that much more development is necessary before universal codes and standards can be adopted. This may be true. But progress is being made, and this becomes obvious if we preface our study of current construction projects with a brief review of historical water distribution systems.

Historical Review (2)

The first water supplies in America were those of the native populations--in the North the Indians, Eskimos and Aleuts. There was little need for distribution networks, since the communities were primarily semi-permanent. Water was obtained from warm springs, melting ice and snow, and summer streams and rainwater when available. Some individuals still rely on this method as a sole source of water. The collection process is very time-consuming, although the two to five gallons per capita per day does not nearly approach that of a modern community.

Intermittent pumping was developed by very small communities where complete control of the water was practical. The distribution system was usually located underground and installed so that all the lines, including those used as service connections, could be quickly and easily drained. In the summer months, the system operated as any conventional system. During the winter, the water could not be left in the lines. Thus on a predetermined schedule, water would be distributed through the system so that each consumer could fill a storage tank in his house. The tank was usually located in an attic so that water pressure was available without the use of individual pumps. When the distribution system was deactivated, all water was removed by gravity drainage. This method is feasible for small communities, but is inadequate for larger numbers of residents. One definite disadvantage is the lack of fire protection afforded the community.

In 1903, Dawson City in the Yukon Territory constructed what was probably the first true water distribution system in the Far North. A conventional system was built, with the provision that water could be bled from each service connection and at the end of each main on a continuous basis during the periods of deep frost penetration. Water was in constant motion through

the piping, preventing freezeup as long as the heat lost between the pump and the end of the main was less than the amount required to form ice. The "bleeding" method of freeze prevention has many disadvantages. Much more water is distributed than is actually used for consumption. If the raw water requires extensive physical or chemical treatment, the economics become very unfavorable. Also, if waste water is discharged into a sewerage system, the resulting dilution of organic wastes will cause excessive hydraulic load on the treatment plant and undoubtedly reduce the efficiency of the biological processes. Even the size of the pipes and treatment facilities will be greater, increasing costs even more. However, in areas of low population and abundant good-quality water, this method still finds some application.

The system commonly used in the northern United States and the southern areas of Canada is to bury the pipes to a depth greater than the expected seasonal frost line. Such a system is also practical in many Far North areas that are not located in regions of permafrost; however, this is the exception rather than the rule. In areas of permafrost, the problem of freezeup in a buried water line can be partially avoided by adding heat to the water before it is pumped into the distribution system and by heavily insulating the line. Although the economics of the highly insulated water main appear good, the system does not solve one major problem--that is, freezing inherent in the individual service connections. The service line must enter the house at approximately foundation level, which is often at a depth severely influenced by freezing. Service lines are usually small-diameter pipes and are thereby more likely to freeze. Most important, water flow through the service lines is intermittent, depending upon demand and time of day. Water not in motion freezes much more rapidly than running water. Experience has shown that heavily insulated systems that do not provide for continuous water movement through the service connections result in a tendency to allow water to run during the night, low-use hours to prevent freezing. Such practices have the same disadvantages as the "bleeding" type system, namely a large amount of wasted water.

A basic solution to the problem of service-line freezeup involves letting the water circulate continuously, both in the main distribution lines and in the individual house connections, and heating the recirculating water (when necessary) as it is cooled through the distribution system. The dual-main line system accomplishes these objectives. The water initially leaves the pumphouse in a high-pressure line. If thermodynamic conditions warrant, heat may have to be added at this point. The house service comes off the high-pressure line, into the dwelling, through a pressure-reducing valve, and out of the dwelling, discharging into a second main operating at a lower pressure. The low-pressure line returns to the pumphouse or intermediate storage facility where it is heated, if necessary, and then returned to the distribution network in the high-pressure main. Thus the dual-main system keeps water constantly in motion throughout the entire piping network. The glaring disadvantage of this system is that two mains must be installed throughout, thereby nearly doubling the first cost of the installation.

One way to circumvent the necessity of providing two mains is to install a single recirculating main, but equip each house or building with its own service loop and continuously operating pump. Water is drawn from the main by the pump, and water not used is returned to the main. Although such a system is workable, and has found limited application, it does require that each customer install and maintain a pump. In 1952, the Arctic Health Research Center of the U.S. Public Health Service began studies to develop a better method of providing a continuously circulating water system. After considerable experimentation, they developed what will be referred to as the single-main recirculation system. Basically, this method of water distribution consists of one water main through which water is continuously pumped. The flow path is from a treatment plant or primary pumping station around a loop and either back into the same pumping station or into another station. Heat is added to the water, when necessary, at the pumphouse. The problem of maintaining flow in the service connections without reverting to bleeding or individual pumps was solved by the development of a device which has become known in the North as the "pitorifice." The name is derived from both pitot tube and orifice, since their principle of operation involves the fundamentals of each device. The pitorifice is inserted into the main as a corporation stop. A dual service connection (two pitorifices) is used: one line in which water flows from the main to the house; a second return water line from the house to the main. Velocity in the service connections is produced by utilizing the velocity head of the water in the main.

In 1952, Fairbanks, Alaska, became the first city in the north to design and construct a full-scale community water distribution system using the single-main recirculating method. Alter (3) considers that project to be the greatest success of the Alaska Public Works Program. Murphy and Hartman (2) feel that the single-main recirculation method is the best devised to date for the Arctic regions. However, they qualify that statement by restricting it to what they consider the private sector--that is, non-institutionalized installations which are not suitable for the more expensive methods developed by the military for camp complexes. Academic institutions, military bases and company facilities may or may not find the single-main method most economical. For instance, a naval site may house many men and yet be constructed in such a way that the entire complex is one large building with a number of wings. Such construction lends itself to the placement of utilities under the floors, in separate indoor utilidors, and other configurations. In the private sector, however, people demand relatively large lots and homesites, similar to what is available in other areas of North America. The most economical solution for such a layout is the one which most closely approaches that found in what can be termed a conventional system. Thus the single-main system is most suitable for the average northern city where the utility does not have complete control over where buildings are located.

The most elaborate approach to freeze protection in polar piping networks is to nest all the utilities in a single highly insulated and heated conduit,

or box-like structure, commonly termed a utilidor. A review of literature suggests that government agencies, especially the military, have spearheaded the development of utilidor systems. This is not surprising, since utilidors tend to be high-technology solutions and require more extensive research and greater capital expenditures than do more conventional heated/insulated piping systems. What's more, as Murphy and Hartman point out, military installations can be planned so that the utility itself is the controlling factor in building size and location. A complex can be configured so that piping runs are minimized while waste heat from nearby power generating equipment is utilized.

Current Considerations

The past few years have seen rapid development of the Far North--not only by the oil industry, but by government construction as well. Both the United States and Canada have made long-term commitments to the people of the region. It has been long recognized that one of the first steps in improving the condition of life for all peoples is the provision of adequate water and sanitation systems. The federal government of Canada has acknowledged the importance of such improvements. The first national objective for the north, which is placed before renewable and non-renewable resource development objectives, is:

> "To provide for a higher standard of living, quality of life and equality of opportunity for northern residents by methods which are compatible with their own preferences and aspirations." (4)

In 1973, the government of the Northwest Territories issued a Water and Sanitation Policy that involved a $120 million, ten-year program. This policy provides for gradual development of piped systems to upgrade water, sewer and solid-waste facilities. Some of the municipal projects resulting from this proclamation will be considered later in this text.

The United States is involved in the development of northern rural utility systems at both the Federal and State government levels. Until 1970, the only active program for providing sanitation services in rural Alaska was the Indian Health Service of the Health Services Administration, U.S. Department of Health, Education and Welfare. In 1969, however, Senators Ted Kennedy and Ted Stevens toured rural Alaska and were appalled at the lack of sanitation services. Their reaction was to promote a combined new Federal and new State program to answer the need for rural sanitation services. The Federal program, the Alaska Village Demonstration Project (AVDP), was created in 1970 by Congress under Public Law 91-224, "to demonstrate methods to provide for central community facilities for safe water and the elimination or control of water pollution in those villages of Alaska without such facilities...(including) water supply systems, toilets, bathing and laundry systems, sewage disposal and other similar facilities."(5) The state action was the Village Safe Water (VSW) program enacted under the Village Safe Water Act of 1970 to provide "safe water and hygienic sewage disposal facilities in villages in the state...and to assure that there will

be at least one facility for safe water and hygienic sewage disposal in each village." The two programs were intended to go hand in hand. The AVDP was to construct about two projects demonstrating how best to supply rural sanitation services, and then the State was to follow along, building sanitation systems as developed by the AVDP. (6)

The Alaska Village Demonstration Projects are administered by the U.S. Environmental Protection Agency in the Office of Research and Development. Responsibility for the AVDP has been assigned to the EPA's Arctic Environmental Research Station in College, Alaska. The Village Safe Water programs are administered by the Alaska Department of Environmental Conservation. Both programs call for the construction of central sanitary facilities as opposed to service to individual homes, the goal of the Canadian development program.

Since there are no rigidly applied standards for the construction of liquid distribution systems in polar regions, water utility design tends to be largely individual and full of innovative detail. Thus existing and proposed water and sanitation systems reflect major differences of opinion. Controversies include the concept of central sanitation services versus individual piping, utilidor versus single-pipe construction, and metal versus plastic pipe usage. One argument which has been settled in many minds is the question of above-ground versus below-ground piping systems. In the past, especially in permafrost regions, above-ground piping was generally used, primarily because of early failures in permafrost construction, lack of hydrophobic insulation materials and insufficient engineering design information. As new low-heat-transfer materials, such as urethane and polystyrene, and powerful hydraulic backhoes became available to handle frozen ground, the trend has reverted to buried insulated utilities. Above-ground piping systems are aesthetically unpleasing. Elevated utilidors tend to restrict the movement of pedestrians and vehicle traffic, thereby unnaturally segmenting a community. They usually require expensive overpasses and restrict land use. Although these problems are mainly concerns of the civil community, they do apply to military establishments as well. Other factors are even more important to military construction. From the standpoint of design, above-ground pipes are subject directly to daily and even hourly temperature fluctuations and must be designed for the minimum air temperature with an appropriate wind-chill factor. From the standpoint of maintenance, exposed pipes usually require many more costly repairs and have a shorter life-span. In addition, they are more prone to vandalism, accidents and even sabotage.

The disadvantages of buried utility systems include difficult and expensive excavation and foundation design. Repairs tend to be more costly and time consuming, especially when frozen ground must be excavated. The situation is even worse in unstable, ice-rich permafrost. The piping system must be designed so that excessive heat loss does not cause differential settlement and heaving of the supports. In addition, in thermally sensitive soils, surface distrubances due to actual construction of the utility line may cause more thaw and settlement than operation of the line itself. Construction

should be scheduled to minimize disturbances and restrict movement of construction equipment. A better method is to excavate the soil to the maximum thaw depth expected and replace the unstable soil with non-frost-susceptible material. Thus the availability of gravel or other thaw/freeze stable materials is a major design criterion. Other alternatives are possible. The Russians have used forced and natural ventilation during the winter to refreeze and supercool the ground under large, open utilidors.

ACCOMPLISHMENTS

Much work has been done in the Far North to develop reliable and economical liquid distribution systems since Reference (1) was issued in 1971. Thus a review of literature and technical publications was conducted under work unit number YF52.555.001.01.006, "Fluid Distribution Systems for Polar Environments," to gather information from various sectors presently involved in cold-weather utility system construction (private industry, the Canadian civil community, and Alaskan rural programs) and also to establish state-of-the-art advances in building materials, water and waste disposal system concepts and engineering design criteria.

Canada (7)

In the continuous permafrost regions of the Northwest Territories of Canada, which have a population of less than 20,000, there are no less than six communities presently constructing piped services of one form or another. Included in these projects are four underground utility systems undertaken by the Department of Public Works of the Government of the Northwest Territories. The installation now under construction at Frobisher Bay was one of the department's first attempts at a buried system in a continuous permafrost area. Other projects are at Norman Wells on the Mackenzie River, Rankin Inlet on Hudson's Bay and Resolute Bay in the high Arctic.

Frobisher Bay is a community of 2500 people located in the eastern Arctic on Southern Baffin Island. It is well above the tree line and in a continuous permafrost zone. The present water distribution system was built originally by Americans to service a military installation and airport. Water is delivered by means of an above-ground utilidor constructed from corrugated metal boxes on piles. Sewage is discharged in a similar manner through a number of outfalls going directly into the sea. Water is preheated at the treatment plant and continually circulated in the lines. The existing above-ground system continues to be an annual maintenance headache. In addition to normal operating costs, major improvements of over $600,000 annually have been required in the last two years and would be additionally required in the next few years to keep the system operational.

The new utility system will connect with the existing utilidor and will still require continued circulation of preheated water; however, it will be placed below ground. It is characterized by two major features. First, construction will use standard components designed for temperate regions: standard concrete manholes, hydrants and trunk-line pipe connections, and standard sewer-line gradients. Second, the entire distribution system is

tied to the permafrost by means of structural beams. Any thermal degradation due to heat loss from the pipes will not affect the structure, since beams will transfer the load to a point where the permafrost has not been disturbed. Settlement is thus prevented. Also, the beams will act as anchors to prevent any heaving caused by frost action in the active zone. The 8-foot-long beams are placed in trenches cut transverse to the main utility trench. All trenches, about 7 feet deep, are filled at least partially with compacted granular backfill and other stable materials.

The piping configuration is basically that of the single main recirculating method. The main protection against freezing is provided by a circulating pump placed in each house to maintain flow through the service lines. In addition, there is a heat-traced backup system which is thremostatically controlled. The house connections are built of 4-inch sewer and 5/8-inch supply and return water lines. The water mains are ductile iron with cement lining and 3 inches of urethane. The sewer mains are similar.

The main construction problems have involved dewatering the site and digging in permafrost. All trenches and excavations had to be continually pumped out because of the constant flow of ground water in the active layer. The contractor used a one-cubic-yard backhoe for excavating and, as a result, wore out an average of two sets of bucket teeth a day. There were often serious delays while teeth and other machinery parts were flown in from Montreal.

The community of Norman Wells, population 400, is located on the Mackenzie River about 90 miles south of the Arctic Circle. The potential long-term increase in population, coupled with the immediate need for a supply of water to a new subdivision, required construction of an enlarged and more reliable utility distribution system. Since the subdivision was created by landfill, it was decided to continue in that area with an above-ground system because of potential instability. Outside the subdivision, work was begun to replace the existing above-grade utilidor with a buried one.

One of the main problems with above-ground utilidors is their susceptibility to frost heaving. If the piles shift differentially because of frost action, gravity sewers within a utilidor must be regraded yearly. In order to overcome that problem, the piles are designed to be anchored into bedrock using grout and reinforcing rod welded to the bottom of the pipe. The below-ground section is being placed in what is potentially a very hazardous soil; fine silts laced with ice lenses in the permafrost areas. The design uses a computer program to predict possible thaw/settlement. As a further safeguard, steel pipe is used.

At the Rankin and Resolute Bay installations, a similar buried piping scheme is used, except that high density polyethylene pipe rather than structural steel pipe is used. In those two communities, the topography is such that the pipes are buried only one to two feet below ground with

slopes in excess of 2 percent. The steep slopes allow for sewage line settlement in contrast to the Norman Wells and Frobisher Bay designs. which attempt to ensure that the system remains stable.

Alaska (8)

The Federally financed Alaska Village Demonstration Projects (AVDP) program was established due to the lack of sufficient water of good quality to permit healthful living conditions in most Alaskan villages. The program is based on the concept that the water-related needs of a small northern Alaska community can more economically be met if people do their laundry and bathing at a central facility. The villages of Wainwright. located on the Arctic Ocean, and Emmonak, located on the Bering Straits. were selected as locations for demonstration projects. Facilities have been provided at both locations, the one at Wainwright serving about 375 and at Emmonak about 500.

Preliminary investigations at Wainwright indicated that water could be obtained from a shallow tundra lake less than two miles from the village. Expected summer quality was satisfactory; however, at other times, with ice on the lake, the water was expected to contain unsatisfactorily high concentrations of organic materials. Thus a large storage tank (1,000,000 gal) was built for winter use. The winter-storage concept was determined to be more cost-effective than other expensive schemes, such as pipeline construction, seawater desalinization and ice harvesting.

At the heart of the Wainwright facility is a two-story. 3000 sq ft building containing showers, saunas, laundry and toilets. as well as waste-water treatment facilities, power generating equipment and heating components. The laundry area contains four heavy-duty washers and five heavy-duty dryers. Treated gray waste-water from the showers and sinks, entirely separated from the potable water system. is used for the washing machines. The dryers are operated using heat from the central heating system. Each shower room contains four shower stalls with flow-control. coin-box timers. In addition, each shower room has two toilets, two lavatories and a sauna bath.

Many water-saving and energy-saving devices are employed in the facility. The largest single saving is through avoidance of standard water-flush toilets. Toilets in the central facility use a combination of air and treated gray-water for flushing, while those in the nearby school are of the recycling type used in aircraft. The washers also use reclaimed graywater. Further reduction is achieved by flow and time regulated showers which minimize water used for bathing. Sauna baths help to fulfill the need for a hot soak without the use of water. Energy cascade and heat salvage systems are provided where practical to conserve energy and minimize fuel consumption.

In addition to the basic on-site services, the facility provides water distribution and waste-water pickup services. A procedure for vehicle delivery has been worked out whereby water customers receive delivery of potable water to their home holding tanks upon request. Graywater and

blackwater collection are accomplished in a similar manner using separate containers for each substance. The vehicles at the Wainwright facility are two tracked Bombadiers with trailers. The Emmonak system is very much similar in construction and operation.

The state-financed Village Safe Water (VSW) program is patterned after the AVDP installations. Under that program, a village receiving a VSW project is not required to contribute toward costs of construction. When a VSW facility is completed, the recipient village must be given title to it. The village must agree to accept ownership and be responsible for operation and maintenance. The State may assist with operation and maintenance expenses when the local governing body lacks sufficient financial resources. By the end of 1977, Village Safe Water sanitation facilities will have been constructed in nine Alaskan communities. Much valuable information about polar design, construction, operation and maintenance should be realized as these projects are seen to fruition.

The past few years have also seen a dramatic surge in the amount of privately financed development and construction in the Far North. Discovery of oil on the North Slope ushered in a new era in water supply and waste disposal facility construction. Concepts for liquid distribution systems and central facilities were catapulted into the space age. Package plants became common and limited water reuse and minimum-flow facilities appeared. This experience is providing a rigorous test of space-age systems with their complex technology and construction. Although the full story on oil-related utility construction is still untold, some preliminary conclusions can be drawn: (3)

1. Any type of system or process can be built, installed or operated in the North, given enough money, energy and manpower.

2. These systems may not be available to persons and groups of less means.

3. Operation and maintenance is a continual problem, even in the situation where private industry has clearly defined responsibilities for operation and maintenance.

In addition, ARCO and EXXON have made available capital and operating cost information for the sewage treatment and water treatment plants in their joint operations center on the North Slope. Before mid-1975, the plant was sized to serve 300 to 400 people and was therefore comparable to the ADVP facilities. Average monthly operating costs were about $12.000 for water treatment and $8,000 for sewage treatment. The $6300 total average monthly cost of operating the Emmonak ADVP facility compares quite favorably with these figures. ADVP capital costs have also generally been lower.

Materials

A promising new trend in utilidor design is the recent development of prefabricated, insulated piping conduits capable of carrying water and sewer mains, as well as heating lines where required. The conduit has a metal or fiberglass-reinforced plastic exterior, insulation, and casing which together provide a self-supporting structure adaptable to either above-or below-ground installations. System appurtenances such as hydrants, valves and junction boxes are prefabricated as modules and inserted in the system as required. The system, shown in Figure (1), is known as U-Dor and is manufactured in Canada by Fiberlite Products Co., Ltd.

According to the designer (9), the approach has many advantages. He believes the system will reduce engineering design time and costs by about two-thirds, since only plan-profile drawings need to be prepared specifying standard components described in the U-Dor manual. The U-Dor should substantially reduce on-site construction time and costs, which account for about 50 percent of total utilidor cost. The use of skilled labor is also reduced, since all components are tested and pre-assembled at the plant before being dismantled and shipped. On site, the modules are linked back up according to a numbering key stenciled on each part. The U-Dor is light, perhaps making it economical to fly the entire installation to the site by aircraft. The engineering characteristics of the system are an additional advantage. The designer feels that heat loss from a U-Dor is significantly less than for existing utilidors. The tough, high-quality materials should give it a life expectancy equal to or in excess of any utilidor now in the North. The structural integrity of the system will enable it to mount directly on pile caps, run on stabilized gravel pads, under road fill or even underground. The final advantage is in operation and maintenance. The longitudinally segmented modules can easily be removed for maintenance without affecting any of the other pipes. Damaged areas can be quickly replaced by similar off-the-shelf modules. The entire utilidor assembly can be easily dismantled. Of course, the true operating characteristics and worth of the U-Dor need be established by time as this system is installed, tested and perhaps finally accepted by utility planners of the polar regions.

There is another prefabricated, insulated piping system that is finding application in the Far North.(10) This system, developed and marketed exclusively by DuPont of Canada Limited, is made up of three basic components: pipe, insulation with jacketing, and electrically heat-traced cable. The pipe, consisting of a core of high density polyethylene, is factory insulated with polyurethane foam and water-proof jacket, and incorporates a constant watt-per-foot heat tracing cable in a channel integral with the pipe. The system is simple and relatively inexpensive to install and operate, and is adaptable to shallow burial as well as above-ground or on-pile installation. Figure 2 shows the basic system components with polyethylene jacket in the top diagram and metal jacket below. When supplied, the ends of each pipe are bare to facilitate joining (using a butt-weld fusion process) in the field. Insulation half-shells are added after joining, and these in turn are covered and sealed with a heat-shrink sleeve.

According to the manufacturer, the high density polyethylene pipe (HDPE) combines excellent cold-weather handling and performance characteristics (will not crack when subjected to long-term cold or freezing) with light weight and a unique, leak-free joining system to provide a balance of properties unmatched by any other piping system. In the past, HDPE pipe has been confused with polyvinyl chloride (PVC) pipe. Both are plastic, light, smooth and non-corrosive. However, PVC has its best balance of properties at higher temperatures. When cold, PVC becomes brittle and loses the mechanical durability necessary for handling and installing. In addition, PVC pipe has bell and spigot joints which cannot guarantee a leak-free system. On the other hand, HDPE pipe retains an excellent balance of mechanical properties at low temperatures. It can be handled, fused, bent and retain impact resistance and ductility when very cold.

The heat-traced cable is not designed for, nor should it be used as a means of heating the water while flowing. Electrical costs would be prohibitive if the cable were used in this way. Rather, the cable is installed to prevent freezing in the event of an operating upset, such as a prolonged no-flow condition. Should freezeup occur, the cable must also be able to thaw the system after power is established.

High density polyethylene piping has been used at various locations in Canada and Greenland. It was mentioned earlier that HDPE is being installed by the Public Works Department of the Northwest Territories in shallow-burial construction projects at Rankin Inlet and Resolute Bay. A section of the new Rankin Inlet pipeline, temporarily installed above ground during very adverse conditions, was actually involved in a two-day power outage. Although pipes in the older, above-ground utilidor froze and burst, the HDPE section was returned to service without mishap, even though it was designed for less severe underground temperature conditions.

Waste Disposal Concepts

Sanitation in northern communities is complicated by such factors as permafrost, bedrock, cold weather, low or non-existent economic base in the community, population size and physical layout of the community. While the installation of conventional sewer and water systems to replace trucked services, including "honey bag" collection, appears to be a desirable goal, in many communities such systems are not practical in the present or readily foreseeable future. Even where sewers can be installed without a prohibitive cost, the availability of a plentiful water supply is often a limiting factor. Under these conditions, the conventional flush toilet is not a viable method of handling human wastes. A number of alternatives to the conventional toilet have been tried in arctic work camps and northern communities; however, to date, the ideal system has not yet been developed. Alter feels that the ideal toilet for northern application must be compatible with the efficient use of water, energy and other resources as well as being economical to purchase and operate.

Two recent innovations from the Scandinavian countries have the potential for upgrading the sanitary conditions and aesthetic acceptability of dry toilet storage systems.(11) The freezing toilet uses cold to preserve the waste and prevent biological breakdown with its accompanying odors. The basic configuration involves placing a toilet seat over a small, insulated freezing compartment which is cooled by an electrically operated compressor. The waste is received in a large waterproof paper bag. Once deposited, it is quickly frozen, thereby preventing decomposition and making it unattractive to flies and other insects. The toilet seat is warmed by heated air from the compressor coils, protecting the user from cold discomfort. It is moderately expensive in capital and operating cost. Models should be available on the North American market in the near future for $500 or less.

The packaging toilet also attempts to improve the sanitary and aesthetic qualities of the bucket-type toilet. Wastes are received in a plastic tube which is heat sealed after each use to form a series of connected sausages. By sealing each segment of waste received, the waste is immediately isolated from the home environment, preventing odors and the spread of pathogens by flies or other vectors. Unlike the freezing toilet, however, decomposition continues, making regular collection an important step toward maintaining sanitary conditions. Capital costs for the packaging toilet are higher than for a standard bucket toilet. Also, its physical configuration is such that mounting of the unit with the collection bag beneath the floor may be difficult in many northern homes. Additional packaging material may cause problems if wastes are ultimately disposed in some sort of treatment system.

Both the packaging and freezing toilets are systems that should be considered as replacements for the honey bag in northern communities. Although they are probably not the final answer to human waste disposal, they have the potential to upgrade the present honey-bag system found in some areas and can contribute to better sanitation in northern housing.

Although the use of composting as a method of handling human waste has been growing for several years in the Scandinavian countries, it is a relatively new concept in North America, where technology has concentrated on using water carriage to remove waste from the home environment. Composting is a process of microbial breakdown of organic material taking place in the solid phase. It differs from fermentation or digestion, which are liquid phase processes, in that pores or passages in the material allow the movement of gases and air into and out of the material. Composting can proceed anaerobically or aerobically. In general, anaerobic composting proceeds slowly with the evolution of small amounts of heat and with the production of end products such as methane, hydrogen sulphide and other odoriferous compounds. Aerobic composting, on the other hand, usually occurs at a faster rate, releases more heat of reaction, and does not produce foul odors. The breakdown of organics is much more complete, with the end products being carbon dioxide and water.

Actual development of composting toilets for use in individual buildings and homes began in Sweden over thirty years ago. Units based on early design utilized a large container located in the basement of the building to receive solid wastes from the toilet and kitchen. Two chutes accepted the wastes, which fell onto an inclined slope, covered with peat moss and soil. The container was vented through the roof of the building. Natural convection drew air through and over the compost heap, keeping it aerobic and evaporating excess moisture. As the organic material decomposed, it slid down the inclined slope to the storage chamber where it remained until manually removed. Because of the large size of the storage chamber, and the length of time the mass underwent decomposition, removal from the unit was only required once every two or three years, even when the unit was in constant use. The large size of the container and volume of material retained allow this type of unit to function under wide loading fluctuations. However, size is also a limiting factor, since it cannot easily be installed in homes already constructed and presents difficulties in those which lack a basement.

The most recent innovation in composting toilets is the development of small units which utilize auxiliary heat and forced aeration to promote rapid decomposition of wastes. The concept behind the design is that by providing an ideal environment for microbial decomposition, the waste can be stabilized in a relatively short time, allowing the composting unit to be kept small. A number of different brands of unit are being manufactured in the Scandinavian countries. The electrically heated units are, in general, small enough to fit easily in a normal bathroom. Installation is relatively easy, since they sit on the floor and only require the installation of an exhaust vent and electrical outlet. Most of these units require only slightly more floor space than a standard water closet. For size reason, their use in northern facilities would seem logical as long as they can provide the service required. However, experience to date has indicated that there are problems. A number of units monitored in western Canada functioned well under ideal conditions, but were easily upset by shock loading of organic and liquid wastes because of the small capacity of the composting container. Since units rely on evaporation to remove moisture, excessive amounts of urine, such as might occur during a party, can easily saturate the compost, preventing oxygen from penetrating into it and thus allowing it to become septic. Once anaerobic conditions are established, unpleasant odors are produced which will become objectionable unless the ventilation system works efficiently. Once a toilet becomes septic, it takes considerable time to re-establish aerobic conditions. Other problems expected include uneven distribution of moisture in the humus, which causes portions of the compost to dry out and cake. The caked material can become very hard, making it difficult to mix and aerate the compost pile. The breakdown of sealing materials between sections of the units is another serious problem. This allows odors to seep out into the room where the toilet is situated. Also, if the vent pipe is not insulated in the attic and above the roof, condensation will occur, returning evaporated moisture to the unit, causing it to become septic.

Whether or not composting toilets will provide a safe and sanitary method of treating and disposing of human waste remains to be determined. Rondale (12) suggests that, all things considered, the compost toilet may be a more sanitary method of handling wastes than the conventional flush toilet. The flush toilet, although it rapidly removes wastes from facilities, dilutes and distributes it, causing pollution and contamination of water resources. The composting process, on the other hand, allows the treatment of waste to take place without removal from the building in which it was produced. When properly designed, composting units require little or no energy input, and wastes are transformed into a sanitary and environmentally harmless product. If a simple sanitary system of mechanical transfer from receiving receptacle to compost unit is developed, a toilet system may well be created that will meet all the criteria necessary for northern use.

Another variation to the conventional flush toilet system that appears practical for northern use, especially in areas where buried pipeline construction is not feasible or water is in short supply, is the concept of the vacuum sewage system.(13) In areas of unstable ground, piped sewer services have often required extensive pumping and the construction of costly utilidors on piling to maintain grades. The vacuum system eliminates both pumping and rigid utilidors, in that it can tolerate slight movement of pipes and, within limits, operate with changing and even reverse grades. In addition, the vacuum toilet uses only about ¼ gallon per flush, as compared to four to five gallons for a conventional toilet. Less water used also means less water that has to be treated.

The basic difference between the vacuum sewer system and the conventional gravity system is that the sewage is carried by air instead of water. A vacuum is maintained in the collection tank at the end of the sewer mains through the use of vacuum pumps, thus keeping the whole system under a constant vacuum. The system requires special toilets and special gray-water valves which collect the wastes from conventional sinks, lavatories, bathtubs and showers. The toilet is actuated by a push button which exposes the wastes in the bowl to the vacuum in the main by activating a discharge valve and at the same time activates a water valve which allows a small quantity of water to enter the toilet for cleaning purposes. The discharge valve closes shortly before the water valve, allowing a small quantity of water to remain in the toilet. The gray-water valve operates under much the same principle, although it is activated by the presence of water upstream from the valve through the use of a small, pressure-operated diaphragm. The diaphragm is mounted on a tee immediately upstream from the valve. As gray water is drained into the line and backs up into the tee, the diaphragm is activated and allows the vacuum in the main to open the discharge valve. The length of time the valve is open is controlled by a timer. This cycle will continue until no more gray water flows into the line and the fixture is empty.

The sewage in the main continues to move toward the vacuum source at the collection point as long as some point upstream from the sewage is open

to the atmosphere, either through activation of a toilet or a gray-water valve. Consequently, pockets of sewage in the line move in stages as upstream toilets or valves are operated. The pipe must be full in order for the air to carry plugs of sewage along the line. For this reason, low pockets are constructed into the system so that when the system is at rest, the liquid will flow to the low spots and ensure that the cross-section is completely filled. This prevents air from escaping over the top of the liquid in a partially filled pipe. After the sewage is collected in the vacuum tank, it can be pumped to a treatment unit using conventional sewage pumps.

The vacuum sewer system has several advantages over a conventional gravity system, since air and not water is the medium of transport. Water is used only to clean the toilet bowl; thus significant savings are realized. The system also eliminates the small but normal amount of exfiltration associated with a conventional sewer system, in that any leaks in the sewer mains are inward, since the system is maintained under constant vacuum. This feature greatly reduces the hazard of ground-water pollution. Also, because water is not used in carrying the sewage, much smaller diameter pipes can be used for both sewer mains and house plumbing. An additional advantage mentioned earlier is the ability of the vacuum system to operate independent of grade. Because the system does not depend on gravity, the pipes can be laid completely flat and also with reverse grades within certain design limits. For a buried system, the cost of excavation can be greatly reduced. House plumbing can be simplified because collector pipes can be laid horizontally and smaller pipes can be used.

Of course, the vacuum sewage method of liquid waste disposal has disadvantages also. The system involves the use of more sophisticated components and more elaborate controls than the conventional gravity system. It requires the use of external power in the form of vacuum pumps to guarantee operation. The vacuum sewage concept appears promising for cold-weather application, but is as yet still unproven by time. However, at least one major test facility now exists in the Far North. The Indian Health Service has installed a comprehensive vacuum sewage network at the Eskimo village of Noorvik, Alaska, which is located about 400 miles northwest of Fairbanks and 20 miles above the Arctic Circle. The system, completed in 1974, presently serves 18 individual houses, four school classrooms, two teacher quarters and a health clinic. The overall system was designed to eventually serve 50 homes.

DISCUSSION AND RECOMMENDATIONS

During the past few years, private industry, civilian public works departments and non-military government agencies have accounted for the greatest portion of cold-regions development and construction. This situation is in contrast to not-so-many years ago when it was the military that spearheaded the research and development required to provide man with an understanding of and solution to cold-weather problems. At that time, the public sector capitalized heavily on technology spinoffs from military

projects. At the present time, it is the military who stands to benefit most from technology transfer. Polar engineering technology is still in a state of continual change and refinement. There are very few uniform codes or universally accepted methods of building--especially in the area of water utility services. Thus it behooves the Navy to not only continue in the support of its own polar research projects, but to also follow the progress of others as well. The objective of this Technical Memorandum is to review recent technological advances in the area of liquid distribution utility systems in the polar regions. Only the highlights of specific construction projects and system concepts are presented. It would be of practical benefit to the Navy to investigate in greater detail some of the subject areas, so that any future construction projects may be better guaranteed the benefits of state-of-the-art technology. Some suggested research topics are included in the section entitled FUTURE WORK.

This Technical Memorandum has considered some recent systems and concepts for delivering water to a northern population and disposing of the waste waters. No consideration was given to the source of such waters. As it turns out, one major problem in many parts of the Arctic, including the North Slope area, is the availability of adequate and reliable sources of water, both for purposes of consumption and disposal. In many regions of the Far North, natural lakes are relatively small and shallow. They either freeze to the bottom during the winter months or freeze to such a depth that the remaining content is full of impurities. These same lakes and ponds are not capable of handling large volumes of liquid wastes. Permanent naval facilities along the coast can resort to methods of desalinization to produce fresh water, but this requires large capital and operating expenditures, as well as high energy consumption. This option may not be available to smaller temporary or semi-permanent camps. There exist a couple of pretty basic questions related to water use in areas where the resource is scarce: What activities are the major consumers of water? How can a limited water supply be best exploited? These questions should be answered (if indeed there is a water problem) in light of planned or possible future naval operations. One obvious answer to the first question is the present liquid-flush concept of waste disposal. This paper discussed some of the alternative schemes introduced during the past 10 years or so, such as toilets that freeze wastes, toilets that compost wastes, and vacuum sewage systems. Another answer to the same question is fire-fighting requirements. It is a well known fact that in larger Arctic communities the fire flow requirements inevitably dictate the size of the mains and storage capacity. In smaller communities, water for fire-fighting purposes may represent 85 to 95 percent of the total storage provided. Through the judicious selection of construction materials and installation of good detection systems and early-stage fire-fighting systems, it may be possible to greatly reduce the amount of water reserves required.

FUTURE WORK

The delivery of water and removal of waste water in the polar regions is technically difficult and very expensive, not only from the standpoint of

construction problems and costs, but because of environmental considerations as well. Much additional research, development and construction experience will be required before uniform standards and building techniques can be refined to the degree common to water-distribution networks in the more temperate climates. It is planned to conduct research under two separate (but interdependent) aspects of water utility service: the environmental and the technical. Environmental studies can best be handled under work unit YF52.555.001.01.003, "Environmental Engineering Factors for Polar Facilities." It is proposed for FY-78 that a literature search and field investigation be conducted to establish problems of water supply, production, consumption and disposal in the polar regions, and define the impact of these problems on naval shore facilities.

The work unit YF52.555.001.01.006, "Fluid Distribution Systems for Polar Environments," will continue to focus on the technical aspects of pipeline and utilidor construction, including engineering design, hardware development and a consideration of material properties. According to William Ryan of the Indian Health Service, a big problem in Northern utility construction has been finding a reliable heat tape and thermostat system to protect service lines from freezing, even though there are quite a few products on the market. Thus during FY-78 it is planned to perform laboratory tests on heat tape and thermostat products to find the most economical and reliable system. However, the problem of freeze protection is even more basic than the mere development of reliable heat-traced piping. For instance, in case of total power failure, even the most reliable system will serve no purpose. Therefore, additional studies will be conducted to develop measures for reducing or eliminating freeze damage to pipes by strategically placing insulation and protection devices to predetermine the point of failure, should unavoidable freezeup occur.

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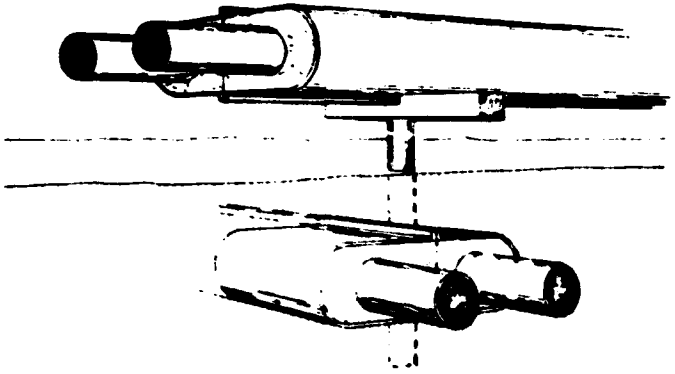
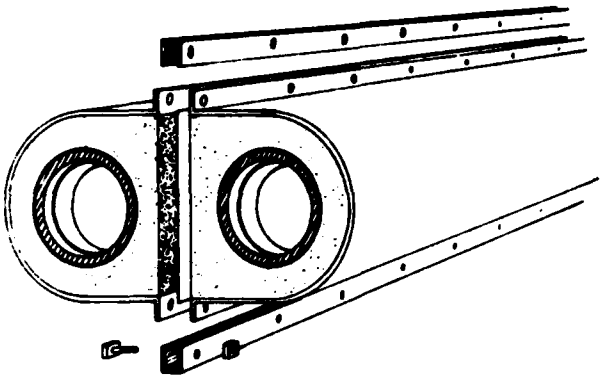
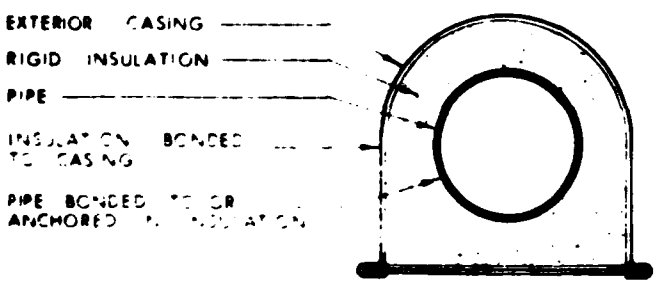


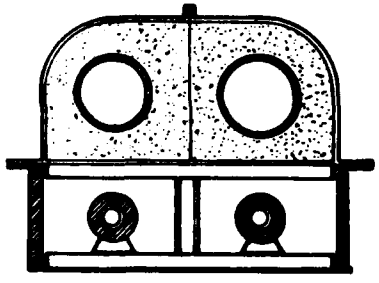
U DOR SHOWING ABOVE AND BELOW GROUND INSTALLATIONS



U-DOR ASSEMBLY WATER & SEWER MAINS



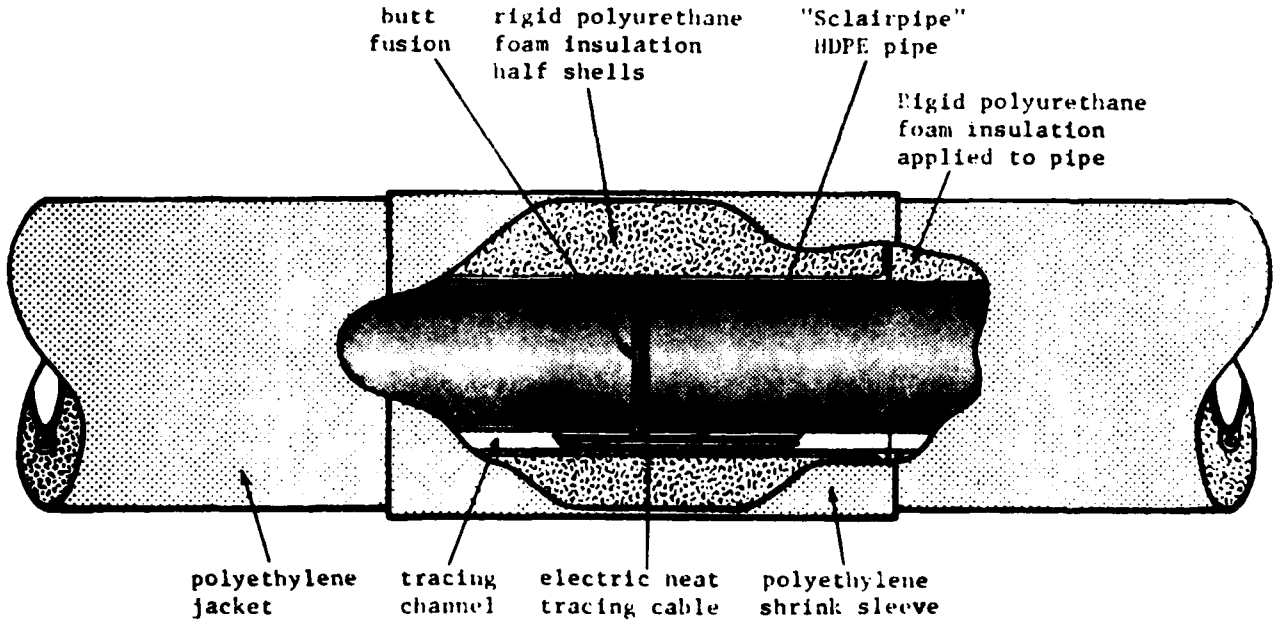
BASIC U-DOR UNIT WATER SUPPLY & SEWER OUTFALL MAINS



TWO UNIT U-DOR WITH HEATING PIPE CHAMBER

Figure 1. U - DOR UTILIDOR
(MANUFACTURED BY: FIBERLITE PRODUCTS CO LTD, EDMONTON)

(Illustrated - butt fusion area)



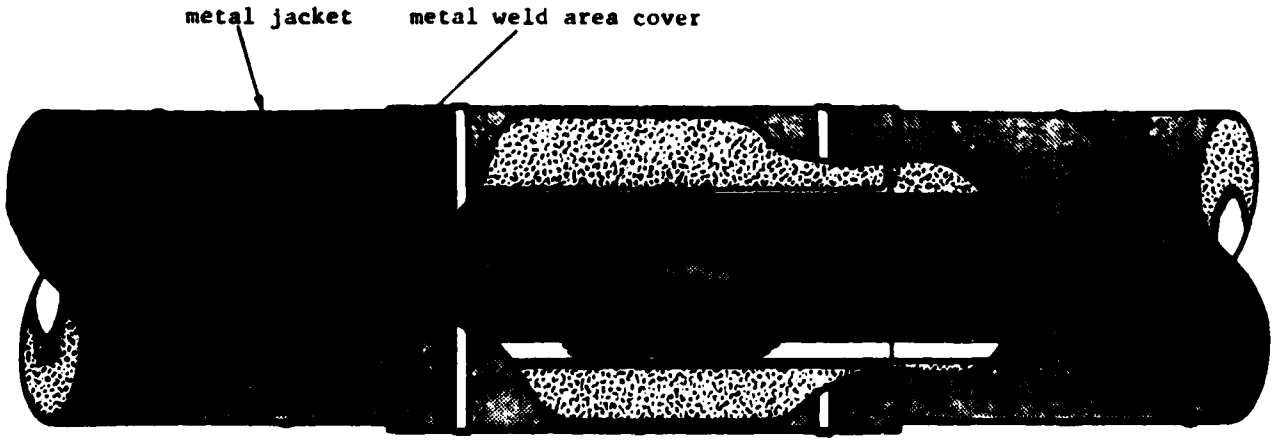


FIGURE 2. BASIC SYSTEM COMPONENTS

APPENDIX 6-B

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TECHNICAL MEMORANDUM

title: CONSERVATION CONCEPTS RELATED TO THE PRODUCTION, DISTRIBUTION AND CONSUMPTION OF POTABLE WATER AT ANTARCTIC STATIONS

author: J. L. Barthelemy

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CONSERVATION CONCEPTS RELATED TO THE PRODUCTION, DISTRIBUTION, AND CONSUMPTION OF POTABLE WATER AT ANTARCTIC STATIONS

61-019

by
J. L. Barthelemy

June 1978

Sponsored by
Naval Support Force, Antarctica

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INTRODUCTION

McMurdo Station is the primary United States base in Antarctica and serves as the center of U.S. research and support activities. It is located on the southern tip of Ross Island, near to where the Ross Ice Shelf meets McMurdo Sound. At this location, it is accessible to both air and ship traffic, and is also relatively close to the South Pole. Most equipment and supplies transported to the Antarctic are brought in each summer by vessel via shipping lanes through McMurdo Sound. Materials destined for all of the outlying stations (except Palmer) are then transported aboard aircraft operating from nearby Williams Field.

From the standpoint of logistic support, McMurdo Station is well situated. However, because of the way it has developed, gradually and for the most part without a master plan, it is presently deficient in operating efficiency. Construction of the utilities system, for instance, has been piecemeal over a span of 20 years, most of which was finished before the surge in cold-weather construction technology during the past five or six years. As a result, utility services to most buildings are neither uniform nor integrated and, as a result, tend to be wasteful of energy and manpower.

This Technical Memorandum considers one segment of the utilities structure at McMurdo Station: the production, distribution and ultimate pattern of consumption of potable water. However, it is not the intent of this report to dictate how, when or even what specific changes should be made, but rather to point out ways in which present services can be improved to conserve water and energy, and to serve as a ready reference for state-of-the-art advances in the design and construction of cold-weather water distribution systems. The ultimate upgrade of utilities will involve an economic decision, dependent upon the future of McMurdo Station as an operating base--that is, whether existing buildings should be refurbished and retrofitted, new buildings should be constructed, or the entire operation relocated to a new site (such as Marble Point).

Conservation is also a very important consideration at the inland stations and polar camps where precious fuel is used to produce water by melting snow. Some of the concepts considered in this text may be applied to the smaller, more isolated locations as well. In particular, the section on self-contained toilets should be studied in light of requirements at outlying camps and stations.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

McMurdo Station was first settled as an outpost of a few buildings in 1956 when it was used as a logistic staging facility for the International Geophysical Year. During the succeeding 20 years, it grew gradually so that today it is a complex of more than 100 structures which must support a summer design population of 700 civilians (or 1,000 military) and winter design population of 160 civilians (or 180 military). However, for the most part, development progressed in piecemeal fashion without a master plan, so that even now the complex is composed of both permanent and temporary facilities built without benefit of the present state-of-the-art in polar construction.

During the early years, most of the potable water supplied to McMurdo Station was produced by melting snow and distributing the water to individual buildings by truck. In early 1962, construction of the PM3-A nuclear reactor power plant on Observation Hill was completed. The installation consisted of a 1.8-megawatt electric power generator and an ancillary steam-reactor/salt-water-distillation unit sufficient to produce 14,400 gallons per day of potable water. Construction of the required water distribution and sewage collection piping began in Deep Freeze 64, during which approximately 6,000 feet of 2-, 4- and 5-inch waterline and 1,500 feet of 6-inch sewerline were placed. The seawater supply, potable-water distribution, brine return and sewage collection lines were all placed above ground on wood cribbing, and were electrically heat-traced, insulated and jacketed to prevent freezing. In the period that followed initial installation, numerous failures occurred in the water and sewer systems that required innovative on-site repairs. Additions were also made which resulted in a conglomerate system using materials from many manufacturers. Portions of the system were built up using on-site materials when preassembled piping was not available. A complete description of the preassembled and on-site assembled pipe, with the details of construction, is contained in Reference (1).

The water distribution system at McMurdo Station was established before the recent surge in cold-weather construction technology: commercial items such as pre-insulated piping and electrically traced heat tape were limited to just a few manufacturers; assembly techniques were still highly experimental and untested by time. Thus it is not surprising that there were operational problems. In addition, it was necessary to route piping into already existing buildings and, at the other extreme, extend piping as new buildings were constructed. The result was a working, but less than optimum, installation.

During the last decade, rapid development of the Far North has spearheaded cold-weather construction technology. Today there is a whole complement of materials and techniques that may be employed to provide reliable and economical water and waste-water distribution systems. One concept more fully developed during the past ten years is that of the utilidor. Basically, the utilidor is an elaborate approach to freeze protection in polar piping networks, and involves nestling all the utility

services into a common, highly insulated and heated box-like structure which may be buried or elevated above ground. In the past, the utilidor was viewed more as a high-technology solution and required extensive research and greater capital expenditure than did more conventional heated/insulated piping systems. A promising new trend in utilidor design is the recent development of prefabricated, insulated piping conduits capable of carrying electrical cables, potable water and sewer mains, as well as heating lines where required. One particular conduit has a metal or fiberglass-reinforced plastic exterior, insulation, and casing which together provide a self-supporting structure adaptable to either above- or below-ground installations. System appurtenances such as hydrants, valves and junction boxes are prefabricated as modules and inserted in the system as required. (2)

In 1972, Bechtel, Incorporated, published the findings resulting from an engineering evaluation of the Antarctic support logistics program. In that study, several station alternatives were investigated. Primary station alternatives included the choice between military or civilian operation and construction, and relocation of McMurdo operations to a new site at Marble Point. In addition, engineering sub-studies based upon the continuation of McMurdo Station as an operating facility were conducted. One of the sub-studies involved a field investigation and assessment of the existing utility structure. The most significant recommendations considered to have top priority were as follows: (3)

1. Decommissioning the PM3-A nuclear power plant

2. Installing a utilidor enclosure system for potable water, electrical power, communications, and sewage lines

3. Constructing permanent buildings throughout McMurdo Station

Current considerations

The first recommendation was fulfilled in 1972 when the nuclear reactor was decommissioned due to a leak in the coolant system. The remaining two recommendations should be taken to heart if it is decided that McMurdo Station will continue as an operating station in the future. It is not uncommon to waste large quantities of water or energy in utility operations. It is, however, unnecessary to waste either. If no attempt is made to reclaim useable byproducts, waste occurs; when salvage is attempted, only losses occur. At present, the distribution system and pattern of consumption at McMurdo Station are wasteful of both water and energy. Alter (4) points out that reclamation of water offers more promise in cold regions than in most other places. Energy salvage, likewise, offers greater benefits and is accomplished with higher efficiency in cold regions than in most other places. (5)

In the Far North, the key word in utility planning has become integration. The integrated utility system is one that accounts for losses and is engineered to minimize wastes. Of course, it is more difficult to realize the full value of the integrated system approach in an already established

community such as McMurdo Station. This is true mainly because of the layout and diversity of structures already existing. This does not mean that the use of integrated design should not be attempted, but rather that the result of implementation may be less dramatic. For the case at hand, considering recommendation #3 from the Bechtel report, the integrated approach can be incorporated into the design and planning of future permanent buildings. Even considering present conditions only, there are ways in which the water-delivery utility structure can be improved. This Technical Memorandum attempts to present some ideas of both immediate and long-range interest, as well as possible alternatives to the conventional pattern of water consumption.

ACCOMPLISHMENTS

CEL was tasked by the Naval Support Force Antarctica (NSFA) to investigate the pattern of potable-water consumption at McMurdo Station and make specific recommendations regarding methods of conservation. Research of the existing utility structure led to the following conclusion: it is difficult to divorce the conservation of water from the conservation of energy required to produce and distribute the water. Because the distribution network was built before cold-weather pipeline construction technology was refined to the point that it is today, the existing system is in many ways deficient. This Technical Memorandum divides the basic problem into three separate (but interconnected) sections.

The first section considers actions which may be taken in the immediate future. It recommends some more obvious changes (which may already be corrected or practiced to a varying degree) as well as a better check on the pattern of water consumption. The second section pertains for the most part to future planning. It considers design changes that would result in a more efficient and more fully integrated distribution structure. The final section presents alternative concepts to one of the largest users of water: the conventional flush toilet. Although the ideal minimum-water-use waste disposal system has not yet been developed, a number of alternatives to the flush toilet have been tried in Arctic work camps and northern communities.

Immediate Actions

Potable water for McMurdo Station is produced by the distillation of seawater, which is pumped from the shoreline into a 5,000-gallon seawater tank at the distillation plant, located about halfway up Observation Hill. Prior to 1972, the 2,000 pounds of steam per hour required to operate the distillation units were provided by waste heat from the PM3-A nuclear reactor power plant. Since that date, steam must be produced by a boiler located within the water distillation plant. The distilled water is stored in two 55,000-gallon tanks in the distillation plant before being distributed to McMurdo Station, and the concentrated brine is returned by insulated, heat-traced line to the sea.

According to Reference (3), "The overall production of distilled water is a manual operation, although the heat tracing, the distillation units themselves, and the steam feed necessarily have automatic controls. There are no level controls on the potable water tanks; consequently, when they are full, the overflow is discharged into the brine return line." This condition represents a most obvious misuse of energy and should be corrected. Controls should be installed on the seawater supply system to shut off the pumps (and drain the line if necessary) when either the salt water or potable water tanks are full.

The fresh water leaving the distillation plant for distribution to McMurdo Station is metered; however, except for the USARP Quarters (Building 166) and the galley, which is part of Building 155, the buildings that are connected to the piping distribution network are not metered. All buildings supplied with piped water should be metered. In this way, a continuous log of usage at each facility or activity can be maintained, making it easier to isolate specific areas of waste or misuse. In the long run, the pattern of consumption should be weighed in terms of what is "proper" or "reasonable" so that changes, limitations or conservation measures can be mandated as necessary.

One obvious area of concern has become the galley in Building 155. During a period in which the total production and distribution of fresh water averaged 20,000 gallons per day, the galley facility accounted for nearly 10,000 gallons. Although this quantity does appear excessive in light of station size, one is not in a position to pass judgment until the basic pattern of consumption is established. To this end, consumption through the galley can be broken down into three major components: (1) consumption due to the operational requirements of machinery (i.e., dishwashers, cookers, etc.); (2) consumption required by galley personnel for activities such as preparing food and drink, and scrubbing floors and tables; and (3) additional consumption which must be classified as waste.

As a first step toward conservation in the galley, one should ask the basic question: what is the minimum quantity of water (per person on a seasonal basis) required to prepare food, wash dishes, clean floors, and so on? The second step is to determine quantitatively some reasonable standard, and see where and why it is not maintained. Regarding item (1) from the preceding paragraph, there may be many ways in which galley equipment is presently misused, creating waste. For instance, many commercial dishwashers will continue to operate on the RINSE cycle, even with no dishes inside, or even after the dishes have been adequately cleaned. The operational habits of galley personnel should be checked against recommended instruction book procedures to ensure proper use of equipment. Again, the use of meters might prove beneficial--this time on individual kichen components so that the quantity of water used can be readily checked against the quantity required.

Item (2) requires a look at the everyday working habits of galley personnel: is excessive water used in cooking foods? Is the faucet left running while just a few vegetables are cleaned and prepared, or while the worker attends to duties elsewhere? Are the water heaters far removed from

kitchen facilities so that large quantities pass down the drain before hot water arrives? These and other questions should be answered in a reivew of present kitchen procedures. The results of observation may be used to devise guidelines for conservation. Observations may even expose design deficiencies that warrant correction. If faucets are left running because hot water tanks are distant, for instance, it may prove beneficial to install a short recirculating loop to the kitchen so that hot water is available instantly at the tap.

Not all water leaving the galley need end up as waste. At present, the laundry (located in Building 155 near the galley) is the only activity at McMurdo Station that uses reclaimed water to some degree. Since water from the galley is "gray" (as opposed to blackwater, which is toilet wastes), it could be treated for reuse using equipment and techniques currently available. Of interest in this regard is the federally financed Alaska Village Demonstration Program (AVDP), based on the concept that the water-related needs of a small community can more economically be met if people do their laundry and bathing at a central facility.(6) A number of water-saving and energy-conserving devices are employed in an installation at Wainwright, Alaska (population 375). A two-story, 3,000 square foot central facility contains showers, saunas, laundry and toilets, as well as waste-water treatment facilities, power generating equipment and heating components. Most noteworthy is the graywater treatment plant which collects runoff from showers and sinks, and reuses it in the washing machines and toilets. Such a system might be considered for Building 155, where runoff from the quarters area, as well as galley wastes, could be reclaimed for distribution to the laundry and toilet systems. Of course, this would involve extensive modification of the present piping network since treated graywater must be separated entirely from the potable water. The reclaimed water could also be stored in tanks to supplement the existing fire-fighting capacity.

The concept of the central facility has even more relevance to the smaller, outlying stations and polar camps. In particular, the inland stations obtain fresh water by melting snow, a process that places high demand on precious fuel reserves. Thus it is important to make the best use of water and energy, and practice methods of reclamation as well as conservation.

Additional water saving techniques were incorporated into the AVDP facility at Wainwright. Since sauna baths were shown to fulfill the need for a "hot soak" without the use of hot water, each shower room contained a sauna bath 60 square feet in area capable of reaching and maintaining a maximum temperature of 200°F. Further reduction was achieved by time and flow regulated showers which minimized water used for bathing. Shower flow was controlled by coin box timer adjustable with a two to ten minute range, and limited to 1½ gallons per minute.

In 1975, CEL conducted a test evaluation of several reduced-flow shower products and shower heads. (7) The results of that study showed that the Nova Model B-6401 shower head[1] not only significantly reduces water/energy

[1]Produced by Ecological Water Products, Inc., Newport, Rhode Island.

consumption, but its operating cost savings result in a pay-back period of only a few months for barracks installation, after which it continues to save water, energy, and money for a number of years. It was the only product that met all of the following design criteria: (1) shower head shall provide a flow rate of approximately 2.5 gpm over a pressure range of 15 to 125 psi; (2) the flow rate will not exceed 3 gpm over the designated pressure range; (3) the shower head shall allow easy removal of mineral deposits, rust scale or other impurities; and (4) the shower head shall aerate and jettison the water, giving a forceful, tingling spray. Thus it was concluded that Naval activities procuring shower heads for installation at shore facilities should include the Nova among the products they consider. The Nova reduced-flow shower head is available through GSA as Special Item No. NIIS-G-4174 under Contract No. GS-00S-04038, effective 4 December 1975.

There are two additional problems which will be more fully discussed in the next section on Future Planning, since they require substantial design changes, but are here introduced because they also represent current deficiencies. The first deficiency involves the operating temperature of the potable water, which is higher than it need be for efficient operation. The temperature of water supplied to buildings connected to the piping system is typically around 75°F, which is too high for drinking. (3) The basic problem is that of design, since freezup of the piping network is prevented by the activation of electric heat-traced elements wrapped around the pipes. Rather than risk the crisis of freezing, wasteful amounts of energy are fed into the moving liquid. During a survey of the water and sewer systems in Deep Freeze 68, a random inspection of thermostats indicated that all were set to the maximum setting of 230°F, and that the heat-mat circuits were operating continuously. Temperatures recorded along the waterline varied between 120°F and 145°F. The high temperature of the potable water was known to the users, but was not investigated because there was some cooling in the water storage tanks at each point of use. (8) Although corrections were made when the high temperature settings were called to the attention of operating personnel, even today a condition exists whereby a number of thermostats have been bypassed completely, so that some circuits are energized all the time. There still exists a reluctance to make any changes in the system, a tendency which may in part be justified, due to the somewhat less-than-satisfactory performance record of the past. A better designed piping system enclosed in a protective utilidor structure could do much to ease the problem of heat-loss control and make for a considerably more reliable operation.

The second deficiency involves the current separation of electrical power plant and seawater distillation facility. Until the PM3-A nuclear generator was decommissioned in 1972, the site on Observation Hill was a convenient location for the distillation equipment. Waste heat from the steam cycle was used as a source of energy to heat and evaporate seawater, and the fresh water produced was then fed by gravity to the camp facilities below. However, now that the nuclear plant has been removed, fuel-fired

boilers must power the distillation process, while waste heat from the replacement diesel-generating system (housed in Building 136) passes unclaimed to the ambient environment. It seems only logical to capture this potential source of energy and use it to heat the incoming supply of seawater. One of three relocation plans should be implemented. Either the diesel generators should be moved onto Observation Hill, or the distillation equipment should be reinstalled near the power plant, or both facilities should be rebuilt at a third location convenient to both functions. This matter is discussed in greater detail in the next section.

Future Actions

This section considers changes which may be made to improve the utility structure at McMurdo Station. It also presents background information related to the development of water distribution system in the cold weather regions--especially in the Far North during the last 10 to 15 years. By tracing the evolution of cold-weather piping technology and looking at a few case histories, it is easier to see ways in which the now-existing structure at McMurdo Station could be upgraded and at the same time made both more efficient and more reliable.

Maintaining water in a liquid state throughout a distribution system has been the major problem confronting the water-supply engineer working in the polar regions. Although many schemes have been developed to this end, there are actually just two variations: either the system is designed so that the water can be removed from the piping prior to freezeup, or enough heat is added during distribution to prevent the liquid from freezing.

Historically, the first method found greater application and can still be used in areas of low population density. Intermittent pumping techniques were first developed by small communities in the Arctic where complete control of water was practical. The distribution system was usually located underground and installed so that all the lines, including those used as service connections, could be quickly and easily drained. In the summer months, the system operated as any conventional system. During the winter, the water could not be left in the lines. Thus on a predetermined schedule, water was distributed through the system so that each consumer could fill a storage tank in his house. When the refill period was over, all water was removed by gravity drainage from the distribution network.

In 1903, Dawson City in the Yukon Territory constructed what was probably the first true water distribution system in the Far North. A conventional system was built, with the provision that water could be bled from each service connection and at the end of each main on a continuous basis during the periods of deep frost penetration. Water was in constant motion through the piping, preventing freezeup as long as the heat lost between the pump and the end of the main was less than the amount required to form ice. Of course, this "bleeding" method of freeze prevention has many disadvantages. Much more water is distributed than is actually consumed. If the raw water requires distillation and/or extensive physical or chemical treatment, then the economics become very unfavorable.

The system commonly used in the northern United States and southern Canada is to bury the pipes to a depth greater than the expected seasonal frost line. Such a system is also practical in some polar areas that are not located in regions of permafrost; however. this is the exception rather than the rule. In areas of permafrost, the problem of freezup in a water main is avoided by the more sophisticated technique of adding heat to the water and heavily insulating the line. Although the economics of the highly insulated water main appear good, the system does not solve one major problem--that is, freezing inherent in the individual service connections. In the private sector, people demand relatively large lots and homesites, similar to what is available in other parts of this country. As a result, construction techniques in the civil communities of the Far North generally copy as closely as possible conventional plumbing procedures. When possible, water mains are placed under the street, and individual homes or community buildings are attached by means of service connections. Herein lies the problem. The service line must enter the house at approximately foundation level, which is often at a depth severely influenced by freezing. Service lines are usually small-diameter pipes and are thereby more likely to freeze. Most important, water flow through the service lines is intermittent, depending upon demand and time of day. Experience has shown that heavily insulated lines that do not provide for continuous water movement through the service connections result in a tendency to allow water to run during the night hours of low use to prevent freezing. Such practices have the same disadvantages as the "bleeding" type system, namely a large amount of wasted water.

A basic solution to the problem of service-line freezup involves letting the water circulate continuously, both in the main distribution lines and in the individual house connections, and heating the recirculating water (as necessary) as it is cooled through the distribution system. The dual-main line system accomplishes these objectives. The water initially leaves the pumphouse in a high-pressure line. If thermodynamic conditions warrant, heat may have to be added at this point. The house service comes off the high-pressure line, into the dwelling, through a pressure-reducing valve, and out of the dwelling, discharging into a second main operating at a lower pressure. The low-pressure line returns to the pumphouse or intermediate storage facility where it is heated, if necessary, and then returned to the distribution network in the high-pressure main. Thus the dual-main system keeps water constantly in motion throughout the entire piping network. Figures 1 and 2, respectively, show the dual-main concept (with well-water source) and service connection details. The glaring disadvantage of this system is that two mains must be installed throughout, thereby nearly doubling the first cost of the installation.

One way to circumvent the necessity of providing two mains is to install a single recirculating main, but equip each building with its own service loop and continuously operating pump. Water is drawn from the main by the pump, and water not used is returned to the main. Although such a system is workable, and has found limited application, it does require that each customer install and maintain a pump. In 1952, the Arctic Health Research Center of the U.S. Public Health Service began studies to develop

a better method of providing a continuously circulating water system. After considerable experimentation, they developed what will be referred to as the single-main recirculation system. Basically, this method of water distribution consists of one water main through which water is continuously pumped. The flow path is from a treatment plant or primary pumping around a loop and either back into the same pumping station or into another station. Heat is added to the water, when necessary, at the pumphouse. The problem of maintaining flow in the service connections without reverting to bleeding or individual pumps was solved by the development of a device which has become known in the Far North as the "pitorifice." The name is derived from both pitot tube and orifice, since their principle of operation involves the fundamentals of each device. The pitorifice is inserted into the main as a corporation stop. A dual service connection (two pitorifices) is used: one line in which water flows from the main to the house; a second return water line from house to the main. Velocity in the service connections is produced by utilizing the velocity head of the water in the main. Figures 3 and 4, respectively, show the single-main concept and service-connection details. Figure 5 is an enlargement of the service-line details.

A single-main recirculating system was constructed at the village of Unalakleet, in western Alaska, during 1964 and 1964. (9) The primary distribution installation consists of two loops, both of which originate and terminate at a pumphouse. The village plan was such that a single loop could not be utilized because the distance from the main to some houses far exceeded the safe distance. All structures connected to the loops use pitorifices in the service connections, with the exception of the Junior High School, which is located too far from the mains to take advantage of their water velocity for recirculation. A pump was installed at the school to guarantee flow.

The pump building houses two boilers of 600,000 BTU rated capacity. These units were put into the system to add heat during the winter months. To conserve on pumping and piping costs, only a small fraction of the water is brought through the boilers. This water is heated in the range of 40 to 60^{o}F and then mixed with the colder water to insure approximately 40^{o}F water entering the loops at all times. In addition, since continuous circulation of water is not required during the warmer summer months, a 40,000 gallon wood stave water storage tank was built. It serves as a constant head tank during the summer and as a reservoir for heated water during the winter months. Under normal conditions, water from the well source enters this tank and is mixed with its contents prior to being discharged into the main distribution system. Likewise, return flow from the loops is mixed in the storage.

The single-main recirculating method of water distribution does have disadvantages. Studies at the University of Washington showed that service lines incorporating pitorifices should not exceed 50 feet in length, otherwise the chance of freezing is increased. Also, pitorifices require a 2 ft/sec or greater velocity in the main to operate properly. Ryan (10) suggests using a more "conventional" design which would allow circulation

through all lines and completely eliminate service lines. This will require the main line to be extended to each house or building with just a short riser from it into the house plumbing directly beneath or beside the house. The easiest way to do this in a small community is probably to extend the mains from house to house directly. Alternately, in larger communities, a single trench for the main could be dug down each street. Smaller trenches could then be extended to each structure so that the main would run back and forth in the same cut. Although this will increase the total length of pipe in most instances, the velocity of circulation can be reduced. The overall headloss and thus operational costs may be reduced considerably at a small increase in initial construction costs.

Extension of the main from building to building most closely approximates the system presently in service at McMurdo Station. That system is not recirculating, however, since potable water is fed by gravity flow from the distillation facility on a once through, demand basis. Most cold weather water distribution systems currently in design or construction consist of the loop-configured piping arrangement where water is pumped continuously at some selected flow rate. Water that is not consumed along the loop is returned to the pumping station where it is reheated as necessary prior to reentry. This arrangement offers several advantages in terms of design and control. Since flow is continuous and basically independent of hourly or seasonal fluctuations in demand, there is less of an opportunity for freezing. Also, since heat is added at a single location, it is easier to monitor incoming and outgoing temperatures, and maintain a satisfactory operating condition. Furthermore, by centralizing the location for pumping and heating, it is easier to utilize sources of waste energy. The present installation at McMurdo Station relies upon resistance heating along the pipeline which is inefficient in terms of energy consumption and not very satisfactory in terms of performance.

Murphy and Hartman (9) feel that the single-main recirculating system is the most practical solution for water distribution in cold-weather regions. All other systems are either more expensive to build or have certain disadvantages which make them unacceptable. However, they restrict this opinion to what might be termed the private sector--that is, non-institutionalized installations where the utility does not have complete control over where buildings are located. Military bases, government installations, academic institutions and company facilities may or may not find this to be the most economical solution. For instance, a military site may house 100 men and be constructed in such a way that the entire complex is one large building with a number of wings. Such construction lends itself to the placement of utilities under the floors, in separate indoor utilidors and other configurations. To be sure, the most elaborate approach to freeze protection in polar piping networks is to nest all the utilities in a single highly insulated and heated conduit, or box-like structure, most commonly termed the utilidor. A review of literature suggests that governmental agencies, especially the military, have spearheaded the development of utilidor systems. This is not surprising, since utilidors tend to be high-technology solutions and require more extensive research than do more conventional heated/insulated piping systems.

The Bechtel report (3) recommends replacing the existing utility structure at McMurdo Station with a utilidor enclosure system which houses water lines, sewage piping and power distribution cable. Further, that report recommends connecting all buildings in which personnel live, work, eat and play to the water piping system. Such a change should do much to improve living conditions and reduce maintenance liability; however, there are a number of basic design factors which should be considered before selecting the type of utilidor system to build. One important consideration is that of above-ground versus below-ground construction. In the past, especially in permafrost regions, above-ground piping was generally used, primarily because of early failures in permafrost construction, lack of hydrophobic (not readily wet by water) insulation materials and insufficient engineering design information. As new low-heat-transfer materials, such as urethane and polystyrene, and powerful hydraulic backhoes became available to handle frozen ground, the trend has reverted to buried insulated utilities. Above-ground piping systems are aesthetically unpleasing. Elevated utilidors tend to restrict the movement of pedestrians and vehicle traffic, thereby unnaturally segmenting a community. They usually require expensive overpasses and restrict land use. Although these problems are mainly concerns of the civil community, they do apply to military establishments as well. Other factors are even more important to military construction. From the standpoint of design, above-ground pipes are subject directly to daily and even hourly temperature fluctuations and must be designed for the minimum air temperature with an appropriate wind-chill factor. From the standpoint of maintenance, exposed pipes usually require many more repairs and have a shorter life span. In addition, they are more prone to vandalism, accidents and even sabotage.

The disadvantages of buried utility systems include difficult and expensive excavation and foundation. Repairs tend to be more time consuming, especially when frozen ground must be excavated. The situation is even worse in unstable, frost-susceptible soils. Piping systems placed in fine-grained, ice-rich permafrost must be designed so that excessive heat loss does not cause differential settlement and heaving of the supports, thereby damaging the installation or disrupting hydraulic grades. In addition, in thermally sensitive soils, surface disturbances due to actual construction of the utility line may cause more thaw and settlement than operation of the line itself. Construction must be scheduled to minimize disturbances and restrict movement of equipment.

Regarding the condition of permafrost soils around McMurdo Station, Reference (1) states the following:

> "In perennially snow-covered areas of McMurdo Station, the permafrost will be found at the ground surface. The depth of the permafrost at McMurdo has not been determined but may extend to 1,000 feet or more. In snow-free areas, permafrost is generally encountered 6 to 18 inches below the surface. Most of the permafrost at McMurdo consists of rock with interstitial ice in joints and other voids within the upper

few feet of the surface. Even if this material were to thaw, overall settlement would be minor except rarely where an unusually large mass of ice occurs, then settlement may be large but would probably be highly localized. In the McMurdo Station area, there are no known occurrences of high-ice-content silty, fine-grained soils of the type typical to the Arctic and sub-Arctic regions which are considered detrimental for building foundations if thaw is permitted."

As mentioned previously, military construction has been a principal force stimulating development of the utilidor-type enclosure. At sites in the Arctic, the layout of buildings is often planned around the utility structure. Since most military installations produce their own power and provide central heating systems, the utilidor is a convenient way of routing steam and condensate lines. Heat lost from these lines is used to prevent freezing in water and sewage piping, although in some instances too much heat is lost, resulting in overheated cold water and dried out sewage. As a rule, utility tunnels exist where central heating is present.

Because of the layout of already existing buildings at McMurdo Station, it may be economically unfeasible to construct a buried utilidor connecting all facilities. Also, since individual buildings have their own heating systems and water storage tanks, it is not necessary to place steam lines within a utilidor enclosure for purposes of central heating. However, it will be very difficult to design a reliable utilidor system--either buried or elevated--that can carry the required water, sewage and power services without an additional line for heating. This is true even if a recirculating-loop of domestic hot water is included in the installation.

Reference (11) describes the design, construction, performance and ultimate failure of a functioning utilidor that relied upon domestic hot water for freeze protection. The installation, the USACRREL Alaska Field Station at Fairbanks, Alaska, had conditions similar to those now existing at McMurdo Station. For 17 years the system of water service was the same: the main line was traced with electric heat tape and heavily wrapped with insulation for thermal protection. However, the addition of sufficient heat to prevent freezing resulted in complaints about high water temperature at the cold water taps in the buildings. It became necessary to install small holding tanks in each building to allow the water to cool down to a desirable temperature.

In 1965, it was decided to replace the original system. Since each of the buildings at the Station had a separate and adequate internal heating system, it was not considered cost effective to modify for a central heating system. The approach selected by the designers was to provide both a recirculating domestic hot water loop and a single, flow-on-demand, cold water line. It was believed that this would eliminate the need for tanks in each building, that both domestic hot and cold water would be continuously available, and that designed heat losses from the cirulating hot water system would provide the necessary thermal protection for the cold water and sewage systems also contained in the utilidor. The concept seemed to provide

a solution to particular local problems as well as offer a somewhat novel approach to thermal protection needs.

Without going into great detail, the system ultimately failed. The waterlines froze and burst. The major problem was one of maintaining acceptable limits on water temperature in the face of a drastically changing environment. The utilidor, placed above ground, was exposed directly to fluctuating air temperature and wind chill. Thermocouple data showed that although the "average" temperature inside the box was well above freezing, it was still nonetheless possible to have below freezing temperatures at the cold water pipe. The conclusion was that constraints imposed on temperature limits for consumers are too restrictive to use domestic hot water as the protective source for utilidor heat. However, the use of circulating hot water or steam as a protective element can be a valid concept if designed as a heating source for connected buildings or for utilidor protection alone.

At the Unalakleet installation, heat was added to the recirculating water supply at a single location. However, that distribution system consisted of a single, heavily insulated main that was buried. The designers had to account for just a single conduction energy exchange between the pipeline and seasonal ground conditions. Utilidor heat-loss design is more complex--especially for one elevated above the ground. There are many more heat exchanges, both between the different lines and air space inside the enclosure, and with the ambient environment outside. If a utilidor system is constructed at McMurdo Station, it may be necessary to include some sort of protective heat source alongside the water and sewer lines which can be controlled to prevent freezing and also avoid excessive cold-water temperatures. Electric heat tape could be used, but that method is inefficient, unreliable and offers little improvement over the present configuration. A better alternative is to use waste heat rejected by the diesel generator power plant.

The power plant and seawater distillation facilities should be consolidated at some compromise location. In light of the foregoing discussion on loop-configured pipelines for cold-weather water distribution, it might be best to move the distillation units from their present location on Observation Hill to a lower elevation near the station powerhouse. As the author sees it, waste heat from the diesel generators can serve two functions: (1) to preheat seawater and provide energy necessary for the distillation process; and (2) to provide heat as necessary to maintain a protective hot-water loop within the utilidor enclosure. Regarding the second provision, the most convenient location for a pumphouse is at a site where piping runs can be held to a minimum and where the recirculating liquid does not have to be pumped up steep grades. In other words, it should be located near the powerhouse rather than atop Observation Hill. It is also desirable to minimize piping required to carry seawater and return brine. In the final analysis, it is probably best to relocate (or rebuild) both the powerhouse and distillation plant at a common location nearer the shoreline.

There are advantages in continuing to use a gravity-fed distribution network. Gravity systems are less sensitive to mechanical breakdown, and can serve as ready-reserve capacity for fire fighting during power failure. Although a protective hot-water loop will require a pump for continuous circulation, the freshwater supply can be designed without a pump to pressurize the line. Water produced at a (relocated) distillation facility could be pumped as is done now to holding tanks on Observation Hill, and withdrawn on a once-through, demand basis. Such a design would also allow more flexibility in terms of changing environmental conditions. During the warmer summer months, there is much less of a need for thermal protection. The hot water line could be deactivated, letting the remainder of the system function as a conventional constant head distribution network.

No matter what the final configuration of utilidor enclosure might be, waste heat produced by the diesel generator power system represents a substantial energy resource which should be included in the design of an integrated water production system. Electric power generation by diesel engine is typically about 30% efficient, with approximately 35% of energy input lost in exhaust heat and another 35% lost in engine and oil cooling. By incorporating heat exchangers in the power generation subsystem, heat can be reclaimed for use in other processes such as heating and evaporating seawater. As an example, the present power generating facility at McMurdo Station consists of 500 kW generators. The rate of chemical energy expended to maintain this electrical output is 57×10^5 Btu/hr at a generating efficiency of 30%. If a heat recovery silencer is installed which has an efficiency of 40%, then 8×10^5 Btu/hr can be reclaimed as exhaust heat energy salvage. If also a heat exchanger is installed in the engine cooling system with an efficiency of 50%, additional heat recovery amounting to 10×10^5 Btu/hr can be realized. When overall station demand is on the order of 2000 kW (four generators on-line), a total waste energy resource of 72×10^5 Btu/hr could be captured. Such an energy salvage system would be a good application of integrated utility design.

Waste Disposal Alternatives

This final section considers alternatives to one of the major consumers of water: the conventional flush toilet. The systems and products discussed should be of special interest to Antarctic field camps and inland stations where fresh water is usually at a premium. Two concepts are considered. The first concept is that of the self-contained toilet, where human wastes are deposited and stored in individual repositories until picked up for discard elsewhere. During the past few years, there have been a number of innovations in this area. The second concept involves low-water-use modifications to the conventional toilet system, whereby wastes are carried from individual receptacles to a central treatment/disposal facility.

Sanitation in the polar regions is complicated by such factors as permafrost, bedrock, cold weather, population size, and water resources. While the installation of conventional sewer and water systems to replace trucked services, including "honey bag" collection, appears to be a desirable goal, such systems are not practical in many areas. Even where sewers can be

installed without prohibitive cost, the availability of a plentiful water supply is often a limiting factor. Under these conditions, the conventional flush toilet is not a viable method of handling human wastes. A number of alternatives to the conventional toilet have been tried in Arctic work camps and Northern communities; however, to date, the ideal system has not yet been developed.

Two recent innovations from the Scandinavian countries have the potential for upgrading the sanitary conditions and aesthetic acceptability of dry toilet storage systems. (12) The freezing toilet uses cold to preserve the waste and prevent biological breakdown with its accompanying odors. The basic configuration, illustrated in Figure 6, involves placing a toilet seat over a small, insulated freezing compartment which is cooled by an electrically operated compressor. The waste is received in a large waterproof paper bad. Once deposited, it is quickly frozen, thereby preventing decomposition and making it unattractive to flies and other insects. The toilet seat is warmed by heated air from the compressor coils, protecting the user from cold discomfort. It is moderately expensive in capital and operating cost. Models should be available on the North American market in the near future for $500 or less.

The packaging toilet also attempts to improve the sanitary and aesthetic qualities of the bucket-type toilet. Wastes are received in a plastic tube which is heat sealed after each use to form a series of connected sausages. Figure 7 is a pictorial of the configuration. By sealing each segment of waste received, the waste is immediately isolated from the home environment, preventing odors and the spread of pathogens by flies or other vectors. Unlike the freezing toilet, however, decomposition continues, making regular collection an important step toward maintaining sanitary conditions. Capital costs for the packaging toilet are higher than for a standard, bucket-type toilet. Also, its physical configuration is such that mounting of the unit with the collection bag beneath the floor may be difficult in some buildings. Additional packaging material may cause problems if wastes are ultimately disposed of in some sort of treatment system.

Although the use of composting as a method of handling human waste has been growing for several years in the Scandinavian countries, it is a relatively new concept in North America, where technology has concentrated on using water carriage to remove waste from the home environment. Composting is a process of microbial breakdown of organic material taking place in the solid phase. It differs from fermentation or digestion, which are liquid phase processes, in that pores or passages in the material allow the movement of gases and air into and out of the material. Composting can proceed anaerobically or aerobically. In general, anaerobic composting proceeds slowly with the evolution of small amounts of heat and with the production of end products such as methane, hydrogen sulphide and other odoriferous compounds. Aerobic composting, on the other hand, usually occurs at a faster rate, releases more heat of reaction, and does not produce foul odors. The breakdown of organics is much more complete, with the end products being carbon dioxide and water.

Actual development of composting toilets for use in individual building and homes began in Sweden over 30 years ago. Units based on early design utilized a large container located in the basement of the building to receive solid wastes from the toilet and kitchen. Two chutes accepted the wastes, which fell onto an inclined slope, covered with peat moss and soil. The container was vented through the roof of the building. Figure 8 shows the arrangement. Natural convection drew air through and over the compost heap, keeping it aerobic and evaporating excess moisture. As the organic material decomposed, it slid down the inclined slope to the storage chamber where it remained until manually removed. Because of the large size of the storage chamber, and the length of time the mass underwent decomposition, removal from the unit was only required once every two or three years, even when the unit was in constant use. The large size of the container and volume of material retained allow this type of unit to function under wide loading fluctuations; however, size is also a limiting factor, since it cannot easily be installed in buildings already constructed and presents difficulties in those which lack basement space.

The most recent innovation in composting toilets is the development of small units which utilize auxiliary heat and forced aeration to promote rapid decomposition of wastes. The concept behind the design is that by providing an ideal environment for microbial decomposition, the waste can be stabilized in a relatively short time, allowing the composting unit to be kept small. A number of different brands of this type of unit are being manufactured in the Scandinavian countries. The electrically heated units are, in general, small enough to fit easily in a normal bathroom. Figure 9 shows a typical model. Installation is relatively easy, since they sit on the floor and only require the installation of an exhaust vent and electrical outlet. Most of these units require only slightly more floor space than a standard water closet. For size reason, their use in polar facilities would seem logical as long as they can provide the service required. However, experience to date has indicated that there are problems. A number of units monitored in western Canada functioned well under ideal conditions, but were easily upset by shock loading of organic and liquid wastes because of the small capacity of the composting container. Since units rely on evaporation to remove moisture, excessive amounts of urine, such as might occur during a party, can easily saturate the compost, preventing oxygen from penetrating into it and thus allowing it to become septic. Once anaerobic conditions are established, unpleasant odors are produced which will become objectionable unless the ventilation system works efficiently. Once a toilet becomes septic, it takes considerable time to re-establish aerobic conditions. Other problems expected include even distribution of moisture in the humus, which causes portions of the compost to dry out and cake. The caked material can become very hard, making it difficult to mix and aerate the compost pile. The breakdown of sealing materials between sections of the units is another serious problem. This allows odors to seep out into the room where the toilet is situated. Also, if the vent pipe is not insulated in the attic and above the roof, condensation will occur, returning evaporated moisture to the unit, causing it to become septic.

Whether or not composting toilets will provide a safe and sanitary method of treating and disposing of human wastes remains to be determined. Rondale (13) suggests that, all things considered, the compost toilet may be a more sanitary method of handling wastes than the conventional flush toilet. The flush toilet, although it rapidly removes wastes from facilities, dilutes and distributes it, causing pollution and contamination of water resources. The composting process, on the other hand, allows the treatment of waste to take place without removal from the building in which it was produced. When properly designed, composting units require little or no energy input, and wastes are transformed into a sanitary and environmentally harmless product. If a simple sanitary system of mechanical transfer from receiving receptacles to compost unit is developed, a toilet system may well be created that will meet all the criteria necessary for cold weather use in the Antarctic.

In addition to the freezing toilet, packaging toilet and compost toilet, which are examples of self-contained systems, there are two sewage collection techniques that more closely approximate the conventional flush-type concept. The vacuum-sewage and pressure-sewage collection systems route toilet and lavatory wastes through piping to a central disposal facility, although they differ from the conventional system in that they do not rely upon gravity flow for drainage. The vacuum technique involves "pulling" sewage through the pipes by maintaining negative pressures in collection tanks at the end of the sewer mains, while the pressure technique is usually a combination of pressure lines (lift stations and force mains) and gravity drainage.

The vacuum sewage collection system is potentially useful in cold-weather regions where buried pipeline construction is not feasible or water resources are in short supply. In areas of unstable ground, piped sewer services have often required extensive pumping and construction of costly utilidors on piling to maintain grades. The vacuum system eliminates both pumping and rigid utilidors, in that it can tolerate slight movement of pipes and, within limits, operate with changing and even reverse grades. In addition, the vacuum toilet uses only about ¼ gallon per flush, as compared to four to five gallons for a conventional toilet. Less water used also means less water that has to be treated. (14)

The basic difference between the vacuum sewer system and the conventional gravity system is that the sewage is carried by air instead of water. A vacuum is maintained in the collection tank at the end of the sewer mains through the use of vacuum pumps, thus keeping the entire system under a constant negative pressure. The system requires special toilets and special gray-water valves which collect the wastes from conventional sinks, lavatories, bathtubs and showers. The toilet (Figure 10) is actuated by a push-button which exposes the wastes in the bowl to the vacuum in the main by activating a discharge valve and at the same time activates a water valve which allows a small quantity of water to enter the toilet for cleaning purposes. The discharge valve closes shortly before the water valve, allowing a small quantity of water to remain in the toilet. The gray-water

valve operates under much the same principle, although it is activated by the presence of water upstream from the valve through the use of a small, pressure-operated diaphragm. The diaphragm is mounted on a tee immediately upstream from the valve. As gray water is drained into the line and backs up into the tee, the diaphragm is activated and allows the vacuum in the main to open the discharge valve. The length of time the valve is open is controlled by a timer. The cycle will continue until no more gray water flows into the line and the fixture is empty.

The sewage in the main continues to move toward the vacuum source at the collection point as long as some point upstream from the sewage is open to the atmosphere, either through activation of a toilet or a gray-water valve. Consequently, pockets of sewage in the line move in stages as upstream toilets or valves are operated. The pipe must be full in order for the air to carry plugs or sewage along the line. For this reason, low pockets are constructed into the system so that when the system is at rest, the liquid will flow to the low spots and ensure that the cross-section is completely filled. This prevents air from escaping over the top of the liquid in a partially filled pipe. After the sewage is collected in the vacuum tank, it can be pumped to a treatment unit using conventional sewage pumps.

The vacuum sewer system has several advantages over a conventional gravity system, since air and not water is the medium of transport. Water is used mainly to clean the toilet bowl, thus significant savings are realized. The system also eliminates the small but normal amount of exfiltration associated with a conventional sewer system in that any leaks in the mains are inward, since the system is maintained under constant negative pressure. This feature greatly reduces the hazard of ground-water pollution. Also, because water is not used to carry the sewage, much smaller diameter pipes can be used for both the sewer mains and house plumbing. An additional advantage already mentioned is the ability of the vacuum system to operate independent of grade. Because the system does not depend on gravity, the pipes can be laid completely flat and also with reverse grades within design limits. For a buried system, the cost of excavation can be greatly reduced.

The vacuum sewage method of liquid waste disposal has disadvantages, also. The system involves the use of more sophisticated components and more elaborate controls than the conventional gravity system. It requires the use of external power in the form of vacuum pumps to guarantee operation. Although the vacuum sewage concept appears promising for cold-weather application, it is as yet still unproven by time. However, at least one major test facility has been constructed in the Far North. (14) The Indian Health Service has installed a comprehensive vacuum sewage network at the Eskimo village of Noorvik, Alaska, located about 400 miles northwest of Fairbanks and 20 miles above the Arctic Circle. The system, which was completed in 1974, presently serves 18 individual houses, four school classrooms, two teacher quarters and a health clinic. The overall system was designed to eventually serve 50 homes.

The pressure-type method of sewage collection is most usually a combination of pressure lines and conventional gravity lines. Several prototype installations around the United States have been built to test pressure system concepts and hardware. The two primary problems encountered have been the reliability and durability of the small pump-grinder units used to remove sewage from each building, and the hydraulic design of the collection lines to prevent grease deposition. Both of these problems have been solves to a degree. (15)

One advantage of the pressure system is that collection lines can be much smaller. They usually vary between 1½ inches and 3 inches, depending on the number of units contributing. Gravity lines usually start at 4 inches and increase in size from there. Another advantage is that collection lines do not have to be graded and can lie on and follow the surface of the ground without the need for elevation. Sewer lines could be placed alongside fresh water lines in a small, relatively inexpensive utilidor which follows the natural contours of the land.

When compared to the vacuum collection method of sewage removal, pressure dystems also have relative advantages. Vacuum systems are limited to a difference in elevation of 15 to 20 feet from one part of the installation to another. Pressure systems are not limited to allowable elevation differences. Also, vacuum collection lines require traps approximately every 150 feet to reestablish plug flow. Pressure lines can be designed for nearly any number of houses, while a given vacuum line can probably not serve more than 30 to 50 facilities. Vacuum systems require special plumbing, toilets and rather complicated discharges valves on sinks, lavatories and other fixtures. Pressure systems can make use of conventional and low-water-use fixtures.

There are also relative disadvantages. It is necessary to locate small pump/grinder units in each building instead of having all pumps located in a central pumphouse. This makes it more difficult to provide standby power for operation of the entire system in case of extended power failure. Even more important is the maintenance and reliability risk of the individual pump/grinder units. Although improvements have been made in recent years. it is still best to provide two complete pump/grinder units in each building sump for 100 percent backup. They should be wired so that if one unit fails to function, a warning alarm will sound and the standby unit will be activated. Also, there is a greater risk of contamination of a water line in a utilidor with a pressure collection line than there is with either a gravity or vacuum line.

DISCUSSION

This Technical Memorandum has discussed some concepts of conservation related to the utilization of fresh-water supplies at U.S. stations in the Antarctic. Of special concern is the present status of, and future prospects for, the utility structure at McMurdo Station. The existing pattern of production, distribution and consumption is wasteful of both water and energy. As pointed out earlier, the integrated utility system is one that accounts

for losses and is engineered to minimize waste. At McMurdo Station, two positive steps toward integration would be consolidation of the powerhouse and seawater distillation facilities (with appropriate heat exchanger equipment for energy reclamation) and construction of a more fully engineered protective pipeline enclosure.

Using captured diesel waste heat to distill seawater and freeze protect a utilidor would result in an appreciable reduction in fuel consumption. Regarding the former, the existing equipment on Observation Hill distills seawater at an average fuel rate of 1 gallon DFA for each 30 gallons of potable product. This means that a daily production of 15,000 gallons requires the consumption of 500 gallons DFA, a quantity which could be saved if waste heat were available. It is more difficult to define the potential savings associated with removal of the electrically traced heat tape system of pipeline protection, since individual circuits now existing are not metered for "on" time. However, it is well known that water delivered to individual buildings is overheated. A $30^{\circ}F$ reduction in operating temperature alone, from the "typical" $75^{\circ}F$ condition now existing to a more acceptable $45^{\circ}F$, would produce a heat savings of 3.75×10^6 Btu (at a daily production schedule of 15,000 gallons). At a generating efficiency of 30 percent, this quantity of "excess" heat represents 12.5×10^6 Btu at the powerhouse. Since the heating value of DFA is approximately 140,000 Btu per gallon, the energy tied up in the overheated water is equivalent to 90 gallons of fuel. The actual daily fuel requirement for pipe line heating is even greater, since some of the energy produced by the electrical heat tape is lost by combined conduction through the thermal insulation and convection to the ambient environment, the exact percentage being seasonally dependent and a function of prevailing air temperature and wind conditions.

As reference, power is presently generated at an efficiency of 11.3 kW-hr per gallon of DFA. At a sustained power level of 1500 kW, the demand for fuel becomes nearly 135 gallons per hour, or 3200 gallons for an entire day. It should be noted with interest that the combined fuel requirement for distillation and overheating (590 gallons per day) amounts to 18 percent of the DFA requirement for power generation. From this brief energy description, the potential conservation benefits to be derived from power plant/distillation facility consolidation and alternate pipeline construction should be obvious.

SUMMARY AND RECOMMENDATIONS

This Technical Memorandum was written to explore ways in which resources could be conserved within water utility distribution structures in Antarctica. Both the immediate situation and long-term potential of McMurdo Station were considered in terms of production, distribution and consumption. In addition, alternatives to the conventional water carriage approach to sewage collection were investigated, with an emphasis on application to the smaller polar camps and inland stations where fresh-water resources are especially dear.

Since there are no rigidly applied standards for the construction of liquid distribution systems in polar regions, water utility design tends to be largely individual and full of innovative detail. Existing and proposed water and sanitary systems reflect major differences of opinion. One bit of advice is in order. Before major redesign of the water distribution structure is started at McMurdo Station, or for that matter at any of the U.S. Stations in Antarctica, it is recommended that similar projects in other cold-weather regions be examined first in anticipation of potential advantages and shortcomings.

In light of the subject matter discussed in this Technical Memorandum, the following recommendations are made:

1. All buildings at McMurdo Station that are presently supplied with piped water should be metered.

2. The consumption pattern of water through the galley should be checked to establish acceptable standards of operation.

3. The treatment of graywater runoff from the galley and quarters areas for possible reuse should be investigated.

4. The applicability of reduced flow shower heads and other water-saving devices should be investigated.

5. The diesel power plant and seawater distillation facility should be consolidated at a convenient location.

6. A new pipeline or utilidor structure should be built at McMurdo Station to distribute fresh water and remove waste water.

7. All living, work and eating facilities should be connected to the water distribution netowrk.

8. Waste energy from the power plant should be used as a heat source for utilidor heating.

9. Alternate techniques of liquid waste collection and disposal should be investigated for application to Antarctic stations.

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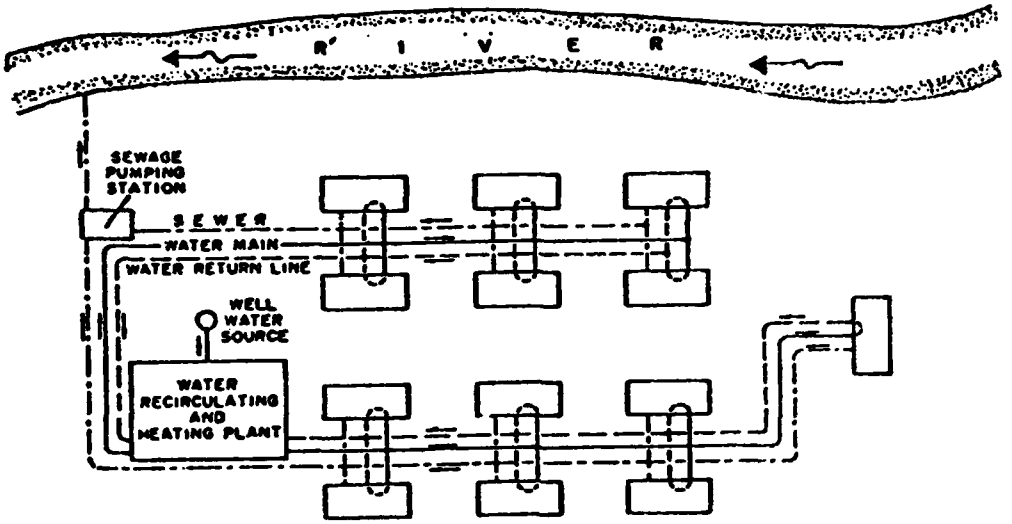
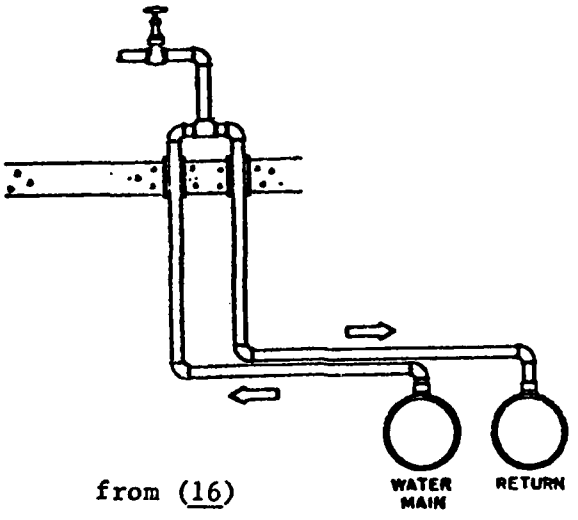


Figure 1. Dual Main Recirculating Distribution System, from (16)



from (16)

Figure 2. Dual Main Service Connection.

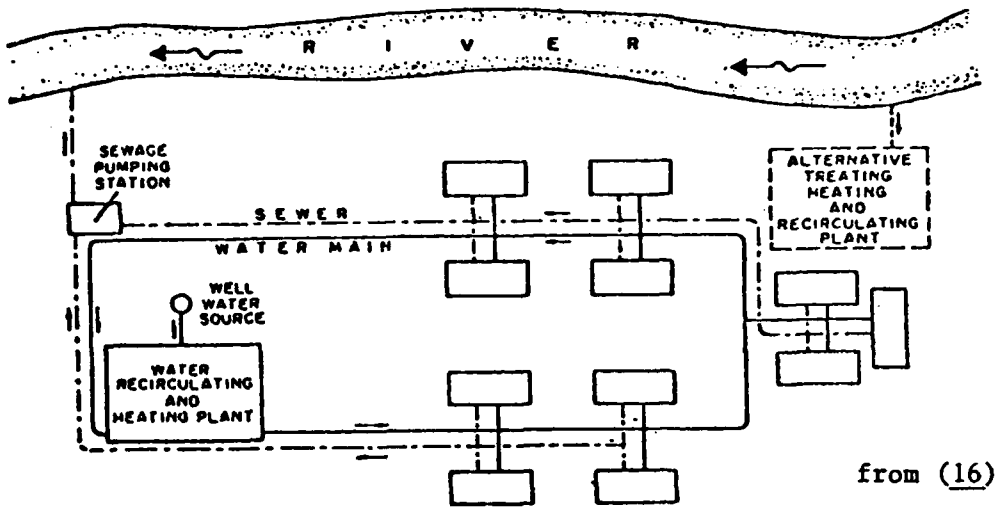


Figure 3. Single Main Recirculating Distribution System.

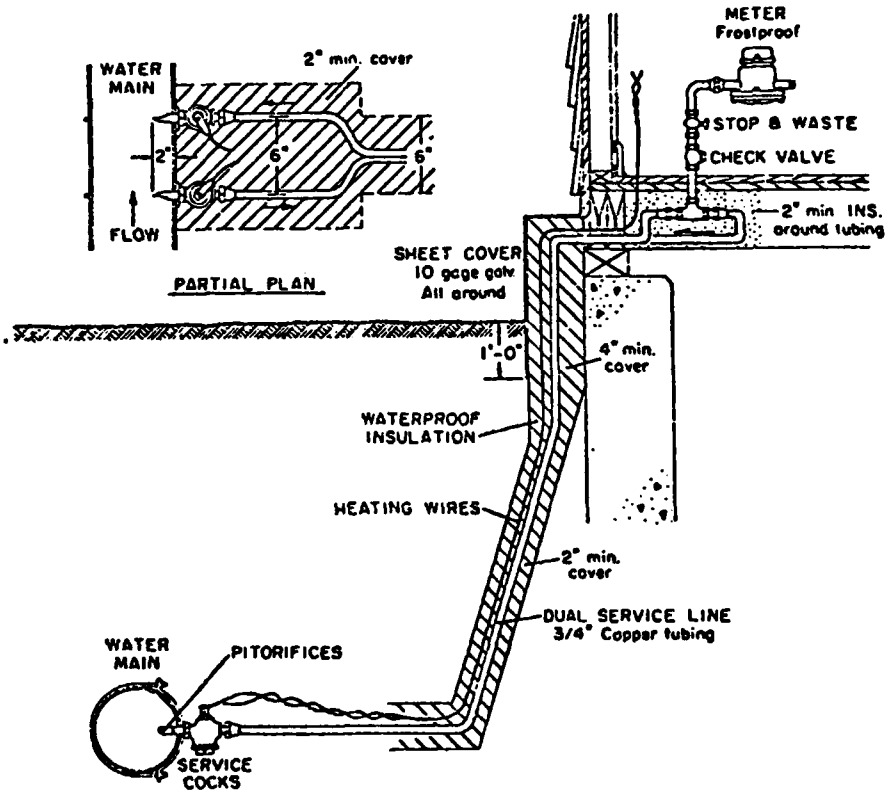


Figure 4. Recirculating Water System with Pitorifices and Service Connections.

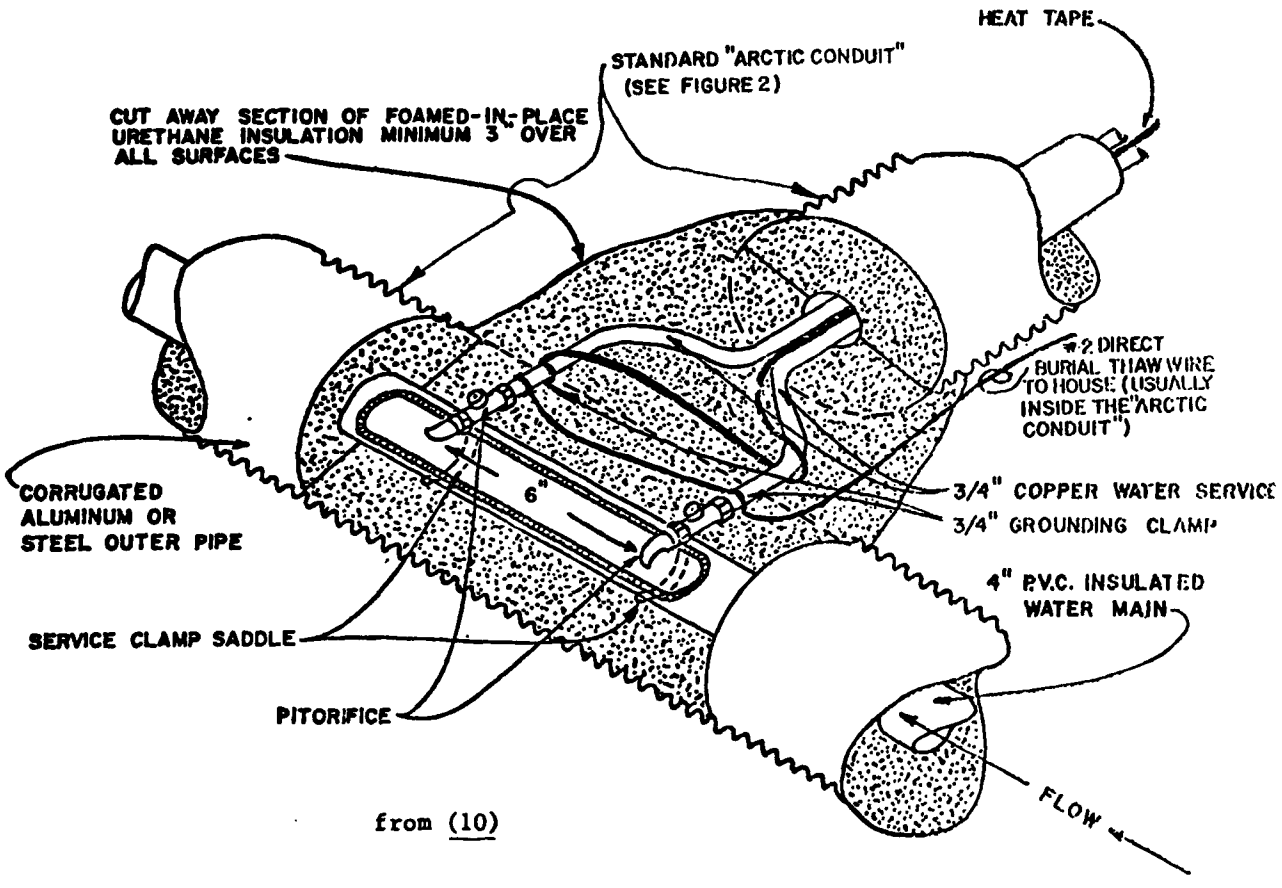
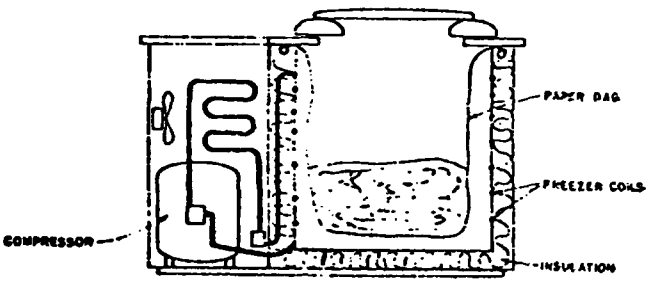
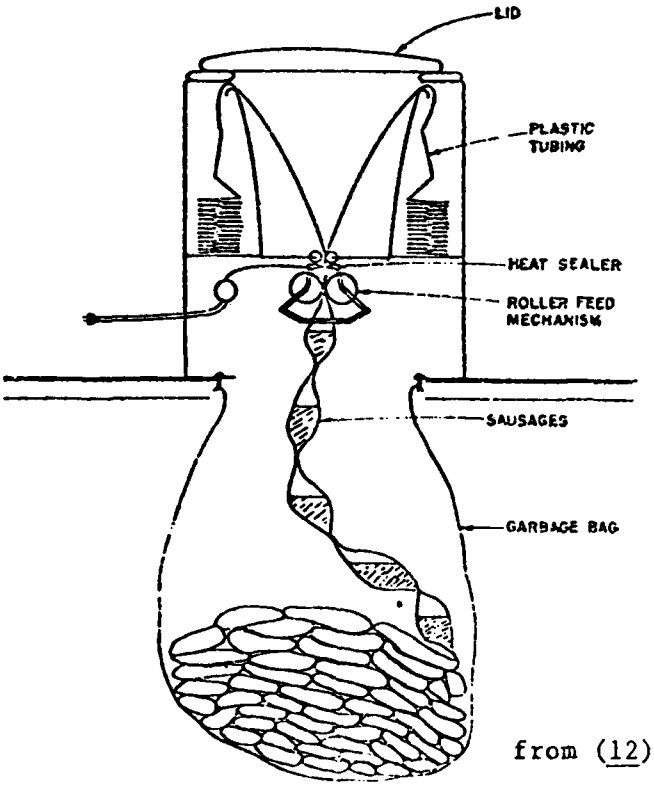


Figure 5. Service Line Detail for Single Main Recirculating System.



from (12)

Figure 6. Freezing Toilet.



from (12)

Figure 7. Packaging Toilet.

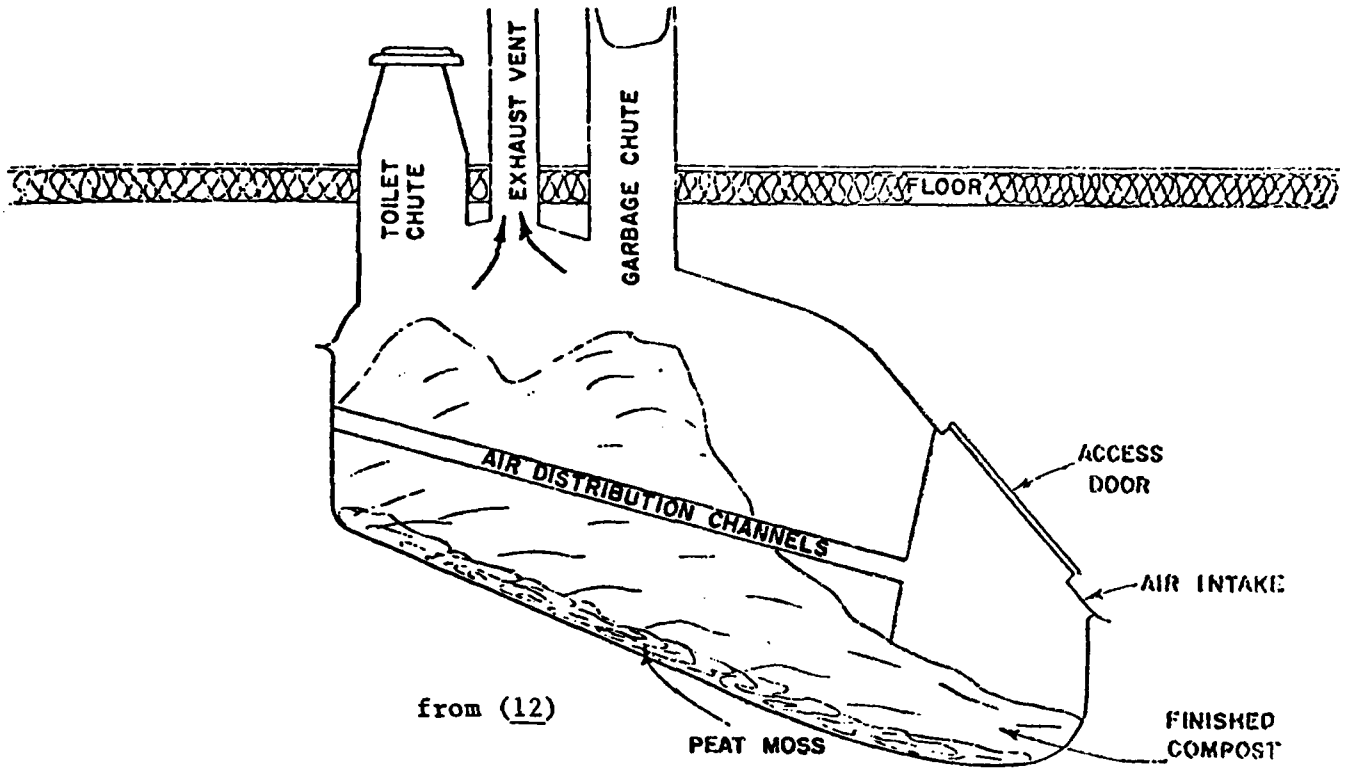


Figure 8. Inclined Slope Composting Toilet.

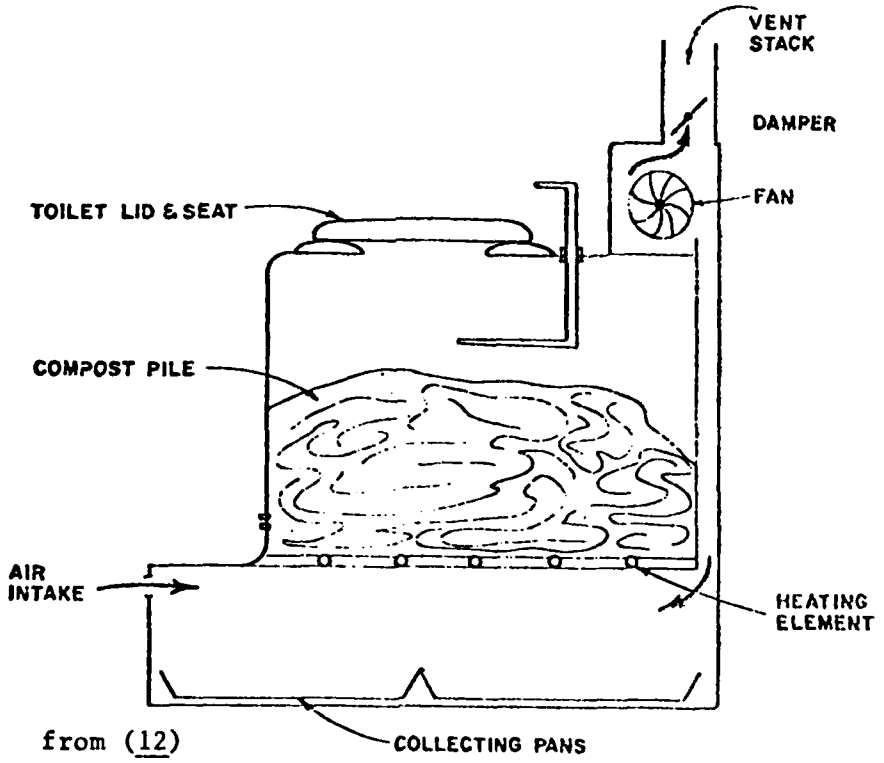
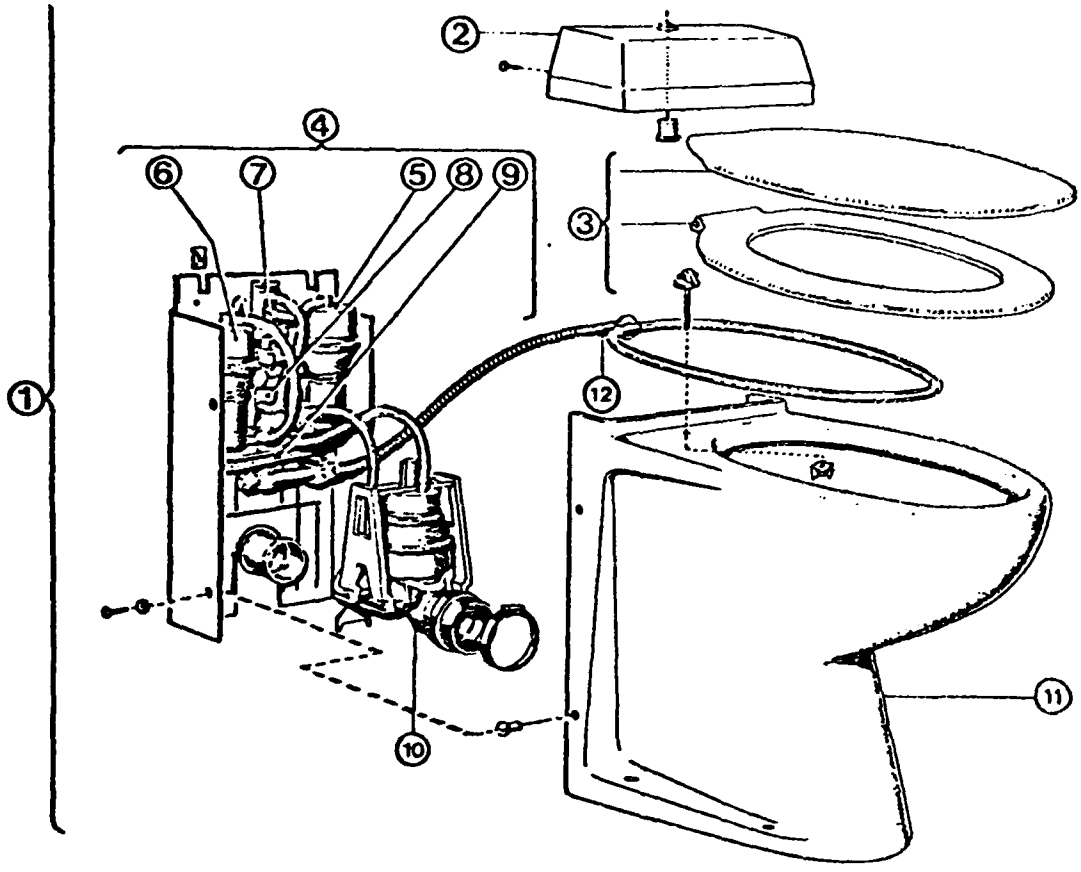


Figure 9. Small Electrically Heated Compost Toilet.



1. Vacuum toilet floor model
2. Cover
3. Seat
4. Operating mechanism
5. Discharge timer
6. Water timer
7. Starter
8. Distribution valve
9. Water valve
10. Discharge valve
11. China bowl
12. Flushing loop

Figure 10. Floor Model Vacuum-type Toilet.
from (14)

Chapter 7

AIRFIELDS AND ROADS

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Chapter 7

AIRFIELDS AND ROADS

INTRODUCTION

The importance of the airfield and road systems at McMurdo Station during Antarctic summer operations is probably surpassed only by the basic need for food and shelter. As a result, construction and maintenance of roads and airfields receive the highest priorities by station personnel and have been the subject of extensive and continuing study and evaluation by NCEL. Investigations of construction methods for compacted-snow runways and roads began in Greenland in 1947, moved to Antarctica in 1960, and continued at McMurdo through DF-74.

Studies of maintenance methods for ice roads and runways during warm weather and periods of high solar radiation were made at McMurdo in early Deep Freeze operations, resulting in maintenance techniques by which ice surfaces can be kept usable throughout the summer, so long as ice thickness is adequate for strength.

AIRFIELDS

At McMurdo Station both ice and snow airfields are used. The annual ice is used for wheeled-aircraft operation from early season until mid- or late December, when ice strength becomes marginal. Operations are then moved to the snow-airfield facility on the McMurdo Ice Shelf and ski-equipped aircraft are used.

Ice

Construction of runways, parking areas, cargo yards, and fueling pits on ice consists primarily of removing excessive snow, laying out runway markings, and proceeding with aircraft operations. Special considerations become necessary, however, to minimize the impact of storms and to provide timely maintenance during periods of warm temperatures and high solar radiation.

Runways. Snow removed from ice runways, whether during original construction or during storm cleanup, should not be windrowed in deep berms at the edges of the runways. This can be avoided by clearing snow with the rotary snowplow and blowing the removed snow as far to the side as possible.

If deep berms are created, a number of detrimental conditions occur:

1. High berms are hazardous to aircraft operations.

2. The weight of the snow surcharge downwarps the sea ice, which may result in runway-centerline cracks and seawater-slush pools beneath the berms at the runway edge.

3. Snow berms at the runway edge trap more wind-borne snow than smoothly tapered transitions.

If centerlin cracks do occur, it is generally not a major factor in determining ultimate bearing capacity of the ice. There is,

however, often concern that aircraft nosewheels can be caught in the widest portions of the crack, particularly those on smaller airplanes.

Sometimes, after initial snow-clearing, the ice surface may be found to contain swales and ridges detrimental to aircraft operations. Such irregularities are often encountered on ice more than 1 year old. Ridges can be reduced in height by cutting them away with the Bros pulvimixer fitted with the ice-chipping drum (Bros Division, American Hoist and Derrick Co., Minneapolis, MN), as described in Chapter 10. The amount of cutting permissible is determined by ice thickness. Swales, can be filled with seawater or seawater and ice chips and allowed to freeze, if the air temperature is near 0^{o}F or colder so that freezing will occur quickly. Such filling should be done in layers limited to 3 to 4 inches at a time, and the previously placed material should be allowed to freeze solid before a new layer is added. If the layered method is not used and flooding is done in a single 12- to 18-inch lift, the area may never freeze enough during the summer to allow safe aircraft operation.

Surface melting on ice runways begins in late November or early December, when warm air temperatures and bright, sunny weather permit high rates of heat absorption into the ice surface. Surface melting of the ice can be retarded by maintaining a continuous cover of clean, white snow or ice chips 1 to 2 inches deep over the ice surface. Material for this white cover can be provided by grading drift snow over the surface and compacting it with the slick drag described in Chapter 10. If clean snow is not available along the runway edge (often the case because of ablation), a white cover can be provided by chipping the surface to about a 1-inch depth with the Bros ice-chipper. This should also be compacted with the slick drag.

After a week or more of continuously warm weather, melting of the white runway covering may occur. This will first be observed as patches on the surface, very light tan in color. Close examination will show free water in a slush-like material. If left without maintenance, these slush spots will rapidly develop into potholes and ponds of free-standing water. For prevention, the wet, protective cover should be removed and replaced with new, clean, dry snow or ice chips. When only small areas are involved, it may be possible to do this by hand-shoveling. At other times it may be necessary to grade the deteriorated covering from the entire runway and cut a new covering with the Bros ice-chipper. This method of maintaining a protective ice cover can keep an ice surface usable throughout the entire summer season at McMurdo Station. This method was used to maintain the ice runways until DF-65. At that time it became no longer necessary to depend on wheeled aircraft for mid- and late-summer aircraft operations.

Aircraft-Parking and Cargo Lots. The construction of aircraft-parking and cargo-handling lots on sea ice is essentially the same as that for the ice runways, except that it is generally permissible to have a thicker covering of protective snow or ice chips. Maintenance of these areas is inherently more difficult because of dirt and other snow contaminants related to the area work. In some respects, maintenance is not as critical as on the runways. Surface-melt ponds, unless developed to the extreme, are more of an inconvenience than a hazard. Nevertheless, reasonable effort should be made to keep the

ice surfaces clean: dirt dropped from vehicles should be shoveled and spillage of oils and fuel prevented. Considerable contamination of the ice surface can be prevented if the parking and cargo yards are not part of the main vehicle-traffic routes to and from the areas.

Snow

When the annual sea ice off Cape Armitage becomes too thin through bottom melting to support aircraft safely, operations are moved to the snow airfield on the ice shelf. This change in location ends the operation of wheeled aircraft and inaugurates ski-only operations.

Runways. The snow runways for ski aircraft are prepared by leveling with the 40- or 80-foot snowplane, rolling with one pass of the 8-foot steel roller, and rough-dragging as required (see Chapter 10 for descriptions of the equipment). This processing compacts the top few inches of the skiway and leaves the surface depressed a few inches below the surrounding surface. Winds which cause heavy drifting on other areas have little effect on the skiway because there are few obstructions to trap the snow. The finger drifts which do result are generally distributed over the surface by "chaining" the runway. In this operation two dozers, moving in the same direction on opposite edges of the runway, drag a heavy anchor chain between them. This spreads the small drifts and breaks up crusted snow.

Surface melting is generally not a problem on the skiways, even in midsummer, except where dirt or spilled oil or fuel contaminate the surface. Dirt areas absorb greater solar heat and quickly melt into the surface. Repair of these melt cavities should be done as soon as they occur to minimize their size. This is accomplished by cleaning the dirty or discolored snow from the hole and filling it with clean material. Burying the dirty material in the hole is not recommended because solar radiation penetrates the snow to a significant depth and subsurface cavitation may occur, necessitating additional repair.

Aircraft-Parking and Cargo Yards. Operations in aircraft-parking areas and the cargo yards generally involve extensive use of wheeled vehicles and equipment. For this reason construction of both areas should resemble more nearly that of the compacted snow roads than construction of the skiway. A good compromise of the two approaches is to grade the surface with a snowplane to remove surface irregularities and then to compact the area, using the same methods developed for snow trails. This method is described in NCEL TechData Sheet 73-7, page 7-13.

Maintenance requirements in the aircraft-parking areas and cargo yard are similar to the skiways, and the methods are the same.

ROADS

Road construction and maintenance at McMurdo Station are of three types: land roads on Ross Island, ice roads over the annual sea ice, and snow roads and trails over the deep snow of the McMurdo Ice Shelf (Figure 7-1). Each presents its own construction requirements. In addition, transition areas from one road type to another require special treatment.

Land

Several miles of land road have been constructed and are maintained in McMurdo Station area. Much of this was created by surface grading, installation of culverts for drainage control, and placement of earth and gravel fill as required to produce the desired road grade.

Construction. The most extensive and challenging road construction in the area was the road from Scott Base to the top of Observation Hill Pass. This construction required some deep earth fill across a small glacier and extensive cuts and fills that required extensive blasting.

Another interesting section of road construction in McMurdo is that crossing the small glacier near the summit of the Scott Base road. This was constructed in DF-71 by placing earth fill over the ice slope. To prevent possible downhill slippage, a bench was blasted in the ice to key the earth fill into the slope. Ice thickness through this section was extremely variable. As constructed, 15 to 18 feet of ice remains beneath the earth roadbed.

The placement of fill material for roadbeds has been accomplished, using whatever rock, gravel, and dirt materials that could be obtained from the surrounding hillsides. Little or no consideration has been given to moisture content, percent compaction, or other parameters of soil mechanics. These techniques have been satisfactory, but in the deep-fill areas on hillsides the newly constructed roads have not been used until stabilization has occurred through freezing of the fill material, generally through the winter. To assure stabilization through freezing, the fill material must have a minimum moisture content. This value has not been determined for materials in the McMurdo area, nor has it been the practice to add water during placement of the fill. Nevertheless, satisfactory results appear to have been obtained.

Blasting with explosives has been used extensively in construction of the Scott Base Road. Larger quantities of explosive are needed when the ground is frozen, but details of this have not been recorded. Where critical, the size of the explosive charge has been determined each time by conservative experimentation.

Maintenance. The greatest maintenance problem on the land-based roads is control of meltwater running over the surface. Prior to the start of surface melting, as much snow as possible should be graded from the surface and roadside ditches. Culverts which transect the road should be opened by clearing of ice and snow. This is most easily accomplished with a portable steam generator or boiler and length of pipe used as a steam lance. Care should be taken not to leave snow or earth berms along the road edge. If berms are left, water running onto the surface from uphill slopes is effectively confined on the surface and can erode the surface for hundreds of feet. This is a particular problem on the Scott Base side of that road.

Ice

Each year in September, coinciding with construction of the ice runway, two road systems are laid out over the annual ice from McMurdo Station to the ice runway. From there, they continue onto the ice shelf and to the Williams Field camp (Figure 7-1). One of these roads is prepared by removing the snow down to the ice surface. The other is simply

flagged and used by tracked vehicles. The departure point from land for these roads has in recent years been the base of VXE-6 Hill, west of the helo-pads. In preceding years, the departure point had been from the pass road on the south side of Observation Hill. This latter route, though shorter, has not been used since DF-68 because of a single line of pressure ridges along the shore which has been essentially impassable to vehicles.

The ice road is prepared by simply removing snow from the ice surface. This is best accomplished with rotary snowplows, because the removed snow is not left in berms along the roadside. If bulldozers are used, the resulting berms along the roadside create a snow trap and cause drifting on the road surface. This drifting can be so heavy that construction of a new ice road is less effort than reopening the drifted-over road, as happened twice during October and November of DF-74.

Intentional or systematic compaction of the snow on the annual ice surface to provide a road for heavy, wheeled vehicles has not been attempted, although it has been found that the compaction obtained from operation of the tracked vehicles in the confined area of the tracked-vehicle road will support many of the operating wheeled vehicles with high-flotation tires. Because of this and the heavy maintenance required some seasons on the annual-ice, wheeled-vehicle road, the experimentation with alternate methods of road construction over the annual ice may be warranted. One alternative approach is illustrated in Figure 7-2 and appears practical because there is no increased labor requirement over presently used methods, except for the possible need for dragging or leveling in step 2b. The resulting wheeled-vehicle road would be slightly higher in elevation than the surrounding area, thereby reducing vulnerability to snowdrift, with a resultant saving of labor.

It is believed that the compaction obtained from the tracked vehicles and the processed snow from the snowblower may be adequate to support heavy-wheeled vehicles through December, prior to the period of maximum snow-cover temperatures.

Compacted Snow

Thinning of the ice sheet and loss of strength from bottom melting in late December and early January requires abandonment of the ice runway. At that time all traffic to Williams Field is rerouted from the annual ice road to a route over the ice shelf. Wheeled vehicles use an elevated road of compacted snow, and tracked vehicles use a parallel route. These roads run from the shore of Pram Point near Scott Base over the ice shelf to Williams Field. The methods for construction of the elevated, compacted-snow road are described beginning on page 7-15.

It has been suggested on several occasions that the compacted-snow road be considered as an all-season road to be used from the beginning of summer operations throughout the season. With this method, no direct ice road would be needed to Williams Field, and ramp problems at the transition of the ice to land could be eliminated. Labor now required to open and maintain an ice road could be used to construct a new compacted-snow road each year early in the season, rather than late in the summer, as is often done. With two snow roads, the one remaining from the previous year and the newly constructed road, it would be possible to close one for maintenance while traffic used the other.

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Reasons for not opening the compacted-snow road to wheeled traffic early in the season have generally included a feeling that the road should be "saved" until the ice road becomes impassable. In NCEL experience there is little indication that compacted-snow roads wear out. Compacted roads built the previous year are at their maximum summer strength in October through December, because the roadbed retains the low temperature from winter. Traffic with high-flotation-tired vehicles may actually be beneficial during this period.

Numerous failures have occurred in compacted-snow roads, but since adoption of the layered-compaction method they generally occur in late summer, and in nearly every case can be traced to an insufficient thickness in the processed-snow mat. Just as concrete paving will fail if too thin compacted-snow roads can be expected to fail if the layer of processed material is too thin. The problem of inadequate processed-snow thickness can be minimized by constructing a new road directly on the surface of an old road. By so doing, a roadbed of essentially twice the thickness is obtained.

In constructing a dual compacted-road system, a few important features should be observed:

1. The new road should be built directly on the oldest road (2 years old) and elevated 12 to 15 inches above the surface by the layered-compaction technique.

2. The two-road system should be separated by 800 to 1,000 feet, so that the elevation of one does not cause drift over the other.

3. Roads bypassing Williams Field should be built for traffic to the ice runway.

4. Snow berms resulting from grading operations must be removed to prevent trapping of drifted snow on the road surface, even if it requires hand-shoveling.

In the dual system, the only section of road which needs to be common to the two roads is the area from shore below the bluffs to the big turn (Figure 7-1). This section has historically held up well on all occasions, undoubtedly because it is shaded by the bluffs every afternoon during the period of highest solar radiation.

Transition Ramps

The most critical areas of construction and maintenance on the McMurdo road system are the points of transition from one road material to another. The following transition conditions exist in the road system: (1) land to annual sea ice, (2) land to compacted snow, and (3) compacted snow to annual sea ice. Each of the zones has different construction and maintenance problems.

In DF-73 NCEL investigated methods for maintaining road transitions in each specific area. From this study one common design approach was found: all transition areas should be made several lanes wide on the ice or snow side. By spreading traffic over a greater area, fewer problems occur. In the case of the sea-ice-to-compacted-snow area, the entire transition should be several lanes wide. If vehicles are forced by poor road design to follow in the same track, potholes and ruts quickly form, due to dropped dirt and the pounding of the wheels in the holes. If a choice of routes is available, vehicles can fan out at the immediate transition point, and, thus, much less difficulty is encountered.

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Land to Annual Sea Ice. The land-to-sea-ice transition in recent years has been at the base of VXE-6 hill. The problem elements in this area are:

1. The working tide crack where the floating ice-sheet contacts the shore

2. Meltwater which runs from the land into the tide-crack area

3. Dirt tracked by vehicles from land onto the ice or snow, accelerating surface melting

Observations of the VXE-6 transition show that about 75 feet of rigid steel or timber ramps are required for bridging from shore to beyond the tide-crack area. In addition, as much as 500 feet of additional surface overlay may be required for extending the ramp to bridge ruts and potholes as they develop. Of the materials used for the overlay, AM-2 aluminum planking and fiberglass-reinforced plastic Mo-Mat were found to be effective because they are thin and can be approached at any point. Melting does occur beneath both materials but can be reduced by painting the surfaces white and by placing 3/4-inch plywood beneath to retard heat transmission.

The use of earth cover on the ice, once thought to be useful, is no longer recommended if other materials are available. The problem with the earth overlay is its weight, which depresses (downwarps) the ice, so that the ice surface beneath and immediately adjoining the dirt is below sea level.

Land to Compacted Snow. The transition from the land to the compacted-snow road is located on the east side of Pram Point near Scott Base. Road construction in this area is confined by pressure-ridge formations on one side and by a steep, rocky bluff on the other.

The immediate area where the road leaves the island is swept by winds rounding the bluff and is nearly always deficient in new, clean snow for road construction. In DF-70 the placement of earth fill on top of the compacted snow base began as a method of alleviating the deficiency in new clean snow. As this dirt is tracked onto the snow road, ruts develop, which have in turn been covered over by extending the earth overlay. By the end of DF-72 the overlay extended about 2,500 feet past the shoreline and ended adjacent to a cliff which shades about 300 feet of the adjoining snow roadway for several hours each day. The shade reduces the exposure to solar radiation and decreases deterioration of the snow road. Extension of the earth overlay past this location is not recommended.

The amount of dirt tracked onto the snow road can be reduced by using 75 to 100 feet of an intermediate surfacing material. The flexible timber surfacing system with its openings to collect dirt (Figure 7-3) is better suited for this transition than prefabricated AM-2 matting or Mo-Mat surfacing materials. The prefabricated surfacing materials become covered with dirt, therefore ineffective in preventing tracking of dirt onto the snow road. As another advantage, the flexible timber surfacing system costs about 60% less than prefabricated surfacing materials.

Since the rate of snow accumulation is high at this immediate area, the flexible timber surfacing material should be stored at some other location during the winter. If this material is fabricated as shown in Figure 7-3, each 20-foot length may be towed to a snow-free location at the end of each summer season.

The surfacing material should be installed at the transition each summer when the snow road is open to traffic. The end of the surfacing material nearest the ice shelf should be buried. Burying the end of the surfacing material will provide a smoother transition onto the ramp. Each section of flexible timber surfacing material should be tied together so the entire ramp acts as a unit.

Compacted Snow to Annual Sea Ice. The road transition from sea ice to compacted snow occurs as the road from the ice runway to Williams Field mounts the ice-shelf barrier. The basic problem in this area is downwarping of the sea ice along the face of the ice shelf, which is caused by the weight of drifted snow on the ice surface and movement of the ice shelf (Figure 7-4). Flooding of the downwarped area results from the open tide crack along the edge of the ice shelf. Early in the season, the flooded snow becomes saline snow-ice. As temperatures rise, the flooded snow does not freeze, but becomes slush. This slush has no strength and eventually may result in collapse of the compacted-snow ramp bridging the slush.

When constructing this ramp, about half its length should be cut back into the barrier itself. This is conveniently done, since the snow taken from the cut can be used as fill on the ice. If the entire ramp were built out from the face of the barrier, the weight of the additional overburden on the annual ice would be likely to cause additional downwarping and flooding on each side of the ramp. To prevent traffic from using the same track, the ramp should be at least 40 feet wide. The shoulders where the ramp is cut into the barrier should be tapered back and rounded to prevent trapping of drift snow on the ramp. The road surface should then be prepared by double-depth processing with a towed pulvimixer.

When cutting into the barrier to build the ramp, a cavity resembling a crevasse is often found at the barrier edge. This is a cornice-like formation caused by snow drifting off the barrier surface. This formation can be filled with snow without difficulty, since there is no relative movement between the annual ice and the barrier, as there is in a tide crack between sea ice and land.

Most problems with the ramp bridging the barrier have occurred because the ramp was too narrow and too steep with too thin a snow bridge over the natural slush zone and because the shoulders of the ramp were not rounded to prevent drifting.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCE

1. Naval Civil Engineering Laboratory. Technical Note N-1317: Improved transition ramps for McMurdo Station, Antarctica, by F. W. Brier. Port Hueneme, CA, Nov 1973.

Revised – 1979

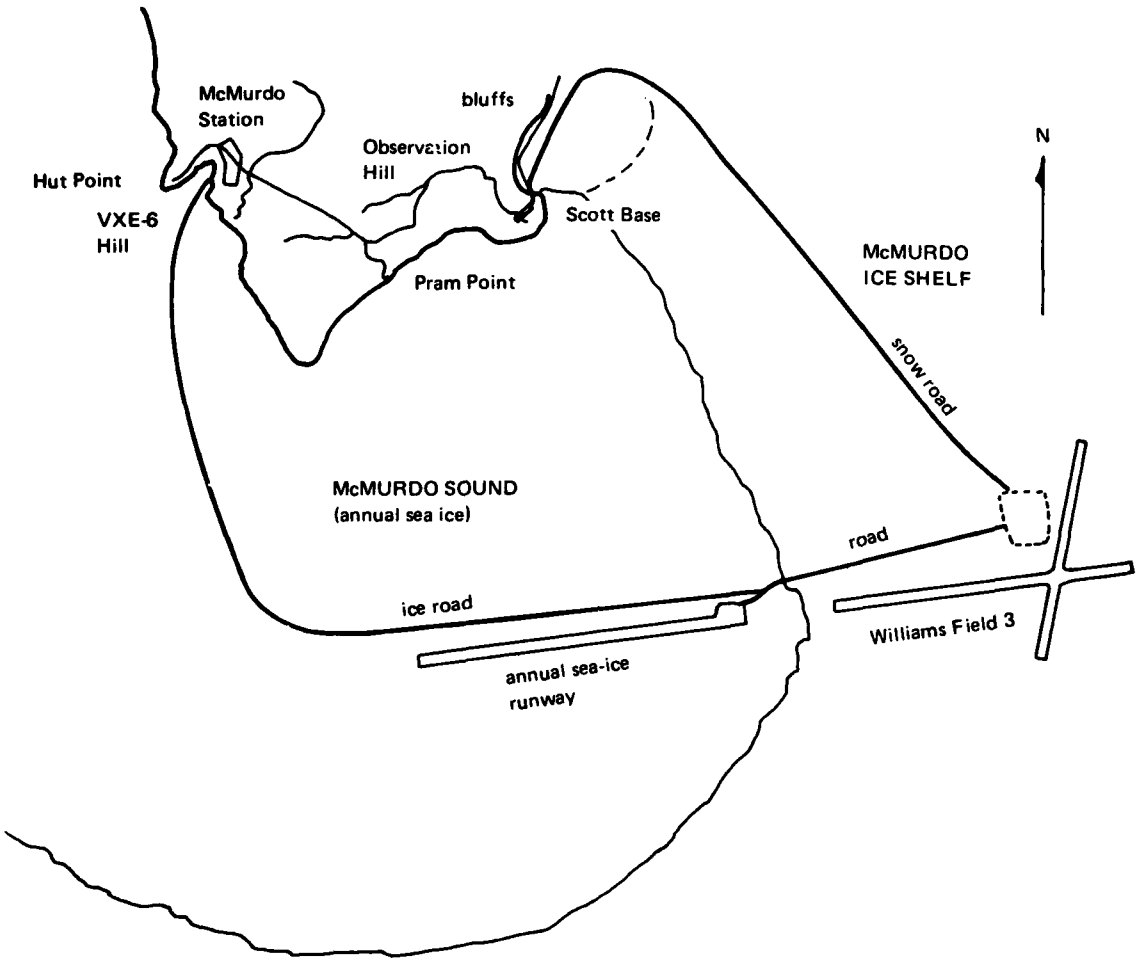
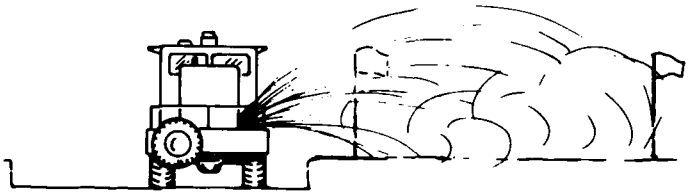


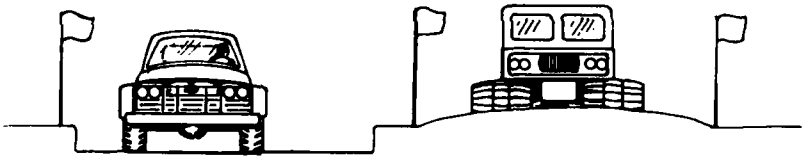
Figure 7-1. Ice, snow, and land roads at McMurdo Station.

Step 1. (September) Flag road for tracked vehicles.



Step 2a. (October 1-15) Make wheeled-vehicle road parallel to tracked road using rotary plow. Deposit blown snow on top of tracked-vehicle road.

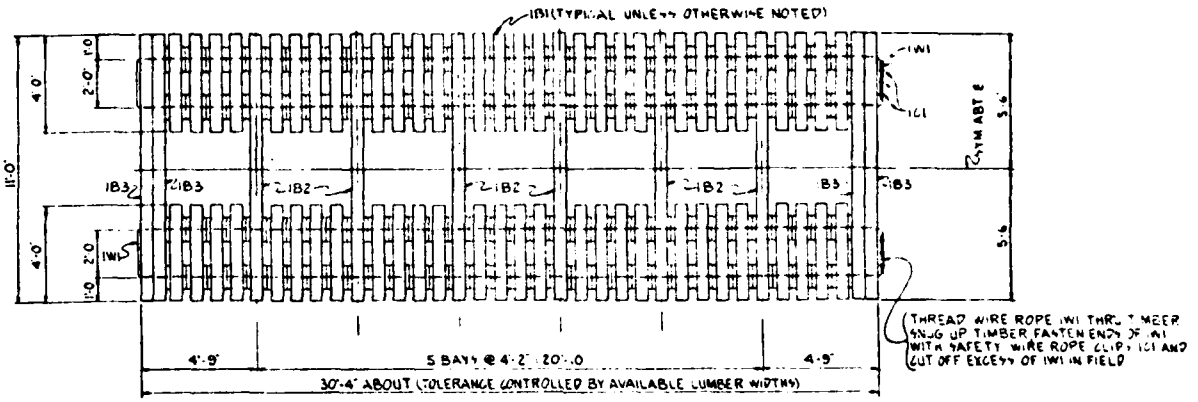
Step 2b. If necessary, level blown material with snowplane or drag.



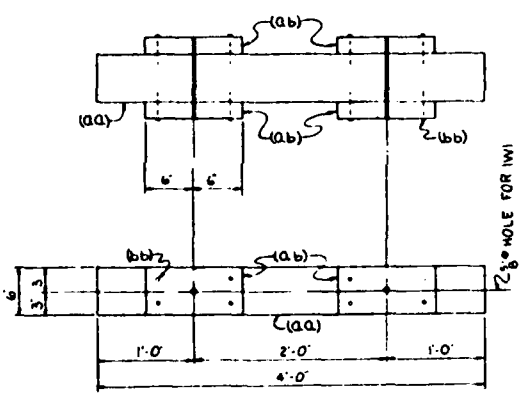
Step 3. (October 15-30) For two weeks use both roads. If wheeled road must be cleared of drift, repeat steps 2a and b.

Step 4. (November) Abandon wheeled road after next storm, move wheeled vehicles to existing tracked road, lay out new tracked vehicle road.

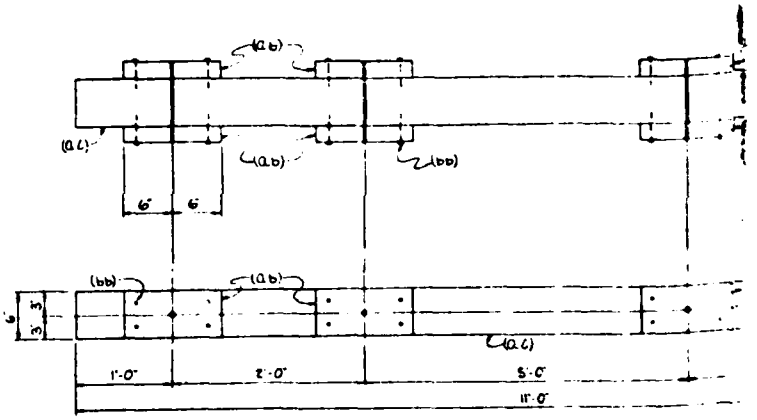
Figure 7-2. Alternative method for construction of ice road for wheeled vehicles.



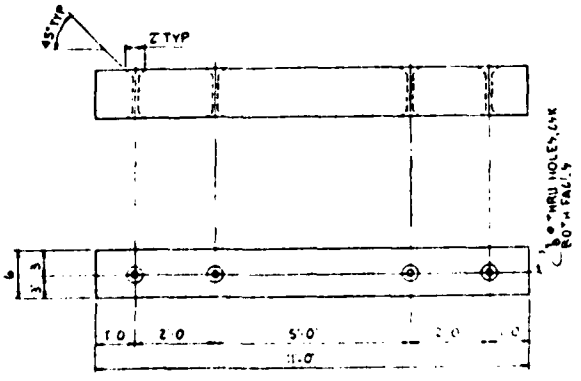
ERECTION PLAN (FIELD ASSEMBLE)



56-WOOD BEAMS-IB1



6-WOOD TIE BEAMS-B2



4-WOOD END BEAMS-B1

Figure 7.3 Flexible ... er

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NOTES

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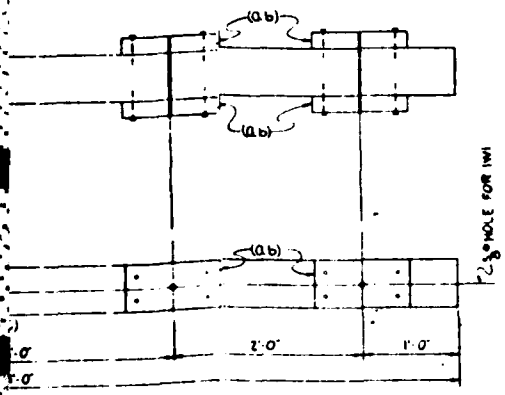

E BEAMS - B2

	2	BOLTS, ⅝ø - 25 FILLER WIRE, LWR'S IMPROVED PLOW STEEL, GALVANIZED	
		2 - TIE CABLES - TWI (NOT DETAILED)	
	6	WIRE ROPE SAFETY CLIPS FOR ⅝" WIRE ROPE, GALVANIZED	
		6 - [illegible] (NOT DETAILED)	
	4	6 x 6	11' 0"
		4 - WOOD END BEAMS - IB3	
bb		NAILS BILLED UNDER (IB)	
aa	6	6 x 6	11' 0"
ab	48	2 x 6	3' 0"
		6 - WOOD TIE BEAMS - IB2	
bb	250	16d COMMON STEEL WIRE NAILS, GALVANIZED	
ab	224	2 x 6	3' 0"
aa	56	6 x 6	4' 0"
		56 - WOOD BEAMS - IB1	

MARK	NO REQD	SIZE	FT - IN LENGTH	REMARKS

BILL OF MATERIAL

PROJ NO 61 017
REEL DWG NO 73-15-1F

DEPARTMENT OF THE NAVY — NAVAL CIVIL ENGINEERING LABORATORY — PORT HUENEME, CALIFORNIA

MOBILE TRANSITION RAMPS
FLEXIBLE TIMBER RAMP
[illegible] PLANS & DETAILS

SIZE	CODE IDENT NO	DWG NO
F	80091	73-1103

SCALE — WT — SHEET 2

TOLERANCES
FRACTIONS ± UNLESS NOTED
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ANGLES ±

APPROVED — DATE
APPROVED — DATE

1/3 Flexible timber ramp

(2)

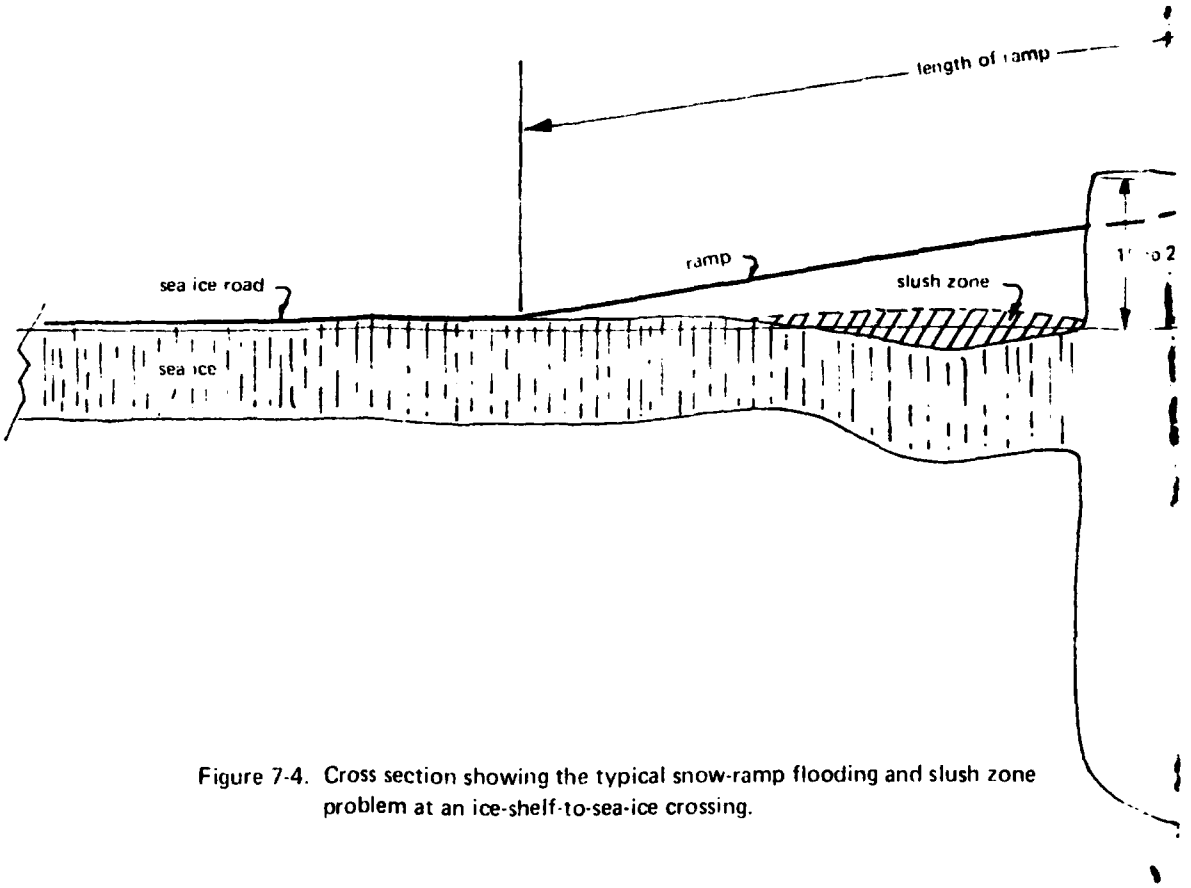
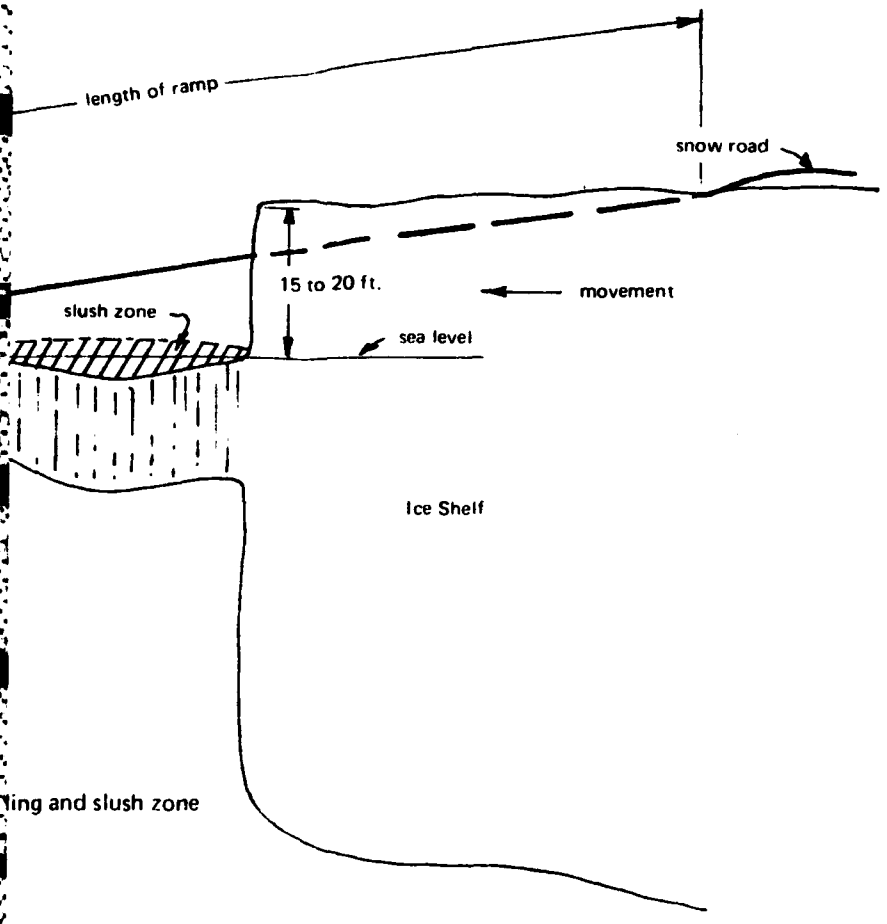


Figure 7-4. Cross section showing the typical snow-ramp flooding and slush zone problem at an ice-shelf-to-sea-ice crossing.


length of ramp
snow road
15 to 20 ft.
movement
slush zone
sea level
Ice Shelf
ling and slush zone

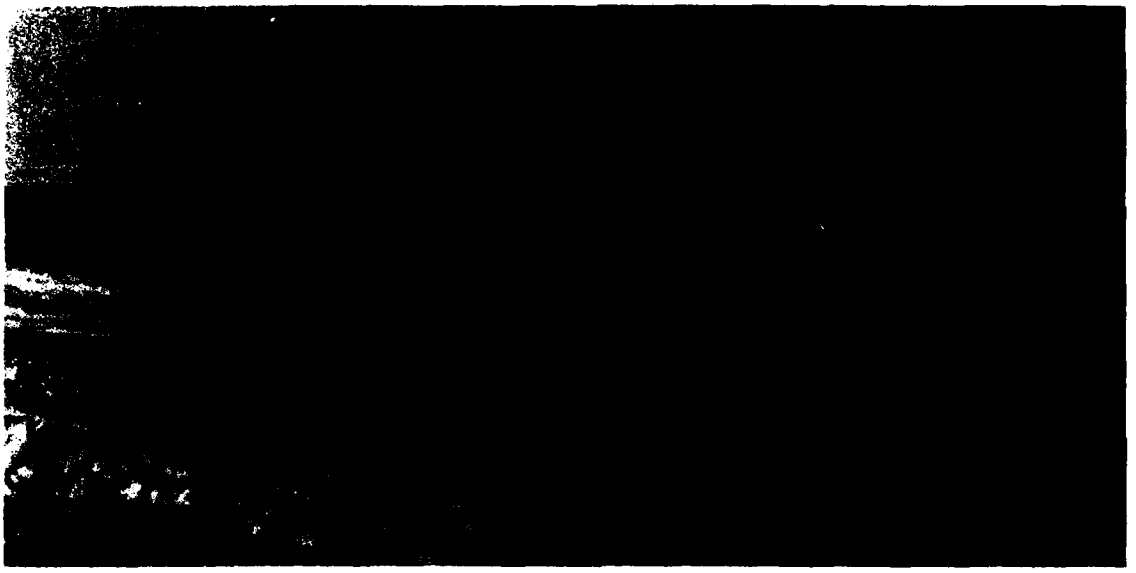
2

Naval Civil Engineering Laboratory

Port Hueneme, California 93043

NCEL
Techdata Sheet

SNOW TRAILS FOR LIGHT, WHEELED VEHICLES



A rapid and economical means of transporting personnel and light cargo by wheeled vehicles over snow, ice, and frozen ground is a major requirement for polar operations. High-grade roads usually are too slow and costly to build. Therefore, special snow trails are needed to: (1) support new facilities during construction before adequate roads are developed, (2) service temporary construction sites, (3) provide rapid ground transportation at low-activity stations where high-grade roads are not warranted, and (4) provide temporary access after severe storms. Snow trails, if they are to be practical and functional, must be:

- Economical to build with available construction equipment
- Ready for use within 24 to 48 hours after construction
- Suitable for travel by 10,000-pound vehicles (GVW) with high-flotation tires inflated to 10 psig
- Dependable and easy to restore following light to moderate drifting
- Easy to rebuild after severe storms

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BUILDING AND MAINTAINING SNOW TRAILS

- Construct trail using a single pass with a Size 6 low-ground-pressure snow tractor or a single pass with a Size 2 snow tractor towing a 8 ft diameter snow-compaction roller. Full trail width to be compacted with one pass.
- Provide a minimum width of two lanes.
- On rough surfaces, level the surface with snow-plane or drag, if available, before compaction.
- Do not open a new trail to traffic for at least 24 hours after construction.
- Level drifting snow with a drag at least once a week for continued use under normal conditions.
- If trails are drifted with heavy snow, close them to traffic, level with a snowplane or drag, and recompact. Usually, the trails can be reopened within 8 hours.

ADVANTAGES OF SNOW TRAILS

- Trails can support continuous traffic by commercial vehicles with gross weights up to 10,000 pounds.
- Light vehicles with standard high-flotation tires can service outlying areas via equipment trails.
- Snow trails can be used all year at high-activity stations, such as McMurdo.

Based on NCEL Technical Report R-540, "Polar Transportation—Snow Trails for Light Wheeled Vehicles," by E. H. Moser, Jr. and G. E. Sherwood, Aug. 1967.

NCEL Contact—W. H. Beard, L61, tel: autovon–360-4284; comm–(805) 982-4284.

Technical Report

R 819

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

April 1975

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, CA 93043

SNOW ROAD CONSTRUCTION BY LAYERED COMPACTION— CONSTRUCTION AND MAINTENANCE GUIDE

by J. L. Barthelemy

Approved for public release; distribution unlimited.

INTRODUCTION

The use of rubber-tired vehicles in Polar regions greatly speeds the movement of cargo and personnel. However, in areas of perennial snow, roads must be provided. Heavy-haul, wheeled transportation equipment, in particular, requires high-strength snow roads while operating on deep snow fields. Specially processed, elevated snow roads, when properly constructed and routinely maintained, can provide dependable service for 2 or more years. This manual outlines those procedures necessary to build and preserve snow roads by means of layered compaction. This construction method, developed by the Civil Engineering Laboratory (CEL) has proved to be the simplest and most rapid method available. In this process, the roadbed is built up to the desired elevation by successive compaction of 4-inch layers of snow deposited by a snowblower.

An alternative method utilizing pulvimixing and compaction techniques was previously documented by CEL*. That method produced high-strength, durable snow roads; however, it required specially built, ski-mounted snowmixers and was critically sensitive to quality control during construction. In situations where the snowblower is not available, the pulvimixing and compaction method should be used.

All snow roads are sensitive to quality control. In order to achieve and maintain a durable road of consistent strength and quality, construction and maintenance efforts must be executed according to detailed procedures. Special attention to detail frequently determines the difference between a functional road and an impassable quagmire during the peak summer months.

CONSTRUCTION PROCEDURES

Basic Steps and Equipment

The basic steps required to produce a persistent, high-strength, elevated snow road include the following procedures:

1. Select and stake the roadbed site
2. Compact and level the roadbed
3. Deposit and shape snow along sides of road bed for containment berms
4. Elevate to grade by compacting successive 4-inch layers of snow blown onto roadbed
5. Level, finish-roll, and age-harden

It is essential that the depositing, spreading, and compacting of each 4-inch layer be completed during a single work shift. A snow road may be built in sections in order to realize this requirement. The following vehicles are recommended for snow roads constructed in segments ranging between 2 and 5 miles:

1. Tracked Personnel and Cargo Carrier
2. LGP** D8 Tractor (for optimum construction four are required)
3. LGP** D4 Tractor With Angle Blade
4. Ski-mounted Snowplow (or Snowblower)
5. Snow Plane – 40- or 80-foot model
6. Pneumatic-tired Wobbly Wheel Roller
7. Eight-Foot-Diameter Steel Roller

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* Naval Civil Engineering Laboratory. Snow Road Construction and Maintenance Manual, by W. H. Beard. Port Hueneme, CA, Jan 1972.

** Low ground pressure tracks.

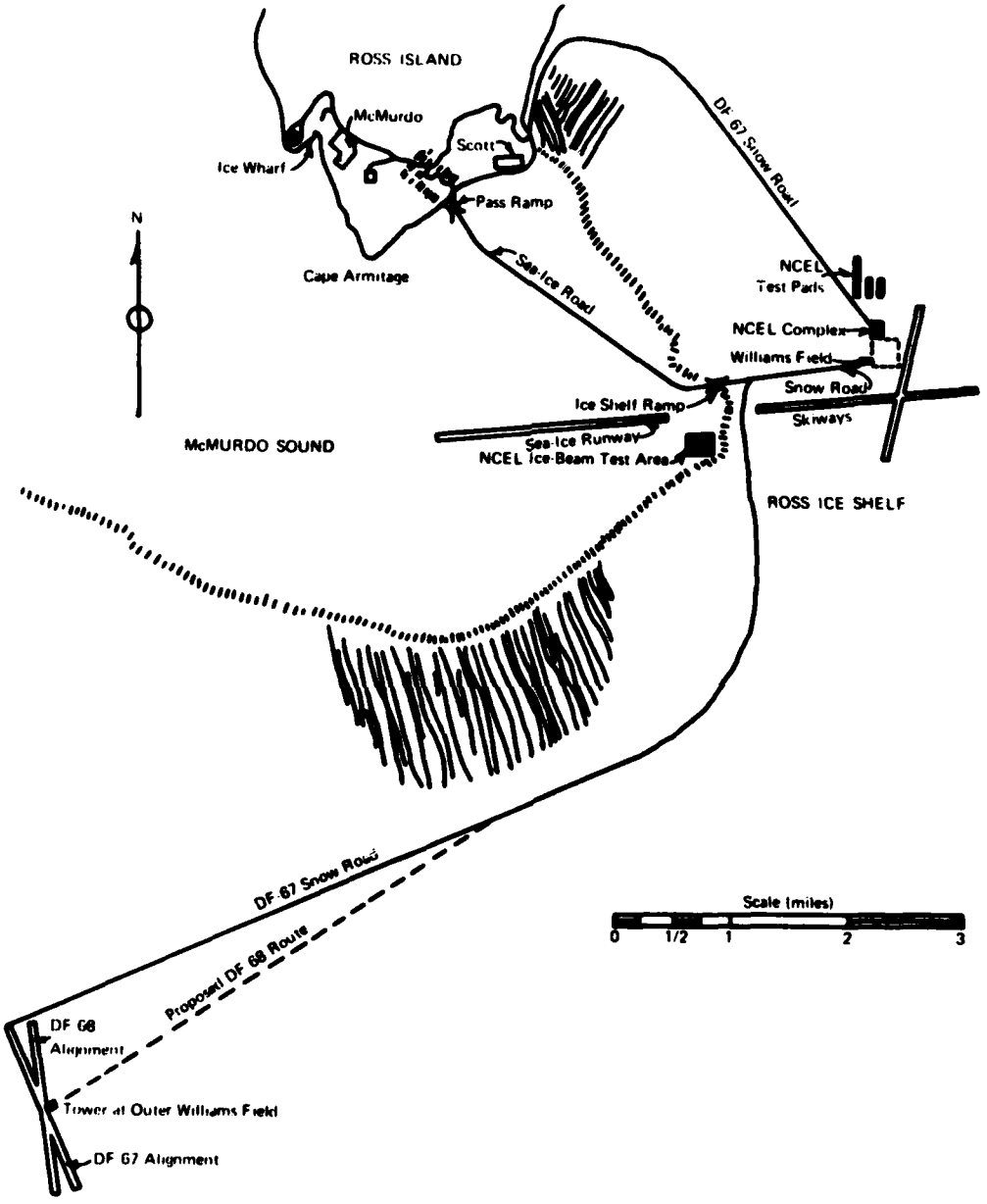

Figure 1. Location of snow roads in McMurdo/Williams Field area.

8. Timber Drag

9. Large Rubber-Tired Tow Vehicle

If construction is completed in 1-mile long segments, the number of LGP D8 tractors required may be reduced to two.

The following paragraphs detail more fully snow road construction by layered compaction. The equipment used during each procedure is denoted by the number in parentheses immediately following the subheading.

Site Selection (1). Site selection for snow roads is an important initial consideration. Construction efficiency and functional life depend upon judicious layout. The following must be considered carefully:

1. Frequently construction equipment cannot negotiate sharp curves. Vehicle traffic is naturally slowed by turns. Avoid curves by skirting crevass or pressure-ridge areas. Make unavoidable curves at maximum possible radius of curvature so that compaction equipment can operate effectively and vehicle traffic can travel safely. A minimum radius of 1,000 feet is recommended.

2. Choice of a site should include the consideration of the availability of good snow for elevating the road. To ensure good snow, avoid dirt, high ablation areas, and melt areas where ice lenses are common. In shallow snow fields, avoid even slight pressure-ridge areas since the accumulation of snow on top of these undulations is minimal.

3. A level surface with as few pressure ridges or depressions as possible should be chosen. Also, try to avoid such obstacles as old berms or old drift areas.

Figure 1 illustrates the site of the McMurdo/ Williams Field road which followed these guidelines.

Roadbed Staking (1). After a site is selected, stake out the roadbed along both edges in order to provide guidelines for equipment operators. Two types of marker stakes should be used to ensure that the road is straight and consistent in both width and height: (1) alignment stakes to indicate proper width and (2) grade stakes to indicate proper height.

The spacing of these stakes should be close enough together – about 300-feet apart – so that operators can easily align the elevating equipment. Place the two types of stakes alternately such that the actual distance between stakes is about 150 feet. The completed road should be 23 feet wide; therefore, stake the roadbed about 35 feet wide. This width provides adequate room for containment berms and processing equipment. The grade stakes should extend about 30 inches about the surface, this height being the approximate final elevation of the road. Measure the height of the stakes to ensure uniformity. It is best to place alignment stakes first since they require no special height adjustment.

Roadbed Preparation (2, 7, 5). It is necessary to prepare the roadbed prior to depositing the first 4-inch layer. This procedure involves packing and leveling the natural snow surface to form a compacted-snow mat of uniform strength. At least nine passes should be made by an LGP D8 tractor pulling an 8-foot-diameter steel roller (weighted with 2,000 pounds of ballast in the axle-slung tanks). In this manner, the entire road surface is covered at least three times. Level the compacted area with a snow plane and recompact, using an LGP D8 tractor without the steel roller.

Depositing Containment Berms (2, 3, 4). The ski-mounted rotary snowplow is the primary mover of snow. It is the only piece of equipment used in road construction by layered compaction which is unique and cannot be substituted. The snowplow, as modified, consists of a rotary cutting head equipped with eight helical cutting blades that cut the snow and mechanically force it into an impeller. The snow is then discharged through a directional spot-casting chute. This chute is hydraulically controlled and permits accurate placement of the snow on the surface to be elevated.

The snowblower, pulled by an LGP D8 tractor, deposits snow as it makes multiple passes along each side of the road. The first pass on each side is used to construct containment berms. The snowplow is pulled at approximately 60 feet per minute just outside the alignment stakes, depositing snow in a windrow just inside the stakes. The snowblower engine speed is between 2,400 and 2,800 rpm in low gear during this operation. An LGP D4 tractor with angled blade follows the snowblower to straighten the containment walls and level the berms to the recommended 24- to 30-inch height.

Figure 2 shows the rotary snowplow blowing snow onto the roadbed at the right.

Figure 2. Rotary snowplow used to elevate snow roads.

Road Elevation (2, 4). Each 4-inch snow deposit requires two passes, one along each side of the roadbed. The snow used to elevate the road is collected from contiguous zones paralleling the roadbed so that ditches or "borrow pits" are formed alongside. Each borrow pit is three rows wide, and each row provides two "cuts," one atop the other. Figure 3 illustrates the sequence of cuts to be made. The inside row and outside row of the borrow pit, each approximately 6 feet wide, are separated by 2 feet. It is necessary to narrow the middle row because the modified snowblower cannot throw snow over the containment berms to the middle of the road when the outside row is spaced farther out. When the road is completed, each borrow pit is approximately 1-1/2 to 2 feet deep and 16 feet wide.

During successive elevation passes, operate the snowplow in high gear at an engine speed between 2,400 and 2,800 rpm. Pilot the tow LGP D8 tractor in low gear at an engine speed between 600 and 800 rpm. In this mode, forward travel is approximately 90 feet per minute. The blown snow should be deposited at the middle of the road to facilitate even spreading between the centerline and containment berms. However, it is impossible to blow snow from the outside row and deposit it as a windrow along the road centerline. The high velocity of the processed snow causes it to spread toward the containment berm at the far side of the road. Therefore, the best procedure is to aim the blown snow at a central section of the road nearer the snowblower.

Leveling (3, 5). The leveling equipment should trail directly behind the snowblower, spreading the snow over the roadbed in a thin, even layer no thicker than 4 inches. The most common piece of equipment used for leveling is an 80-foot-long snowplane towed by a crawler tractor (usually an LGP D4). The snowplane is mounted on skis, with the rear skis hydraulically steered by the operator and the front skis

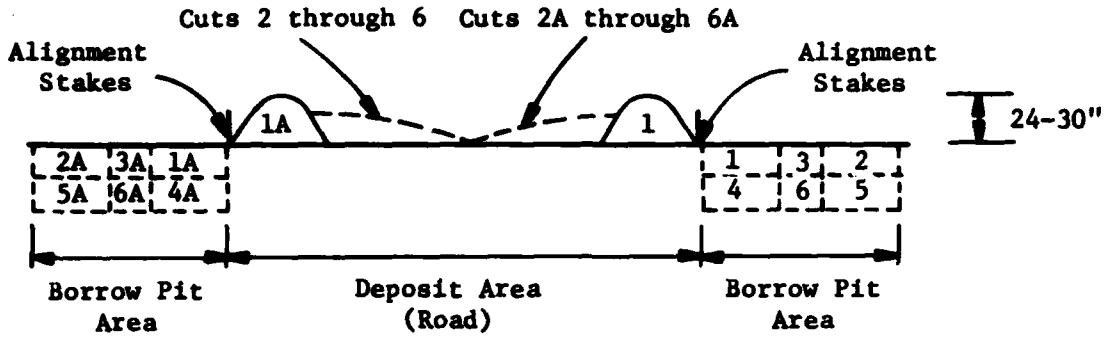

Figure 3. Cross section showing sequence of passes for elevating snow roads with a snowblower.

steered by the towing vehicle through a drawbar arrangement. The plane's blade is hydraulically raised and lowered and can be pivoted for grader operations. The blade is equipped with detachable wings that are used for leveling operations; these wings can be quickly removed when the grader configuration is required.

Substitutions may be made during this operation: a 40-foot snowplane may replace the longer model, and an LGP D8 can be used as the tow vehicle. Figure 4 shows the 80-foot-long snowplane during leveling operations.

Layer Compaction (2). D8 tractors are used to compact each newly leveled snow layer. Walk the tractors over the roadbed so that the entire surface is covered by at least three passes. After the road is elevated to the desired 24 to 30 inches, finish-level the final compacted layer using the 80-foot snowplane and remove all excess berm material above the level of the road and at the outer edges of the road.

In order to produce a quality snowroad of consistent strength, the outlined procedures of blowing, leveling, and compacting must be completed during a single workshift for each successive 4-inch layer. Construct the road in sections such that the available equipment and work force can meet this requirement.

Surface Hardening (6, 8, 9). The final step in building a snow road is to harden the top 4 inches to provide a strong mat that will resist damage from wheeled vehicular traffic. Wait at least 3 days after all other procedures have been completed before starting surface-hardening procedures. The road should be sufficiently hardened to prevent the tires of the wobbly wheel roller from cutting deep furrows into the compacted material.

With the 13 smooth, pneumatic tires inflated to 45 psi, weight the bed of the wobbly wheel roller to approximately 4 tons with steel material (any scrap will do). The weighted roller hardens the road surface. Make at least three passes over the entire roadbed surface and then finish-smooth using a timber drag. The wobbly wheel roller and the timber drag must be towed by a rubber-tired vehicle, preferably a 1-ton pickup.

After 4 days the road should be ready for normal traffic. Figure 5 presents a typical cross section of the finished road.

Transition Areas

The sections of a completed snow road are interfaced together smoothly. Each transition is actually an overlap between neighboring sections. Overlap is a necessary consequence of equipment movement; the snowblower and snowplane must turn around and reposition each time they complete a return pass in order to line up for the start of a new pass.

Figure 6 illustrates a typical turnaround configuration. After the snowblower completes a return pass alongside the unfinished road section under construction, it must be pulled over the road and

Figure 4. Leveling with an 80-foot snowplane towed by an LGP D4 tractor.

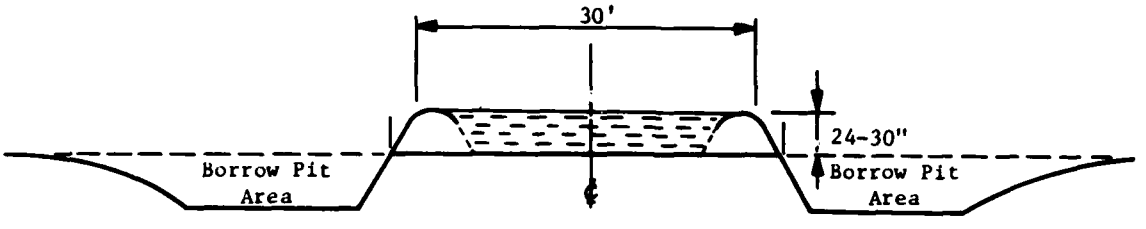

Figure 5. Typical cross section showing finished road.

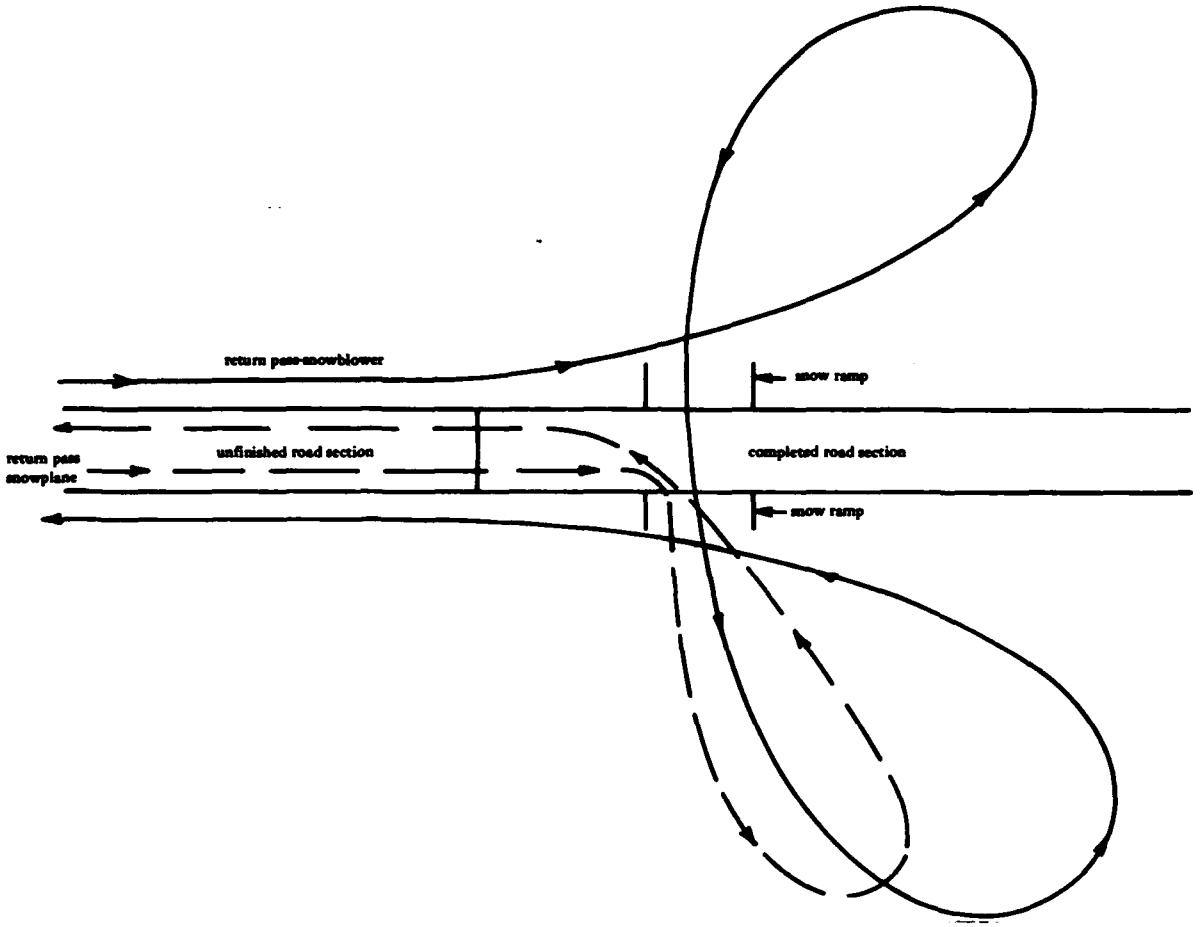

Figure 6. Turnaround scheme for repositioning snowblower and snowplane.

repositioned on the opposite side. Similarly, the snowplane must be angled off the unfinished section, turned around, and angled back onto the road.

Construct access ramps by pushing up snow alongside a selected segment of the completed road section (see Figure 6). The ramps should be sloped to accommodate both the snowblower, which crosses perpendicular to the road, and the snowplane, which angles off of and onto the roadbed. Leave adequate distance between ramps and unfinished section so that the snowblower can be circled over the road and repositioned on the opposite side in time to start a new pass. Make sure that this spacing also allows the snowplane a sufficient turnaround distance. Both pieces of equipment require approximately 200 feet turning radius. Be sure that the overlap area is properly leveled and compacted according to the outlined construction procedures. Remove the ramps after the road is finished. The final result is a continuous road of uniform quality.

In addition to the interface between sections of the road other types of transition areas exist where the snow road meets and interfaces with areas of dirt, bare ice, or ice with minimal snow cover. These transition areas are aggravated by such problems as melting, surface runoff, and drifting snow. In addition, ice cracks can become wide enough to hinder wheeled-vehicle traffic. Several methods of construction are available to help alleviate problems in these areas.

Ramps To Clear Tidal Cracks. Where ice and snow fields connect with land, tidal action and ice movement cause cracks in the ice. These cracks are

small at times, but with changing tides they can become wide enough to hinder transportation. For example, tires can become stuck in the cracks, springs can be broken, or cargo can be dislodged from trucks. Wooden ramps can be constructed to bridge these areas, permitting uninterrupted transportation.

Dirt Overlay on Areas With a Minimal Snow Covering. Ice areas close to land usually have a minimal snow cover, and in such areas it is difficult to obtain enough material to build or maintain snow roads. In such cases, a dirt overlay 16 to 20 inches thick can be placed, extending to a point where enough snow is available to construct an elevated snow road. The thick dirt layer will insulate the ice to avoid or delay melting.

Culvert Drain and Rock Base. In areas where elevated snow roads connect with land, there is usually runoff of water from melting snow. If this runoff is near the road system, steps should be taken to minimize washout or undermining of the roads. Culvert drain pipes can be used to control flow, and a rock base for the road in low sections near runoff areas will protect the road from damage and minimize maintenance.

Road Extension. Dirt tracked by vehicles from land to ice or snow accelerates surface melting, producing potholes. To help control tracking of dirt onto snow or ice surfaces, a timber road 50 feet or longer at the end of the dirt road can be used to catch dirt and mud dropped from the undersides of vehicles.

MAINTENANCE PROCEDURES

Properly constructed, high-strength snow roads should hold traffic throughout the season. However, the strength and durability of the roads depend on temperature; and high temperatures and solar radiation are prevalent during the midsummer season. As the temperature of snow rises, the snow becomes weaker and softer and is easily damaged by heavy traffic of wheeled vehicles. Surface damage is greater if vehicles are operated with high tire pressure. Periodic maintenance is required to keep snow roads in usable condition.

Ordinarily, conscientious, routine maintenance is sufficient to maintain snow roads. However, timing and prevention are vital for effective maintenance. If proper procedures are not followed in time, major road repairs will probably become necessary. The following sections describe measures for routine road maintenance and also the steps required to effect major road repairs should they become necessary.

Routine Maintenance

The three major maintenance problems on high-strength snow roads are drifting, rutting, and formation of potholes. The areas where the snow road abuts the land also pose particular maintenance problems.

Drifts. Drifting is usually minimal on elevated roads, but when drifting does occur it is most often caused by poor maintenance. If berms are left at the road edge during maintenance work, drifts will form during storms or high winds. This problem can be avoided by taking two simple steps:

1. Windrow excess snow to the center of the road during maintenance operations.

2. Blow this snow off the road with a rubber-tired rotary snowplow.

Finger drifts (finger-like tapering drifts) will form in some places even on a smooth, elevated road during storms. Although these finger drifts do not normally make a road impassable, they will harden if left for any length of time, producing an extremely rough road surface. To prevent this, the road should be dragged with the rough drag immediately after a storm. This procedure will spread the snow over the surface in a thin layer, and subsequent wheeled traffic will compress the snow. Dragging has the additional benefit of covering dirty spots and protecting the road to a large extent from solar radiation damage. It is worthwhile to point out again that drift control, like all road maintenance, requires prompt action. If the road is neglected too long, major repairs will be required.

Ruts. Ruts are formed on the roadbed when the snow loses its strength because of high temperatures and solar radiation. The snow surface melts and softens so that wheels cut the surface. Equipment operators tend to follow these ruts, and this continual traffic over the same track eventually deepens the

ruts until the road is severely damaged or completely wrecked. Many ruts can be prevented by taking the following steps:

1. Remove visible traces of ruts when possible to discourage operators from following the ruts.

2. Instruct equipment operators to vary their driving patterns and not to follow in the same tracks when possible.

3. Do not allow tire pressure on wheeled vehicles to exceed 30 psi for the 20-ton truck-tractor and trailer combinations and 10 psi for the W300 pickups.

When ruts do form, however, corrective maintenance can be used. The equipment used depends on the depth of the ruts. For shallow ruts, the rough drag followed by the smooth drag will usually repair the road surface. If the road has been neglected too long, a standard road grader must be used to repair the deeper ruts. Tire pressures on the grader should be kept as low as possible on snow roads.

In addition, the following guidelines should be observed when eliminating ruts by corrective maintenance:

1. The snow should be moved and leveled rather than cut deeply. Cutting of the mat will thin the compacted snow and weaken the road.

2. Any excess material should be windrowed to the road center and removed with the rotary snowplow. Pushing it to the side of the road will cause drifting.

3. In the warmest times of the operating season, the road should be surfaced with the smooth drag after grading. This will help force the moisture into the snow mat and also will present a smooth white surface to the sun, helping to alleviate solar radiation damage.

4. Drift or berm material which will form around marking stakes and flags during maintenance should be knocked down with a shovel to eliminate drift-forming areas.

Potholes. Potholes can form in the roadbed in two ways:

1. If dirt and oil are left on the road surface, solar radiation will weaken the snow so that holes can form.

2. Soft or rough spots in the road that are hit with the wheel time after time will form increasingly deeper holes. If left unrepaired, these potholes could cause damage to tires and/or axles.

When temperatures are at or below freezing, the quickest and best method for repairing potholes is to fill the hole with ice chips and spray a small amount of water over the patch. The water will freeze and bond the ice chips into the hole, giving a long-lasting patch. Ice chips can be obtained from an area of sea ice with the Bros ice chipper used for runway maintenance. Water can be sprayed by hand from drums, using a barrel pump.

Areas Where Snow Abuts Land. Any area where the snow abuts the land requires the heaviest maintenance because several conditions detrimental to the snow road are found in such areas. Providing proper transition areas will help minimize these problems, but regular maintenance is still necessary. Surface runoff from the land mass during warm weather will undermine the road and weaken the snow mat. Dirt carried from the land will darken the snow surface and absorb the sun rays, causing melted and rutting.

One of the best methods for eliminating the runoff water problem is to use dirt and rock fill until the road is beyond the potential problem area. Dirt fill at least 18 inches thick will insulate the snow or ice from solar radiation. Culvert pipe can control runoff water and divert it to cracks in the ice where it will not form pools.

The snow road immediately abutting the dirt fill will become dirty. Wooden ramps in this area will help prevent dirt from accumulating in the immediate transition zone. New snow deposited at frequent intervals in a thin layer over the dark area will help to reflect solar radiation and prevent damage. When temperatures go below freezing, these areas will usually form ice and, even though they are still dark, will have a hard surface that will support heavy wheeled traffic.

Most snow road construction is in the Antarctic. The usual high maintenance months in that region are December and January. Again proper timing is essential; surfaces should be maintained daily during these months.

Major Road Repairs

On occasion, a road may deteriorate so badly in certain areas that filling with ice chips, grading, or any other maintenance procedure is not sufficient to repair the damage. More drastic measures are necessary. If the deteriorated section is large, the snowblower should be used. The procedure is the same as that used in road building. First, containment berms are constructed and snow is deposited in 4-inch layers. Each layer is leveled and compacted. After the repaired section is elevated to grade, the entire surface is hardened and dragged. If the damaged area occurs in small, scattered sections, use procedures as outlined under transition areas. The 4-inch layers are deposited, spread, and compacted using two LGP D8 bulldozers. Traffic should be kept off these sections until they have hardened, usually 2 to 4 days depending on weather conditions and the degree of repair required.

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SNOW ROAD CONSTRUCTION EQUIPMENT

This section presents a brief review of equipment used by CEL to construct snow roads by the method of layered compaction. The Techdata Sheets summarize the important design and performance characteristics of each piece of equipment.

December 1972 72-6

Naval Civil Engineering Laboratory

Port Hueneme, California 93043

NCEL
Techdata Sheet

SNOW COMPACTION EQUIPMENT—SNOW ROLLERS

Figure 1. Snow-compacting roller.

Figure 2. Snow-hardening roller.

PROBLEM

In polar regions, the most accessible building material for roads and runways is snow. The Navy, therefore, has investigated the feasibility of producing static and dynamic load-bearing snow. The Naval Civil Engineering Laboratory has been instrumental in developing cold-processing techniques that produce high-strength snow capable of supporting vehicles and aircraft on both annual and perennial snow fields.

SNOW ROLLERS

The Laboratory has developed two rollers that are used together in a series of passes to process snow:

- Snow-Compacting Roller—A 10,240-pound, 8-foot-diameter roller that initially compacts the snow (compressively) and also compacts new snow on previously compacted areas (Figure 1).

Approved for public release; distribution unlimited.

- Snow-Hardening Roller—A 13-ton, standard construction roller with 13 pneumatic wheels that further compacts the snow, thereby providing the hard finish needed to support wheeled aircraft and vehicular traffic (Figure 2).

The snow-compacting roller is detailed in BuDocks Drawings Nos. 813399 to 813404, August 1958, for competitive procurement.

SNOW-COMPACTING ROLLER

- Effective at speeds up to 500 fpm; covers up to 4.9 acres/hr under good conditions.
- Easy to maneuver in all types of snow except extremely soft, deep, new snow.
- Can be used singly, in tandem, or in gang.
- Can be used without difficulty in temperatures down to -50°F.
- Scraper blade effectively prevents excessive snow buildup on roller. (In wet, sticky snow, wax is used to prevent buildup.)
- Relatively simple to disassemble and package for shipment in all types of carriers.
- Can be assembled with simple tools under adverse field conditions.
- Suitable for construction in small shops.

SNOW-HARDENING ROLLER

- Effective at a speed of 300 fpm; easily covers up to 2.9 acres/hr under good conditions.
- Most effective when the tire penetration is 1/2 inch or less.
- Suitable for shipment in all types of carriers without disassembly.
- Requires no modifications of standard construction equipment.

For further details see NCEL Technical Report R-107, "Snow-Compaction Equipment—Snow Rollers," by J. B. Camm, January 1961.

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Naval Civil Engineering Laboratory

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NCEL

Techdata Sheet

D4 LOW GROUND PRESSURE SNOW TRACTOR

The LGP snow tractor is a basic D4 tractor, modified to achieve required ground pressure (4 psi), minimum shipping weight, and lower gear ratio. Other features are:

- Dual-rail track system with 36-inch aluminum tracks
- Standard and underspeed transmissions
- Angle bulldozer
- Winterized steel cab

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- Winch
- Electric start, gasoline-pony engine
- Maximum drawbar pull—13,000 pounds

The D4 snow tractor performs effectively in bulldozing and towing operations on uncompacted snow. It also maneuvers easily in tight places, yet is large enough to tow most major snow-compaction equipment. Other advantages are:

- It can be air-transported in a C-130 with minimum disassembly.
- The cab, dozer blade, and winch can be removed quickly to reduce shipping weight and volume of tractor.
- The underspeed transmission gives a wider range of travel speeds, including speeds low enough to tow slow-moving snow-compaction equipment.
- The system of counterweights balances the tractor with maximum drawbar pulls.
- It is effective for snow drift control around camp because of its small size.
- The dozer angle can be adjusted to remove snow close to buildings.

The seating capacity of the cab accommodates only the operator.

Procurement source: Commercial; drawings of the modifications are available from NCEL.

Based on NCEL Technical Report R-449, "Polar Construction Equipment—LGP D4 Series D Snow Tractor," by Douglas Taylor, June 1966.

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Civil Engineering Laboratory

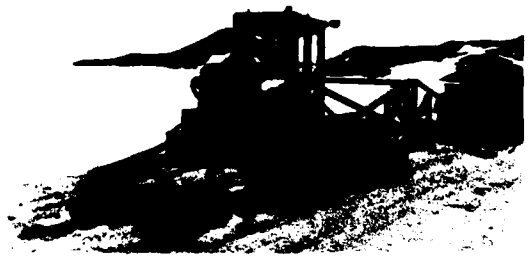
Naval Construction Battalion Center

Port Hueneme, California 93043

CEL

Techdata Sheet

SNOW-LEVELING AND GRADING EQUIPMENT 40- AND 80-FOOT SNOW PLANES



40-Foot Snow Plane

80-Foot Snow Plane

Most annual and perennial snow fields in polar regions must be graded and leveled to achieve the uniform compaction required to produce high-strength, load-bearing snow. CEL has developed two snow planes which effectively accomplish this job: (1) the 40-foot snow plane, which adequately levels and grades both natural and compacted snow and (2) the 80-foot snow plane, which was developed specifically to level snow fields that have long-wave sastrugi. The latter plane is very similar to the Model 40 except for its larger size. The snow plane is an important piece of equipment in the layered compaction method of snow-road construction; it is used to distribute the snow over the road surface after the snow is deposited by a snowblower.

FEATURES OF THE SNOW PLANE

The Model 40 and 80 snow planes are modified versions of commercially available agricultural land planes with the following features:

- Tractor-drawn unit with eight basic components: frame, skis, tongue, turntable, bowl/blade, hydraulic system, operator cab and load platform.

- Portable hydraulic power-pack unit, mounted on the frame.

	40-Foot Plane	80-Foot Plane
• Weight, pounds	6,120	12,350
• Length with tongue, feet	57	96
• Width-frame (outside skis), feet	8.5	11
• Blade width, feet	12	15
• Height, with cab, feet	9	10

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ADVANTAGES OF THE SNOW PLANE

- Levels up to 1-1/4 acres of snow per hour; grades up to 3 acres per hour.
- Hydraulically powered by either hydraulic power-pack mounted on snow plane or tow tractor.
- Easily operated by trained personnel.
- Requires only routine maintenance.
- Converts simply from planer to grader and back under field conditions.
- Can be constructed in small shops.
- Is relatively easy to disassemble for shipment on all types of carriers.

REFERENCES

Based on NCEL Technical Report R-110: Snow-Compaction Equipment—Snowplane, by E. H. Moser, February 1961, and its supplement, which give further details on the snow planes, as do Technical Notes N-463: Specifications for the Model 80 Snow Plane, by N. E. Pierce and E. Moser, October 1962, and N-504: Specifications for the Model 40 Snow Plane, by N. E. Pierce, April 1963.

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October 1974 74-06

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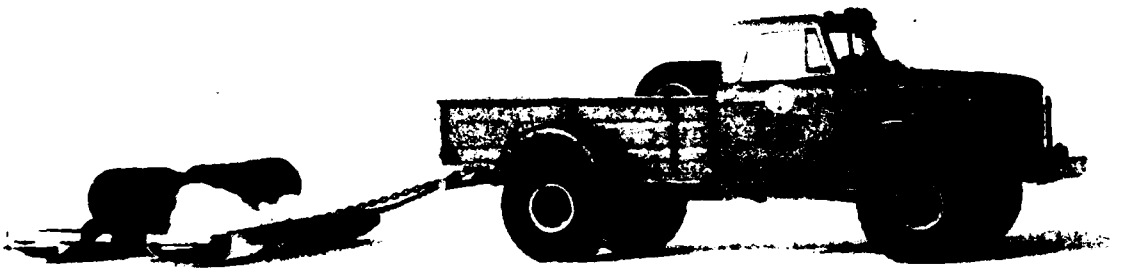
SNOW-COMPACTION EQUIPMENT—SNOW DRAGS

Snow Leveling Drag



Snow Finishing Drag

High-strength compacted snow is vital for construction of roads, runways, and skiways, a fundamental need in year-round polar operations. For use in constructing and maintaining compacted snow, two CEL snow drags have been developed: one for leveling and one for finishing. The leveling and

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finishing drags are described in detail in Y&D Drawings 813537 and 813538 (1 September 1959), respectively.

FEATURES OF THE SNOW DRAGS

Snow-Leveling Drag – Used to finish and maintain surface of completed snow road, spread windrows left by other equipment, spread and level shallow drift and light snowfall and remove slight surface irregularities.

- Weight – 925 pounds; made of Douglas fir
- 12 feet wide, 8 feet long
- Tow speed (general operation) 350 feet per minute (about 4 mph)

Snow-Finishing Drag – Used in final construction when required to obtain a hard, smooth finish on compacted snow. This drag is used primarily for maintenance of snow runways.

- Weight – 2,830 pounds; made of steel
- 12 feet wide, 7 feet 6 inches long
- Tow speed in general operation – 350 feet per minute (about 4 mph)

ADVANTAGES OF THE SNOW DRAGS

- Are highly maneuverable on all types of snow
- Function effectively in temperatures down to -50°F
- Can be used singly or in multiple tow
- Can be constructed in small fabricating shops
- Are easily disassembled and packaged for shipment by any type of carrier.
- Can be assembled under adverse field conditions without difficulty.

REFERENCE

Based on NCEL Technical Report R-109: Snow-Compaction Equipment–Snow Drag, by J. B. Camm, October 1960.

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SNOW TRANSPORT EQUIPMENT
MODEL 1000 TOWED SNOWPLOW CARRIER

The CEL Model 1000 Towed Snowplow Carrier is an important piece of equipment in the layered compaction method of elevated snow-road construction. The snowplow is used to deposit blower-processed snow from borrow pits onto the road surface to create each new 4-inch layer to be compacted. These elevated roads are comparatively immune to severe drifting. In addition, the snowplow is effective in clearing drift snow from previously compacted snow and ice roads. Specification details for the snowplow are given in NCEL Drawings 67-38-1F through 17F

FEATURES OF THE TOWED SNOWPLOW

- 56 feet 9 inches long
- Ski mounted
- Two hydraulically controlled grader blades which windrow snow into the cutter blades and impeller
- Liquid-cooled, 6-cylinder diesel engine
- 175 horsepower at 2,800 rpm
- Shipping weight: 34,000 pounds
- Shipping cube: 2,700 cubic feet

ADVANTAGES OF THE TOWED SNOWPLOW

- Long frame permits uniform removal of snow from borrow pits in construction of snow roads and other snow removal operations.
- Ski-mount eliminates pitching and rolling on deep snow.
- Casting chute allows controlled placement of snow, depositing it as far as 100 feet, at rates up to 1,700 cubic yards per hour.
- Snowplow is easily assembled in approximately 108 man- hours in the field, using standard weight-handling equipment.

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LIST OF APPENDIXES

Chapter 7

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

7-A. **Civil Engineering Laboratory. Technical Memorandum M-61-77-3: Investigation of aircraft takeoff problem at the Williams Field skiway, McMurdo Station, Antarctica, by K. D. Vaudrey, Apr 1977.**

7-B. **Naval Civil Engineering Laboratory. Technical Note N-1317: Improved transition ramps for McMurdo Station, Antarctica, by F. W. Brier, Nov 1973.**

7-C.

7-D.

7-E.

7-F.

7-G.

7-H.

7-I.

7-J.

APPENDIX 7-A

TM no. M-61-77-3

TECHNICAL MEMORANDUM

title: INVESTIGATION OF AIRCRAFT TAKEOFF PROBLEM AT THE WILLIAMS FIELD SKIWAY, McMURDO STATION, ANTARCTICA

author: K. D. Vaudrey, Ph.D.

date: April 1977

sponsor: NAVAL SUPPORT FORCE, ANTARCTICA

program nos: 61-019

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

Addition – 1979

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INVESTIGATION OF AIRCRAFT TAKEOFF PROBLEM AT THE WILLIAMS FIELD SKIWAY, McMURDO STATION, ANTARCTICA

61-019

by
K. D. Vaudrey, Ph.D.

April 1977
Sponsored by Naval Support Force, Antarctica

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INTRODUCTION

To provide logistics support for United States scientific research being conducted in Antarctica the Naval Support Force must construct airfields of natural material--ice and snow. In the early stages of the austral summer an annual ice sheet is prepared and maintained for wheeled aircraft. However, as the air temperatures increase during December the ice runway gradually deteriorates and is generally abandoned around Christmas, depending on ice conditions. Then all air traffic moves to Williams Field, a skiway located on a deep snowfield of the Ross Ice Shelf. At this time a fleet of ski-equipped C-130 aircraft are tasked with a dual role: to resupply inland stations and to redeploy a large contingent of summer support personnel.

One pressing problem continues to plague air operations during January as the air temperatures continue to increase. That problem is the requirement of making multiple takeoff runs before lift-off can be achieved from the skiway. This wastes both time and precious fuel. At present, the intermediate solution has been to schedule takeoff flights at Williams Field only between 0100 and 0600 hours, taking advantage of the coolest time of the austral summer day. However, this procedure is not always successful and severely compresses an already tight flight schedule. An alternate solution should be investigated in lieu of revising the flight schedule.

An investigation has been conducted not only to determine the cause of the aircraft takeoff problem but also to review present skiway construction and maintenance procedures and provide recommendations for improved techniques. In such practical problems that involve sliding a ski over snow, any resistance to motion includes surface friction and sinkage resistance. Sinkage resistance comes from energy dissipation as a result of compacting snow beneath the ski and shearing snow at the sides and front of the ski. However, if the snow is already adequately compacted and supports the aircraft without sinkage, the resistance to motion becomes purely frictional.

Initially, the coefficient of friction for skis on snow will be reviewed showing influences of various parameters. In addition, the skiway problem may be influenced by two associated friction topics: adhesion and suction. Their probable impact in this problem will be assessed. Sinkage resistance and snow compaction will be discussed, along with some recommendations on skiway preparation and maintenance techniques.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

SURFACE FRICTION

The classical laws of dry friction state that frictional resistance is directly proportional to the normal force between the sliding surfaces, but independent of the area of contact. The coefficient of friction is the ratio of the sliding resistance to the normal force, and is a constant for a given pair of materials. Friction between snow and an

aircraft ski coated with Teflon conforms approximately to these laws for a given temperature, but significant deviations can and do exist. The coefficient of friction may vary with size, shape and bearing pressure of the contact area, with sliding speed, and, of course, with temperature (1).

Temperature Effects

Generally, for most runner materials friction is low on dry snow at temperatures near the melting point, but at very low ambient temperatures (e.g., $-25^{\circ}C$) snow loses its capacity as a low-friction material and becomes more like dry sand or other powdered solids. Minimum friction occurs at $0^{\circ}C$ with the snow in a "dry" condition, i.e., with no appreciable amount of unbound water. If the snow becomes wet and slushy, the coefficient of friction will increase suddenly for some materials, especially those which tend to be water absorbent. However, this adverse behavior should be no problem with Teflon-coated aircraft skis, since Teflon is strongly hydrophobic. Generally, as temperatures decrease below $0^{\circ}C$, the friction of most metals and polymers on snow increases almost linearly (2). Some special ski waxes, however, exhibit an abrupt increase in their friction coefficient as the temperature drops to around $-10^{\circ}C$. Coefficient of friction for steel, Teflon, and several ski waxes is shown as a function of temperature in Figure 1.

Sliding Velocity Effects

In general, friction decreases as the speed of sliding increases. This effect can be explained by frictional melting of the snow providing additional lubrication. At high speeds over snow containing a lot of unbound water it is possible to encounter viscous drag effects which might reverse the advantage of lubrication. However, tests conducted on Teflon-coated runners over snow very close to $0^{\circ}C$ showed no significant variation of friction for all speeds. Of course, on snow at $0^{\circ}C$ sliding velocity may be unimportant, since a lubricating film already exists and pressure melting increases the amount of water regardless of the speed. Since Teflon has peculiar properties which make it less dependent on presence of water for lubrication, it exhibits a relatively constant coefficient of friction at all speeds for any given temperature below $0^{\circ}C$.

Bearing Pressure Effects

If pressure melting makes a significant contribution to the lubrication of a sliding interface, then a variation in the coefficient of friction with contact pressure can be expected. For Teflon-coated aircraft skis this should not be the case.

It seems likely that some increase in bearing pressure does produce a decrease in friction over the range of pressure created by aircraft

skis (~4-7 psi); however, it is very possible that any frictional advantage is far outweighed by increased sinkage resistance.

Slider Material Behavior

It is evident that there is no single value for the coefficient of friction of a given material sliding on snow. But Table 1 contains some magnitude values for both steel and Teflon (3). Teflon is an outstanding example of one of a number of plastics which exhibit superior frictional qualities at all temperatures and sliding speeds. It appears to be largely independent of water lubrication, but is not hampered by the presence of water since it is extremely hydrophobia.

Metals sliding at low temperatures lose their frictional heat quite rapidly as a consequence of high thermal conductivity; consequently, they suffer frictionally. They are also prone to adhesion of snow when melted water refreezes after they slow down from a high-speed slide.

Static Friction and Adhesion

In Table 1 coefficients are listed for both kinetic and static friction. Up to now the discussion has been centered on kinetic friction, assuming the slider is already in motion. This section is devoted to static friction, the resistance that must be overcome to restart motion immediately after a slider has been brought to rest. Thus, static friction can be considered a limit of kinetic friction as a moving slider approaches zero velocity. The word "restart" is used in the definition to differentiate between static friction and adhesion, the shear strength developed between the snow and ski by prolonged rest causing metamorphism of the snow at the ski-snow interface.

While true static friction is always greater than sliding friction, frictional melting theory states the coefficient of static friction at $0^{o}C$ should not be much higher than the kinetic coefficient. Consequently, aircraft awaiting takeoff at the end of the skiway should not experience high static friction during early January due to the relatively high temperatures.

However, once the aircraft begins its takeoff run down the skiway there is a possibility, during warm weather of a free water film creating a suction force between ski and the snow surface. This suction force could be a partial contribution inhibiting lift-off, but it seems unlikely that this suction force would dissipate after several takeoff attempts. Consequently, other controlling factors, besides static friction, kinetic friction, or water film suction forces, exist to prevent takeoff during warm temperatures, but are reduced after multiple passes by the aircraft.

SINKAGE RESISTANCE

From the previous discussion on surface friction effects, it appears that Teflon-coated aircraft skis will perform better, or at least just as well, in wet snow. However, this assumes that the aircraft remains on top of the snow surface; consequently, no sinkage or rutting by the skis has been considered. When air temperatures are above $0^{o}C$ weakened snow surface layers break down under the weight of moving aircraft, and it sinks and forms ruts in the skiway. In sinking, the aircraft does improve both the bearing capacity and shear strength of the snow under its skis, but a portion of the total forward thrust is expended in compacting snow. If sinkage becomes excessive, the aircraft skis must "bulldoze" snow, as well as compact it, expending sufficient energy to prohibit takeoff.

Ultimate Strength

Since sinkage is actually a snow failure, it is necessary to briefly discuss snow behavior and its ultimate strength before solution techniques are proposed for the skiway problem. When loaded by moving aircraft skis, snow behaves elastically since this type of load is of short duration. Therefore, creep of snow under sustained loading will not be considered. The ultimate strength of snow is dependent on the index properties: density, temperature, and grain structure.

As density increases, strength increases. Below a density of 0.4 g/cm^3, snow has very little strength. It is interesting to observe here that natural age-hardened snow on the Ross Ice Shelf generally has a density between 0.35 and 0.40 g/cm^3(4). This low density snow has a open, weakly-bonded grain structure in which grains have considerable freedom of movement, so the snow is readily compressible. On the other hand, very high density snow (greater than 0.55 g/cm^3) is relatively strong, and strength is heavily dependent on the density. Normally, snow roads processed by layered compaction or pulvimixing achieve such high densities between 0.55 and 0.60 g/cm^3(5,6). At this density range, grains are closely packed, so that the snow can be deformed only by straining the actual grains or destroying the bonds that connect them.

Of course, snow strength also depends on temperature, becoming stronger as the temperature decreases. A thermal gradient exists in any snow layer. During January of an austral summer, this gradient all but vanishes for surface snow layers; thus, the skiway becomes essentially isothermal. Even though snow grain bonds form more rapidly as the temperature increases, once the temperature exceeds $0^{o}C$ bonding quickly deteriorates and snow loses its supportive strength (7).

Initial ski sinkage is due to a compressive strength failure in a localized area surrounding the aircraft ski. Continued sinkage resistance to a moving aircraft comes from bulldozing or plowing snow ahead and alongside the skis causing shear strength failure in successive

snow grains. Both of these failure modes seem to be the prime contributors to the takeoff problem at Williams Field.

SKIWAY COMPACTION TECHNIQUE

At present the skiway is prepared during early season by leveling with the 80-foot snow plane. Continued maintenance occurs periodically, or after each storm, by "chaining" the drifted snow on the skiway. Chaining is the simple technique of dragging a heavy chain strung between two LGP tractors walking along both sides of the skiway. Consequently, the skiway snow is not processed at all, but must rely solely on age-hardening for its strength. During January this sintered, but shallow, crust loses all its support capability.

Early Season Preparation

Instead of just planing and chaining the skiway surface to keep it level and smooth, it would be better to process the skiway snow by a modified layered compaction technique. During early October the skiway should be planed as usual with the 80-foot snow plane (8) towed by either an LGP D-4 or 955 tractor. Once the skiway surface is leveled, two LGP D-8's can provide the initial surface compaction by walking the entire skiway, making three passes over each section. This operation should take two days using two D-8's.

Due to the compressibility of the natural snow, the initially compacted skiway surface will be depressed at least 3-4 inches below the surrounding terrain. Instead of employing drift control measures (9) snow accumulation should be encouraged to obtain additional snow layers on the skiway without using auxiliary equipment like the towed, ski-mounted snowblower. In fact, depression of the skiway plus the grouser prints of the D-8's should allow sufficient snow collection to provide a 2"-3" layer distributed over the width of the skiway. It is anticipated that such snow accumulation will occur at least every 2-3 weeks during the early season.

Once enough snow has accumulated, two LGP D-8's towing timber drags (10) should walk the skiway to distribute the snow into a more even 2"-3" layer. If timber drags are not available, chaining the skiway may level the drifted snow sufficiently. After the snow is distributed, the two LGP D-8 tractors should continue walking the skiway without drags or chain, until two more passes have been made over the complete skiway. This layer-compacting operation should take 2-3 days and be repeated whenever there is enough snow to make a uniform layer 2"-3" thick, usually every 2-3 weeks until the skiway is required for aircraft operations. By this time, generally around Christmas, at least three 2"-3" layers of compacted snow will have been added to the initially compacted skiway surface, providing an 8"-12" base for aircraft support.

Snow compaction by walking LGP D-8's will leave grouser marks in the skiway surface. This washboard effect has two advantages: (1) providing relief to catch snow for additional layers, and (2) reducing or eliminating the possibility of any water film suction created beneath the skis. All track prints will be perpendicular to the length of the skiway so aircraft skis should have no difficulty traversing these marks. However, in the past there has been a reluctance to allow any tracked vehicle traffic on the skiway. If grouser marks provide too rough a surface for aircraft operations, then following compaction of the last layer, a single pass can be made with either a slick (10) or timber drag to smooth the skiway surface.

After the skiway operations started, maintenance practices could proceed as they have in the recent past, using the chaining method to distribute new-fallen or drifted snow. Under no circumstances should this clean, loosely-consolidated snow be removed since it provides excellent protection against solar-radiation ablation of the skiway. Every effort should be made to keep the skiway surface clean and white.

CONCLUSIONS

1. The aircraft takeoff problem at the Williams Field skiway during January is not a result of increasing friction. Upon investigation it appears that friction is actually reduced as the snow temperature reaches its melting point.

2. Associated frictional properties, adhesion and suction, have a minimal effect, if any, on the aircraft takeoff problem.

3. Sinkage resistance is primarily responsible for inhibiting takeoffs. Skiway snow loses its support due to low density and high temperatures.

RECOMMENDATIONS

It is recommended that a modified layered compaction technique be employed to provide an adequate supportive base for the skiway at Williams Field, Antarctica. Having a processed snow skiway should reduce the takeoff problem by allowing the moving aircraft to remain on top of the skiway, thus avoiding sinkage resistance which currently hampers takeoffs.

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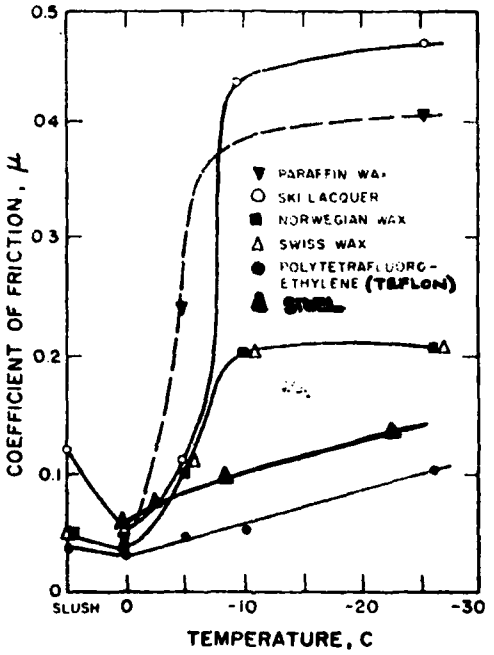

Figure 1. Coefficient of static (low speed) friction plotted against temperature for various ski-facing materials.

Table 1. Coefficients of friction of sled runners on compacted virgin snow (Greenland).

Payload (tons)	Steel Runners			Teflon Runners		
	Dry	Moist	Wet	Dry	Moist	Wet
			Coefficients of Kinetic Friction			
5	0.12	0.09	0.08	0.06	0.05	0.05
	0.15	0.18	0.14	0.06	0.06	0.10
10	0.12	0.12	0.08	0.07	0.06	0.05
	0.15	0.17	0.16	0.06	0.08	0.10
15	0.12	0.07	0.08	0.07	0.05	0.05
	0.15	0.13	0.18	0.09	0.07	0.11
			Coefficients of Static Friction			
5	0.30	0.34	0.42	0.17	0.20	0.17
	0.37	0.48	0.51	0.06	0.06	0.10
10	0.40	0.37	0.40	0.20	0.19	0.19
	0.44	0.49	0.57	0.16	0.17	0.24
15	0.35	0.37	0.39	0.14	0.13	0.17
	0.31	0.48	0.50	0.16	0.16	0.27

APPENDIX 7-B

Technical Note N-1317

IMPROVED TRANSITION RAMPS FOR MCMURDO STATION, ANTARCTICA

By

F. W. Brier

November 1973

Sponsored by
Naval Support Force, Antarctica

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NAVAL CIVIL ENGINEERING LABORATORY
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IMPROVED TRANSITION RAMPS FOR MCMURDO STATION, ANTARCTICA

Technical Note N-1317

61-017

by

F. W. Brier

ABSTRACT

Wheeled vehicle travel between McMurdo Station and Williams Field is via a processed snow road on the Ross Ice Shelf or on an annual sea ice road across McMurdo Sound. The critical areas of construction and maintenance on the McMurdo road system are at points of transition from one road material to another material. Three transition conditions exist in the road system: annual sea ice to snow, snow to land, and annual sea ice to land. Each of the three transition zones has different construction and maintenance problems. These problems were reviewed and field tests were conducted on various types of surfacing materials at Port Hueneme, California, and McMurdo Station, Antarctica. The field tests showed AM_2 aluminum planking was more durable than Mo-mat, but Mo-mat has sufficient strength to support vehicular traffic when it is properly anchored. The field tests also indicated than when placed on sea ice AM_2 aluminum planking and Mo-mat must be insulated to prevent surface melting of the ice.

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INTRODUCTION

McMurdo Station is the logistics center for all United States air operations in Antarctica. The station is located on Ross Island near the tip of Hut Point Peninsula. Aircraft landing and support facilities for McMurdo Station are located at Williams Field which is about five miles away on the Ross Ice Shelf (Figure 1). Wheeled vehicle travel between McMurdo Station and Williams Field was initiated in 1965. Prior to 1965, tracked vehicles were used exclusively for over-snow transport at McMurdo Station. For an efficient air logistics operation using wheeled vehicles for over-snow transport, it is essential that a road system be maintained between McMurdo Station and Williams Field. Travel between McMurdo Station and Williams Field is via a processed snow road on the Ross Ice Shelf or on an annual sea ice road across McMurdo Sound (Figure 1).

The critical areas of construction and maintenance on the McMurdo road system are at points of transition from one road material to another material. Three transition conditions exist in the road system: annual sea ice to snow, snow to land, and annual sea ice to land.

The transition from sea ice to snow occurs where the Ross Ice Shelf and annual sea ice in McMurdo Sound adjoin. The transition from snow to land occurs near Scott Base where the Ross Ice Shelf abuts Ross Island. Since Deep Freeze 69 (DF-69), the transition from sea ice to land has been at VXE-6 Hill. Prior to DF-69, the transition from sea ice to land occurred on the shoreline between Observation Hill and Scott Base on what was called the Pass Road.

Each of the three transition zones has different construction and maintenance problems. The major problems at the sea ice to snow transition are snowdrift accumulation, high gradient, and downwarping of the sea ice. If downwarping occurs, salt water pools form on the surface of the sea ice causing deterioration of the roadway. At the transitions from snow to land and sea ice to land, the major problem is deterioration of the roadway surface by melting. At these transitions, dirt is tracked by vehicles from land onto snow or sea ice roadway, where it absorbs solar radiation. During the summer, high solar radiation and near-or-above thawing temperatures decrease the wear resistance of the snow or sea ice surface; the ice surface becomes rough and granular, and the compacted snow road becomes soft and mushy. Working tide cracks between the floating sea ice and Ross Island present additional problems at the sea ice to land transition. Vehicular traffic over tide cracks causes the shoulders of the crack to collapse. Eventually, holes 2- to 3 feet wide and a foot or more deep develop at the tide crack impeding vehicular traffic.

To improve trafficability and reduce maintenance cost of the McMurdo Road system, techniques and surfacing materials are needed to minimize deterioration of the three transition zones. This technical note covers field tests on surfacing materials

conducted at Port Hueneme, California, during August 1972, and at McMurdo Station, Antarctica, during the austral summer 1972-1973. Construction and maintenance techniques at the three transition zones are also discussed in this technical note.

BACKGROUND

Since the introduction of wheeled vehicles to Operation Deep Freeze in 1965, travel between McMurdo Station and Williams Field has been hindered by adverse conditions at locations of transition from annual sea ice to land, snow to land, and annual sea ice to snow. Each of the three transition zones has different construction and maintenance problems. Weather conditions, amount of vehicle traffic, and maintenance techniques influence the intensity of the problems at each transition zone. Since these factors vary from year to year, the intensity of the problems also changes.

Early attempts at improving the trafficability of transition zones consisted of compacted snow roadways or ramps (Figure 2). This technique was satisfactory at the transition from sea ice to snow, but was unsatisfactory at transitions to land. Large quantities of snow are sometimes difficult to obtain near the transitions from sea ice or land, and dirt near the transitions to land caused rapid deterioration of the snow ramps.

During DF-68, the Naval Civil Engineering Laboratory (NCEL) fabricated and installed a 32-foot long timber ramp (Figure 3) over the tide crack at the transition from sea ice to land on the Pass Road between McMurdo Station and Williams Field (Figure 1). The ramp was fabricated with 16-foot long, 6x6 stringers covered with 2x6 decking. The experimental timber ramp, which was tested under NCEL Work Unit YF 53.536.001.01.002, "Vehicle Road Systems on Snow and Ice," improved trafficability, but only slightly. The major shortcoming of the experimental ramp was its limited length. It was also time consuming to construct and required frequent repair.

In DF-69, the Antarctic Support Activities, which is now called the Naval Support Force, Antarctica (NSFA), constructed several timber ramp sections with a total length of about 100 feet and placed them at the VXE-6 Hill sea ice to land transition. The construction of the ramp sections was similar to the DF-68 experimental ramp but larger timbers were used for all members. The ramp improved trafficability over the tide crack area but was insufficient in length to eliminate problems of surface melting. Surface deterioration of the sea ice up to 500 feet from the shoreline hindered and sometimes stopped vehicle traffic.

In DF-70, the timber ramp sections were again used at the transition from sea ice to land at VXE-6 Hill, but as the sea ice surface deteriorated a timber planked roadway (Figure 4) was field fabricated to bridge potholes and other surface irregularities. During each austral summer since DF-70, timber ramp sections have been used to span the tide cracks and a field fabricated timber planked roadway has been used where surface deterioration of the sea ice occurred. The timber ramp sections and roadway are expensive and time consuming to construct and have minimal salvage. Maintenance and repair of the timber ramp and roadway required constant vigilance.

Tests by NCEL at Williams Field in DF-69 demonstrated that an 18-inch thick earth overlay on snow provided a durable roadway for wheeled vehicles. The test also showed that deterioration of the snow surface at the ends of the earth overlay was very rapid. During the austral summer of DF-70, NSFA began construction of an earth overlay at the snow to land transition near Scott Base. Placement of earth overlay at this transition continued during the summer seasons of DF-71 and 72. During the summer as the snow road deteriorated at the end of the earth overlay, the earth overlay was lengthened to cover the area that had deteriorated. By the end of DF-72, the earth overlay extended about 2500 feet past the shoreline.

At the present time, the end of the earth overlay is adjacent to a cliff which shades about 300 feet of adjacent roadway several hours each day (Figure 5). The shade reduces exposure to solar radiation and decreases deterioration of the snow road. Extension of the earth overlay past its present location will increase deterioration of the snow road and impede vehicular traffic.

CONCEPT

To improve trafficability of the transition zones, various construction techniques and maintenance procedures were reviewed and analyzed to determine the most satisfactory concept for each location. Since the problems encountered at each transition zone are different, the concepts for improving trafficability are also different.

A review of problems encountered at the transition from sea ice to snow indicated improved construction techniques will alleviate snow accumulation and downwarping problems that hinder vehicular traffic.

Review of problems encountered at the transitions from sea ice and snow to land indicated that surfacing material is required to prevent deterioration of the sea ice and snow roadway near the transitions. At the transition from sea ice to land, surfacing material must be structurally capable of supporting wheeled vehicles over 3-foot wide tide cracks. To reduce construction time, prefabricated or shop-fabricated surfacing materials should be used in place of the field fabricated timber roadway. An in-service field test will be required to determine what type of surfacing materials is best suited for use at McMurdo Station.

SELECTION OF SURFACING MATERIAL

Prefabricated Surfacing Materials

A survey of aircraft runway planking and roadway matting showed that many prefabricated surfacing materials suitable for use at the transitions from sea ice and snow to land are produced commercially (Table 1). Because of availability, only AM_2 planking and

a plastic matting called Mo-mat were selected for testing at McMurdo Station. Comparisons of these two materials provide sufficient data to evaluate the various types of prefabricated surfacing material.

The AM_2 aluminum planking is a system of interlocking double faced extruded panels 2 feet wide by 12 feet long by 1.5-inches thick. The panels have a bonded non-skid wearing surface on one side and interlock on their long side to form a 12-foot wide roadway. For the transition improvement field tests, sixty-four AM_2 aluminum panels were obtained from the Construction Battalion Center, Port Hueneme, California, and shipped to McMurdo Station.

Mo-mat is fabricated from fiberglass reinforced plastic in 12-foot wide by 48.5-foot long panels. For structural strength, panels are molded into a waffle configuration with an overall thickness of 5/8 inch and a material thickness of 1/10 inch. The panels have a non-skid material bonded to the top surface and holes on the periphery for connecting one panel to another or attaching edge stiffeners and anchor plates. Plastic nut plate strips are used in conjunction with bolts and washers to attach edge stiffeners or joining panels. The panels are shipped in rolls 3 to 4 feet in diameter. For the transition improvement field tests, five Mo-mat panels were obtained from CBC, Port Hueneme, California, and shipped to McMurdo Station.

Heat transfer calculations indicated that high solar radiation and above freezing air temperature will cause melting beneath AM_2 and Mo-mat placed on snow or ice. Accurate data is not available on solar radiation intensity at McMurdo, so precise calculations to determine the amount of melting beneath surfacing material of these types could not be made. The necessity to prevent melting beneath surfacing materials was therefore selected as a parameter to be studied during tests on improving trafficability of transition zones.

Two methods exist for preventing or reducing melting beneath surfacing materials: reflect solar radiation or insulate against heat transfer. Standard AM_2 aluminum planking has a dark green non-skid wearing surface. Solar radiation absorption factors* of various colors indicated that solar energy absorbed by AM_2 aluminum panels could be reduced up to 50 percent by painting the wearing surface white. For comparison of solar radiation absorption rates for light and dark colored materials, half of the AM_2 aluminum panels obtained for field tests at McMurdo Station were painted white. The remainder of the aluminum panels were left dark green. To fully cover the dark colored wearing surface, two coats of white epoxy paint were applied to the aluminum panels. The first coat had a wet film thickness of 6 mils and the second coat which was applied 24 hours later had a thickness of 12 mils. Labor and material for painting 32 aluminum panels averaged $1.10 per square foot of wearing surface.

Many types of insulation are available which could be used to prevent melting beneath surfacing materials. However, all insulations lose their thermal resistance when saturated with water. Free standing water is common on the sea ice during December and January. Heat transfer calculations indicated that 1/4-inch thick plywood greatly reduces

* Clifford Strock. Handbook of Air Conditioning, Heating, and Ventilating. New York, The Industrial Press. 1959, p. 1-181.

melting beneath AM_2 aluminum planking or Mo-mat placed on sea ice or snow. Plywood is also low in cost compared to commercial insulation and easier to salvage. To evaluate the performance of plywood in preventing melting beneath surfacing materials on sea ice, twenty-one sheets of 1/4-inch plywood were allocated for use in the transition improvement field tests. The plywood sheets were placed under an 80-foot long section of Mo-mat.

Shop-Fabricated Surfacing Materials

Because of the high cost of prefabricated surfacing materials (Table 2) and the need for a structural system to span the tide crack, NCEL designed two timber surfacing systems. A flexible timber system using 6x6 timbers tied together with steel cables was designed (NAVFAC Drawing No. 943603) as a substitute for the prefabricated surfacing material. The flexible timber decking system is approximately 50 percent cheaper than either AM_2 aluminum planking or Mo-mat (Table 2).

Since none of the prefabricated surfacing materials are structurally adequate to span a tide crack under the anticipated loading, NCEL designed a rigid timber panel (NAVFAC Drawing No. 943604). The rigid timber panel utilized 6x6 timbers placed longitudinally and tied together transversely with steel bars 2 feet on center. The panel was designed to span a 36-inch wide tide crack. The basic function of the rigid timber panel is the same as the timber ramp sections used at the sea ice to land transition at McMurdo Station during the austral summers between DF-69 and DF-72. The rigid timber panels were designed to be more durable than the timber ramp sections.

FIELD INVESTIGATION

Port Hueneme Tests of Flexible Timber Ramp System

A prototype flexible timber ramp similar to NAVFAC Drawing Number 943603 was tested on a level paved road and beach sand in the NCEL compound at Port Hueneme, California, in August 1972. The ramp was composed of two test sections. Test section A used 11-foot long rough cut 6x6 timbers placed transverse to the direction of traffic; test section B used 4-foot and 11-foot long rough cut 6x6 timbers placed transverse to the direction of traffic configured to form two parallel tracks.

Material cost for this type of ramp is reduced by using spacers between the timbers. Measurements of 11.00x15 high-flotation tires indicated that the distance between timbers could be as great as 4 inches. If the spacing is greater than 4 inches, vehicles with this size tire or smaller will experience rough rides when traversing the ramp. A 4-inch space was maintained between the timbers in the prototype flexible ramp by placing 1/2-inch pipe nipples over the 3/8-inch longitudinal cables (Figure 6). A 4-inch space between each timber reduced the cost of prototype ramp by 30 percent per linear foot.

A Dodge W-500 equipped with 19.75x20 high-flotation tires was used to traverse the prototype ramp fifty to sixty times (Figure 7). Observations were made to determine the effects of traffic on the durability of the two test sections. When placed on a hard, level road, the Dodge W-500 caused very little movement in the ramp and no damage. However, when placed on beach sand, the timbers in both test sections twisted as the Dodge W-500 traversed the ramp. As the timbers twisted, the pipe spacers cut into the wood. After only a few passes with the Dodge W-500, each timber had a hole worn at each spacer. Inspection of the prototype ramp indicated that except for wear around the pipe spacers, the performance of both test sections was satisfactory.

It was concluded from these tests that a flexible timber ramp configured similar to test section B, except with wood spacers instead of pipe spacers, would be tested at McMurdo Station.

McMurdo Station Tests

The six sections of surfacing material listed in Table 2 were installed on sea ice to land transition zone at VXE-6 Hill during the second week of November 1972. Test section 1 spanned the tide crack at the sea ice to land interface. All other test sections were placed on the sea ice in the order list in Table 2. Test section 1 was a 16-foot long rigid timber panel similar to NAVFAC Drawing Number 943604. The panel was assembled on a low bed trailer in the Public Works garage at McMurdo in about 30 man-hours. This figure would be much higher if assembly had been at the test site instead of in a heated building.

Test section 2 was a 28-foot long flexible timber surfacing system similar to NAVFAC Drawing Number 943603. The timbers for this test section were cut to size and drilled to accommodate 3/8-inch wire rope ties in the builders shop at McMurdo Station. In lieu of pipe spacers, as used in the Port Hueneme tests, 2x6x12-inch wood spacers were nailed to the 6x6 timbers at each cable (see NAVFAC Drawing No. 943603). The flexible timber section was assembled on the sea ice near the test site in 24 man-hours. All timbers in test section 2 were redrilled in the field during assembly because the holes for the wire rope were plugged with snow and wood shavings. The timbers had been stored in the open and snow had accumulated in the holes. Test sections 1 and 2 were pinned together with 3/4-inch bolts (Figure 8) and towed into position at the test site (Figure 9).

Test sections 3 and 4 each consisted of 32 AM_2 aluminum panels. The panels in test section 3 had natural dark green wearing surface. The panels in test section 4 were painted white to reflect solar radiation. To provide a smooth transition between the 6-inch thick flexible timber section (test section 2) and the 1-1/2-inch thick AM_2 panels, a 4-inch high snow ramp with 3/4 inch plywood insulation was built beneath the first four AM_2 panels in test section 3 (Figure 10). Test sections 3 and 4 were installed in 6 man-hours.

Mo-mat was used as the surfacing material in test sections 5 and 6. Test section 5 consisted of 80 linear feet of Mo-mat with a layer of 1/4-inch plywood insulation beneath it. Test section 6 consisted of 180-feet of Mo-mat placed directly on the sea ice surface

Because of its low weight, about 1.0 lb/ft^2, Mo-mat must be anchored or weighed down to resist wind loads. An anchoring system of 2x4 posts frozen in sea ice was used in test sections 5 and 6. Posts were placed in holes drilled in the sea ice about 3-feet from the edge of the Mo-mat at 25-foot intervals. Rope ties (Figure 11) were used to connect the Mo-mat to the anchor posts. Test sections 5 and 6 were installed in 10 man-hours.

All tests sections performed satisfactorily until late November when melting was observed under test section 3. All AM_2 planks in test section 3, except those used in the snow ramp to test section 2 (Figure 10), had sunk into the sea ice one inch or more. Melting beneath some planks was as great as 3-inches (Figure 12).

During late November and early December, three cracks developed in sea ice parallel to the shoreline through the test site (Figure 13). The width of these cracks varied from a maximum of 4-inches to a minimum of less than an inch. The cracks were located about 20-feet, 50-feet, and 130-feet from the shoreline. In early December, deterioration of the sea ice in test sections 3 and 4 was intensified because of frequent flooding of the test site with sea water. During periods of high tide, test sections 3 and 4 were flooded with 2- to 3-inches of seawater which flowed through the cracks in the sea ice.

On 7 December 1972, the surface of the sea ice under and around test sections 3 and 4 had melted 2- to 6-inches. Surface melting had also occurred on all sides of test sections 5 and 6 and made traversing of the ramp approach very difficult. Relocation and extension of the ramp was required to put it back in reliable service. The ramp was closed to traffic for ten hours on the night of 8 December and the following work was performed: (1) test sections 3, 4, 5, and 6 were taken up; (2) three timber sleds, about 12-feet wide by 16-feet long, were placed on the seaward end of test section 2 and about 15 yards of earth fill was placed at the end of the timber sleds; (3) the earth fill was leveled and AM_2 aluminum planking was placed over 1/4-inch plywood on top of the earth fill; and (4) 250-feet of Mo-mat with 3/4-inch plywood insulation beneath it was placed at an angle to test site (Figure 14).

During relocation of the surfacing material on 8 December 1972, a major disadvantage in using AM_2 planking in cold regions was observed. When the aluminum matting was disassembled, water on the AM_2 planking froze. Ice in the interlocking joints of the AM_2 planking had to be melted and chipped away before it could be used again. About 6 man-hours was required to remove ice from the interlocking joints of the AM_2 planking.

Rapid surface deterioration and extensive cracking in the sea ice near the shoreline resulted in termination of the test program in mid December. In an effort to prolong use of the sea ice road, Public Works, NSFA, fabricated and installed two 50-foot-long steel ramps at the sea ice to land interface and placed 400-feet of earthfill roadway on the sea ice. A timber planked roadway similar to Figure 4 was field fabricated on the earth fill.

Both sides of the earth fill roadway was flooded with 6-inches of water a few days after its construction. The sea ice road was closed to traffic on 26 December when a free floating section of ice under the roadway sank 16-inches below sea level. Sinking of the ice was attributed to overloading with earth fill.

APPLICATION

Sea Ice to Snow Transition

Review of problems encountered at the transition from sea ice to snow indicated improved construction techniques will alleviate the conditions that hinder vehicular traffic. Snowdrift accumulation can be reduced by constructing the snow ramp at least 75-feet wide and rounding the shoulders of the cut in the ice shelf. The difference in elevation between the sea ice and the ice shelf is about 15-feet. For wheeled vehicles to maintain traction on the snow ramp under all weather conditions the grade of the ramp should not exceed 10 percent.

Downwarped area and pressure ridges in the sea ice are normally caused by ice shelf movement. Both are common along the ice shelf.* The magnitude and extent of downwarping depend on the position and configuration of the ice shelf edge. Downwarping may also be caused by surface loading the sea ice. The snow ramp at the transition from sea ice and snow should be constructed at a site where downwarping has not occurred, and should be cut into the ice shelf as far as possible to minimize surface loading of the sea ice (Figure 15).

Snow to Land Transition

The snow to land transition near Scott Base required 75 to 100 feet of surfacing material to reduce the amount of dirt tracked onto the snow road. The flexible timber surfacing system (Figure A-1) is better suited for this transition than prefabricated surfacing materials because it has openings to collect dirt. Prefabricated surfacing materials become covered with dirt, therefore, ineffective in preventing tracking of dirt onto the snow road. The flexible timber surfacing system also has the advantage that it cost about 60 percent less than prefabricated surfacing materials.

Since the rate of snow accumulation is high at this transition, the flexible timber surfacing material should be stored at some other location during the winter. If the flexible timber surfacing material is fabricated as shown in NAVFAC Drawing No. 943603, each 20-foot length may be towed to a snow free location at the end of each summer season.

The surfacing material should be installed at the transition each summer when the snow road is open to traffic. The end of the surfacing material nearest the ice shelf should be buried as shown in Figure 16. Burying the end of the surfacing material will provide a smoother transition onto the ramp. The section of flexible timber surfacing material should be tied together as shown in Figure 16 so the entire ramp acts as a unit.

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* Naval Civil Engineering Laboratory. Technical Note N-840, Ice and Snow Terrain Features, McMurdo Station, Antarctica, by R. A. Paige, Port Hueneme, California, September 1966

Sea Ice to Land Transition

Field tests and observations indicate that a minimum of 75 feet of timber ramps or rigid timber panels (Figure A-2) and 500-feet of surfacing material is required at the VXE 6 Hill sea ice to land transition. The first timber ramp or rigid timber panel should be placed over the tide crack at sea ice and land interface and the remainder of the ramps or panels placed on the sea ice.

Because of rapid deterioration at locations where vehicles track dirt on the sea ice, several approaches to the surfacing material should be provided. The prefabricated surfacing material such as Mo mat and AM_2 aluminum planking are better suited for multiple approaches than the flexible timber system because they are thin. Mo-mat is 0.63 inches thick and AM_2 planking is 1.5-inches thick compared to 6 inches for the flexible timber system.

The approaches to the surfacing material should be regulated so that dirt is not tracked onto the sea ice indiscriminately. The approach to the surfacing material should initially be at the seaward end. As the sea ice at one location deteriorates, the approach should be re-located closer to shore. Deterioration of the sea ice can be reduced by keeping a clean snow cover on the sea ice adjacent to the surfacing material until used as a vehicle approach.

FINDINGS

1. AM_2 aluminum planking is suitable for use as surfacing material on sea ice, but requires some type of insulation between it and the sea ice to prevent surface melting.

2. Ice in the joints of the AM_2 planking will prevent the panels from interlocking.

3. Five hundred feet of surfacing material is required at VX-6 Hill to provide a usable maintenance-free transition ramp until mid December.

4. The flexible timber system is an economical surfacing material, but it is limited to use at locations where vehicle access is bidirectional.

5. Mo-mat is suitable for use as surfacing material on sea ice, but it must be well anchored and insulation is required between it and the sea ice to prevent surface melting.

6. Plywood, 1/4-inch thick, did not eliminate melting of the sea ice surface beneath Mo-mat. However 1/4-inch thick plywood did reduce the amount of melting beneath the Mo-mat.

7. Mo-mat is easier to install and recover than AM_2 aluminum planking when used on ice or snow.

CONCLUSIONS

1. Prefabricated surfacing material may be used to provide a low maintenance roadway at the transition zone from sea ice to land. Of the two prefabricated surfacing materials tested, AM_2 aluminum planking is the most durable. However, Mo-mat is durable enough to withstand vehicular loading encountered at the sea ice to land transition if it is properly anchored.

2. Installation and recovery of AM_2 aluminum planking is more difficult than Mo-mat.

3. Any of the prefabricated or shop fabricated material tests may be used at the transition from snow to land, but because of its low cost and ability to collect dirt, the flexible timber system should be used.

Table 1. Tabular Summary of Prefabricated Aircraft Runway Planking and Roadway Matting*

Item	Federal Stock Number	Source	Cost ($/ft^2)	Weight (lb/ft^2)	Panel Dimensions
Aluminum Mats					
AM_1		Butler Mfg Co. Kansas City, MO			12 ft x 2 ft x 2 in.
AM_2	5680-072-8680	Harvey Aluminum Co. Torrance, CA	3.00 (1961)	6.3	12 ft x 2 ft x 1.5 in.
AM_3		Alcoa New Kensington, PA		7.87	8.11 ft x 3.27 ft x 5.5 in.
AM_5				4.31	12 ft x 2 ft x 1.5 in.
AM_6		Harvey Aluminum Co. Torrance, CA	4.50 (1971)	3.7	12 ft x 2 ft x 1 in.
M9M1			1.32 (1971)	5.3	12 ft x 2 ft x 1.7 in.
M9M2			1.32 (1971)	7.6	12 ft x 2 ft x 1.9 in
XM18	5680-089-7260	Dow Chemical Co. Midland, MI	5.30	4.8	12 ft x 2 ft x 1.5 in.
XM18E1		Dow Chemical Co. Midland, MI	3.72 (1971)	4.8	12 ft x 2 ft x 1.5 in.
XM19	5680-089-5920	Kaiser Aluminum and Chemical Sales Co. Oakland, CA	5.00 (1970)	4.1	4.19 ft x 4.13 ft x 1.5 in.
XM19 All Bonded		Kaiser Aluminum and Chemical Sales Co. Oakland, CA		4.25	4.19 ft x 4.13 ft x 1.5 in.
XM20		Dow Chemical Co. Madison, IL	4.35 (1968)	6.08	12 ft x 2 ft x 1.5 in.
Goodyear All Bonded		Goodyear Aero-space Corp. Akron, OH	4.00 (1971)	3.99	4.08 ft x 4.08 ft x 1.5 in.
Harvey 1- by 6-feet		Harvey Aluminum Co. Torrance, CA	4.00 (1971)	4.6	6 ft x 1 ft x 1.5 in.
Modified T11		Dow Chemical Co. Madison, IL	3.00 (1968)	4.5	12 ft x 2.16 ft x 1.6 in.

continued

* Naval Civil Engineering Laboratory. Technical Note N-1212, Marginal Terrain Platforms, by A. Widawsky, Port Hueneme, California, June 1972.

Table 1. Continued

Item	Federal Stock Number	Source	Cost ($/ft^2)	Weight (lb/ft^2)	Panel Dimensions
Aluminum Mats (continued)					
Alcoa T11		Alcoa New Kensington, PA		3.8	12 ft x 2 ft x 1.6 in.
Fenestra				5.0	8.5 ft x 1.78 ft x 1 in.
Aluminum Trackway			2.38 (1967)	4.10	255 ft x 11 ft
Plastic Mats					
Mo-Mat	5680-806-0864	Air Logistics Corporation Pasadena, CA	3.05 (1971)	1.0	48.5 ft x 12.17 ft x 0.63 in.
Modified T12		Strato-Tek Los Angeles, CA		4.44	12 ft x 2 ft x 1.2 in.
T13		Lunn Laminates Huntington Sta., NY		5.40	12 ft x 3 ft x 1.8 in.
T14		Pacific Plastic Co. Seattle, WA		6.29	11.87 ft x 1.85 ft x 1.75 in.
Magnesium Mats					
T7		Dow Chemical Co. Madison, IL		3.93	12 ft x 1.65 ft x 1.63 in.
T8		Dow Chemical Co. Madison, IL		4.27	12 ft x 2.29 ft x 1.63 in.
Steel Mats					
M8		Military	0.56 (1971)	6.96 7.27	11.81 ft x 1.63 ft x 1.14 in.
M8A1	5680-782-5577	Kaiser Steel Fontant, CA	1.00 (1971)	7.5	11.81 ft x 1.63 ft x 1.13 in.
U.S. Steel 3.5A		U.S. Steel		3.6	4 ft x 4 ft x 1.5 in.
U.S. Steel 4.5A		U.S. Steel		4.9	4 ft x 4 ft x 1.6 in.

Table 2. Surfacing Material Tested at the McMurdo Station Sea Ice to Land Transition

Test Section Number	Material	Length of Test Section (ft)	Cost ($/ft^2)
1	Rigid Timber	16	2.00[a]
2	Flexible Timber	28	1.10[a]
3	AM_2 Aluminum Planking (Standard)	64	4.10
4	AM_2 Aluminum Planking (White Surface)	64	3.00
5	Mo-Mat (with 1/4-inch plywood)	80	3.30
6	Mo-Mat	160	3.05

[a] Material cost only; labor for fabrication and assembly not included.

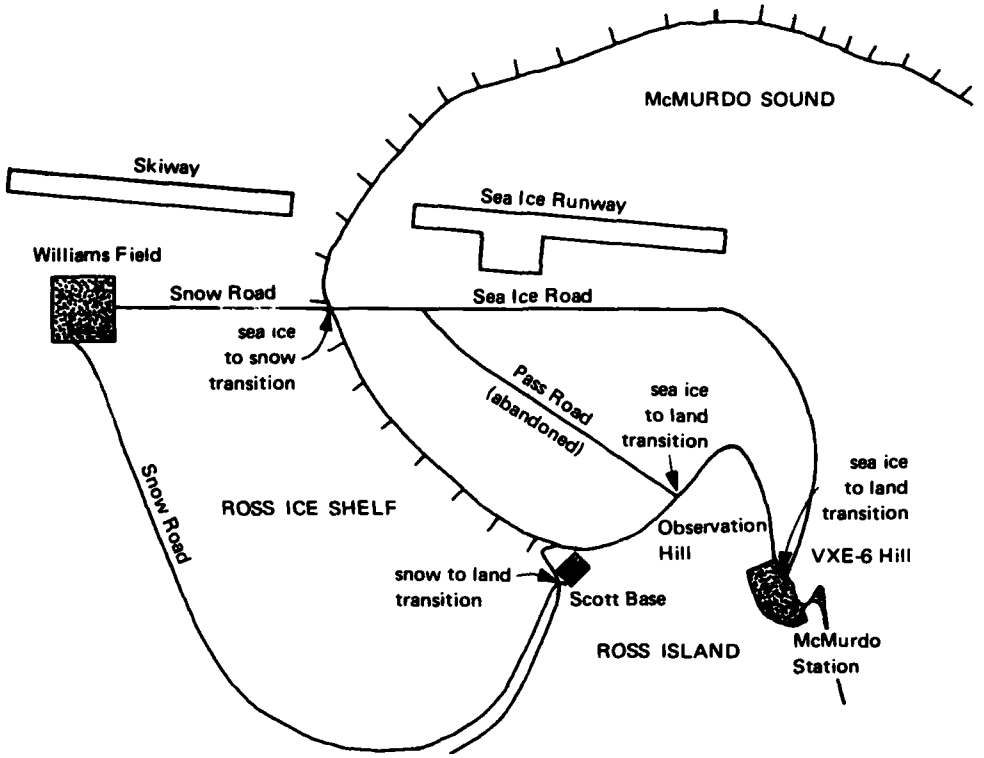


Figure 1. Map of McMurdo Station road system.

Figure 2. Compacted snow roadway at Pass Road.

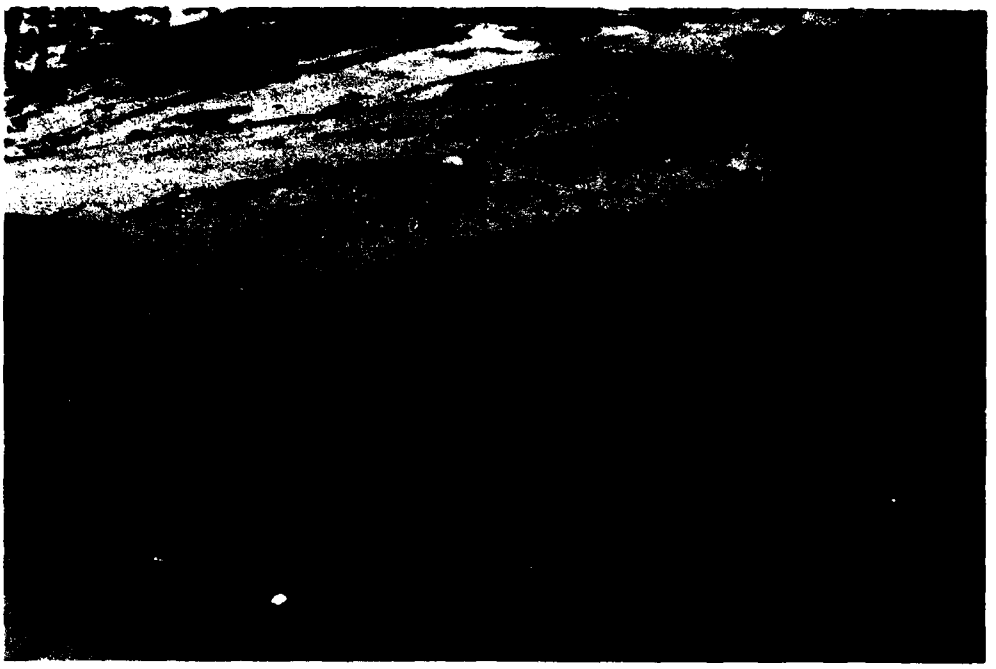


Figure 3. Timber ramp constructed during DF-68 at sea ice to land transition.

Figure 4. Field fabricated timber planked roadway.

Figure 5. Shaded section of snow road near Scott Base.

Figure 6. Prototype flexible timber ramp being assembled using 4-inch long pipe nipples as spacers.

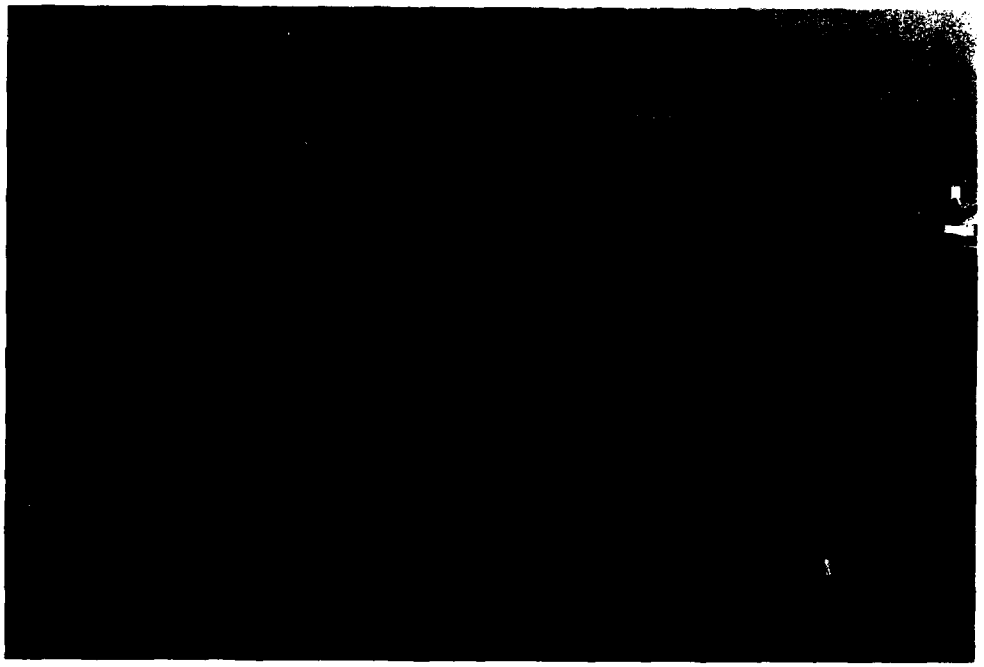


Figure 7. Dodge W-500 traversing prototype timber ramp on beach sand.

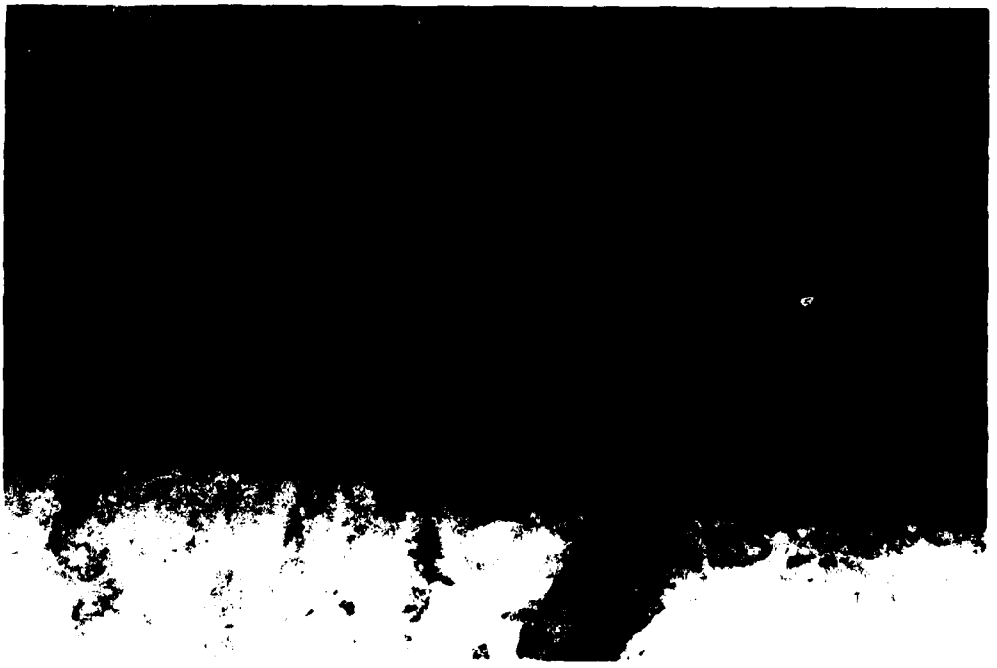


Figure 8. Pin assemble between rigid and flexible timber surfacing systems.

Figure 9. Timber test sections being moved into place.

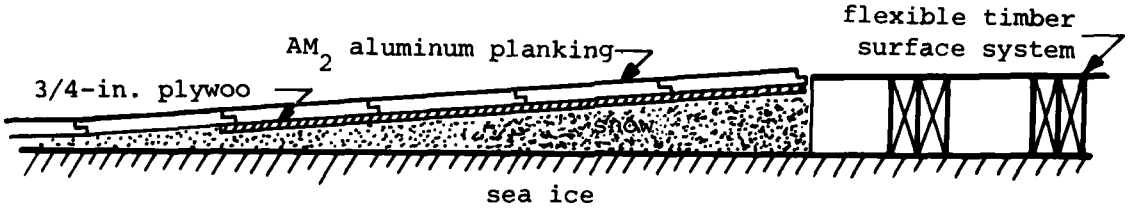


Figure 10. Snow ramp between test sections 2 and 3.

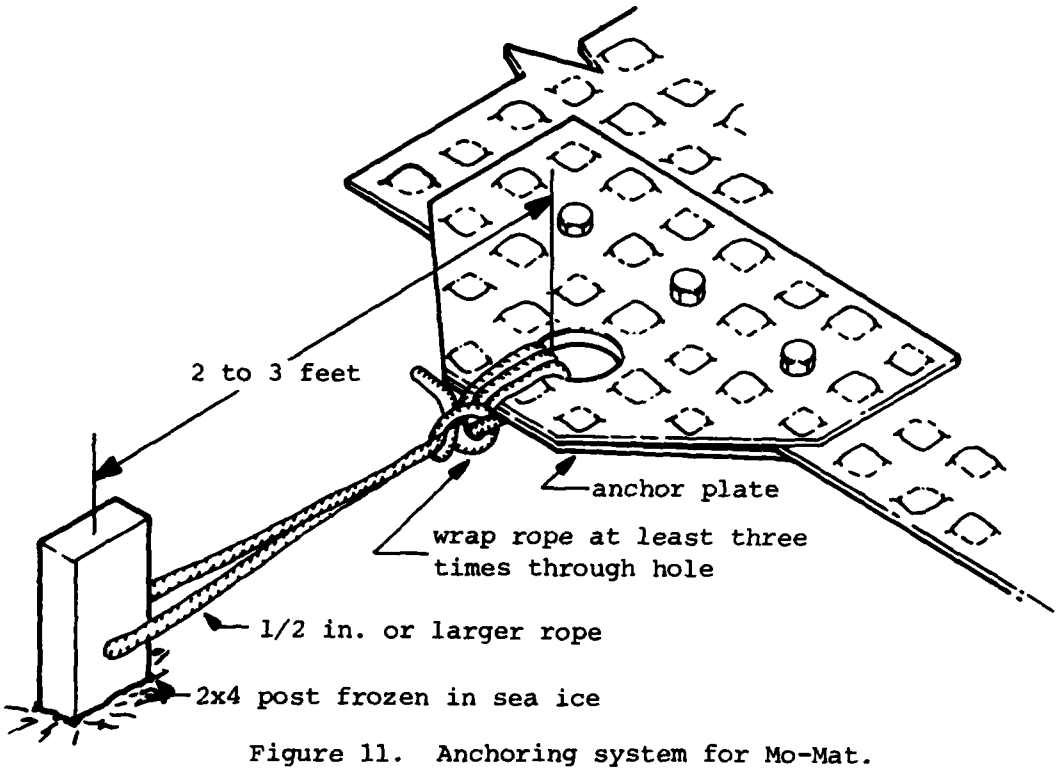


Figure 11. Anchoring system for Mo-Mat.

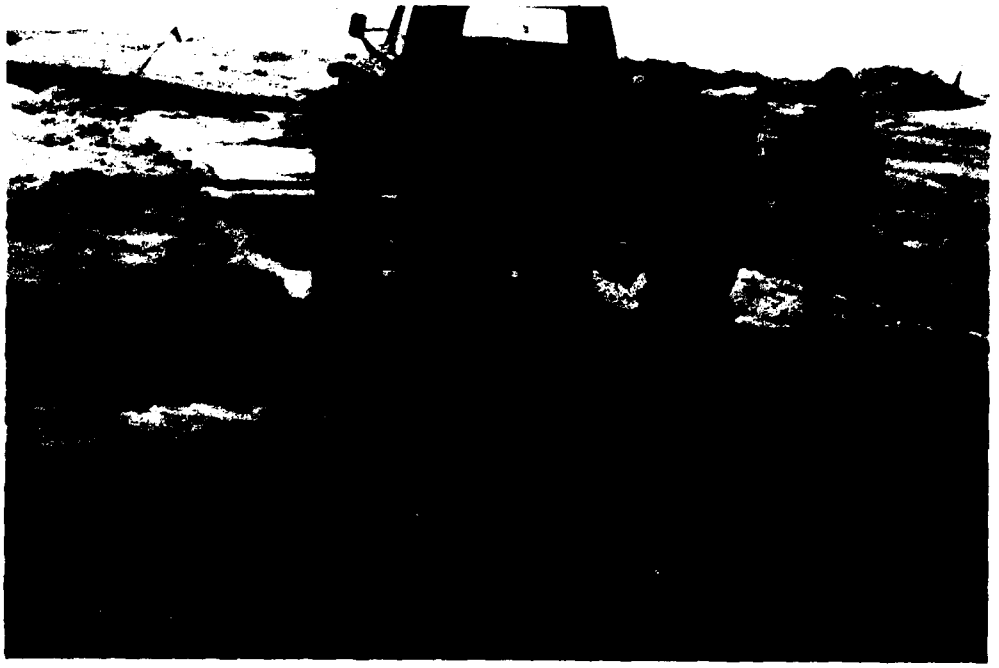


Figure 12. AM_2 aluminum planking after melting occurred.

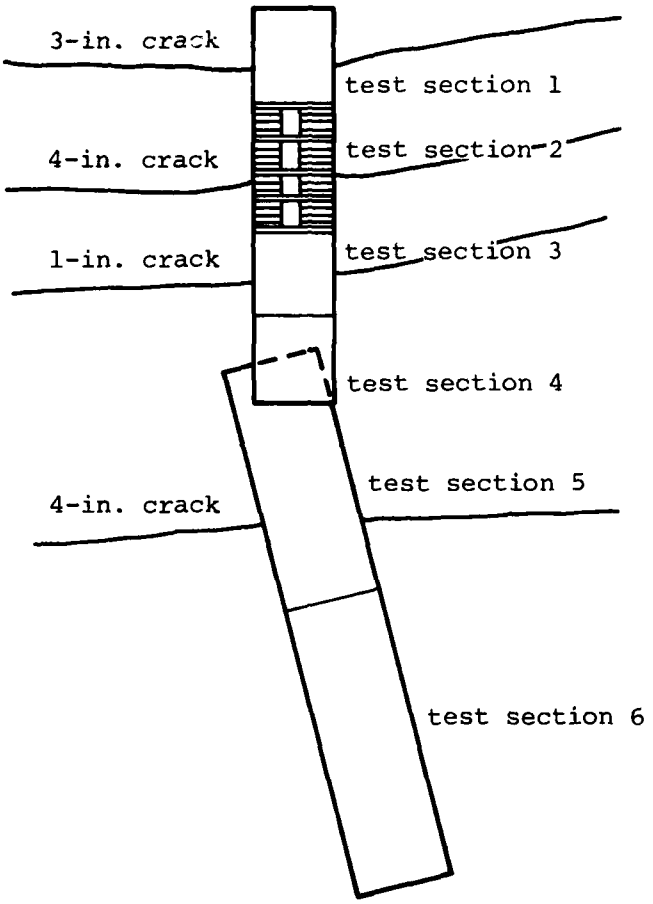


Figure 13. Tide crack configuration in sea ice during late November 1972.

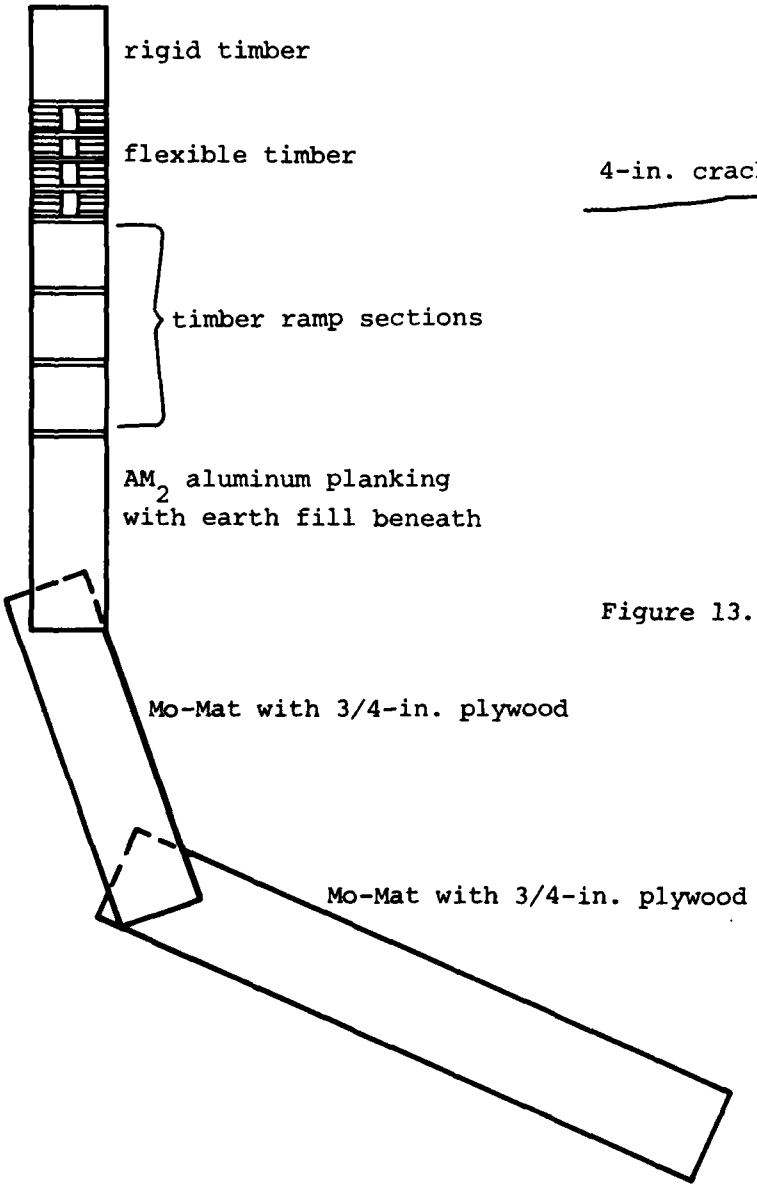


Figure 14. Ramp configuration on 9 December 1972.

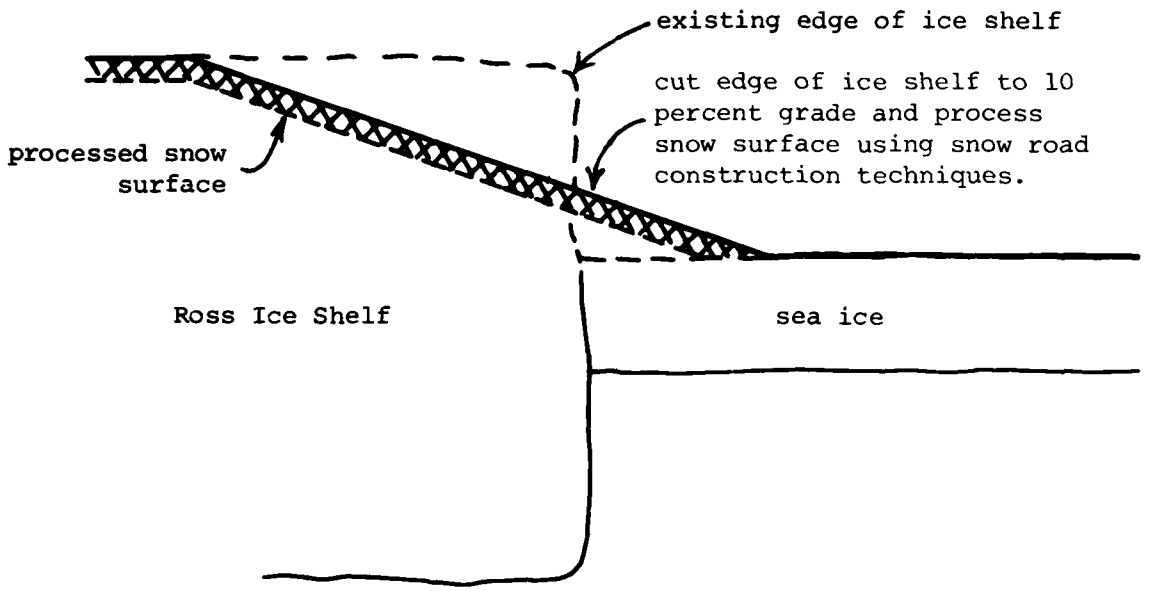


Figure 15. Sea ice to snow transition.

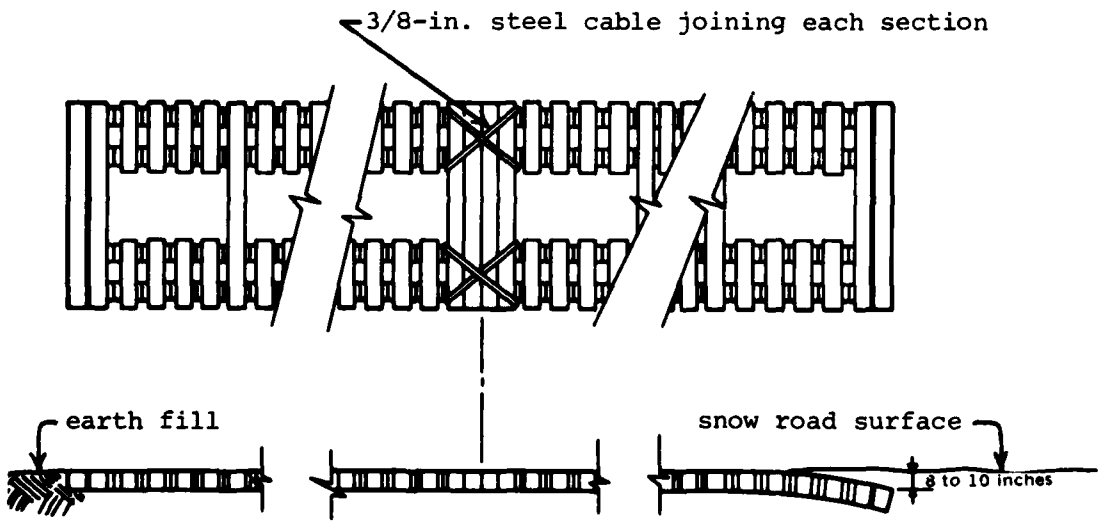


Figure 16. Installation of flexible timber surfacing material.

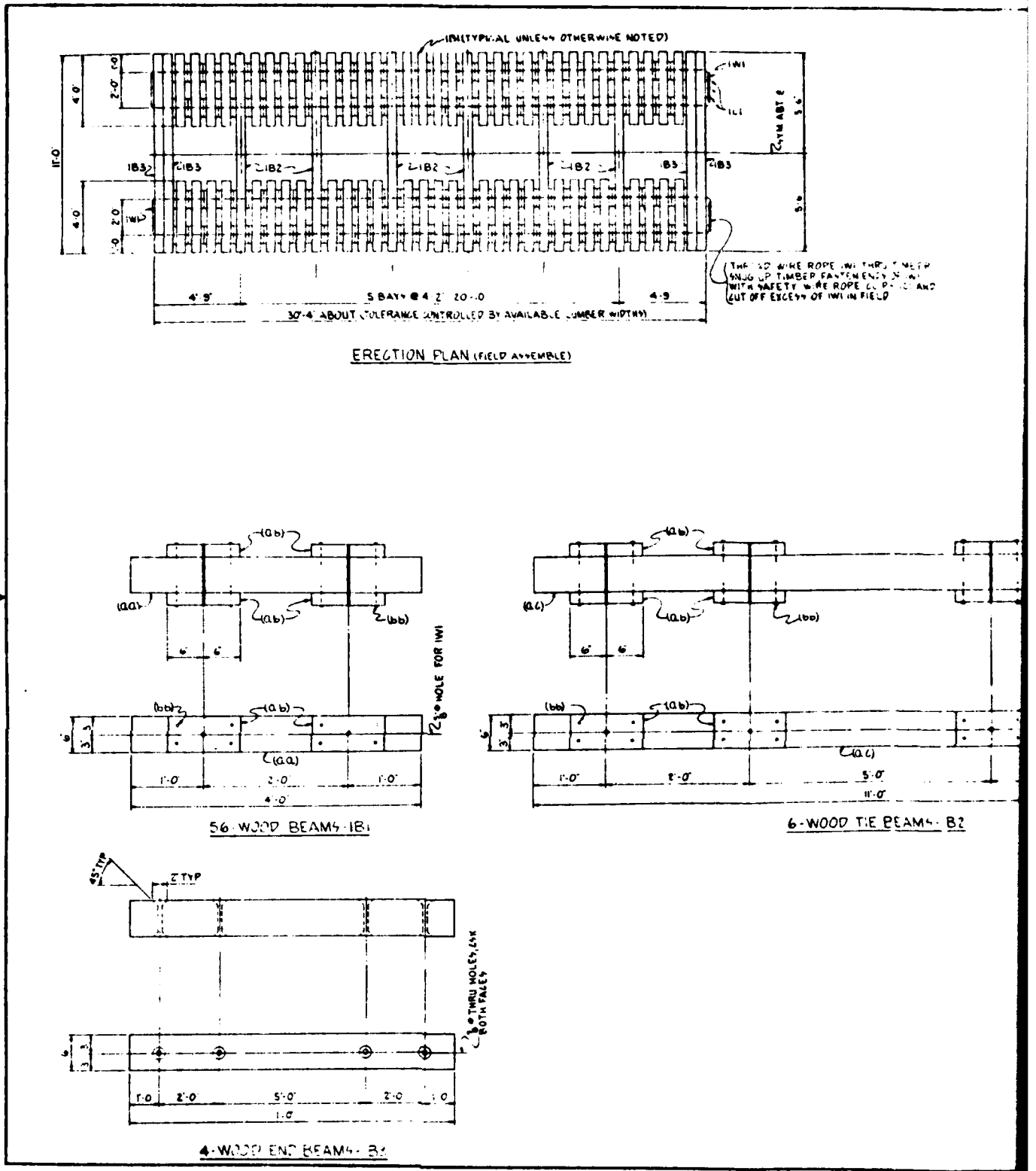
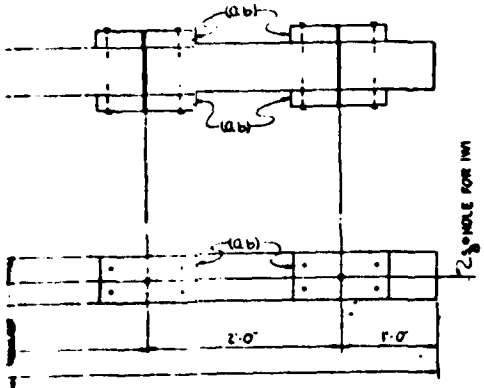


Figure A-1. Flexible

TIMBER
OF
ICE AND

NOTES

1. ALL LUMBER TO BE DOUGLAS FIR CONSTRUCTION GRADE, ROUGH SAWN.



E:M4- B2

	2	BOFE, $\frac{5}{8}$"ø x 25 FILLER WIRE, LWR & IMPROVED PLOW STEEL & GALVANIZED			
		2-TIE CABLES-1W1 (NOT DETAILED)			
	6	WIRE ROPE SAFETY CLIPS FOR $\frac{5}{8}$" WIRE ROPE, GALVANIZED			
		6-CLIPS-1C1 (NOT DETAILED)			
	4	6 x 6	11	0	
		4-WOOD END BEAMS-1B3			
bb		NAILS BILLED UNDER (1B4)			
aa	6	4 x 6	11	0	
ab	48	2 x 6	1	0	
		6-WOOD TIE BEAMS-1B2			
bb	2SUM	16d COMMON STEEL WIRE NAILS, GALVANIZED			
ab	224	2 x 6	1	0	
aa	84	6 x 6	4	0	
		36-WOOD BEAMS-1B1			

MARK	NO REQ'D	SIZE	FT	IN LENGTH	REMARKS

BILL OF MATERIAL

NAVFAC DWG NO. 4-B17	DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND
NCEL DWG NO. 73-15-IF	NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA
	MCMURDO TRANSITION RAMPS
	FLEXIBLE TIMBER RAMP
	ERECTION PLAN & DETAILS
APPROVED	SIZE F
	CODE IDENT NO 80091
	DWG NO 743603
	SCALE NONE
	SHEET 1 OF 2

FRACTIONS ± 1/64 UNLESS NOTED
DECIMALS ± .
ANGLES ± 1°

Flexible timber ramp.

7-B-25

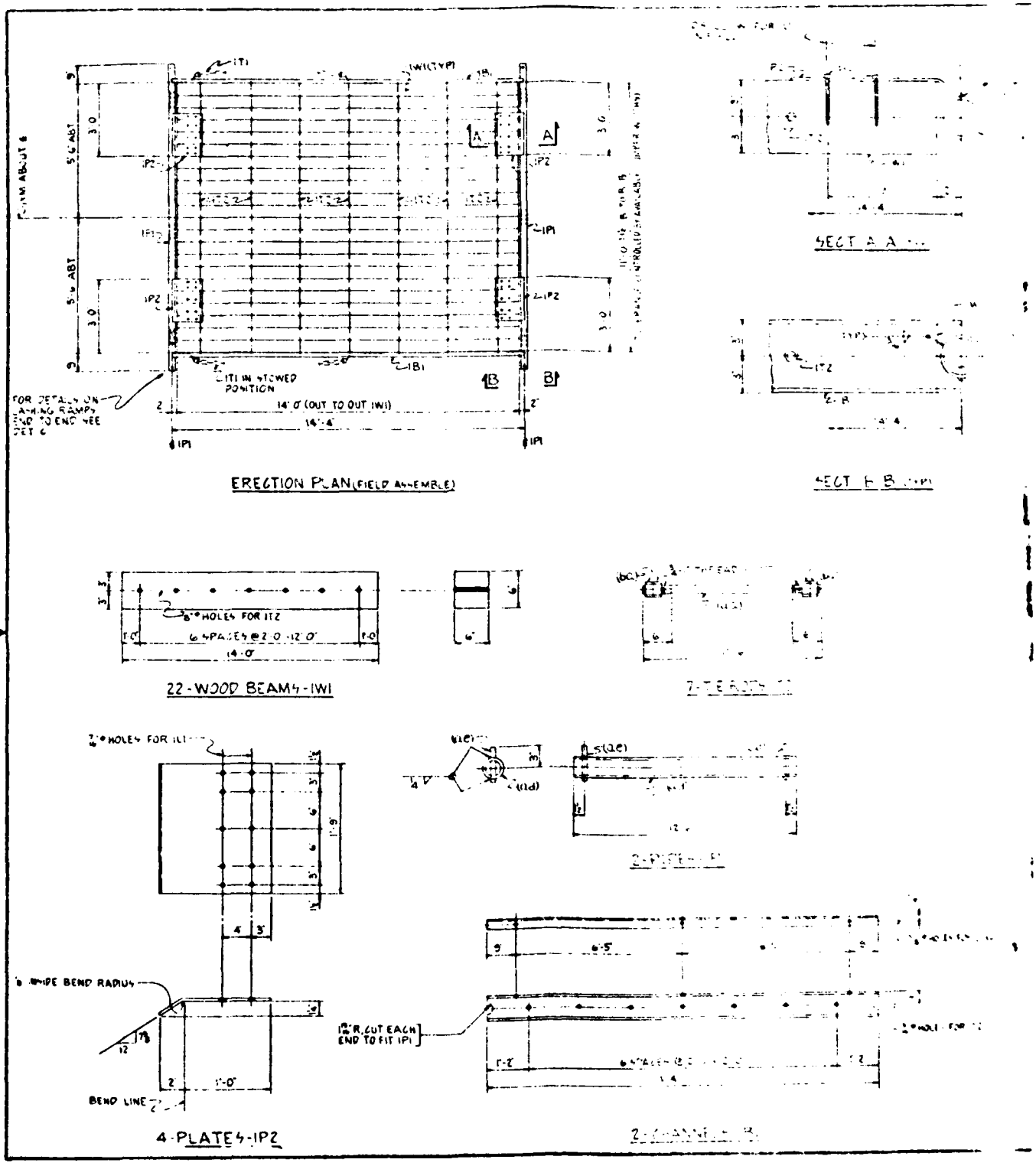
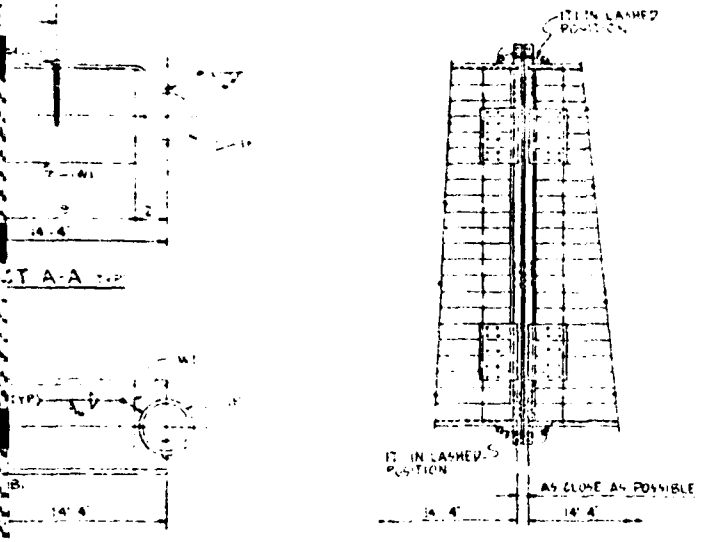


Figure A-1. Right si



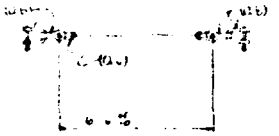
T A-A

T B-B

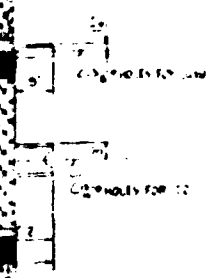
DET C
(LASHING RAMPS)

NOTES

1. ALL LUMBER TO BE DOUGLAS F R CONSTRUCTION GRADE, ROUGH SAWN



2 LASHINGS (TYP)



QTY	NO REQD	SIZE	REMARKS
	40	2" x 4" LEG	HEAD SCREWS OF VARIOUS STEEL
QC	4	BAR	
	2	PIPE	
	2	C6x8.2	
	4	R	
QC	2		
	8		
QC	28	1/2-10 HEX NUT MILD STEEL	
QC	7	BAR	
	22		

PROJ NO 61-017
SHIP DWG NO 73-15-PF

NAVAL CIVIL ENGINEERING LABORATORY

RICE TIMBER RAMP

F

A-2. Rigid timber ramp.

Chapter 8

SHIP OFFLOADING FACILITIES

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Revised – 1979

CHAPTER 8*

SHIP OFFLOADING FACILITIES

HISTORY OF NATURAL ICE WHARF

Construction materials and consumables for resupply of McMurdo and the inland stations arrive in the Antarctic by ship. The wide variety of cargo includes refrigerated foodstuff, all types of dry stores, and bulk and drummed POL** products. In DF-63*** and earlier when the Williams Field Air Facility was located west and south of Hut Point (Chapter 1, Figure 1-3), the cargo was offloaded onto the annual sea ice a mile or more west of the air facility and as much as 6 miles from McMurdo. Cargo for inland stations was segregated at nearby Williams Field and the McMurdo cargo hauled to Ross Island by sled train over the sea ice.

In DF-64, the annual sea ice was thinner than in the preceding few years and a safer area for cargo operations was needed than that afforded by the annual ice. Drawing from history and Scott's experience, Winter Quarters Bay was opened for the first time in Deep Freeze history; and the fast ice along the east side of Hut Point Peninsula was used as a natural wharf. For the first time, all cargo ships and POL tankers were able to unload directly onto Ross Island; and the sometimes hazardous, time-consuming offloading on annual sea ice was eliminated.

The ice wharf was located on the southeastern shore of Hut Point, a small promontory that forms the western side of Winter Quarters Bay (Figure 8-1). The bay forms a sheltered anchorage with a diurnal tide on only 2.2 feet (U. S. Navy Hydrographic Office Chart 6712). About 1/2 mile of dirt road connects the wharf with the central storage area of McMurdo station.

The shoreline along Hut Point is about 1,200 feet long and when originally opened provided berthing space for three ships in water 27 to 60 feet deep and additional berthing space for one ship near the northeastern side of the bay (Figure 8-2). The surface area of the wharf in DF-72 varied from 20 to 40 feet wide along most of the western shore except at the northern end where a larger area approximately 30 feet wide and 400 feet long exists.

Although an effective cargo dock was established by removing the annual ice at Winter Quarters Bay Point, this action was simultaneously deleterious to wharf survival. The vertical ice face, no longer protected by the annual sea ice, was exposed directly to ablative melting caused by wave action and warm water from ship discharge systems. At sea level, caverns

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*This chapter has been completely rewritten in 1979.

**Petroleum, oil and lubricants.

***The Deep Freeze (DF) year begins in July and ends in June.

were melted along the vertical face creating a cantilevered lip which would periodically break off, reducing the width of the cargo area and leaving an underwater bench which held the ships away from the dock face. In 1969, it was estimated that each year 10,000 square feet of surface area were irretrievably lost. During both DF-66 and DF-67, observations recorded a 10- to 15-foot recession in the position of the ice face. Even more serious than the loss of cargo handling area, however, was the reduced depth of water alongside as the wharf eroded.

During DF-67, a series of exploratory holes were drilled in the ice wharf to determine the depth to rock and other subsurface conditions. Seven holes up to 60 feet deep were drilled with a tricone bit designed for ice and ice-rock conglomerate. A description of these bits and the drilling equipment is contained in Chapter 10. A diagrammatic cross section of subsurface conditions at the ice wharf is shown in Figure 8-3. The bottom conditions shown are based on observations during DF-67 and extrapolation from core drill data obtained nearby on the east side of Hut Point in DF-63 (BuDocks Contract NBY-45840). It is quite likely that bottom conditions adjacent to the ice wharf are similar to those along the eastern shore of Hut Point.

The profile of temperatures in the wharf to depths from 12 to 38 feet are shown in Figure 8-4. The deepest profile was obtained from various depths along the 38 feet of core extracted about 16 feet back from the ice edge. The other two curves are representative of fast-ice temperatures about 8 feet back from the ice edge. Temperatures near the vertical ice face, especially below sea level, are higher than those farther back because of the warming influence of seawater. Subsurface temperatures in the wharf are also related to the seasonal air temperatures.

Numerous methods have been considered for creating a permanent wharf, some of which are described in References 1, 2, and 3. To prevent further wave damage and also to maintain a vertical docking face, the Naval Facilities Engineering Command (NAVFAC) designed a protective dock face. In a 4-year period ending in DF-72, a total of 464 feet of steel and timber facing was installed. Structural steel beams, placed on the wharf and anchored to steeel piles set in the ice (Figure 8-5), were used to support a steel framework backed with timber panels (Figure 8-6). This network, which extended from approximately 10 feet above sea level to 20 feet below, prevented wave action against the ice face. Earth fill was placed between the timber panels and natural ice face, thereby further reducing the possibility of ablative melting.

During March 1972 a major portion of the wharf was either destroyed or severely damaged by storm. High tides and pounding waves ripped out many of the steel-faced timber panels, bending the I-beam supports and washing away most of the fill material. Exposed portions of the natural ice face were extensively eroded, leaving insufficient water depth off the dock face to accommodate the supply ships.

HISTORY OF ARTIFICIAL ICE WHARFS

In order to utilize Winter Quarters Bay for DF-73 cargo activities, remedial measures were clearly needed. To accommodate the T5-class tanker's draft of 30 feet, a fender had to be provided between ship and shore. Such a fender was realized in the form of a small iceberg-like piece of manmade ice; the experimental "ice cube" was built by the DF-72 winter-over personnel. The ice cube was constructed along the edge of the wharf by repeatedly flooding and freezing an enclosed 25-foot-wide by 50-foot-long section of annual ice to obtain a thickness of 15 feet. This ice fender functioned well, but a more comprehensive long-term solution was required.

During DF-73 the winter-over Public Works personnel at McMurdo Station constructed the artificial ice wharf shown in Figure 8-7. The structure was located at former Berth 3 (Figure 8-2) and was trapezoidal in shape: 460 feet long on the seaward edge and 635 feet long on the back edge. The width was approximately 170 feet and the final thickness 29 feet. The method of construction was similar to that described as confined flooding in Reference 4.

In January DF-74 the experimentally flooded ice structure was freed from the annual ice and tied to the shore through a system of bollards and cables. Although cracked in a few places during ice-breaker clearing operations, the structure functioned well for berthing and unloading of cargo and POL. The vertical berthing face of the wharf was produced by blasting techniques which were supervised by Army Cold Regions Research and Engineering Laboratory personnel.

During the bay ice-clearing operation by the ice breaker for DF-75 the ice wharf was fractured into several pieces. Although the pieces were contained for satisfactory ship cargo handling they separated widely before winter freeze-up. Subsequently, for the DF-76 operation only about 40% of the original wharf was available. Even this section had to be maneuvered into a position for docking the ships in deep enough water. At the completion of the shipping season, the bay was cleared of all wharf fragments, and plans were made for the winter-over Public Works personnel to construct the DF-76 ice wharf. The wharf is still in service at this time (DF-79). The completed wharf is shown in Figure 8-8. The surface area to be flooded during construction was approximately 262,000 square feet. The area usable as a wharf was approximately 300 by 800 feet. It is estimated the construction required pumping approximately 40 million gallons of seawater placed in 34 lifts to produce the 5 million cubic feet of ice buildup. This wharf was designed appreciably longer than the DF-73 wharf to provide greater stability against movement by keying into irregularity of the shoreline. It featured a cable-reinforced 200 by 500-foot core. The reinforcement was placed at the midthickness to provide a string-together capability and thus prevent section separation if cracks developed such as those experienced with the DF-73 wharf.

The DF-76 ice wharf design attempted to overcome the short

service life experienced with the DF-73 wharf by enlarging the size and including a reinforced section. Additional advantages realized from the increased size are (1) easier ship docking due to extending the seaward face into deeper water and (2) more surface area for cargo handling and movement of vehicles.

The sections that follow will describe the how-to techniques that have subsequently been developed for construction and operation of artificial ice wharfs at Winter Quarters Bay. A review of References 5, 6 and 7 are recommended for those undertaking design and construction of an ice wharf to derive the benefits provided by the more detailed instructions, including field logs that reconstruct actual events.

DESIGN AND CONSTRUCTION

During the development of the design package, it should be kept in mind that the field construction team will be executing the plan under adverse weather and other unpredictable situations. Such conditions frequently lead to the need for field innovation. While the plan should be based on good engineering practice and the best state-of-the-art from past experience, the specifications and guiding instructions should provide sufficient alternative methods and room for innovation to fit the unpredictable field conditions during the process of construction.

Design Guidelines

The following design guidelines should be used:

1. Assemble climatological records, tidal data, and detailed maps of shoreline features and sea bottom contour of the ice wharf construction site to be used in developing the design package.

2. Based on site conditions and operational requirement, design the ice wharf as either a fully floating or a completely grounded structure. If only partially grounded, high stress levels sufficient to cause fracture cracks can develop. Although a fully grounded ice wharf would be the ideal structure because of its resistance to movement and of the possible increase in longevity, a fully floating ice wharf for most sites is the logical design. All ice wharfs constructed to date at McMurdo's Winter Quarters Bay have been the floating type because of the need to extend the wharf into water of sufficient depth to accommodate 30-foot draft ships. To construct a bottom-resting wharf at the location would greatly increase the construction effort and involves the inherent difficulty of producing a tapered shape that would rest evenly on the sea bottom.

3. Restrain the floating ice wharf from drifting out of position by the use of bollards and cable lash-up. The degree of cable restraint required can be greatly reduced if the wharf design utilizes shoreline features for keying or as a point of wedging to resist movement.

4. Greatly increase operational life of an ice wharf by oversizing the wharf to that actually required for the shipping operation.

The oversize allows for the natural retreat of the seaward face due to the loss of ice in the required annual trimming and straightening of the ship docking face. Retreat from 15 to 20 feet of the docking face a year is estimated from this operation. Likewise, if the wastewater discharge from a berthed ship is permitted to impinge on the dock face, the undercutting and erosion of the ice can amount to 6 to 8 feet in a 24-hour period. It is extremely important that the dock manager work closely with the ships' engineering officers to minimize the volume of discharge and to install flow diversion screens at appropriate locations.

5. Greatly increase the longevity of an ice wharf by strengthening the ice with reinforcing material. However, for most cases it will not be economically feasible to reinforce sufficiently to insure failure from fracture. To stay within economic feasibility the DF-76 McMurdo ice wharf was only reinforced in the central core with 12,000 feet of 1-1/2-inch steel cable. The cable was installed at approximately the midpoint between the top and bottom surfaces and was considered as providing only a string-together capability rather than a reinforcement to prevent fracture. Experience has shown that if the icebreaker channel-cleaning operations in the vicinity of an ice wharf are not performed cautiously and with precision, it can result in cracks propagating from the annual ice into the ice dock. Without the string-together reinforcement, the dock could separate into several pieces of unusable size. The reinforcement in the DF-76 dock was set back from the face 100 feet to accommodate several years of face trimming before reaching the reinforced area.

6. Construction to begin soon after 2 feet of annual ice has formed because of the length of time required to construct an ice wharf. The limited bearing capability of this thin ice cover requires formulating the design and construction procedures to accommodate lightweight equipment. Past experience has shown that snow removal and dike construction can be accomplished with blade-equipped small tractors such as the D4 Caterpillar. Electrically driven, specially configured, submersible pumps set within the dock construction area have been found as the most suitable for pumping the flood water. The design and pump specification should provide a construction procedure that will permit flooding the ice wharf surface to a nominal 4-inch depth in a period of about 4 hours. This sequence of flooding is repeated every 24 hours, provided ambient air temperature is low enough to permit complete transformation of the flood water to solid ice (Figure 8-9). The DF-76 ice wharf was constructed using two 1,500-gpm submersible pumps set 350 feet apart within the flood zone. They were operated individually and concurrently, depending on the flood coverage desired. The construction team, through observing the operation, quickly learns to interpolate the correct flooding procedure as affected by the air temperature, drifting snow, surface conditions, and even the tilt effect on the structure caused by tidal change.

7. Full awareness by the designer, in preparing the documents to be used by the field team, that the team will be performing under the most severe winter conditions (including darkness, which requires lighting of the construction area). The worker will be in bulky clothing often coated with ice. For safety, especially during flooding when surfaces are slippery and ice fog engulfs the area, most operations will require the "buddy" system of two or more people working together.

The design package should be available to the construction team for review and planning well in advance of the scheduled start-up as it is unlikely that team members will have had previous experience. Suggested alternative methods for accomplishing various phases of the work should be discussed in the instructions and sketches detailing normal construction techniques. This additional information will prepare the field team for their onsite responsibility for making adjustments in the plan with innovative how-to techniques in response to unpredictable situations. All construction procedures specified in the design should be kept as simple as possible due to the adverse working conditons. For example, although wharf layout sketches will show distances and angles, precise measurement is seldom necessary. In such cases, line-of-site bearings on terrain features to fix control points will greatly expedite the work. The construction team, however, should be required to make reasonably accurate as-built sketches and keep a daily log of the effort for future reference. The DF-76 ice wharf construction covered a period from mid-March through early September. The construction log indicated approximately 2,400 man-hours were expended over approximately 150 productive work days.

Construction Procedures

The following is a chronological listing of construction events:

1. Area Inspection. Proposed construction area is inspected for working and open cracks. Field team judgment will be required to correct or alter the design plan to avoid uncorrectable conditions.

2. Ice Thickness. Ice thickness is measured at several locations to insure the ice will support construction equipment.

3. Staking. The wharf perimeter is staked to define boundaries, and the stakes are set in shallow augered holes. Corner stakes should be tall and sturdy and flagged to provide reference throughout construction. Intervening line stakes set at about 100-foot intervals are shorter and less sturdy since their purpose is to provide alignment for constructing dikes to retain the flood water.

4. Snow Cover. The snow cover is removed from the wharf construction area. If the design specifies snow dikes for retaining the flood water, which will generally be the case, the snow can be pushed by a small blade-equipped tractor into a continuous berm covering the perimeter stakes. If the design plan specifies another type of dike construction, the snow

would be moved to a waste area. A snow cover of 2 to 3 inches in the flood area will not interfere with flooding, but drifts should be leveled to the 2-to-3-inch depth. Barring abnormal weather, total snow fall at McMurdo will average about 2 inches from the period beginning with the first formation of sea ice and its growth to a thickness from 24 to 30 inches.

5. Dikes. Snow dikes in the early stages of construction should be limited to 18 to 24 inches in height to avoid excessive localized dead weight, which can cause downwarping in the surrounding ice sheet and result in excessive depth accumulation of flood water or seepage of the sea water from below. Experience from previous wharf construction has indicated that the base of the snow dike should be 4 to 6 feet wide. The dike requires compaction by walking the surface with a tracked vehicle to minimize water seepage. An alternative diking method that may be either specified in the design or initiated in the field as a solution to a special problem would be to construct a fence of fabric material (cheesecloth-like) supported by posts set at about 10-foot intervals. The fabric is spray-coated to form an ice jacket about 3/8-inch thick. Another reportedly successful technique is that of letting the wick action of the cloth form the ice barrier ahead of the flood depth.

6. Gages. The ice thickness measuring gages are installed at the locations specified in the design plan. The premarked poles (marked at 6-inch intervals) are needed to keep a record of ice buildup as the flooding operation proceeds.

7. Pumps. The flooding pumps are set as specified in the design plan. If electric motor-driven submersible pumps are used, they most likely will be set within the flood zone. Two 1,500-gpm submersible pumps, weighing about 1,000 pounds each, were used to construct the DF-76 ice wharf. The pump was configured as a 19-inch constant diameter tube set in a hole drilled through the ice and permitted to freeze in place. Seven to eight feet of the tube projects above the surface to permit several feet of flood ice buildup before the electrical heating system of the unit is energized to melt the tube free for setting it at a higher elevation for continuation of the flooding operation. The pumps were a high-volume, low-head (13-foot) design and were driven by a 7-1/2-hp electric motor requiring 240-volt line service (Figure 8-10). The DF-76 pumps were spaced 350 feet apart with the intent that an average flood radius of 200 feet would be produced by each pump. The 20% flood area overlap between the pumps followed the recommended placement for multiple-pump installations based on previous experience.

Both an air pressure system and electrical heating system were a part of the pump design to prevent freeze-up during periods of non-operation. The pumps were fitted to discharge the water in three modes: vertically upward, through a 90-degree swivel elbow attachment, and with a 25-foot length of 6-inch diameter hose added to the elbow. The hose addition severely reduces the flow and is not recom-

mended for general use. Low-head pumps are the most efficient for flooding operations but cannot be coupled to lengthy water distribution lines.

At the time of pump installations area lighting should be adjusted for best illumination to observe the water spread during flooding operation. Six 400-watt mercury vapor lamps provided excellent lighting of the area during DF-76 wharf construction (Figure 8-11). The small floodlights provided with the equipment were found to be totally inadequate for almost all phases of the construction.

8. Flooding. Flooding proceeds as a series of outward spreading circles (Figure 8-12). Each successive flood extends the radius of the freezing front, until it is stopped by a perimeter dike. Because of ice-sheet deflection and surface roughness, a uniform water depth is seldom achieved over a large area. The flood depth will generally be greatest near the pumps and decrease gradually toward the leading edge of the spread pattern. A particular flooding operation should be discontinued once it becomes impossible to encourage the outward spread of the water and the water depth continues to increase beyond the desirable 4-inch depth in localized spots. As a practical guide, the maximum desirable flood depth corresponds to that distance from the ice surface to the top of the white rubber thermal boots that the construction team will likely be wearing. Since the flow of water over the ice is primarily a function of natural forces, the velocity of the leading edge decreases until it stops when a barrier of ice is formed. The backed-up water increases the hydraulic pressure, causing random breakdown of the barrier and further outward flow; once this natural phenomenon stops, crew action is necessary to continue the spread. Foot traffic can be applied to break down the ice barrier; or, as found in DF-76 wharf construction, a hand-pushed squeegee offers moderate success as does wave action created by trafficking a large rubber-tired vehicle in the flood zone. This equipment was also found useful in breaking the ice crust over large air bubbles that frequently form during freezing of the flood. Bubbles have to be broken up before applying new flood to obtain maximum ice strength. As the ice sheet thickens from the flooding operation and deflection decreases, a greater surface area can be covered with each flood application. It was reported in the DF-76 work that noticeable ice deflection occurred until 5 feet of thickness had been achieved. It was also found that spot flooding creates ridges and is not recommended as a technique for increasing area coverage.

9. Tidal Cracks. Working cracks form in the ice cover near the shore due to tidal action. These cracks or any other cracks within the flood area can be a problem if they permit drainage of flood water. It has generally been found that the drainage can be stopped by packing the crack with snow; however, some other field innovation, such as covering the crack with a strip of impermeable plastic material, may be necessary

to solve the problem. No problems with water loss through the tidal cracks were observed during construction of the DF-76 wharf. They appeared either to be naturally sealed at the bottom which prevented drainage or, in some cases, only to penetrate part way through the ice sheet.

10. Wharf Reinforcement. Only general comments on the technique for reinforcing the ice are appropriate since each wharf design concept will specify the requirement. The ice mass can be reinforced in either of two ways: either totally reinforced to resist formation of fracture cracks (which is generally economically unrealistic) or patterned after the DF-76 design concept which provided a string-together capability for prevention of segment separation should fracture cracks develop. The string-together concept assumes the fractured sections will be held together in close contact, thus maintaining the wharf in usable condition with the probability that the cracks will reheal to reform a solid ice block.

The DF-76 ice wharf was reinforced only in the central cone, an area approximately 200 by 500 feet, using 12,000 feet of 1-1/2-inch-diameter steel cable. The design specified placing two layers of cable at approximately the midpoint of the final planned thickness. The procedure follows:

(a) Sturdy posts, cut from telephone pole stock and approximately 4 feet long, were set on the ice surface in the specified pattern when the wharf thickness was about 9 feet.

(b) Flooding was resumed until an additional foot of ice was formed to fix the position of the posts (eliminating the need for drilling holes for the posts).

(c) Reinforcement cable was woven around the post in seven closed loops, with only enough tensioning to straighten kinks.

(d) After producing an additional foot of flood ice a second layer of reinforcement cable configured the same as the first was placed.

(e) Flooding was resumed to complete the final thickness.

This type of wharf reinforcement provides a good disposal site for old discarded cable free of severe kinks.

Wharf Completion

Considerable construction effort remains to make the ice wharf operationally ready to receive ship traffic after completing the flooding operation and removal of the equipment from the area.

Roads and Bridges. A ramp/road system of dirt fill to handle heavy cargo traffic during ship offloading and onloading is placed to protect the ice from the shore to the wharf proper. For the most efficient cargo movement, separate entry and exit transition ramps are desirable. The transition ramps almost always include installing free-span bridges over certain areas of ice in the tidal crack zone. These areas are too poor in quality, as well as too thin in depth, to

support vehicle loads. The bridge requirements for the DF-76 ice wharf transition ramps consisted of a 75-foot span for the main traffic route and two 25-foot spans for the second point of entry. Intermediate sound ice permitted use of the two short span bridges. A bridge width of 15 feet is considered minimum for safe cargo movement. For the McMurdo ice wharf the bridges were field-fabricated, using heavy steel WF, I-beam girders set directly on the dirt fill. The dirt fill approaches to the bridge were protected with an overlay of steel grating. Having prefabricated bridges available, such as the Bailey type, would greatly reduce the transition ramp construction effort; however, matching available bridges with span requirement may cause other construction problems. The bridge construction should allow at least 4 feet of footing at each end.

For the DF-79 ice wharf operation a 4 x 10 (28 x 60-foot) section of pontoon causeway was successfully used to replace the 75-foot free-span bridge that had collapsed during the previous off-season. The causeway was set to bear on the ice within the tidal zone (which departs from past practice of bridging over this area of generally thinner and lower strength ice). Although the pontoon causeway would float if the supporting ice failed, adapting this as the standard practice for providing road access to the ice wharf should be viewed with caution since severe displacement of the road surface could occur if the ice failed when a heavily ladened vehicle was on the causeway.

Bollard. Bollard placement for ship mooring and anchoring the floating ice wharf to the shore should be scheduled at least 2 weeks prior to required use to assure reliable holding strength. The bollards can be of heavy timber or steel. If a choice is available, wood bollards are preferred because of less heat transfer into the ice. Holes for the bollards can be easily drilled with the equipment described in Chapter 10. The large diameter auger bits work well in plain ice but when the wharf surface has more than just a few inches of frozen dirt cover the tungsten carbide-chip-coated tub bit should be used. Holes 5 to 6 feet deep are generally adequate for bollard placement. Once the hole has been drilled it will soon start to fill with concentrated brine seeping from the surrounding ice. It is very important to set the bollard in a dry hole since the high brine concentrate will not freeze. If hole drilling and bollard placement can be coordinated, it is easiest to immediately fill the hole with freshwater, set the bollard, and add the backfill of fine earth or gravel to obtain a saturated slurry before seepage occurs. If bollard placement is delayed the holes will have to be pumped just prior to setting. The best adhesional bond between bollard and slurry is generally achieved when the earth backfill is saturated with freshwater at about 35°F temperature. Seawater can be used but there is an accompanying loss of bonding strength and a longer period required for freeze-back. In placing the backfill, care is necessary to insure that the space around the bollard is uni-

formly filled with the earth-water slurry. The cable tie-off between bollard and the shore anchor point for restricting wharf movement can be laid on the ice surface and, in some cases, covered with earth fill, which eliminates interference with vehicle traffic.

Earth Fill. An overlay of earth fill is placed on the wharf surface to protect the ice from damage by vehicle traffic and thaw during periods of warm weather. The best time to have the fill in place is before the face trimming of the wharf is started. By extending the fill a little beyond the planned trim line the earth will extend at a uniform depth to the very edge of the wharf. Because of the volume of fill material that would be required to surface the entire area produced by the flooding, the earth overlay is generally limited to that area where ships will actually dock and conduct cargo transfer. The work area for the DF-76 wharf utilized only about two-thirds of the total flooded area. The area not protected by the earth overlay nevertheless is important to the overall stability of the wharf and should receive attention directed at minimizing deterioration. Because of loss of wharf freeboard from the weight of the earth overlay, it is recommended that it be limited to a maximum depth of 12 inches (earth overlay on the DF-76 ice wharf was 6 to 8 inches thick). Grading and compacting the fill are necessary to produce a satisfactory work surface.

Trimming Wharf Face. Trimming the seaward face of the ice wharf is required annually to prepare the wharf for receiving the resupply ships. A reasonably vertical face to moor the ships against is required both for safe operation and because of cargo boom length limitation. Removing the unwanted ice from the wharf face is done in conjunction with the ice breaker operation of clearing a shipping lane through the annual sea ice. To minimize damage to the ice wharf, close coordination between the trimming effort and icebreaker operation is necessary.

Shaping the wharf face for the first time after new construction is more difficult than it is likely to be in successive years of operating the wharf. In the first shaping operation, the annual sea ice to be sheared away in front of the wharf is thicker than normal and must also be trimmed back into the wharf proper to remove the snow dike area and any construction misalignments. The thicker-than-normal ice formation attached to the front of the wharf is the result of a downwarp condition produced in the natural ice sheet by the added weight of the construction ice to the wharf. This area eventually becomes depressed below sea level and is subsequently flooded by upward movement of seawater through cracks. The ice formation in this region is a conglomerate of naturally formed sea ice, ice formed from flood water, and ice formed from water-saturated snow.

The DF-73 ice wharf was fractured at several locations when the ice breaker tried to cleave off this section of ice from the wharf. Blasting techniques were employed for opening the DF-76 constructed wharf to avoid the type of catastrophe encountered with the DF-73 wharf. Since this was only the

second attempt to use explosives for this purpose, the trimming effort proceeded slowly, involving considerable experimentation with various types of explosive charges and patterns of charge placement.

The basic procedure followed was to shear away the frontal ice by creating a series of fracture cracks running parallel to the planned wharf face. The first line of explosive charges was set approximately 20 feet out from the wharf face. The pattern for the successive inward lines of explosive charges were determined by the results of the preceding firing. A wait of several hours was sometimes necessary for the crack pattern to develop to the point that it could be defined. Particular attention was given to diverting the direction of cracks that appeared to be heading into the wharf proper. Charges were set in 3-1/2-inch-diameter holes drilled to a depth of about 6 feet. The hole spacing was 3 feet with some lines having as many as 45 holes. Reference 7 gives greater detail on the operation.

The general conclusions from this effort of trimming the wharf face by using explosives were:

1. Slow-firing explosives (e.g., 60% gelatin dynamite which has a speed of 15,000 ft/sec) produced the best results for initiating and controlling crack development. They produce less shatter ice than explosives with higher firing speeds; however, they need to be contained so that the energy will not be released or vented to the atmosphere.

2. Gelatin stick dynamite 2-1/2 x 24 x 2 inches in size produces superior results over 1-1/2 x 8 x 1/2-inch sticks.

3. Best results are produced when holes are loaded with the heaviest charge at the bottom.

4. Composition UDTMK-133 Demo-pack, which has a firing rate of about 26,000 ft/sec, is useful for pulverizing ice and for applications where venting to the atmosphere cannot be prevented.

5. Plastic-covered detonation cord is more flexible and easier to handle at low temperatures than fabric-covered cord.

6. The gelatin dynamite used for the DF-76 effort did not appear to have lost an appreciable amount of potency although it had gone through several freeze/thaw cycles during storage.

7. The gelatin dynamite, as expected, gave the handlers severe headaches due to nitroglycerin absorption through the skin.

The how-to technique developed for the annual ice wharf face trimming in the years following the initial opening of the DF-76 wharf has proved both successful and considerably simpler than the initial opening. A recount of the DF-78 trimming indicates that the explosive charge produced a straight vertical shear. With the charge line set back about 15 feet from the previous year's face, the detonation produced a 2 to 3-foot immediate horizontal heave. Only minor dirt and ice fly occurred, and the crack

was contained within 1 foot of the end charges. All unwanted ice and debris had separated and moved away from the wharf face for easy clearing by the icebreaker within 6 hours after charge detonation. It should be noted that to provide room for the unwanted ice to separate from the wharf, the face trimming charge should not be detonated before the icebreaker has relieved the pressure of the annual ice against the wharf face. Otherwise, a freeze-back of the shear crack can occur.

The procedure for the DF-78 and -79 trimming operation follows:

1. A rock drill was used to drill a single line of 4-inch-diameter 12-foot-deep holes on 3 to 4-foot centers.

2. Each hole was loaded with a uniform charge of 1,600 gr/in. by looping and tying 48 feet of 400 gr/in. plastic-covered detonation cord to a 12-foot length of bamboo pole. The loop configuration provided for both ends of the cord to be exposed above the wharf surface.

3. The bamboo pole with the attached charge was inserted its full 12-foot length soon after drilling to avoid freeze-back problems.

4. The string of charged holes was detonated simultaneously, using standard chemical primacord and fuse caps (Figure 8-13).

WHARF MAINTENANCE

Routine observations and maintenance to correct conditions that accelerate erosion and deterioration of the wharf are necessary to prolong the service life. If left unattended, natural and man-created destructive forces can consume several years of service life in a single season.

Protection of Wharf Face

Experience has shown that erosion of the wharf face can be kept within acceptable limits if: (1) a protective curtain of sufficient size is installed to divert the ship's liquid discharge away from the wharf, and (2) the ship's engineering officer exercises maximum control over the ship's systems to minimize coolant and waste water discharge from the berthed side of the ship. The protective curtain should be in place before the ship docks, and the engineering officer should be prepared to make the earliest possible adjustments to the ship's systems. The engineering officer should be informed of the problem well in advance of ship arrival to plan for maintaining the ship's systems and yet satisfying the ice wharf requirement. For example, the cargo ship USNS OTIS BLAND that docks at the ice wharf has a normal coolant water discharge of 12,000 gpm from the main plant but is reduced to 8,000 gpm upon docking. However, by diversion of the load to the starboard auxiliary plant, the discharge can be reduced to 2,200 gpm within 4 hours and to 800 gpm or less thereafter. By following this procedure the volume of coolant water discharged against the wharf is approximately one-tenth that of normal operation.

Since the wharf face curtain has to be installed and retrieved

annually, the design should be: (1) lightweight for easy handling, (2) tough for wear and abrasion resistance, (3) rigid for position holding, and (4) large enough for full screening of the wharf from the ship discharge. In current use with the DF-76 wharf is a field-fabricated, 50 x 12-foot curtain. The 12-foot dimension projects down when installed. It was fabricated by bolting together sections of fiberglass road-surfacing material known as Mo-Mat. This is an Advanced Base Function Component System item approximately 1/8-inch thick with a waffle-surface pattern.

To further reduce wharf face erosion, a metal deflector shield should be suspended between the wharf curtain and the ship at port locations where low-volume high-temperature water is discharged. The current recommended design is an 8-foot x 8-foot x 1/2-inch-thick steel plate stiffened with timber struts, which also fender both the ship and the wharf curtain from scuffing by the plate. The deflector has to be positioned accurately to insure that the hot discharge does not flow against the wharf face. In some cases, a larger-sized or more than one deflector plate may be required (Figure 8-14).

Meltwater Control

The greatest problem with the wharf surface is controlling meltwater drainage. Meltwater cannot be permitted to pond on the surface nor can it be permitted to flow over the surface. Both result in formation of sump holes and erosion channels. The winter snow accumulation should be removed before the icebreakers arrive to clear the shipping channel. All previous season drainage ditches should be inspected and maintained to capture surrounding terrain run-off water. During the melt season quick action must be taken if the drainage system is incapable of handling the meltwater flow and it begins flowing onto the wharf proper or onto surrounding ice that provides wharf longevity.

Bridges and Bollards

Bridge footings can pose unexpected problems because of the constant movement in the relative position between the wharf and shore terrain, resulting from tidal action. Bridge footings should be thoroughly inspected before cargo operations start and throughout the operation.

Likewise, all bollards and surface cables should be inspected and replaced as necessary before the wharf is opened to cargo operation.

The operating and maintenance crews of an ice wharf should always be acutely aware that their effort to maintain the useful life of the wharf is small when compared to that expended during construction.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision to the basic material in the chapter.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Note N-933: McMurdo ice wharf - Surface and subsurface observations during DF-67, by R. A. Paige. Port Hueneme, Calif., Oct 1967.

2. _____. Technical Note N-1030: McMurdo ice wharf - Physical characteristics and criteria for protection, by R. A. Paige. Port Hueneme, Calif., Apr 1969.

3. _____. Technical Report R-466: Seasonal damage to the McMurdo ice wharf during DF-66, by R. A. Paige. Port Hueneme, Calif., Aug 1966.

4. _____. Technical Report R-511: Ice construction - Methods of surface flooding, by C. R. Hoffman. Port Hueneme, Calif., Jan 1967.

5. _____. Special Report 61-76-9: Design and construction guide for a surface-flooded ice wharf - McMurdo Station, Antarctica, by J. L. Barthelemy. Port Hueneme, Calif.

6. _____. Technical Memorandum M-64-76-2: Pumping equipment for McMurdo ice wharf construction - McMurdo Station, Antarctica, by C. R. Hoffman. Port Hueneme, Calif., Jan 1976.

7. Naval Support Force Antarctic. Special Report: Artificial ice wharf: Construction and operation, by Lt. K. K. Ball, Engr. Officer NSFA. Nov 1978.

Figure 8-1. Ships docked at natural ice wharf in Winter Quarters Bay (January 1966).

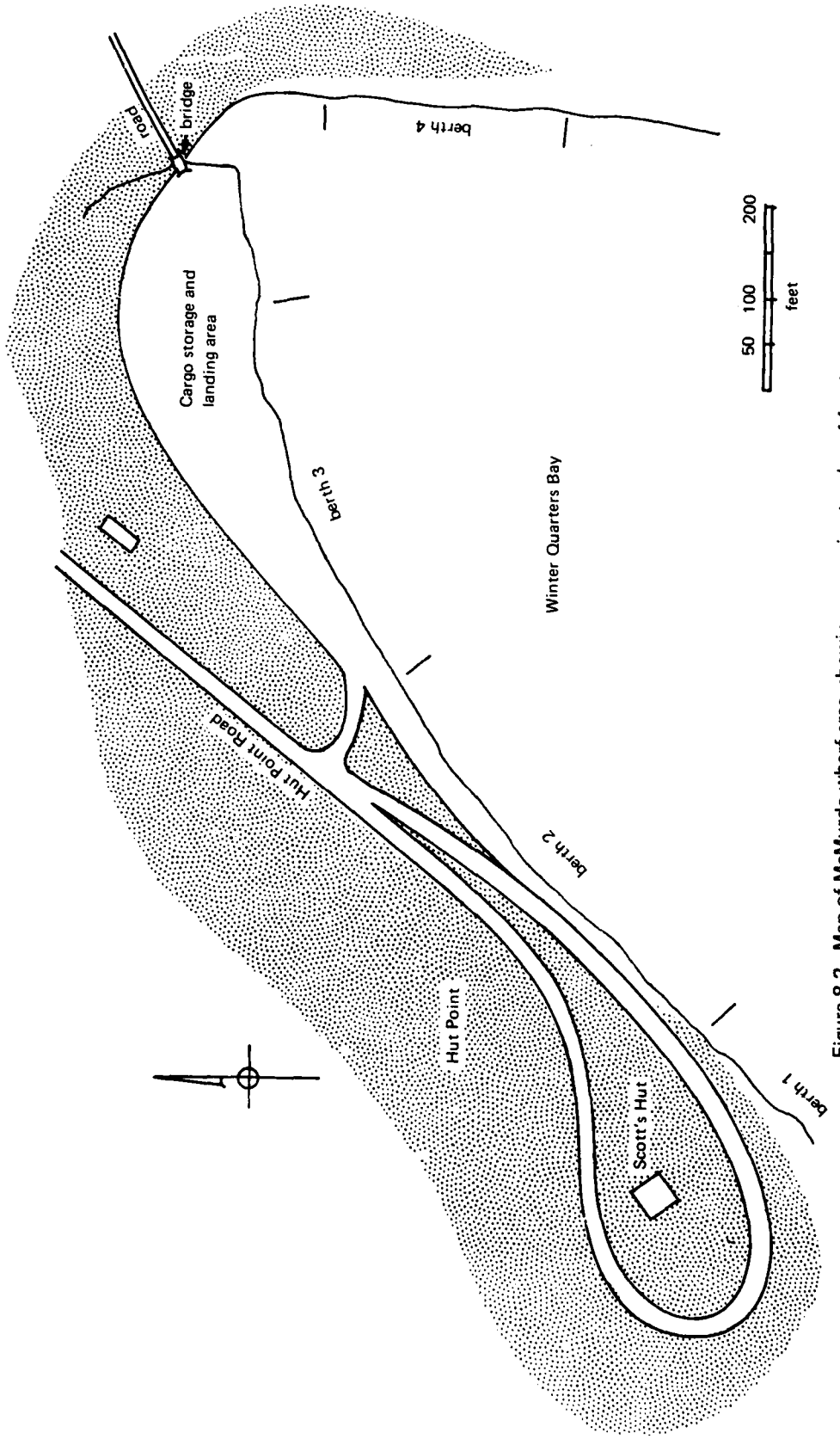


Figure 8-2. Map of McMurdo wharf area, showing approximate edge of fast ice.

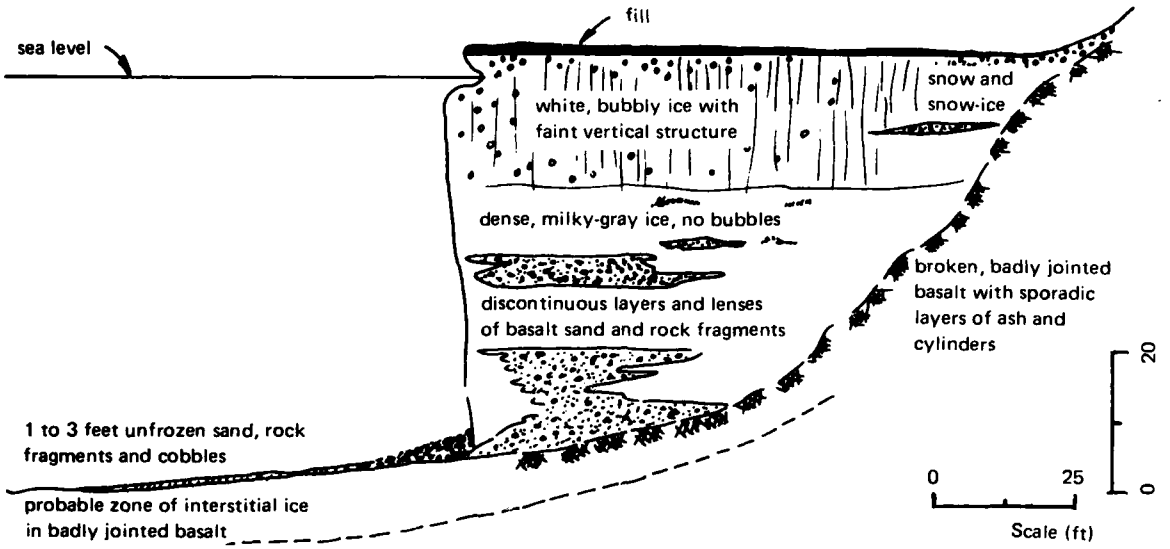


Figure 8-3. Diagrammatic cross section of the McMurdo natural ice wharf in berth 3. See Figure 8-1 for location.

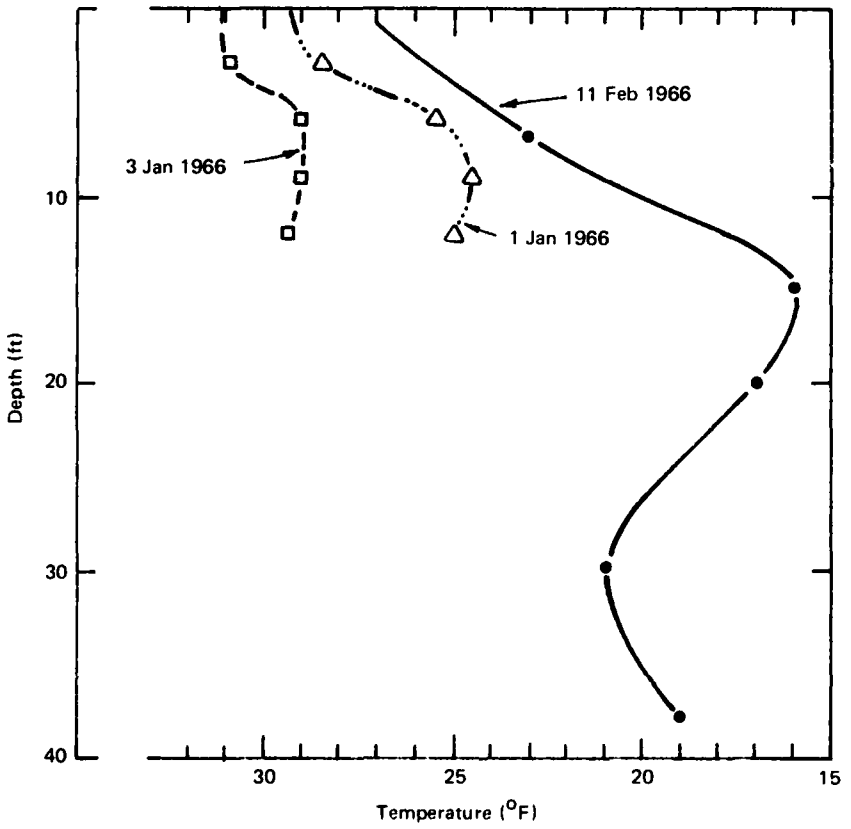


Figure 8-4. Temperature profiles of the fast ice in the McMurdo ice wharf.

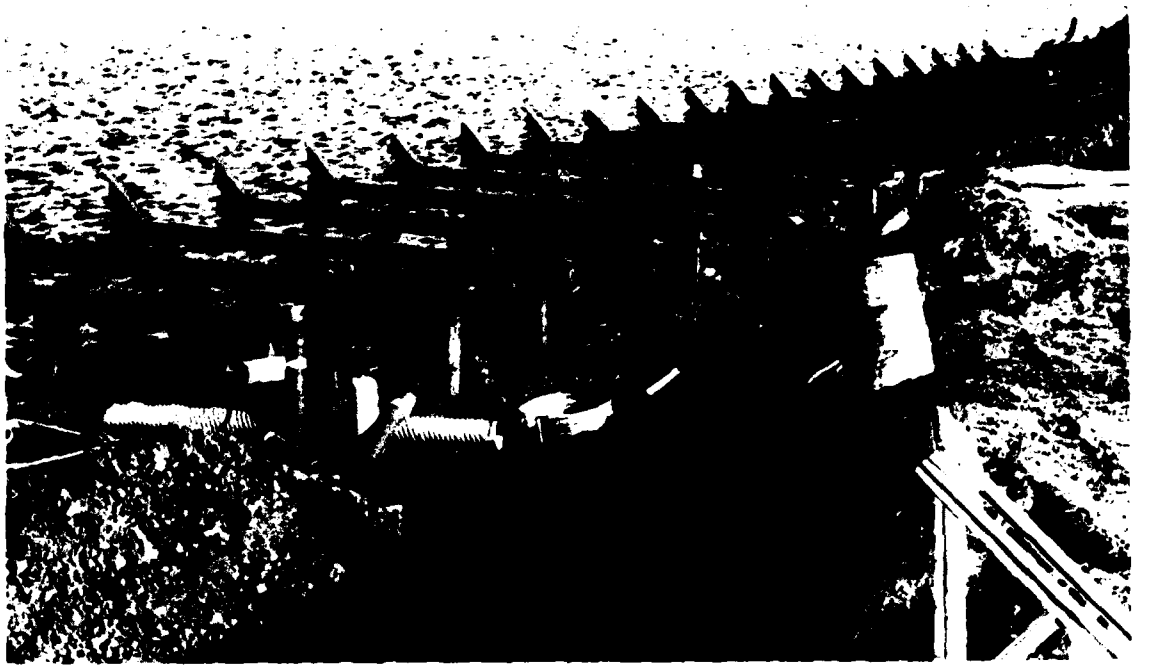
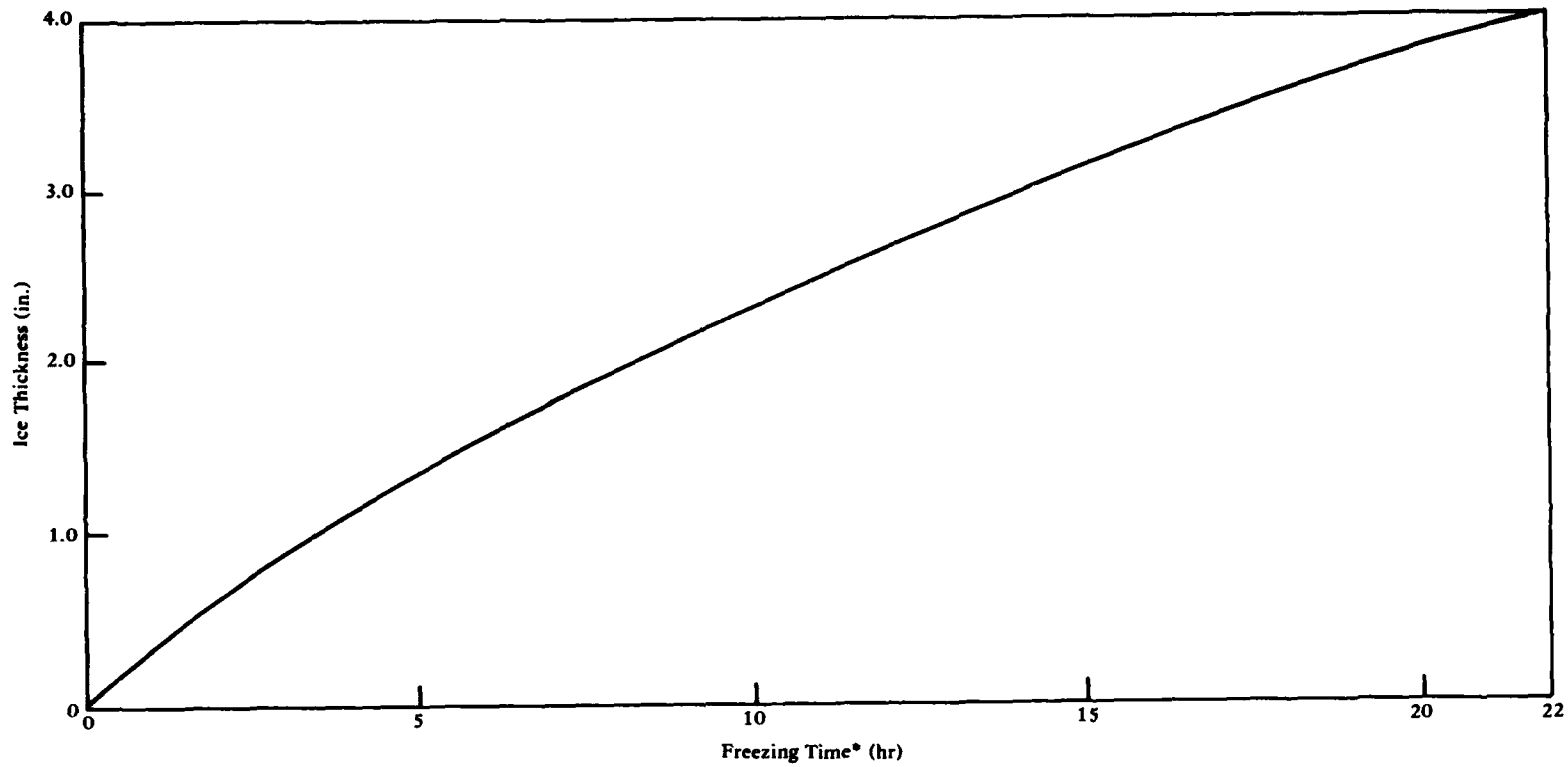


Figure 8-5. Steel structure for supporting protective face on ice wharf.

Figure 8-6. Protective face of steel and timber in place on ice wharf.

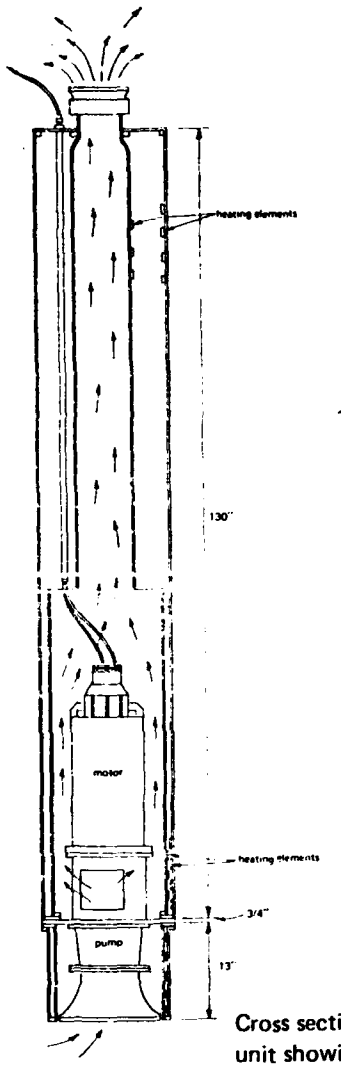
Figure 8-7. Cargo ship unloading at the artificial ice wharf constructed by DF-73 winter-over personnel.

Figure 8-8. Artificial ice wharf constructed by DF-76 winter-over personnel. Although the flood construction extended to the shore in foreground, the area selected for berthing ships and cargo handling is indicated by dirt fill.

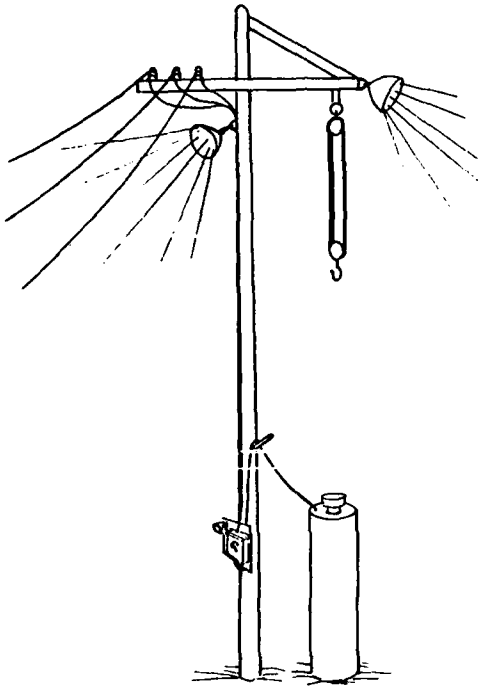


*Based on average winter weather conditions.

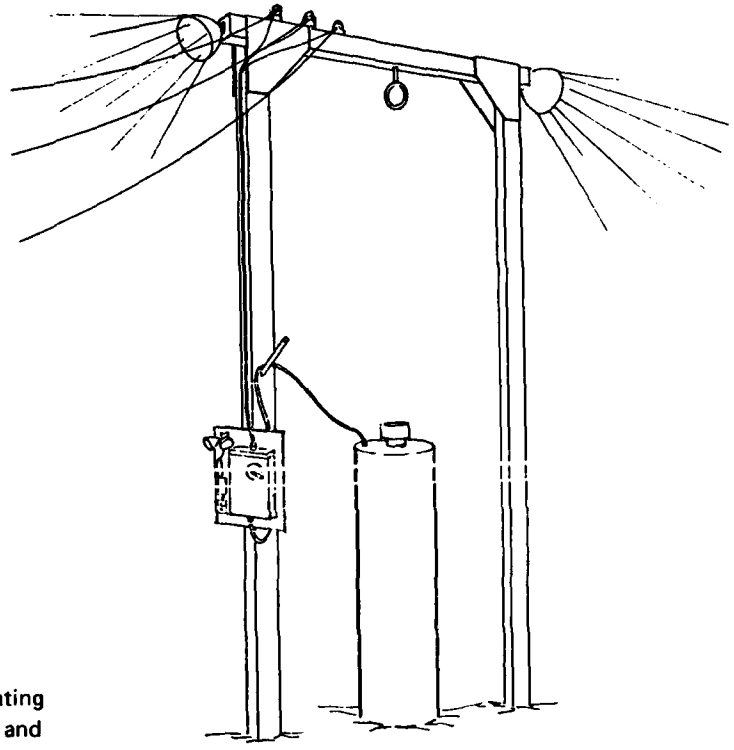
Figure 8-9. Flood depth as a function of freezing time for ice-wharf construction in Winter Quarters Bay.



Cross section of pump unit showing arrangement of parts and water flow.



Method of installing and operating pump unit, using 30-foot pole and crossarm.



Method of installing and operating pump unit, using timber frame. Limited length of timbers will require frame replacement as ice builds up around legs.

Figure 8-10. CEL-developed DF-76 electric submersible pump and methods of installation.

Figure 8-11. Typical illumination of work area during construction of DF-76 ice wharf.

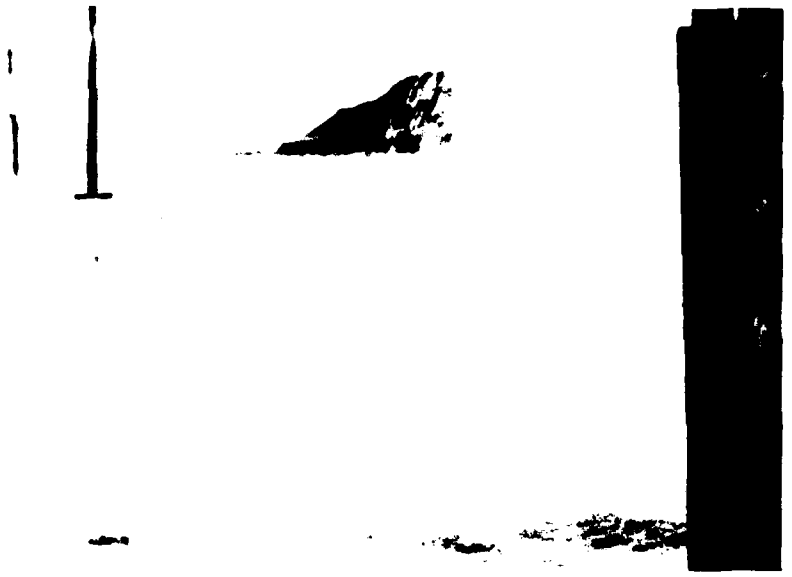


Figure 8-12. Specially designed tube-type 1,500-gpm electrically driven submersible pumps used for DF-76 wharf construction in operation. (Two pumps were set 350 feet apart.)

Figure 8-13. DF-78 wharf face trimming operation at instant of charge detonation.

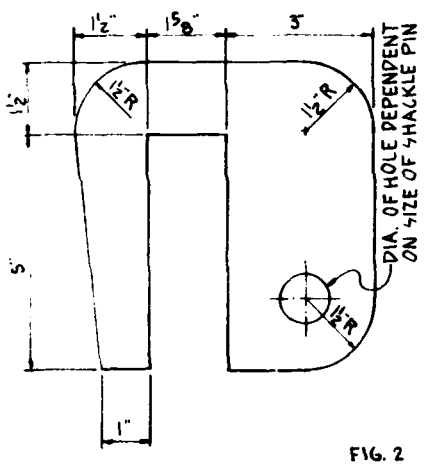


FIG. 2

CUT FROM ½" STEEL PLATE
(2 EACH REQUIRED)

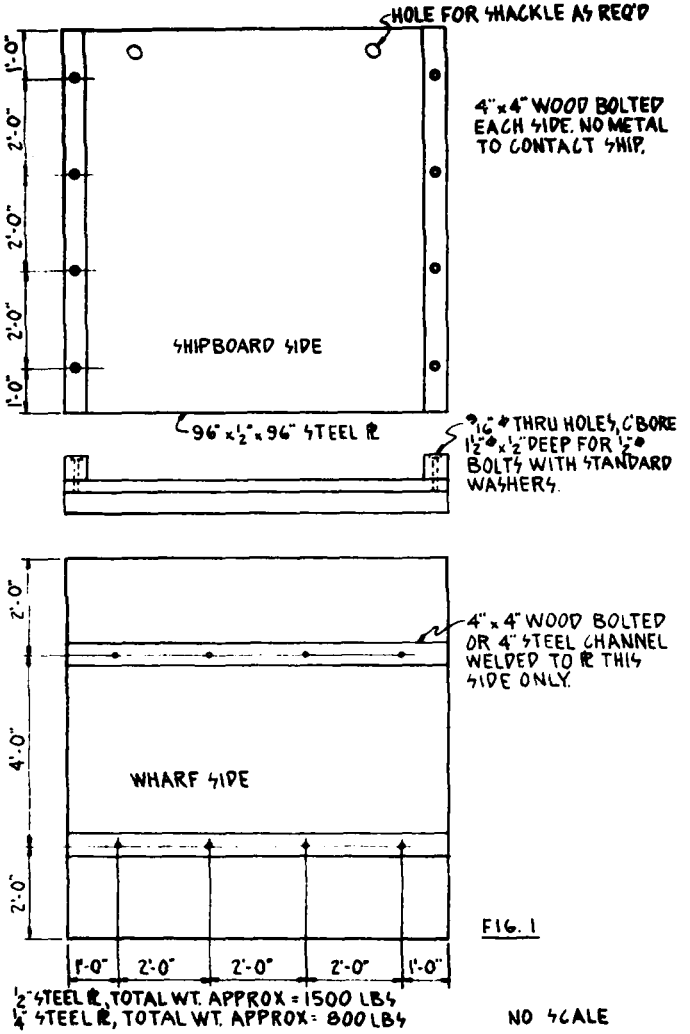


FIG. 1

½" STEEL PL, TOTAL WT. APPROX = 1500 LBS
¼ STEEL PL, TOTAL WT. APPROX = 800 LBS

NO SCALE

Figure 8-14. Typical design for field fabricated ship discharge deflector shield.

LIST OF APPENDIXES

Chapter 8

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

8 A. **Civil Engineering Laboratory. Technical Note N-1416: Sea-ice techniques for Winter Quarters Bay, Antarctica, by F. W. Brier and K. D. Vaudrey, Dec 1975.**

8 B.

8 C.

8 D.

8-E.

8-F.

8-G.

8-H.

8-I.

8-J.

Addition – 1979

APPENDIX 8-A

Technical Note N-1416

SEA-ICE REMOVAL TECHNIQUES FOR WINTER QUARTERS BAY, ANTARCTICA

By

F. W. Brier and K. D. Vaudrey

December 1975

Sponsored by

NAVAL SUPPORT FORCE, ANTARCTICA

Approved for public; distribution unlimited.

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

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INTRODUCTION

Docks and harbors in polar regions are difficult to construct and maintain because of ice conditions during much of the year [1]. Prior to Deep Freeze 64 (DF-64),[a] ships supplying McMurdo Station, Antarctica, offloaded all cargo onto the annual sea ice in McMurdo Sound (Figure 1) several miles from the station. The offloading and transportation of cargo from the ships to McMurdo Station were a dangerous and time-consuming operation. In DF-64 an area of fast ice along the north shore of Winter Quarters Bay near McMurdo Station was used effectively as a wharf for ship unloading. Cargo ships were able to offload directly onto trucks and trailers for the short haul to McMurdo cargo yards.

Surface erosion and undercutting of the vertical face by wave action contributed to a gradual deterioration of the natural ice wharf. In 1969, it was estimated that each year 10,000 square feet of surface area was lost to wave action [1]. A more serious problem than the loss of cargo-handling area was the reduced water depth along the face of the wharf.

To prevent further damage to the wharf the Naval Facilities Engineering Command (NAVFAC) designed a protective dock face. In a 4-year period ending in DF-72, 464 feet of steel and timber protective dock facing were installed [2]. In March 1972, a major portion of the newly constructed dock facing was destroyed during a storm [3]. High tides and pounding ice ripped away much of the steel and timber facing, leaving the wharf exposed to more erosion. The water depth at the face of the wharf also became more critical because earth fill was washed into the bay.

As a temporary solution to the problem an artificial ice wharf was constructed on the north side of Winter Quarters Bay during the winter of DF-73. The artificial ice wharf, which was constructed by surface flooding, was 29 feet thick, had a 460-foot landward face, and a width of 170 feet (Figure 2).

In January, 1974, the artificial ice wharf cracked at several locations while the icebreaker USCG Staten Island was attemping to cleave annual sea ice from the seaward face. As a remedial measure bollards were used to tie sections of the artificial ice wharf together during cargo offloading operations. Subsequent discussion indicated that an open-water area adjacent to the seaward face would have prevented the damage.

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[a] The Deep Freeze (DF) year begins July and ends in June.

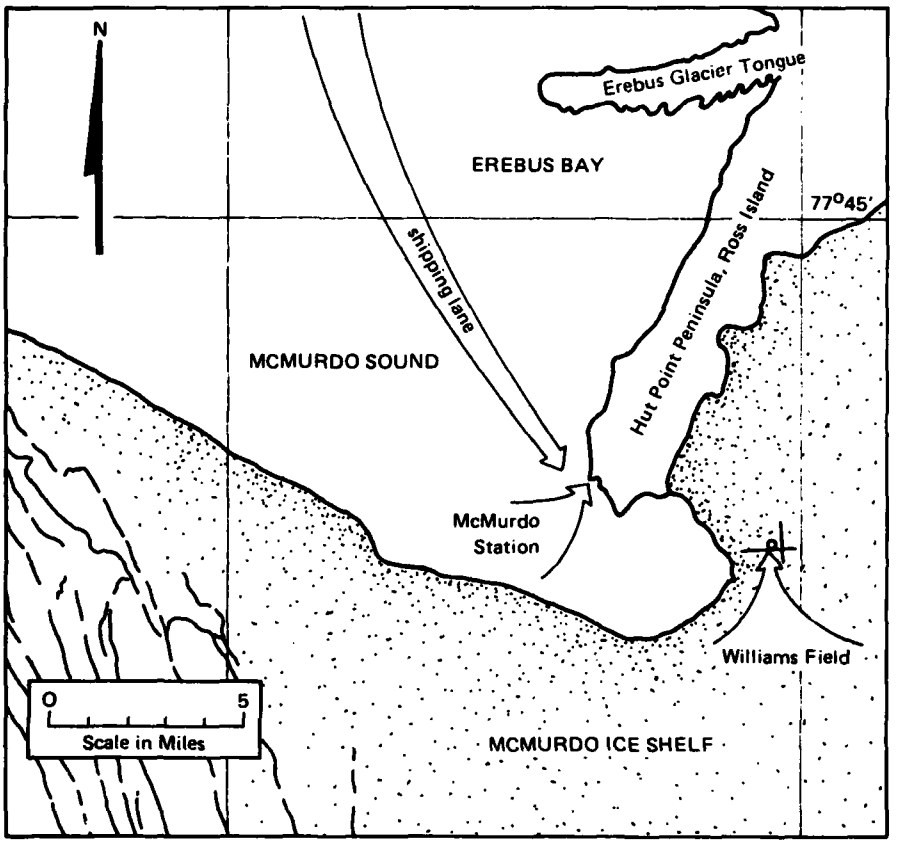


Figure 1. Area map of McMurdo Sound.

Figure 2. Artificial ice wharf during docking of the cargo ship USNS Private John R. Towle, January, 1974.

During June, 1974, the Civil Engineering Laboratory (CEL) conducted laboratory tests on an ice excavation machine for burial of utilities in ice and high-density snow. The machine used in the laboratory tests was a Davis Model TF-700 trencher. The TF-700 is powered by a 30-hp air-cooled engine with mechanical drive to the trencher chain and hydraulic drive to the tracks. The maximum recommended depth for excavating in dirt with normal cutting chain is 72 inches for a 6-inch-wide trench; however, the TF-700 was equipped with a frost chain capable of excavating both ice and frozen earth, but only to a depth of 58 inches for an 8-inch-wide trench. Cutting tests were conducted comparing the commercial tungsten-carbide-tipped teeth with CEL-developed 30-degree conical pointed teeth. The maximum travel speed using the carbide-tipped teeth was 7.5 fpm, compared to 13.9 fpm for the conical teeth when cutting 31 inches of seawater ice.

It was concluded from the laboratory tests that a trenching machine similar to the one tested at CEL could be used to create an open-water area adjacent to the seaward face of the artificial ice wharf. This technical note describes field tests of a trenching machine used for this purpose.

EQUIPMENT DESCRIPTION

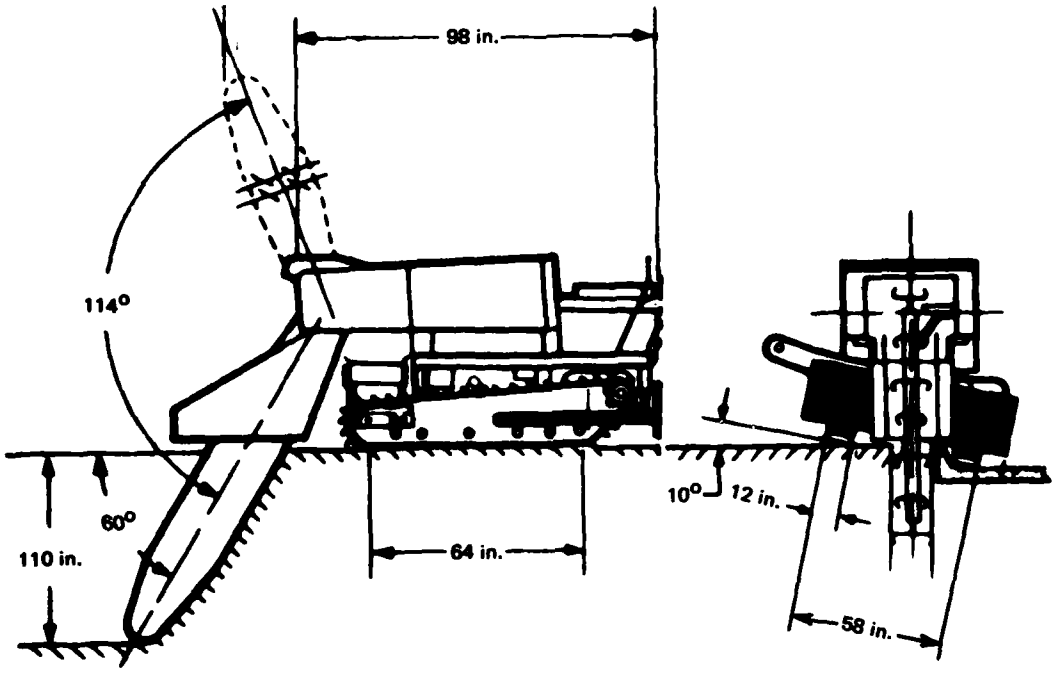
Trenching Machine

A ladder-type Davis Model Task Force-1000 (TF-1000) was procured from Case Power and Equipment for this project. The TF-1000 (Figure 3) is equipped with a 60-hp diesel engine, 86-inch trenching boom, 8-inch frost chain, 10-inch cleat pads, and a roll over protection system. The total cost was $15,612. The TF-1000 weighs about 9,000 pounds and has an overall length of 8 feet 2-3/4 inches without the boom.

The TF-1000 is equipped with a hydra-static drive providing infinitely variable speed control from a two-speed gear transmission. Trenching speeds of 0 to 900 fph are obtainable in low range; transport speeds of 900 to 1,500 fph are obtainable in high range.

Two manually operated hydraulic actuators tilt the entire upper structure of the trencher, including the boom. This allows the machine to cut vertically with tracks resting on slopes up to 20%. The hydraulic power tilt shifts the center of gravity of the machine to maintain stability.

The steering, brakes, clutches, and digging chain are all hydraulically controlled. The digging chain has a hydraulic relief to provide torque limit protection for the driveshaft, cutting teeth, and engine. Dual controls permit operation from either the front or rear of the machine.



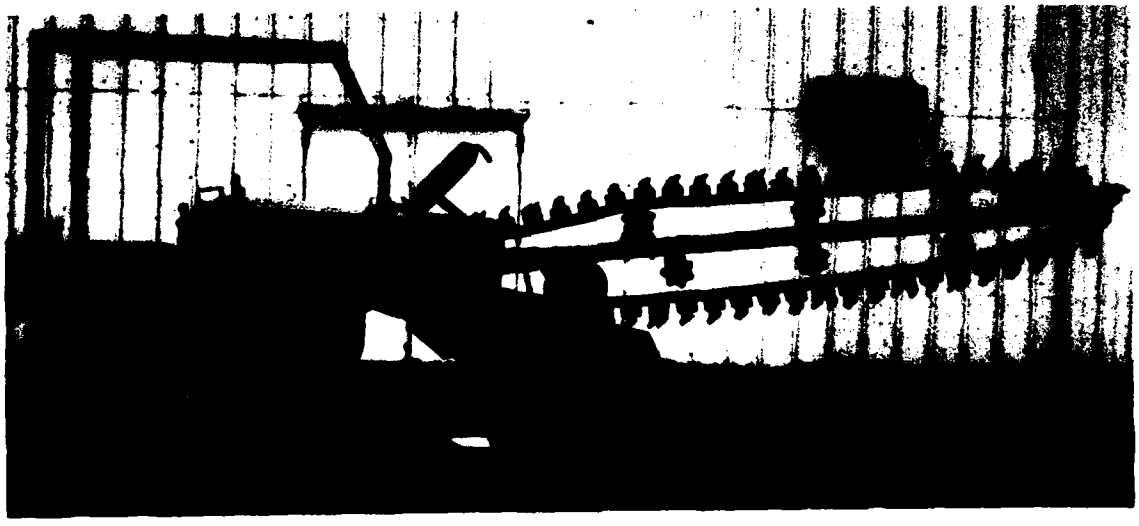


Figure 3. Davis TF-1000 trencher.

Modifications

Two modifications were designed and fabricated for the TF-1000. One was a 2-foot boom extension and the other conical trenching teeth.

Boom Extension. To increase the trenching depth of the TF-1000 to 120 inches a 2-foot boom extension was designed and fabricated. The boom extension consists of a 4-inch-square structural tube with 8-inch-square end plates. The 86-inch boom was cut 42 inches above the end roller, and 1/2-inch plates were welded at the joint to match those on the extension.

Trenching teeth. Various configurations for ice cutting teeth were reviewed for maximum cutting rate and minimum horsepower requirements. It was concluded that teeth with a 30-degree conical point developed by CEL in 1960 for use on an ice dozer were the most suitable configuration. This was confirmed in the laboratory tests of the TF-700. One hundred and fifty conical teeth (Figure 4), which are interchangeable with commercial carbide-tipped teeth, were fabricated for the TF-1000 at a cost of $765.

OPERATIONAL PROCEDURES

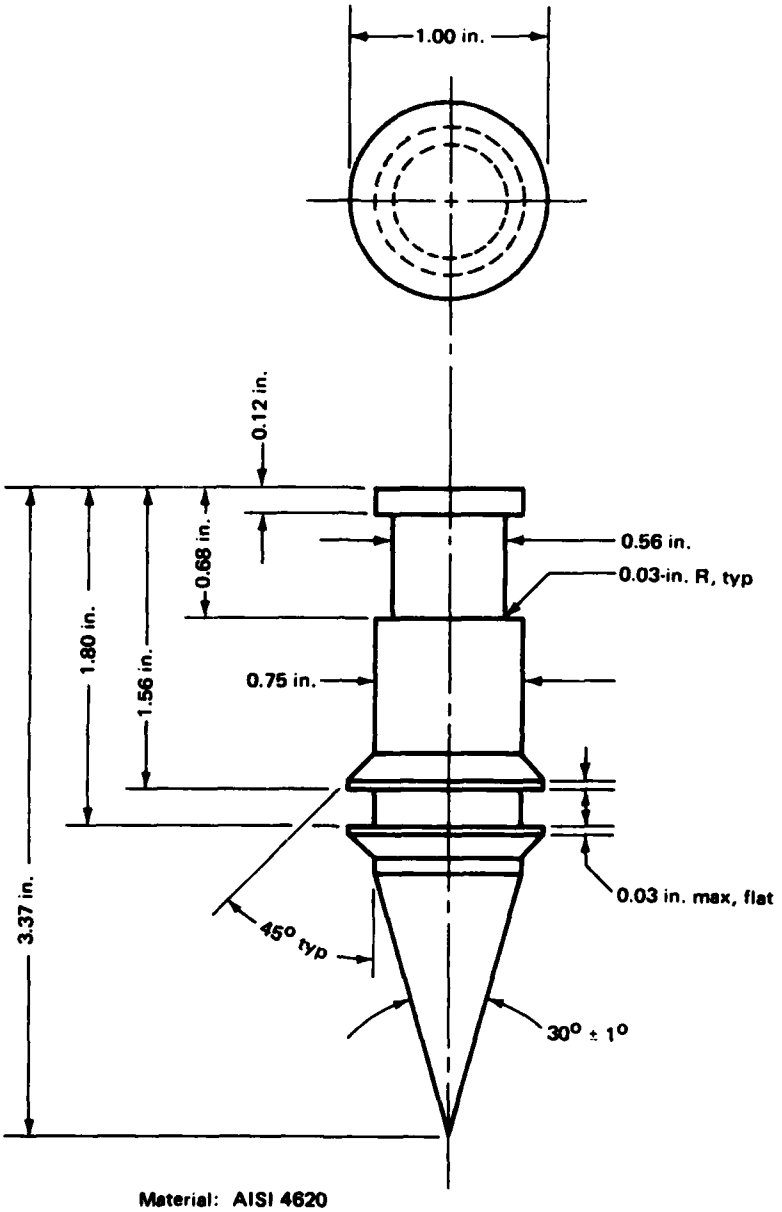
It was planned to utilize the TF-1000 to excavate 8-inch-wide trenches completely through the sea ice in Winter Quarters Bay during December 1974. The ice block formed by the cuts then would be towed out of the bay by an icebreaker. The exact trenching pattern could not be selected until a site investigation had been conducted to determine sea-ice thicknesses, ice-wharf face configuration, and surface conditions.

Site Investigation

On 29 and 30 December 1974 a site investigation was conducted in Winter Quarters Bay to determine the trenching pattern. Sea-ice thicknesses ranged between 68 and 74 inches. Melt ponds up to 24 inches deep existed along the seaward face of the artificial ice wharf and adjacent to the shoreline near Scott's Hut (Figure 5). The sea ice in the remainder of the Bay was covered intermittently with melt ponds 4 to 6 inches deep. It was very difficult for people to walk on the sea ice in the Bay. The surfaces of shallow melt ponds, which had refrozen, collapsed under weight. In addition, several refrozen and wet cracks traversed the Bay.

Trenching Pattern

A trenching pattern to minimize melt-pond interference was marked with bamboo poles (Figure 5). Lines AB and GH terminated at a 6-inch-wide wet crack. Lines AB and GH were intentionally laid out to diverge with DF and EG. This was essential if an icebreaker was to tow the blocks of ice out of the Bay.



Material: AISI 4620
After machining, heat-treat as follows:

1. Carburize 1 hour at 1700°F
2. Oil quench, draw 450°F for 3 hours

Figure 4. Conical ice chipping teeth.

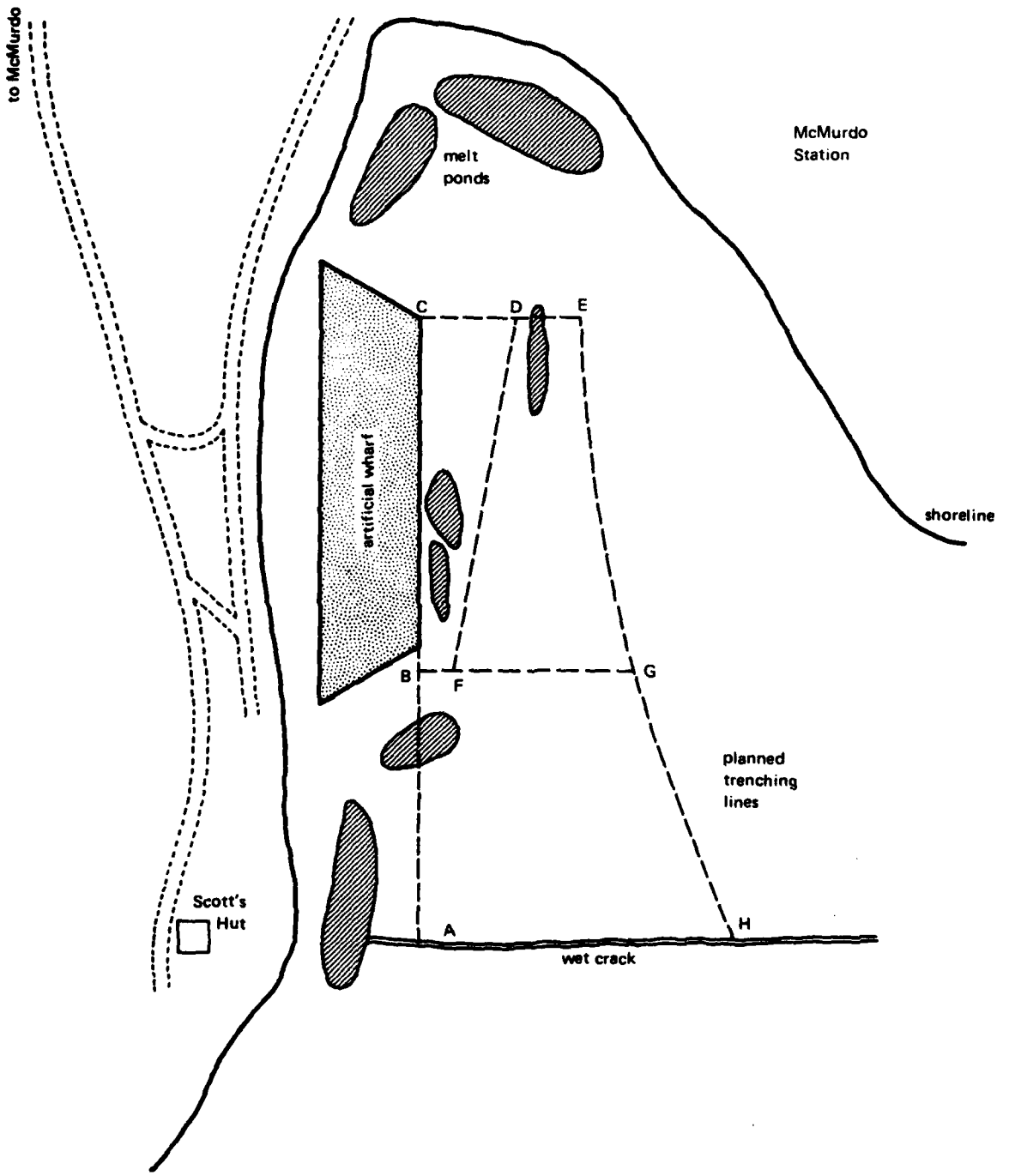


Figure 5. Winter Quarters Bay in December 1974.

Two major obstacles interfered with this trenching pattern. One was a large melt pond, about 2 feet deep and 16 feet wide, which intersected line AB. The second was a 1-1/2-foot-deep by 4-foot-wide melt pond between points D and E; this melt pond was about 30 feet long. Graphic analysis showed that, when equipped with a 2-foot beam extension, the TF-1000 could cut a continuous trench from both sides of a pond 24 feet wide. It was planned to use this procedure at the two locations described above.

Preliminary Trenching Tests

Preliminary trenching tests on the sea ice in Winter Quarters Bay showed that several inches of freeze-back occurred on the top surface of a trench within 6 hours when a cut was made entirely through the ice sheet. Air temperature during the tests was above freezing, but apparently had little affect on the freeze-back rate.

It was observed that a high percentage, more than 80%, of the cuttings was removed from a trench as long as it remained dry; however, once filled with water, approximately 2 feet of ice chips floated in the trench. Ice chips cut by the TF-1000 formed a berm on each side of the trench as it was cut. As the chain moved (cutting the ice), seawater was pumped to the surface; the water then ran back into the trench, carrying ice chips with it. The ice-bath effect of a 2-foot layer of ice chips caused rapid freeze-back.

Several attempts at adjusting the dirt deflector and dirt chute failed to alleviate the ice chip problem.

Another attempt to counter the freeze-back problem utilized partial-depth trenches, 3 to 4 feet deep. Partial-depth trenches were cut in the sea ice, removing most of the ice chips. However, these partial trenches did not remain dry, but soon filled with surface-melt runoff. Although these partial-depth trenches did not refreeze for several days, the final cut was difficult to make because the rough ice surface prohibited tracking with the trencher. Therefore, partially cut trenches were abandoned as a practical method of eliminating the freeze-back problem occurring with fully cut trenches. Other expedient field attempts to circumvent freeze-back, such as dragging heavy anchor chain through the trench, were unsuccessful.

Although the trencher with the standard boom was capable of making 86-inch-deep cuts at a 60-degree angle (Figure 3), it was hoped that a longer boom would aid in removing ice chips from the trench. Therefore, the 2-foot boom extension and 500 pounds of counterweight were added to the trencher. The extended boom made the machine slightly nose-heavy, even with the counter weight. In negotiating several melt ponds, the trencher came close to tipping over on its front end while climbing out of the pond.

Trenching Operation

The trenching operation was initiated on the afternoon of 12 January and completed about 16 hours later, during the early morning hours of 13 January. During this period five trenches (Figure 5) were cut, totaling about 1,800 feet. Trench GH was not cut because of time limitations.

During the trenching operation, lumber was used to support the TF-1000 when cutting through some surface melt ponds. At three locations melt ponds existed in the line of cut that were too deep for the machine to cross. At these locations cuts were made from both sides of the pond to obtain a continuous trench through the ice sheet.

The rough surface of the sea ice made it impossible to maintain a straight cut, even when following a string line (Figure 6). Frequently, the TF-1000 had to be backed up and several feet of trench recut to maintain diverging lines DF and EG.

After trenches AB and BG were completed, the icebreaker USCG Burton Island moved into Winter Quarters Bay and fragmented the sea ice on the seaward side of trench BG (Figure 7). It was observed that trenches AB and BG did in fact serve as crack arresters during icebreaker operations.

After the trenches around the wedge-shaped block (DEGF) were cut, an attempt was made by the icebreaker to tow it away. However, the ship was unable to move it, and it was subsequently fragmented by the icebreaker. At the time towing was attempted, Trench DF had refrozen to a depth of 3 to 6 inches.

Blasting Operation

After the icebreaker had fragmented the sea ice on the seaward side of trench DF, Dr. M. Mellor from the Cold Regions Research and Engineering Laboratory supervised blasting the outboard face of the wharf to obtain a straight, vertical face. Four-inch-diameter holes were drilled through the wharf at 4-foot intervals in a line parallel to and about 10 feet from the edge (Figure 8). A series of controlled explosions fractured the wharf, providing the desired straight vertical face on the line of drill holes. During a test blast for technique development by Dr. Mellor before the icebreakers arrived, the TF-1000 was used to create a stress relief trench, cut in the sea ice parallel to and about 20 feet from the line of test charges.

EQUIPMENT PERFORMANCE

Approximately 24 man-hours were required for assembling the TF-1000 after shipment to McMurdo Station. The boom, chain, counterweights, and roll-over protection system had been removed to facilitate air transport from New Zealand to McMurdo Station. The only difficulty encountered during the assembly was in attaching the frost chain to the boom. The chain was heavy and awkward to handle.

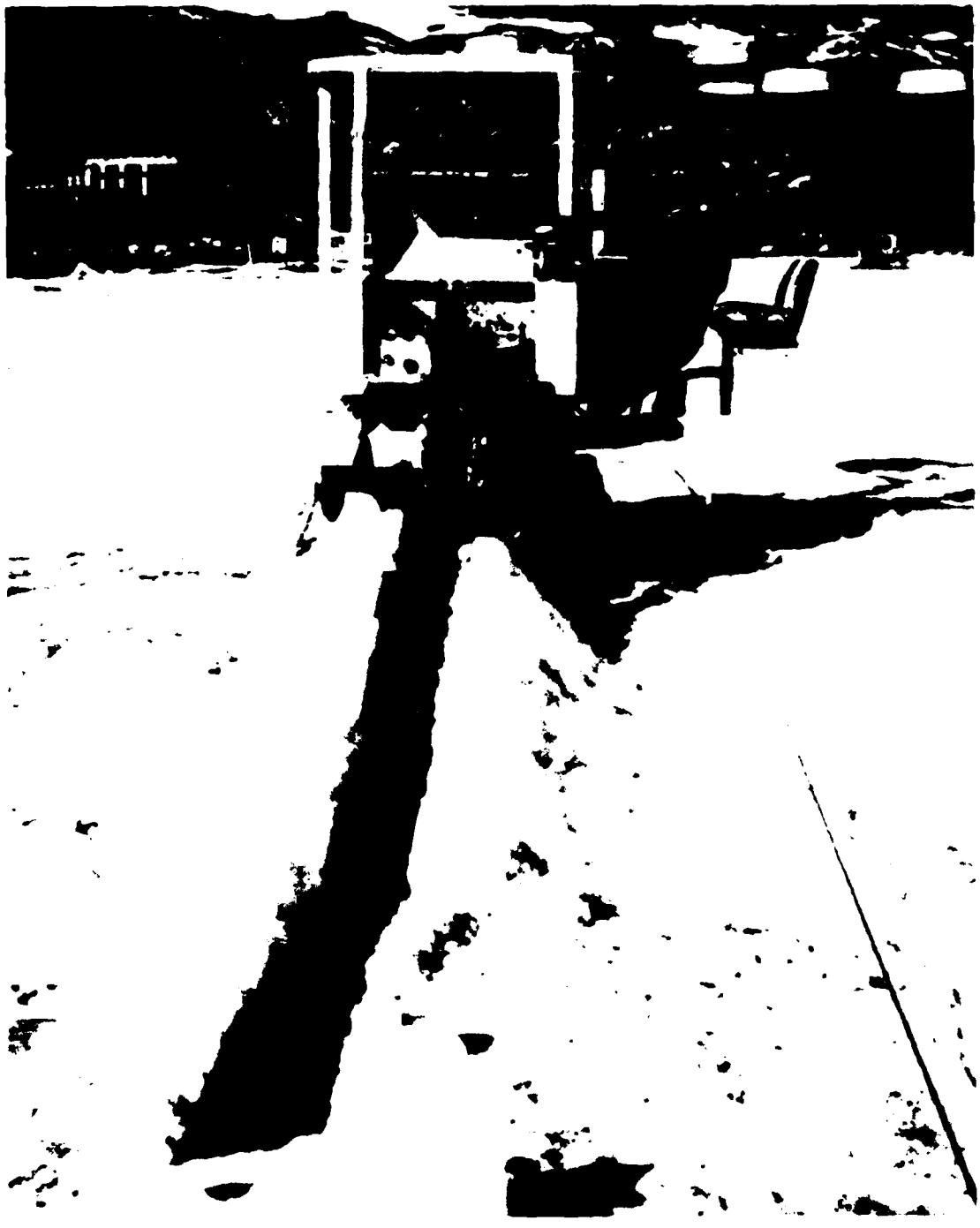


Figure 6. Trencher attempting to follow string line.

Figure 7. TF-1000 trenching in Winter Quarters Bay as icebreaker fragments sea ice.

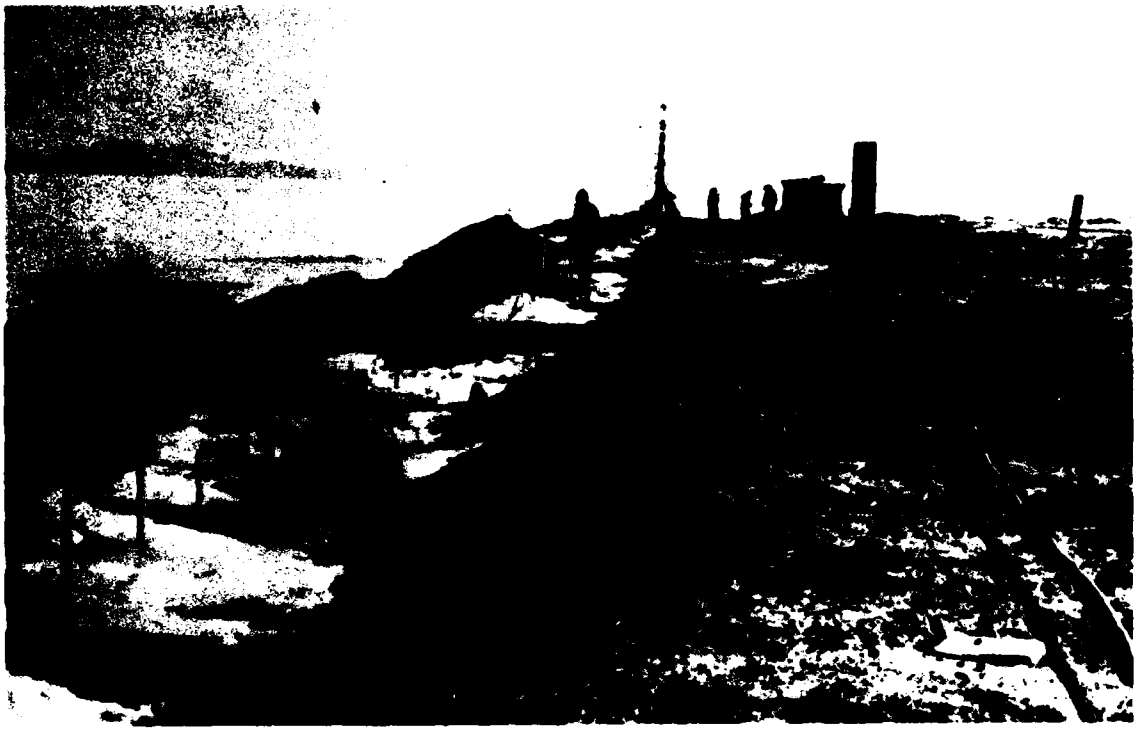


Figure 8. Blast line on seaward side of artifical ice wharf.

During the preliminary tests on smooth ice, which was essentially isothermal (26°F) at the surface, the TF-1000 cut an 8-1/2-inch-wide trench through 72 inches of sea ice at a travel speed of 10 fpm. However, because surface ablation had made the sea ice in Winter Quarters Bay very rough, travel speed had to be reduced to 3 fpm. During the cutting operation the maximum lineal chain speed was measured to be 300 fpm.

The specific energy consumption for the TF-1000 to cut and remove the ice was calculated to be 206 psi. Specific energy is found by dividing the power required to excavate material by the volume rate of material removed. Tests by the U.S. Army Cold Regions Research and Engineering Laboratory [4] showed that many excavating machines deliver about 60% of their rated power to the cutting elements. The calculation was based on this assumption.

The conical teeth were inspected several times during preliminary tests and trenching operations. The wear was imperceptible.

Initially, there was concern that the boom would bind against the side of the trench if the tilt operation was not performed during sloping cuts or if abrupt changes of cutting direction were attempted. These fears were unsubstantiated, because the TF-1000 had sufficient power to cut a wider trench as the boom swung against the side. Although the

recommended boom angle for operation in dirt is 30 degrees from vertical, the trencher operated effectively in ice with the boom in a near-vertical position.

The uneven ice surface caused by severe ablation made it impossible to maintain a straight cut, even while following a string line. As the trencher moved over the undulating surface, constant attention of the operator was required to perform the ''tilt'' motion to maintain a vertical trench. At the same time, an almost constant braking of the lower track was required to keep the trench straight. Braking of the lower track caused the upper track to slip. Also, as the trencher started down an incline the operator had to lower the boom to assure a full-depth cut. All of these factors caused the trencher to deviate from a straight line.

The machine performed very well during the 16-hour, continuous-trenching operation. The only problem occurred while attempting to cut a refrozen preliminary test trench, about 2 weeks old. The 24-inch-deep ice chip aggregate conglomerate was much harder than the natural ice sheet, and the TF-1000 was unable to cut it. After several unproductive attempts, this area was abandoned in favor of adjacent natural sea ice. The problem remains unexplained, except perhaps the conglomerate of ice chips produces ice with randomly oriented crystal growth, making cleavage by the trencher teeth difficult.

Overall, the trencher was easy to operate and quite simple to learn for the novice operator. From a human-factors standpoint, the machine was extremely noisy and, at times, exhaust fumes drifted back into the operator's face. Both of these problems could be corrected by the addition of an exhaust pipe extension.

FINDINGS

1. The Davis Model TF-1000 Trencher with a 60-hp engine and conical ice cutting teeth is capable of trenching through 72 inches of sea ice at a travel speed of 10 fpm.

2. The TF-1000, as configured during tests at McMurdo Station, Antarctica, did not remove sufficient ice cuttings from the trench to prevent freeze-back. Freeze-back occurred on the surface of the trench within 6 hours.

3. The TF-1000 can be used effectively to cut trenches in sea ice to provide crack arresters for preventing propagation of unwanted cracks.

4. The TF-1000 can be operated on an undulating ice surface, but travel speed is reduced by more than 50%.

CONCLUSIONS

The idea of using a modified earth trencher to eliminate damage to the artificial ice wharf in Winter Quarters Bay, McMurdo Station, Antarctica, has been found to be partially applicable. The performance of the trenching machine was excellent. The 10-fpm cutting speed exceeded initial estimates. However, rapid freeze-back of the trench prevented removal of the sea ice by towing. This necessitated the icebreaker to fragment the sea ice in place.

Had a method for preventing refreezing been available, an ice breaker would have been able to tow the ice blocks, cut with the trenching machine, out of Winter Quarters Bay.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Note N-1030: McMurdo Ice Wharf-Physical Characteristics and Criteria for Protection, by R. A. Paige. Port Hueneme, CA, Apr 1969.

2. "Ship Operations, Deep Freeze 73," Antarctic Journal of the United States, Vol. VIII, No. 4, Jul-Aug 1973, pp 220-224.

3. Civil Engineering Laboratory. Technical Note N-1376: The Man-Made McMurdo Ice Wharf-History, Construction and Performance, by J. L Barthelemy. Port Hueneme, CA, Feb 1975.

4. Cold Regions Research and Evaluation Laboratory. Technical Note: Cutting Frozen Ground with Disc Saws, by M. Mellor. Hanover, NH, Jul 1972.

Chapter 9

POLLUTION CONTROL

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Revised – 1979

Chapter 9

POLLUTION CONTROL

INTRODUCTION

Preservation of the pollution-free environment in Antarctica is required by the articles of the Antarctic Treaty of 1 December 1959, and is highly desired for validity of scientific studies. Considerable investigation has been done by the National Science Foundation and others on the most suitable method for pollution control and for minimizing the environmental impact resulting from man's alien presence in the Antarctic.

Pollution sources at McMurdo consist primarily of solid wastes, sewage, exhaust gases from the combustion of diesel fuel and gasoline, and possible water pollution due to oil spillage during transfer and storage. Also, wind-blown dust resulting from construction activities and vehicle travel over untreated road surfaces is contaminating the permanent snowfields, causing their recedence.

SOLID WASTE

Studies at McMurdo show that summer-day solid-waste volume consists of approximately 60 gallons of garbage, 60 cubic yards of burnable rubbish, and 14 cubic yards of nonburnable rubbish. Since the start of Deep Freeze operations the disposal method for this material has been to place it on the annual ice and allow it to drift to sea with the annual ice breakout. In summer the solid waste is sometimes burned to reduce the volume and to reduce the scattering by winds. This disposal on the sea ice is aesthetically unsatisfactory and results to some extent in contamination of McMurdo Sound.

In DF-72 an incinerator facility was constructed between the main station area and the ice wharf. It was found to be unsuitable and, therefore, is not used because of the limited capacity and the large man-effort requirement for operation.

Continued studies of various methods, including possible backloading of solid waste for disposal at sea or return to the United States, suggest that a sanitary landfill is the most economically feasible method currently available for disposal of solid waste. In DF-79, NCEL conducted an investigation of the solid waste situation at McMurdo, examining the volume and type produced and the various alternatives for waste disposal (see LIST OF APPENDIXES). A shredding, baling, and landfill operation was found to be the most economical, aesthetically pleasing solution currently available and has been incorporated into the long-range development plan for the station.

SEWAGE DISPOSAL

Normal sewage treatment (i.e., settling tanks, chlorination, etc.) was considered for McMurdo, and a

package treatment plant was shipped to the site in DF-71. It was subsequently recognized that the ocean in McMurdo Sound provides a very effective biodegradable system rich in benthic invertebrate organisms that scavenge the waste produced by the five- to six-thousand Weddell seals living in the McMurdo Sound region. It was concluded that the relatively small addition of human waste and garbage from McMurdo Station can be absorbed by this ocean system. To accomplish this in the most suitable manner, the food and human waste should be macerated before discharge into the water.

AIR POLLUTION

Problems of air pollution at McMurdo Station are not clearly defined, and no critical requirement for procedural change has been identified. One condition, however, is apparent. Particulate from combustion of fuel oil, along with dirt carried by the wind from hillsides scraped for fill material, contaminates the snowfields in the McMurdo area. Through increased absorption of solar energy many of the permanent snowfields in the station area have disappeared or are receding. Until DF-64, when road construction and the larger earth-fill projects began, snow for the camp water supply was gathered from permanent snowfields in the immediate station area. Now these are gone, as are others within more than a mile radius of the station. This melting of the snowfields is still in progress and can be clearly observed on the large ice field crossed by the McMurdo-to-Scott-Base road. As the snowfields melt, more land area is exposed to the wind, and a pyramiding effect may occur. Some consideration has been given to oiling the vehicle road surfaces to hold down the dust, but this has not been done because of the possibility of meltwater carrying oil into the sea.

OIL SPILL HAZARDS

The possibility of contaminating Winter Quarters Bay and the adjoining sea and ice fields with spilled fuel oils is of concern. Since the best way to deal with a spill is to prevent its occurrence, a constant vigil should be maintained during fuel transfer operations. Fortunately, most of the petroleum products used at McMurdo are the lighter more volatile fractions of natural crude which tend to readily evaporate, leaving behind little residue with long-lasting effects. Unless the fuel spill is catastrophic in size, the process of evaporation may account for most of the spill removal with only a minimal harvesting of saturated materials necessary to complete the cleanup. Catastrophic spillage would likely call for specialty skills and equipment beyond local capability.

If the nature of the spill dictates a strenuous cleanup effort, the procedure should begin as soon as possible to minimize spreading of the spill, increased absorption by the surrounding surfaces, and emulsification with the seawater. Delays in cleanup generally result in a disproportionate increase in the amount of effort required. The use of absorbents and burning appear to be the most suitable cleanup techniques for the McMurdo operation.

A number of natural and processed materials are suitable for absorbing fuels and oils, but to be effective in the presence of water, they must have a hydrophobic characteristic. Also, because of evaporation of the lighter fuel fractions and because of temperature chill, absorbents lose much of their efficiency as the viscosity of the spillage increases. One of the best of the processed absorbents is shredded, open-cell, polyurethane foam; of the natural materials, straw has been the favorite because of low cost, availability, and ease of spreading and retrieval. Straw under the right conditions absorbs about five times its own weight in oil. After accomplishing its mission it can be stacked and burned, leaving little residue and harm to the environment. In some cases, if conditions are right, it can even be burned in place. New Zealand with its agricultural industry should be a readily available source of supply. Bails of straw were shipped to McMurdo in DF-73 as an on-land supply for spill cleanup. Shredded polyurethane foam can be reused by pressing or squeezing the material to remove the oil. This material is not biodegradable, and its release during cleanup may present a collection problem unless contained in a mesh bag or similar container.

Burning can be effective in reducing the volume of an oil spill if conditions are right to start and maintain combustion and the fire does not endanger adjacent facilities.

> CAUTION: GASOLINE SPILLS ARE EXTREMELY DANGEROUS AND NO ATTEMPT SHOULD BE MADE AT PHYSICAL REMOVAL--ALLOW THEM TO EVAPORATE AND TAKE PRECAUTIONARY MEASURES TO AVOID ACCIDENTAL IGNITION OF VAPORS.

Small scale experiments (Reference 1) with techniques for burning crude oil on both ice and water surfaces indicate the technique has some potential as a method for cleaning up oil spills in polar regions. It was estimated that the residue from burning Prudhoe Bay crude oil was in the range of 2% to 10% of the original volume. From this, it would be reasonable to expect very little residue to remain from burning light distillates. The following quotes from Reference 2 on the experimental results reported in Reference 1:

> "Experimental as well as actual oil burns in the Arctic and subarctic with and without fire promoters and burning agents involving oil on cold water and oil on ice have demonstrated the effectiveness of this method. In repeating the results of their burns, the USCG* made the following observations: (1) The ability of North Slope crude to burn seemed to be virtually unhampered by its residence on ice; (2) The burning agents had some effect on the residue; (3) Ice and snow

*United States Coast Guard.

aided combustion by providing a wick action; (4) The wind was a definite factor in forcing the oil into pools thick enough to support combustion without the presence of burning agents. It was also observed that above a certain wind velocity blowing snow would keep extinguishing the fire."

The Reference 1 experiment tried fumed-silica and glass-bead-type burning agents as well as straw for combustion promoters.

Oil spilled beneath the ice will be buoyed to the ice-water interface due to the difference in densities of oil and water. To what extent it will spread cannot be predicted since this is related to volume of oil spilled, entrapment features of the ice surface, and water turbulence. Locally, the oil will try and collect along the underside of the ice in pockets and at the crest of surface undulations. If the location of such characteristics are known, they can be tapped and the oil will float to the surface for recovery. Holes drilled through the annual sea ice sheet can serve as sumps for gathering oil initially trapped in the ice matrix. Release of the oil should begin with the transition from ice growth to bottom melting, which for the McMurdo begins in early December.

Containment barriers may be of some assistance in preventing the spread of an oil spill under the right conditions, such as reasonably calm water and the absence of large amount of broken and brash ice. If a spill should occur under such conditions in the shipping channel of Winter Quarters Bay, placing a barrier across the channel mouth will help contain the oil and restrict spreading into McMurdo Sound. If a commercial boom is not available, a boom fashioned from utility poles banded to a steel cable should be used. If the channel is clogged with broken ice, it will act as the containment mechanism if not permitted to move into McMurdo Sound. The cleanup, however, will be considerably more complex due to the presence of broken ice.

Included in oil spill hazards is the responsibility to report and monitor the effect on the environment. Overall management of such efforts is, at best, little understood. From the environment legal standpoint, it is best to acknowledge clearly the extent of the perturbation as failure to do so may place liabilities upon those in charge.

On 23 October 1978, the President signed into law the Antarctic Conservation Act of 1978 as passed by Congress. Amongst other provisions, the act provides for the protection of the ecosystem and makes it unlawful for any United States citizen, unless authorized by regulation or permit "to discharge, or otherwise dispose of any pollutant within Antarctica."

Acknowledgment is made for the valuable background information provided by References 1 and 2; and the direct quotation from Reference 2, that was used in preparing this text on oil spill hazards.

APPENDIXES

The material provided in the Appendixes supplements the chapter

text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCES

1. Paper #OTC 1551: A Study of the Behavior of Oil Spills in the Arctic, by LT (J.G.) J.L. Glaeser and CMDR George P. Vance, USCG, presented at Fourth Annual Offshore Technology Conference, Housten, TX, May 1-3, 1972.

2. Paper #OTC 1523: Measurements to Combat Offshore Arctic Oil Spills, by W.R. McLeod and D.L. McLeod, Montana College of Mineral Science and Technology, presented at Fourth Annual Offshore Technology Conference, Houston, TX, May 1-3, 1972.

LIST OF APPENDIXES

Chapter 9

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

9-A. Civil Engineering Laboratory, Technical Memorandum M-64-79-10: Feasibility of baling and incineration of solid waste at McMurdo Station, Antarctica, by Carter J. Ward, Jul 1979.

9-B.

9-C.

9-D.

9-E.

9-F.

9-G.

9-H.

9-I.

9-J.

Addition – 1979

APPENDIX 9-A

TM no. M-64-79-10

TECHNICAL MEMORANDUM

title: FEASIBILITY OF BALING AND INCINERATION OF SOLID WASTE AT MCMURDO STATION, ANTARCTICA

author: Carter J. Ward, Ph D

date: July 1979

sponsor: Naval Support Force, Antarctica

program nos: 61-019

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INTRODUCTION

As noted in Reference 1, preservation of a pollution-free environment in Antarctica is required by the articles of the Antarctic treaty of 1 December 1959. The flags of 19 nations fly over the Antarctic, but no country owns any of its real estate. It is the only land mass in the world where the explosion of nuclear bombs is specifically prohibited.

Considerable investigation has been done by the National Science Foundation and others on the most suitable method for pollution control in Antarctica. Pollution sources at McMurdo consist primarily of solid waste, sewage, exhaust gases from the combustion of diesel fuel and gasoline, and water pollution due to oil spillage during transfer and storage.

In FY-78 the Civil Engineering Laboratory (CEL) reinvestigated* solid waste disposal at McMurdo Station to determine if compactors or balers could be employed. CEL's primary goal was to indentify available compactor/baler units of a suitable size, including capacity, characteristics of output material, initial cost, and energy requirements. The secondary goal was to identify alternative waste disposal schemes, including the reutilization of the two existing incinerator units at McMurdo Station. Results of the study (Ref 3) indicated that disposal techniques utilizing commercially available equipment for baling McMurdo solid waste appeared to be possible. The waste disposal system proposed by CEL as a result of the FY-78 study used a small baler system that could also include reutilizing the two existing incinerator units at McMurdo for further volume reduction.

Reference 3 also recommended that the baling system proposed be tested by CEL prior to implementation at McMurdo Station. The tests would be conducted to determine:

(1) Adequacy of size reduction method using the modified container doors

(2) Reliability of the shredder and related refuse separation equipment and techniques

(3) Combustibility of compacted bales using incinerators

(4) Adequacy of a two-man crew to process the 80 yd^3 (61 m^3)/day - about 2,000 lb (910 kg) - of refuse in a single 8-hour shift

*Reference 2 documents the original study on solid waste disposal at McMurdo Station.

In FY-79 a field study at McMurdo was conducted to determine the feasibility of implementing a baler/incinerator solid waste disposal system. Because of the large quantity of metal waste materials found in the refuse during the field study, a shear-type shredder larger than the one recommended in Reference 3 was investigated for possible use at McMurdo. A procedure for implementing the proposed baler/incinerator solid waste disposal system is outlined in this document.

BACKGROUND

Station population figures from Deep Freeze (DF)-78 show that the population at McMurdo averages 610 persons for a period of 18 weeks (early October through mid-February). This excludes the population at the Williams Field airstrip (which currently handles its own solid waste by burial in the snowfield on which it sits). Inclusion of these persons would increase the figure by about 100 persons from mid-December through early February. Winter-over population at McMurdo (March through September) is 70 to 80 persons.

Currently, trash is collected in 28 dumpsters, each having a capacity of about 250 ft^3 (7 m^3). Building trash cans are emptied into the dumpsters located outside the buildings. A modified Caterpillar 944 front loader, which has been converted into a forklift, transports the dumpsters. There is also one standby 944 converted forklift. One operator is assigned to collect, empty, and return the dumpsters. In addition to solid waste collection by dumpsters, large crates, cardboard boxes, and other large items are carried by the forklift directly to the dump site. Even so, a large amount of trash, consisting of crates, cardboard boxes, and other solid waste (Ref 3), has accumulated around McMurdo Station.

The present solid waste dump site is located downhill from McMurdo Station, near sea level and close to the sewer outfall. All types of materials are disposed of in the dump. The equipment and discarded vehicles which are disposed of at the site are usually dumped on the ice. When the ice melts, the vehicle or the equipment sinks down to the sea bottom. Until this takes place, the area presents quite an unsightly appearance. As of the first of January 1979, another dump site (Figure 1) for noncombustibles has been located uphill, as recommended in Reference 2. This site is currently used for disposing of large metal pieces; it could be used, however, to store bales of compacted noncombustible materials (such as soda cans) if a full-scale refuse-source-separation system were implemented, using the proposed baler.

Two small incinerator units at McMurdo are located inside a building that has a "tipping" floor*. Each of these units contains an auxiliary oil burner system for burning wet trash, and each has a 500-lb/hr (227-kg/hr) capacity. Two units were installed so that one can be cleaned while the other is in operation. The problem encountered with these units is the large amount of manpower required for operation. The

*"Tipping" floor is a floor structured to withstand dumping and storage of heavy and sharp items such as solid waste.

charging doors are small, about 2 ft^2 (0.6 m^2). Thus, dumpsters must be emptied on the tipping floor, and the contents hand-fired into the unit. With these incinerators, additional problems arise in reducing such large trash as shipping crates to a chargeable size.

Studies at McMurdo show that summer-day solid waste volume consists of approximately 60 gallons (230 liters) of garbage, 60 yd^3 (46 m^3) of burnable rubbish, and 14 yd^3 (11 m^3) of nonburnable rubbish. Since the start of Deep Freeze operations, the disposal method for this material has been to place it on the annual ice and allow it to drift to sea with the annual ice breakout. In summer, the solid waste is sometimes burned to reduce the volume and to reduce the scattering by winds. This disposal on the sea ice is aesthetically unsatisfactory and results to some extent in contamination of McMurdo Sound (Ref 1).

DISCUSSION

Presentation of the proposed solid waste handling system is divided into four sections:

1. Equipment, describing the hardware components proposed for selection, how they work, and why these specific components were selected over others that are commercially available.

2. Labor, giving the requirements of the proposed solid waste handling system from the source of the outside 250 ft^3 (7 m^3) dumpsters to and including the landfill operation.

3. Economics, giving a brief accounting of the primary cost factors using current dollar figures to predict the overall operational cost of the proposed equipment.

4. Problem areas, discussing the operational effects of McMurdo's cold environment on the proposed equipment.

Other areas of possible concern are also addressed.

Equipment

Description of the proposed system will begin at the point of generation at the wastebasket and follow the same path as that to be used for refuse disposal.

Initial Waste Generation. Wastebaskets located in the living quarters are emptied by the users either into 30-gallon (115-liter) containers placed inside the large personnel buildings or directly into the outside containers of the smaller quarters. Offices, warehouses, and other work areas' interior containers are also serviced in this manner. Consequently, a source separation program to separate the combustibles (i.e., paper, plastic, cardboard, and wood) from the non-combustibles (i.e., soda cans, metal strips, bottles) should prove to be fairly easy to implement and control. Those personnel who do not separate their refuse can be easily located because the few people who use the containers are known. The 30-gallon (115-liter) containers located inside the buildings are usually grouped in pairs or are located within

50 feet (15.2 meters) of each other, and the pair serves as a disposal site for no more than 50 personnel, but usually considerably less. The containers located in the rest rooms contain mostly paper towels. All the 30-gallon (115-liter) containers should be labeled as to their refuse type. As a result, if two separate containers are located outside where there is currently one, and if they are clearly labeled, the personnel responsible for transporting the refuse from the labeled 30-gallon (115-liter) containers to the outdoor containers need only maintain the separation process.

The galley currently separates the wet garbage from the boxes and cans. They need only further separate the dry waste.

Because there are only 20 outdoor container locations currently in use at McMurdo, there should be no problem acquiring the 20 additional outdoor containers to implement the proposed program. It is important to note that the additional containers do not impact the refuse generation rate and, therefore, do not require more labor to collect the separated waste.

Figure 2 shows the outdoor containers currently used at McMurdo. These containers were designed and fabricated at McMurdo to be compatible to the modified Caterpillar 944. Figure 3 is a view of the Caterpillar forklift used for hauling the containers. This vehicle has proven to be an excellent container transfer vehicle for the harsh Antarctic environment.

The containers do not have a topcover, but have a side door horizontally hinged at the top (see Figure 2). On the opposite side are two cantilevered plates with vertical holes (see Figure 2). After the modified Caterpillar forks mate to the container, the operator places a pin through the two holes of the plates to lock the container to the fork's 10 cross-member supports. When pinned, the container may be lifted to a height of 12 feet (3.66 meters) and rotated so that the hinged door opens and the refuse dumped out.

During the field survey, CEL found that oversized refuse is rarely dumped into these containers because the large material sizes interfere with the hinge door mechanism. The oversized refuse material is currently taken directly to the dump site by the refuse generator or by Public Works.

Table 1 lists the results of the CEL survey on the types of solid waste generated at McMurdo Station, and Figures 4 and 5 show typical McMurdo container refuse. Figure 6 shows the contents of a container that has been designated "for metal only"; however, because no label or other sign appears on the container indicating its intended use, nonmetal refuse is sometimes included. Figure 6 is not typical, however, according to the refuse collection crew. Their experience is that it usually has very few nonmetal materials mixed in it even though only word-of-mouth is used to inform personnel. This separation experiment, originated voluntarily by the USARP* garage personnel, shows the high interest of McMurdo personnel in source separation.

Incinerator Building. The incinerator building at McMurdo has an enclosed 20 by 40-foot (6.1 by 12.2-meter) tipping floor with a 12-ft-(3.66-m-) wide garage door entry. Also, a personnel door is located to

*United States Antarctic Research Program.

the right of the garage door. On each side of the floor are three windows, approximately 3 feet (0.9 meter) wide by 4 feet (1.2 meters) high, evenly spaced across the wall. The bottom sill is about 4-1/2 feet (1.4 meters) from the floor surface, which consists of 4 by 8-foot (1.2 by 2.4-meter) steel plates welded together. At the end opposite the garage door are the incinerator doors. Figure 7 shows the incinerator building and the location of the proposed solid waste loading shoot. Height of the shoot is estimated as 6 feet (1.8 meters) from the ground surface. The forklift should be able to easily dump the refuse from the container into the outdoor loading shoot. The loading shoot should have an incline adequate to feed the refuse to the conveyor by gravity. Figure 7(c) shows a top view layout of the proposed baler and auxiliary equipment. The shredder, baler, and roller equipment recommended for use at McMurdo are shown in Figures 8 and 9. Only combustible bales should be incinerated (two to three at a time).

Handling of Noncombustibles. Noncombustibles such as glass, light metals, and wet materials, but not including heavy metal objects, may be processed exactly the same as the combustibles to form compacted bales. Also, the ash residue from the incinerators may be reprocessed into bales mixed with the noncombustibles. The noncombustible bales may be stacked on pallets and stored temporarily on the tipping floor. The metal detector (see Figure 7c) should be sensitive to heavy hard metals and not cans. It is included to stop the conveyor before the heavy metal is dropped into the shredder where it could damage the shearing blades.

Advantages of Baling Refuse. Utilization of a baler for solid waste disposal has advantages over disposal of unprocessed refuse at the landfill. Bales, stacked in rows and tiers as shown in Figure 10, take up less space than uncompacted landfills. Bales stack almost void free, so the disposal area lasts longer. The lack of blowing paper or debris adds considerably to the aesthetic value of the surrounding area, as may be seen by comparing Figures 10 and 11. The bales could also possibly be used as structural material.

Baler. In regard to the equipment selection process, the baler illustrated in Figure 9 is the only commercial horizontal baling system found that can produce a bale small enough to fit through the 2 by 2 foot (0.6 by 0.6 meter) doors of the incinerators currently installed at McMurdo. Vertical balers must be hand-fed.

Compactors, as opposed to balers, are designed to reduce refuse volume by compacting the material inside a container or truck. Their use is limited to reduction of container pickups or for increasing carrying capacity of refuse trucks; neither function would reduce the solid waste pollution at McMurdo.

The working principle of the selected baler is simple, and skilled operators are not required. The baling press is a hydraulically operated packing ram. Depending on the waste material, the volume can be reduced to between one-sixth and one-tenth of its original size. The operator loads the hopper via the shredder/conveyor. When the hopper is full, the hydraulic ram is activated by a pushbutton or an electric eye, and the baler compacts the material. The operation may be repeated several times with additional loads until the baler's automatic sensing device

indicates full bale weight or size; the operator then inserts wires or twine through slots in the machine and ties the bale, an operation that requires less than 3 minutes. Table 2 lists the spare parts for the model NA-5005 baler.

Hoppers, Metal Detectors, Conveyors. A thorough search of hoppers, metal detectors, and conveyors was not made. However, these items are not cost-intensive; therefore, extensive searches are not required.

Shredder. The shredder illustrated in Figure 8 was selected because it is capable of shredding glass and metals, such as bottles and cans, in addition to wood and paper. It has been observed shredding whole refrigerators and 55-gallon barrels with no problem. Because this shredder is expensive, for cost-effectiveness the larger, more durable one is recommended.* This item further reduces the waste volume in the bales as well as distributes air voids throughout the paper products, making them easier to completely burn.

The working principle of the shredder is simple, and skilled labor is also not required. Two counteracting cutter shafts rotate at low-rpm/high-torque to produce cutting action. Cutters are clover-shape and made of high chromium steel. Table 3 lists the spare parts required for the model 52-32 shredder.

Power. Equipment power requirements are 3/4 hp (0.56 kW) for the conveyor, 150 hp (112 kW) for the shredder, and 10 hp (7.5 kW) for the baler. All the motors are electric and come in a variety of voltage combinations.

Other Considerations. It is important to note that if more than one system is purchased by the Navy for use in other stations besides McMurdo, then a "modulized" unit (such as that illustrated in Figure 12) could be more cost-effective and space-saving.

The combustible oversized refuse is mostly wood and cardboard. Consequently, it can be burned completely (without unburned residue) in the open during the summer months; and the flame temperature need not be controlled, as required with paper products. After the current combustible waste landfill has been covered with soil, this area could be used for a burn site of the easily flammable oversized refuse. These materials burn completely because of their porosity; when burned, they should not be aesthetically unsatisfactory to the surrounding environment. The ash should blend with the native dark volcanic soil of the McMurdo Station area.

Labor

Labor requirements are mostly dependent on the refuse generation rates. A maximum generation rate of approximately 80 yd^3 (61 m^3)/day - about 2,000 pounds (910 kg) - occurs in the summer months. Each bale - 36 by 22 by 22 inches (91 by 56 by 56 cm) - is expected to weigh between 100 to 200 pounds (45 to 90 kg). If the incinerators are not used, approximately 10 to 20 bales would be generated per day. Handling the

*The shredder recommended in Reference 3 could only handle light metals such as beverage cans.

bales and baler machine should not require more than 3 man-hr/day, including minor machine maintenance. It should take fewer than 3 man-hours to operate the incinerators using the bale technique. As a result, a total of two fulltime operators is estimated to be adequate to collect, empty, and return the containers, plus process the refuse, incinerate it, and place the bales at the landfill during the summer months. The winter months would require less operating manpower.

Economics

To replace an existing solid waste disposal system with a new process requires an economic analysis of the proposed system before implementation to verify its cost-effectiveness. Rather than going into a detailed analysis here, the primary cost factors are briefly given using current dollar figures.

The equipment is assumed to have a 10-year life. If money worth (interest) is 10%, then the cost per year is the capital recovering factor times the equipment procurement and installation cost. The capital recovering factor in this case is 0.163. This factor when multiplied by the total investment cost gives the uniform annual payments to repay the debt for a given number of years (10) at a specific interest rate (10%). The cost breakdown for annual equipment payments is given in Table 4, but these costs do not include labor or maintenance.

Problem Areas

The cold temperature environment is not expected to present any difficulty to the proposed system, in that the new system will not be any more adversely affected than the existing solid waste management system.

Burning of frozen bales is not viewed as a potential problem. Combustible solid waste has generally a low specific weight, and the specific humidity is very low in cold air. Also, the relative temperature difference between a +70°F ambient versus a -70°F ambient, compared to the solid waste flame temperature (1,500 to 2,000°F), is small.

The baled combustible waste might ignite faster if the waste is not fully compacted, and the baler is adjustable. For less compaction, the hydraulic pressure setting may be reduced on the packing ram via the automatic sensing device which controls bale weight. Which bale density is the most efficient to incinerate (i.e., requires the least amount of auxiliary oil per pound of solid waste) will have to be determined. The sensitivity of efficient burning when related to density variation will also have to be determined during operation.

Baling of frozen refuse, in particular the noncombustible, may present a problem in that these materials, when baled, might not hold together. These materials, because of their density, might not compact to form bales, but they will not be scattered by the winds at the landfill, either, if left unbaled. The primary problems with the existing system concern the combustibles, which compose 75% of the total waste volume.

Implementing and maintaining the source separation program could prove difficult; however, the successful volunteer effort by the Antarctic personnel already indicates that such a system could work.

No known documentation has been found on the use of compacted bales for useful purposes, such as for a structure material. Field use of the compacted, frozen bales at McMurdo could prove beneficial as wind screens, snowdrift control fences, and fill material in areas that will stay frozen and have a dirt fill overlay.

CONCLUSIONS

1. Disposal techniques which utilize commercially availabe equipment for baling McMurdo solid waste appear to be possible.

2. The proposed alternative waste disposal system utilizing a small baler system could also include use of the two existing incinerator units at McMurdo for further volume reduction. Figure 13 is a schematic of the operation of the system.

3. Though Reference 3 recommended testing of the baling system before implementation at McMurdo Station, it is now concluded that pre-testing of the baler/incinerator system is unnecessary prior to implementation because:

(a) Results of the field study indicate that modifying the present trash container to accept only smaller sized waste is not required.

(b) Cost of conducting the test program would almost equal the initial cost of the equipment. Since the recommended commercial equipment already has a proven in-service record, little would be gained from a state-side test.

(c) Burnability of compacted baled waste can best be evaluated onsite, using the incinerator system at McMurdo Station.

RECOMMENDATIONS

It is recommended that the baler/incinerator system outlined in this report be installed by an appropriate contractor and that checkout of the system and waste handling methods be as follows:

1. The first step is to test burnability of baled combustible waste on a limited scale. This will determine the practicality of the concept and indicate the extent that waste separation should be undertaken. If found unsatisfactory the alternative solution is step 2.

2. The mixed waste would be baled as received, densifying the bales as much as possible for use as landfill.

It is highly recommended that the spare parts listed in Tables 3 and 4 be procured and made available at McMurdo Station at the time of initial equipment procurement.

REFERENCES

1. Civil Engineering Laboratory. Engineering manual for McMurdo Station, by C. R. Hoffman et al. Port Hueneme, Calif., 1974.

2. Bechtel Corp. U.S. Antarctic Research Program Report Study. 1972.

3. Civil Engineering Laboratory. Technical Memorandum M-61-78-5: Baling and incineration for solid waste disposal at McMurdo Station, Antartica, by C. J. Ward. Port Hueneme, Calif., May 1978.

Table 1. January 1979 McMurdo Station Solid Waste Contaier Survey Results

Bldg. No.[a]	Source Description	Service Schedule	Rating[b]	Contaminants
155	Galley	2/day	9	Food cans
155	Qtrs., Store	1/day - 2/day	10	Soda cans
165	Admins.	1/day	10	Soda cans
15	CPO, Photo Lab, Qtrs.	1/day	6	Soda cans
78	Theater, Qtrs.	1/day	4	Soda cans, glass
140	GSK	4/wk	9	Soda cans, metal straps
136	PPL	4/wk	7	Light drop metal
121	Supply, Store Warehouse			
61	Cargo, Post Office	3/wk	6	Soda cans, metal straps
56	Bio. Lab, USARP Qtrs.	3/wk	8	Soda cans
160	Berg Field Center	3/wk	9	Metal straps
159	(UXE-6) Shops, Offices	3/wk	8	Soda cans
76	O'Club, Special Services	2/wk	6	Soda cans, metal parts
174	Flammable Warehouse	2/wk	10	Soda cans
75	Gym, Hilo Hanger	2/wk	10	Soda cans
58	USARP Garage	2/wk	7	Metal parts
156	(UXE-6) Warehouse	2/wk	9	Metal straps
182	Fire House	2/wk	6	Soda cans
142	Dispensary	1/wk	10	Soda cans
189	WD	3/mo	--	Highly variable

[a]Twenty container locations with 28 containers total; several locations have more than one container.

[b]10 = very low noncombustible impurities;
1 = very high quantity of noncombustible impurities.

Table 2. Spare Parts for NA-5005 Baler

Quantity	Item
1	Pressure switch
2	Limit switches with arm
1	Motor starter and contacts set
1	Set of internal control relays and contacts
1	0-10 second time delay
3	6 amp buss fuses
1	Door cylinder seal kit (soft)
1	Main ram seal kit (soft)
2	Solenoid coil
1	0.250 VA transformer
1	2092 manifold
1	Pump seal kit
3	Dog spring
1	Door selector valve
1	Motor to pump flex
2	Oil filter
1	Crest head wear strip kit
1	Crest head wiper bar
1	Set guide bars (for crest head)
1	Set of all hydraulic hoses

Table 3. Spare Parts for Model 52-32 Shredder

Quantity	Item
	Hydraulic Power
2	Thermisters
12	Low pressure filter elements
12	High pressure filter elements
1	Accumulator bladder
1 each	Gages
1	Solenoid pilot valve
2	Solenoid coils
1	Main pump
1	Primer switch
1	Pressure relief cartridge
1	Main block manifold
1	Extra hoses
2 each	Hose fittings, 3/8" by 1" jic
	Shredder
1	Set of blades and spacers
1	Set of end bearings
	Control Panels
1	Set of electrical relays
1	Set of thermo relays
2	Timers

Table 4. Equipment Capital Cost and Equivalent Annual Payments

Equipment	Capital Cost ($)	Annual Payment ($)
Loading Shoot	2,000	336
Model 52-32 Shredder	55,000	8,965
Belt Conveyor, Hopper, Metal Detector	5,000	815
NA-5005 Baler [a]	8,230	1,342
Contractor Fee and Start Up	20,000	3,260
Total	90,230	14,718

[a]Includes cost of modifying baler to reduce bale size.

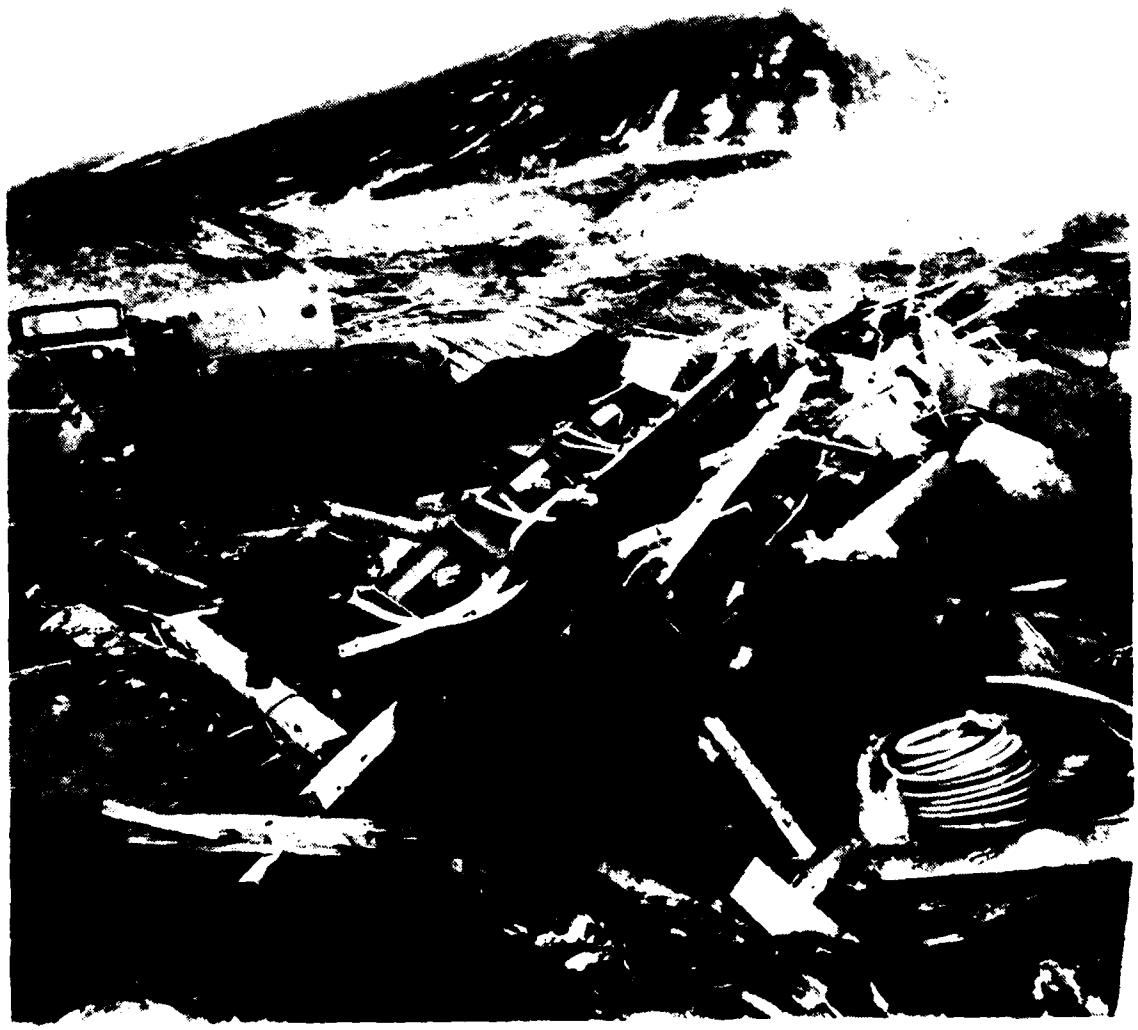


Figure 1. Large metals dump site.

Figure 2. Top view of a typical outdoor refuse container at McMurdo Station, showing one bar over another to allow pin to be inserted and the hinges on the door at the opposite side.

Figure 3. Caterpillar 944 forklift used for transporting refuse containers.

Figure 4. Typical McMurdo Station container refuse; plastic bags contain beverage cans.

Figure 5. Typical McMurdo Station container refuse; metal ram (or air pump) located in center.

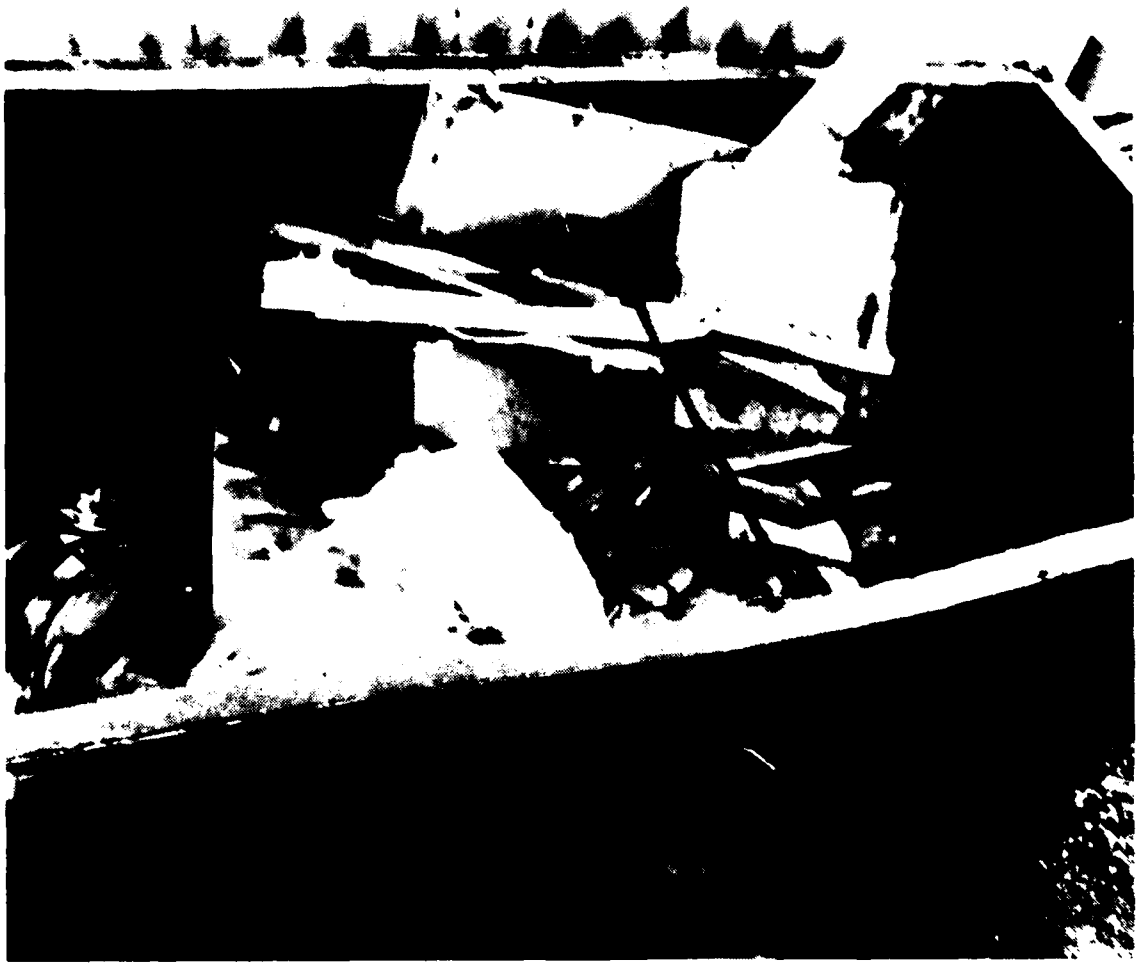
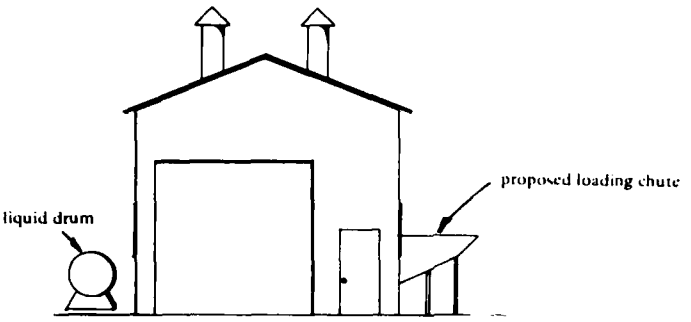
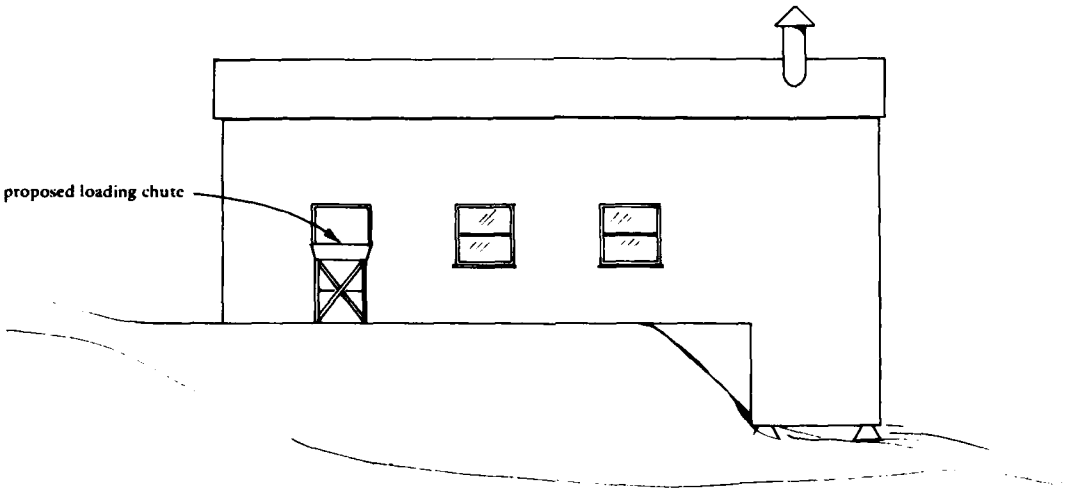


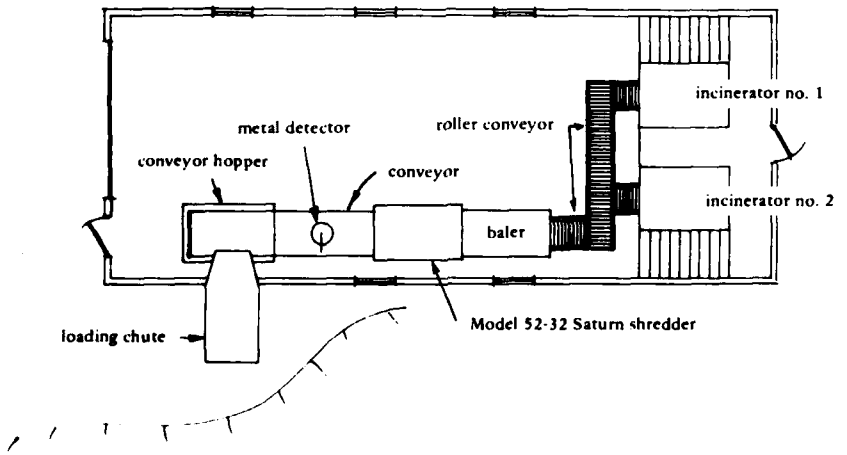
Figure 6. Container marked for "metals only" (note the square plywood boards and cardboard box).



(a) Front view.



(b) Side view of the downhill slope of incinerator building.



(c) Plan view of incinerater building, showing the proposed baler system.

Figure 7. McMurdo Station incinerator building.

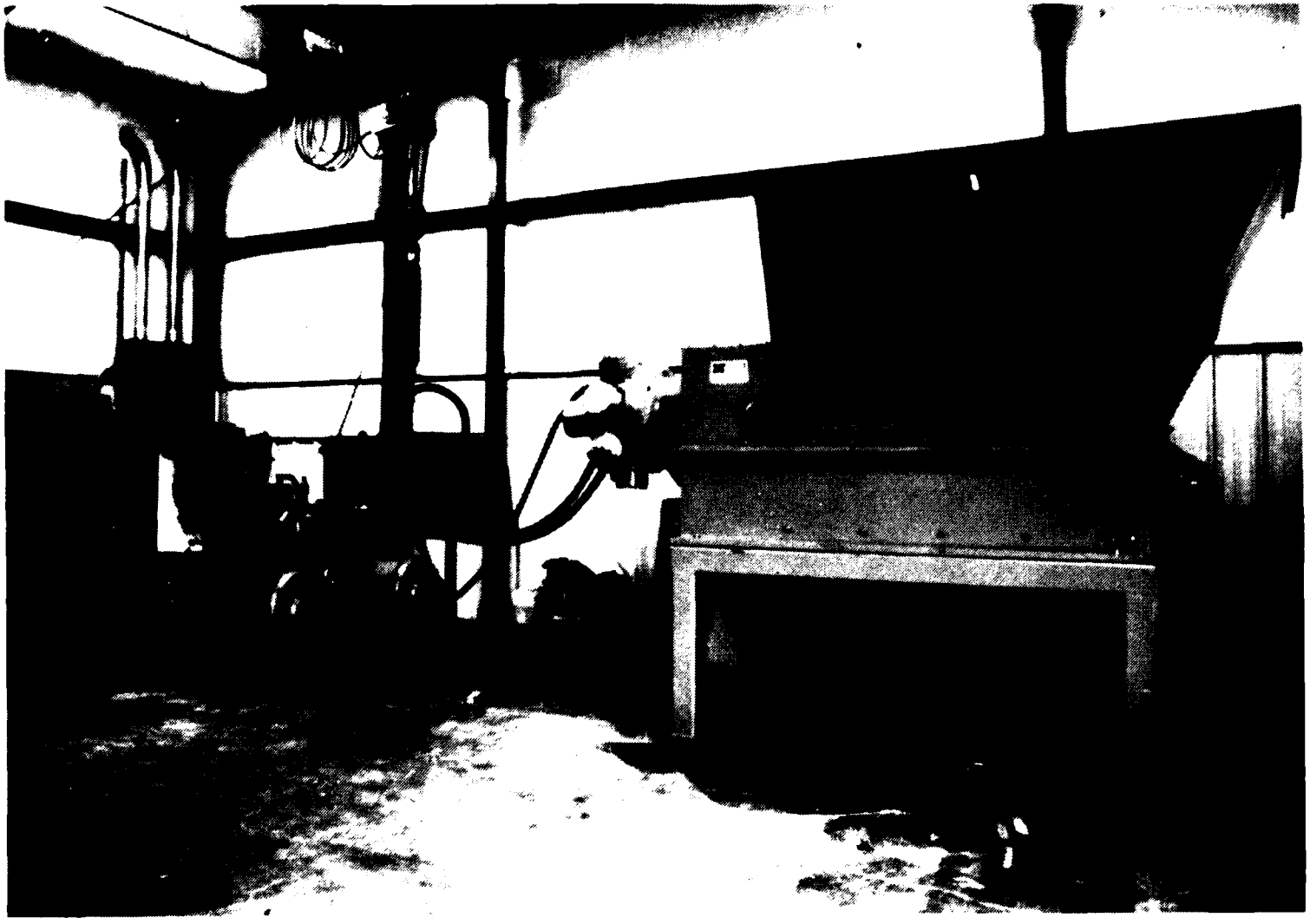
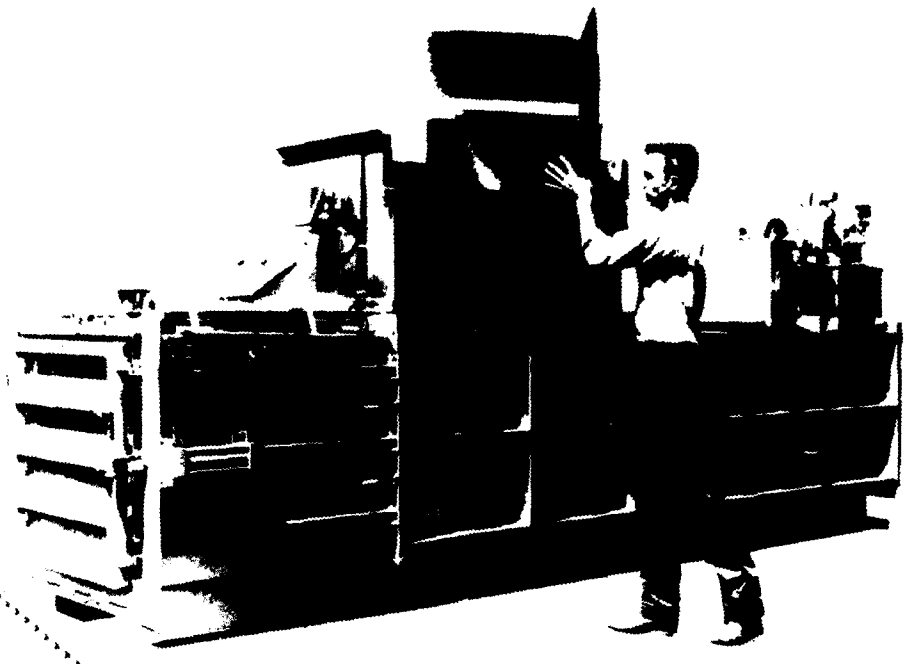
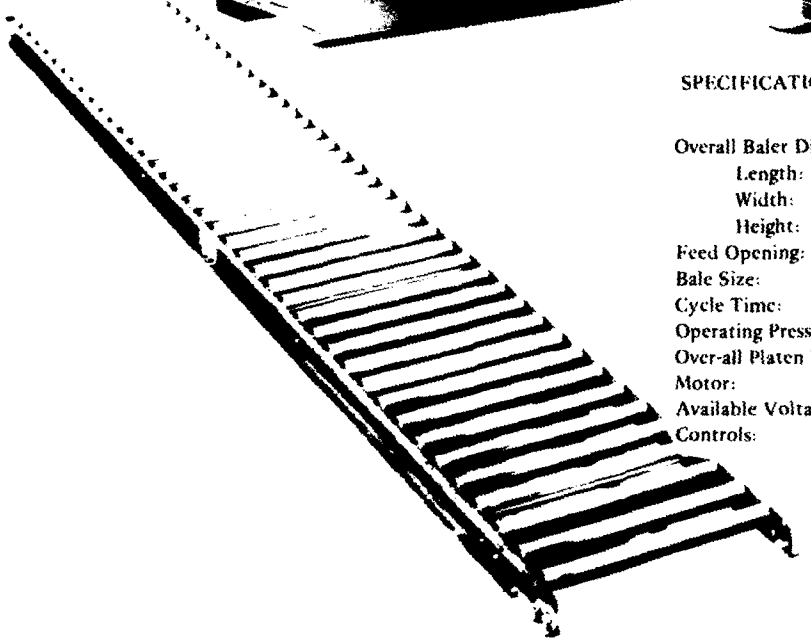


Figure 8. View of recommended shear shredder manufactured by Saturn Inc., Wilsonville, Ore.





SPECIFICATIONS

Overall Baler Dimensions	
Length:	185¾"
Width:	39½"
Height:	66"
Feed Opening:	50" x 28" x 30"
Bale Size:	36" x 22" x 22"
Cycle Time:	15 seconds
Operating Pressure:	1800 lbs.
Over-all Platen Pressure:	23,000 lbs.
Motor:	10 H.P. 3 Ph 60 Cycle
Available Voltages:	208/230/460
Controls:	J.I.C. and NEMA Standards. 110-Volt Control voltage

Figure 9. NA-500s automatic horizontal baler with oversized hopper manufactured by International Baler Corporation. Roller Conveyor shown is Model 12G-138-18G3 manufactured by Valley Forge Conveyor, Inc.

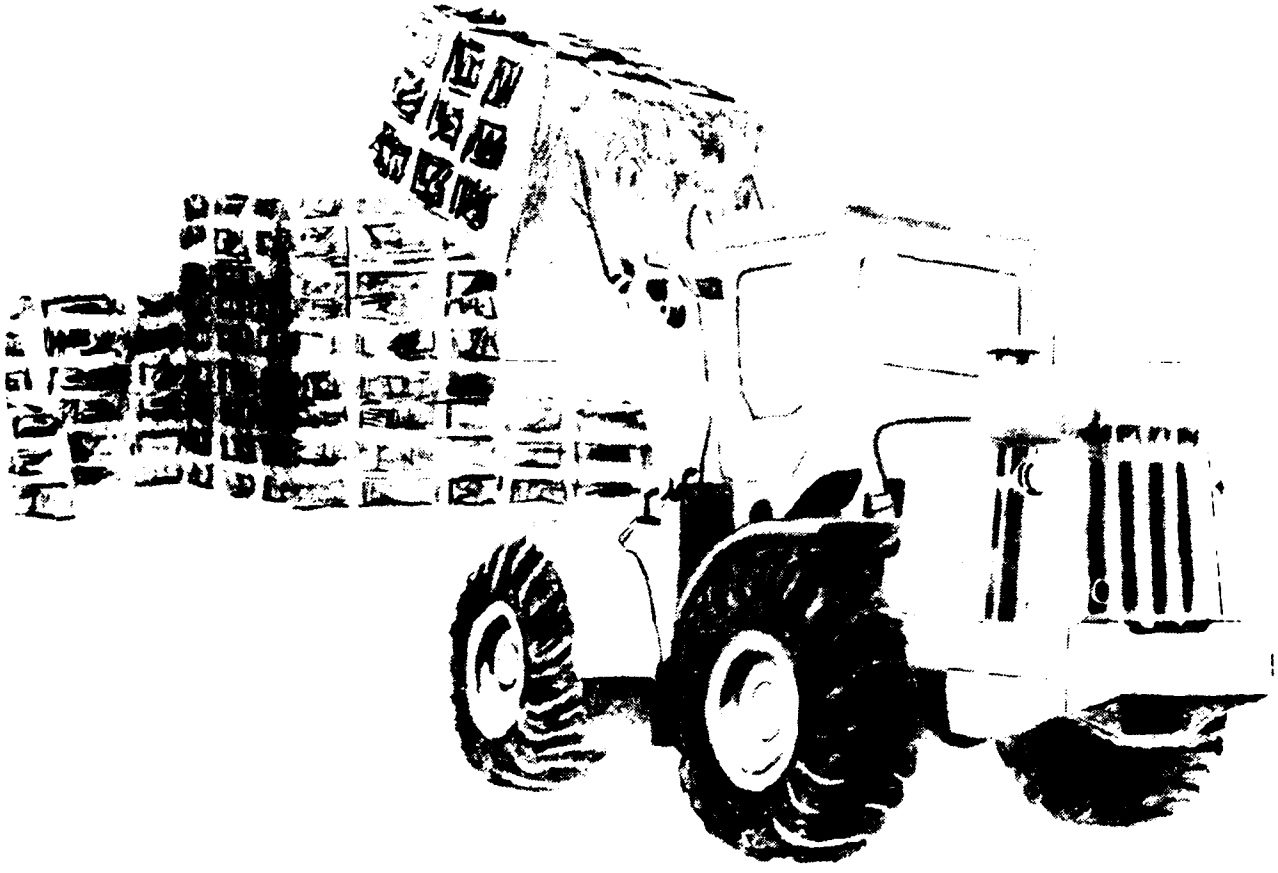


Figure 10. Concept: Solid waste landfill utilizing compacted bales.

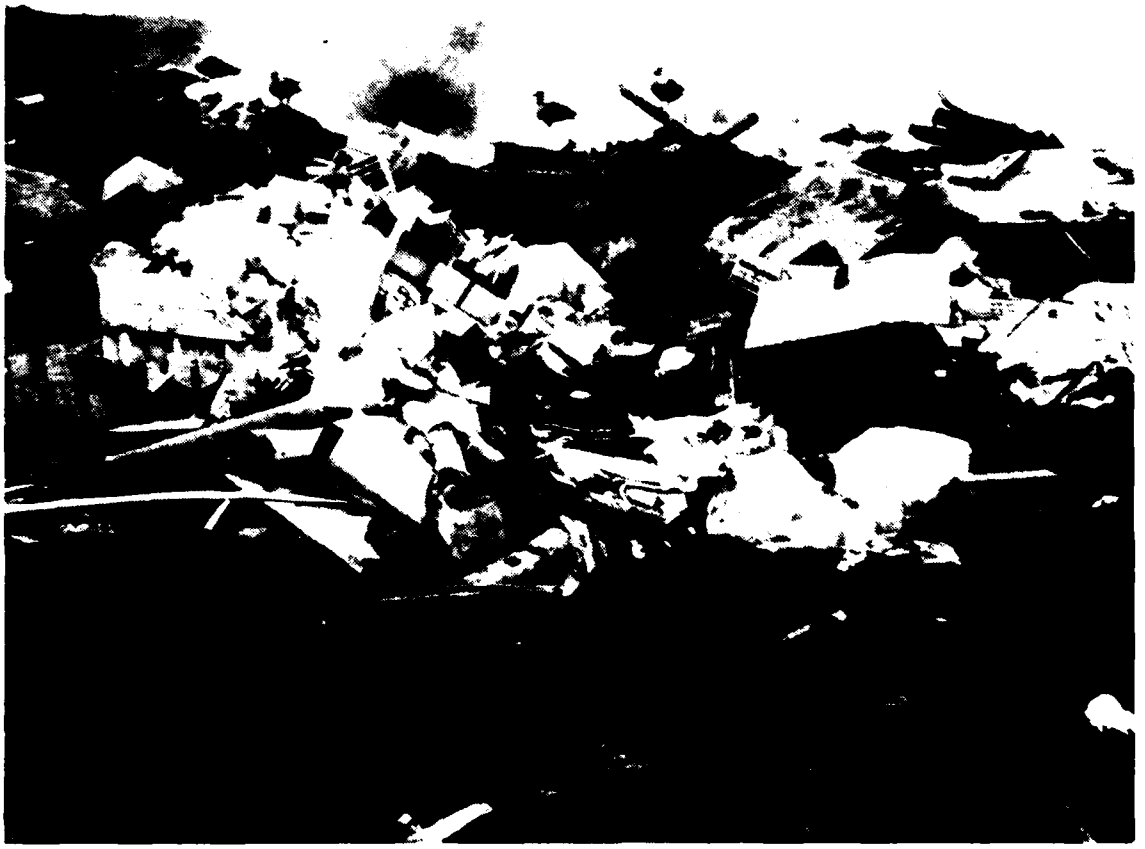


Figure 11. View of a portion of the McMurdo Station dumpsite.

Modulization

International Balers are designed for modulized installation. For instance, a shredder, hogger or auto-tie can be added to a horizontal baler in separate additional installation, thus spreading a customer's investment over a period of time concurrent with actual requirements.

All machines made by International Baler Corp. are designed for integration into a total solid waste disposal system.

Figure 12. Modulized conveyor, shredder, baler.

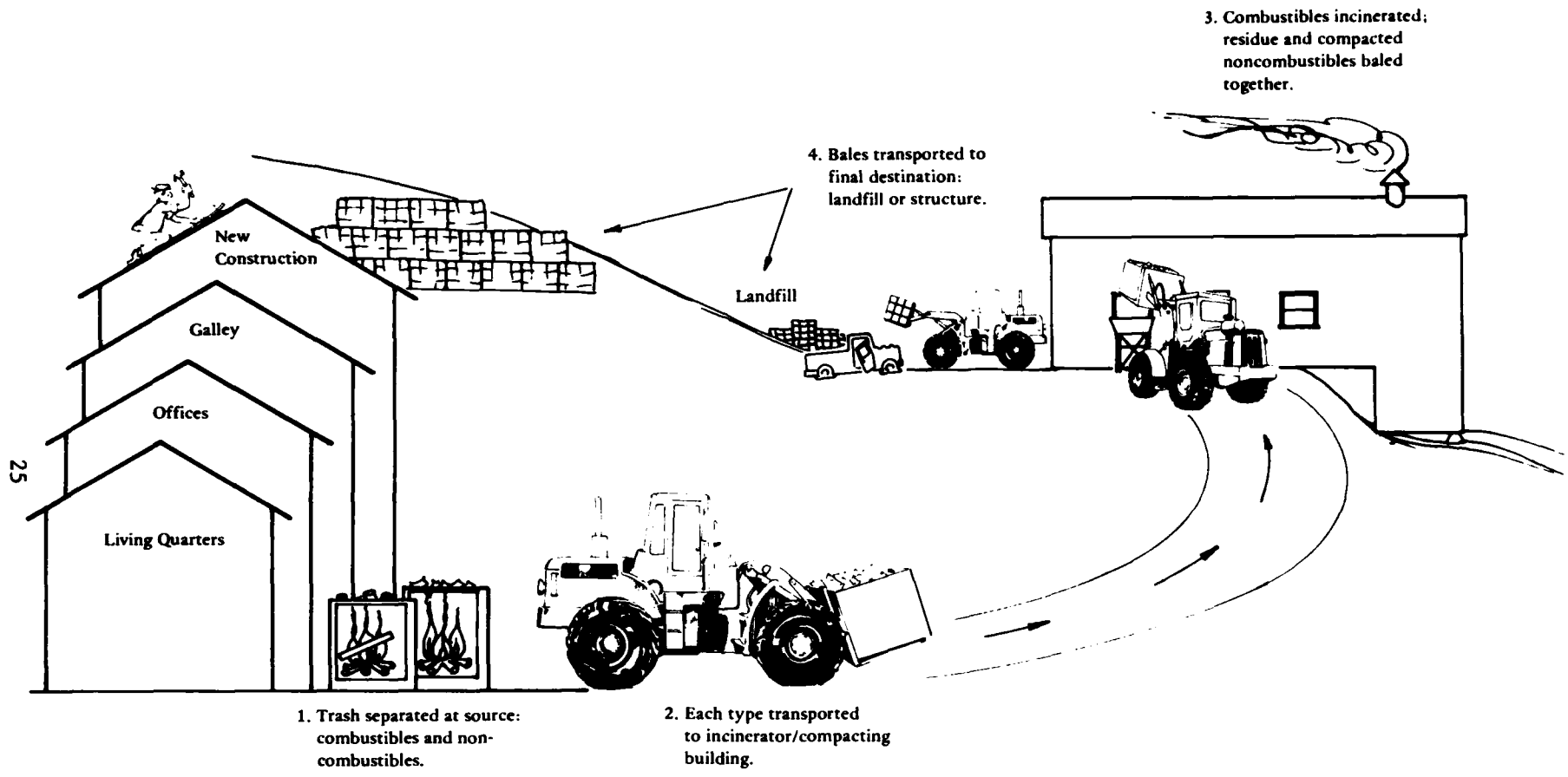


Figure 13. Schematic of alternative solid waste disposal system proposed for McMurdo Station.

Chapter 10

TRANSPORTATION AND CONSTRUCTION EQUIPMENT

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Chapter 10

TRANSPORTATION AND CONSTRUCTION EQUIPMENT

INTRODUCTION

The variety of transportation and construction equipment at McMurdo Station exceeds that found at naval shore facilities many times larger in size. This diversity results from the great variety of construction projects undertaken, the different terrain conditions on which operations are conducted, and a continuing equipment-evaluation program intended to improve Antarctic operations. In this chapter, proper cold-weather operating and maintenance procedures are discussed, as well as a brief background on the specifications, operation, and maintenance of the construction and transportation equipment peculiar to the Antarctic.

COLD-WEATHER OPERATION

Many administrative and operating personnel do not fully understand the problems of operating equipment in cold temperatures and therefore do not always agree on procedures. In addition, failures which result from improper cold-weather operation are not clearly identifiable as such and are often passed off without procedural change.

Cold-weather equipment operation at McMurdo has been examined by a few knowledgeable persons, but there has been little sustained effort toward overcoming problems and implementing recommendations.

Equipment Starting

A common problem at low temperatures is the inability to start an engine on some piece of equipment. A well-tuned gasoline engine with points, plugs, and timing properly set and no defective parts should start after standing all night at temperatures at least as low as 0°F. Diesel engines, because of design, are increasingly difficult to start as the temperature becomes colder. Ignition of the diesel fuel depends on the temperature of compression reaching the ignition temperature (flash point) of the fuel. When the engine block is cold, more cranking is required before this temperature is reached within the cylinders.

The practice of leaving equipment running because of the difficulty of restarting is basically unacceptable. Not only is it wasteful of fuel, but it is harmful to the equipment. In more than one case, engines left idling have been ruined when they have run out of lubricating oil and have seized or thrown a connecting rod through the engine block.

More can be done to facilitate cold-weather starting if care is taken when purchasing new equipment. This includes specifying that cold-weather starting kits be supplied on the new equipment. Furthermore, when a choice of engine-cranking systems is available, those most suitable for cold-weather operation should be

selected, even though more expensive. When choices exist, the higher-voltage starting systems are preferred. Batteries of the higher amp-hour capacity should be selected. Electric-starting, gasoline pony engines for cranking diesel engines are highly preferable to the alternative direct-electric-start systems. The latter systems do not provide sufficient cranking time with cold-storage batteries, and oil pressure cannot be established before loading the engine.

When equipment will not start because of the cold, some corrective action is required. The preferred action is to equip the engines with starting aids which, when connected to an electrical outlet, will keep the critical engine components warm. When starting kits are not available, engines have to be preheated from an external heat source. As a last resort, a more volatile fuel with lower flash point can be injected into the air cleaner, with hope of obtaining ignition.

Engine Preheaters. Two types of portable external heat sources are made commercially for preheating engines in cold climates. The least often encountered is a portable engine-coolant heater which, through quick-disconnect couplings in the engine-coolant hoses, can circulate hot antifreeze through the engine. This type can heat a cold engine in less than 10 minutes.

The more common hot-air engine preheater, as used at McMurdo Station, is more versatile but less efficient. In operation, hot air at temperatures up to 200°F is blown into the engine compartment or under blankets thrown over an engine. With this type of preheating, 30 minutes or more of preheat may be required before an engine is warm enough to attempt starting.

Starting Kits. A variety of engine-starting aids in kit form are available commercially. They are permanently mounted on the equipment and when plugged into a 110-volt electrical outlet will keep various engine components warm. The three areas of starting-aid application are (1) warming the engine coolant, (2) installation in the oil pan to heat the lubricating oils, and (3) installation under the battery.

Starting kits are made of differing quality. The most satisfactory engine-coolant heaters mount at the lowest point of the cooling system. When energized, the electric heating element warms the antifreeze, which continuously circulates through the engine by convection. One of the more commonly used units is made by Kim Hotstart Mfg. Co. of Spokane, WA.

Head-bolt heaters, which are inserted into the engine in place of a head bolt, in theory perform the same function as the engine-coolant heaters. However, experience has shown that they provide insufficient heat at temperatures much below 0°F.

Another important engine-starting aid is the oil-pan heater. This not only keeps the oil warm to reduce the energy needed to crank the engine, but it also provides for better lubrication when the engine is started. Three types of electric oil-pan heater elements are available.

1. A long, slender element is inserted into the oil sump through the dipstick hole. This type is

unsatisfactory because the surface temperature of the small-diameter element is too great, causing the oil to carbonize on the element, preventing its withdrawal through the dipstick hole.

2. An element replaces the oil-pan drain plug. This is generally staisfactory in operation but is subject to damage when changing oil. Also, in many cases drain plugs are at the end of the sump, which provides less satisfactory heat distribution than a central location.

3. A hole is drilled and threaded in the pan or a threaded boss is brazed or welded to the pan to accept a threaded heating element of an oil-pan heater. This type of heater is preferred because it can be installed near the center of the sump yet kept out of the way of preventive maintenance operations.

The purpose of heaters to keep the equipment batteries warm is to provide the full capacity of the batteries for engine cranking. These heaters are generally made in the form of a flat heating element that fits under the battery in the holder. To reduce heat loss at very low temperatures, insulated battery boxes are also used in many installations.

Ether Starting Fluid. When a cold engine won't start, it can sometimes be made to fire by injecting ether into the air-intake system. Ether ignites easily in both gasoline or diesel engines and is often effective. The hazard in using ether is that it burns in the engine with an explosive force, as opposed to the progressive flame propagation with diesel fuel or gasoline. If an excess of ether is introduced into an engine, the pressures resulting from combustion can be excessive. This can break engine cylinder heads, blow head gaskets, or blow a hole in the top of the pistons. As a result, the use of ether should be restricted to the more experienced and responsible persons.

Lubricants

In general, equipment manufacturers recommend using lighter weight lubricants in engines and gear boxes during winter operation than during summer operation.

Synthetic oils have been gaining wider acceptance for use in equipment operating in cold climates. In addition to being an excellent lubricant when fortified with proper additives, they have a nonthickening characteristic which reduces engine cranking effort, provides lubrication during engine warm-up, and resists vaporization under high engine load and operating temperature. Military Specifications MIL-L-46167, MIL-L-46152, and MIL-L-2104C allow engine oils to be compounded from either petroleum or synthetically prepared products, but such oils must be fortified with the necessary additives to meet the specifications. Presently, three distinct classes of synthetic oils are being produced: polyglycols, esters, and synthetic hydrocarbons.

The Naval Support Force Antarctica (NSFA), in the mid-70's, adopted a program for a gradual switch to synthetic hydrocarbon oil

as an engine lubricant for automotive and construction equipment. This oil is compatible with standard motor oil and no serious lubrication loss occurs if, through error, they are accidentally mixed. See the LIST OF APPENDIXES for current information and policy on use of synthetic oils.

Batteries

Lead-acid storage batteries of conventional form are used exclusively in the automotive and construction equipment. As seen in Figure 10-1, the capacity of a lead-acid battery decreases drastically with decreases in temperature. At -22°F a battery has less than 10% of the energy for engine starting than it has at 80°F.

Other types of batteries with better cold-weather characteristics, such as nickel-cadmium, have been considered for use but because of cost and availability have not been used.

Special attention should be given to care of storage batteries. A nearly discharged battery will freeze if left outdoors, and the case will often break.

Liquid level in the cells should be checked often for loss of water; if low, only clean, unheated water should be added. After water is added and if the vehicle will be stored outside, the battery should be charged for 20 minutes, either by running the engine or by using a battery charger. This will mix the newly added water and the electrolyte and prevent freezing and damage to the battery. More electrolyte should never be added to a battery low on liquid, since this increases the acid concentration and will soon ruin the battery.

High-Flotation Tires

With the advent of the compacted-snow road and greater use of wheeled vehicles, an interest developed for high-flotation tires for on- and off-road use. Such tires, with large ground-contact area, provide low groundbearing pressures and enable vehicles to negotiate soft-snow areas which would not support the same equipment with standard tires. NCEL, as a result of its work with various vehicles, selected four high flotation tires for use on light, medium, and heavy equipment. The U. S. Antarctic Research Program (USARP) personnel and the NSFA supply and transportation personnel have made other selections. Table 10-1 lists the different tires, along with their various suppliers and applicable vehicles.

Comparative tests of limited duration were conducted at McMurdo to determine the most suitable tire for the 1-ton Power Wagon. Details of these tests are presented in Reference 1. Results showed that mobility on all types of snow was similar between a Power Wagon equippped with Martin 17.00x16 tires and a similar truck equipped with Terra tires, size 46x18-16R front and 46x24-16R rear. These tire sizes are not currently available. Cost of either of the Terra tires and rims, however, is approximately four times more than the Martin tire. The Goodyear 16.00x16 sand tire performed poorly compared to the other two types of tires on snow surface, where all tires penetrated two or more inches. This poor performance was clearly the result of the ribbon tread pattern, which provides little traction and

Table 10-1

High-Flotation Tires in Use at McMurdo Station

Tire		Manufacturer	1974 Cost	Applicable Vehicle	PSI
19.75x20 Recap FloPower Rib	24-28PR 18-in. rim	Martin Tire Co.	$201.25	6x6 Trucks, FABCO Trailers, 5-ton Military Truck	25-35
19.75x20 Ultraflo	18 PR 17-in. rim	Martin Tire Co.	$384.75	6x6 Trucks, FABCO Trailers, 5-ton Military Truck	35
17.00x16 3-in-1	10 PR 11-in. rim	Martin Tire Co.	$156.19	1-1/4-ton Military truck, Small Trailers	10-15
16.00x16 Sand Tire	6 PR	Goodyear	$148.74	1-1/4-ton Military Truck, Small Trailers	35
66x43x25 Terra Tire	6 PR 36-in. rim	Goodyear	$848.30	Nodwell FN100TT Water Trotter, and Delta Series 3 Truck	15-20

does not grip the snow as effectively as the chevron tread. If vehicles are driven by inexperienced personnel the nonaggressive tread of the sand tire will reduce breakage of front axles and drive trains at a considerable loss of vehicle mobility. Conversely, with experienced drivers, axle breakage is not a serious problem, and the operation can use chevron-treaded tires to take advantage of their superior mobility.

The procurement of the proper rim for the high-flotation tire is very important. A rim too narrow for the tire squeezes the tire together in cross section and reduces the ground-contact area, thus reducing the effectiveness of the tire.

Tire-inflation pressure is also very important in obtaining maximum performance from high-flotation tires. Pressure higher than necessary causes the tire to take a more nearly circular cross-sectional form, thereby reducing ground-contact area and mobility. Conversely, an air pressure too low causes the tire to slip on the rim.

TRANSPORTATION EQUIPMENT

The transportation equipment at McMurdo Station is a combination of military tactical and commercial vehicles. The preferred equipment is not easily determined because each type has certain advantages. Maintenance and operation of the tactical vehicles is familiar to NSFA personnel. Furthermore, model changes are less frequent with the tactical vehicles, which simplifies spare-parts support. However, the vehicles are heavy and harder to operate under marginal road conditions. Commercial vehicles are, in many cases, more readily available and are easier and more comfortable to operate.

The availability of automatic transmissions in commercial vehicles is also considered a distinct advantage, particularly for operators inexperienced in driving on ice and snow. In NCEL experience in driving on marginal road surfaces, it is often necessary to downshift to maintain forward motion. This need is anticipated by an automatic transmission, and the change is quick and smooth. With a manual transmission, downshifting is often delayed until too late; and when done, all forward momentum is lost. In soft snow conditions this often means that the vehicle is stuck.

The complexity of repair of an automatic transmission is generally beyond the ability of the average mechanic without special training, and complete replacement of the transmission is needed. However, very few problems have been experienced with automatic transmissions in Antarctic equipment operation.

RUBBER-TIRED VEHICLES OF PAST DF-OPERATIONS

Beginning in 1964, NCEL procured various commercial rubber-tired vehicles in support of field test and evaluation programs. Several of the vehicles were subsequently procured by NSFA for general use. Although none of the vehicles are in current use, the brief descriptions that follow will be helpful in selection of future equipment.

Cargo Truck, 1-Ton, 4x4

For Deep Freeze 65, NCEL developed modifications for two 1-ton 4x4 trucks with high-flotation tires (Figure 10-2). The 1-ton Dodge Model S6W300 Power Wagons, Federal Stock Number FSN C2320-087-8741, were converted to light-duty, all-purpose vehicles. Each had a 251-cubic-inch 6-cylinder engine with 125 hp at 3,600 rpm, a 4-speed transmission and high- and low-range transfer case to provide eight forward speeds, and a 4-wheel drive with the front driving axle manually engaged and disengaged to allow optional 2-wheel drive. The stock trucks were modified as follows:

1. The 7.50x16-6PR tires and standard wheels were replaced with recapped 17.00x16-10PR aircraft tires with low-profile 3-in-1 (flotation, traction, and roadability) directional tread and suitable wheels. Tire pressure was 8 psig.

2. The fenders were changed to clear and cover the larger tires.

3. Heavy-duty, industrial-type hydraulic steering units were added to overcome the increased steering effort required for the larger tires in snow.

The Power Wagons gave outstanding service with normal maintenance. They were used on snow roads and trails, bare ice, and frozen ground, hauling passengers and light cargo easily at speeds up to 30 mph in 4-wheel drive, high range, second or third gear. In two-wheel drive, they were unsatisfactory on slippery surfaces because of operator difficulty in maintaining directional stability. The vehicles could negotiate the 10% to 20% dirt grades at McMurdo in 4-wheel drive, low range, and second or third gear. More information on this equipment is given in Reference 2.

Truck-Tractor, 7-1/2-Ton, 6x6

A 6x6 truck-tractor and 20-ton semitrailer were developed in DF-66. The truck-tractor was a Ford Model CT850 with a 477-cubic-inch V8 engine which delivered 222 net horsepower at 3,200 rpm, an automatic transmission with six forward speeds, six wheels with four drive wheels, air brakes, speed retarder, and power steering. The truck was modified by FABCO, Los Angeles, CA, as follows (see Figure 10-3):

1. A steerable, front-end drive axle was installed in place of the standard axle to provide a 6-wheel drive. The axle drive was engaged or disengaged by vacuum shift to allow optional 4-wheel drive.

2. A transfer case with direct and 2.23:1 underdrive was installed.

3. The cab was modified to seat four men.

4. Two towing hooks were installed in front on the main frame, and a 6,000-pound-pull, quick-release towing hitch was installed at the rear.

5. The 8.25x20-10PR tires and standard wheels (dual on the tandem rear axles) were replaced with recapped 19.75x20-20PR aircraft tires and suitable drop-center wheels, single on all axles. The

tires were suitable for the anticipated use at inflation pressures of 20 to 30 psig.

The 20-ton flatbed semitrailer had tandem axles, each with a capacity of 17,000 pounds. Tires and wheels were the same size as used on the truck-tractor. The load deck, 8 feet wide by 30 feet long, was 5 feet above the ground.

The truck-tractor/semitrailer combination gave satisfactory service performance with only normal maintenance. The combination hauled cargo loads on roads over snow, ice, and frozen ground at speeds up to 30 mph. The tires were inflated to 20 psig for the snow roads, but this pressure had to be increased to 30 psig for the heavy hauls and steep grades on the island dirt roads because the wheel torque caused slippage between the tire and rim.

The truck-tractor, without the semitrailer, performed construction work towing snow-road equipment (snowplane, snow roller, and snow drag), and towed dolly-converted trailers with 10-ton loads. More information on this equipment is given in Reference 3.

Passenger-Cargo Panel Truck, 4x4

For Deep Freeze 67, NCEL introduced a 4-wheel-drive vehicle with panel-delivery body for transporting personnel and light cargo. This vehicle was a 1967 Model Jeep Wagoneer fitted with a 2-door panel-delivery body (Figure 10-4). It was equipped with a 327-cubic-inch V8 engine with three-speed automatic transmission, a high-low-range transfer case, front-wheel drive operated with a single lever, and power steering.

The vehicle was modified as follows:

1. The standard wheels and 7.75x15 four-ply tires were replaced with 11.00x15 eight-ply, bar-tread high-flotation tires.

2. The rear fender well housings were relieved about 1 inch along the outer edge to accommodate the tires.

3. Front springs were replaced with 7-leaf heavy-duty units, which gave an additional 500-pound load capacity.

The Jeep vehicle operated effectively on the improved gravel roads on permafrost, the bare ice road, and the compacted-snow roads. The vehicle is not suitable for over-snow travel and was marginal on packed-snow trails (the primary disadvantage being inadequate ground clearance). The safe travel speed is about 30 mph. The recommended tire pressure is 18 pounds in the front and 12 pounds in the rear. More information on this vehicle is given in Reference 4.

Passenger-Cargo Van, 4x4

A cargo-coach van of special body design was procured for Deep Freeze 66. The basic vehicle was a 4x2 Ford Model C-700 truck chassis with a V8 engine which delivered 330 hp at 3,400 rpm, automatic transmission with six forward speeds, and power steering (Figure 10-5). The chassis was modified by FABCO as follows:

1. A steerable front-end-drive

axle was installed in place of the standard axle to provide a 4-wheel drive. The axle drive was engaged or disengaged by vacuum shift to allow optional 2-wheel drive.

2. A transfer case with direct and 2.23:1 underdrive was installed.

3. The standard tires and wheels were replaced with recapped 19.75x20-20PR aircraft tires and drop-center wheels. The tires were suitable for the anticipated use at 20-psig inflation pressure.

4. The van body was 8 feet wide, 22 feet long, and 7 feet high, and used a steel frame with an exterior skin of aluminum-covered plywood, insulated inside with 2-inch polyurethane foam. Floor plates (1/4-inch, diamond-tread aluminum) were used over a light-gage sheetmetal deck. The cargo-passenger deck was 12 inches lower than the operator's area.

The vehicle net weight was 14,000 pounds, payload 6,000 pounds, for a gross vehicle weight of 20,000 pounds. The van seated 20 passengers.

The cargo-personnel van performed satisfactorily and became the primary mode of transportation for personnel and light cargo between McMurdo and Williams Field. It could travel over the roads on snow, ice, and frozen ground at speeds up to 40 mph and climb 24% grades on dirt roads with a full load. More information on this equipment is given in Reference 5.

RUBBER-TIRED VEHICLES OF PRESENT DF-OPERATIONS

This section provides a brief description of the rubber-tired vehicles procured in the later 1970's for the McMurdo Station transportation system. This information can be used together with other records in selecting future vehicles for procurement. Selection of new equipment should be based on performance of past equipment. Knowledge of past vehicle performance is of particular importance because of the frequent changes in NSFA staff personnel responsible for selection and procurement of new equipment.

Truck-Tractor, Military 5-Ton 6x6

The tactical military 6x6 chassis is now the standard heavy-duty truck for the McMurdo Station transportation system. This vehicle is available in various configurations, enabling it to fulfill many roles. Within the current inventory this chassis is configured as a semi-tractor, a dump truck, a cargo truck, and various types of tankers (Figure 10-6). By utilizing this standardized piece of equipment the logistics of support parts has been greatly lessened.

These trucks are equipped with either a Hercules multifuel engine or an NH250 Cummins diesel. They have a 5-speed standard transmission and a 2-speed transfer case. For Antarctic service the trucks are fitted with 19.75x20-20 PR aircraft tires and the required drop center wheels.

Cargo Truck, 15-Ton, 6-Wheel, All Terrain

The Delta Series 3 vehicle (Figure 10-7) is manufactured by Foremost Ltd., Calgary, Alberta,

Canada. It is powered by a 6V-53 GMC diesel engine through either a 3- or 4-speed Allison automatic transmission with a single-speed transfer case which provides a capability of either 4- or 6-wheel drive. The vehicle is equipped with low ground pressure 66x43x25 Goodyear Terra tires, making it suitable for use on all types of terrain in the McMurdo area. The curb weight of the vehicle is 28,300 pounds and is rated at 15-ton load capacity.

A Delta Series 2 vehicle, somewhat smaller than the Series 3, is also used in the McMurdo Station transportation system.

Cargo Truck, 3/4-Ton 4x4

The Ford Model F250 truck is a replacement for the Dodge W300 Power Wagon previously used for general utility and light cargo movement. It is powered by a 300 C.I.D., 6-cylinder engine through a 4-speed manual transmission and a 2-speed selective transfer case. The front axles are fitted with selective drive hubs for 4-wheel drive. This vehicle was originally equipped with 14.35x15 Goodyear Terra tires but these were found unsuitable because of fender clearance and premature failure of wheel studs and manual steering boxes due to the additional stress caused by the wide tire. The vehicles have since been retrofitted back to standard wheels and tires (12.00x16.5 size). In this wheel-tire configuration the vehicle has good traction on ice and light snow cover but cannot negotiate in deep snow or through heavy snowdrifts.

Passenger-Cargo Van, 3/4-Ton 4x4

The Ford Model E250 12-passenger van is the replacement for the FABCO 20-passenger bus previously used for the shuttle service between McMurdo Station and Williams Field. This vehicle is powered by a 302 C.I.D. V8 engine through a C-6 automatic transmission and a 2-speed selective-drive transfer case. It is also equipped with a Pathfinder 4-wheel conversion, power steering, and front power-disc brakes. The wheels and tires are standard equipment (12.00x16.5 size).

SPECIAL CONSTRUCTION EQUIPMENT

The unusual operational requirements and construction material at McMurdo have resulted in the development of several special pieces of construction equipment. These include special equipment for construction of compacted-snow roads and also special machines for grading, trenching, and drilling in ice. Brief descriptions of this equipment follow with details on use. References are also given to NCEL publications where development criteria and procurement information can be found.

Snow-Compaction Equipment

Ski-Mounted Snow Blower. The principal use for the ski-mounted snow blower (Figure 10-8) is to elevate a snow surface in snow-road construction. It was designed and first used by NCEL in

developing techniques for snow-road construction. The unit initially cost $32,000 and consists of a model R1000 Snow Blast rotary snowplow cutter head mounted on a specially designed ski carrier. This machine has a snow-moving capacity of about 700 tons per hour. A 6-cylinder, 175-hp Cummins diesel engine is used to drive the cutter and blower system. The general procedures for operating this piece of equipment are:

1. For engine starting, follow the general guidelines outlined for tractor starting.

2. The blower engine should be run at 2,400 rpm for proper operation; if the engine lugs down either a lighter cut of snow or a reduction in the forward speed of the tow tractor can accomplish this.

3. The two snow-collector blades feeding snow to the cutter will be damaged if permitted to cut into ice. The hydraulic cylinders that operate the blades may also be damaged.

4. An LGP-D8 tractor is required to tow this piece of equipment.

5. The proper method for elevating a snow road is described in the NCEL "Snow Road--Construction and Maintenance Manual," January 1972 (Reference 6) and "Snow Road Construction by Layered Compaction Construction and Maintenance Manual," (see Technical Report R-819 in Chapter 7).

A technical report on this machine is being prepared. Specifications may be obtained by requesting NCEL drawings 67-38-1F through 17F.

Snow Mixer (Pulvimixer). The Pulvimixer (Figure 10-9) was designed and used by NCEL in developing techniques for snow-road construction. The basic principle of the machine is to break up the existing snow structure into smaller particles so that the snow will compact into a more dense mass. Each machine costs approximately $32,000. It is basically a standard road mixer that has been adapted to a specially designed ski-mounted carrier. The power plant is a D333 turbocharged Caterpillar diesel engine. The general procedures for operating this equipment are:

1. For engine starting, follow the general guidelines for tractor starting.

2. Grease the mixers after 8 hours of operation while they are still warm. (Note: Greasing of rotary shaft end bearing is extremely important.)

3. The pulvimixer is limited to a low forward speed and must be towed with an LGP-D4 tractor modified with a high-low gear-reduction box.

4. For the actual operation of the mixer in road construction, it is necessary to study and follow the procedures outlined in Reference 6.

5. Details on development of this machine are given in Reference 7.

Snow Leveler (Snow Plane). This piece of equipment, built in both 40-foot and 80-foot models (Figure 10-10 and 10-11), was designed for use in snow-road

construction. Basically for leveling farm land, this standard piece of equipment has been converted to skis and provided with a self-contained hydraulic power system. In snow-road construction, it is used for both spreading and leveling the snow. A Vickers power pack driven by a Continental 20-hp gasoline engine is used in the hydraulic system. The general procedures for operating this piece of equipment are:

1. For engine starting, follow the general guidelines for tractor starting.

2. For proper operation of the equipment, follow the instructions outlined in Reference 6.

3. The 40-foot model is used for rough grading.

4. The 80-foot model is used for finish grading and leveling of the snow road surface. The framing members of the 80-foot model are subject to damage if used for the initial snow spreading and rough-grading operation.

See References 8 and 9, respectively, for details of the 80-foot and 40-foot snowplanes.

Snow Rollers and Drags. The snow roller (Figure 10-12) and drags (Figures 10-13, 10-14, 10-25, and 10-26) are simple but important pieces of snow-road construction equipment. For their application in snow-road construction, follow the instructions outlined in Reference 6. Except for snow sticking to the metal surfaces in contact with the snow on initial start-up, the equipment operates essentially trouble-free. This sticking problem is the result of the sun warming the metal above the snow temperature. These surfaces will quickly cool down under operation; and if the snow accumulation is removed, no further problem will be encountered. Details of snow-roller design are presented in Reference 10. Details on construction of the snow drags are presented in Figures 10-25 and 10-26 since this equipment can be field-fabricated.

Ice-Cutting Equipment

Three special pieces of equipment have been procured by NSFA for working on sea ice. These are the Bros pulvimixer with ice-cutting drum, the Davis trenching machine with ice-cutting chain, and Mobile drill rig with augers and hard-rock bits for producing holes in ice and frozen ground.

Bros Ice Chipper. About DF-67 NSFA purchased three rubber-tired pulvimixers made by Bros, Inc., Minneapolis, MN. These are all Model SPRM-84B Rota-Mixers (Figure 10-15). In DF-69 NCEL procured an ice-chipper conversion drum for one of the machines under contract N62399-68-0032. The drum (Figure 10-16) is the same diameter as the standard mixer drum but is fitted with hardened steel ice-pick-like teeth with a 30-degree conical point. This conversion for ice cutting is very effective, and the machine works well for cutting a protective ice-chip cover on the ice runway. It is also used effectively to level ice ridges in the runway when they occur. In DF-75 a second Bros Rota-Mixer was con-

verted to ice cutting by replacement of the drum. No NCEL technical publications have been prepared on the machine.

Davis Ice Trencher. In DF-74 NCEL resumed* the investigation of ice-excavating machines and found that a ladder type trencher (Figure 10-17) could be successfully modified for cutting ice. The modification consisted of the substitution of a hardened-steel tooth with a 30-degree conical point (Figure 10-18) for each standard tooth.

Based on this work, NSFA purchased a larger machine of similar design for cutting ice in Winter Quarters Bay. This machine, the Task Force 1000 Trencher, is made by the Davis Manufacturing Company, a division of J. I. Case, Wichita, KA. In addition to the primary function of cutting ice for ship berthing, it should be effective for trenching ice and dense snow around buildings at Williams Field during relocation, in addition to burying utility lines. The trencher cannot be used for digging in the frozen, rocky ground in McMurdo, but must be used in ice and snow only. Details on the performance of this machine are given in Reference 12.

Mobile Ice and Permafrost Drill. The construction and scientific program at McMurdo often requires the drilling of holes in all types of terrain in the area. This can be accomplished with the rotary drill made by Mobile Drilling Co. Inc., Indianapolis, IN. Figure 10-19 shows a nearly identical, but earlier unit evaluated by NCEL.

This drilling unit is extremely versatile and is designed both for auger and fluid drilling. Figure 10-20 shows the drive head set up for augering in snow or ice. Augers cannot be used in the frozen rocky ground in McMurdo. Conversion of the machine from auger drilling to the use of a fluid to clear cuttings from the hole requires removal of the universal joint on the drive head and the intermediate guide, and substitution of the fluid swivel and NW-size threaded drill rod adapter as seen in Figure 10-21. Either compressed air or water can be used as the cutting fluid when so configured. A 300-cfm air compressor is adequate for small holes, but a larger unit is preferred.

Three basic types of drilling tools are used iwth this machine, and each has a different purpose. The auger in Figure 10-22 is for drilling in ice or snow only. If used to drill in the frozen ground in McMurdo, the augers are soon destroyed. Teeth for these augers are replaceable.

The second type of drilling tool is the tricone roller rock bit for hard rock formation (Figure 10-23). This bit, which can be used with the drill in sizes up to 5 inches, is best for drilling holes in the rock and frozen ground in McMurdo. It works well for drilling holes for guy anchors and also is excellent for drilling deep holes in snow or sea ice.

*Studies were originally begun on an ice-cutting bulldozer about 10 years ago.

The third type of bit is the tube core drill (Figure 10-24). This bit is best for drilling holes for bollards in the frozen earth-covered ice wharf and for drilling holes in McMurdo for utility poles. The cutting edge of this drill is castellated and coated with 1/8- to 1/4-inch chips of tungsten carbide in a brazing alloy matrix. To be effective, this cutting edge needs to be rebuilt frequently with new cutting particles, sometimes after each hole when drilling basaltic rock. Water is best for removing cuttings with this bit because it cools the cutting edge; although air can also be used. This machine is probably less familiar to Navy operating personnel than any other item of construction equipment. Before use of the equipment by a new operator, a study of Reference 13 is recommended.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

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12. _____. Technical Note N-1416: Sea-ice removal techniques for Winter Quarters Bay, Antarctica, by F. W. Brier and K. D. Vaudrey. Port Hueneme, CA, Dec 1975.

13. _____. Technical Report R-713: Polar construction equipment--Construction drilling for snow, ice, and frozen ground, by C. R. Hoffman and R. A. Paige. Port Hueneme, CA, Feb 1971.

What does the watt rating of the battery mean to you . . .

The chart shows what everybody knows from starting a car in the winter—that is, that the colder it gets the harder it is to start the engine. As you can see the power available from a battery decreases while the power required by the engine increases.

Available starting power (watts) is lost because the power-producing chemical reaction in the battery plates is slowed down by low temperatures. When you consider this effect of low temper. res you can see the importance of having plenty of starting power available to begin with.

The tremendous increase in starting power (watts) *required* by a cold engine is largely due to the effect of low temperatures on engine oils. This is why you should follow the vehicle manufacturer's recommendation to change oil for winter driving.

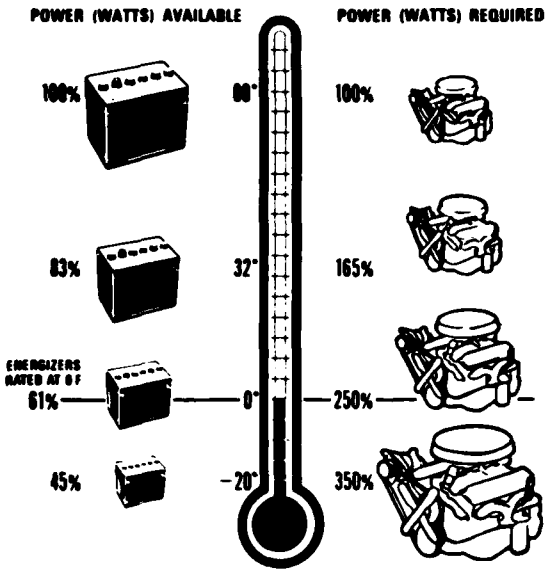


Figure 10-1. Graph showing relationship of capacity of lead-acid battery to temperature.

Figure 10-2. Power Wagon on compacted-snow road.

Figure 10-3. Truck-tractor and semitrailer on compacted-snow road.

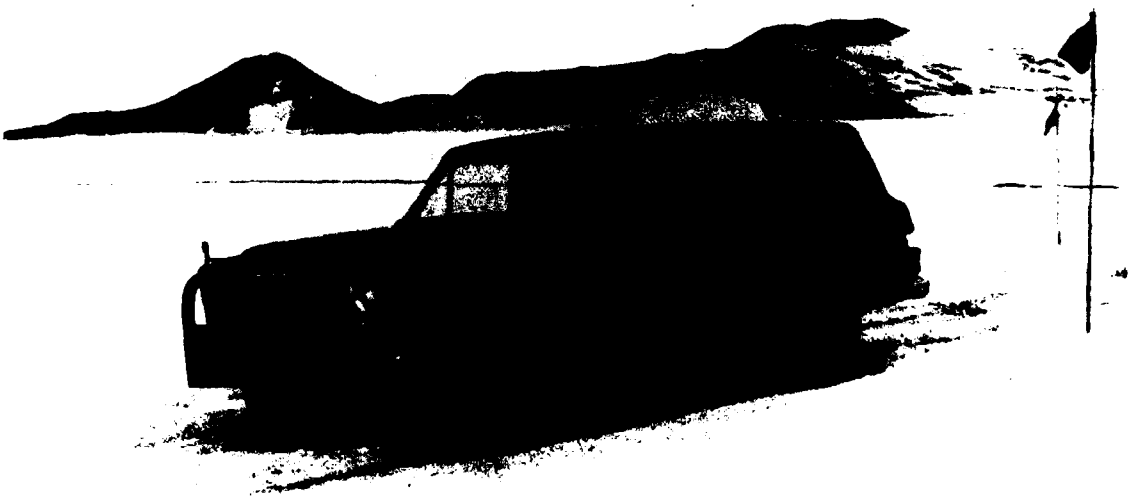


Figure 10-4. Jeep on snow road.

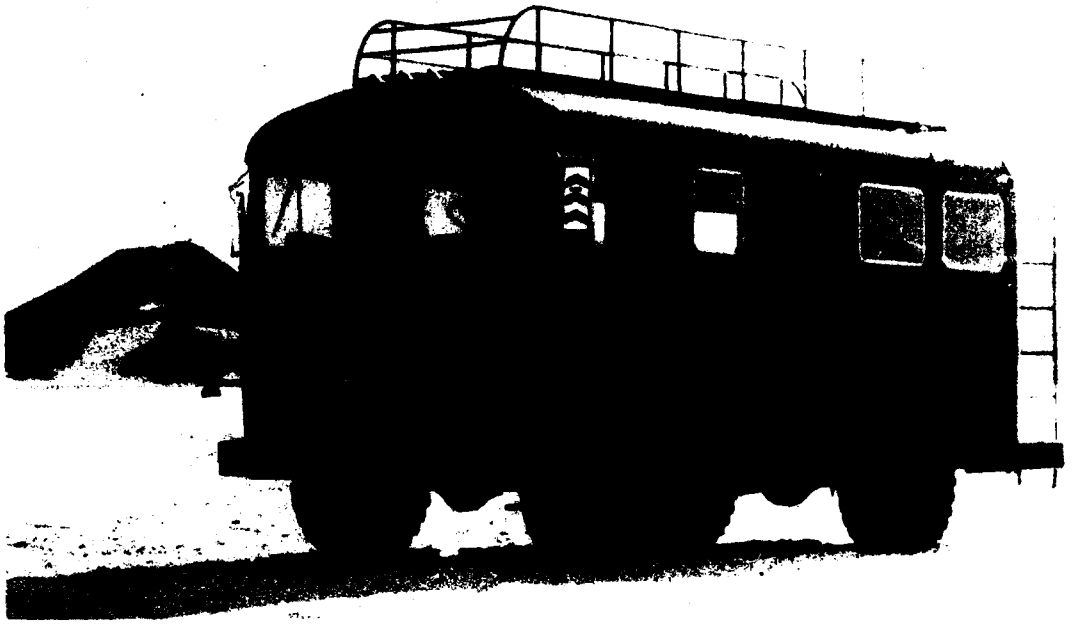


Figure 10-5. Cargo-Passenger van on ice road.

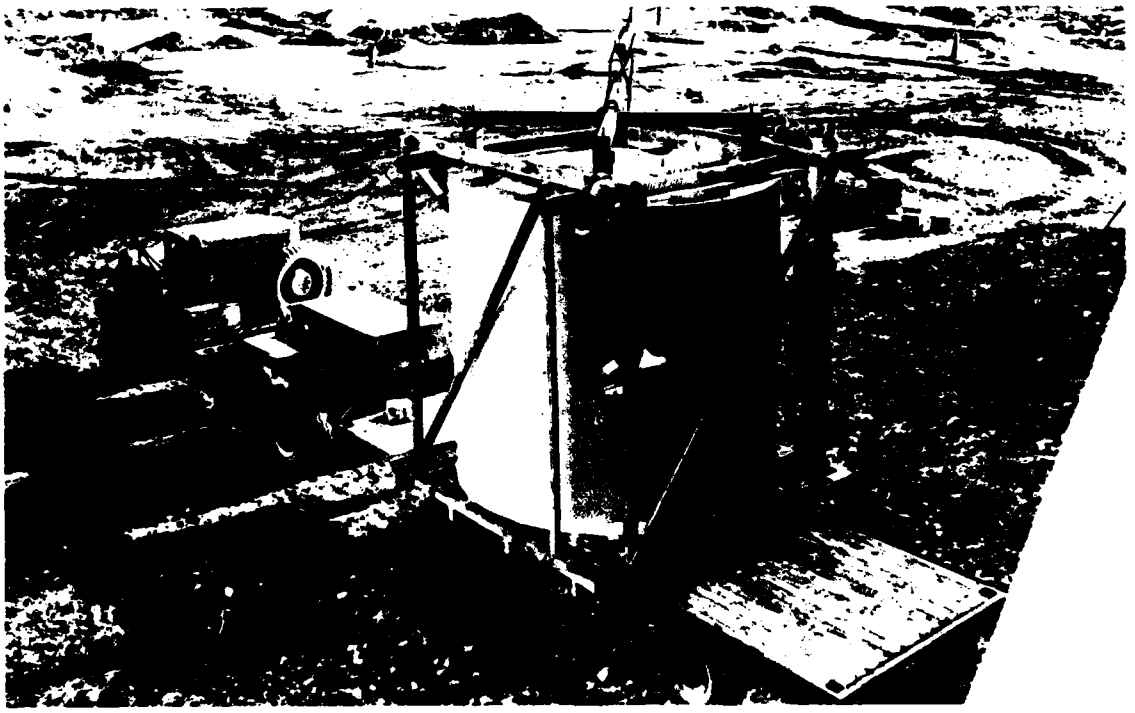


Figure 10-6. Five-ton tactical military 6x6 receiving cargo at McMurdo Ice Wharf.

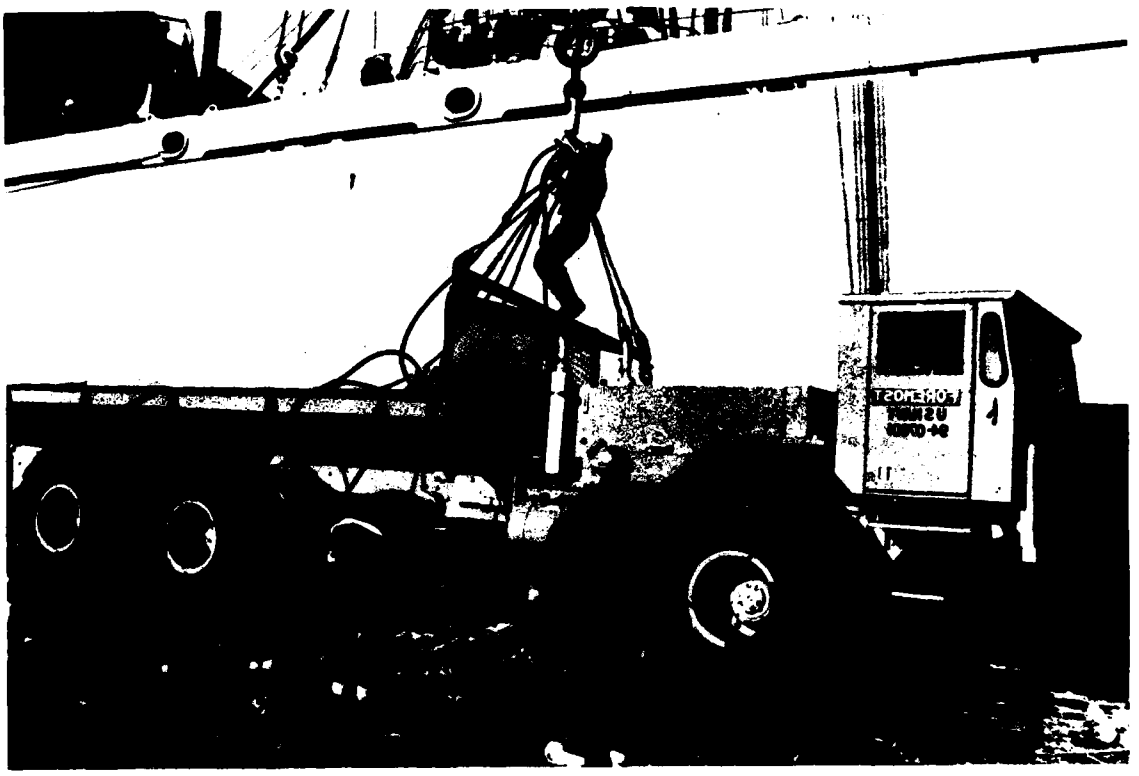


Figure 10-7. Delta Series 3, 15-ton all terrain, cargo truck during ship offloading.

Figure 10-8. Ski-mounted snow blower.

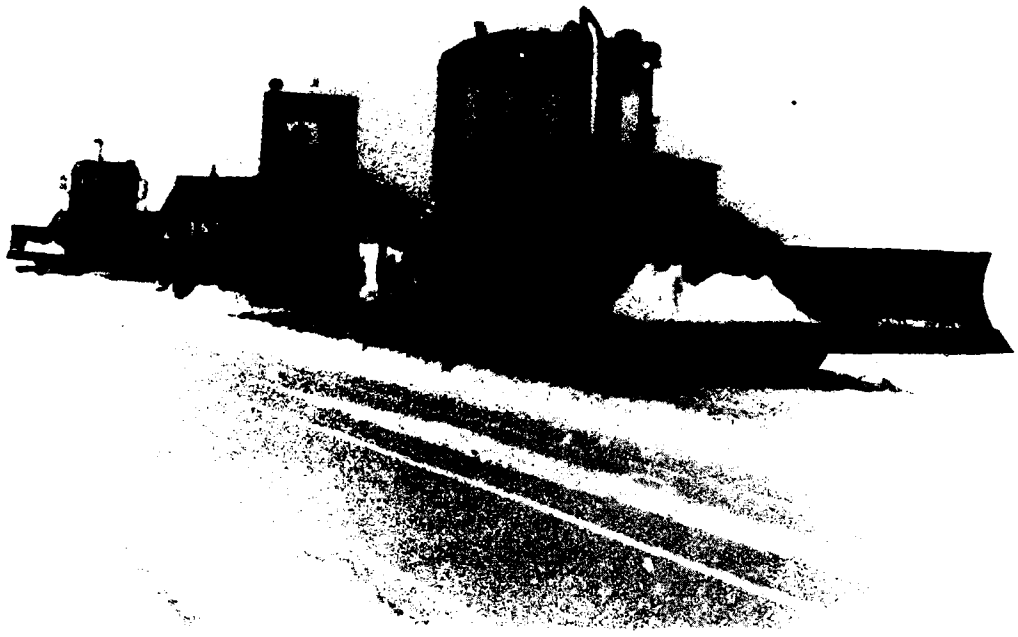


Figure 10-9. D4 tractor pulling pulvimixer used in snow road construction.

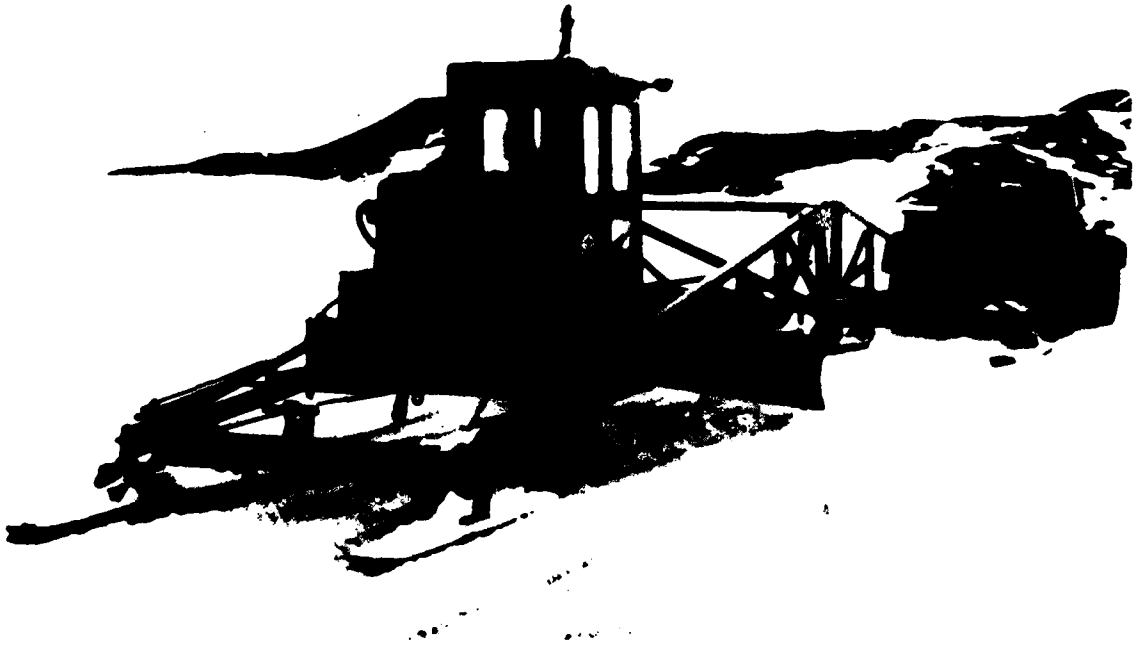


Figure 10-10. Forty-foot snow plane.

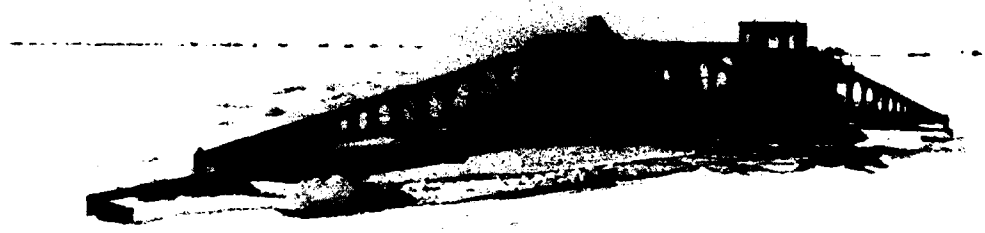


Figure 10-11. Eighty-foot snow plane.

Figure 10-12. Snow roller used in road and runway construction.

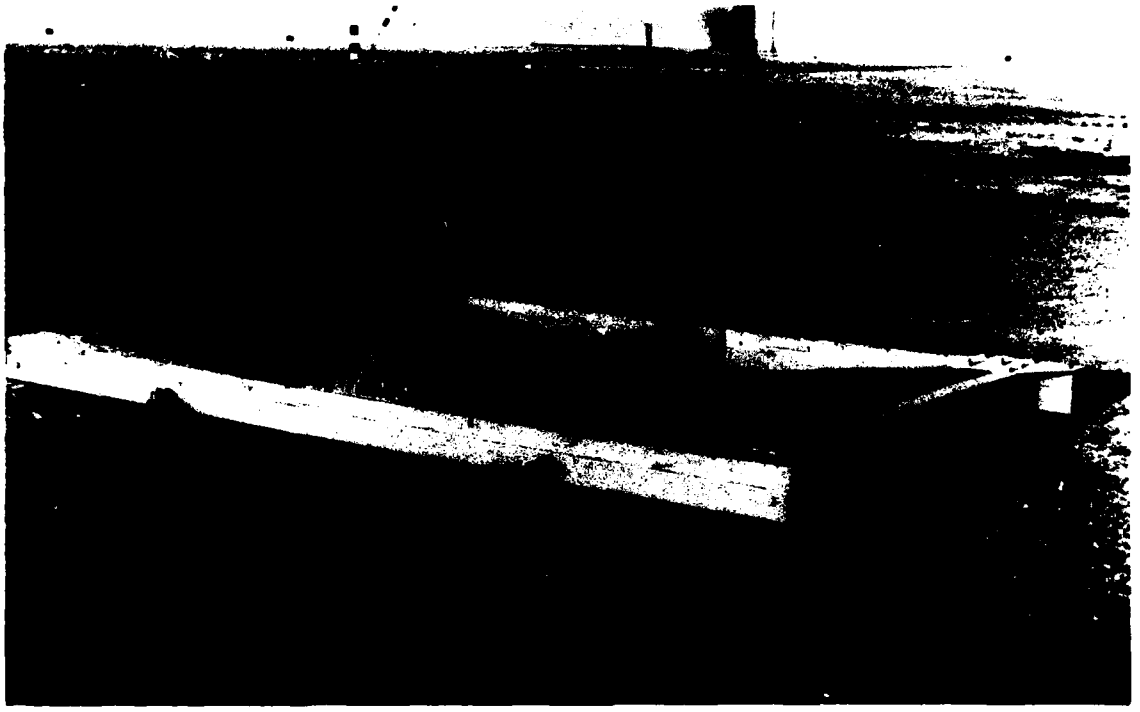


Figure 10-13. Rough drag used in road and runway construction.

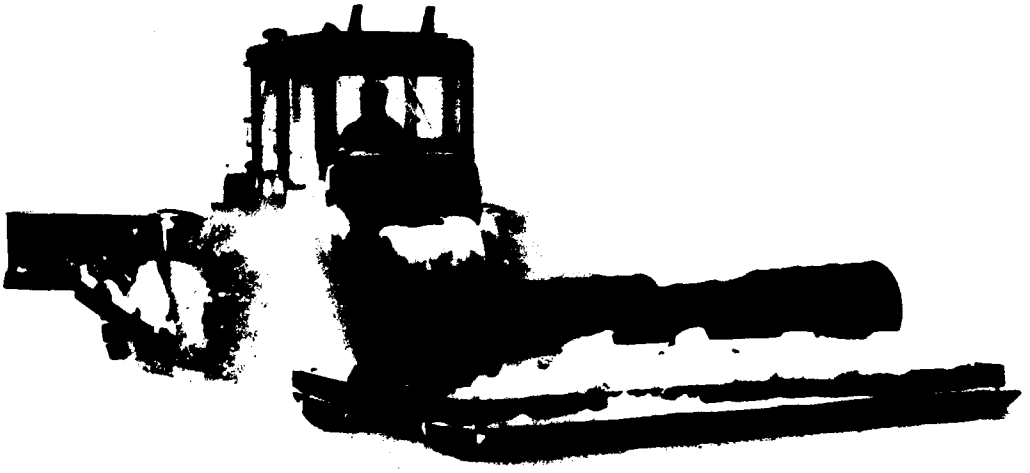


Figure 10-14. Smooth drag used in road and runway construction.

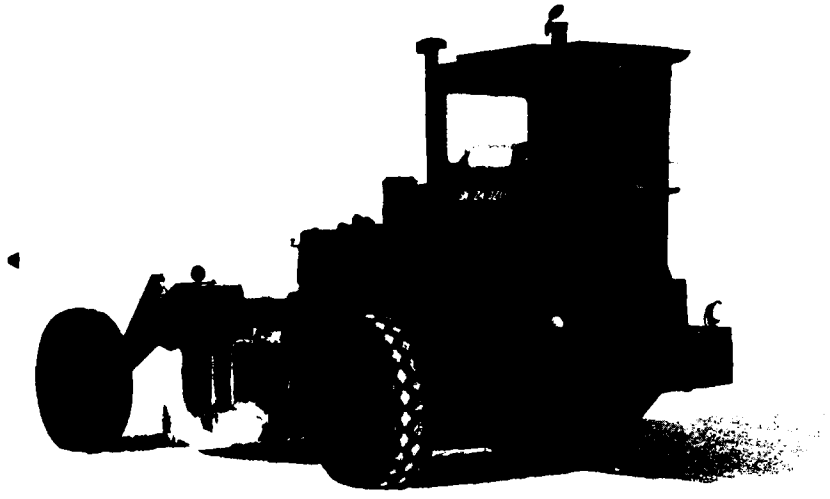


Figure 10-15. Bros Rota-Mixer.

Figure 10-16. Special ice chipper drum on Bros Rota-Mixer.

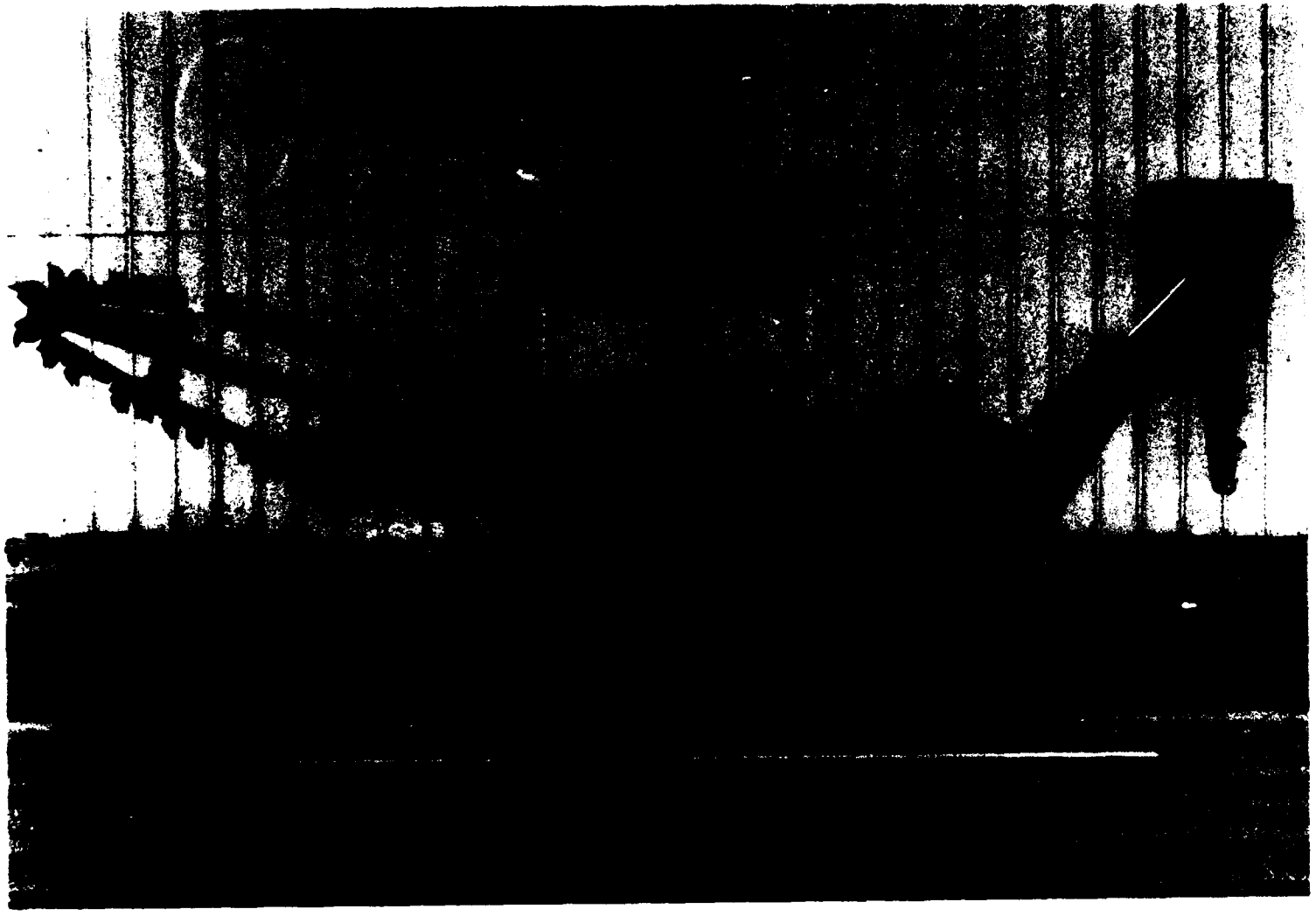
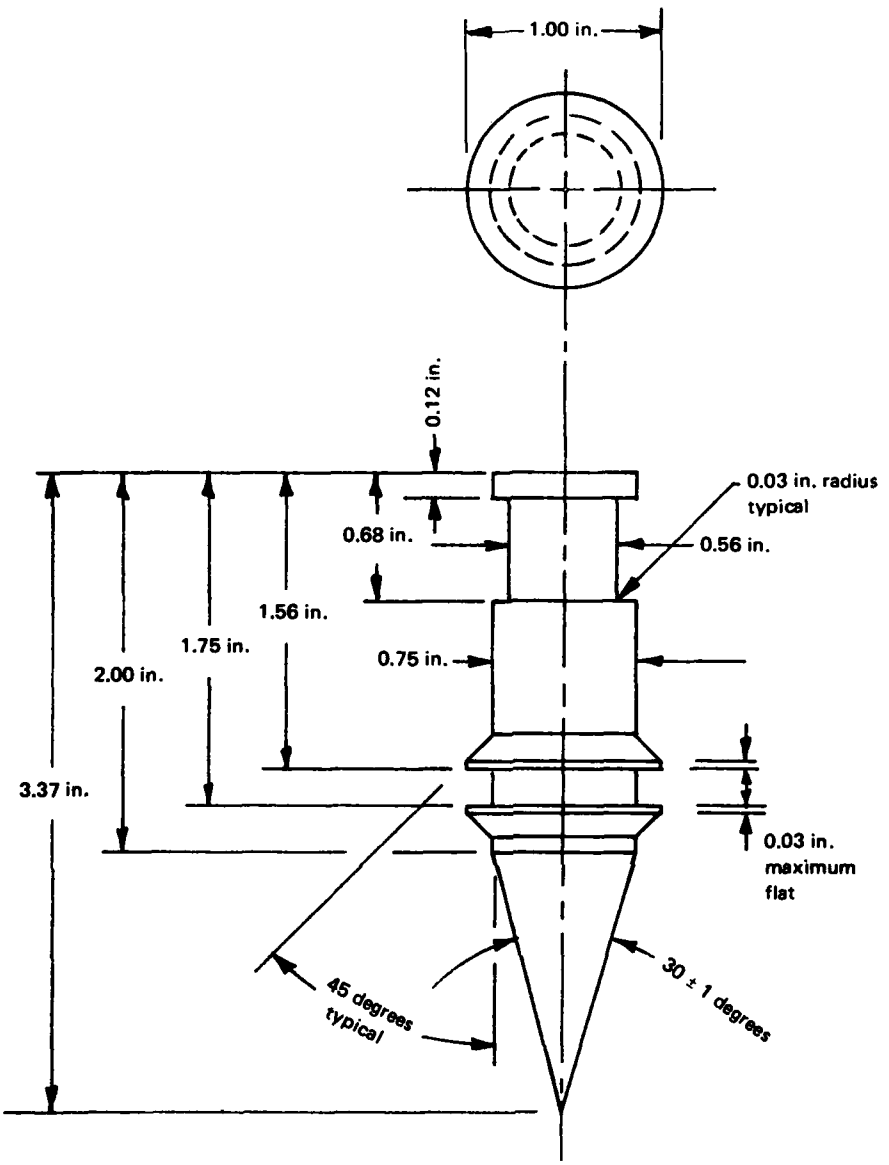


Figure 10-17. NCEL trencher converted to ice excavation.



Material: A.I.S.I. 4620 Steel
After machining, heat-treat as follows:
1. Carburize 1 hour at 1,700°F.
2. Oil quench, draw 450°F for 3 hours.

Figure 10-18. Conical ice-chipping tooth used on ice trenching machine.

Figure 10-19. Mobile drill unit for drilling in snow, ice, or frozen ground. Photo shows drilling hole for utility pole using water and the tube drill.

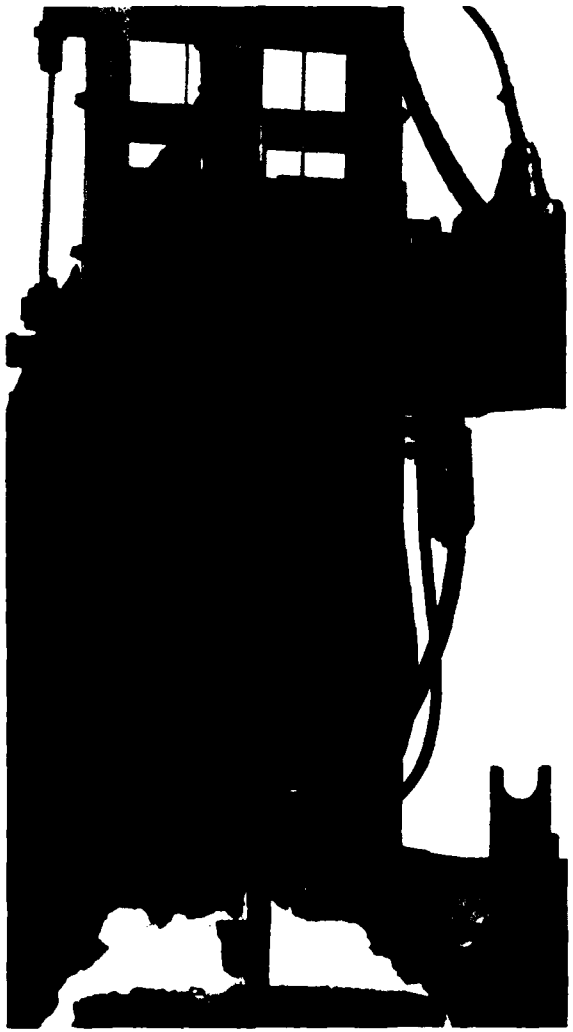


Figure 10-20. Drive head of Mobile Drill set up for auger drilling.

Figure 10-21. Drive head of Mobile Drill set up for fluid drilling.

Figure 10-22. Auger for drilling in ice or snow.

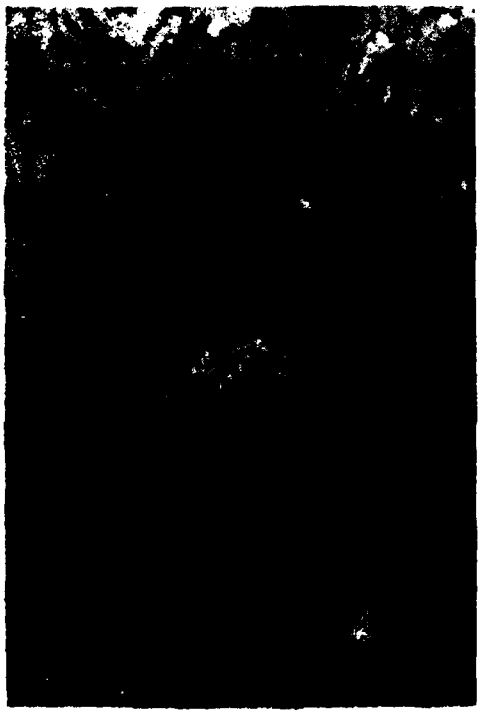


Figure 10-23. Tricone bit for drilling in frozen ground or ice.

Figure 10-24. Tube core drill with 14-inch-diameter and tungsten carbide cutting edge.

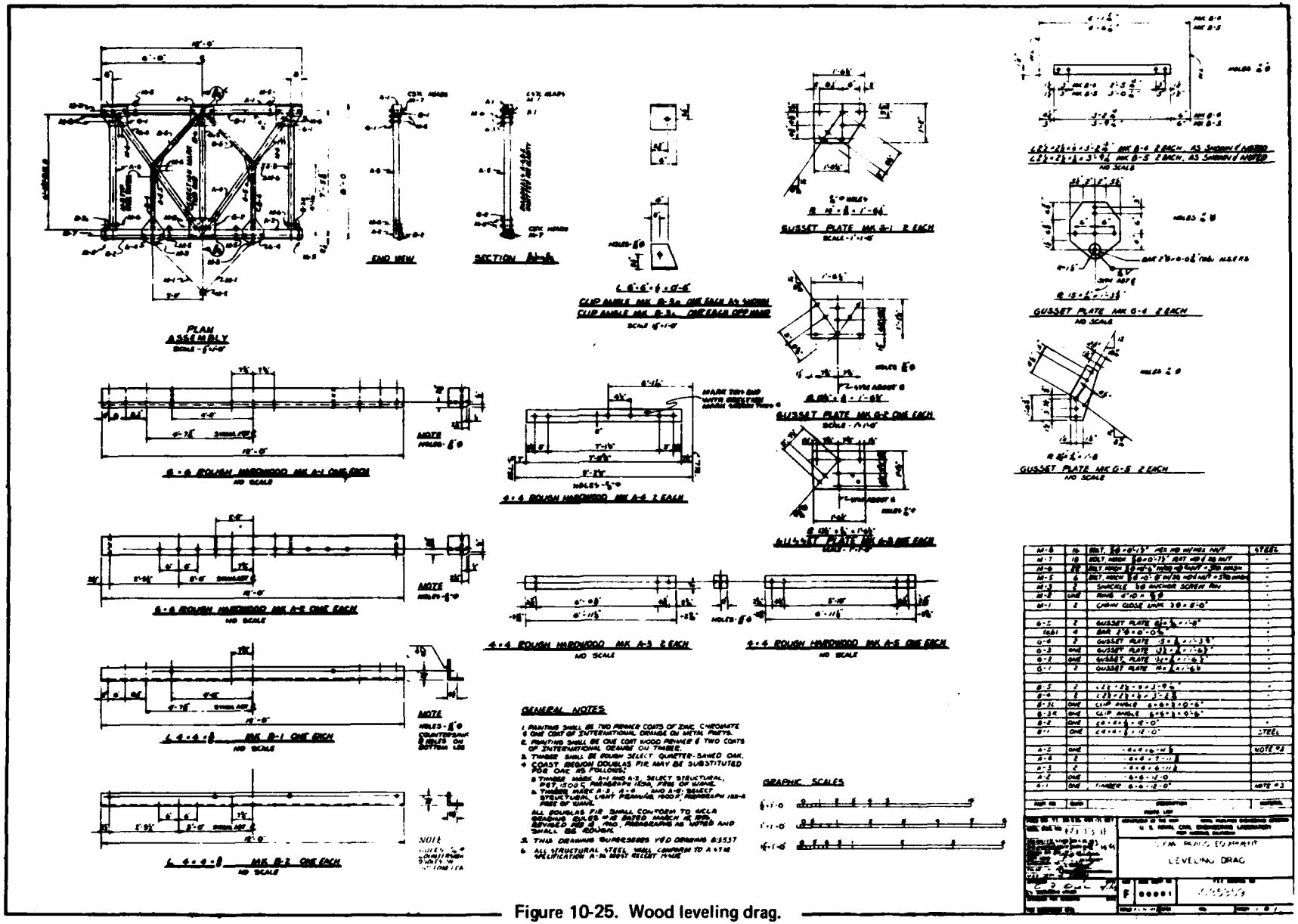


Figure 10-25. Wood leveling drag.

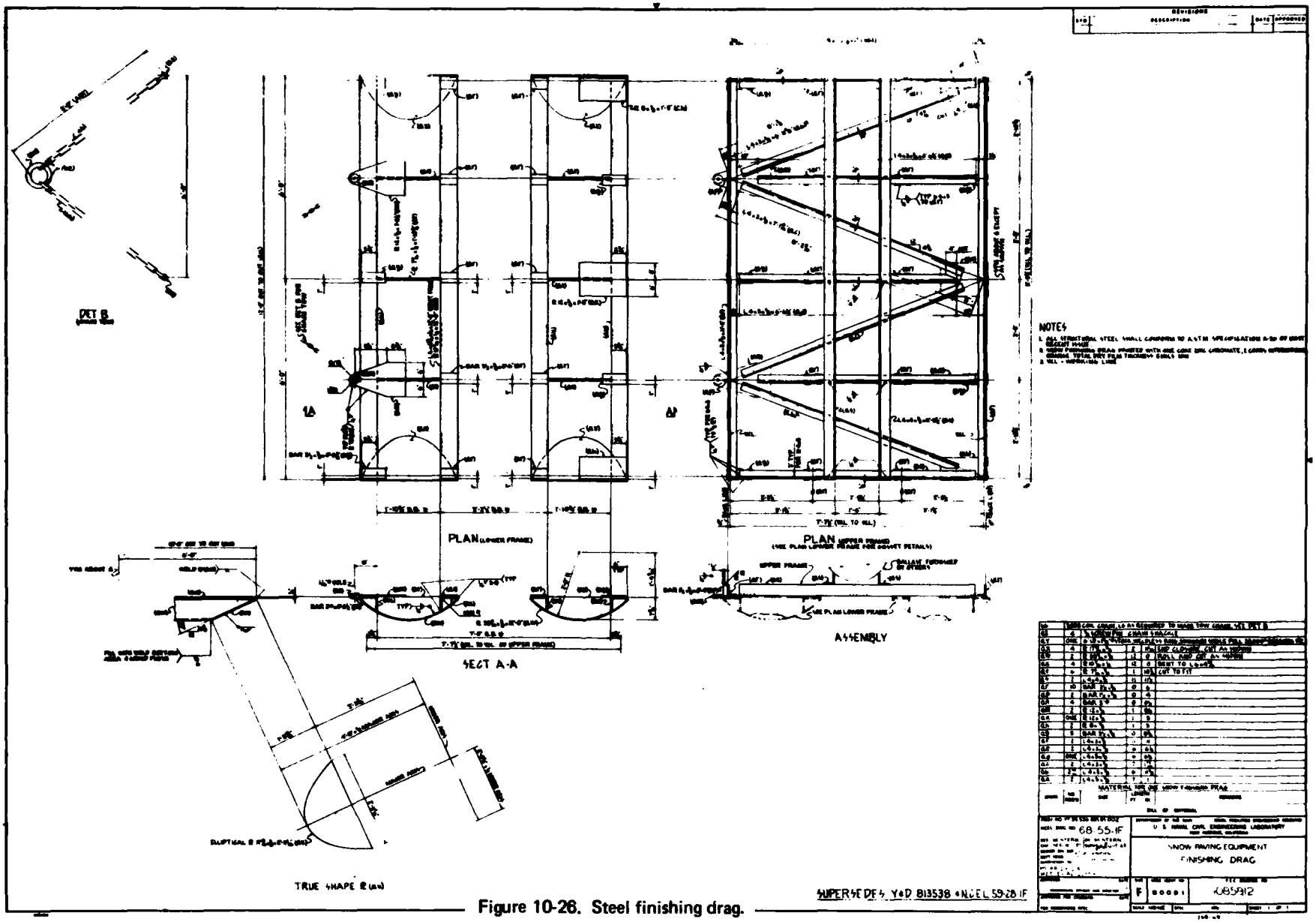


Figure 10-26. Steel finishing drag.

LIST OF APPENDIXES

Chapter 10

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

10-A. Naval Task Force Equipment. Lubrication Policy (1979)

10-B. Civil Engineering Laboratory. Technical Memorandum M-61-78-2: Application of synthetic lubricants or heaters for polar operations, by M. W. Thomas, Mar 1978.

10-C. Specifications for Caterpillar Co. Crawler Tractors (Table).

10-D. Civil Engineering Laboratory. Technical Memorandum M-61-74-4: Air transportability study of Antarctic construction and maintenance equipment, by M. W. Thomas, Jul 1977.

10-E. Cold Regions Research and Engineering Laboratory. Special Report 78-11: Construction equipment problems and procedures: Alaska Pipeline Project, by B. Hanamoto, Jun 1978.

10-F.

10-G.

10-H.

10-I.

10-J.

Appendix 10-A

NAVAL TASK FORCE EQUIPMENT LUBRICATION POLICY

(1979)

CONCO DN600 engine oil, a hydrocarbon synthetic 10-weight oil, replaces standard 30-weight oil, which was formerly recommended and used. The CONCO DN600 should be used in almost all diesel engines and in all gasoline engines. Manual transmissions, some Caterpillar power shift transmissions, differentials, power steering systems on most military 5-ton 6x6 vehicles, and compatible hydraulic systems of most equipment would also use DN600 oil.

DN600 oil can be mixed with all oil presently used at McMurdo Station.

This oil is not recommended for engines that use or burn excessive amounts of oil. Its high cost and the difficulty of resupply in a season would discourage its use.

NOTE: THIS IS DATED MATERIAL.

TM no. M-61-78-2

TECHNICAL MEMORANDUM

title: APPLICATION OF SYNTHETIC LUBRICANTS OR HEATERS FOR POLAR OPERATIONS

author: M. W. Thomas

date: March 1978

sponsor: NAVAL SUPPORT FORCE, ANTARCTICA

program nos: 61-019

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

APPLICATION OF SYNTHETIC LUBRICANTS OR HEATERS FOR POLAR OPERATIONS

61-019

by
M. W. Thomas

March 1978
Sponsored by Naval Support Force, Antarctica

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INTRODUCTION

The low temperatures encountered in polar regions greatly affect the starting and operation of transpo··ation and construction equipment. Various ways and methods have been d··eloped over the years and used to assist starting of engines. However, very little attention has been directed toward hydraulic systems and drive train components, i.e., clutches, transmissions, final drives and axle assemblies.

This report covers research on the use of synthetic lubricants and commercially available methods of heating these components.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

External heaters, mainly the Herman Nelson hot-air type, have been used extensively in polar regions to start equipment. The use of hot air to warm the engine, engine coolant, oil and other components with which the heated air comes in contact, assists in the starting and initial movement of the equipment. Therefore, very few problems have been encountered with drive train components attributed to stiff or solid lubricants, because of the hot-air pre-heat. However, with the introduction of synthetic and synthesized hydrocarbon oils for use in engines, the requirements for heating to assist starting have been greatly reduced and almost eliminated at temperatures down to -25°F (-32°C). This allows the engine to be started and equipment moved and operated while the lubricant in the hydraulic system and drive-line components is too stiff to provide adequate lubrication.

Inquiries were made to Caterpillar Tractor Company (CAT) on their recommendations on use of synthetic lubricants for equipment. Information was requested from several companies on recommendations and specifications for heaters manufactured by them for the engine, hydraulic, and drive-line components (Appendix A). Appendix A also contains a listing of the major manufacturers of synthetic oils.

SYNTHETIC OILS

The use of synthetic engine lubricants is increasing and has met wide acceptance in transportation and construction fleets. For the most part synthetics were designed for the cold-weather applications and only in recent years are the other claimed benefits, i.e., better lubrication and longer change intervals, starting to be realized. There is a lot of confusion concerning synthetic lubricants and a lot of it stems from the tendency to lump all synthetic oils together in one category. Actually, there are many different synthetic compounds capable of providing lubrication to one degree or another. The question, of course, is: which synthetics are most suitable for fleet and construction equipment use?

Although original research into synthetic lubricants goes back some 45 years, most recent interest is in three general classes of synthetic lubricants as being useful in gasoline and diesel engines. There are polyglycols, esters or di-esters and synthetic hydrocarbons.

Polyglycols

Polyglycols--or more correctly, polyalkylene glycols--are a class of synthetic lubricant chemically similar to brake fluid and antifreeze, which themselves are somewhat oily substances. When the energy crunch began to spur deeper investigation of synthetics, polyglycols were at first listed in a number of technical papers as possible alternatives to petroleum lubricants. But gradually such mention tapered off. The problem: polyglycols are not compatible with petroleum oil. A quart of regular oil accidentally poured into a crankcase of polyglycol would result in a jelly-like mess (as when antifreeze leaks into a crankcase containing conventional oil). For this reason polyglycols are generally considered "out of the running" as petroleum substitutes--not that they aren't good lubricants. In fact, their high viscosity index, excellent detergent qualities and smokeless running are ideal for high-performance two-cycle engines where oil mixing is not a problem. However, in fleet and construction equipment applications, there is too much chance for error in getting mixed.

Esters

A group of compounds called esters and di-esters makes up the second class of synthetic lubricants. These are the ones that are so often referred to as jet engine lubricants. Like other synthetics, esters retain their viscosity at extremely high temperatures, yet pour freely at extreme sub-zero temperatures. They also seem to resist oxidation much better than petroleum oil and have phenomenal detergent/dispersant qualities. The basic molecular building blocks that go into their making can come from petroleum or from animal fats like tallow or vegetable material such as castor, linseed or even coconut oil. In addition, they are compatible with standard motor oils.

Synthetic Hydrocarbons

More promising as an automotive engine lubricant is a class of fluids known as synthesized hydrocarbons. Closer kin to natural petroleum than any other type of synthetic, these lubricants are created by breaking down petroleum into its basic building blocks--hydrogen and carbon--and rearranging the molecular structure to produce man-made oils.

The reason for doing this is to obtain a more uniform and stable lubricant. Crude oil as it comes from the ground is a potpourri of heavy, medium, and lightweight hydrocarbon molecules contaminated by numerous undesirable impurities such as sulfur and waxes. The normal refining process combs out a majority of the impurities and unwanted-weight hydrocarbons to arrive at a lubricating-grade base stock. But it is practically impossible to remove all the undesirables and end up with an oil that is

all one type of molecule. Any product of conventional refining will be a less-than-perfect mix of some light and some heavy hydrocarbons along with a dash of impurities. The heavier elements thicken and resist flow at cold temperatures; the light ones thin out too much and can actually evaporate when the oil gets hot. Impurities like sulfur combine with combustion products and water vapor to form acids that eat away at bearing materials. In addition, natural petroleum oxidizes at relatively low temperatures--temperatures which hard-worked engines can exceed.

Chemists have found that by synthesizing hydrocarbons from smaller building blocks, it is possible to create oils that are completely homogenous compounds--with no undesirable impurities. Moreover, these oils can be designed from the start to possess specific characteristics such as a higher viscosity index or resistance to thinning, less evaporation and better lubricity than natural mineral oils. And unlike the polyglycols, synthesized hydrocarbons can be mixed freely with regular petroleum lubricants.

As a result of synthetics' excellent performance in Sheridan tanks undergoing endurance testing at Fort Greely, Alaska, they were accepted by the U.S. Army as an Arctic-service lubricant in the late '60s. Shortly thereafter, synthetic Arctic-service oils appeared on the Alaskan market and proved immediately popular.

A di-ester product called Frigid-Go, made by Emery Industries, Cincinnati, Ohio, and three synthetic hydrocarbon oils--Conoco's Polar Start DN-600, Mobil's Delvac HSC and Chevron's Sub-Zero Fluid--have practically revolutionized many Alaskans' approach to cold-weather starting. Where once they had to rely on electric engine heaters--or in remote areas even cruder methods of operation such as 24-hour idling, diluting crankcases with kerosene or building fires under engines--Alaskan fleets and motorists simply change to synthetic Arctic oil in the fall and drain in the spring. However, the majority of the synthetics can now be used year-round without problems. The synthetics' ability to flow at temperatures as low as -65°F (-54°C) will allow easier starting in the severest of Alaska winters. By comparison, some regular petroleum lubricants freeze solid at temperatures as high as 0°F (-18°C) and almost all are solid at -25°F (-32°C).

One of the most frequently complained of problems with synthetic lubricants is seal leakage. In mineral oils the various types of seal materials will swell slightly, making the joint even tighter, a factor which is allowed for in the design of the seal. With some esters, seals swell considerably more, while with synthesized hydrocarbons they swell less, and may even shrink. However, the larger major companies now producing synthetics are formulating the products to be compatible with the various seal materials. This appears to have eliminated the major problems of this type. Mobil is mixing some polyol ester into synthesized hydrocarbon Mobil 1 to control seal swell and make it perform about the same as petroleum products.

Despite some of the controversial claims made for synthetic oils, these attributes stand out:

1. The bulk of the evidence indicates that they are excellent lubricants when fortified with proper additives.

2. They have excellent non-thickening characteristics for cold-weather engine starting and operation, since they reduce engine cranking effort, provide lubrication during engine warm-up, and do not then appreciably vaporize under high engine load or operating temperature.

The most controversial claim for the synthesized oil lies in the claim that these oils permit extension of oil-drain intervals. The engine manufacturers generally agree synthetic oils are satisfactory as long as they meet the standard performance specification for petroleum oils. Oils meeting these specifications, however, must be drained at present standardized intervals. The problem is that extended-drain performance standards have not been established for oils. Although the Society of Automotive Engineers (SAE) and the American Society for Testing and Materials (ASTM) are working on performance standards for synthetic oils, these standards are not expected to be available in the near future, since it took about 30 years to establish the present test sequence for classifying petroleum oils.

Extensive testing of these new synthetic lubricants has been carried out by industry as well as Government agencies; however, the reports fall short of recommending their use for all applications. Reference 1 is a good example of the many reports and articles found on this testing. It recommends a comprehensive, full-scale engine dynamometer test program and an operational fleet evaluation test be undertaken to further test synthetic lubricants.

Military Specifications MIL-L-46167[2], MIL-L-46152[3], and MIL-L-2104C[4] allow engine lubricating oils to be compounded from either petroleum or synthetically prepared products or a combination of the two types with the addition of the necessary additives to meet the specifications.

While many reports and articles were found on the testing and use of synthetics in engine and hydraulic systems, very little could be located on their use in gear-train components. Military Specification MIL-L-2105C[5] covers multi-purpose gear-lubricating oils that can be synthetically prepared or be a homogenous petroleum product or a combination of the two types. These lubricants are multiviscosity grades, 75W, 80W/90W and 85W/140 and supersede standard lubricants manufactured under Military Spec MIL-L-2105B[6] and the sub-zero lubricating oils manufactured under Military Spec MIL-L-10324A[7]. These lubricants are available from several manufacturers, as listed in OPL-2105-10[8] However, most of these appear to be standard petroleum products and each company would have to be contacted to determine what type lubricant they manufacture. Some companies, like Conoco, are producing synthesized hydrocarbon gear lubricants that do not meet MIL-L-2105C but provide excellent lubrication at extreme temperatures.

One of the major items to check in any multi-purpose gear lubricant, either synthetic or petroleum products, for use in extreme cold temperature is the "channel point" of the lubricant. The term "channel point" comes from a now outdated test in which a putty-knife was drawn through a pan of chilled gear lube. If the oil slumped into the channel made by the knife, it was reasoned that the same oil at the same temperature would flow well enough inside a gearbox or differential housing to be picked up by the revolving gears and provide adequate lubrication. If, however, the temperature was low enough that the oil in the pan didn't slump back, lubrication was considered impossible, since half-submerged whirling gears would make similar channels and soon run dry. In short, the oil had reached its "channel point."

However, rather than use this once popular test, the Society of Automotive Engineers (SAE), now specifies low-temperature properties according to the temperature at which a gear lube reaches a maximum viscosity of 100,000 centipoises (cP). This measurement is more precise and has a built-in safety factor since channeling only occurs at viscosities higher than 100,000 cP.

Therefore, the selection and use of any gear lubricant that meets or exceeds MIL-L-2105C requirements for the 75W or 80W/90W grades should give satisfactory lubrication to drive-line components at the low temperatures at which engines can be started with the synthetic oils.

CAT has recommended since 1973[9] the use of synthetic or synthesized hydrocarbon lubricants in engines, hydraulic systems and transmissions for temperature ranges of +20°F to -65°F (+5°C to -54°C). In 1977 CAT has also included final drives and differentials for both wheeled and tracked equipment[10]. However, both References 9 and 10 are recommendations for later model track-type equipment that use engine oils in the transmission and final drive. In discussions with Caterpillar service representatives, they state that the engine grade of oils can also be used in the older tracked equipment in the low temperatures encountered in polar operations. This equipment, however, should not be operated for extended periods at high temperatures. The final drives and differentials of Caterpillar wheeled equipment still require gear lubricants due to the load-carrying and extreme-pressure characteristics. This is also true for most automotive-type differentials used in truck and other construction equipment.

Most transmissions, including trucks, can be changed to the lower grade or weight engine oils for extreme cold-weather operation with no adverse effects. This is recommended by Ford service representatives and is being done by some trucking fleets.[11]

The main disadvantage of using the synthetic or synthesized hydrocarbon gear lubricants is their cost, which averages 100% to 500% above standard petroleum base lubricants. At this time the synthesized hydrocarbons are the least expensive of the synthetics, and it is felt that their superior

lubricating capabilities at the low temperatures encountered in polar operation would justify their use.

HEATING UNITS

There are two types of heaters that could be used for heating equipment: all-electric or fuel-burning. The advantages and disadvantages are listed below.

Electric Heaters

There are three basic types of electrical 120- or 240-volt heaters:

1. Tank-type heaters for engine coolant.

2. Direct-immersion-in-block type for engine coolant.

3. Direct-immersion type for oil pans and gear boxes.

The manufacturer's basic recommendations for the temperatures encountered in the polar regions are as follows:

1. Engine coolant, approximately 4-5 watts per cubic inch of engine displacement.

2. Engine oil, transmission, differentials/final drives and hydraulic reservoir up to 1.5 gallons capacity - 125 watts; 1 to 5 gallons - 150 watts; 5 to 15 gallons - 300 watts; and 15 to 30 gallons - 600 watts.

The engine heaters would be of assistance to drive-line components only by routing the coolant line around or through them. This would require pumping systems and larger heating elements for the increased amounts of coolant. This type of system would also probably be a high maintenance item, in that the plumbing would lead to several possibilities of leaking coolant.

The direct-immersion type oil heaters appear to be the best way of heating the drive-line components and hydraulic reservoirs. However, there are several problems encountered in adapting the heaters to the various gear boxes and tanks. Most of the heaters are ½-inch, 3/4-inch or one-inch pipe thread, and therefore could be installed within drain holes, providing there is adequate clearance so that the elements do not touch the metal housing and do not interfere with moving gears. Mounting holes could also be cut and threaded at other suitable location in the housing for installing the heater. As the reservoir dimensions or specification of the gear housing are not readily available, each application would be more or less a custom installation. Table 1 lists the reservoir capacity of various Caterpillar equipment deployed to Antarctica.

There are three important factors to be followed when isntalling the direct-immersion type heater:

1. The elements should be at least one inch away from any metal to facilitate the oil flow around them.

2. The watts per square inch of element area should not exceed 20 to 22 to insure that additives in the oils do not boil off or carbonize on the element.

3. Thermostats should be used to maintain even temperatures and to conserve electrical energy.

The main advantage of the electric heater is that various sizes and types are available and can be adapted to different types of equipment. This will allow each component to be heated and maintained at even temperature levels. The big disadvantage is the high power requirement and initial cost. The wattage required to heat all components of the D8 tractor would be approximately 7000 watts or approximately 60A at 115V (Table 2). This includes heating the engine, which might not be required except in extreme low temperatures if synthetic low temperature oils were used. The initial list cost for electric heaters for the D8 would be approximately $470, less any government or quantity discounts, if applicable.

Fuel Burning Heaters

Fuel burning heaters are available for heating engine coolant or hot air circulation. Like the electric engine heaters, the heated engine coolant would require routing around or through the drive-line components to heat them. In lieu of using the engine coolant, the hot exhaust gases of this heater could be utilized to heat drive-line components. The hot air circulating heaters can be used to heat the engines, drive line components and cabs of some units. Extreme care must be taken to insure exhaust gases do not enter cab areas if these heaters are used during equipment operation.

The main advantage of the fuel-burning heaters is that they are self contained on the equipment. Thus the heater can be used wherever the equipment is located, eliminating the need for extensive electrical plug-in systems. This is especially useful at small, outlying field camps.

The big disadvantage of the fuel-burning heater is its vulnerability to extreme vibration present in construction equipment. In past years, the reliability of this type heater on construction equipment has not been good. However, new concepts and designs may have eliminated these problems, and testing of new units might be required. Also, these heaters require battery power to energize the circulating and fuel pumps and for firing, thus weakening the battery and possibly causing problems in starting engines.

DISCUSSION

Synthetic oils in their present formulation are a relatively new product line and, as generally is the case with the marketing of new products which have wide sales appeal, many companies made exorbitant claims in regard to their capability. This has led to both confusion and disillusion, which in some cases may have been the result of using an inferior product or the wrong application of an otherwise good product. Guidance on the use of these oils is also not available at this time, as no standard performance specifications have yet been established by such authoritative bodies as the Society of Automotive Engineers or the American Society for Testing and Materials. Currently there is one Military Specification (MIL-L-46167 dated 15 February 1974) written specifically for arctic lubrication oils for use in internal combustion engines. At this point, as near as can be determined, none of the major companies are producing synthesized hydrocarbon oils that fully meet this specification. Conoco, a company producing synthesized hydrocarbon oil, states it is currently reformulating its oil to meet this specification, while Gulf Oil is currently marketing a synthetic product that meets the specification.

It was the construction of the Alaskan Pipeline that first produced the widest and probably the most severe testing of the qualities of the synthesized hydrocarbon oils as lubricants for equipment operating at extremely low temperatures. More recently, at the opposite end of the world, the Naval Support Force Antarctica has adopted a program of a gradual switch to this type of oil for engine lubrication in its automotive and construction equipment. There is an abundance of evidence, although not well documented, that hydrocarbon synthetic oils have performed well.

The itemized listing that follows, except for Items 1 and 2, is primarily a synopsis of the material covered in Caterpillar Company's Operation, Lubrication and Maintenance Guide, "Cold Weather Operation," dated November 1977[10]. The material selected only covers equipment lubrication and only to the extent of that considered pertinent to the Antarctic operating environment. The material as presented in this report is intended for use as a condensed source of information that may be helpful in selecting lubricants. The "Cold Weather Guide" by Caterpillar Co. covers the full spectrum of servicing and maintenance of their equipment in cold weather and should be referred to if questions arise on material presented in the report.

1. The new, specially formulated polar grades of synthetic oils will reduce the requirement for engine preheat of transportation and construction equipment operating in polar regions.

2. Polar grade synthetic oils should eliminate much of the need to idle the engine because of difficult engine starting, during periods when the equipment is not operating. Engine shut-down will both reduce wear and conserve fuel.

3. Reference 10, the Caterpillar Company guide to cold weather operation, recommends that engine and transmission oils meet specification CC (MIL-L-46152) and CD (MIL-L-2104C). If CC engine classified oils are used, they recommend one-half normal drain interval. For ambient air operating temperatures of approximately 20°F (-5°C) to -65°F (-55°C) use special purpose oils meeting diesel performance of Engine Service Classification CC or CD, with added stipulation that oils for power-shift transmissions must satisfy the friction retention performance requirements of Caterpillar Test No. CD/TO-2.

4. For multipurpose-type gear lubricant Reference 10 specifies using lubricants designated GL-5 (MIL-L-2105B). This specification is dated 1962 and has been replaced by MIL-L-2105C dated January 1977. The GL-5 designation indicates the lubricant's suitability for hypoid axles experiencing high-speed shock loads, in addition to various combinations of low and high speed and torque loads. Lubricants without proper fortification for the extreme pressures resulting from the sliding friction of hypoid gearing will not stand up under such loads.

For the final drive of track vehicles, reference 10 recommends SAE 10W for ambient air operating temperatures from 30°F (0°C) to -40°F (-40°C) and special oils for temperatures 30°F (0°C) to -65°F (-55°C). These oils must meet Engine Classification CC or CD.

For the final drive and differential of wheel vehicles operating in air temperatures 50°F (10°C) to -40°F (-40°C) SAE 75W (MIL-L-2105C) is recommended. For temperatures 30°F (0°C) to -65°F (-55°C), use GL-5 special purpose lubricants that meet SAE 75W viscosity with pour and channel points no higher than -65°F (-54°C).

5. For cold weather hydraulic systems, Reference 10 recommends for ambient air temperatures 90°F (30°C) to -65°F (-55°C) the use of special engine oil formulated to meet Engine Service Classification CC (MIL-L-46152) or CD (MIL-L-2104C) stipulating for year-round operation they have shear stability and viscosity at 212°F (100°C) of at least 5.7 centistrokes. It is also stipulated these oils must contain anti-wear (zinc dithiophosphate), anti-foam, and anti-corrosion additives, and have a pour point lower than ambient starting temperature.

RECOMMENDATIONS

After the review of available literature and extensive conversation with Caterpillar representatives, it is recommended:

1. The use of synthetic hydrocarbon lubricants, such as Conoco Polar Start DN600 Fluid, Mobil DELVAC 1, or equivalent, be continued and expanded for all engine lubrication and hydraulic systems in all equipment in polar regions.

2. The use of these synthesized hydrocarbon lubricants be expanded to include transmission of tracked and wheeled construction equipment and all transportation equipment.

3. That the use of the synthesized hydrocarbon lubricants, such as Conoco Polar Start DN600 Fluid, Mobil DELVAC 1, or equivalent, be also expanded to the final drives of all tracked construction equipment for polar operations. This will meet with the recommendation of CAT set forth in Reference 10. However, caution must be noted that any equipment using this type of lubricant in transmissions and final drives must not be operated at continued high ambient temperatures. That is, if this equipment is returned stateside for any reason, operation must be for short duration only.

4. That synthetic or petroleum lubricants that meet the 75W grade of MIL-L-2105C, such as Mobilube HD Gear Lube, or synthesized hydrocarbon lubricants, such as Conoco Polar Start DN600 Gear Lube, Mobilube SHC Gear Lube, or equivalent, be used in differentials of all wheeled vehicles.

5. It is further recommended that the Naval Support Force, Antarctica, give serious consideration to testing the use of a "front-to-back" lubricant in the construction equipment used in the Antarctic. Utilization of one or more of the new LGPD6 tractors currently planned for new procurement, or one of the wide-track 941's procured last year, could be used for this test. The Conoco Polar Start DN600 Fluid or Mobil DELVAC 1 appear to be excellent candidates for this testing. This would entail the use of one type and make of lubricant in the engine, transmission, final drives, hydraulic system, track rollers and idlers. A comprehensive test plan with adequate documentation would have to be followed to insure data and records to properly evaluate the results.

6. It is also recommended that electric or fuel-burning heaters be installed on emergency or priority type equipment only; i.e., crash/rescue vehicles, fire trucks, priority cargo or personnel equipment, or in equipment that is used frequently and has to be left outside at stations such as South Pole or small inland stations.

REFERENCES

1. Lestz, Sidney J., et al., Evaluation of Synthetic Automotive Crankcase Lubricants for Military Applications, Interim Report AFLRL No. 71, U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, and U.S. Army Mobility Equipment Research & Development Command Laboratory 2000, Ft. Belvoir, VA. December 1975.

2. Military Specification MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Arctic. 15 Feb 1974.

3. Military Specification MIL-L-46152, Lubricating Oil, Internal Combustion Engine, Administrative Service. 20 Nov 1970.

4. Military Specification MIL-L-2104C, Lubricating Oil, Internal Combustion Engine, Tactical Service, 20 Nov 1970.

5. Military Specification MIL-L-2105C, Amendment 1, Lubricating Oil, Gear, Multipurpose, 28 Jan 1977.

6. Military Specification MIL-L-2105B, Lubricating Oil, Gear, Multipurpose, 19 February 1962.

7. Military Specification MIL-L-10324A, Lubricating Oil, Gear, Sub-Zero, 7 Feb 1957.

8. Military Qualified Products List QPL-2105-10, 31 Aug 1977, for Military Spec MIL-L-2105C.

9. Caterpillar Tractor Co. Publication GEGO 2178, Cold Weather Operation Guide, September 1973.

10. Caterpillar Tractor Co. Publication SEBU5338, Cold Weather Operation Guide, November 1977.

11. "Winterizing for Winter," Commercial Car Journal, Vol. 134, Number 3, November 1977.

Table 1. Caterpillar Equipment

Equipment	Cu. In. Displacement	CAPACITIES - GALLONS							
		Cooling System	Engine Crankcase	Transmission Power Shift	Transmission Direct Drive	Final Drive/or Diff.(ea)	Hydraulic Reservoir	Hydraulic System	Bevel Gear & Steer. Clutch
D8	1246	32	9	31	35	9.5	18.5		
D4	425	8	5	10	6	2.5	6.5		
955	425	10.5	5		9	2.5	25	39	17.5
931LGP	318	6.5	3	4.5		2.5	8	13	4
950	425	7.5	5	8		8.5	29	41	Front Diff. 7

Table 2. Wattage and Cost of Electric Heaters

Equipment	ENERGY REQUIREMENTS - WATTS						
			Transmission				
	Cooling System	Engine Crankcase	Power Shift	Direct Drive	Final Drive/or Diff.(ea)	Hydraulic Reservoir	Batteries
D8	5000	300	600		300	600	(2) 150
D4	2000	150	300		150	300	75
955	2000	150	300		150	600	75
931LGP	2000	150	150		150	300	75
950	2000	150	300		300	600	75

Kim Hot Start Mfg. Co. Price List, 1 Sep 1977
Quantity or Government Discounts May Apply

Watts	Cost
5000	$129.80
2000	71.40
600	65.81
300	65.81
150	65.81
75 (battery)	39.30

APPENDIX A

Heater Manufacturers

Mastermotive, Inc.
445 West Nixon Street
Savage, MN 55378
612-890-2360

Pacific Chromalox Division
Emerson Electric Company
2150 N. Rulon White Blvd.
Ogden UT 84404
801-782-3030

General Electric Co.
Industrial Heating Business Dept.
1 Progress Road
Shelbyville, IN 46176
317-398-4411

Edwin L. Wiegand Division
Emerson Electric Co.
7506 Thomas Blvd.
Pittsburgh, PA 15230
412-242-6400

Phillips Co.
8200 Grand Ave. South
Minneapolis, MN 55420
612-888-4105

Southwind Division
Stewart-Warner Corp.
1514 Dover St.
Indianapolis, IN 46221
317-632-8411

Webasto North America
71 Park St.
Troy, MI 48084
313-585-5880

Kim Hot Start Mfg. Co.
P.O. Box 42
Spokane, WA 99210
509-328-4020

Major Manufacturers of Synthetic Oils

Conoco
Continental Oil Co.
S. Greenway Plaza East
P.O. Box 2197
Houston, TX 77001

Mobil Oil Corp.
150 East 42 St.
New York, NY 10017

Emery Industries
4900 Este Ave.
Cincinnati, OH 45202

Chevron USA, Inc.
Product Engineering Dept.
225 Bush St.
San Francisco, CA 94120

Gulf Oil Corp.
P.O. Drawer 2038
Pittsburgh, PA 15230

SPECIFICATIONS FOR CATERPILLAR CO. CRAWLER TRACTORS

	New D8K		LGPD7G		LGPD6D		LGPD5		LGPD4D		LGPD3		Old LGPD8
Rated Horsepower	300 @ 1330 RPM		200 @ 2000 RPM		140 @ 1900 RPM		105 @ 1750 RPM		75 @ 2000 RPM		62 @ 2400 RPM		191
	Weight (lbs)	Cost ($)	Weight (lbs)	Cost ($)	Weight (lbs)	Cost ($)	Weight (lbs)	Cost ($)	Weight (lbs)	Cost ($)	Weight (lbs)	Cost ($)	Weight (lbs)
Basic Unit	54,675	116,420	41,000	98,130	31,650	72,830	24,310	50,240	16,205	30,160	12,350	22,890	51,020
Cab & ROPS	1,525	8,350	1,640	8,160	1,640	3,985	2,065	5,200	2,180	4,985	910	2,320	1,100
Enclosure, Engine	190	1,205	189	920	225	775	180	720	NL	NL	35	135	
Guard, Crankcase	333	630	420	595	225	357	100	306	NR	NR	145	383	
Heater, Cab	28	725	53	725	53	725	63	376	55	376	20	418	
Starter Group, Low Temp	NL	NL	20	428	14	428	12	239	110	263	5	68	
Total	56,751	127,330	43,322	108,958	33,807	79,100	26,730	57,081	18,550	35,784	13,465	26,214	52,120
Ground Bearing Pressure (psi)	10.4		5.3		4.1		3.5		3.5		3.3		3.0
Bulldozer	12,080	17,630	7,960	14,280	4,900	9,350	3,957	6,640	2,487	5,450	2,650	4,840	15,000
Total	68,831	144,960	51,282	123,238	38,707	88,450	30,687	63,721	21,037	41,234	16,115	31,054	67,120
Ground Bearing Pressure (psi)	12.7		6.3		4.7		4.1		4.0		4.0		3.9
Winch	2,960	13,040	2,989	10,970	2,360	10,120	2,360	10,000	1,800	6,460	NL	NL	2,960
Total Complete Unit	71,791	158,000	54,271	134,208	41,067	98,570	33,047	73,721	22,837	47,694	16,115	31,054	70,080
Ground Bearing Pressure (psi)	13.2		6.7		5.0		4.4		4.3		NL		4.1
Track													
Width (in.)	22		34		36		34		30		25		54
Length on Ground (in.)	124		120		113.38		111		87		81.6		159.75
Total Contact Area (sq in.)	5,437		8,140		8,163		7,548		5,290		4,080		17,253
Length													
Without Blade (in.)	207		166		155		150		128		109		243
With Blade (in.)	260		224		203		197		169		145		299
Width													
Without Blade (in.)	120		131		119		115		109		90		164
With Blade (in.)	159		164		146		138		120		95		202
Height													
Without Cab (in.)	96		89		80		77		68		68		96
With Cab (in.)	134		128		113		111		106		107		128
Mfr Rated Drawbar Pull at Max Speed in 1st Gear (lbs)	56,000 @ 1.7 MPH		38,890 @ 1.6 MPH		25,360 @ 1.7 MPH		19,340 @ 1.7 MPH		15,580 @ 1.5 MPH		NL		45,020 @ 1.5 MPH
Calculated Drawbar Pull for Compacted Snow (lbs) (Wt x Coefficient of Traction)*	18,000		13,600		10,300		8,300		5,700		4,000		17,500

Approximate Cost of Equipment based on U.S. Port of Entry or Factory FOB, effective 27 Jun 1977.

NL = Not listed
NR = Not required

*Based on the assumption that the track contact area provides sufficient flotation to keep the tracks operating on the surface.

TM no. M-61-77-4

TECHNICAL MEMORANDUM

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author: M. W. Thomas

date: July 1977

sponsor: NAVAL SUPPORT FORCE, ANTARCTICA

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CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

FOR OFFICIAL USE ONLY

AIR TRANSPORTABILITY STUDY OF ANTARCTIC CONSTRUCTION AND MAINTENANCE EQUIPMENT

61-019

by
M. W. Thomas

July 1977
Sponsored by Naval Support Force, Antarctica

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INTRODUCTION

Remote inland stations and emergency camps in Antarctica require air delivery of equipment for camp construction and maintenance, cargo handling and research support. This report summarizes in tabular format the basic weight and dimensions of various equipment and accessories that are either currently in Antarctica or obtainable as standard production from the manufacturer. Cited with the weight size tabulation for each piece of equipment is a reference number directing the reader to a section of the report containing information on the weight and component part disassembly and reassembly time to make the equipment acceptable for transport by LC-130R aircraft.

This memorandum was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

EQUIPMENT DESCRIPTION

The maximum payload that can be delivered by LC-130R aircraft to a particular site is dependent upon such variables as flight distance, station altitude, refueling accommodations, weather, and condition of runway/skiway or natural surface at both the departure and receiving sites. This study attempts to relate the sequence of removing component parts from the basic equipment to achieve a weight/dimension package for aircraft load ranges of 25,000 pounds (maximum), 21,000 pounds (middle), and 18,000 pounds (low). The maximum dimension for a transportable package of the equipment considered is limited by the size of the LC-130R cargo door, which is 120 inches wide and 108 inches high. None of the equipment covered approaches the allowable length of 492 inches accepted by the aircraft. Tables 1 and 2 provide the weight and dimensions for the basic equipment and accessories, and the total weight and dimensions for the complete unit with all accessories installed. The note column in the tables refers to information contained in sections titled "Removal of Component Parts."

REMOVAL OF COMPONENT PARTS

The time standards given are based on studies of actual time required for component disassembly and reassembly under normal shop conditions. It is likely that the time requirements will more than double when performed in cold weather and/or in exposed, unsheltered conditions, and without many of the tools available in a normal shop. The tabulated labor hours indicate the total time required for removing and replacing the component.

NOTE 1.

TRACTOR LGP-D8 AND STD D8. To effectively reduce the weight of these large Caterpillar tractors to the load parameters established will require major disassembly. This will include removal of the complete bulldozer assembly,

cab, winch, complete track assemblies, track roller frames, and engine with all accessories.

The component weights listed below are estimated, based on the limited information and specifications available for the 1955 and 1959 units.

Component Assemblies	Weight (lbs) LGPD8	STD D8
Track assembly (both sides) (Includes shoes, links, pins and hardware)	12,960	5,200
Track Roller Frame assembly (both sides) (Includes all rollers, idlers and sprockets)	11,500	10,800
Engine	7,500	7,500
Accessories (starter, engine, radiator guards, covers, fuel and lubricants)	2,500	2,500
Total Weight	34,460	26,000

Time Standards for Removing and Replacing Standard D8 Components

Component	Manhours
Track Assembly (one side)	3.4
Frame Assembly (one side)	8.0
Engine	15.8
Dozer Assembly	4.0
Cab	4.0
Winch	4.0

NOTE 2.

TRACTOR LGP-D4 DUAL RAIL WITH ALUMINUM TRACK SHOES. This specially configured Caterpillar LGP-D4 will meet the maximum load range with the removal of the complete bulldozer assembly, and the middle range by removing the cab, winch, drawbar and guards for the radiator, engine and crankcase. The removal of the bulldozer is also required to meet the maximum width dimension allowed. To meet the low load range will require the additional removal of the dual-rail track and track roller frame assemblies. However, serious consideration should be given to exceeding the lower load range by not removing the track roller frame assembly, due to the time and equipment required.

Component Parts	Weight (lbs)
Track Assembly (both sides) (Includes shoes, links, pins and hardware)	2,340
Track Roller Frame Assembly (both sides) (Includes rollers, idlers and sprockets)	4,230
Dozer Assembly	3,070
Guards	
Radiator	130
Crankcase	305
Engine Enclosure	125
Drawbar	235
Cab	750
Winch	1,500
Total Weight	12,685

Time Standards for Removing and Replacing LGP-D4 and D4 Components

Component	Manhours
Track Assembly (one side)	2.4
Track Frame Assembly (one side)	6.0
Rear Drive Sprocket Dual Rail (one side)	5.0
Dozer Assembly	3.0
Cab	4.0
Winch	4.0

NOTE 3.

TRACTOR D4 STANDARD. The standard Caterpillar D4 will meet the maximum and middle load range without removal of any components, and the lower load range by removing the bulldozer.

The time standards will be the same as the LGP-D4.

NOTE 4.

TRACK-TYPE LOADER LGP955 DUAL RAIL. The Dual-Rail Caterpillar LGP955 is listed here for reference purposes only. There is only one of these units in Antarctica, and its present condition will probably preclude it being flown to inland stations.

NOTE 5.

TRACK-TYPE LOADER LGP955 SINGLE RAIL. The Single-Rail Caterpillar LGP955 will meet the maximum load range with the removal of the bucket/fork assembly and the cab, and the middle load range by removing the winch and lift arms. The lower load range will require the additional removal of both track assemblies, 1,976 lbs. The cab must be removed to meet the 108-inch height requirement.

Time Standards for Removing and Replacing
LGP955 Components

Component	Manhours
Bucket/forks	2.0
Cab	4.0
Lift Arms	4.0
Track Assembly	5.2

NOTE 6.

TRACK-TYPE LOADER 955 STANDARD. The Caterpillar STD 955 will meet the maximum load range fully assembled but will require the removal of the cab to meet the 108-inch height requirement. The middle load range can be met with the additional removal of the bucket/fork assembly and the lift arms. The additional removal of the winch will then meet the lower load range.

The time standards for the STD 955 are the same as the LGP955.

NOTE 7.

TRACK-TYPE LOADER LGP931. The Caterpillar LGP931 will meet all load ranges and the height requirement by removal of the cab and bucket.

Time Standards for Removing and Replacing
LGP931 Components

Component	Manhours
Cab	5.0
Bucket	1.5

NOTE 8.

TRANSPORTATION VEHICLE (PERSONNEL) CF60. The NODWELL CF60 meets all load and dimension requirements and can be driven on and off the aircraft without removal of any components.

NOTE 9.

TRANSPORTATION VEHICLE (AMBULANCE) CF110. The NODWELL CF110 meets all load ranges but is five inches over the maximum 108-inch allowed height. The height can be reduced two inches and the width 24 inches by removing the track assemblies; however, the tires and wheels must also be removed to meet the allowed dimensions.

Time standards are not available for the NODWELL vehicles.

NOTE 10.

TRACTOR LGPD7G (NEW SERIES). The new Caterpillar Tractor Series LGPD7G will require major disassembly to meet the load and dimension parameters established. The removal of the cab, winch, bulldozer, track assembly and track roller frame assembly will be required to meet the maximum load range and dimensions. The radiator guard and radiator assembly must also be removed to meet the middle range, and the complete engine assembly removed to meet the lower range.

Component	Weight (lbs)
Track Assembly (both sides)	6,990
Track Roller Frame Assembly (both sides)	9,950
Radiator Guard and Radiator	1,625
Dozer Assembly	7,960
Cab	1,640
Winch	2,990
Engine	2,250
Total Weight	33,405

Time Standards for Removing and Replacing
LGP7G Components

Component	Manhours
Track Assembly (one side)	1.5
Track Frame Assembly (one side)	4.0
Dozer Assembly	4.0
Cab	6.0
Winch	4.0
Engine	13.6

NOTE 11.

TRACTOR LGPD6D (NEW SERIES). The new Caterpillar Series LGPD6D tractor will require the removal of cab, bulldozer, winch and track assembly to meet the maximum load range and dimension, and the track roller frame assembly to meet the middle and low load ranges.

Component	Weight (lbs)
Track Assembly (both sides)	7,530
Track Roller Frame Assembly (both sides)	8,250
Radiator and Radiator Guard	1,410
Dozer Assembly	4,900
Cab	1,640
Winch	2,360
Total Weight	26,090

Time Standards for Removing and Replacing
LGPD6D Components

Component	Manhours
Track Assembly (one side)	1.3
Track Frame Assembly (one side)	3.5
Dozer Assembly	4.0
Cab	3.0
Winch	4.0

NOTE 12.

TRACTOR LGPD5 (NEW SERIES). The new Caterpillar Series LGPD5 tractor will require the removal of the cab, bulldozer and winch to meet the maximum load range and dimensions. Additionally, the track assembly will need to be removed to meet the middle load range, and the radiator and radiator guard to meet the low load range.

Component	Weight (lbs)
Track Assembly (both sides)	5,950
Radiator and Radiator Guard	1,150
Dozer Assembly	3,960
Cab	2,065
Winch	2,360
Total Weight	15,485

Time Standards for Removing and Replacing LGPD5 Components

Component	Manhours
Track Assembly (one side)	1.3
Dozer Assembly	3.0
Cab	4.0
Winch	4.0

NOTE 13.

TRACTOR LGPD4 (NEW SERIES). The new Caterpillar Series LGPD4 Tractor will meet the maximum load range for both weight and dimensions. However, due to the maximum 120-inch width of the dozer blade, it might be advisable to remove the blade. The complete bulldozer assembly must be removed to meet the middle load range, followed by the cab to meet the low load range.

Component	Weight (lbs)
Dozer Blade only	919

The time standards for removing and replacing LGPD4 (New Series) components are the same as for the older LGPD4's.

NOTE 14.

TRACK-TYPE LOADER 941 (WIDE GAUGE). The Caterpillar Wide Gauge Track-Type Loader will require the removal of the bucket/forks and the cab to meet the maximum load range and dimensions. The additional removal of the winch, lift arms and hydraulic cylinders will be required to meet the middle load range, and track assemblies to meet the low load range.

Component	Weight (lbs)
Track Assembly (both sides) (Includes shoes, link, pins and hardware)	4,220
Bucket	1,600
Lift Arms and Hardware	1,605
Hydraulic Cylinders	295
Cab	2,420
Winch	1,910
Total Weight	12,050

The time standards for removing and replacing components for the 941 will be the same as those for the LGP 955.

Table 1. Existing Antarctic Equipment

Manufacturer	Equipment	Weight (lbs)	Length (in.)	Width (in.)	Height (in.)	Note
Caterpillar	LGPD8	51,020	243	164	96	1
	Cab	1,100	68	72	56	
	Winch	2,960	75	50	90	
	Bulldozer	15,000	183	202	60	
	*Total	70,080	299	202	128	
	STD 8	42,240	182	107	96	1
	Cab	1,100	68	72	56	
	Winch	2,960	75	50	90	
	Bulldozer	12,000	183	160	60	
	*Total	58,300	238	160	128	
	LGPD4	21,840	155	112	71	2
	Cab	750	55	46	56	
	Winch	1,500	34	28	34	
	Bulldozer	3,070	126	158	33	
	*Total	27,160	190	158	107	
	STD D4	15,515	152	80	71	3
	Cab	750	55	46	56	
	Winch	1,500	34	28	34	
	Bulldozer	2,955	126	121	33	
	*Total	20,720	184	121	105	
	LGP955	25,660	148	128	90	4
	Cab	750	50	42	65	Dual
	Winch	1,440	34	35	40	Rail
	Bucket	1,650	50	128	50	
	Lift Arms	4,000				
	*Total	33,500	210	128	127	
	LGP955	19,660	132	116	90	5
	Cab	750	63	57	67	Single
	Winch	1,440	34	35	40	Rail
	Bucket	1,650	46	116	50	
	Lift Arms	4,000				
	*Total	27,500	190	116	120	
	STD 955	17,160	132	86	90	6
	Cab	750	63	57	67	
	Winch	1,440	34	35	40	
	Bucket	1,650	46	86	49	
	Lift Arms	4,000				
	*Total	25,000	190	86	120	
	LGP 931	16,642	135	90	75	7
	Cab	1,310	50	63	67	
	Winch	1,500	20	34	20	
	Bucket	770	33	95	40	
	*Total	20,222	168	95	112	
Nodwell	CF60	10,400	193.75	97.5	99.75	8
	CF110	18,200	252	119	113	9

*Complete unit with accessories installed

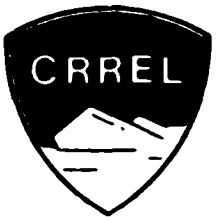
Table 2. Available New Equipment

Manufacturer	Equipment	Weight (lbs)	Length (in.)	Width (in.)	Height (in.)	Note
Caterpillar	LGPD7	41,000	166	131	89	10
	Cab	1,640	74	64	74	
	Winch	2,989	50	46	48	
	Bulldozer	7,960	144	164	50	
	*Total	53,589	224	164	128	
	LGPD6	31,650	155	119	80	11
	Cab	1,640	71	65	63	
	Winch	2,360	45	48	52	
	Bulldozer	4,900	125	146	45	
	*Total	40,550	203	146	113	
	LGPD5	24,755	150	115	76	12
	Cab	2,065	71	65	63	
	Winch	2,360	45	48	52	
	Bulldozer	3,957	125	138	38	
	*Total	33,137	197	138	111	
	LGPD4	16,670	133	100	67	13
	Cab	2,180	72	48	60	
	Winch	1,800	34	35	41	
	Bulldozer	2,487	126	120	38	
	*Total	23.137	169	120	105	
	941	22,990	127	94	86	14
	Cab	2,420	68	57	64	Wide
	Winch	1,910	34	35	41	Gauge
	Bucket	1,600	36	96	44	
	*Total	28,920	178	96	112	

*Complete unit with accessories installed

APPENDIX 10-E

Special Report 78-11



CONSTRUCTION EQUIPMENT PROBLEMS AND PROCEDURES: ALASKA PIPELINE PROJECT

Ben Hanamoto

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PREFACE

This report was prepared by Ben Hanamoto, Research General Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded under OCE Order No. ENG-CRREL-76-1.

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INTRODUCTION

Construction of the Trans-Alaska pipeline, with its requirements for a large variety and amount of equipment, and harsh environmental working conditions, posed many problems which are not encountered on projects in the "lower 48." With suitable facilities, competent personnel, proper care, maintenance, and operation and climatic conditions that are not too adverse or extreme, near maximum service can be realized from construction equipment. But much of the work on the Alaska pipeline was not accomplished under these conditions.

Factors contributing to the difficulty were: temperatures as low as -70°F (-57°C) and common winter temperatures of -30°F (-34°C), the remoteness and isolation of some of the work camps, the mental attitudes and physiological effects resulting from the working environment, and the quality of the personnel willing to work under such adverse conditions. Certain combinations of the above factors can make it impossible to obtain any useful work from either man or machine, and the single factor of extremely low temperature overtaxes both.

A unique feature of the project was the complex management and work contract system of the Alyeska Pipeline Service Company. The entire line was divided into five sections, with a prime contractor responsible for the work in each one. Work progressed simultaneously. This work allotment scheme increased the number of pieces of equipment and machinery needed, since each section required a complete assortment. With such a fleet of equipment, the maintenance and repair task became one of major proportions and importance. This report describes some of the typical problems encountered with construction equipment in the far north and the procedures and remedies for solving the problems or at least tempering their effects so that productive work could be accomplished. The report is based in part on observations and discussions in the field on the Trans-Alaska pipeline construction project in June 1976.

LUBRICANTS, HYDRAULIC FLUIDS AND FUELS

Preventive maintenance played a key role in equipment operation, and a strict lubrication schedule had to be maintained on all pieces of equipment. This included oil and filter changes and lubrication plus scheduled oil sample analyses. Samples were taken on a scheduled basis from such units as the final drive, transmission, power shift transmission, and engine. A chemical analysis was run on the samples for wear.

Detection of metals such as lead, copper, iron, chrome, aluminum and molybdenum, and of fuel contaminants such as silicon, salt and water helped identify specific parts such as bearings and gears that might be wearing, and helped pinpoint potential trouble areas. If excess contaminants were found in a piece of equipment, the sampling intervals were shortened so that the wearing part could be identified and remedial steps of repair or replacement taken before a major failure occurred. A sample wear analysis report is shown in Figure 1.

Motor oils meeting the performance standards of engine service classification CD, MIL-L-2104C in SAE 10, 30 and 40W and multi-weight SAE 5W-20 were acceptable. Brand names included: Union Guard All, Chevron Delco 760, Shell Rotella, Mobil Delvac Universal Oil and Texaco URSA Oil Super 3. Lubricants and oils containing base stock which was either synthetic or synthesized hydrocarbons were also acceptable. Brand names of synthetic oils included: Conoco DN-600, Emery Frigid-GO 85 and Mobil SHC.

Gear lubricants for transmissions and differentials were SAE 75-140 multi-grade. All-purpose automotive greases with a lithium base meet arctic requirements. Acceptable were: Chevron AVI Motive Grease, Lubriplate Lo-Temp, Mobil MT-502, Shell B&B Grease and the synthetic Conoco DN-600 Grease.

Hydraulic fluids were either petroleum-base or synthetic-base types. Texaco and Chevron market an arctic hydraulic oil meeting specifications under MIL-5606. Aviation hydraulic oil can also be used, but with the drawback of not meeting the valve wear test as the temperature gets warm. SAE 10W motor oil also meets the manufacturers' requirements for the hydraulic systems on all equipment. Acceptable were: Mobil DTE Oil, Texaco Regal R&O, Union Redline Turbine Oil and Shell Turbo Oil. Acceptable synthetic fluids were: Emery Frigid-GO 85 and Conoco DN-600 AWH (antiwear hydraulic).

No. 2 diesel fuel is sufficient for normal operations. No. 2 becomes sluggish at low temperatures, however, and at -50°F (-46°C) will not flow. At these low temperatures, aviation jet A grade fuels were recommended, with JP-4 and JP-5 working well.

Other fluids used in the equipment included 95% ethylene glycol based antifreeze. When mixed 50-50 with water, this gave a solution which did not freeze until the temperature reached -65°F (-54°C). Methanol was used as a fuel deicer.

STARTING, WARM-UP, AND COLD WEATHER EFFECTS AND PROCEDURES

Equipment manufacturers install special winterization items on equipment being sent to the cold regions. Some of these items for diesel engines include:

N C WEAR ANALYSIS REPORT
05/28/76

ALYESKA-PIPELINE SA-76-30/TAX

MAKE: CATERPILLAR
MODEL: D4
SERIAL NO: 7U32994
EQUIP NO: A12-492
APPLICATION: TRACK TYPE TRACTOR
AREA: LEFT

ATTN:
CUSTOMER NO: 0361306
COMPARTMENT: FINAL DRIVE

	SAMPLE A DELTA	SAMPLE B	SAMPLE C	SAMPLE D	SAMPLE E
SAMPLE NO.	F32151				
DATE RECEIVED	05/21/76				
DATE SAMPLE TAKEN	05/17/76				
TOTAL COMP HOURS	002811				
OIL USED HOURS	1500				
QTS OF OIL ADDED					
LEAD-PB	66				
COPPER-CU	187				
IRON-FE	280				
CHROME-CR	1.0				
ALUMINUM-AL	103				
SILICON-SI	168				
MOLYBDENUM-MO					
MAGNESIUM-MG					
SOOT					
WATER	1%				
SALT WATER					
GLYCOL					
% FUEL DILUTION					
VISCOSITY					

ANALYZED BY:

COMMENTS:
A-PINION SEAL LEAKAGE EVIDENT
FLUSH SYSTEM TO REMOVE CONTAMINATION: RESAMPLE IN 100 HOURS

NOTE:
METALS ARE SHOWN IN PARTS PER MILLION (PPM) AND ARE EVALUATED ACCORDING TO HOURS OR MILES IT HAS BEEN IN USE, AMOUNT OF OIL ADDED, RECENT REPAIRS, TYPE OF OPERATION AND OTHER CONDITIONS WHICH MIGHT AFFECT THE CONCENTRATION.

THIS ANALYSIS IS INTENDED AS AN AID IN PREDICTING MECHANICAL WEAR. NO GUARANTEE, EXPRESSED OR IMPLIED, IS MADE AGAINST FAILURE OF THIS COMPONENT.

Figure 1. Oil sample wear analysis report

1. Engine coolant heaters
2. Quick oil change systems
3. Ether starting aids
4. Heavy duty starting systems
5. Heavy duty electrical systems
6. Special starting cable receptacles
7. Special seals
8. Curtains for sides, engines, radiators

As the weather gets colder, some cold weather pre-operation and operating hints include:

1. If the oil viscosity has been changed, be sure to change filters too. Also drain heavy oil from all hydraulic cylinders and lines and then after changing the oil be sure to run the machine to set the thinner oil circulating.

2. Use alcohol injection into the air system on any machine with an air compressor to prevent any moisture present in the system from freezing.

3. Keep the engine crankcase breather pipe free of any obstruction of ice or snow to prevent engine seal and gasket damage.

4. Check antifreeze solution frequently to assure adequate protection.

5. Keep batteries fully charged and warm if possible.

6. Check air cleaners and intakes daily and as required when operating in snowfall.

7. Fill fuel tank at end of each shift.

8. Check condition of rubber components frequently.

9. Pre-condition all hydraulic hoses before operating below -40°F (-40°C).

10. Use starting fluids cautiously.

11. Prepare the vehicle by using compartment enclosures, heaters, and storage facilities as required.

12. Leave machine idling or stored in warm area if temperatures are below -10°F (-23°C).

A general inspection of the vehicle conducted before getting into the cab included a check of: a) hydraulic hoses, tires and belts for cuts, cracks and worn spots; b) electrical wiring and connections for fraying and worn insulation; c) tracks, idlers, sprockets and rollers for wear and ice and frozen mud; d) all dip sticks for proper levels.

Engine start-up did not require added precautions until the ambient temperature fell below +32°F (0°C). Four categories or temperature ranges are cited by the Caterpillar Tractor Company where different techniques and procedures are required for a start-up[1]:

Category 1, +32°F (0°C) to +10°F (-12°C).

Use of glow plugs required on electric start vehicles. Normally, direct injection engines will not require starting aids in this temperature range.

Category 2, +10°F (-12°C) to -15°F (-26°C).

Use of glow plugs and coolant heaters required on electric-start vehicles. Starting fluids may also be required. External starting power source will be needed if battery is not fully charged. Ground lead must be connected to frame at point below and away from the battery to prevent any sparks near the battery. Glow plugs or starting fluid should be used as required for diesel engines equipped with gasoline starting engines.

Category 3, -15°F (-26°C) to -40°F (-40°C).

Engine and battery compartments should be closed and heated. Starting fluids, glow plugs and pre-heating of coolant are required on all vehicles. Where external power source is used, a permanent booster cable should be provided to prevent arcing battery terminals. It is normal practice to idle engine rather than shut down at temperatures under -10°F (-23°C).

Category 4, below -40°F (-40°C).

It is necessary that engine be idled or vehicle kept in heated area since starting cannot be assured at these temperatures. If this recommendation cannot be followed, pre-heating of coolant and oils for 2 to 4 hours or longer will be required to provide water outlet, battery cell, and oil temperatures of 0°F (-18°C) minimum prior to attempting a start. A heated battery compartment or external power source will be required. Even though the engine may start because the coolant and oil have been preheated, it must be remembered that all other components are frigid.

In addition to these starting procedures for various temperature levels, other cold weather precautions were followed before a unit was put to work. In all cases, a careful inspection of the oil in the hydraulic system had a high priority. At temperatures around 0°F (-18°C, transmission and hydraulic systems work sluggishly, and these units were excercised carefully and slowly for 15 minutes in order to get oil moving and warmed throughout the system, especially the hydraulics. The warm-up excercise started with the hydraulic system. The engine was run at less than 1/3 throttle while gradual exercise of each circuit was begun. The raise/lower, extend/retract sequence was continued and gradually the amount of piston travel was lengthened with each cycle. This was done for all implement circuits. To exercise the transmission and power train, operation was begun with the engine running slightly above low idle. Alternately the first forward and reverse speeds were selected several times with the service brake on. Then the brakes were released and the machine alternately moved slightly forward and backward. The travel distances were lengthened after a few minutes, then the machine was excercised for the required time (15 min). In the temperature range down to -20°F (-29°C), after engine start-up, the vehicle was exercised for a minimum of 30 minutes before normal operation, starting with the hydraulic system. After the hydraulic circuit warm-up, the vehicle was moved slowly in forward and reverse only a foot or two. This allowed the face-type seals in the rollers, idlers, and final drive a chance to rotate. After the machine was moved a few times 3 feet or so in each direction, it was stopped and inspected for seal leaks.

When the temperature was -40°F (-40°C) or lower, machines were "tented" and preheated for a 24-hour period. (A very good fire retardant tenting material is Griffolyn T-55 produced by the Griffolyn Company of Houston, Texas.) Often a tent, a good generator, and two Herman-Nelson heaters handled the preheating task. Vehicle were exercised for one hour before normal operation. At these extreme temperatures, "cold soaking" of the hydraulic circuits that were not being used was very rapid. Any period of prolonged idling was followed with careful exercising to warm the fluid and condition the hydraulic circuits.

Another precaution with prolonged idling or operation under light load conditions was to check for freezing of the vent tubes, especially the engine crankcase breather tubes. Freezing and blockage of the breather tubes can cause high presures inside the crankcase, resulting in blown gaskets and seals or the forcing of crankcase oil into the combustion chamber and down the valve guides. The first indication of this condition is light blue smoke coming out of the exhaust stack. Breather tubes were checked and the machine thoroughly inspected when this condition occurred to prevent engine damage and failure.

For idling, engine RPM had to be high enough so that oil pressures sufficient to lubricate all parts of the engine were maintained. For GM

diesels, 1100 RPM was required; at 600 RPM low idle the valve system could burn out due to lack of oil. A speed of 900 RPM was sufficient for Caterpillar diesels. Another problem at low idling conditions was that the engine did not come up to normal operating temperatures (175° - 180°F), perhaps reaching only 100°F (38°C). At extreme temperatures of -50°F (-46°C) to -60°F (-51°C), gaskets, liners and O-rings on the cold engine block tended to contract and shrink to different degrees so that engine coolant leaked into the engine compartment and crankcase. Inspection of the fluid and oil levels alerted operators to this condition. After the warm-up and exercise period, the vehicle was ready for use under light load until the systems reached normal operating temperature.

Vehicles, especially tracked vehicles, were often parked on wooden planks to avoid the possibility of the pads and tracks freezing in. Also, implements were supported on wooden blocks. Before a tracked vehicle was parked, it was driven back and forth on a hard, dry surface to free the track components of any snow, ice, frozen mud or debris. Machines that were frozen in had their pads broken loose with a hammer before an attempt was made to move them; this prevented damage to the final drive gears.

Metallurgy was another area of concern. As the temperature drops below -30°F (-34°C), metals begin a severe change. Most structural steels are tough and ductile at higher temperatures. The transition from tough to brittle starts at temperatures around -20°F (-29°C), but is somewhat unpredictable because it is dependent on several factors. These include: 1) rate of loading (shock loads can cause brittle fracture); 2) the type of steel (this and the practice used in its manufacture affect brittle fracture); 3) stress risers (notches, cracks, weld defects, and inclusions in the metal all increase the likelihood of brittle fracture).

At temperatures around -40°F (-40°C) and lower, brittle fracture problems were always encountered. To keep this problem to a minimum, some precautions were followed. Equipment was inspected regularly to locate cracks and breaks. All cracks were repaired when first observed, since cracks promote brittle fracture. Weld repair of cracks was done only after preheating the area surrounding the crack. The general recommendation was to preheat steel to 60°F (16°C) before welding. Welding was done with low hydrogen welding processes.

Special precautions were required for welding pipes. Pipe welding was done in heated shelters when the temperature dropped below zero. Below-ground tie-ins could not be made at temperatures below +10°F (-12°C). For above-ground tie-ins, -20°F (-29°C) was the limit. Welding on VSM's (vertical support members for elevated sections of the pipeline) was not permitted below -10°F (-23°C). Another precaution was to avoid shock loadings on blades, buckets, booms, cables, hooks, and lifting eyes. At

these low temperatures, the equipment would not stand abuse. Side booms rated at 100 tons have been known to fail with 30-ton loads. One particular weak spot was the curl spider on the bucket manipulator of a backhoe (Fig. 2).

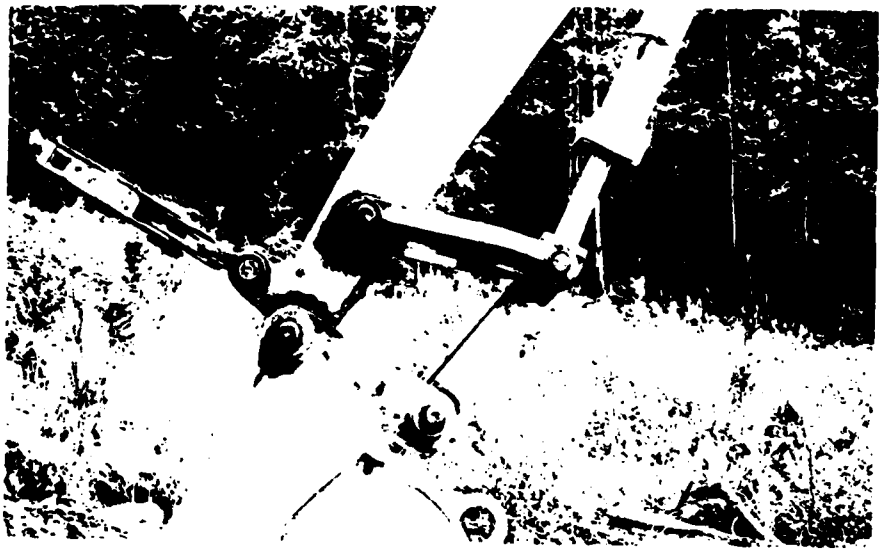

Figure 2. Curl spider on backhoe bucket manipulator.

Scrapers also ran into special problems with their brakes below -35°F (-37°C). At these temperatures, hard braking causes brake drum cracking and failure. As many as 16 drums a week would break on a particular 21-scraper spread if the temperature was -40°F (-40°C) to -45°F (-43°C). Another brake problem with scrapers at these low temperatures was with the air dryer system. When brakes were applied, they did not release because ice in the lines blocked air flow, causing the brake shoes to wear out rapidly.

The cold weather appeared to be especially hard on hydraulic systems. Hydraulic fluids, sluggish from the low temperature or from a system not properly warmed, sometimes caused pump bearing failure where bearing lubrication depended on pump oil flow. Pumps also did not want to prime with the fluid sluggish, resulting in aeration and cavitation causing pump end scouring, vane and ring wear, and side face wear. For circulating fluid systems, SAE 10W motor oils functioned well under most conditions. To guard against extremely cold conditions, the non-petroleum base synthetic fluids were used, namely Frigid GO and DN-600. Field users stated that the latter was causing pump failures at very low temperatures. This fluid apparently did not have sufficient lubricating

properties at -40°F (-40°C) and below, so that scouring of shafts and cylinder walls occurred. Also the fluid would foam and cause cavitation, resulting in pump gear failures. Frigid GO performed adequately down to -60°F (-51°C). Some problems occurred when changing from petroleum-base fluids to synthetic fluids because the two did not mix. About three successive changes were needed to flush the system completely. Old seals used with petroleum base oils leaked with synthetic oil in the system.

Hydraulic hoses were also a problem. At extremely cold temperatures connections failed and hoses burst. One specific hydraulic connector (Fig. 3) was prone to failure. This was on a metal line in the control system for the boom, swing, and cable drive of a backhoe.

Figure 3. Metal hydraulic connector, backhoe control system.

A bright spot in the repair and maintenance picture was problem solving in the field by innovative mechanics. One example was the hydraulic system of the large dump trucks. The body dump system was used only when unloading, so between dumps the fluid cooled off and became sluggish, and the cylinders became inoperative. The field solution is shown in Figure 4. A piece of exhaust pipe welded onto the engine exhaust system conducted hot gas over the hydraulic fluid reservoir. The heat from this line was enough to keep the dump body hydraulic system operative.

Figure 4. Hydraulic fluid reservoir heater: field fix.

Another means of utilizing available heat was to install a reversible blade fan in the engine cooling system so that cold air was not pulled into the engine compartment in cold weather and warm air could be drawn over the engine. Curtains and shrouds of fire-retardant material were installed to restrict the inflow of cold outside air.

NON-MACHINE FACTORS IN NORTHERN CONSTRUCTION

A cold weather problem in equipment operation, as mentioned earlier, was keeping the equipment running 24 hours a day when the temperature dropped below -20°F (-29°C) to -30°F (-34°C). When a large fleet had to be kept idling during the non-working hours (12-14 hours per day), monitoring and surveillance of the vehicles became a chore. Checks on idle speed, oil pressure, and breather tube frost-up could easily be overlooked or neglected during the dark and cold, and most of the day working crew were sleeping. Some contractors had a warm-up and exercising crew continually rotating among vehicles during the non-working hours, keeping the necessary vehicles warm.

The effects of arctic conditions on the equipment required for a specific task and on production are quite different from the effects of temperate conditions. Excavating sometimes required drilling and blasting

when the soil was frozen, and most scrapers were not powerful enough to handle the frozen ground. These cases required push dozers or material loosening (blasting or ripping) before scraper operations. A benefit of frozen ground was the improvement in trafficability. Use of more mobile rubber-tired equipment was made possible. Ice formations also caused excavating problems requiring additional equipment such as backhoes and front-end loaders for material removal. In other cases, ice was a benefit. Ice bridges and working platforms could easily be constructed over and near waterways to facilitate traffic and provide working areas. The effects of cold temperatures in clearing operations were helpful; vegetation became brittle and 6-inch trees were felled at the maximum crawling speed of a dozer.

Still another problem that must be faced when working in the arctic winter months is the lack of daylight. In the Prudhoe Bay area, the sun remains below the horizon from the end of November until late in January. In the Fairbanks area there is less than 2 hours of sunlight, with the sun low on the horizon, near the end of December. The cold and the darkness combine to create safety problems as well as operational problems which directly limit productivity.

There is a third element that must be considered in the overall construction operation scheme besides the equipment and the environment, and that is the human element - the operators, workers and support personnel. Contractor reports state that at -20°F (-29°C) labor productivity was about 25% of that obtained in the summer months[2]. At -35°F (-37°C), all a person can think of is keeping warm in warm-up shacks or at fires, with no energy remaining to expand on work. Most severely affected were those workers without benefit of protection from the cold. The efficiency of surveyors, mechanics and other outside workers including supervisory personnel was reduced to near zero at -35°F (-37°C) and lower. A job that would take a mechanic 30 minutes in a heated garage might take him all day if he was working outside without protection. The task of changing a large tire on a scraper can become a major time-consuming chore at low temperatures.

Other human element problems included inexperienced personnel, worker attitudes, and personnel turnover. Among the equipment used on the line were prototypes and highly sophisticated pieces of machinery, over-designed in many cases, which required special skills for maintenance and operation. All such units had a technical representative with them but still the equipment suffered from lack of training for the working personnel assigned to the unit.

The mental attitudes and morale of the workers were not conducive to high production during the winter season, especially at the remote camps. The combination of a work schedule of 10 to 12 hours per day, seven days a week, with a minimum of 8 weeks in the field before an

R&R (rest and relaxation) can be demoralizing, especially when daylight hours are limited or non-existent, the weather is cold, there is no place to go, and recreation facilities are limited. This leads to the last people-problem: excessive personnel turnover. Even high pay, room and board, and other benefits could not reduce a high turnover rate. One job area with frequent personnel changes was oilers and greasers. One contractor's turnover rate was as high as 70% during the cold months. The reason for this could have been the nature of the jobs. But also the pay rate was at the bottom of the scale, and the workers moved on to any other job as openings occurred. As a result, the major equipment maintenance function, keeping a rigid oil and lube schedule with competent people, was very difficult to maintain. Consequently vehicle down-time increased. Negligent or sloppy care in oil and filter change schedules was cited as a big problem area by one of the contractors.

MAINTENANCE AND REPAIRS

The cold environment and the accompanying problems in keeping equipment operating show up as increased maintenance and repair times and costs. With the additional running of the machines plus cold engines decreasing fuel burning efficiency, fuel consumption and costs rise proportionately. Wear rates increase with decreasing temperature, for both internally working parts and outer parts such as blades, booms, buckets, cables, tracks, road wheels, and rubber tires. Lack of proper lubrication may be the prime cause for internal metal wear, and metal brittleness may be the cause for outer metal parts wear and failures.[3] In one case 35% of the diesel engines on one construction spread required major repairs during the cold months. The cold also decreases the flexibility of rubber and hoses covered with synthetic materials. Rubber tires become brittle in the cold and small sticks and sharp stones easily cause punctures. Observations by contractors and Corps of Engineers inspectors showed that the normal maintenance capability was reduced by 1 percentage point of availability for every degree below -20°F (-29°C)[3]. If a company normally had 92% availability of dozers under temperate conditions, it expected about 77% availability at -35°F (-37°C).

Beginning in the fall of 1975, Alyeska Pipeline Service Company, through Bechtel Incorporated (the construction technical services contractor) and the prime contractors in each of the five sections of the pipeline, engaged in a winter maintenance program costing more than $7 million[4]. Each section started in November to set up priorities on use of equipment and to check on what equipment would be needed for the spring start-up. Inspection, servicing, and repairing priorities were placed on these pieces of equipment. Others were set for repairs if there was time. The aim of the program was to prepare heavy equipment for the spring-summer season and to reduce breakdowns and down-time on

the job. By doing the maintenance during the winter shutdown of the pipeline work, parts could be replaced before they wore out and, more importantly, the equipment could be worked on in the camp garages and shops. The cost savings of such a preventive maintenance program are said to be substantial when a rigid work schedule must be maintained during the spring-summer work months. Equipment breakdown and replacement, down-time, and schedule delays all add up to additional expenses.

A full work force on the line consisted of over 20,000 personnel. The support force during the winter shutdown in 1975 numbered 7400. This increased to 10,000 by the end of January 1976, with a full work force by March and April. Once work had begun, keeping the equipment running became the main task of the maintenance and repair crew.

Mechanics were assigned to an equipment spread to do all the field fixes. Pick-ups and larger trucks carried all tools, cutting and welding equipment, jacks and hoists to go out on the line with the field mechanics. Mechanics at the base camp garages serviced the equipment requiring shop facilities. Since downtime of equipment meant increased costs and delays, all possible repairs were conducted in the field. Major repairs and parts replacements such as engine, transmission and final drive changes were made in the field using available equipment to move and lift the parts. Work on large and bulky pieces of equipment which were difficult to transport back to a shop area were also field-repaired if possible. When the repairs required teardown of the engine, transmission, differential, etc., where cleanliness was a requirement, these components were taken back to the base shops to be worked on.

Maintenance schedules and repair logs were kept on each piece of equipment. Schedules for engine oil changes were set for 130-150 hours of operation. Gear box lube changes were scheduled after each 500 hours of operation. Engine oil filter changes were set at 500 hours and hydraulic fluid filters at 200 hours of running. No logs were kept on minor repairs, but the daily time cards of the mechanics noted the types of repairs along with the vehicle identification. Major repairs were recorded in the vehicle log: work such as engine overhauls and transmission or power train repairs and replacements. The mechanic foreman was then able to keep a record of vehicle operating time, down-time, and standby hours through a check of the work schedule, daily time cards, and the vehicle maintenance and repair log book. From this overall performance record, scheduling changes, vehicle utilization and efficiency levels, specific problem areas and remedial action steps could be either studied, pinpointed or initiated.

SUMMARY

The amount of equipment required for the Alaska pipeline project, estimated at 2500 pieces of heavy equipment[4], called for an extensive preventive maintenance program. Contractors were familiar with the procedures, and equipment dealers and manufacturers stressed the importance of this approach to avoid costly down-times. Putting the practice into effect was the difficult task. Personnel skills and attitudes, weather conditions, and the working environment all increased the difficulty of maintaining a strict program and added to the high cost of vehicle and equipment operation. But with competent support personnel maintaining and repairing the equipment, and with operators using caution and common sense as dictated by a harsh, cold environment, construction projects can be carried out in the northern regions during the winter months without taking a heavy toll of equipment and machinery.

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Chapter 11

MATERIALS FOR LOW TEMPERATURE USE

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Chapter 11

MATERIALS FOR LOW TEMPERATURE USE

INTRODUCTION

The change in properties of materials at low temperatures is not as severe at McMurdo as at the inland stations where colder temperatures are encountered. Even so, some special consideration is required if problems are to be avoided.

Care should be taken in the selection of materials and the interpretation of manufacturers' literature. Often manufacturers state that their product will perform satisfactorily at low temperature but fail to indicate that the material must be applied at warmer temperatures, often above freezing. For example, epoxy and polyester resins are usable at low temperatures when cured, but they will not cure at temperatures below freezing.

The information contained in this chapter is not all-inclusive but provides a general outline to which new information may be added as available.

METALS

The properties of metals and alloys at temperatures from 80°F to well below those encountered in Antarctica are detailed in the National Bureau of Standards Monograph 13 [1].* These data show that metal failures at low temperature most often result from decrease in impact resistance (brittleness). The tensile and yield strengths of all common metals actually increase at lower temperatures, and failures from this source are less likely to occur than in temperate climates.

Steel

Carbon steel 1020 and 1030, which are the common structural steels, show a severe loss in impact resistance with decrease in temperature. From Figure 11-1 it can be seen that the impact energy required to fracture a specimen of 1020 or 1030 steel at -10°F is about 60% less than at 80°F. High-strength structural steels such as T-1 have a nearly constant impact strength from 80°F to -50°F and are therefore well-suited to cold regions (Figure 11-2).

The impact energy causing fracture with change in temperature for other alloy steels is shown in Figures 11-3 through 11-7.

* In the graphs in this chapter taken from the monograph, the impact energy is the energy absorbed by a standard specimen in breaking under an impact load. In every case the type of impact specimen is indicated on the graph by a note which identifies it with one of the specimens described in test method E23-56T of the American Society for Testing Materials. The notation "Charpy V" refers to the type "A" specimen having the V-notch. "Charpy K" refers to the type "B" specimen with the keyhole notch, and "Charpy U" refers to the type "C" specimen with the U-shaped notch. Izod specimens are type "D" in the ASTM specifications.

Cast Iron

The impact energy required for fracture of the cast irons at various temperatures is shown in Figure 11-8. These cast irons are the types often used in heavy castings for construction equipment and other machinery frames. As can be seen, their brittleness increases very little in the gray and acicular cast irons with change in temperature from 80°F to -100°F.

Other Metals

Impact energy data for stainless steel, cast and rolled aluminum, and copper are shown in Figures 11-9 through 11-12. These data show that the resistance to impact for these metals actually increases from 80°F to -100°F. Failures in these metals should not be attributed to cold weather.

WOOD

Wood materials are used extensively at McMurdo and are generally handled without difficulty during the summer construction season. Some loss of workability does occur, however, and there is a tendency for lumber to split due to dryness and salt impregnation for fire retardation. Lumber also tends to split when frozen, due to loss of compressibility of the wood fibers. Also, when frozen the strength of wood in bending is decreased and splitting along the grain occurs more readily.

PLASTICS

Plastics encountered in exterior construction are limited generally to those used in piping, insulation on electric wires and cables, plastic sheeting, and plastic pressure-sensitive tapes.

More than one type of plastic is generally available in each of the products. The choice of material is also increased because of different grades and types within each basic type. Often manufacturers' literature gives little or no information on low temperature properties, even though high temperature properties are thoroughly covered. Some general guidelines can be given to aid in selecting the most suitable material. Plastics described as "high-density" or "high-molecular-weight" have a long-chain molecular structure, and are more flexible when cold than those plastics of low-density and low-molecular-weight.

Plastics described as having a cross-linked molecular structure are being made for improved high-temperature properties. These, however, are not so well-suited for low temperature as the straight-chain molecular structure.

In the selection and specification of a particular plastic product, considerable variation may occur in a product apparently the same from two manufacturers. One reason for this comes from the use of plasticizers which increase flexibility, but which result in the loss of other physical characteristics.

The most reliable method of obtaining a usable product is to subject actual manufacturers' samples to cold chamber tests and to purchase products found satisfactory from previous use.

Polyethylene

Polyethylene, often abbreviated PE, is one of the plastics most usable at low temperatures. It is produced as a clear,

colorless material or pigmented to a black color which is resistant to the ultraviolet rays of the sun. Polyethylene is made into pipe and is generally available in long, coiled lengths in smaller sizes. It is the common plastic film supplied as sheeting in long lengths and widths. It is also often used as insulation on electric wires and cables and as the material for plastic electrical tape and other types of pressure-sensitive tape.

When exposed to decreasing air temperatures polyethylene becomes stiff and less flexible and is more difficult to stretch and puncture. At temperatures to -50°F there is little tendency toward brittleness. These properties are most readily observed on polyethylene-insulated electrical wire and cables. Wire removed from a coil tries to remain coiled, and increased toughness makes insulation more difficult to strip from the wire conductors.

High-density or high-molecular-weight polyethylene is less affected by decreases in temperature and is preferable when a choice exists.

Polyethylene plastic can be joined by thermal welding but cannot be solvent welded. Joining with epoxy or other adhesives is generally unsatisfactory because of the lack of bond to its smooth surface.

Poly(Vinyl Chloride)

Poly(Vinyl Chloride) (PVC), often used as plastic pipe and insulated pipe jackets, is generally unsatisfactory at subzero temperatures because of increased brittleness and loss of impact strength. When used, PVC parts can be joined by the conventional solvent welding method, which is satisfactory at very low temperatures, provided additional time is allowed for the slower curing and evaporation of the solvent.

Fluorinated Ethylene Propylene

Fluorinated ethylene propylene (FEP) is used primarily in construction as insulation on electrical wiring. Experience has shown it to be serviceable to -50°F and possibly lower.

Acrylonitrile-Butadiene Styrene

Acrylonitrile-Butadiene Styrene (ABS) is most often found as piping in construction work. It has higher impact resistance than PVC but not as great as polyethylene. ABS may be solvent-welded at very cold temperatures but is not often used in cold regions.

Teflon

Teflon retains its flexibility and good impact resistance at temperatures well below zero. Its greatest application in public works functions is as a pipe-sealant tape and occasionally as gaskets or bearing blocks. Relatively high cost prevents more extensive use.

Glass-Reinforced Plastics

Glass-reinforced plastics, such as fiberglass and epoxy pipe and polyester resin and fiberglass materials, retain appreciable impact resistance at low temperatures and find application as piping and radar-antenna enclosures. Joining or repairing glass-reinforced plastics using on-site mixed and catalyzed resins cannot be accomplished at temperatures below freezing. Components become too viscous to mix, and catalyzation does not occur in the cold.

RUBBER

For low-temperature applications, the effects of greatest concern include changes in flexibility, changes in compression set characteristics, and occurrence of brittleness. The commonly encountered names of rubber compounds such as neoprene, buna, and butyl are broad classifications and may or may not be suitable at low temperature, depending on their formulation by the individual manufacturer. Plasticizers are often added to increase the low-temperature performance but result in loss of other properties, such as wear resistance. Butyl rubber, generally used in inner tubes because of its impermeability to gases, it not suitable in this application at low temperature, but natural rubber inner tubes are. The only rubber compounds which appear to be suitable at low temperature in nearly all formulations are the silicone rubbers. Almost all are usable to -50°F, and many are serviceable to -150°F. Cost of the silicone rubbers, however, prevents their being widely used in many common products. The room temperature vulcanizing (RTV) silicone materials are usable at temperatures below -50°F but are slower to cure because of the lower humidity of the air.

CAULKING AND SEALING COMPOUNDS

A large variety of caulking and sealing compounds are available for application with hand caulking guns from 1/12-gallon cartridges. Testing of silicone, butyl, polysulfide, polyurethane, acrylic, and oil-based compounds at low temperatures has shown that only the silicone compounds can be applied at temperatures in the -50°F range [2]. The most suitable products are Dow Corning Silicone 781 and General Electric Silicone Construction Sealant.

APPENDIXES

The material provided in the Appendixes supplements the chapter text. The contents of the Appendixes will change from time-to-time as new, up-to-date information is added and outmoded material is deleted. This avoids the recurring and costly revision of the basic material in the chapter.

REFERENCES

1. U. S. Department of Commerce. National Bureau of Standards Monograph 13: Mechanical properties of structural materials at low temperatures – A compilation from the literature, by R. Michael McClintock and Hugh P. Gibbons. Washington, DC, Jun 1960.

2. Naval Civil Engineering Laboratory. Technical Report R-812: Caulking compounds for application at low temperatures, by C. R. Hoffman. Port Hueneme, CA, Jun 1974.

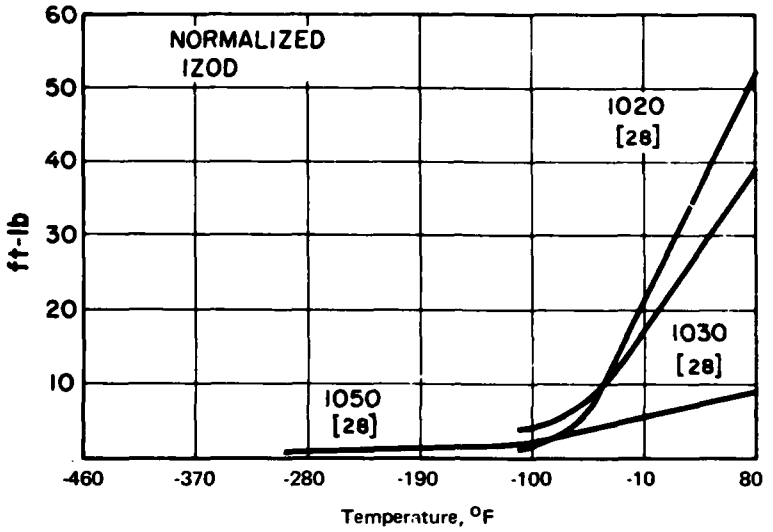


Figure 11-1. Impact energy causing fracture of some special proprietary constructional steels.

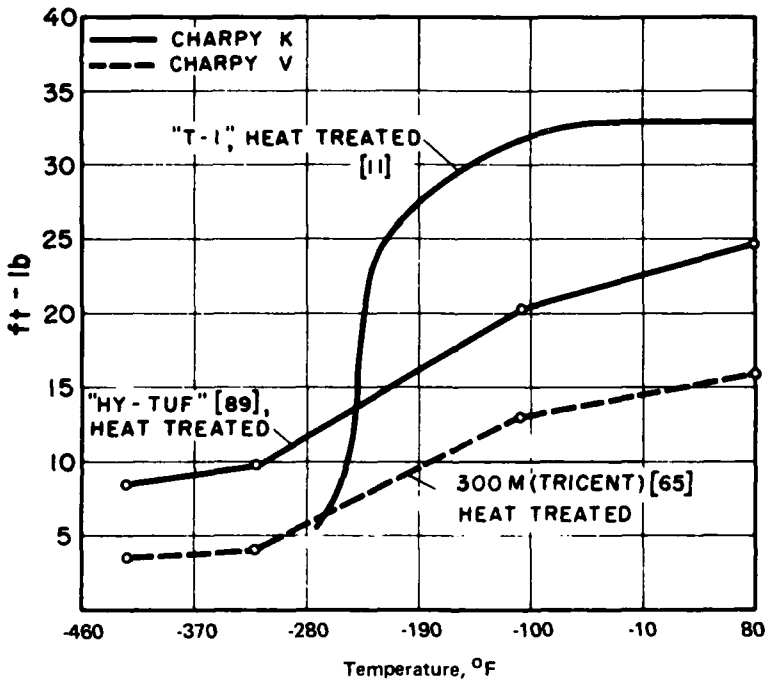


Figure 11-2. Impact energy causing fracture of AISI-SAE plain carbon steels.

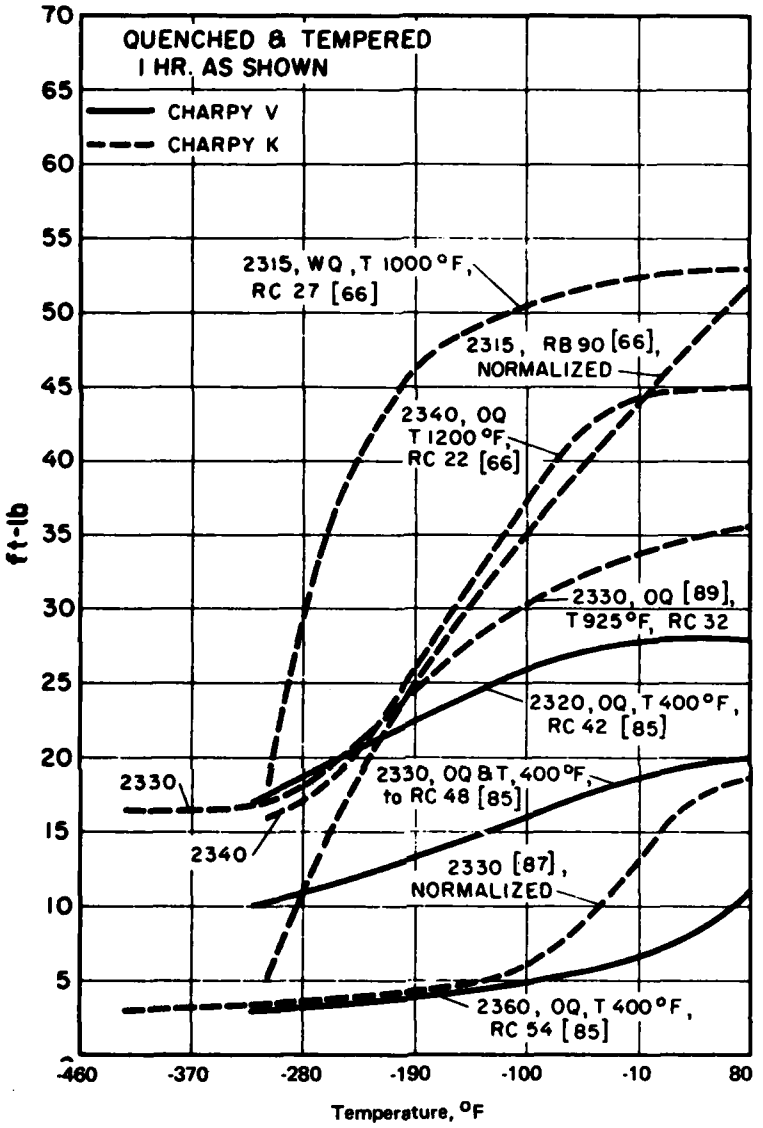


Figure 11-3. Impact energy causing fracture of AISI-SAE 2300 series constructional steels.

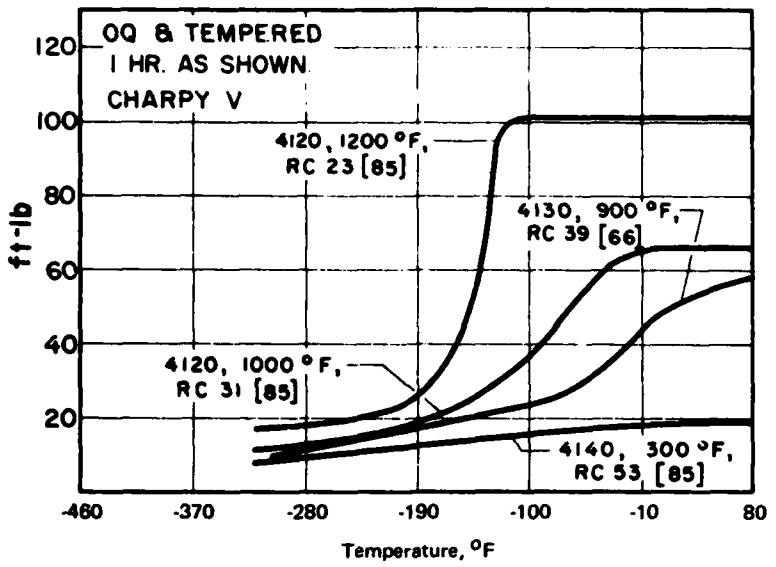


Figure 11-4. Impact energy causing fracture of AISI-SAE 4100 series constructional steels.

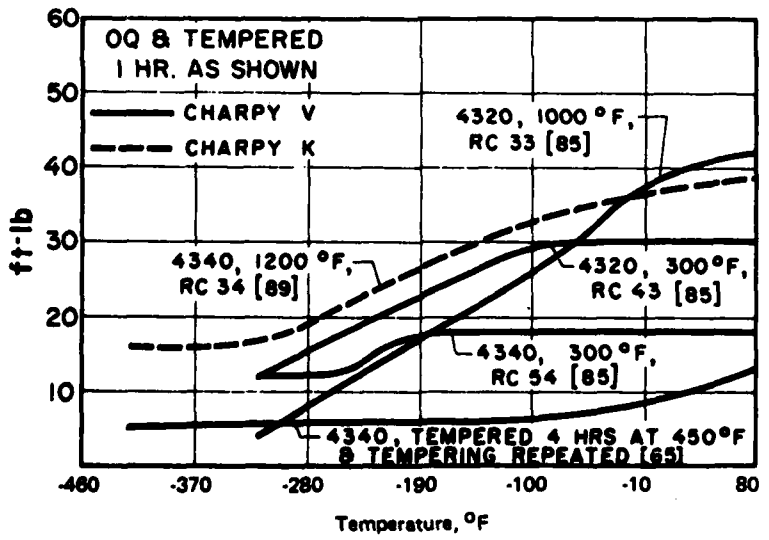


Figure 11-5. Impact energy causing fracture of AISI-SAE 4300 series constructional steels.

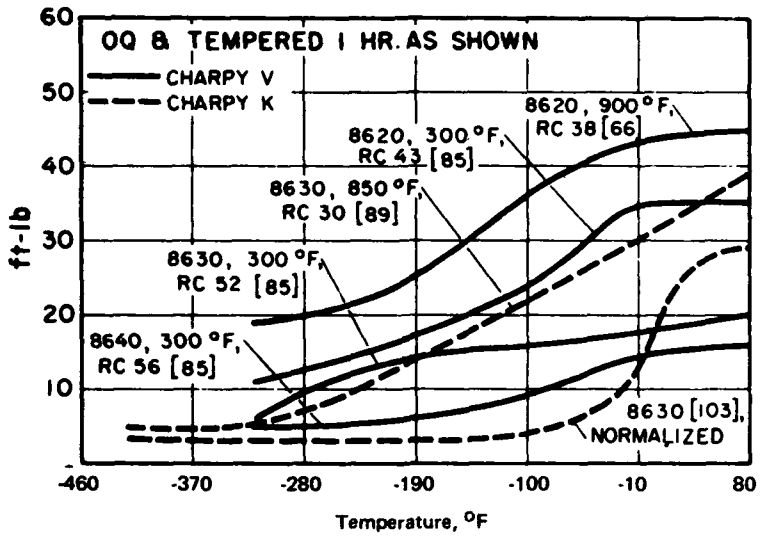


Figure 11-6. Impact energy causing fracture of AISI-SAE 8600 series constructional steels.

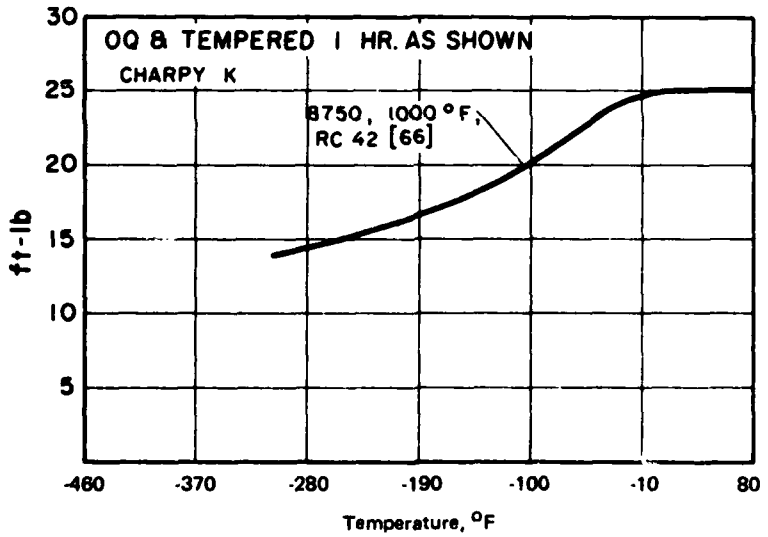
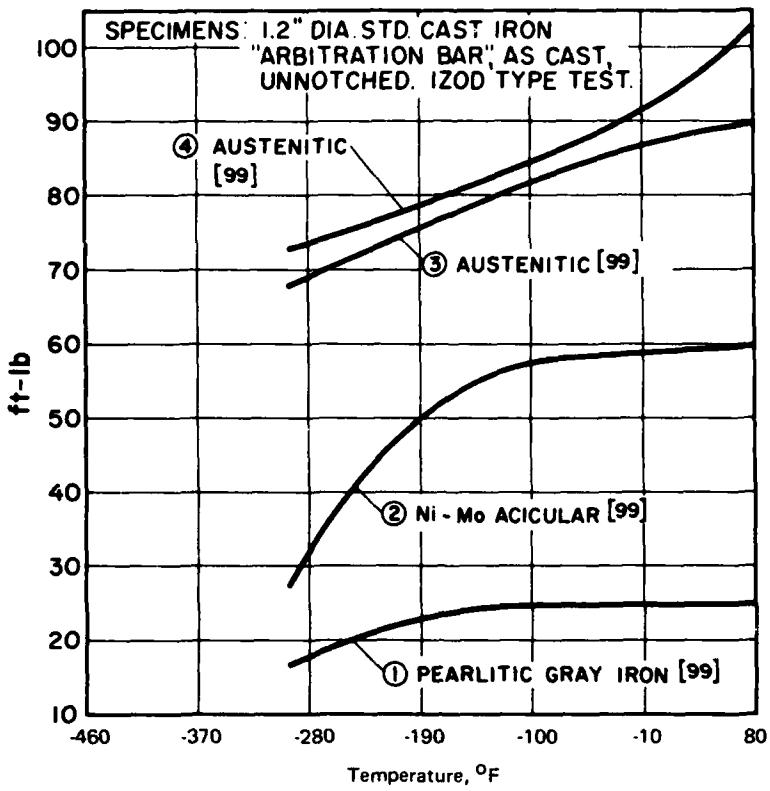


Figure 11-7. Impact energy causing fracture of AISI-SAE 8700 series constructional steels.



NOMINAL COMPOSITIONS:

IRON	%C	% Si	% Mn	% Ni	% Cr	OTHER
①	3.2	2.0	1.2	-	-	-
②	3.0	1.9	.7	1.6	-	.5 Mo
③	2.7	1.9	1.1	14.5	2.2	6.3 Cu
④	2.3	1.5	1.0	34.5	3.0	-

Figure 11-8. Impact energy causing fracture of some flake graphite cast irons.

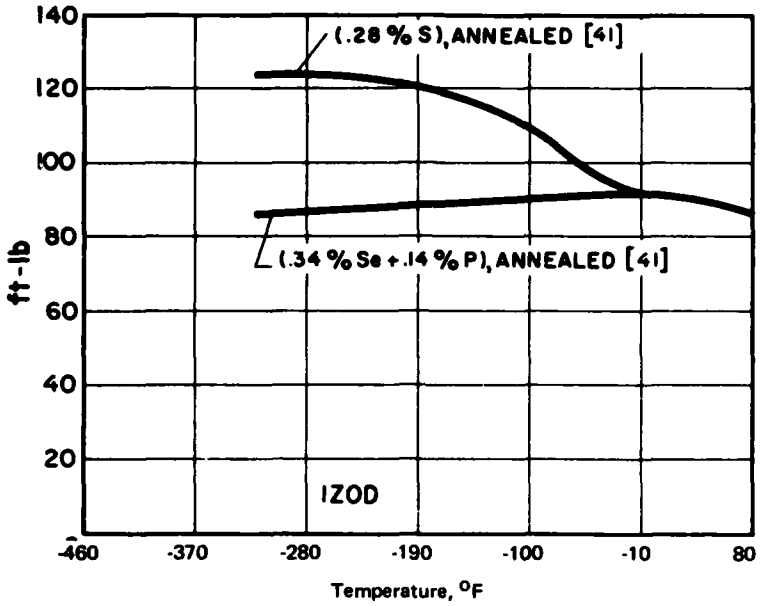


Figure 11-9. Impact energy causing fracture of AISI 303 stainless steel.

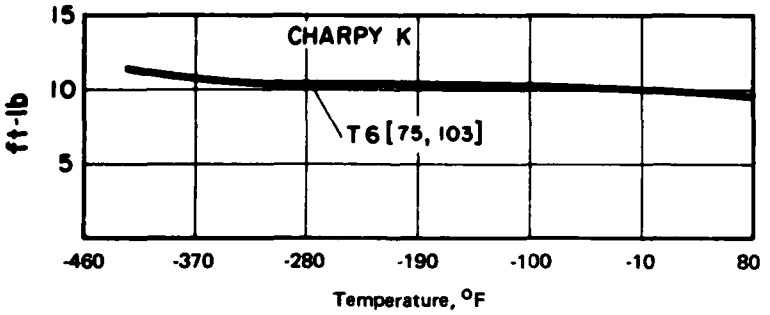


Figure 11-10. Impact energy causing fracture of 6061 aluminum.

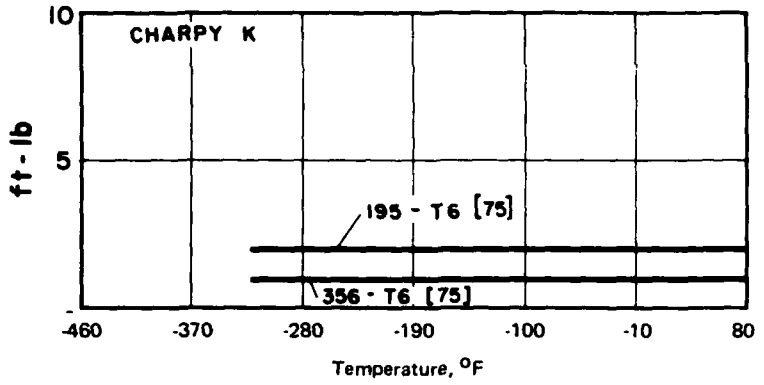


Figure 11-11. Impact energy causing fracture of sand cast aluminum alloys.

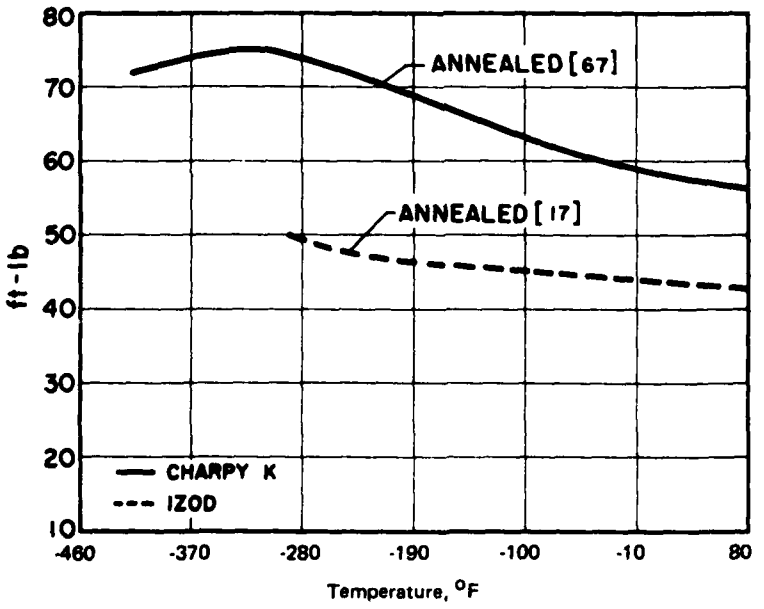


Figure 11-12. Impact energy causing fracture of oxygen free high conductivity copper.

LIST OF APPENDIXES

Chapter 11

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

11-A. _____

11-B. _____

11-C. _____

11-D. _____

11-E. _____

11-F. _____

11-G. _____

11-H. _____

11-I. _____

11-J. _____

Chapter 12

ANNOTATED REFERENCES TO PUBLICATIONS ON COLD-WEATHER CONSTRUCTION

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Revised – 1979

CHAPTER 12

ANNOTATED REFERENCES TO PUBLICATIONS ON COLD-WEATHER CONSTRUCTION

This chapter has been added to the 1979 edition of the McMurdo Manual to give the reader an annotated listing of the publications available to ease or solve the construction problems which could be encountered in the cold-weather environment at McMurdo.

TM no. M-61-76-7

TECHNICAL MEMORANDUM

title: AN ABBREVIATED REFERENCE MANUAL FOR COLD-WEATHER CONSTRUCTION

author: J. L. Barthelemy

date: July 1976

sponsor: NAVAL FACILITIES ENGINEERING COMMAND

program nos: YF52.555.001.01.003

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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AN ABBREVIATED REFERENCE MANUAL FOR COLD-WEATHER CONSTRUCTION

YF52.555.001.01.003

by
J. L. Barthelemy

July 1976
Sponsored by Naval Facilities Engineering Command

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INTRODUCTION

This report contains a listing of select engineering publications which cover diversified areas of cold-weather construction technology. Reports in SECTION I are listed by title, number and originating agency under six subject areas. SECTION II presents more detailed publication information as well as abstracts for each of the references from the first section. The report is designed to serve as an abbreviated reference manual for Naval Construction Forces operating in cold-weather regions, including arctic and subarctic Alaska, and Antarctica. It is abbreviated to the extent that only a sampling of the vast literature available on cold-weather construction is represented; however, it is also comprehensive in that the subject material of the selected references reflects the current status of technology. For the most part, only the most appropriate and recent publications from each subject area have been included. The subsection entitled "Bibliographies and Surveys" cites references which contain a much more complete list of cold-weather engineering and construction publications.

This report was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the Government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

A process of research, review and selection was used to assemble the subject material contained in this ready reference manual. As a first step, promising titles were chosen from the list of publications of three major research and development organizations engaged in cold-weather engineering and construction technology: the Civil Engineering Laboratory (CEL) of the Naval Construction Battalion Center; the United States Army Cold Regions Research and Engineering Laboratory (CRREL); and the National Research Council of Canada (NatRCC). As a second iteration, the candidate reports were procured and reviewed for content. Current and milestone reports were retained for use in the manual. At the same time, an effort was made to locate relevant reports that were issued as publications from other organizations and journals, or as conference proceedings. Using the services provided by the Defense Documentation Center, a computer search of all reports documented by the Department of Defense was initiated using key words pertinent to cold-weather construction. The final print-out consisted of nearly 1000 entries. Unfortunately, many of the publications cited were not highly, or in some cases even remotely, applicable. Other entries were for reports previously selected, and still others were journal articles that appeared in similar or identical form as technical reports from CEL, CRREL, and NatRCC. However, several appropriate additions were discovered from this computer search.

After the final selection was made, the reports were organized according to subject matter into the six subsections, or topic areas,

that appear in SECTION I. Abstracts were drafted for those publications that did not already have one. These abstracts appear with detailed publication information in SECTION II.

SECTION I

In the design, construction and maintenance of roads, runways, utility systems and buildings in cold-weather regions, the existence of snow, ice and permanently frozen ground presents many problems which are not encountered in temperate regions. At extremely low temperatures, material properties change and common operations such as concreting and asphalting must be modified. Also, special designs are necessary to protect utility distribution systems from the cold. Care must always be taken to preserve the integrity of frozen ground, since it is fragile and very sensitive to thermal disturbance. Thawing and refreezing of soils under buildings or other structures often causes settling and heaving. In areas of excessive ice and snow, vehicle trafficability and foundation as well as drift and melt control can be real problems. Thus the proper location for construction is equally as important as proper design. SECTION I lists references that consider the topics of site selection, utility systems and construction on ice, snow and frozen ground.

The following abbreviations are used to designate the originating organizations for reports listed in SECTION I and SECTION II.

CEL	Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, CA
CRREL	United States Army Cold Regions Research and Engineering Laboratory, Hanover, NH
DA	Department of the Army, Head, Washington, DC
NAS	National Academy of Sciences, Washington, DC
NatRCC	National Research Council of Canada, Ottawa, Canada
NAVFAC	Department of the Navy, Naval Facilities Engineering Command, Washington, DC 20390

Bibliographies and Surveys

This subsection lists major bibliographies dealing with cold-weather construction and engineering. Entries 1-3 are the result of literature search and contain journal articles from international publications and conference proceedings. Entry 4 is a list of all reports produced by the U.S. Army Cold Regions Research and Engineering Laboratory. Entry 5 is truly all-encompassing. It is a continuing publication issued each year since 1951 and lists all materials on cold-weather technology accessioned to the Science and Technology Division of the Library of Congress. The last two entries are also literature surveys and they deal with cold-weather construction practices.

1. CRREL
   A Bibliography on Winter Construction, 1940-1967

2. CRREL
   Bibliography on Winter Construction, 1967-1971

3. NatRCC B. 10
   A Bibliography on Cold Weather Construction

4. CRREL SR-175
   USA CRREL Technical Publications

5. CRREL TR-12
   Bibliography on Cold Regions Science and Technology

6. CRREL SR-76
   A Survey of Winter Construction Practices Earthwork, Concrete and Asphalt

7. CRREL SR-172
   Literature Survey of Cold Weather Construction Practices

General Provisions and Site Selection

Reports listed in this subsection contain general information concerning the nature of cold regions, including basic principles and considerations to be used in site selection. Site selection is especially important in cold regions, since construction is adversely affected by fragile ground conditions, drifting snow, poor drainage, or a number of other environmental factors. The references recommended here expose design dangers associated with improper site location and outline methods of avoidance.

8. CEL N-1406
   Earth Science Related Environmental Factors in Polar Region Construction

9. DA TM 5-349
   Arctic Construction

10. DA TM 5-852-1
    Arctic and Subarctic Construction. General Provisions

11. DA TM 5-852-2
    Arctic and Subarctic Construction. Site Selection and Development

12. DA TM 5-852-6
    Arctic and Subarctic Construction. Calculation Method of Determination of Depths of Freeze and Thaw in Soils

13. DA TM 5-852-8
Arctic and Subarctic Construction. Terrain Evaluation in Arctic and Subarctic Regions

14. CRREL CRSE-1A2
Permafrost

15. CRREL CRSE-2A1
Heat Exchange at the Ground Surface

16. CRREL CRSE-3A2b
Investigation and Exploitation of Snowfield Sites

17. CRREL CRSE-3A3b
Snow Removal and Ice Control

18. CRREL CRSE-3C5a
Water Supply in Cold Regions

19. NatRCC NRC-8276
Difficulties Associated with Predicting Depth of Thaw

20. NatRCC BBB-6
Winter Construction

21. CRREL SR-223
Temporary Enclosures and Heating during Construction

22. CRREL TR-95
Rotary Drilling and Coring in Permafrost

23. CRREL TR-191
Soil Sampling and Drilling near Fairbanks, Alaska

24. NAVFAC DM-9
Design Manual: Cold Regions Engineering

25. DA TM 5-852-7
Arctic and Subarctic Construction: Surface Drainage Design for Airfields in Arctic and Subarctic Regions

26. CEL R-767
Snowdrift Control Techniques and Procedures for Polar Facilities

Frozen Ground

Permafrost, or perennially frozen ground, underlies much of the regions of high latitude. Whether it is found as continuous or discontinuous frozen ground, it presents to engineers difficulties in

construction, operation, and maintenance. To live and work in the cold regions, one must first appreciate the destructive forces of permafrost which are released when the environment in which it exists is altered. Reports in this subsection describe methods by which man can best adapt his needs to a permafrost environment and better coexist with the natural elements.

27. NAVFAC DM-9
Design Manual: Cold Regions Engineering

28. CRREL CRSE-1A2
Permafrost

29. CRREL CRSE-3C4
Foundations of Structures in Cold Regions

30 DA TM 5-852-3
Arctic and Subarctic Construction: Runway and Road Design

31. DA TM 5-852-4
Arctic and Subarctic Construction. Building Foundations

32. DA TM 5-852-6
Arctic and Subarctic Construction. Calculation Method of Determination of Depths of Freeze and Thaw in Soils

33. CRREL SR-79
Pile Foundations in Discontinuous Permafrost Areas

34. NatRCC NRC-5108
Building in Northern Canada

35. NatRCC NRCC-11843
Construction on Permafrost

36. NatRCC CBD-64
Permafrost and Foundations

37. NatRCC BBB-5
Permafrost and Buildings

38. NAS
Engineering Design and Construction in Permafrost Regions: A Review

39. NAS
Designing Friction Piles for Increased Stability at Lower Installed Cost in Permafrost

40. NAS
Pile Foundations in Permafrost

41. NAS
Pile Construction in Permafrost

Ice and Snow

Ice and snow are two material substances found throughout the cold-weather areas of the world. There are two major problems associated with construction on permanent snowfields. The first is the inevitable settlement resulting from the continuous densification of snow; the second is the excessive and undesirable accumulation of snow through deposition and drifting. Construction on ice has consisted primarily of research stations established on drifting ice packs or glacial ice fields. Major problems with construction on ice include melting, ablation and breakup. Reports recommended in this subsection explain how best to attend to these problems.

42. NAVFAC DM-9
Design Manual: Cold Regions Engineering

43. CEL R-819
Snow Road Construction by Layered Compaction--Construction and Maintenance Guide

44. CEL R-767
Snowdrift Control Techniques and Procedures for Polar Facilities

45. CEL R-511
Ice Construction--Methods of Surface Flooding

46. CEL R-402
Ice Construction--Survey of Equipment for Flooding

47. CEL R-700
Holding Strength of Piles in Ice

48. CRREL CRSE-3A2a
Methods of Building on Permanent Snowfields

49. CRREL CRSE-3A2b
Investigation and Exploitation of Snowfield Sites

50. CRREL CRSE-3A2c
Foundations and Subsurface Structures in Snow

51. CRREL CRSE-3A2d
Utilities on Permanent Snowfields

52. CRREL TR-151
A Straight-wall Cut-and-cover Snow Trench

53. CRREL TR-219
Design of Footing Foundations on Polar Snow

54. CRREL SR-198
Expedient Snow Airstrip Construction Technique

55. CRREL TR-175
Spread Footing Foundations on Snow

56. CRREL TR-214
The 50-man Winter Camp at Tuto, Greenland

57. CRREL TR-212
Design Criteria for Snow Runways

Utilities

The existence of ice, snow and permafrost introduces problems in the provision of water supply, sewage disposal, central heating, and electrical power, particularly in the distribution systems. The basic engineering principles governing the design of water supply and sewage disposal systems in temperate climates also apply in arctic and subarctic regions; however, modified design and special construction techniques are often necessary to account for the effects of extreme temperatures and fragile ground conditions. Reports recommended in this subsection consider some of the special problems and possible solutions for utilities in cold regions.

58. CEL R-733
Single-line, Heat-traced Piping for Polar Regions

59. CEL R-734
Aboveground Utilidor Piping Systems for Cold-weather Regions

60. DA TM 5-852-5
Arctic and Subarctic Construction. Utilities

61. CRREL CRSE-3A2d
Utilities on Permanent Snowfields

62. CRREL CRSE-3C5a
Water Supply in Cold Regions

63. CRREL CRSE-3C5b
Sewerage and Sewage Disposal in Cold Regions

64. CRREL SR-95
Design, Construction and Performance Data of Utility Systems Thule Air Base

65. NatRCC NRC-4056
Protection of Utilities against Permafrost in Northern Canada

66. NAVFAC DM-9
Design Manual: Cold Regions Engineering

Materials and Concreting

The references listed in this subsection involve material properties at low temperatures, including cold-weather concreting and asphalting.

67. CEL R-812
Caulking Compounds for Application at Low Temperatures

68. NAVFAC DM-9
Design Manual: Cold Regions Engineering

69. CEL R-671
Portland Cement Concrete for Antarctica

70. CRREL SR-76
A Survey of Winter Construction Practices: Earthwork, Concrete and Asphalt

71. CRREL SR-245
Cold-Weather Construction Materials: Part I - Regulated-set Cement for Cold-Weather Concreting

72. NatRCC CBD-116
Durability of Concrete under Winter Conditions

SECTION II

This section presents complete publication information for reports from SECTION I. All technical reports issued by CEL and USA CRREL are accessioned to the Defense Documentation Center (DDC) and may be purchased by accession number (AD number) from the National Technical Information Service (NTIS), Springfield, VA 22151.

The technical manuals issued by the Department of the Army may be acquired at cost from the U.S. Army AG Publication Center, 1655 Woodson Road, St. Louis, MO 63114.

Copies of NAVFAC Manual DM-9 are available upon request from the Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

The Canadian publications can be ordered from the Division of Building Research, National Research Council, Ottawa, K1A OR6, Ontario.

Proceedings from the first and second international permafrost conferences are available from the Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418.

1. Fulwider, C. W. and Stearman, J. H.
A BIBLIOGRAPHY ON WINTER CONSTRUCTION, 1940-1967.
CRREL Special Report SR-83. April 1968.
AD-675 415

ABSTRACT: This bibliography was derived primarily from a search of the U. S. Army Cold Regions Research and Engineering Laboratory library, the Arctic Bibliography, the Bibliography on Snow, Ice and Permafrost (USA CRREL Report No. 12, Volumes 1-20), the Polar Bibliography, the Industrial Arts Index and the Applied Science and Technology Index. The period covered by the bibliography purposely was limited to the years after 1940 because of the rapid technological advances since World War II. The 751 references are subdivided into twenty-two categories.

2. Kaplar, C. W. and Metrish, R. M.
BIBLIOGRAPHY ON WINTER CONSTRUCTION, 1967-1971.
CRREL Special Report SR-204. April 1974.
AD-778 742

ABSTRACT: The bibliography covers world literature published during 1967-1971 on the subject of construction during cold weather. The contents are drawn mainly from the continuing current literature search performed by the Science and Technology Division of the Library of Congress for the U.S. Army Cold Regions Research and Engineering Laboratory. The contents include 746 items grouped into 17 categories, plus an author index. This bibliography is an addendum to the revised edition of USA CRREL Special Report 83, A Bibliography on Winter Construction, 1940-1967, published in 1968.

3. Williamson, W. F.
A BIBLIOGRAPHY ON COLD WEATHER CONSTRUCTION
NatRCC Bibliograph B. 10. February 1971

ABSTRACT: This bibliography was derived primarily from a search of literature contained in the following Canadian references: the Engineering Index Service, The Industrial Arts Index and various reports in the Library of the Division of Building Research.

4. Corporate Author: Cold Regions Research and Engineering Laboratory
USA CRREL TECHNICAL PUBLICATIONS
CRREL Special Report 175. December 1975.

ABSTRACT: This report is a cumulative listing of all technical reports and publications issued by the U.S. Army Cold Regions Research and Engineering Laboratory. Entries are indexed by report number, author and subject.

5. Corporate Author: Cold Regions Research and Engineering Laboratory
BIBLIOGRAPHY ON COLD REGIONS SCIENCE AND TECHNOLOGY, VOLUME XXVI, PT. 1
CRREL Report 12. September 1972.

ABSTRACT: This report is a continuing publication released approximately yearly by CRREL. It lists all materials dealing with cold-weather science and technology that are accessioned to the Science and Technology Division of the Library of Congress.

6. Yoakem, Delmar
A SURVEY OF WINTER CONSTRUCTION PRACTICES EARTHWORK, CONCRETE AND ASPHALT
CRREL Special Report 76. July 1966.
AD-801 626

ABSTRACT: A survey was made by submitting questionnaires to various state, federal, local and private agencies engaged in cold-weather construction, soliciting their specification requirements and practices in relation to soil, concrete, and asphalt used in foundations, structures and pavements. The report presents a summary of the results of the survey, evaluation of and comments on the results.

7. Havers, J. A. and Morgan, R. M.
LITERATURE SURVEY OF COLD-WEATHER CONSTRUCTION PRACTICES
CRREL Special Report 172. May 1972.
AD-745 395

ABSTRACT: The objective of this study was to survey existing literature on cold-weather construction practices. The seasonality problem was defined and its economic and operational implications were identified. The effects of cold weather on men, material, and equipment were reviewed. Cold-weather construction tasks were examined for technological constraints and comparisons were made with existing military and civilian codes. Research and observations pertaining to the construction tasks being examined were listed to provide a base for current and future development of cold-weather construction techniques. An attempt was made to analyze the natural and technological constraints imposed by the weather on men, material, and equipment. The economic feasibility of cold-weather construction was examined by reviewing the recorded experience of many segments of the international construction industry, and the economic advantages of cold-weather construction were listed. It was concluded that 1) construction seasonality in the United States is a major economic problem; 2) reducing it and overcoming its effects are major tasks to be accomplished; and 3) cold-weather construction is not a panacea for seasonal unemployment, but would help to alleviate it.

8. Cronin, J. E.
EARTH SCIENCE RELATED ENVIRONMENTAL FACTORS IN POLAR REGION CONSTRUCTION
CEL Technical Note N-1406. November 1975.
AD-A017 697

ABSTRACT: A literature search was conducted to identify earth-science related environmental factors affecting construction and transportation in the polar regions. The three polar "earth materials"--snow, ice, and frozen ground--were considered. The study was to produce a document that would provide an overview of the subject and bring together a source of references for more detailed study as required.

9. Corporate Author: Department of the Army
ARCTIC CONSTRUCTION
Department of the Army Technical Manual TM 5-349. February 1962.

ABSTRACT: This manual supplies engineer officers and noncommissioned officers of battalion and group level with pertinent facts covering construction requirements and engineer problems peculiar to arctic and subarctic areas. Part one describes conditions in the Arctic and Subarctic as they affect construction. Part two covers arctic construction of roads, airfields, base camps, and bridges, including advance planning, concreting in cold weather, use of ice and snow as construction materials, and the effect of arctic cold on explosives.

10. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION. GENERAL PROVISIONS
Department of the Army Engineering Manual for Military Construction
TM 5-852-1. 1966.

ABSTRACT: In the design, construction, and maintenance of roads, runways, buildings, and other structures, the existence of permanently frozen ground in arctic and subarctic regions presents many problems which are not encountered in temperate zones. The problems are due to thawing of the frozen ground beneath the structures, to freezing and thawing processes in the layers of soil overlying the permanently frozen ground, and to drainage conditions peculiar to such regions. The principles which control the action of such soils and the application of these principles to problems encountered in construction are discussed in this part of the Engineering Manual.

11. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION. SITE SELECTION AND DEVELOPMENT
Department of the Army Engineering Manual for Military Construction
TM 5-852-2. 1966.

ABSTRACT: The types of data to be collected for the selection of a site are essentially the same as those used for engineering design in temperate regions, but complete information is essential. It is not

feasible to prescribe the detailed information required for a given site selection or development problem as each project requires judgment in the development of an adequate program of investigation and analysis: only the basic principles and considerations are included in this chapter. In addition operational requirements of the future using agency, or other similar considerations beyond the scope of the present manual, may impose unusual and unforeseeable requirements. Observations made in arctic and subarctic regions of North America form the basis for this chapter, and, while local details may vary considerably, the basic concepts presented should be generally applicable. An example outlining a step-by-step procedure for the selection of an airbase site in an undeveloped region is presented in Appendix A to this chapter and a discussion of the principles of interpretation of natural features is given in Appendix B.

12. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION. CALCULATION METHOD FOR THE DETERMINATION OF DEPTHS OF FREEZE AND THAW IN SOILS
Department of the Army Engineering Manual for Military Construction TM 5-852-6. 1966.

ABSTRACT: Determination of the depths to which freezing or thawing may occur is very important in the design of roads, runways, buildings, and other structures in permafrost areas. Methods for making such calculations, based on heat transfer principles, are presented in this chapter. Available data on the characteristics of the materials necessary for solutions are also presented. Derivations of basic equations and the underlying theory are not given in this chapter. Note that the methods presented herein are simplified procedures, in which only factors of predominant influence are taken into account.

13. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION. TERRAIN EVALUATION IN ARCTIC AND SUBARCTIC REGIONS
Department of the Army Technical Manual TM 5-852-8. June 1966.

ABSTRACT: This manual presents and illustrates briefly the methods by which ground conditions in permafrost areas of the Arctic and Subarctic may be evaluated from airphotos, surface observations, and other data. The material presented is concerned primarily with about the upper four feet or less of the soil profile in the Arctic and about the upper 8 feet or less in the Subarctic and does not apply to deep foundation problems or to water supply.

14. Stearns, S. Russell
PERMAFROST (PERENNIALLY FROZEN GROUND)
CRREL Cold Regions Science and Engineering Report CRSE 1-A2. August 1966.
AD-642 730

ABSTRACT: This monograph summarizes information on permafrost for engineering construction in cold regions. The distribution and origin of permafrost is discussed and information on structure, thickness, and thermal regime is summarized. Patterned ground and vegetation in the cold regions are discussed and the engineering significance of permafrost is reviewed.

15. Scott, R. F.
HEAT EXCHANGE AT THE GROUND SURFACE
CRREL Cold Regions Science and Engineering Report CRSE 2-A1. July 1964.
AD-449 434

ABSTRACT: This paper summarizes existing (as of 1964) knowledge of heat exchange at the ground surface from an engineering viewpoint, aiming at the solution of the problem of predicting the ground penetration of the freezing point isotherm from weather, soil, and surface conditions. The parameters used in solution are radiation, wind and air temperature, soil and subsurface temperatures, surface heat balance, and freezing and thawing indexes.

16. Mellor, Malcolm
INVESTIGATION AND EXPLOITATION OF SNOWFIELD SITES
CRREL Monograph CRSE-3A2b. January 1969.
AD-686 314

ABSTRACT: This monograph is the second of a series of 5 on Snow Engineering: Construction. It covers the site investigations and laboratory tests in connection with construction on a permanent snowfield, and then deals with the technology of excavation and building where snow is almost the only constructional material. The author draws heavily on the work of the Cold Regions Research and Engineering Laboratory (CRREL) in the development of Camp Century and other projects on the Greenland ice sheet and shows the application of the techniques to Antarctic Research Stations.

17. Mellor, Malcolm
SNOW REMOVAL AND ICE CONTROL
CRREL Cold Regions Science and Engineering Report CRSE-3A3b. April 1965.
AD-615 795

ABSTRACT: Climatology of snow cover in the northern hemisphere is briefly presented along with a description of significant snow properties. More extensively treated are the various equipment and methods used to control ice and snow. Snow plows, heating systems and chemical means of snow removal are compared and techniques are presented.

18. Corporate Author: Cold Regions Research and Engineering Laboratory
WATER SUPPLY IN COLD REGIONS
CRREL Monograph CRSE-3C5a. January 1969.

ABSTRACT: The monograph outlines the influence of a cold environment on sanitary engineering works and services. It then deals with water supply in cold regions: sources, distribution systems, treatment processes and possible future supply from other than geological sources.

19. Brown, W. G.
DIFFICULTIES ASSOCIATED WITH PREDICTING DEPTH OF FREEZE OR THAW
National Research Council of Canada Research Paper NRC 8276. November 1964.

ABSTRACT: Calculations using the Neumann solution (as modified by Aldrich) and thermal properties of soils (obtained by Kersten) show that the frost penetration depth for the same freezing index for essentially all soils with any moisture content and for dry sand and rock varies by a factor of about 2 to 1. The extremes calculated in this way bracket the experimentally determined design curve of the US Army Corps of Engineers and give it theoretical support. The theoretical calculations and additional experimental data are used as a basis for a small alteration in the slope of the design curve. This modified design curve is recommended for field use because of (1) inherent imperfections in existing theory and (2) practical limitations to precise specification of field conditions.

20. Corporate Author: National Research Council, Division of Building Research
WINTER CONSTRUCTION
National Research Council Better Building Bulletin Number 6.

ABSTRACT: This bulletin attempts to indicate some of the techniques used in Canada by contractors working throughout the winter months. There is little to be found in these pages which will be new to those familiar with winter construction but it is hoped that many contractors who in the past have stopped construction in the late fall, will be encouraged to so plan their construction that it will be possible for them to continue throughout the winter months. It should be pointed out that while many protective measures must be taken during the winter, good control can be maintained of the various jobs associated with construction work. This often results in a superior structure over one built, for example, during extremely hot summer weather when it is very difficult to provide protective measures for concrete and masonry.

21. Bennett, F. Lawrence
TEMPORARY ENCLOSURES AND HEATING DURING CONSTRUCTION
CRREL Special Report 223. September 1975.
AD-A015 566

ABSTRACT: Temporary enclosures and heating activities during the construction of the Laboratory Building Addition, University of Alaska, were observed during the winter of 1973-74. Methods for providing enclosures and temporary heat are described; a total cost of $14,110, or 0.79% of the construction contract price, is estimated for these activities, which focused mainly on the first floor of the three-story building. Records of temperatures inside and outside the building were maintained, and a least squares linear regression relationship with correlation coefficient 0.523 was developed between these temperature differences and the heating requirement. Extensive photo documentation was developed, part of which is contained herein.

22. Lange, G. Robert
ROTARY DRILLING AND CORING IN PERMAFROST. Part I, Preliminary Investigation, Fort Churchill, Manitoba
CRREL Technical Report 95, Part I. November 1968.
AD-681 218

ABSTRACT: A small rotary drill rig was instrumented and used at Fort Churchill, Manitoba, to investigate the problems of drilling and coring in permafrost. Small diameter augers were also tested. Adequate rates of penetration were easily achieved. However, difficulties were encountered when hole walls and core were thawed by warm drilling fluid. Some success was achieved when coring with water cooled by ice. It was concluded that the feasibility of using a low freezing point liquid and/or compressed air and a portable refrigerator should be investigated.

23. Davis, R. M. and Kitze, F. F.
SOIL SAMPLING AND DRILLING NEAR FAIRBANKS, ALASKA: EQUIPMENT AND PROCEDURES
CRREL Technical Report 191. January 1967.
AD-816 654

ABSTRACT: Soils explorations were conducted by core drilling methods and by drive sampling methods in thawed and frozen silty soils. Temperatures ranged from 28° to 31.5°F in the permafrost and from 20° to 27°F in the active layer. The Cyclone churn drill, equipped with a field-fabricated 3 in. diameter pipe sampler, is an effective means for drive sampling in frozen silt soils to a depth in excess of 100 ft. Core drilling and sample recovery has been accomplished by using the Longyear, Acker, and Chicago Pneumatic core drills. A Concore exploration drill has been effective in obtaining core samples from 20 to 30-ft depth in frozen soils. A tripod arrangement for supporting a 350-lb drive hammer operated manually by a rope from the cathead of both Acker

and Chicago Pneumatic core drills was also effective for drive sampling frozen silty soils to depths up to 20 ft. In general, the Acker split and solid tube samplers have been more effective for driving into frozen soils than the same type samplers of Sprague and Henwood. Manual driving of a sampler fabricated from thin wall electrical conduit proved to be effective for sampling frozen soils to depths of about 10 ft. Sampler driving by pneumatic hammer and recovery by truck mounted winchline was effective to 10 to 15 ft depth.

24. Corporate Author: Department of the Navy, Naval Facilities Engineering Command
DESIGN MANUAL: COLD REGIONS ENGINEERING
NAVFAC DM-9. March 1975.

ABSTRACT: Basic criteria and requirements are presented on cold regions engineering for naval shore facilities. The contents include general information concerning the nature of the cold regions, basic considerations in the planning and design of cold regions construction, and specific criteria on the design of buildings and structures, utility systems, roads, and airfields.

25. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION: SURFACE DRAINAGE DESIGN FOR AIRFIELDS IN ARCTIC AND SUBARCTIC REGIONS
Department of the Army Engineering Manual for Military Construction
TM 5-852-7, Part XV, Chapter 7. 1965.

ABSTRACT: The discussion and examples contained in this chapter are presented to promote a better understanding of the problems involved in the design of drainage facilities, and to outline convenient methods of estimating design capacities for airfield drainage facilities in arctic and subarctic regions. While the design data developed in this chapter have been developed mainly for Alaska, the methods used are generally applicable to other locations in arctic and subarctic regions.

26. Brier, F. S.
SNOWDRIFT CONTROL TECHNIQUES AND PROCEDURES FOR POLAR FACILITIES.
CEL Technical Report R-767. June 1972.
AD-744 237

ABSTRACT: Accumulation of windblown snow causes an assortment of problems at polar facilities. In addition to curtailing personnel and vehicular movement, snowdrift accumulation may damage structures and disrupt aircraft operations. In an effort to develop techniques and procedures for alleviating snowdrift accumulation, scale-model studies on building shapes, orientations, and groupings were conducted in wind ducts, and field studies were conducted on snow collection systems. The scale-model wind duct studies of a camp showed that

snowdrift accumulation can be reduced by elevating the camp on a snow platform, orienting the buildings 45-degrees to the snow-carrying wind, and placing the structures and utilities to permit easy snow removal. The field studies on snow collection systems on airfields showed 3- to 4-foot-high windrows with a borrow pit on their leeward side are effective in controlling drift on skiways and runways when located on the upwind side of the surface to be protected.

27. See Entry 24.

28. See Entry 14.

29. Sanger, Frederick J.
FOUNDATIONS OF STRUCTURES IN COLD REGIONS
CRREL Monograph CRSE-3C4. June 1969.
AD-694 371

ABSTRACT: This monograph describes the various kinds of foundations used for structures on permafrost with a brief discussion of foundations in areas of seasonal frost. Special attention is given to piled foundations in permafrost and the design of ventilation systems for controlling thaw under heated buildings. Appendixes outline techniques for computing the depth of freezing or of thawing, the design of refrigeration systems for artificial freezing, and the recommended procedure in the USSR for static pile tests. Included in the main text are 51 figures and 62 selected references.

30. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION: RUNWAY AND ROAD DESIGN
DA TM 5-852-3. 1954.

ABSTRACT: The construction of satisfactory roads and runways in permafrost areas is normally more difficult than in temperate regions because the imperviousness of the underlying permafrost tends to produce poor soil drainage conditions, and because disturbance of the natural surface may set in motion adjustments in thermal regime, drainage, and slope stability which may have serious and progressive consequences. Considerations are the effect of subgrade soil conditions on design, effect of frost and permafrost conditions and effect of ground water. Cuts should be avoided if possible and side slopes in fill composed of fine-grained materials should be kept to a 4 to 1 ratio or flatter.

31. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION: BUILDING FOUNDATIONS
DA TM 5-852-4. 1954.

ABSTRACT: Buildings in arctic and subarctic regions, when constructed on frost-susceptible soils, are subject to considerable heaving and settlement, due to freezing and thawing in the underlying soil. Differential movements cause sloping floors, jammed doors and windows, cracks in walls and ceilings and may even cause stresses leading to structural failure. Consideration of the fundamentals of frost action in soils in the design of building foundations will hold such movements to a minimum and thus limit the structural damage. Whenever possible, buildings should be located on clean, granular soils. Heaving and settlement are comparatively small in such materials because segregated ice is uncommon. This chapter covers the various factors which should be considered in the foundation design, such as type of building, soil conditions, frost and permafrost conditions, and heat transfer to the foundation.

32. See Entry 12.

33. Crory, Frederick E.
PILE FOUNDATIONS IN DISCONTINUOUS PERMAFROST AREAS
CRREL Special Report 79. March 1967.
AD-814 700

ABSTRACT: The design and installation of piles in areas of warm permafrost present many unusual problems. Design considerations and construction methods and controls to minimize disturbance of the delicate thermal balance of warm permafrost are included in an evaluation of pile installation techniques. The importance of adequate site investigations and proper construction inspection and control is emphasized. Preconstruction temperature information is used with climatological records and theoretical methods to predict the freezing and/or thawing that will be experienced under the structure. Natural and artificial freezeback of piles are discussed in terms of construction schedules, installation methods, and the volumetric heat capacity of the permafrost.

34. Legget, R. F. and Dickens, H. B.
BUILDING IN NORTHERN CANADA
NatRCC NRC-5108. March 1959.

ABSTRACT: Building in northern Canada in recent years has become a most important part of the nation's construction activity. Despite its limited volume, its strategic location and defense implications give northern building a singularly important consideration in the national economy. This paper considers various aspects of northern construction, including permafrost and its effects, building superstructures and logistics and economics.

35. Crawford, C. B. and Johnston, G. H.
CONSTRUCTION ON PERMAFROST
NatRCC Technical Paper NRCC 11843. May 1971.

ABSTRACT: Permafrost, or perennially frozen ground, occurs widely throughout the northern half of Canada. Experience has shown that special design and construction techniques are required for building on permafrost in order to avoid disturbing the delicate thermal balance that preserves the frozen ground. The state of knowledge is reviewed with respect to site investigations, foundation designs, water supply and sewage disposal, the construction of transportation facilities, and the influence of surface flooding, drainage and other disturbances on the ground thermal regime. Attention is drawn to an extensive literature and research needs are outlined.

36. Johnston, G. H.
PERMAFROST AND FOUNDATIONS
NatRCC CBD-64. April 1965.

ABSTRACT: This Digest briefly describes permafrost and discusses problems related to foundation design in permafrost areas.

37. Corporate Author: National Research Council of Canada, Division of Building Research
PERMAFROST AND BUILDINGS
NatRCC Better Building Bulletin BBB-5.

ABSTRACT: This pocket-size guide lists practical considerations that need be studied before building in areas of permafrost. It gives simple sketches for the construction of surface and buried foundations.

38. Linell, A. L. and Johnston, G. H. "Engineering design and construction in permafrost regions: a review." In Permafrost: Proceedings from the Second International Conference. National Academy of Sciences, Washington, DC, 1973, pp. 553-575.

ABSTRACT: In North America, development of the permafrost regions is advancing at a rapidly accelerating rate. This creates increasingly intense pressure on the technical community to formulate engineering design and construction principles that will accurately ensure predictable behavior and minimum costs. This paper summarizes the progress made in these areas in the past few years. Since it is impossible to reference all significant literature in the paper, only the references indicative of the state of the art are included.

39. Long, E. L. "Designing friction piles for increased stability at lower installed cost in permafrost." In Permafrost: Proceedings from the Second International Conference. National Academy of Sciences, Washington, DC, 1973, pp. 693-699.

ABSTRACT: The material contained in this discussion was drawn from the experience of the author and evaluation of others' work. It discusses various configurations for piles in permafrost and some of the stress and material consideration important in design.

40. Crory, F. E. "Pile foundations in permafrost." In Permafrost: Proceedings of an International Conference. National Academy of Sciences, Washington, DC, 1966, pp. 467-476.

ABSTRACT: Foundation design in permafrost areas must differ from foundation design in temperate climate because of unstable soil conditions. Of the considerations essential to the design of building foundations in permafrost areas, many are applicable to all foundation types; but particular emphasis is given to the development of design criteria for pile foundations. Results of field tests and observations from which the design criteria were derived are briefly presented, where appropriate.

41. Johnston, G. H. "Pile Construction in Permafrost." In Permafrost: Proceedings of an International Conference. National Academy of Sciences, Washington, DC, 1973, pp. 477-480.

ABSTRACT: This paper summarizes the results of field observations by the Division of Building Research and of discussions with many people who have contributed greatly by making available their valuable experience in northern construction. A large construction program monitored at Inuvik showed the success of preplanning the time of foundation placement so as to allow time for refreezing of piles before the superstructure is erected. Construction schedules were rarely disrupted by pile foundations not being ready for loading. Thus the selection and use of piles as the most suitable foundation type for the majority of buildings and facilities erected at Inuvik was justified.

42. See entry 24.

43. Barthelemy, J. L.
SNOW ROAD CONSTRUCTION BY LAYERED COMPACTION--CONSTRUCTION AND MAINTENANCE GUIDE
CEL Technical Report R-819. April 1975.

ABSTRACT: The use of rubber-tired vehicles in polar regions greatly speeds the movement of cargo and personnel. However, in areas of perennial snow, roads must be provided. Heavy-haul, wheeled transportation equipment, in particular, requires high-strength snow roads

while operating on deep snow fields. Specially processed, elevated snow roads can provide dependable service for 2 years or more. This construction guide outlines those procedures necessary to build and preserve snow roads by means of layered compaction, the simplest and most rapid technique developed by CEL. In this process, the roadbed is built up to a desired elevation by successive compaction of 4-inch layers of snow. A modified rotary snowplow is used to gather, process and deposit the construction material.

44. See Entry 26.

45. Hoffman, C. R.
ICE CONSTRUCTION--METHODS OF SURFACE FLOODING
CEL Technical Report R-511. January 1967.
AD-645 917

ABSTRACT: Two surface-flooding techniques for improving natural ice areas have been developed by the U. S. Naval Civil Engineering Laboratory. Confined flooding, in which the flood is contained by natural barriers or man-made dikes, is used principally for filling and leveling ice areas where deflection of the natural ice is not a problem. Free flooding, in which the outward flow of water is governed by natural forces such as gravity and freezing of the flood perimeter, is generally used for the accelerated buildup of thinner natural ice areas where deflection is encountered.

Adequate methods have been developed for surface flooding a relatively small area with a maximum dimension of 1,200 feet and for increasing ice thickness by as much as 5 feet. Continued investigation is required for the multipump flooding of areas 5,000 feet long, the flooding of deep snow, and the construction of ice roadways through tidal and pressure-ice areas.

46. Hoffman, C. R. and Dykins, J. E.
ICE CONSTRUCTION--SURVEY OF EQUIPMENT FOR FLOODING
CEL Technical Report R-402. January 1966.
AD-628 548

ABSTRACT: Two surface-flooding techniques for improving natural ice areas have been developed by the U. S. Naval Civil Engineering Laboratory (NCEL). Confined flooding, in which the flood is retained by natural boundaries and dikes, is used principally for filling and leveling thick natural ice areas. Free flooding, in which the outward flow of water is retained by freezing of the flood boundary, is generally used for accelerated thickening of relatively thin natural ice.

This survey shows that adequate surface pumping units and flood distribution systems have been developed for confined flooding, and subsurface pumping units are being developed for free flooding. Mobile power-handling equipment is available for moving, lifting, and placing the pumps and other heavy gear required for ice construction, but the available man-handling gear for this work is less than adequate. Drills

and augers are available for boring shallow holes in ice but not for deep holes. Electrical equipment and materials are available for cold-weather operation of single pump installations but systems for operating several pumps from a single power source have not been fully developed. Hot-air heaters, air compressors, chain saws, and other miscellaneous gear required for all types of ice flooding are available from commercial sources.

It was concluded that continued development of the subsurface pumps and the necessary supporting equipment is needed to advance the techniques for leveling and strengthening natural ice areas.

47. Stehle, N. S.
HOLDING STRENGTH OF PILES IN ICE
CEL Technical Report R-700. October 1970.
AD-714 165

ABSTRACT: Piles are used in polar regions for many of the same purposes as in temperate regions, including foundations for structures in areas of permafrost and ice. The bearing capacity of piles set in permafrost and ice depends on the holding, or tangential adfreezing, strength. Tests were conducted at the Naval Civil Engineering Laboratory to determine the influence of pile material, shape, ground temperature, and backfill on tangential adfreezing strength in ice. General criteria for application were developed based on laboratory and field information. It was concluded that ground and air temperatures are the most influential parameters in determining the pile type and backfill. Design load, however, should be based on tangential adfreezing strength after long-term loading; this strength was determined to be one-half to two-thirds the tangential adfreezing strength after no previous loading.

48. Mellor, Malcolm
METHODS OF BUILDING ON PERMANENT SNOWFIELDS
CRREL Monograph CRSE-3A2a. October 1968.
AD-681 889

ABSTRACT: Construction on the polar ice sheets of Greenland and Antarctica is a challenge, mainly because of the mechanical and thermal sensitivity of snow, the major constructional material. Adverse weather, logistical difficulties, and lack of experience add to the problem to make every project a costly experiment. This monograph describes the development of building in, on, and of, snow, beginning with the Eskimo snowhouse for temporary shelter, and leading to permanent installations like 6500-ton steel structures above the snow surface, and a large subsurface encampment maintained with the help of a nuclear reactor. The work is introductory to other monographs dealing with specific aspects of design, construction and operation.

49. See Entry 16.

50. Mellor, Malcolm
FOUNDATIONS AND SUBSURFACE STRUCTURES IN SNOW
CRREL Monograph CRSE-3A2c. October 1969.
AD-669 336

ABSTRACT: Various types of foundations suitable for use in very deep snow are described, and design principles are given. Dependence of settlement rate on heaving pressure, size and shape of foundation, snow temperature, and snow density is treated analytically, and field data from test procedures for foundation design are outlined. In treating the design of tunnels, shafts and subsurface structures in very deep snow, the distributions of stress, strain and displacement in polar ice sheets are first obtained analytically. Observed patterns of deformation are given for a variety of excavations and deformable structures, and methods of analysis are put forward. The loading of restraining structures is discussed, and finally some notes on the monitoring and maintenance of subsurface structures are given.

51. Mellor, Malcolm
UTILITIES ON PERMANENT SNOWFIELDS
CRREL Monograph CRSE-3A2d. October 1969.
AD-699 337

ABSTRACT: The topics covered in the monograph include water supply, waste disposal, heating, ventilating and fire protection at installations built on polar ice sheets. The section on water supply discusses energy requirements, consumption rates, water quality and treatment, techniques and equipment for melting snow and ice, and water distribution systems. A number of actual water supply systems are described in detail. The section on waste disposal deals with sewage and sewage sinks, latrines, garbage, trash and scrap and radioactive waste. Examples of sanitation systems at polar bases are described in some detail. The section on heating discusses heating load, heat losses and insulation, energy sources, and heating systems. The ventilation section covers air demands, intakes and exhausts, ventilation of undersnow tunnels, and carbon monoxide problems. The report concludes with some notes on fire protection.

52. Tobiasson, Wayne and Rissling, Donald L.
A STRAIGHT-WALL CUT-AND-COVER SNOW TRENCH
CRREL Technical Report 151. October 1966.
AD-646 306

ABSTRACT: A straight-wall cut-and-cover snow trench was constructed at Camp Century, Greenland, during the 1962 summer, to house tests performed by USA CRREL Project 33, Feasibility Study of Pile Foundations in Snow. In this report, the parameters used to design the trench and the equipment and methods used in the construction are presented and evaluated. Time-motion studies covering all phases of construction are included as a guide for the planning and evaluation of similar construction. Performance is discussed and documented by instrumentation installed in the trench. (Author's abstract)

53. Reed, Sherwood C.
DESIGN OF FOOTING FOUNDATIONS ON POLAR SNOW
CRREL Technical Report 219. September 1974.
AD-787 287

ABSTRACT: Settlement of spread footings on snow is dependent on time, snow density, snow temperature, load intensity, footing size and footing shape. Empirical equations, based on field test results at Camp Century, Greenland, relating these parameters are developed in this report. The equations are written to permit simple hand calculations so they do not require a complex mathematical technique or computer application.

54. Clark, E. F., Abele, G. and Wuori, A. F.
EXPEDIENT SNOW AIRSTRIP CONSTRUCTION TECHNIQUE
CRREL Special Report 198. December 1973.
AD-774 290

ABSTRACT: Specialized snow runway processing and construction equipment ordinarily is not available to Army engineer troop units. Therefore, utilization of existing equipment and devices improvised in the field is necessary. Disaggregation of the natural snow cover, followed immediately by compaction and grading, is the fundamental procedure required for preparing a snow pavement capable of supporting, after age hardening, wheeled aircraft of the Caribou and C-47 class. A peg-toothed A-frame harrow, a corrugated roller and drags, constructed in the field, can be used with available D-7 or D-8 bulldozers for the disaggregation, compaction, and grading processes.

55. Reed, S. C.
SPREAD FOOTING FOUNDATIONS ON SNOW
CRREL Technical Report 175. April 1966.
AD-637 112

ABSTRACT: A series of nine spread footing tests was installed on snow at Camp Century, Greenland, in 1961 and continuously observed through the 1963 summer. The influence of footing load, size and shape on settlement were investigated and the effects of the uncontrolled parameters (temperature and snow density) were recorded. The results indicate that settlement is dependent on 6 basic parameters: time, snow density, temperature, load intensity, footing size, and footing shape. Snow deformation beneath a footing occurs in a bulb-shaped zone whose lateral and vertical dimensions approach 1.5 times the footing width. In general, spread footings placed on snow in the density range 0.4 to 0.5 g/cm^3 can be expected to show a high initial settlement rate, occurring during the construction period in an actual installation. Rectangular spread footings will produce the least settlement if all other factors are equal, but care should be exercised in the design of large or very long shapes as differential settlement could induce severe stresses in any rigid structure. To

minimize differential settlements all footings should be placed on snow having similar characteristics with a density approaching 0.5 g/cm^3 and all footings should be designed to have about the same size and load intensity.

56. Lufkin, Major L. E. and Tobiasson, Wayne
THE 50-MAN WINTER CAMP AT TUTO, GREENLAND
CRREL Technical Report 214. August 1969.
AD-694 375

ABSTRACT: In 1965 a U. S. Army research camp was constructed near Thule, Greenland. Research needs, site conditions and available equipment strongly influenced design and construction. Data collected from other facilities in Greenland were used to establish space, utility and power requirements. Orienting structures to minimize snow drifting, elevating floors to prevent degradation of permafrost, and protection of utility lines from freezing were given particular attention. Timber spread footings resting on non-frost-susceptible fill were used to support two rows of wooden T-5 Arctic buildings, interconnected by a corrugated steel passageway. Water was piped 4470 ft from a glacial lake and waste water discharged into a lagoon downwind of the facility. Excavation of permafrost with a routing tooth was the major construction problem. The extra effort expended to consider the special problems of the Arctic site was fully justified: snow drifting and utility problems were minimal and the overall performance of the facility exceeded that of several previously constructed camps.

57. Abele, Gunars, Ramseier, René O., and Wuori, Albert F.
DESIGN CRITERIA FOR SNOW RUNWAYS
CRREL Technical Report 212. November 1968.
AD-681 220

ABSTRACT: The physical characteristics of snow and those processes of metamorphism which contribute to its strength are important considerations in planning the construction of compacted snow runways. Two distinct temperature-dependent processes affect the physical properties of snow: sintering and strength increase with decreasing temperature. The rate of strength increase and the ultimate strength of snow may be greatly increased by mechanical agitation or depth processing followed immediately by surface compaction. Leveling to produce a smooth surface for aircraft is also necessary. Various combinations of processing and compaction are required depending on the size of aircraft to be operated on the runway. After construction is completed, the natural process of sintering or strengthening must be allowed to proceed for some time before aircraft operations can be initiated. The mechanical properties of processed snow have been correlated with its wheel-load supporting capacity. The correlation shows the effect of such parameters as wheel load, tire contact pressure, and repetitive wheel coverages on the required hardness or strength of a compacted snow layer. Strength profiles which can be expected from certain snow processing and compaction

procedures are shown and compared with required strength profiles for various types of wheeled vehicles and aircraft. The purpose of this study was to combine the knowledge gained from fundamental research in the processes of sintering with methods and procedures developed by engineers for using snow as a construction material. The results are readily applicable to the construction of snow runways for a large variety of wheeled aircraft and the construction of snow roads for wheeled vehicle traffic.

58. Hoffman, C. R.
SINGLE-LINE, HEAT-TRACED PIPING SYSTEM FOR POLAR REGIONS
CEL Technical Report R-733. June 1971.
AD-886 566

ABSTRACT: Single-line piping systems for the distribution of freezable liquids, such as water and sewage, were investigated for Navy polar application. The investigation, which included the testing of three preassembled pipe systems, shows that a commercially available system consisting of preassembeld insulated jacketed X-50 piping freeze-protected with Electro-Wrap heat-tracing tape is well suited for Navy polar application. An X-50 piping system containing one to three pipes appears to be more cost effective than an equivalent multiline utilidor system of four to six pipes. Proposed outline specifications delineating material options are presented to facilitate procurement of this cold-weather piping system. Also, performance information is provided on the full-scale, single-line, liquid distribution systems at Point Barrow, Alaska, and McMurdo Station, Antarctica.

59. Hoffman, C. R.
ABOVEGROUND UTILIDOR PIPING SYSTEMS FOR COLD-WEATHER REGIONS
CEL Technical Report R-734. June 1971.
AD-728 013

ABSTRACT: Utilidors, which contain multiple pipe systems for the distribution of freezable liquids were investigated by the Naval ivil Engineering Laboratory. These systems require one of the pipes to carry either hot water or steam which can be used as the heating source for the utilidor. A state-of-the-art survey was made to ascertain design requirements for the utilidor. Sufficient information was obtained to permit detailed designing for specific locations. Assembly and low temperature tests were performed and data were acquired on a 32-foot-long test section. A thermal performance analysis and a computer program are presented for designing a utilidor for a specific location. It is concluded that a single-line, preassembled, insulated, electrically heat-traced piping system appears to be most cost effective for one to six distribution lines; however, the advantage is so slight for four- to six-line systems that the availability of an inexpensive source of heat (heated liquid or steam) or an intangible consideration, such as esthetics, may warrant the use of an utilidor system for a specific Naval facility.

60. Corporate Author: Department of the Army
ARCTIC AND SUBARCTIC CONSTRUCTION. UTILITIES
DA TM-5-852-5. 1954.

ABSTRACT: The existence of permafrost introduces problems in the provision of water supply, sewage disposal, central heating, and electrical power, particularly in the distribution systems. This chapter considers the special problems encountered in arctic and subarctic regions.

61. See Entry 51.

62. See Entry 18.

63. Corporate Author: Cold Regions Research and Engineering Lab
SEWERAGE AND SEWAGE DISPOSAL IN COLD REGIONS
CRREL Monograph CRSE-3C5b. October 1969.

ABSTRACT: The main items dealt with in this monograph are: practice and problems encountered by builder and operator of sewerage works facilities in cold regions; collection and transport systems; treatment and processing of sewage; thermology; reuse and regenerative processes for treating waste water; and construction and operation of sewage facilities. Six appendixes treat stabilization ponds, ventilation of buildings having sewage treatment plant, management of solid waste and classification of wastes and incinerators.

64. Corporate Author: Cold Regions Research and Engineering Lab
DESIGN, CONSTRUCTION AND PERFORMANCE DATA OF UTILITY SYSTEMS
THULE AIR BASE
CRREL Special Report SR-95. February 1966.
AD-483 678

ABSTRACT: The report covers the design, construction, performance, and maintenance of the utilities systems of Thule Air Base as modified for the arctic climate and permafrost conditions. The basic designs are covered in various U. S. Army engineering manuals for military construction. The modifications were primarily concerned with foundations of structures and heating and insulation of pipe lines.

65. Copp, S. C., Crawford, C. B. and Grainge, J. W.
PROTECTION OF UTILITIES AGAINST PERMAFROST IN NORTHERN CANADA
NatRCC Research Paper NRC-4056. September 1956.

ABSTRACT: Development of the Canadian northland has progressed so rapidly during the last decade that the problem of providing the facilities of modern living in the North has become one of the greatest current engineering problems. Owing to unusual features of the climate and the ground, it is apparent that engineering practices of more temperate regions cannot be applied without modification.

This is particularly true of the design of water and sewer services in regions of permafrost. Descriptions of some systems that have been engineered and constructedare contained in this paper.

66. See Entry 24.

67. Hoffman, C. R.
CAULKING COMPOUNDS FOR APPLICATION AT LOW TEMPERATURES
CEL Technical Report R-812. June 1974.
AD-920 678L

ABSTRACT: Experience in polar climates has demonstrated the difficulty of applying caulking and sealing compounds at low temperatures due to loss of extrudability. Also, it has been found that caulking compounds kept warm for ease of application still fail to adhere to cold surfaces.

Caulking compounds available commercially for general construction applications were reviewed for possible cold weather application, and cold chamber and Antarctic field tests were conducted on eight products of three basic types considered most suitable.

The results of these tests showed that butyl rubber and polysulfide-based compounds become too stiff to extrude from hand caulking guns at temperatures near 15°F. Some silicone compounds, however, can be applied and cured well at temperatures to -45°F. The most satisfactory of these products is Dow Corning 781. GE Silicone Construction Sealant is also usable but is more viscous and more difficult to apply at the lower temperatures.

68. See Entry 24.

69. Keeton, J. R.
PORTLAND CEMENT CONCRETE FOR ANTARCTICA
CEL Technical Report R-671. April 1970.
AD-705 994

ABSTRACT: A satisfactory concrete mix was developed in the Naval Civil Engineering Laboratory for use in Antarctica. This mix was subsequently utilized at McMurdo Station, Antarctica, during Deep Freeze 1969 to construct simulated footings and slabs. Techniques were developed in the field which led to formulation of recommended procedures for batching, mixing, placing, and curing of portland cement concrete in Antarctica. The pertinent features of the mix and design and related procedures are as follows:

Cement: 594 lb/yd^3, portland type III

Mixing water: 35 gal/yd^3 heated at 140°F to 180°F

Total aggregate: 3,210 lb/yd^3 (1-inch maximum)

Sand (passing no. 4 sieve): 1,188 lb/yd^3 (37% of total aggregate)

Slump: 3 inches

Air content: 5% to 7% of concrete volume

Calcium chloride: 12 lb/yd^3 (2% of cement weight)

Temperature of concrete when placed: 50°F to 70°F

Curing: Heat (50°F to 70°F) applied to the concrete surface for 3 days following casting

70. See Entry 6.

71. Houston, B. J. and Hoff, G. C.
COLD WEATHER CONSTRUCTION MATERIALS PART I: REGULATED-SET CEMENT FOR COLD WEATHER CONCRETING
CRREL Special Report SR-245. December 1975.

ABSTRACT: The U.S. Army carries on construction projects in localities such as Alaska, the northern tier of the United States, northern Europe, Greenland and other arctic sites where the concrete placing season is shortened considerably by the cold climate. At ambient temperatures below 50°F, concreting operations become considerably more expensive since U.S. Army Corps of Engineers specifications require freshly mixed and placed concrete to be protected from ambient temperatures. This report covers part of an investigation to locate and evaluate existing and new cementing materials that allow concrete to be placed at ambient temperatures as low as 15°F. A newly developed cement termed "regulated-set" cement, which is an accelerated set cement, appeared to have great promise and was selected for study in this stage of the investigation. Both mortars and concretes made with regulated-set cement were studied with the following results: 1. The longer freshly mixed regulated-set cement concrete remains above freezing before exposure to below freezing temperatures the greater the subsequent early strength gain; however, considerable strength gain was exhibited by specimens exposed at 15° immediately after casting. Specimens protected one hour before exposure exhibited almost as much strength at 28 days age as specimens cured at 70° ± 3°F for the full time. 2. The heat development in 3-, 6- and 12-in.-thick slabs exposed at 15°F immediately after casting, peaked in one to two hours at 46.5°, 58° and 69°F, respectively, and remained above freezing long enough to gain considerable strength. 3. The introduction of a retarder into the mixture caused an increase in slump and a 13 to 19% decrease in 28-day strength in specimens exposed at both 70° ± 3°F and 15°F. There was still considerable strength developed, however, in the specimens exposed at low temperatures.

72. Swenson, E. G.
DURABILITY OF CONCRETE UNDER WINTER CONDITIONS
NatRCC CBD-116. August 1969

ABSTRACT: Concrete is a versatile and widely used construction material. Its excellent record of durability is remarkable when one

considers the variety of severe exposures to which it is subjected. There are, however, processes that can produce considerable damage if well known precautions are not taken. One of these is deterioration due to frost action. It is now well established, in the laboratory and in the field, that ordinary concrete can be made highly resistant to winter conditions with little or no extra complication or cost. This has been possible through improved understanding of the nature of the freeze-thaw process in concrete--understanding that has led to procedures that minimize frost damage.

TM no. M-61-77-11

TECHNICAL MEMORANDUM

title: AN ABBREVIATED REFERENCE MANUAL FOR COLD-WEATHER CONSTRUCTION - FY77 SUPPLEMENT TO TM M-61-76-7

author: J. L. Barthelemy

date: September 1977

sponsor: NAVAL FACILITIES ENGINEERING COMMAND

program nos: YF52.555.001.01.003

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

FOR OFFICIAL USE ONLY

AN ABBREVIATED REFERENCE MANUAL FOR COLD-WEATHER CONSTRUCTION - FY77
SUPPLEMENT TO TM M-61-76-7

YF52.555.001.01.003

by
J. L. Barthelemy

September 1977
Sponsored by Naval Facilities Engineering Command

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INTRODUCTION

Under work unit YF52.555.001.01.003, "Environmental Engineering Factors for Polar Facilities," Technical Memorandum TM-61-76-7, "An Abbreviated Reference Manual for Cold-Weather Construction," was issued in July 1976. That document contained a list of select engineering publications covering diversified areas of cold-weather construction technology. This Technical Memorandum is a supplement to the initial report and annotates reference material published during the last half of 1976 and first half of 1977. It is organized in the same style as the parent report to facilitate usage. The supplementary reports in SECTION I are listed by title, number and originating agency under six subject areas. SECTION II presents more detailed publication information, as well as abstracts for each of the references from the first section.

This report was prepared for use as an internal working document. Therefore, its distribution is limited, and disclosure of all or part of its content outside the Government must have prior approval of the Civil Engineering Laboratory or the sponsor of the work reported.

BACKGROUND

During the past year, candidate reports were selected from a number of sources, including the list of publications provided by the United States Army Cold Regions Research and Engineering Laboratory (USA CRREL) and National Research Council of Canada (NatRCC). In addition, CRREL report TR-12, "Bibliography on Cold Regions Science and Technology," was monitored on a monthly basis. That publication lists all material dealing with cold-weather science and technology that is accessioned to the Science and Technology Division of the Library of Congress. Some of the selected reports were procured for study and review. For reports not readily available, the on-line computer services provided by the Defense Documentation Center (DDC) were used to obtain abstracts and relevant publication information.

The following abbreviations are used to designate the originating organizations and mailing addresses. NOTE: All technical reports accessioned to the Defense Documentation Center should be purchased by accession number (AD or ADA number) directly from the National Technical Information Service (NTIS), Springfield, VA 22151.

Acronyms Used to Identify Organizations Originating Reports

ASCE American Society of Civil Engineers
345 East 47th St., New York, NY 10017

CEL Civil Engineering Laboratory, Naval Construction Battalion Center
Port Hueneme, CA 93043

CANMET Center for Mineral and Energy Technology (Canada). Address not known.

CREPA Cold Regions Engineers Professional Association
Department of Civil Engineering, University of Alaska
Fairbanks, AK 99701

CRREL United States Army Cold Regions Research and Engineering Laboratory
Hanover, NH 03755

EPS Environmental Protection Service
Northern Technology Centre
Room 905, 10025 Jasper Ave
Edmonton, Alberta, Canada T5J 2X9

NAHB National Association of Home Builders
Research Division
Rockville, MD

NatRCC National Research Council of Canada
Division of Building Research
Ottawa KIA OR6, Ontario, Canada

SECTION I

This section lists relevant publications under six subject headings. The starting number sequence of 73 is a continuation of the TM-61-76-7 listed reports.

Bibliographies and Surveys

73. CRREL TR-12 (Volumes 30 and 31)
Bibliography on Cold Regions Science and Technology

74. ASCE
A Half-Century of Cold-Regions Construction

General Provisions and Site Selection

75. CREPA
Proceedings of the Second International Symposium on Cold Regions Engineering

76. NAHB
All-Weather Home Building Manual

77. CRREL TL-570
Public Buildings for the North

78. CRREL TL-572
Lightweight Buildings for Living and Work

Frozen Ground

79. NatRCC
Permafrost Engineering Manual

80. Twenty-fourth Canadian Chemical Engineering Conference Foundation Requirements in the Canadian Arctic

81 NatRCC TT-1865
Handbook for the Design of Bases and Foundations

82. NatRCC Technical Memorandum No. 110
Engineering in the North - A Review of the Engineering Problems of Permafrost and Muskeg Regions

83. CRREL SR-226
Mechanics of Cutting and Boring, Part I: Kinematics of Transverse Cutting Machines

84. CRREL 76-16
Mechanics of Cutting and Boring, Part II: Kinematics of Axial Rotation Machines

85. CRREL 76-17
Mechanics of Cutting and Boring, Part III: Kinematics of Continuous Belt Machines

86. CRREL 77-7
Mechanics of Cutting and Boring, Part IV: Dynamics and Energetics of Parallel Motion Tools

Ice and Snow

87. CRREL SR-146
USA CRREL Snow and Ice Testing Equipment

88. CEL
Engineering Manual for McMurdo Station

89. CRREL TL-478
Planning and Construction of Settlements in The Far North: Defense Against Snowdrifts

90. CRREL 76-23
Study of Piles Installed in Polar Snow

Utilities

91. EPS Report No. EPS-3-WP-77-1
Proceedings: Symposium on Utility Delivery in Arctic Regions

92. CEL
Engineering Manual for McMurdo Station

Materials and Concreting

93. CANMET Report No. 76-1
Metals and Alloys for Arctic Use

94. NAHB
All-Weather Home Building Manual

SECTION II

This section presents more complete publication information and abstract material for reports listed by subject area in SECTION I.

73. Corporate Author: Cold Regions Research and Engineering Laboratory
BIBLIOGRAPHY ON COLD REGIONS SCIENCE AND TECHNOLOGY, VOLUMES XXX and XXXI
CRREL Report 12.

ABSTRACT: This report is a continuing publication released approximately yearly by CRREL. It lists all materials dealing with cold-weather science and technology that are accessioned to the Science and Technology Division of the Library of Congress. The two volumes here mentioned are for the calendar years 1976 and 1977.

74. Bennett, F. L.
A HALF-CENTURY OF COLD-REGIONS CONSTRUCTION
American Society of Civil Engineers: Journal of the Construction Division. 101(CO4) Dec 1975.

ABSTRACT: During the 50-year history of the Construction Division (of ASME) a great deal of construction has taken place in cold regions of the world. The current emphasis on cold-regions construction tends to overshadow the significant accomplishments of the past. The record shows, however, a series of projects completed under severe cold conditions. This paper reports on several cold-regions construction projects in the United States and Canada which have taken place in the past half-century. Near the end of the paper, mention is made of work in foreign countries with a brief glimpse at current projects.

75. Burdick, J. L. and Johnson, P. (editors)
PROCEEDINGS OF THE SECOND INTERNATIONAL SYMPOSIUM ON COLD REGIONS ENGINEERING
Cold Regions Engineers Professional Association. Department of Civil Engineering, University of Alaska, Fairbanks, Alaska. May 1977.

ABSTRACT: These proceedings cover reports presented at the University of Alaska during a conference held 12-14 August 1977. It was the intent of that meeting to emphasize the interdisciplinary nature of cold-regions engineering and focus on "Engineering" solutions to the challenge of the cold regions. Thus the over-fifty papers represented in this volume contain much useful information covering a wide range of subject matter.

76. Corporate Author: National Association of Home Builders, Research Foundation, Inc., Rockville, MD. Nov 1975.
ALL-WEATHER HOME BUILDERS MANUAL

ABSTRACT: This manual covers a whole range of building methods and techniques, including cold-weather excavation, construction and foundations. Also, it considers meteorological factors, cost analysis and materials.

77. Corporate Author: Cold Regions Research and Engineering Laboratory
PUBLIC BUILDINGS FOR THE NORTH
CRREL Translation TL-570
ADA-035 973

ABSTRACT: The report discusses the design of a public center for a village of 1,000 residents in the Siberian Arctic. It was designed for construction on permafrost soils with a calculated winter air temperature of -45 F. The paper includes layout designs for the building.

78. Corporate Author: Cold Regions Research and Engineering Laboratory
LIGHTWEIGHT BUILDINGS FOR LIVING AND WORK
CRREL Translation TL-572
ADA-035 936

ABSTRACT: The planned structure of the building was predetermined by the need to house laboratory workers, joined by common work and joint living in the severe climate of the Arctic. Lightweight prefabricated supporting and enclosing components of efficient materials comprise the design feature of the building.

79. Corporate Author: National Research Council of Canada, Associate Committee on Geotechnical Research
PERMAFROST ENGINEERING MANUAL (in preparation)

ABSTRACT: This manual will consider engineering problems as related to permafrost. Included will be foundation and utility piping systems. The manual is due for distribution around January 1978.

80. Auld, R. G.
FOUNDATION REQUIREMENTS IN THE CANADIAN ARCTIC
Proceedings: Twenty-fourth Canadian Chemical Engineering Conference. 1974.

ABSTRACT: This paper sets forth the requirements for building foundations in permafrost areas. It includes such factors as soil compacting, thermal properties and surface temperature variation.

81. Corporate Author: National Research Council of Canada
HANDBOOK FOR THE DESIGN OF BASES AND FOUNDATIONS
NatRCC IT-1865 1976.

ABSTRACT: This technical translation is drawn from an original Russian source. The subject matter includes general design criteria for building on permafrost. In particular, special attention is given to the design of bases and foundations. The handbook analyzes such design variables as the seasonal freeze-thaw cycle and active-layer penetration by means of a permafrost heat-transfer model.

82. Laing, J. M.
ENGINEERING IN THE NORTH - A REVIEW OF THE ENGINEERING PROBLEMS OF PERMAFROST AND MUSKEG REGIONS
NatRCC Technical Memorandum No. 110. March 1974.

ABSTRACT: Experience has shown that special design and construction techniques are required for building on permafrost in order to avoid disturbing the delicate thermal balance that preserves the frozen ground. This report reviews permafrost and muskeg areas with respect to site investigation, foundation design, water supply and sewage disposal. Also considered is the construction of transportation facilities and roads and the influence of drainage and other disturbances on the ground thermal regime.

83. Mellor, M.
MECHANICS OF CUTTING AND BORING, PART I: KINEMATICS OF TRANSVERSE ROTATING MACHINES
CRREL Special Report SR-226 May 1975.
ADA-010 634

ABSTRACT: This report, which is one in a series of the mechanics of cutting and boring in rock, ice and permafrost, deals with the kinematics of machines such as disc saws, drum millers, rotary planers

and bucket-wheel excavators, in which the rotary cutting element revolves about an axis that is normal to the direction of working travel. The analysis covers the geometry and motion of various components of the cutting system, touching on topics such as chipping depth, cutting transfer, excavation rate, tool trajectories and tool layout. Worked examples are given to illustrate various points.

84. Mellor, M.
MECHANICS OF CUTTING AND BORING, PART II: KINEMATICS OF AXIAL ROTATION MACHINES
CRREL Report 76-16 June 1976.
ADA-027 279

ABSTRACT: This report, which is second in a series on the mechanics of cutting and boring in rock, ice and permafrost, deals with the kinematics of machines such as rotary drills, augers, tunnel boring machines, corers, and raise borers, in which the rotary cutting unit revolves about an axis that is parallel to the machine's direction of advance. Worked examples are given to illustrate the application of various equations to practical problems.

85. Mellor, M.
MECHANICS OF CUTTING AND BORING, PART III: KINEMATICS OF CONTINUOUS BELT MACHINES
CRREL Report 76-17 June 1976.
ADA-027 833

ABSTRACT: This report, third in a series on the mechanics of cutting and boring in rock, ice and permafrost, deals with the kinematics of machines which utilize a continuous belt as the cutting unit. Such machines include coal saws, shale saws and digger-chain trenchers. Discussion and analysis cover the geometry and motion of various components of the cutting system, including the production and conveyance of cutting, tool trajectories and arrangement of cutting tools on the belt. Worked examples are included to illustrate the application of various equations to practical problems.

86. Mellor, M.
MECHANICS OF CUTTING AND BORING, PART IV: DYNAMICS AND ENERGETICS OF PARALLEL MOTION TOOLS
CRREL Report 77-7 April 1977.

ABSTRACT: This report deals with the cutting of rock, ice and permafrost by parallel motion tools. It examines cutting forces and energy requirements, taking into consideration tool geometry, wear, operating conditions, and material properties. After an introductory discussion of terminology, some general principles are outlined, and relevant theoretical ideas on metal cutting and rock cutting are reviewed. The next section, which is the heart of the report, reviews experimental data on the magnitudes and directions of cutting forces. There is a graphical

compilation of data, including some from obscure or unpublished sources. The variables covered include chipping depth, rake angle, relief angle and material properties.

87. Ueda, H., Sellman, P., and Abele, G.
USA CRREL SNOW AND ICE TESTING EQUIPMENT
CRREL Special Report SR-146 September 1975.
ADA-015 512

ABSTRACT: This paper summarizes available information on the history, development, and application of three items of special equipment designed or modified by USA CRREL for testing and sampling snow and ice. These items have become universally known and accepted, providing measurement techniques that are used, in some cases, on an international basis. The equipment described includes the 3-in. ice coring auger, the ice thickness kit and the Rammsonde.

88. Hoffman, C. R.
ENGINEERING MANUAL FOR MCMURDO STATION (special publication sponsored by the U.S. Naval Support Force, Antarctica) 1974.

ABSTRACT: This manual describes the terrain and environmental features in the vicinity of McMurdo Station, Antarctica, and presents engineering methods and operational procedures for working within these natural constraints. The information contained has been developed from experience as well as from direct applied research. Considerable technical data are contained which should be of value in the solution of problems on-site; however, the contents deal specifically with McMurdo Station and are not intended to apply to other areas even though the information could have broader application.

89. Corporate Author: Cold Regions Research and Engineering Laboratory
PLANNING AND CONSTRUCTION OF SETTLEMENTS IN THE FAR NORTH: DEFENSE AGAINST SNOWDRIFTS
CRREL Technical Translation TL-478 May 1975.
ADA-030 112

ABSTRACT: The difficulties caused by snow in settled areas in the Soviet Far North, where winter is 8 to 10 months long and snowdrifts of 30m or more are recorded, are described, and planning of cities for maximum protection against snow is discussed. Effective control is achieved by proper site selection and planning and the use of mechanical snow-removal equipment. Houses at the periphery of a settlement should face 30 degrees into the prevailing wind. Small settlements should be built as a row, with streets parallel to the prevailing wind and clear. Buildings must be tall with smooth walls and a minimum perimeter. Roads outside the settlement are best constructed on embankments.

90. Kovacs, A.
STUDY OF PILES INSTALLED IN POLAR SNOW
CRREL Report 76-23 July 1976.
ADA-029 191

ABSTRACT: This report describes the study of piles tested in polar snow at Camp Century, Greenland. More than 20 piles of various lengths and sizes were driven, including timber, closed-end and open-end steel pipe piles, and I- and H-piles. Driving records were obtained and are discussed. Analysis of the driving response of various piles revealed that the Hiley formula, and presumably other similar pile-driving formulas, cannot be used to predict the ultimate supporting capacity of piles driven in snow. Factors such as pile inertia, rigidity, size and tip resistance are discussed in relation to their apparent influence upon pile penetration. The results of this exploratory study give insight into the general load-carrying capability of a number of piles in snow. The information obtained may be used with engineering discretion and judgment as a guide for utilizing pile foundations where the snow, pile and embedment conditions are similar.

91. Smith, D. W. (editor)
PROCEEDINGS: SYMPOSIUM ON UTILITIES DELIVERY IN ARCTIC REGIONS
Environmental Protection Service Report No. EPS 3-WP-77-1 January 1977.

ABSTRACT: During the past 20 years, a great variety of systems have been used in attempts to provide utility services in permafrost regions. The learning and development process has been costly, however. A great deal of work which has been done has not been reported in a fashion which would allow wide dissemination of the results. One objective of the symposium was to provide the needed forum for discussion of recent work in the area of utilities delivery in permafrost regions. The proceedings consist of 28 manuscripts.

92. See entry 88.

93. Thurston, R. C. A. (editor)
METALS AND ALLOYS FOR ARCTIC USE
Centre for Mineral and Energy Technology. CANMET Report 76-1. 1976.

ABSTRACT: This report is composed of twelve separate chapters or sections dealing with metals and alloys for Arctic use. The individual sections are titled as follows: (1) Design and construction for low temperatures: fracture toughness; (2) Design and construction for low temperature: welding and weldability; (3) Design and construction for low temperatures: corrosion; (4) Design and construction for low temperatures: fatigue; (5) Structural materials at low temperatures: steels; (6) Structural materials at low temperatures: aluminum alloys; (7) Structural materials at low tempe atures: magnesium alloys; (8) Structural materials at low temperatures: titanium alloys;

(9) Structural materials at low temperatures: copper, tin and lead alloys; (10) Structural materials at low temperatures: nickel and nickel alloys; and (11) Structural materials at low temperatures: zinc alloys and galvanized coatings.

94. See entry 76.

LIST OF APPENDIXES

Chapter 13

The contents of this Appendix supplement the chapter text by providing pertinent and updated information on new technology that is applicable to Antarctic operation. Such supplements should be logged and added to this section as they become available. The Appendix should be periodically reviewed for deletion of outdated material. Removal of contents for study should be avoided.

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