ENGINEERING MANUAL

FOR

MCMURDO STATION

Sponsored by

U.S. NAVAL SUPPORT FORCE, ANTARCTICA

Prepared by

C. R. Hoffman

with contributions from

W. H. Beard, F. W. Brier, J. E. Dykins, R. A. Paige, and M. W. Thomas

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

1974

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
PORT HUENEME, CA 93043

AUTOVON: 360-5021
IN REPLY REFER TO:

L61/CRH/hla
61-018

SERIAL 615

28 MAR 74

AIR MAIL

From: Officer in Charge
To: Commander, Naval Support Force, Antarctica, Fleet Post Office New York 09501

Subj: Engineering Manual for McMurdo Station Antarctica, Chapters 1 through 5

Ref: (a) CEL Work Unit Summary 61-018

Encl: (1)(SC) Subject Manual (75 copies)

1. Enclosure (1) is forwarded in accordance with reference (a).

2. The balance of the manual, chapters 6 through 11, are being prepared for distribution in early FY-75. It is suggested that recipients of the first element of the manual be carefully logged so that the second distribution can be made accurately to assure unity of the two parts.

WARREN A. SHAW
BY DIRECTION

Copy to: (w/encl)
Head OPP, NSF
NAVFAC (Code 032A)

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.

4. Title and Subtitle

(6) Engineering mamdual for McMurdo Station.

5. Report Date

(11) Mar[redacted]974

6.

7. Author(s)

C. R. Hoffman et al

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043

(12) 232p.

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

U.S. Naval Support Force, Antarctica
Port Hueneme, California 96601

13. Type of Report & Period Covered

(9) Final rept.

14.

15. Supplementary Notes

12 chapters numbered separately

16. Abstract (Limit: 200 words)

Describes terrain and environment of McMurdo, the main U.S. station in Antarctica. Presents engineering methods and operational procedures. Discusses McMurdo Ice Shelf, sea ice, building design, utilities, airfields and roads, wharf, pollution control, transportation and construction equipment, and materials.

(10) C. R./Hoffman, W. H./Beard,
J. E./Dykins, R. A./Paige
M. W./Thomas

17. Document Analysis a. Descriptors

Antarctic regions
Access roads
Buildings
Harbor facilities
Maintenance Management

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

391 111

18. Availability Statement

Unlimited

19. Security Class (This Report)	21. No. of Pages
Unclas	
20. Security Class (This Page)	**22. Price**
Unclas	

See ANSI–Z39.18) — See Instructions on Reverse — OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

INSTRUCTIONS

Optional Form 272, Report Documentation Page is based on Guidelines for Format and Production of Scientific and Technical Reports, ANSI Z39.18–1974 available from American National Standards Institute, 1430 Broadway, New York, New York 10018. Each separately bound report—for example, each volume in a multivolume set—shall have its unique Report Documentation Page.

1. Report Number. Each individually bound report shall carry a unique alphanumeric designation assigned by the performing organization or provided by the sponsoring organization in accordance with American National Standard ANSI Z39.23–1974, Technical Report Number (STRN). For registration of report code, contact NTIS Report Number Clearinghouse, Springfield, VA 22161. Use uppercase letters, Arabic numerals, slashes, and hyphens only, as in the following examples: FASEB/NS–75/87 and FAA/RD–75/09.
2. Leave blank.
3. Recipient's Accession Number. Reserved for use by each report recipient.
4. Title and Subtitle. Title should indicate clearly and briefly the subject coverage of the report, subordinate subtitle to the main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific volume.
5. Report Date. Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected (e.g., date of issue, date of approval, date of preparation, date published).
6. Sponsoring Agency Code. Leave blank.
7. Author(s). Give name(s) in conventional order (e.g., John R. Doe, or J. Robert Doe). List author's affiliation if it differs from the performing organization.
8. Performing Organization Report Number. Insert if performing organization wishes to assign this number.
9. Performing Organization Name and Mailing Address. Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hierarchy. Display the name of the organization exactly as it should appear in Government indexes such as Government Reports Announcements & Index (GRA & I).
10. Project/Task/Work Unit Number. Use the project, task and work unit numbers under which the report was prepared.
11. Contract/Grant Number. Insert contract or grant number under which report was prepared.
12. Sponsoring Agency Name and Mailing Address. Include ZIP code. Cite main sponsors.
13. Type of Report and Period Covered. State interim, final, etc., and, if applicable, inclusive dates.
14. Performing Organization Code. Leave blank.
15. Supplementary Notes. Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of . . . Presented at conference of . . . To be published in . . . When a report is revised, include a statement whether the new report supersedes or supplements the older report.
16. Abstract. Include a brief (200 words or less) factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.
17. Document Analysis. (a). Descriptors. Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b). Identifiers and Open-Ended Terms. Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c). COSATI Field/Group. Field and Group assignments are to be taken from the 1964 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the primary Field/Group assignment(s) will be the specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).
18. Distribution Statement. Denote public releasability, for example "Release unlimited", or limitation for reasons other than security. Cite any availability to the public, with address, order number and price, if known.

19. & 20. Security Classification. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED).

21. Number of pages. Insert the total number of pages, including introductory pages, but excluding distribution list, if any.
22. Price. Enter price in paper copy (PC) and/or microfiche (MF) if known.

TABLE OF CONTENTS

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.

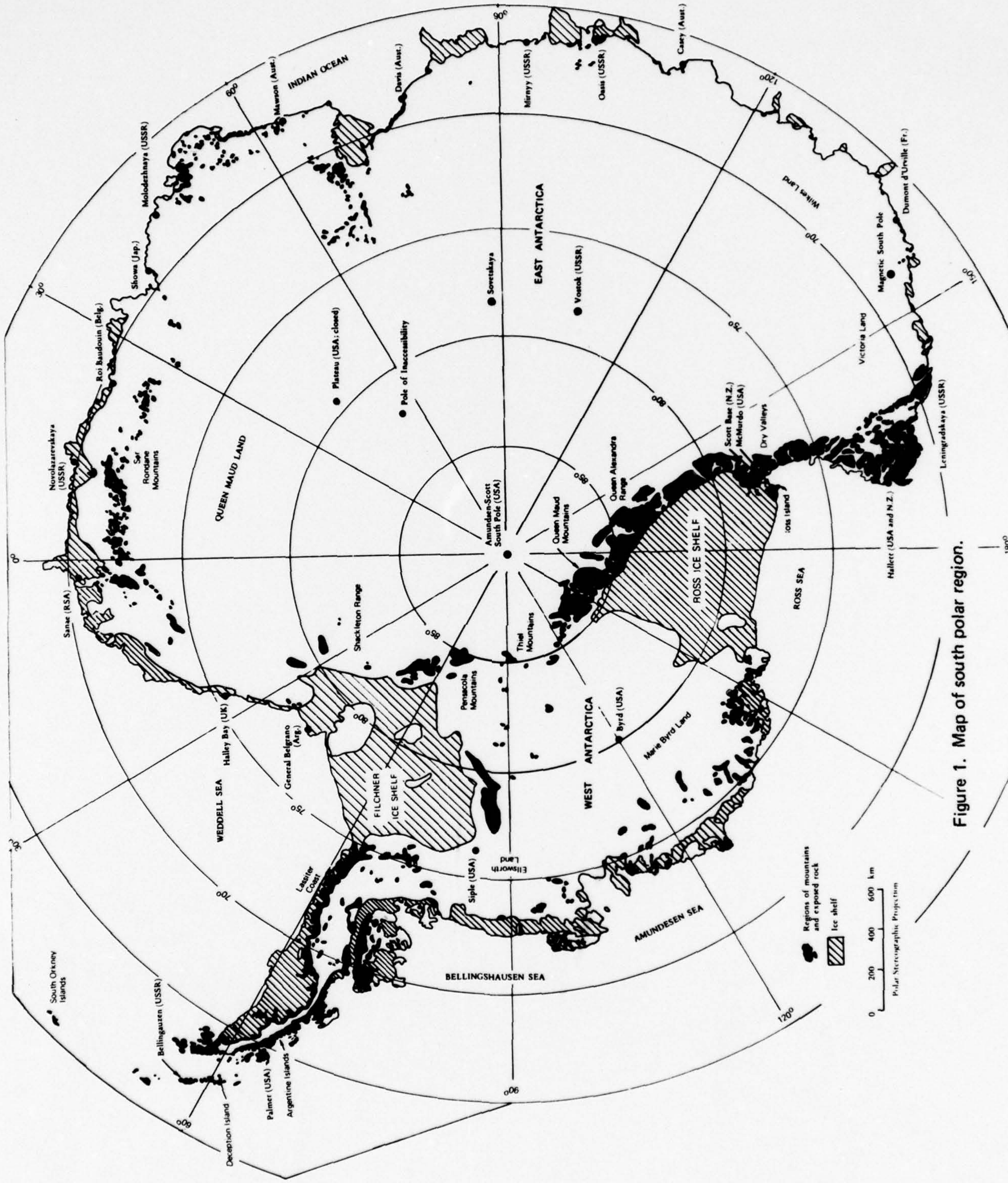


Figure 1. Map of south polar region.

CHAPTER 1

Chapter 1

PHYSIOGRAPHY OF THE MCMURDO AREA

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].

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.

REFERENCES

1. W. J. P. Macdonald and T. Hatherton. "Movement of the Ross Ice Shelf near Scott Base," Journal of Glaciology, vol. 3, no. 29, 1961, pp. 859-867.

2. New Zealand Department of Scientific and Industrial Research. Bulletin 140: New Zealand IGY Antarctic expeditions, Scott Base and Hallett Station, by T. Hatherton. Wellington, New Zealand, 1961, p. 45.

3. D. C. Thompson and W. J. P. MacDonald. "Radiation measurements at Scott Base," New Zealand Journal of Geology and Geophysics, vol. 5, no. 5, Dec. 1962, pp. 874-910.

4. 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, Port Hueneme, California, 1968.

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 (^{o}F)

Stations	Lat	Long.	Elevation (ft)	Years of Record	January			February			March		
					Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
McMurdo (USA)	77°51'S	166°40'E	59	13	42	26	4	39	17	-7	26	0	-46
South Pole Station (USA)	90°00'S		9,186	12	6	-20	-42	-7	-40	-69	-19	-66	-95
Byrd (USA)	80°01'S	119°32'W	4,959	12	31	5	-21	26	-4	-38	16	-19	-64
Cape Hallett (US-NZ)	72°19'S	170°13'E	16	9	47	30	9	40	27	15	31	13	-12
Eights (USA)	75°15'S	77°06'W		3	34	14	-9	29	-1	-27	28	-13	-43
Ellsworth (USA)	77°43'S	41°08'W	131	6	33	17	-9	27	4	-23	25	-10	-40
Little America (USA)	78°11'S	162°12'W	138	3	42	20	-6	32	12	-36	29	-9	-52
Plateau (USA)	79°15'S	40°30'E	11,890	3	-1	-30	-56	-13	-49	-77	-33	-72	-104
Vostok (USSR)	78°27'S	106°52'E	11,200	3	-8	-31	-57	-13	-49	-83	-36	-67	-103
Davis (Australia)	68°35'S	77°58'E	40	7	45	32	17	42	27	5	37	17	-16
Wilkes (Australia)	66°01'S	110°32'E	31	7	48	31	18	42	28	10	37	20	-1
Decepcion (Argentine)	62°59'S	60°43'W	26	8	51	34	19	48	34	20	46	32	12
Dumont D'urville (France)	66°40'S	140°01'E		8	41	30	16	40	23	5	37	17	-8
Halley Bay (Base Z) (United Kingdom)	75°31'S	26°36'W		6	36	22	-8	32	14	-17	26	2	-35

Stations	July			August			September			October			November	
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
McMurdo (USA)	24	-15	-59	18	-19	-57	19	-13	-47	24	-4	-39	37	16
South Pole Station (USA)	-29	-75	-113	-27	-75	-108	-35	-75	-110	-21	-60	-89	-2	-38
Byrd (USA)	10	-33	-82	8	-34	-80	14	-35	-80	12	-24	-73	24	-7
Cape Hallett (US-NZ)	25	-16	-44	20	-16	-54	21	-12	-41	28	-1	-41	38	17
Eights (USA)	15	-29	-62	8	-36	-76	17	-30	-61	26	-20	-69	24	1
Ellsworth (USA)	10	-28	-61	20	-28	-61	20	-23	-60	25	-9	-70	31	5
Little America (USA)	23	-30	-70	22	-35	-78	21	-27	-73	29	-13	-53	30	6
Plateau (USA)	-47	-91	-123	-42	-96	-121	-36	-86	-120	-35	-75	-112	-16	-49
Vostok (USSR)	-47	-89	-117	-62	-96	-127	-48	-90	-116	-41	-75	-104	-28	-49
Davis (Australia)	30	1	-36	30	1	-34	29	1	-30	33	11	-18	38	23
Wilkes (Australia)	34	3	-35	31	5	-30	30	5	-30	30	11	-19	40	22
Decepcion (Argentine)	40	16	-13	41	17	-18	39	22	-10	45	27	2	42	29
Dumont D'urville (France)	32	0	-28	31	1	-29	30	3	-34	32	9	-19	38	19
Halley Bay (Base Z) (United Kingdom)	23	-18	-60	24	-21	-58	23	-16	-58	29	-2	-50	30	11

April			May			June		
Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
25	-7	-39	19	-12	-48	21	-11	-40
-18	-73	-99	-30	-72	-100	-24	-71	-105
19	-22	-70	20	-28	-79	13	-30	-75
29	0	-27	21	-9	-35	20	-10	-37
20	-24	-52	15	-28	-57	15	-29	-59
25	-18	-58	36	-19	-66	13	-26	-59
30	-19	-58	30	-21	-63	25	-21	-60
-45	-87	-108	-38	-88	-113	-27	-92	-116
-46	-82	-100	-45	-83	-109	-53	-89	-114
32	10	-18	32	5	-26	31	4	-25
35	13	-24	39	7	-28	32	3	-25
47	28	2	42	23	-6	39	19	-16
34	12	-13	32	5	-26	28	1	-28
28	-7	-54	29	-11	-55	18	-19	-60

	December			Annual Mean	Record Temp	
Min	Max	Mean	Min		Max	Mean
-19	42	26	2	0	42	-59
-66	-2	-19	-38	-57	6	-113
-42	27	5	-22	-19	31	-82
-14	44	28	8	4	47	-54
-24	36	11	-19	-15	36	-76
-40	32	18	-4	-9	36	-70
-34	39	22	-2	-8	42	-78
-87	-5	-28	-54	-70	-1	-123
-74	-6	-28	-54	-68	-6	-127
5	49	31	14	13	49	-36
-6	42	30	6	15	48	-35
7	45	33	18	26	51	-18
-8	43	28	13	12	43	-34
-20	36	21	-6	-2	36	-60

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 Stations

Stations	Years of Record	Peak Gusts (mph) and Direction									
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
McMurdo	13	62S	75S	81SE	79SE	95S	99S	116SSE	100SE	106S	84SS
South Pole Station (USA)	12	48NNW	45N	36NW	39N	54NNE	40N	43NNE	51N	52NNW	48N
Byrd	12	47NE	60NNE	67N	71NNE	71NNE	87N	83NW	82NE	89ENE	70N
Cape Hallett	9	72S	92S	89S	87S	120SSW	92SSW	92S	99S	104S	114S
Eights	3	44S	44SE	58ENE	82NNE	71N	77NNE	75NNE	75N	70NNE	70NN
Ellsworth	4	35S	46S	47NE	65E	63NE	61ENE	81SW	81S	82NE	66NE
Little America	3	37SW	40NNE	48NNW	46NNE	77NNE	59NNE	78NNE	80NNE	61NNE	67NN
Plateau	2	20WNW	27N	35NE	40NE	35W	48NNE	30N	33NNE	25NNE	29W
Vostok[a]											
Davis	5	67NE	96NE	101NE	116ENE	100ENE	99NE	96ENE	81ENE	98NE	111N
Wilkes (Australia)	7	89ESE	113ESE	101E	134E	136E	131E	121E	128E	111E	138E
Decepcion (Argentine)[b]											
Dumont D'urville (France)[c]											
Halley Bay	6	66	48	85	74	77	89	86	81	77	94

[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.

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

ct	Nov	Dec	Annual
SE	76SSW	77SSE	116SSE
[illegible]	38NNE	30NNW	54NNE
[illegible]	62N	62NE	89ENE
SSW	97S	67S	120SSW
NE	71N	39S	82NNE
E	43NE	33S	82NE
NE	44NE	61NNE	80NNE
[illegible]	55NNE	28WNW	55NNE
NE	88ENE	105NE	116ENE
ESE	115E	76ESE	138ESE
[illegible]	68	84	94

2

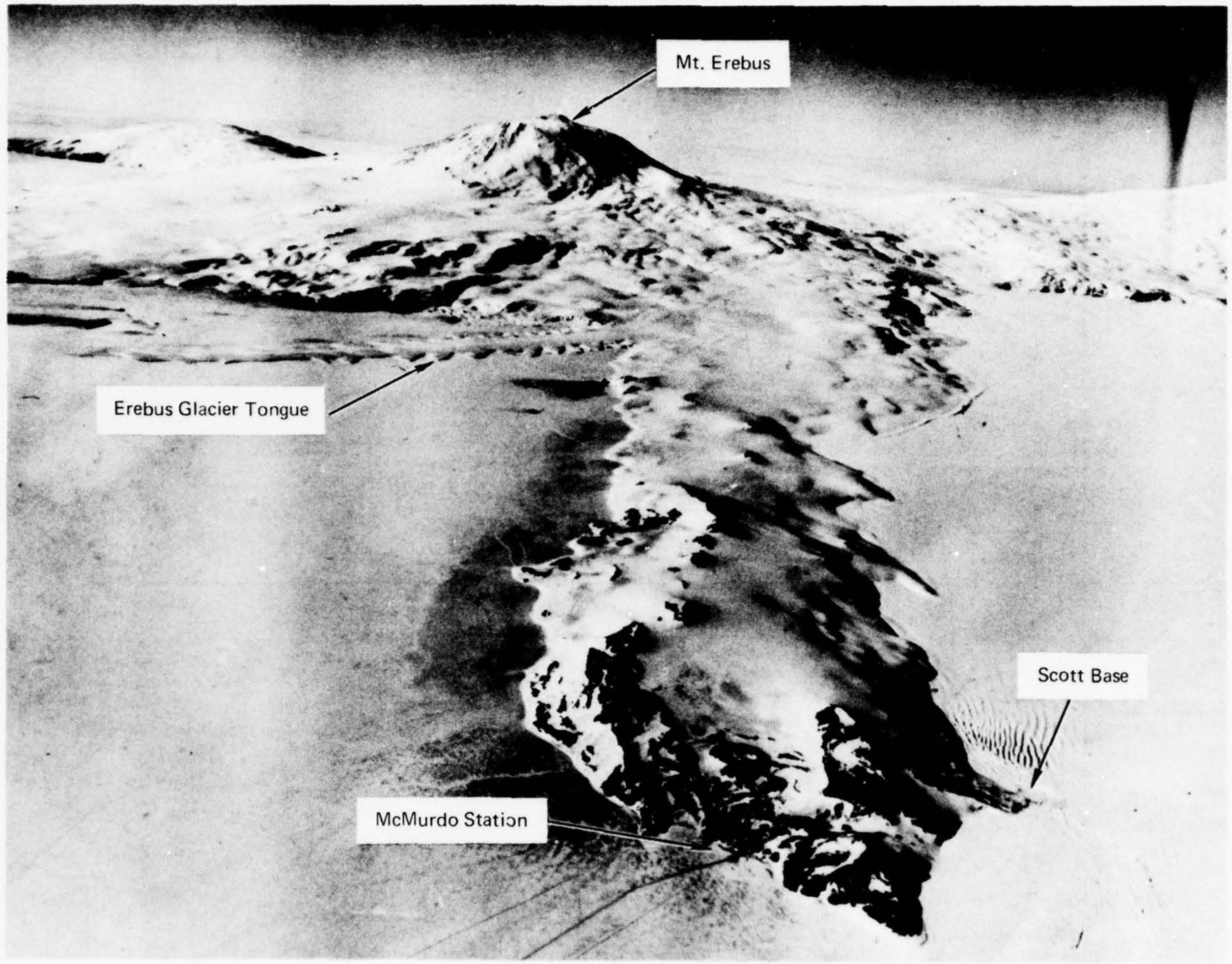


Figure 1-1. Hut Point Peninsula extending south from Ross Island.

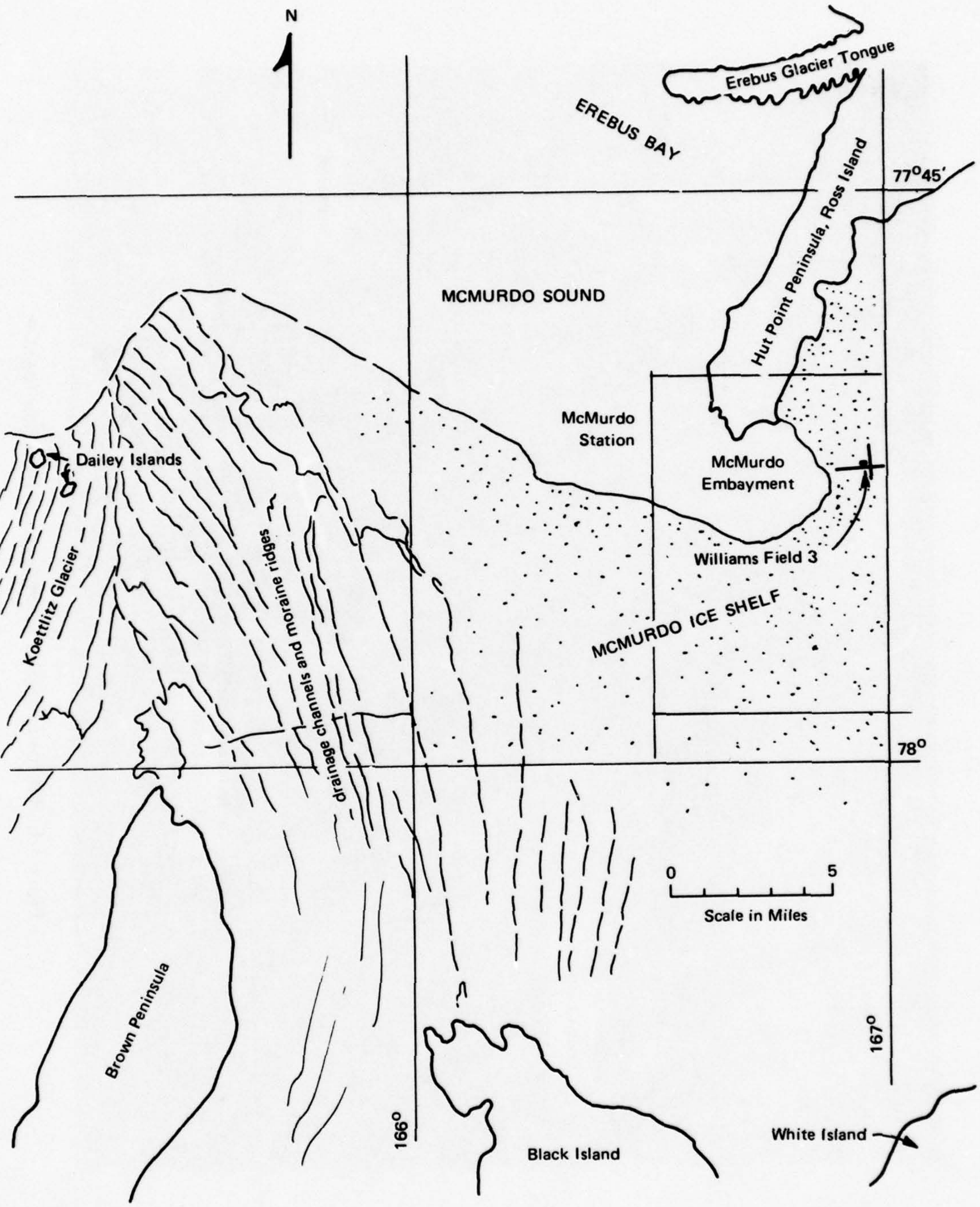


Figure 1-2. McMurdo Ice Shelf.

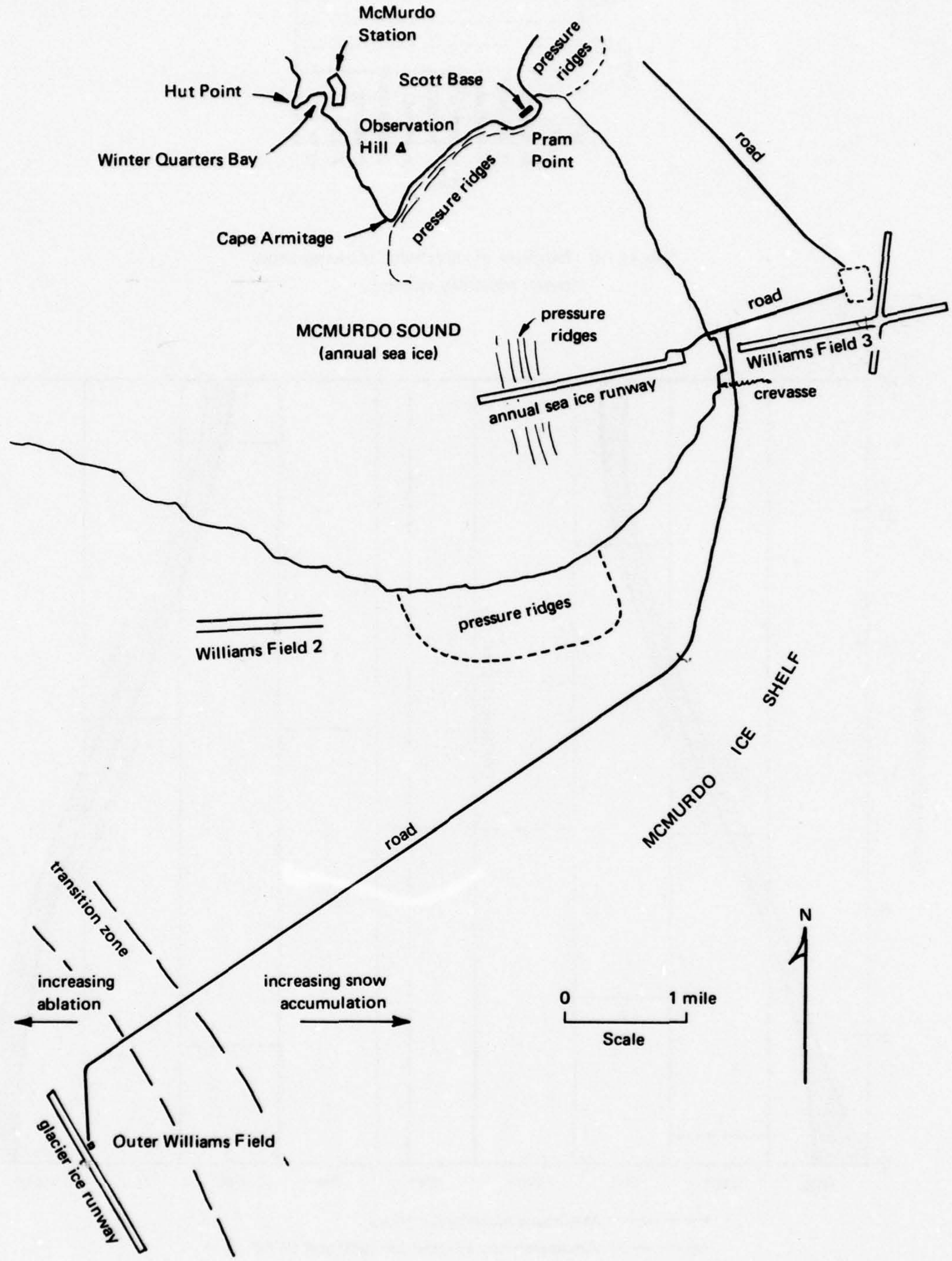


Figure 1-3. Facilities and features on the McMurdo Ice Shelf.

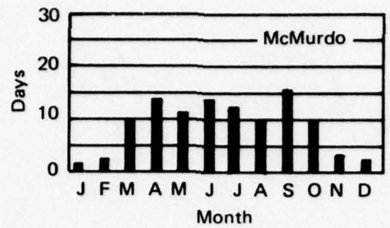


Figure I-4. Number of days with blowing snow
(mean monthly values).

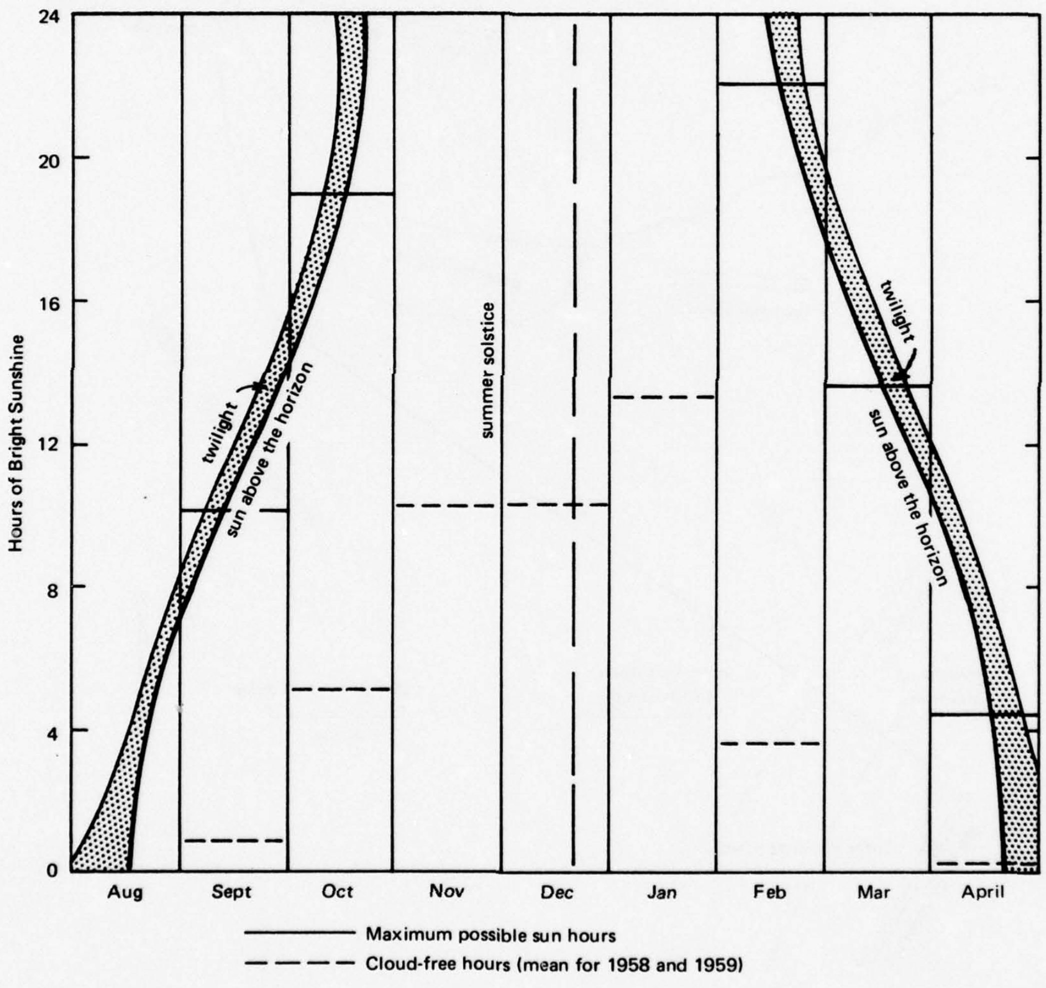


Figure 1-5. Average daily hours of bright sunshine for each month, March 1957 to February 1959, Scott Base. (After Reference 2.)

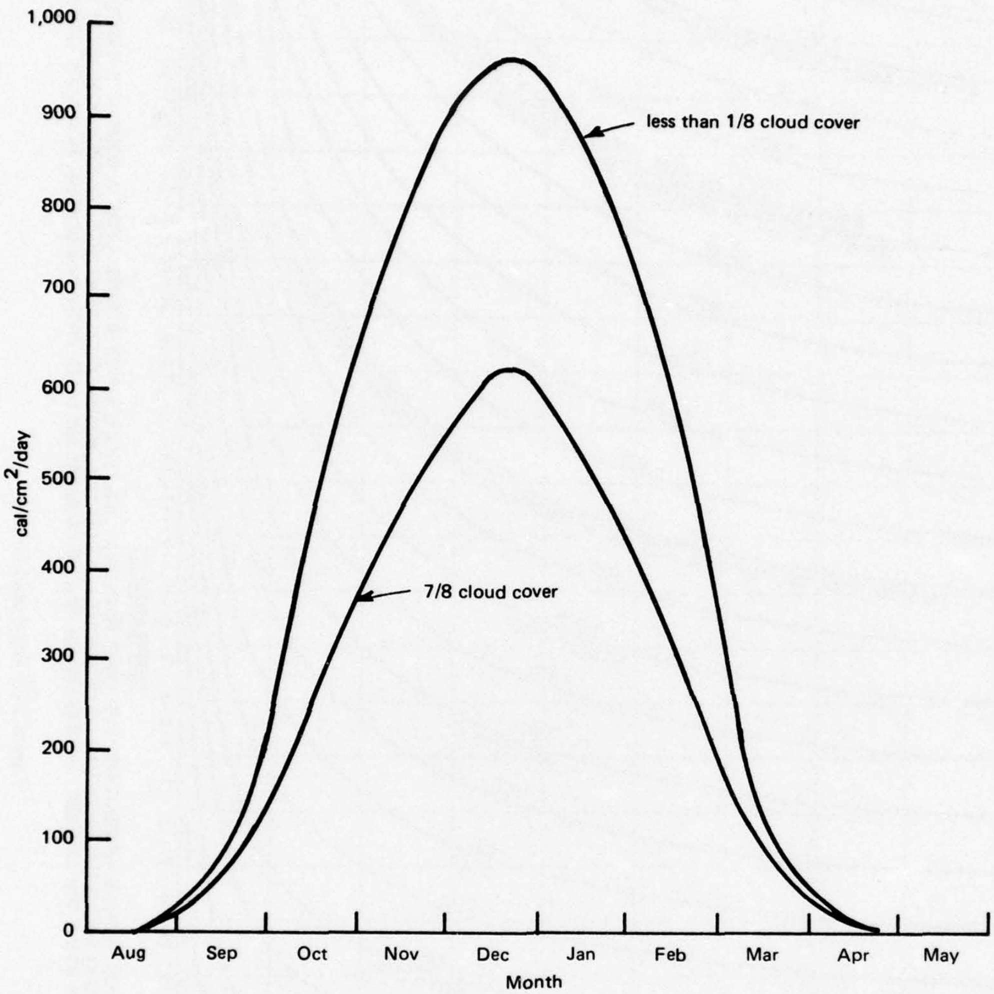
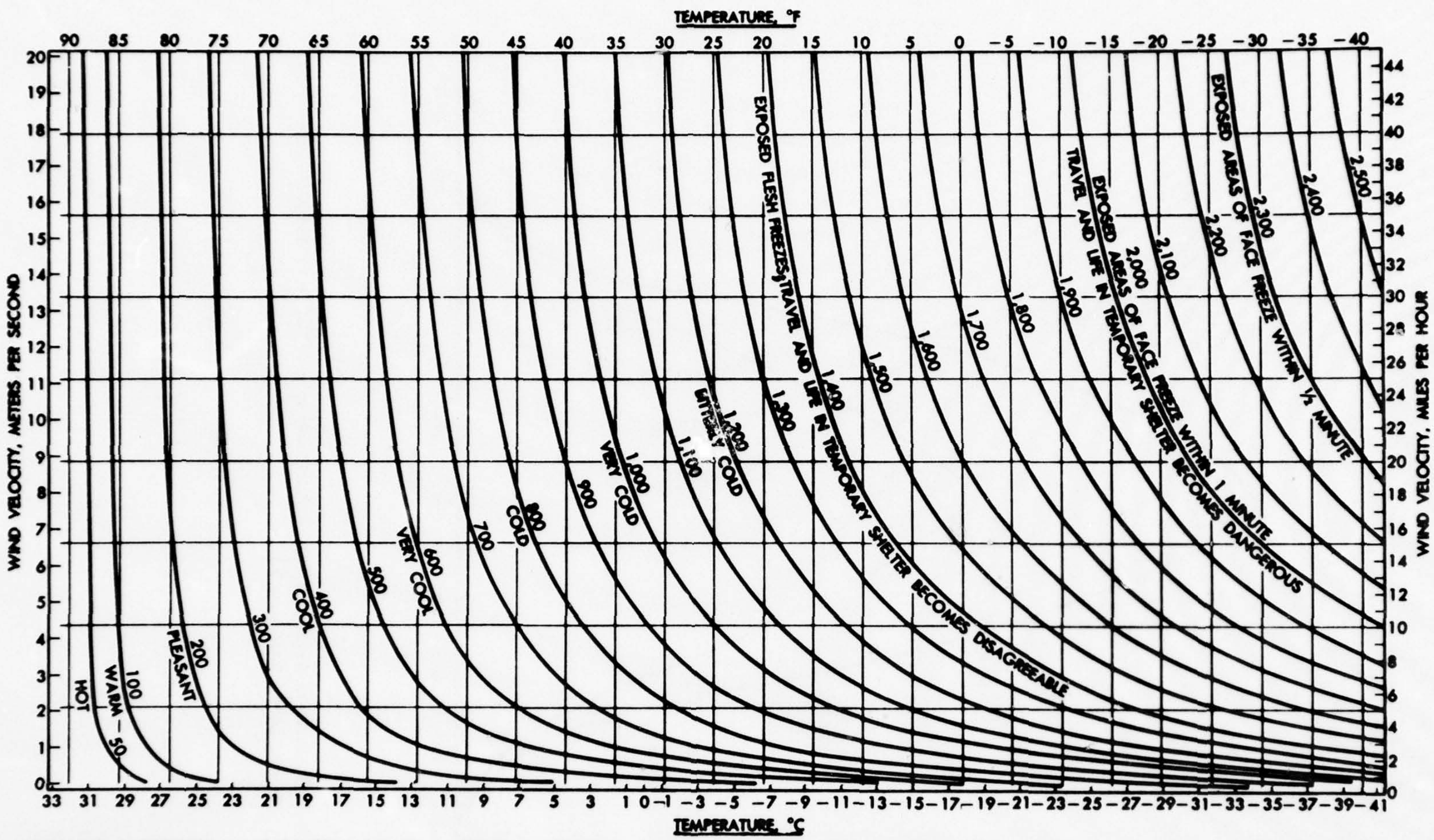


Figure 1-6. Daily totals of downward flux of short-wave solar radiation for the McMurdo Sound region. (After Reference 3.)



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	20	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

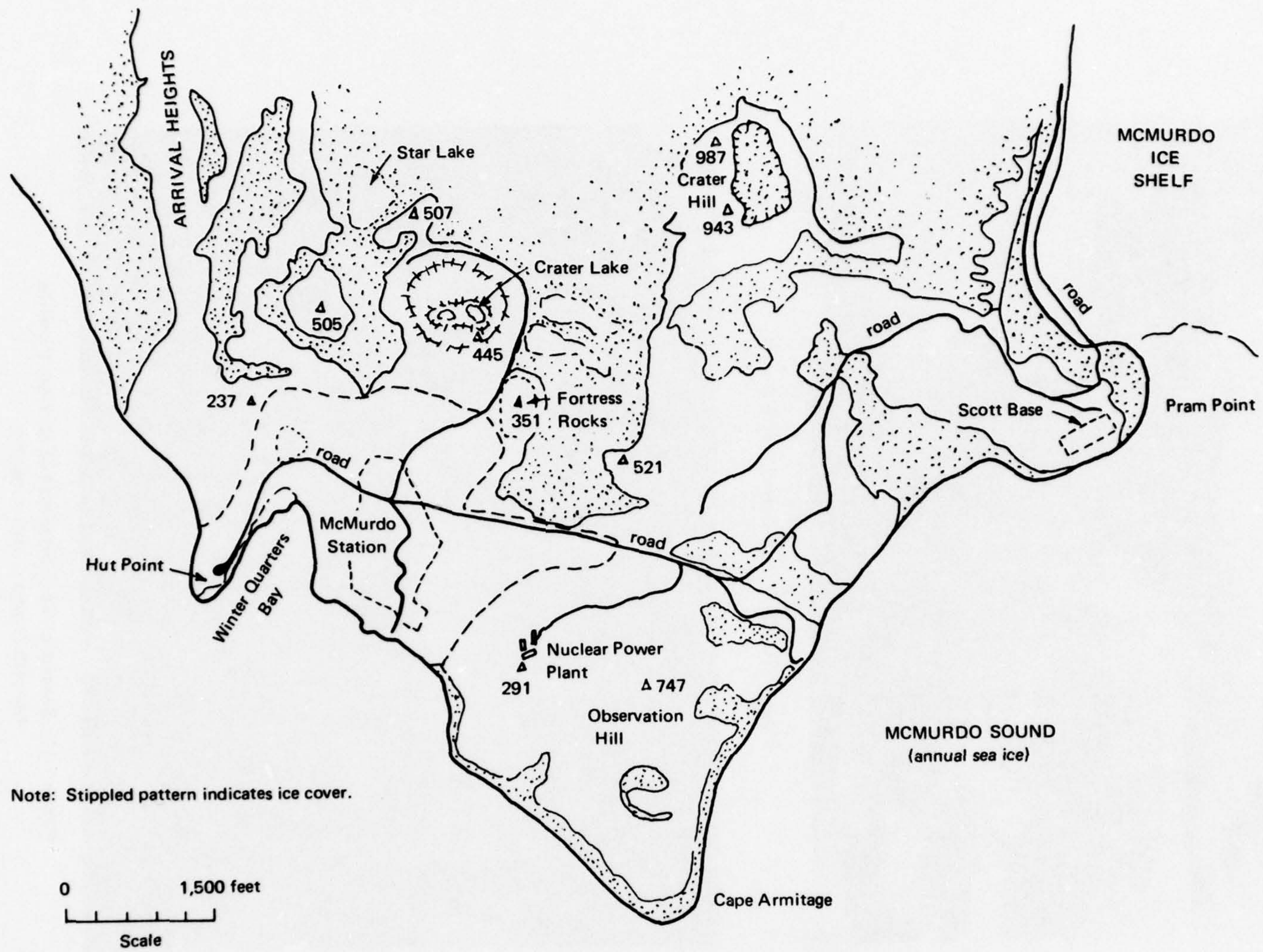
THERE IS NO SUBSTITUTE FOR IT. THE TABLE SERVES ONLY AS A GUIDE TO THE COOLING EFFECT OF THE WIND ON BARE-FLESH WHEN THE PERSON IS FIRST EXPOSED. GENERAL BODY COOLING AND MANY OTHER FACTORS AFFECT THE RISK OF FREEZING INJURY.

(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.



Note: Stippled pattern indicates ice cover.

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.

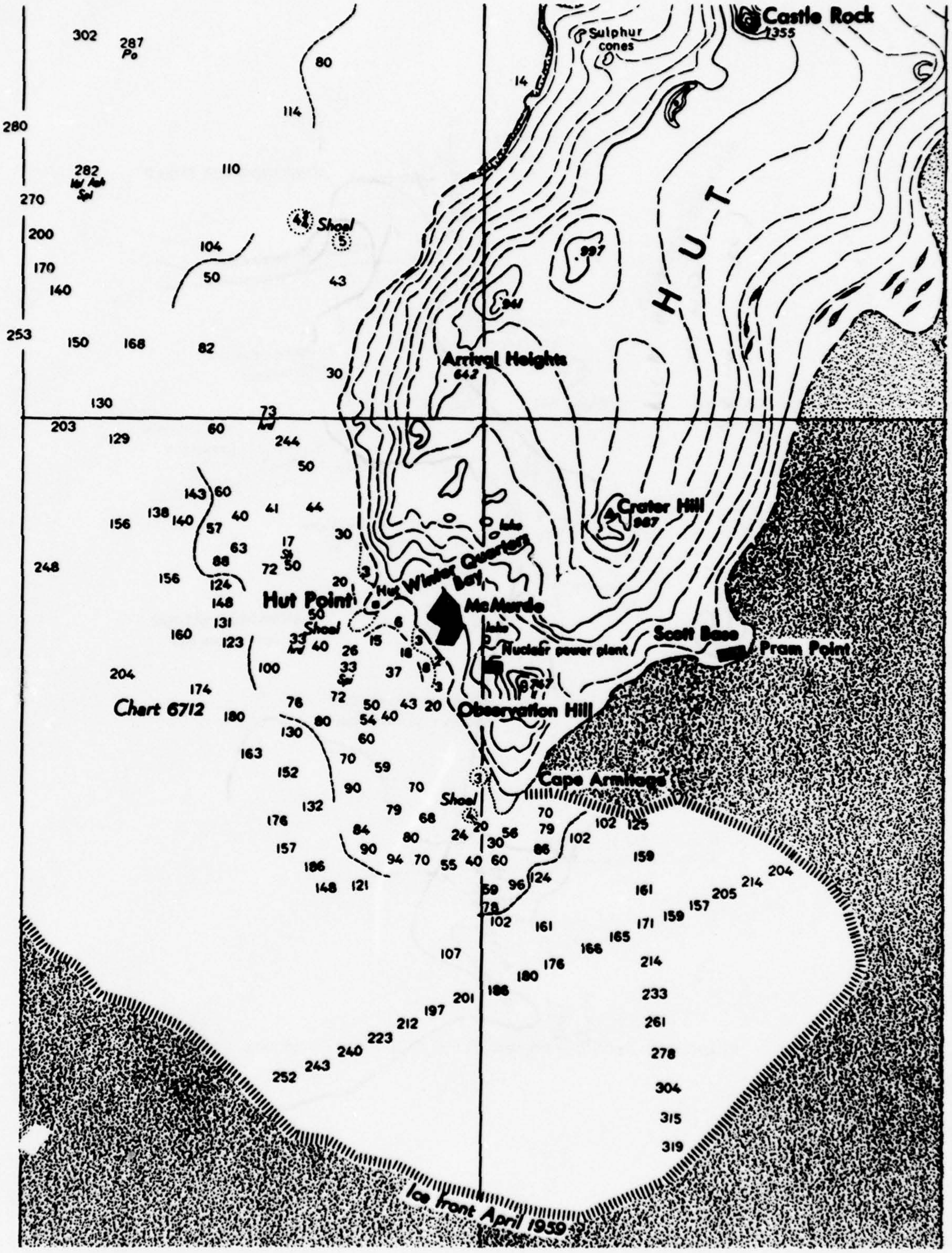


Figure 1-12. McMurdo Sound soundings in fathoms, height in feet. Scale 1:50,000.

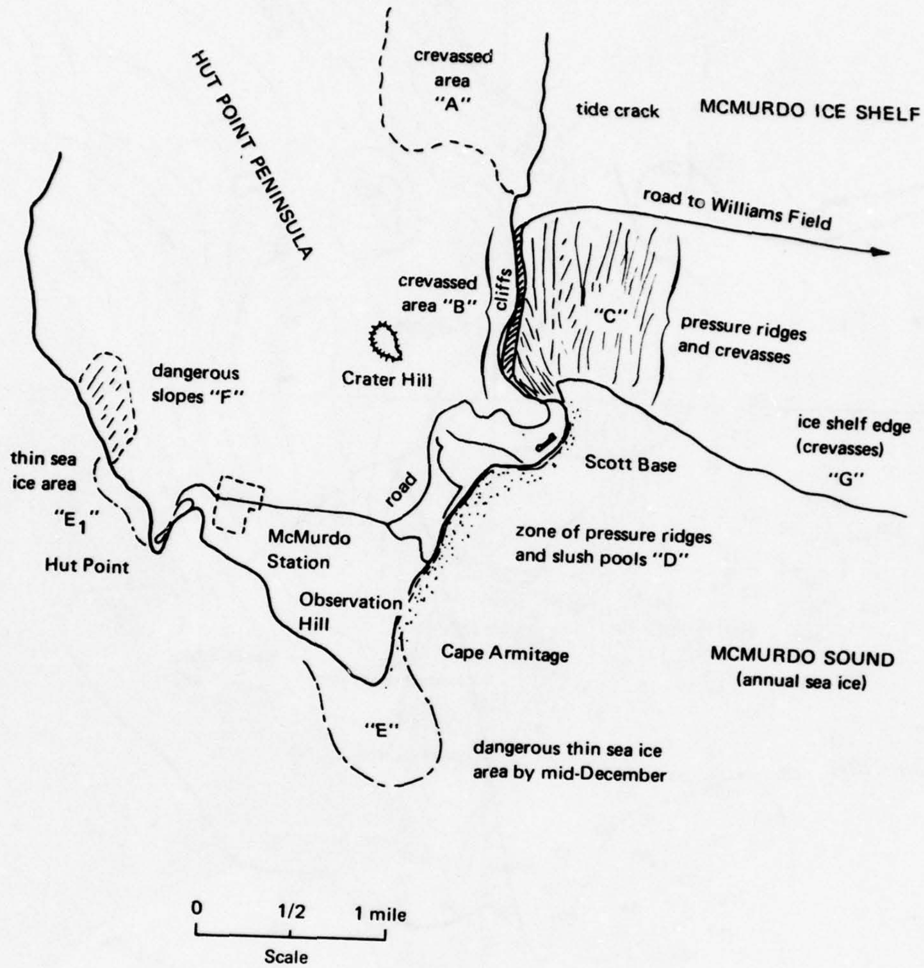


Figure 1-13. Hazard areas near McMurdo Station, Antarctica.

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

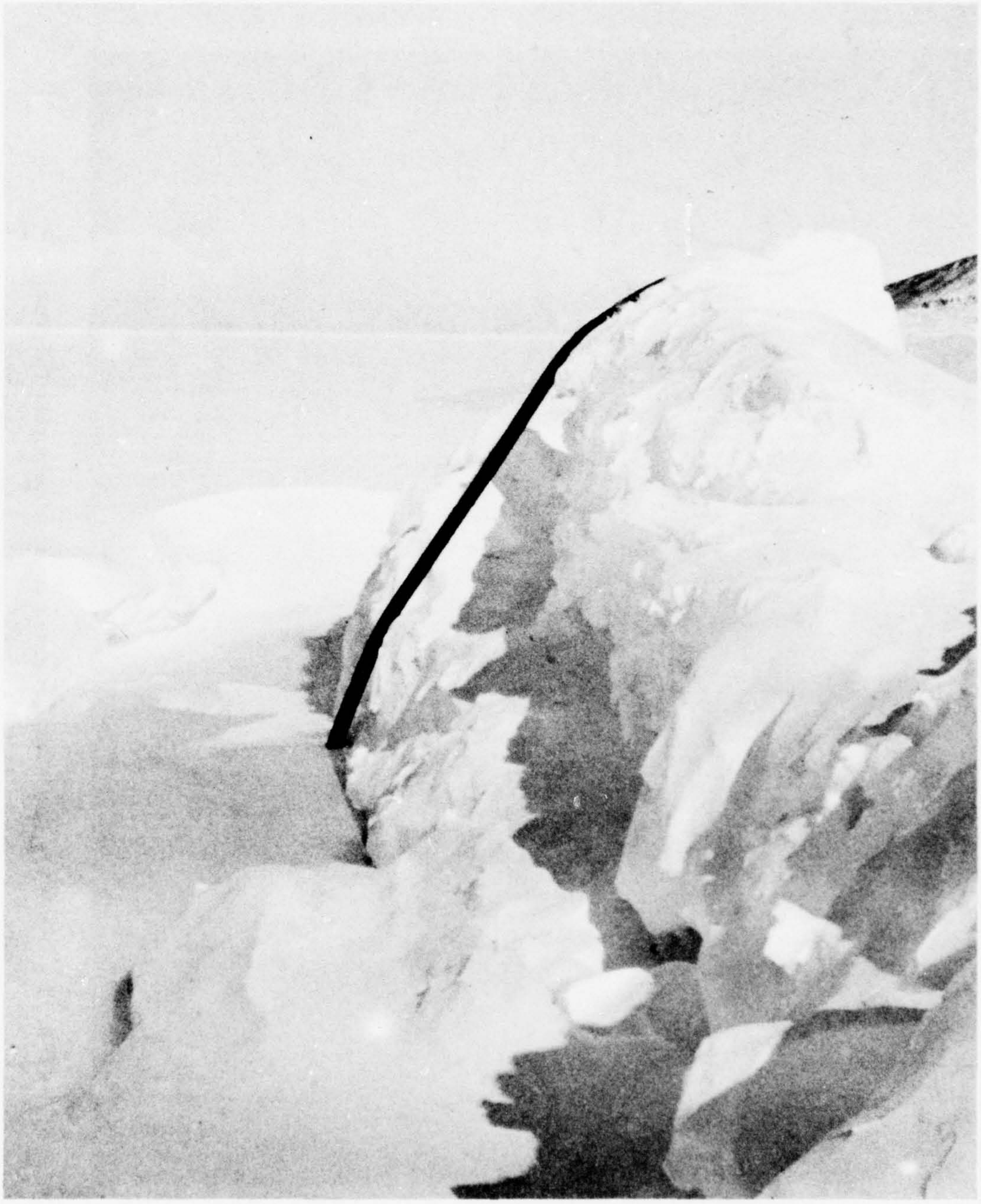


Figure 1-15. Hazardous pressure ridge and slush pool between Scott Base and Cape Armitage.

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

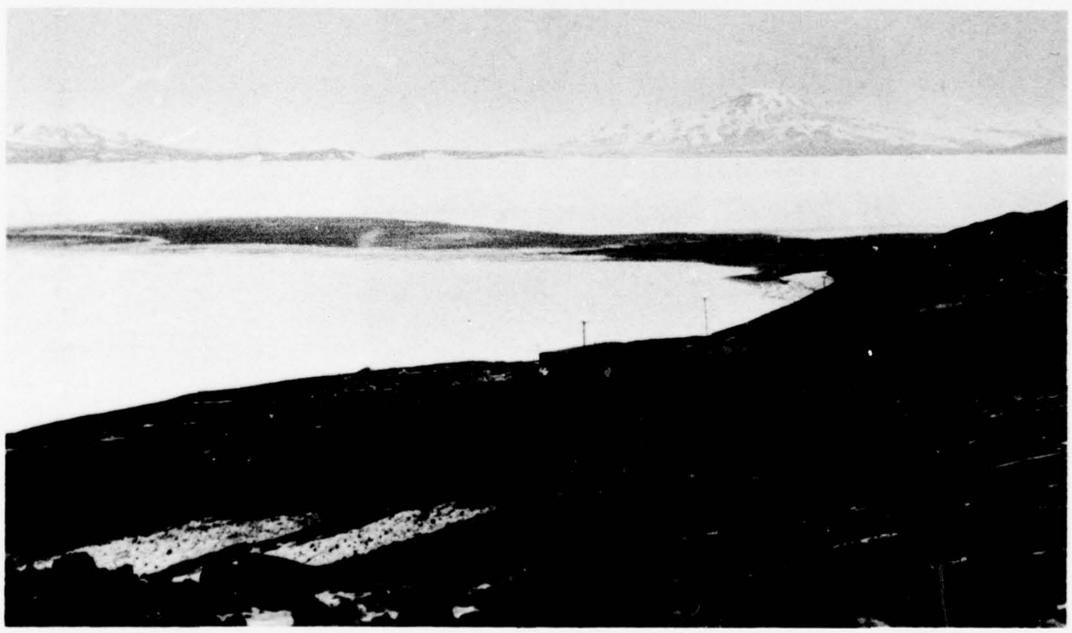


Figure 1-17. Sea ice melted away in-place off Cape Armitage.

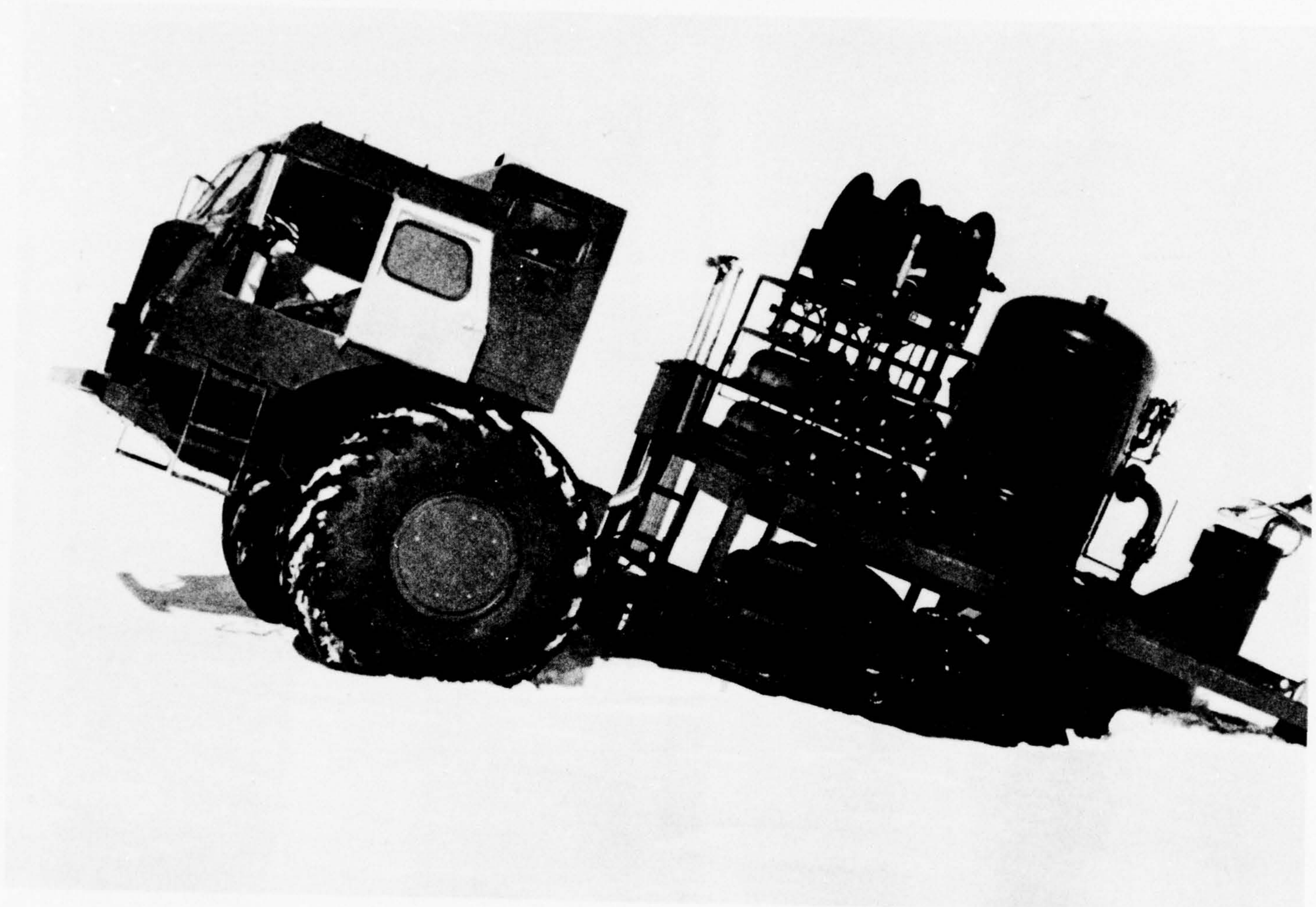


Figure 1-18. Water-Trotter immobilized in crevasse-like cornice of edge of McMurdo Ice Shelf.

CHAPTER 2

Chapter 2

MCMURDO ICE SHELF

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.

REFERENCES

1. W. J. P. MacDonald and T. Hatherton. "Movement of the Ross Ice Shelf near Scott Base," Journal of Glaciology, vol. 3, no. 29, 1961, pp. 859-867.

2. A. W. Stuart and C. Bull. "Glaciological observations on the Ross Ice Shelf near Scott Base, Antarctica," Journal of Glaciology, vol. 4, no. 34, 1963, pp. 399-415.

3. A. J. Heine. "The McMurdo Ice Shelf, Antarctica: a preliminary report," New Zealand Journal of Geology and Geophysics, vol. 10, no. 2, 1967, pp. 474-479.

4. 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.

5. A. J. Gow. "Antarctic glaciological studies," Antarctic Journal of the United States, vol. 2, no. 4, July-August 1967, pp. 121-122.

6. A. J. Heine. "Ice breakout around the southern end of Ross Island, Antarctica," New Zealand Journal of Geology and Geophysics, vol. 6, no. 3, 1963, pp. 395-402.

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.

8.———. Technical Note N-840: Ice and snow terrain features McMurdo Station, Antarctica, by R. A. Paige. Port Hueneme, Calif., Sept. 1966.

9. New Zealand Department of Scientific and Industrial Research. Report No. 47: Geophysical measurements on the McMurdo Ice Shelf, Antarctica, during 1965-66, by M. P. Hochstein and G. F. Risk. Wellington, 1967.

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

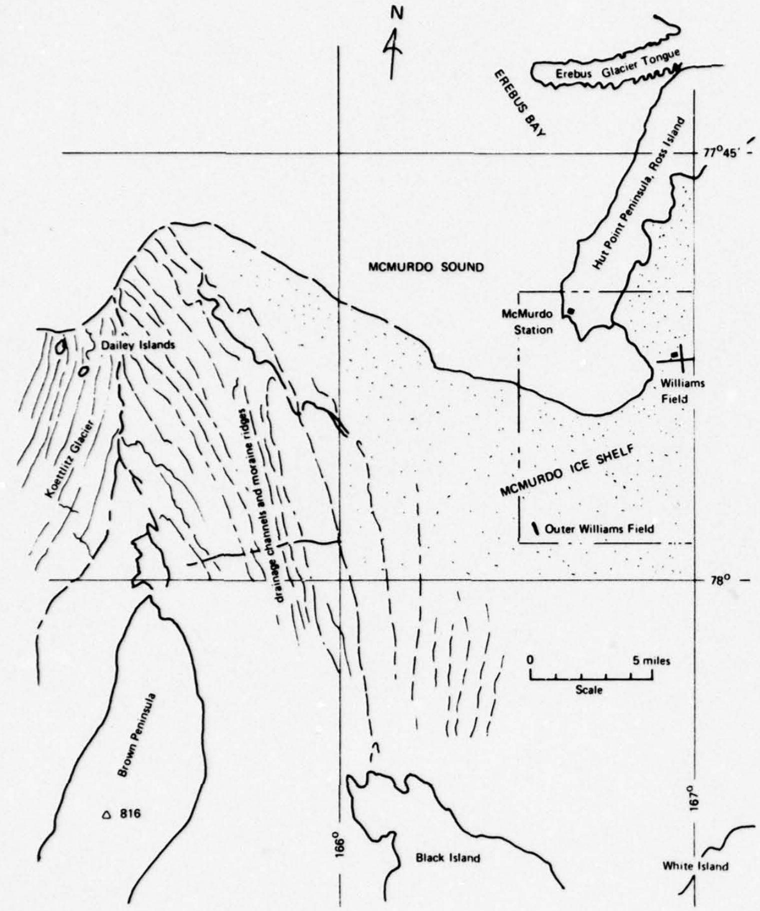


Figure 2-1. Overview of McMurdo Ice Shelf. See Figure 2-2 for details of inset outlined by broken line.

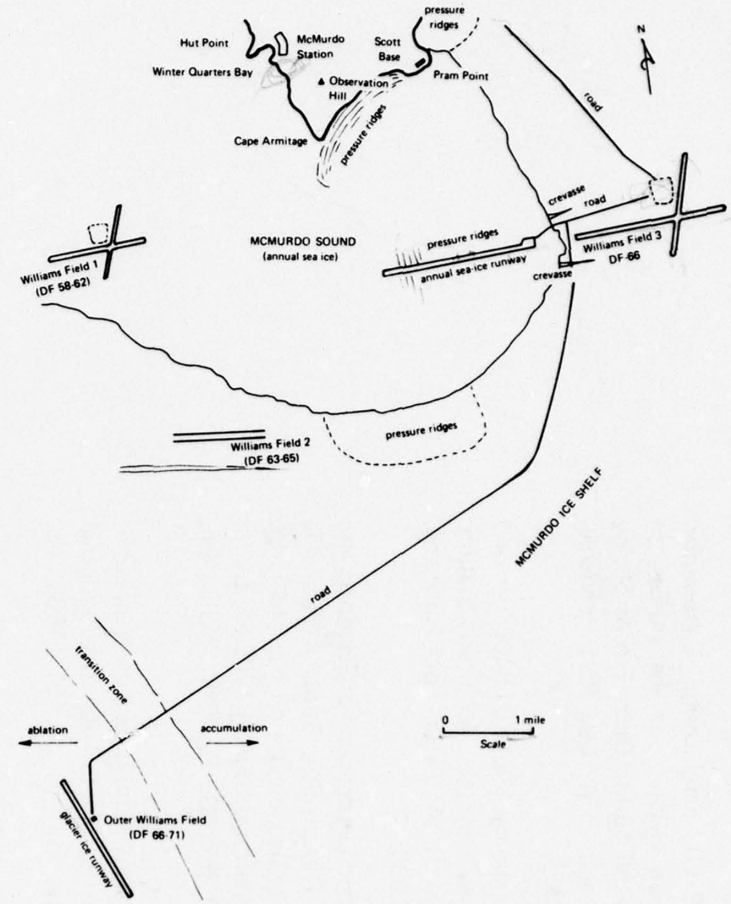


Figure 2-2. McMurdo Ice Shelf (inset from Figure 2-1) showing features and historical sites of the Williams Field air facilities.

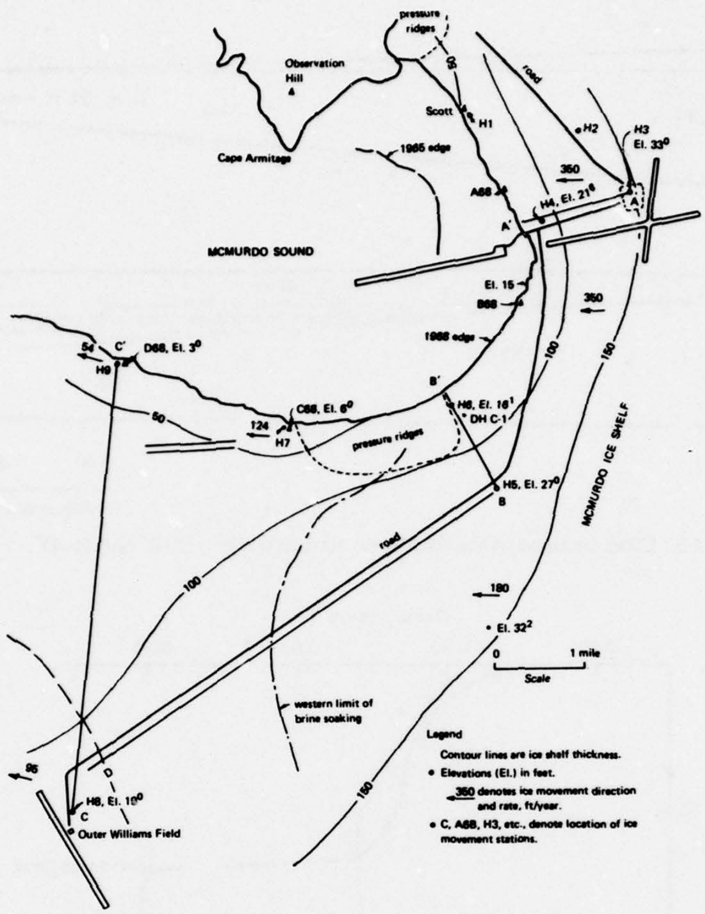


Figure 2-3. Movement and thickness of the McMurdo Ice Shelf.

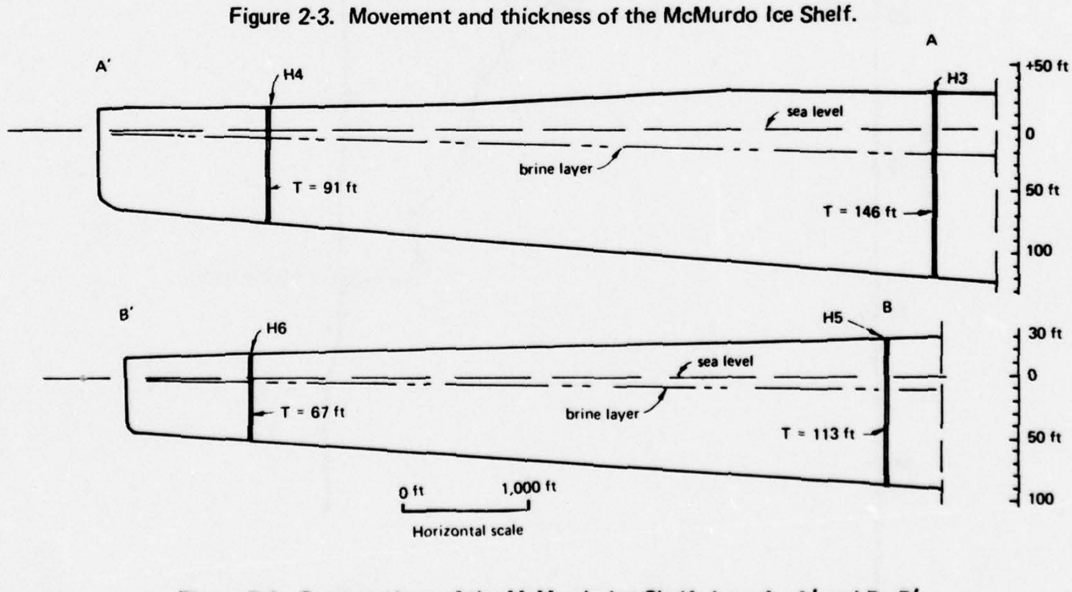


Figure 2-4. Cross sections of the McMurdo Ice Shelf along A—A′ and B—B′.

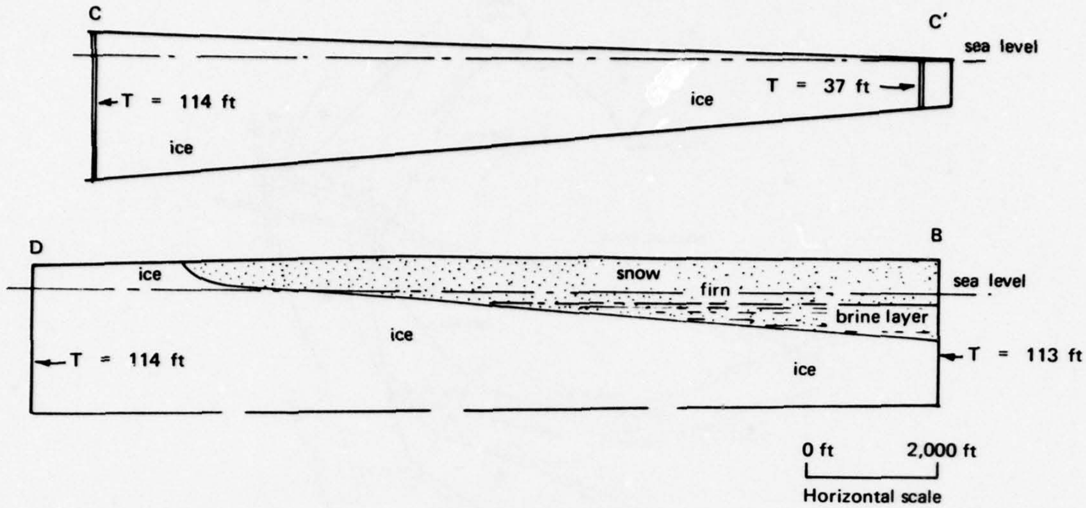


Figure 2-5. Cross sections of the McMurdo Ice Shelf along C—C′ and D—D′.

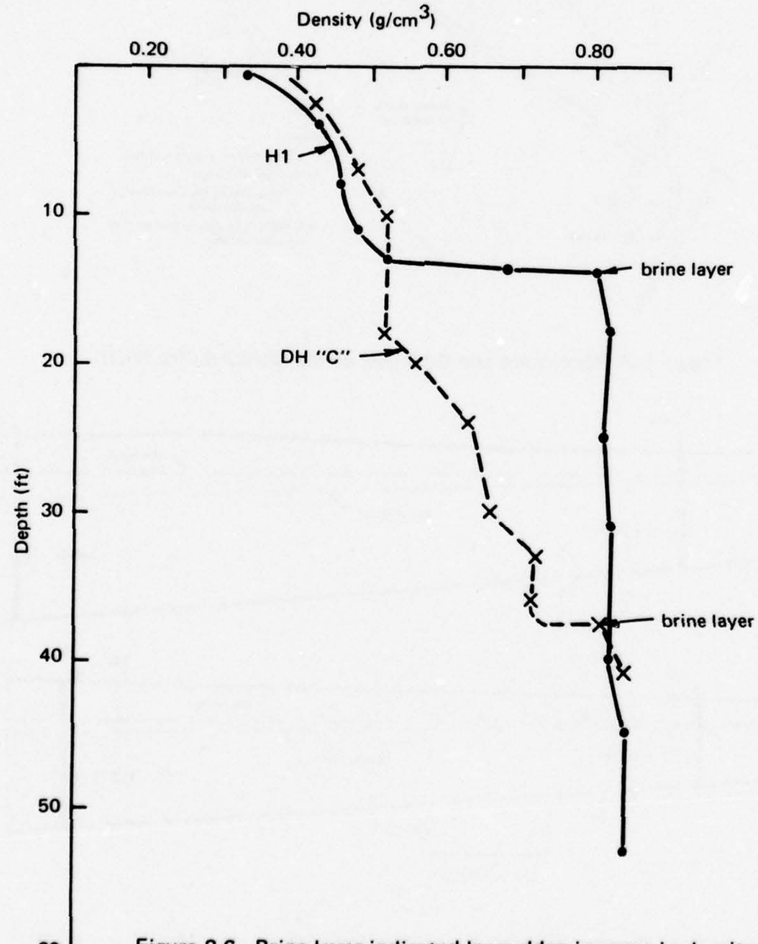


Figure 2-6. Brine layer indicated by sudden increase in density.

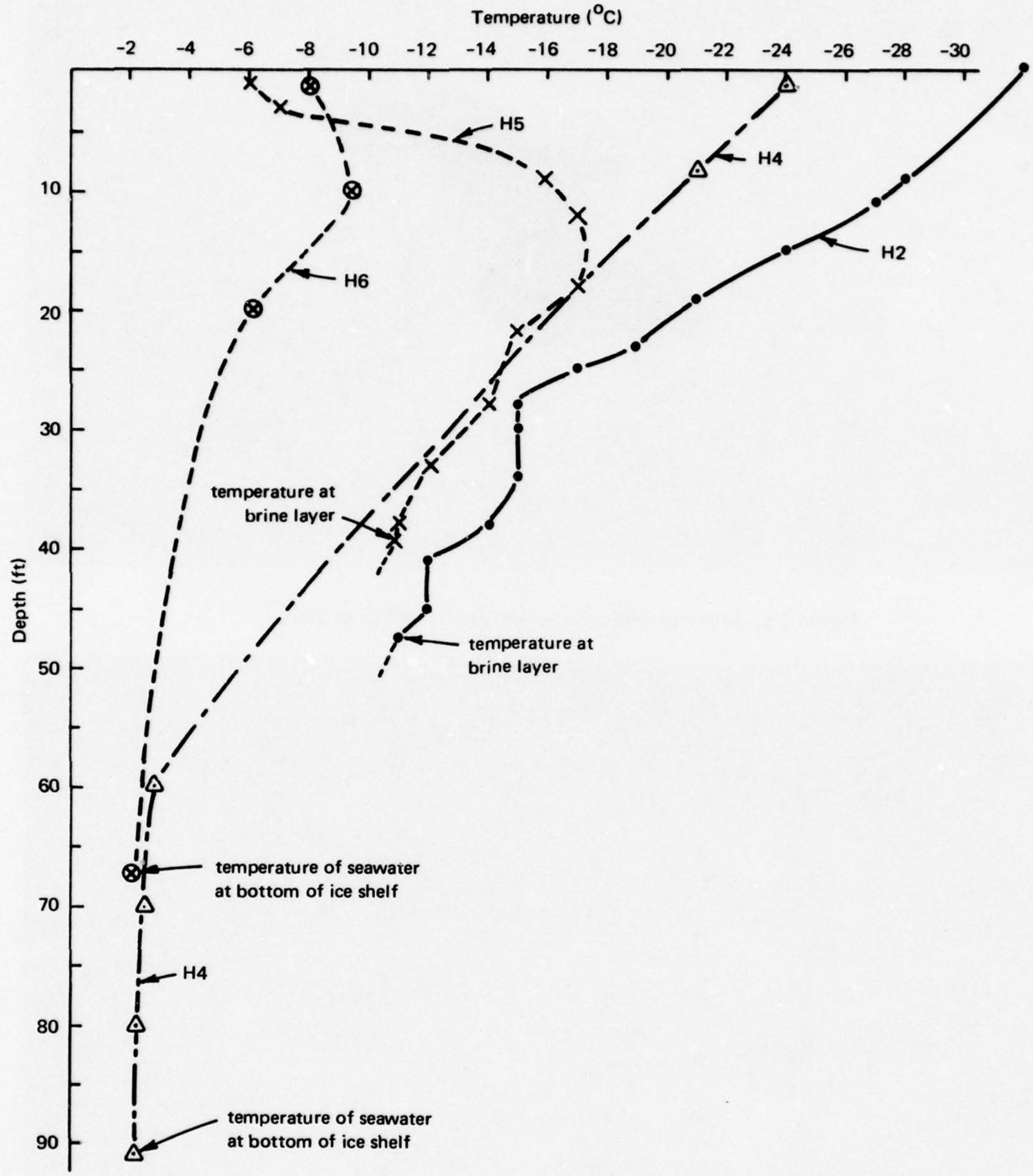


Figure 2-7. Effect of brine infiltration on temperature of McMurdo Ice Shelf.

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.

CHAPTER 3

Chapter 3

SEA-ICE SHEET

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.

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 reoccur 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.

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.

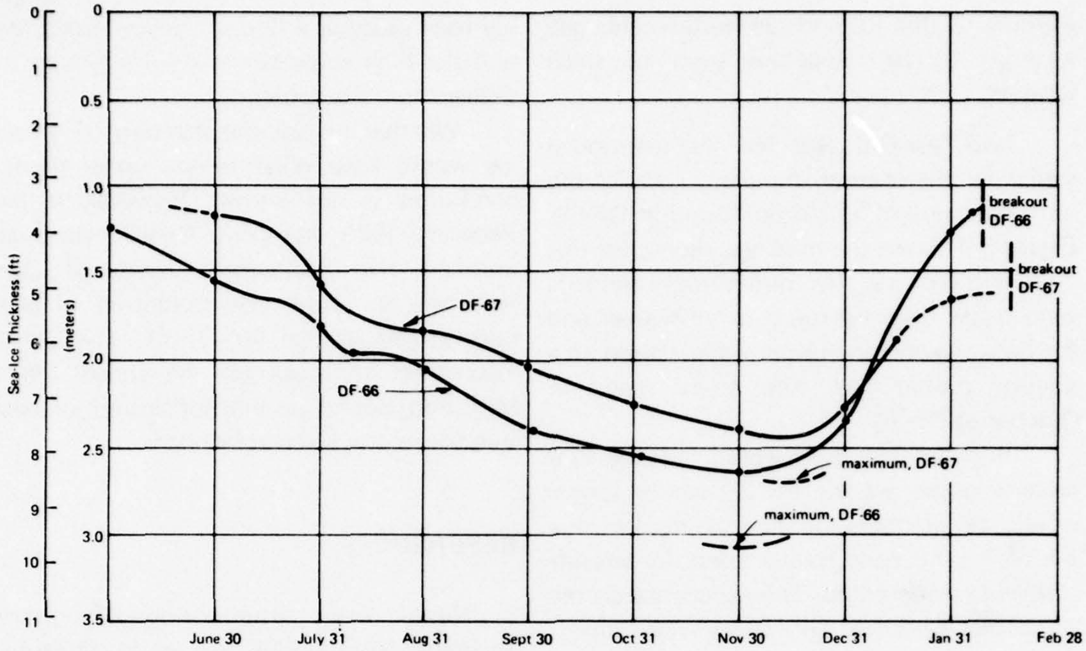


Figure 3-1. Growth and thinning of the annual sea ice in McMurdo Sound during Deep Freeze 66 and 67.

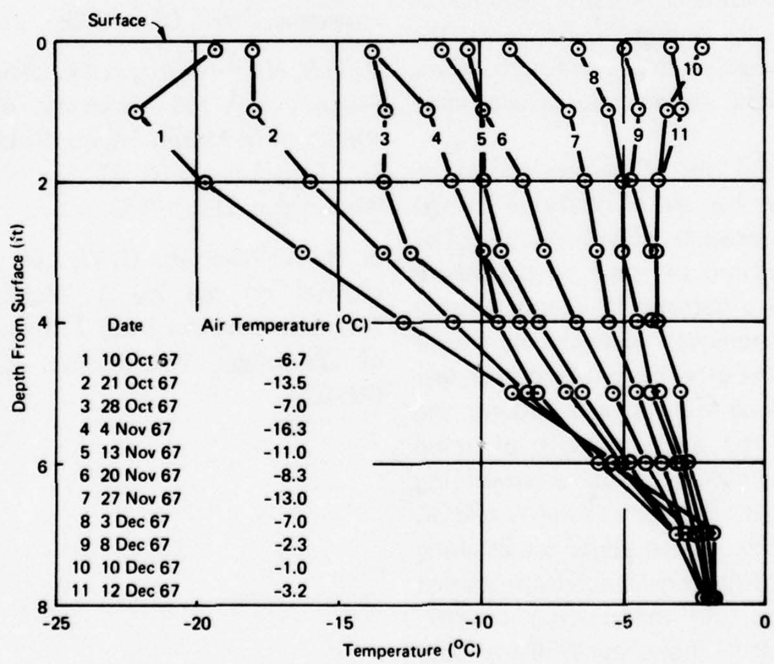


Figure 3-2. Temperature of annual sea-ice sheet, McMurdo (near shelf end of runway, no snow cover, DF-68).

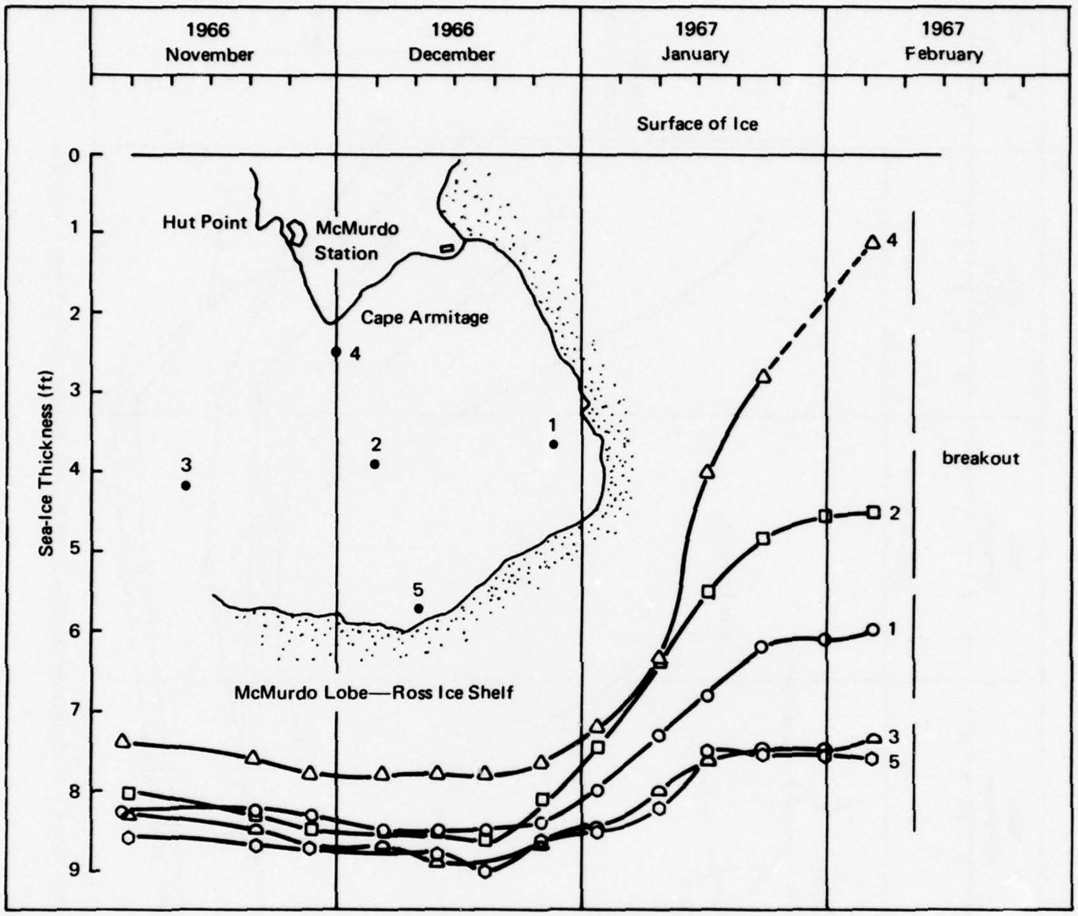


Figure 3-3. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 67.

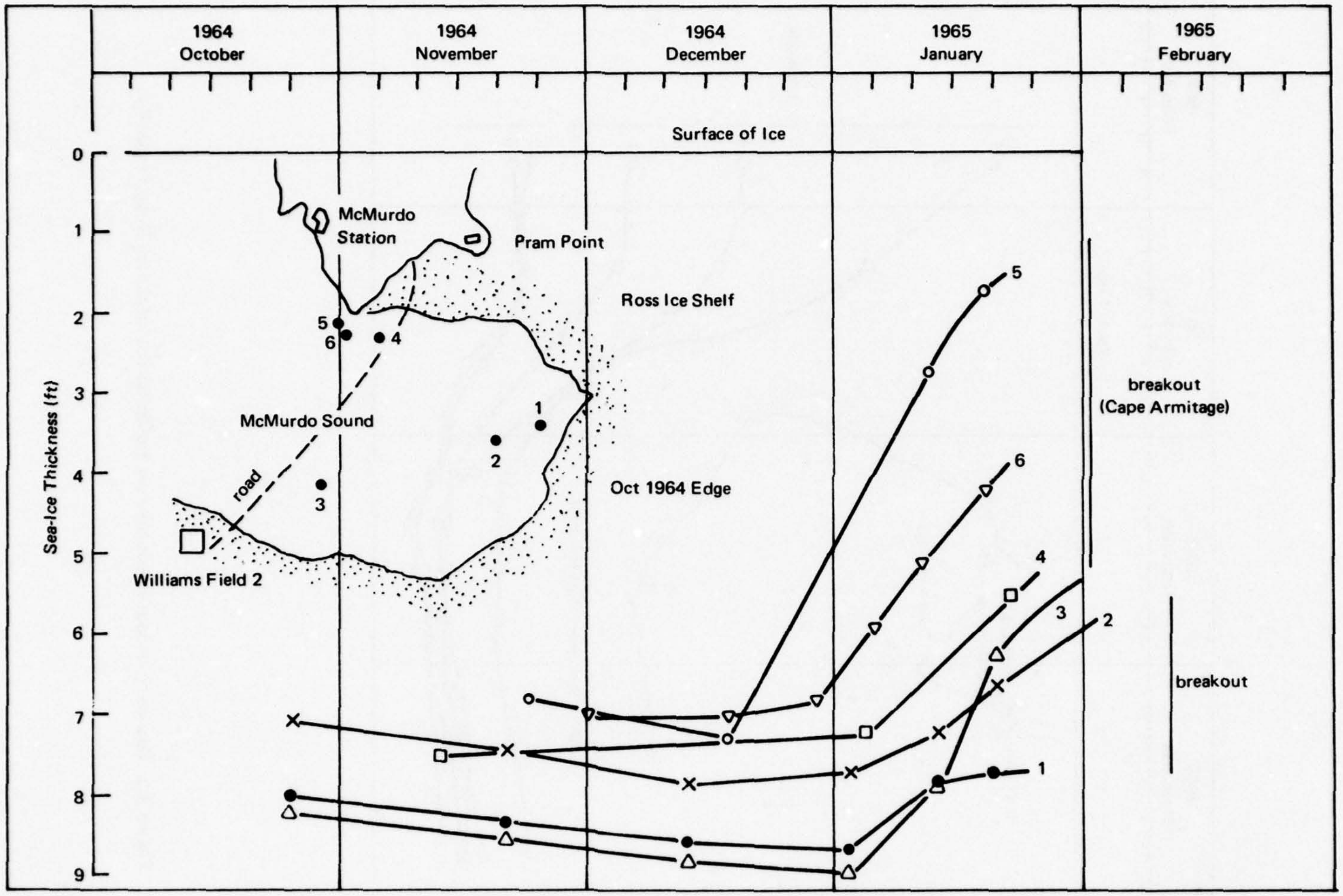


Figure 3-4. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 65.

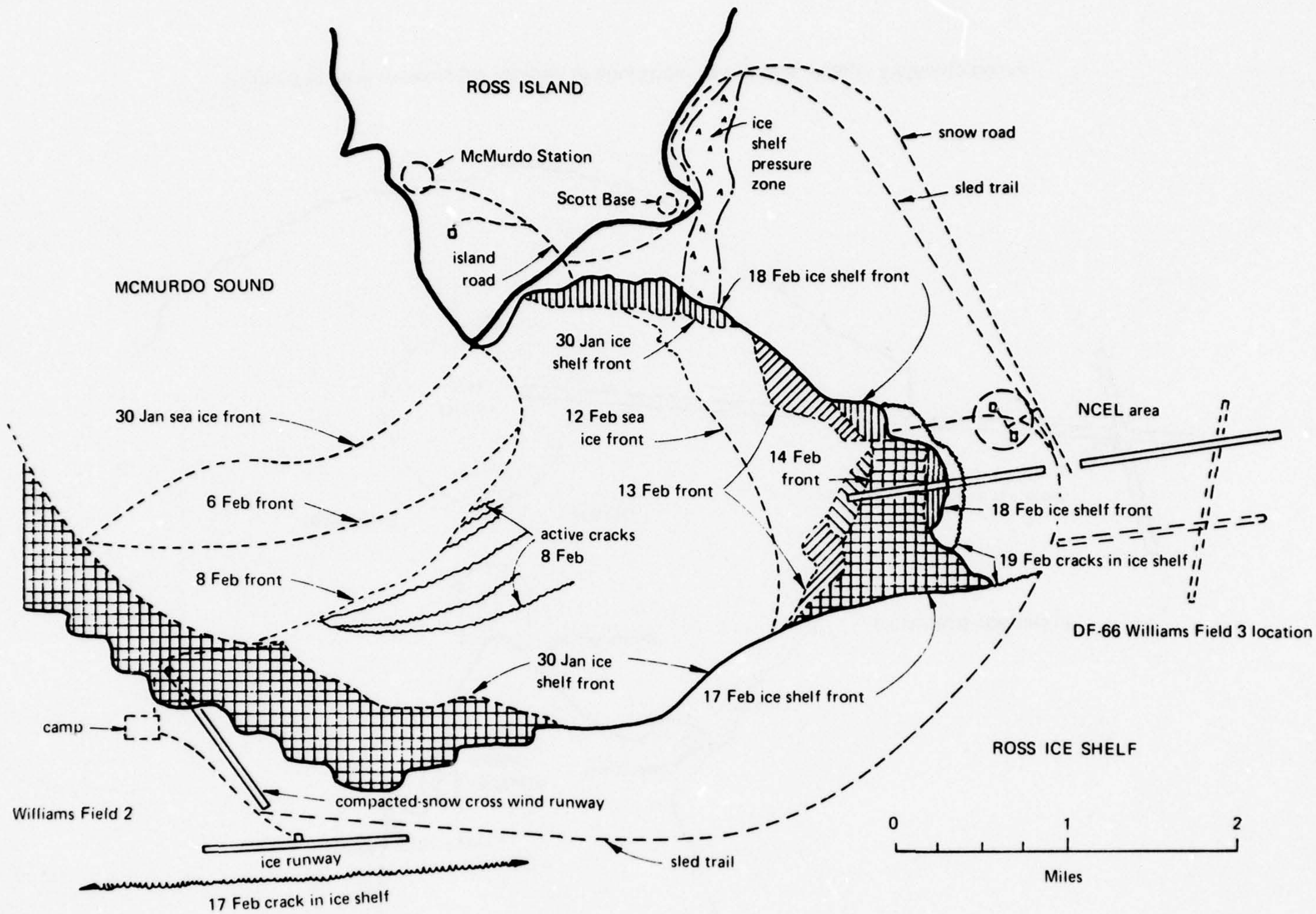


Figure 3-5. Progression of ice breakout at McMurdo Station during February 1965. Shaded areas are breakouts of ice shelf and fast ice.

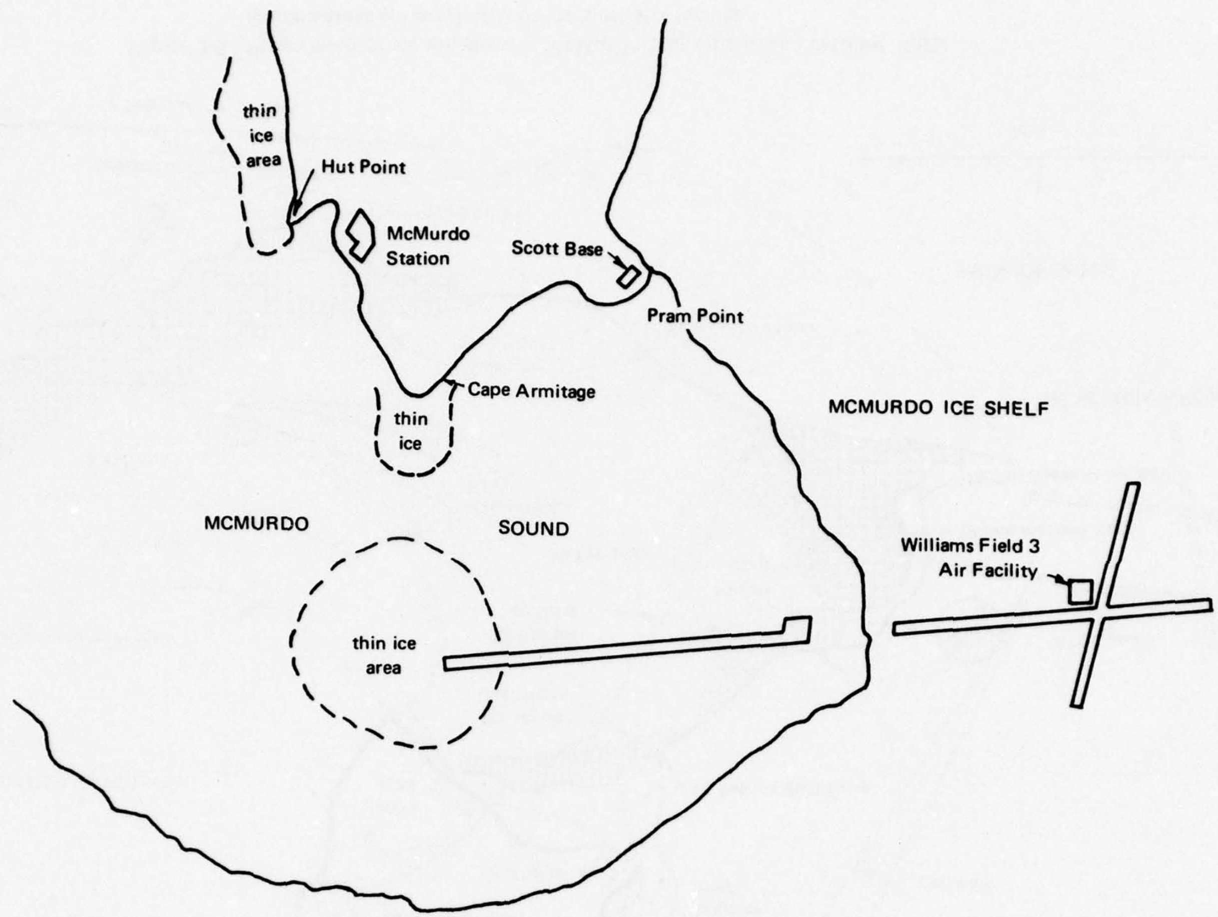


Figure 3-6. Map showing the location of anomalous thin sea-ice areas in McMurdo Sound.

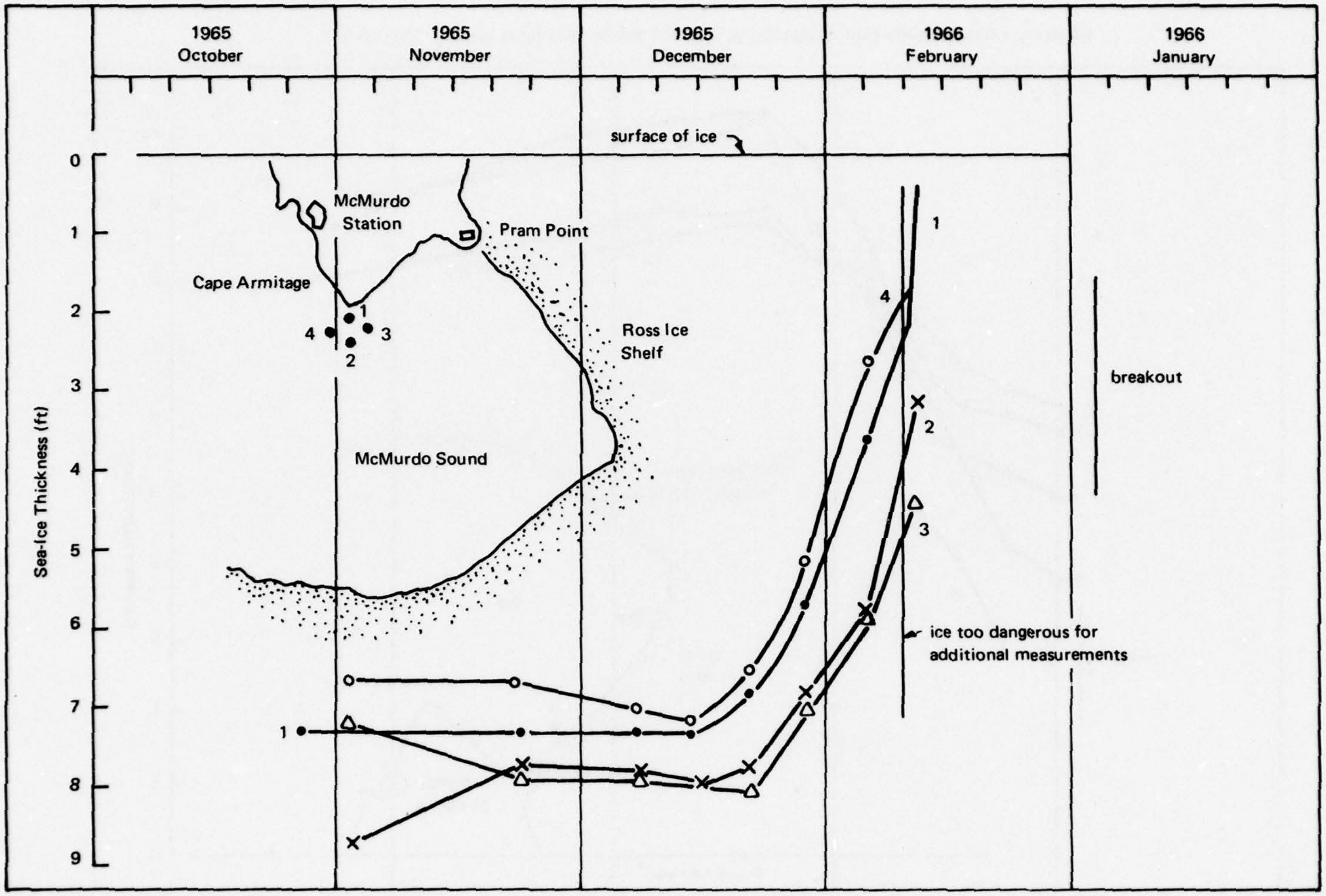


Figure 3-7. Sea-ice thickness versus time at Cape Armitage during Deep Freeze 66.

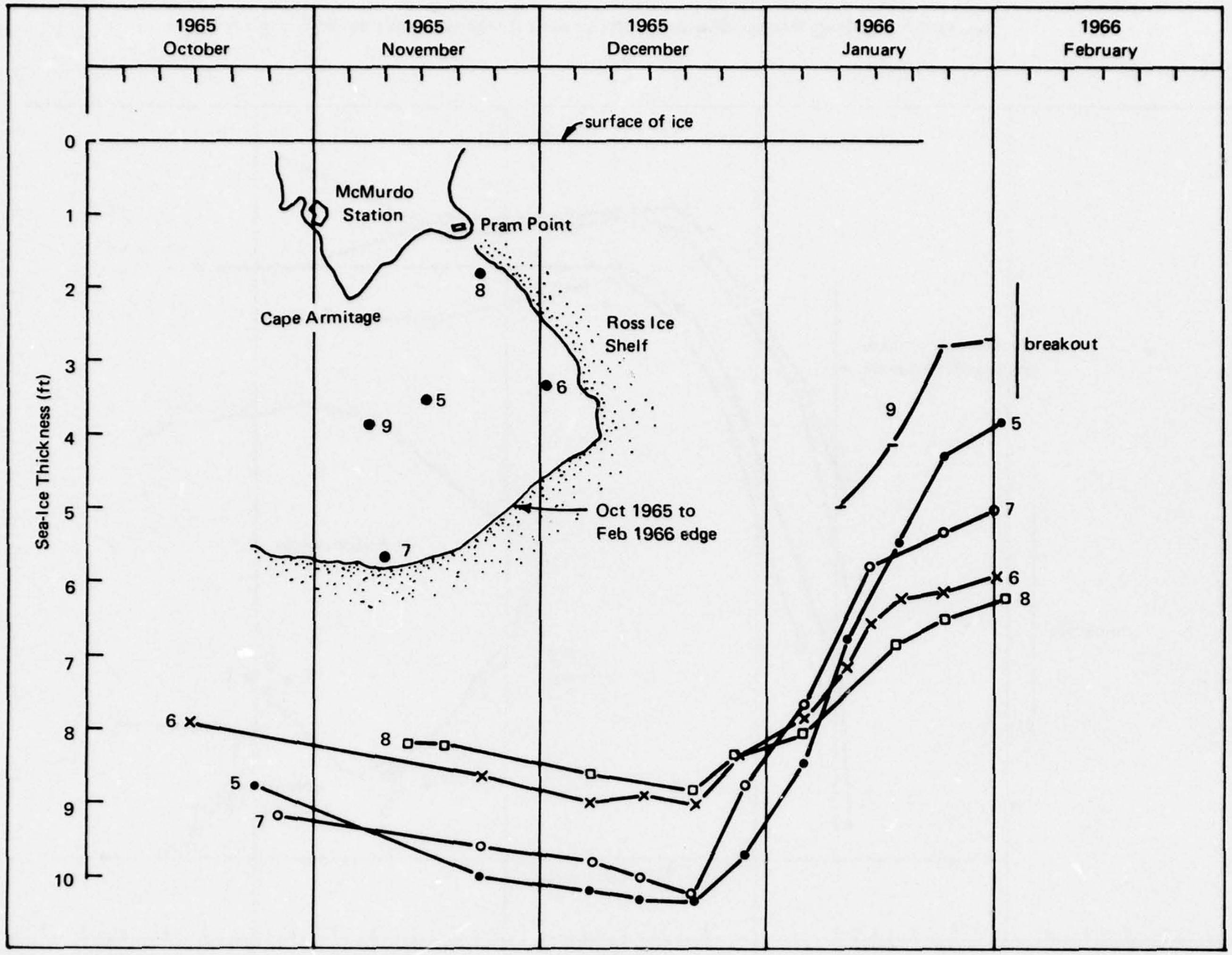


Figure 3-8. Sea-ice thickness versus time on McMurdo Sound during Deep Freeze 66.

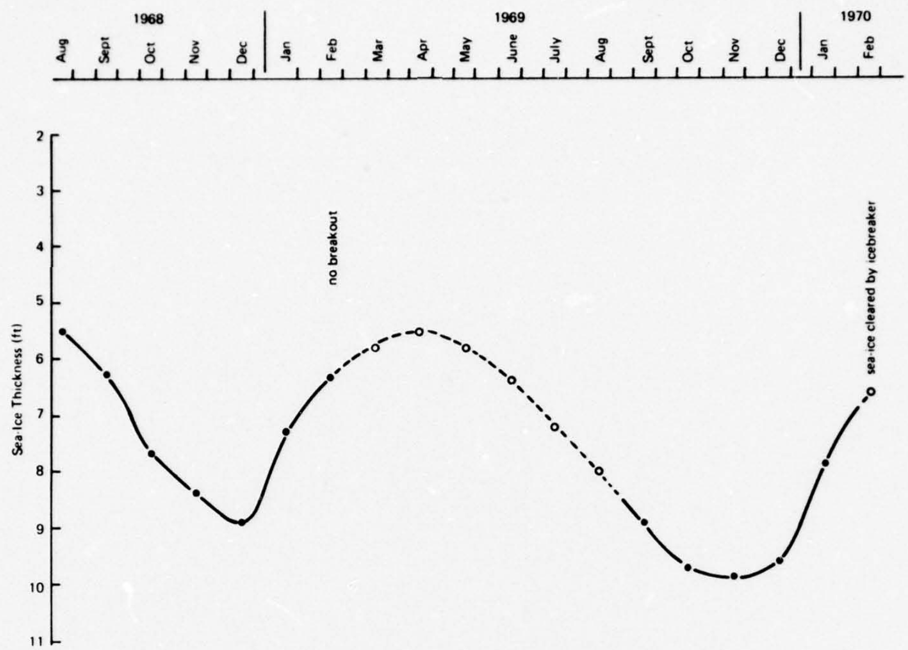


Figure 3-9. Average mid-month sea-ice thickness for 2-year-old sea ice in McMurdo Sound, Antarctica. Dashed part of curve is interpolated from a salinity profile.

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

CHAPTER 4

Chapter 4

PROPERTIES OF SNOW, ICE, AND PERMAFROST

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 drectly 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)	Density (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°C and -12°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°C to -12°C (+19°F to 10°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°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 $Btu/hr/ft^{2}/^{o}F/ft$.

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.

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. It purposely has not been included here by the fact it would soon become dated for lack of established procedure or assurance that the content would include updating for new developments in operation criteria and procedures. This type of critical information is considered best obtained from a single source.

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.

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.

REFERENCES

1. NAVFAC Design Manual DM-9.

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.

3. Naval Civil Engineering Laboratory. Technical Report R-706: Snow compaction—investigation of metamorphism of snow, by N. S. Stehle. Port Hueneme, Calif., Dec. 1970.

4. ______. Technical Report R-480: Compacted snow runways in Antarctica Deep Freeze 65 trials, by E. H. Moser, Jr., and G. E. Sherwood. Port Hueneme, Calif., Sept. 1966.

5. ______. Technical Report R-689: Ice engineering—tensile properties of sea ice grown in a confined system, by J. E. Dykins. Port Hueneme, Calif., July 1970.

6. ______. Technical Report R-720: Ice engineering—material properties of saline ice for a limited range of conditions, by J. E. Dykins. Port Hueneme, Calif., April 1971.

7. Cold Regions Research and Engineering Laboratory. Monograph CRSE II-C3: Cold Regions Science and Engineering, pt. 2, Physical Science, Sec. C3: The mechanical properties of sea ice, by W. Weeks and A. Assur. Hanover, N.H., Sept. 1967. (AD 662716)

8. University of Alaska. Geophysical Institute. Technical Report UAG R-182: Sea ice strength, by H. R. Payton. College, Alaska, Dec. 1966 (Contract NONR-2601(01) (AD653883)

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.

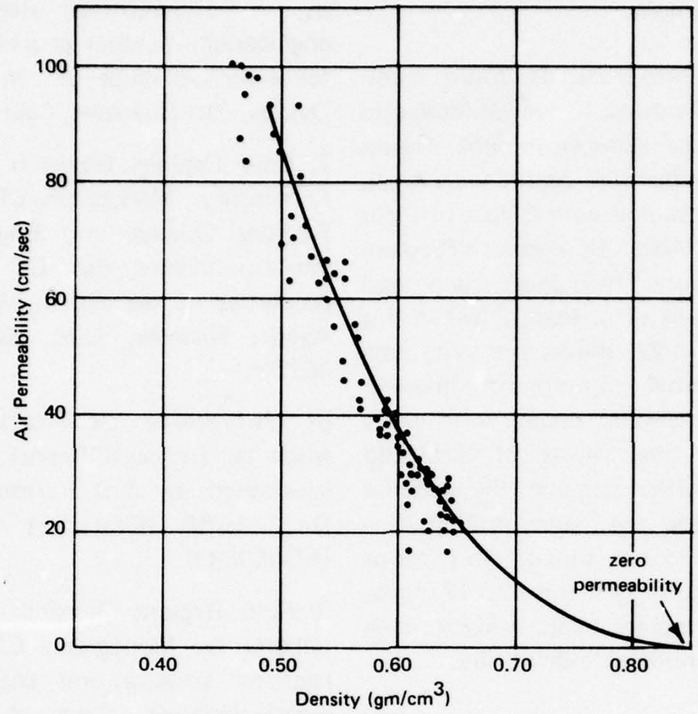


Figure 4-1. Decrease in air permeability of snow with increase in density.

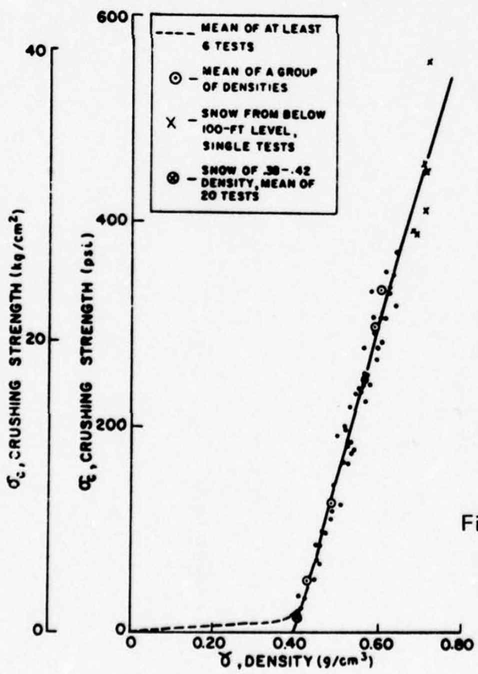


Figure 4-2. Unconfined crushing strength versus density for high-density snow. (Data adjusted to a common snow temperature of -10°C.)

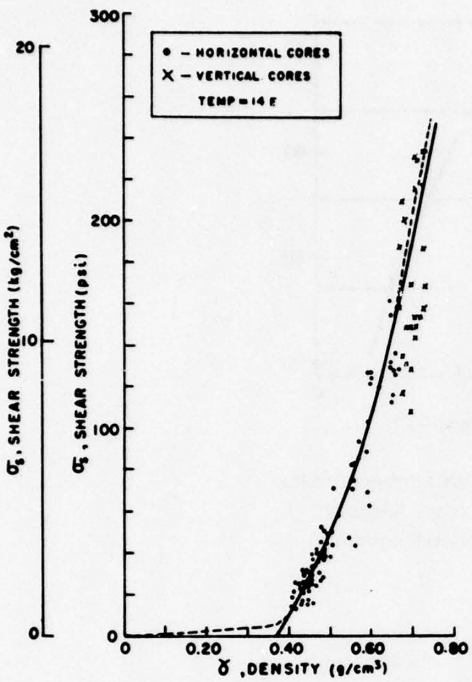


Figure 4-3. Unconfined double shear versus density for high-density snow. (Data adjusted to a common snow temperature of -10°C.)

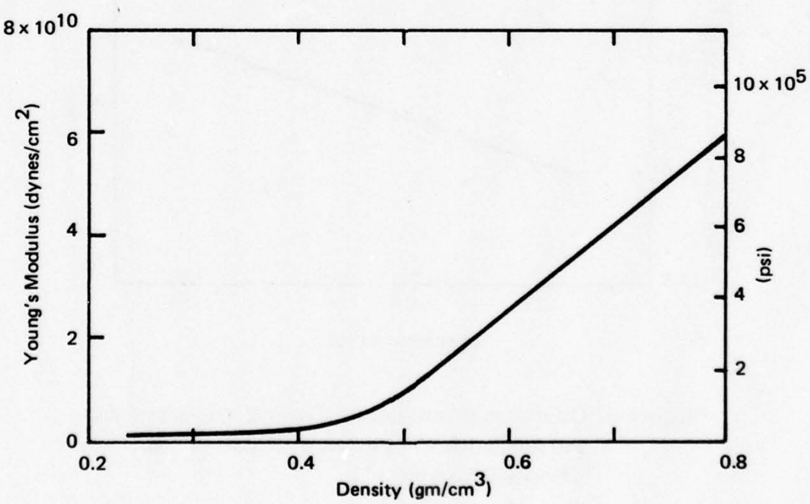


Figure 4-4. Relationship between the dynamic Young's modulus, as measured by the viscoelastic meter, and snow density for a range of Greenland snow type.

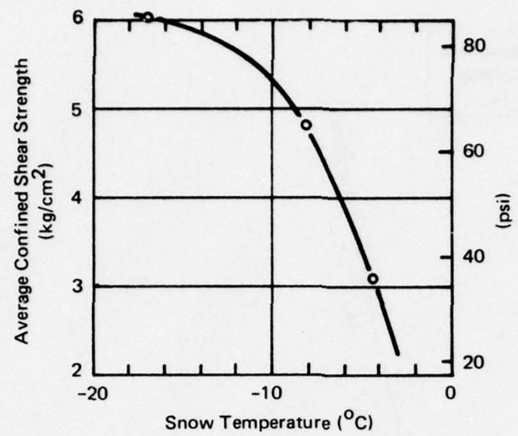


Figure 4-5. Strength versus temperature for compacted snow. (Density approximately 0.6 gm/cm^3.)

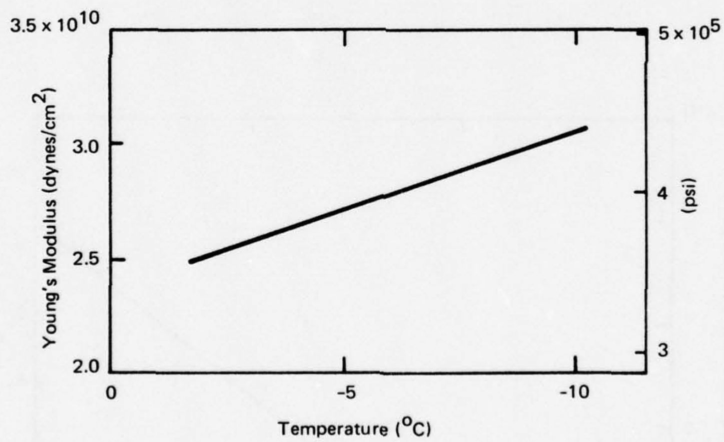


Figure 4-6. Relationship between the dynamic Young's modulus and temperature in the range -2^{o}C to -10^{o}C. (Density 0.63 gm/cm^3.)

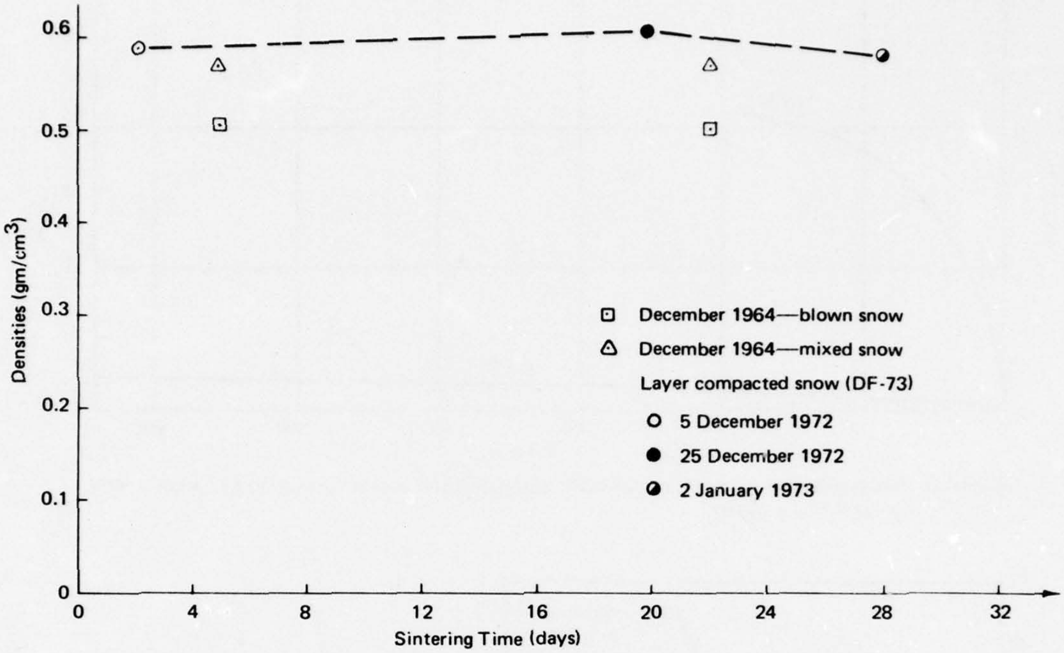


Figure 4-7. Sintering time versus average density for snowblown and pulvimixed roads.

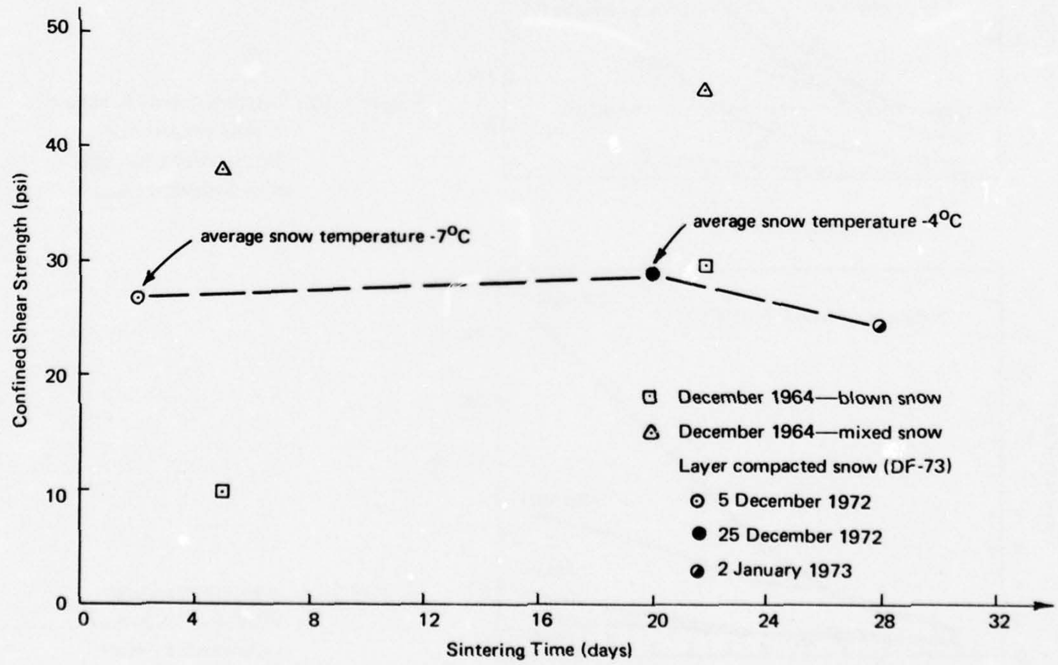


Figure 4-8. Sintering time versus average shear strength for snowblown and pulvimixed roads.

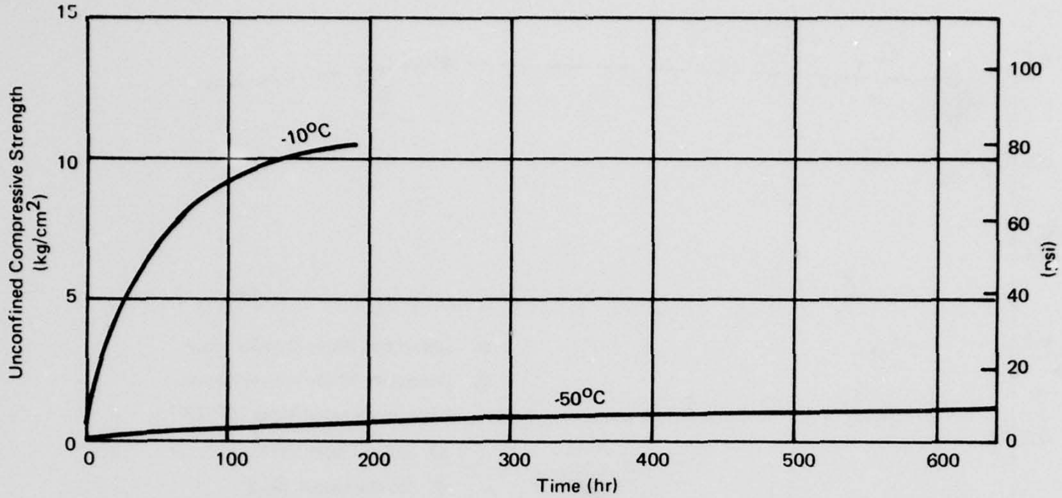


Figure 4-9. Age-hardening curves for artificially disaggregated snows setting up at temperatures of -10°C and -50°C.

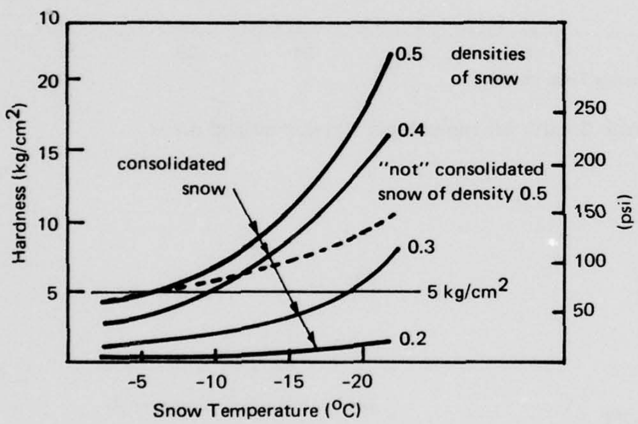


Figure 4-10. Relationship of hardness to temperature for depth-processed snow of various densities.

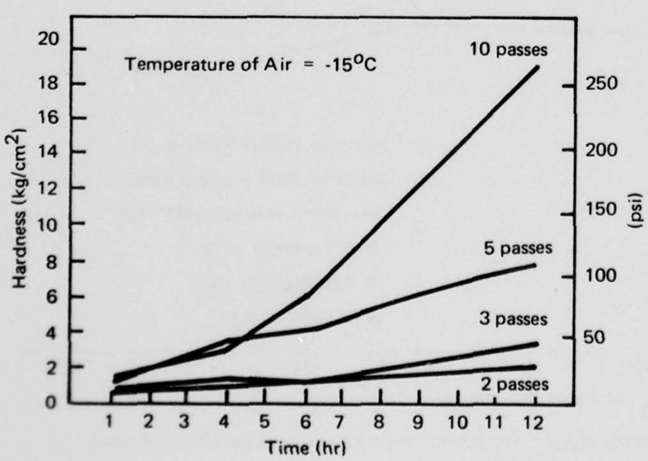


Figure 4-11. Hardening of snow after various sets of consecutive passes of 4.5-ton roller.

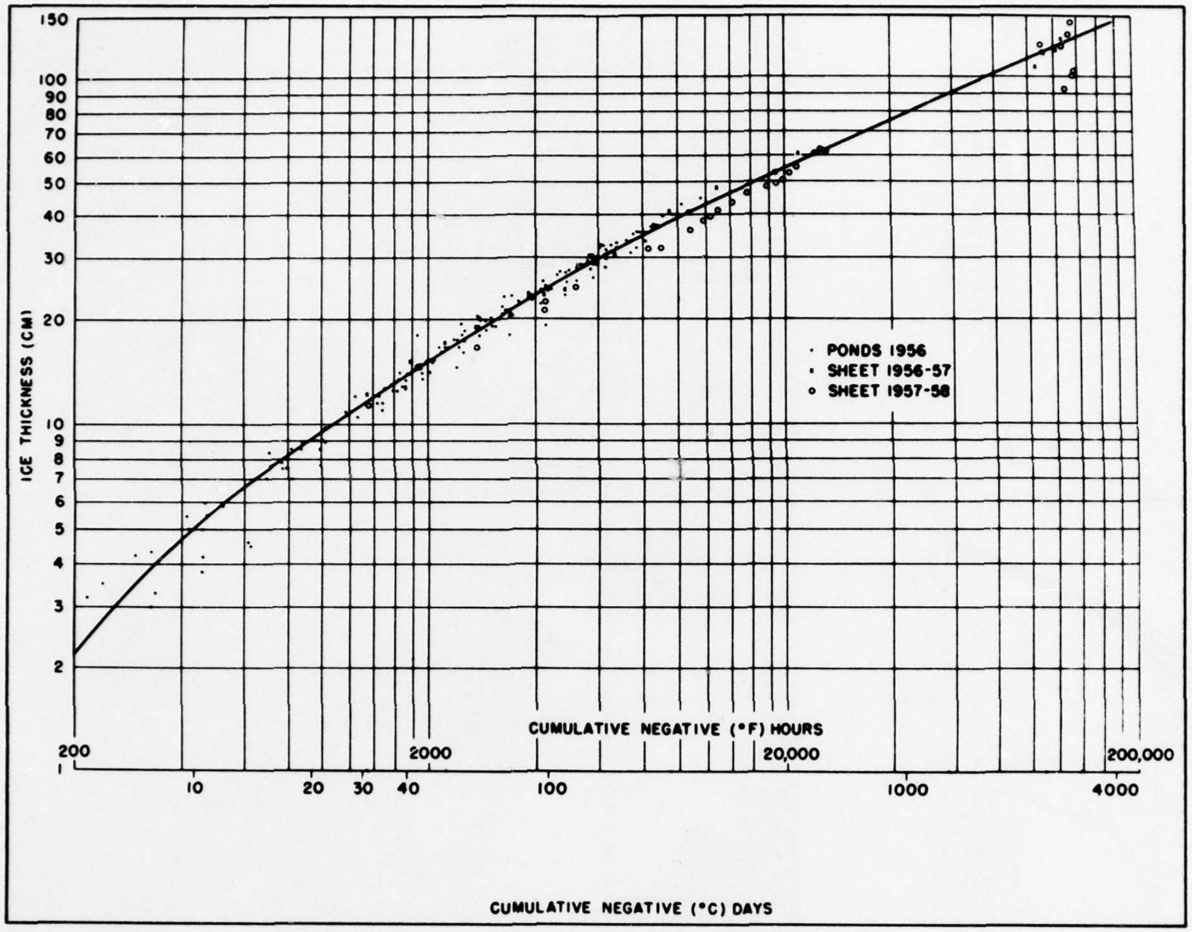


Figure 4-12. Typical growth rate of freshwater ice or sea ice.

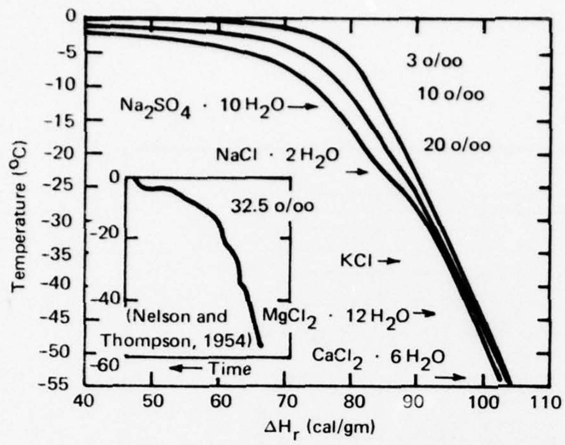


Figure 4-13. Heat required to completely melt and bring to 0°C one gram of sea ice versus initial temperature.

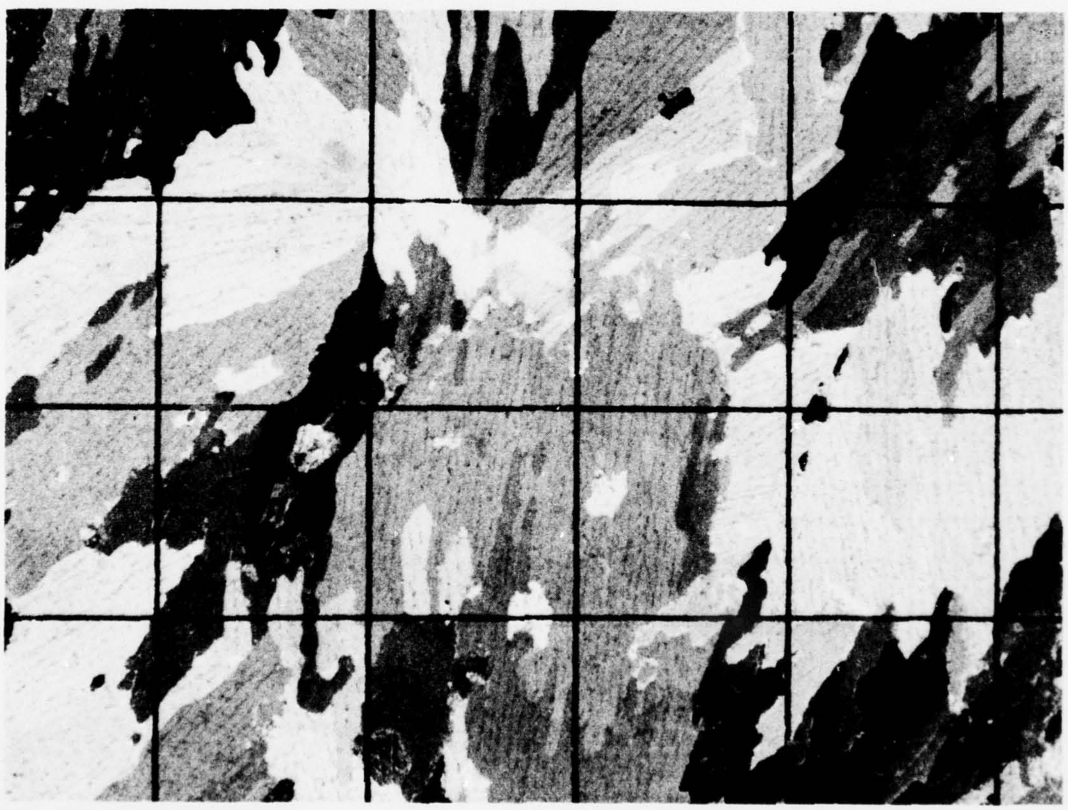
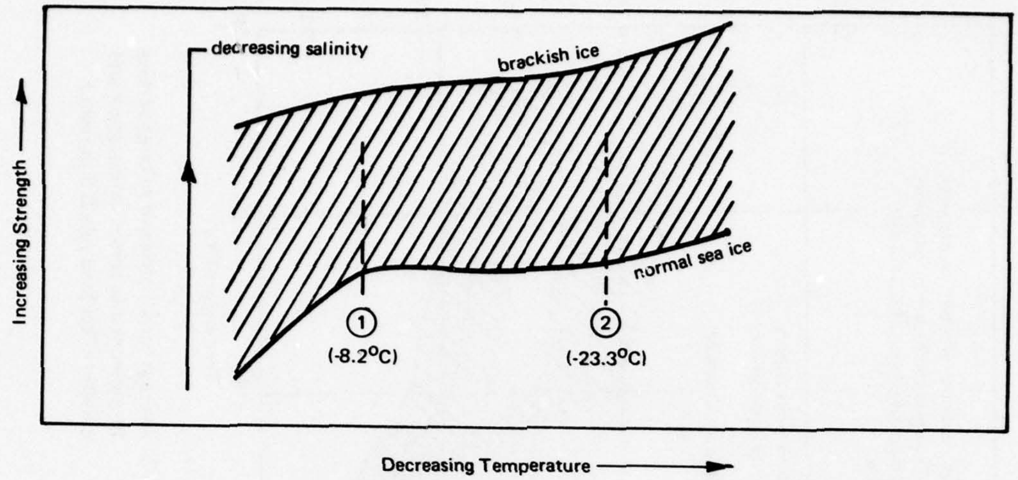


Figure 4-14. Horizontal thin section of natural seawater ice enlarged to show crystal and subcrystal structure. The grid is 1 cm on a side.



Salts in brine concentrate precipitate out of solution

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

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

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

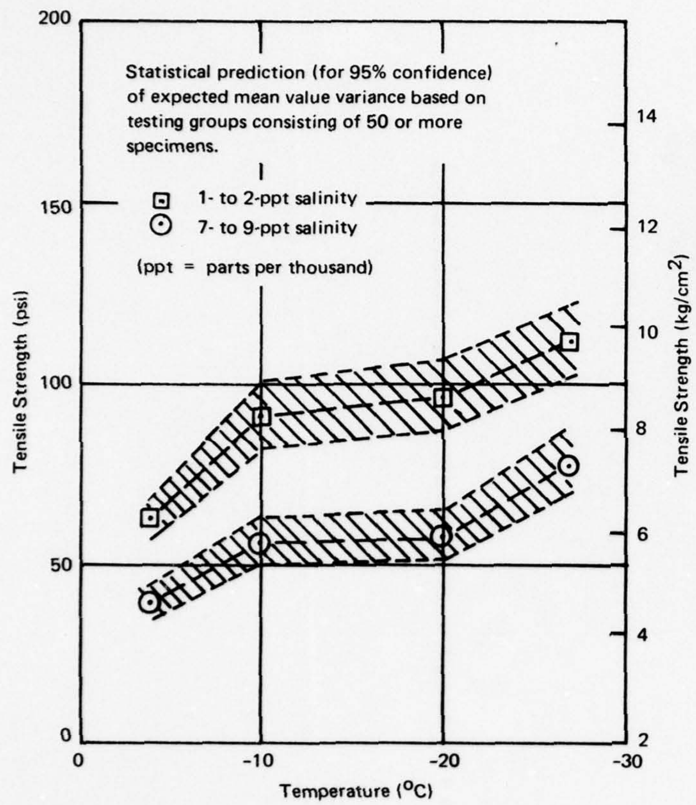


Figure 4-16. Average tensile strength of large horizontal specimen group versus temperature and salinity. (Test load rate 0.5 in./min.)

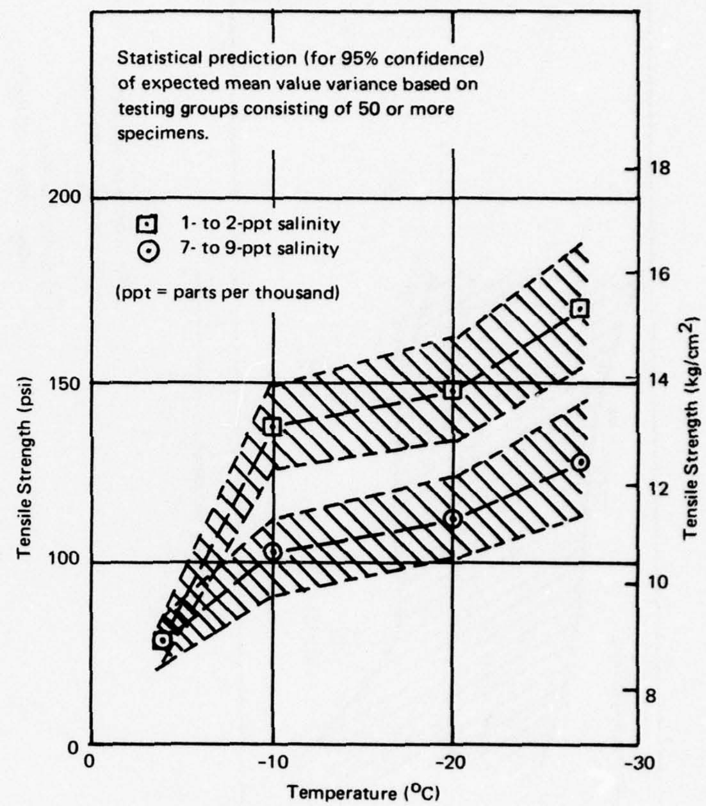


Figure 4-17. Average tensile strength of large vertical specimen group versus temperature and salinity. (Test load rate 0.5 in./min.)

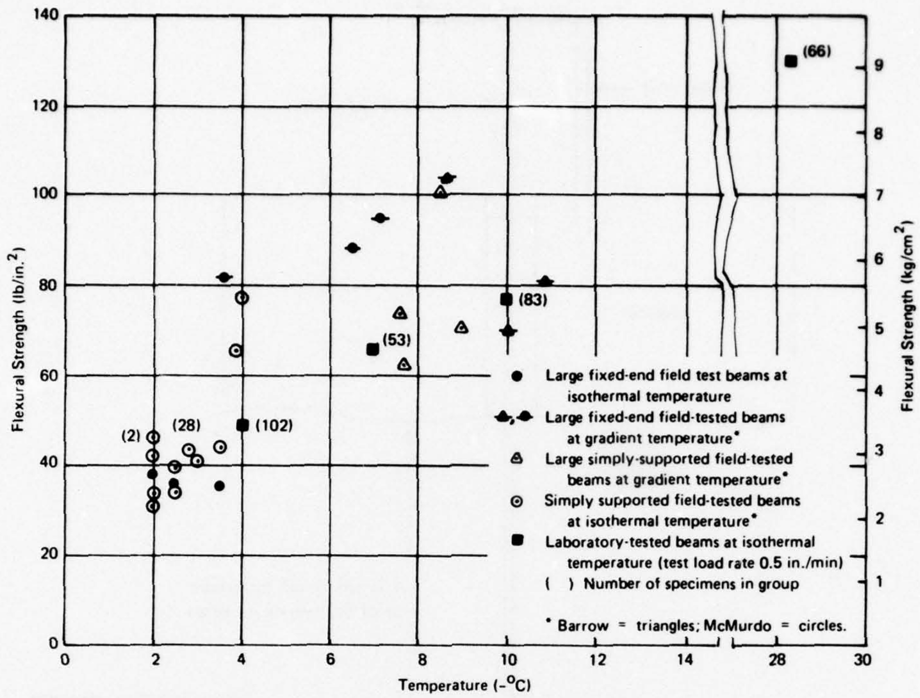


Figure 4-18. Flexural strength (rupture modulus) versus temperature.

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

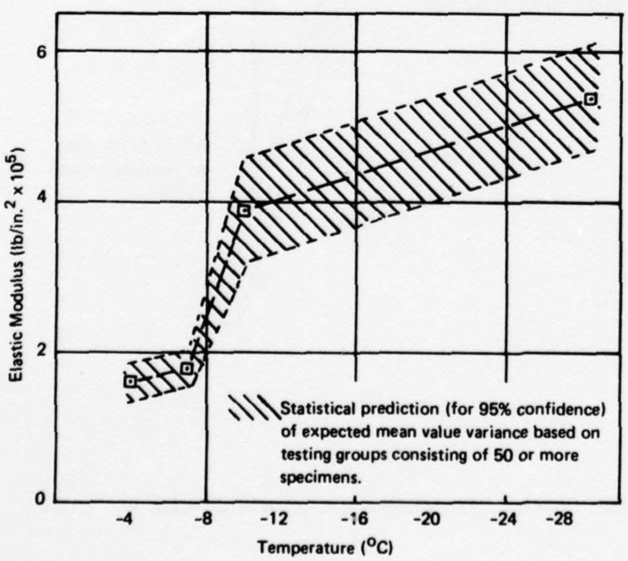


Figure 4-19. Average apparent elastic modulus of large specimen group versus temperature.

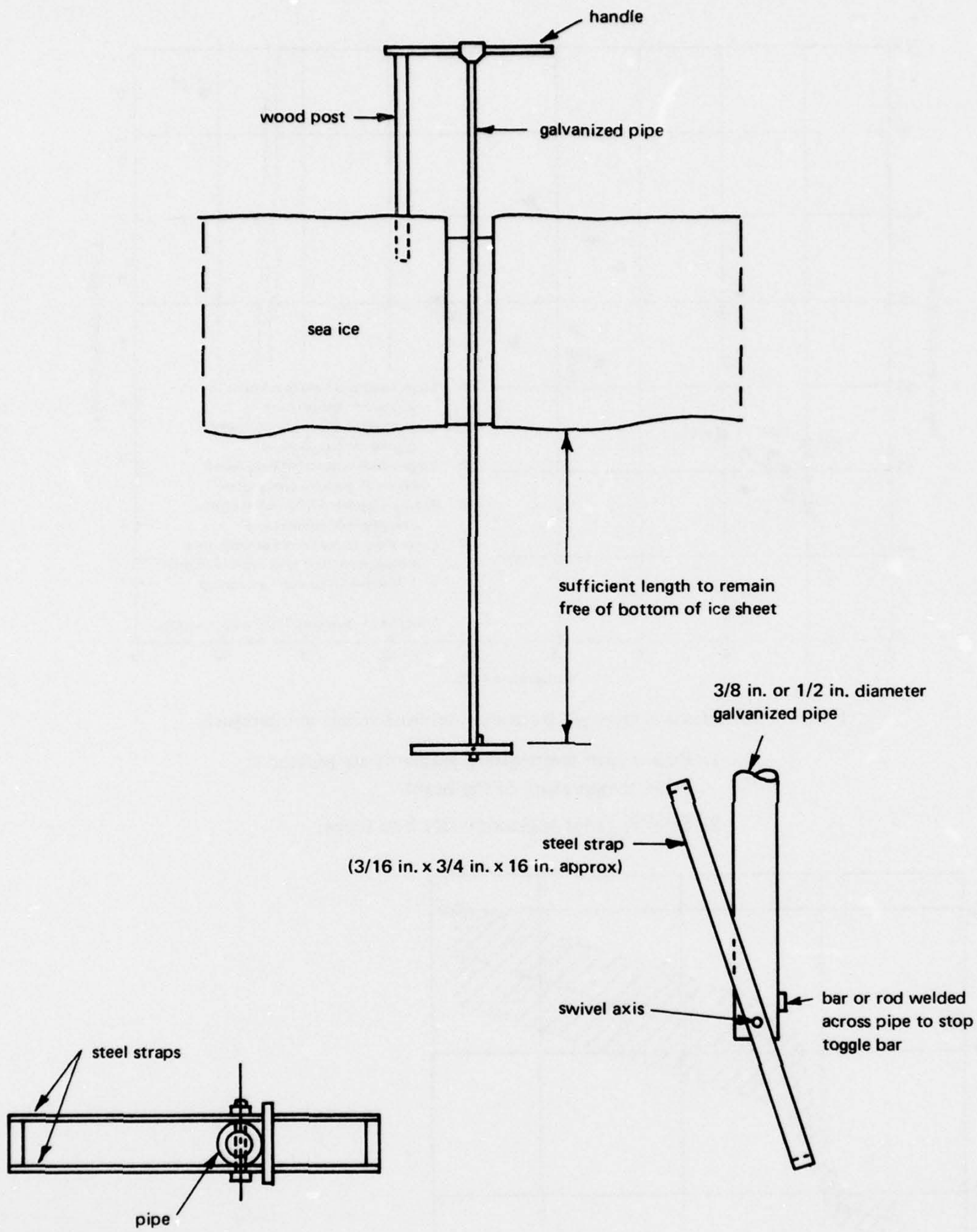


Figure 4-20. Detail of permanent sea-ice thickness station using galvanized iron pipe.

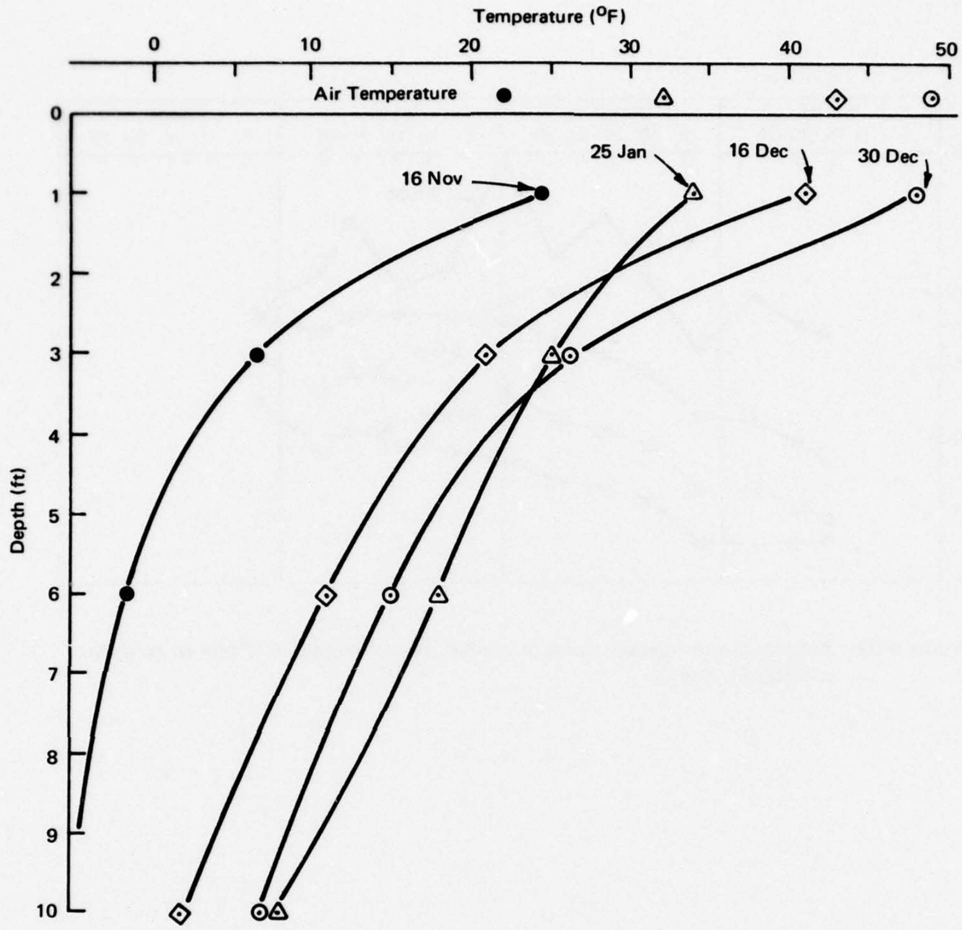


Figure 4-21. Ground temperatures in jointed rock covered with 2 feet of earth fill at McMurdo Station.

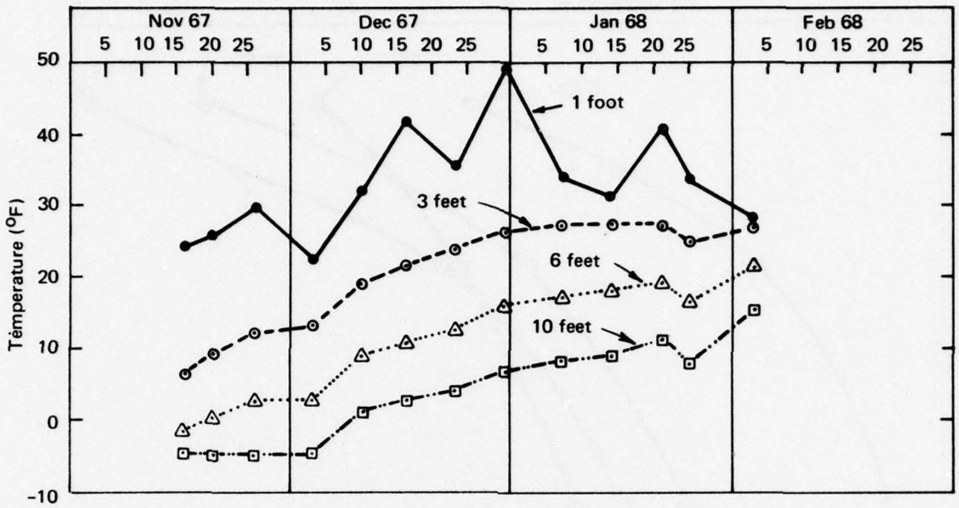


Figure 4-22. Summer ground temperatures in jointed rock covered with 2 feet of earth fill at McMurdo Station.

CHAPTER 5

Chapter 5

BUILDING DESIGN AND MAINTENANCE

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 hanger 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 other than cut and fill methods common 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 that guide is included at the end of this chapter.

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 psychrometric 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.

REFERENCES

1. 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. Port Hueneme, Calif., Dec. 1968.

2.———. Technical Report R-671: Portland Cement Concrete for Antarctica, by J. R. Keeton. Port Hueneme, Calif., April 1970.

3.———. Technical Note N-1248: Building Foundation Study at McMurdo Station, Antarctica, by R. A. Paige. Port Hueneme, Calif., Sept., 1972.

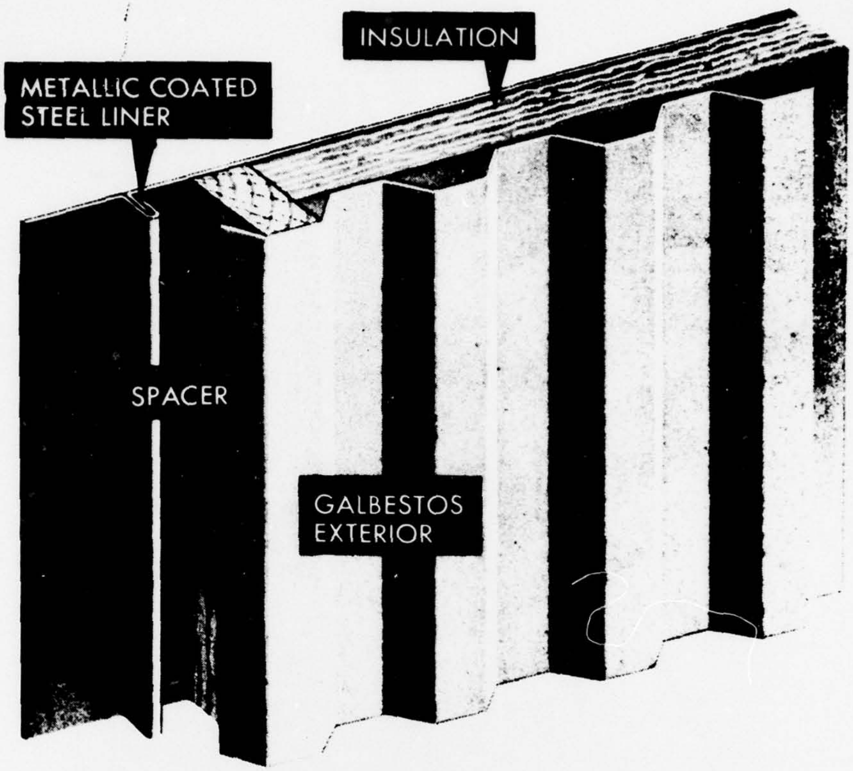


Figure 5-1. Typical building panel in permanent structures at McMurdo Station.

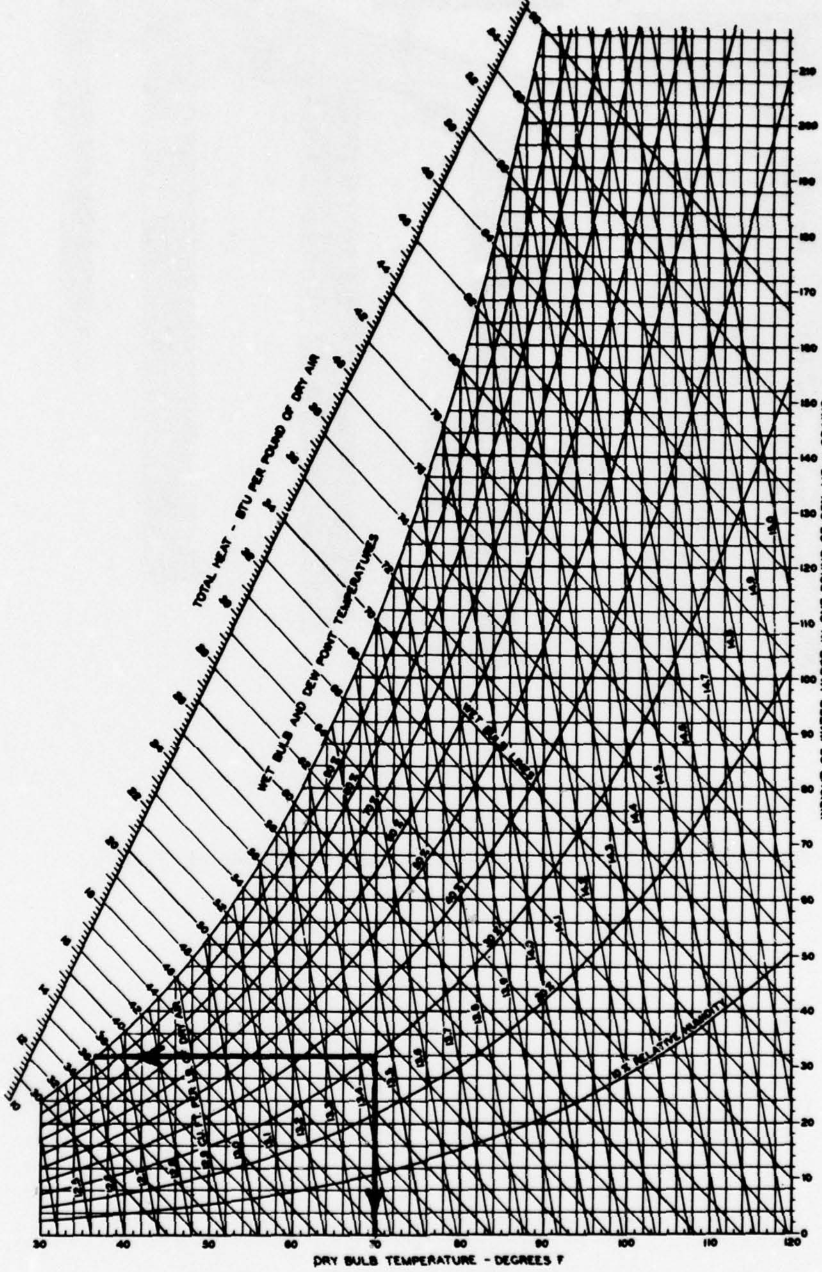


Figure 5-2. Psychometric properties of air at 29.92 inches of mercury absolute pressure. Dew point temperature of 70°F air at 30% relative humidity depicted.

Technical Note N-1060

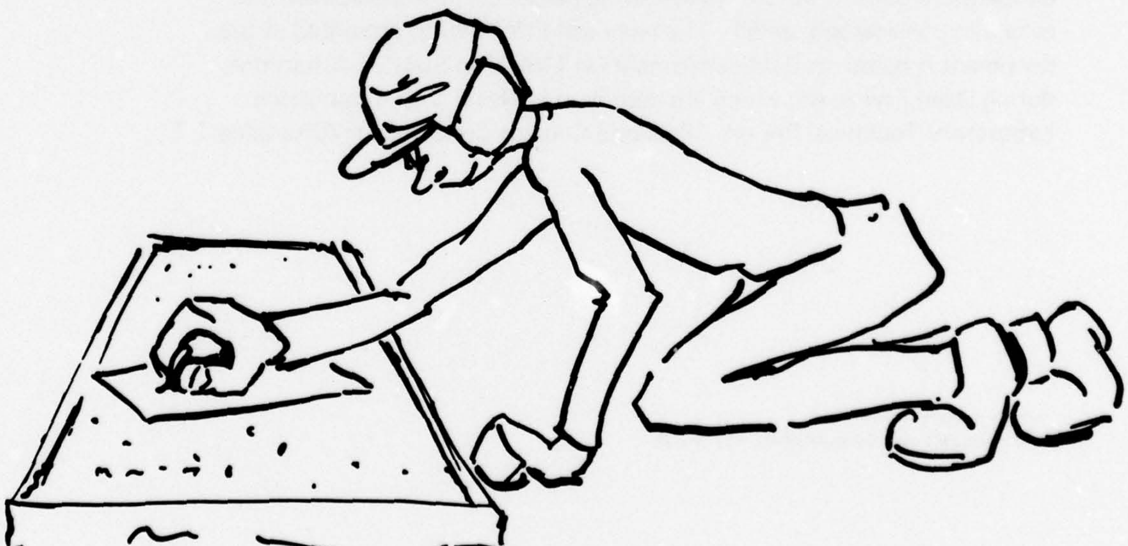
FIELD GUIDE FOR PORTLAND CEMENT CONCRETE CONSTRUCTION IN ANTARCTICA

October 1969

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

by John R. Keeton



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^{O}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.

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°F to 70°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 $0^{\circ}F$ to $220^{\circ}F$

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 stock-piled for later removal to the jobsite.

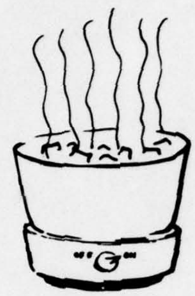
3. The rock and sand should be taken to the jobsite and placed in separate stockpiles.

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.

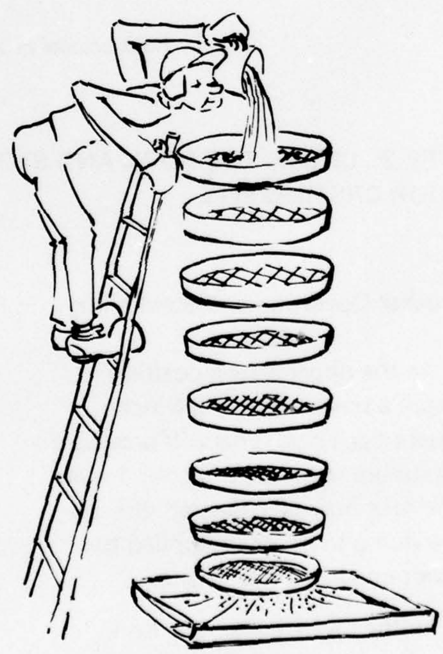


Table 2. Example Sieve Analysis of Rock

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

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

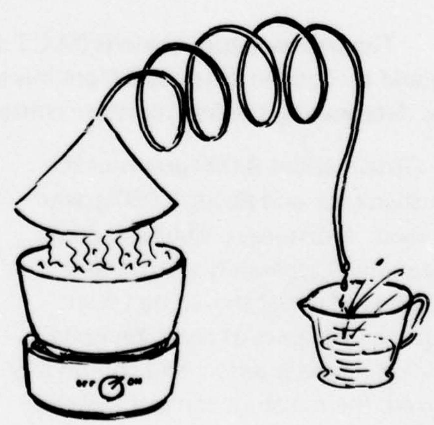
A corresponding adjustment is made for 1 yd^3. Assuming a free M.C. of 8% in the sand and assuming that the sand will be 37% of the total aggregate, the weight of sand for 1 ft^3 is

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

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.

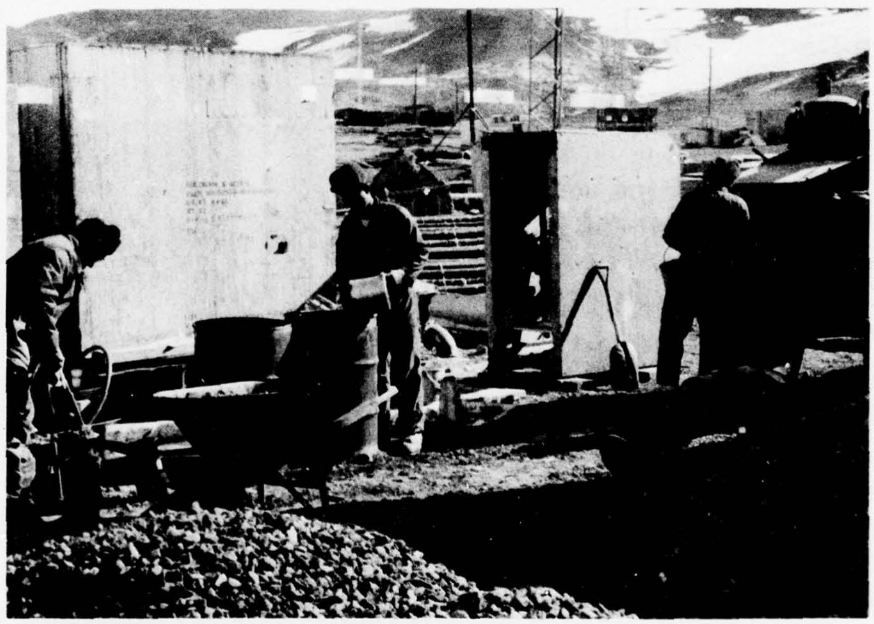
The ingredients can be stored in specially prepared bins or boxes.

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 (°F)	Required Mixing Water Temperature (°F)
15	180*
20	175
25	170
30	160
35	150
40	140

* Water temperature shown will provide a minimum temperature of 60°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.

Table 7. External Heat Requirements for Freshly Cast Concrete

Prevailing Air Temperature Range (°F)	Required Temperature Range for Heated Air (°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

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.

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°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.

BIBLIOGRAPHY

1. Naval Civil Engineering Laboratory. Technical Report: Portland Cement Concrete for Antarctica, by J. R. Keeton. Port Hueneme, Calif. (to be published)

2. American Concrete Institute. ACI Manual of Concrete Practice, Three Volumes, Detroit, Mich., 1968.

3. Portland Cement Association. Design and Control of Concrete Mixtures, 11th Ed., Skokie, Ill., 1968.

CHAPTER 6

Chapter 6

UTILITY DISTRIBUTION SYSTEMS

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 subsidance 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.

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.

Figure 6-1. Freshwater line as seen from Observation Hill.

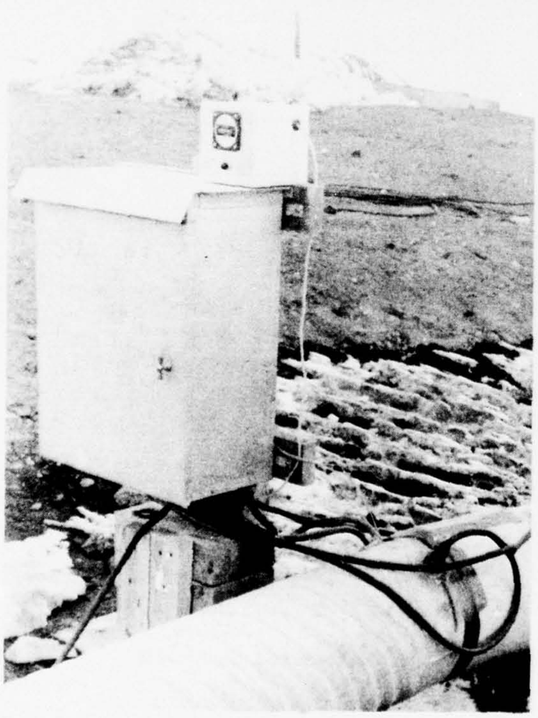


Figure 6-2. Typical corrugated-steel-jacketed piping used in first liquid distribution system.

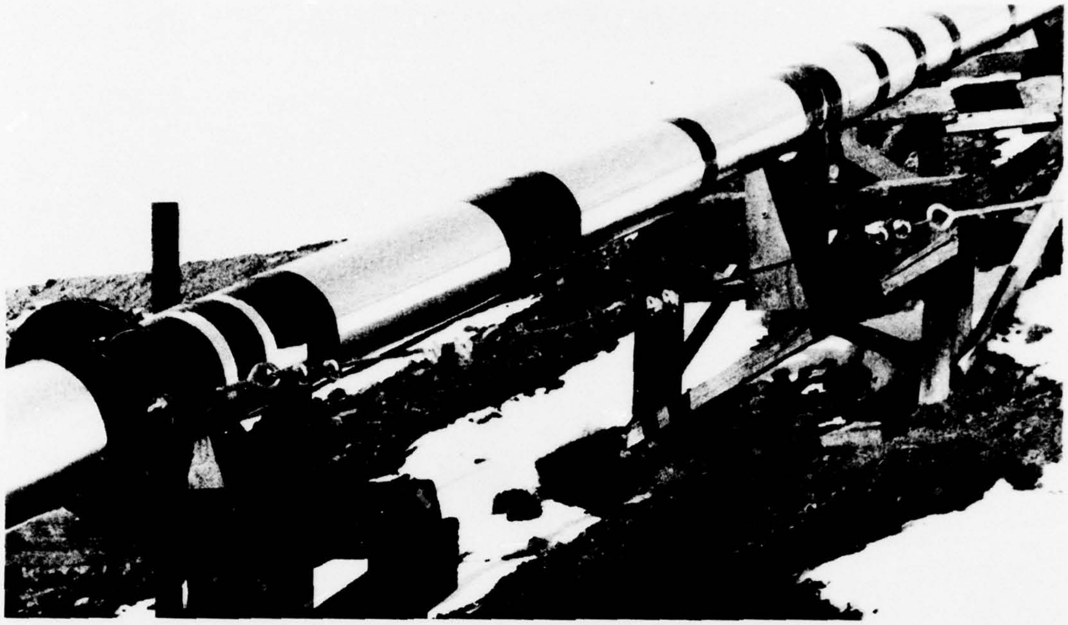


Figure 6-3. Waterline with 3-inch fiberglass insulation and heavy aluminum foil and kraft-paper jacketing.

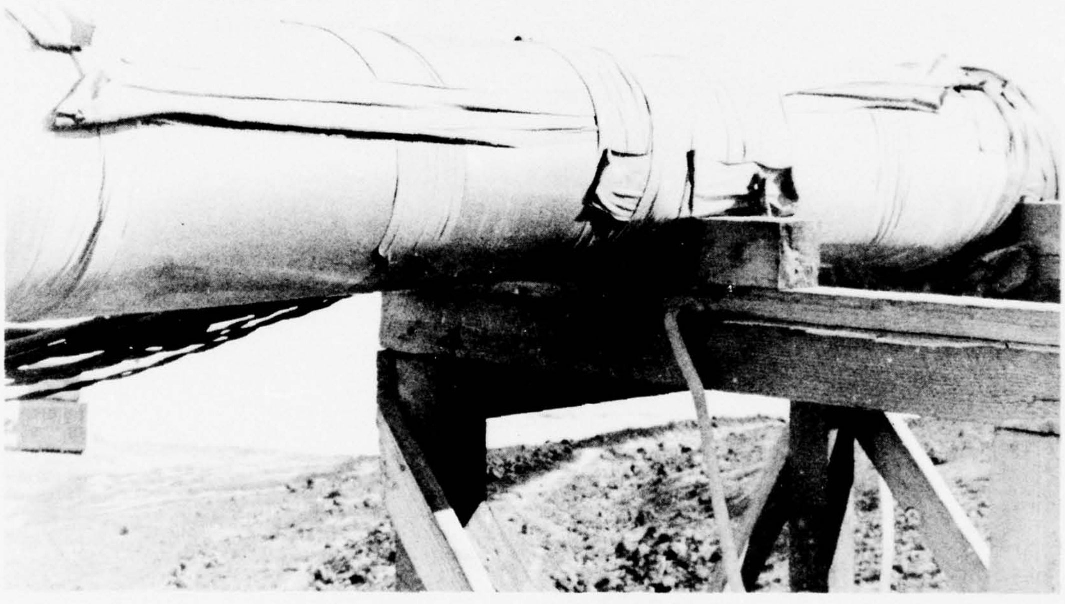


Figure 6-4. Polyethylene tape peeling from aluminum-jacketed sewerline after 1 year.

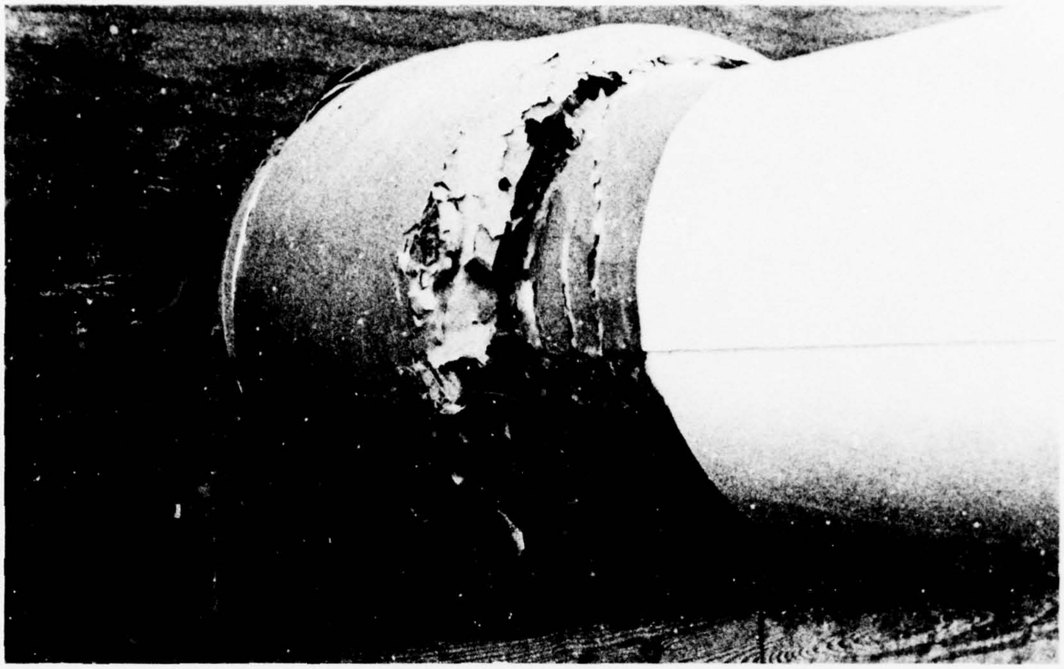


Figure 6-5. Weathering and splitting of polyethylene tape over pipe flange insulation after 1 year of service.

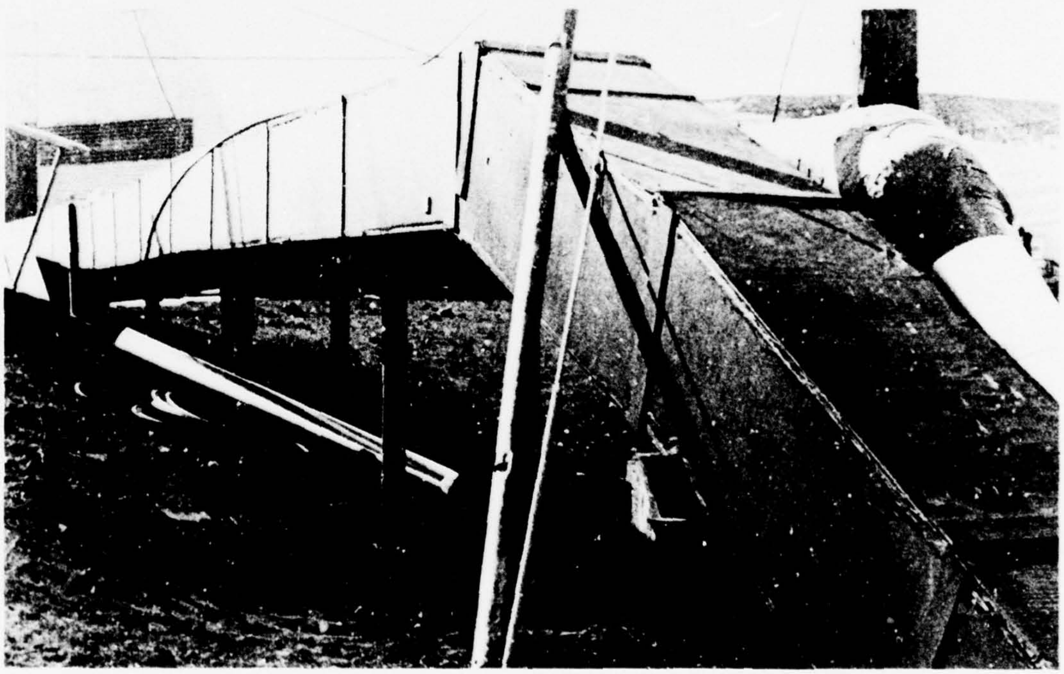


Figure 6-6. Plywood enclosure for fiberglass-insulated sewerline.

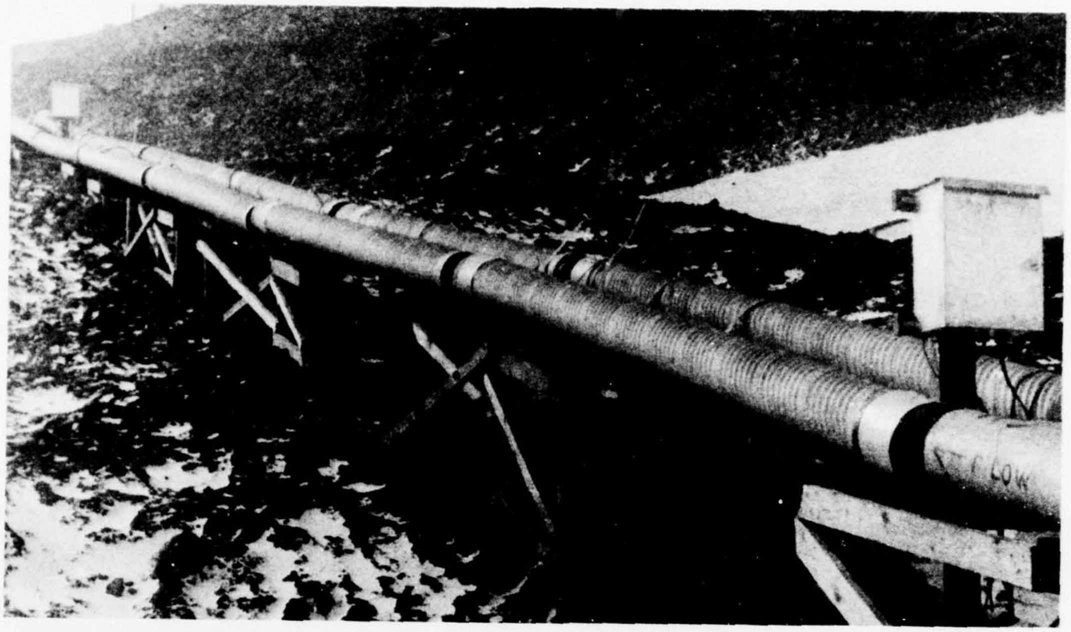


Figure 6-7. Typical wooden cribbing supporting piping system. Piping is original saltwater and brine-return lines.

Figure 6-8. Loss of pipeline foundation support caused by ablation of ice beneath dirt.

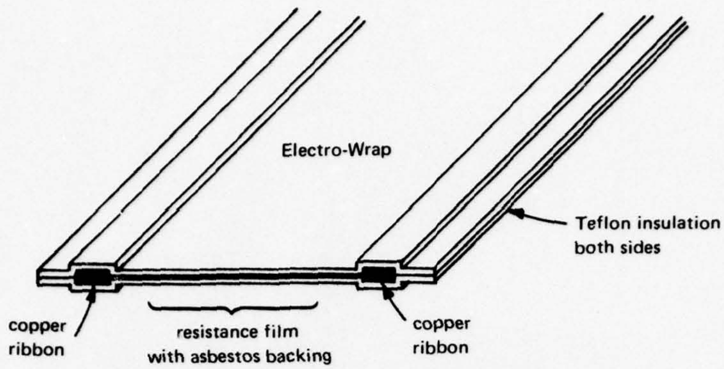


Figure 6-9. Construction of 8- and 24-watt-per-foot Electro-Wrap heat-tracing tape.

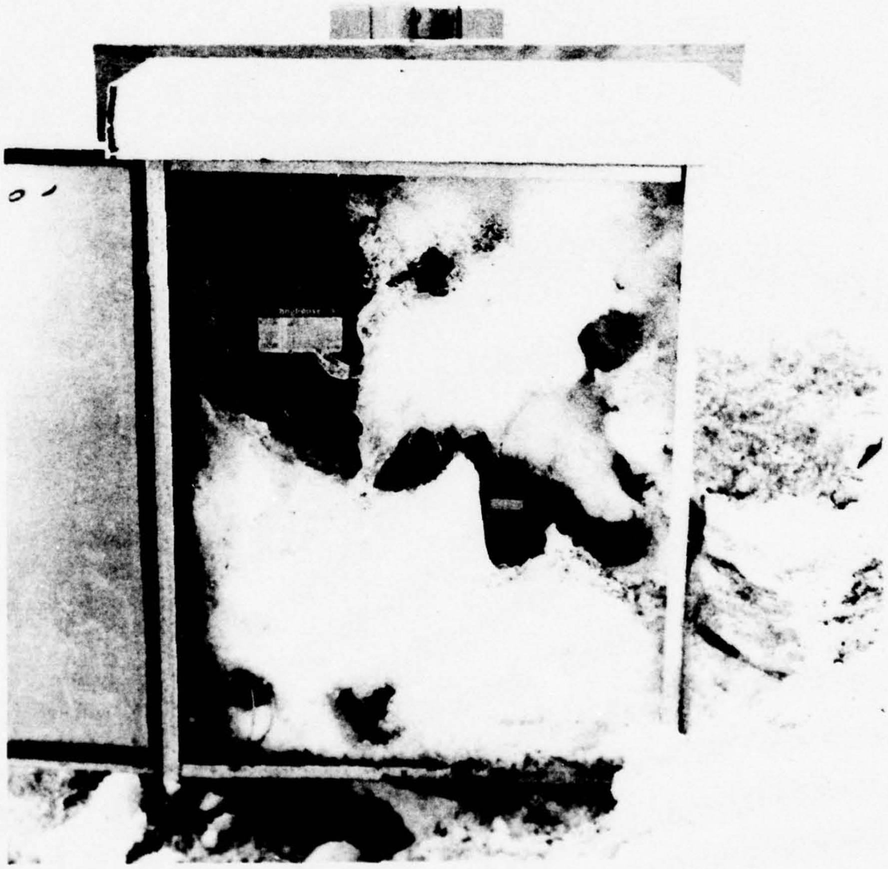


Figure 6-10. Wind-driven snow accumulation inside electrical distribution panel for waterline and sewerline heat tracing.

CHAPTER 7

Chapter 7

AIRFIELDS AND ROADS

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 centerline 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°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 considered 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 Appendix A of this chapter (NCEL Techdata Sheet 73-7).

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 contained in Appendix B for this chapter.

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.

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; this work is detailed in Reference 1. 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.

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.

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.

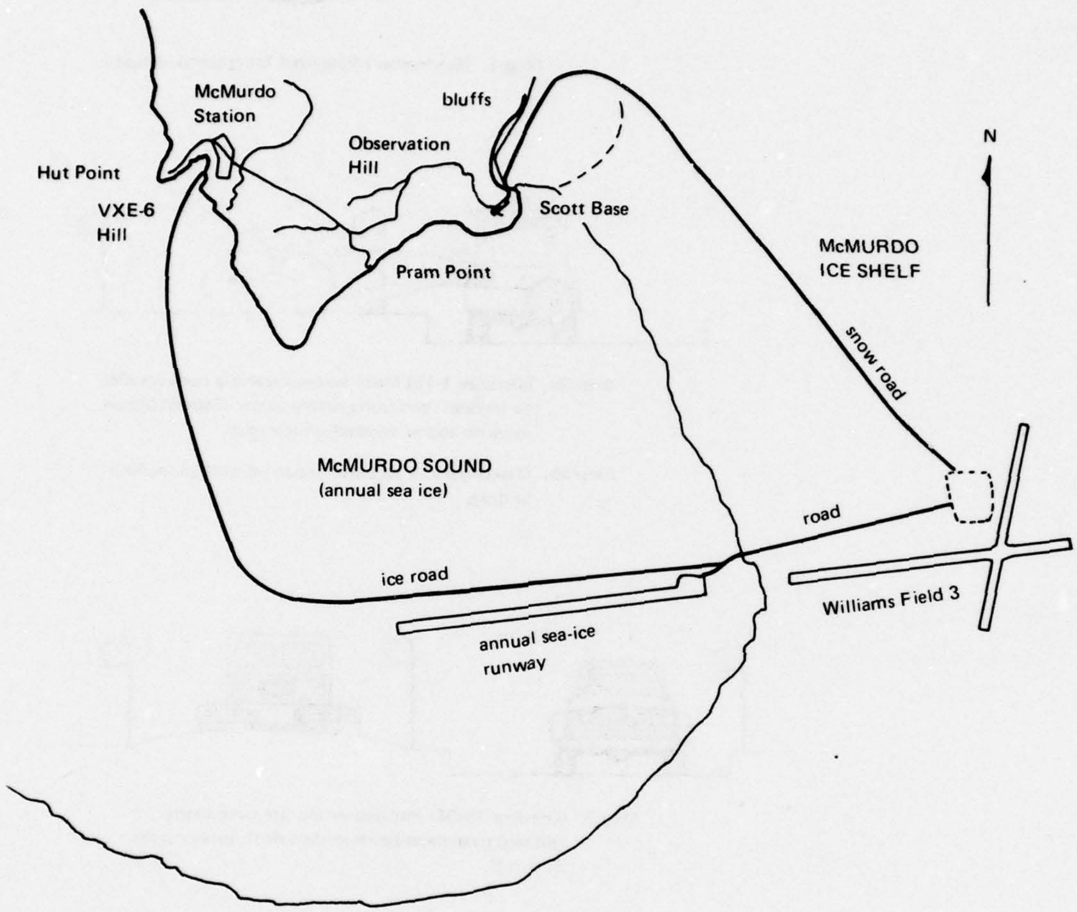
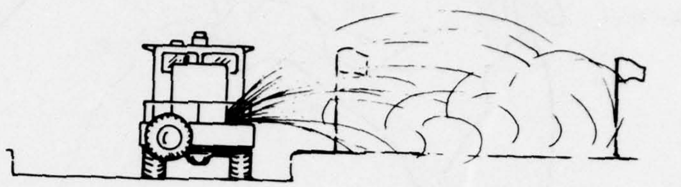


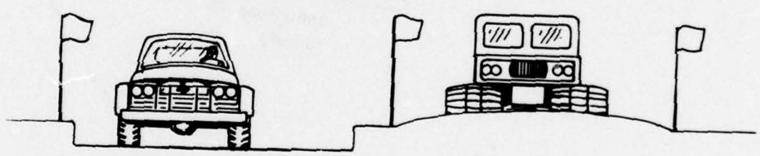
Figure 7-1. Ice, snow, and land roads at McMurdo Station.

Step 1. (September) Flag road for tracked vehicles.

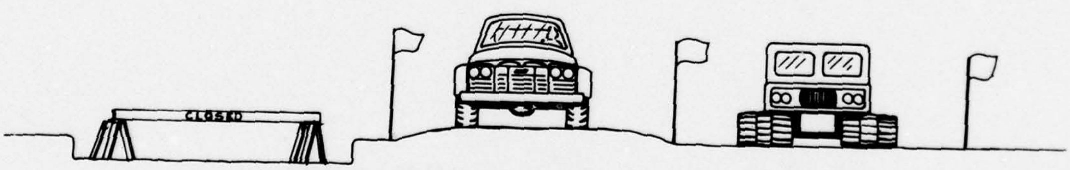


Step 2a. (October 1-15) Make wheeled-vehicle road parallel to tracked road using rotary plow. Deposit blown snow on top of tracked-vehicle road.

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.

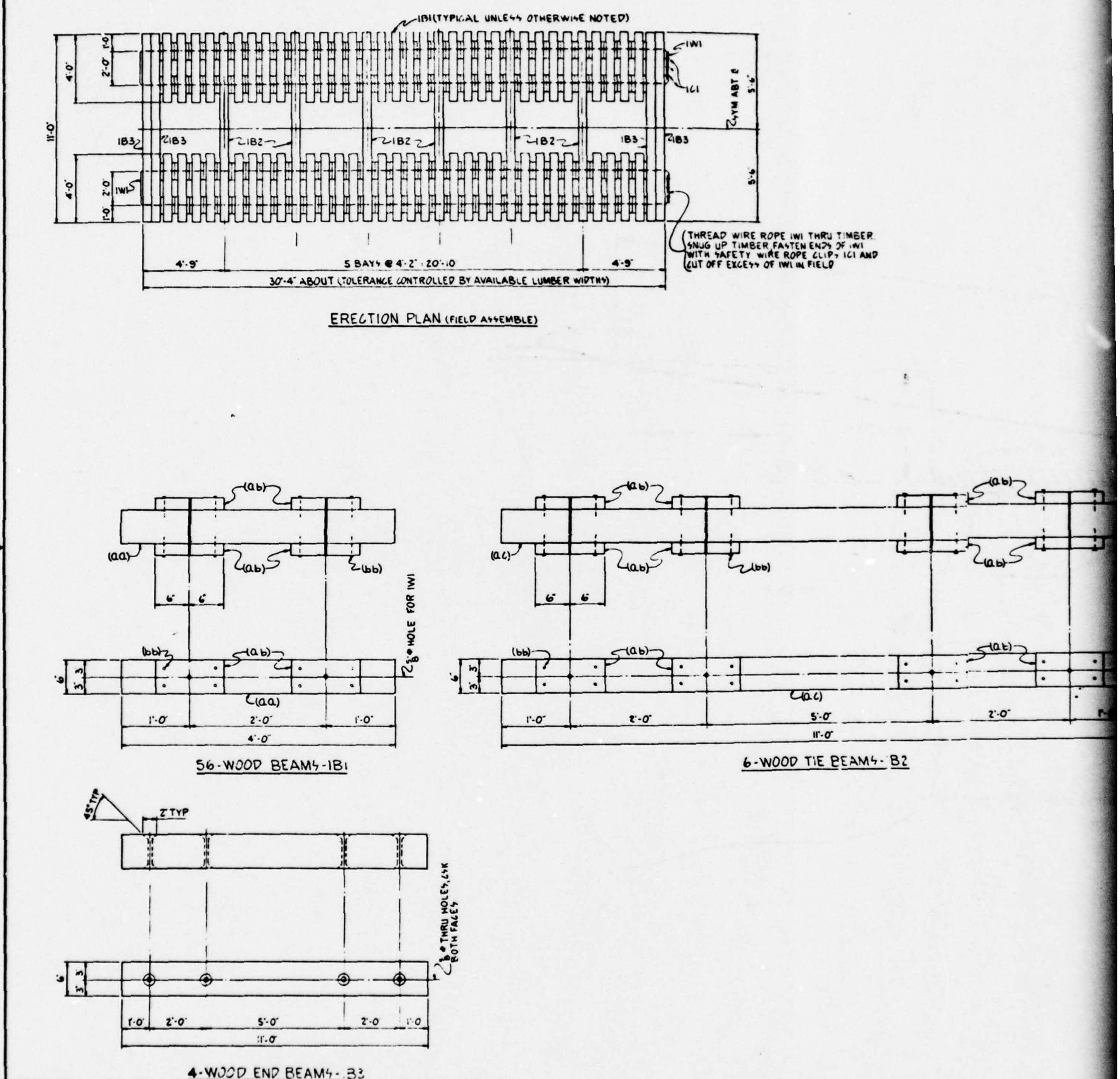
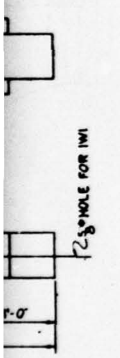


Figure 7-3. Flexible timber ramp.



NOTES

1. ALL LUMBER TO BE DOUGLAS FIR CONSTRUCTION GRADE, ROUGH SAWN.

MARK	NO REQ'D	SIZE	LENGTH FT	LENGTH IN	REMARKS
	2	80FT, 5/8 6×25 FILLER WIRE, IWRC IMPROVED PLOW STEEL & GALVANIZED			
2-TIE CABLES-1W1 (NOT DETAILED)					
	6	WIRE ROPE SAFETY CLIPS FOR 5/8" Ø WIRE ROPE, GALVANIZED			
6-CLIPS-1C1 (NOT DETAILED)					
	4	6×6	11	0	
4-WOOD END BEAMS-1B3					
bb		NAILS BILLED UNDER (1B1)			
ac	6	6×6	11	0	
ab	48	2×6	1	0	
6-WOOD TIE BEAMS-1B2					
bb	25LB	16d COMMON STEEL WIRE NAILS, GALVANIZED			
ab	224	2×6	1	0	
aa	56	6×6	4	0	
56-WOOD BEAMS-1B1					

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN FEET AND/OR INCHES
TOLERANCES:
FRACTIONS ± 1/16 & NOTED
DECIMALS ±
ANGLES ± 1°

PROJ NO 61-017
NCEL DWG NO. 73-15-1F
DES F BOYER | DR M STERN
CHK K Mack | SUPV
DESIGN DIV DIR
DEPT HEAD
SATISFACTORY TO
POLAR PGM
APPROVED — DATE 4/6/73
COMMANDING OFFICER
APPROVED — DATE
FOR COMMANDER, NAVFAC

DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA

MCMURDO TRANSITION RAMPS
FLEXIBLE TIMBER RAMP
ERECTION PLAN & DETAILS

SIZE F | CODE IDENT NO 80091 | NAVFAC DRAWING NO. 943603
CONSTR CONTR NO
SCALE NONE | SPEC | SHEET 1 OF 2

2

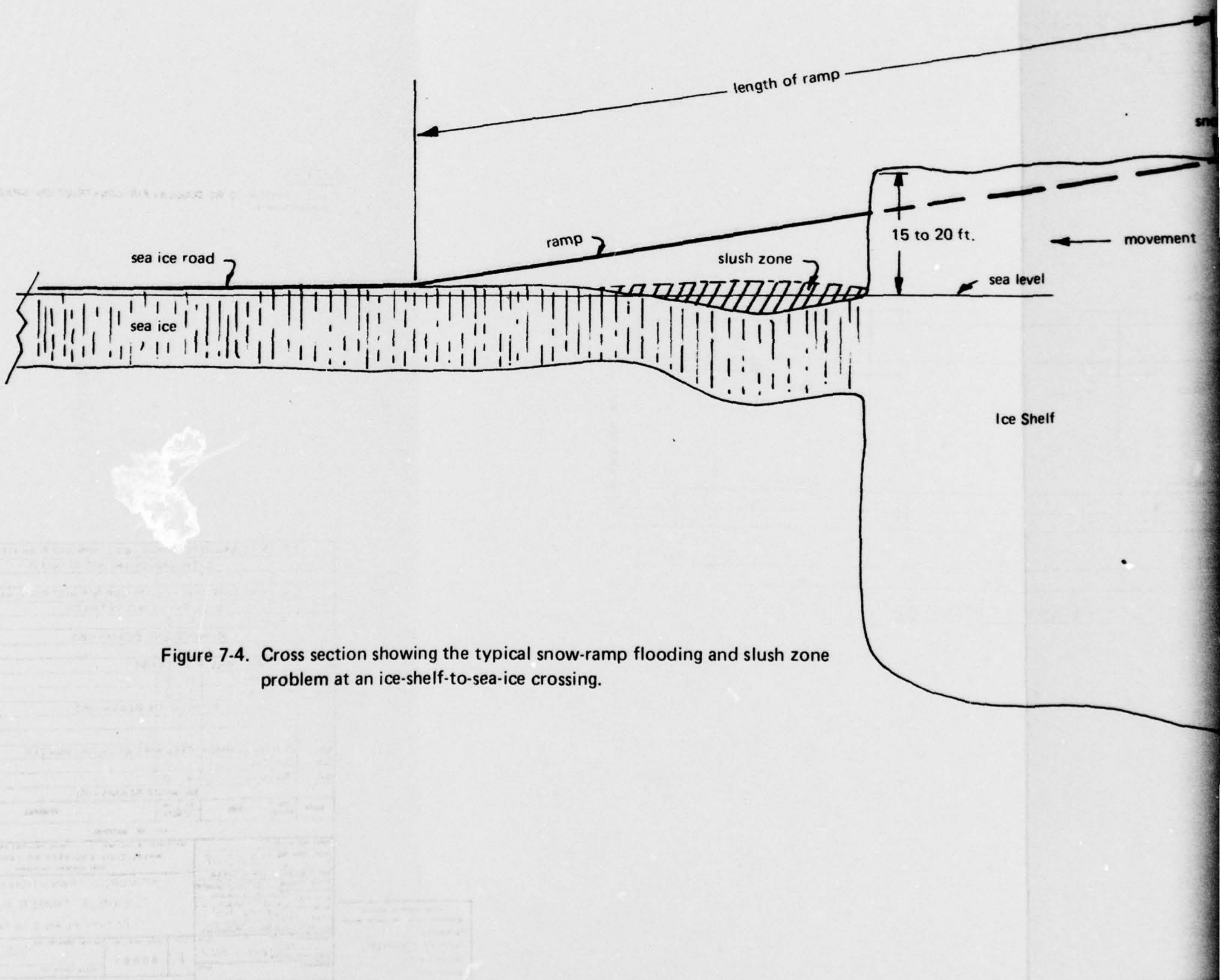
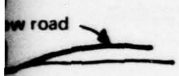


Figure 7-4. Cross section showing the typical snow-ramp flooding and slush zone problem at an ice-shelf-to-sea-ice crossing.


w road

Appendix A

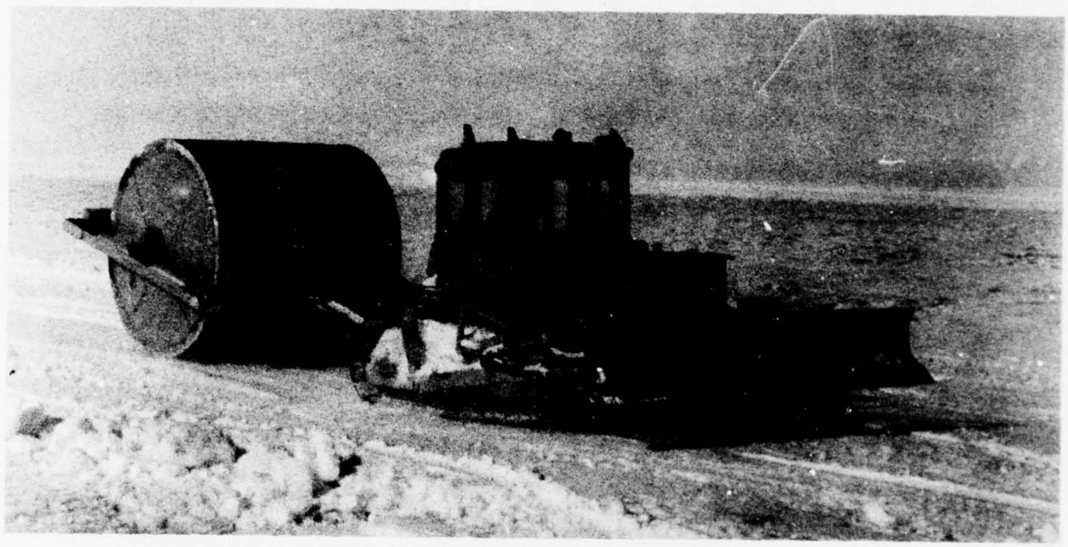
COPY OF NCEL TECHDATA SHEET 73-7

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

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.

Appendix B

Technical Report

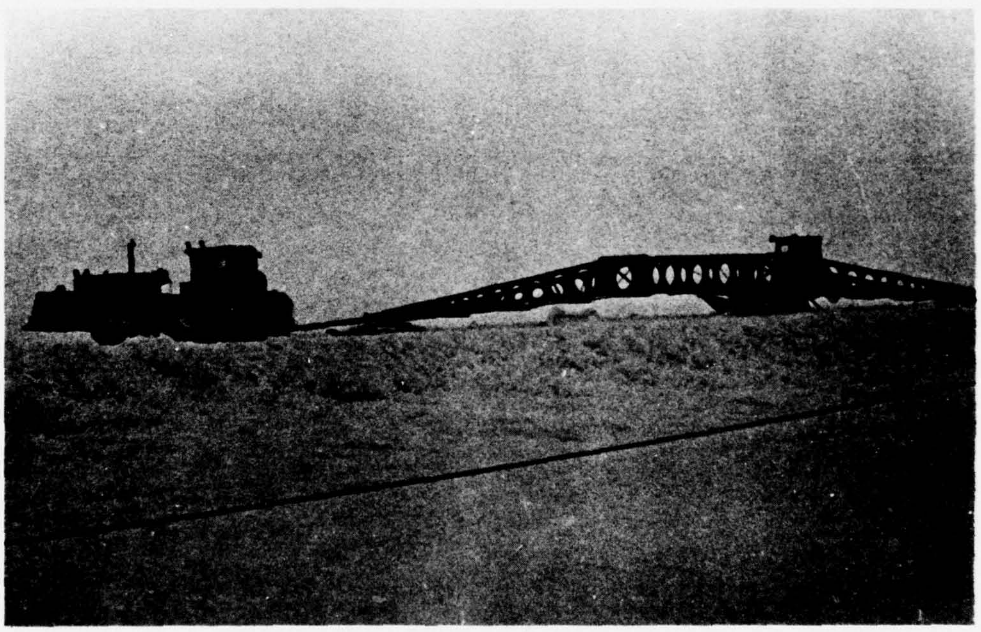
R 819

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

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TR-819	2. GOVT ACCESSION NO. DN744029	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SNOW ROAD CONSTRUCTION BY LAYERED COMPACTION—CONSTRUCTION AND MAINTENANCE GUIDE		5. TYPE OF REPORT & PERIOD COVERED Not final; Jul 1966 to Jan 1973. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. L. Barthelemy		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Civil Engineering Laboratory Naval Construction Battalion Center Port Hueneme, CA 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62759N; YF52.555.001.01.001
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, VA 22332		12. REPORT DATE April 1975 13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

layered-compaction, elevated snow roads, rubber-tired vehicles, transition areas

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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

continued

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20. Continued

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.

Library Card

Civil Engineering Laboratory
SNOW ROAD CONSTRUCTION BY LAYERED COMPACTION—CONSTRUCTION AND MAINTENANCE GUIDE (Not final), by J. L. Barthelemy

TR-819 21 p. illus April 1975 Unclassified

1. Layered-compaction 2. Elevated snow roads I. YF52.555.001.01.001

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.

CONTENTS

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

---

* *Naval Civil Engineering Laboratory. Snow Road Construction and Maintenance Manual,* by W. H. Beard. Port Hueneme, CA, Jan 1972.

** Low ground pressure tracks.

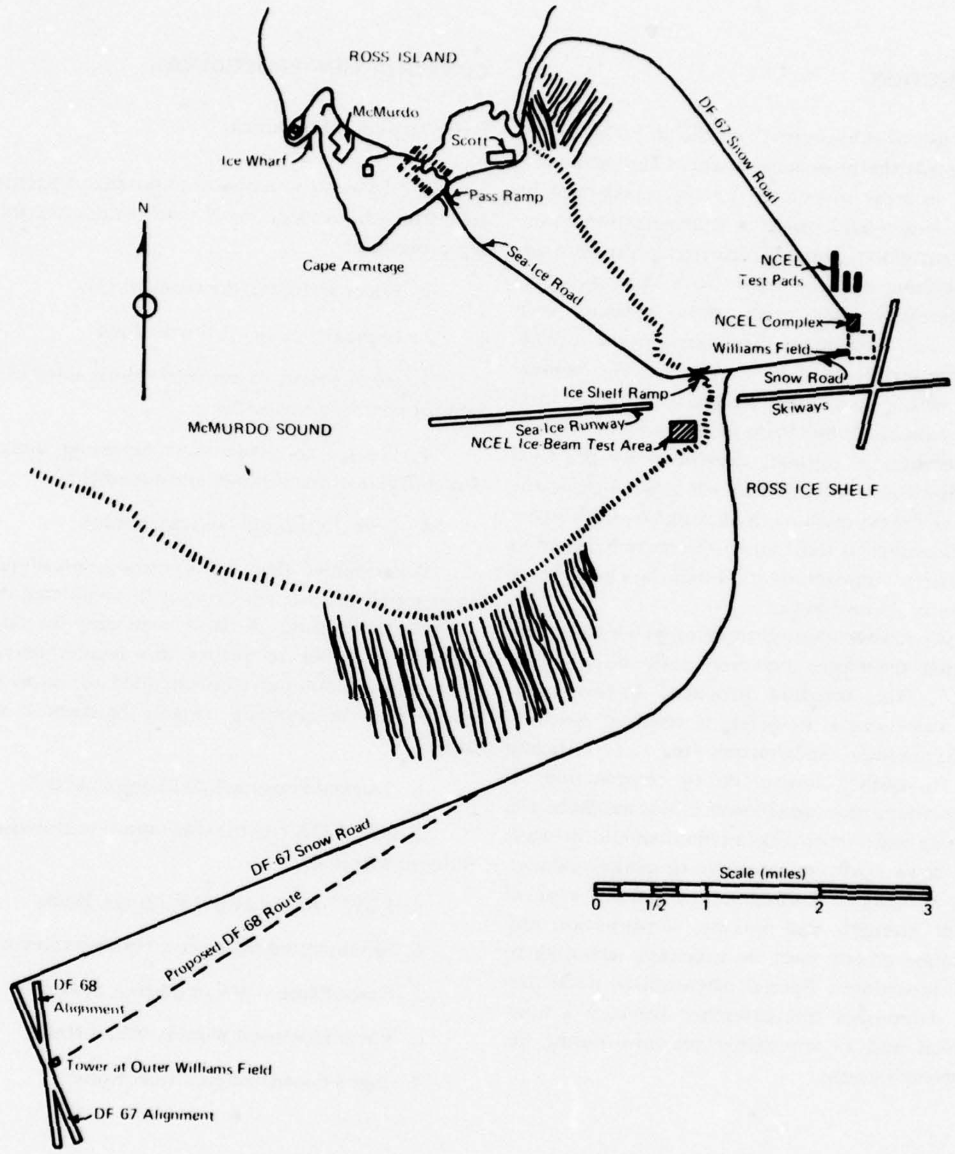


Figure 1. Location of snow roads in McMurdo/Williams Field area.

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.

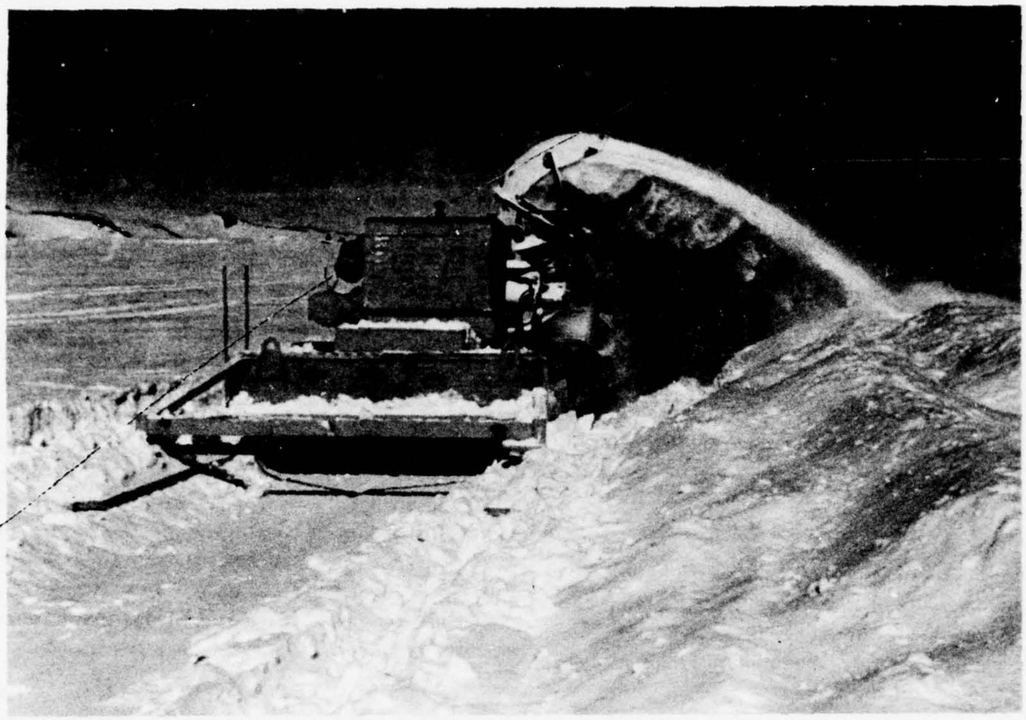


Figure 2. Rotary snowplow used to elevate snow roads.

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

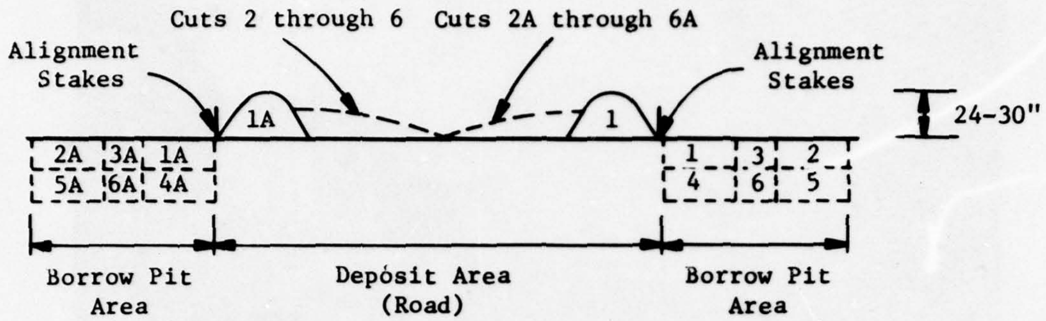


Figure 3. Cross section showing sequence of passes for elevating snow roads with a snowblower.

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.

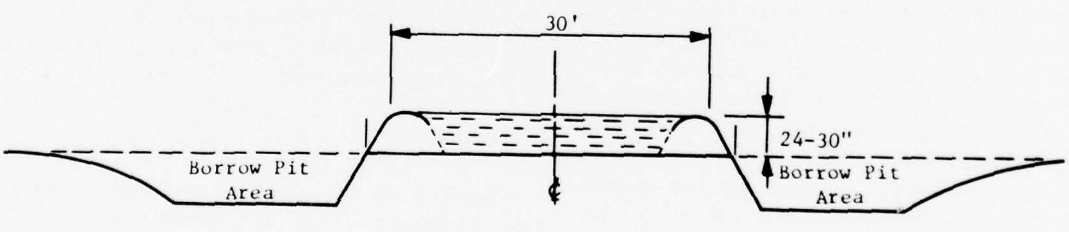


Figure 5. Typical cross section showing finished road.

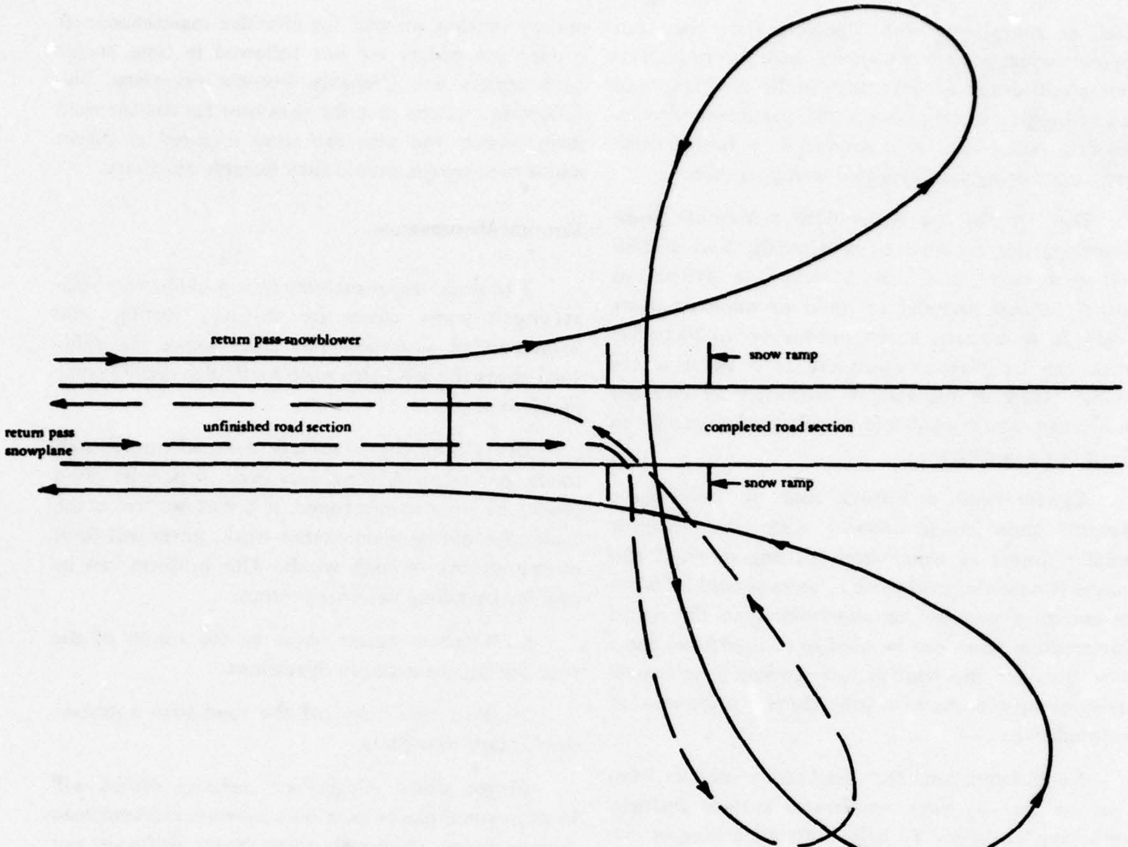


Figure 6. Turnaround scheme for repositioning snowblower and snowplane.

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.

BIBLIOGRAPHY

Naval Civil Engineering Laboratory. Technical Report R-107: Snow Compaction Equipment – Snow Rollers, by J. B. Camm. Port Hueneme, CA, Jan 1961.

____. Technical Report R-109: Snow Compaction Equipment – Snow Drags, by J. B. Camm. Port Hueneme, CA, Oct 1960.

____ Technical Report R-110: Snow Compaction Equipment – Snow Planes, by E. H. Moser. Port Hueneme, CA, Feb 1961.

____. Technical Report R-487: Snow-Compaction Equipment Model 36/42 Snow Mixer, by G. E. Sherwood and R. W. Hansen. Port Hueneme, CA, Oct 1966.

____. Technical Note N-1305: Layered Compaction of Snow Blower Processed Snow, by M. W. Thomas and K. D. Vaudrey. Port Hueneme, CA, Aug 1973.

____. Snow Road Construction and Maintenance Manual, by W. H. Beard. Port Hueneme, CA, Jan 1972. (This publication provides guidelines for producing snow roads using the process of pulvimixing.)

APPENDIX

This appendix presents a brief review of equipment used by CEL to construct snow roads by the method of layered compaction. The enclosed Techdata sheets summarize the important design and performance characteristics of each piece of equipment.

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).

- 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.

NCEL Contact: W. H. Beard, L61 (Polar Division); tel: autovon—360-4675
comm—(805) 982-4675

April 1973 73-14

Naval Civil Engineering Laboratory

Port Hueneme, California 93043

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

- 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.

NCEL Contact—W. H. Beard, L61, Tel: autovon—360-4284, comm—(805) 982-4284.

Civil Engineering Laboratory

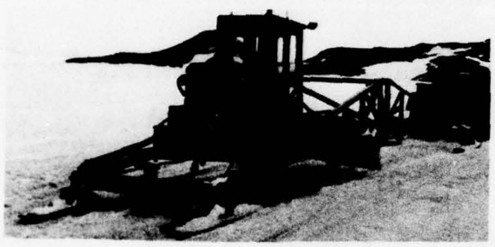
Naval Construction Battalion Center

Port Hueneme, California 93043

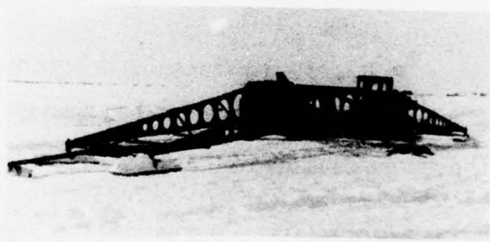
CEL

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

ADVANTAGES OF THE SNOW PLANE

- Levels up to 3-1/4 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.

CEL Contact:
M. W. Thomas, L61 (Polar Division); tel: autovon 360-5444, comm (805) 982-5444.

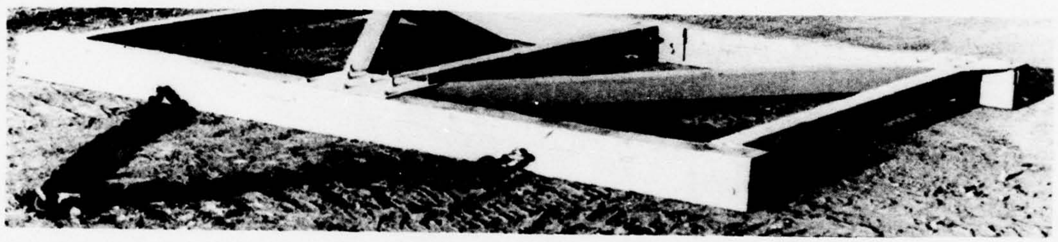
Civil Engineering Laboratory

Naval Construction Battalion Center

Port Hueneme, California 93043

CEL Techdata Sheet

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 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.

CEL Contact:
Mr. M. W. Thomas, L61; tel: autovon 360-5444 or 4284, comm (805) 982-5444 or 4284.

November 1974 74-10

Civil Engineering Laboratory

Naval Construction Battalion Center

Port Hueneme, California 93043

CEL

Techdata Sheet

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.

CEL Contact: Mr. M. W. Thomas, L61 (Polar Division); tel: autovon 360-5444, comm (805) 982-5444.

DISTRIBUTION LIST

SNDL Code	No. of Activities	Total Copies	
–	1	12	Defense Documentation Center
FKAIC	1	10	Naval Facilities Engineering Command
FKNI	6	6	NAVFAC Engineering Field Divisions
FKN5	9	9	Public Works Centers
FA25	1	1	Public Works Center
–	6	6	RDT&E Liaison Officers at NAVFAC Engineering Field Divisions and Construction Battalion Centers
	94	96	CEL Special Distribution List No. 12 for persons and activities interested in reports on Polar Engineering

CHAPTER 8

Chapter 8

SHIP OFF-LOADING FACILITIES

Chapter 8

SHIP OFF-LOADING FACILITIES

INTRODUCTION

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 (Figure 2-2), 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 the 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 (Figure 8-1). 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.

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. Between late January and early March of DF-65, progressive undercutting was observed along the vertical face. Caverns were melted at sea level, 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 to wave action. 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.

As a result, efforts were begun to improve and stabilize the wharf area for future cargo operations.

PHYSICAL FEATURES

The ice wharf is located on the southeastern shore of Hut Point, a small promontory that forms the western side of Winter Quarters Bay (Figure 8-2). The bay forms a sheltered anchorage with a diurnal tide of 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.

* Petroleum, oil, and lubricants.

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 8-3). The surface area of the wharf in DF-72 varied from 20 to 40 feet along most of the western shore except at the northern end where a larger area approximately 30 feet wide and 400 feet long exists.

In DF-66, DF-67, and DF-68, studies were made to determine the nature of the wharf and identify the parameters needed for long term protection of the facility [1, 2]. This included exploratory drilling to determine the subsurface characteristics of the wharf; measurement of temperatures within the wharf; and studies of surface maintenance, drainage problems, and the nature of erosion of the wharf face.

Composition

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 hard rock, and one hole was drilled with a 14-inch coring drill 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 8-4. This sketch is based on all drilling data projected to berth 3 (Figure 8-3), the largest and most important part of the wharf. Near the surface, the ice is bubbly, with the number and size of bubbles decreasing with depth and density. An unusually sharp contrast exists at a depth of 20 feet between white, bubbly ice and dense, gray ice with no bubbles but with large quantities of rock debris. These discontinuous layers and lenses of sand and basaltic rock fragments vary widely in thickness and relative percent of ice and rock. The sand and rock probably originated as slope wash deposited on the fast-ice surface during periods of summer melt.

The bottom conditions shown in Figure 8-4 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 bottom probably consists of 2 to 4 feet of dense, basaltic mud and sand containing many rock fragments overlying jointed basalt with interstitial ice. During DF-63, the bottom on the east side of Hut Point was explored using a 2-1/2-inch-diameter sampling spoon and a 300-pound hammer falling 14 inches. Refusal of the sampling spoon occurred at a depth of about 2 feet because the sediments became either very dense or frozen.

Subsurface Temperatures

The profile of temperatures in the wharf to depths of 12 to 38 feet are shown in Figure 8-5. 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 [3]. 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.

SURFACE MAINTENANCE AND DRAINAGE

The surface of the ice wharf consists of 1 to 3 feet of earth fill placed on top of the fast ice. This insulates the surface, preventing surface melting, and provides a work surface that is easy to maintain. The greatest problem on the wharf surface is control of meltwater drainage. This is best controlled by clearing the surface of the wharf of snow before the ice-breakers open Winter Quarters Bay and by maintaining the drainage ditch at the landward edge of the wharf to intercept hillside drainage. Snow removed from the drainage ditch and wharf surface can be deposited on the annual ice surface where it will be carried away when the bay is cleared. Figures 8-6 and 8-7 show gullies and sump holes that form in the wharf surface when meltwater warmed by the sun to as much as 45^{O}F is allowed to run over and through the porous earth surface.

DETERIORATION OF THE WHARF FACE

Observation of the wharf following the first season of use indicated that serious damage was occurring due to progressive undercutting of the vertical face by wave action and ship discharge of warm water during the berthing period. The undercutting of the vertical face was the most critical of the problems and resulted in large cantilevered sections of the wharf surface breaking off. This is continuing, thereby reducing the dock area, producing an underwater bench which holds the ship off, and making cargo handling more difficult (Figures 8-8 and 8-9). Some restoration of the undercut area occurs each winter with formation of the annual ice, but the net loss appears to be nearly 10 feet annually. Numerous methods have been considered for creating a permanent wharf, some of which are described in Reference 1. 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 steel piles set in the ice (Figure 8-10), were used to support a steel framework backed with timber panels (Figure 8-11). 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.

WHARF RECONSTRUCTION

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 it was necessary to provide a fender between ship and shore. Such a fender was realized in the form of a small iceberg-like piece of man-made ice, the experimental "ice cube" built by the DF-72 winter-over personnel. This test section was constructed along the edge of the wharf by repeatedly flooding and refreezing an enclosed 25-foot-wide by 50-foot-long section of annual ice. By this method an ice cube 15 feet thick was obtained. This ice fender functioned well, but a more comprehensive long-term solution was required. This solution was envisioned in the form of a very large man-made ice wharf over 600 feet long, extending 200 feet into Winter Quarters Bay.

Artificial Ice Wharf

During DF-74 the winter-over Public Works personnel at McMurdo Station constructed an artificial ice wharf approximating the conceptual design. The structure was located at berth 3 (Figure 8-3) 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 ice wharf through a system of bollards and cables. Although cracked in a few places during ice-breaker clearing operations, the structure functions well for berthing and unloading of cargo and POL. At the termination of DF-74 summer operations the constructed ice wharf was still in place and will be used again in future operations.

Bollard Placement

One important task in operation of the ice wharf is the placement of bollards for the mooring of ships and constructed ice platforms to the ice wharf. To assure reliable holding strength the bollards, which can be either timber or steel, should be placed not less than 2 weeks before their use. Holes for bollard placement are most easily produced by drilling with the equipment described in Chapter 10. The large-diameter auger bits are satisfactory for use in ice. If the ice is covered with frozen earth more than a few inches thick, the tube core bit faced with tungsten carbide chips is most satisfactory. Holes 5 to 6 feet deep are generally adequate for bollard placement. After drilling, any water in the hole should by pumped out before setting the bollard. This is very important, since this water, often of very high salt content, is largely unfrozen brine that has drained from the surrounding ice. If this water is not removed, the bollard may never freeze in place.

After the bollard is placed in a dry hole, the hole may be backfilled with earth and water. Freshwater at a temperature of about 35^{o}F is preferred but is often hard to provide. Though seawater can be used, it does not develop high holding strengths as rapidly as the freshwater. The proper method for backfilling is to (1) pour water into the space around the bollard to a depth of about 2 feet; (2) slowly shovel fine earth and gravel into the hole; and (3) when water is no longer visible, add more water and more dirt as before. This method will assure that the earth fill is entirely water-saturated. If dry earth is dumped into a dry hole and water poured over the top, there is no assurance that the earth backfill will be saturated, and the holding strength of the bollard is uncertain. Properly set bollards should be allowed to freeze in place for 10 to 14 days before use.

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, CA. Oct 1967.

2.——. Technical Note N-1030: McMurdo Ice Wharf - Physical Characteristics and Criteria for Protection, by R. A. Paige. Port Hueneme, CA, Apr 1969.

3.——. Technical Report R-466: Seasonal Damage to the McMurdo Ice Wharf During DF-66, by R. A. Paige. Port Hueneme, CA, Aug 1966.

4.——. Technical Report R-511: Ice Construction - Methods of Surface Flooding, by C. R. Hoffman. Port Hueneme, CA, Jan 1967.

Figure 8-1. View west over McMurdo Station, Winter Quarters Bay, Hut Point, and McMurdo Sound, DF-66.

Figure 8-2. Ships docked at ice wharf in Winter Quarters Bay (January 1966).

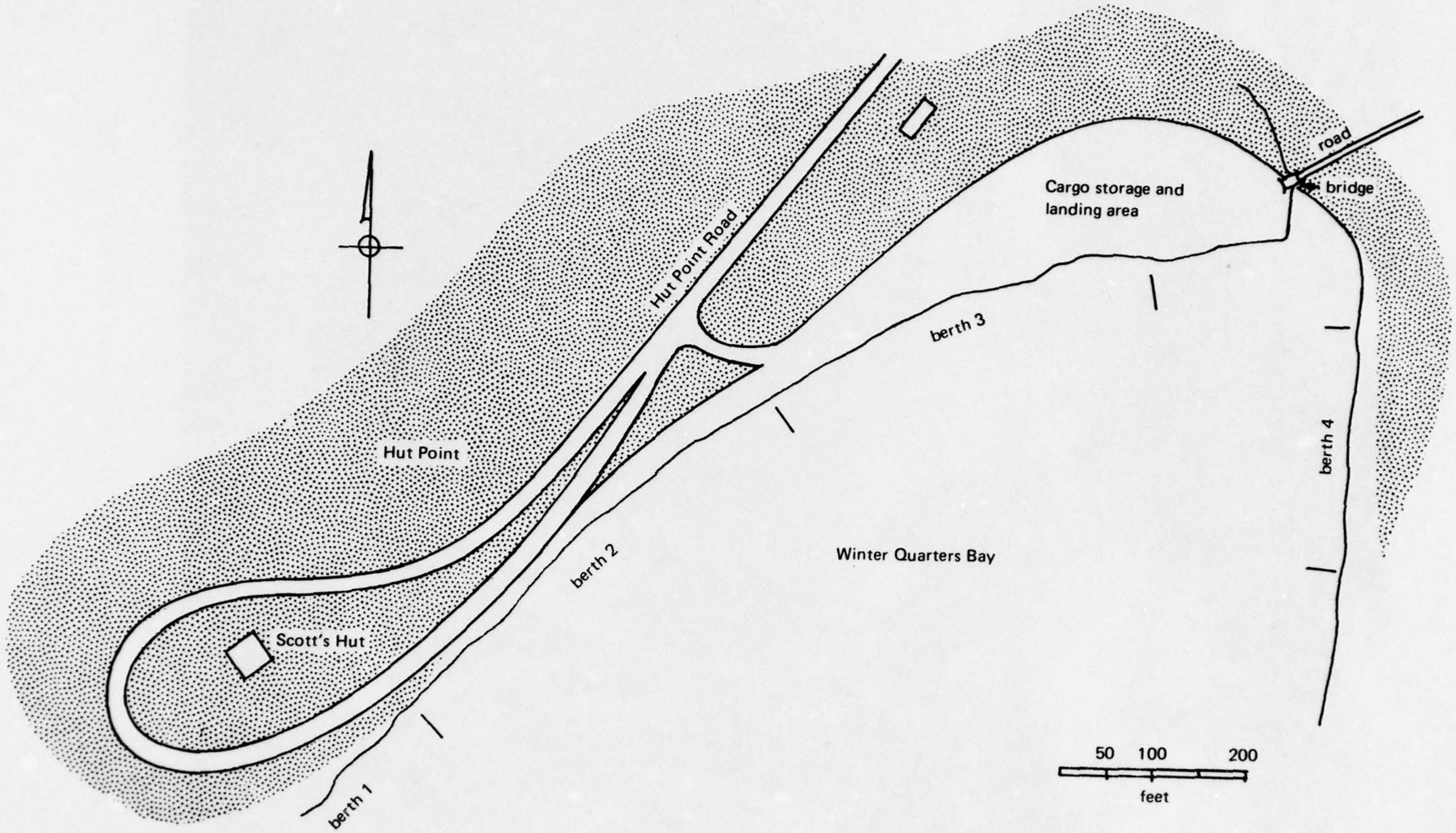


Figure 8-3. Map of McMurdo wharf area, showing approximate edge of fast ice.

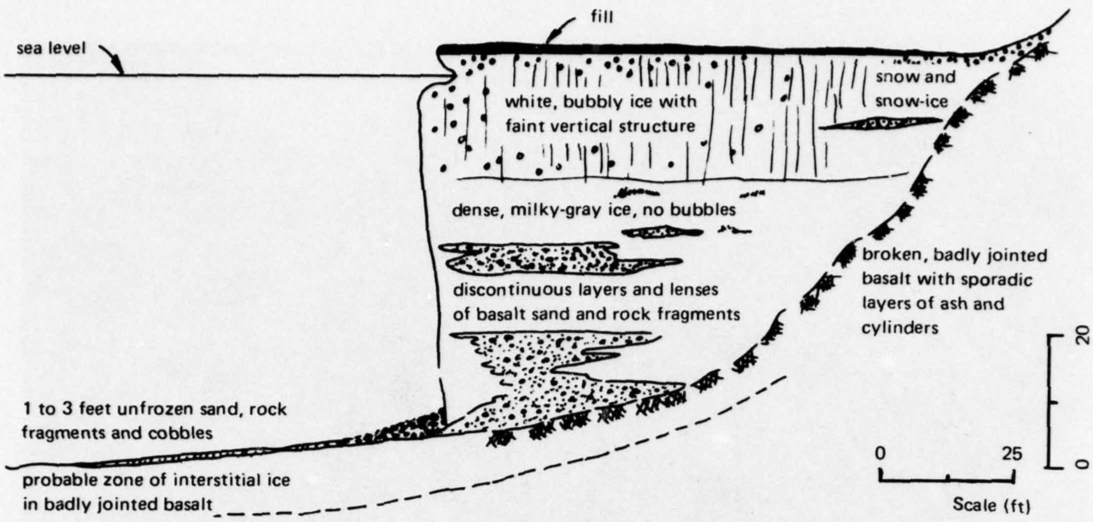


Figure 8-4. Diagrammatic cross section of the McMurdo ice wharf in berth 3. See Figure 8-3 for location.

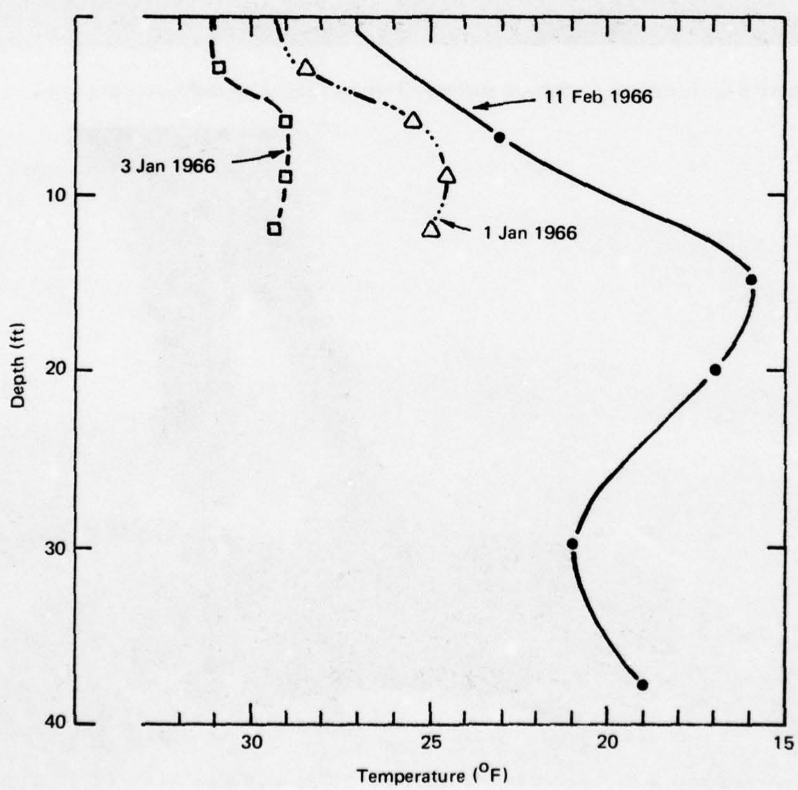


Figure 8-5. Temperature profiles of the fast ice in the McMurdo ice wharf.

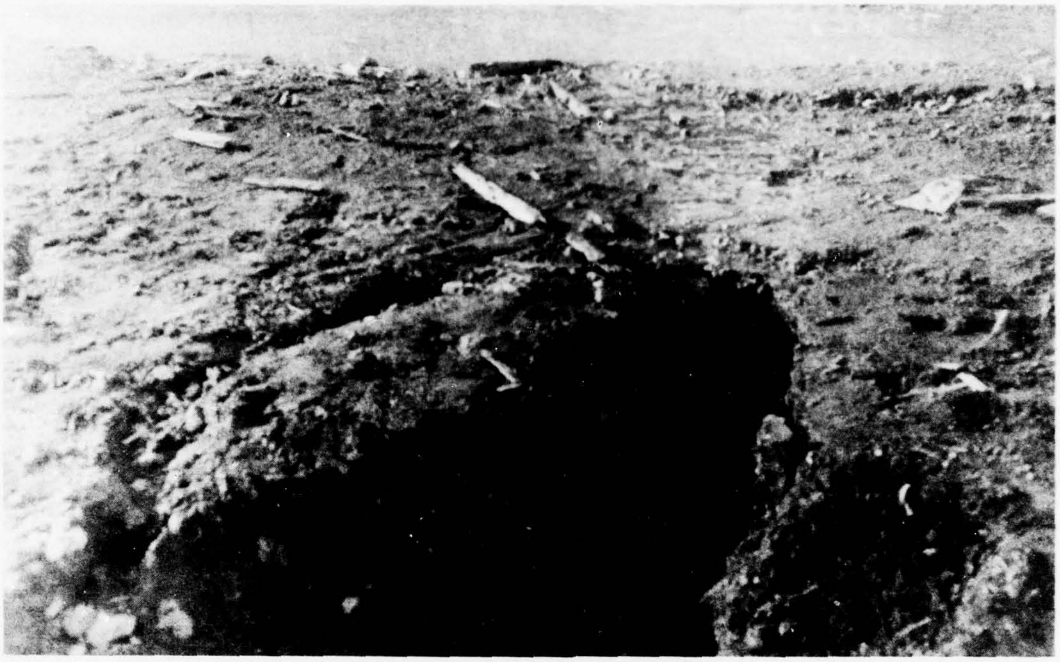


Figure 8-6. Erosional damage to surface of wharf caused by meltwater drainage.

Figure 8-7. Pothole formed in surface of the wharf by subsurface melting and collapse.

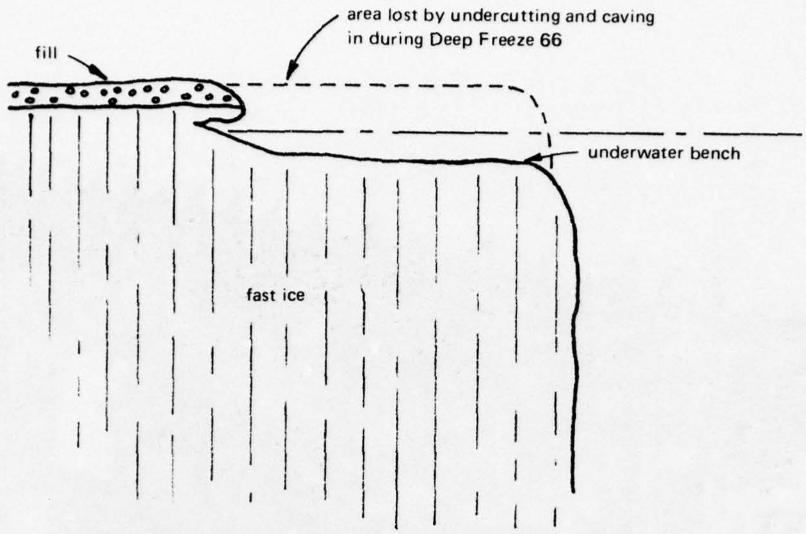


Figure 8-8. Diagrammatic cross section of wharf showing loss of surface, undercutting and underwater bench.

Figure 8-9. Surface loss in berth 3 by undercutting and wave-in.

Figure 8-10. Steel structure for supporting protective face on ice wharf.

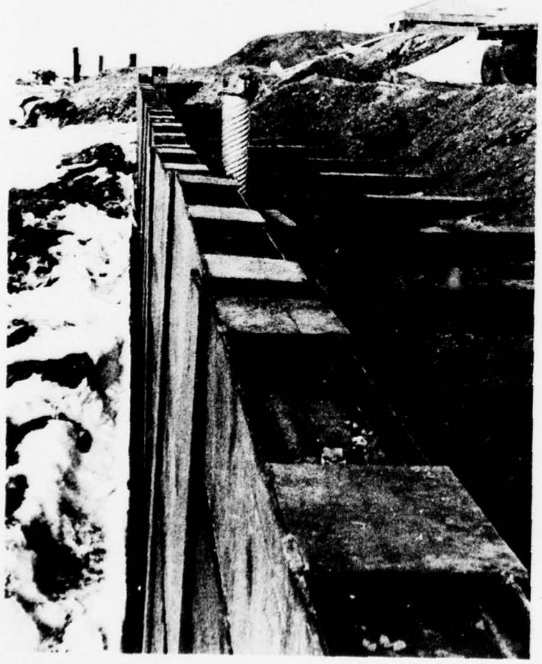


Figure 8-11. Protective face of steel and timber in place on ice wharf.

CHAPTER 9

Chapter 9

POLLUTION CONTROL

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. As of DF-74, such a method has not been initiated.

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, contaminate 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 with spilled fuel oils has been considered and is of some concern. If oil is spilled when the annual ice is in place, cleanup entails the harvesting of saturated snow and the recovery of oil and water from the tide crack areas. If the sea is clear of ice, collection of oil from the water surface is possible by established means, such as the use of bales of straw sent to McMurdo in DF-73 for this purpose. No satisfactory procedure has been found for cleaning oil from water filled with broken ice. Fortunately, most oil products at McMurdo are the lighter, more volatile fractions which evaporate more readily and do not have the long-lasting deleterious effects of the crude and residual oils.

CHAPTER 10

Chapter 10

TRANSPORTATION AND CONSTRUCTION EQUIPMENT

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 satisfactory 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

The selection of proper lubricants for use at McMurdo Station is one area in which several opinions are evident. In most cold regions, the lubricants recommended by equipment manufacturers for use in winter in engines and gear boxes are lighter in weight than those used in the summer.

The most recent experience at McMurdo Station indicates that 30-weight engine oils and 80- and 90-weight gear oils are being used year round in automotive equipment. The reasoning behind this practice is that when an engine is warm the 30-weight oil is needed, even though a lighter grade would facilitate starting and provide the needed lubrication when the engine is cold.

A logical solution appears to be use of multiviscosity oils, which are free-flowing when cold but retain good lubricity at normal engine-operating temperatures. The use of such oils is not common in the Navy System, and they are not known to be available in the McMurdo supply system. Because of the lack of information on the current practices and policies at McMurdo, a study of this subject appears warranted. This should include the gathering of data on equipment manufacturers' recommended lubricants for temperatures from +40°F to -50°F operation. Such recommendations should always be taken in preference to personal opinions.

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.

Table 10-1. High-Flotation Tires in Use at McMurdo Station

Tire		Manufacturer	1974 Cost	Applicable Vehicle	PSI
19.75 x 20 Recap FloPower Rib	24-28 PR 18-in. rim	Martin Tire Co.	$201.25	FABCO 6 x 6 Trucks, FABCO Bus FABCO Trailers, 5-ton Military Truck	25-35
19.75 x 20 Ultraflo	18 PR 17-in. rim	Martin Tire Co.	$384.75	FABCO 6 x 6 Trucks, FABCO Bus FABCO Trailers, 5-ton Military Truck	35
17.00 x 16 3-in-1	10 PR 11-in. rim	Martin Tire Co.	$156.19	Dodge W300 Power Wagons 1-1/4-ton Military Truck, Small Trailers	10-15
16.00 x 16 Sand Tire	6 PR	Goodyear	$148.74	Dodge W300 Power Wagons 1-1/4-ton Military Truck, Small Trailers	35
66 x 43 x 25 Terra Tire	6 PR 36-in. rim	Goodyear	$848.30	Nodwell FN100TT Water Trotter	15-20
48 x 20 x 20 Terra Tire	4 PR 16-in. rim	Goodyear	$524.00	LGPV-16	10-30

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 ground-bearing 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 Naval Support Force Antarctica (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 of these tests are presented in Reference 1. Results showed that mobility on all types of snow was similar between a Power

Wagon equipped with Martin 17.00 x 16 tires and a similar truck equipped with Terra tires, size 46 x 18-16R front and 46 x 24-16R 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 16.00 x 16 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 does not grip the snow as effectively as the chevron tread.

Even though the ribbon-tread sand tires perform poorly, their use by USARP and NSFA continues. Experience by USARP shows that the nonagressive tread of the sand tire reduces breakage of front axles and drive-train components by inexperienced drivers and is preferred in spite of reduced mobility.

Experience by NSFA indicates maximum mobility is desired and that frequency of axle breakage is acceptable, especially since axle breakage seldom occurs with more experienced drivers. In spite of this experience, new 1-ton vehicles obtained for NSFA are often equipped with the ineffective ribbon-tread sand tire, apparently because of a small cost saving.

The procurement of the proper rim for the high-flotation tire is very important. Several recently procured vehicles at McMurdo are fitted with rims too narrow for the tires. Such a rim squeezes the tire together in cross section and reduces the ground-contact area, 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.

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 to be 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. Very few problems have been experienced with the automatic units, however; of the 10 or 11 units in use since 1966, only one replacement has been made.

Beginning in 1964, NCEL procured various items of commercial equipment in support of the field test and evaluation programs. Several of these items were subsequently procured by NSFA for general use. Brief descriptions of this equipment follows.

Cargo Truck, 1-Ton, 4 x 4

For Deep Freeze 65, NCEL developed modifications for two 1-ton 4 x 4 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 7.50 x 16-6PR tires and standard wheels were replaced with recapped 17.00 x 16-10PR aircraft tires with low-profile 3-in-1 (flotation, traction, and road-ability) 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 are still in use and give outstanding service with normal maintenance. They are 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. Two-wheel drive proved unsatisfactory on slippery surfaces because the vehicle fishtails and whips so that the operator has difficulty in maintaining control. The vehicles can 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, 6 x 6

A 6 x 6 truck-tractor and 20-ton semi-trailer 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, 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 8.25 x 20-10PR tires and standard wheels (dual on the tandem rear axles) were replaced with recapped 19.75 x 20-20PR aircraft tires and suitable drop-center wheels, single on all axles. The tires were suitable for the anticipated used 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 forthe 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.

The truck-tractor/semitrailer combination was recommended as an interim standard cargo carrier for the McMurdo area. It was adopted by the Naval Support Forces Antarctica. More information on this equipment is given in Reference 3.

Passenger-Cargo Panel Truck, 4 x 4

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 7.75 x 15 four-ply tires were replaced with 11.00 x 15 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 is 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, 4 x 4

A cargo-coach van of special body design was procured for Deep Freeze 66. The basic vehicle was a 4 x 2 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 19.75 x 20-20PR 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 can 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.

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 10-6) 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 [6] and "Snow Road Construction by Layered Compaction - Construction and Maintenance Manual," Appendix B, 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 10-7) 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 (Figures 10-8 and 10-9), 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 10-10) and drags (Figures 10-11 and 10-12) 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 Appendixes A and B and Reference 11.

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 10-13). In DF-69 NCEL procured an ice-chipper conversion drum for one of the machines under contract N62399-68-0032. The drum (Figure 10-14) 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 converted 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 10-15) 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 10-16) 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. No technical publications have been prepared on use of this machine.

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 10-17 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 10-18 shows the drive head set up for augering in snow or ice. Augers cannot be

* Studies were originally begun on an ice-cutting bulldozer about 10 years ago.

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 10-19. 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 with this machine, and each has a different purpose. The auger in Figure 10-20 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 10-21). 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.

The third type of bit is the tube core drill (Figure 10-22). 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- to1/4-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 12 is recommended.

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Report R-540: Polar transportation – Snow trails for light wheeled vehicles, by E. H. Moser, Jr. and G. E. Sherwood. Port Hueneme, CA, Aug 1967.

2.———. Technical Report R-401: Polar transportation equipment – One-ton power wagon with high-flotation tires, by W. H. Beard and G. E. Sherwood. Port Hueneme, CA, Aug 1965.

3.———. Technical Report R-409: Polar transportation equipment – Six-by-six truck-tractor and 20-ton semitrailer with high-flotation tires, by W. H. Beard and G. E. Sherwood. Port Hueneme, CA, Oct 1965.

4.———. Technical Report R-630: Polar transportation equipment – Four-wheel-drive vehicle with high-flotation tires, by W. H. Beard. Port Hueneme, CA, Jun 1969.

5.———. Technical Report R-464: Polar transportation equipment – 4 x 4 cargo-personnel van with high-flotation tires, by W. H. Beard. Port Hueneme, CA, Aug 1966.

6.———. Snow road – Construction and maintenance manual. Port Hueneme, CA, Jan 1972.

7.———. Technical Report R-487: Snow-compaction equipment model 36/42 snow mixer, by G. E. Sherwood and R. W. Hansen. Port Hueneme, CA, Oct 1966.

8.———. Technical Note N-463: Specifications for the model 80 snow plane, by N. E. Pierce and E. H. Moser. Port Hueneme, CA, Oct 1962.

9.———. Technical Note N-246: Snow plane – 40-foot span. Port Hueneme, CA, 1956.

10.———. Technical Note N-245: Snow rollers – 8-foot diameter, by J. E. Dykins. Port Hueneme, CA, Jan 1956.

11.———. Technical Note N-109: Pontoon tie-rod yoke, by F. N. LeDoux. Port Hueneme, CA, Aug 1952.

12.———. 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 temperatures 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.

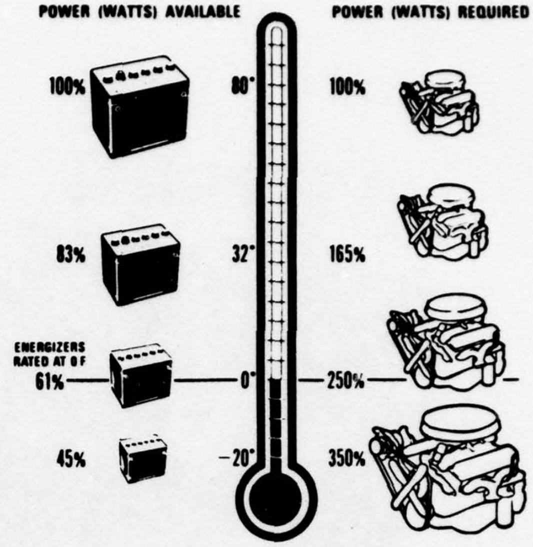


Figure 10-1. Graph showing relationship of capacity of lead-acid battery to temperature.

Figure 10-2. Power Wagon on compacted-snow road.

Figure 10-3. Truck-tractor and semitrailer on compacted-snow road.

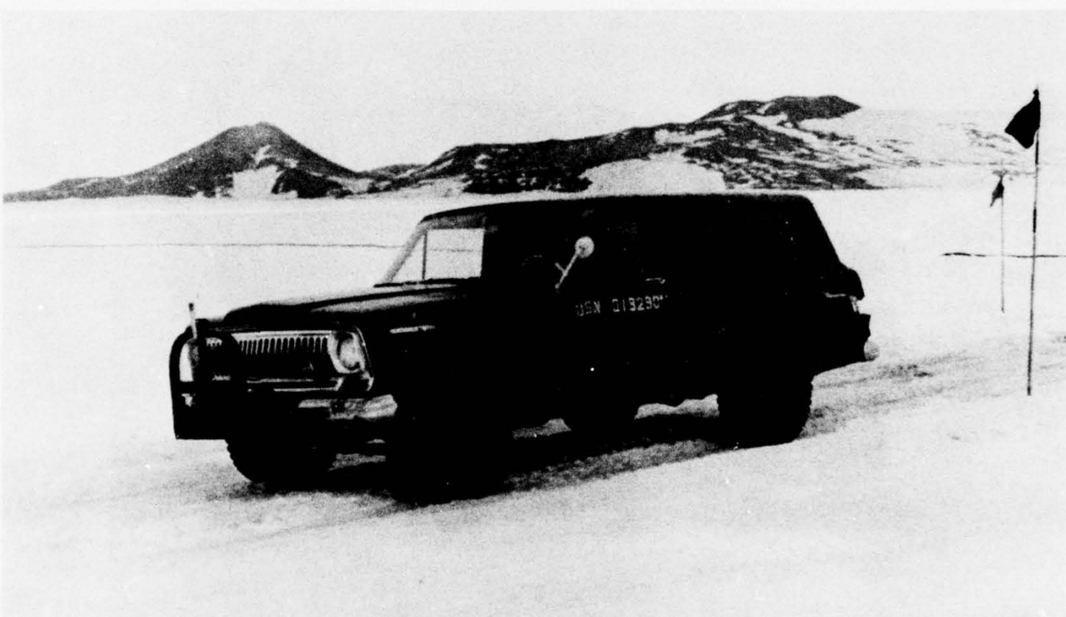


Figure 10-4. Jeep on snow road.

Figure 10-5. Cargo-Passenger van on ice road.

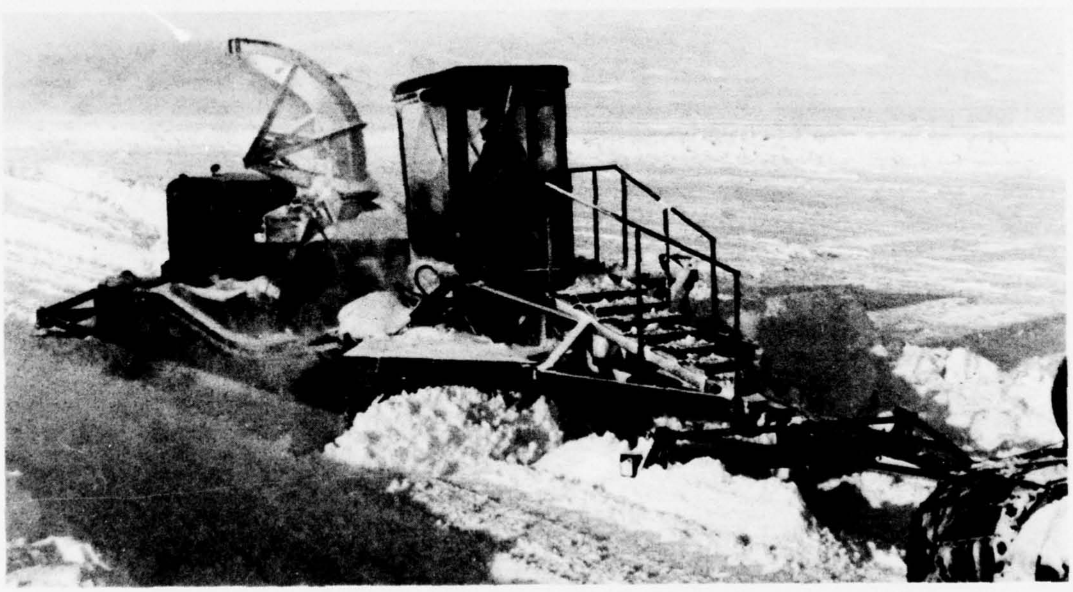


Figure 10-6. Ski-mounted snow blower.

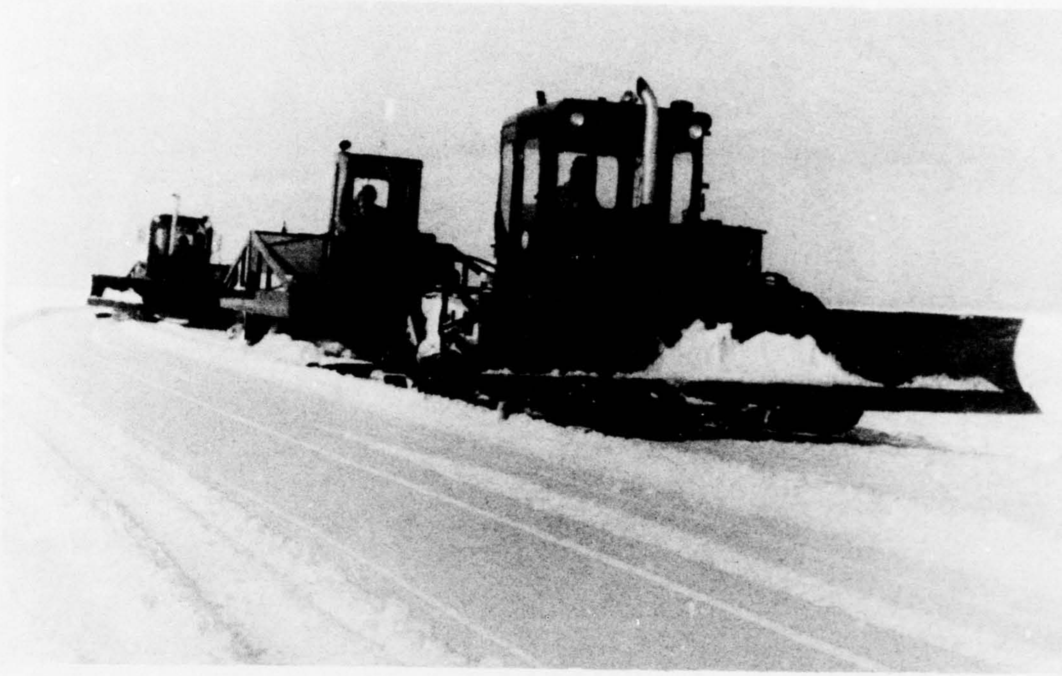


Figure 10-7. D4 tractor pulling pulvimixer used in snow road construction.

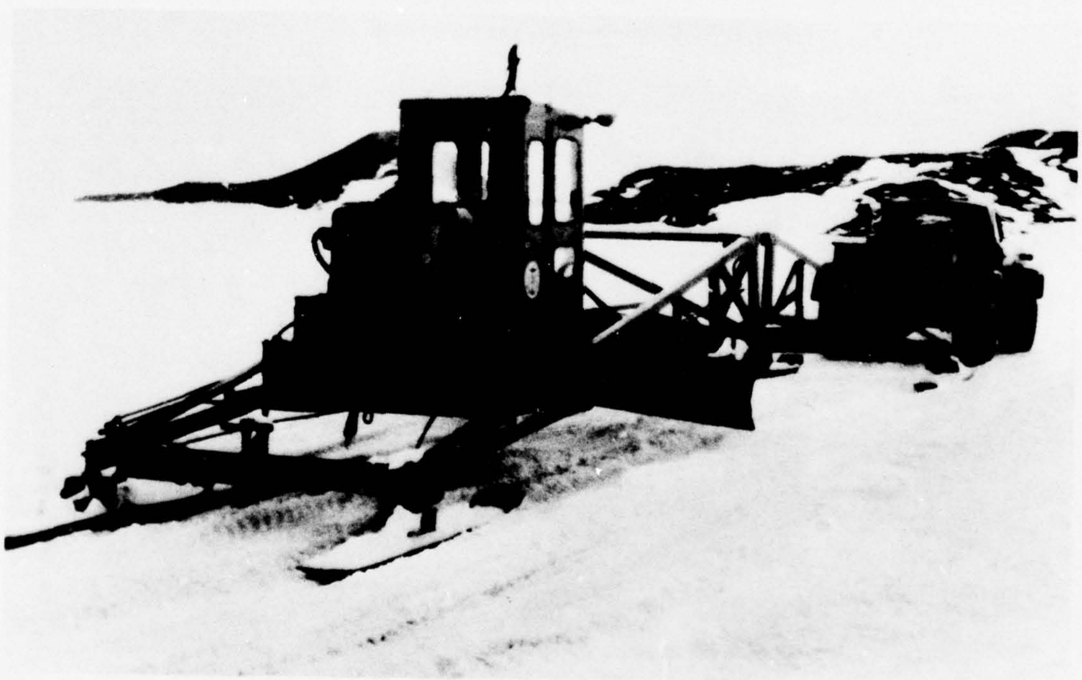


Figure 10-8. Forty-foot snow plane.

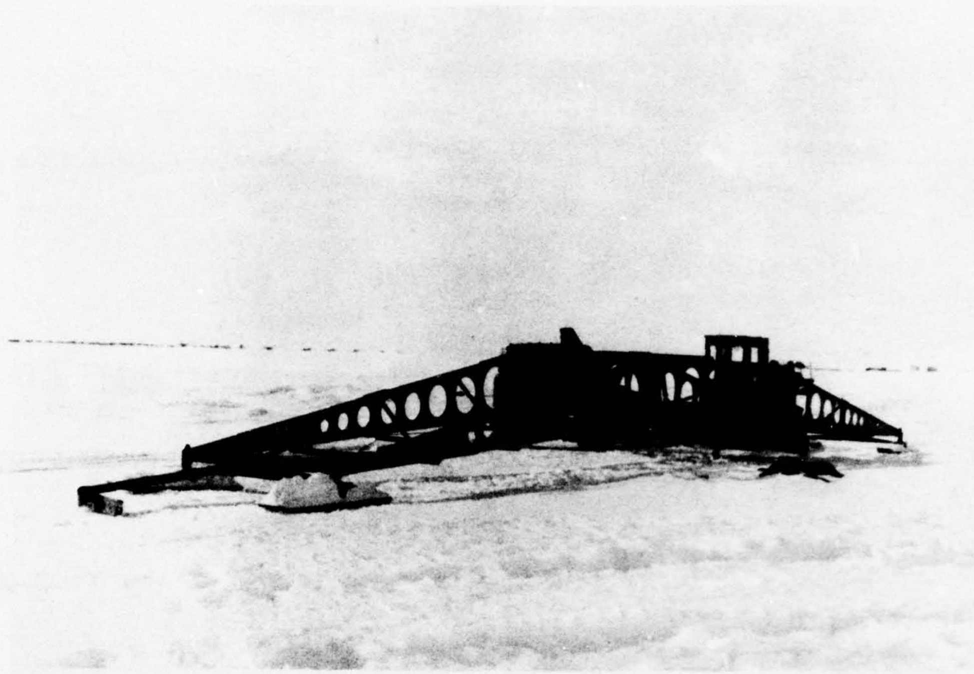


Figure 10-9. Eighty-foot snow plane.

Figure 10-10. Snow roller used in road and runway construction.

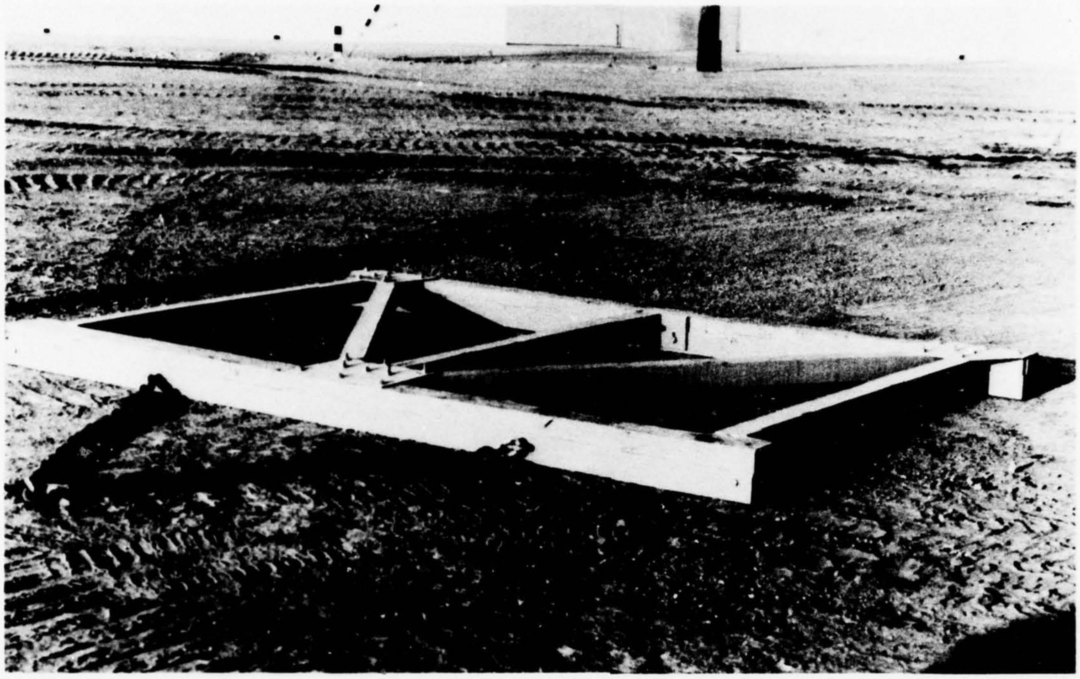


Figure 10-11. Rough drag used in road and runway construction.

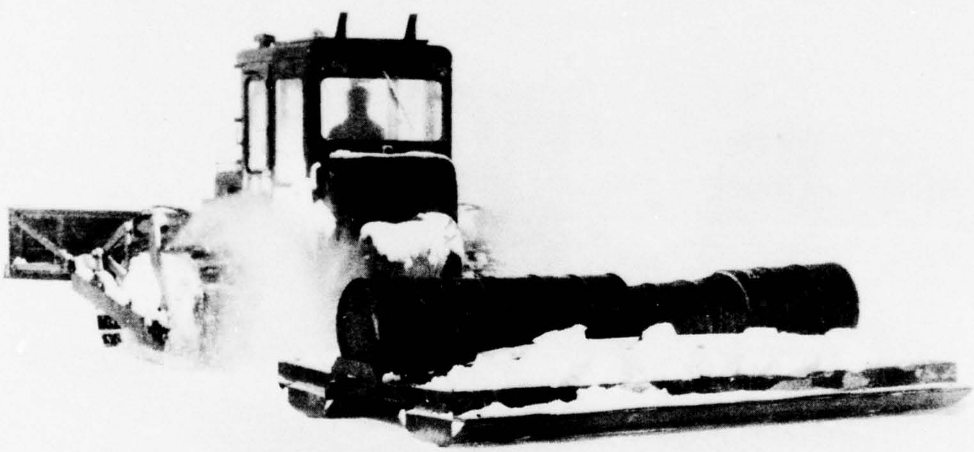


Figure 10-12. Smooth drag used in road and runway construction.

Figure 10-13. Bros Rota-Mixer.

Figure 10-14. Special ice chipper drum on Bros Rota-Mixer.

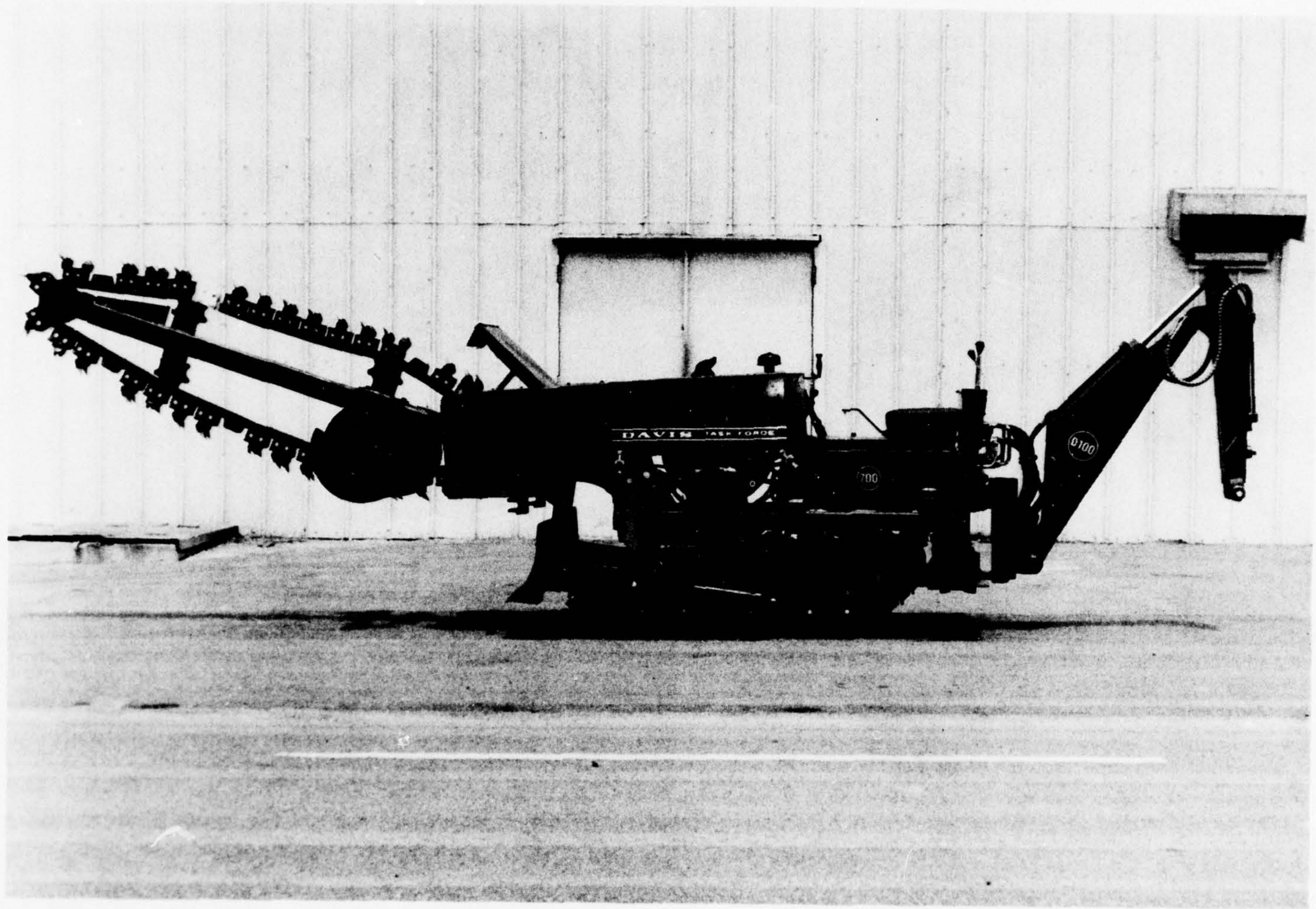
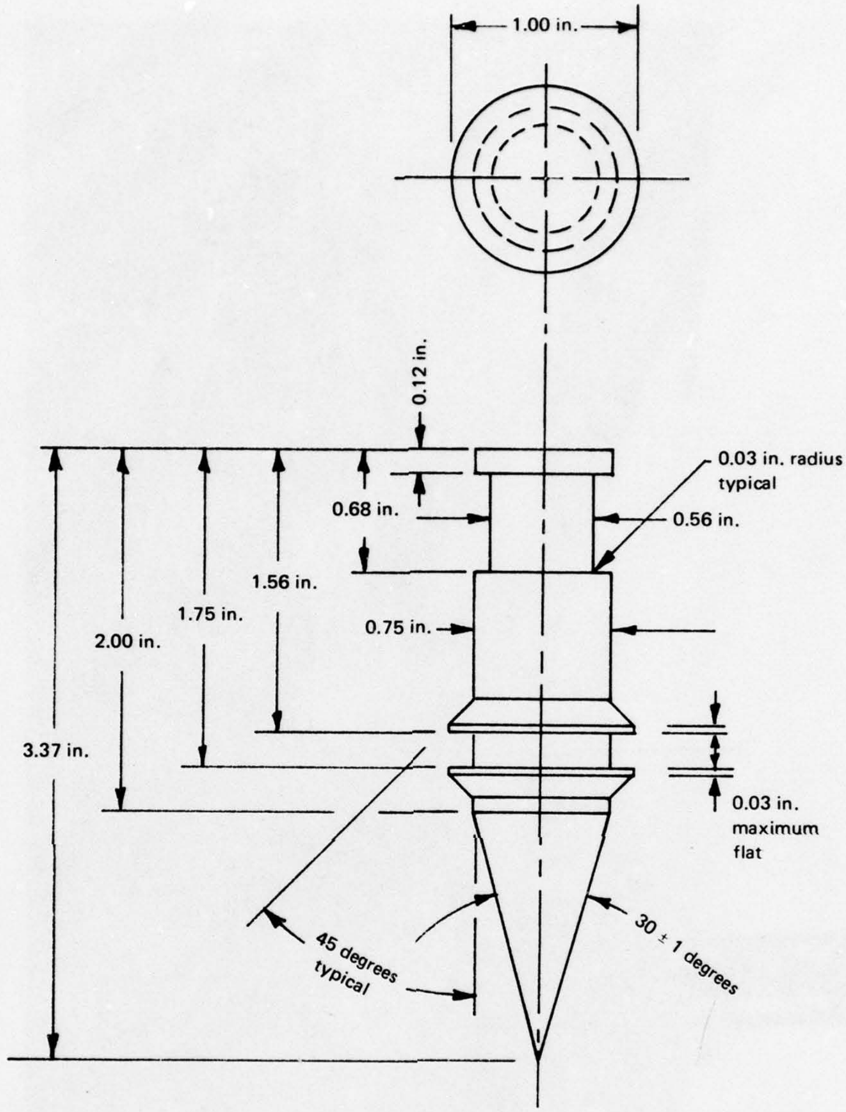


Figure 10-15. NCEL trencher converted to ice excavation.



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 10-16. Conical ice-chipping tooth used on ice trenching machine.

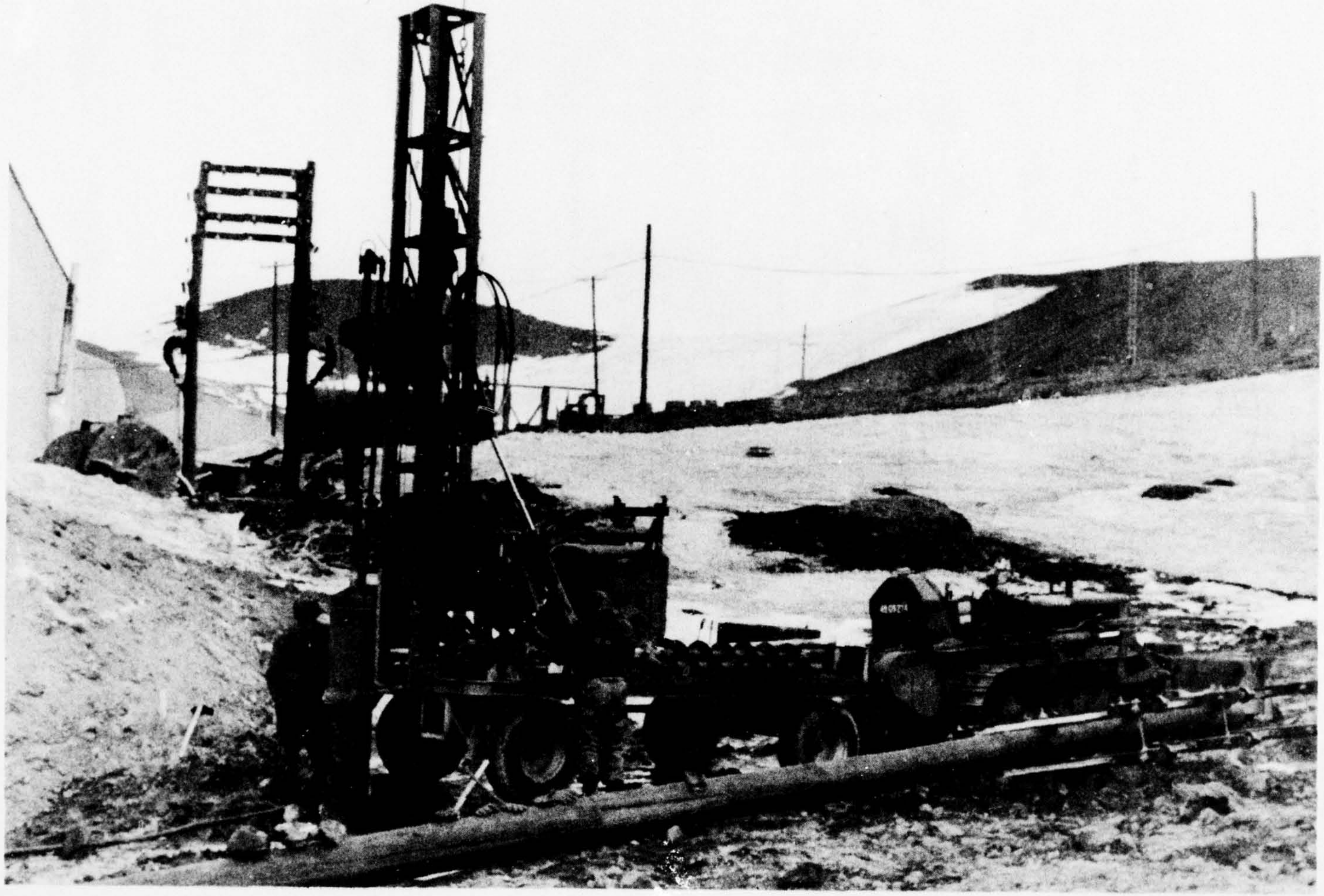


Figure 10-17. Mobile drill unit for drilling in snow, ice, or frozen ground. Photo shows drilling hole for utility pole using water and the tube drill.

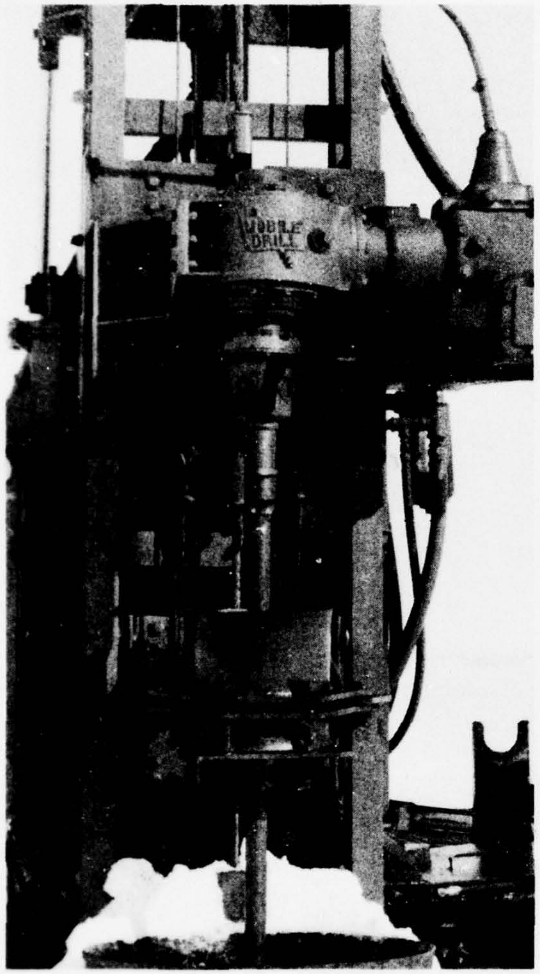


Figure 10-18. Drive head of Mobile Drill set up for auger drilling.

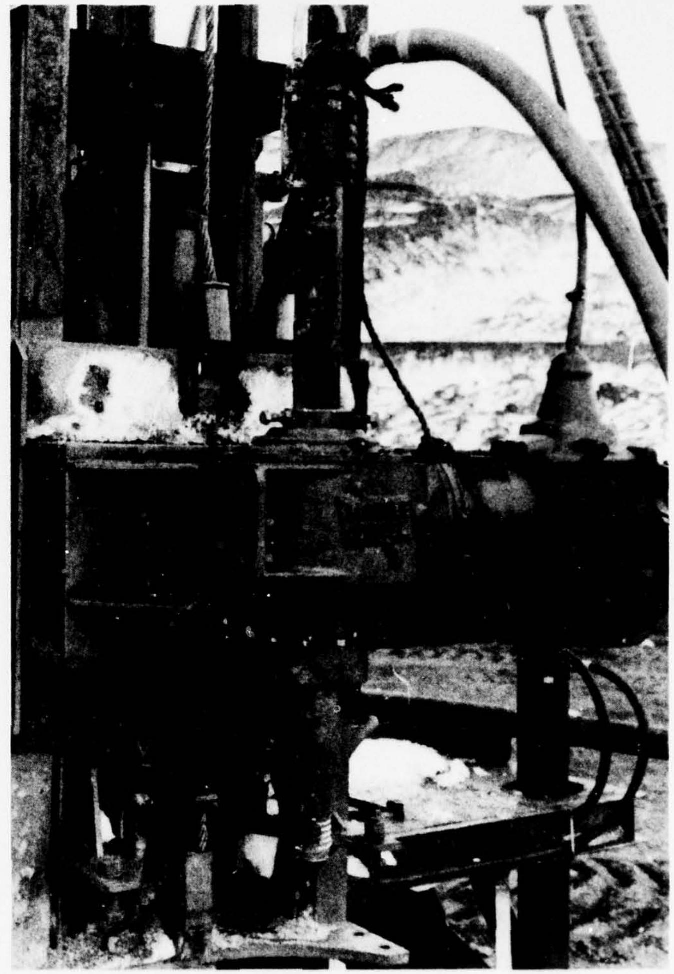


Figure 10-19. Drive head of Mobile Drill set up for fluid drilling.

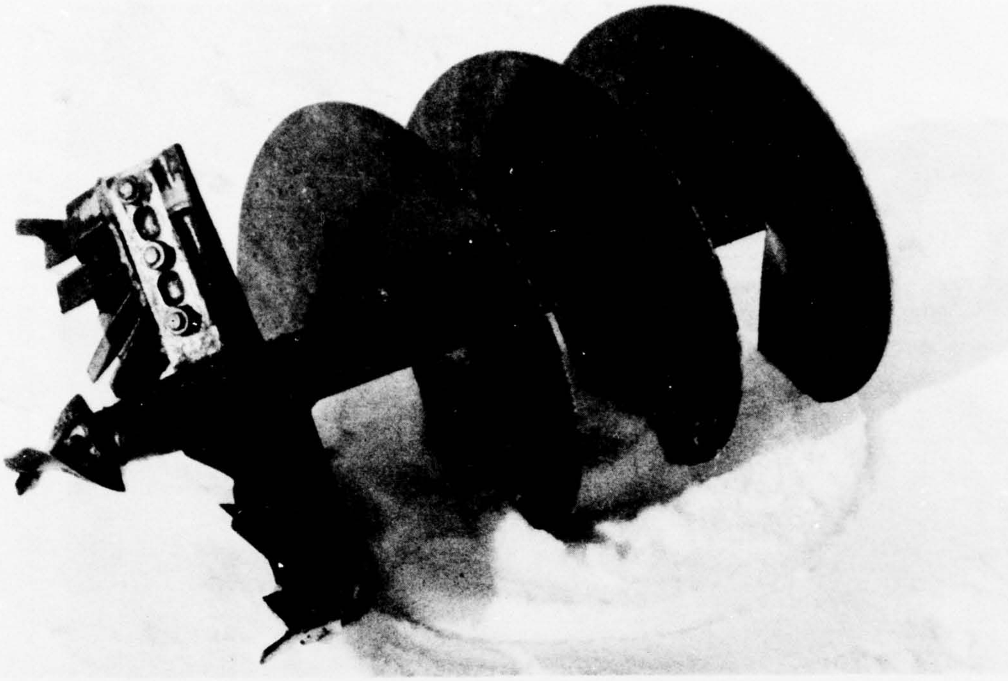


Figure 10-20. Auger for drilling in ice or snow.

Figure 10-21. Tricone bit for drilling in frozen ground or ice.

Figure 10-22. Tube core drill with 14-inch-diameter and tungsten carbide cutting edge.

Appendix 10A

SHOP DRAWING: LEVELING DRAG FOR SNOW ROADS

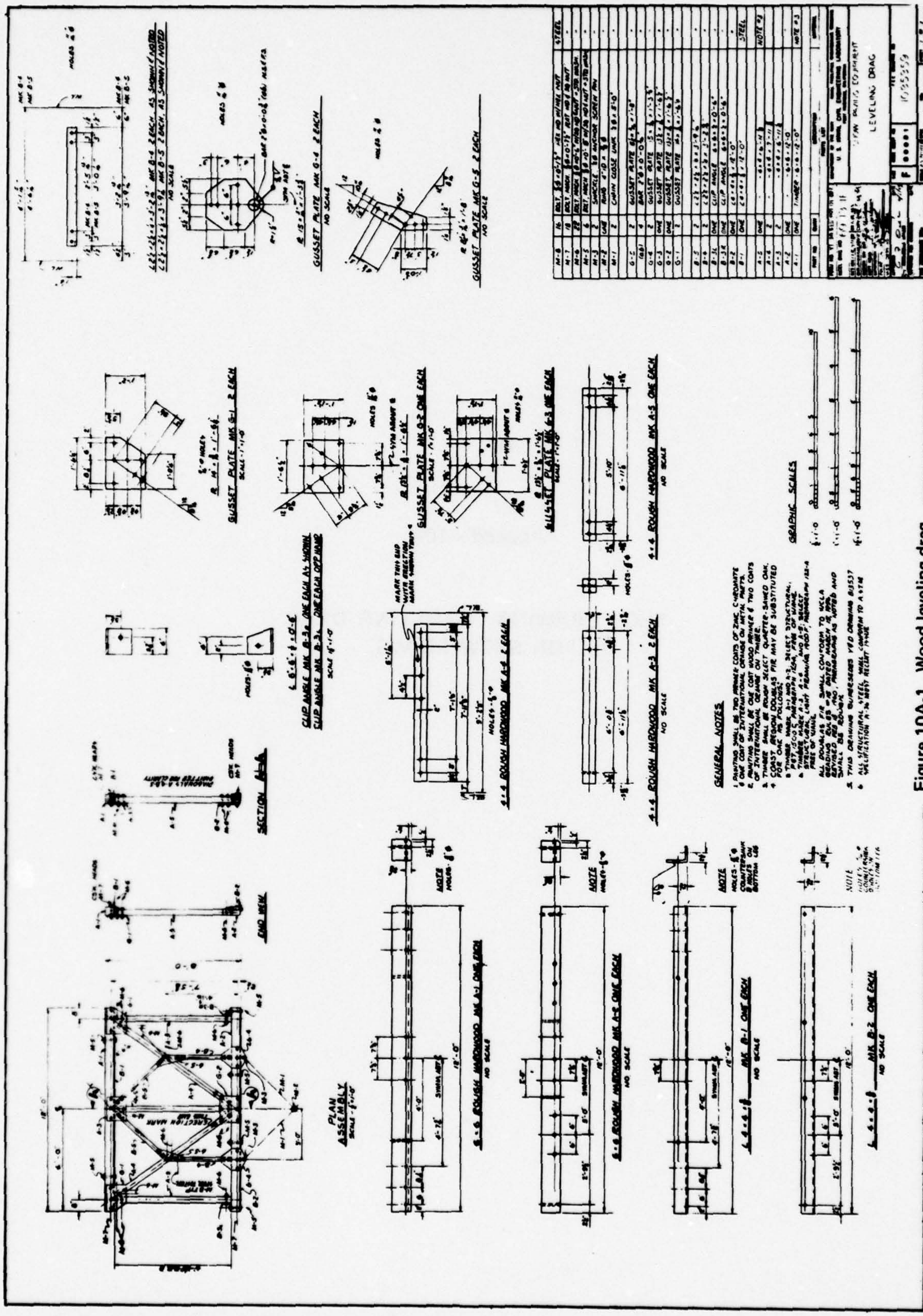


Figure 10A-1. Wood leveling drag.

Appendix 10B

SHOP DRAWING: FINISHING DRAG FOR SNOW ROADS

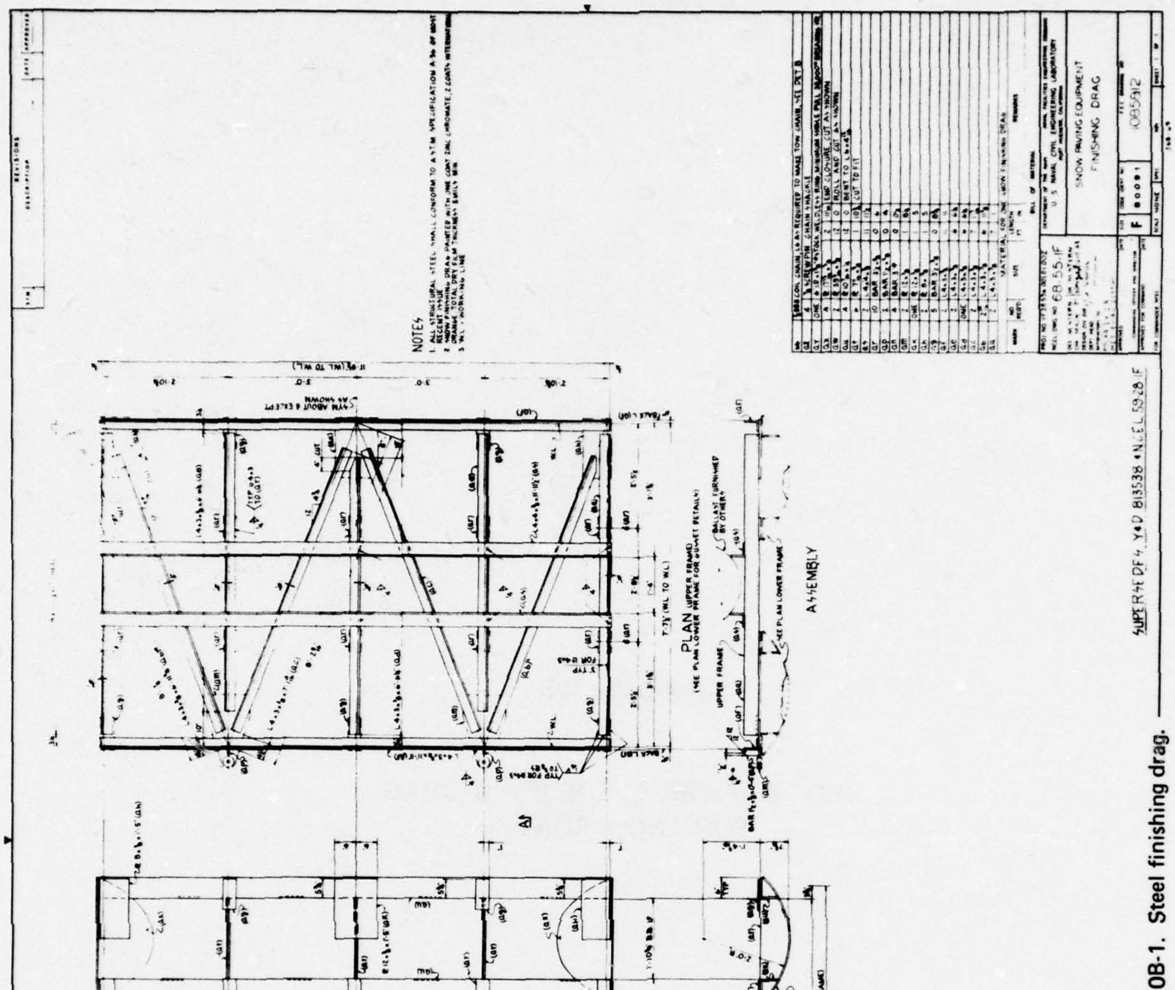


Figure 10B-1. Steel finishing drag.

CHAPTER 11

Chapter 11

MATERIALS FOR LOW TEMPERATURE USE

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.

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.

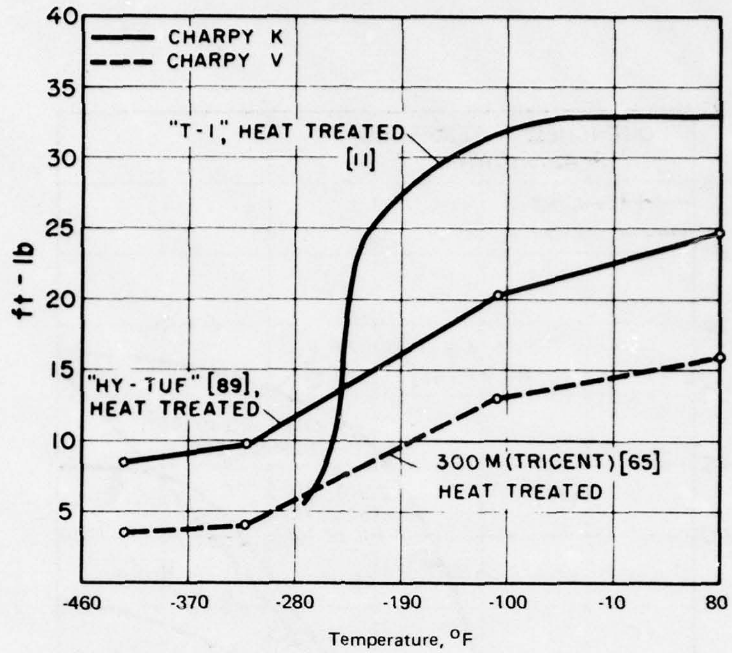


Figure 11-1. Impact energy causing fracture of AISI-SAE plain carbon steels.

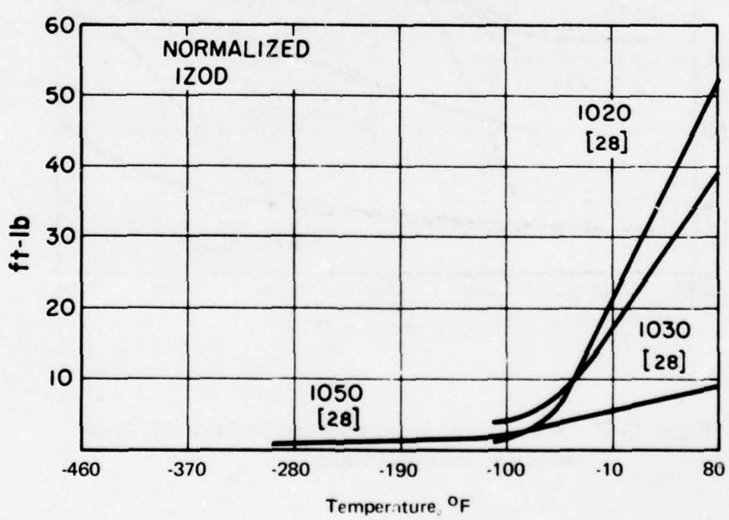


Figure 11-2. Impact energy causing fracture of some special proprietary constructional steels.

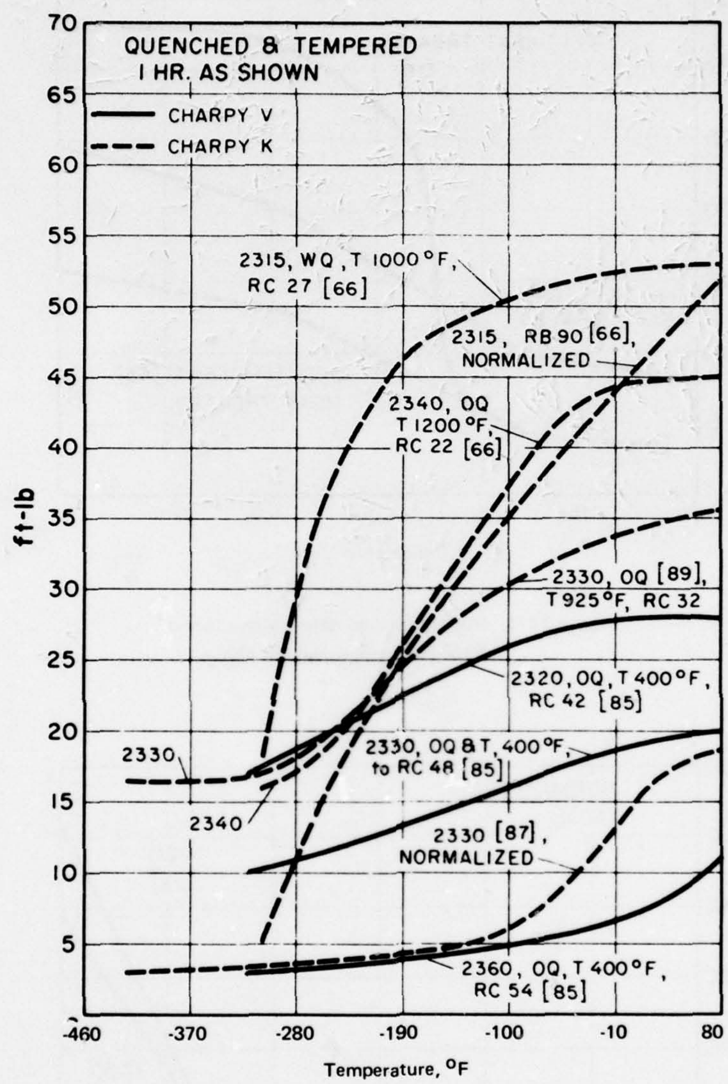


Figure 11-3. Impact energy causing fracture of AISI-SAE 2300 series constructional steels.

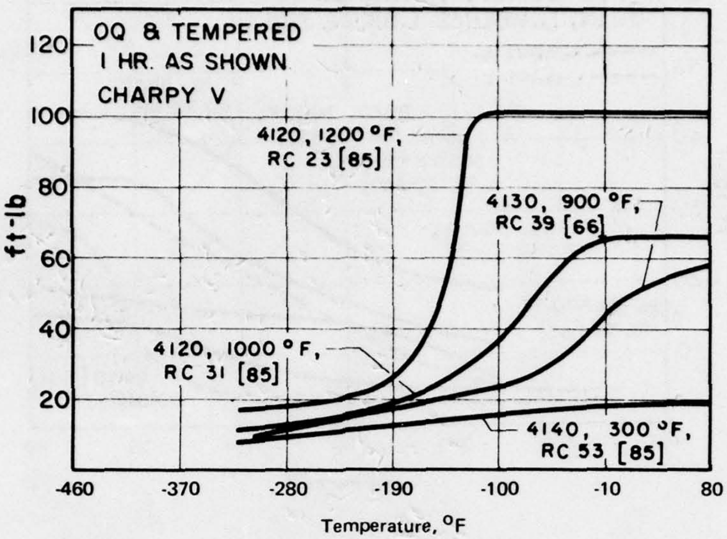


Figure 11-4. Impact energy causing fracture of AISI-SAE 4100 series constructional steels.

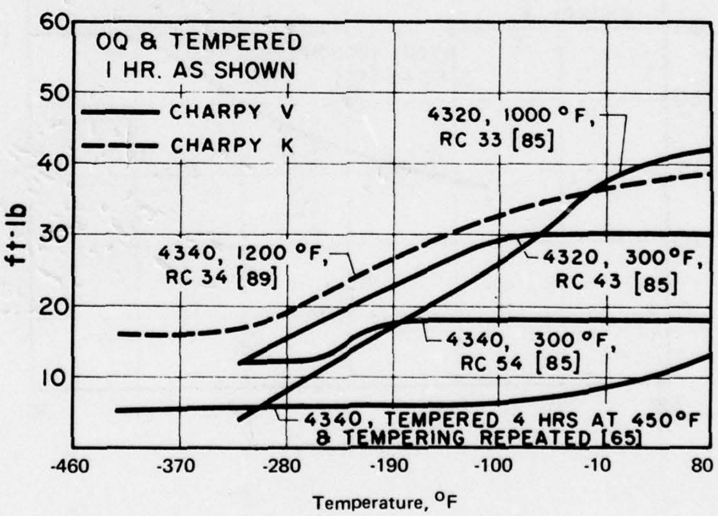


Figure 11-5. Impact energy causing fracture of AISI-SAE 4300 series constructional steels.

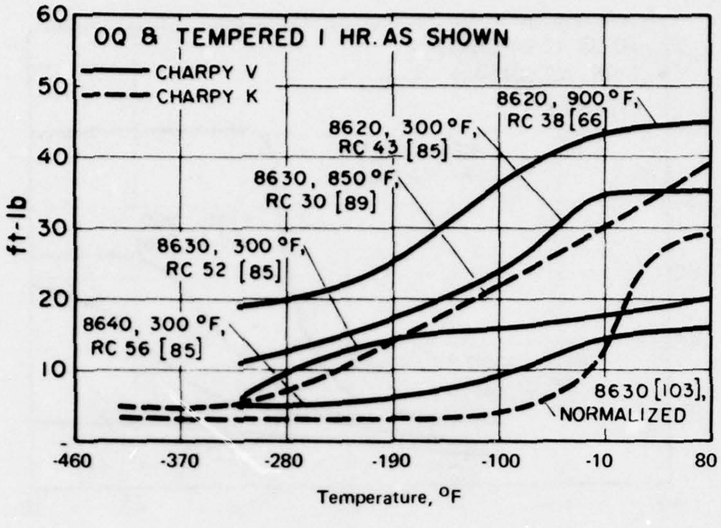


Figure 11-6. Impact energy causing fracture of AISI-SAE 8600 series constructional steels.

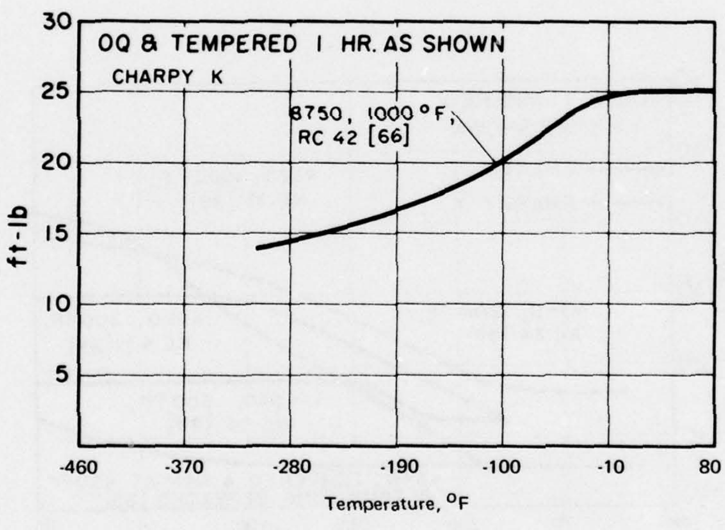
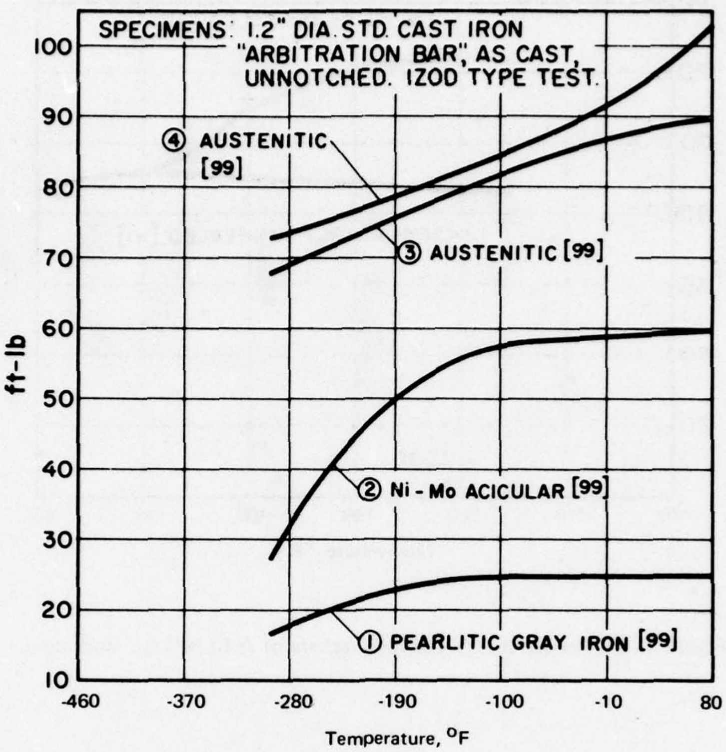


Figure 11-7. Impact energy causing fracture of AISI-SAE 8700 series constructional steels.



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.

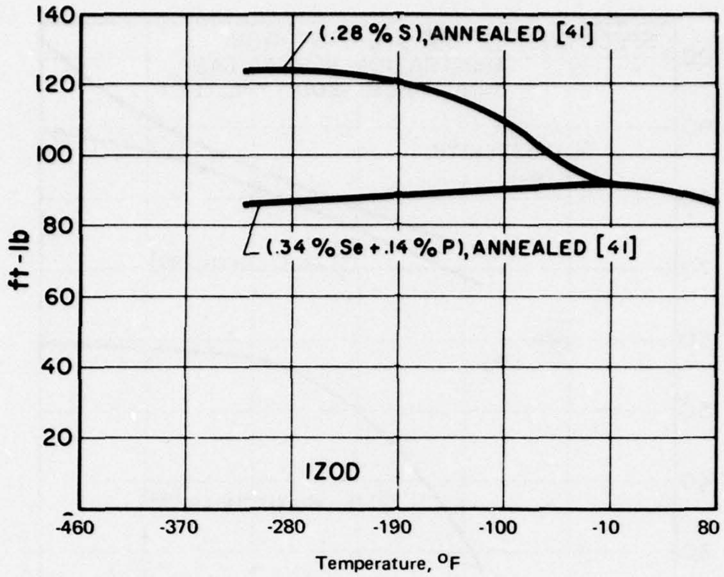


Figure 11-9. Impact energy causing fracture of AISI 303 stainless steel.

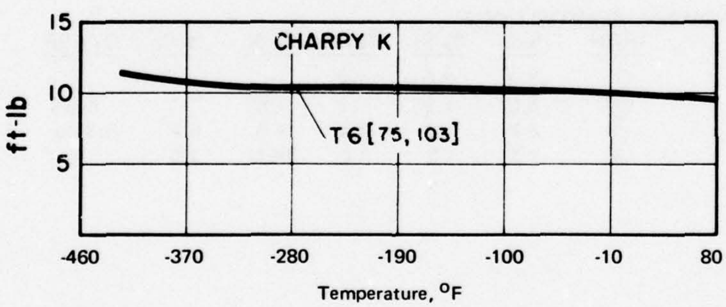


Figure 11-10. Impact energy causing fracture of 6061 aluminum.

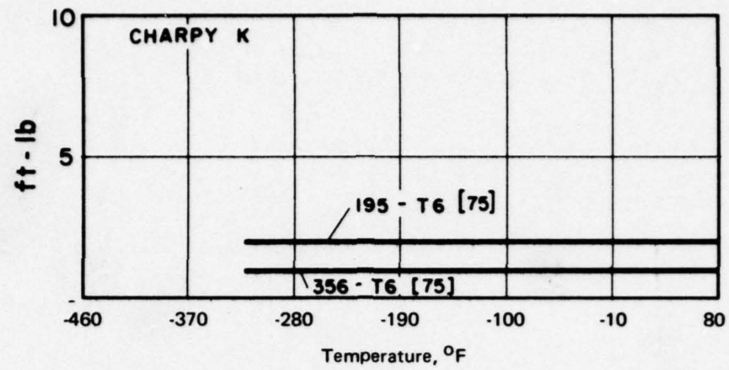


Figure 11-11. Impact energy causing fracture of sand cast aluminum alloys.

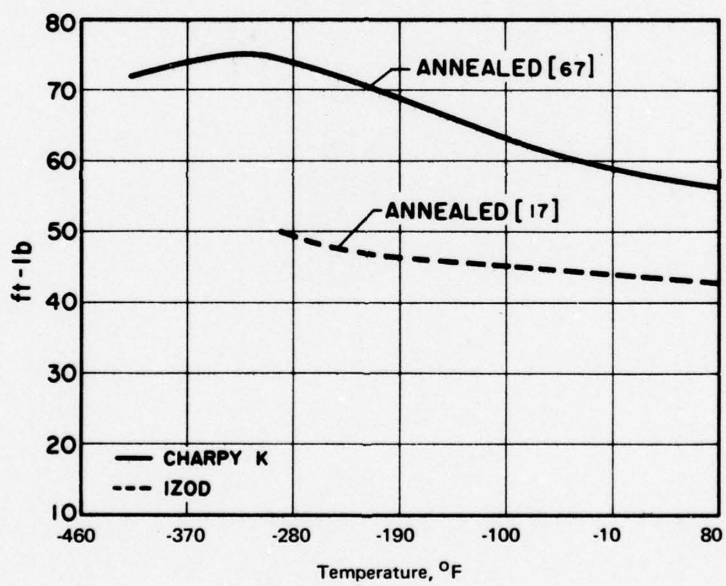


Figure 11-12. Impact energy causing fracture of oxygen free high conductivity copper.

CHAPTER 12

CHAPTER 12 – INDEX

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES

NOTES