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UNITED STATES NAVY

ARCTIC ENGINEERING

TECHNICAL PUBLICATION

NAVDOCKS TP-Pw-11

15 MARCH 1955

DEPARTMENT OF THE NAVY
BUREAU OF YARDS AND DOCKS
WASHINGTON 25, D. C.

DEPARTMENT OF THE NAVY
Bureau of Yards and Docks
Washington 25, D. C.

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1. Purpose. To provide a cross reference within the Navy Directives system and a brief outline of the contents of the above-noted publication, and to specify that it has been designated "For Official Use Only."

2. Contents. The referenced publication is intended to serve as a guide to Bureau and field personnel engaged in the planning, design, construction, operation, alteration, repair, and maintenance of facilities in areas of extremely low temperatures. Chapter 1 presents data for recognizing and evaluating control factors imposed by environments existent in the Cold Regions. Chapter 2 contains technical data useful in the development of engineering design for low-temperature areas. Chapter 3 presents information essential to the accomplishment of construction or development projects in the Cold Regions. The operation of construction equipment, maintenance and repair of such equipment, and site maintenance are discussed in Chapter 4.

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For over a century the Navy has taken an increasing interest in the frigid regions of the earth. In 1839 Lieutenant (later Rear Admiral) Charles Wilkes, USN, sailing his three small ships under great difficulties through the vast icepack, was one of the first to sight the frozen Antarctic continent. His exploration, one of the most notable of his day, was the first Navy expedition authorized by Congress.

Commander (later Rear Admiral) Robert E. Peary (CEC), USN, spent many years exploring and learning to live in the Arctic, and on 6 April 1909 was the first man to reach the North Pole.

Rear Admiral Richard E. Byrd, USN, first to fly over the South Pole and first to fly over both Poles, was accompanied on his last Antarctic expedition, during 1946 and 1947, by two CEC officers and a Seabee unit.

Since World War II, the Navy has investigated still further the problems of living and operating in the polar areas. This Bureau, in its laboratory and field research, has contributed to scientific knowledge on the effects of very low temperatures on materials, the theory of heat transfer, techniques of snow compaction and removal, and other developments for expediting construction and reducing the cost of bases in the Cold Regions.

This publication, the first of its kind for practical engineering application, provides the basic data required by Civil Engineer Corps officers and civilian personnel concerned with the design, construction, maintenance, and operation of facilities and equipment in such areas.

J.R. PERRY
RADM (CEC) USN
Chief, Bureau of Yards and Docks

TO USERS OF THIS TECHNICAL PUBLICATION

This is one of a series of Technical Publications prepared by the Bureau of Yards and Docks as concise guides to approved practices, procedures, instructions, and methods for construction, maintenance, and operation of naval shore facilities.

The TP series is planned to cover all administrative and technical operations for which this Bureau is responsible.

The engineering TP's are designed to supplement, but not to replace, the standard handbooks and similar sources of technical information. The TP's present in some detail the special phases of practices and standards that are considered most effective and best adapted for use by naval shore activities.

In many subject areas, the Technical Publications represent the Bureau's initial effort to document practices that have evolved and become generally accepted through traditional application.

It is anticipated, therefore, that the quality and usefulness of these Technical Publications will steadily increase as they undergo thorough field tests.

Suggestions for improvement will be welcomed and should be forwarded to the Chief, Bureau of Yards and Docks, via channels.

Requests for additional copies of this publication should give the TP number as well as the title and should be addressed to the District Publications and Printing Office.

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FOREWORD

This publication, which is divided into four chapters, provides guidance to Bureau and field personnel engaged in the planning, design, construction, alteration, repair, and maintenance of facilities in areas of extremely low temperatures.

Chapter 1 presents general information relating to responsibilities and data for recognizing and evaluating control factors imposed by environments existent in the Cold Regions.

Chapter 2 contains technical data useful in the development of engineering design for low-temperature areas.

Chapter 3 presents information essential to the accomplishment of construction or development projects in the Cold Regions.

Chapter 4 is devoted to the maintenance and repair facilities and engineering equipment in cold areas.

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ACKNOWLEDGMENTS

Figure or Table	*Source*
Figures 2A2-5, 2A2-12, 2A2-13, 2A7-9	*Soil Mechanics, Foundations, and Earth Structures*, Gregory P. Tschebotarioff, McGraw-Hill Book Company, Inc., 1951.
Tables 2A8-6, 2A8-8	*Heat Transmission*, William McAdams, McGraw-Hill Book Company, Inc., 1933 and 1942 editions.
Figure 4A1-4	Detroit Arsenal, Department of the Army, Center Line, Michigan.
Figure 4A2-4	Perfection Stove Company, Cleveland, Ohio.
Figures 4A2-3, 4A2-5	Corps of Engineers, US Army, Engineer Research and Development Laboratories.
Figure 4A2-6	Stewart-Warner Corporation, Indianapolis, Indiana.

CHAPTER 1. THE COLD REGIONS

PART A. INTRODUCTION

Section I. GENERAL

IA1.01 PURPOSE AND SCOPE

1. PURPOSE. This publication has been prepared by the Bureau of Yards and Docks as a compact and practical handbook on construction in cold areas. It is intended for the use of technically trained military and civilian personnel who are responsible for the design, construction, maintenance, and operation of engineering projects in the Cold Regions.

2. SCOPE. Presented herein are the special criteria applicable to the practices and techniques of engineering work in the Cold Regions. Also presented are the policies and responsibilities of other bureaus and offices insofar as they affect this Bureau's performance of its functions.

All personnel concerned should have at their disposal the standard works listed below, or their equivalent. Material contained in these handbooks has not been duplicated in this publication, except for certain modifications or extensions that are required for application to the Cold Regions. They are *Handbook of Engineering Fundamentals*, by Eshbach; *General Engineering Handbook*, by O'Rourke; *Mechanical Engineers' Handbook*, by Marks; *Mechanical Engineers' Handbook*, by Kent; *American Civil Engineers' Handbook*, by Merriman and Wiggin; *Electrical Engineers' Handbook*, by Pender, Del Mar, and McIlwain; and *American Society of Heating and Ventilating Engineers Guide*.

IA1.02 GENERAL AUTHORITY AND RESPONSIBILITY

By authority vested in it by *Navy Regulations*, the Bureau of Yards and Docks is responsible for the planning, design, construction, alteration, development, cost estimates, and inspection of public works and public utilities at all shore activities of the Naval Establishment. This Bureau also is responsible for the technical control of the alteration, repair, and upkeep of public works and public utilities, and the operational standards and procedures pertaining thereto.

IA1.03 SOURCE MATERIAL

1. REFERENCES. Publications from which useful data have been gathered in the preparation of this publication and that have been used directly or indirectly as source material, as well as other publications that may be of value when more detailed information is desired, are listed in the Bibliography and the References.

2. TERMINOLOGY. In order to clear up possible confusion resulting from vagueness and differences in the meaning of words, particularly with regard to the local terms used by natives in the Cold Regions, several definitions of uncommon terms are given. The text follows the usage most common to the Military Services. Acceptable military terminology of terms not used in the text is given in Appendix A, Glossary.

3. GEOGRAPHICAL ZONES. For the purpose of this publication, the Cold Regions are considered to include the North Pole and South Pole areas, commonly termed the Arctic and Antarctic. Detailed statistical data pertaining to specific areas have been grouped according to area in Appendix B, The Arctic.

4. TABLES. To increase the usability of this publication, tables of physical constants and measurement conversion factors, adapted from compilations of the Office of Naval Research, September 1953, are given in Appendix C.

IA1.04 DEFINITIONS

1. ARCTIC. On the basis of temperatures, the

Arctic is considered to include these areas: (a) the area lying north of the boundary fixed by the isotherm of 50° F (10° C) for the warmest month, or the isotherm of 14° F (−10° C) for the coldest month; (b) areas having a mean temperature of 32° F, or below; and (c) all areas where the sum of the average temperature in degrees centrigrade of the warmest month plus one tenth of the temperature of the coldest month is less than 9° C (Nordenskjoldwall formula used by the Soviet Union).

Each of the following four definitions of the term Arctic is valid, the choice depending on the type of engineering problem to be solved.

(1) That region north of the tree line (approximately along the 50° F summer isotherm), or the area where cold (excluding other inhibiting factors, such as sterility of soil, moisture, and wind) precludes tree growth.

(2) Areas with large seasonal variations in duration of daylight and darkness, such as all areas north of lat 66° 33′ N (difference between 90° and the maximum northerly declination of the sun).

(3) Areas where there are water areas on which ice acts as a barrier or is a hindrance to all navigation (not related to static global areas), these ice areas persisting from time to time in various high latitudes so that they present more or less constant problems.

(4) Areas distinguished by such factors as the extent of permanently frozen ground or combinations of extreme cold and high winds.

2. SUBARCTIC. The Subarctic is defined in terms of temperature as areas where the mean temperature for less than four months is higher than 50° F (10° C) and the mean temperature for the coldest month is less than 32° F (0° C).

3. COLD REGIONS. The term Cold Regions, as used in this publication, includes the Arctic, Antarctic, and Subarctic. The Cold Regions are defined as (a) areas adjacent to present shorelines where action of the sea, whether frozen or containing moving ice floes, is a controlling factor in the engineering design of a shore facility or the logistics essential to accomplishment of a mission; (b) areas where only frozen ground or water is present in the superficial covering of the earth's surface, except for a very definite active zone; (c) areas of permanently frozen ground containing localized thawed zones; (d) areas where permanently frozen ground occurs only in islands, lenses, stringers, or strata; and (e) areas that may have temperature ranges of −95° F to 100° F.

Section 2. BUREAU OF YARDS AND DOCKS RESPONSIBILITIES

1A2.01 GENERAL RESPONSIBILITIES

The responsibility of the Bureau of Yards and Docks for advanced bases, public works, and public utilities at naval shore activities includes such facilities in the Cold Regions. In carrying out its overall responsibility for such facilities, this Bureau provides technical guidance to management control bureaus and field activities, as well as to architectural-engineering and engineering studies contractors.

1A2.02 SPECIFIC RESPONSIBILITIES

1. DESIGN AND CONSTRUCTION. This Bureau, in connection with its functions in the Cold Regions, is responsible for engineering investigations and the preparation of surveys, drawings, and specifications used in planning, development, design, construction, alteration, and cost estimating for advanced bases, as well as for public works and public utilities at all naval shore activities.

2. REPAIR AND MAINTENANCE. This Bureau also is responsible for engineering studies and the preparation of surveys, drawings, specifications, and standards used for the alteration, repair, and upkeep of public works and public utilities facilities of the Navy, including those in the Cold Regions.

1A2.03 FIELD RESPONSIBILITIES

1. BUREAU REPRESENTATIVES. The Chief of the Bureau of Yards and Docks has delegated certain specific phases of his authority to field representatives of the Bureau, namely, Directors, Overseas Divisions, Bureau of Yards and Docks; Officers-in-Charge of Construction; and District Public Works Officers.

a. *Director, Overseas Division.* The Director, Overseas Division, is responsible for the administration, within defined geographical areas, exclusive of Naval Districts, of technical programs of the Bureau of Yards and Docks pertaining to the construction, maintenance, and operation of overseas shore activities. This includes, on request of the cognizant command, engineering advice, engineering service, and planning assistance to Fleet, Force, Type, and Base Commands. The Director, Overseas Division, also furnishes engineering services, assistance in procurement matters, assistance in personnel matters, and planning assistance to Naval Construction Forces; administers real estate matters, as assigned; and provides assistance in the procurement and shipment of materiel and personnel from the Zone of the Interior. As appropriate, these responsibilities apply to the design, construction, maintenance, and operation of facilities in the Cold Regions.

b. *Officer-in-Charge of Construction.* It is the responsibility of the Officer-in-Charge of Construction to represent the Chief of the Bureau of Yards and Docks in connection with specific construction contracts and to supervise the construction of civil works for other bureaus and offices of the Department of the Navy. Similar responsibilities, under the cognizance of this Bureau, are discharged by an Officer-in-Charge for architectural-engineering contracts and types of contracts that do not involve construction.

c. *District Public Works Officer.* The District Public Works Officer is responsible for the administration, within his Naval District, of the technical programs of the Bureau of Yards and Docks pertaining to design, construction, alteration, inspection, repair, maintenance, and administrative supervision of operation of public works and public utilities facilities, including those at shore activities in the Cold Regions. He is also responsible for this Bureau's program with regard to real estate, transportation, and construction and weight-handling equipment, as assigned.

2. PUBLIC WORKS OFFICER. The Public Works Officer (PWO) has such authority as may be delegated and such responsibility as is assigned to him by his Commanding Officer for the administration and operation of the Public Works Department. The PWO, who is a Civil Engineer Corps officer, is assigned the responsibility and delegated the authority to apply the professional and technical standards and the legal restrictions promulgated by the Bureau of Yards and Docks in accomplishing the public works tasks assigned to him by his Commanding Officer. Such tasks usually include maintenance and operation of public works and public utilities in the Cold Regions.

1A2.04 RELATIONSHIP WITH OTHER BUREAUS, OFFICES, AND GOVERNMENT AGENCIES

Design and construction of facilities at naval shore activities in the Cold Regions, which are the responsibilities of the Bureau of Yards and Docks, must conform to the operating requirements defined by directives and orders of the management control bureaus and offices. In general, management bureaus at shore activities direct the operation of these facilities and finance their maintenance.

PART B. CHARACTERISTICS OF COLD REGIONS

Section I. ENVIRONMENTAL FACTORS

1B1.01 LIMITATIONS

Prevailing natural forces definitely limit man's activity in the high latitudes of the world. Conquest of these areas, therefore, requires recognition and sufficient understanding of the limitations, so that adaptation to, and modification of, restricting natural forces can be successfully undertaken. The restricting natural forces are known as environmental factors. The descriptions of cold that follow are intended to aid in the understanding of these factors as they pertain to the Cold Regions.

1B1.02 PHYSICAL EFFECTS OF COLD

1. CONDENSATION. As air is cooled it loses its capability to retain moisture. It is natural, therefore, that the Polar Regions have a comparatively dry atmosphere. Condensation, as warm and cold air meet, is manifested by low coastal fogs and localized steam fogs or mists above rivers, lakes, and heated structures, and around machines, men, and animals. Mirages are common because the differential density of air prevents light passing through the boundary between a layer of cold surface air and warmer air above. The consequent bending of light rays produces images, often inverted and appearing low or high, of objects 100 miles or more distant.

2. VISIBILITY. In the absence of fog, visibility in the clean, cold air of high latitudes is exceptionally good. Normal horizontal visibility of 50 miles is ordinary and under special conditions may be as high as 150 miles. However, the lack of contrast caused by the barrenness of land and sea and the long shadows resulting from more or less horizontal rays of sunlight deceive judgment of actual distances. The extreme whiteness and magnitude of snow and ice cause a great deal of glare when the sun is above the horizon and the sky is overcast.

3. SOUND. Sound travels with great clarity in the dry, cold air. Sharp sounds can be distinctly heard at distances of 10 miles or more.

4. WIND. Wind at low temperatures is a serious handicap to human activity because it rapidly dissipates body heat, and blowing snow greatly reduces visibility. The latter is particularly true in high latitudes that have no natural windbreaks across barrens and icepacks. Winds of 15 mph or more will lift the dry, light snow of the Polar Regions high enough to obscure buildings; 30-mph winds may whisk surface snow 50 to 100 feet in the air in the form of clouds.

1B1.03 WIND CHILL

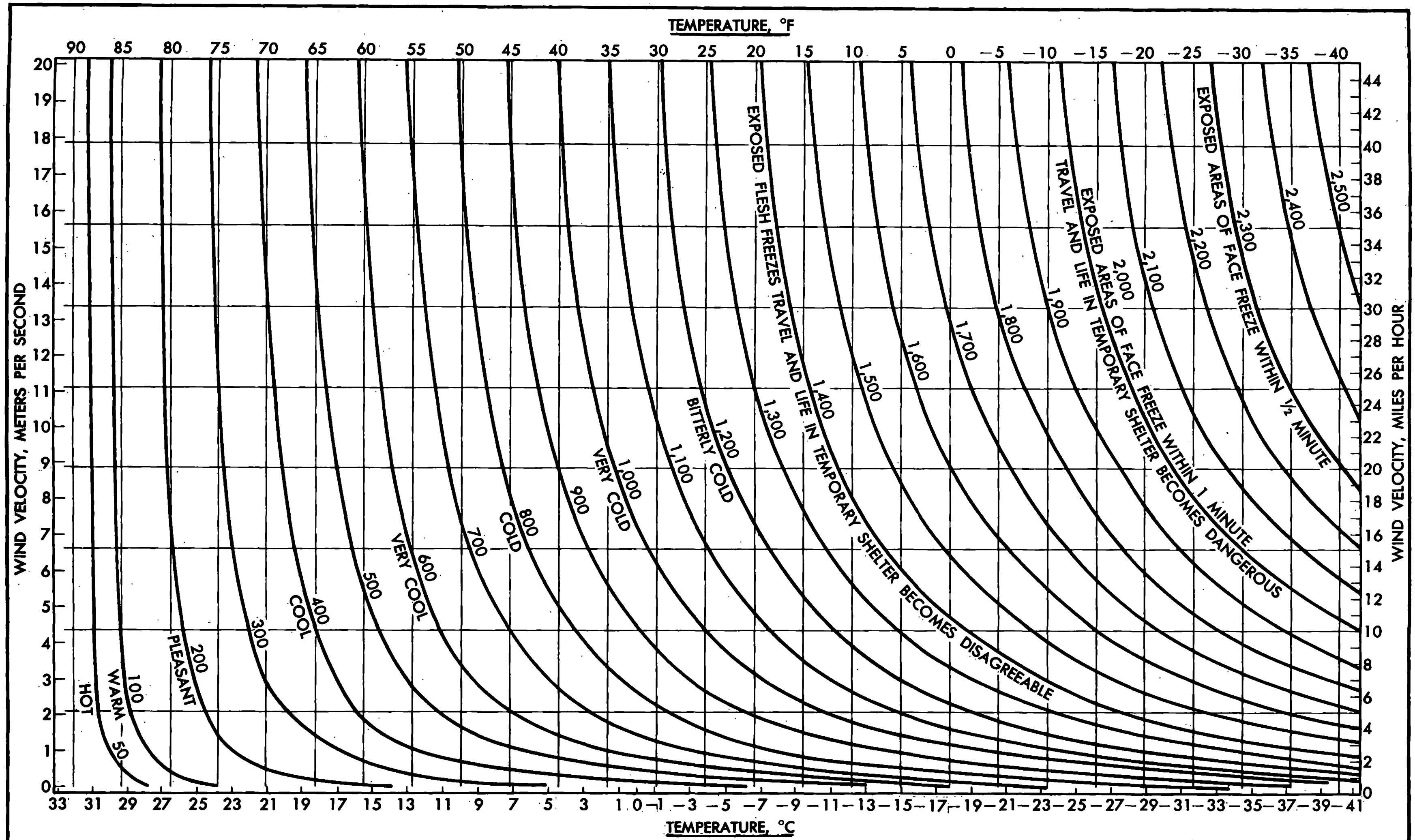
The cooling effect of wind below freezing temperatures is very pronounced. In 1939, Doctor Paul A. Siple called this "wind chill" and developed an empirical formula for measuring its effect in terms of exposed area, temperature, and wind, as follows.

$$K = (\sqrt{100W} + 10.45 - W)\ (33 - T)$$

K = total cooling, kg cal/sq m/hr
W = wind velocity, m/sec
T = temperature of air, °C

The formula is applicable to measurement of the sensible cooling of humans. As more reliable data have become available, the formula has been refined and applied to the design of climatic zone charts of the world, clothing effectiveness and, to a limited extent, to the cooling rates of machine parts. The curves in Figure 1B1-1 give the values of wind chill in terms of relative human discomfort.

Although the wind chill curve is useful, it does not consider all the means by which humans exchange heat with the atmosphere. It should be used, therefore, with the common-sense understanding of cold environments. An internal combustion engine, for example, may falter at −40° F



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 1B1-1

Wind Chill Curve

and an individual at $-50°$ F. Yet differences in individuals because of age, race, acclimatization, diet, physical condition, mental attitude, and especially degree of muscular activity may allow one to feel comfortable while another has difficulty adjusting himself to the weather.

Section 2. NATURE OF COLD REGIONS

1B2.01 GENERAL

1. GEOGRAPHY. Both the North Polar and South Polar Regions are located in high latitudes dominated by cold, snow, and ice; otherwise, there is little geographic similarity between them. The North Polar Region (Figure 1B2-1) is a central sea surrounded by continental land; the South Polar Region (Figure 1B2-2) is a continent (Antarctica) encircled by the sea. Even the ice itself tends to develop forms peculiar to each region. The Arctic Ocean of the North Polar Region, as a body of water, absorbs, retains, and radiates heat; but the Antarctic, being an ice-covered land mass of the South Polar Region, acts as a cold reservoir, the ice shielding the underlying land and water from direct insolation.

2. INFLUENCE OF LATITUDE.

a. *Seasons.* The higher the latitude, the longer the winters and the shorter the summers. Winter and summer, with a wide differential in temperature, are well defined, but autumn and spring are short and not so distinct. (Topography may slightly modify this tendency for particular areas.) Generally, spring is late and quickly merges into summer, with the melting of snow and ice and the breakup of river, lake, and coastal (fast) ice as longer days give more sunshine. Conversely, autumn arrives early, as shorter days give less sunshine; temperature decreases, snow flurries are frequent, and ice begins to form along coasts and on rivers and lakes.

b. *Length of Days.* At high latitudes (above the Arctic and Antarctic Circles) the length of day and night varies greatly during winter and summer because of the inclination of the earth's axis as it rotates around the sun. The sun remains above the horizon 6 months (summer) and below the horizon 6 months (winter). This results in the so-called 6 months of darkness (winter) and 6 months of light (summer) in the Polar Regions. The sun, for example, does not appear above the horizon at the Arctic Circle on December 21 nor at the Antarctic Circle on June 21, except for mirages, in which extreme low temperature and dense ground air bend the light rays and may make the sun appear visible as far as 60 miles above the Circles. Unless the skies are overcast, however, these are not periods of total darkness but of twilight, because a considerable quantity of light from the stars, moon, and auroras filters through the cold, clean air and is reflected by the total surface cover of snow and ice. Possible hours of daily sunlight above lat 65° N may be determined from Figure 1B2-3.

c. *Magnetic Fields.* The earth's magnetic field, at distances well removed above the surface, is roughly that of a magnet at the earth's center oriented along the axis of two auroral zones. The northern auroral zone is a belt about 10° of latitude in width located approximately 1,200 miles radially from a center near Etah, Greenland, passing near the whole north coast of Europe and Asia and dipping south through Iceland, Alaska, and Canada. A similar zone exists in the Antarctic, with its radial center at lat 78° 30′ S and long. 111° E. These zones are believed to exist because of charged particles, possibly electrons, emanating from the sun. They are deflected on entering the earth's magnetic field so that they tend to spiral down and around the lines of force, striking the ionosphere night and day. The visible effect of the particles striking the ionosphere is the aurora, called Aurora Borealis in the Northern Hemisphere and Aurora Australis in the Southern. They can be seen directly overhead nearly 100 percent of all clear, dark nights. Ionospheric storms, created by variable auroras, disturb radio wave propagation to the extent that high-latitude communication blackouts are not uncommon.

d. *Polar Seismic Belt.* The seismic belt in the North Polar Region (Figure 1B2-4) is the Mid-Atlantic Ridge. For the most part, it is an irregular submarine mountain range extending northward from south of Iceland past Spitsbergen and along the European side of the Polar Basin to the Lena River, where it may join the Kharaulakh and Khayakhak Mountains. Not all the epicenters shown on the map have been plotted exactly, but they follow the pattern of seismic disturbances.

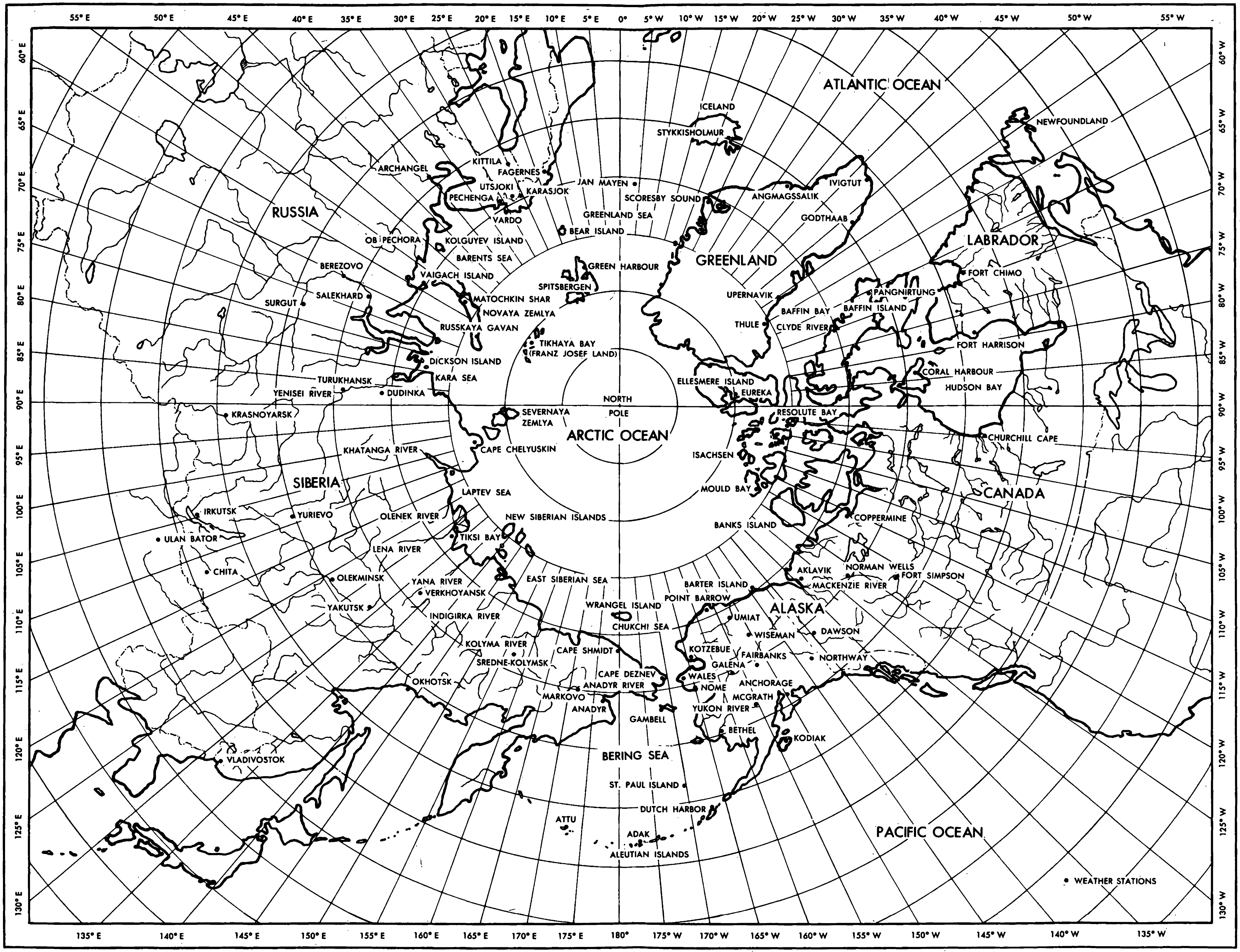


FIGURE 1B2-1

North Polar Region

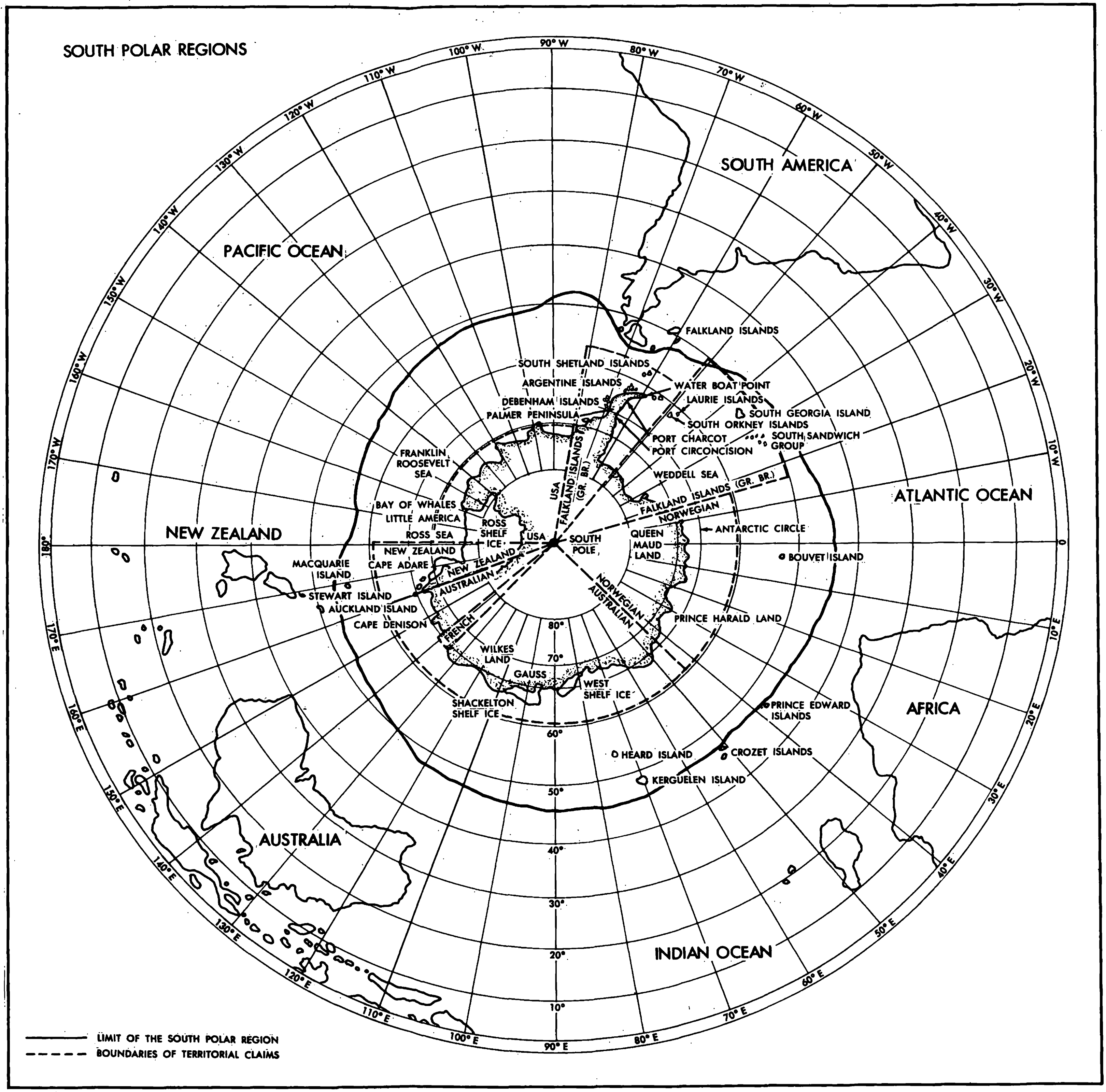


FIGURE 1B2-2

South Polar Region

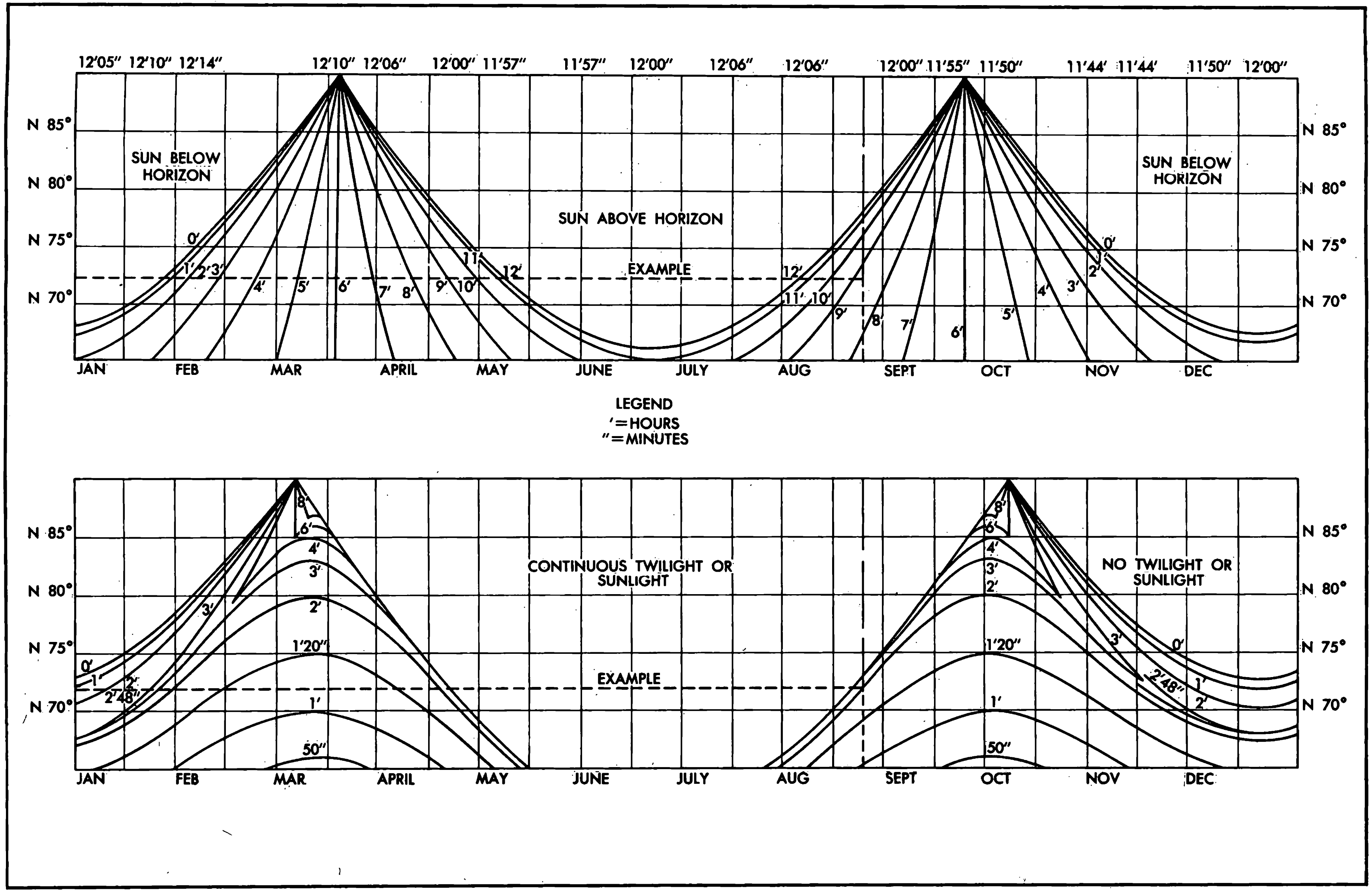


FIGURE 1B2-3

Semiduration of Sunlight and Duration of Twilight (Ref. 1)

The epicenters near Bering Strait belong to the circum-Pacific seismic belt.

1B2.02 GEOLOGY

1. **GENERAL.** Geological knowledge of the Polar Regions is scant. However, the geological pattern of the earth's history, as outlined in Table 1B2-1, applies to the Polar Regions as well as to better known areas. Less than 10 percent of the North Polar Region has been investigated in detail geologically and then only in widely separated areas. Nearly all the meager knowledge of South Polar geology is physiographic in character.

TABLE 1B2-1

Geologic Time Scale

Era		Period	Characteristic life	Total estimated years
Cenozoic	Quaternary	Recent Pleistocene	Man	1,000,000
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Mammals and modern plants	70,000,000
Mesozoic		Cretaceous Jurassic Triassic	Reptiles and cycad-like gymnosperms	200,000,000
Paleozoic		Permian Carboniferous	Amphibians and giant club mosses	500,000,000
		Devonian	Fishes	
		Silurian Ordovician Cambrian	Invertebrates	
Pre-Cambrian or Archean (Europe)	Proterozoic (N. America)	Keweenawan Huronian	Primitive invertebrates and algae	2,000,000,000
	Archeozoic (N. America)	Timiskaming Keewatin	None known	

2. **NORTH POLAR REGION.** Much of the North Polar Region is underlain by Pre-Cambrian rocks of shield character. Four shields have been recognized: Canadian, Greenland, Russian Baltic, and Angara. (See Figure 1B2-5.) They face and for the most part surround the Arctic Ocean and are separated by intrashield orogenic (mountain-building) belts, which project into the Arctic Ocean and are covered by it. The orogenic belts are linear intrashield areas of weakness or mobility, as opposed to shields, which are the great stable areas of the earth's crust. The shields, then, are the underlying elements on which rest various types of rocks ranging from Paleozoic to recent times. Except for the Alaskan orogenic belts and their continuation into Anadyr Peninsula in Siberia (the Alaska-Siberia Region), the Polar Basin is girdled by the four shields.

a. *Alaska-Siberia.* In contrast to most of the Arctic, which is the Atlantic type, the Alaska-Siberia Region is the type known as Pacific marginal. Its geologic history, therefore, is different. It has been the site of geosynclinal (depositional) and orogenic (including volcanism) activity from early Paleozoic to the present. It was, therefore, a region of mountain chains and volcanic islands that would have served effectively as a migration route both for land and shallow-water fauna.

b. *Atlantic.* In the Atlantic type of region, such as eastern North America and much of Arctic Eurasia, the structural lines of the earth's crust and the trend of the shore are divergent; that is, the shorelines follow the parallels and the structural lines the meridians. Arctic Eurasia is composed of seven stable segments separated by seven weaker ones (Figure 1B2-6). At one time, all of these masses were connected and formed the old Eurasian continent. They were separated by block faulting during late Silurian or early Devonian crustal movements. The projecting stable land masses are horsts, or positive elements; the weaker sunken segments are graben, or negative elements. The horsts have remarkable symmetry in their distribution, forming peninsulas and related offshore islands, all of which exhibit a geologic structure similar to the mainland. Examples of these connections and symmetry are Vaigach and Novaya Zemlya Islands, north of the Urals; Severnaya Zemlya, north of Taimyr Peninsula; and New Siberian Islands, north of Tas-Khayakhtakh Mountains, an extension of Cherski Range.

Spitsbergen is composed of old and recent rocks, which include Pre-Cambrian, early and late Paleozoic, Jurassic, Cretaceous, Tertiary, and Quaternary. It has been subjected to at least two crustal movements accompanied by faulting, folding, and volcanism, and finally to glacial erosion and deposition. The geologic structure is shown in Figure 1B2-7.

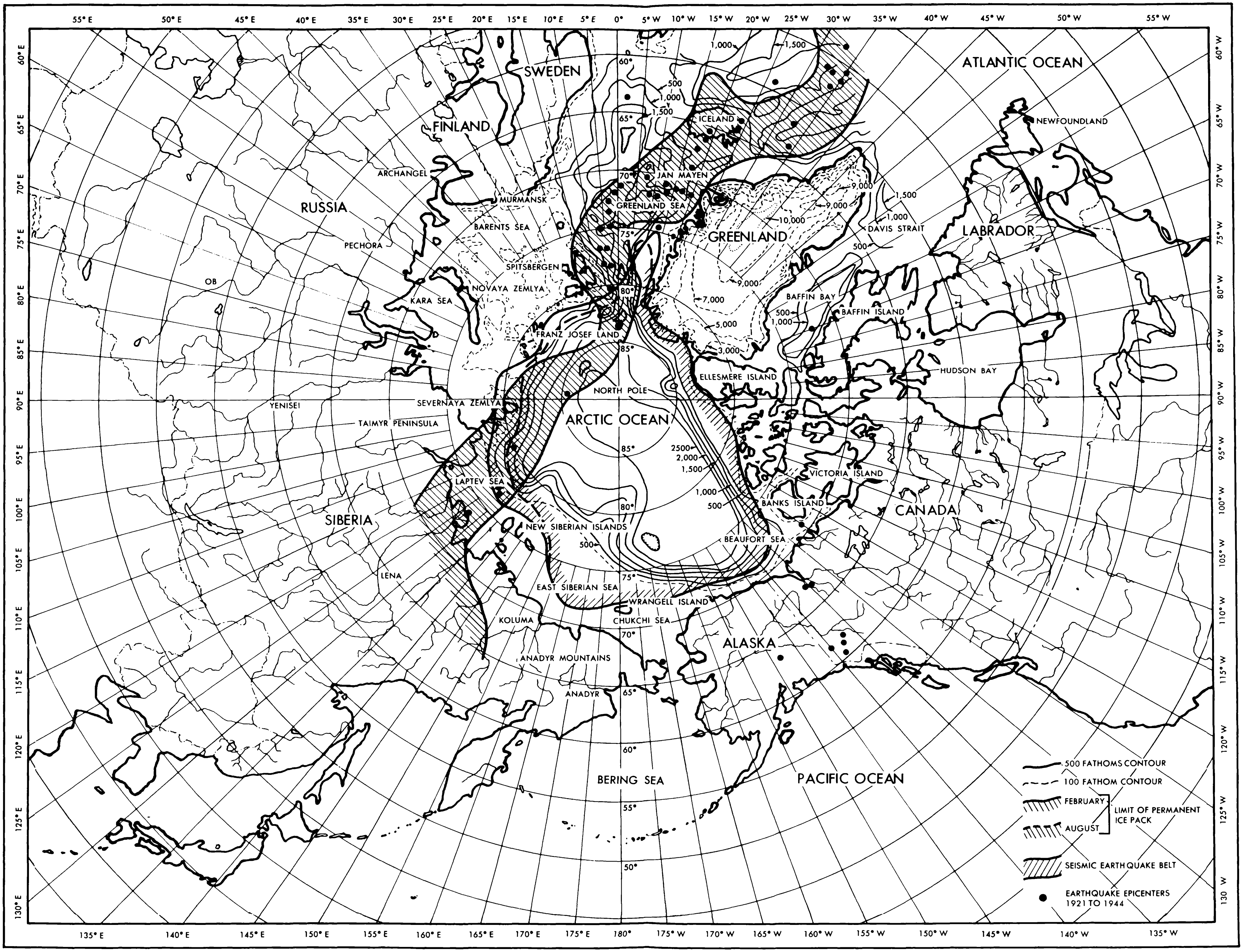


FIGURE 1B2-4

North Polar Region—Earthquake Belt and Epicenters

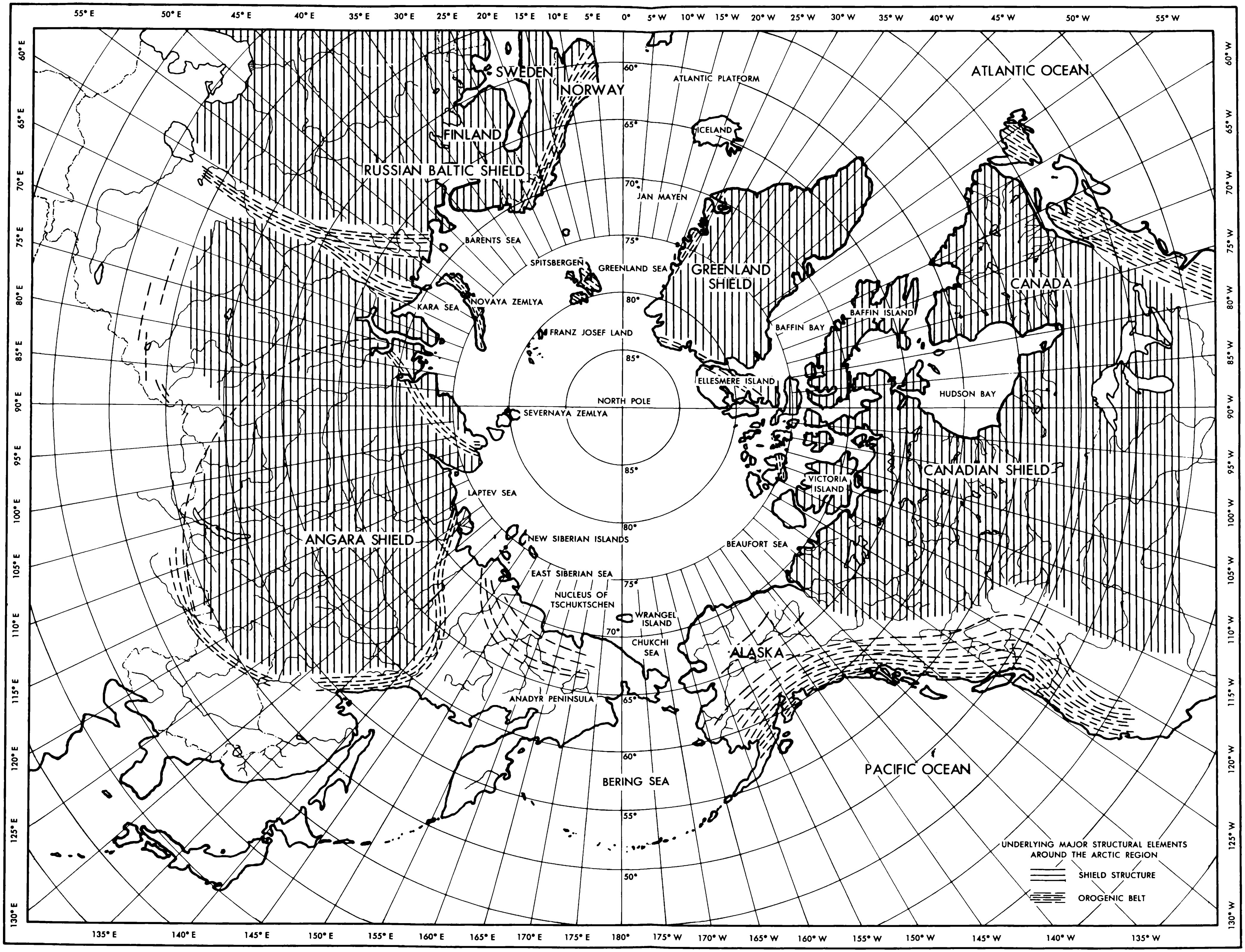
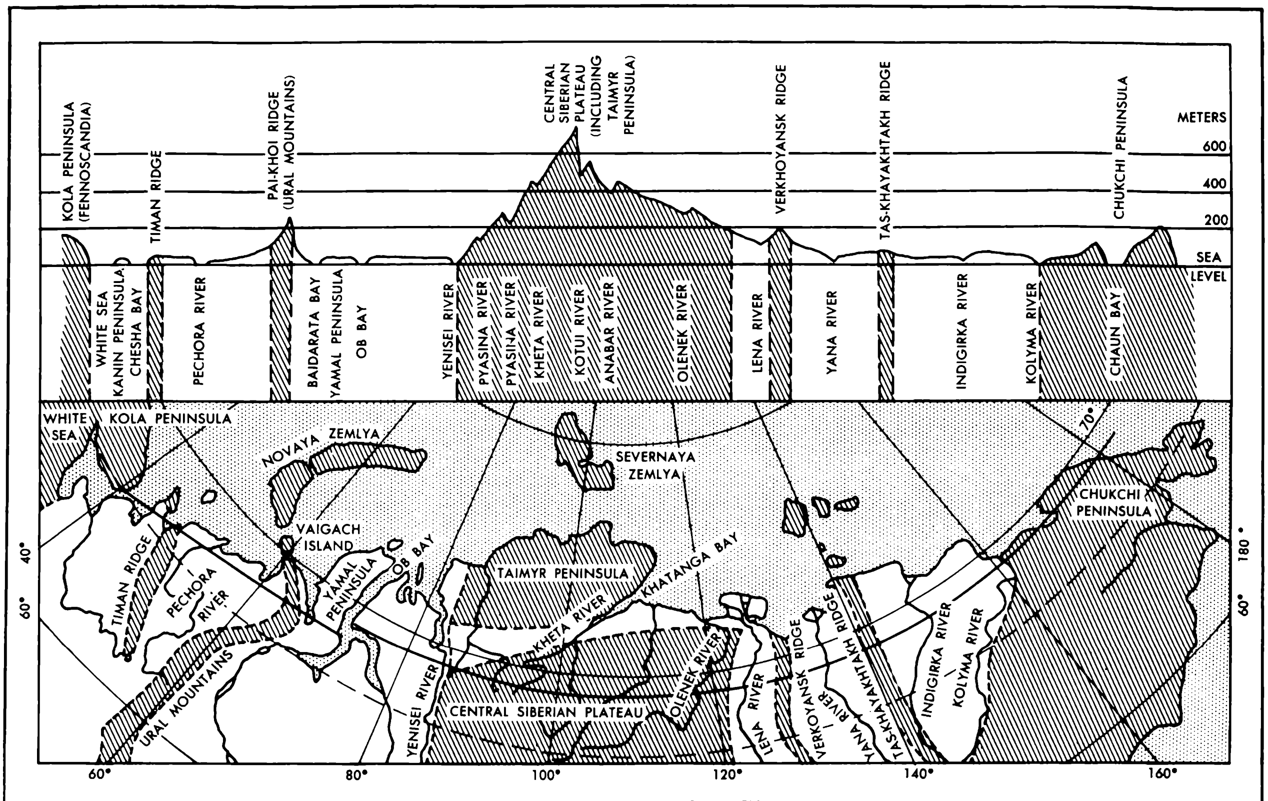


FIGURE 1B2-5

North Polar Region—Major Underlying Structural Elements



DIAGRAMMATIC PROFILE SHOWING RELATION OF HORSTS AND GRABEN (POSITIVE AND NEGATIVE ELEMENTS) IN ARCTIC EURASIA. ORIGINALLY BOTH ELEMENTS WERE PART OF SAME GEOLOGICAL BODY—THE OLD EURASIAN CONTINENT—NOW SEPARATED THROUGH SINKING OF INTERMEDIATE SECTIONS ALONG ZONES OF FAULTING. VERTICAL SCALE GREATLY EXAGGERATED.

FIGURE 1B2-6

Geologic Structure of Arctic Eurasia

3. SOUTH POLAR REGION. The outstanding difficulty confronting geologists in the South Polar Region is the vast ice sheet overlaying Antarctica and hiding its structure. Victoria Land and Palmer Peninsula, the best known of the South Polar Regions, present divergent structures. The relationship between them is still not solved, but several suggestions have been made, two of which are considered the more probable.

The first is that the whole of Antarctica, with the exception of Palmer Peninsula, is a plateau, the underlying element of which is a peneplained shield on which lie younger horizontally bedded rocks intruded by sills and dikes; that a great horst crosses the plateau from Victoria Land to the region southwest of Weddell Sea; and that the Andean folds, fringing the Pacific Ocean, skirt the plateau, passing north of Edward Land in an arc toward New Zealand.

An alternate suggestion deserving equal consideration is that the horst of Victoria Land is a continuation of Palmer Peninsula and that folding of the latter formed the hard resistant shield of the plateau and a line of great faults.

1B2.03 GLACIERS

1. GENERAL. The type and distribution of glaciers, which are slow-moving fields or bodies of ice, are influenced by elevation, latitude, climate, and typography. The two fundamental types are valley glaciers and ice sheets.

Valley glaciers are ice rivers flowing into and through valleys in mountainous cold areas. Hubbard Glacier in Alaska is a typical valley glacier.

Ice sheets are expansive areas of ice spreading out in several or all directions from a center, covering valleys or plateaus at high altitudes. Small ice sheets are called icecaps. The most important

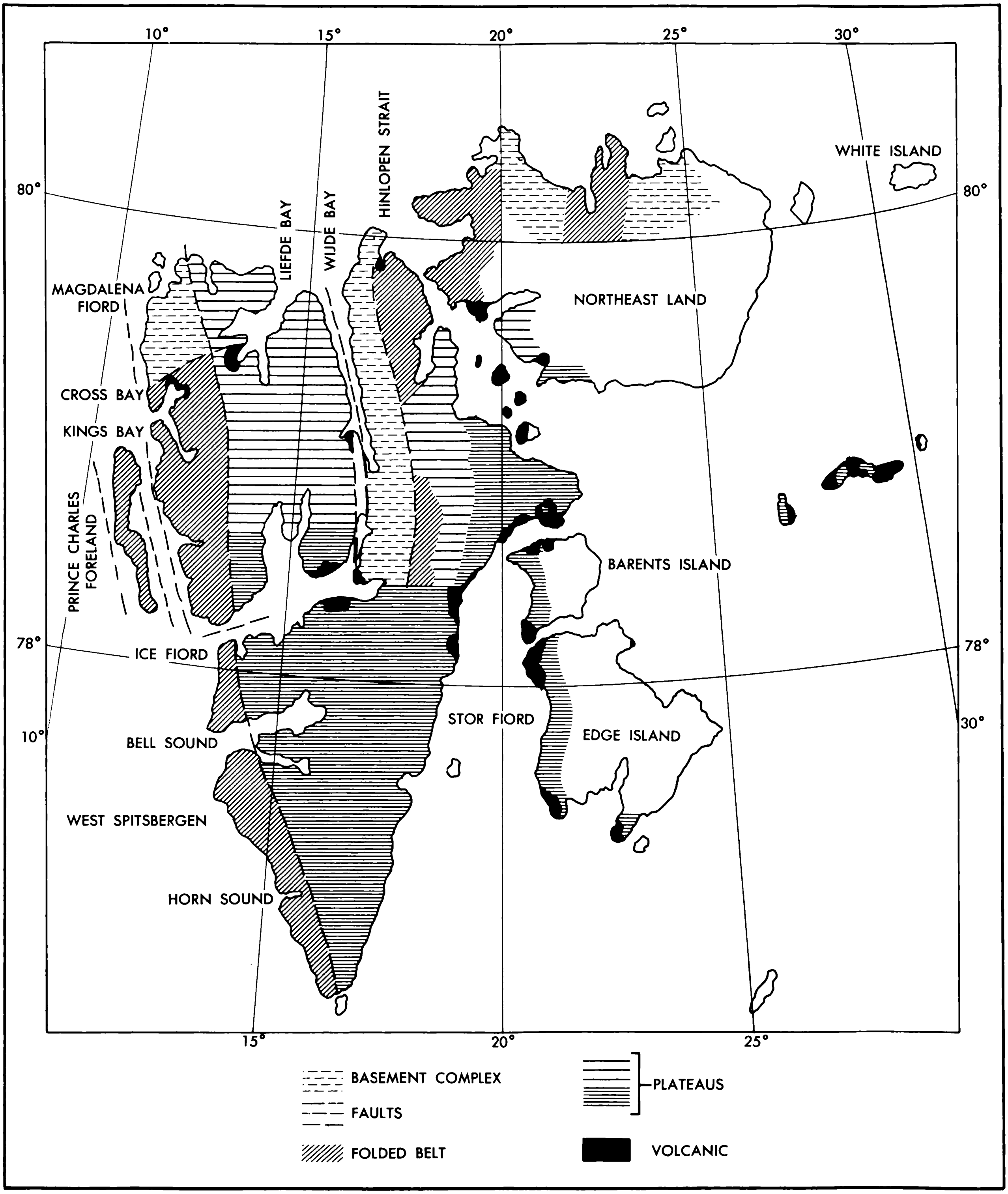


FIGURE 1B2-7

Geologic Structure of Spitsbergen

ice sheets are those covering Greenland, commonly called an icecap, and the Antarctic. Many icecaps are found on the Canadian Arctic Archipelago.

Piedmont glaciers are intermediate between valley glaciers and ice sheets. As piedmont implies, these glaciers are expanded extremities of valley glaciers. Malaspina Glacier on the south coast of Alaska is a piedmont glacier.

2. EFFECTS OF GLACIATION. Glaciers, as agents of erosion and deposition, have done both constructive and destructive work. The extensive glaciation of the last Ice Age influences much of the economic development of the Arctic. For example, in areas where soil and weathered rocks have been removed, prospecting has been made easier, although quantities of valuable minerals may have been carried away during glaciation. In areas of deposition, glacial drift has covered the bedrock so completely in places that prospecting has been difficult if not impossible. But, as in the case of erosion, deposition has also been a help: glacial deposits in some of the numerous late-Pleistocene lakes are excellent agricultural soil; outwash and beach gravel are principal sources of construction materials and road materials; and deposits such as porous sand and gravel form excellent reservoirs to store subsurface water, which has aided both agricultural and industrial development.

1B2.04 PERMAFROST

Permafrost (permanently frozen soil) is a phenomenon peculiar to the Cold Regions of the Northern Hemisphere. It extends to lower latitudes in the eastern than in the western sections of the continents. Figure 1B2-8 depicts the southern boundary of permafrost. Within this area, in the Subarctic, are small isolated areas in which permafrost is not present because of localized climatic conditions. Permafrost depth varies from zero thickness at its southern boundary to more than 1,300 feet near the Arctic Ocean. The following factors are related to the presence of permafrost.

(1) Low mean annual temperature of $-21°$ to $-25°$ F.

(2) Impermeability to water.

(3) Overlying active surface layer (1 to 3 feet thick) usually subject to summer thawing.

(4) Effect on vegetation.

(5) Less depth (based on inconclusive evidence) in areas glaciated during the Ice Age.

(6) Current climatic conditions.

1B2.05 CLIMATOLOGY

Weather is the total effect of temperature, precipitation, and wind over a short period of time. Climate takes into account the average weather and its departures from the average over a long period. The weather at any particular time may be quite different from the general climatic elements that follow.

1. TEMPERATURE. Because days are shorter and the sun's rays strike the earth obliquely in the high latitudes, less heat is absorbed than in the lower latitudes. Consequently, the world's lowest mean annual temperatures occur in the Polar Regions. Local winds, topography, and proximity to large bodies of water modify local temperatures considerably. This is manifest because the coldest recorded areas in the Northern Hemisphere are more than 200 miles south of the Arctic Circle ($-80°$ F near the Alaska-Yukon border and $-90°$ F near Verkhoyansk, northeastern Siberia); yet the temperature at the North Pole seldom drops below $-50°$ F. Summer temperatures of 80° F in the shade have been recorded frequently in many places, and a record of 100° F in the shade was set at Fort Yukon, Alaska, on the Arctic Circle. In general, the Polar Regions are cold the year around, and the Subpolar Regions have warmer winters and cooler summers along coastal areas and extremely cold winters and warm summers in the interior areas. Local temperatures in the high latitudes vary considerably, often within a few hours. As a general rule, temperature may be considered to decrease about one degree for each 1,000-foot increase in altitude.

2. PRECIPITATION. Precipitation in the high latitudes is generally very light, ranging from 5 to 10 in. annually in most areas (14 to 18 in. in southern Baffin Island). Approximately half falls as snow (10 in. of snowfall equals about 1 in. of rainfall). Snow has been recorded every month of the year.

1B2.06 HYDROLOGY

Fundamentally, hydrology is the same in the Cold Regions as in the Temperate Zone. Insufficient technical data, however, and the effect of glaciers and permafrost, as well as extreme climatic and topographic variations of the Cold Regions, increase the difficulty of understanding Cold Region hydrology.

Although permafrost acts as an impervious layer, it affords storage and release of water from its active layer and from taliks. Glaciers and snow may retain one year's precipitation and release it partially or totally in a subsequent year. This, of course, disturbs the usual hydrological pattern of streamflow and precipitation runoff.

1. DESIGN STORM. Figure 1B2-9 illustrates the 1-hour rate of rainfall and the rate for shorter and longer intervals. It is believed that these intensity-duration relations are applicable to any Arctic or Subarctic region where either convergence or convection is the dominant and rain-producing factor. There is little chance that for storms of 20-year frequency the 1.2 curve will ever be exceeded in the northern Cold Regions north of the south limit of permafrost and south of the 50° F mean July isotherm. The curve designated as 0.2 is recommended for any location in the northern Cold Regions north of the 50° F mean July isotherm. (Ref. 2.) From the foregoing, the design storm for 20-year frequency can be estimated for areas with elevation less than 1,000 feet.

2. RUNOFF. Runoff is precipitation that has escaped the actions of interception, evaporation, transpiration, and deep seepage. Flowing from the earth's crust, runoff consists in part of water that has never been below the surface (surface runoff) and in part of water that has previously passed into the soil (subsurface runoff). Figure 2D2-2 shows the effect of temperature on the load of suspended material that may be carried by runoff. Although these data relate to the silt load of water, they are indicative of the glacial silt loads that may be found in some Subarctic waters.

1B2.07 THE ARCTIC

1. OCEANOGRAPHY.

a. *Polar Basin.* The North Polar Region (Figure 1B2-1) is predominantly maritime. Its principal feature, the Arctic Ocean, is a conical basin (the Polar Basin) that covers approximately 5,400,000 square miles, including the Greenland and Norwegian Seas. The egg-shaped bottom of the basin, eccentric to the North Pole, is about 15,000 feet deep near the eastern North American and Greenland shores. To the west is a narrow submarine continental shelf along the Canadian Arctic Archipelago and north coast of Alaska that increases in width to about 375 miles adjacent to Siberia. Within the Arctic Ocean are several archipelagoes and islands. Contiguous local water areas are the Barents, Kara, Laptev, East Siberian, Chukchi, and Beaufort Seas.

b. *Currents.* The Arctic Ocean receives cold fresh surface water from northward-flowing rivers of the North American and Eurasian continents and warm saline water at medium depths from the Atlantic Ocean west of Spitsbergen. The clockwise currents empty mainly into the Greenland and Norwegian Seas. Generally, there are three temperature layers: (a) 28.6° to 32° F down to 500 to 600 ft, with comparatively little salinity; (b) increase in temperature and salinity from this depth to about 2,500 ft; and (c) 30.6° to 32° F below this. Tides average from a few inches to 4 or 5 ft along the coasts, but in channels, fiords, and inlets they may reach 30 ft as the water piles up in the restricting narrows.

c. *Polar Ice.*

(1) *Extent.* Throughout the year approximately three-fourths of the Arctic Ocean is a frozen elliptical surface of pack ice impenetrable to navigation. The greatest density of the pack ice, called the Pole of Relative Inaccessibility, is at lat 83° 50′ N, long. 160° W. Although conditions vary yearly, during the winter about 90 percent of the ocean is covered with unnavigable pack and fast ice, which extends from the permanent pack to bordering coasts, seas, and bays by April or May. In July and August there is a brief period of about six weeks in which fast ice melts and floats out to sea, opening Arctic coasts to navigation.

Most of the ice in the Arctic Ocean is sea ice rather than land ice derived from glaciers and rivers. Its forms are many and diverse, depending on age and the influence of weather and ocean currents. It usually grows 5 or 6 ft annually to a maximum level thickness of 8 ft by the end of two years. This thickness is sufficient insulation to prevent further freezing on the underside. As the pack ice constantly moves with ocean currents, however, it splits and telescopes so that frequently it piles up 200 ft deep with very rough, jagged surfaces. Pack ice formed from water freezing between the splits or leads is smooth and may be extensive enough for aircraft landings.

(2) *Formation.* Because Polar seas have lower than average (35‰) salinity, ice begins

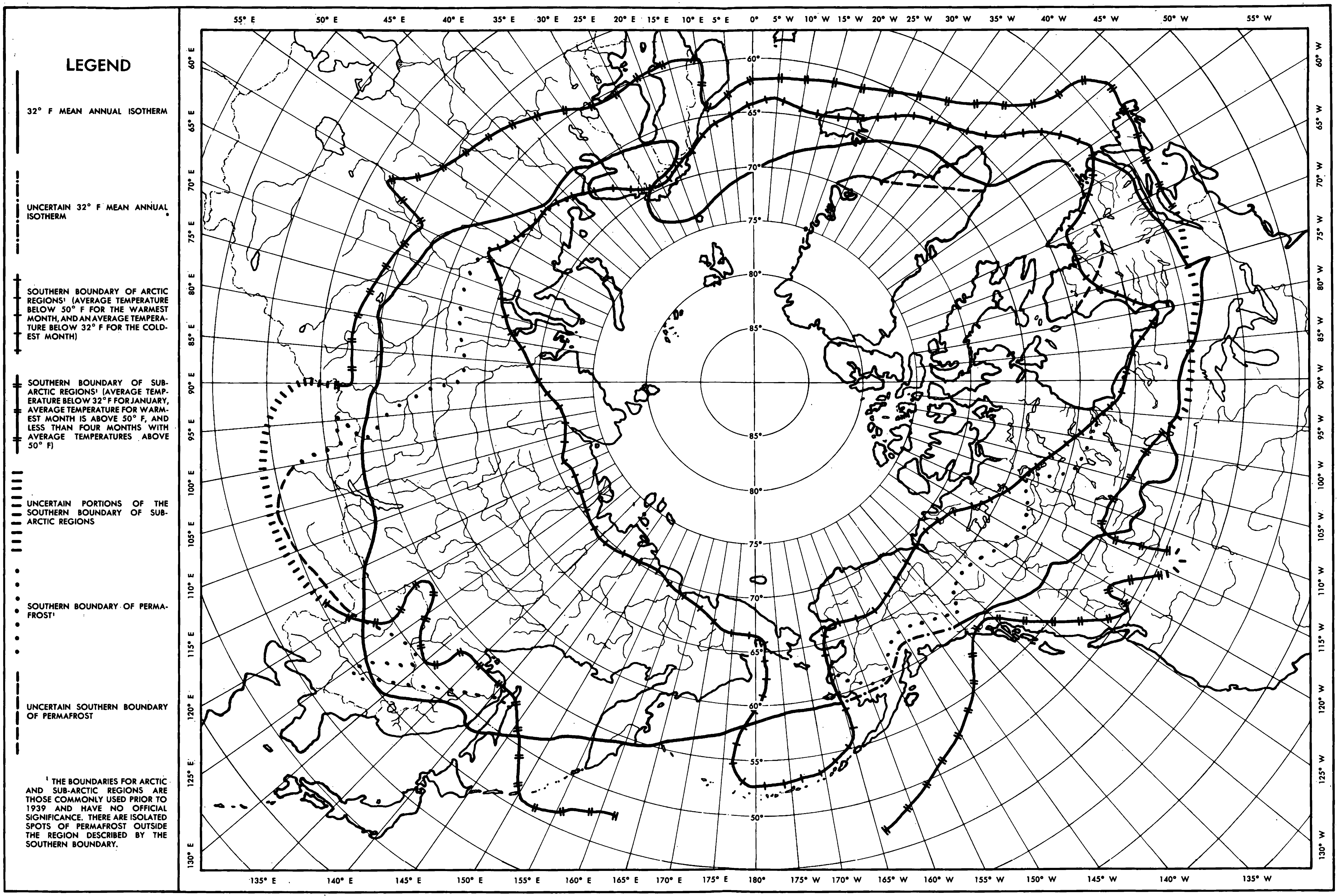


FIGURE 1B2-8

Arctic and Subarctic Regions

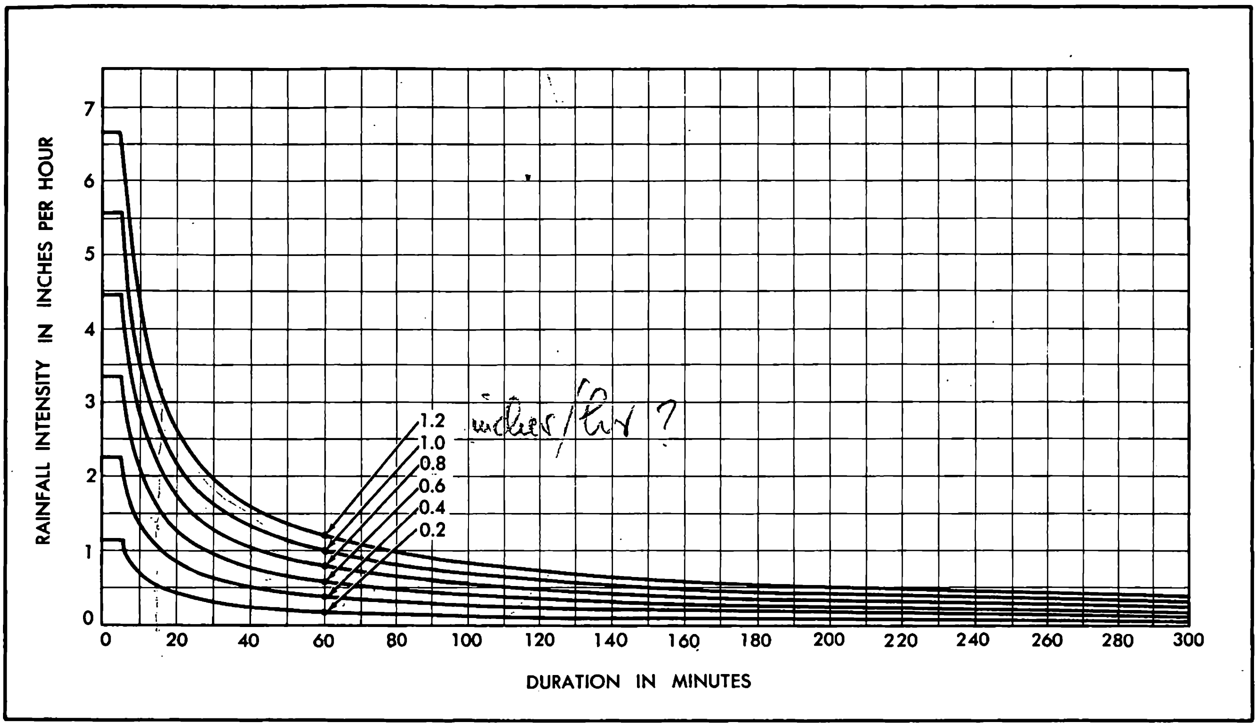


FIGURE 1B2-9

Intensity-Duration Relations in Arctic and Subarctic Regions (Ref. 2)

to form on the Arctic Ocean at a higher temperature than the usual 29° F for more temperate climates. At first, ice may be salt free. As ice crystals continue to grow, however, they entrap salt between them so that the ice melts on top during summer and pools of fresh surface water appear. The fresh water percolates through the remaining ice thickness, carrying salt with it. Ice aged a year or more, therefore, is not salty to the taste. The fresh surface water seeping downward refreezes on the bottom and causes an upward migration of debris frozen in the ice. This accounts for rocks, shells, and seaweed frequently seen on the ice surface.

(3) *Icebergs.* Icebergs in the Arctic, in contrast to those in the Antarctic, are irregular and more picturesque. Topography and calving, as well as temperature, are factors in determining their shape. Arctic bergs occasionally tower 200 to 300 ft above the surface and may measure five or more times as long from end to end. Because they float with about five sixths of their mass below the surface, their total height may be 1,200 to 1,800 ft. The proportion submerged varies according to moraine and air content.

Once freed from the fiords, the icebergs move out to open water and drift long distances with wind and current, but because of their relatively deep draft they are less affected by wind than is pack ice (Figure 1B2-10). Yet, in general, their southerly drift conforms closely to that of the pack ice, that is, through the East Greenland Current along eastern Greenland and the Labrador Current along eastern North America. The Labrador Current, especially, carries a vast number of bergs out of Davis Strait and past the eastern coast of Newfoundland into the Gulf Stream, where they finally melt.

In the Northern Hemisphere the number of icebergs reaches a maximum between March and early July, as does pack ice. It is then that icebergs constitute a navigational menace between North America and Europe. The southernmost limit at which bergs have usually been observed roughly follows the 40th parallel.

Since the *Titanic* was sunk by a berg in 1911, a ship patrol (the International Ice Patrol) has prescribed sailing routes south of the normal ice barrier and has maintained a continuous patrol in the ice areas south of Newfoundland. The reports of its work constitute some of the most accurate information on the behavior of Arctic ice. Canada also maintains a patrol every spring in the Gulf of St. Lawrence, which often is congested with pack ice drifting into it through the strait of Belle Isle.

(4) *Arrival and Departure Dates.* Table 1B2-2 gives the approximate dates of arrival and departure of sea ice at some Arctic stations.

TABLE 1B2-2

Approximate Arrival and Departure Dates of Sea Ice at Arctic Shore Stations (Ref. 3, 4, 5, 6)

Station	Approximate location		Pack ice	
	Lat N	Long. W	Arrival	Departure
Alaska				
Barter Island	70° 80′	143° 50′	Seldom free	
Gambell	65° 51′	171° 36′	Early November	Late May
Kotzebue	66° 52′	162° 38′	Late October	Late May
Nome	64° 30′	165° 26′	Late October	Early June
Point Barrow	71° 18′	156° 47′	Mid-November	Late July
St. Paul Island	57° 09′	170° 13′	Usually free	
Wales	65° 37′	168° 03′	Mid-October	Early July
Greenland				
Angmagssalik	65° 36′	37° 35′	Mid-October	Mid-July
Arsuk-Ivigtut	61° 10′	48° 30′	Early April	Mid-June
Godthaab	64° 10′	51° 45′	Usually free	
Jakobshavn	69° 14′	51° 07′	Mid-December	Early May
Scoresby Sound	70° 28′	22° 00′	Seldom free	
Thule	76° 32′	68° 45′	Mid-October	Mid-June
Upernavik	72° 47′	56° 10′	Mid-December	Early June
Canadian Archipelago				
Baffin Bay				
East entrance			Late September	July
Within			By October	May be July
Cape Dyer, south of			October	July
Coronation Gulf			Late November	Late July
Dolphin and Union Straits			...	August[1]
Hudson Bay			Late October	Early July
Hudson Strait			Late October	Late July
King William Island, north of			Seldom free	
Queen Maud Gulf			Late November	Late August
Simpson Strait			...	Early August
Victoria Strait			...	August[1]

[1]May be blocked all year.

2. TOPOGRAPHY.

a. *Arctic.* Land surrounding the Arctic Ocean, within the region defined as the Arctic (par. 1 of 1A1.04), is generally flat, marshy, and treeless barren country. Covering the land is a vegetative mat (tundra) about a foot thick composed of varieties of moss, grass, sedge, and low bushy shrub. The insulating effectiveness of the tundra is such that heat from the summer sun penetrates and thaws only to a foot or so (permafrost active layer). Because the underlying permafrost is impermeable to water, flat Arctic land areas having no hydrological gradient become saturated swamplands of countless shallow, impassable ponds and lakes, which in winter freeze solid and afford, with frozen rivers, excellent cross-country ice roads.

In mountainous topography, glaciers exist at higher elevations where temperatures are constantly low. The surface of Greenland is covered by an ice sheet. As the ice gravitates downward, it forms valley glaciers and fiords, which empty directly into the Arctic Ocean or adjacent seas or feed Arctic rivers. Glaciers that terminate in tidewater break off as huge cliffs, which float out to sea as icebergs.

Rivers drain into the Arctic Ocean or adjoining seas. In spring, the ice breakup or thaw of the rivers is a rapid and violent event. The force of water flooding down the channels tears up the ice and drives it seaward at about 4 knots. Bends or constrictions in the channel cause temporary piling up; water and icebergs flood the valleys until the pressure breaks the ice barrier. In a week or less an entire river will completely rid itself of ice. River levels rise tremendously during the breakup, reaching 70 feet or more above winter levels.

b. *Subarctic.* Land areas defined as Subarctic (par. 2 of 1A1.04) are for the most part heavily forested and in certain sectors are quite mountainous. The transition of the Arctic into the Subarctic is evidenced by the presence of scattered individual and isolated clumps of shallow-rooted, short, coniferous trees. As latitude decreases, the trees increase in size, variety, and quantity, becoming large dense forests. Scattered through the forests are innumerable shallow lakes, ponds, and marshes. Tundra surrounding the lakes gradually spreads over the water so that many lakes are actually floating bogs (muskeg) during summer. Over the years, muskeg has in turn given way to the growth of many dense forests in the more favorable climates.

Permafrost underlies most of the Subarctic and especially the heavily forested areas where dense foliage does not permit the sun's heat rays to thaw the ground. In flat topography, such as interior zones, the poor drainage caused by perma-

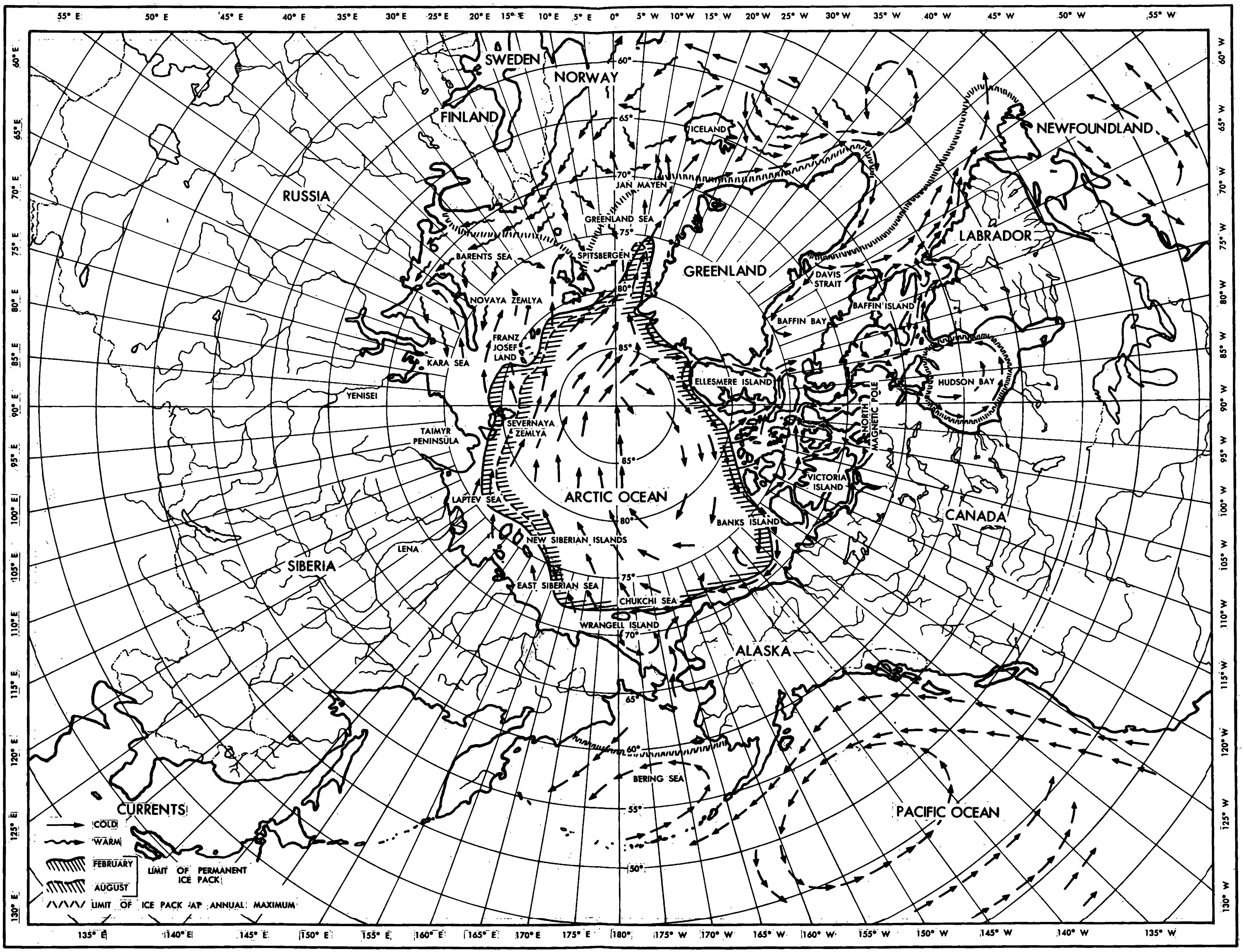


FIGURE 1B2-10

North Polar Region—Ocean Currents and Pack Ice

frost and the lack of hydrological gradient, as well as the absence of wind barriers, restrict tree growth to much lower latitudes. The protection from strong winds and better drainage afforded by mountains is manifested by tree growth at higher latitudes. Subarctic mountains are bare or usually bare (depending on latitude) of vegetation on their northern slopes, which are never fully exposed to the sun.

Rivers and streams of the Subarctic vary in their drainage pattern, which is governed by mountain ranges and interior continental shields. Some, therefore, flow north into the Arctic while others flow east or west in the Subarctic or south into the Temperate Zone.

3. CLIMATE.

a. *Temperature.* The position of the ice-covered Polar Basin strongly influences the climate of the characteristically cold, desolate bordering lands of the Arctic Ocean. The mean temperatures of the warmest and coldest months give a good indication of the climate. During winter, the mean temperature on the icepack of the Arctic Ocean is about −30° F; along the Arctic coast it is about −20° F; and in the interior Arctic Zone it varies from about −11° to −21° F. In the Subarctic coastal areas and along the Aleutian Chain, winter is mild, with mean temperatures varying from 16° to 36° F, depending on locality. During summer, the mean temperature on the Arctic icepack stays fairly constant at 32° F; in the Aleutians it varies from 43° to 49° F; in the Subarctic coastal area it varies between 49° and 57° F; and in the interior Arctic it is about 60° F. The mean annual temperatures of the Northern Hemisphere are given in Figure 1B2-11.

The coldest month of the year in the Arctic is usually February. For many localities it is March, and in some years even April has a lower mean than January. The warmest month over both land and sea, with few exceptions, is July. The August temperature chart, however, is representative of summer conditions. January and July isotherms around the world are shown in Figures 1B2-12 and 1B2-13, respectively.

b. *Precipitation.* Precipitation above the Arctic Circle is generally light, ranging from 5 to 10 in. annually in most areas. Approximately 50 percent is snow, which may fall any time during the year. The aridity of Arctic land areas is also evident in their low relative humidity. Light precipitation occurs because air at the prevailing low temperatures can not hold much moisture. Moreover, winds blowing over the large icefields covering the region most of the year can not absorb as much moisture as from open water.

The mean annual precipitation in the Subarctic is also relatively light, ranging from 10 to 20 in. The Aleutians, however, have a high precipitation ranging from 29 to 76 in. on an average of 290 to 348 days per year. Subarctic coastal areas have a total precipitation varying from 15.5 to 230 in., but the number of wet days is fewer (91 to 296).

c. *Wind.* The frequency and velocity of high winds in the Arctic is not as great as in the more temperate climates. Therefore, except for local areas of intense storms, such as Greenland and the Herschel Islands, where gusts of 162 mph have been recorded, the Arctic is not considered windy. The strongest winds occur during winter along the coast, with comparatively mild winds inland. The reverse may be expected in summer. At Point Barrow, for example, maximum winds of 100 mph during winter and 41 mph during summer have been recorded. The most intense storms occur on or near land, especially where high land faces the sea. Winds of gale violence seldom extend more than 10 to 15 miles out to sea. As a rule, extreme low temperatures are accompanied by calmness. Rapid directional changes in local winds are common.

4. NATURAL RESOURCES.

a. *Subsurface.* Coal of different degrees of quality has been found throughout the Arctic. Although there are indications of iron deposits in some areas, no important ones have been found. On the other hand, copper is quite extensive in some locations; and apatite, tin, gold, silver, platinum, and uranium are also present. Petroleum has been discovered in many sections of the Arctic and Subarctic.

b. *Surface.* The most abundant natural resource of the region is its rich vegetation. In summer the tundra abounds with a wide variety of grasses, plants, and flowers. The longer summer days in the Subarctic provide enough warmth to promote rapid growth among the more common plants. The coniferous forests often extend north of the Arctic Circle and are an extremely valuable source of fuel, building material, and pulp.

c. *Animal Life.* Caribou (undomesticated reindeer) thrive on tundra and provide food for natives and carnivorous animals. Moose and musk ox, though not as numerous as caribou, also thrive in the Arctic and Subarctic. Mountain sheep and goats, Arctic hares, snowshoe rabbits, ground squirrels, and lemmings are other noncarnivorous animals. The polar and grizzly bears, Arctic wolf, Arctic fox, Canada lynx, wolverine, marmot, porcupine, and weasel are fur-bearing animals found in particular areas. Migratory birds such as geese, ducks, and swans, and native birds such as the snowy owl and ptarmigan are found above the Arctic Circle. The cold streams, rivers, and lakes furnish trout, pike, salmon, and Arctic graylings; the salt-water areas supply whale, seal, walrus, flounder, herring, and similar aquatic life. Although the Polar Regions contain a wide variety of food and fur-bearing wild life, that life is not as abundant as might be expected.

In summer, the tundra abounds with insects, particularly when disturbed. It is estimated that in more than two thirds of the tundra there are ten times as many insects per square mile as in the tropics. These insects include mosquitoes, black flies, deerflies, and midges. The numerous marshes and shallow lakes, and the long sunny days with slight temperature change from night to day during summer, provide ideal conditions for insect incubation. These insects are an extreme torment to man.

5. DETAILED INFORMATION. More detailed data on specific Arctic and Subarctic areas are given in Appendix B.

1B2.08 THE ANTARCTIC

1. SOUTH POLAR REGION. The South Polar Region (Figure 1B2-2) is largely occupied by a continent (Antarctica) more than five million square miles in area. Although far from being symmetrical about the South Pole, the region may be thought of as bounded by lat 70° S. Water of oceanic depth (the Antarctic Ocean) separates the entire continent from the nearest other land mass by 650 miles. Between lat 55° and 65° S, therefore, no land interferes with west to east circulation of sea and air. This creates permanent west winds and the westerly drift, which, like the wandering albatross, ceaselessly circle the continent. Here are found the roughest seas and fiercest winds known. There is no exchange of warm and cold air and water between the Temperate Zone and the Polar Regions, as there is in the Northern Hemisphere.

2. ANTARCTICA. Antarctica is encircled roughly by lat 60° S. It is believed that the greatest part of the continent is a continuous plateau, which is covered by a permanent ice sheet up to perhaps 2,000 ft in maximum thickness, but more in basins. Only a very small proportion of the land surface—comparatively new areas of dark volcanic rocks and peaks of the higher mountain regions—is exposed. The average altitude is around 6,000 ft. The ice sheet is the source of countless glaciers that fringe the entire coast and fill numerous ice-worn valleys.

3. ICE. Many of the glaciers form immense flat floating ice sheets 500 to 1,500 feet thick, grounded at the coast and extending into the sea where they are exposed to ocean currents. Each summer, when the breakup of winter sea ice allows the full force of the ocean swell to reach the outer floating ends of the ice sheets (or barriers as they are sometimes called), large fragments are calved and float northward, disintegrating in warmer, stormier waters. The largest and best known ice sheet, the Ross Barrier or Ross Shelf Ice (Figure 1B2-14), is about the size of France. It extends to within 300 miles of the South Pole, and because of its flat smoothness, affords the easiest approach to the Pole.

Antarctic sea ice is comparatively temporary, forming in sheltered bays by the end of January and usually completely frozen by March. Frequent strong winds cause large yearly variations in the extent of sea ice formed. In sheltered bays, however, the ice increases to a maximum thickness of 7 feet by October or November. It begins to break up and drift northward in December, but the ice trapped in inner bays may not break up until February, and occasionally not for several successive years. The belt of drifting pack ice encircling the continent is composed of ice from these breakups.

4. CLIMATE. Climatological summaries of available data on Antarctica are given in Table 1B2-3.

a. *Temperature.* The mean Antarctic temperature is approximately 5° F lower than corresponding northern latitudes. The lowest recorded temperature known is −75° F at the Bay of Whales; −83° F, however, has been reported 94 miles from this location. Probably lower temperatures prevail farther inland. Low summer temperatures are prevalent; there is no month in which

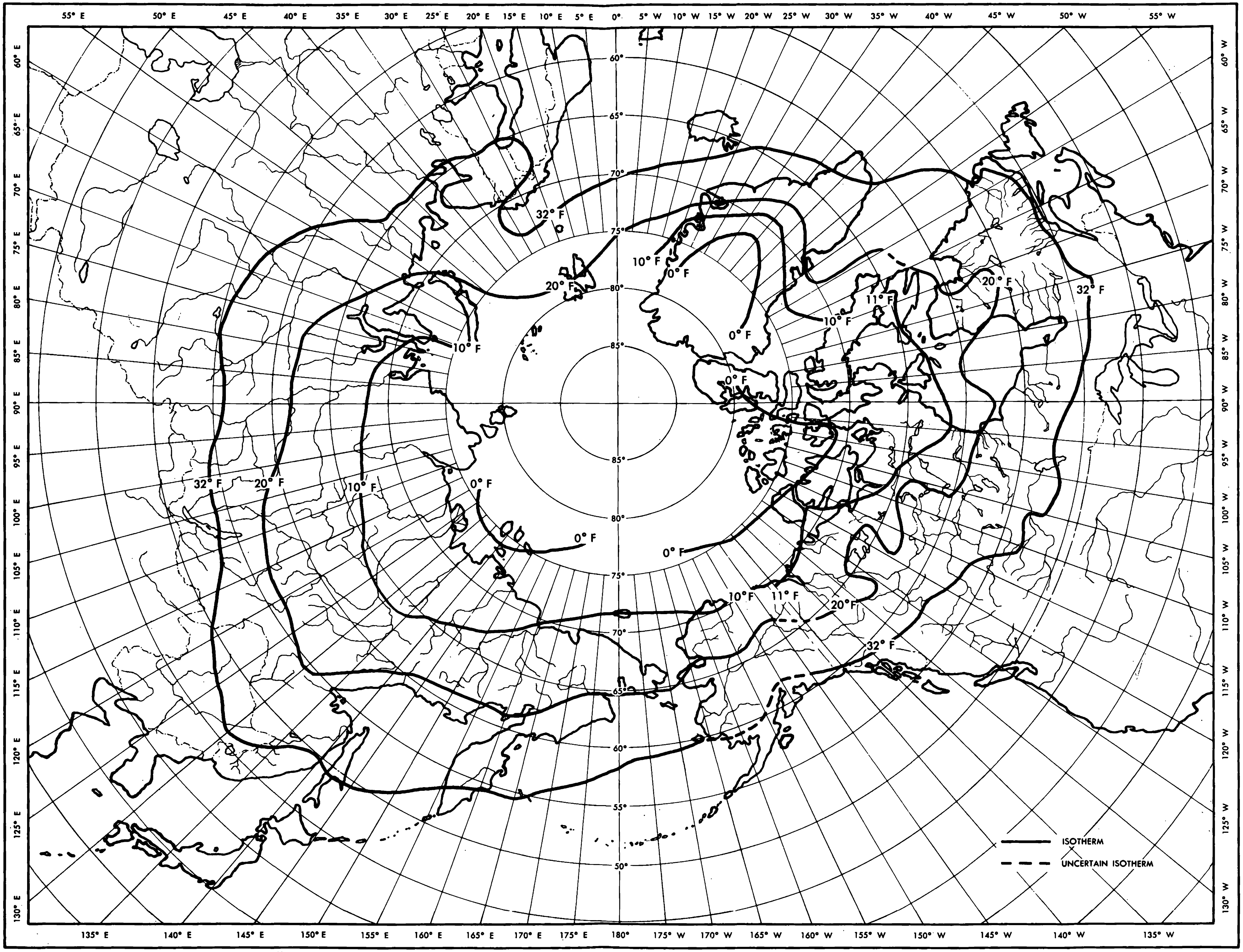


FIGURE 1B2-11

Mean Annual Temperatures of Northern Hemisphere

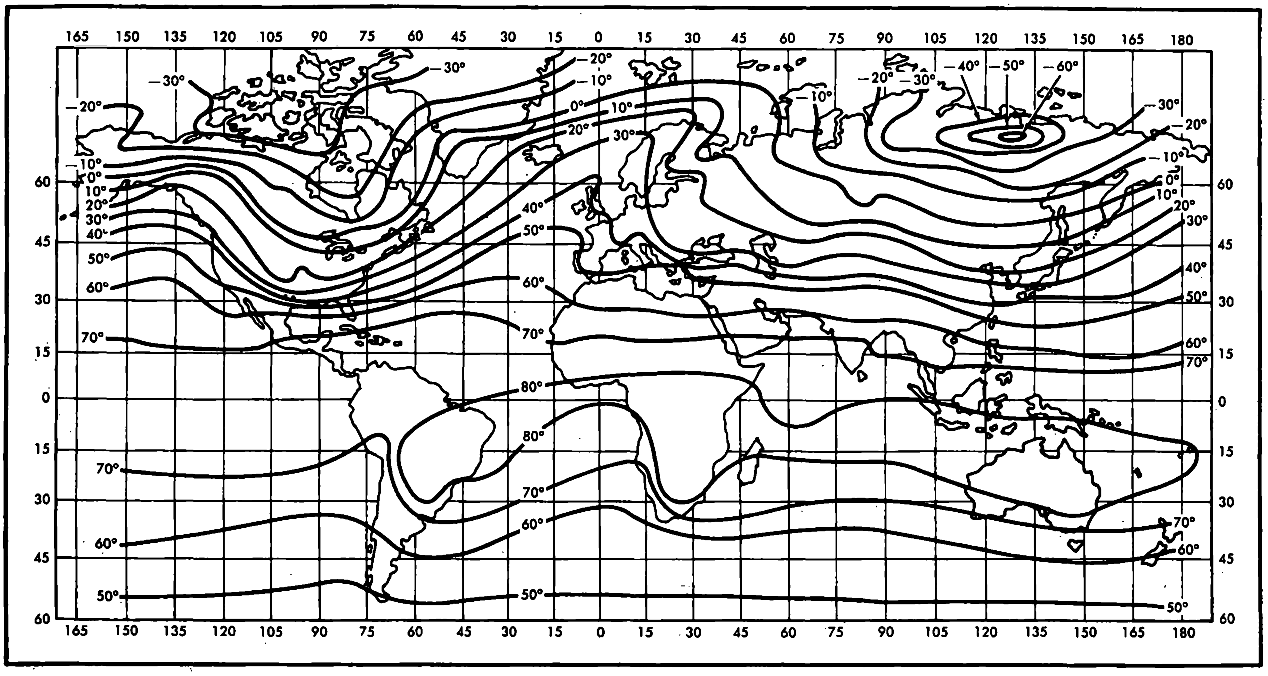


FIGURE 1B2-12

World January Isotherms (in °F)

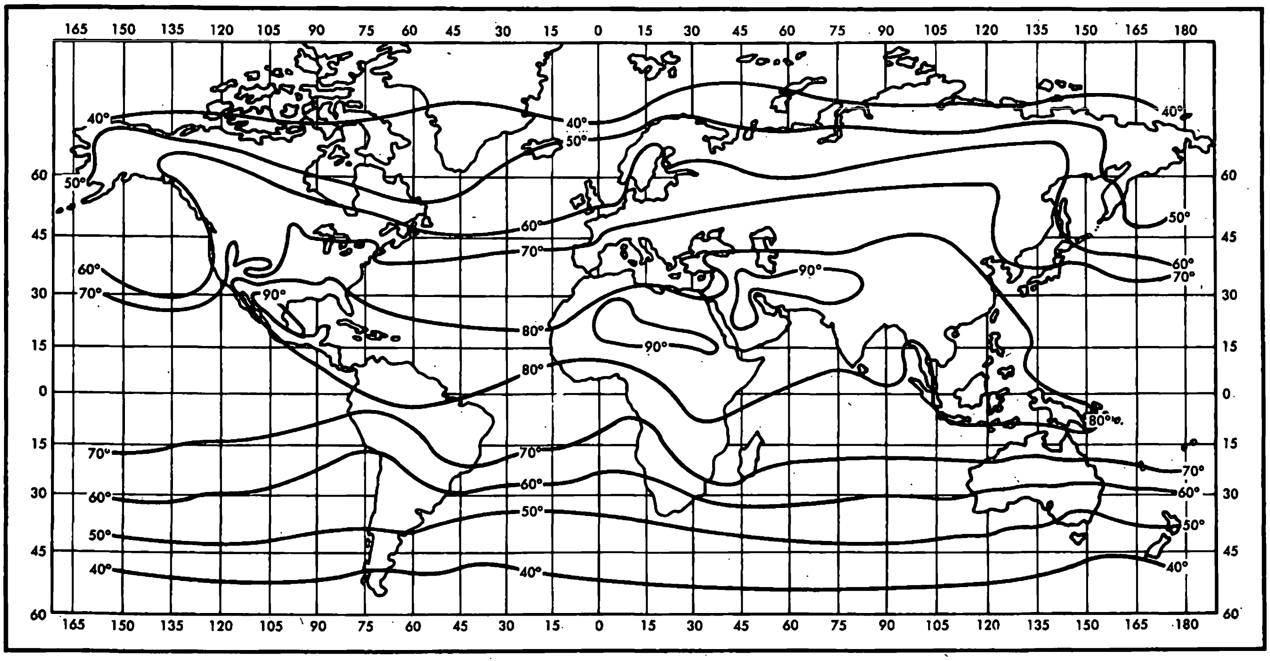


FIGURE 1B2-13

World July Isotherms (in °F)

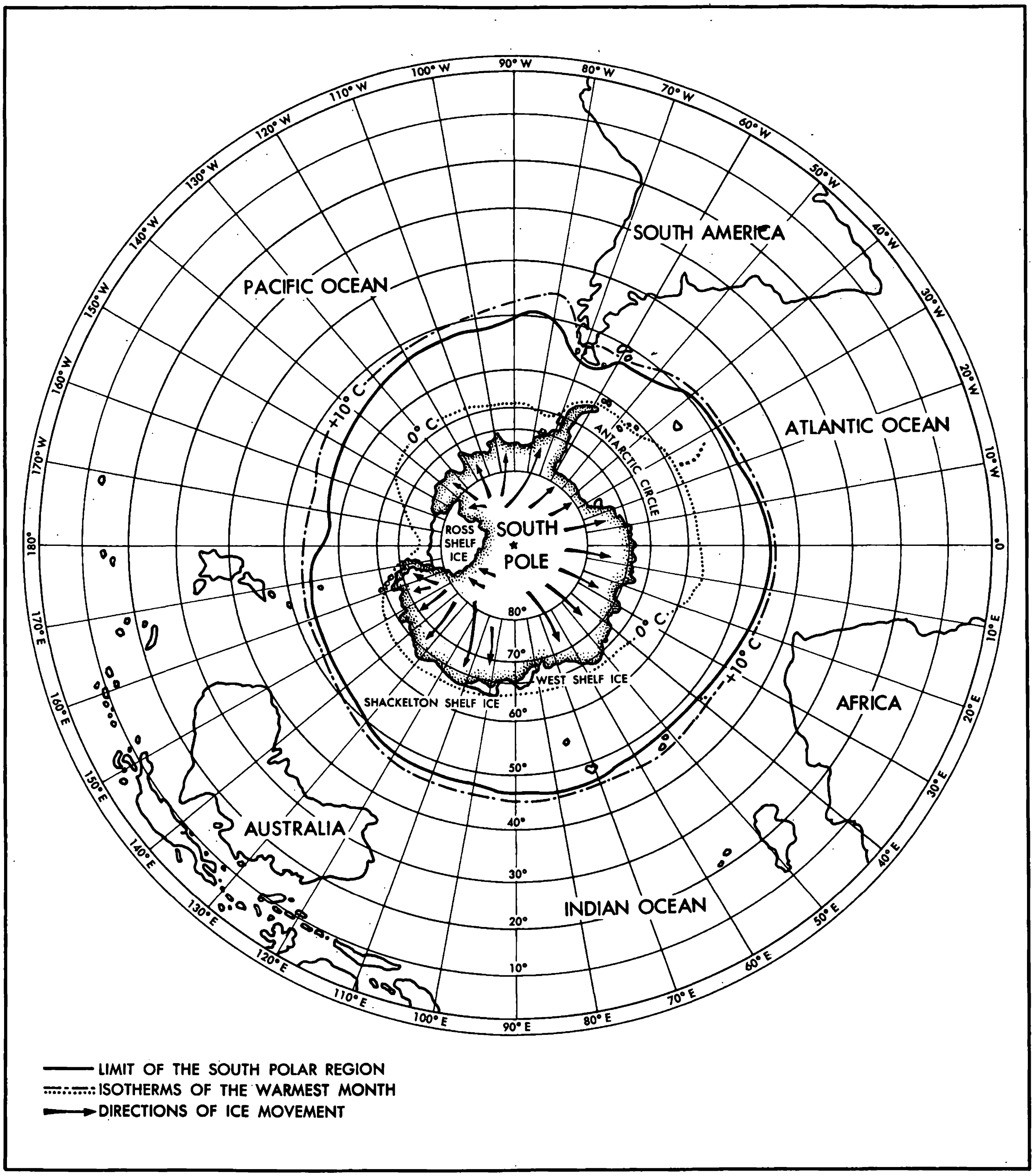


FIGURE 1B2-14

South Polar Region—Ice Currents

the mean air temperature exceeds 32° F (Ref. 6a). Hot springs are thought to be the cause of the unfrozen lakes.

b. *Precipitation.* Rain is virtually nonexistent within the Antarctic Circle. Measurement of depth of snowfall is extremely difficult because of inability to distinguish between falling and blowing snow. At sea level, annual snowfall is less than 1 ft. Elsewhere, it has been reported as varying from 10 to 15 in., the greatest being in the northern part along the west coast of Palmer Island.

Fog is common along the coasts. Cloud cover is high throughout the Antarctic, ranging from 60 to 90 percent and increasing somewhat from December through March. (Ref. 6a.)

c. *Wind.* Atmospheric pressure increases near the Pole. The high pressure lying over the Antarctic interior is surrounded by low pressure along the coasts. Pressure distribution and topography produce excessively strong winds that, accompanied by snow and drifting, become blizzards. These winds prevent formation of fast ice along portions of the coast or they continually break off the fast ice that does form, blowing it into the ocean pack ice.

From the continent, outward-blowing winds prevail. Because the coast generally has an east-west trend, the winds, which always have a leftward deviation caused by the earth's rotation, ordinarily blow from the African Quadrant.

The Commonwealth Bay area is believed to be the windiest in the world. During 22 months, from 1911 to 1914, the wind averaged 43 mph; during July 1913, a gale of 96 mph was experienced in which an average speed of 89 mph was maintained for 12 hours. Blizzards generally do not extend far out over the sea and they are rare during summer (November, December, and January). Blizzards are usually associated with northerly winds.

5. NATURAL RESOURCES. Coal is probably the principal natural resource. Covered by an ice sheet, the continent is devoid of vegetation and is inhabited only by penguins, which feed on fish.

TABLE 1B2-3

Weather Data for the Antarctic (Ref. 6a)

Station	Lat	Long.	Mean maximum and minimum temperature, °F, except as noted																								Years of record
			Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec		
			Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	
Argentine Islands	65° 15′ S	64° 16′ W	39	31	...	...	36	28	30	23	28	21	27	21	18	7	5	−7	18	5	30	22	32	23	36	30	1
Cape Adare	71° 18′ S	170° 09′ E	37	30	...	...	22	14	16	5	3	−11	−5	−19	−1	−18	−4	−23	−4	−19	5	−11	24	9	36	27	1
Cape Denison[1]	67° 00′ S	142° 40′ E	34	26	29	21	18	10	6	−2	6	−2	3	−3	0	−8	6	−3	4	−6	8	−3	22	21	31	23	1
Debenham Islands	68° 08′ S	67° 06′ W	39	30	36	27	34	25	30	20	14	1	10	−10	18	−6	17	−5	25	13	...	19	36	26	40	29	1
Framheim[2]	78° 38′ S	163° 37′ W	27	1	...	...	...	...	12	−54	−4	−59	13	−73	9	−66	−12	−74	15	−64	16	−40	23	−18	32	2	1
Gauss	66° 02′ S	89° 54′ E	34	24	30	22	23	10	10	−3	11	1	8	−9	6	−9	−3	−14	6	−7	16	0	24	12	33	24	1
Laurie Island	60° 45′ S	44° 43′ W	42	24	43	24	43	18	40	6	37	−8	35	−18	35	−21	37	−20	38	−14	41	−3	40	14	41	22	22
Little America	78° 34′ S	163° 56′ W	31	18	11	−19	21	−45	10	−49	17	−58	20	−49	18	−65	−9	−62	−4	−62	7.5	−38	18	−26	30	7	1
Port Charcot	65° 03′ S	64° 00′ W	35	30	36	27	37	23	36	10	29	−3	32	−10	23	−27	31	−4	32	16	32	2	34	23	34	27	1
Port Circoncision	65° 10′ S	64° 12′ W	38	33	38	31	38	30	27	19	27	19	26	15	25	14	28	15	27	16	34	20	38	23	...	...	1
Water Boat Point[2,3]	64° 48′ S	62° 43′ W	50	27	49	25	42	20	47	20	38	4	38	14	33	−12	39	−16	35	2	36	14	42	13	48	27	1

Station	Number of days on which gales (winds greater than 34 mph) were recorded												Years of record
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Argentine Islands	0	...	2	2	4	3	2	2	2	8	1	0	1
Cape Adare	11	...	5	5	5	7	6	6	6	7	6	8	1
Cape Denison[1]	16	13	26	26	30	30	27	29	26	30	21	12	1
Debenham Islands	4	6	3	6	10	4	3	9	6	10	5	14	1
Framheim[2]													
Gauss	3	6	1	5	11	6	9	12	5	6	1	4	1
Laurie Island	3	11	20	17	12	12	8	21	25	17	9	6	7
Little America	0	2	5	9	5	2	3	3	6	3	1	0	1
Port Charcot	12	9	9	8	8	10	6	12	11	12	11	7	1
Port Circoncision	1	0	5	1	0	4	11	12	12	9	4	...	1
Water Boat Point[2,3]	5	8	8	9	8	10	10	8	11	10	8	7	1

[1] Number of days with winds greater than 30 mph recorded.
[2] Absolute maximum and minimum temperatures.
[3] Highest wind force (Beaufort) recorded during month.

CHAPTER 2. DESIGN

PART A. GENERAL CONSIDERATIONS

Section 1. CRITERIA

2A1.01 GENERAL

The first requirement for successful design and construction of an engineering facility in the Cold Regions is a recognition of the disciplines in the area where the project is to be located. To assist in making available a knowledge of these factors, the material in Chapter 1 and Appendix B has been compiled from the best available sources.

The engineering principles governing and controlling any design in the Cold Regions are the same as those used and applied in the Temperate Zone. In using these principles, the disciplines must be recognized, and the design and construction necessary to accomplish the purpose of the mission must be such that the project is feasible and can successfully meet the requirements imposed by climate, terrain, and other local factors.

The design should be governed by and make optimum use of the conditions to which the facility will be subjected and of the materials available in the area. Experience has definitely shown that failure to recognize, cooperate with, and use the forces of nature in the Polar Regions often makes an otherwise practicable project unfeasible.

Section 2. SITE SELECTION AND SAMPLING

2A2.01 GENERAL

All site studies will be governed by the disciplines of the area and by the type, character, and importance of the development as outlined in the assigned mission. In selecting sites for specific types of developments, emphasis is often required on factors that for other types of facilities may not be critical. In the pertinent Sections of this publication, supplementary considerations applicable to the selection of sites for structures of a specific functional nature are suggested.

At the earliest practicable date, it should be determined whether the active or passive method of construction will be used; when practical and consistent with the mission, diffusivity measurements of materials in place should be made. (See Section 2A8.) In some cases, both methods may be indicated. Site studies should, in general, develop information regarding the following points.

(1) Possible access routes with emphasis on those factors that may interfere with transportation, unloading, and storage operations.

(2) Vulnerability of shore and near-shore installations to storms, winds, high tides, and pack and offshore ice. (During periods of storm and high offshore wind, pack and offshore ice may be forced high above indicated ice levels.)

(3) Vulnerability to avalanches, snowslides, drifting snow, floods, icing, solifluction, and other potentially destructive phenomena.

(4) Exposure to prevailing winds and the sun, and possible effects of such exposure.

(5) Character of vegetation and of such soil as can be readily exposed.

(6) Occurrence, type, and distribution of permafrost and taliks.

(7) Thickness of seasonal frost and the depth of thaw.

(8) Land formation, topography, and drainage.

(9) Ground water and possible sources of water supply.

(10) Availability of construction materials.

Site surveys and planning should be based on a practical time schedule governed by the disciplines of the area involved and contingent upon the personnel, material, and equipment that can be made available.

2A2.02 RECONNAISSANCE AND PRELIMINARY SURFACE SURVEYS

1. AIR RECONNAISSANCE. Where practicable, an air reconnaissance should precede ground surveys and exploration. Aerial photographs, when interpreted by personnel trained in such work, can be of great assistance in the preliminary study of the site, especially in outlining the presence and extent of the permafrost area. Wherever practicable to do so, they should be taken so as to provide means for a stereoscopic study of the surface phenomena, including land forms, drainage, and vegetation, as well as existing roads and railways and potential routes for future lines of transportation.

In the evaluation of a permafrost area as a probable site for the development of an engineering project, the topographical portion of the area in terms of its existing disciplines is probably one of the most important factors in helping to indicate the character and nature of the materials in the area.

Vegetational clues to permafrost and ground water are discussed in Section 2A5. The appearance of vegetation, including trees and shrubs, will show on air photographs. The topography of the area, as indicated from the air photographs, will show whether or not the area is mountainous, an upland plateau or terrace with good or retarded drainage, a flood plain, or a combination of these. Transition zones can usually be identified and an estimate made of the character of the material filling the smaller valleys.

The presence of taliks will usually be indicated by vegetation, and a good estimate can be made of the nature and extent of the active layer.

The surface of many permafrost areas, where the active layer is shallow and composed of fine-grained materials such as silt or clay, is frequently marked by geometric patterns called polygons, as illustrated in Figures 2A2-1 and 2A2-2. These patterns are the result of the segregation of ice and soil masses. Many types exist; the two principal ones are illustrated. In Figure 2A2-1 the centers of the blocks are depressed, but in Figure 2A2-2 they are raised. Wherever such polygons exist (the active layer and frequently for some distance below it), the upper soil masses may be separated by

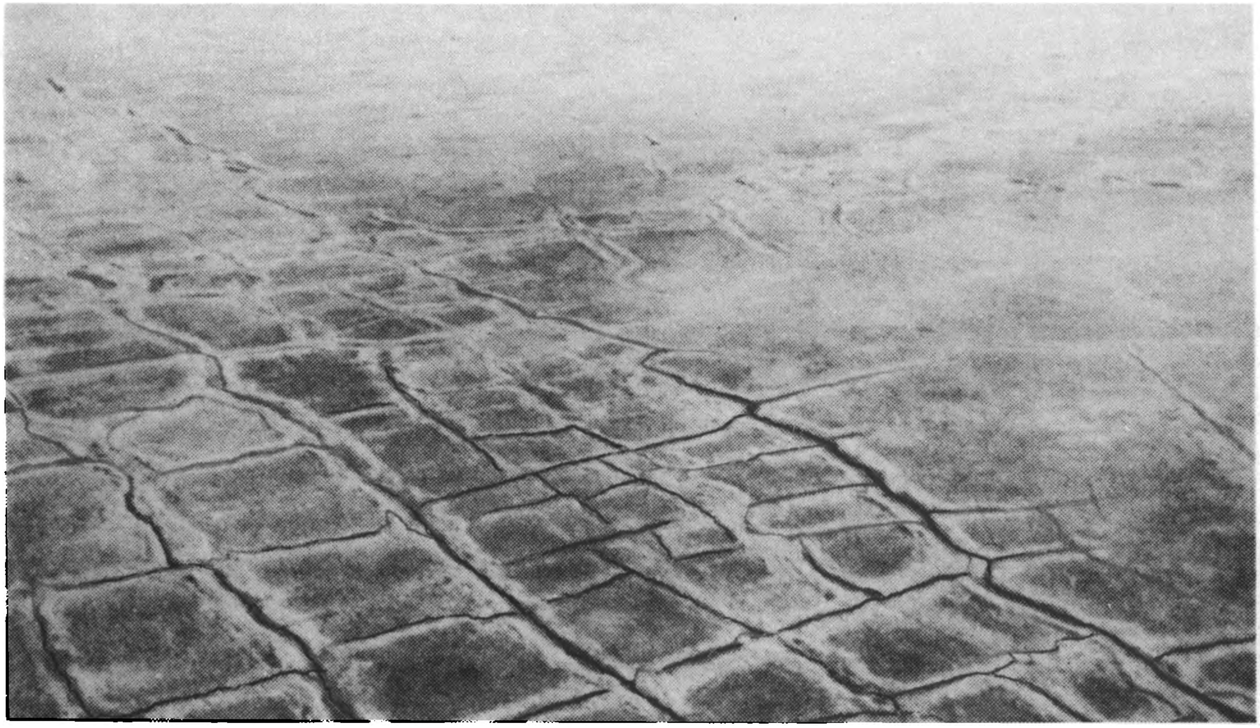


FIGURE 2A2-1

Depressed-Center-Type Polygons About 200 Feet Across (Ref. 7)

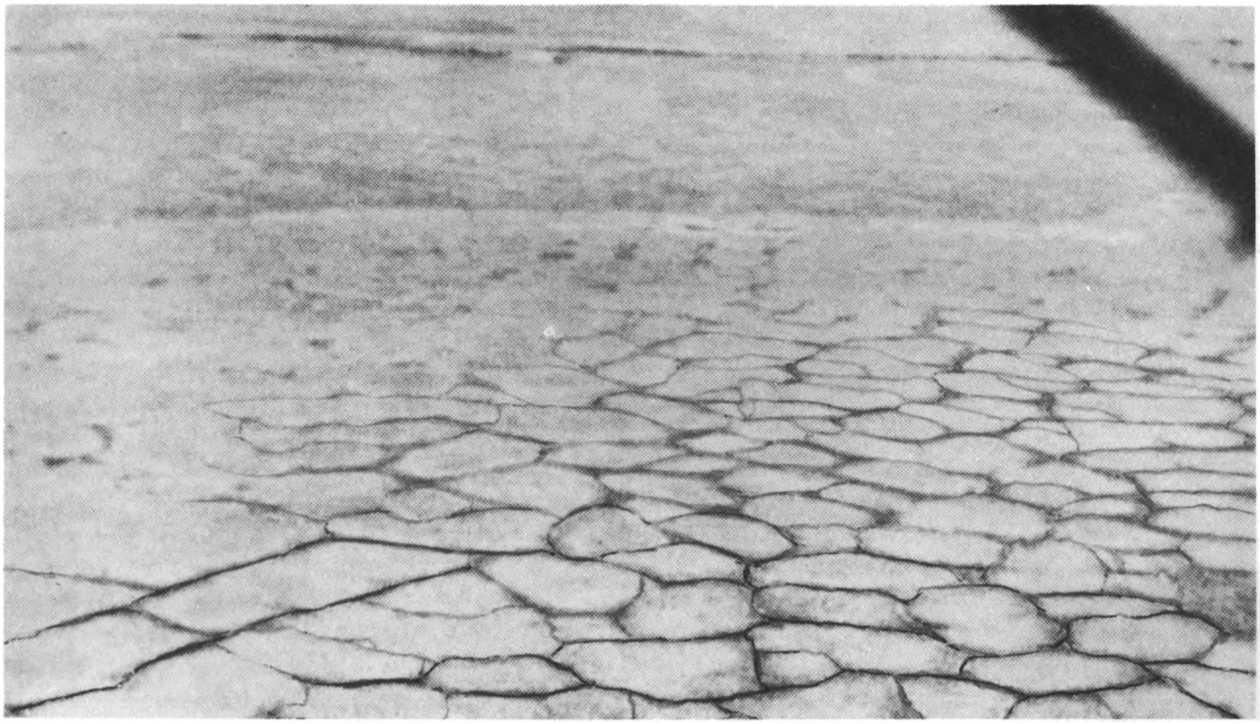


FIGURE 2A2-2

Raised-Center-Type Polygons About 75 Feet Across (Ref. 7)

lenses and stringers of ice (Section 2A5). In these areas the passive method of construction is usually indicated, except for very temporary structures (Ref. 7). (See Sections 2A6 and 2C2.)

2. GEOPHYSICAL METHODS. Geophysical methods of soil exploration on the surface can develop valuable data, especially when they are used to ascertain the depth of permafrost or the depths at which rock is located.

3. GROUND SURVEYS. Usually the only equipment involved in the preliminary ground survey will be hand excavation and probing tools, thermometers for taking air, water, and soil (including permafrost) temperatures, and whatever instruments are necessary to obtain required information on topography and location. All information gathered during the preliminary surveys, including pertinent factors developed from the aerial reconnaissance as well as the results of the geophysical and preliminary surface and subsurface explorations, should be recorded. A surface plat should be prepared showing details pertaining to vegetation, types of soil, and topography, with emphasis on drainage, snow covering, and evidence of icing and other potentially detrimental phenomena, as well as the location of permafrost and taliks in and near the area under consideration. However, the amount and type of information developed should be consistent with the purpose and importance of the assigned mission. Such a plat should, in every case, show the political subdivision in which the area is located and the proper reference to monuments and lines of known geographic location. It is recommended that the surface plats be made so as to be capable of being superimposed one on the other or on other maps that may later be made of the area.

2A2.03 SUBSURFACE INVESTIGATIONS

1. GENERAL. In permafrost areas it is usually essential that studies of the subsurface conditions extend over a greater area and be carried to a greater depth than for a similar investigation in the Temperate Zone.

The subsurface exploration should develop information as to the thickness and nature of the cover, the depth of the seasonal freeze and thaw, and the depth to the permafrost to determine whether or not the permafrost is sufficiently near the surface so that it, too, must be studied.

Where the active layer is shallow and the permafrost is only a few feet from the surface, the preliminary study can be made in part by probing or sounding with a rod or pipe, by using an auger, or by test pits. Studies of the active layer should be sufficiently thorough so that consideration can be given to the following.

(1) Swelling
(2) Longitudinal movement
(3) Uneven freezing and thawing
(4) Ground water
(5) Expected settlement
(6) Depth of seasonal freeze and thaw

If permafrost comes within the province of the study, the nature of the contact between the permafrost and the active layer should be carefully considered. For all strata that may be considered a part of the foundation, consideration should be given to the advisability of taking in-place samples so that necessary studies can be made to determine the structural properties of the material in place. Such studies will include nature of the matrix, its compaction, water content, and stratification, and a mechanical analysis of the material other than the matrix.

2. PROBING, SOUNDING, AND PENETRATION TESTS.

a. *Simple Probing.* The simplest type of sounding consists of driving a steel bar into the soil to determine the approximate elevation of various strata, especially permafrost. Fine silt, unfrozen soil, and gravel strata also usually can be detected by this method and, of course, bedrock and some clayey formations.

b. *Drop-Penetration Test.* Another method of sounding, called drop penetration, consists of driving a steel rail or rod for a few feet into the soil and recording the number of blows required to drive one foot. The following from an unpublished paper is of interest in reference to the resistance of frozen ground to the penetration test.

> Experience has led to the following tentative conclusions regarding the resistance of frozen ground against the penetration of test rails. If the number of blows per foot of penetration of a test rail (rail with a weight of about 70 lb per yard, hammer with a weight of 2,200 to 2,500 lb and 10-ft drop) is smaller than 10, the ground is probably unfrozen, and if it is greater than 12, it is probably frozen. If the number of blows per foot of penetration is between 10 and 12, one can not know whether or not the ground is frozen. As a rule the increase of the number of blows at the boundary of the permafrost is so conspicuous, that there can not be any doubt regarding the location of this boundary. (Ref. 8.)

When using the drop-penetration method to judge soil density, it should be borne in mind that it is only indicative of density when used in granular materials. It is particularly unreliable in cohesive silt or clay, or wherever adfreeze has developed because of delays in driving. Also, except at comparatively shallow depths, friction along the rail or rod may be sufficient to obscure the significance of the driving data in respect to the density of the soil penetrated. Wherever practicable, therefore, in-place samples should be taken.

c. *Combination Drop Penetration and Sampling.* A more satisfactory method of sounding combines the drop-penetration method with boring and sampling operations. In this method a casing is driven and a spoon sampler is substituted for the steel rail or rod. The spoon is then driven, as in the conventional drop-penetration method, and the number of blows per foot of penetration is recorded.

> Information on the degree of compactness of a deposit of cohesionless material is obtained by counting the number of blows of the drop weight that are needed to drive the sampling spoon to a depth of one foot into the soil located beneath the bottom of the drill hole. A weight of 140 lb and a drop of 30 in. are considered standard, and the penetration test performed under standard conditions is called the *standard penetration test.* Experience has disclosed the following approximate relation between the number of blows, N, per foot of penetration, and the corresponding degree of compactness of sand. (Ref. 8.)

Number of blows, N				
0-4	4-10	10-30	30-50	over 50
Degree of compactness				
very loose	loose	medium	dense	very dense

The dimensions of the sampler used in obtaining the above data are 2.0 in. OD and 1.375 in. ID.

There are in existence several procedures other than this, which involve different types of spoons, weights, and heights of drop of a hammer for which correlations of penetration resistance and soil properties have been tabulated. All data concerning the specific procedure used should always be reported on any driving record.

It is emphasized that extreme caution should be exercised in using any table of correlations outside the areas or for other conditions than those for which correlations have been established; even then, large deviations from such correlations have been reported. The penetration resistance depends not only on dimensions of the equipment and the consistency or relative density of the soil, but it may also vary with the method or operation, depth below ground surface, and other factors not yet fully investigated. (Ref. 9.)

Although they may give only an approximate indication of density, driving records of dry-sampling spoons are useful for comparative purposes and are much more reliable than the overall penetration record of a borehole casing because the overall frictional resistance is less.

3. TEST PITS. The validity of all interpretations, conclusions, and designs based on test results and study of a specimen depends on the sample and how truly the sample represents the material from which it is taken. Wherever practicable and consistent with the importance of the project, test pits are recommended. They have the definite advantage of permitting an in-place study of the materials, and in all cemented or cohesive materials they permit obtaining of samples in place for field and laboratory study. Samples, after being taken from test pits, should be immediately wrapped in cheesecloth and paraffined, as indicated in Figure 2A2-3. Samples of frozen materials so taken should be preserved in their frozen state until moisture content, compaction, and nature of material have been studied. In some cases, shear tests to be made in a cold room on frozen sections may be indicated.

The in-place volume of an irregular block or chunk taken from a test pit for sampling purposes can be determined, after it has been covered with cheesecloth and paraffin, by immersing the block in cold water and measuring the volume of water displaced. When the sample is from thawed, granular material, the following procedure is recommended.

A cloth or tarpaulin to collect the sample is

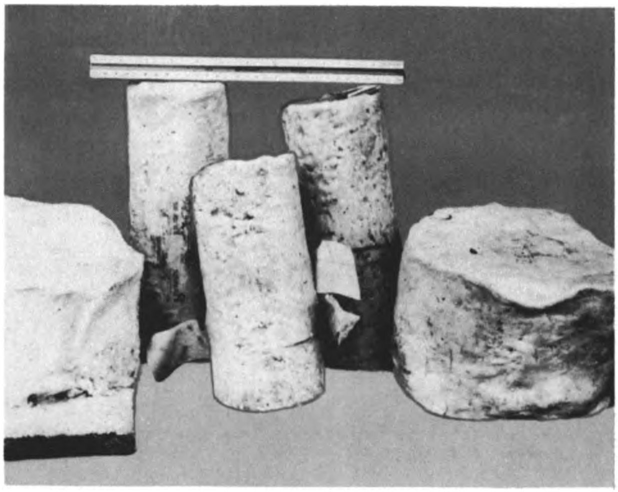


FIGURE 2A2-3

In-Place Samples Paraffined and Ready for Transportation to Soil Mechanics Laboratory

placed at the bottom of the pit next to the bank. A hand shovel or pick is used to dig a vertical channel from top to bottom of the face being sampled until 50 to 100 pounds of material are collected.

Such samples can be studied and reduced by quartering. It is recommended that measurements be taken so that a calculation can be made of the in-place volume of the material recovered. Before quartering, it is recommended that the volume occupied by this material be studied so as to get some indication of its packing *in situ*. Should it be desired to reduce the sample after its loose volume is determined, standard quartering procedure can be followed.

4. SOLID CORINGS. The refinement of the sampling method and the type and size of the sampler used should be such that the sample is as representative of the essential properties of the soil as is practicable and consistent with the purpose for which the sample is to be used. Taking in-place samples by an appropriate sampler (par. 7 of 2A2.03) ahead of the casing, if casing is used, is frequently termed dry sampling, even though, in many cases, the sample must be recovered from a drillhole filled with water. There is no such thing as a completely undisturbed sample taken from a borehole. Every effort, however, should be made to secure an in-place sample with a minimum amount of disturbance to the material.

All samples should be properly identified with duplicate labels that will remain readable under field conditions. Labels should indicate the following things.

(1) Location of work

(2) Hole designation

(3) Sampler number

(4) Elevation of bottom of sample referenced to station datum

(5) Classification (soil type) of sample

(6) Date taken

(7) Length of sample

(8) Weight of sample, plus container, prior to sealing

a. *Disturbed Samples.* Samples of hard, granular, and cohesionless soil that are impracticable to obtain without disturbing the material should be taken by the dry-sampling method with an approved split-barrel sampler equipped with a flap valve, which will prevent the sample from falling out while the sampler is being removed from the hole. (See Figure 2A2-8.) Each sample should be placed in a widemouthed airtight container of at least one-pint capacity. The container should be completely filled, capped to exclude air, sealed, and labeled.

b. *Undisturbed Samples.* Undisturbed samples should be taken below the bottom of the casing, when casing is used, with a Sprague and Henwood, Shelby tube, or other approved type of sampler. (See Figures 2A2-9, 2A2-10, 2A2-11, and 2A2-12.) The bottom foot of soil in the casing should be cored out with a spoon-type sampler and discarded, after which the undisturbed sample should be taken immediately below the bottom of the casing. The sampler should be jacked or pushed into the soil in such a manner that there will be a minimum disturbance of the sample. Immediately after taking the sample, the soil should be cut off flush with both ends of the tube and the tube closed with tight-fitting metal covers, which should be sealed with friction tape and paraffin or quick-drying varnish. No plugs of any kind should be inserted in the ends of sample tubes in place of metal caps. In the event that a full tube is not obtained, the sample should be discarded and a new full tube should be taken from the material directly below.

c. *Run-Ins.* Careful measurements should be made of the position of the core in relation to the cutting shoe so that the record will indicate the amount of run-in that occurs as the drilling progresses. Such information will also determine whether or not it is practicable to drill and sample ahead of the cutting shoe. A time and distance record should be made for all casing driven so that the penetration into each stratum can be determined and correlated to the amount of core carried in the casing. In the case of California-type wells, the pressures used, length of time applied, and distances advanced should be noted.

When possible run-ins are indicated, it is recommended that the casing be kept full of water, with the fines carried in suspension while the liquid is being agitated. In this way the weight of liquid within the casing will be increased, the difference in pressure at the shoe is reduced, and the amount of run-in at the cutting shoe will be reduced to a minimum. If the sand and water have insufficient weight to prevent the movement of the material into the casing from below the shoe, consideration should be given to increasing the weight of the drilling fluid. In either case, after the hole has been cleaned out and agitation of the liquid reduced, it is suggested that metal slugs be dropped into the casing before the sample is cut. Such slugs will be recovered in the sample and will indicate the line of demarcation between the fine material, which has settled in the bottom of the hole, and the material that was in place. (See Figure 2A2-4.)

d. *Records.* Written records in the required number of copies should be kept and should indicate (a) the ground elevation at the location of each boring, (b) a description of the character of

FIGURE 2A2-4

Sample Showing Use of Iron Slugs

the materials, including the elevations at which they were encountered, and (c) the elevation of the ground-water level when first encountered and again 24 hours after completion of the boring. All elevations should be referenced to the station datum. Driving information should be recorded, as well as the size of casing used and the size and description (manufacturer and model) of the sampler.

5. WASH BORINGS. Wash-boring samples are frequently used, but even though they show the character of the material penetrated, they do not indicate the nature, density of packing, or matrix. Usually the finer sizes are washed up and many of these may be lost in whole or in part. Correct determination of the distribution of the fines in such samples is usually impracticable. Wash samples alone, therefore, can be extremely misleading and wholly inadequate for design purposes. It is believed that wash samples in permafrost regions have even less value than in the Temperate Zone.

Figure 2A2-5 illustrates typical equipment for making wash-drill borings. The rope for raising and lowering the casing may be manipulated either by a motor winch, as shown, or by hand. A hand-driven pump may be substituted for the motor-driven pump indicated. (See Ref. 10, p. 484.)

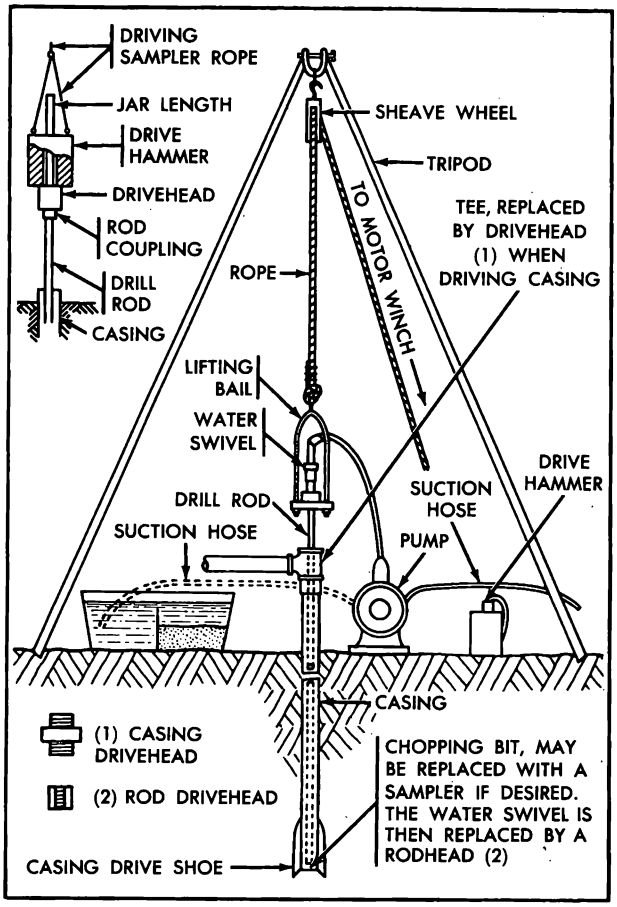


FIGURE 2A2-5

Equipment for Making Wash-Drill Borings (Ref. 9)

6. CHURN DRILLS. Another method of obtaining wash-boring samples makes use of churn or percussion drills of the type manufactured by Bucyrus-Erie Co., Keystone Drilling Co., and others. This type can drill to relatively great depths. Samples from the drillhole may be obtained down to 1,000 feet, depending on size of casing and character of ground. The accuracy of the sample depends greatly on the character of the material and whether it is frozen or thawed. Usually, when samples are obtained by this type of equipment, the fines are lost and the degree of compactness can not be satisfactorily determined.

The casing used is usually 6 in. in diameter, although casing as large as 16 in. has been used. Extraheavy casing is recommended where many boulders are encountered or when the casing must be driven to great depths. Casing smaller than 6 in. is sometimes used, but for hard driving at depths over 50 ft, 6-in. or larger casing is recommended because it can be pulled with less chance of damage to, or loss of, the casing. To protect the lower end of the casing from injury while driving, a wrought-iron drive shoe is used. On 6-in. casing the drive shoe is usually made 7½ in. in diameter at the cutting edge. It is slightly beveled inward, has a tempered edge, and is threaded to receive the casing, which rests on a shoulder of the shoe. (Ref. 11, 12.)

No casing is usually required in churn drilling in permafrost where no taliks are present. Casing is required when drilling through the active layer and should penetrate the permafrost to a sufficient depth so there will be no infiltration of water from the surface or the contact between the active layer and the permafrost. The usual required penetration into permafrost is approximately 10 feet.

Various types of drive heads are used, one type being made of a standard coupling and a nipple of extraheavy pipe. The casing is driven by striking the driving head on the casing with driving clamps attached to the drill stem. The stroke of the drill represents the length of the blow, and the entire weight of the drilling tool represents the weight of the hammer. (For another method of sinking casing, refer to par. 8 of 2A2.03.) Such casing is pulled from the ground by substituting a pipe-pulling jar for the drill bit. A threaded flange screwed into the top coupling of the casing is jarred by a series of upward blows imparted by the drilling motion of the rig, each blow terminating at the end of the upward stroke in a powerful pulling action. (Ref. 11, 12.)

In this type of drilling, the hole is cleaned out from time to time by a valve bailer or pump consisting generally of an iron pipe containing a valve in the bottom. A line operated by a special sand reel on the drilling rig rapidly drops the bailer, causing it to suck in the material at the bottom of the casing. A small quantity of water is required in the casing when recovering material by this method. Bailers may be of various types, depending on the material being recovered. When the casing is sufficiently large in diameter (12 to 16 inches), a small orangepeel bucket is sometimes substituted for the bailer. Such equipment is particularly efficient in removing large chunks of boulder or heavy gravel from the hole. (Ref. 13.)

Figure 2A2-6 illustrates one type of portable percussion drill. The tool string setup to drive, bail, and pull the casing is typical of the equipment used by all percussion-type drills.

7. SELECTION OF THE SAMPLER. The technique of sampling is developing rapidly and new types of sampling devices are constantly being designed to keep pace with new developments in soil mechanics. This trend, although limiting the older methods and equipment to specific uses, does not make them obsolete; instead, it emphasizes the point, already mentioned, that no one method or type of equipment can serve all purposes for which soil samples may be required. Experience, good judgment, and knowledge of the character of the soil and use of the sampler are necessary to obtain samples that are representative of the material. Regardless of the type of sampling device selected, it should be capable of recovering a sample sufficiently large in diameter to permit the necessary paring before the sample is studied.

a. *Solid-Barrel Sampler*. The cores shown in Figure 2A2-3 were taken with a solid-barrel sampler made from a 4-inch pipe with holes near its top to permit air and water to escape. The cutting edge of the core barrel was slightly bent inward so that friction was reduced as much as possible on the inner surface of the pipe as it was driven into the soil. The sample in a core barrel of this type may be removed with an ordinary screw jack, as shown in Figure 2A2-7, and immediately wrapped in cheesecloth and coated with paraffin to retain the moisture of the material in place. A 4-inch sample obtained from a core barrel of the above type is shown in Figure 2A2-4. This type of sampler is not adapted for recovery in noncohesive materials in open packing.

b. *Split-Barrel Samplers* (Ref. 14). A somewhat more versatile sampler, known as the split-barrel sampler, is illustrated in Figure 2A2-8. It can be used with or without flap valve, a feature that permits wide use of this sampler. When sampling clay or other plastic formations, the valve is not used; but in materials in which there is little cohesion, the valve is essential to prevent the sample from falling out while the sampler is being removed from the hole.

The sampler consists of three main parts—barrel, head, and shoe. The barrel is split lengthwise so that it can be taken apart and the sample removed with a minimum of disturbance. The head has a female rod connection in the top and is equipped with a ball check valve for passage of air and water. The shoe is beveled to facilitate driving and is hardened to increase ruggedness. Standard sizes are 1½ to 3 inches ID.

The Maine-type sampler (Figure 2A2-9) is quite similar to the split-barrel sampler. The head and connection are somewhat different and the standard sizes are larger in the Maine type, running from 3½ to 5 inches. Two types of flapper valves can be furnished with this sampler, a single flap valve or quadruple flap valve. The type of valve selected depends on the material to be tested.

c. *Driving*. Samplers of the type described in the foregoing paragraphs are usually driven into the ground with the same equipment that is used to sink the casing. In obtaining samples, the number of blows required to drive the sampler into the soil should be recorded because such records will be useful in evaluating the soil density.

d. *Thin-Walled Samplers*. An extensive study of the problem of undisturbed sampling by M. G. Hvorslev led to the wide adoption of thin-walled samplers of the type shown in Figures 2A2-10 and 2A2-11. Hvorslev's studies indicated

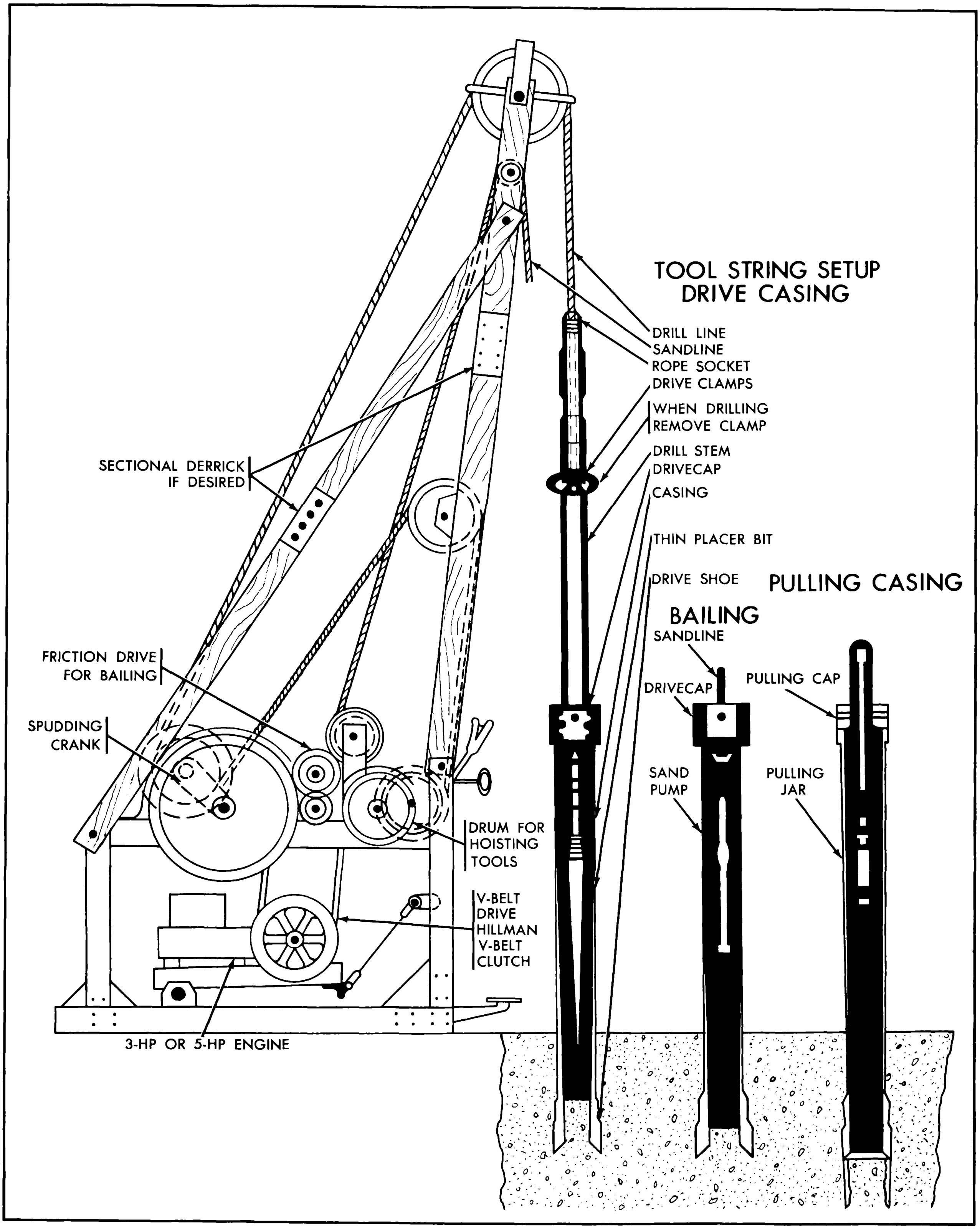


FIGURE 2A2-6

Diagram Showing Tools and Drilling Operations of Hillman Airplane Tracer Drill

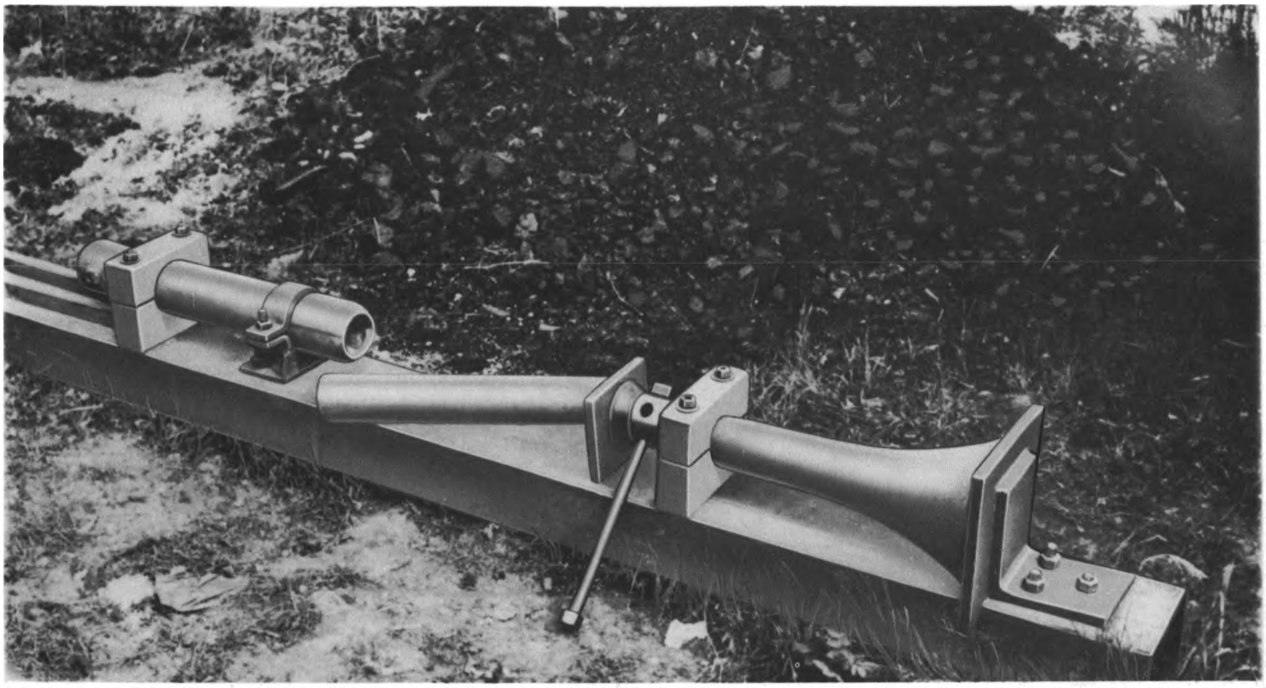


FIGURE 2A2-7

Barrel Sampler and Press-Out Apparatus

that best results were obtained when such samplers were pressed into the soil rather than being driven; and when their so-called area ratio, C_A, that is, the ratio of the area of the displaced soil to the area of the soil sample (Figure 2A2-12), was reduced to a minimum. The equation is

$$C_A = \frac{D_W^2 - D_E^2}{D_E^2} \qquad \text{(Ref. 9)}$$

The thin-walled Shelby tube sampler (Figure 2A2-10) was developed as the result of Hvorslev's studies. (Ref. 9.) This sampler consists of a thin-walled metal tube (usually steel), the upper end of which is attached to the sampler head with flathead machine screws. A ball check valve is built into the head, the function of which is to permit the escape of air and water when the sampler is forced into the soil and to prevent an inrush of water that may wash the sample from the tube. After the tube has been pressed into the ground the desired depth, it is raised from the hole, and the thin-walled tube containing the sample is detached from the head.

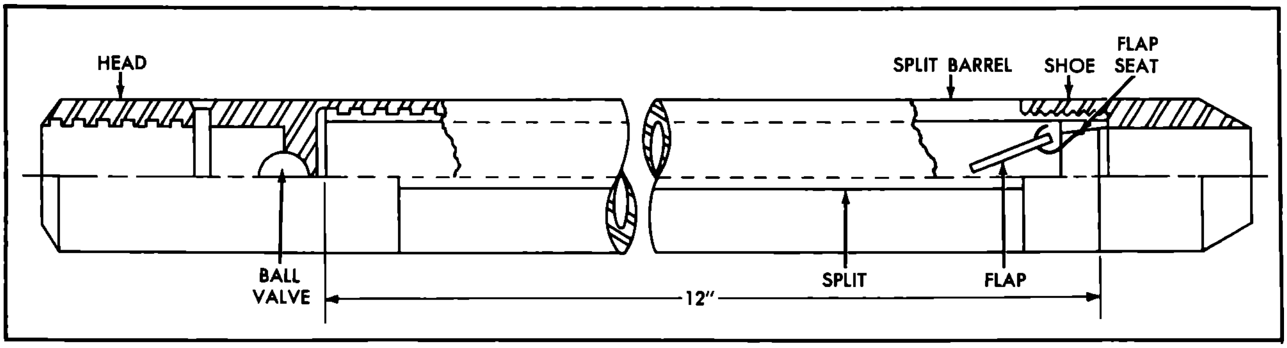


FIGURE 2A2-8

Sprague and Henwood Split-Barrel Sampler

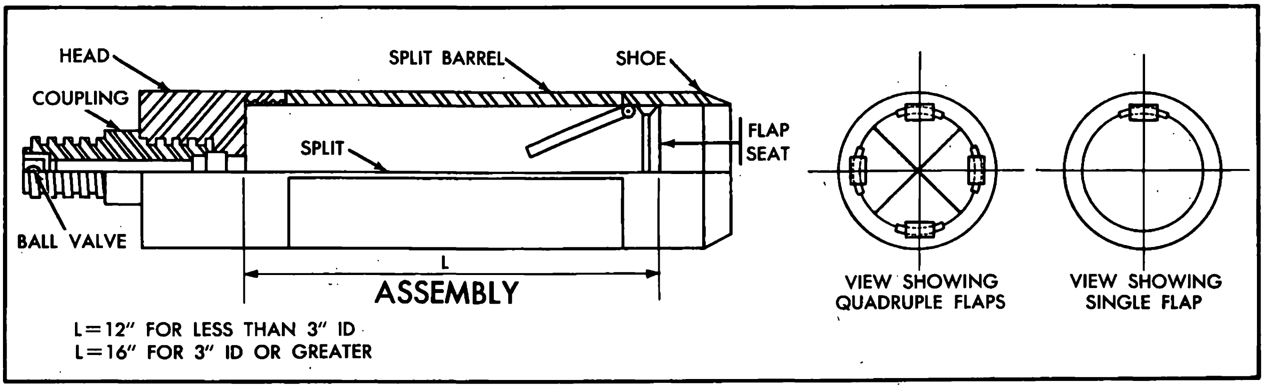


FIGURE 2A2-9

Sprague and Henwood Maine-Type Sampler (Ref. 14)

The space at both ends of the tube can be filled with paraffin, and the tube capped and sealed. Standard sizes are 2 to 2⅜ inches ID. (Ref. 14.)

In soft clay, the material in the ground is often squeezed up by the weight of the overlying soil and clings to the inside of the casing. In soil of this type a stationary piston-type sampler, illustrated in Figure 2A2-11, may be advantageous because it can be pushed down through the casing and soft clay clinging to it to the elevation where the sample is to be taken without the entrance of the disturbed material into the sampler. This sampler consists of a thin-walled tube, a close-fitting piston operated by a separate piston rod, and a sampler head with spring and piston rod check. The head is equipped with vents to permit the escape of air or water during sampling operations. The separate piston rod extends all the way to the surface, where it is clamped in place. (Ref. 14.)

In regular operation, the piston is clamped flush with the cutting edge of the tube while the sampler is lowered into the drillhole to the desired sampling depth. When the depth at which a sample is desired is reached, the piston rod clamp is removed from the drill rod and the piston is then clamped to the casing at the surface. The piston is held at constant elevation while the sampler tube is forced past it into the soil. (Ref. 14.)

When the sampler is removed from the hole, the piston rod is held in place by the check in the head of the sampler; this prevents the piston of the sampler from being lowered into the tube again by any means except removing the sampler and manually removing the check from the head. (Ref. 14.)

The stationary piston-type sampler is designed for use in silt or clay free from obstructions and containing little or no granular material. It must always be jacked or forced into the ground under steady pressure (Figure 2A2-13). It should never be driven into the ground with a drop weight.

After the sampler has been removed from the hole, the tube is detached from the head by remov-

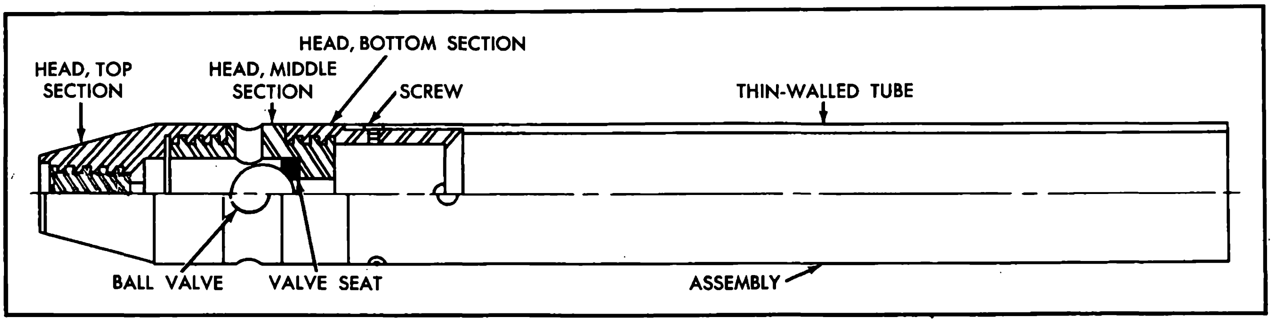


FIGURE 2A2-10

Thin-Walled Shelby Tube Sampler (Ref. 14)

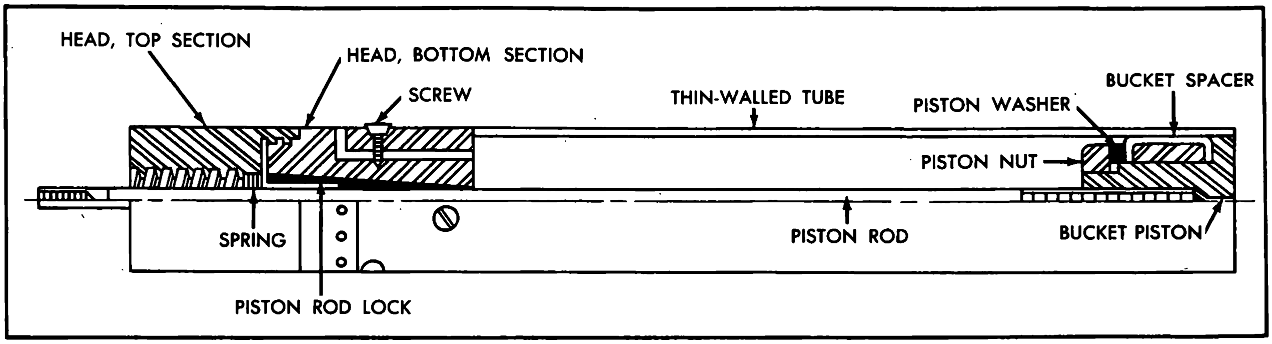


FIGURE 2A2-11

Improved Stationary Piston-Type Sampler (Ref. 14)

ing the four screws in the top of the tube. In order to prevent any vacuum being caused by the withdrawal of the piston from the top of the tube, a few backward turns of the piston rod will admit air and thus prevent the vacuum that would otherwise distort the sample. The space on both ends of the sample can be filled with paraffin, the tube capped and sealed, and then sent to the laboratory. Standard tubes are approximately 30 in. long and from 2 to 2.8 in. ID. (Ref. 14.)

8. CALIFORNIA-TYPE WELLS. In securing dry samples of relatively large diameter, casing larger than is practical to drive by the method described in par. 6 of 2A2.03 is sometimes required. As mentioned previously, large drilling machines can sink casing 16 inches in diameter, but casing of this size, which must be heavy enough to drive and pull successfully, is extremely cumbersome and difficult to handle. The weight and awkwardness of the wrenches needed to connect and disconnect the casing necessitate more manpower than can usually be justified in sampling operations. Therefore, when large-diameter casing is required, it is recommended that consideration be given to using comparatively light stovepipe casing that, after being sunk, is not recovered. Such casing, usually from 10 to 30 inches in diameter, is pulled into the ground by hydraulic jacks instead of being driven. The casing is standard 4-foot sections and is usually 10 to 12 gage. The sections are sized to fit into each other by one half of the length of the section so that the assembled casing is 2-ply and, if necessary, 3-ply thickness. In assembling the string of casing, the first section is fitted into a starter section, which is much heavier and several times as long as a section of casing. A drive shoe with a hard-faced cutting edge protects the lower end of the starter section.

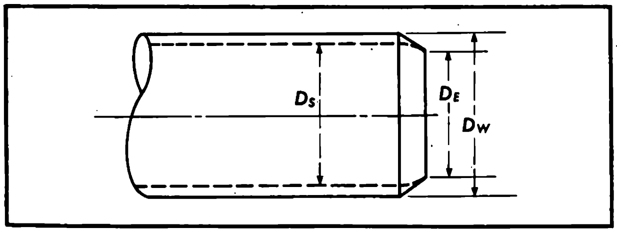


FIGURE 2A2-12

Illustration of Term Area Ratio of Sampler (Ref. 9)

Hydraulic jacks used to sink the casing are the type shown in Figure 2A2-14. It is customary to place the jacks in pairs, but, if the casing is very large or the need of very high pressure is foreseen because of the knowledge of the ground, four jacks may be used. The maximum working pressure recommended on jacks of this type is 2,000 psi. (Ref. 15.)

Preparatory to sinking, an excavation is made in which anchor timbers are placed. Anchor bolts are fastened to the anchor timbers and the lower ends of the jacks are attached to them. The jacks are then placed in a vertical position until the water or oil pipes have been attached and brought above the surface. Then the hole is filled with dirt, except around the casing where enough room is left to center and plumb the casing before the sinking operations. (Ref. 15.)

A pump is mounted on one side of the drilling rig and controlled from the drilling position. Lines are connected so that pressure may be exerted at separate times above and below the pistons of the jacks. Either end of the jacks may be exhausted

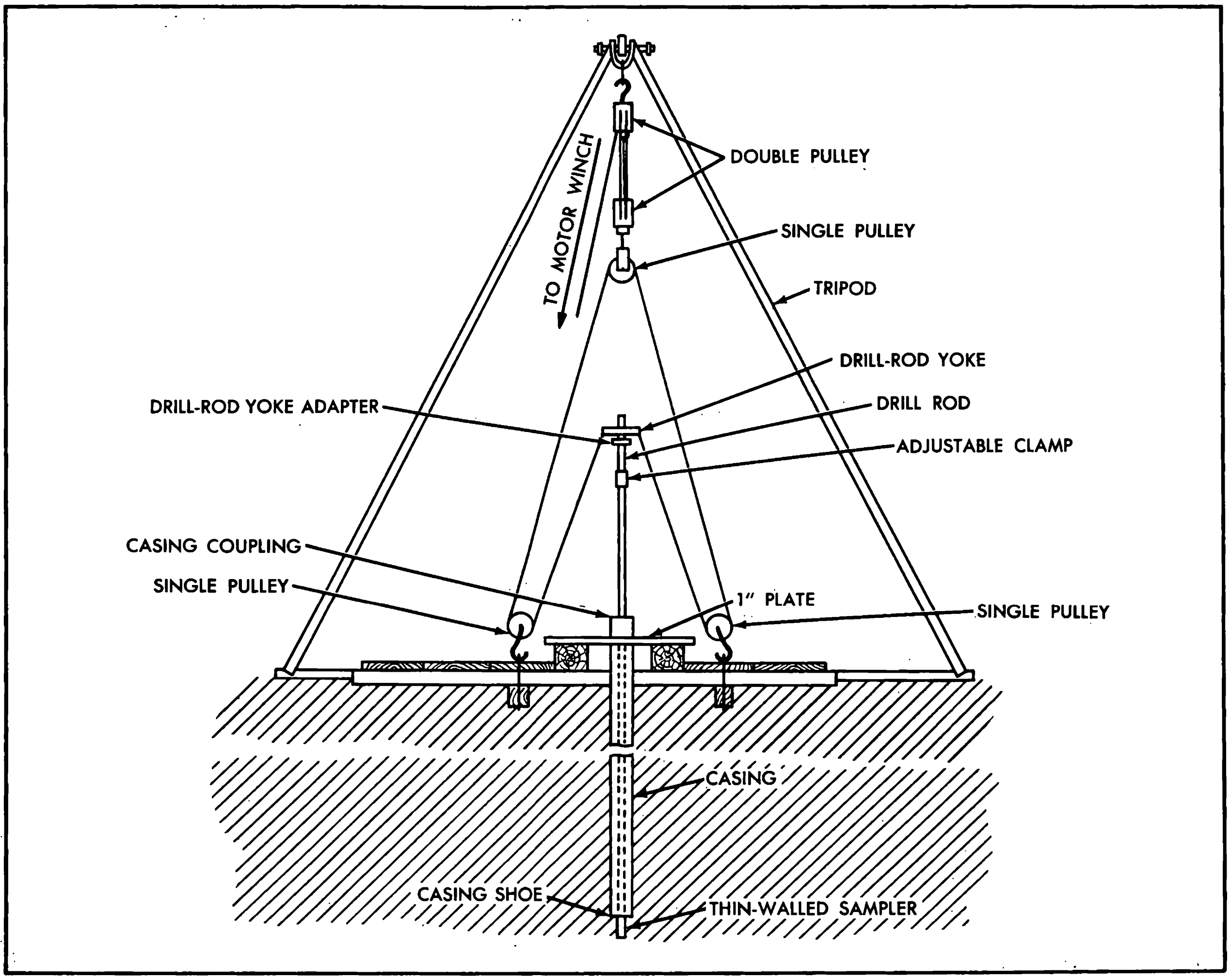


FIGURE 2A2-13

Equipment for Undisturbed Sampling (Ref. 9)

back to the storage tank while the other end is under pressure. (Ref. 15.)

To prepare for sinking, the well cap is mounted at the top of the casing and the clevises on the jacks are hooked over the well cap ears. Pressure is applied above the jacks' pistons, and the casing is pulled into the ground. After the starter section and length of casing have been sunk to the limit of the piston stroke, a new section of casing is placed. Its lower half should be sharply pinged in one or two places with a center punch or similar tool to provide a slight projection that will protect against parting of the casing sections if soft ground is encountered. The action of the pistons is then reversed and the clevises brought back to their starting position. The material within the section of casing that has been sunk is then removed, as described in par. 6 of 2A2.03. The well cap is mounted on the new section, the clevises are hooked over the cap ears, and the sinking operations are repeated.

It is obvious that the jacking method described above is advantageous when taking samples by thin-walled samplers of the type described in par. 7d of 2A2.03. In such cases the jacks would be used to pull the drill stem, to which the sampler is attached, into the ground in the same manner as casing is sunk.

9. ROTARY CORE DRILLS. If solid or ledge rock is encountered in any boring, the rock should be cored to a depth of not less than 5 feet.

Rotary or revolving core drills are used to pene-

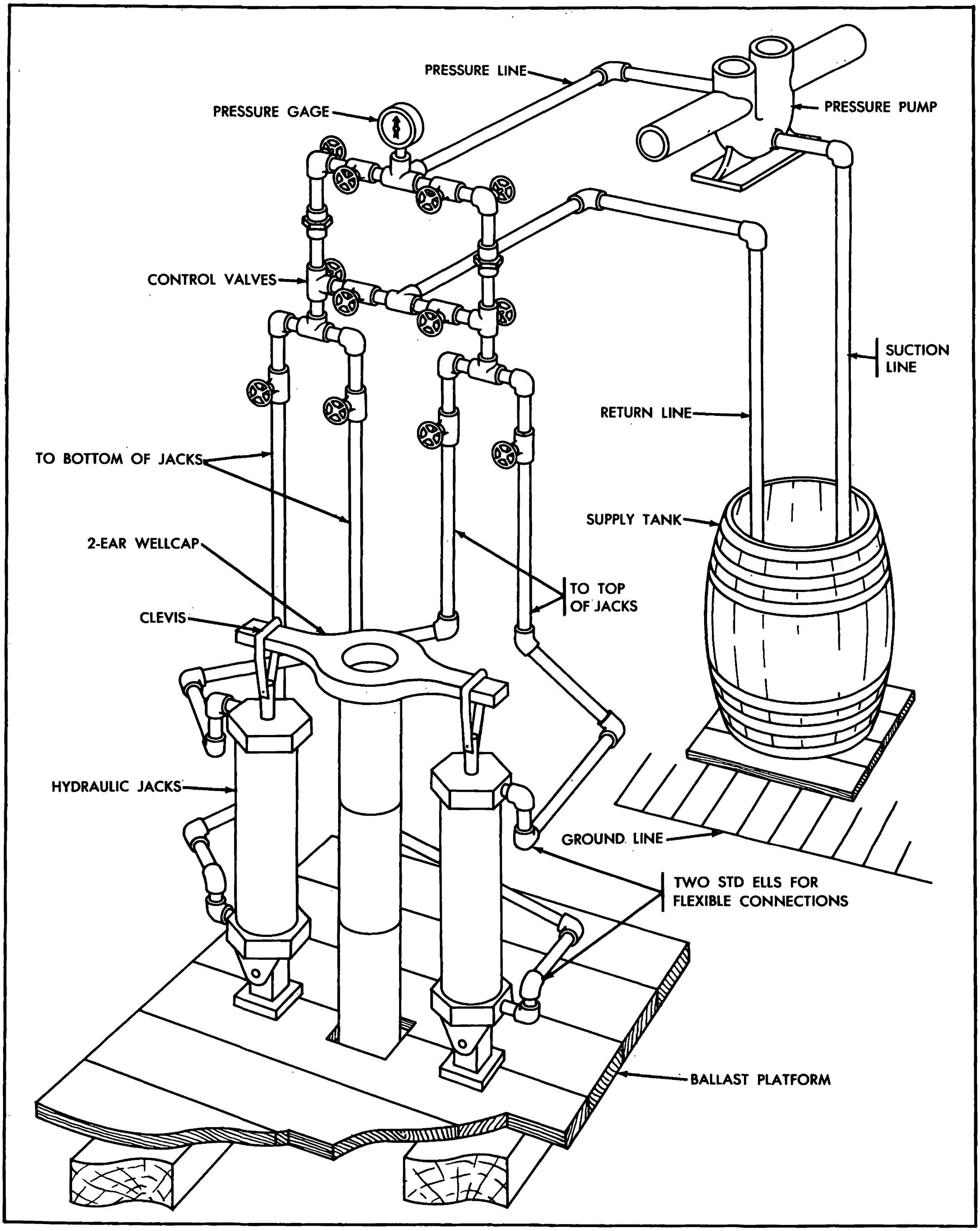


FIGURE 2A2-14

Surface Equipment Required for Sinking Stovepipe Casing (California-Type Well) (Ref. 15)

trate and take core samples from rock. They are excellent for exploratory drilling, foundation test drilling, and grout hole drilling for bridges and other heavy structures, particularly when the rock is seamless. When there are horizontal cleavages present in the rock, continuous cores are often difficult to obtain; special types of core barrels are available, however, that assure fairly good recovery even in broken strata. Rotary core drills can not be used with success in gravel, loosely packed sand, loose boulders, and most types of clay, whether thawed or frozen, because the loose formations will immediately close up the borehole on withdrawal of the drilling tool. They have given excellent results in permanently frozen bedrock.

Very satisfactory cores of frozen silt and sand, with a diameter of about 6 inches, have been obtained by the US Army Engineers with rotary drills equipped with a saw-toothed cutter. When the equipment was used in frozen sand and gravel, difficulties were encountered. The outer layer of the core melted on account of the heat developed by the rotating tool and the core slipped out of the barrel. Better results were obtained when the wash water was mixed with alcohol and cooled to about 32° F. (Ref. 8.)

Section 3. SNOW

2A3.01 GENERAL

The duration and amount of snow cover in the Cold Regions depend on the disciplines existent within the area. Snow is extremely important to most cold-weather engineering operations; although it complicates many such undertakings, it also is a definite necessity to others. At large installations a major maintenance problem is often created by the necessity for snow removal and storage, and there may be frequent disruptions to transportation and other operations by snowslides or drifting snow. Good judgment in site selection and proper design and protection of exposed operating areas can accomplish much in reducing the importance of such hazards. In general, the advantages of a snow cover far outweigh its disadvantages. By smoothing surface irregularities and by covering marshes and lakes, it affords a ready means of transportation over areas that are otherwise inaccessible. Snow itself constitutes a building material of excellent insulation value that can be utilized in construction of temporary shelters and emergency or seasonal airstrips. Such facilities, if properly constructed, will give satisfactory service with a minimum of maintenance. Melted snow furnishes a ready source of water for emergency needs and can often fulfill the total seasonal requirements of small operations.

Snowcrete, snow removal, protection from drifting snow, and snow compaction are discussed in par. 5b of 2A9.01, par. 1, 2, and 3 of 4C2.03, and Sections 3B1 and 3D1 respectively.

2A3.02 PRECIPITATION OF SNOW COVER

Water vapor rising into the atmosphere is transformed into ice crystals when it passes through zones of freezing temperature. For this reason, high clouds usually consist of infinitesimal ice crystals rather than fog, as is the case with those closer to the earth's surface. These very fine crystals float in the upper atmosphere for long periods before gradually sinking to earth. During their descent they may pass through a warmer stratum of air and dissolve into fog, or further crystallization may occur, resulting in the formation of snow. The temperature of the atmosphere layer adjacent to the surface of the earth, therefore, determines whether moisture is precipitated in liquid form as rain or in solid form as snow. In some cases, drops of water freeze in midair and fall as hail, or liquid and solid forms can fall together constituting a mixed type. (Ref. 16.)

2A3.03 TYPES OF SNOW PRECIPITATION

Snow cover may consist of a number of forms of precipitation, both liquid and solid. The general types of solid precipitation making up the snow cover are classified by one source (Ref. 16) as:

(1) Snow—precipitation in the form of snowflakes, which are crystals of ice having various forms. (See Figure 2A3-1.)

(2) Granular snow—opaque, white grains 1.0 to 5.0 mm (0.04 to 0.20 in.) in diameter, having a structure similar to snow. This material is very frangible, readily compressible, and usually falls at temperatures close to 0° C (32° F), most frequently before or simultaneous with ordinary snow.

(3) Soft hail—translucent, round, sometimes conical grains that are 2.0 to 5.0 mm (0.08 to 0.20

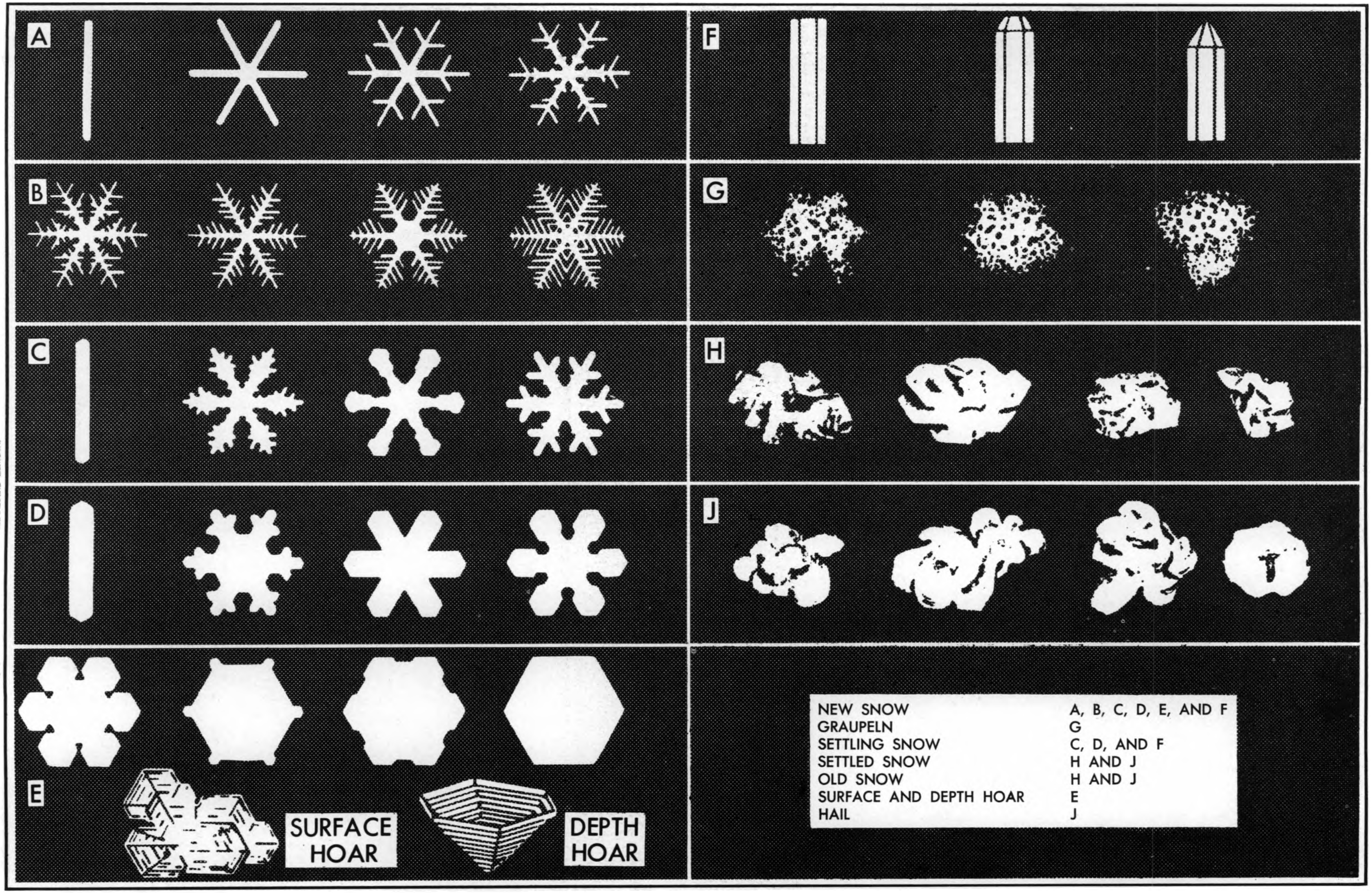


FIGURE 2A3-1

Types of Snow Precipitation

in.) in diameter. These grains are only slightly frangible and compressible, and when falling on a hard surface they do not break apart. They usually fall at temperatures close to 0° C (32° F), often simultaneous with rain, and may consist of grains of granular snow covered with a thin layer of ice.

(4) Grains of ice—hard, transparent grains, 1.0 to 4.0 mm (0.04 to 0.16 in.) in diameter, formed when drops of rain fall through a cold layer near the surface of the earth and freeze. When these particles fall on a hard surface they bounce high but do not break apart.

(5) Griesel—grains that are less than 1 mm (0.04 in.) in diameter, similar to granular snow, that usually precipitate from fog and occur in small quantities. When they strike a hard surface they neither bounce nor break.

(6) Ice needles—tiny ice crystals in the shape of needles or flakes, which are seemingly suspended in midair. They are most clearly visible when shining in the sunlight and may be the cause of vertical luminescent columns and similar optical illusions. This form of precipitation occurs most frequently during stable winter weather under conditions of extreme cold.

(7) Sleet—precipitation in the form of melting snow, or snow and rain occurring simultaneously.

(8) Rime—ice crystals precipitated from moist air on supercooled surfaces, usually occurring at night when the sky is clear and cloudless and when there is a high degree of heat radiation from the surface in question. Rime frequently occurs on snowy surfaces.

(9) Hoar frost—ice crystals that are usually formed in foggy weather when the temperature is below freezing. Hoar frost may be observed on vertical surfaces, thin branches and wires, and the points and corners of buildings. It may also be formed from drizzling fog or supercooled drizzle, in which case it has a structure similar to soft hail.

(10) Glazed frost—transparent layers of ice formed on vertical or horizontal surfaces in the presence of hoar frost or supercooled rain.

2A3.04 MAJOR FACTORS DETERMINING STRUCTURE AND PROPERTIES OF SNOW COVER

The many forms of precipitation that constitute the snow cover, and the changes that occur because of local factors, greatly complicate the study of its properties and create difficulties in developing a system of classification. In general, the structural, physical, and mechanical properties of snow cover are the result of the following fundamental conditions (Ref. 16).

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

(2) Degree of deformation of the snowflakes while falling.

(3) Changes in the snow cover resulting from precipitation of rime and hoar frost and from evaporation.

(4) Increasing density of the snow cover caused by force of gravity, thawing of the snow followed by subsequent freezing, recrystallization of snow and firnification, and mechanical effects of wind and snowstorms.

(5) Changes in the snow caused by subsequent liquid precipitation.

(6) Foreign matter in the snow cover (mineral particles and similar material).

(7) Nature of the surface beneath the snow, its behavior under snow cover (freezing, for example), and the temperature regime within the snow cover.

2A3.05 PHYSICAL AND MECHANICAL PROPERTIES OF SNOW COVER

1. GENERAL. As previously mentioned, the physical and mechanical properties of snow cover are usually the result of a combination of actions. An evaluation of any of them, therefore, in terms of a single variable is mainly of scientific interest and would have only an indirect bearing, if any, when considered for its engineering uses. Also, when snow cover is utilized for engineering operations, the properties of in-place snow cover are either modified or completely changed by some artificial means to meet certain requirements satisfactorily. In this paragraph, consideration is given to the engineering performance that can be expected from snow having certain properties as indicated.

2. DENSITY. Density of snow is the ratio of the quantity of water that can be derived from a given mass of snow to the initial volume of the snow. This is one of the most important physical and mechanical properties of snow because all the other properties are related to it. Snow density is also an important index to the possible utilization of snow with respect to transportation and con-

struction. Density of snow cover varies from 0.01 to 0.7 g/cu cm (0.6 to 43.0 lb/cu ft) depending on many factors. A general classification that describes the snow covering in general terms with respect to density is given in Table 2A3-1 (adapted from Ref. 16).

TABLE 2A3-1

Density of Snow Cover

Snow cover	Density	
	G/cu cm	Lb/cu ft
Very loose	0.01 to 0.1	0.6 to 6.3
Loose	0.1 to 0.25	6.3 to 15.7
Medium	0.25 to 0.35	15.7 to 22.0
Dense	0.35 to 0.45	22.0 to 28.4
Very dense	over 0.45	over 28.4

Table 2A3-2 (adapted from Ref. 17) shows thickness and density requirements of snow covers subjected to varying traffic conditions. Other sources give density requirements at 0.32 to 0.35 g/cu cm (20 to 22 lb/cu ft) for pedestrian traffic and 0.5 to 0.6 g/cu cm (31 to 37 lb/cu ft) for truck traffic. The supporting power as related to density values applies only at temperatures below 32° F because the supporting power of snow above that temperature may be changed greatly by moisture content while the changes in density are negligible. (Ref. 16.)

3. HARDNESS. Hardness or supporting power of snow is a measure of the cohesive bond formed between the snow crystals. Although hardness is affected by many variables, it is caused primarily by aging. This term covers the complex processes that take place over a period of time and result in the development of a new, large, granular or crystalline structure. Hardness values, as determined from tests on snow cover carrying different types of traffic, are shown in Table 2A3-2. It can only be assumed that satisfactory trafficability existed in these areas. Figure 2A3-2 shows the relationship of hardness versus depth of penetration for different vehicles. (Ref. 16, 17.)

4. SHEAR STRENGTH, COHESION, AND TENSILE STRENGTH. The reported values of these properties show a wide variation that can not readily be explained. These properties depend on a number of variables (par. 2A3.04), but the values obtained for these variations also differ greatly between observers so that no precise relationship has been established.

Snow is an unstable material; the variations in some physical and mechanical properties have been mentioned previously. Shear strength values vary 35 percent or more, fluctuating around 7 psi at density of 25 lb/cu ft. (See Table 2A3-3, adapted from Ref. 18.) Shear failures may be influenced particularly by surface cohesion between crystals,

TABLE 2A3-2

Test Data Showing Variation of Hardness in Relation to Depth of Snow Surfacing Various Types of Roads

Type of traffic	Thickness		Volume		Weight		Density		Hardness	
	Cm	In.	Cu cm	Cu in.	G	Lb	G/cu cm	Lb/cu ft	Kg/sq cm	Lb/sq in.
Auto only	38	15	1,860	113	1,163	2.56	0.625	39.1	14.0	19.9
Horsedrawn	35	13.6	1,710	104	800	1.76	0.467	29.3	7.0	9.95
Pedestrian only	41	16.1	2,010	122	925	2.04	0.462	28.9	4.6	6.55
Crust of snow (upper stratum)	6	2.4	294	18	135	0.30	0.458	28.9	4.2	5.96
Entire depth of snow	43	16.9	2,105	217	512	1.13	0.243	15.2	2.2	3.13
	Depth where hardness was measured, cm									
	0		5		10		15		Average	
	Kg/sq cm	Psi	Kg/sq cm	Psi	Kg/sq cm	Psi	Kg/sq cm	Psi	Kg/sq cm	Psi
Mixed traffic	15.0	213	15.0	213	12.1	172	10.3	146	14.0	199
Horsedrawn	15.1	214	6.0	85.2	5.1	71.0	1.3	18.5	7.0	99.4
Pedestrian only	11.2	159	4.0	56.8	1.5	21.3	1.5	21.3	4.6	65.4
Crust of undisturbed snow	6.8	96.5	1.6	22.7	0.3	4.3	0.3	4.3	2.2	31.2

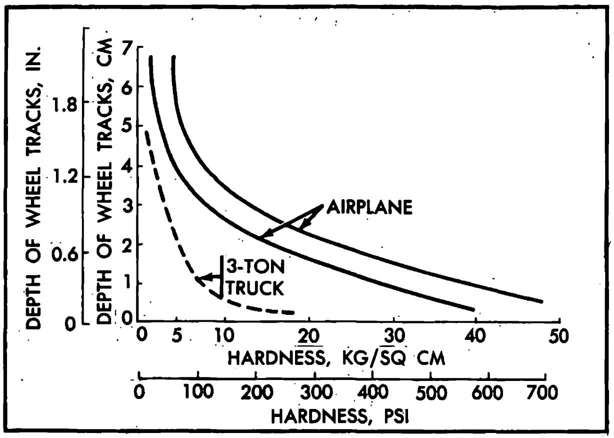


FIGURE 2A3-2

Relation of Hardness to Depth of Penetration for Wheeled Vehicles

by the presence of ice fusion bonds between the crystals, and by crystal size.

Cohesion or shear strength at zero load depends on crystal structure and growth and intercrystalline bonding that results from the factors mentioned in par. 2A3.04. Cohesion values increase with time (Table 2A3-4) and also with decreasing temperatures. The results of these factors and others previously mentioned give snow a structure that at low temperatures is similar to that of a cinder block. Snow in this condition lends itself readily to the construction of temporary snow shelters. (See par. 2E2.05.)

Cohesive strength of snow is also increased with application and subsequent removal of load. This is due to deformation and change in crystal structure, which results in improved crystalline bonding.

Tensile strength values of snow, as measured by using a centrifugal apparatus, are shown in Table 2A3-3. The variations in these results are probably due to the inhomogeneity of the snow and the small size of the individual samples. (Ref. 18.)

The compressive strength of snow usually increases with age and is a function of its character, temperature, density, cohesion, and the intercrystalline bond existing between its particles. It is believed that the ultimate compressive strength may approach that of ice as the density of snow approaches the density of ice.

5. HEAT CONDUCTIVITY OF SNOW. Snow cover, which is composed of a large amount of air voids, has a very low heat conductivity. The results of this fact are (a) a comparatively shallow freezing of the underlying soil, especially where heavy snowfall or drifting snow occurs; (b) a method of regulating the depth of freezing by varying snow cover depth; (c) a means of survival against cold by building snow shelters or snowhouses; and (d) marked reduction in the development of lake and river ice. One source reports a reduction in ice formation of 40 mm (1.57 in.) under a snow covering of 5 mm (0.20 in.), which results in a total freezing thickness of only 16 mm (0.63 in.) over a 24-hr period. In general, heat conductivity is a function of snow density. Ref. 17 gives this relationship as $k = 0.0067d^2$, where d

TABLE 2A3-3

Tensile and Shear Strengths of Snow at Zero Normal Load (University of Minnesota)

Test number	Density		Permeability		Tensile strength, T		Shear strength, S	
	γs kg/cu m	Lb/cu ft	Cm/sec	In./sec	Kg/sq m	Psi	Kg/sq m	Psi
1	408	25.5	71	27.9	0.32	4.5		
2	408	25.5	90	35.4	0.94	13.4		
3	422	26.4	72	28.4			0.39	5.5
4	406	25.3	72	28.4			0.50	7.1
5	408	25.5	91	35.8	0.36	5.1		
6	396	24.7	94	37.0	0.55	7.8		
7	432	26.9	75	29.5			0.60	8.5
8	434	27.1	55	21.7	0.72	10.2		
9	418	26.1	81	31.9	0.87	12.3		
10	384	24.0	112	44.1	0.58	8.2		
11	456	28.5	66	26.0	0.61	8.7		
12	394	24.6	79	31.1	0.37	5.2		
Average					0.59	8.4	0.50	7.1

TABLE 2A3-4

Variation of Cohesion With Age

Test series	Density		Permeability		Age in days	Cohesion (c)	
	Kg/cu m	Lb/cu ft	Cm/sec	In./sec		Kg/sq m	Psi
1	142	8.86	70	27.6	¼	1.0	0.14
2	151	9.42	72	28.4	1	1.7	0.24
3	151	9.42	70	27.6	3	1.9	0.27
4	150	8.86	72	28.4	7	3.3	0.47

is the density in the metric system and k is the calories/sq cm/sec/cm. From this formula, Table 2A3-5 (adapted from Ref. 16) was computed for various snow densities. Conversion to the English system was made for convenience of use.

6. SOLAR RADIATION. Because of the partial transparency of snow, there may exist an effective heat source below the snow surface. Under equilibrium conditions the temperature below the surface of the snow cover may be greater than at the surface. Consequently, melting may occur within the snow cover when the air temperature and ground temperature are both below freezing. This effect has been observed at air temperatures as low as −4° F. (Ref. 18.)

7. SLIPPERINESS AND MOBILITY. The slipperiness of snow and ice depends on a large number of factors. It results from the fact that the force needed to overcome resistance to motion is transformed into heat, and this has the effect of warming the ice or snow beneath the runner or ski to the freezing point and then melting a little of it. The water resulting from this melting is the lubricant that increases the slipperiness. At halts, the lubricant again freezes and the runners freeze to the snow or ice. (Ref. 16.)

TABLE 2A3-5

Thermal Conductivity Values of Snow

Density	k = Btu/sq ft/hr/in.
0.05	0.048
0.10	0.193
0.15	0.440
0.20	0.782
0.25	1.23
0.30	1.77
0.35	2.41
0.40	3.14
0.45	3.98
0.50	4.94
0.90	18.5

Loose snow offers greater resistance to motion over its surface than dense snow. Soft snow, which occurs at higher temperatures, is sticky and increases resistance to motion over its surface. Tests indicate that the greatest resistance occurs at 1.5° C (34.7° F). As the temperature decreases, the snow becomes harder and resistance decreases. The width of runner or ski, because it determines the unit load, affects the degree of stickiness. Narrow skis, therefore, are preferred when temperatures are high. (Ref. 16.)

8. ADFREEZE. Adfreeze, or adhesion of frozen soil to objects with which it is in contact, is discussed in par. 2 of 2A9.02. The phenomenon of adfreeze is an important consideration in transportation over snow and ice, for upon its intensity will depend the effort required to move a vehicle after a halt. Snow immediately beneath a runner melts while the runner is at rest and freezes to the snow layer below it. The intensity of adfreeze depends on the length of the pause between movements, the heat conductivity of the material, the contact surface, the state of the snow or ice, and the ambient temperature. Since wood is a poorer thermal conductor than metal, wooden runners adfreeze more readily than metal. Fine-grained woods adfreeze more readily than course-grained woods. Rough, unpolished surfaces adfreeze more readily than polished surfaces. Because of adfreezing, the coefficient of stress at the beginning of motion may be up to 16 times as great as during further movement. On a snow road, the ratio will be 7–8:1, and on an ice road, 3–5:1. Thus, it takes several times as great an effort to move a sledge from its place of rest than to keep it in motion (Table 2A3-6). To budge a sled from a dead stop, a maximum ratio of motive force to weight of 0.3 is required. N. A. Pavlov has conducted experiments that resulted in determining the magnitude of the coefficient of adfreezing and motion and also the ratio between them for various types of snow cover. (Ref. 16.)

9. FRICTION (Ref. 16).

a. *Resistance to Slide of Sledge (or Ski) Transport*. Resistance to sliding motion over snow depends not only on adfreeze but also on the following factors.

(1) Degree to which runners sink into the crust. Resistance increases with depth.

TABLE 2A3-6

Coefficient of Adfreeze k_1 and Coefficient of Slide k_2 of Sledges, and Ratio $k_2 : k_1$

Atmospheric temperature		State of surface (ruts)	Load		k_1	k_2	$k_2:k_1$
°C	°F		Kg	Tons			
−5	23.0	Pure ice	17,500	19.3	0.028	0.007	0.25
−18	−0.4	Snow over ice	17,500	19.3	0.057	0.017	0.30
2	35.6	Ice thawing in sunlight	40,000	44.1	0.031	0.011	0.35
−10	14.0	Pure ice	25,500	28.1	0.039	0.011	0.28

(2) Displacement of the snow by the runners. Resistance increases with the strength of adherence within the cover. The movement of snow particles over each other increases friction.

(3) Packing of snow under runners. Packing increases with vehicle loads, higher temperatures, and looseness of the snow. As the temperature rises, the load must be reduced. Sledge roads resist damage better when temperatures are low.

(4) Friction between the surface of the snow and the vehicle runners. This depends on the ambient temperatures, on the shape, quality, and material of the runners, and on the state of the snow cover. The coefficient of friction of wooden runners at medium temperatures, according to Sobennikov, is as follows: 0.125 on freshly fallen snow, 0.033 on a clean, little-used road, 0.016 on a well-smoothed road, and 0.012 on ice.

The friction of iron runners is less than half of the above. Wood runners are often doused with water and allowed to freeze to reduce their coefficient of friction. Friction increases with declining temperature, but it increases when the snow is wet.

b. *Resistance to Motion of Wheeled Traffic.* The coefficient of resistance to the motion of wheeled traffic differs greatly from the coefficient of friction of sliding sledges. (See Table 2A3-7, adapted from Ref. 16.) On ice and loose snow the coefficient of resistance to the motion of wheeled vehicles is almost ten times as great as the coefficient of friction of sledges. The relationship changes if the snow is very dirty, in which case wheeled vehicles meet a friction resistance that is little more than half that faced by sledges.

According to Kishinskii, the coefficient of resistance to motion of pneumatic-tired wheeled vehicles on a good, solid snow road is 0.02 to 0.03, which is hardly different from that on a good highway. On the same type of snow road the coefficient for caterpillar tractors is 0.05 to 0.1, and for wheeled tractors, 0.1 to 0.4.

When moving over a snow road, automobile wheels have a much lower coefficient of grip than when passing over the same road in summer.

A wheeled tractor has a coefficient of grip of 0.2 to 0.5 on a snow road. That of a caterpillar tractor depends on the degree to which the snow has been packed down and also on the distance between the ribs of the tracks and the force exerted on them.

A caterpillar tractor has a much higher coefficient of grip than a wheeled tractor. The highest has been recorded by a track having 8 lugs at a distance of 19.5 cm (7.7 in.) from each other.

The lugs (grousers) of caterpillar tractors rapidly ruin the surface of snow roads, and the loose snow thus formed fills the spaces between the lugs, causing contact and adhesion to grow worse rapidly.

Ice roads show a very low coefficient of grip and are rapidly broken up by the lugs of caterpillar tracks, which makes the roads most unsuitable for tractor use. The high slipperiness of ice and iced snow roads is extremely dangerous to both wagon and truck traffic. Sledges and machines slip sideways, get out of control, and hold up traffic. This makes it necessary to take various measures to reduce slipperiness, such as spreading sand, slag, ashes, or various antiglaze mixtures (CaCl or NaCl with sand). Spreading devices attached to vehicles or special spreading machines are used for this purpose. Grades perfectly permissible in summer become impassable in winter because of slipperiness.

10. TESTS. As noted in previous paragraphs, snow density and hardness or supporting power are the most important properties of snow from the standpoint of transportation and construction. It is important, therefore, to be able to make accurate field determinations of these properties.

TABLE 2A3-7

Comparative Data on Coefficient of Friction of Wheeled Vehicles and Sledges

State of surface	Temperature		Coefficient of resistance to motion		Permissible load		Remarks
	°C	°F	Sledges	Vehicles	Kg/sq cm	Psi	
Ice or icy road	4	39.2 or less	0.008–0.01	0.05–0.08	0.3–0.4	4.3–5.7	Coefficient of friction pertains to undersurface of smooth steel ski.
Rolled snow road	4	39.2 or less	0.012–0.018	0.08–0.1	0.3	4.3	
Native snow road, slightly loose	4	39.2 or less	0.02 –0.025	...	0.3 –0.25	4.3–3.5	Coefficient of rolling friction of rubber caterpillars or broad balloon tires.
Road over loose snow	4	39.2 or less	0.025–0.05	0.2	0.1 –0.15	1.4–2.1	
Loose virgin snow	4	39.2 or less	0.03 –0.08	0.25–0.3	0.06–0.07	0.8–1.0	
Fresh loose virgin snow	...	...	0.1–0.15	0.3	0.045–0.06	0.6–0.8	
Mealy snow	–2	28.4 or less	0.15				
Virgin snow in thaw	–4	24.8 or less	0.2				
Very dirty snow road	...	...	0.2–0.3	0.1–0.15			
Bare soil, sand, stone	...	...	0.4–0.5				

a. *Density*. Determinations of density values are made by equipment that usually consists of a cylindrical snow sampler, a snow cutter and mallet, and a precise balance. Detailed instructions on the correct use of the various types of density-measuring equipment that are available are usually furnished by a sponsoring organization.

b. *Hardness*. Field determination of hardness is usually made by measuring the snow penetration under the pressure of a metal cone. Although there are some doubts as to exactly what mechanical properties can be measured by this method, there seem to be definite relationships between penetration readings and hardness or snow strength, which probably will permit a correlation of hardness values, as obtained by such equipment, with traffic performance. (Ref. 19.)

Figure 2A3-3 (from Ref. 19) shows one type of penetrometer that has been used to determine snow hardness values. By varying the height of cone fall, a wide range of penetration measurements can be taken with accuracy to 0.05 in. Figure 2A3-4 (also from Ref. 19) shows relationships between penetration depths (measured by a cone having an angle of 75 deg) and hardness. If a 60-deg cone is used, the strength readings in the diagram for respective penetrations should be multiplied by 1.77; if a 90-deg cone is used, the multiplying factor is 0.59.

With very hard snow, when the penetration of the cone falling down from a 40-cm (15.5 in.) height is only 1 to 3 cm (0.4 to 1.2 in.), the method should be discarded because the readings are scattered too widely. (Ref. 19.)

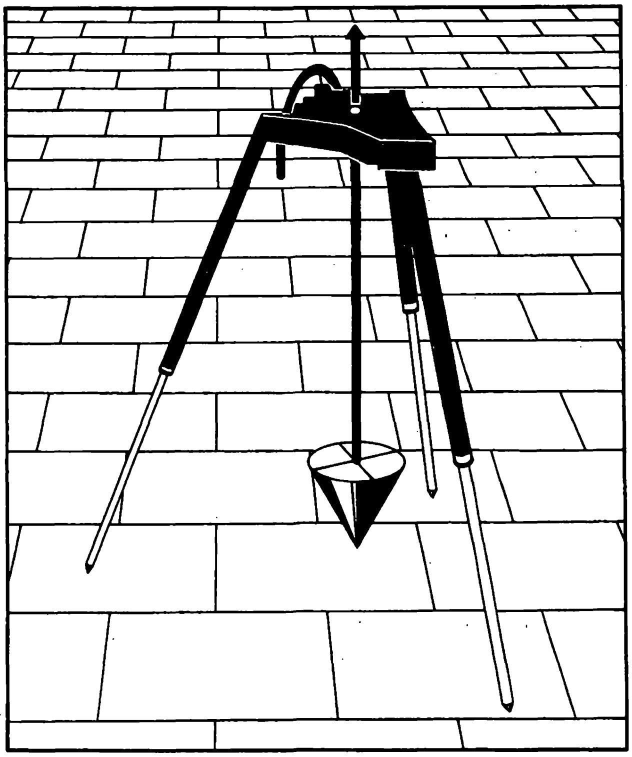


FIGURE 2A3-3

Equipment for Measuring Snow Hardness (Ref. 19)

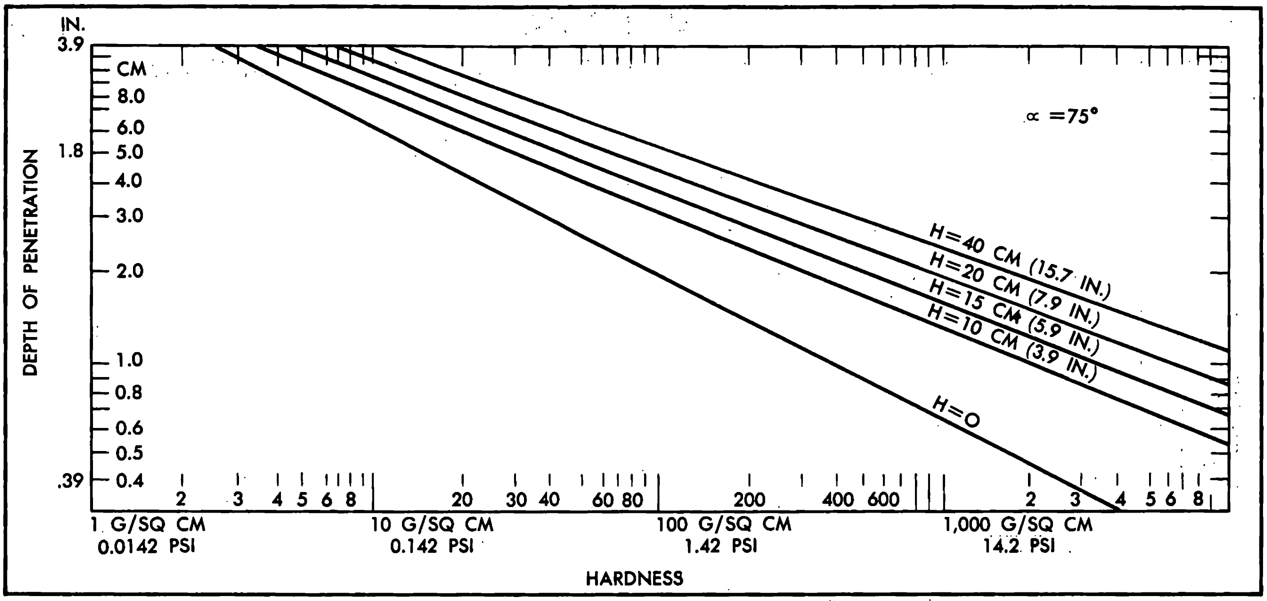


FIGURE 2A3-4

Hardness-Penetration Relationship for Various Cone-Fall Heights, H (Ref. 19)

Section 4. ICE

2A4.01 INTRODUCTION

In this Section, only those properties of ice that are of particular engineering interest in the Polar Regions are discussed. Many studies of other properties have been made and reported, an excellent summary of which has been given by Dorsey (Ref. 20). Such topics as seasonal variation of ice distribution, ice movement, breakup of ice in the sea and on rivers, operations on icefields and icecaps, and navigation through ice are not discussed in this Section.

Although ice is frequently a hindrance to transportation in the Arctic Regions, it is more often an asset. In the Arctic and Subarctic Regions, where normal transportation methods are very inadequate, travel across ice frequently results in greatly shortened routes and reduced travel time. In many regions, the tundra is all but impassable except in the winter when frozen. Under such conditions this is the preferred time of year for movement of heavy supplies and equipment (Chapter 3, Part B). The ice on frozen lakes, rivers, and on the Arctic Ocean is also of importance in the establishment of airbases. Attempts to estimate and also to improve the load-supporting capacity of ice have met with some success.

A rather large amount of experimental data is available concerning the structural properties of ice, but great difficulty has been encountered in attempts to interpret and apply these data. This problem is discussed further in paragraphs 2A4.07 and 2A4.09.

2A4.02 PHASE RELATIONSHIPS

Ice may exist in any one of several allotropic forms, depending on the ambient temperature and the pressure exerted on the ice. These forms are illustrated by phase diagram (Figure 2A4-1). It is indicated that as temperature decreases and the pressure increases from atmospheric up to approximately 30,000 psi, water solidifies into the common form, Form I. As the temperature is further lowered and the pressure increased to the 30,000- to 31,000-psi range, Form I ice may be changed to Form II or Form III ice. This traditional period is represented by the line AB. At 50,000 psi, Form III ice passes instantaneously through an unstable Form IV (shaded area) into Form V at temperature ranges from approximately −13° to 2° F. At temperature ranges from about −13° to −30° F, increases beyond 50,000 psi cause direct conversion of Form II into Form V ice.

Only the common form, Form I, is found under natural environmental conditions and has, consequently, engineering significance. Figure 2A4-1 and Table 2A5-2 show the decrease in the melting point of Form I ice in relation to pressure. It is this decrease in pressure that is responsible for regelation of ice (par. 4 of 2A4.03).

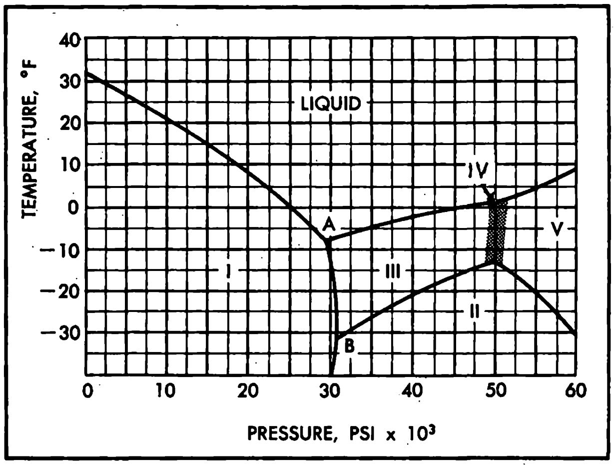


FIGURE 2A4-1

Partial Phase Diagram for Ice (Ref. 20)

2A4.03 SUPERCOOLING, FREEZING, MELTING, AND REGELATION

1. SUPERCOOLING. Even though the normal freezing point of water is 0° C (32° F), it may be appreciably supercooled before freezing begins, particularly if the water is of high purity. In open water occurring in nature, the degree of supercooling varies from a few hundredths of a degree to about −1.2° C (29.8° F). After supercooling has occurred, freezing may be initiated by seeding or by such measures as impact or splashing. The rate at which crystallization occurs depends on the degree of supercooling; in slightly supercooled water, such as is normally encountered in nature, the rate of crystallization may be sufficiently slow so that supercooled water will coexist with ice in quiet ponds or lakes for a measurable period of time. In rapidly moving streams, supercooled water may exist for hours or even days and is of importance in the formation of underwater ice (par. 2A4.04).

2. FREEZING. The formation of ice, as a rule, depends on the removal of heat from the upper surface by convection or radiation to the air. (For exceptions, see par. 2A4.04.) Generally, the air temperature must be appreciably below 0° C (32° F) for freezing to occur; otherwise, the rate at which heat is supplied from the earth and from the lower layers of water will be greater than the rate of its removal. As heat is removed at the upper surface during and prior to the formation of ice, the colder water sinks, and warmer, less dense water rises; thus, convection assists in cooling the entire body of water. However, because water has its maximum density at about 4° C (39.2° F), the convection essentially ceases after this temperature is reached by the whole body. Thereafter, the densest, warmest water remains at the bottom. As a consequence, the rate at which heat will be supplied from the bottom will be markedly reduced and the freezing at the surface accelerated.

In Finland, air has been bubbled through pipes reaching to near the bottom of ponds. This serves to bring the warmer water to the surface, preventing or retarding the freezing of the pond surface. The rate at which ice forms in quiet water may be calculated by using the equation and table given in par. 3 of 2A8.04. It is assumed that the ice is free of snow; if snow is present on the surface, it acts as an excellent insulator and will markedly reduce the rate of increase in ice thickness. It is rather common practice to remove snow from ice surfaces where greater thickness is desired for the support of loads. Compacting the snow will reduce its insulating value but is not, of course, as efficient as removal. (Ice thicknesses have also been increased by flooding the surface.)

3. MELTING. Both warm air and solar radiation are important factors in the melting of ice occurring naturally. In the Polar Regions, where air temperatures are low, the solar radiation is by far the more important. The radiation is absorbed within the ice, particularly by impurities. During the spring, fresh-water ice thaws along the crystal boundaries and becomes extremely weak while still of appreciable thickness. (See par. 2A4.05 and 2A4.09.) In sea ice the radiation is absorbed, particularly in regions where there is an accumulation of salt, causing thawing to start at these sites. A certain amount of radiation will penetrate the ice and warm the underlying water, which then also assists in thawing the ice sheet. Because of the internal absorption of radiation by ice, appreciable melting will take place when the surface temperature of the ice is still lower than the freezing point.

Under such circumstances heat will continue to be removed at the surface by convection, but if this rate of removal is less than the rate of internal supply by radiation, internal heating and melting occur. These effects have been observed at temperatures as low as −15° C (5° F) to −20° C (−4° F). The same effects are noted in snow. Occasionally thawing has been accelerated by coating either snow or ice with soot or some other material of high emissivity. So far as is known, no attempts have been made to cover snow or ice with materials of low emissivity to reduce this thaw in the spring.

4. REGELATION. It has long been known that when two pieces of ice at temperatures near the melting point are brought together with slight pressure, fusion of the two pieces will take place. This phenomenon, regelation, is a consequence of the fact that increased pressure decreases the melting point of ice; when the two pieces are brought together, the stress causes melting and as the stress is thus relieved, the water refreezes, joining the two blocks together. Regelation will occur if axes of the two (or more) crystals are in any orientation with respect to each other, but the strength of the bond formed is strongest when the crystals have the same relative orientation. Examination of Figure 2A4-1 shows that at temperatures appreciably below the normal melting point of ice, the pressures required to cause regelation become very large; it is thus a common occurrence only at temperatures near the melting point. When ice is near the melting point, regelation may be responsible for some of the plastic flow observed in ice. However, it is clearly not the only factor, for such flow will also occur at lower temperatures under loads that are much too small to cause melting. (See par. 2A4.07.) Thus, regelation is not the explanation for the plasticity of ice.

5. EFFECT OF IMPURITIES ON MELTING POINT. As pointed out in par. 3 of 2A4.03, melting usually starts along grain boundaries and at impurity sites. This is the result of a decrease in melting point at these sites, as well as increased load absorption of radiation. The depression of the freezing point is treated in detail in standard textbooks of physical chemistry. All substances that dissolve in water depress the freezing point, and for dilute solutions the depression is proportional to the amount of impurity. Figure 2A4-2 shows the melting point for solutions of salt in water.

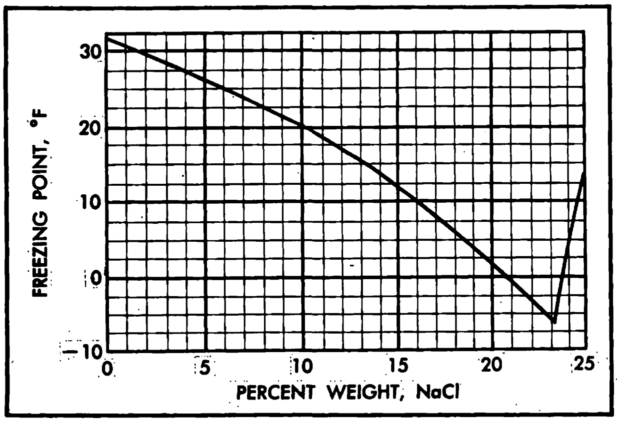


FIGURE 2A4-2

Freezing Point of Sodium Chloride Solutions

6. EFFECT OF IMPURITIES IN ICE. In any body of natural water there will be some dissolved minerals and other impurities. Sea water at one extreme is an obvious example, but even the clearest natural fresh-water body is not without impurities. When each ice crystal forms, it tends to reject these impurities, which then form a layer of concentrated impurities about the crystal. When adjoining crystals meet, the impurities form a layer between the crystals of a lower melting point than the crystals themselves. This may greatly affect the physical properties of the ice even though the amount of impurities is very small. Melting will always begin at these boundaries between the ice crystals, and at a lower temperature than 32° F. Fresh-water ice becomes rotten as thawing, starting at the inner crystal boundaries, separates the ice into separate needles or columns. This ice is said to be candled. As a result of this crystal structure in bulk, the physical properties of ice may vary widely, especially when its temperature is near the melting point, depending on the amount of impurities in the ice, the temperature, the age of the ice, and the length of time that near-freezing temperatures have persisted.

In formation of sea ice, the effect of the salt content is, of course, very pronounced. Freezing of the water portions does not begin until a temperature of 28.6° F is reached in undiluted sea water, and the structure produced is porous, containing pockets of brine from which solid salt crystals begin to precipitate when the ice cools to about 17° F. The structure and, consequently, the strength properties of sea ice improve with time as the concentrated brine drains and as the salinity of the ice becomes gradually smaller. Newly formed salt-water ice of relatively high salinity is flexible and elastic as compared to ice formed on fresh-water bodies (which is characteristically brittle), and it does not candle. Salt-water ice more than one year old is much tougher and stronger than young ice, but its surface is much more likely to be rough. It is reported that when old sea ice becomes sufficiently modified so that it approaches the composition of fresh-water ice, it, too, will exhibit a tendency to candle.

From Soviet data, young sea ice requires about 1⅔ times the thickness of old sea ice to carry the same load, but this rule is generalized. Lake ice is usually assumed to be 2 to 3 times stronger than sea ice (par. 2A4.09), although its brittleness does not permit it to stand as much bending without cracking. River ice is generally not quite as strong as lake ice.

7. TEMPERATURES DURING ICE FORMATION. When ice forms very rapidly at extremely low temperatures, there is less opportunity for dispersion of the impurities that are rejected by the ice crystals. Young sea ice formed at 14° F has entrapped about 5 parts per 1,000 of salt, but that formed at −40° F has 10 to 15 parts per 1,000. Differences in structure (and consequently of strength) of the ice would be expected to result from such differences in actual volume of included matter and the manner of its inclusion. It may be noted that the more concentrated brine surrounding the freezing crystals during fast freezing would tend to cause formation of the individual ice crystals at still lower temperatures than in ordinary sea water, with possible effects upon the ice properties.

The surface effects that are present, when very finely divided soil particles are in contact with water, may also cause appreciable lowering of the freezing point of the water, especially when the amount is small. In this case, as with salt solutions, the purest water freezes at the highest temperature, increasing the salt or soil concentration and reducing the freezing point of the remaining water so that there is no constant melting point but rather a continual gradation. (See Table 2A8-11.)

As previously noted, freezing is sometimes a most effective method for removing salt or other impurities from water. This purification occurs because of the effect described above.

2A4.04 TYPES OF ICE

Depending on the circumstances under which it is formed, Form I ice may have somewhat different properties. The effect of impurities is discussed in par. 6 of 2A4.03, and the properties of salt-water ice in par. 2A4.06 and 2A4.07. Measurement of ice thickness is discussed in par. 3F3.05.

1. FRAZIL AND ANCHOR. These two forms of underwater ice are found in rapidly moving streams and rivers. Frazil ice consists of small crystals or disks of ice that are distributed throughout a turbulent stream. These crystals may cluster together to form spongelike masses. Anchor ice is underwater ice that is formed at and firmly attached to the stream bed. Both forms may be sources of difficulty in the development of hydroelectric power because the ice tends to dam up and clog up grates on which it forms. Heated grids have been used to overcome this trouble, and measures taken to reduce supercooling and turbulence in the stream may also be effective. There has been some dispute as to the mechanism that forms underwater types of ice; probably it is a consequence of supercooling, which may be slight, and nucleation at sites in the water (frazil ice) and on the stream bottom (anchor ice). The turbulent supercooled stream water is an excellent medium for carrying away the latent heat of solidification, and thus it makes growth possible. Irregular surfaces provide more favorable sites for growth than smooth surfaces; therefore, irregularities in the stream bottom become accentuated, a factor tending to cause damming of the stream. There is also an extension of growth by accumulation and adhesion (caused by regelation) of frazil ice on the anchor ice. (Ref. 18.)

2. GLACIAL. The ice of glaciers and of icecaps is formed primarily as a result of accumulation and periodic melting and freezing of snow. The physical qualities may vary markedly, depending on the age and pressure to which the ice is exposed. All glacial ice has an appreciable amount of entrapped air.

Variations in density from 21 lb/cu ft at the surface of glaciers to 34 lb/cu ft at a depth of 50 ft have been noted.

Because of the large amount of air entrapment and its method of formation, the structural and thermal properties of this kind of ice differ greatly from those of ice formed at water surfaces.

2A4.05 CRYSTALLOGRAPHY

It is generally agreed that when ice forms at the surface of a body of water the optic axes of the crystals are perpendicular to the surface. The structural and thermal properties of ice appear somewhat dependent on the orientation of the optic axes. (See par. 2A4.06, 2A4.07, and 2A4.08.) As previously indicated, ice appears to form normally in long needlelike crystals, the axes of which have the same orientation as the optic axes. This explains the phenomenon of candling that occurs when fresh-water ice melts (par. 6 of 2A4.03).

2A4.06 THERMAL PROPERTIES

The thermal properties of pure ice have been determined to degrees of accuracy that are more than adequate for most engineering purposes. They are summarized below. For ice containing large entrapments of air (glacial ice) or salt (sea ice) the conductivities will, of course, be different. For glacial ice, the conductivity may be appreciably less; for sea ice the conductivity and diffusivity will also probably be less, though as far as is known no data are available. Probably for sea ice the values are sufficiently close to those for pure ice so that the data given for the latter may be used for most purposes. For pure ice:

(1) Heat of fusion at 0° C (32° F) = 79.67 cal/g = 143.4 Btu/lb. At lower temperatures, that is, melting under pressure, the heat of fusion is less; for example, at −5° C (23° F), it is approximately 73 cal/g.

(2) Specific heat, c, at 0° C (32° F) = 0.5057. For most engineering purposes the change in specific heat with temperature can be neglected. If more accurate values are needed, the equation

$$c = 0.5057 + 0.00186\left[\frac{5}{9}(t-32)\right] - \frac{0.004}{\left[\frac{5}{9}(t-32)\right]^2}$$

may be used where t is the temperature in °F.

(3) Thermal conductivity, k, at 0° C (32° F) = 0.0050 cal/°C/cm/sec = 1.21 Btu/°F/ft/hr. The thermal conductivity may be taken as constant for most engineering purposes. If more accurate values are required, the equation

$$k = 1.21\ (1 - 0.0017t)\ \text{cal/°F/cm/sec}$$

may be used where t is the temperature in °F. There is evidence that the conductivity is somewhat greater in the direction of the optic axis than perpendicular to it; the two values, however, are sufficiently close so that the above value and equation may be used for most purposes regardless of the direction of the crystal orientation.

(4) Thermal diffusivity $\alpha = \frac{k}{\rho c}$. α can be calculated using the data above together with the density. The density, ρ, is 0.9168 g/cu cm at 0° C (32° F), and the increase on going to lower temperatures is sufficiently slight so that it can be neglected for most purposes. Thus, at 0° C (32° F)

$$\alpha = 0.0108 \text{ sq cm/sec} = 0.042 \text{ sq ft/hr}$$

(5) The coefficient of cubical expansion, β, at 0° C (32° F) = 0.000160/°C = 0.000089/°F. This value may be used for most purposes at any temperatures likely to be encountered in nature.

2A4.07 STRUCTURAL PROPERTIES

Ice is generally accepted to be a plastic material and consequently should be described by Maxwell's equation

$$T - f_s = n\frac{d_r}{d_t}$$

in which

T = shearing stress in psi

f_s = elastic limit in psi

n = viscosity in $\frac{\text{lb/sec}}{\text{sq in.}}$

$\frac{d_r}{d_t}$ = rate of deformation

In much of the work that has been reported, it has been assumed that f_s is zero, that is, that ice is a truly viscous material. Although the elastic limit is very small, an analysis of the flow of glaciers indicates that it is not zero. It has been reported that at −5° C (23° F) the rate of creep is imperceptible when the loading on ice is less than 2 kg/sq cm (28.4 psi), but with loads larger than this the rate of creep becomes appreciable and increases rapidly. There is evidence that the viscosity of ice depends considerably on the orientation of the optic axis relative to the applied stress. Thus, results of tests show ice to be elastic if the stress is applied perpendicular to the optic axis but otherwise to behave as a plastic. A number of determinations of the viscosity of ice have been reported,

TABLE 2A4-1

Elastic Properties of Ice

Temperature		E		G		λ
°C	°F	Dynes/sq cm × 10^{10}	Psi × 10^5	Dynes/sq cm × 10^{10}	Psi × 10^6	
−10	14	9.5	13.8			
−30	−22	10.2	14.8			
−15	5	9.8	14.2	3.68	5.34	0.33
−5 to −15	23 to 5	9.17	13.3	3.36	4.87	0.365

but the lack of consistency is so great that at the present time presentation of quantitative results seems to be of little value. All of the reports indicate a marked increase in viscosity with decreasing temperature.

A large number of determinations of the elastic properties of ice have been reported, but again there is a marked lack of agreement, especially among the early results. Most of the early determinations were made using static loading and assuming ice was truly elastic rather than plastic. In view of present knowledge they should, however, be discounted. More recently, measurements have also been made using sonic methods; in these cases consistent results have been obtained that are probably reliable. The evidence indicates that both Young's modulus and the shear modulus (rigidity) do not depend appreciably on crystal orientation; both appear to increase slightly with decreasing temperature. Representative values for Young's modulus, *E*, the modulus of shear, *G*, and Poisson's ratio, λ, are given in Table 2A4-1. Variations of about 10 percent have been obtained in different measurements (using the same methods).

In determining the ability of ice to sustain a load, consideration should be given to the effect of impulse and frequent repetitions of load in terms of time as well as to the deformation and structural change that may result from a static and/or a gradually applied load.

A number of reports are available of tests of compressive, tensile, flexural, and shear strength of ice. The lack of consistency is very great because the values obtained depend on the rate of loading and also on orientation. A summary of the ranges obtained is given in Table 2A4-2.

Except for strengths of single crystals, the minimum values should actually approach zero, corresponding to the condition when ice is rotting or candled and is able to support virtually no load. Possibly the compressive strength values show the greatest range, in part because more investigators have used this relatively easy test than the other types.

TABLE 2A4-2

Ranges of Ice-Strength Test Results

Type test	Values reported, psi
Compressive strength	70 to 1,800
Tensile strength	36 to 223
Flexural strength	44 to 311
Shear strength	39 to 353

Attempts to improve the structural properties of ice by the inclusion of wood pulp in the ice have been promising. Thus with 14 percent pulp content the compressive strength has been increased to 1,100 psi and the tensile strength to 700 psi.

2A4.08 EFFECTS OF STRATIFICATION, CRACKING, AND RESIDUAL STRESSES

1. HORIZONTAL STRATIFICATION. The strength of ice may be affected by development of horizontal laminations of variable properties. Variations in temperature, temporary thaws, rains, formations of snow ice, flooding, and driving by the wind of salt spray onto the surface of otherwise relatively fresh ice or snow will all form horizontal layers in the ice sheet, the effect of which may be important in relatively thin ice but will be insignificant in heavy ice.

Another stratification development occurs in coastal areas where river and stream inflows and tidal effects cause variations in the salinity of the water during the ice formation period. An influx of relatively fresh water under the ice surface will result in rapid freezing to this surface, which may have cooled to as low as 28.6° F when normal salt water was present under the ice. The same effect occurs in the Polar seas during the summer thaw periods when melt water from the surface sinks down through holes and freezes onto the cold undersurface of the icepack. Such stratification in the lower part of the ice sheet, where critical tensile stresses occur when the ice is loaded, may be expected to have far greater effect on the overall bearing capacity than laminations that develop in the upper half of the sheet.

In the Polar icepack much less regular horizontal structure layering occurs when pressure causes rafting and buckling of the ice sheet.

2. VERTICAL CRACKS. Cracking of the ice sheet under the effect of temperature stresses causes a pattern of vertical defects or discontinuities distributed over the ice sheet. These do not ordinarily extend more than part way through the depth of the ice. Although they are conspicuous in the upper surface of the sheet at low temperatures and may be readily visualized as a possible cause of weakness, static load tests by the Soils, Foundations, and Frost Effects Laboratory, in 1947, registered essentially no observable effect of such cracks on the bearing capacity or failure action of the ice under a load. Cracks formed because of the load show very little tendency to follow the existing partial cracks. These tests, however, involved only single-load applications, and it is reported that under heavy traffic, temperature cracks do have an effect in reducing the load-bearing capacity of the ice sheet. Cracks that pass all the way through the ice sheet seriously lower the load capacity and are especially hazardous if they occur under a snow blanket because the snow may delay their refreezing and hide them from view.

3. RESIDUAL STRESSES. Residual stresses may exist in ice from unadjusted temperature effects or purely mechanical causes. These may affect the structural properties. It is believed that variability in measured structural properties of test samples may be in part the result of such residual stresses.

2A4.09 BEARING CAPACITY

At the present time, by far the most important structural use of ice is as a load-supporting material for the movement of equipment, landing of aircraft, and so on. In determining the load-bearing capacities of ice, particularly in regard to airstrips and the loads imposed by planes, several methods of study and investigation have been followed. In general, these methods are (a) empirical, (b) theoretical or elastic-theory application, and (c) direct observation of actual landings.

1. EMPIRICAL METHOD. Of the various empirical methods employed, Moskatov's has been the most widely used. His formulas are simple and indicate that the carrying capacity of ice varies as the square of the ice thickness. This contention is borne out, to some extent, by the elastic-theory analysis, provided somewhat different ice strengths are assumed.

According to the Russians, 20 percent greater ice thickness is required for airplanes with wheels than those with skis. The design curves adapted from the 20 percent, including allowance for wheel spacing, are shown in Figures 2A4-3 and 2A4-4.

The Moskatov empirical formulas are summarized in the following table.

Type of ice	*Aircraft on skis*	*Aircraft on wheels*
River ice	$t = \frac{15}{4}\sqrt{P}$	$t = \frac{9}{2}\sqrt{P}$
Lake ice	$t = \frac{27}{8}\sqrt{P}$	$t = \frac{81}{20}\sqrt{P}$
Old sea ice	$t = \frac{27}{4}\sqrt{P}$	$t = \frac{81}{10}\sqrt{P}$
Young sea ice	$t = \frac{81}{8}\sqrt{P}$	$t = \frac{243}{20}\sqrt{P}$

P is the gross weight of aircraft in tons; t is the ice thickness in inches. The formulas apply only for ice formed and maintained at a temperature below 16° F. At higher temperatures, 25 percent greater thickness will be required.

2. ELASTIC-THEORY APPLICATION. In the elastic-theory application, it is assumed that within permissible stress limits the ice behaves approximately as an elastic material, and elastic theories of stress and strain may be applied to obtain thickness required for given conditions of loading. For present purposes it is assumed that the ice sheet is floating, that it is sufficiently large to be infinite for the purpose of analysis, and that it is unstressed and in equilibrium. Actually, an ice cover may be partly suspended, as in the case of a stream or long, narrow lake where the shores offer some support at the two opposite long sides. An ice cover is probably never free from temperature stresses. Static loading offers a more critical condition than dynamic loading; only static loading, therefore, is considered for any ice test.

The formulas and graphs shown here are applicable only where the load is far from the icefield edge. For loading near a free edge the load-carrying capacity should be assumed as roughly ⅓ to

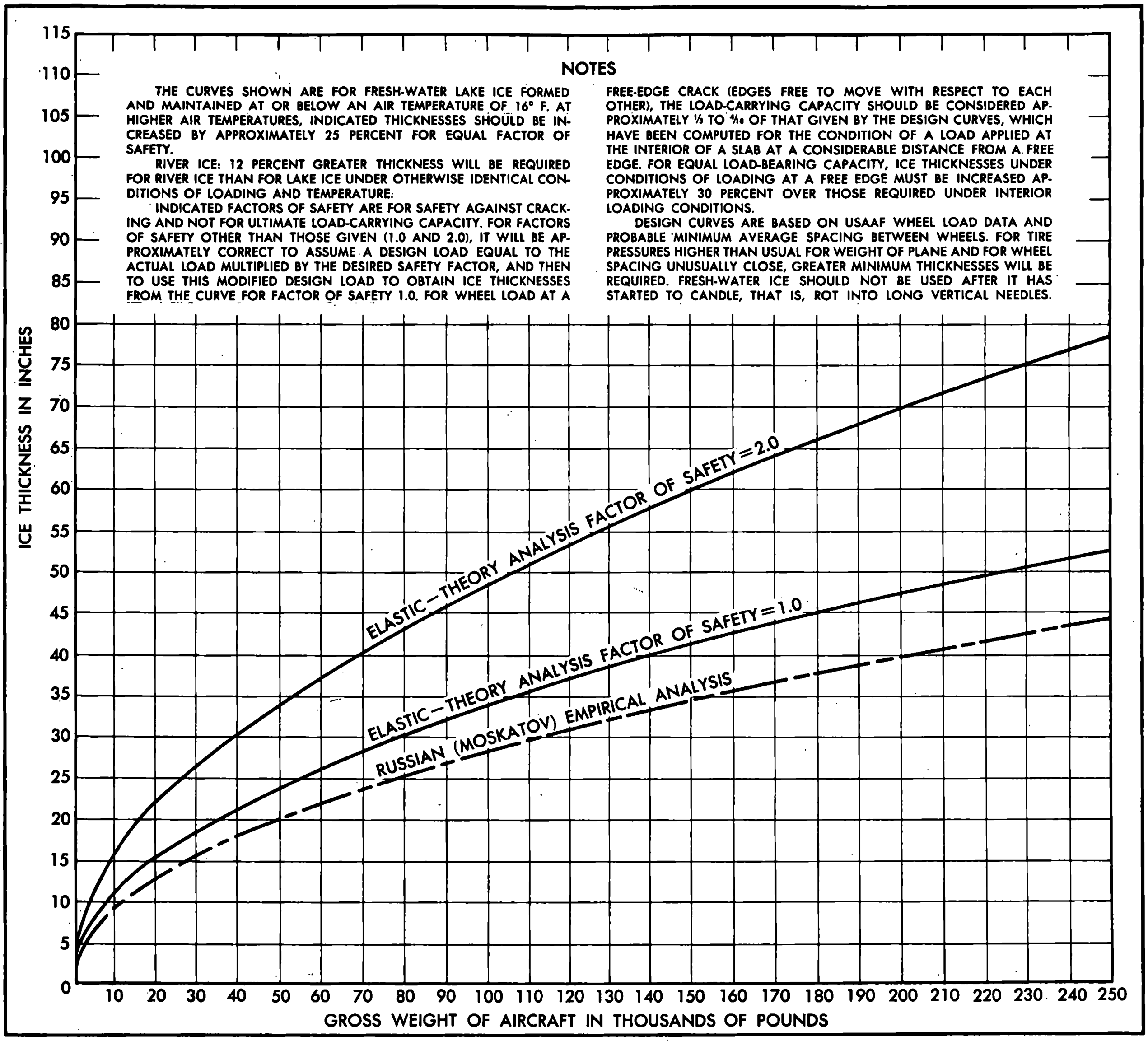


FIGURE 2A4-3

Bearing Capacity of Fresh-Water Ice for Wheeled Airplanes (Ref. 21)

4/10 of that determined from the formulas or graphs. At a corner, 1/4 the load-carrying capacity should be assumed.

Deflection of an ice surface will depend on its thickness, density, elastic properties, and conditions of loading. Minor cracking can probably be tolerated without danger of failure as long as the temperature is appreciably below freezing. At thicknesses near the required minimum, repeated loading will fatigue the ice so that rest periods must be provided to permit recovery of ice strength if the traffic is heavy. To circumvent this obstacle to continuous operation, it is desirable that sufficient airstrip area be provided to permit alternate use of traffic lanes and runways.

The elastic-theory application assumes that ice is elastic, which is a questionable assumption because ice is truly elastic only over an insignificant range. However, it has been found that cracking occurs approximately in accordance with the theory, and that a large reserve of strength is available after the first cracks appear. At the time of initial cracking, therefore, the safety factor against breakthrough may be as high as 4 for a single load application. The data, however, are as yet too scanty to permit definite conclusions, and the dura-

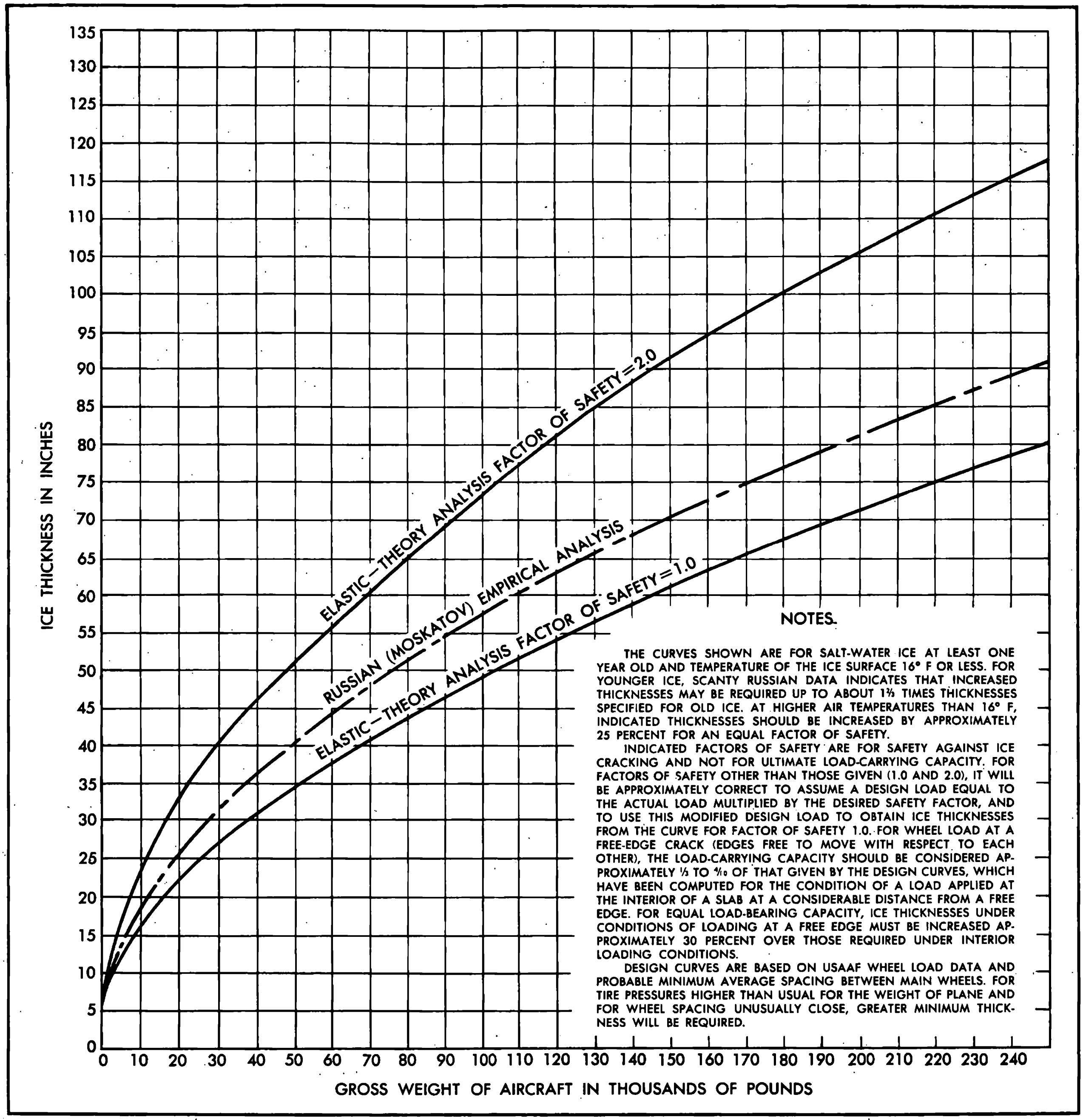


FIGURE 2A4-4

Bearing Capacity of Salt-Water Ice for Wheeled Airplanes (Ref. 21)

tion of loading, for instance, which is a highly important factor, has not been investigated.

Owing to the uncertainties in ice thickness and strength as found in nature, the doubtful accuracies of analyses and formulas, and the possible hazards to equipment and personnel, it is suggested that a safety factor of 2.0 against formation of initial cracks be required. Curves representing the elastic-theory application, with safety factors of 1.0 and 2.0, are shown in Figures 2A4-3 and 2A4-4.

When selection of an airstrip on ice is preceded by sufficient strength investigation, the safety factor for the ice may be modified. It must always be remembered, however, that the hazards increase rapidly as minimum thickness is approached.

3. DIRECT OBSERVATION. Records of actual landings on ice have yielded the most reliable data on ice bearing capacities, but unfortunately there has been little correlation between the loading conditions and the thickness and strength of the ice. Some actual landing records of moderately heavy planes are listed in Table 2A4-3. The data available are meager.

As indicated in Figures 2A4-3 and 2A4-4, the safe loads for airstrips on ice depend on wheel spacings. Figure 2A4-5, based on elastic-theory analysis, indicates the nature of this dependence.

In addition to the listings shown in Table 2A4-3, it is reported that landings have been made on sea ice about 88 in. thick and about 2 years old by the Air Transport Command at Cambridge Bay, Victoria Island, N. W. T., Can., in May 1947, with plane weight up to 145,000 lb.

A comparison of ice thickness shown in Table 2A4-4 with the computed minimum thicknesses as required by Figures 2A4-3 and 2A4-4 shows that a large reserve of strength was available in almost all cases. These records of actual landings in the Arctic clearly demonstrate that suitable ice airstrips for airplanes of over 120,000 lb gross weight may be found during the winter months.

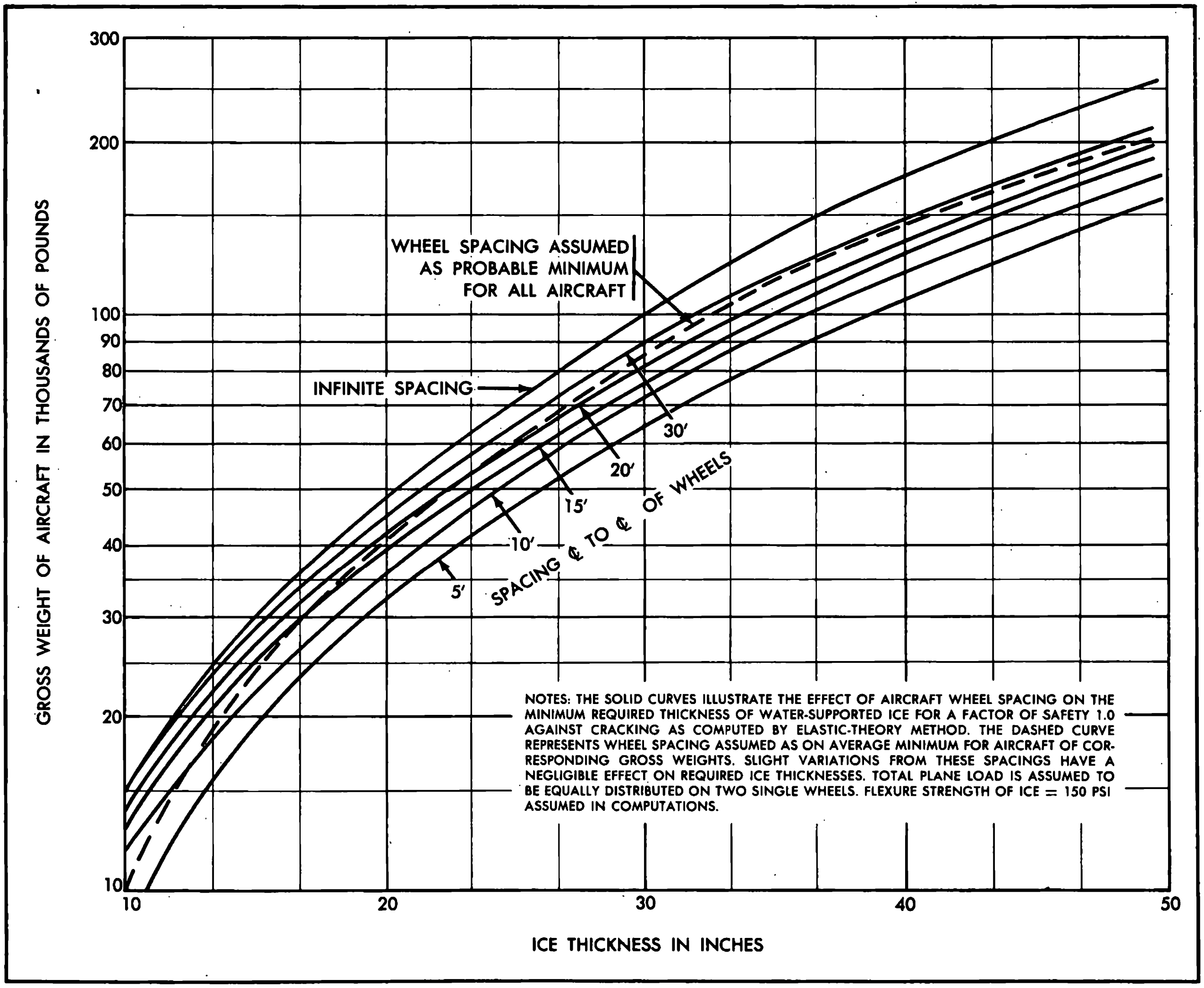


FIGURE 2A4-5

Effect of Aircraft Spacing on Required Ice Thickness (Ref. 21)

TABLE 2A4-3

Heavy Airplane Landings on Ice (Ref. 21)

Location	Date	Air temp, °F	Ice thickness, inches	Type of ice (fresh or salt)	Distance from shore	Surface characteristics	Ice structure	Ice color	Weight of plane, pounds	Type landing gear	Remarks
Arctic Ocean (near North Pole)	May 1937		...	Salt	Ice floe	...		...	46,000 to 56,000	Skis	Russian planes, type PS-6.
Queen Victoria Sea and Arctic Ocean	May 1937 June 1937		Minimum 35 to 47	Salt	Ice floe	...		...	46,000 to 56,000	Skis	Russian planes, types SP, ARK-LP-5, PS-6, and PS-7.
North of lat 83° N	June 1937		Minimum 35 to 47	Salt	Ice floe			...	46,000 to 56,000	Skis	A number of heavy Russian planes of type PS-6 operated successfully in this area from ice floes. Data for weights of planes questionable. 16-in. snow cover.
Lat 83° 37′ N, long 61° 30′ W	8 June 1937		39.4	Salt	Ice floe			...	46,000 to 56,000	Skis	16-in. snow cover. Evidently an emergency landing.
Near Padloping Island (Davis Strait)	1941–45		63	Salt	Near shore	...		...	60,000	Wheels	Ice apparently smooth and clear.
Near Padloping Island (Davis Strait)	1941–45		44	Salt	Near shore	...	...	...	25,000 ±	Wheels	Ice apparently smooth and clear.
Port Radium, N.W.T., Can.	April 1946		64	Fresh	50 yd	Smooth, clear	Very clear except for lacelike cracks	Blue-gray	29,000	Wheels	No snow cover. Airstrip used extensively.
Baker Lake, N.W.T., Can.	3 Mar 1946		96	Fresh	200 yd	Smooth, clear, or slush	Clear with 4-mm air bubbles	Blue-gray	29,000	Wheels	4,000-ft runway on lake cleared of 6 in. of snow.
Cambridge Bay, N.W.T., Can.	21 Mar 1946	−26	79	Brackish	100 yd	Smooth, clear	Clear, some small air bubbles	Green-blue	29,000	Wheels	No snow cover.
Lake in northwest Greenland	24 Feb 1947	−35 to −40	Over 108	Fresh		Snow-covered		...	60,000	Wheels	2- to 10-in. snow cover. 3,800 ft used in landing. 800 ft used in JATO. Landing and takeoff described as smooth. Crust flew out ahead of plane. B-29 made emergency belly landing here; no takeoff.
Kazhevnikova Bay, U.S.S.R., lat 73° 40′ N, long 110° 30′ E	18 Mar 1941		...	Salt		...		...	54,000	Skis	Russian 4-motored plane, N-169 (probably type PS-6), made numerous landings and takeoffs from ice airfields while engaged in Polar research, March, April, and May, 1941.
Rodgers Bay, Wrangel Island, U.S.S.R.	20 Mar 1941	...	65	Salt	...	...		...	54,000	Skis	
Lat 81° 4′ N, long 178° 20′ E	3 Apr 1941	−18.5	77	Salt	Ice floe	...		...	54,000	Skis	
Lat 78° 26′ N, long 176° 40′ E	13 Apr 1941	− 4	...	Salt	Ice floe	...		...	54,000	Skis	
Lat 80° 00′ N, long 170° 00′ E	23 Apr 1941	− 2	59	Salt	Ice floe	...		...	54,000	Skis	
Mouth of Taimyr River, U.S.S.R.	6 May 1941	...	...	Brackish	...	...		...	54,000	Skis	
Eureka Sound, N.W.T., Can.	April 1947			Salt		...		...	29,000	Wheels	Initial landing reported made with C-47's followed by C-84's in setting up Arctic weather station.

TABLE 2A4-4

Investigation of Airdromes on Ice, 1946–1947, and Comparison of Analysis Methods (Ref. 21)
Method A: Russian Empirical Analysis[1] — Method B: Elastic-Theory Analysis[2]

Loading characteristics of aircraft							Minimum required thickness of ice, in.											
							Aircraft on skis[7,9]						Aircraft on wheels[8,9]					
							Lake ice		River ice		Sea ice		Lake ice		River ice		Sea ice	
Aircraft weight, lb	Ski dimensions, ft x in.[3]	Ski contact area, sq in.	Avg ski contact pressure, psi	Tire contact area, sq in.[6]	Radius of tire contact area, in.[6]	Tire contact pressure, psi[6]	Method A	Method B	Method A	Method B	Method A	Method B	Method A	Method B	Method A	Method B	Method A	Method B
2,315[3]	7.2 × 13.1	1,132	1.02	30	3.1	38.7	3.6	3.4	4.0	3.8	7.1	5.1	4.3	4.7	4.8	5.2	8.6	6.3
2,385[3]	4.6 × 14.2	784	1.32	30	3.1	39.8	3.7	3.7	4.1	4.1	7.3	5.5	4.4	4.8	4.9	5.3	8.8	6.4
4,190[3]	7.2 × 16.9	1,460	1.43	50	4.0	41.9	4.9	4.4	5.4	5.0	9.7	6.7	5.8	6.3	6.5	7.0	11.7	9.2
5,950[3]	...	...	...	69	4.7	43.1	5.8	...	6.5	...	11.6	...	7.0	7.5	7.8	8.4	13.9	11.0
7,385[3]	5.9 × 18.9	1,338	2.76	85	5.2	43.4	6.5	6.4	7.2	7.0	12.9	9.6	7.8	8.4	8.6	9.2	15.5	12.2
9,040[3]	...	...	...	102	5.7	44.3	7.2	...	8.0	...	14.4	...	8.6	9.3	9.6	10.2	17.3	13.5
9,920[3]	...	...	...	110	5.9	45.0	7.5	...	8.4	...	15.0	...	9.0	9.7	10.0	10.7	18.0	14.0
10,000	...	...	...	111[4]	5.9	45.0[4]	7.5	...	8.5	...	15.1	...	9.1	9.7	10.1	10.7	18.1	14.1
13,670[3]	10.2 × 29.9	3,660	1.87	146	6.8	46.8	8.8	8.3	9.8	9.3	17.6	12.5	10.6	11.4	11.8	12.4	12.1	16.5
15,430[3]	12.1 × 35.4	5,140	1.50	158	7.1	48.8	9.4	8.9	10.4	9.9	18.8	13.3	11.3	12.1	12.5	13.3	22.5	17.7
20,000	...	...	...	200[4]	8.0	50.0[4]	10.7	...	11.9	...	21.3	...	12.8	13.7	14.2	15.1	25.6	19.9
30,000	...	...	...	273[4]	9.3	55.0[4]	13.1	...	14.5	...	26.2	...	15.7	16.6	17.4	18.3	31.4	24.2
48,450[3]	18.1 × 57.5	12,489	1.94	424	11.6	57.3	16.6	15.7	18.4	17.4	33.2	24.8	19.9	20.3	22.1	22.3	39.8	29.4
74,000	...	...	...	570[4]	13.5	65.0[4]	20.5	...	22.8	...	41.0	...	24.6	26.2	27.4	29.0	49.3	38.1
120,000	...	...	...	800[4]	15.9	75.0[4]	26.1	...	29.0	...	52.2	...	31.3	33.3	34.8	36.9	62.6	48.8
200,000	...	...	...	1,086[5]	18.6	92.2[5]	33.8	...	37.6	...	67.5	...	40.5	43.2	45.0	47.9	81.0	63.2

[1]From Landings on Ice, K. A. Moskatov.

[2]Flexural strength of ice as assumed for method B:
Lake ice, 150 psi
River ice, 125 psi
Sea ice, 75 psi (old sea ice).

[3]Data from Climatology of the Arctic Regions, Part II, Air Weather Service, USAAF.

[4]Wheel load data from Chapter XX, Engineering Manual, Corps of Engineers.

[5]Wheel load data estimated from loading characteristics of lighter USAAF aircraft.

[6]Except when note 4 applies, wheel load data interpolated and extrapolated from data on USAAF aircraft.

[7]Methods A and B for case of skis agree very closely if the following flexure strengths are assumed for method B:
Lake ice, 142 psi (10 kg/sq cm)
River ice, 114 psi (8 kg/sq cm)
Sea ice, 43 psi (3 kg/sq cm).

[8]Moskatov empirical method assumes 20 percent greater thickness of ice necessary when wheels used instead of skis. Elastic-theory method indicates that when wheels used instead of skis, 25 to 35 percent greater thicknesses are required.

[9]Landing gear spacing affects required ice thicknesses. Closer spacings require greater thicknesses.

Tables 2A4-5, 2A4-6, 2A4-7, and 2A4-8 give information on loads other than aircraft that ice may be required to support. N is the safety factor required (Table 2A4-6).

The permissible time for load halting on ice is determined by the following equation.

$$T = \frac{(p_m - p)^2}{p_m p}(\theta + 1)^3$$

T = permissible time in hours
p = weight of load standing on ice
p_m = permissible load for ice of given thickness
θ is determined from Table 2A4-8.

TABLE 2A4-5

Minimum Thickness of Ice Necessary for Passage of Specific Loads Over Fresh-Water Ice at Air Temperatures Between —1° and —12° C (30.2° and 10.4° F) (Ref. 18)

Type of load	Weight, tons	Ice thickness at various values of coefficient N									
		N = 1		N = 1.2		N = 1.4		N = 1.6		N = 1.9	
		Cm	In.	Cm	In.	Cm	In.	Cm	In.	Cm	In.
Single ski trooper	...	3	1.2	4	1.6	...	...	5	2.0		
Air sleigh with 4 skis	1.5	7	2.8	9	3.5	12	4.7	14	5.5	16	6.3
Light car	2.7	16	6.3	17	6.7	19	7.5	21	8.3	23	9.1
5-ton truck	10.0	32	12.6	36	14.2	39	15.3	42	16.5	47	18.5
Loaded caterpillar, Max	20.0	41	16.1	46	18.1	51	20.1	55	21.6	61	24.4
Loaded caterpillar, Max	65.0	77	30.0	87	34.2	95	37.4	108	42.5	113	44.5

TABLE 2A4-6

Coefficient of Safety Factor and Amount of Cracks, N (Ref. 18)

Character of crossing	Condition of ice		
	Level ice without cracks	Dry cracks not through, up to 30 cm (11.8 in.) wide	Wet cracks through, up to 5 cm (1.98 in.) wide
Crossing at the limit of safety factor with special risk	1.0	1.2	1.6
Crossing with lowered safety factor	1.2	1.4	1.9
Normal crossing	1.6		

TABLE 2A4-7

Simplified Formulas for Calculations (Ref. 18)

For loaded wheeled vehicles on nonreinforced ice		$p_m = \frac{100}{N} h^2 KS$
For loaded caterpillar vehicles on nonreinforced ice	up to 18 t,	$p_m = \frac{125}{N} h^2 KS$
	above 18 t,	$p_m = \frac{115}{N} h^2 KS$

p_m = permissible load in tons
h = actual smallest ice thickness, not counting snow
K = temperature correction factor $= \frac{T + 100}{100}$
S = salinity correction factor $= \frac{1}{(1 + 0.02 s_i)^2}$
s_i = salinity in ppt

TABLE 2A4-8

Determination of θ (Ref. 18)

Value of θ	Specific occasions
0	1. Halting a transport on roads not cleared of snow, or if ice is covered by water. 2. Basic long-range constructions, cribwork, flooring, and so on. 3. Halting loads on cleared or partially cleared ice at a temperature less than −5° C (23° F).
1	1. Halting a transport on roads cleared of snow at a temperature less than −5° C (23° F). 2. Halting a transport on roads partially cleared of snow at a temperature less than −10° C (14° F).
2	1. Halting a transport on roads cleared of snow at a temperature less than −10° C (14° F). 2. Halting a transport on roads partially cleared of snow at a temperature less than −15° C (5° F).
3	1. Short halt of a transport on roads cleared of snow at a temperature less than −15° C (5° F).

Section 5. PERMAFROST

2A5.01 INTRODUCTION

Permafrost is an engineering material like ice, snow, and concrete. In evaluating permafrost, consideration should be given to the fact that it is one of the end results of the disciplines existent in the area. When these permanently frozen materials are thawed, because of a change in the disciplines, they must be evaluated the same as materials in a like condition in the Temperate Zone. Consideration should be given not only to the quality and grading, but also to the compaction and confinement of the materials and the conditions under which the materials will continue to exist in their thawed state.

2A5.02 DISTRIBUTION

Permanently frozen material in the superficial covering of the earth's surface is existent in a large portion of the Cold Regions. The thickness of permafrost varies from a few feet to several hundreds of feet. (See Table 2A5-1.)

TABLE 2A5-1

Reported Depths of Permafrost

Location	Depth, feet	Source of data
Near Fairbanks, Alaska lat 64°49′ N long 147°52′ W	360	Actual drilling and studying of in-place samples.
Nordvik, Siberia lat 73°52′ N long 112°10′ E	2,000	Unpublished material, method of determination unknown.
Cape Simpson, Alaska lat 71°00′ N long 154°39′ W	1,030	Unpublished material, determination made by actual measurements.

2A5.03 NATURE

1. FORM. Permafrost may be present in a continuous stratum of varying thickness over a great area, or it may exist as stringers, sheets, islands, kidneys, pipes, or lenses and dikes (Figure 2A5-1). (See also Figure 2A5-25.) A permafrost area may contain stringers, strata, sheets, lenses, dikes,

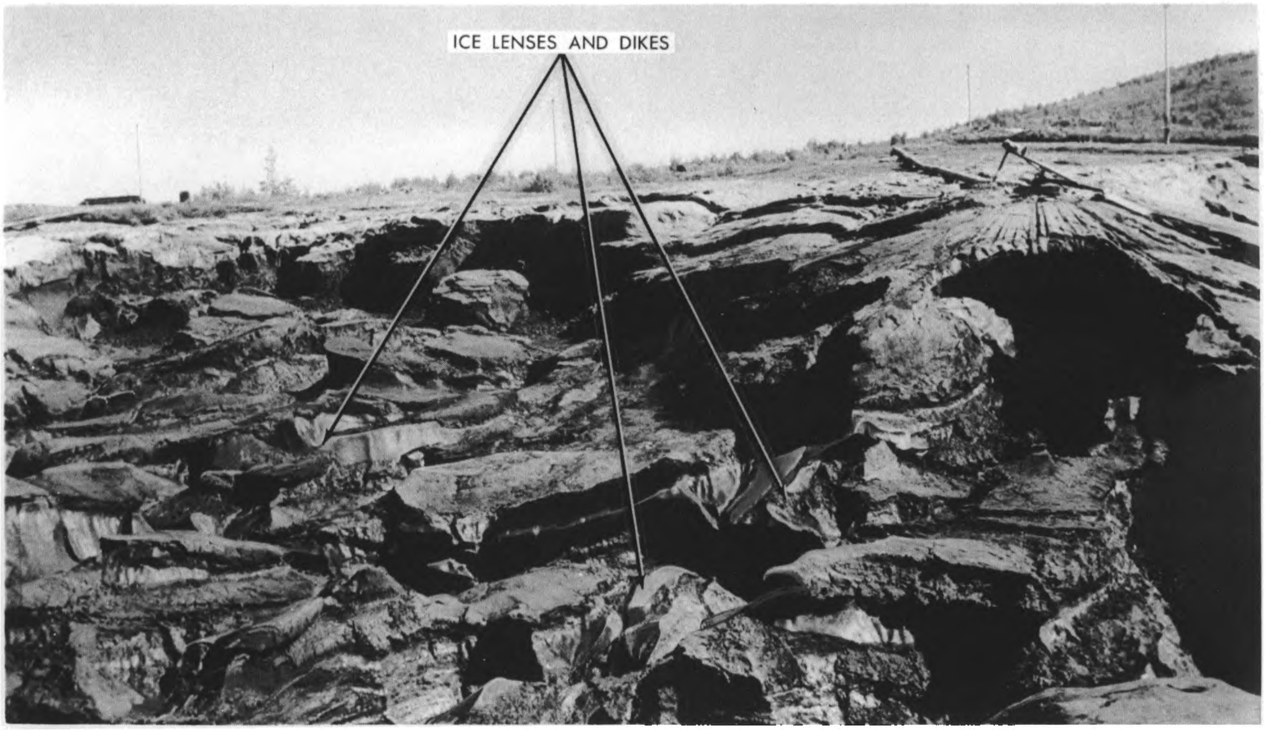


FIGURE 2A5-1

Ice Lenses and Dikes in Black Muck Near Fairbanks, Alaska

islands, kidneys, or pipes of permanently thawed material. Figure 2A5-2 illustrates some of the possible ground conditions in permafrost areas.

In addition to the forms just described, the portion of the permafrost that is ice may exist as minute uniformly disseminated grains, which coat the solid particles other than ice, or as crystals distributed between the particles of the other solid materials. The amount and nature of the matrix must be considered in the interpretation of any test data. (See Section 2A4.)

Some materials are permanently frozen with an ice matrix insufficient to fill the voids. This is termed dry permafrost. Properties of permafrost are, in many instances, altered because of temperature changes; especially, the properties may be altered radically when there is a change of phase in the matrix.

2. PROPERTIES. The thermal conductivity of water is less than that of ice. NOTE: In circumstances, however, where there is comparatively free movement of the water, the effective conductivity may be increased as a result of convection. Because of the increased conductivity of ice, the conductivity of certain sands in place may be trebled by freezing, and that of certain clays increased by as much as 50 percent. (See Section 2A8.)

Ice under stress flows (Section 2A4); therefore, in evaluating and interpreting test data pertaining to such properties as compression, tension, elongation, shear, elasticity, and adfreeze, consideration should be given to the duration of time for which loads are applied.

The chemical and bacterial processes are retarded because of the low temperatures. The process of soil formation, therefore, is limited to a thin layer; and the weathering process is more physical than chemical, resulting in a relative scarcity of clay and an abundance of dustlike (silt) soil in permafrost areas.

The electrical conductivity of frozen materials may be much less than that of the same materials in the thawed state; consequently, adequate and proper grounding of electrical apparatus in permafrost areas often presents difficulties. (See par. 2B4.08.)

2A5.04 EVALUATION DATA

A report on permafrost as an engineering material should include the following items.

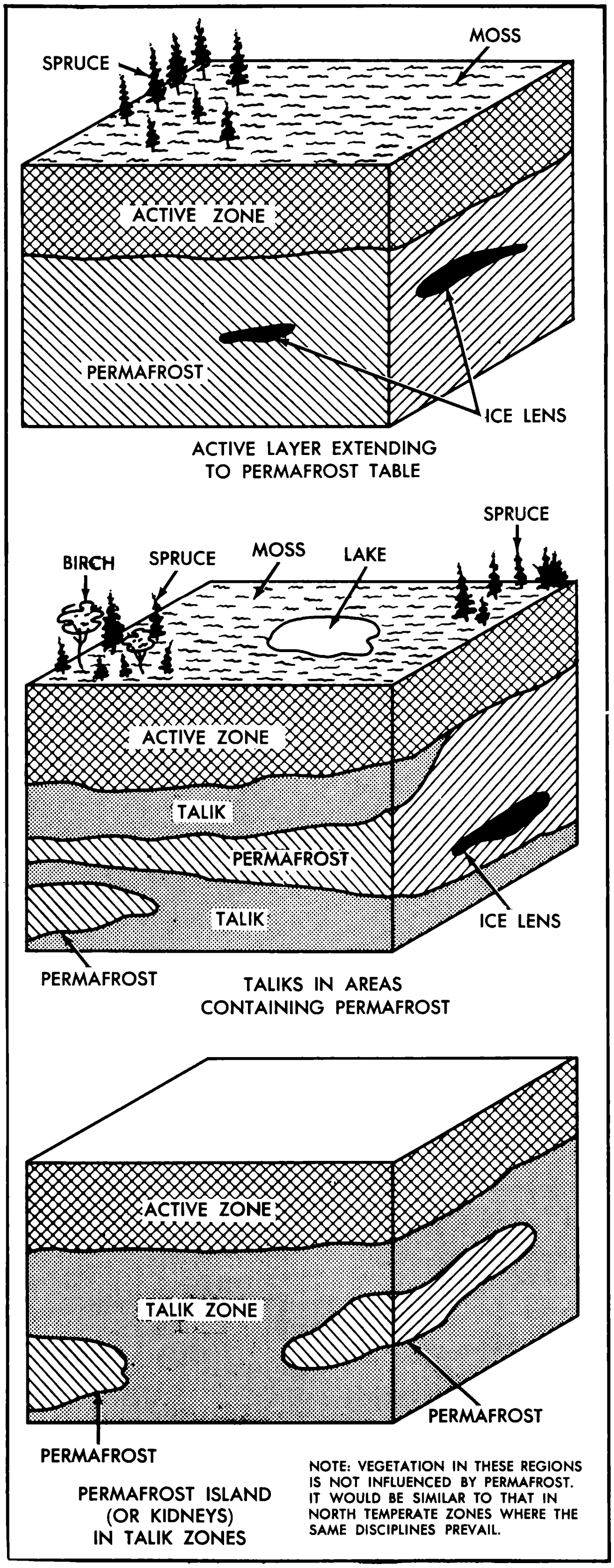


FIGURE 2A5-2

Typical Forms of Permafrost

(1) Geographical location.

(2) Extent, including depths of permafrost and of active layer.

(3) Form. (See par. 1 of 2A5.03.)

(4) Water (ice) content.

(5) Particle size, character, and packing of materials.

(6) Temperature of frozen materials.

(7) Chemical composition of matrix.

(8) Nature of materials.

(9) Geological deposition of materials.

A knowledge of the nature of the geological deposition of the materials is often of considerable help in the overall solution of an engineering problem. This is especially true where old buried beaches or drainage systems are located in a permafrost area.

2A5.05 ACTIVE LAYER

Because of the seasonal freezing and thawing of the active layer in a permafrost area, the following must be given consideration in the design and construction of any engineering facility.

(1) There is the possibility of swelling and/or settling ground, which may deform the surface to such an extent that vertical movement of any structure may take place. (See Sections 2A6 and 2A8.)

(2) There is the possibility of uneven freezing and thawing of the ground because of the characteristics of the ground and disciplines involved.

(3) There is the possibility of horizontal movement of portions of the active layer because of the development of sliding surfaces, which may result in extreme horizontal pressures.

(4) There is the possibility of development of hydrostatic pressure. (See Section 2A7.)

2A5.06 TALIKS

The presence of taliks (thawed zones) in a permafrost area may indicate a treatment of an engineering problem quite different from that in a permafrost area where no taliks are present.

Taliks are usually the result of (a) moving ground water; (b) local transfer of heat from a perched lake or other body of water, such as an arm or bay of a sea; (c) a change in the disciplines in the area, such as cover, exposure, and so on; and (d) a mean annual temperature that will permit a thawed zone to exist between the annual frozen cover and the permafrost below such cover. Taliks resulting from the last condition may be cyclic.

In voids where water is under pressure (or contains minerals in solution), the water may exist as a liquid at temperatures less than 0° C (32° F), as shown in Table 2A5-2. The matrix under these conditions is a liquid, and therefore such zones must be considered as a talik for engineering purposes. A change in the pressure without a change in temperature, however, may transform this talik into permafrost.

TABLE 2A5-2

Melting Point of Ice as Function of Pressure

Pressure, atmospheres	Temperature, °F
0.00603	32.01782 (convergence) water, water vapor, Form I ice
1.0	32.0
14.4	31.82
67.5	31.1
133	30.2
259	28.4
590	23.0
2,047	−7.6 (convergence) water, Form I ice, Form III ice

[1]Interpolated from data of Bridgeman, ICT 4, II (1928).

2A5.07 FROST ACTION

Occasionally, moving water contiguous to permafrost may penetrate the contact between two frozen layers and fill the space between them. If the water continues to flow, progressive thawing of the ground may occur and a new water channel be established. Where water freezes, a sheet of ice may result and the freezing of the water may cause the formation of a group of crystals, ultimately resulting in surface deformation.

1. SWELLING. Freezing of water on contact between the permafrost and the active zone frequently causes swelling of the ground and may result in the formation of frost mounds, pingos, or frost blisters. The regime of such water requires careful study and investigation before any construction work is contemplated in areas where swelling is present or indicated.

a. *Cause of Swelling.* Swelling of the ground is caused by various conditions, the most common of which are the following.

(1) Hydrostatic pressure built up be-

tween the permafrost table and the frozen crust of the active zone.

(2) Freezing of an active layer composed of silt, fine sand, and clay deposits, which may or may not have been saturated when frozen and which have access by capillary action to an additional supply of water. In this case, swelling may be caused by the expansion of water freezing *in situ*, which increases its volume about 9 percent. This freezing may be the result of a decrease in temperature or of a decrease in pressure. (See Table 2A5-2.)

b. *Capillary Rise and Ice Formation in Soil.* Bodies of clear ice can not possibly be formed in a body of soil unless the water migrates through the voids of the soil toward the centers of freezing. The water may come out of the soil that freezes or it may be drawn out of an aquifer located below the zone of freezing. These possibilities are illustrated by Figure 2A5-3.

Figure 2A5-3 represents three cylindrical specimens of a finely saturated silt. Specimen A rests on a solid base, but the lower ends of specimens B and C are immersed in water. The temperature of the upper end of each specimen is kept below the freezing point. In A, the water entering the ice layers is drawn out of the lower part of the specimen. As a consequence, the lower part consolidates in the same manner as if the water were pulled by capillarity toward a surface of evaporation at the upper end. The growth of the ice layers probably continues until the water content of the lower part is reduced to the shrinkage limit, provided the temperature is sufficiently low. Because all the water entering the ice layers comes from within the specimen, the sample is referred to as a closed system. The volume increase associated with the freezing of a closed system does not exceed the volume increase of the water contained in the system. It commonly ranges between 3 and 5 percent of the total volume.

In B, the water required for the initial growth of the ice layers is also drawn out of the specimen, whereupon the lower part of the sample consolidates. As the consolidation progresses, however, more and more water is drawn from the pool of free water located below the specimen. Finally, both the rate of flow toward the zone of freezing and the water content of the unfrozen zone through which the water percolates become constant. Such a sample constitutes an open system. Experience in permafrost regions shows that the total thickness of the ice lenses contained in such a system can increase to many feet.

The open system represented by B can be transformed into a closed system by inserting a layer of

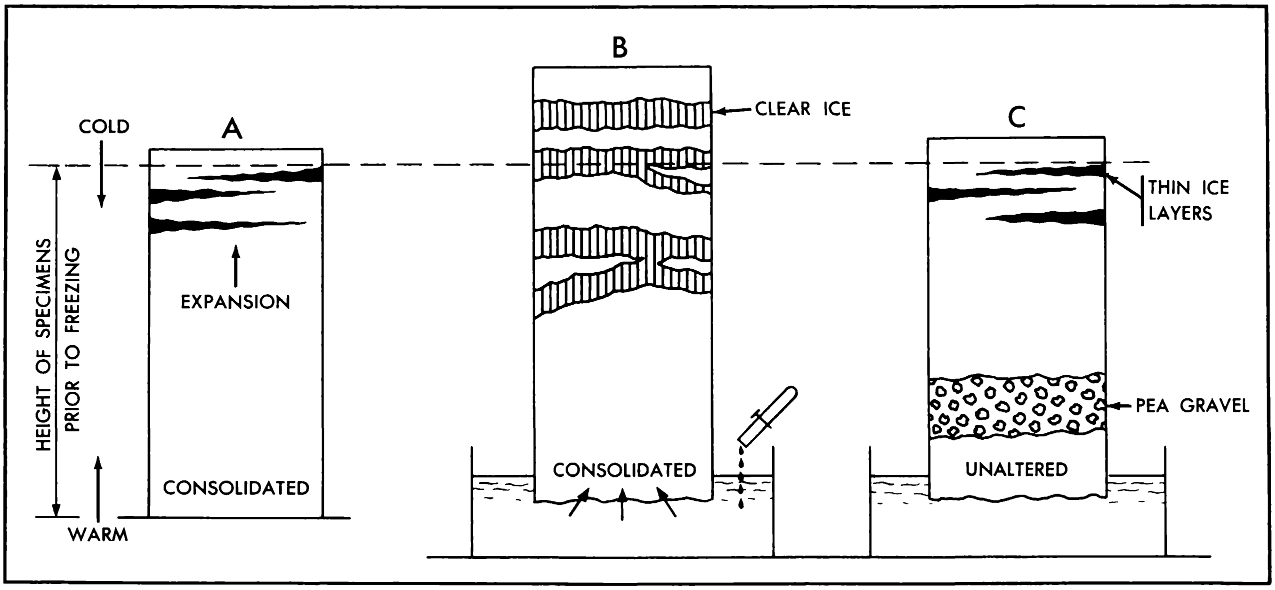


FIGURE 2A5-3

Ice Layer Formation in Closed System A and Open System B, With Layer of Pea Gravel in Specimen C Changing Upper Part of Specimen Into Closed System (Ref. 22)

coarse-grained material between the zone of freezing temperature and the water table, as shown by C. Because the water cannot rise by capillarity through the coarse layer, the upper part of the sample represented by C constitutes a closed system. The lower part of the closed system is subject to drainage by frost action.

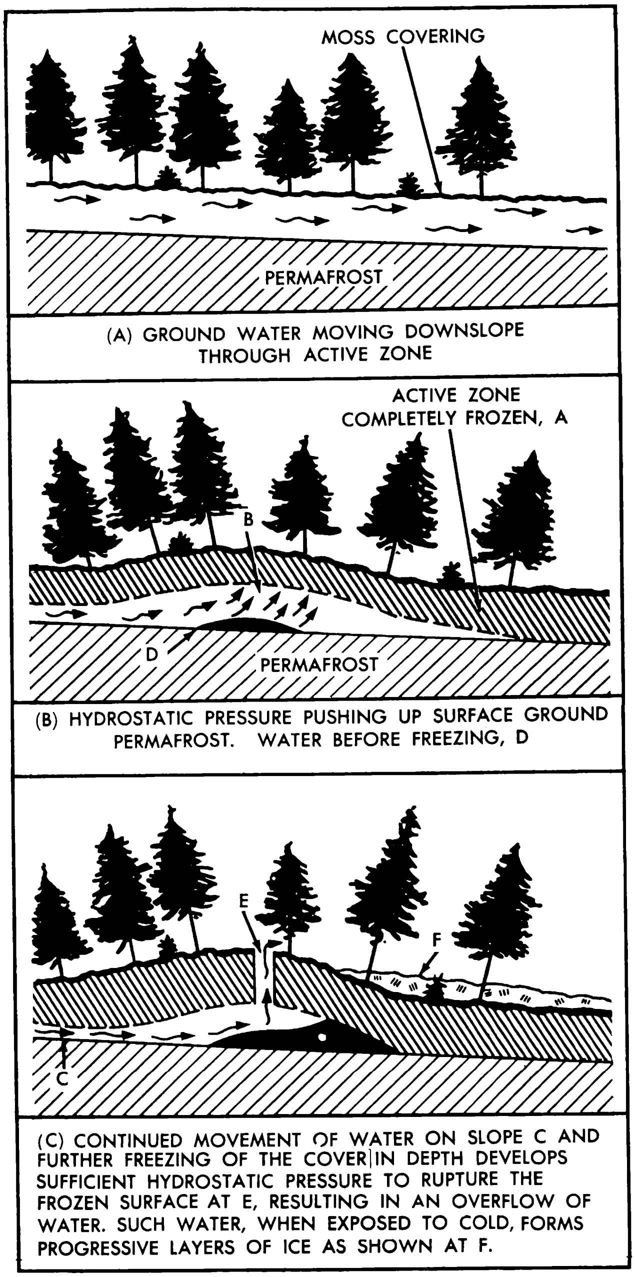
It has been found that ice layers do not develop as a result of freezing unless the soil contains at least a small percentage of soil particles passing the 200-mesh sieve. (See Table 2A6-1.)

c. *Frost Mounds.* Frost mounds are the most conspicuous manifestations of ground swelling. They vary widely in size, structure, origin, and duration; and in only a few cases have their origin, morphology, and history been thoroughly and objectively described. The term frost mound generally applies to all mounds produced by frost action unless their specific character, origin, and structure are known. The following are specific types.

(1) *Pingos.* Pingos are large mounds that may attain heights of 300 ft and perimeters of over 3,000 ft. Pingos are of many years duration, but the factors that control their life cycle have not yet been determined. Pingos are known to occur along the Arctic coast in flat, poorly drained areas near river deltas or in old lake basins. Pingo-like structures have also been described in the vicinity of Yakutsk and in Transbaikalia, Siberia. Pingo summits are usually broken by radiating fissures from which potable water may issue. (Ref. 23.)

(2) *Frost Blisters.* Frost blisters (Figure 2A5-4) are moderate in size, seldom exceeding 25 feet in height, and ruptured at the summit. They are usually caused by the complete freezing of the active layer and the presence of water, which may be under sufficient hydrostatic pressure to rupture the overlying crust of frozen ground. Such blisters may last only a year or two, or for several years, depending on whether the ice within them melts during summer. Frost blisters usually form along sloping ground and may shift their position from year to year.

(3) *Icing Mounds.* Icing mounds are much like frost blisters, and in many cases sharp distinction between them can not be made. They are composed almost entirely of ice and are usually annual, forming during winter and melting during summer, although some such mounds have been known to last a number of years. They may appear from year to year in exactly the same place, they may spring up in slightly different places, or they may suddenly make an appearance in an entirely new locality. They are formed by the freezing of subsurface layers of water that may issue from the ground (Figure 2A5-5) or from a fissure in river ice. Thus, they are similar in



(A) GROUND WATER MOVING DOWNSLOPE THROUGH ACTIVE ZONE

(B) HYDROSTATIC PRESSURE PUSHING UP SURFACE GROUND PERMAFROST. WATER BEFORE FREEZING, D

(C) CONTINUED MOVEMENT OF WATER ON SLOPE C AND FURTHER FREEZING OF THE COVER IN DEPTH DEVELOPS SUFFICIENT HYDROSTATIC PRESSURE TO RUPTURE THE FROZEN SURFACE AT E, RESULTING IN AN OVERFLOW OF WATER. SUCH WATER, WHEN EXPOSED TO COLD, FORMS PROGRESSIVE LAYERS OF ICE AS SHOWN AT F.

FIGURE 2A5-4

Formation of Frost Blister or Ice Mound

origin to frost blisters, with the difference that the source of their water is not so limited. For this reason, icing mounds issue water for a considerably longer period. They may measure from 1 to 30 ft high and are commonly surrounded by a more or less extensive sheet of layered ice.

FIGURE 2A5-5

Icing Mound With Fracture at A

Figure 2A5-4 illustrates the formation of a frost blister and the corresponding icing that may result when the blister is broken. In (B) of Figure 2A5-4, the flow of water is interfered with because of complete freezing of the active zone at A and the development of a hydrostatic head at B. If, in place of freezing, sufficient compaction of the active zone is effected at A to partially retard the water movement at A, a hydrostatic head again could develop at B, resulting in blisters and icing similar to that illustrated in Figure 2A5-6. Installation of a French drain (par. 2 of 2A7.04) at A could have avoided the swelling at B.

2. SUBSIDENCE. The subsidence (Figure 2A5-7) of silt, clay, sand, and gravel when thawed varies with the ice content and compaction of the materials. From an engineering standpoint, therefore, the ice content of soil is extremely important, and it is necessary that the conditions responsible for ice formation be recognized and evaluated so that unfavorable locations can be avoided.

The amount of ice that can form in the ground depends on several factors, the most important of which are the following.

FIGURE 2A5-6

Cross Section of Icing Mound Near Fairbanks, Alaska

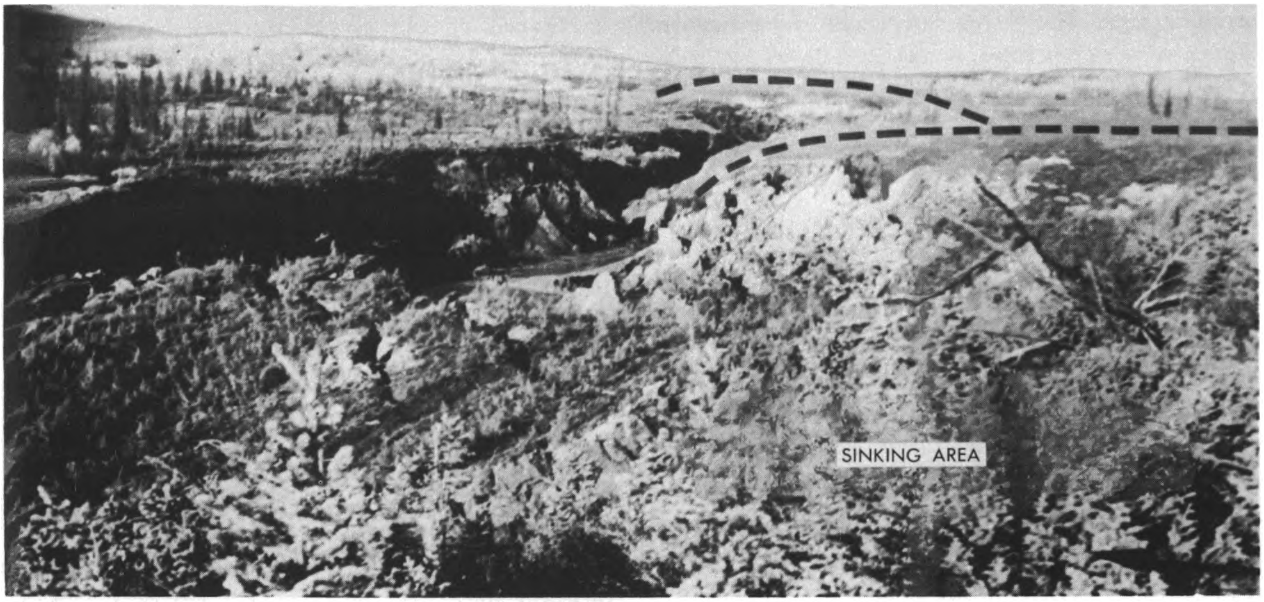


FIGURE 2A5-7

Subsidence in Black Muck Area Near Fairbanks, Alaska

(1) The amount of interstitial water (water in voids) in the ground before freezing.

(2) The available supply of water in the adjacent ground.

(3) The texture of the ground.

There is a definite relationship between the abundance of ground ice and the conditions that are favorable for the accumulation of ground water. Ice lenses and layers are, therefore, more frequently found in poorly drained low places than in more elevated locations. The types of soils that are particularly susceptible to ice formation are loose, silty soil and very fine sand, in which capillary water action is most prevalent and which freeze while in a state of capillary saturation within the voids. Loose clay soils act like silt, but when well consolidated and free of cracks, they are relatively unaffected because they are almost impervious to ground-water movement. Coarse-grained sand and gravel also are usually unaffected. When soil in a high state of capillary saturation freezes, the soil grains are separated by the force of expansion. When such soil thaws, it becomes a soft, mucky substance of extremely low bearing capacity, unstable and plastic, and susceptible to settling and caving.

2A5.08 SOLIFLUCTION

1. MASS MOVEMENT. When water is present in the active zone and/or at the contact between the active zone and permafrost, the material of the contact area may be so affected that a slow gravitational movement of the superficial mass can occur. Areas of this character should be avoided for construction and development, unless provision is made to correct the conditions that make such movement possible. Wherever practicable, such movement may be arrested by freezing the materials that cause the trouble or, where feasible, by providing sufficient drainage to divert the water that is responsible for the condition of the materials causing the trouble. Areas where solifluction may be expected are usually indicated by (a) numerous local glaciers or icings in the early spring, such icings forming a pattern; (b) trees leaning in the same direction; or (c) ridges or folds in the ground surfaces resulting from horizontal pressure exerted by the moving mass.

2A5.09 SUBSURFACE TEMPERATURES

1. CONTROLLING FACTORS. The temperatures in permafrost are controlled by the disciplines of the area involved and are the result of the combined action of all existent factors. Therefore, if one of the factors is changed, the thermal regime of the area may be altered. Good cold-weather engineering necessitates a proper evaluation of any change in terms of the result of all old and

new factors. The distribution of heat in the materials of a permafrost area is affected by mean annual temperature, cover, exposure, conductivity, and diffusivity of the materials involved, the nature and character of deposition, movement of subsurface water, and proximity to large bodies of water.

Tables 2A5-3a through 3f show the annual and monthly air and soil temperatures at a number of stations in the Cold Regions. Table 2A5-3g shows the average depth to the upper surface of permafrost in various locales. A study of these tables will indicate the effect of the disciplines in terms of frost penetration. The range of amplitude of the seasonal variations diminishes downward and becomes negligible at a level depending on the materials and disciplines of the area. This horizon is termed the level of zero amplitude. (See Figures 2A5-8 and 2A5-9.) Below the level of zero amplitude, the temperature of the permafrost has a gradient, which, unless the disciplines are changed, remains stable from season to season and probably from year to year.

TABLE 2A5-3a

Monthly and Annual Air, Snow, and Soil Temperatures in °F, Fairbanks (Weeks Field), Alaska, 1947

Month	Air[1]		Snow		Depth, ft							
					0.1		0.4		2.0		10.0	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan			22	−56	30	27	31	28	32	30	33	31
Feb	44	−53	32	−56	29	25	30	25	33	30	33	30
Mar	50	−14		−13	32	28	32	29	32	31	32	31
Apr	48	3	32	− 2	47	30	34	31	32	32	32	32
May	83	29			67	32	49	32	32	29	32	29
June	74	42			81	42	53	35	33	29	33	29
July	80	51			81	52	64	48	45	34	33	31
Aug	67	44			65	38	54	42	48	45	35	32
Sept	53	30			52	29	47	28	45	35	35	32
Oct	49	6			34	24	36	30	39	34	35	34
Nov			32	−10	31	26	31	29	34	32	34	35
Dec			25	−21	31	23	31	26	33	32	34	32
Annual	83	−53		−56	81	23	64	25	46	29	35	29

[1]These temperatures were taken 9.8 ft above the earth's surface.

The results of the exposure of the area are usually reflected in the upper subsurface temperatures. (See Figure 2A5-10.) Diffusivity and the latent heat of fusion of the materials involved determine the rate and character of the distribution of heat. The proximity to nearby bodies of water in many instances materially affects the temperature of nearby subsurface materials.

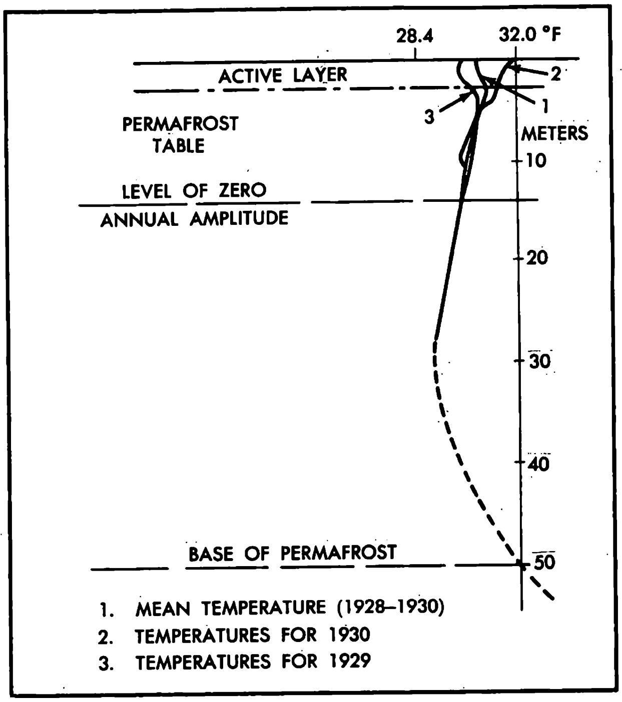


FIGURE 2A5-8

Temperature Gradient in Permafrost, Skovorodino, Siberia (Ref. 23)

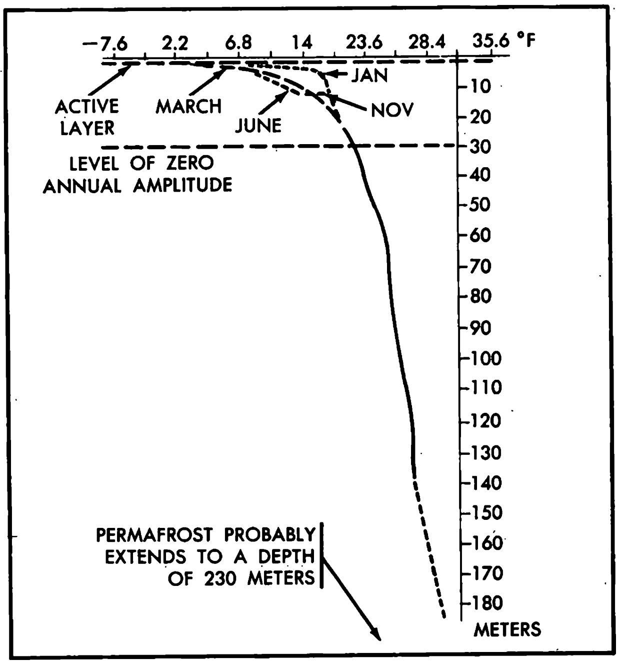


FIGURE 2A5-9

Temperature of Permafrost in Shargin Shaft, Yakutsk, Siberia (Ref. 23)

TABLE 2A5-3b

Monthly and Annual Soil Temperatures in °F, Nome, Alaska—Lat 64° 30' N, Long. 165° 26' W

Month	Depth, ft											
	0.0		0.6		2.8		5.7		10.7		19.6	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan	29.3	5.4	31.9	30.6	31.5	30.8	31.8	31.1	30.9	30.1	31.3	31.0
Feb	31.6	22.6	31.5	31.1	31.5	31.0	31.8	31.2	30.9	30.3	31.5	30.2
Mar	28.0	20.9	31.3	30.9	31.8	31.2	31.9	21.5	31.1	30.3	31.8	31.1
Apr	32.9	28.6	32.9	31.0	32.6	31.4	32.8	31.6	32.0	30.9	32.7	31.6
May	56.2	31.8	33.1	32.7	32.7	32.4	32.8	32.4	32.2	31.9	32.8	32.4
June	75.0	41.2	36.4	33.3	32.1	30.7	31.8	31.0	31.3	30.3	31.7	30.8
July	79.1	40.7	53.0	31.8	44.6	30.0	36.3	27.0	31.9	28.0	31.3	27.7
Aug	66.7	48.0	51.2	40.2	33.7	32.4	31.6	31.3	31.0	30.6	31.4	31.2
Sept	49.0	34.8	38.7	32.2	33.3	31.5	32.2	31.1	31.9	30.2	32.3	31.0
Oct	44.2	17.9	33.7	31.2	33.0	31.1	32.1	31.3	32.0	30.4	31.9	30.6
Nov	31.0	−4.1	32.3	28.0	32.5	29.6	32.7	31.6	32.7	30.0	32.5	31.0
Dec	30.3	7.3	32.0	31.1	31.6	29.4	32.3	31.7	31.4	30.8	32.1	30.8
Annual	79.1	−4.1	53.0	28.0	44.6	29.4	36.3	27.0	32.7	28.0	32.8	27.7

2. EXAMPLE OF SUBSURFACE TEMPERATURE DISTRIBUTION IN PERMAFROST AREA. Geothermal investigations near Point Barrow, Alaska, indicate that below the level to which seasonal changes penetrate, ground temperatures do not fall below about −10° C (14° F). (See Figure 2A5-11.) The depth of the 0° C (32° F) geo-isotherm ranges from 670 to 1,300 ft, increasing with the distance from the nearest large body of water. Thermal disturbances caused by drilling in and through the permafrost persist for many months so that thermal readings taken in freshly drilled holes have little value.

In drilling through permafrost, this disturbance is always in the direction of higher temperatures, except below the base of the frost if the well is deep enough to penetrate the full thickness. "Cooling curves" have been plotted for several drilled wells, and in all analyzed so far, they approximate a hyperbola (Figure 2A5-12) of the general form

$$Y = \frac{x}{ax + b} + c$$

The constants a, b, and c vary from one well to the next and from one depth to another in the same

TABLE 2A5-3c

Monthly and Annual Soil Temperatures in °F, Resolute, Canada—Lat 74° 41' N, Long. 94° 34' W

Month	Depth, ft											
	Surface		0.3		0.67		1.5		3.25		5.0	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
January	−21.5	−35.6	...	...	−19.4	−26.2	−17.4	−22.4	−13.1	−17.6	− 8.4	−12.9
February	−26.8	−39.4	...	...	−24.7	−30.4	−22.7	−26.0	−17.9	−20.8	−13.2	−16.2
March	−13.1	−36.1	...	...	−17.2	−29.6	−17.4	−25.5	−17.0	−21.0	−15.0	−17.1
April	−12.0	−20.1	...	...	−13.6	−18.3	−13.3	−17.4	−12.9	−15.8	−11.8	−15.0
May	15.3	−11.2	...	...	9.7	−12.6	5.8	−12.6	1.1	−12.7	− 2.4	−11.7
June	52.4	12.4	...	...	38.1	9.8	29.5	6.3	23.3	1.7	10.3	− 1.8
July	54.6	37.2	...	...	40.2	33.4	34.1	29.6	28.6	23.5	23.8	18.7
August	...	...	...	...	40.7	31.8	35.2	31.7	31.8	28.7	26.5	24.0
September	...	...	33.8	13.2	32.4	14.5	31.8	17.8	31.9	18.7	26.8	23.2
October	...	...	17.2	1.3	17.1	2.5	18.5	8.6	18.8	7.3	23.2	13.1
November	...	...	1.2	−19.1	1.7	−16.3	6.6	−11.3	7.5	−10.6	13.5	− 0.5
December	...	...	− 4.2	−29.9	− 4.5	−26.5	− 4.2	−18.6	− 3.7	−17.6	0.2	− 6.3
Annual	...	...	...	...	40.7	−30.4	33.5	−26.0	31.9	−21.0	26.8	−17.1

TABLE 2A5-3d

Monthly and Annual Air and Soil Temperatures in ° F, Thule, Greenland— Lat 76° 33' N, Long. 68° 49' W

Month	Air		Ground		Depth, ft 1.09		Depth, ft 2.18		Depth, ft 3.28	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1949										
Dec	11.8	−29.7	9.0	− 6.0	6.2	−21.0	3.0	− 1.0	8.9	5.0
1950										
Jan	12.6	−34.6	− 3.1	−20.2	−10.4	−34.6	− 3.2	− 9.5	4.0	− 1.4
Feb	1.0	−40.6	−11.2	−27.8	−15.0	−43.5	−11.0	−16.2	−3.0	− 6.6
Mar	25.2	−40.4	5.0	−24.0	0.5	−35.0	− 6.6	−18.4	−4.5	−10.5
Apr	28.0	−32.7	3.3	−14.0	11.0	−23.8	− 4.2	−10.4	1.1	− 3.8
May	44.0	−10.8	17.8	6.5	36.0	11.0	7.7	− 1.0	8.4	− 4.0
June	50.1	24.6	66.2	48.0	80.0	42.5	32.0	26.9	31.2	26.1
July	58.8	25.7	66.6	54.5	60.0	43.2	38.2	31.0	34.0	32.7
Aug	51.2	27.7	70.0	50.0	58.0	41.5	37.2	34.0	34.6	34.1
Sept	37.8	10.0	41.5	21.8	34.9	18.7	39.3	32.8	34.4	34.0
Oct	28.4	−14.1	27.8	12.8	21.2	− 1.2	21.7	19.6	29.6	28.0
Nov	30.5	−29.1	44.5	− 2.5	30.2	− 8.5	20.5	10.4	24.0	10.0
Annual	58.8	−40.6	70.0	−27.8	60.0	−43.5	39.3	−18.4	34.6	−10.5

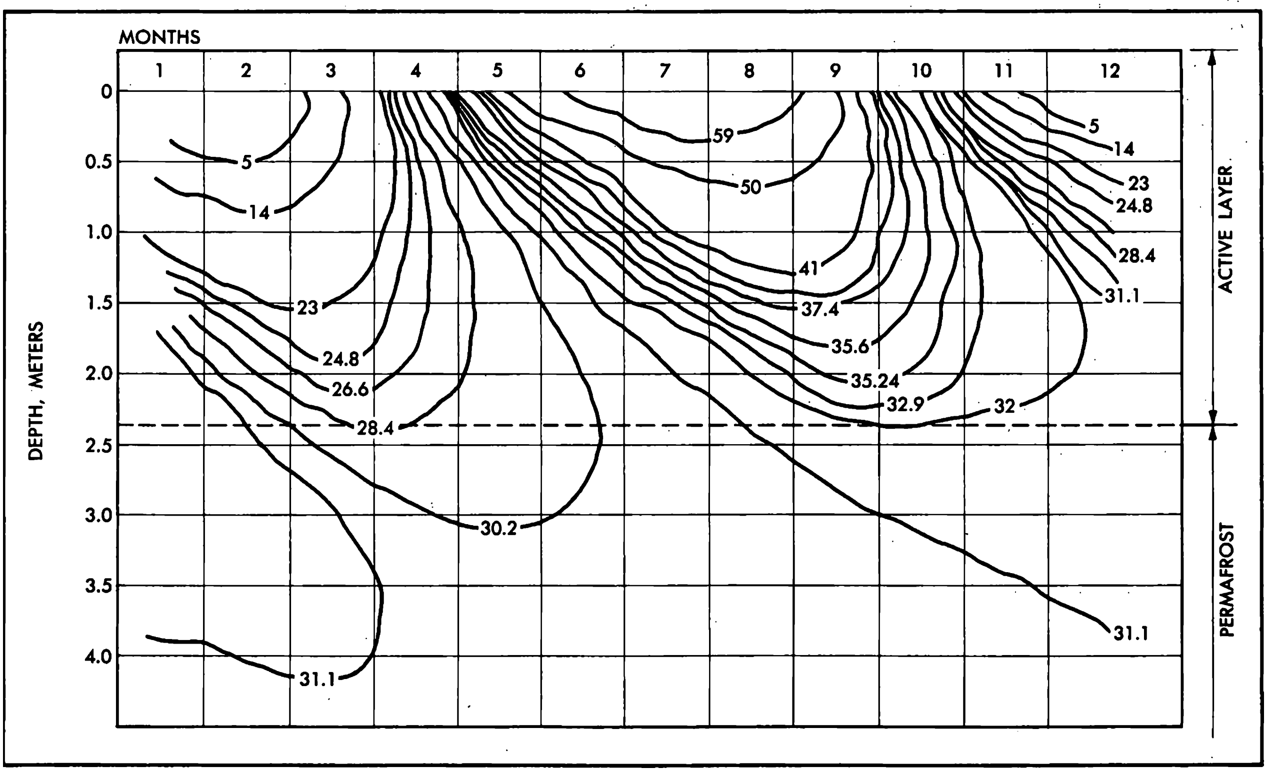


FIGURE 2A5-10

Thermal Regime of Ground in °F at Skovorodino, Siberia, 1928–1930 (Ref. 30)

TABLE 2A5-3e

Mean Monthly and Annual Ground Temperatures in °F, Siberia (Ref. 23)

Depth, meters	Period of observation	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
(lat 54° 42′ N long. 128° 52′ E)														
1.5 (active layer)	1910–1919	30.56	27.32	25.16	26.78	29.66	30.78	31.46	30.56	34.88	33.26	32.18	32.0	30.56
2.0 (active layer)	1910–1919	31.82	29.84	27.68	27.50	29.48	30.38	30.96	31.64	32.54	32.36	32.09	32.0	33.12
2.8 (permafrost)	1911–1919	31.64	31.91	29.84	29.12	29.48	30.20	30.78	30.96	31.28	31.46	31.64	31.64	30.78
(lat 54° 05′ N long. 123° 51′ E)														
0.4 (active layer)	1928–1930	8.78	8.60	14.92	26.06	32.54	44.16	51.26	53.24	45.32	34.70	28.04	16.32	30.38
0.8 (active layer)	1928–1930	17.06	14.72	18.32	26.60	30.38	34.88	43.52	47.30	43.52	34.88	32.0	25.88	30.56
1.6 (active layer)	1928–1930	30.38	26.60	24.26	26.78	29.48	30.38	31.28	29.66	36.32	33.80	32.18	32.0	30.56
2.0 (active layer)	1928–1930	31.28	28.68	26.24	27.32	29.30	30.20	30.78	32.0	33.80	33.08	32.18	32.0	30.56
2.5 (permafrost)	1928–1930	31.64	31.64	30.20	28.64	29.66	30.20	30.56	30.78	30.28	31.64	31.64	31.64	30.96

well. It is realized that a more complicated expression is called for by theory, but the simple hyperbola gives such a close fit to the observed data that it is thought wisest to wait until more data are at hand before attempting a more complicated formula. (Ref. 25.)

Figure 2A5-13 shows the thermal logs for three drill holes in the Point Barrow area; Figure 2A5-14 shows the thermal regime of another drill hole. Figure 2A5-15 shows a typical drill log.

The reason for the change in gradient between 600 and 700 ft in Simpson No. 13 is not at all clear. The gradient does not seem to correlate with any marked change in stratigraphy, as evidenced by the driller's log, nor is there more than a vague suggestion of correlation with the electric logs. It seems most probable that the sudden change in gradient is caused by a change in thermal conductivity in the earth materials at this depth,

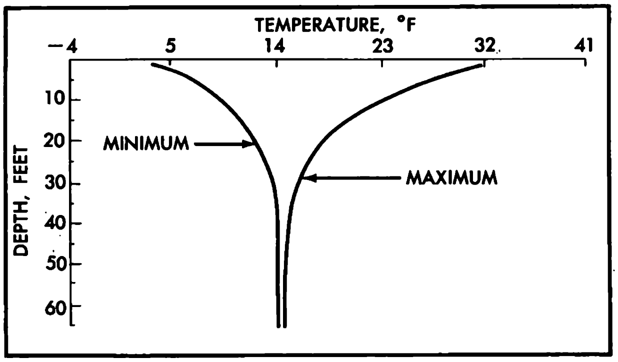


FIGURE 2A5-11

Temperature Variations With Depth (Ref. 25)

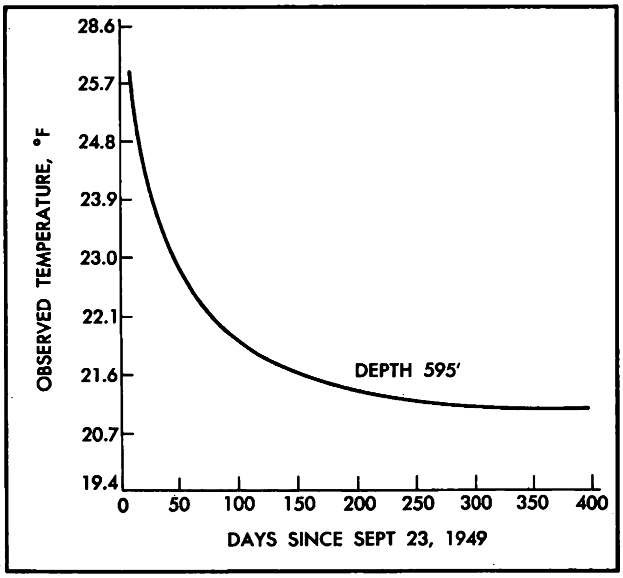


FIGURE 2A5-12

"Cooling Curve," South Barrow No. 3 (Ref. 25)

TABLE 2A5-3f

Subsurface Temperatures in °F on Ross Shelf Ice, North Side of Campsite, Little America III—Lat 78° 34' S, Long. 163° 56' W (Ref. 24)

Depth, meters	Period[1]										
	24	25	26	1	2	3	4	5	6	7	8
Air	6.62	−4.27	−17.14	−29.02	−31.54	−29.02	−29.02	−13.72	−33.16	−25.06	−30.46
Surface	−1.12	−7.78	−17.68	−29.02	−31.54	−30.82	−29.92	−30.22	−28.66	−24.34	−30.64
¼	...	...	...	−26.86	−27.58	−30.20	−23.44	−19.84	−18.40	−26.50	−25.42
½	...	...	...	−14.26	−20.20	−14.62	−18.22	−17.86	−14.98	−23.26	−21.28
1	9.32	4.18	0.40	−4.18	−10.84	−12.10	−14.98	−15.52	−13.36	−20.02	−18.94
2	3.74	3.74	−1.12	−1.30	−4.00	−6.52	−8.14	−9.76	−10.12	−11.92	−13.36
3	0.14	0.14	−2.38	−1.84	−2.56	−4.36	−5.62	−6.88	−7.78	−8.32	−9.76
4	...	...	...	−2.02	−2.74	−3.64	−4.72	−5.80	−6.52	−7.24	−7.96
5	−4.0	−3.82	−4.54	−4.18	−4.36	−4.54	−5.08	−5.62	−6.34	−6.70	−7.24
10	...	−10.30	−9.94	−9.76	−9.58	−9.40	−9.22	−9.04	−9.04	−8.86	−8.86
15	...	−8.86	−9.76	−10.12	−9.94	−9.94	−10.12	−9.94	−9.94	−9.94	−9.76
20	...	−8.68	−9.04	−10.22	−9.22	−9.40	−9.40	−9.40	−9.40	−9.40	−9.40
25	...	−8.32	−8.50	−8.68	−8.86	−8.86	−8.86	−8.86	−8.86	−8.86	−8.86
30	...	...	−8.32	−8.32	−8.32	−8.32	−8.32	−8.32	−8.32	−8.32	−8.32
36	...	...	−7.78	−7.78	−7.78	−7.78	−7.78	−7.78	−7.78	−7.78	−7.78
41	...	...	−7.06	−7.42	−7.60	−7.60	−7.60	−7.60	−7.60	−7.60	−7.60

Depth, meters	Period[1]										
	9	10	11	12	13	14	15	16	17	18	19
Air	−29.38	−59.98	−41.62	−12.64	−9.04	−7.42	9.50	9.86	15.62	26.60	19.04
Surface	−28.66	−64.84	−32.34	−3.28	−10.30	−3.10	15.44	16.34	25.70	32.18	26.96
¼	−24.52	−41.08	−38.38	−19.12	−18.04	−28.30	−12.64	8.42	15.98	38.20	25.70
½	−21.64	−30.46	−33.16	−21.46	−18.40	−12.64	−1.84	−19.12	10.58	18.50	21.02
1	−19.30	−24.16	−29.02	−22.72	−18.58	−14.98	−9.40	−3.82	1.04	6.44	15.90
2	−14.08	−14.98	−18.04	−19.12	−17.50	−15.70	−12.46	−9.72	−4.72	−0.76	5.64
3	−10.12	−10.66	−11.74	−13.36	−14.08	−13.72	−13.54	−12.64	−11.38	−9.94	−6.34
4	−8.50	−9.04	−9.76	−10.84	−11.74	−12.28	−12.46	−12.10	−11.74	−10.84	−9.40
5	−7.60	−7.96	−8.50	−9.04	−9.76	−10.30	−10.84	−10.84	−11.20	−10.84	−10.30
10	−8.68	−8.68	−8.68	−8.68	−8.68	−8.86	−9.04	−9.04	−9.40	−9.58	−9.40
15	−9.58	−9.58	−9.20	−9.58	−9.40	−9.40	−9.58	−9.40	−9.58	−9.58	−9.40
20	−9.22	−9.04	−9.04	−9.22	−9.40	−9.22	−9.40	−9.40	−9.58	−9.58	−9.22
25	−8.68	−8.68	−8.68	−8.68	−8.68	−8.86	−8.86	−8.86	−9.04	−9.04	−8.86
30	−8.32	−8.32	−8.32	−8.32	−8.14	−8.14	−8.14	−8.14	−7.78	−7.78	−8.32
36	−7.60	−7.60	−7.78	−7.78	−7.78	−7.78	−7.78	−7.78	−7.60	−7.42	−7.24
41	−7.60	−7.42	−7.60	−7.60	−7.42	−7.60	−7.60	−7.42	−7.42	−7.42	−7.42

[1] Inclusive dates

24—14 Mar to 27 Mar
25—28 Mar to 10 Apr
26—11 Apr to 24 Apr
1—25 Apr to 8 May
2—9 May to 22 May
3—23 May to 5 June
4—6 June to 19 June
5—20 June to 3 July
6—4 July to 17 July
7—18 July to 31 July
8—1 Aug to 14 Aug
9—15 Aug to 28 Aug
10—29 Aug to 11 Sept
11—12 Sept to 25 Sept
12—26 Sept to 9 Oct
13—10 Oct to 23 Oct
14—24 Oct to 6 Nov
15—7 Nov to 20 Nov
16—21 Nov to 4 Dec
17—5 Dec to 18 Dec
18—19 Dec to 1 Jan
19—2 Jan to 20 Jan

although there is no proof whatever that this is so. (Ref. 25.)

2A5.10 BODIES OF WATER AND PERMAFROST

1. THAWING EFFECT. Where there are perched lakes and meandering streams, many of the lakes over a period of time change their shape and size, and meandering streams change their courses by sloughing of banks and erosion. In areas of this type, where granular materials such as sand or gravel are present in any appreciable amount, the beds of the meandering streams, and very often the bottoms of perched lakes and swamps, are composed of thawed sand and gravel. Borings made by J. M. Fulton on the Mackenzie River in Canada indicate that the bed of the Mackenzie is thawed. While many islands in the Mackenzie are permanently frozen, some of these are perched on thawed gravel. D. W. McLachlan reported that beds of some swamps in the vicinity of Port Nelson, Canada, were frozen. (Ref. 27.)

Borings taken on the beach at Churchill, Canada,

TABLE 2A5-3g

Average Depth to Upper Surface of Permafrost

Location	Latitude	Surface	Kind of soil	Depth, ft
Alaska				
Point Barrow	71° 18′	Moss	Loamy sand	2±
Fairbanks	64° 50′	Moss	Silt	3 to 6
Kotzebue	66° 52′	Moss	Peat, sand, and gravel	3±
Nome	64° 30′	Moss	Loam and sandy loam	3 to 4
Wales	65° 37′	Stripped	Sand	4±
Northway	62° 58′	Moss and Peat	Fine silty sand	3 to 5
Russia	South of 55°		Sandy	9 to 12
			Clayey	5.5 to 7.5
			Peaty	2 to 3
	62°		Sandy	6 to 7.5
			Clayey	4.5 to 6
			Peaty	1.5±
	North of 70°		Sandy	3.5 to 5
			Clayey	2 to 3
			Peaty	0.5 to 1

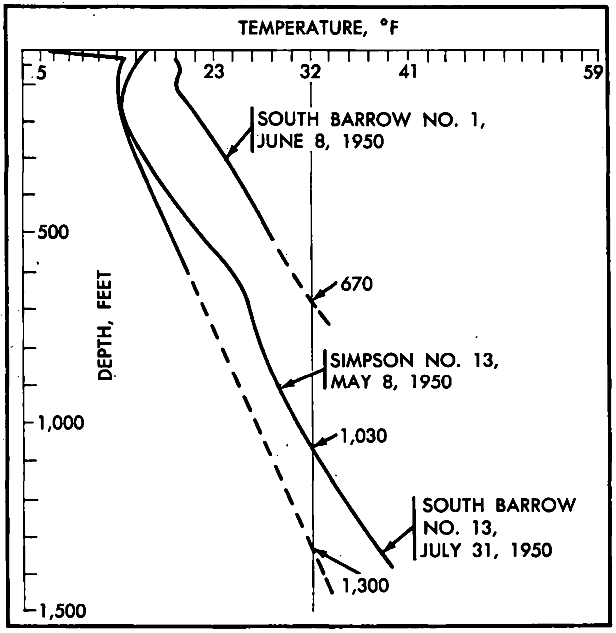


FIGURE 2A5-13

Thermal Logs Showing Permafrost Depth (Ref. 25)

and similar studies made on the Seward Peninsula, where sand and gravel or similar granular materials are present, indicate that bodies of water are usually surrounded by and/or superimposed on thawed materials. Such thawed materials are en-

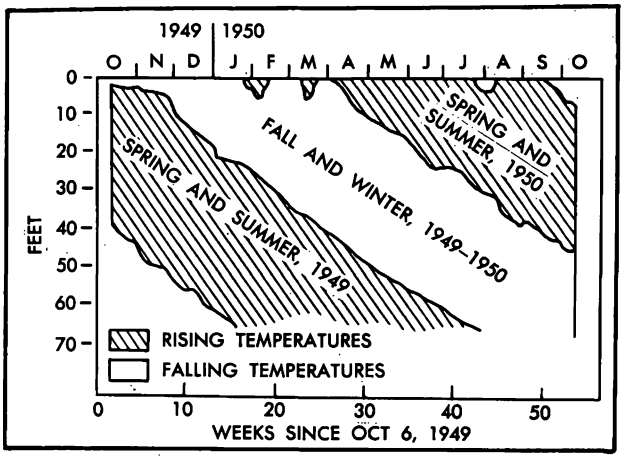


FIGURE 2A5-14

Phase Lag in Thermal Regime of Drill Hole Near Point Barrow, Alaska (Ref. 25)

veloped in permanently frozen materials, as indicated in Figure 2A5-16. Because of this fact, a special investigation to determine the extent of thawed materials or the extent of taliks with respect to the surface of permanently frozen materials is recommended for all shore or near-shore installations.

2. MODIFICATION FROM COMPACTION. In the Seward Peninsula area, where the sea level was originally higher than at present, the plane of demarcation between the thawed materials and the permafrost area immediately adjacent to and near the thawed materials is outlined in many instances by a very tight granular material representing a higher beach. An analysis of this material showed that it contained many fines and was tightly compacted by the jigging action of the sea. Most of the material was permafrost. This may have been the result of either or both of the following factors.

(1) Because of the high degree of compaction, the material was relatively impervious to water and was therefore resistant to the thawing action of migrating water.

(2) Because of the fineness of the material, its thermal conductivity may have been sufficiently small so that it remained frozen.

2A5.11 VEGETATIONAL CLUES TO PERMAFROST AND GROUND WATER

1. HUMMOCKS. Thick moss, cotton grass tussocks, muskegs, and hummocky tundra in treeless areas indicate a wet zone above a thin active layer,

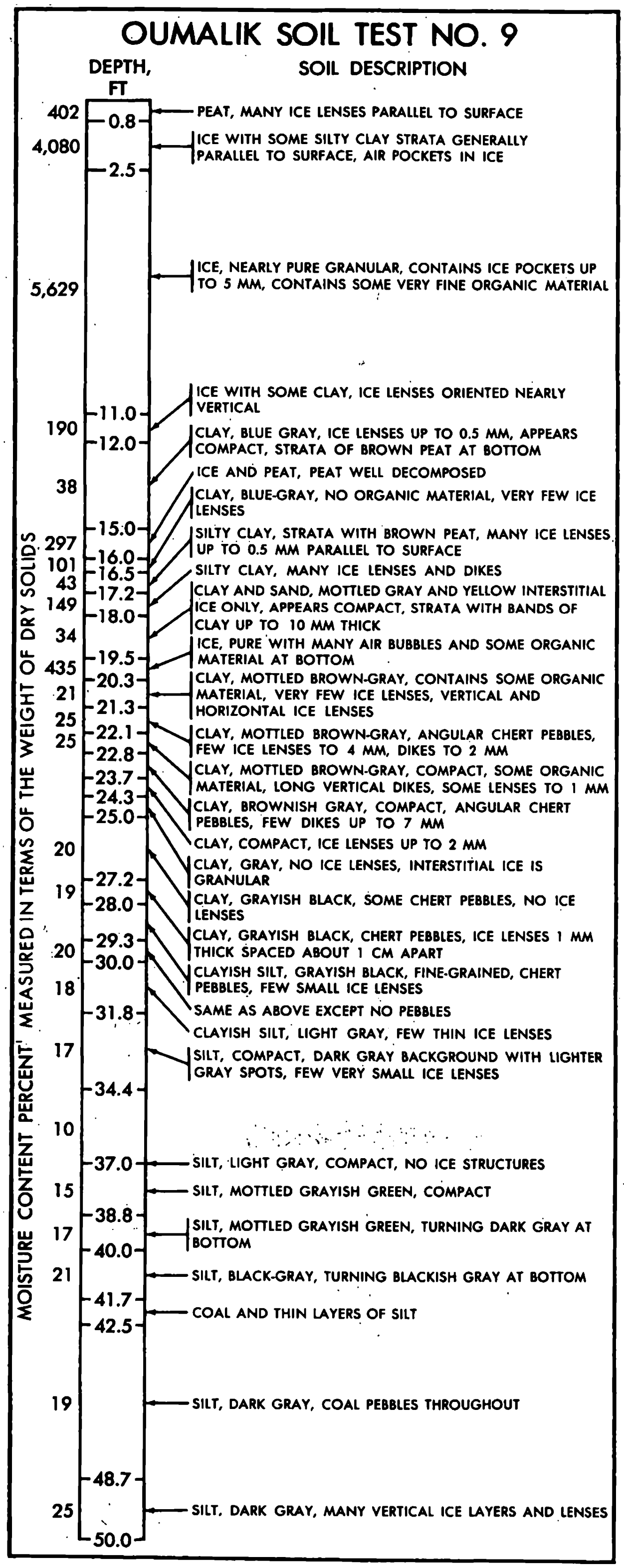


FIGURE 2A5-15

Drill Log Near Point Barrow, Alaska (Ref. 26)

and very poor drainage. This may be true even of terraced terrain where each succeeding terrace may be as wet as the lower one. Figure 2A5-17 illustrates a type of terrain found frequently in the Arctic where no timber is present. Immediately below the surface, black frozen muck is usually found. (See Figure 2A5-1.) The hummocks shown in Figures 2A5-17, 2A5-18, 2A5-19, 2A5-20, and 2A5-21 are the results of intensive frost action and have developed in poorly drained permafrost areas where silty and mineral soils are present. Hummocks are found on benches, summits, relatively flat slopes, and in lowlands.

2. FORMATION OF PEAT RING. Figure 2A5-18 is a series of diagrammatic sketches showing the evolution of a peat ring.

a. *Stage A—Unusually Warm Summer.* In most areas, the depth of thaw does not extend below the base of the peat, but mineral soil is thawed in a few areas where peat is exceptionally thin.

b. *Stage B—Late Autumn, Same Year.* The thawed mineral soil expands on freezing and breaks the thin overlying cover of peat, initiating a frost scar.

c. *Stage C—Early Autumn, Several Years Later.* The frost scar has been enlarged by the shoving aside of peat at the margins of the bare soil area. The surface of the scar expands upward as surface layers of the soil freeze and expand. Dilation cracks (miniature *zellenboden*) are formed.

d. *Stage D—Late Autumn, Several Years Later.* After the surface layers of soil have frozen, a hard cover of frozen soil resists further uparching. Continued expansion caused by the deeper layers of soil freezing is relieved by lateral thrusting. The ridge of peat is raised around the bare soil center.

e. *Stage E—Late Autumn, Several Years Later.* The ridge of perennially frozen ground beneath the peat ridge and the thick layer of seasonally frozen ground in peat at the surface prevent further widening of the bare soil area by lateral thrusting. Instead, lateral expansion of the soil center causes intrusion of masses of silt into the peat of the ridges, forcing some of the peat to move in the opposite direction along the surface of the frozen ground beneath the frost scar.

f. *Stage F—Summer, Several Years Later.* Seedlings of cotton grass take root at the inner edge of the peat ridge.

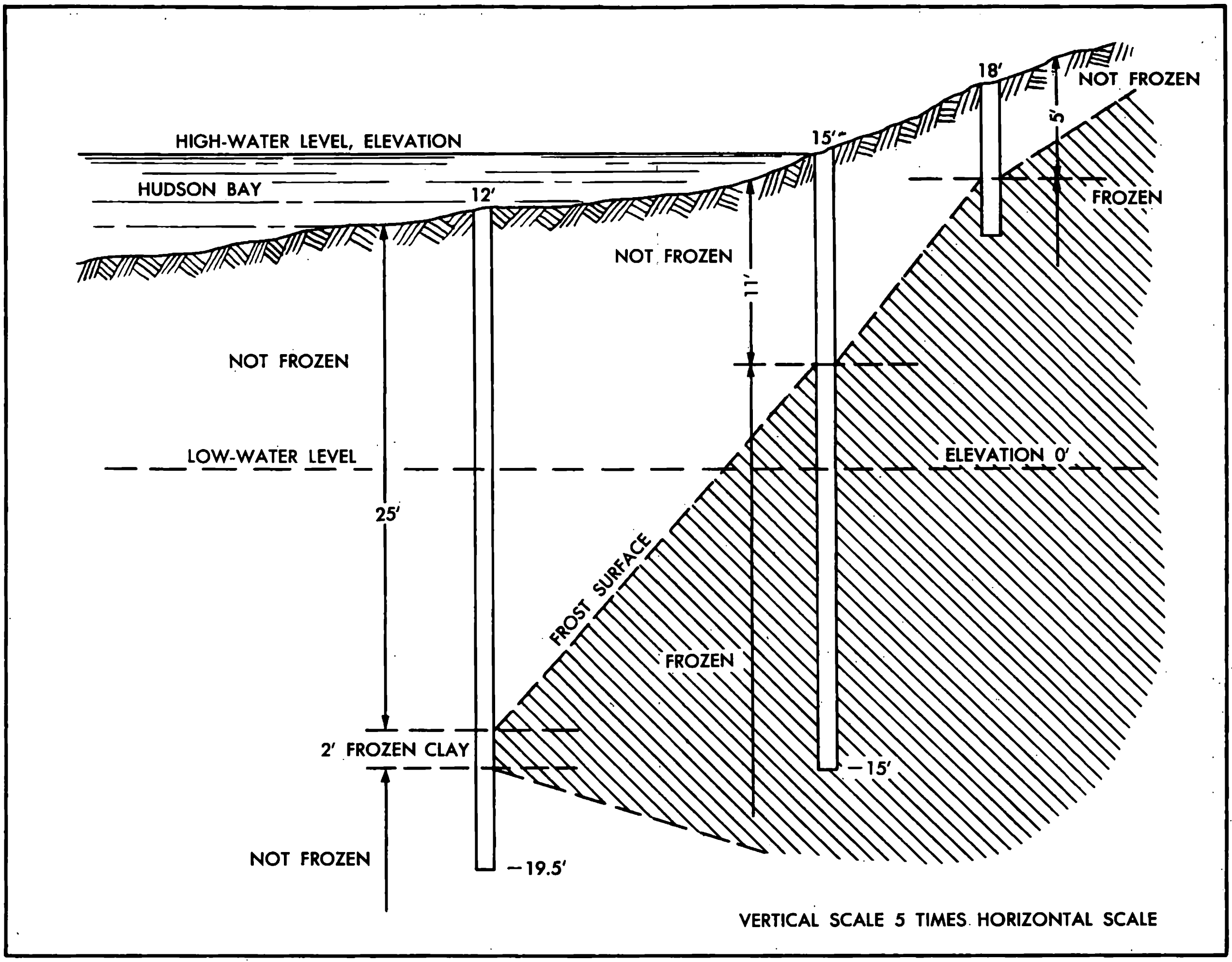


FIGURE 2A5-16

Borings on Beach, Oct. 3 to 10, 1929, Showing Effect of Sea on Permafrost, Churchill, Canada (Reproduced from unpublished plan by D. W. McLachlan in the files of the Department of Transport, Ottawa) (Ref. 27)

g. *Stage G—Early Autumn, Same Year.* The bare soil has frozen several inches deep, but the soil beneath the tussocks is still thawed. Lateral expansion forces the freezing soil beneath the tussocks, heaving them upward. The peat ridge is no longer affected by lateral thrusting from the soil center.

3. TREES. During reconnaissance, types of vegetation are often valuable clues to permafrost soil and drainage problems. The following are examples.

(1) Aspen are usually found on dry, unfrozen slopes.

(2) Spruce in a permafrost area may indicate frozen materials a few feet below the moss cover.

(3) Birch indicates a thawed zone in or above the permafrost.

(4) Where spruce and birch grow in a permafrost area, small taliks will usually be found in the permanently frozen materials.

(5) Spruce and tamarack stands may be found growing on frozen muskeg and moss-covered, water-logged peat stratified with silt.

(6) Balsam and poplar are confined to sites adjacent to an active zone that has loose, sandy soil reasonably well drained and usually unfrozen to a depth of several feet; or these trees may indi-

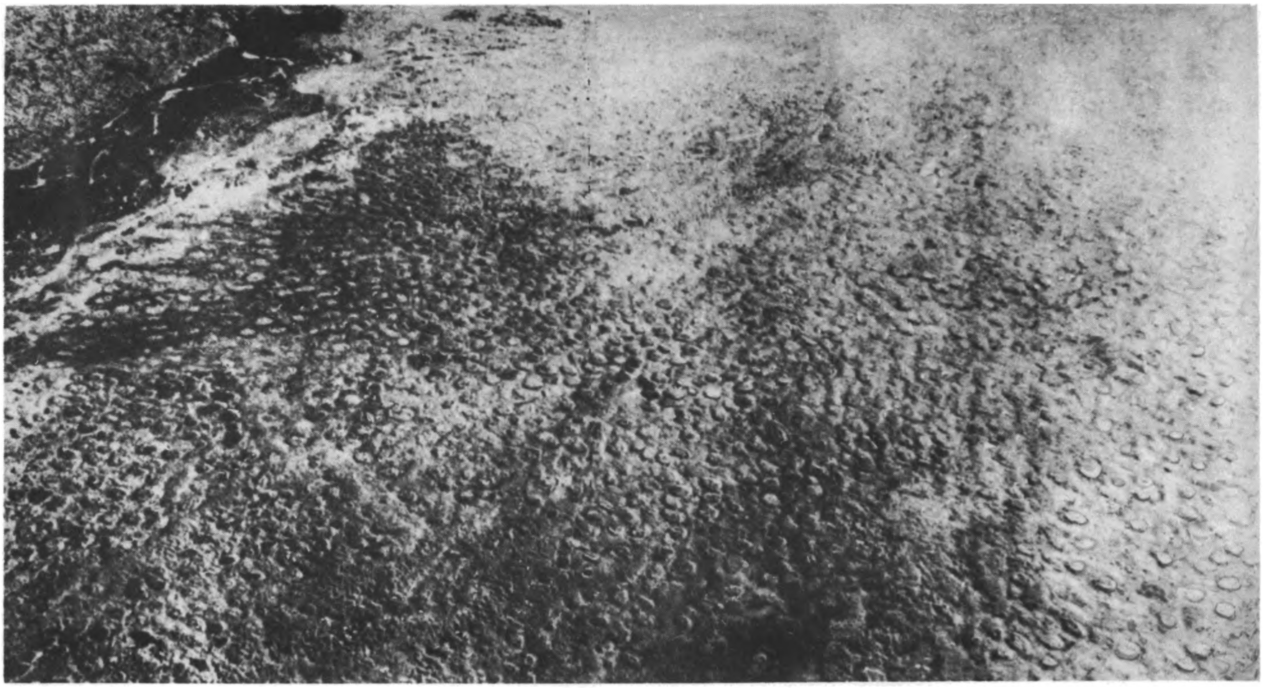


FIGURE 2A5-17

Peat Rings on Valley Slopes (Ref. 28)

TABLE 2A5-4

Analyses of Frozen Black Muck, Cripple Creek District, Fairbanks, Alaska

	Ester	Cripple	Cripple	Cripple	Pedro	Pedro	Fox	Fox	Goldstream Creek area	Goldstream Creek area	Engineer Creek area	Engineer Creek area	Chatanika	Chatanika	Little Eldorado	Little Eldorado
Voids ratio, percent voids	63.9	49.8	55.2	64.3	65.3	59.0	73.2	60.0	82.0	52.7	67.7	66.7	80.8	65.3	57.4	63.2
Mechanical analysis, percent by weight retained on:																
#20	...	...	...	...	...	0.1	...	...	...	0.3	...	...	...	0.1		
#40	...	...	...	...	0.2	0.7	0.1	...	0.3	1.6	0.2	0.1	0.1	0.3	0.1	0.1
#60	0.1	0.1	...	...	1.0	2.1	0.5	0.1	2.1	5.2	0.4	0.2	0.2	0.6	0.2	0.3
#100	0.5	0.3	0.1	0.1	3.2	5.4	1.5	0.3	8.6	13.8	1.3	0.4	0.7	1.2	0.6	0.6
#140	0.9	0.6	0.3	0.4	5.0	7.5	2.6	0.8	12.5	18.4	2.3	0.7	1.0	1.9	1.1	0.9
#200	2.9	2.1	1.3	2.5	8.2	11.4	4.9	3.1	17.5	23.2	5.1	1.9	1.9	4.0	2.8	2.5
0.050 mm	18.5	17.0	15.0	23.4	11.9	17.9	14.9	17.8	35.0	37.7	16.3	14.9	5.6	17.4	11.7	11.9
0.020 mm	66.7	62.4	56.6	57.4	37.9	51.9	56.9	61.9	73.5	73.7	62.0	56.4	29.4	58.3	50.5	47.7
0.006 mm	93.9	92.3	89.6	92.1	83.1	87.6	90.8	91.4	90.3	93.6	92.4	90.7	77.3	90.4	90.5	90.7
0.002 mm	97.7	97.0	95.9	98.4	95.9	96.6	97.9	98.8	98.5	98.8	98.1	96.3	93.4	96.8	97.7	98.0
-0.002 mm	2.3	3.0	4.1	1.6	4.1	3.4	2.1	1.2	1.5	1.2	1.9	1.7	6.6	3.2	2.3	2.0
Moisture (in place) percent	58.8	32.4	40.6	58.5	64.8	51.0	91.5	51.6	150.8	36.9	70.9	68.0	139.0	64.8	45.8	57.2
Specific gravity of grains	2.71	2.75	2.73	2.77	2.61	2.53	2.69	2.71	2.71	2.72	2.65	2.73	2.72	2.61	2.64	2.69

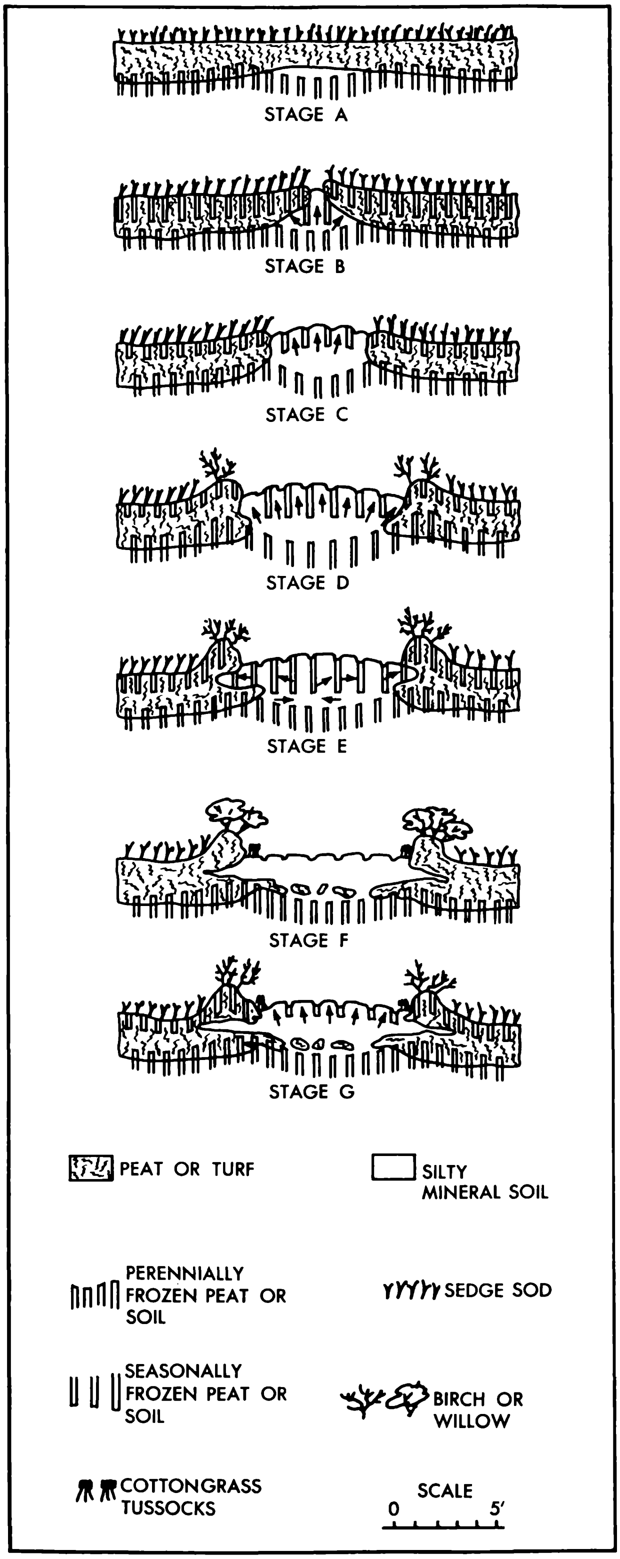


FIGURE 2A5-18

Formation of Peat Ring (Ref. 28)

TABLE 2A5-5

Analyses of Frozen Reddish Muck, Cripple Creek District, Fairbanks, Alaska

	No. 1	No. 2	No. 3
Voids ratio, percent voids	58.0	51.7	
Mechanical analysis, percent by weight retained on			
# 20	...	...	0.1
# 40	...	...	0.2
# 60	0.1	0.1	0.4
#100	0.5	0.3	0.7
#140	1.3	0.5	0.9
#200	2.9	1.7	1.7
0.050 mm	14.5	11.4	11.7
0.020 mm	60.3	44.1	44.3
0.006 mm	92.3	83.3	82.8
0.002 mm	98.2	96.0	95.9
−0.002 mm	1.8	4.0	4.1
Moisture (in-place), percent	45.3	34.7	13.7
Specific gravity of grains	2.76	2.78	2.78

TABLE 2A5-6

Characteristics of Greenish Muck, Cripple Creek District, Fairbanks, Alaska

	Sample 1 (odoriferous)	Sample 2 (no odor)
Apparent cohesion, lb/sq ft	560	600
Angle of internal friction	15° 58′	28° 54′
Voids ratio	0.842	0.666
Percent voids	45.6	40.0
Mechanical analysis, percent by weight retained on		
# 60	0.1	0.1
#100	0.3	0.2
#140	1.0	0.5
#200	3.0	1.6
0.050 mm	30.2	25.2
0.020 mm	66.8	57.0
0.006 mm	82.8	85.9
0.002 mm	90.9	95.2
−0.002 mm	9.1	4.8
Dry base, percent		
Hygroscopic moisture	1.35	0.51
Liquid limit	33.6	27.7
Plastic limit	24.7	23.1
Plastic index	9.0	5.0
Shrinkage limit	22.6	23.1
Shrinkage ratio	1.65	1.62
Moisture (in-place)	32.0	25.1
Specific gravity of grains (2.48 muck organic matter)	2.63	2.65
Permeability, k, cm/day	0.59	0.57

FIGURE 2A5-19

Hummocky Terrain, East Coast of Greenland

cate a faulted zone with moisture migration to the surface (Figure 2A5-22).

(7) Willows are generally restricted to sites near bodies of water on fine or coarse-grained soil, with permafrost in many cases a few yards below the surface.

(8) Scrub and low bushy willows occur in tundra, with permafrost a few feet from the surface.

2A5.12 SOIL

1. GENERAL. In many cases, it is essential that the characteristics of the materials, as shown in Tables 2A5-4, 2A5-5, and 2A5-6, be determined from in-place samples. (See also Figure 2A5-27.) The methods of taking such samples and their proper care are discussed in Section 2A2.

2. EXAMPLE: FAIRBANKS AREA, ALASKA. Figure 2A5-22 illustrates an interesting permafrost area near Fairbanks, Alaska. Before stripping, tree growth in areas A and C consisted of Sitka spruce, which is typical of permafrost areas in many sections of Alaska where the ground surface consists of a moss covering underlain with

FIGURE 2A5-20

Hummocky Terrain Near Fairbanks, Alaska

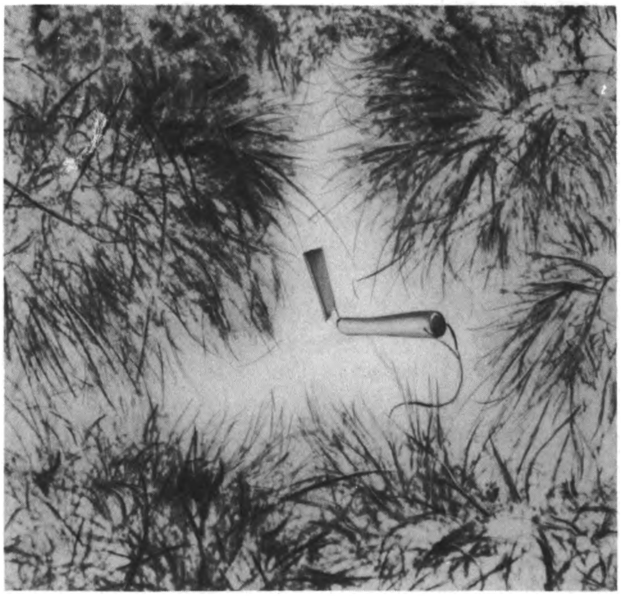


FIGURE 2A5-21

Closeup of Cotton Grass Hummocks (Ref. 28)

frozen muck. The depth of the active layer depends on the disciplines of the area. When there is a black frozen muck (a waterborne deposit) protected by a shallow active layer, trees will readily be overturned because of the absence of taproots. Several observations in the area suggested the existence of localized ground water and, when taken together, the presence of a fault zone. (Drilling and other further studies confirmed these observations.)

Some lighter colored trees (poplar, birch, and willow), shown by B in Figure 2A5-22, indicate a region where the migration of ground water from bedrock up through a fault zone could be expected. (Bedrock was later found to be about 300 ft below the surface in this region.) In the foreground of the picture, where adequate drainage existed, there were mostly poplars with some birch.

Investigation revealed that animal trails led to salt licks among the trees located at B. These salt

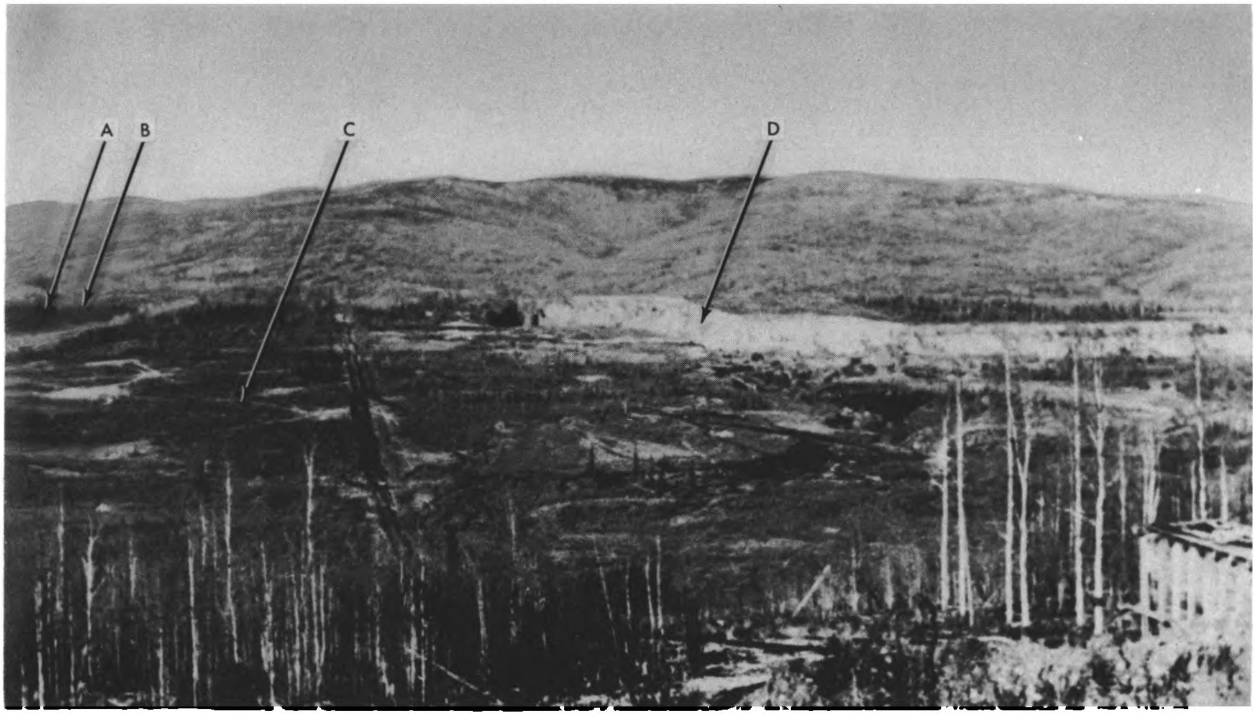


FIGURE 2A5-22

Permafrost Area, Cripple Creek District, Fairbanks, Alaska

FIGURE 2A5-23

Thawed Holes in Frozen Surface of Small Lake Near Fairbanks, Alaska

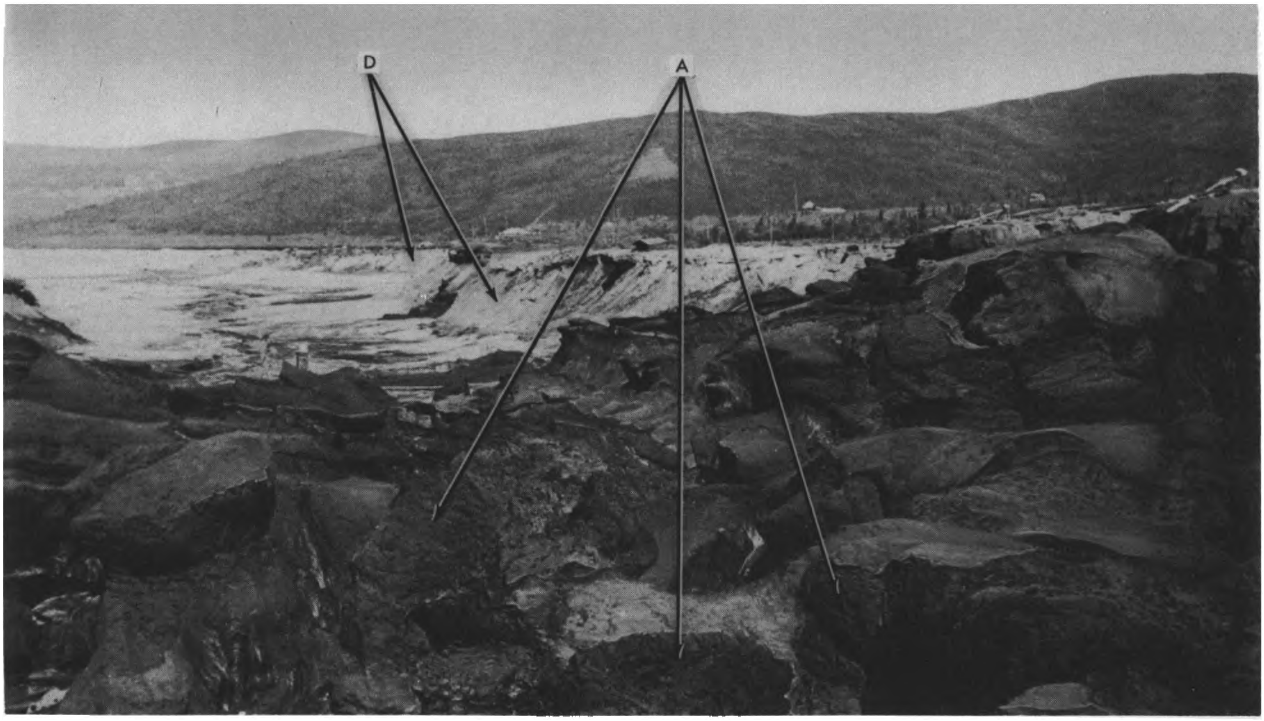


FIGURE 2A5-24

Black and Reddish Mucks Near Fairbanks, Alaska

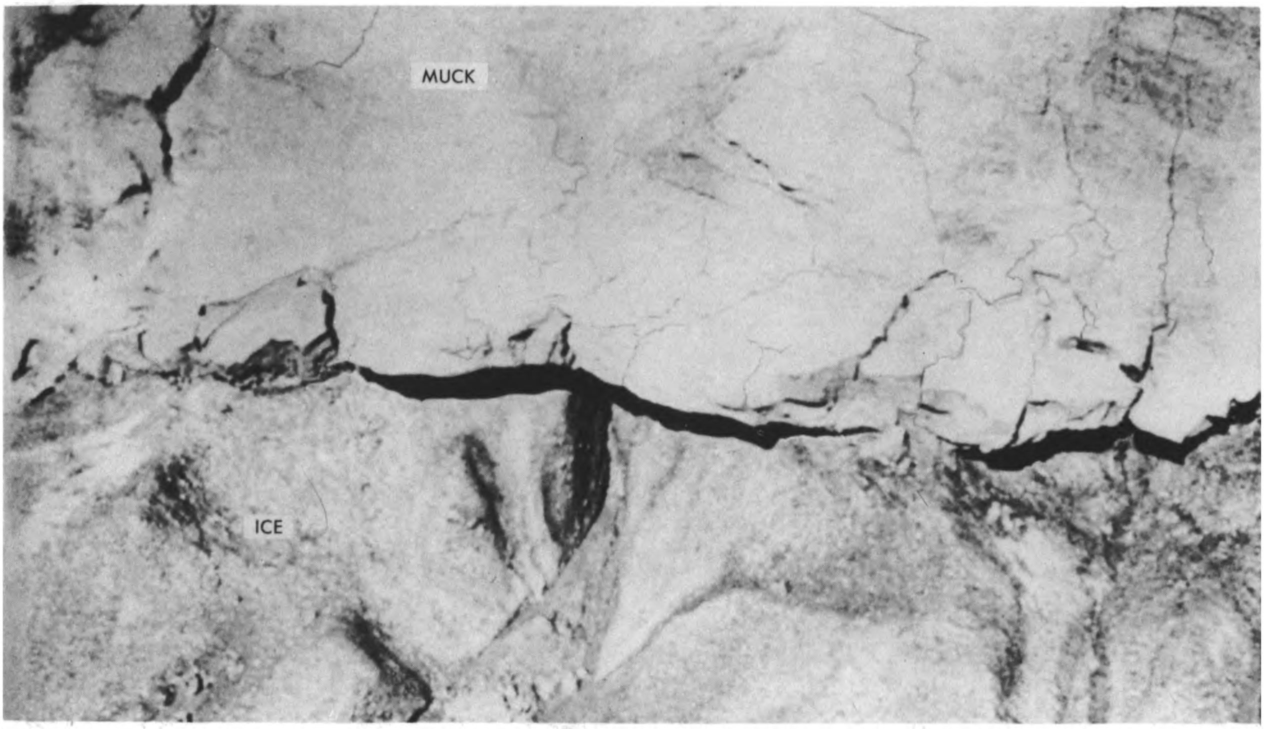


FIGURE 2A5-25

Black Muck With Ice Lenses Near Fairbanks, Alaska

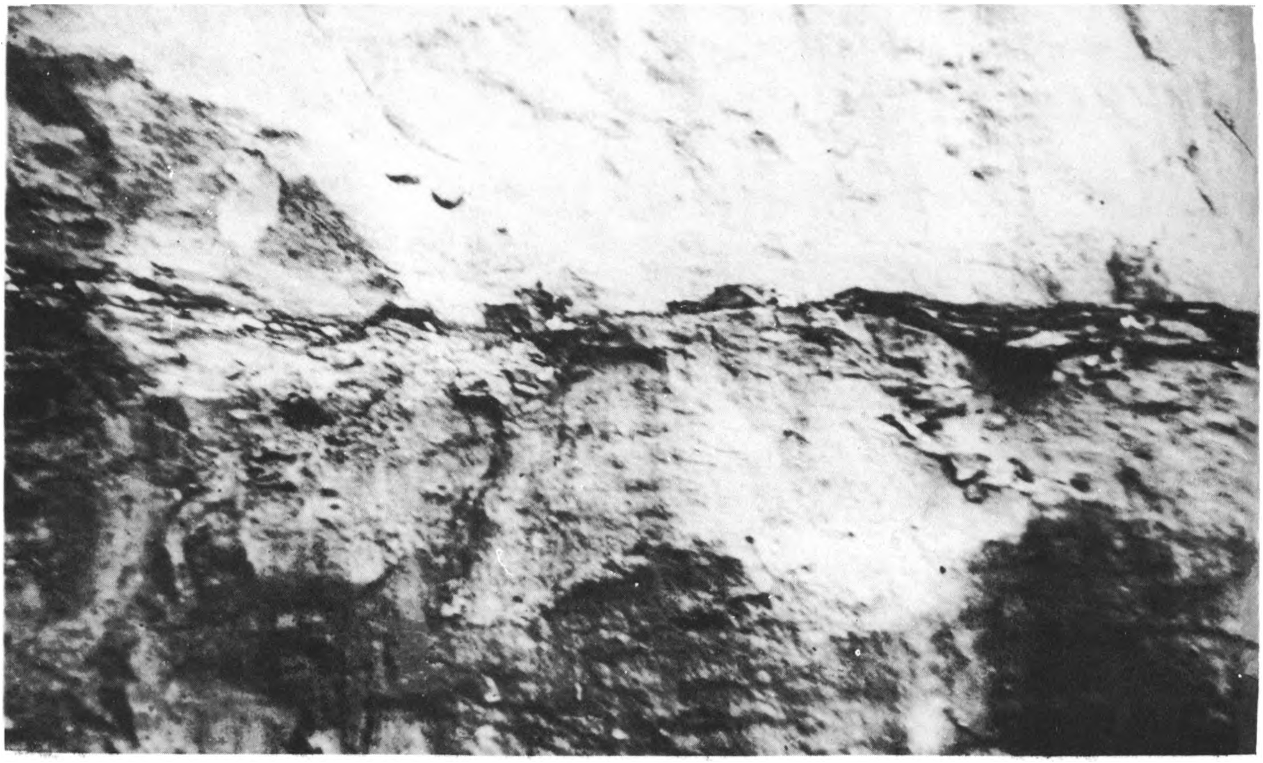


FIGURE 2A5-26

Reddish Muck With Band of Volcanic Ash Near Fairbanks, Alaska

licks also indicated that there may have been an upward ground-water movement.

In a number of cases throughout the area, 6-in. casings driven through gravel to bedrock produced artesian flows of warm water containing methane gas. It was also observed that during cold weather methane gas was discharged through open holes in the surface of one of the lakes in the area (Figure 2A5-23), but all of the other small lakes in the area were frozen solid. These observations taken together led to the conclusion that the lake was located on a fault zone and that the holes in the lake were probably the result of warm water migrating upward through the fault zone from joints in the bedrock, or the result of water moving on the contact between the bedrock and the superimposed materials.

Drill cores and excavations showed the presence of two general types of muck in the area: (a) a black muck indicated by A and C in Figure 2A5-22 and A in Figure 2A5-24, and (b) a reddish muck indicated by D in the same figures.

Both black and reddish mucks were permanently frozen. The waterborne black muck contained clear ice lenses, as illustrated in Figures 2A5-1 and 2A5-25. The depth of this muck varied from a few feet to over 200 ft. The reddish muck was windblown and contained no ice lenses, but did contain two bands of volcanic ash, one of which is shown in Figure 2A5-26. The average depth of the reddish muck was 120 ft. Underneath was a greenish muck, which in most cases was thawed. Tables 2A5-4 and 2A5-5 show the analyses of the black and reddish mucks. Table 2A5-6 shows some of the characteristics of the greenish muck.

The gravel between the muck and the bedrock was thawed. This thawed condition resulted from an upward movement of relatively warm water, under hydrostatic head, from the bedrock contact and/or joints in the bedrock. The gravel was stratified, having two bands of clay. The graphs shown for Wells 1, 2, 3, 4, 12, 15, and 18 (Figure 2A5-27) are representative of the gravel below the reddish, green, and/or black muck in the Cripple Creek district. (See Figure 2A5-22.) Figure 2A5-27 indicates the mechanical analysis of the gravel in the Fairbanks area.

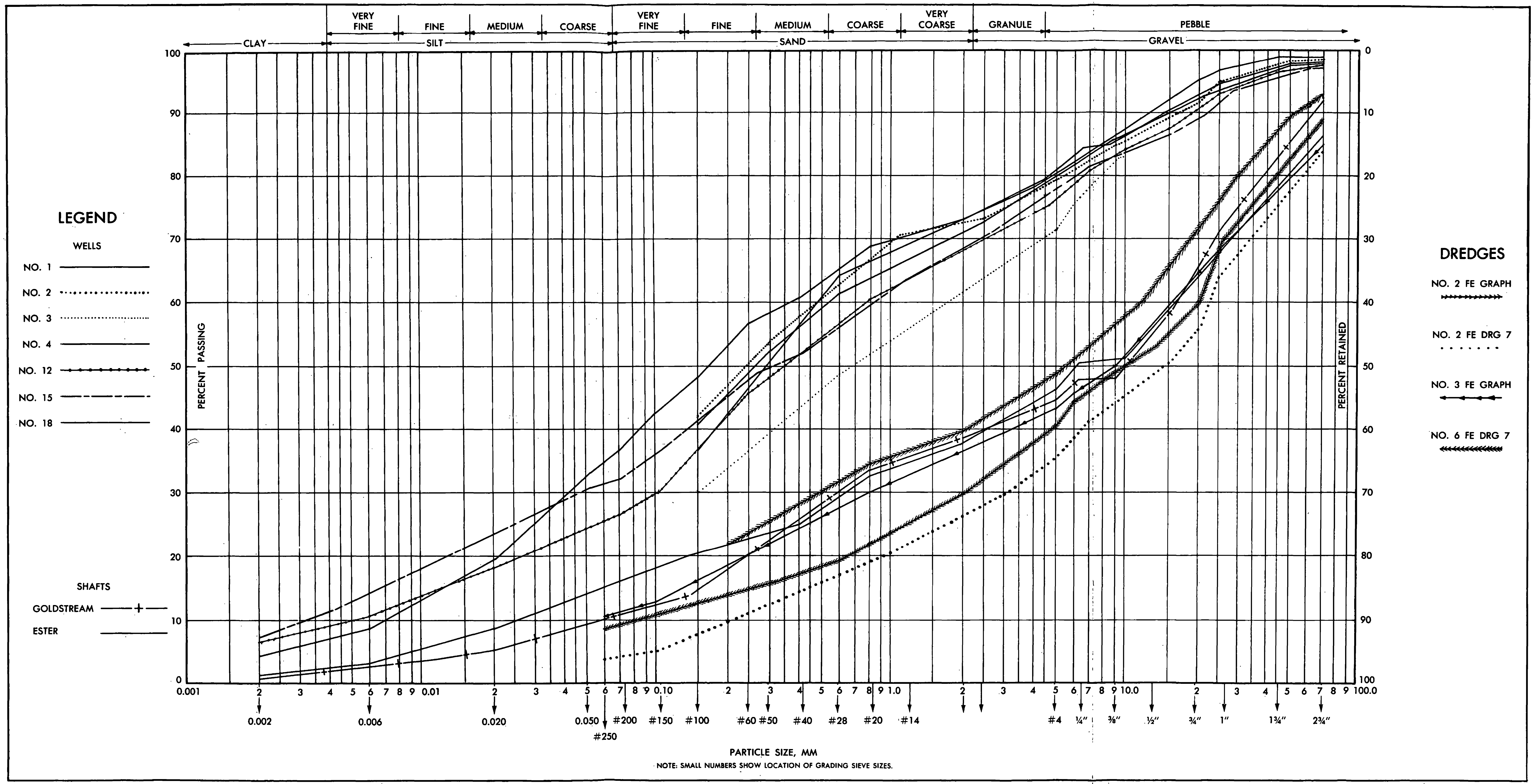


FIGURE 2A5-27

Mechanical Analysis of Gravel in Fairbanks Area, Alaska

2A6.01 GENERAL CRITERIA

Foundations in the Cold Regions must fulfill all requirements of foundations for a similar purpose in the Temperate Zone. In addition, full consideration must be given to the disciplines in the area and to the thermal regime determined by these disciplines. A consideration of these disciplines will indicate the effect of the construction on the thermal regime. The proper design of foundations in permafrost areas must make practicable the maintenance of the thermal regime in the area during the life of the structure, except that the thermal regime may be locally altered during construction if adequate provision can be made for its reestablishment.

The principal factors that may cause an alteration in the thermal regime are the following.

(1) Change in the surface and/or subsurface flow of water. (See Sections 2A5 and 2A7.)

(2) Change in the cover.

(3) Change in the heat sinks or heat sources present in the area.

(4) Change in packing of the materials.

Figure 2A6-1 indicates the effect on the permafrost table of piling coarse gravel and rocks on the ground surface in a permafrost area. Figures 2A6-2 and 2A6-3 illustrate the effect of heated and unheated structures on a permafrost table. This effect may be materially modified by the movement of ground water.

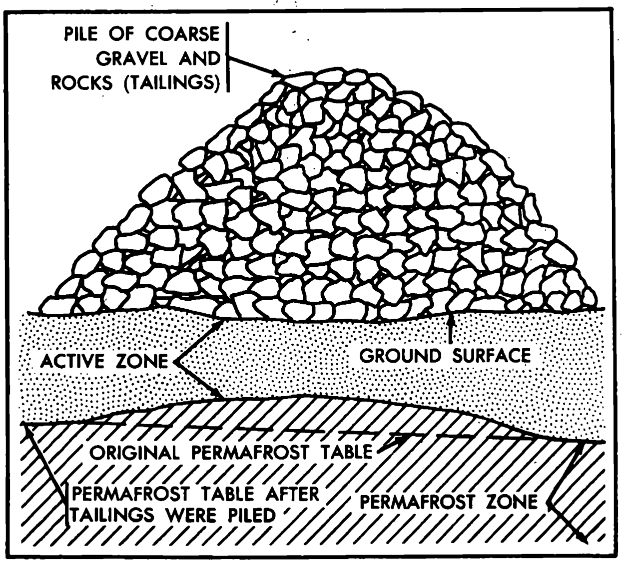


FIGURE 2A6-1

Aggradation of Permafrost Under Tailings Pile Near Fairbanks, Alaska

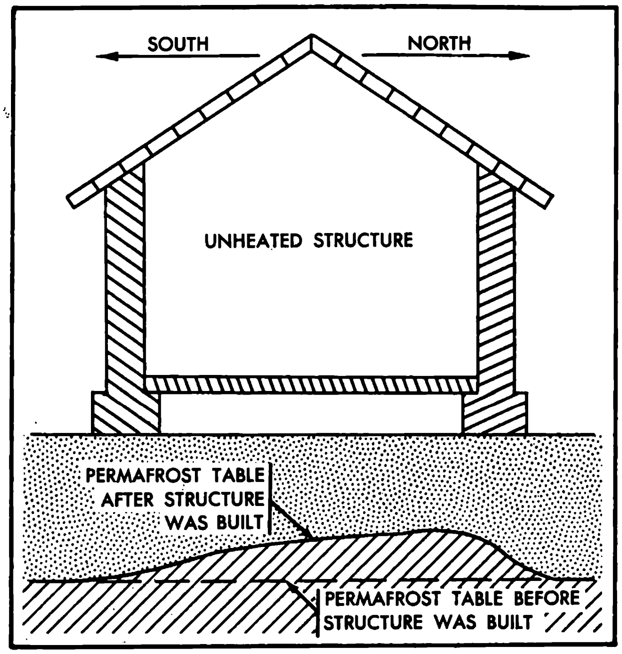


FIGURE 2A6-2

Aggradation of Permafrost Under Unheated Structure

2A6.02 METHODS OF CONSTRUCTION IN PERMAFROST AREAS

There are two general methods of construction in permafrost areas—active and passive. Where the active method of construction is used, some of the permafrost may be eliminated because it is not used for its structural value. Where the passive method is used, sufficient permafrost is preserved to be used for maximum structural value. In some instances this structural value has been increased by refrigeration. (See Section 2A8.) NOTE: These definitions of active and passive construction differ somewhat from those used by certain other authors. The proper development of a project may indicate the advisability of using both methods in the same area. For example, it may be advisable to use the active method for light construction such as temporary barracks, but it is usually more advantageous to use the passive method for the founda-

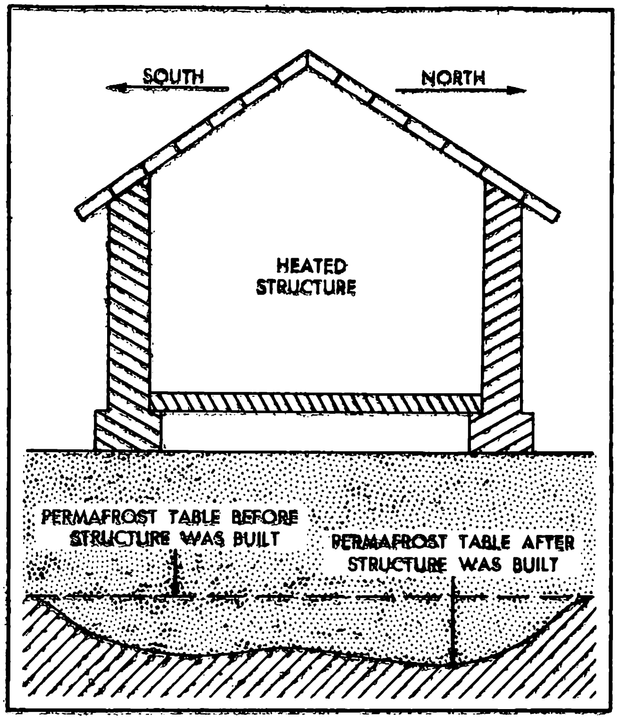


FIGURE 2A6-3

Degradation of Permafrost Under Same Structure When Heated

tions of heavy structures such as large hangars, warehouses, powerplants, and so on.

1. ACTIVE CONSTRUCTION.

a. *General.* This type of construction is used on taliks and has many features common to construction in the Temperate Zone. Taliks are usually in more open packing than similar materials in the North Temperate Zone; therefore, it is recommended that, in most cases, the bearing power of the materials in place be carefully studied. In order that a safe practical bearing value may be determined, such studies should include investigations regarding the deformation or the settlement resulting from repetition of load. (See par. 2A9.02.) An analysis should be made to determine whether or not the materials will be sufficiently consolidated by the proposed development to cause aggradation of the permafrost. Such consolidation may change the movement of ground water in the immediate vicinity of the foundation, which may result in icing or the development of additional uplifting forces.

b. *Flotation.* Many taliks are subjected to seasonal and cyclic changes of the ground water and may at times be entirely submerged. Because seasonal changes in ground water in permafrost areas are much more frequent and less evident than in the Temperate Zone, it is important that consideration be given to the hydraulic uplift pressure to which the structure may be subjected, especially during construction when the foundations may not be sufficiently loaded to prevent flotation. During the construction of two powerplants in the Fairbanks region, provision was made for flooding the basements to prevent flotation in the event that high water made this necessary. Electrical equipment was not placed in the basements until vulnerability to flotation was eliminated.

c. *Stress Distribution.* On large foundations of the slab type, even though the loads are uniformly distributed over the area of a homogeneous mass, the stress distribution in the supporting materials will not be uniform. The tendency for settlement or compaction will be greater at the center than at the perimeter, and weaker soils, even at considerable depths below the footing, may be affected by the load distributions developed in the materials immediately above them. This is particularly important in taliks because of the usual open packing and because of the possibility of permafrost aggradation when packing is changed. Any direct load and settlement tests made on a talik material, in or near the surface that is to be loaded, are only indicators of the probable bearing value to a few feet in depth. These indicators must be carefully interpreted in terms of the characteristics and the packing of the existing materials in place, the disciplines to which these materials are subjected, and the size, character, and importance of the structure to be supported.

d. *Load Distribution.* Loads on foundations that are supported on taliks should preferably be so arranged that the center of gravity of all loads (live and dead) will coincide, as nearly as possible, with the center of gravity of the foundation. The slab should be constructed so that the loads will be uniformly distributed to the supporting materials in terms of their expected deformation under load. Where it is impracticable by arrangement of the load to reduce as much as desired the moment arm between the centers of gravity of the loads and their supporting area, it may be advisable to extend the foundation as indicated in Figure 2A6-4, where ABCD represents the area of the slab required to support and transmit the total load (both live and dead) to the foundation materials. The center of gravity of the area ABCD is indicated by E, and the center of gravity of all loads to be supported on the slab ABCD is indicated by F. In this case an extension, BGHC, was constructed. This extension and the fill materials above it did not reduce the moment arm the desired amount; therefore, a plane of weakness was incorporated in the slab design, indicated by IJ. Each section of the slab, that is, AIJD and IGHJ, was designed so that if there were settlement, each section would settle uniformly and independently of the other because the loads on each resulted in equal distribution, in terms of deformation, of the materials supporting each section of the slab.

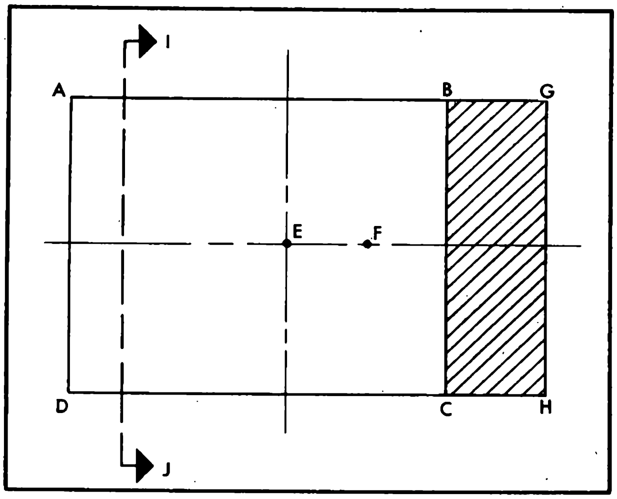


FIGURE 2A6-4

Slab Foundation Plan Showing Plane of Weakness

2. PASSIVE CONSTRUCTION. The maintenance of the thermal regime, as emphasized in par. 2A6.01, is particularly important where passive construction is used. In general, during construction, or as a result of construction, some of the factors determining the thermal regime will be altered. For example, construction usually results in some change in cover because of increased compaction or removal of cover. There may also be compaction of the materials below the cover. Such factors as changes in compaction, interruption of water channels, or the establishment of new channels because of blasting and other operations may change the flow of water. Also, any heated structure acts, of course, as a heat source. Because there are almost always some changes of the type outlined above, it is almost always necessary to take special precautions where passive construction is used, to assure that the thermal regime is not permanently altered or temporarily altered in an irreparable way. Five examples follow.

Example 1

Figure 2A6-5a illustrates a permafrost terrain before construction. Figure 2A6-5b illustrates a type of foundation successfully used on such terrains when reasonably good drainage and materials of relatively open packing are available. Before adopting this type of foundation for passive construction, a very careful study of the subsurface drainage and ground-water conditions existent in the area is recommended.

Sections at MM and OO in Figures 2A6-5a and 2A6-5b are assumed to be representative of conditions before the surface was disturbed. These sections consist of moss-covered vegetation plus active-zone materials. T is the hydraulic channel that must be maintained for drainage other than surface flow. The insulating and hydraulic properties of any sections such as AB and CD in Figure 2A6-5b must be equal to or greater than these properties at MM and OO in Figures 2A6-5a and 2A6-5b. It will be noted that because of the increased rise in permafrost under the structure as shown at D (Figure 2A6-5b), the water moving downhill will back up, as indicated; the thermal diffusivity at sections such as GH is therefore changed from that at MM (Figure 2A6-5a). The development of sufficient hydrostatic head may cause overflow (Section 2A7), or the change in thermal diffusivity may cause a change in the permafrost level at G. To avoid either of these, the apron or insulating materials on the surface should be extended beyond the point H so that the thermal and hydraulic properties will be the same as at MM and OO.

Example 2

If the structure shown in Figure 2A6-5b is such, or is so constructed, that it will supply heat to the supporting materials in sufficient quantity to destroy, over a period of time, the supporting permafrost, and if the estimated life of the structure is sufficiently long so that serious damage or undue settlement would result, then provision must be

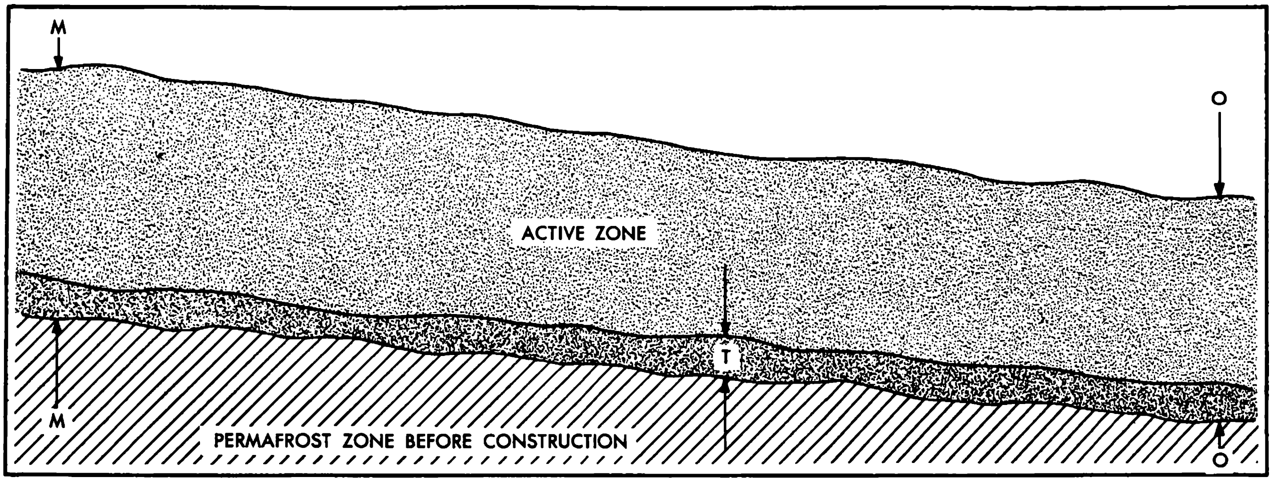


FIGURE 2A6-5a

Section in Equilibrium Under Area Disciplines

made to dissipate the heat from the structure. This has been accomplished in many ways, one of which is to insert pipes in the supporting materials through which air may be thermally or artificially circulated in sufficient quantity to dissipate the excess heat (Figure 2A6-6). When conductor pipes are installed as shown, consideration should be given to providing for their drainage if there is a tendency for water to accumulate in the pipes during periods of high water or from other sources.

Example 3

Figure 2A6-7 is adapted from Department of the Army Technical Bulletin 5-255-3 with a few

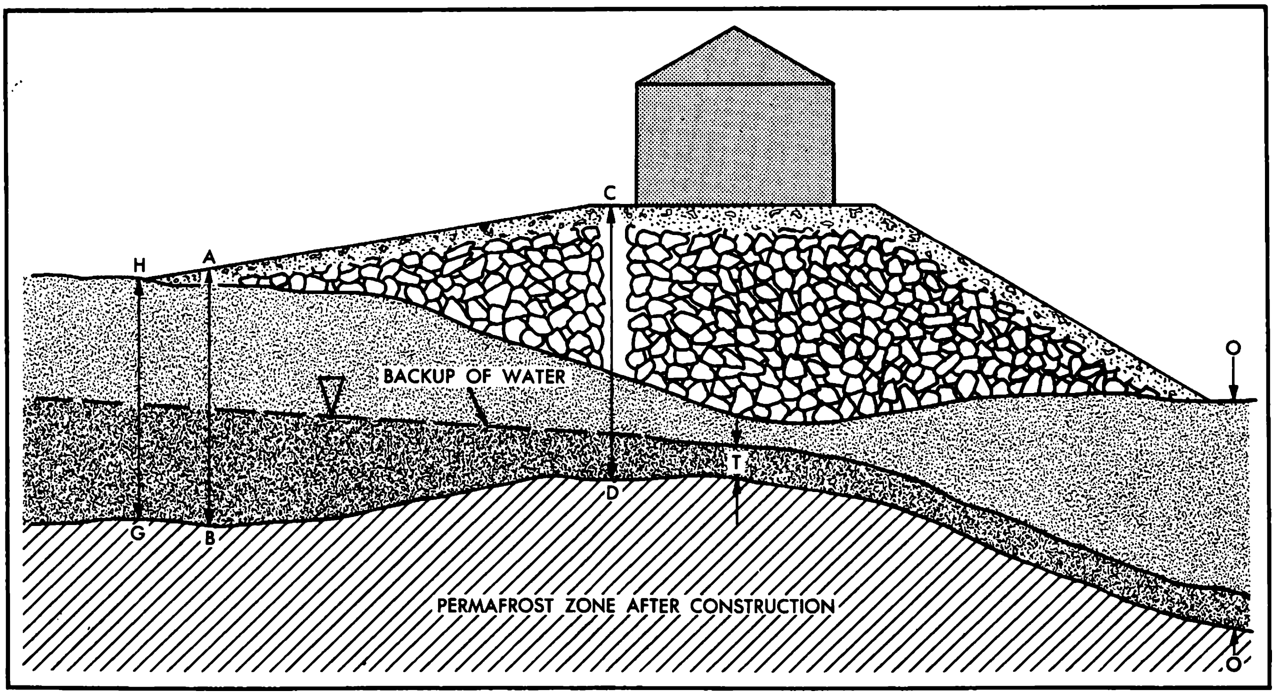


FIGURE 2A6-5b

Foundation Design To Maintain Equilibrium Shown in Figure 2A6-5a

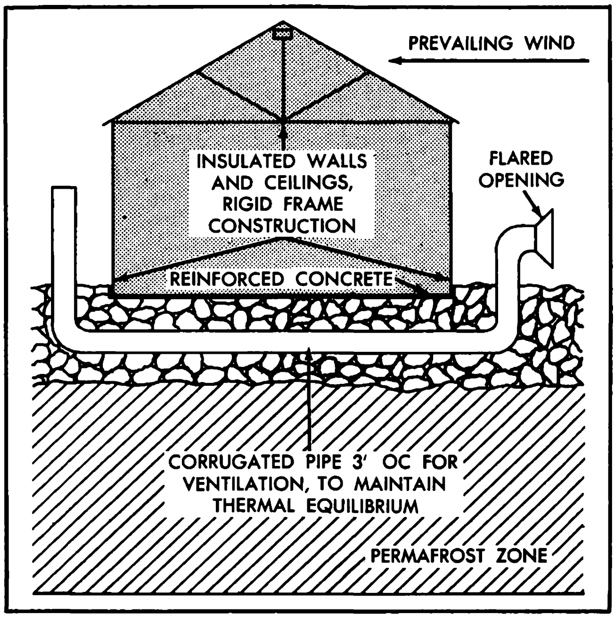


FIGURE 2A6-6

Corrugated Pipe for Ventilation To Maintain Thermal Equilibrium (Ref. 29)

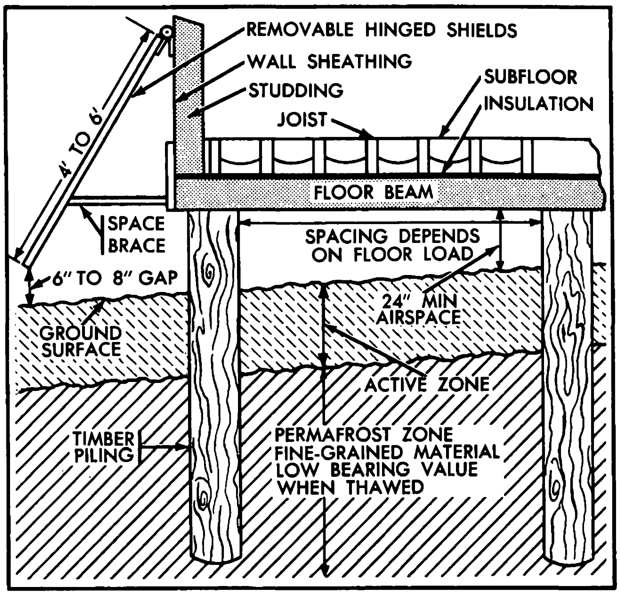


FIGURE 2A6-7

Typical Design of Structures To Maintain Permafrost by Insulation and Ventilation

modifications. (Ref. 29.) In this case an airspace is provided between the floor and the active zone so that excessive heat from the structure may be dissipated.

Example 4

Many satisfactory foundations in permafrost areas have been constructed by preparing a subbase for the foundations on nonswelling granular materials supported on permafrost. The critical size for such materials is covered in Table 2A6-1. This type of subfoundation construction is usually accomplished by laying out an area somewhat larger than that required for the foundation of the structure. All active-zone materials within this area are then removed, the excavation being carried into the permafrost. Backfilling with coarse-grained nonswelling materials should rapidly follow the excavation. If the excavation is made during the warmer months, the backfill should be placed and compacted in a manner that will result in a minimum amount of thawing of the exposed permafrost.

This method of providing a good foundation is excellent, provided the design is such that the thermal regime of the supporting and confining permafrost will not be unduly disturbed in the future. In the design and construction of this type of foundation, attention is specifically directed to Figure 2A6-6 and to Section 2A8.

Example 5

Figure 2A6-8 illustrates a footing in permafrost when the passive method of construction is used. Factors to be noted in the footing are as follows.

(1) Frost batter, B.

(2) Precast concrete slab, wood mat, or gravel fill, A, to provide for dissipation of heat (heat of hydration) during the curing period of the concrete pier or wall.

(3) Sand and gravel backfill around footing to assist in minimizing any possible uplifting force caused by freezing of materials around footing.

(4) Airspace to dissipate heat from the structure and assist the disciplines of the area in maintenance of the permafrost.

(5) Clay fill to provide proper drainage and divert surface water from footings.

(6) Louvers, C, to provide ventilation of airspace.

Several other examples of both active and passive construction are given in Section 2E1.

CAUTION: Whenever permafrost is used for its structural worth, provision must be made so that

TABLE 2A6-1

Limits Between Frost-Heaving and Nonfrost-Heaving Soil (Data from Gunnar Beskow, Soil Freezing and Frost Heaving With Special Application to Roads and Airfields) (Ref. 30)

Soil group	Soil formation	Average diameter, mm	Percent passing through		Capillarity, K_F, meters	Hygroscopicity value, W_h
			0.062-m sieve	0.125-m sieve		
Nonfrost-heaving under any circumstance	Sediment Moraine	0.1 ...	<30 <15	<55 <22	<1 <1	
Frost-heaving only at surface and for very high ground water	Sediment Moraine	0.1 to 0.07 ...	30 to 50	...	1 to 1¾	
Same, except affects whole road base for very high ground water	Sediment Moraine	0.08 to 0.05 ...	15 to 25	22 to 36	1¼ to 2½	
Normally frost-heaving and liable to frost boils for ground water	Sediment (1½-m depths) Moraine (1-m depth)	<0.05	>50 >25	2 to 20 >36	... 2 to 20	<5 1 to 4
Frost-heaving clay but not liable to boils	Sediment	...	...	...	20 and above	5 to 10 (probable)
Nonfrost-heaving stiff clay	Sediment	...	...	...	Unknown	10 (probable)

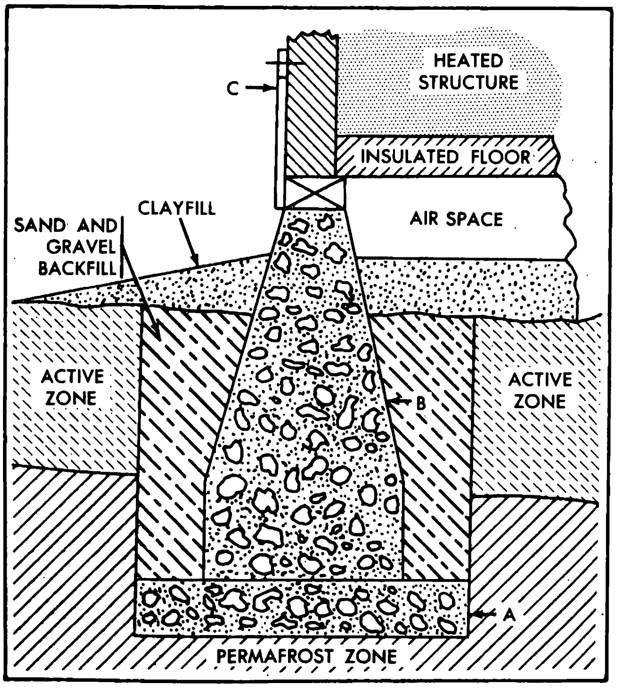


FIGURE 2A6-8

Foundation Section Used in Permafrost Area (Passive Method)

during the life of the structure the materials comprising the permafrost will be maintained as permafrost unless the materials are such that in a thawed state they would also be structurally satisfactory. (A frozen bedrock or a tightly compacted and uniformly frozen gravel, with no excess of frozen water in the voids, would have approximately the same structural values in both the frozen and thawed states.)

2A6.03 FROST BATTERS

Frost batters are useful in foundation construction to help overcome the effect of the forces caused by the increase in volume from freezing of certain materials in the active zone. The use of these batters is illustrated in Figure 2A6-9. An empirical batter of 1 ft to 3 in. is recommended, although a batter of 1 ft to 2 in. has been successfully used.

2A6.04 DRAINAGE

Drainage and subdrainage, including the use of French drains, are discussed in detail in Section 2A7.

2A6.05 PILES AND PILING

1. TYPES. Piles used in permafrost areas may be wood (treated or untreated), steel (hollow or

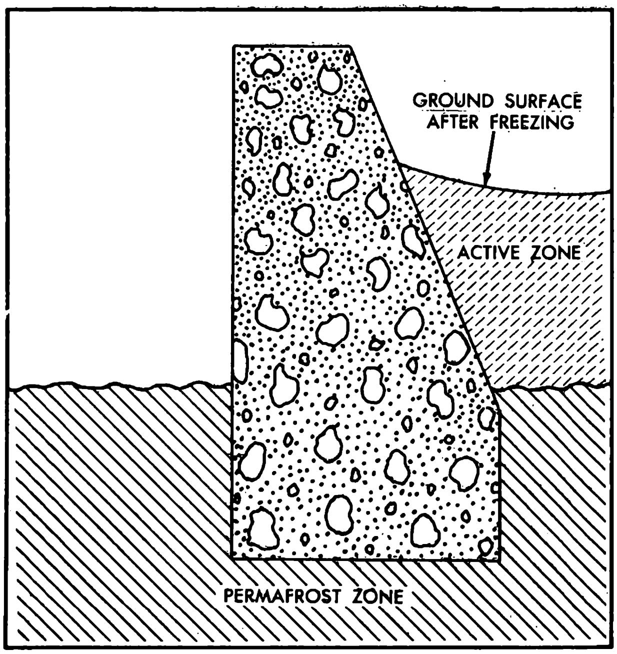


FIGURE 2A6-9

Frost Batter

structural shapes), or precast concrete. Under suitable conditions and disciplines, materials in place may be frozen and used as piling for the transfer of loads through an active zone to undisturbed permafrost.

2. PLACING PRECAUTIONS. Piles used in permafrost areas where taliks (par. 1 of 2A6.02) are present may be driven or even jetted, although jetting is not recommended except in situations where the disciplines in the area affecting the piles are similar to those of the Temperate Zone. For example, it may be advisable to use jets to assist in placing piles where they pass through a confined quicksand to a firm support below the quicksand.

a. *Jetting*. Wherever jetting is resorted to, the return water from the operation should be carefully watched. If there is any indication that the water is not coming to the surface as anticipated, an investigation should be made to determine whether or not a channel is developing that will permit the future movement of ground water. Such a change in the ground-water movement may result in a change in the local thermal regime of the area and should be carefully evaluated.

When jetting is used, provision should be made so that openings in the piling, if any, can not become filled with water that might freeze and cause rupture of the pile.

b. *Driving in Taliks*. When piles are driven in taliks, the compaction resulting from the driving reduces the permeability and may change the ground-water movement; consequently, there may be subsequent changes in the local thermal regime of the area that will cause aggradation of the permafrost.

c. *Driving in Dry Permafrost*. Piles, especially metal piling, may sometimes be driven into dry permafrost. (See par. 3 of 2A6.05, with reference to the safe bearing loads for such piling.)

d. *Setting Piles*. When piles are used in permafrost, they are usually set in holes previously prepared in the permafrost. The holes may be drilled, excavated by hand, or prepared by thawing the permafrost with steam or using some other suitable method. (See par. 3C1.02.) The pilings are frequently set in the colder months of the year, and the insulating covering to the permafrost is not replaced until the materials surrounding the piles have had an opportunity to backfreeze in place.

When this method of setting piles in permafrost is used, consideration may be given to placing the piling, if wood, butt down.

e. *Effect of Water*. When piles are set or placed in permafrost, consideration must be given to the possibility of surface or subsurface water finding its way to the piling and down along the contact between the piling and the surrounding materials. This water may cause a breaking of the bond developed through adfreeze, as indicated in Figure 2A6-10, where the movement of water is indicated by the arrows A and/or B. The movement of surface water is represented by A, and the movement of water from within the active zone or at the contact between the active zone and the permafrost by B. Water migrating to the base of the pile may freeze in successive layers, as indicated at C, causing uplift, or it may thaw some of the materials supporting the pile, permitting subsidence.

f. *Pile Spacing*. In taliks and where the permafrost has been thawed and remains thawed, pile lengths and spacings should be the same as in the more temperate zones for similar loads, materials, and conditions of packing. In permafrost, however, a slightly different problem is presented. The pile transfers its load to the permafrost as an

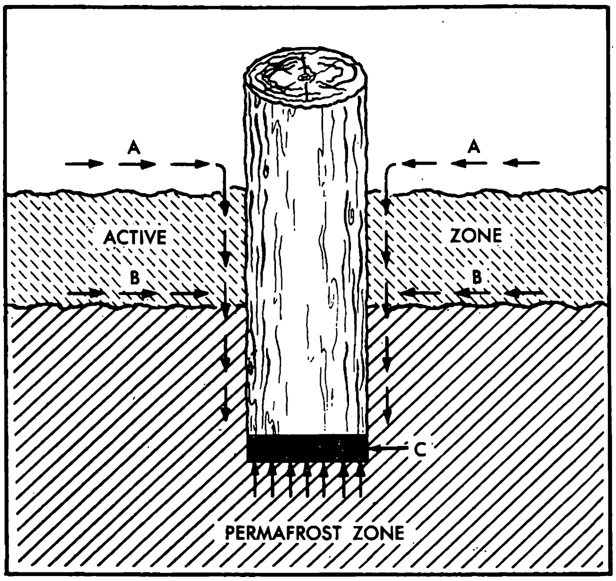


FIGURE 2A6-10

Water Movement Around Pile in Permafrost Area

end-bearing pile aided by adfreeze. Little is known regarding the value of adfreeze in its ability over a period of time to help and continue to help distribute the load from a pile or group of piles. (See par. 2 of 2A9.02.)

The minimum spacing of the piles should be such as to distribute the load adequately to strata of permanently frozen materials capable of resisting such stresses without undue settlement or displacement. Where the permafrost consists of stratified materials of varying packing and ice content, care should be exercised so that piles are a sufficient length to distribute the load most advantageously to the materials most capable of resisting the load. In this connection a permanently frozen, granular material in close packing, and with a saturation not exceeding 100 percent, would probably distribute the stress in a manner somewhat similar to a mild sandstone, but the stress distribution of a material with an ice saturation greater than 100 percent would approach that of pure ice.

CAUTION: As illustrated in Figure 2A5-16, perched taliks are usually present at shore and offshore installations in permafrost areas. Where this condition exists, it is, of course, important that the stress distribution within the soil from any load-bearing pile or group of piles is not unduly affected by the contact between the frozen and unfrozen materials.

3. BEARING POWER. In some permafrost areas the safe load for a pile is the safe load developed because of the penetration into thawed materials, supplemented by the support that the materials may receive because of their proximity to permafrost. Such a safe load, however, may not be the load that should be used in designs where piles are supported only by permafrost or are driven in taliks with no permafrost support. (See par. 1 of 2A9.02.)

The load sustained by the permafrost and the thawed materials varies with their respective deformations, and the total sustaining power is not the summation of the two when each acts independently, because the deformations ultimately resulting from the load vary with the character of the supporting materials.

The bearing power of the piles in some instances may be increased by improving or extending the adfreeze. (See par. 1 of 2A9.02.)

The energy-delivered method for evaluating the safe load for pilings in thawed areas (Ref. 10, p. 497) may be used to determine the safe load for pilings in taliks. However, as soon as aggradation takes place or permafrost develops near the piling, the energy-delivered method of judging the safe load on the piling can no longer be used.

The energy-delivered method of evaluating safe loads may be used and relied upon for piling driven into dry permafrost only in the very special case where there is no change whatever in the permafrost and the contact between the piling and the materials into which the piling is driven. (See par. 2 of 2A9.02.)

As shown in Figure 2D2-6, ground water has a tendency to migrate along the contact surfaces of different materials. Any such migration on the contact between the piling and the dry permafrost would probably, over a period of time, destroy the indicated load-bearing value of the piles.

4. CONCRETE PILES. Wherever reinforced concrete piles are used in the Cold Regions, provisions should be made (especially in the zone of the active layer and above the ground surface) for the concrete to be of such a nature that moisture will not penetrate in sufficient quantities to cause spalling of the concrete by freezing of the moisture or rusting of the reinforcing steel. (See Chapter 3, Part E.)

5. UPLIFT. Consideration must be given to the uplift of piling from the forces developed by the freezing of all or part of the active layer. In Figure 2A6-11, the original ground surface is represented by A. The pressure caused by freezing of the whole or a portion of the active zone may resolve itself into a vertical and horizontal force; the resultant of these two forces is represented by R, the vertical component tending to cause uplift of the pile. The following methods to avoid such uplifts have been used.

The pile shown in Figure 2A6-12 has sufficient

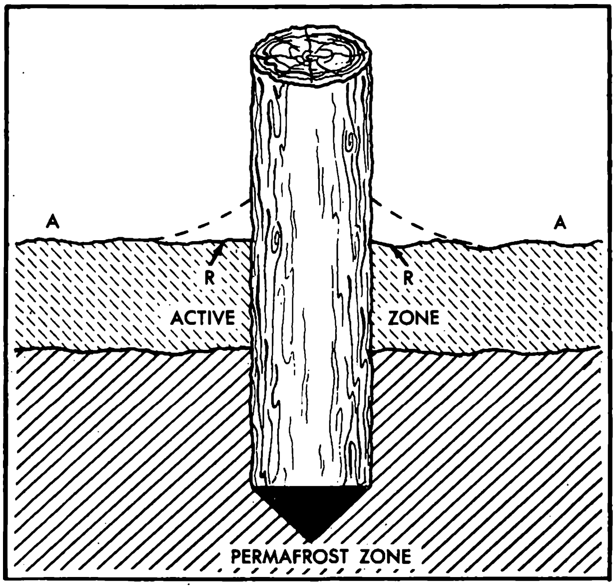


FIGURE 2A6-11

Uplift Force on Pile From Freezing of Active Zone

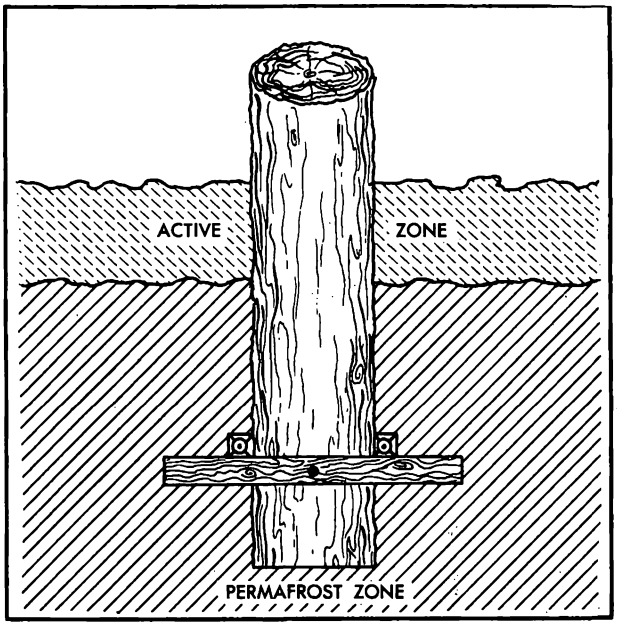


FIGURE 2A6-13

Anchor Pile Used in Permafrost Zone

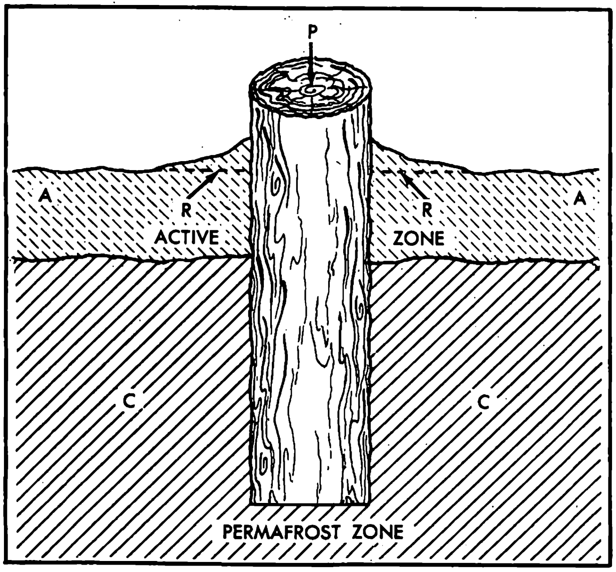


FIGURE 2A6-12

Pile in Equilibrium Under Action of Forces

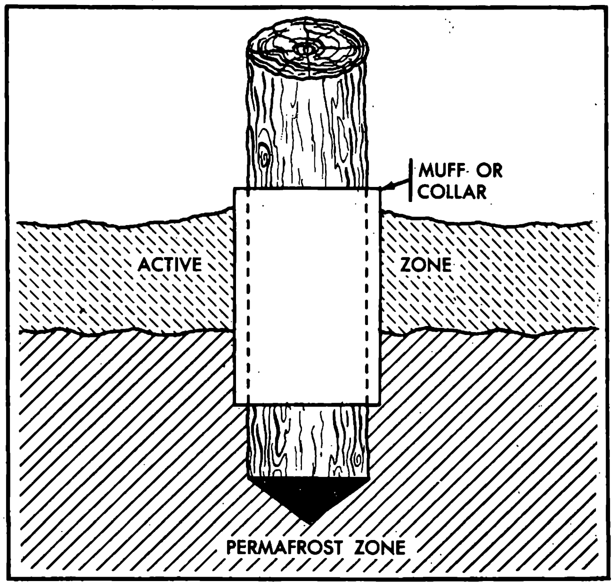


FIGURE 2A6-14

Piles Showing Collar or Muff To Minimize Uplift

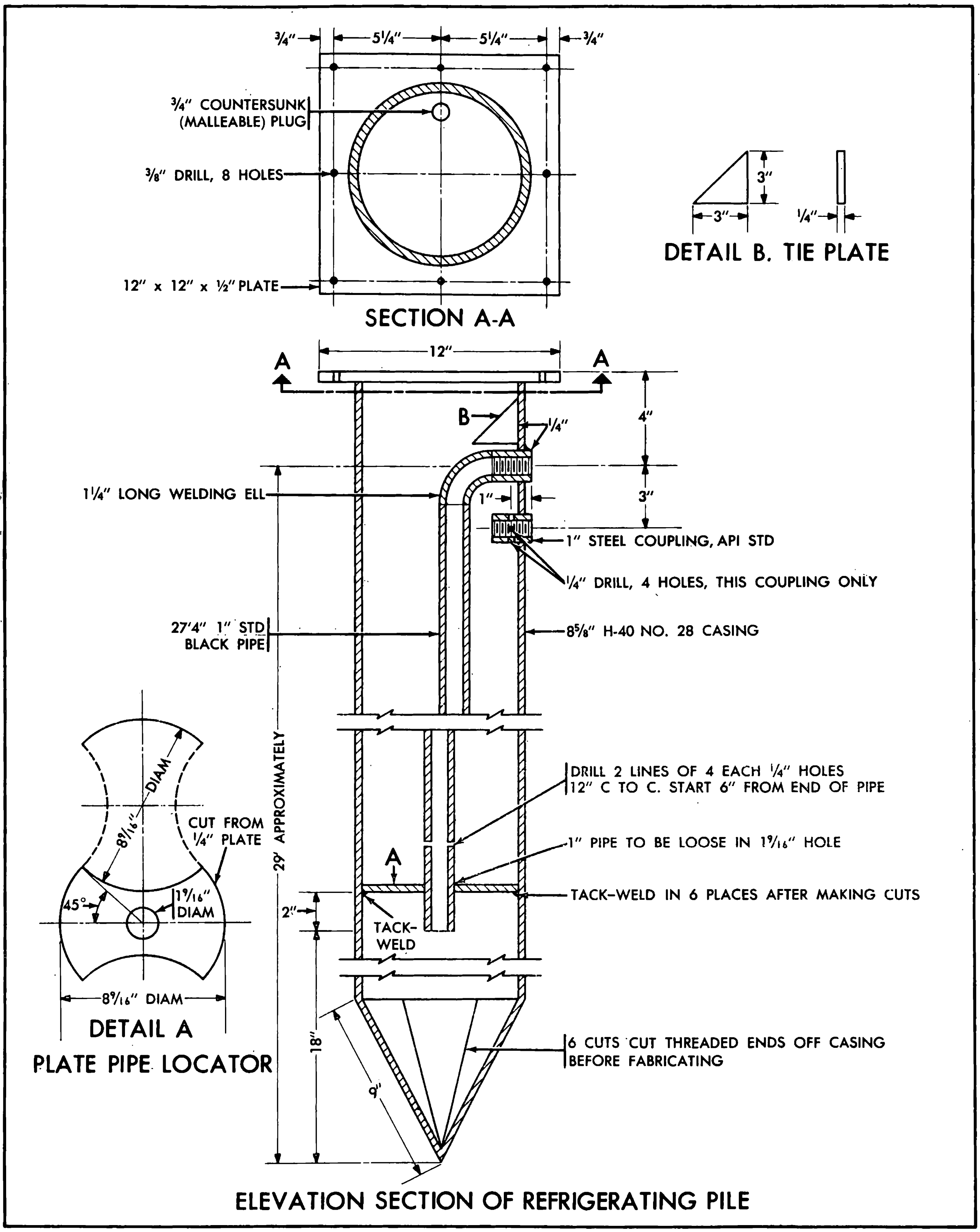


FIGURE 2A6-15

Refrigerating Pile Used in Point Barrow Area, Alaska (Ref. 26)

penetration below the active zone, A, so that the adfreeze or friction, whichever applies in applicable zone, C, plus load, P, will provide ample resistance to overcome the thrust resulting from the force, R.

French drains (par. 2 of 2A7.04), when properly installed, have been very effective. The purpose of such drains, in respect to the uplift on piling, is to reduce the moisture content of the active zone at the time of frost penetration to such an extent that the resulting thrust from the freezing in the active zone is not great enough to cause uplift.

Anchored piles (Figure 2A6-13) may also be used so that the piles can withstand the upward thrust from freezing or swelling ground. The installation of anchors requires excavation and backfilling, which results in the development of greater contact planes for the migration of water than in the methods previously mentioned.

A jacket, muff, or collar of wood, tar paper, brush, or other material (Figure 2A6-14) may be used to reduce the effect of the uplifting force on the pile. In most cases the effectiveness of this method is of very limited duration.

6. REFRIGERATION. Materials in place may be frozen and used as piles or as a supplement to other piling, thus forming a composite pile, usually of steel and materials in place. (For methods of estimating required refrigeration, see Section 2A8.) These frozen pillars have been used in the stabilization of banks and also as load-bearing piles to transfer loads to the undisturbed permafrost.

Figure 2A6-15 illustrates a refrigerated pile successfully used by Arctic contractors in northern Alaska. The use of this type of piling in the presence or vicinity of taliks, or where the normal temperature of the permafrost is greater than 31° F, is not recommended unless careful control factors are established for the maintenance of proper temperature equilibrium. (See Section 2A8.)

Section 7. DRAINAGE

2A7.01 GENERAL

Properly designed and constructed drainage facilities are vital to the success of any important project, and construction should not be undertaken until provisions for adequate drainage have been made. Experience in permafrost areas has shown that the most satisfactory drainage systems are those that least interfere with the natural movement of water. Wherever practicable, therefore, sites are selected to minimize the amount of work. (See Section 2A2.) Early recognition of potential disturbance to thermal equilibrium is important, but lack of reliable data frequently may make it impossible to predict undesirable effects. For this reason, installation of drainage facilities should be made as far in advance of the construction as possible so that difficulties can be discovered and corrected before permanent damage has been done. During construction, additional drainage facilities should be provided, as required, to prevent interference with the work by accumulations of water, mud, and ice.

2A7.02 SURFACE DRAINAGE

1. DESIGN CRITERIA. A study of the maximum probable rate of snowmelt in many Arctic areas, assuming the worst conditions, indicates that for each region in the permafrost area, the rate of snowmelt is not greater than the probable 1-hour rainfall. (Ref. 21.)

Because of varying conditions, it is always difficult to determine surface runoff and infiltration rates. In the Cold Regions the problem is complicated by the presence of permafrost, glaciers, and other phenomena peculiar to the regions. Under these conditions, the design of surface drainage facilities should be based on whatever climatic information is available, as well as on the size and appearance of the natural drainage channels and the topography of the watershed area. Such approximations, however, are undesirable in the case of airfield design because of the danger of underdesign and disastrous consequences. If time permits, a careful study of rain intensity, snowmelt, and other pertinent factors should be made for the particular area where the airfield is required. If, however, this is not practicable for sites in vital forward areas, overdesign can usually be justified. (Ref. 31.) (See par. 2C1.04.)

2. SURFACE STRUCTURES.

a. *Open Channels.* Open channels are used, whenever practicable, to receive outfall flow from operating areas, from which it is removed by means of adequate crowns or transverse slopes. Such channels should be capable of handling all surface drainage from the completed operation, as well as water intercepted from higher ground adjacent to the site and ground water intercepted during excavation. Open channels are preferred to covered structures because they are easier to construct and maintain. Underground storm drains are rarely used, except at locations where open channels would create an operating hazard. Wide, shallow channels, although less subject to erosion than deep, narrow ones, are difficult to maintain in fine-textured frost-action materials containing ice lenses. Silt, when thawed, will become plastic and semifluid, and unless countermeasures are taken, open channels in such materials will slump and become inoperative. Deep, narrow channels with relatively small exposure to the atmosphere will be less suspectible to slumping, and their depth will allow free flow of water for a longer period in the late fall than will shallow ones. Erosion and slumping of channels may be checked by lining their sides and bottom with moss, if available, or with other materials. At every opportunity drainage water should be discharged from collection ditches to outfalls leading to natural drainage channels, because the more rapidly surface water can be disposed of the less chance there is for seepage into the subgrade. Where runoff is silt laden, special care must be given to velocity to prevent silt deposition within the facilities. Excessive velocities and turbulence should be avoided or countermeasures should be taken. (Ref. 32.)

b. *Culverts.* Culverts should be large enough to carry the maximum amount of water that may flow through them under flood conditions. Deep, narrow, or egg-shaped sections are preferable because the additional depth allows a free flow of water under low-temperature conditions longer than do square or round sections. Culverts are usually constructed of logs, timber, or corrugated steel; but they are often improvised, to save time and transportation, by welding together a number of oil, gasoline, or asphalt drums. Care should be taken in using a torch or other tools on gasoline or fuel oil drums unless they have been completely emptied and the fumes removed. Culvert placement in the Cold Regions should, in general, conform to usual practice unless departures are necessitated by local conditions. On long culverts in locations where bad icing conditions are encountered, the Alaska Road Commission has found it advisable to control such icing by installing in the culverts, prior to freezeup, pipes of relatively small diameter, carrying their ends out and up to easily accessible locations along the roadway. The ends are capped to prevent plugging by condensation. Control of ice can then be accomplished by attaching a line from a mobile steam boiler. On short culverts, which are accessible for their full length, permanent steam-line installations are unnecessary. A relief culvert is sometimes installed by the Alaska Road Commission near the top of large fills above the icing height. Such an installation will handle spring runoff until the lower culvert thaws open. (Ref. 31, 33.)

2A7.03 SUBSURFACE DRAINAGE

1. GENERAL. The function of subsurface drainage is to intercept and collect detrimental ground water and to convey it to preselected discharge points. Subsurface drains serve as a channel for ground water from or around construction sites and potentially troublesome icing areas, or they may be installed to divert ground water before it can rise into the subgrade or to the surface of the operating area. It is extremely important to maintain the continuity of flow of ground water. Interruption or disturbance of the flow may cause settling, heaving, formation of frost or ice mounds, icefields, erosion, and other problems. Excavation, cutting, filling, ground compaction, and other construction activities may retard or stop the flow of ground water and result in one or several of these situations. For this reason, the necessity for thorough study of the area and an endeavor to predict the effect of every construction operation on the natural movement of ground water are emphasized.

2. DESIGN CRITERIA. Design criteria for underground drainage sometimes are difficult to establish. For each problem it is necessary to consider the type of flow involved, its rate, whether it is intermittent or continuous, the head under which it is operating, the effect on the thermal regime of all materials involved because of water or air movement through the drainage system, and the extent to which all of these factors may change during and after the construction of the facilities. Underground drainage structures should be designed and located so that frost penetration will not affect their operation. Slope should be suffi-

cient to assure as high a velocity as is practicable throughout the system, but not less than 2½ fps for smooth pipe. (See also par. 2A7.04.) Outfalls should discharge above possible backwater levels.

3. CONTROL BY DRAINAGE. The following three examples illustrate the application of drainage methods to situations typical of those commonly encountered in permafrost areas.

Example 1

In providing a siphon crossing in a valley in a permafrost area adjacent to the Chatanika River near Fairbanks, Alaska, the 60-in. pipe of the siphon was carried on pile bents 8 to 12 ft above the moss that covered the bottom of the valley. The installation of these piles created a weak spot in the moss cover. The water, moving below the frozen cover and above the permanently frozen materials of the valley, slowly developed at the siphon crossing a hydrostatic head sufficient to cause the water to break through the frozen moss cover (where it had been weakened because of the piling) and overflow onto the surface. Because of the exposure to the cold air of winter, the water formed in successive sheets of ice, as shown in Figure 2A7-1. Heaving of some of the pile bents also occurred during the first and second winters because the water froze in the active layer. (See Figure 2A6-11.) At this crossing, and at others where similar situations developed, the installation of French drains in many cases wholly corrected the trouble. At the end of these drains, weak spots were provided in the moss cover below the siphon crossings. Many of the siphons have now operated for 25 years without a recurrence of trouble from icing or heaving.

Example 2

Poorly drained operating areas, such as roads and runways subject to heavy traffic and kept clear of snow in the winter, are particularly susceptible to frost boils and soft spots, which often develop during the spring thaw. Frost in these cleared areas penetrates deeper than under the side slopes and shoulders and thaws sooner and faster in the spring than does the frost under the snow-protected shoulders. This thawing directly beneath the surface of the operating area produces an excessive amount of water that is unable to escape through the still-frozen subgrade materials. Although the surface may be dry and dusty, holes may develop and, as the crust is churned by traffic,

FIGURE 2A7-1

Icing at Siphon Crossing Near Fairbanks, Alaska

the gravel becomes a semifluid mass. Thawing of the underlying frozen materials by steam may be attempted, but it is an expensive procedure and its success depends on the permeability of the subgrade materials when they are thawed. A method that has successfully eliminated such a condition is the use of a French or similar drain of required dimensions to cut through the troublesome spot and conduct the entrapped water to outfalls or collection ditches discharging into outfalls.

Example 3

An example of a troublesome condition that can develop at the toe of a fill is illustrated by Figure 2A7-2. (A) of this figure indicates the ground surface before and after placing the fill. The horizontal arrows represent ground water moving through the materials of the active layer and on the contact between the active layer and the permafrost table. After the fill has been placed, its weight may compress the materials of the active layer and reduce their water-carrying capacity; also, the insulation value of the moss and the active layer materials is reduced by compaction, so that frost penetration during the winter months may increase, as shown in (B), to the extent that water can no longer flow. The reservoir of water collected above the obstruction may back up the slope for a considerable distance. (See also Figure 2A6-5b.) The hydrostatic head and pressure so developed may be sufficient to cause a breakthrough at some weak point upstream from the obstruction, resulting in the icing conditions indicated in (B). These situations have been remedied by installing French drains of the required length upstream and downstream from the toe of the slope. The amount of area to be protected and the subsurface conditions at the various sections along the toe of the fill will determine the number and sectional area of drains that will be required.

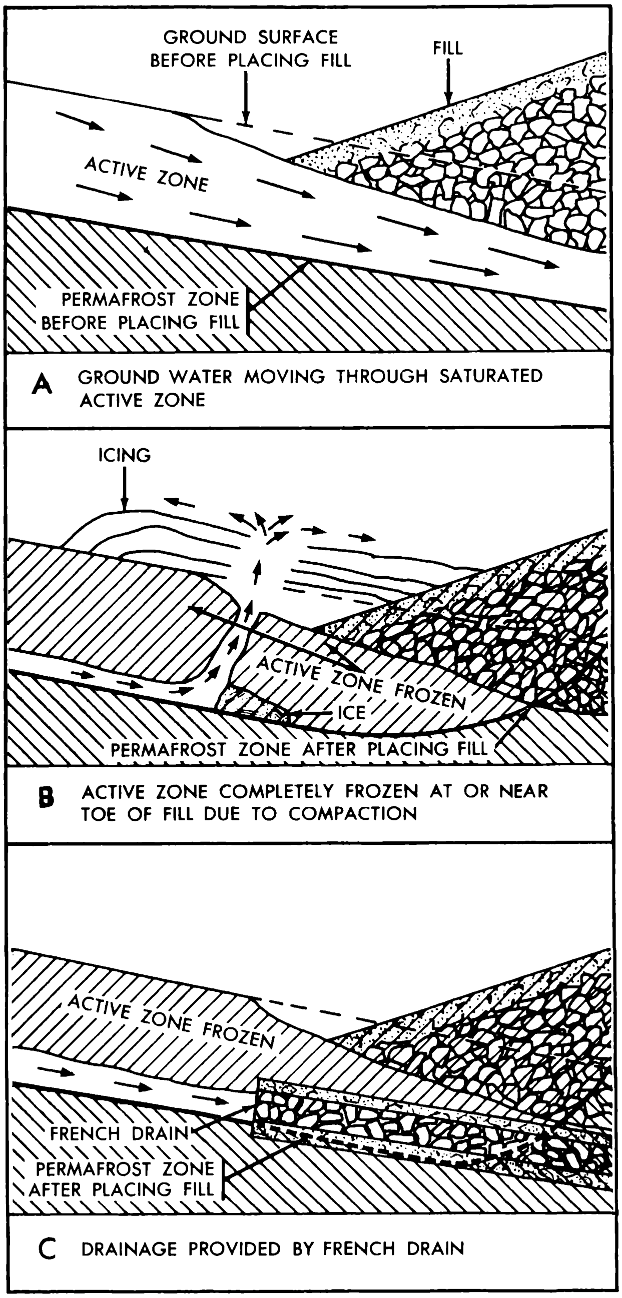


FIGURE 2A7-2

Troublesome Condition Developed at Toe of Fill

2A7.04 DRAINAGE STRUCTURES

1. UNDERGROUND STORM DRAINS. The usual method of collecting surface water runoff is by side ditches. (See par. 2a of 2A7.02.) Underground storm drains with catch basins, however, are occasionally installed when open ditches are hazardous to air operations or for other reasons. Piping for this service may be of asbestos cement, creosoted wood stave, or rust-resistant steel. Ceramic tile is not recommended for installation in permafrost. Underground storm drainage pipes should be installed below the active zone and should be laid with closed joints. In passing through permafrost, the pipe should be surrounded on all sides by a cushion of sand or other suitable bedding and insulation. A coarse backfill is then

laid over this material and thoroughly tamped (Figure 2A7-3). (Ref. 21.)

Gradient of drainage pipes should be sufficient to give the water a minimum velocity of 2½ fps in order to avoid the accumulation of silt. When sufficient grade is not available, the bottom of catch basins can be made lower than the bottom of the pipe invert to allow for the collection of silt. (Ref. 34.)

a. *Catch Basins.* Catch basins discharging into lower ditches or piping are usually located along the lines of the side drains and/or in the low interior sections of the operating area for removal of surface runoff. They are commonly constructed of timber or wood staves, but concrete may be used if the additional expense is warranted. Sides of catch basins below the pipe invert should slope inward to provide relief for forces caused by the freezing of water that may collect in the silt clean-out pockets. Wood-stave catch basins are common in the Fairbanks area. Covers should be removable for access and should be heavy enough to support the maximum anticipated wheel load.

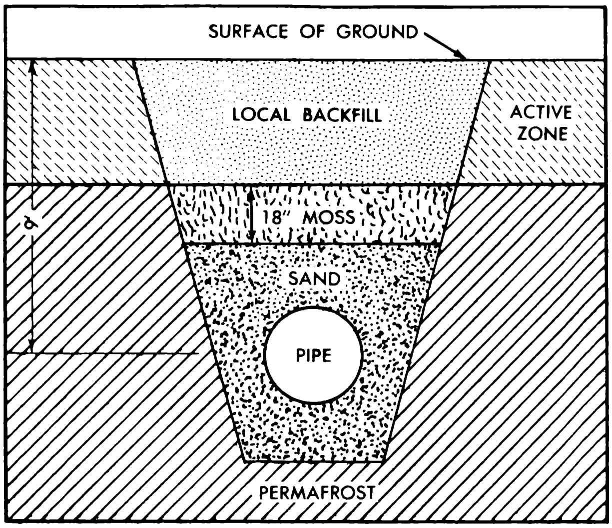


FIGURE 2A7-3

Storm Drain in Permafrost Area (Ref. 21)

2. FRENCH DRAINS. French drains are inexpensive to construct and are sometimes useful in maintaining the continuity of subsurface drainage in an area. Flow of subsurface water may be retarded or obstructed by the local advancement of frost in the active zone because of the removal of snow and/or compaction caused by a superimposed load, such as a fill, or by travel over the surface by tractors, sleds, or even men on skis.

a. *Application.* In Figure 2A7-4, A represents the ground surface before local compaction of the cover; B indicates elevation of the ground surface after compaction. Such compaction may cause not only a restriction of the water channels of the active zone, C, but also a reduction of the insulating value of the cover in the compacted area. Removal of snow in the winter will further reduce the insulating value of the cover.

In many drainage areas the active zone, C, will be saturated or nearly saturated in the fall of the year, with water slowly moving through it as indicated by the arrows in Figure 2A7-4. After the

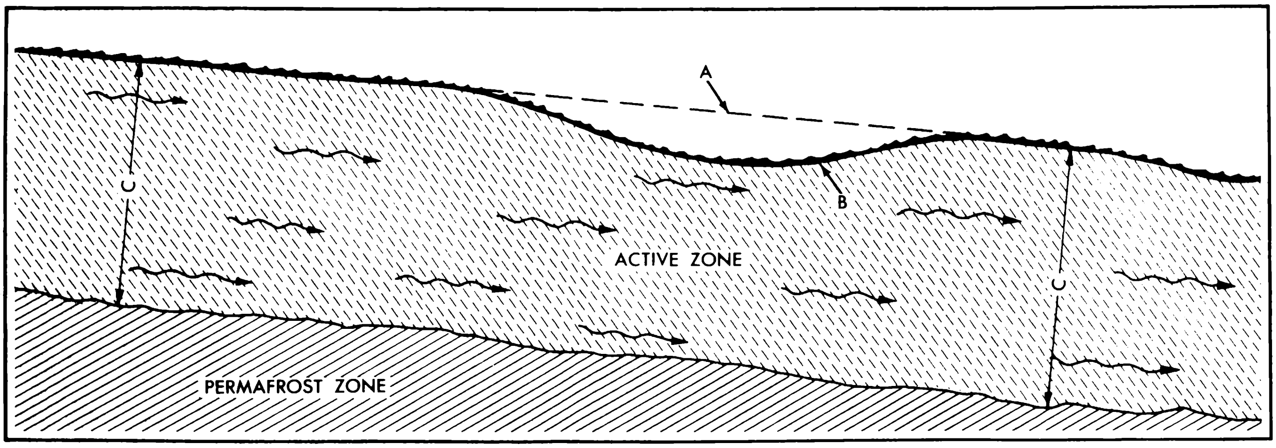


FIGURE 2A7-4

Saturated Active Zone Showing Flow Restriction by Compaction

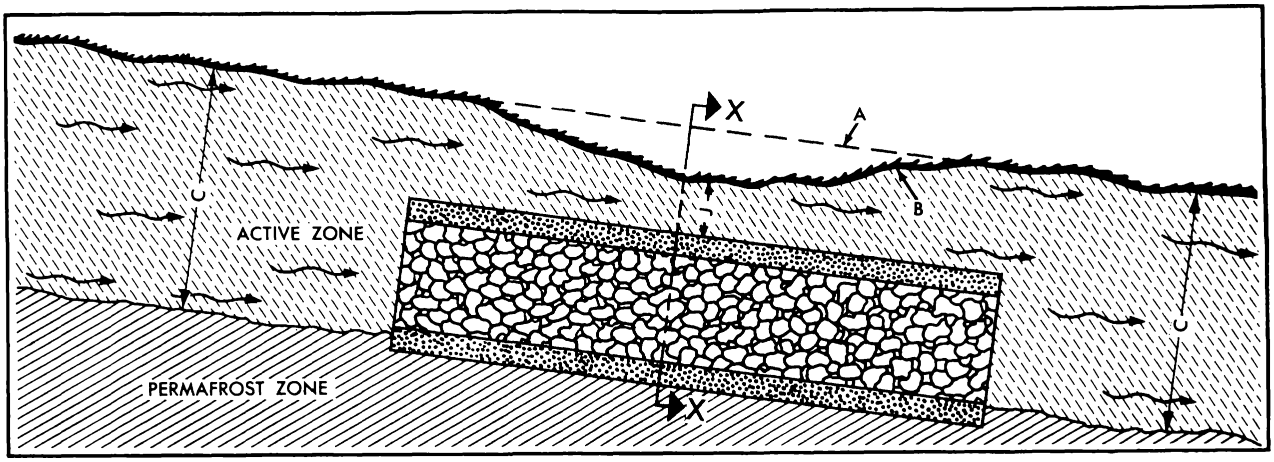


FIGURE 2A7-5

Saturated Active Zone Showing French Drain Installation

freezeup, the movement of subsurface water continues in the active zone and on the contact between the active zone and the permafrost, but, inasmuch as no more surface water can enter during this period, the water table slowly falls. Because of increased thermal conductivity of the cover immediately below the area indicated by B, the freezing in this compacted section progresses more rapidly and penetrates to greater depth than in the adjacent undisturbed area of the active zone, and may penetrate sufficiently deep to interfere with the flow of subsurface water in the section below B. The obstruction of the flow may cause hydrostatic pressure to develop in this section; the pressure may be sufficiently great to cause a rupture of the frozen cover and an overflow of water, as illustrated in (B) of Figure 2A7-2. In these cases a French drain may be useful in increasing the water-carrying capacity of the active layer through the section below B and in retarding the depth of penetration of the frost. This kind of drain may be constructed as indicated in Figure 2A7-5. The cross section is shown in Figure 2A7-6. Here, E and F represent mixtures of sand and gravel graded and packed so as to protect the coarse material, G, from infiltration of fines from below and above. G represents a carefully placed and selected coarse material, so graded that the resulting voids will be sufficient to provide water channels equal to or greater than those originally existent in C of Figure 2A7-4. Attention is directed to par. 3b of 2A7.04 regarding the selection of graded filter materials to prevent the detrimental movement of soil from the sides and bottom of the trench. In certain soil types this is most important.

b. *Operation.* After the freezeup, the frost slowly penetrates the active zones, C and J, advancing at a more rapid rate at J than at C because of the increased conductivity of J. When the frost reaches the water running in the coarse material, G, the water in E will have frozen and a layer of

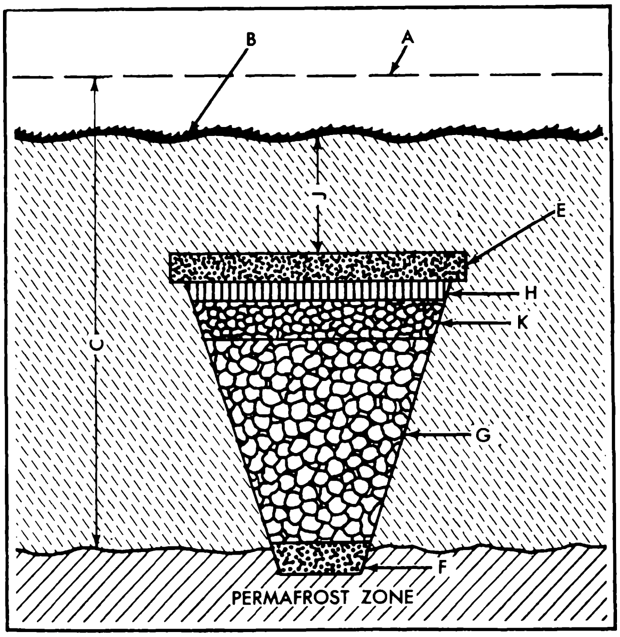


FIGURE 2A7-6

Cross Section XX of French Drain in Figure 2A7-5

ice will be formed at H. As the ground water drops and the drain is no longer running full, the frost continues to penetrate the active zone around the drain, but it is retarded inside the drain because of the entrapped air in the coarse material between the surface ice, H, and the surface of the water, K, in the drain. The thermal conductivity of the compacted material, J, plus the sand and gravel cover, E, plus the ice sheet, H, plus the filter material, G, with its entrapped air, is less than the thermal conductivity of the adjacent section in the active layer from which no snow has been removed and at which no compaction has occurred; it thus provides a drain that will permit movement of subsurface water at the critical area as long as such water continues to flow through a portion of the active zone, C, that remains unfrozen or on the contact between C and the permafrost.

c. *Location of Laterals.* Laterals to the drain should be constructed so that protection contributed by the ice sheet, H, is retained; therefore, they should enter the lower portion of the drain between H and F.

d. *Sloping Sides.* A trench of the shape indicated in Figure 2A7-6 is preferable to one with vertical sides because the depth and velocity of flow, when only a small amount of water is moving, will increase as the width of the bottom is narrowed; also, sloping sides provide some relief to the forces created by the water freezing, which may be of some assistance in preserving the sides of the trench during the freezeup period.

e. *Additional Requirements.* To operate successfully, French drains must be designed and installed so the voids existent in the coarse material, G, will not become obstructive to the passage of water because of sediment, ice, moss, or some other clogging material. In order to help in accomplishing this, it is advisable to design and install the drains so that the upper section of the coarse material, G, will be in the active zone.

There is often a possibility that, because of a fill or other structure, the permafrost table may rise (Figure 2A6-1) and wholly surround the drain, as shown in (C) of Figure 2A7-2. In this case, continuity of airspace must be provided for those times when the drain is not running full. This permits movement of future water through the drain so that ice, which may have accumulated during the colder months, can be removed by the water flowing through during the warmer season.

3. BASE COURSE AND INTERCEPTING DRAINS. Subsurface drains of the types illustrated in Figures 2A7-7 and 2A7-8 are often used under or adjacent to the side of an operating area to provide drainage for the base course layer or to collect and dispose of subsurface seepage from springs or other sources. Perforated pipes, with the joints closed, are placed below the depth of frost penetration and carefully laid to specified grades. Perforations may be either up or down, depending on the type of area being drained. If the water table to be controlled or lowered is continuous and level, the pipe is laid with perforations down to minimize infiltration of fine materials and to maintain hydraulic efficiency. When drainage water must pass over unsaturated pervious strata, the pipe is laid with the perforations up so that its lower half provides a water channel and prevents infiltration of the drainage water into the pervious materials. If the pipe is laid with the perforations up, the pipeline should be set deep enough to place the holes below the water-bearing strata. (Ref. 31.) Perforations should be smaller than the smallest stone in the materials surrounding the pipe. Open-joint pipes are not recommended in permafrost because of the possibility of the openings becoming covered with ice. Drains of this type should, when practicable, be backfilled with a selected filter material meeting the requirements listed in the following paragraph. Frequently, however, it may be necessary to backfill with whatever granular materials are available even though they may lack the complete requirements of ideal

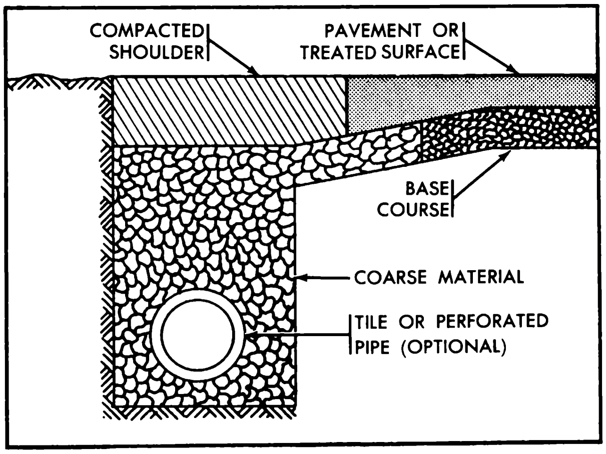


FIGURE 2A7-7

Base Course Drain (Ref. 34)

filtering materials. Concrete aggregates can usually be graded so as to permit water to enter the drain, yet prevent movement of soil from the trench sides.

a. *Combination Drains.* Drains of the type indicated in Figures 2A7-7 and 2A7-8 are sometimes modified by substituting coarse gravel for the impervious top layer to permit entrance of surface runoff. Such modification, however, may result in a decrease in efficiency of the drain and necessitate periodic cleaning of the pipe. (Ref. 34.)

b. *Filtering Material.* The material for backfilling subsurface drains must be very carefully selected. It must permit water to enter the drain, but it must prevent the detrimental movement of the surrounding soil, which causes clogging of drains and settlement of overlying surfaces. The use of a filter material is most important when the soil to be protected is a cohesionless or slightly plastic fine sand or silt. A desirable filter material should meet the following requirements as determined from gradation curves. Percentage sizes define the diameter of the soil grain, which is larger than the diameters of the given percentage of grains. Thus, a 15-percent size is larger than 15 percent of the soil grains. The following ratios, added to referenced text for clarity, should govern.

(1) When soil to be protected is well graded

$$\frac{\text{15-percent size — filter}}{\text{85-percent size — protected soil}} = \text{less than 5}$$

$$\frac{\text{15-percent size — filter}}{\text{15-percent size — protected soil}} = \text{more than 25}$$

(2) When soil to be protected is uniform

$$\frac{\text{15-percent size — filter}}{\text{85-percent size — protected soil}} = \text{less than 4}$$

$$\frac{\text{15-percent size — filter}}{\text{15-percent size — protected soil}} = \text{more than 5}$$

(3) Relationship between filter material and openings in pipe

$$\frac{\text{85-percent size — filter}}{\text{size of perforations in pipe}} = \text{more than 2}$$

(Ref. 31)

4. WARMTH RETENTION MEASURES. Special methods must be used to protect shallow drainage structures from freezing and forming nalyed (surface icing) at undesirable points. Two of these methods are illustrated in Figure 2A7-9. Drains of this type are useful in drawing water away from a natural icing area (for example, a roadway fill or freeze belt) to a selected induced icing area. (See par. 2 of 2A7.05.) (Ref. 9.)

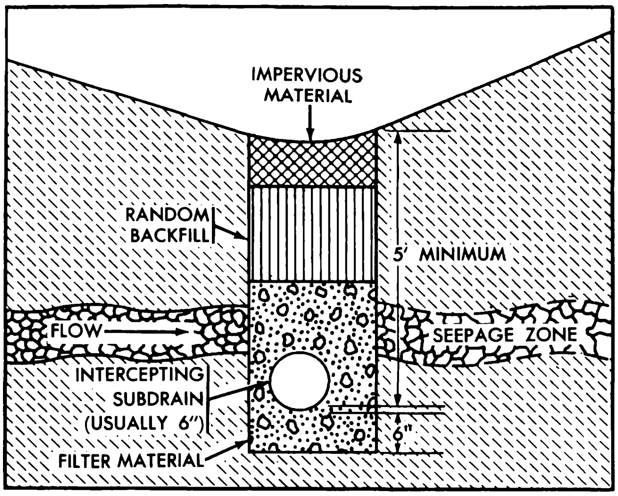


FIGURE 2A7-8

Intercepting Drain (Ref. 34)

2A7.05 ICING

1. OCCURRENCE. Ground water, forced from the ground or from fractures in rock formations during winter, may spread and freeze in successive layers into fields of surface ice. These icefields occur as long as water is forced to the surface to feed them; if not controlled, they may cover large areas with ice several feet in thickness and jeopardize the stability and use of construction installations in their vicinity. An example of seepage icing caused by disturbance of the thermal equilibrium of the subsurface by construction activity is illustrated in Figure 2A7-1. A method of eliminating it is demonstrated in Figure 2A7-10. NOTE: The trench was filled after a French drain had been constructed in its bottom. The original icing, similar to that shown in Figure 2A7-1, has not recurred since the drain was built 25 years ago. Attention is directed to the siphon crossing in the distance.

Seepage icing, however, is caused more often by natural processes of the hydrologic regime than by human activity and may occur whenever seepage or subsurface flows are forced to the surface during winter. Formations of the ice masses vary unpredictably with ground, water, and weather conditions.

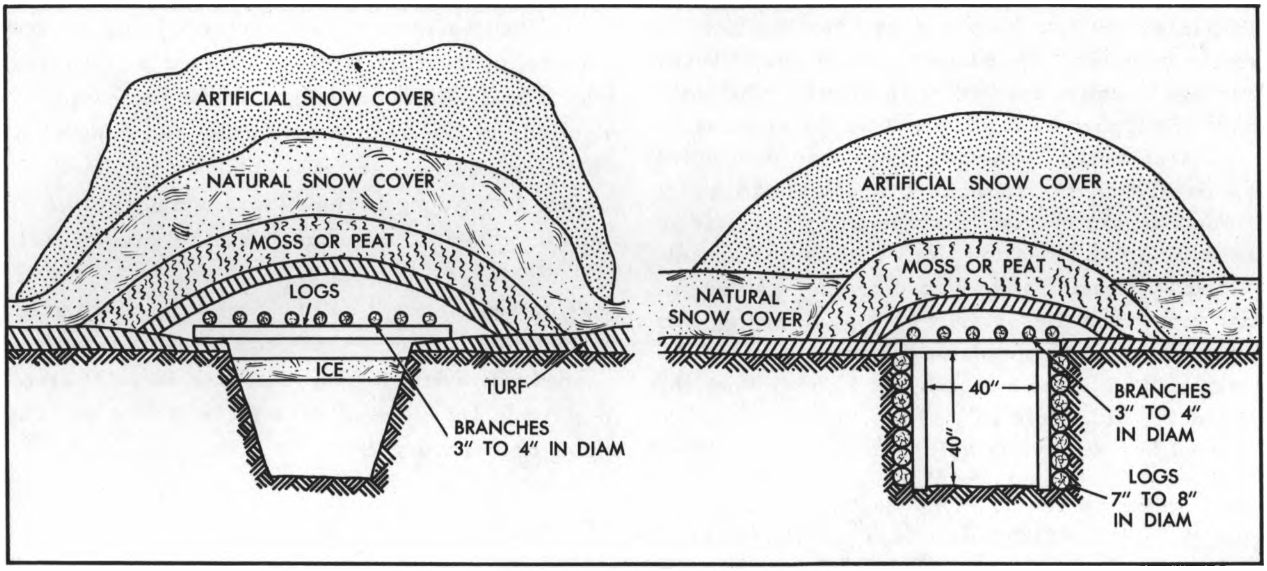


FIGURE 2A7-9

Insulated Drainage Structures Designed To Prevent Freezing (Ref. 9)

FIGURE 2A7-10

Prevention of Seepage Icing at Siphon Crossing

The severity of the winter, the direction of exposure, the nature of the season prior to the freezing, whether wet or dry, the amount of snowfall and whether it falls early in the season or late—all are contributing factors toward resultant icing possibilities. (Ref. 33.) The fact that serious icing conditions or potential icing conditions are known to exist should be considered in the selection of sites for roadways, airfields, and other facilities. Exposure is sometimes sufficient to prevent rapid freezing on south-facing slopes, but on north-facing slopes the tendency is toward complete freezing. Icings, therefore, are more severe on south-facing slopes because of the more prolonged flow of ground water. Location of facilities on south-facing slopes or near their bases should be avoided unless it is apparent that icing, if it does occur, can be satisfactorily controlled.

Outfalls, on the other hand, should when possible terminate on southern slopes with their outlets protected from the cold air by an insulating cover of brush or snow. (Ref. 33.)

2. SURFACE-ICE CONTROL. It is sometimes possible to eliminate natural icing conditions entirely by diverting the flow of water close to its source. This type of control can be used effectively when the ground water flows near the surface and can be intercepted at some distance from the operating area. Often such water will retain suffi-

cient latent heat to keep it from freezing until it reaches its natural discharge point, especially if the drainage canal is covered with brush sufficiently thick to support an insulating blanket of snow.

Another method, which is frequently used when it is possible to intercept the flow of ground water at some distance from the operating area, is to induce icing at a selected site. This can be accomplished by clearing the selected area of its vegetation cover and removing the topsoil, using this material to form a simple impounding dike, which does not have to be watertight. Neither does the ice storage area have to be level, because ice does not pool like water but builds up downslope (Ref. 21). When surface water is retarded and frozen in place, no further stress is exerted against the dike, which allows its height to be increased, as required, by the addition of brush and tundra or whatever materials are available. By this method, surface ice can be brought to a vertical wall of control at almost the exact point desired. (Ref. 21.)

Protection of roads and bridges from damage by stream icing is discussed in Section 2C1.

Adequate drainage facilities must be established to provide for disposal of melt water when the spring thaw occurs.

Section 8. HEAT TRANSFER, LOSS, AND ABSORPTION, AND TEMPERATURE MEASUREMENT

2A8.01 DEFINITION OF SYMBOLS

The symbols used in this Section are defined in the following list. The units of measurement are those most frequently used. Others are used only occasionally. When the symbols are combined in dimensionless groups, any self-consistent dimensions may be used. In many instances in which tables have been reproduced, the symbols have been changed for the sake of consistency.

Symbol	*Definition*	*Unit*
A	Area	sq ft
B	Shape factor (Table 2A8-7)	
C_p	Heat capacity	Btu/°F/lb
c	Heat capacity per unit volume	Btu/°F/cu ft
D	Diameter	ft
E	Energy per unit volume	kwhr/cu yd
F_a	Shape factor (Table 2A8-6)	
F_e	Emissivity factor (Table 2A8-6)	
$F(y_o)$	Function of y_o defined, equation (2A8-16b)	
$f(y_o)$	Function of y_o defined, equation (2A8-16c)	
G	Mass velocity per unit area	lb/sq ft/hr
g	Mass velocity	lb/hr
H	Quantity of heat	Btu
h	Film coefficient or surface conductance	Btu/hr/sq ft/°F
I	Thawing index	°F/day
I	Electrical current	amp
J	Function of temperature (Table 2A8-4)	
k	Coefficient of thermal conductivity	Btu/hr/°F/ft
L	Latent heat of fusion of water in 1 cu ft of soil	Btu/cu ft
M	Dimensionless group	
N	Dimensionless group	
n	Day of the year	
Nu	Dimensionless group	
p	Emissivity	
Pr	Dimensionless group	
Q	Heat flux per unit area	Btu/hr/sq ft
q	Heat flux	Btu/hr
R	Thermal resistance	Btu/hr/°F
R	Electrical resistance	ohms
r	Radius	ft
Re	Dimensionless group	
S	Correction factor	
T	Temperature	°F
t	Time	hr or days
U	Conductance coefficient	Btu/hr/°F/sq ft
V	Velocity	mph
W	Shape factor (Table 2A8-7)	
w	Water content of soil in percent of dry weight	
X	Distance	ft
x	Distance	ft
y	Dimensionless group	

Symbol	*Definition*	*Unit*
y_o	Dimensionless group	
Z	Distance	
z	Distance	ft
α	Diffusivity	sq ft/hr
β	Pressure	mm of Hg
ε	Constant	dimensionless
μ	Viscosity	lb/hr
ρ	Density	lb/cu ft
ϕ	Dimensionless group	
ψ	Constant	degrees
ω	Constant	time unit used

2A8.02 INTRODUCTION

Most of the heat transfer problems encountered in ordinary engineering practice in the Temperate Zone also manifest themselves in the Polar Regions. However, the conditions are often much more extreme, and the thermal aspects of a given problem may assume enhanced proportions. In addition, there is a class of problems encountered both in Polar and in Temperate Regions that are basically the same except for the fact that thermal considerations may be of considerable importance in the former but of no importance in the latter. Finally, there are certain problems more or less uniquely characteristic of the Polar Regions that are primarily problems in the maintenance of, or controlled change in, the thermal equilibrium in a given area. These arise particularly in connection with construction in or on permafrost or ice, where it is essential that thawing be prevented if the structural properties of construction materials are to remain unaltered. In other cases, structural properties may be improved by freezing soil materials in place; and in certain instances thawing may be desired, particularly in connection with the removal of ice or permafrost.

Unfortunately, many of the heat transfer problems likely to be encountered in actual practice are of sufficient mathematical complexity so that exact solutions have not yet been obtained; in certain other cases, other complexities of a nonmathematical nature make exact solutions impossible. Various approximation methods have been developed for some of these problems, and others are in the process of development. In the case of heat transmission by conduction or radiation, the physical principles can easily be expressed quantitatively, the differential equations and boundary conditions can usually be written down, and in some instances, particularly for problems involving simple geometrical shapes, exact solutions are obtainable. Heat transmission by convection is still, to a large extent, traceable only on an empirical basis.

In the following Sections, the simpler classical problems in heat transmission are presented, and examples of more complex problems of the type likely to be encountered in work in the Polar Regions are considered. This compilation is by no means exhaustive, and probably the practicing engineer will be compelled to be content in a large number of situations with very approximate solutions. Consequently, he will have to use large safety factors or else work out satisfactory methods on a purely experimental basis. Reference to more exhaustive treatments on heat transmission and/or the use of models are recommended when sufficient time and the necessary materials are available.

Problems in conduction may be divided conveniently into two major classes: (a) steady state problems where the temperature is a function of the space coordinates only and does not vary with time, and (b) unsteady or transient state problems where there is a variation of temperature with time.

Solutions of conduction problems require knowledge of the thermal properties of materials. At the present time, only a limited amount of reliable thermal data on soil is available. Some of this information is summarized in par. 6 of 2A8.08, and methods for determining thermal properties are also indicated in Example 5 of Problem 5, par. 2 of 2A8.04.

Some of the equations that follow and all of the graphical equations are set up in terms of dimensionless groups so that any consistent set of units may be used.

2A8.03 STEADY STATE CONDUCTION

The basic equation for conduction in either steady or transient state is

$$\frac{dH}{dt} = -kA\frac{dT}{dx} \qquad (2A8\text{-}1)$$

$\frac{dH}{dt}$ = rate of heat flow

A = area through which heat flows

$\frac{dT}{dx}$ = temperature gradient along path of heat flow

k = a proportionality factor, the coefficient of thermal conductivity, which is characteristic of the substance under consideration

For most substances the change of k with temperature is small and linear; for small temperature gradients it can be assumed constant without the introduction of serious error. In the following treatment this will be done. When possible, a value of k corresponding to the average temperature should be used.

1. CONDUCTION THROUGH HOMOGENEOUS PLANE WALL. Consider the case where the two faces of a homogeneous plane wall of thickness x and thermal conductivity k are kept at temperatures T_1 and T_2, the problem being to determine the heat transmitted through the wall. Because this is a steady state problem, $\frac{dH}{dt}$ is a constant, say q. Then

$$q = -kA\frac{dT}{dx} \qquad (2A8\text{-}2)$$

In this problem, $\frac{dT}{dx}$ does not vary with x and so may be replaced by $\frac{T_1 - T_2}{x_1 - x_2}$.

Then

$$q = \frac{-kA(T_1 - T_2)}{x_1 - x_2} \qquad (2A8\text{-}2a)$$

Example

Calculate the rate of heat loss through a 50-ft x 20-ft x 1-in. wooden floor (average $k = 0.08$ Btu/hr/ft/°F), the two surfaces being maintained at 70° F and −30° F. Then

$$q = 1{,}000\left[\frac{0.08(100)}{1/12}\right]\text{Btu/hr} = 96{,}000\ \text{Btu/hr}$$

The same solution can be applied to a well-insulated homogeneous rod, the two ends of which are maintained at constant temperatures.

2. CONDUCTION THROUGH HOMOGENEOUS CYLINDRICAL SHELL. This problem arises particularly in connection with insulation of wires and pipes. (See Figure 2A8-1.)

The equation in this case is

$$q = kA_{\log}\left[\frac{T_2 - T_1}{r_2 - r_1}\right] \qquad (2A8\text{-}3)$$

$r_2 - r_1$ = thickness of cylindrical shell
T_2 and T_1 = temperatures at r_2 and r_1
$A_{\log}$ = logarithmic average area
X = length of pipe

Then

$$A_{\log} = \frac{A_2 - A_1}{2.3\log_{10}\left[\frac{A_2}{A_1}\right]} = \frac{2\pi(r_2 - r_1)X}{2.3\log_{10}\left[\frac{r_2}{r_1}\right]} \qquad (2A8\text{-}4)$$

Where $r_2 - r_1$ is small compared to r_2,

$$A_{\log} \approx \frac{A_1 + A_2}{2} \qquad (2A8\text{-}4a)$$

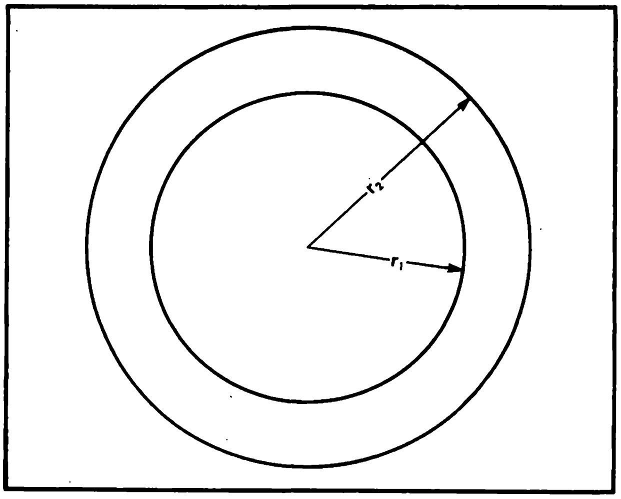


FIGURE 2A8-1

Conduction Between Concentric Cylindrical Shells

Example

A 6-in. steampipe is covered with 1-in. asbestos insulating material. Calculate the heat loss per foot, assuming the outside of the insulation maintained at 0° F and the inside at 250° F. Use 0.1 for the value of k for asbestos.

$$A_{\log} = \frac{2\pi(r_2 - r_1)X}{2.3\log_{10}\left[\frac{r_2}{r_1}\right]} = \frac{\left[2\pi\frac{(4-3)}{12}\right]X}{2.3\log_{10}\left[\frac{4}{3}\right]} = 1.82X$$

Alternatively,

$$A_{\log} = \frac{A_1 + A_2}{2} = \left[\frac{2\pi(r_1 + r_2)}{2}\right]X = 1.82X$$

$$q = 0.1\left[1.82X\left(\frac{250}{\frac{1}{12}}\right)\right] = 0.1(1.82X\ 3{,}000)$$

$$\frac{q}{X} = 546\ \text{Btu/ft/hr}$$

3. RESISTANCE CONCEPT — COMPOSITE WALLS. The differential equations applicable to heat transfer problems are essentially the same as

those found in many other problems in physics, and it is frequently advantageous in making calculations or designing models to utilize this similarity.

In comparing the phenomena of heat transmission and electrical transmission, the potential difference, current, electrical conductivity, capacitance, and resistance are the analogs of temperature difference, rate of heat flow, thermal conductivity, heat capacity, and thermal resistance. The same solutions apply in both cases.

There follows a concept analogous to electrical resistance, used in consideration of a composite wall. (See Figure 2A8-2.)

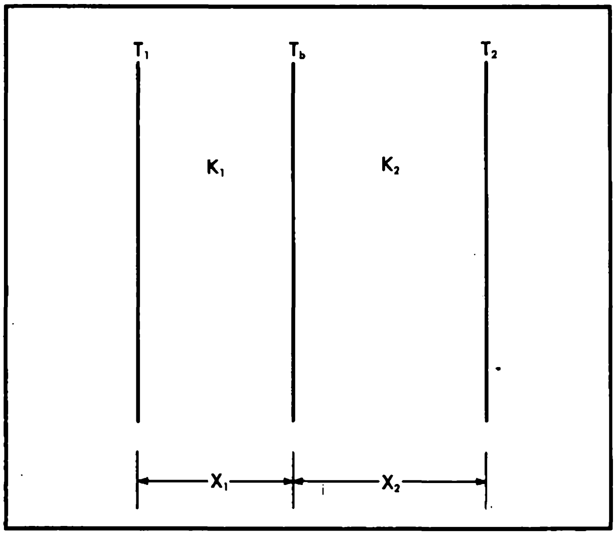


FIGURE 2A8-2

Conduction Through Composite Wall (Ref. 35)

For regions 1 and 2

$$q_1 = k_1 A \left[\frac{T_1 - T_b}{X_1}\right] \quad q_2 = k_2 A \left[\frac{T_b - T_2}{X_2}\right]$$

The thermal resistance per unit length $= \frac{1}{kA}$, or for a length X

$$R = \frac{X}{kA} \qquad \text{(2A8-5)}$$

For equilibrium

$$q_1 = q_2 = q = \frac{T_1 - T_b}{R_1} = \frac{T_b - T_2}{R_2} \qquad \text{(2A8-6)}$$

$$qR_1 - T_1 = -T_b \qquad qR_2 + T_2 = T_b$$

$$qR_1 + qR_2 + T_2 - T_1 = 0 \qquad q = \frac{T_1 - T_2}{R_1 + R_2}$$

(2A8-6a)

or for the general case

$$q = \frac{\Delta T}{\Sigma R} \qquad \text{(2A8-6b)}$$

Example 1

Apply this equation to the previous problem of the steampipe, but assume the inside of the pipe to be 250° F. Assume an OD of 6 in. and an ID of 5.25 in. for the pipe. For steel, assume $k = 26.0$. From the previous example,

$A_{\log}$ asbestos $= 1.82X$

For the pipe,

$$A_{\log} \simeq \frac{2\pi\left(\frac{6 + 5.25}{24}\right)}{2} X = 1.48X$$

$$R \text{ asbestos} = \frac{\frac{1}{12}}{0.1 \times 1.82X} = \frac{0.458}{X}$$

$$R \text{ steel} = \frac{\frac{375}{12}}{26.0 \times 1.48X}$$

$$R \text{ total} = \frac{0.459}{X}$$

$$q = \frac{\Delta T}{R \text{ total}} = \frac{250X}{0.459}$$

$$\frac{q}{X} = \frac{250}{0.459} = 545 \text{ Btu/ft/hr}$$

It is seen in this case that the answer is approximately the same as in the previous calculation. This is because the steel pipe is such a good conductor, compared to the insulating covering, that its conductivity can justifiably be assumed to be infinite.

Example 2

An insulated pipe with an original temperature of 30° F is laid in permafrost. Water at 50° F is pumped through the pipe. In this case there will be a temperature drop between the bulk of the water and the inner pipe surface. Calculate the rate of the heat leak, assuming the following.

Pipe OD, 6 in.
Pipe ID, 5.5 in.
Insulation thickness, 2 in., with $k = 0.1$ Btu/hr/ft/°F
k of pipe, 26 Btu/hr/ft/°F
Film coefficient from water to pipe h, 550 Btu hr/ft/°F

This may be calculated using Figure 2A8-18 and the data in Table 2A8-10. A value of 5 fps has been assumed for water velocity.

Using equations (2A8-4) and (2A8-5),

$$R \text{ insulation} = \frac{0.815}{X}$$

$$R \text{ pipe} = \frac{0.0008}{X}$$

$$R \text{ film} = \frac{1}{hA} = \frac{1}{550\left[\frac{0.55}{12}\right]\pi X} = \frac{0.00128}{X}$$

$$\Sigma R = \frac{0.817}{X} \qquad q = \frac{\Delta T}{\Sigma R} = \frac{18}{0.817}\, X$$

$$\frac{q}{X} = 22.0 \text{ Btu/hr/lin ft}$$

Of course, the value here calculated is applicable only when circulation begins. As time passes, the ground temperature will increase above 30° F near the pipe and the flux will decrease; the value calculated is also applicable only at the point in the pipe where the water is at 50° F, because it will cool on flowing. Later examples illustrate more complicated problems, which take into account changes in fluid and ground temperatures.

4. CONDUCTION BETWEEN CYLINDER AND INFINITE PLANE. (See Figure 2A8-3.) In this case,

$$R = \frac{\cosh^{-1}\left[\frac{z}{r}\right]}{2\pi k X} \qquad (2A8\text{-}7)$$

and

$$q = \frac{\Delta T}{R}$$

ΔT = difference between cylinder temperature and that of plane
z = distance from plane to center of cylinder
r = cylinder radius
k = thermal conductivity of material between cylinder and surface
X = length of cylinder

Example

Assume a buried pipe to be maintained at 32° F, with a ground surface temperature constant and equal to 45° F. Calculate the heat leak from the ground surface to the pipe, assuming

z = 1 ft
r = 1 in.

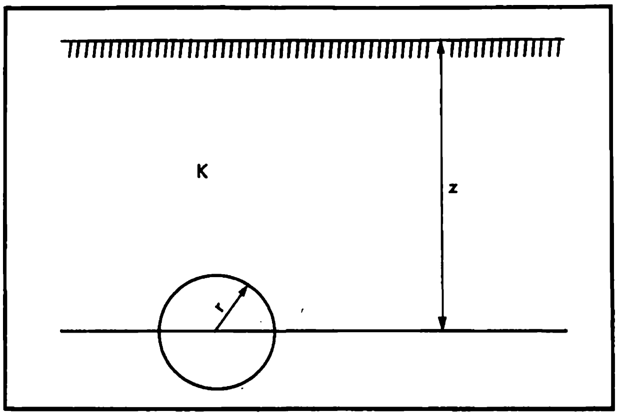


FIGURE 2A8-3

Conduction Between Cylinder and Infinite Plane

k = 0.945 Btu/hr/ft/°F
Pipe length = 50 ft

Then

$$R = \frac{\cosh^{-1}\left(\frac{12}{1}\right)}{2\pi \times 0.945 \times 50} = \frac{3.18}{297} = 0.0107$$

and

$$q = \frac{45 - 32}{0.0107} = 1{,}215 \text{ Btu/hr}$$

If the pipe is insulated, an extra resistance factor must be added to that of the soil. The radius of the outside of the insulation must, of course, be used in equation (2A8-7).

2A8.04 TRANSIENT STATE CONDUCTION

1. INTRODUCTION. Unfortunately, most of the important problems likely to be encountered in the Polar Regions are not amenable to exact general solution. Complications arise particularly because of freezing and melting. In certain instances, however, no account need be taken of this phase change; for example, in soil with very low water content the heat of fusion may be small compared to $\int_{T_1}^{T_2} C_p dT$, particularly if the difference between T_1 and T_2 is large. (C_p is heat capacity, T is temperature.) In other instances, the 0° C (32° F) geo-isotherm may be sufficiently far removed from the heat source or sink so that it is moving only slightly with the addition of heat, in which case it may, as an approximation, be treated simply as a surface maintained at a constant

temperature. If the 0° C (32° F) geo-isotherm is sufficiently far removed, it may in certain instances be neglected and the solid treated as an infinite or semi-infinite solid. Other applications of the solutions outlined in the next paragraph may also arise. Further, certain qualitative effects are more easily presented if the change of state is neglected.

Because of the slight curvature of the earth, small regions of its surface may be treated as a semi-infinite solid to an excellent approximation. (See Figure 2A8-4.) The semi-infinite solid is assumed to extend indefinitely in the Z direction from a surface taken to be the xy plane. The extent in the xy plane is taken to be infinite in all directions.

2. PROBLEMS NOT INVOLVING FREEZING OR THAWING.

PROBLEM 1

The semi-infinite solid with original temperature T_0 *constant or a linear function of depth* $T_1 = T_0 \left[\frac{dT}{dz}\right]_0 z$, *the surface suddenly brought to and maintained at a temperature* T_s.

The solution is given by the equation

$$T = T_s + (T_o - T_s)\ \text{erf}\,\frac{z}{2\sqrt{\alpha t}} + \left[\frac{dT}{dz}\right]_o z \qquad (2A8\text{-}8)$$

T = temperature distribution at time t
α = diffusivity (See Table 2A8-1.)
t = time

$$\text{erf}\,\theta = \text{probability function} = \frac{2}{\sqrt{\pi}}\int_0^{\theta} e^{-u^2}du$$

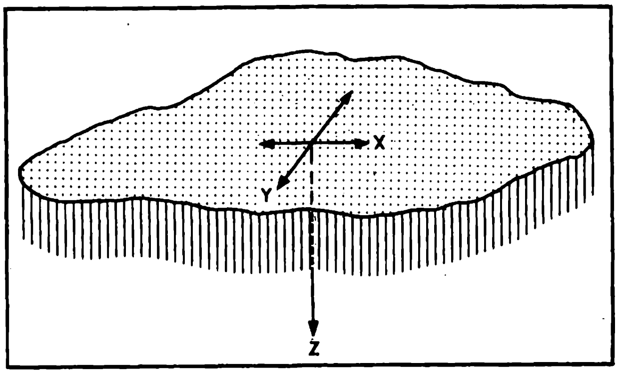


FIGURE 2A8-4

Semi-Infinite Solid (Ref. 35)

(See Figure 2A8-5.) NOTE: The equation $T_i = T_o + \left[\frac{dT}{dz}\right]_o z$ is a fairly good approximation to actual temperature distributions over many regions of the earth's surface, except for periodic variations resulting from daily and seasonal changes in surface conditions. For moderate depths, the term $\left[\frac{dT}{dz}\right]_o z$ is usually nearly negligible.

Example

A large structure is to be built on a concrete slab and the surface maintained at 70° F. The ground on which the building is to be constructed has an original temperature of 40° F, a conductivity $k = 0.50$ Btu/hr/ft/°F, and a diffusivity $\alpha = 0.015$ sq ft/hr. Assume the concrete has the

TABLE 2A8-1

Thermal Conductivities and Diffusivities of Some Common Substances (Ref. 36)

Substance	Density, ρ lb/cu ft	Heat capacity, C_p Btu/lb/° F	Conductivity, k Btu/hr/ft/° F	Diffusivity, $\alpha = \frac{k}{\rho C_p}$ sq ft/hr
Air	0.0805	0.240	0.0140	0.725
Granite	162	0.21	1.44	0.043
Limestone	156	0.22	0.97	0.028
Sandstone	144	0.23	1.44	0.043
Average rock	...	...	1.02	0.046
Ice	58.4	0.502	1.28	0.045
Concrete (1:2:4)	144	0.23	0.53	0.0163
Snow (fresh)	6.2	0.5	0.060	0.0194
Soil (average)	156	0.2	0.56	0.0178
Soil (sandy, dry)	103	0.19	0.152	0.0078
Soil (sandy, 8 percent moist)	109	0.24	0.34	0.0128

Note: See also par. 6 of 2A8.08 and tables in standard handbooks.

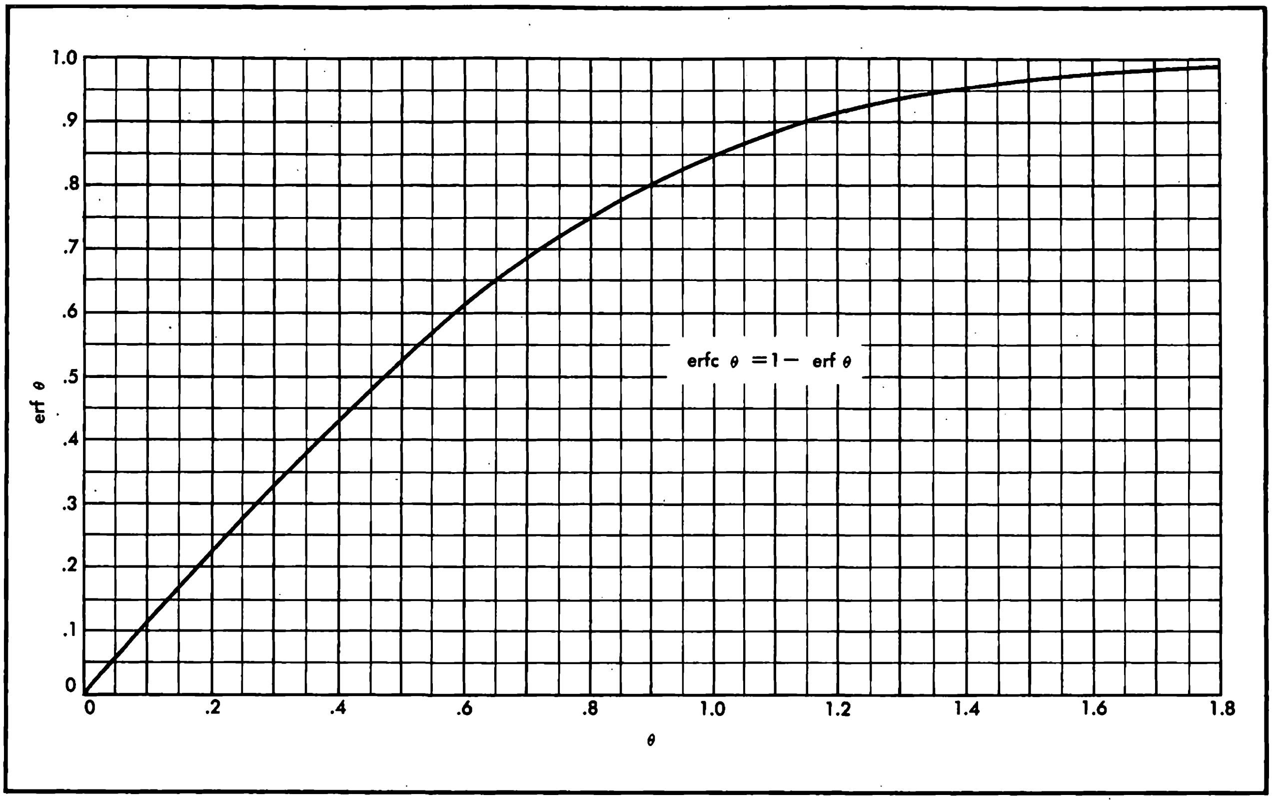


FIGURE 2A8-5

erf and erfc

same conductivity and diffusivity as the soil. Calculate the temperature 6 ft below the slab surface after one month and after one year. Calculate the heat leak through the slab at the same times.

1 mo = 30 days = 720 hr

1 yr = 365 days = 8,760 hr

In order to use Figure 2A8-5,

$$N = \frac{z}{2\sqrt{\alpha t}} = \frac{6}{2\sqrt{0.015 \times 720}} = 0.913$$

$$N = \frac{z}{2\sqrt{\alpha t}} = \frac{6}{2\sqrt{0.015 \times 8{,}760}} = 0.262$$

From Figure 2A8-5,

erf 0.913 = 0.803

$$T = 70 + (40 - 70)0.803 = 45.9° \text{ F}$$

erf 0.262 = 0.288

$$T = 70 + (40 - 70)0.288 = 61.4° \text{ F}$$

Heat leak through the floor ($z = 0$) in Btu/hr/sq ft $= k\,\dfrac{dT}{dz}$.

$$\frac{dT}{dz} = (T_o - T_s)\left[\frac{d\left(\text{erf}\,\frac{z}{2\sqrt{\alpha t}}\right)}{dz}\right] + \left[\frac{dT}{dz}\right]_o$$

Here

$$\left[\frac{dT}{dz}\right]_o = 0$$

$$\frac{d\left(\text{erf}\,\frac{z}{2\sqrt{\alpha t}}\right)}{dz} = \frac{e^{\left(\frac{-z^2}{4\alpha t}\right)}}{\sqrt{\pi\alpha t}}$$

hence

$$\frac{dT}{dz} = (T_o - T_s)\left[\frac{e^{\left(\frac{-z^2}{4\alpha t}\right)}}{\sqrt{\pi\alpha t}}\right]$$

At $z = 0$,

$$e^{\left(\frac{-z^2}{4\alpha t}\right)} = 1$$

For 1 mo, $\sqrt{\pi\alpha t} = \sqrt{(\pi 0.015)(720)} = 5.823$

For 1 yr, $\sqrt{\pi\alpha t} = 20.32$

$$\frac{dT}{dz} = (40 - 70)\,\frac{1}{5.823}$$
$$= -5.13° \text{ F/ft}$$

$$\frac{dT}{dz} = (40 - 70)\,\frac{1}{20.32}$$
$$= -1.46° \text{ F/ft}$$

$k = 0.50$ Btu/hr/ft/°F

$$k\frac{dT}{dz} = -2.56 \text{ Btu/hr/sq ft} \qquad k\frac{dT}{dz} = -0.73 \text{ Btu/hr/sq ft}$$

Alternatively, Figure 2A8-6 may be used to calculate temperatures. Here h, the film coefficient, is to be taken equal to infinity; then $N = \infty$ (that is, the concrete surface and air are assumed to be in perfect thermal contact, so both have the same temperature; but for many purposes this is not a satisfactory approximation).

Using the equation $\phi = \dfrac{z}{\sqrt{\alpha t}}$

For 1 mo,

$$\phi = \frac{6}{\sqrt{(0.015)(720)}} = 1.826$$

For 1 yr,

$$\phi = \frac{6}{\sqrt{(0.015)(8{,}760)}} = 0.524$$

Then, from Figure 2A8-6, with $N = \infty$,

$$M = 0.803 = \frac{T - 70}{40 - 70} \qquad M = 0.288 = \frac{T - 70}{40 - 70}$$

$$T = 45.9° \text{ F} \qquad T = 61.4° \text{ F}$$

PROBLEM 2

The semi-infinite solid with original temperature T_o, ***the flux of heat through the surface being proportional to the difference between the surface temperature*** T_s ***and that of a nearby medium*** T_m; ***that is, in this, the radiation condition,*** $k\dfrac{dT}{dz} + h(T_m - T_s) = 0$, ***where*** h ***is the film coefficient.*** (See par. 2A8.05.)

In many actual cases of heat transfer, this situation is a better approximation to that actually encountered than that described in the previous problem. For example, where there is air or another fluid maintained at temperature T_m in contact with a solid, the surface of the solid is in general at some temperature, T_s, where T_s is not equal to T_m until equilibrium is finally reached. In this case,

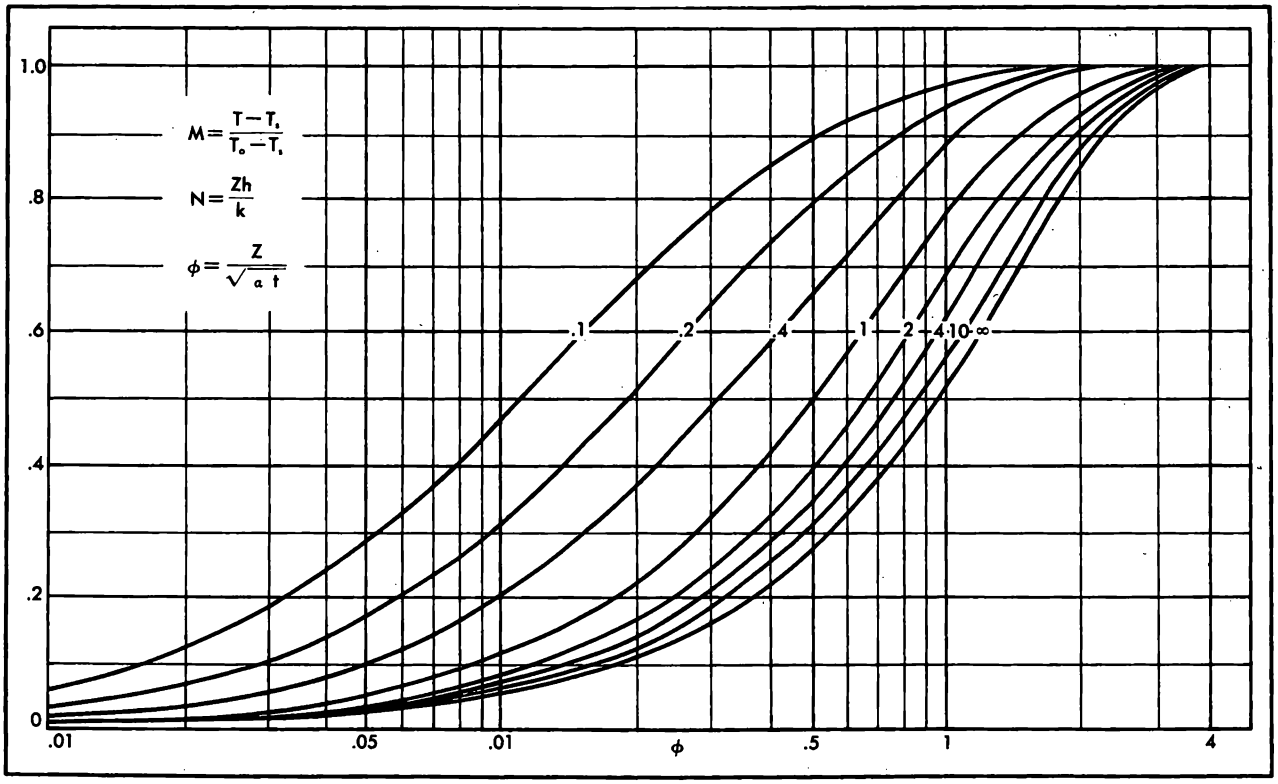


FIGURE 2A8-6

Temperature at Depth Z in Semi-Infinite Solid, With Surface Film Coefficient h, Diffusivity α, Conductivity k, Original Temperature T_o, and Surface Temperature T_s

the flux of heat from the solid to fluid or vice versa is a function of $T_m - T_s$. In other cases where there is imperfect contact between two solids or between a solid and a fluid (for example, because of boiler scale in steam boilers), the same equations apply. The problem has the same type of solution where there is a deliberately introduced insulating layer of negligible heat capacity between the semi-infinite solid and the heat source or sink. Finally, where all the heat transmission is by actual radiation, the same equations apply if the difference in the absolute temperatures of the two media is not too great. Actually, the amount of heat transmitted by radiation is proportional to $(T_m)^4 - (T_s)^4$.

For T_s, T_m is much greater than $(T_m - T_s)$. This reduces approximately to $4T^3(T_m - T_s)$, where T is the average of T_m and T_s.

If T_m is the temperature of the medium to which or from which there is radiation, the following equation applies.

$$\frac{T - T_o}{T_m - T_o} = \operatorname{erfc}\frac{z}{2\sqrt{\alpha t}} - e^{\left(\frac{hz}{k} + \frac{h^2\alpha t}{k^2}\right)} \operatorname{erfc}\left(\frac{z}{2\sqrt{\alpha t}} + \frac{h\sqrt{\alpha t}}{k}\right) \quad \text{(2A8-9)}$$

k, T_o, z, α, and t have the same meaning as in the previous example.

Values for erfc ϕ are given in Figure 2A8-5. Alternatively, Figure 2A8-6 may be used.

Example

Suppose a building is to be built under the same conditions as in the previous problem. Assume, however, that the earth's natural cover is not removed, so that it acts as an insulating layer. Assume this layer to be 1 ft thick, of negligible heat capacity, and with a k value of 0.04 Btu/hr/ft/°F. Calculate the temperature at a depth of 6 ft below the insulating cover after one year.

For use in equation (2A8-9),

$$h = \frac{0.04 \text{ Btu/hr/ft/°F}}{1 \text{ ft}} = 0.04 \text{ Btu/hr/sq ft/°F}$$

$$\frac{z}{2\sqrt{\alpha t}} = 0.262$$

$$\frac{hz}{k} + \frac{h^2\alpha t}{k^2} = 0.48 + 0.84 = 1.32$$

$$\frac{z}{2\sqrt{\alpha t}} + \frac{h\sqrt{\alpha t}}{k} = 0.262 + 0.916 = 1.178$$

$$\frac{T - T_o}{T_m - T_o} = \operatorname{erfc} 0.262 - e^{1.32} \operatorname{erfc} 1.178$$

$$\frac{T - 40}{70 - 40} = 0.712 - 3.75 \times 0.0958 = 0.352$$

$$T = 40 + 30 \times 0.352 = 50.5° \text{ F}$$

Using Figure 2A8-6,

$$N = 0.48$$

$$\phi = 0.524$$

$$M = 0.66 = \frac{T - T_m}{T_o - T_m} = \frac{T - 70}{40 - 70}$$

$$T = 70 - 0.66 \times 30 = 50.2° \text{ F}$$

A comparison of the value calculated here with that obtained in the previous example will show the marked effect of the insulating cover.

PROBLEM 3

Semi-infinite solid with the surface temperature a periodic function of time.

In many cases, both the daily and the seasonal variations in the temperature of the earth's surface may be approximated as a harmonic function of time. For greater accuracy, the surface temperature may be represented by a Fourier series.

(1) Using a simple harmonic function and assuming the mean earth temperature independent of depth and equal to T_o, $T_s = \psi \cos(\omega t - \varepsilon)$ = surface temperature, and

$$T = \psi e^{-z\sqrt{\frac{\omega}{2\alpha}}} \cos\left[\omega t - z\sqrt{2\frac{\omega}{\alpha}} - \varepsilon\right] \quad \text{(2A8-10)}$$

where the period is $\frac{2\pi}{\omega}$. (ψ, ω, and ε are constants.)

Three conclusions can be drawn from equation (2A8-10). (Ref. 36, pp. 48, 63.)

(a) The amplitude of the temperature oscillations diminishes as $e^{-z\sqrt{\frac{\omega}{2\alpha}}}$ and thus falls off more rapidly for large ω. Actually, the temperature oscillations resulting from daily temperature variations become negligible usually at a depth of 3 or 4 ft, and the oscillations resulting from seasonal surface variations become negligible at depths of about 70 ft.

(b) There is a progressive lag in the phase of the temperature wave, $z\sqrt{\frac{\omega}{2\alpha}}$.

(c) The temperature fluctuations, for example, the positions of the maxima and minima of temperature, are propagated into the solid with a velocity $\sqrt{2\alpha\omega}$.

(2) If a series

$$T_s = \psi_o + \psi_1 \cos(\omega t - \varepsilon_1) + \psi_2 \cos(2\omega - \varepsilon_2) + \ldots$$

is used to represent the surface temperature, the temperature at any depth, z, is given by

$$T = \psi_o + \psi_1 e^{-z\sqrt{\frac{\omega}{2\alpha}}} \cos\left(\omega t - z\sqrt{\frac{\omega}{2\alpha}} - \varepsilon_1\right) + \psi_2 e^{-z\sqrt{\frac{\omega}{2\alpha}}} + \cos\left(2\omega t - z\sqrt{\frac{\omega}{\alpha}} - \varepsilon_2\right) + \ldots \quad (2A8\text{-}11)$$

It is to be noted that the above equations can be used to obtain values for diffusivities of soil; however, there are serious limitations that must be considered. Particularly, they are not valid if (a) the moisture content of the soil varies appreciably during the cycle considered, (b) the soil is not homogeneous, or (c) a phase change occurs. Qualitatively, behavior similar to that described above is observed in permafrost regions. Where permafrost is several feet below the surface, an approximate value for the diffusivity may be determined by considering only the daily temperature oscillations; however, difficulties are encountered in this case because of the day to day variations in temperatures, equations (2A8-10) and (2A8-11) being valid only for truly cyclical variations.

PROBLEM 4

The temperature at radius r in a solid, originally at temperature T_0, bounded internally by a cylindrical source or sink of radius r_1, the surface of which is suddenly brought to and maintained at temperature T_s.

This type of problem arises particularly in the case of buried pipes, wells, or shafts. The solutions to the problem and the related ones that follow are presented only in graphical form because of mathematical complexities. (See Figures 2A8-7 and 2A8-8 following, and also 2A8-11.)

Example 1

A structure is to be supported by piles A, B, C, and D (Figure 2A8-9) in a permafrost region where the permafrost temperature is 31° F. In order to obtain sufficient adfreeze strength, it is estimated that a temperature of 28° F must be obtained. Calculate the temperature at the piles if the refrigeration well, X, is maintained at a temperature of 10° F for 10 days. Assume the diffusivity of the permafrost to be 0.04 sq ft/hr, the OD of the well, X, 6 in., and perfect thermal contact between well pipe and soil.

For use in Figure 2A8-9,

$r_1 = 3$ in. $= 0.25$ ft

$r = 48$ in.

$\frac{r}{r_1} = 16$

$\alpha = 0.04$ sq ft/hr

$t = 10 \times 24 = 240$ hr

$$\frac{r_1}{\sqrt{\alpha t}} = \frac{0.25}{\sqrt{0.04 \times 240}} = 0.08$$

From Figure 2A8-7,

$$\frac{T - T_o}{T_s - T_o} = \frac{T - 31}{10 - 31} = 0.135$$

$$T = 31 - 21 \times 0.135 = 28.2° \text{ F}$$

Example 2

A structure is built on a refrigerated foundation to be maintained throughout the year at a temperature of 32° F or less. During the summer, refrigeration is to be accomplished by circulation of brine through the foundation and through wells in permafrost. (See Figure 2A8-10.) Assume the diffusivity of the permafrost to be 0.04 sq ft/hr, $k = 1$ Btu/hr/ft/°F, and the original permafrost temperature 22° F. If the well has an OD of 6 in., calculate the rate of heat flow at the end of two months, assuming the brine has at all times been maintained at 31° F. (Because of the decreasing flux, the situation can be approximated if there are a number of wells and if the circulation is begun by using only one well and then the others as needed.)

For use in Figure 2A8-8,

$k = 1$ Btu/hr/ft/°F

$\alpha = 0.04$ sq ft/hr

$t = 2$ mo $= 60 \times 24 = 1{,}440$ hr

$r_1 = 3$ in. $= 0.25$ ft

$$\frac{\sqrt{\alpha t}}{r_1} = \frac{\sqrt{0.04 \times 1{,}440}}{0.25} = 30.4$$

From Figure 2A8-8,

$$\frac{k(T_s - T_o)}{r_1 Q} = 3.89$$

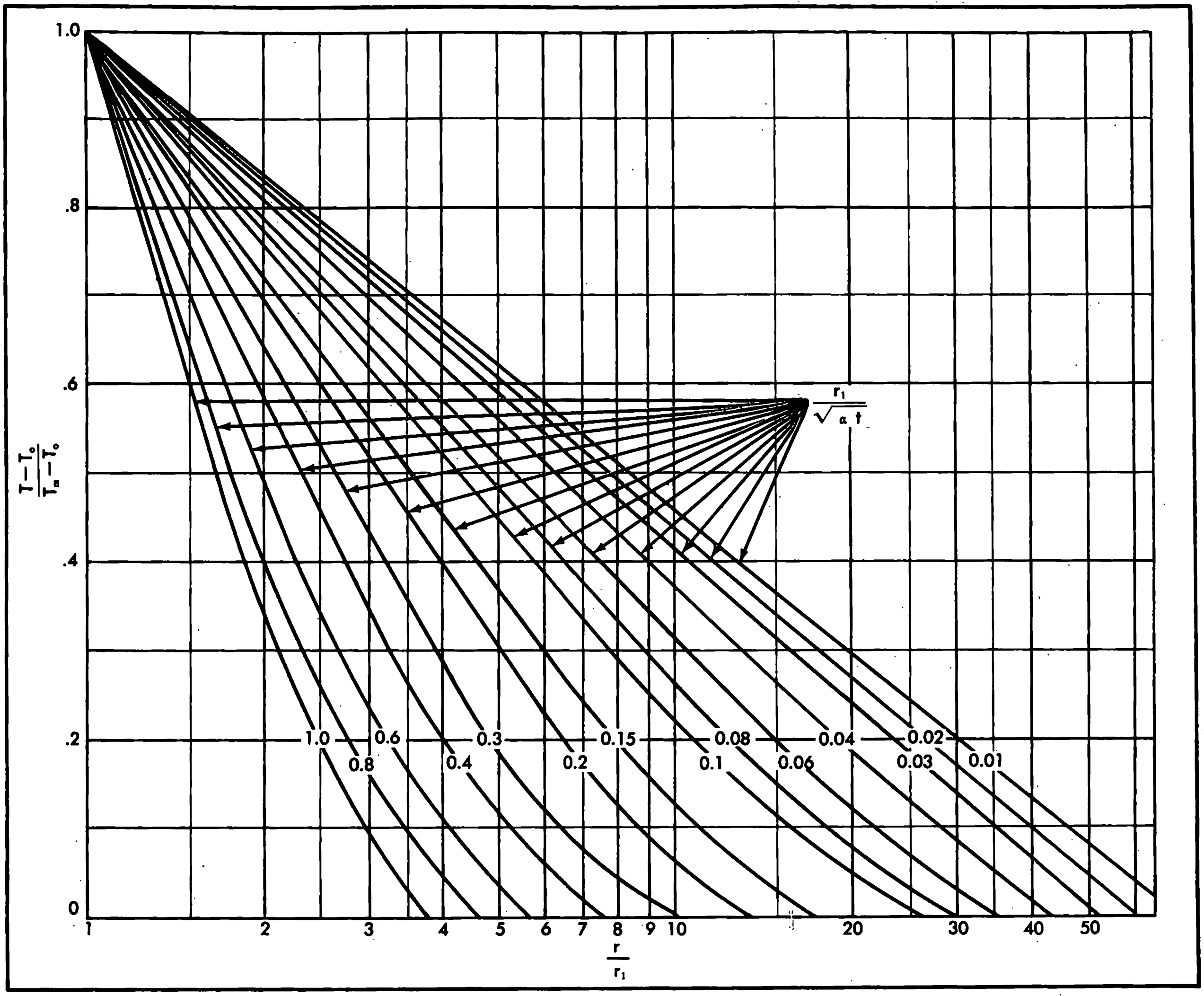


FIGURE 2A8-7

Temperature T at r in Region Originally at T_o, Bounded Internally by Cylindrical Source of Radius r_1 Maintained at T_s

$$Q = \frac{k(T_s - T_o)}{r_1 \times 3.89} = \frac{1(31 - 22)}{0.25 \times 3.89}$$
$$= 9.26 \text{ Btu/hr/sq ft}$$

The circumference is 0.5π ft; thus, the flux is 9.26 × 0.5π = 14.6 Btu/hr/ft length.

When air temperatures are lower than temperatures in the ground at J and K (Figure 2A8-10), valve B is closed; the refrigerant circulates through the radiator, removing heat from the ground through well K and from the foundation and ground through pipes at J. When air temperatures are warmer, C and A are closed and the refrigerant, which removes heat from J, circulates to K, where the heat is removed from the refrigerant by the cold ground; J is thus kept refrigerated throughout the year, using K as a heat sink during the warmer months. (All piping aboveground that is to be covered with insulation is not shown.)

PROBLEM 5

Surface temperature T_s of the region bounded internally by a circular cylinder of radius r_1, with initial temperature T_0 and constant flux Q at the surface.

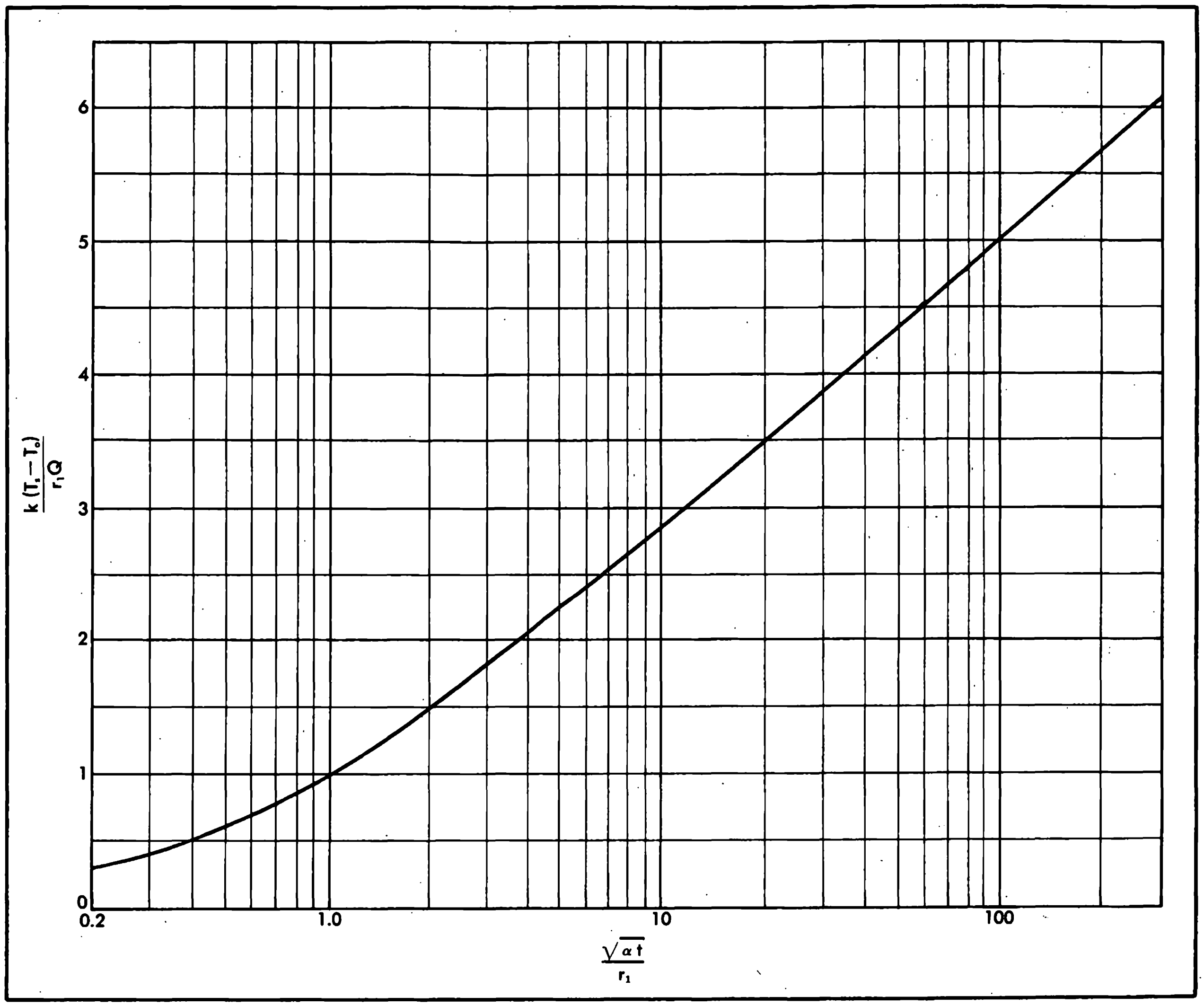


FIGURE 2A8-8

Flux Per Unit Area Q at Surface With Radius r of Region Originally at T_o, Bounded Internally by Cylindrical Source of Radius r, Maintained at T_s

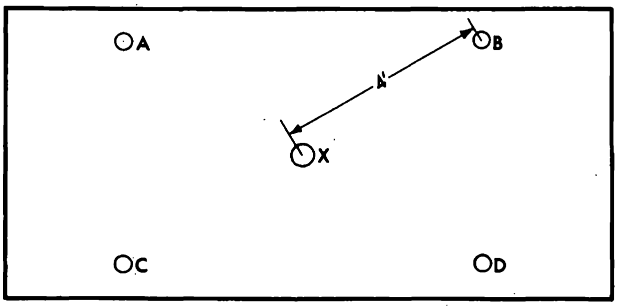


FIGURE 2A8-9

Piling With Refrigerating Well

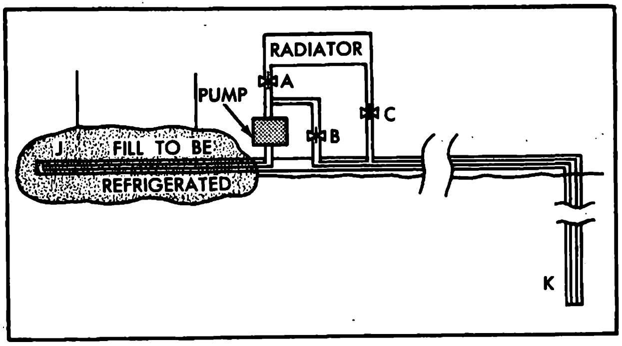


FIGURE 2A8-10

Example of Refrigeration System

Example 1

A condition of this type might be encountered in a situation similar to that in Example 2 of Problem 4. Thus, if the flux Q from the building to the refrigeration pipes in the foundation is approximately constant, equilibrium may be obtained if the rate of refrigeration circulation is so manipulated that the total flux through the well walls is also Q. (Perfect insulation along the connecting pipes is assumed so that there is no heat leak through these pipes.) Calculate T_s after three months, assuming a constant flux through the foundation of 10,000 Btu/hr. Assume the properties of the permafrost are the same as in the previous example and that one well 100 ft deep and 6 in. in diameter and 3 wells, each 300 ft deep and 6 in. in diameter, are available.

For use in Figure 2A8-11,

$k = 1$ Btu/hr/ft/°F
$\alpha = 0.04$ sq ft/hr
$t = 3$ mo $= 2{,}160$ hr
$r_1 = 0.25$ ft

$$\frac{\sqrt{\alpha t}}{r_1} = 37.2$$

From Figure 2A8-11,

$$\frac{k(T_s - T_o)}{r_1 Q} = 4.03 \qquad (T_s - T_o) = \left(\frac{r_1 Q}{k}\right) 4.03$$

One 100-ft well	Three 300-ft wells
$100 \times 0.50 = 157$ sq ft	$900 \times 0.50 = 1{,}413$ sq ft
$Q = \frac{10{,}000}{157} = 63.7$ Btu/hr/sq ft	$Q = \frac{10{,}000}{1{,}413} = 7.08$ Btu/hr/sq ft
$T_s - T_o = \left[\frac{63.7 \times 0.25}{1}\right] 4.03 = 64.2°$ F	$T_s - T_o = \left[\frac{7.08 \times 0.25}{1}\right] 4.03 = 7.1°$ F
$T_s = 22 + 64.2 = 86.2°$ F	$T_s = 22 + 7.1 = 29.1°$ F

The value 86.2° F has, of course, been obtained without taking into consideration possible thawing; the complications resulting from thawing are treated in Example 2 following.

Most structures would, of course, be maintained at temperatures below 86° F. The first solution, therefore, is meaningless in that the flow of heat will simply stop when the well temperature and the temperature of the structure are the same. However, from the calculations it is clear that a single 100-ft well would not be adequate to keep the foundation refrigerated for the three months, although the three 300-ft wells would.

Another constant-flux problem arises as a result of heat generation in buried electrical cables, if the change in resistance with temperature can be neglected. The solution given in Figure 2A8-11 assumes also that the cable is buried at a sufficient depth so that the heat from the cable has a negligible effect at the surface and, further, that the insulation may be assumed to have the same thermal properties as the surrounding materials.

Example 2

Assume a 1-in. copper cable is buried 6 ft below the surface in permafrost with the same thermal properties as in the previous example. Assume the cable has a resistance of 0.000011 ohms/ft and that it carries a current of 500 amp. Calculate the temperature of the cable after the current has been flowing for one month.

For use in Figure 2A8-11,

1 watthr = 3.413 Btu

$$Q = 3.413 \times I^2R = 3.413(500)^2(1.1 \times 10^{-5}) = 9.38 \text{ Btu/ft/hr}$$

$$r_1 = \frac{0.5}{12} = 0.0417 \text{ ft}$$

$\alpha = 0.04$ sq ft/hr
$k = 1$ Btu/hr/ft/°F
$t = 30 \times 24 = 720$ hr

Using Figure 2A8-11,

$$\frac{\sqrt{\alpha t}}{r_1} = \frac{\sqrt{0.04 \times 720}}{0.0417} = 128.6$$

$$Q = \frac{9.38}{2\pi \times 0.0417} \text{ Btu/hr/sq ft}$$

$$\frac{k(T_s - T_o)}{r_1 Q} = 5.27$$

$$T_s - T_o = 0.0417 \left[\frac{9.38}{2\pi \times 0.0417}\right] \left[\frac{5.27}{1}\right] = 7.86° \text{ F}$$

$$T_s = 22 + 7.9 = 29.9° \text{ F}$$

Thus, within one month there will be no thawing. A qualitative consideration, using Figure 2A8-7,

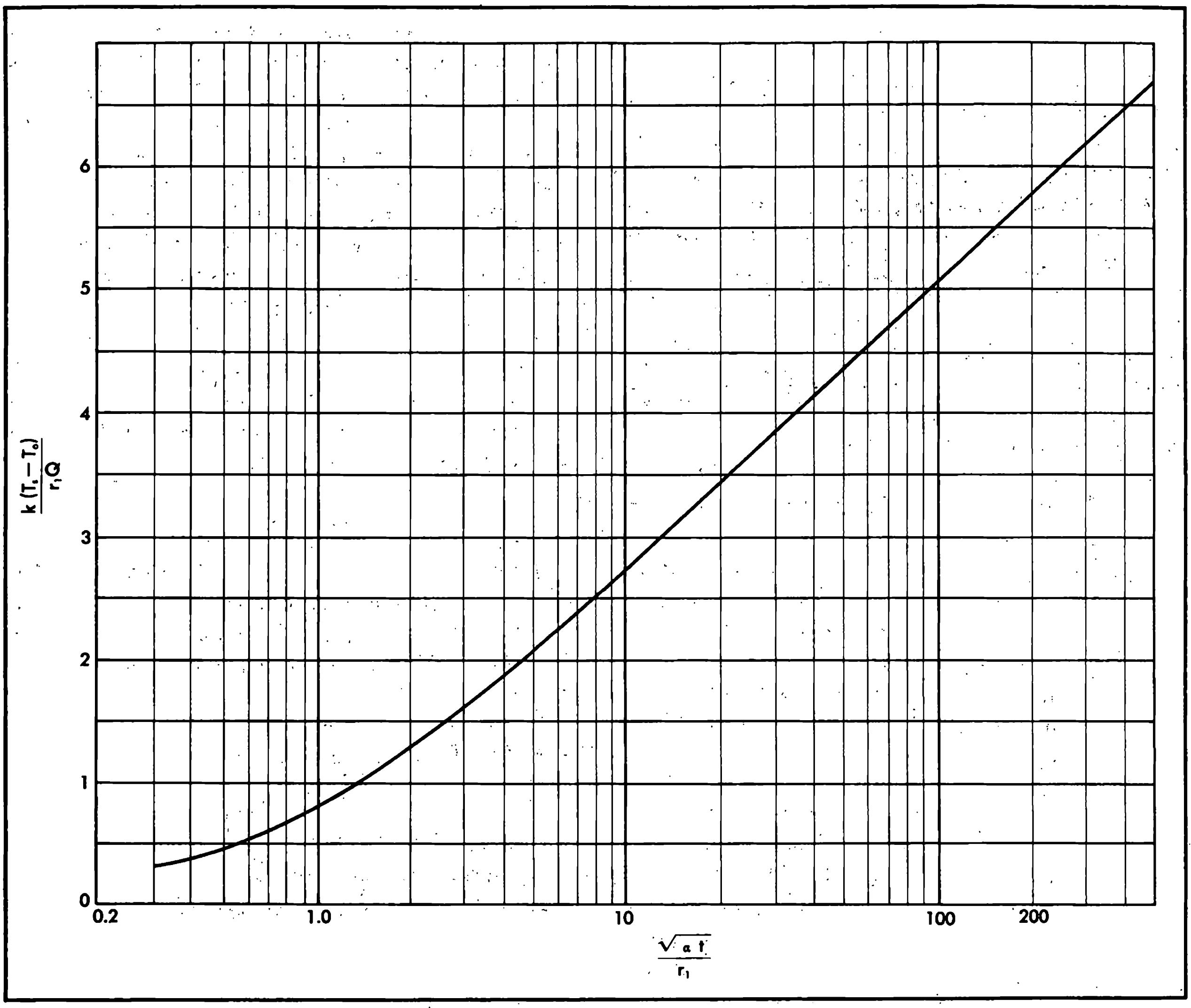


FIGURE 2A8-11

Temperature T_s at Surface With Radius r_1 of Region Originally at T_0, Bounded Internally by Cylindrical Source of Radius r_1, With Constant Flux Q at Surface

will show that at 6-in. depth $\frac{T - T_0}{T_s - T_0}$ is very small; and thus the solution given in Figure 2A8-11 is reasonably valid, that is, surface effects can reasonably be neglected for the period of time considered.

In some cases, the problem of thawing permafrost by steam, water, or sewage pipes or utilidors may be treated approximately as a constant-flux problem.

Example 3

An insulated steampipe is to be buried in permafrost. Calculate the time before thawing of the permafrost begins, assuming the following:

OD of pipe, 6 in.
Insulation thickness 1 ft with $k = 0.04$ Btu/hr/ft/°F
Permafrost originally at 25° F
$k = 1.2$ Btu/hr/ft/°F
$\alpha = 0.04$ sq ft/hr
Steam temperature, 250° F

Because most of the thermal resistance will be provided by the insulation, for a first approximation assume the outside of the pipe also at 250° F.

For a more accurate solution, a steam-to-pipe resistance factor would have to be included. (See Example 4 following.)

In this problem the temperature at the outside of the insulation will rise from 25° to 32° F. Because the difference is small compared to the difference between these temperatures and the steam temperature, the rate of heat flow through the insulation will decrease only slightly as the insulation surface temperature rises from 25° to 32° F. Therefore, as a fairly good approximation, the problem may be treated as one of constant flux. Both 25° and 32° F may be used to calculate upper and lower limits of the flux. If the calculation is carried out on this basis, the true time required for melting to start will lie between the two calculated values. The calculations are summarized herein.

To calculate the flux, steady-state equations (2A8-3) and (2A8-4) are used.

$$A_{\log} = \frac{2\pi(r_2 - r_1)X}{2.3\log_{10}\left(\frac{r_2}{r_1}\right)}$$

$$q = kA_{\log}\left[\frac{T_1 - T_2}{r_1 - r_2}\right]$$

$$q = k\left[\frac{2\pi(r_2 - r_1)X}{2.3\log_{10}\left(\frac{r_2}{r_1}\right)}\right]\left[\frac{T_1 - T_2}{r_1 - r_2}\right]$$

$$= k\left[\frac{2\pi X(T_2 - T_1)}{2.3\log_{10}\left(\frac{r_2}{r_1}\right)}\right]$$

Assuming insulation surface = 25° F,

$$q = 0.04\left[\frac{2\pi X(250 - 25)}{2.3\log_{10}\left(\frac{0.25}{1.25}\right)}\right] = -35.1X$$

Assuming insulation surface = 32° F,

$$q = 0.04\left[\frac{2\pi X(250 - 32)}{2.3\log_{10}\left(\frac{0.25}{1.25}\right)}\right] = -34.0X$$

At insulation surface, q per unit area is

$$Q = \frac{-35.1X}{2\pi X(1.25)} = -4.47 \text{ Btu/hr/sq ft} \qquad Q = \frac{-34.0X}{2\pi X(1.25)} = -4.33 \text{ Btu/hr/sq ft}$$

For use with Figure 2A8-11, $\frac{k(T_s - T_o)}{r_1 Q}$ equals

$$\frac{1.2(32 - 25)}{1.25(4.47)} = 1.50 \qquad \frac{1.2(32 - 25)}{1.25(4.33)} = 1.55$$

Using Figure 2A8-11, $\frac{\sqrt{\alpha t}}{r_1}$ equals

2.65   2.80

$$t = \frac{2.65^2(1.25^2)}{0.04} = 274 \text{ hr} = 11.4 \text{ days} \qquad t = \frac{2.80^2(1.25^2)}{0.04} = 306 \text{ hr} = 12.8 \text{ days}$$

Example 4

A concrete utilidor is buried in permafrost with the same properties as in the previous Example. Calculate the time before thawing begins, assuming the following additional information.

The utilidor may be assumed circular, with a 7-ft ID and 6-in. concrete walls; $k = 0.5$; and ambient temperature in the utilidor, 50° F. Assume also that a 1-ft layer of consolidated material with a k value of 0.5 surrounds the utilidor.

The problem may be solved as previously. But instead, only one calculation is made, assuming the temperature at the outer surface of the consolidated material is 30° F for calculating the flux.

Using the arithmetic average radius (4.25) instead of the logarithmic radius (par. 2A8.03) to calculate the heat transmitted through the pipe plus consolidated material,

$$q_1 = 2\pi X(4.25)0.5(T_p - 30)$$

where T_p is the temperature of the inner surface of the utilidor. This must equal the heat transmitted from the air to the pipe.

$$q_1 = q_2 = 2\pi X(3.5)h(50 - T_p)$$

where h is the film coefficient.

As an approximation, assume

$h = 0.27\Delta T^{0.25}$ (See Table 2A8-8.)

$$(T_p - 30)2\pi X(4.25)(0.5) = 2\pi X(3.5)(0.27)(50 - T_p)^{1.25}$$

$$2.2(T_p - 30) = 0.945(50 - T_p)^{1.25}$$

$$T_p = 39.0$$

$$q = 2X(4.25)(0.5)(39 - 30)$$

$$Q = \frac{q}{A} = \frac{(4.25)(0.5)(39 - 30)}{5}$$

at the outer surface of consolidated material.

For use with Figure 2A8-11,

$$\frac{k(T_s - T_o)}{r_1 Q} = \frac{1.2(32 - 25)}{\frac{5(4.25)(0.5)(39 - 30)}{5}} = 0.44$$

From Figure 2A8-11,

$$\frac{\sqrt{\alpha t}}{r_1} = 0.48$$

$$t = \frac{(0.48)^2 5^2}{0.04} = 144 \text{ hr} = 6 \text{ days}$$

Examples 3 and 4 indicate the danger of running uncooled piping or utilidors over permafrost if the permafrost is incapable of supporting the loads when thawed.

The use of heated cylindrical sources for the determination of thermal conductivity and diffusivity of soil in place has been suggested by Misener, Hooper, and others (Ref. 35, pp. 51, 57). Although a number of different conditions may be used, those to which Figure 2A8-11 is applicable are probably the simplest. The requirement here is that a cylindrical source be heated with a regulated current so that the flux is constant. Measurements of the temperature at the source can then be used to determine the values of k and α. The probe should be of sufficiently small heat capacity so that an appreciable fraction of the energy will not be used in raising its temperature, and it must be in good thermal contact with the ground so that its temperature will be representative of ground temperature at its surface. Temperature-responsive elements should be placed near the center of the probe to avoid end effects. If heat flow along the probe is not kept at a low level, it must be considered in the calculation.

Example 5

Suppose a steel pipe 1 in. in diameter and 8 ft in length, with an internal resistance heating element and thermocouples soldered to the pipe near its center, is used. (See Figure 2A8-12.) After the pipe has come to the same temperature as the ground, heating is begun, using 110 v. Assume the current remains approximately constant at 0.328 amp. If the original soil temperature is 24° F and the pipe temperatures are 28.5° F and 30.0° F after 2 and 10 hours respectively, calculate α and k.

Using Figure 2A8-11,

$$r_1 = 0.5 \text{ in.} = \frac{1 \text{ ft}}{24}$$

$$Q = \frac{110 \text{ v} \times 0.328 \text{ amp} \times 3.413 \text{ Btu/hr/watt}}{8 \text{ ft} \times \frac{2\pi}{24} \text{ sq ft/ft}}$$

$$= 58.6 \text{ Btu/hr/sq ft}$$

$t = 2$ hr	$t = 10$ hr
$T_s - T_o = 28.5 - 24 = 4.5°$ F	$T_s - T_o = 6.0°$ F
$\frac{k(T_s - T_o)}{r_1 Q} = \frac{k(4.5)}{1/24(58.6)} = 1.84k$	$\frac{k(T_s - T_o)}{r_1 Q} = 2.46k$
$\frac{\sqrt{\alpha t}}{r_1} = \frac{\sqrt{2\alpha}}{1/24} = 34\sqrt{\alpha}$	$\frac{\sqrt{\alpha t}}{r_1} = 76\sqrt{\alpha}$

By successive approximation, using Figure 2A8-11: As a first approximation, assume $k \doteq 1$; then for 2 hours

$$k\frac{(T_s - T_o)}{r_1 Q} = 1.84$$

Using Figure 2A8-11,

$$\frac{\sqrt{\alpha t}}{r_1} = 3.88$$

$$\sqrt{\alpha} = \frac{3.88}{34} = 0.114$$

Similarly, for 10 hours

$$\sqrt{\alpha} = 0.100$$

These values are significantly different. This means that the first assumed value of k is in error. Different values of k are assumed until the calculated values of α are the same for both times. Alternatively, values of α could be assumed and

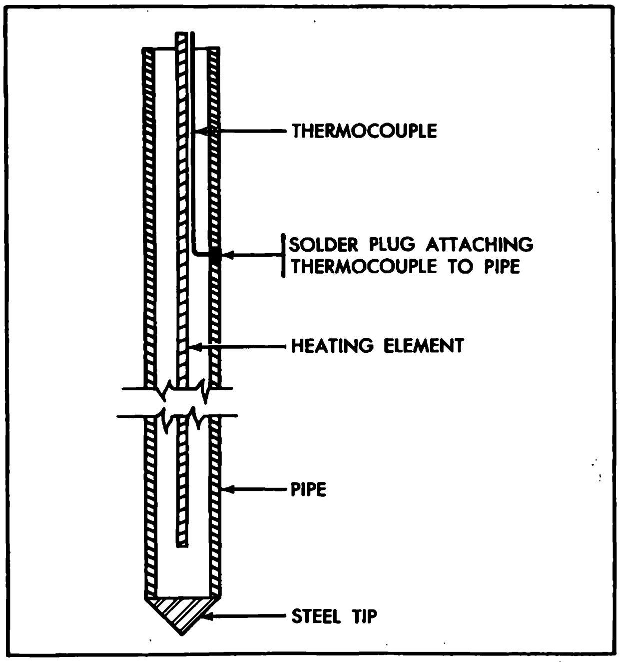


FIGURE 2A8-12

Probe To Determine Conductivity and Diffusivity (Ref. 35)

values of k calculated until they agree. However, α may vary among different soils, as a rule more than k; hence, more guesses may be required. The successive approximations are summarized here.

k	$\sqrt{\alpha}$ (*using 2-hr equations*)	$\sqrt{\alpha}$ (*using 10-hr equations*)
1	0.144	0.100
2	0.777	2.64
1.2	0.172	0.167
1.25	0.190	0.189

Therefore,

$k = 1.25$ Btu/hr/ft/°F

$\sqrt{\alpha} = 0.190$

$\alpha = 0.036$ sq ft/hr

NOTE: In the above determination, a precise knowledge of the temperatures is required. For example, if the temperature after 2 hours is 28.7° F and the temperature after 10 hours is 29.9° F, the values of 1.58 and 0.165 are obtained for k and α respectively. The necessary high precision can best be obtained by using resistance thermometers or thermistors in place of thermocouples. (See par. 1 of 2A8.08.) As a much less satisfactory alternative, several thermocouples may be installed, an average taken of more than two measurements made, and an average of the several calculated values for k and α used. Finally, the rate of heat input may be increased or the time intervals increased to obtain greater temperature differences. If, however, the measurements are to be made on permafrost, all temperatures must, of course, remain below 32° F.

3. PROBLEMS INVOLVING FREEZING OR THAWING. The foregoing development and examples have all neglected to consider the possibilities of freezing and thawing in soil. Unfortunately, these problems, which are by far the most important, are also difficult from a mathematical point of view, and little has yet been done with regard to their solution. The solutions that follow are only approximate.

PROBLEM 1

The existence and lower limits of permafrost.

For permafrost to exist without change from year to year, the average annual temperature gradient in the ground in a homogeneous soil layer below maximum seasonal thaw must remain the same. Inasmuch as heat flows from the depths of the earth to the surface, the temperature gradient must be negative toward the surface because heat always flows from warmer toward cooler regions. The depth of the bottom of permafrost is a function of the natural temperature gradient in the ground and of the mean annual surface temperature. When the mean annual surface temperature and the temperature gradient in the soil are known, a projection of the gradient to 32° F gives the approximate depth of permafrost, provided the soil characteristics in the projected depth are the same as in the known depth.

If the mean annual temperature of the surface or any soil layer below the surface is raised, the heat balance is destroyed and the natural temperature gradient is changed. The new temperature gradient from the bottom to the top of permafrost decreases the heat flow from the bottom and, because the heat flow from the depths of the earth does not change, less heat flows to the ground surface from the bottom of permafrost than is received there, resulting in thaw at the latter plane. In other words, raising the mean annual temperature of the earth's surface causes a decrease in the thickness of permafrost. This thawing at the bottom of permafrost is very slow, but it continues until the heat flowing to and from the bottom of permafrost is in equilibrium. (Ref. 37, p. 33.) For most purposes, this type of thawing need not be considered.

It should be noted that permafrost can exist even when the mean annual temperature is greater than 32° F because of differences in the summer and winter surface correction factors. (See Table 2A8-2.) On the other hand, a mean annual temperature of appreciably less than 32° F does not necessarily assure the existence of permafrost for the same reason.

PROBLEM 2

Thawing and the depth of permafrost under buildings and other structures.

This problem is particularly important when construction is necessary in regions where the water content of the permafrost is great, where the soil is clayey or silty when thawed, and where there is apt to be ground-water movement. Under any of these circumstances, severe settlement and/or heaving is to be anticipated if adequate precautions are not taken in the construction of founda-

TABLE 2A8-2

Correction Factors for Various Surfaces (Ref. 37)

Type of surface	Correction factor	
	Winter	Summer
1. Spruce trees, brush, and moss over peat soil	0.29	0.37
2. Cleared of trees and brush, but with moss in place over peat soil	0.25	0.73
3. Silt loam cleared and stripped of trees and vegetation	0.33	1.22
4. Gravel	0.70	2.00
5. Concrete	0.77	2.03
6. Bituminous	0.72	2.19

Note: Snow was removed from surfaces 4, 5, and 6. Snow was not removed from surfaces 1, 2, and 3.

tions. (See Section 2A6.) In almost any construction on such materials, some precautions must be taken if the structure is to be permanent or semipermanent. Two possible foundations are illustrated in Figure 2A8-13.

In (A) of Figure 2A8-13, piles are driven or preferably set. (See par. 2A6.05.) In order to support the load, it is necessary that the permafrost in the immediate vicinity of the pilings remain frozen. (It may be necessary that the temperature immediately adjacent to the pilings remain appreciably below 32° F if sufficient adfreeze is to be maintained. (See par. 2 of 2A9.02.)

In (B) of Figure 2A8-13, some of the material of the active zone has been removed and replaced by a gravel or other consolidated material capable of supporting the load in the thawed state. If there is to be no settlement or heaving, it is necessary to assure that at all times the 32° F geo-isotherm is within the fill. (See par. 3 of 2A8.04.)

Given below are derivations of approximate equations for calculating the depth of the 32° F geo-isotherm. (Ref. 37.)

In order to thaw a layer of permafrost of thickness Z and a 1-sq-ft area, ZL Btu are required, where L is the latent heat of fusion in Btu/cu ft of the water in the soil. In the case of one thawing layer, the average thermal resistance during the period that thaw is taking place may be written $R_{av} = \frac{R_z}{2}$ or $\frac{Z}{2k}$. The heat, Q, transferred into 1 sq ft of ground is $\frac{24I_g}{R_{av}}$, where I_g is the ground thawing index in degree-days, R the thermal resistance, and k the thermal conductivity of the thawed soil. The thawing index is obtained by summation of the number of degree-days of thaw during the thawing season. (To obtain I_g, ground temperatures must be used or else a correction factor applies, as indicated below.) If the heat re-

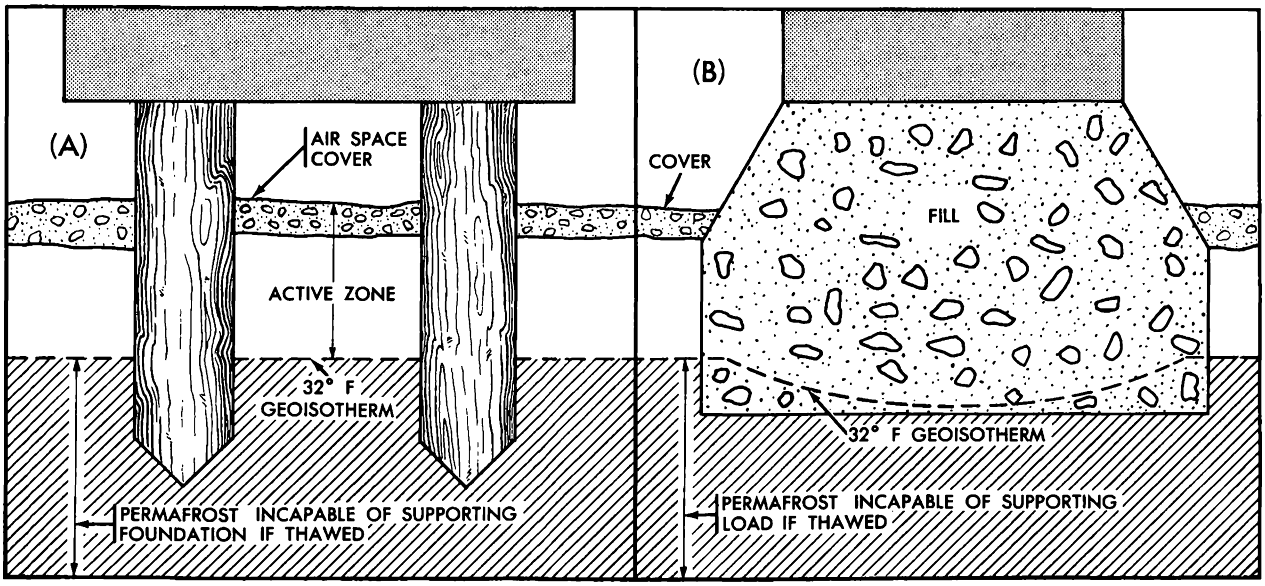


FIGURE 2A8-13

Possible Foundations in Permafrost Areas

quired to change soil temperatures is neglected, the value Q is equal to the heat required for fusion. Thus,

$$ZL = \frac{24I_g}{\frac{R_z}{2}} = \frac{48I_g k}{Z} \qquad \text{(2A8-12a)}$$

Because air temperatures, which are normally used in calculating thawing indexes, are not the same as ground temperatures, a correction factor, S, must be included in the above equation if air temperatures are used. (See Table 2A8-2.)

Thus,

$$ZL = \frac{48I_a kS}{Z}$$

where I_a = air thawing index.

Calculating the depth of thaw,

$$Z = \frac{\sqrt{48kI_aS}}{L} \qquad \text{(2A8-12b)}$$

$L = 1.434w\rho$, where w is the water content of the soil in percentage of dry weight and ρ is the dry density of the soil in lb/cu ft.

Failure to take into account in the above equation the heat required to raise ground temperatures results in a calculated depth of thaw greater than actually occurs. However, if the water content of the soil is large and the temperatures near 32° F, the difference is small. A more exact calculation will take into account the heat required to raise ground temperatures. Thus, the heat required to raise the temperature of the thawed soil to the mean temperature during the thawing period is

$$\frac{I_g\rho z}{2t}\left[\frac{w}{100} + C_p\right] \quad \text{or} \quad \frac{I_aS\rho z}{2t}\left[\frac{w}{100} + C_p\right]$$

z = thickness of soil layer in feet
C_p = specific heat of dry soil
t = number of days in thawing period

The amount of heat required to raise the temperature of the frozen soil to 32° F is

$$(32 - T_o)(0.5\frac{w\rho z}{100} + C_p\rho z)$$

where T_o is the mean annual soil temperature and the C_p for ice is 0.5. For homogeneous permafrost extending to surface, $z = Z$.

$$ZL + \frac{I_aS\rho Z}{2t}\left[\frac{w}{100} + C_p\right] + Z(32 - T_o)(0.5\frac{w\rho}{100} + C_p\rho) = \frac{48I_akS}{Z}$$

$$Z = \sqrt{\frac{48I_akS}{L + \frac{I_aS\rho}{2t}\left[\frac{w}{100} + C_p\right] + (32 - T_o)\left[\frac{0.5w\rho}{100} + C_p\rho\right]}} \qquad \text{(2A8-13)}$$

The depth of thawing in ground composed of two or more different strata of materials may be computed very closely by determining the part of the annual corrected thawing index required to melt the ice in the voids of each stratum. The summation of these partial indexes in the various strata, equal to the annual corrected thawing index for the locality and existing ground surface, may be used to determine the depth of thaw. From equation (2A8-12a) the partial index required to melt the ice in the top layer is

$$I_1 = \left(\frac{L_1z_1}{24}\,\frac{R_1}{2}\right)$$

L_1 = latent heat of water/cu ft of soil
z_1 = thickness of soil layer in ft
$R_1 = \frac{z_1}{k_1}$ = thermal resistance of soil layer
k_1 = thermal conductivity of soil layer

The partial index required to melt the ice in the second layer is

$$I_2 = \frac{L_2z_2}{24}\left[R_1 + \frac{R_2}{2}\right]$$

The partial index required to melt the ice in the *n*th layer is

$$I_n = \frac{L_nz_n}{24}\left[\Sigma R + \frac{R_n}{2}\right] = \frac{L_nz_n}{24}\left[\Sigma R + \frac{z_n}{2k_n}\right] \qquad \text{(2A8-14)}$$

The summation of partial indexes $I_1 + I_2 + \ldots + I_n$ is equal to the annual corrected thawing index. The total depth of thaw Z is equal to $z_1 + z_2 + \ldots + z_n$. The term z_n may be equal to or less than the thickness of the *n*th layer. (Ref. 37.)

Example 1

A sample computation of depth of thaw in ground composed of several different soil layers is given in Table 2A8-3. The thawing index for 1947, based on air temperatures at Fairbanks, was 3,055. The correction factor for a bituminous surface is 2.19. (See Table 2A8-2.) Values for thickness, density, and moisture content of the various soils are based on field tests. (Ref. 37.)

TABLE 2A8-3

Computed Depth of Thaw (Ref. 37)

Layer material	z Thickness of layer, ft	ρ Dry density of soil, lb/cu ft	w Water content of soil, percent of dry wt	L 1.434 wρ Volumetric latent heat of fusion	k Thermal conductivity, Btu/sq ft/hr/°F/ft	$R = \frac{z}{k}$ Thermal resistance	ΣR	$\Sigma R + \frac{R_n}{2}$	I = Thawing index[1] Increment	Summation
1. Asphalt	0.4	150	0	0	$\frac{10.3}{12} = 0.86$	0.47	0	0.24	0	0
2. Gravel (GW)	3.8	143	3.7	759	$\frac{22.0}{12} = 1.83$	2.08	0.47	1.51	$\frac{759 \times 3.8 \times 1.51}{24} = 181$	181
3. Silt (MH)	2.5	99	27.7	3,932	$\frac{10.0}{12} = 0.83$	3.02	2.55	4.06	$\frac{3{,}932 \times 2.5 \times 4.06}{24} = 1{,}665$	1,846
4. Peat	1.5	25	81.9	2,936	$\frac{2.0}{12} = 0.17$	8.80	5.57	9.97	$\frac{2{,}936 \times 1.5 \times 9.97}{24} = 1{,}824$	3,670
5. Silt and peat	1.0	62	50.0	4,445	$\frac{6.0}{12} = 0.50$	2.00	14.37	15.37	$\frac{4{,}445 \times 1.0 \times 15.37}{24} = 2{,}840$	6,510
6. Silt and peat	z = 0.05 9.25	78.2	39.5	4,429	$\frac{7.5}{12} = 0.63$	$\frac{z}{0.63}$	16.37	$16.37 + \frac{z}{1.26}$	$\frac{4{,}429 \times z \times \left(16.37 + \frac{z}{1.26}\right)}{24} = 180$	6,690

Note: Thawing index for 1947 based on air temperature = 3,055. Corrected = 3,055 × 2.19 = 6,690.

[1] $I_1 = \frac{L_1 z_1}{24}\left(\frac{R_1}{2}\right)$ $I_2 = \frac{L_2 z_2}{24}\left(R_1 + \frac{R_2}{2}\right)$ $I_3 = \frac{L_3 z_3}{24}\left(R_1 + R_2 + \frac{R_3}{2}\right)$ $I_n = \frac{L_n z_n}{24}\left(\Sigma R + \frac{R_n}{2}\right)$

Solving for z in layer 6, $I_6 = \frac{L_6 z_6}{24}\left(\Sigma R + \frac{\gamma z_6}{2k}\right)$

$$180 = \frac{4{,}429 z}{24}\left(16.37 + \frac{z}{1.26}\right)$$

z = 0.05 ft: computed depth = 9.25; actual depth = 10.2

Computed depths of thaw for uniform layers of peat, silt loam, sand, and gravel from Northway and the research area near Fairbanks are shown in Figure 2A8-14. It may be noted that for a given density condition large variations in moisture content have very little effect on the depth of thaw in peat and silt loam and that the variation in depth beween the high and low density conditions is only a few feet. From the knowledge of the fact that the thermal conductivity increases generally as the moisture content increases, it may appear strange that the depth of thaw does not also increase as the moisture content is increased. However, the latent heat of fusion capacity of the soil varies in proportion to the moisture content and, in the case of the peat and silt loam studied, acts very nearly to compensate for the increase in the thermal conductivity. In the case of sand or gravel, the latent heat of fusion capacity increases faster than the effect of thermal conductivity, and as a result the depth of thaw is less in wet than in dry sand or gravel. The effect of density on depth of thaw is very pronounced in sand or gravel, with a range of about 15 ft from maximum to minimum. High density in either silt loam or gravel causes thawing to greater depths than does low density. It is evident that greater depths of thaw are likely to occur in coarse-grained material, such as gravel, than in fine-grained material, such as silt loam. (Ref. 37.)

Examination of Table 2A8-2 will show that correction factors for summer are very much greater than for winter. Thus, backfreezing during the winter will be relatively less effective under a bituminous surface than thawing. Consequently, at the end of each successive summer of thawing, the upper surface of the permafrost will be lower. Calculation of the depth after more than one summer can be made by taking a total thawing and freezing index for the period considered. In doing so, the freezing index (using the winter correction factor) must be subtracted from the thawing index (using the summer correction factor).

Thawing under a building depends to a large extent on the size of the building. A long, narrow

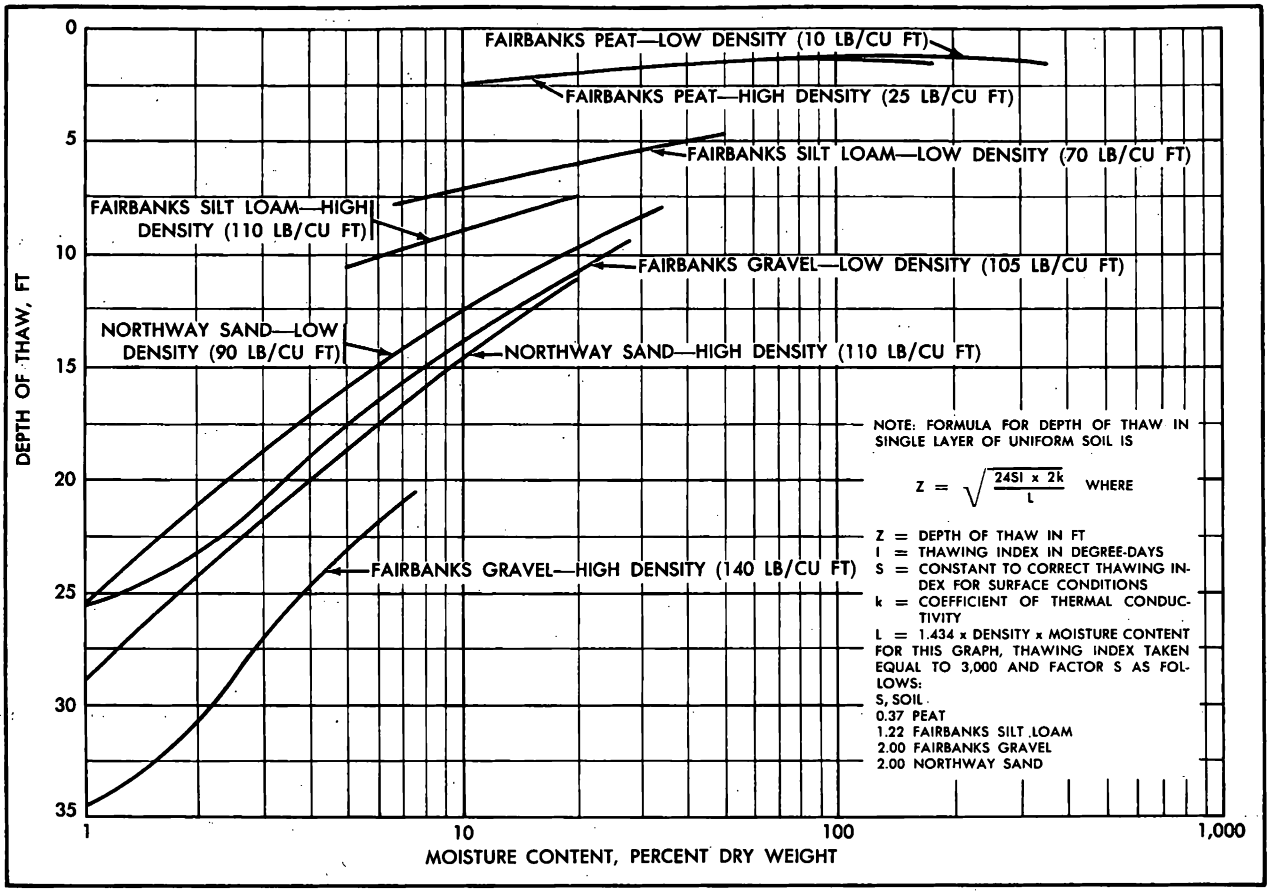


FIGURE 2A8-14

Computed Depth of Thaw in Peat, Silt Loam, Sand, and Gravel, Fairbanks, Alaska (Ref. 37)

building will have a lesser depth of thaw than a square building with the same ground area because of the difference in heat flow laterally. In general, the depth of thaw in permafrost under a building subject to a uniform interior heat condition is proportional to the square root of the time during which the heat condition is maintained. (Ref. 37.) This may be deduced from equation (2A8-12b). NOTE: Here I_aC may be replaced by T_t, where t is the time in days of thawing and T the difference between building floor and permafrost surface.

Example 2

A sample calculation using equation (2A8-13) and available data from observations of the hangar at Northway Airfield, Alaska, follows, based on uniform soil conditions and the assumption that there is no lateral heat flow.

For sandy soil,

$$w = 25 \text{ percent}$$

$$\rho = 93 \text{ lb/cu ft}$$

$$k = \frac{19.5}{12} = 1.62$$

$$C_p = 0.17$$

$$T = 60^\circ \text{ F (at floor surface)} - 32^\circ \text{ F} = 28^\circ \text{ F}$$

$$L = 143.4\, w\rho = 143.4 \left(\frac{25}{100}\right) 93$$

$$= 3{,}334 \text{ Btu/cu ft}$$

The hangar was constructed in 1943 and heating started on 1 Nov 1943.

(1) Where computed depth of thaw from time of construction to 1 Nov 1945 ($t = 730$ days) is found, in the following equation, to be

$$Z = \sqrt{\frac{48 \times 1.62 \times 28 \times 730}{3{,}334 + \frac{28 \times 93}{2}(0.25 + 0.17)}}$$

$$= \sqrt{\frac{1{,}590{,}000}{3{,}334 + 560}} = \sqrt{408} = 20.2 \text{ ft}$$

NOTE: In this equation the term for the heating of the frozen ground to the melting point

$$(32 - T_o)(0.5 \frac{w\rho}{100} + C_p\rho)$$

has been omitted. The resulting error is very small because permafrost temperatures in the Fairbanks region are close to 32° F. Lateral flow will become particularly important as the depth of thaw approaches the building dimensions; thus, the value of Z for 30 years may be appreciably too large.

(2) Where computed depth of thaw from time of construction to 1 Nov 1946 ($t = 1{,}095$ days) is

$$Z = 20.2\sqrt{\frac{1{,}095}{730}} = 20.2 \times 1.225 = 24.8 \text{ ft}$$

Actual depth was 22.5 ft.

(3) Where computed depth of thaw in 10 years ($t = 3{,}650$ days) is

$$Z = 20.2\sqrt{\frac{3{,}650}{730}} = 20.2 \times 2.24 = 45.2 \text{ ft}$$

(4) Where computed depth of thaw in 30 years ($t = 10{,}950$ days) is

$$Z = 20.2\sqrt{\frac{10{,}950}{730}} = 20.2 \times 3.88 = 78.4 \text{ ft}$$

The size of this building is 162 by 208 ft, and the concrete floor was placed directly on a sand and gravel fill. For a building with a large ground area, these calculated depths would be very nearly correct at the center of the area. However, lateral heat flow would reduce the accuracy at the edges. (See Ref. 37, p. 31.)

It should be emphasized that the foregoing methods are definitely approximate, even with the inclusion of factors that consider the heating of the thawed ground. Particularly, not all of the flow of heat into the permafrost prior to melting has been considered. Because of this, even equation (2A8-13) will still give calculated depths of thaw greater than those observed. If the permafrost temperature is near 32° F, the resulting error is particularly small.

PROBLEM 3

Freezing and thawing in still, fresh water.

Carslaw and Jaeger (Ref. 36, p. 73) have given a theoretical treatment of this problem after Neumann. The solution is strictly applicable only for pure water. If the water is moving rapidly, the values of α and J for still water are of course not applicable.

This development further presupposes a constant surface temperature, T_s. Obviously, an average value will generally have to be used in place of this, and if air temperatures are used, a correction factor will have to be included.

$$Z = J\sqrt{t}$$

Z = depth of ice
t = time

Values of k for different temperature conditions are given in Table 2A8-4.

T_s = surface temperature of ice
T_l = liquid temperature as Z approaches ∞ (or bottom of pond)
J is given in cgs units and °F

NOTE: J is approximately equal to $0.012\sqrt{T_s}$.

TABLE 2A8-4

Values of k for Different Temperature Conditions

T_s		T_l					
°C	°F	0° C 32° F	1° C 33.8° F	2° C 35.6° F	3° C 37.4° F	4° C 39.2° F	5° C 41.0° F
−1	30.2	0.012	0.012	0.011	0.011	0.011	0.010
−2	28.4	0.017	0.017	0.016	0.016	0.016	0.015
−3	26.6	0.021	0.020	0.020	0.020	0.019	0.019
−4	24.8	0.024	0.023	0.023	0.023	0.022	0.022
−5	22.0	0.027	0.026	0.026	0.026	0.025	0.025

Example 1

Assuming no supercooling, calculate the ice thickness and the rate of ice formation in a still pond after the surface of the water has been kept at an average temperature of −5° C (22° F) for a period of 10 days, assuming an average value of 2° C (35.6° F) for the water near the bottom of the pond.

$t = 10 \times 24 \times 3{,}600$ sec

$Z = 0.026\sqrt{10 \times 24 \times 3{,}600} = 24.2$ cm

$$\frac{dZ}{dt} = \frac{J}{2\sqrt{t}} = \frac{0.026}{2\sqrt{10 \times 24 \times 3{,}600}}$$
$$= 1.4 \times 10^{-5} \text{ cm/sec}$$
$$1.4 \times 10^{-5} \times 3{,}600 = 0.05 \text{ cm/hr}$$

PROBLEM 4

Thawing and freezing of ground, using cylindrical sources or sinks.

Thawing of ground to limited depths can be accomplished by removing the insulating cover in spring, but for deep thawing the most common procedure is to sink either steam points or wells through which steam or water can be circulated. The reverse problem arises when it is desirable to freeze ground or to keep it frozen to great depths.

A development similar to that used in Example 2 of this problem may be used to obtain an approximate solution.

$$t = \frac{\left[r_2^2 ln\left(\frac{r_2}{r_1}\right) + \frac{r_1^2 - r_2^2}{2}\right] \rho \left[1.434w + C_p(T_{av} - T_2) + \frac{w}{100}(T_{av} - 0.5T_2 - 16)\right]}{48k(T_1 - 32)} \quad \text{(2A8-15a)}$$

r_1 = radius of thawing or refrigerating pipe in ft
r_2 = radius of thawed or frozen zone in ft
T_1 = average pipe temperature in °F
T_2 = original ground temperature in °F
k = thermal conductivity of thawed soil for thawing problems and conductivity of frozen soil for freezing problems in Btu/hr/ft/°F

$$T_{av} = (T_1 - 32)\left[\frac{1}{2ln\left(\frac{r_2}{r_1}\right)} + \frac{1}{\left(\frac{r_1}{r_2}\right)^2 - 1}\right] + T_1 \quad \text{(2A8-15b)}$$

Other terms have the same meaning as in equation (2A8-13). Equation (2A8-15a) may be modified if the source or sink is insulated. Thus,

$$t = \frac{\left[r_2^2 ln\left(\frac{r_2}{r_1}\right) + (r_1^2 - r_2^2)(\tfrac{1}{2} - 2\pi k R_i)\right]\rho(1.434w)}{48k(T_1 - 32)} \quad \text{(2A8-15c)}$$

r_1 = outer radius of insulation instead of pipe radius
R_i = resistance factor for insulation for homogeneous insulation with conductivity k_i

$$R_i = \frac{ln\frac{r_1}{r_3}}{2\pi k_i}$$

where r_3 = pipe radius.

For multilayer insulation,

$$R_i = \Sigma R_j$$

where

$$R_j = \frac{ln\frac{r_a}{r_b}}{2\pi k_j}$$

r_a and r_b being the radii of the outside and inside surfaces of each layer.

Equation (2A8-15c) neglects the heat required to raise ground temperatures and the temperature of the insulation. A somewhat more complicated equation may be derived to include these factors.

Another approximate solution to the same problem has been given by Pekeris and Slichter. (Ref. 38.) This solution assumes the ground to be at freezing temperature so that the approximation becomes progressively worse as the difference between the original ground temperature and the freezing temperature increases; the accuracy of this solution, like that of the previous one, is greatest for soil with a high water content.

$$y = \left(\frac{r_2}{r_1}\right)^2 = y_o\left[1 + \frac{c_2}{L}(T_1 - T_o)\frac{f(y_o)}{y_o}\right] \quad \text{(2A8-16a)}$$

T_1 = pipe temperature
T_o = freezing temperature of ground at 0° C (32° F)
c_2 = heat capacity per unit volume of thawed material for thawing problems, or heat capacity per unit volume of frozen material for freezing problems
L = latent heat of fusion per unit volume
t = time in hr for English system, in sec for cgs system

y_o may be obtained from the equation,

$$y_o ln y_o + 1 - y_o = \frac{4k}{r_1^2 L}\int_0^t (T_1 - T_o)dt = F(y_o) \quad \text{(2A8-16b)}$$

$$\frac{f(y_o)}{y_o} = \frac{2(y_o - 1)}{y_o(ln y_o)^2} - \frac{1 + y_o}{y_o ln y_o} \quad \text{(2A8-16c)}$$

Both of these functions, equations (2A8-16b) and (2A8-16c), are plotted in Figure 2A8-15. For a good approximation, the second term in equation (2A8-16a) can be neglected, that is, y is approximately equal to y_o.

Example 1

Permafrost at an original temperature of 26° F is to be thawed by circulating water at an average temperature of 40° F in a well with 6-in. OD. Calculate the time required to thaw a cylinder of radius 5 ft. Assume the permafrost to have the following properties.

C_p = heat capacity of the dry soil = 0.2 Btu/lb/°F
ρ = 100 lb/cu ft
w = 25 percent
k = 1.5 Btu/hr/ft/°F

Using equations (2A8-15b) and (2A8-15a),

$$T_{av} = (40 - 32)\left[\frac{1}{2 ln \frac{5}{0.25}} + \frac{1}{\left(\frac{0.25}{5}\right)^2 - 1}\right] + 40$$

$$= 8(0.167 - 1.0025) + 40 = 33.2° \text{ F}$$

$$t = \frac{\left[5^2 ln\left(\frac{5}{0.25}\right) + \frac{0.25^2 - 5^2}{2}\right]\left[100(1.434 \times 25 + 0.2)(33.2 - 26) + \frac{25}{100}(33.2 - 0.5 \times 26 - 16)\right]}{48 \times 1.5(40 - 32)}$$

$$= \frac{(74.9 - 12.5)100(35.85 + 1.44 + 1.05)}{48 \times 1.5 \times 8}$$

$$= 416 \text{ days}$$

Using equations (2A8-16a), (2A8-16b), and (2A8-16c),

$$L = 1.434 w\rho = 1.434 \times 25 \times 100$$
$$= 3{,}590 \text{ Btu/cu ft}$$

$$c_2 = \left(\frac{w}{100} + C_p\right)\rho = (0.25 + 0.2)100$$
$$= 45 \text{ Btu/cu ft/°F}$$

$$T_1 - T_o = 40 - 32 = 8° \text{ F}$$

$$y = \left(\frac{5}{0.25}\right)^2 = 400$$

If the second term in equation (2A8-16a) is neglected,

$$y_o = 400$$

From Figure 2A8-15 and equation (2A8-16b),

$$F(y_o) = 2{,}000 = \frac{4 \times 1.5}{0.25^2 \times 3{,}590}\int_0^t 8dt$$

$$= \left[\frac{4 \times 1.5}{0.25^2 \times 3{,}590}\right] 8t$$

$$t = \frac{2{,}000 \times 0.25^2 \times 3{,}590}{4 \times 1.5 \times 8} = 9{,}270 \text{ hr}$$

$$= \frac{9{,}270}{24} = 386 \text{ days}$$

If the second term in equation (2A8-16a) is not neglected,

$$y_o\left[1 + \frac{45}{3{,}590} \times 8\,\frac{f(y_o)}{y_o}\right] = 400$$

$$y_o\left[1 + 0.103\,\frac{f(y_o)}{y_o}\right] = 400$$

For $y_o \simeq 400$,

$$\frac{f(y_o)}{y_o} = -0.112$$

From Figure 2A8-15,

$$y_o = \frac{400}{1 - 0.103 \times 0.112} = 405$$

$$F(y_o) = 2{,}015$$

$$t = 9{,}340 \text{ hr or } 389 \text{ days}$$

Difficulties similar to those in the preceding Example are frequently encountered in permafrost regions, particularly if large-scale excavation is contemplated. In actual practice, in most cases steam or water is not circulated within a closed system, but simply forced into the ground and allowed to percolate to the surface. When this is done, it is possible for the water to circulate to some extent through the soil so that there is an appreciable amount of heat transmission by convection rather than by ordinary conduction. Thus, if this method of circulation is used, the results may be appreciably better than indicated by the preceding type of calculation. If the gravel is quite coarse, this effect will be so pronounced that the foregoing types of calculation are meaningless. (See Example 2 of this Problem.) To an approximation, the foregoing method in some cases might be used if r_1 were replaced by an effective radius corresponding roughly to the radius of the zone through which percolation is occurring.

In actual practice, because of economic considerations, the thawing is commonly discontinued before the desired radius of the thawed zone has been obtained. When the thawing is discontinued,

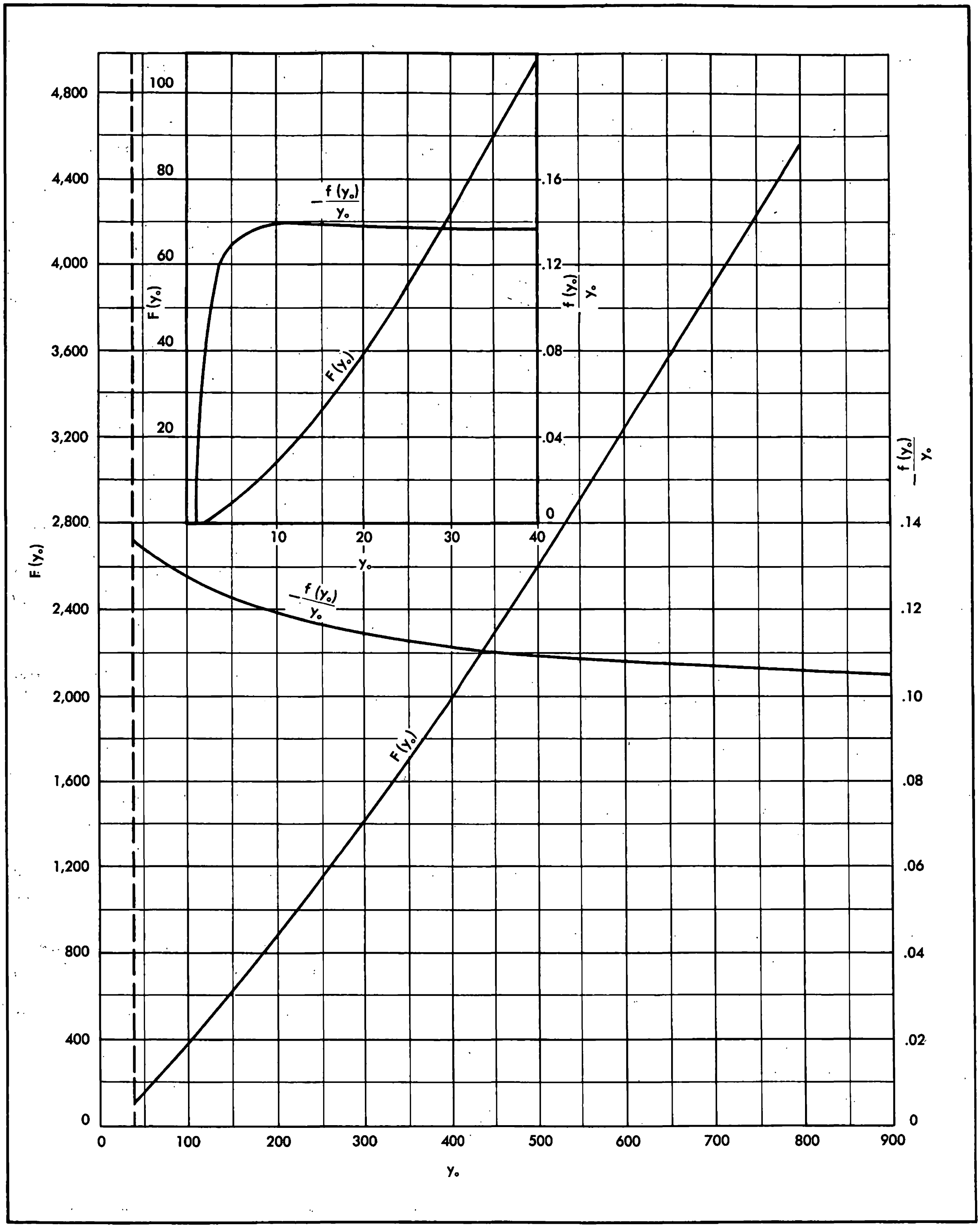


FIGURE 2A8-15

Functions of Equations (2A8-16b) and (2A8-16c)

there will, of course, be a considerable amount of heat stored in the soil that has been raised to temperatures above the freezing point. This heat is available for further thawing and will in time diffuse from the source, causing further thawing. When thawing is discontinued prematurely, it is therefore necessary to allow sufficient time to elapse before excavation begins so that this diffusion may take place; in practice, this time has been as much as two years. The actual calculation of the time required has not, so far as is known, been attempted. In view of the approximate nature of these solutions, it does not seem worth while at this time to give any solution to this problem, particularly because it would depend rather strongly on the temperature of the source as a function of time, rather than on $\int_0^t (T_1 - T_o)\,dt$, and on factors not considered in the previous treatment. An approximate calculation can be made of the duration of circulation required to thaw any zone of any shape. This calculation gives only the minimum amount of heat required, and if only this minimum is supplied, an infinite amount of time will be required to thaw the soil at the point farthest from the source; a generous margin of safety should, therefore, be included. This calculation may be made by using the equation

$$H = \pi(r_2^2 - r_1^2)Z\rho\left(\frac{w}{100} + C_p\right)(T_{av} - 32) \tag{2A8-17}$$

to give the amount of heat in the thawed zone when circulation is stopped above that required for thawing.

When there is an appreciable amount of circulation of water through the gravel, H can be better determined experimentally if a record of water temperatures and volumes has been kept. Thus,

$$H = \int_0^t (T_1 - T_o)g\,dt$$

T_1 = input temperature
T_o = output temperature
g = rate in lb/hr
t = time in hr

If this method is used, the total H obtained should be used in equation (2A8-18), and r_2 in that equation should be replaced by r_1.

This heat will, in an infinite amount of time, diffuse to thaw an additional amount of soil, the radius of which may be calculated as

$$r_3 = \sqrt{\frac{H}{\rho\left[1.434w + \left(\frac{0.5w}{100} + C_p\right)(32 - T_2)\right]} + r_2^2} \tag{2A8-18}$$

where r_3 is the radius of the total thawed zone at $t = \infty$.

It is, of course, possible to get some idea of the rate at which the radius will continue to increase, immediately after circulation has ceased, by extrapolation (a nonlinear extrapolation) of the rate during circulation, because the rate will not change abruptly with the cessation of circulation.

In most instances in which this method of thaw has been used, the area to be thawed has been so large that it was necessary to put down a lattice of wells. The spacing to be employed in such a problem must be calculated by balancing the cost of putting down wells and supplying the necessary distribution system against the time available for thawing, with consideration given to the thermal properties of the soil and the thermal properties and cost of the circulating medium. The optimum arrangement of pipes is on a triangular lattice, though rectangular arrangements have been used (Figure 2A8-16).

In the region around Fairbanks and Nome, Alaska, this method has been extensively used. For shallow thawing it has generally proved most economical to drive points of ¾-in. to 1½-in. diam, with a spacing of 12 to 16 ft between centers. For deeper thawing, 6-in. wells have been bored, and pipes of usually 1½-in. diam have been set in the holes. In this case, the spacing has usually been about 30 ft. With average water temperatures of 45° to 50° F, the thawing is usually complete in from 5 to 15 weeks for the driven points and in from 1 to 3 full thawing seasons with the set points. In the latter case, usually an additional

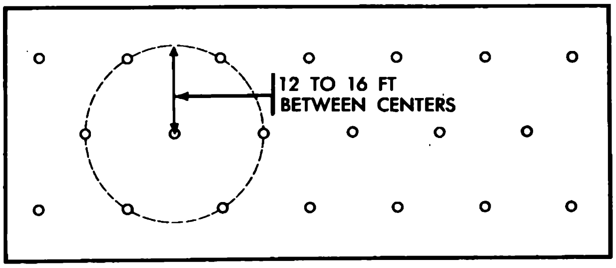


FIGURE 2A8-16

Optimum Lattice for Thawing or Freezing

time interval is allowed to intervene before excavation or dredging is begun. The times calculated, assuming circulation within a closed pipe system, are of the order of ten times as great as those previously discussed and observed when percolation occurs. The thawing is followed by observing temperatures in appropriately spaced temperature holes. (See par. 2A8.08.)

Example 2

A column of soil is to be frozen by circulating brine in a 6-in. well. Calculate the radius of the frozen column on March 1 if circulation begins November 15, assuming the following:

$C_p = -0.2$ Btu/lb/°F
$\rho = 100$ lb/cu ft
$w = 25$ percent
$k = 2.5$ Btu/hr/ft/°F
n = number of the day in the year

Brine temperature can be approximated by the equation

$$T_1 = 35\left[1 - \sin\frac{\pi(n+70)}{182.5}\right]$$

$$T_1 - 32 = 3 - 35\sin\frac{\pi(n+70)}{182.5}$$

Using equation (2A8-16b),

$$F(y_o) = \frac{4 \times 2.5}{0.25^2 \times 3{,}590} \int_{\text{Nov 15}}^{\text{Mar 1}} \left[3 - 35\sin\frac{(n+70)}{182.5}\right] dt$$

$24n = t$

$dt = 24\,dn$

$$F(y_o) = \frac{4 \times 2.5 \times 24}{0.25^2 \times 3{,}590}\left[3\int_{-46}^{60} dn - 35 \int_{-46}^{60} \sin\frac{\pi(n+70)}{182.5}\right] dn$$

$$= 1.07\left[3(60+46) + 35 \times \frac{182.5}{\pi}(\cos 2.24 - \cos 0.413)\right]$$

$$= 1.07[318 + 2{,}033(\cos 128.3°\text{ F} - \cos 23.6°\text{ F})]$$

$$= 1.07[318 + 2{,}033(-0.620 - 0.916)]$$

$$= 1.07(318 - 3{,}122)$$

$$= -3{,}000$$

Neglecting the second term in equation (2A8-16a), $y = y_o$, and using Figure 2A8-15, $y_o = 567$

$$r_2 = \sqrt{567} \times 0.25 = 5.96 \text{ ft}$$

Problems of the type treated in this example are occasionally encountered in temperate zones where it is necessary to stabilize banks during excavation. A related problem is encountered in permafrost regions where it is necessary to keep banks frozen. (See Example in par. 4 of 2A8.03.)

Quite commonly, situations may be encountered in which a thawing or refrigeration medium is being circulated in a pipe when thawing or refrigeration is not desired. Such situations develop in the cases of buried sewers, water pipes, and so on. Another such problem developed in the exploration for petroleum in northern Alaska. Calculations similar to those outlined above showed that the circulation of warm drilling mud during the drilling of deep wells would cause sufficient thawing around the pipe so that the foundations of the drilling rig would be impaired before the desired depths were reached. Therefore, precautionary measures were considered.

For example, calculations were made to ascertain the effects of cooling the drilling mud before recirculation. The effects of insulating the pipe were also considered. Finally, the mud was cooled prior to recirculation and concentric pipes were used so that an insulating airspace would be present; moreover, a radiation shield was inserted in the airspace to further reduce the heat transfer. A diagram of this installation is shown in Figure 2A8-17. The effects of the insulating airspace, the radiation shield, and mud cooling are illustrated in the approximate results given in Table 2A8-5.

TABLE 2A8-5

Estimated Radius of Thawed Zone

Time, days	Hot mud, no insulation	Hot mud airspace, no shield	Hot mud airspace, with shield	Cold mud airspace, with shield
40	5 ft	3 ft 1 in.	2 ft 4 in.	2 ft 4 in.
100	11 ft	7 ft 11 in.	5 ft 9 in.	4 ft 2 in.
360	19 ft	15 ft 1 in.	11 ft 5 in.	5 ft 4 in.

Example 3

An insulated steampipe is to be laid in a permafrost region. Calculate the time required to thaw a 4-ft zone surrounding the insulated pipe. Assume the pipe to be at a sufficient depth so that surface effects need not be considered. Use the following data.

Pipe OD, 6 in.
Permafrost originally at 25° F (k = 1.2 Btu/hr/ft/°F)
Insulation thickness, 1 ft (k_i = 0.04 Btu/hr/ft/°F)
Water content, 25 percent
Dry density, 100 lb/cu ft
Heat capacity dry soil = 0.2 Btu/lb/°F
Steam temperature, 250° F

Because most of the thermal resistance will be provided by the insulation and the thawed soil, assume as an approximation that the outer surface of the pipe will be at 250° F. This assumption will be more valid than in the related problem (Example 5 of Problem 5 following) where the conditions are approximately the same, except that thawing has not started.

For use in equation (2A8-15c),

$r_1 = 1 + 0.25 = 1.25$
$r_2 = 4 + 1 + 0.25 = 5.25$
$r_3 = 0.25$
$k = 1.2$
$k_i = 0.04$
$w = 25$
$\rho = 100$

$$R_i = \frac{ln \frac{1.25}{0.25}}{2\pi 0.04} = 6.40$$

$$t = \frac{\left[5.25^2 ln \frac{5.25}{1.25} + (1.25^2 - 5.25^2)(\frac{1}{2} - 2\pi \times 1.2 \times 6.40)\right] 100(1.434)(25)}{(48)(1.2)(250 - 32)}$$

= 343 days

Equations (2A8-15a) and (2A8-15b) or (2A8-16a), (2A8-16b), and (2A8-16c) may be used in conjunction with electrically heated probes to determine the thermal properties of soil in place in a manner similar to that discussed in Problems 3 and 5 in par. 2 of 2A8.04. If these equations are to be used in the form given, however, an additional thermocouple probe or probes would have to be put down at a distance from the source. It should be noted that these equations are approximate; the results, therefore, will not be as significant as those obtained using Figure 2A8-11.

PROBLEM 5

Qualitative considerations and general comments with regard to heat transmission in permafrost regions.

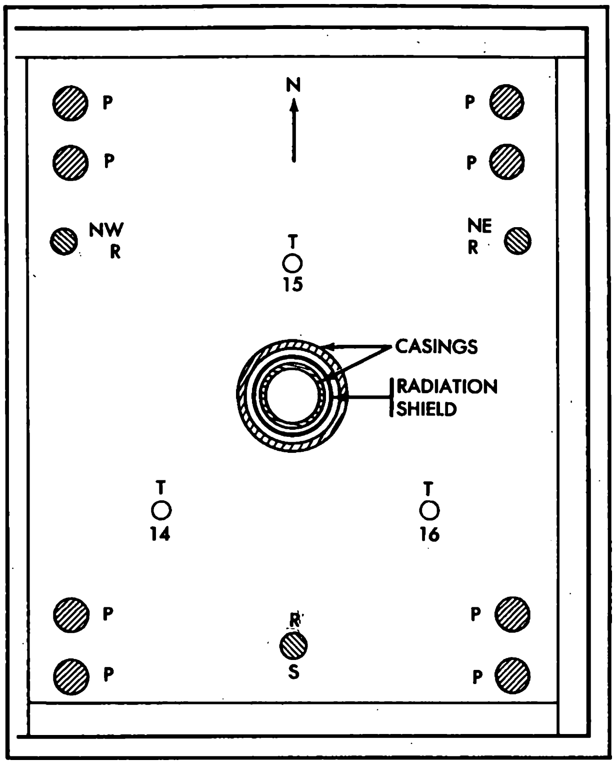


FIGURE 2A8-17

Oil Well With Adjacent Piling—Refrigeration and Temperature Wells

a. *Coefficient of Thermal Conductivity.*

(1) Above freezing, it increases slightly with an increase in mean temperature.

(2) Below freezing, for soil of low moisture content, it shows very little change; for greater moisture content, it shows an increase for a decrease in temperature.

(3) For a change from unfrozen to frozen soil, it changes variably, according to the moisture content; for dry soil, it does not change; for soil of low moisture content, it decreases; and for soil of high moisture content, it increases.

(4) At a constant moisture content, it increases with an increase in dry density. The rate of increase is about the same for all moisture contents and is not markedly different for frozen or unfrozen soil.

(5) At a constant dry density, it increases with an increase in moisture content.

(6) For saturated unfrozen soil, it decreases with a decrease in density. For saturated frozen soil, the data indicate no well-defined relationship between density and conductivity.

(7) It varies, in general, with the texture of the soil, being high for gravel and sand, lower for sandy loam, and lowest for silt and clay.

(8) It differs appreciably for different soil minerals. Quartz has greater conductivity than plagioclase feldspar and pyroxene.

(9) Angular soil particles have from 20 to 50 percent greater conductivity than rounded soil particles.

The specific heats of dry soil are all approximately the same and vary in proportion to the temperature.

The coefficient of thermal conductivity of lightweight concrete slabs has been found to vary directly according to their densities.

Materials that have low conductivity when dry are very poor insulators when wet. Very few insulating materials do not absorb water when it is present. (See Ref. 37, pp. 58, 64.)

b. *Effects of Natural Vegetative Cover.* Less thawing occurs under natural vegetative cover than in places where the cover has been partially or entirely removed. The deepest thawing occurs where the cover has been entirely removed.

Colder ground temperatures occur where the natural vegetative cover is left rather than in places from which it has been removed, because the ground freezes solid earlier in the season if there is less thawed material to refreeze and because frozen ground is a better thermal conductor than unfrozen ground.

Natural surface vegetation acts as an insulator during the summer, when it is dry, and as a good thermal conductor during the winter, when it is saturated and frozen. It disperses considerable heat during the summer by transpiration. Removal of surface vegetation causes subsequent seasonal thawing to greater depths. (See Ref. 37, pp. 60, 63.)

c. *Base Courses.* When a granular or gravel fill is being placed on frozen silt or frost-heaving materials, the fill should be placed immediately after stripping or without stripping to avoid thawing the subgrade. A thawed subgrade becomes quagmire in which tractors bog down, greatly delaying the work. To prevent delays in backfilling and consequent thawing, it is essential to have the fill materials stockpiled adjacent to the work, because haul roads often break down under heavy traffic.

A fill of coarse-grained material under the floor of a building is not effective as an insulator in preventing heat transfer into the ground. However, the fill will reduce and equalize the effect of settlement in the subgrade as well as provide improved drainage. Results of calculations based on data from field and laboratory tests indicate that depth of thaw is greater in coarse-grained materials (sand and gravel) than in fine-grained materials (silt and peat). That portion of a fill placed below the ground-water table will be somewhat more effective than the portion above the ground-water table in reducing the depth of thaw. (See Ref. 37, pp. 61, 62.)

d. *Size and Location of Buildings.* Thawing under large, heated buildings will be greater than under small ones or long, narrow ones, other conditions being the same, because of edge effects.

Under large, heated buildings the permafrost table will be lower on the south side of the building area than on the north side because of the greater amount of solar radiation received on the south side. This may cause differential settlement of the structure and must be considered in the design. (See Ref. 37, pp. 61, 62.)

2A8.05 RADIATION

1. RADIATION EQUATION. The equation (Ref. 39, p. 50) generally used for heat transmission by radiation is

$$q = 0.172A\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)\right](F_a)\ (F_e) \qquad \text{(2A8-19)}$$

q = Btu/hr
A = area of one of surfaces in sq ft
T_1, T_2 = temperatures of two surfaces in °F
F_a = shape factor
F_e = emissivity factor

(See Table 2A8-6 and also standard handbooks.)

Most of the problems encountered in the Polar Regions in which heat transmission by radiation is important have their counterparts in practice in

TABLE 2A8-6

Radiation Between Solids—Factors for Use in Equation (2A8-19) (Hottel) (Ref. 39, p. 54)

Case	Surfaces between which radiation is being interchanged	A	Area angle factor F_a	Emissivity factor F_e[1]
1	Infinite parallel planes	Either	1	$\frac{1}{\frac{1}{p_1}+\frac{1}{p_2}-1}$
2	Completely enclosed body,[2] small compared with enclosing body (subscript 1 refers to enclosed body)	A_1	1	p_1
3	Completely enclosed body,[2] large compared with enclosing body (subscript 1 refers to enclosed body)	A_1	1	$\frac{1}{\frac{1}{p_1}+\frac{1}{p_2}-1}$
4	Concentric spheres or infinite cylinders (subscript 1 refers to enclosed bodies, 2 to surroundings)	A_1	1	$\frac{1}{\frac{1}{p_1}+\frac{A_1}{A_2}\left(\frac{1}{p_2}-1\right)}$

[1] p_1 and p_2 are individual emissivities.
[2] Enclosed body must contain no negative curvature if A_1 is used. Replace any dimples in surface by equivalent planes in evaluating A_1, and raise effective emissivity from p_1 toward unity in proportion to depth of dimple.

the Temperate Zone. With respect to them, reference may be made to standard handbooks.

2. SOLAR HEATING. Solar heating is particularly important in permafrost regions because it is used very effectively in thawing. In gold mining, frozen ground is frequently thawed, after removal of the overburden, by simple exposure to the air and sun during the summer. The exposed materials always have very high emissivity and absorb a considerable amount of heat. In the Fairbanks area, an average of about 2,000 Btu/sq ft/day of solar radiation is received at the earth's surface in June; by October this has fallen to an average of about 300. The amounts falling on southern slopes are, of course, greater than the amounts on flat terrain or northern slopes because the intensity of radiation depends on the cosine of the angle between the plane of the earth's surface and the line from the surface to the sun. Unfortunately, reliable estimates of the amount that is radiated from the earth do not seem to be available so that calculations of thaw depths can not be made from these data. Experience has shown, however, that a freshly exposed flat surface will usually thaw to a depth of about 4 in. in one day.

Common practice is to expose a large surface to the sun. Each day's thaw is then swept off by water and carried away in suspension. (See Ref. 40, p. 190.)

In recent years, success has been achieved with solar thawing without immediate removal of the thawed materials. For the best results, the materials are stripped clean down to the gravel. When this is done, it has been found possible to thaw down to about 10 ft in one summer in central Alaska and the Yukon Territory and to depths of about 25 ft in three seasons. (See Problem 2 in par. 3 of 2A8.04.) Backfreezing to depths of 6 to 8 ft occurs during the intervening winters, but this winter frost has been dissipated early in the summer. (See Ref. 40, p. 190.)

2A8.06 CONVECTION

1. CONVECTION EQUATIONS. As in the case of radiation, many of the problems encountered in the Polar Regions are very similar to those occurring in practice in the Temperate Zone. Selected empirical equations and charts applicable to certain convection problems are given in Figure 2A8-18, Tables 2A8-7 and 2A8-8, and equation (2A8-20). For further details, reference may be made to standard handbooks or works on heat transmission.

For free convection per unit area of surface to air, Heilman (Ref. 42, p. 287) suggests using the following empirical equations.

TABLE 2A8-7

Shape Factors for Use With Equation (2A8-20)

Shape	B	Values of W, inches
Horizontal cylinders	1.061	Outside diam of tube
Vertical cylinders greater than 36 in. long	1.235	Cylinder length for lengths greater than 3 ft, otherwise use W = diam × length for product less than 24 in. (Ref. 168, p. 168)
Vertical plates (not recommended for height less than 24 in.)	1.394	Plate height for heights 24 in. For heights greater than 24 in. use 24 in.
Horizontal plates, face up	1.790[1]	Plate width
Horizontal plates, face down	0.890[1]	Plate width
Spheres	1.820	Outside diam

[1] These values were obtained for the cooling of heated surfaces; when the surfaces are colder than the air, the values should probably be reversed, that is, 0.890 used for plates face up and 1.790 for those face down.

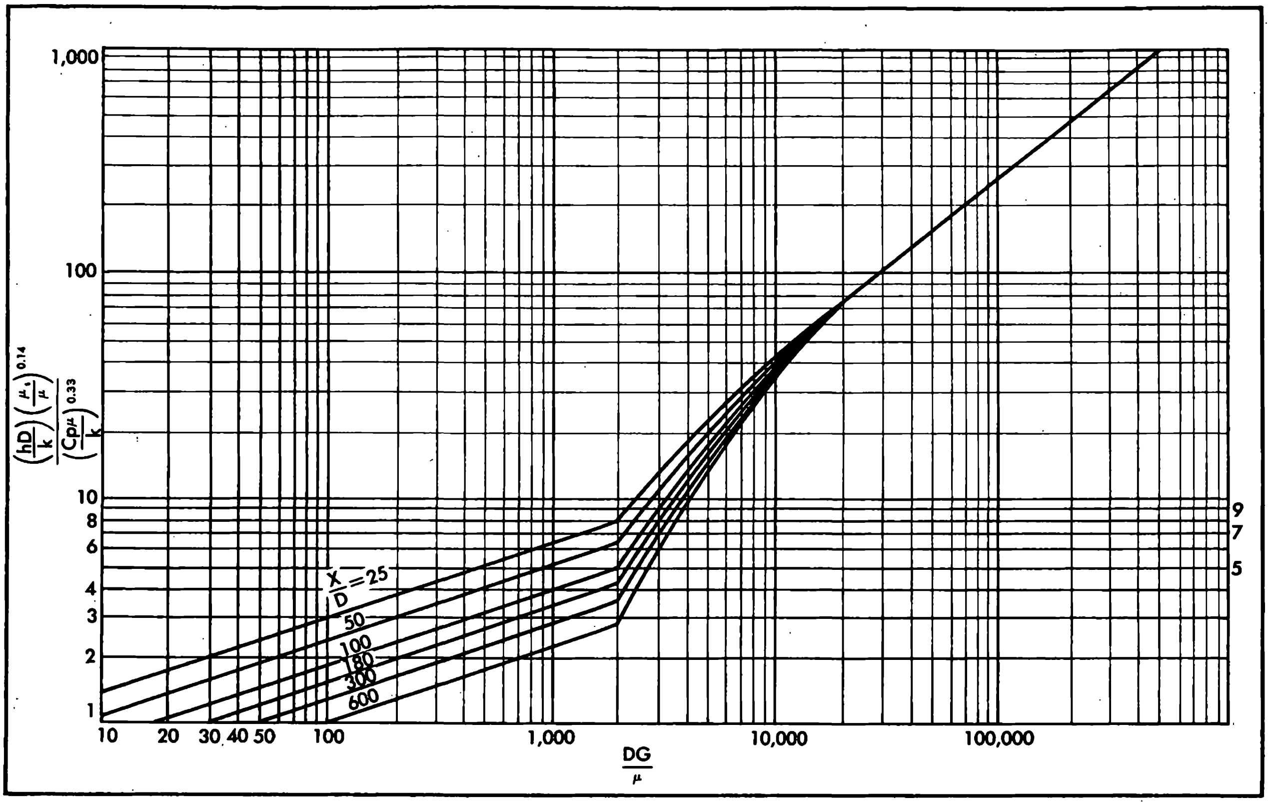


FIGURE 2A8-18

Convection Coefficient for Moving Fluid Through Pipes

$$Q = B\left(\frac{1}{W}\right)^{0.2}\left(\frac{\beta}{760}\right)^{0.533}\left(\frac{1}{T_m}\right)^{0.181}(T_w - T_f)^{1.266} \quad (2A8\text{-}20)$$

Q = flux per sq ft
β = pressure in mm
T_w = radiated wall temperature in °F
T_f = radiated fluid temperature in °F

$$T_m = \frac{T_w + T_f}{2}$$

B and W are factors depending on the shape of the objects. (See Table 2A8-7 for values for common shapes.)

The convection loss per unit area from small horizontal plates and short vertical cylinders is known to decrease as the size of the plate and the height of the cylinder increase. The exact limits of this increase are not known. Until further experimental work is done, Heilman suggests that 24 in. be taken as the limit. That is, for plate sizes or cylinder heights greater than 24 in., the convection loss per unit area is assumed to be constant and equal to that of 24 in.

TABLE 2A8-8

Natural Convection to Air From Various Shapes (Ref. 41, pp. 240–241)

Shape	h
Horizontal pipes	$0.27\left(\frac{\Delta T}{D}\right)^{0.25}$
Vertical pipes more than 1 ft high	$0.27\left(\frac{\Delta T}{D}\right)^{0.25}$
Vertical plates or walls more than 1 ft high	$0.27(\Delta T)^{0.25}$
Horizontal plates, face up	$0.38(\Delta T)^{0.25}$*
Horizontal plates, face down	$0.2(\Delta T)^{0.25}$*

D = diam in ft
ΔT = temperature difference in °F
h = film coefficient in Btu/hr/sq ft/°F

*See note, Table 2A8-7.

Figure 2A8-18 may be used for heating or cooling of moving fluid in pipes. Values of $\frac{DG}{\mu}$ over 10,000 are for streamlined flow, and values of $\frac{DG}{\mu}$ less than 2,100 are for streamlined or viscous flow.

Intermediate values are for the transition range and are probably least reliable.

k = thermal conductivity
C_p = specific heat
D = ID of pipe
X = length or effective length
G = mass velocity per unit area
h = film coefficient or coefficient of heat transfer between fluid and surface, which is equal to flux (Q divided by temperature differences ΔT)
μ = absolute bulk viscosity at temperature of stream
μ_s = viscosity at t_s, surface temperature

The dimensionless groups $\frac{DG}{\mu}$, $\frac{C_p}{k}$, and $\frac{hD}{k}$ are commonly referred to, respectively, as the Reynolds number (Re), Prandtl number (Pr), and Nusselt number (Nu).

If the range of temperature differences is not too great, the temperature-dependent term in each of the equations in Table 2A8-8 can be taken as constant. (Ref. 41, pp. 240-241.) Table 2A8-9 gives recommended values for surface conductance to still air and across airspaces of the size likely to be encountered in construction practice. (Ref. 43, pp. 114, 120.) (These values were determined for 3⅝-in. spacing. For narrower airspaces, conduction becomes more important and convection less so. The net result is an increase in conductance with decreasing thickness of the airspace; for example, for vertical spaces of ¼ in. the conductance is approximately 1.6.) The values in Table 2A8-9 are for normal heating conditions and include a factor for radiant heat transmission.

2. GROUND-WATER MOVEMENT. Transmission of heat by ground-water movement is particularly important in permafrost regions because of the effects on the permafrost. Unfortunately, convection problems in such media as sand and gravel are not amenable to any simple treatment. Where convection is known or suspected to be substantial, it must be considered because the effects of water movement may be great, and in many cases may be the governing factor. Thus, calculations made assuming only conduction to be important may be radically in error. (See Example 1 of Problem 4 in par. 3 of 2A8.04.)

TABLE 2A8-9

Surface and Airspace Conductances (Ref. 43, pp. 120, 176, 253)

Position of surface	Direction of heat flow	Surface-to-air conductance		Conductance across airspace
		p = 0.83	p = 0.05	p = 0.83
Horizontal	Upward	1.95	1.16	1.32
Horizontal	Downward	1.21	0.44	0.94
Vertical	...	1.52[1]	0.74	1.17

p = emissivity
Conductance is in Btu/hr/sq ft/°F
[1]A value of 1.65 has also been recommended for nonreflecting surfaces.

2A8.07 METHODS OF REFRIGERATION AND THAWING

1. AIRSPACES AND AIR CIRCULATION. The use of airspaces and air circulation under structures is illustrated in Figures 2A6-6, 2A6-7, and 2A6-8. These methods have proved to be among the most useful for the prevention or reduction of thaw under the structures. A calculation of the rate of heat flow in the steady state with an airspace under a structure is illustrated herein. For further details regarding the convection and radiation calculations, reference may be made to standard handbooks. Comparison calculations are made for structures without an airspace and with a double airspace. (Figure 2A8-19.)

Example 1A

The following conditions are assumed.

Air temperature in building, 70° F
Ground temperature at surface, 35° F
Concrete thickness, 3 in.
k for concrete, 0.4 Btu/ft/hr/°F
Surface conductance for upper surface of concrete, 1.21 Btu/sq ft/hr/°F (Table 2A8-9)
Airspace conductance, 0.94 Btu/sq ft/hr/°F (Table 2A8-9)

Overall conductance, U, is $\frac{1}{\Sigma RA}$.

$$U = \frac{1}{\frac{1}{1.21} + \frac{3/12}{0.4} + \frac{1}{0.94}} = 0.396 \text{ Btu/hr/sq ft/°F}$$

$$Q = 0.396 \times 35° \text{ F} = 13.8 \text{ Btu/hr/sq ft}$$

With elimination of the airspace

$$U = \frac{1}{\frac{1}{1.21} + \frac{3/12}{0.4}} = 0.689$$

$$Q = 0.689 \times 35° \text{ F} = 24.1 \text{ Btu/hr/sq ft}$$

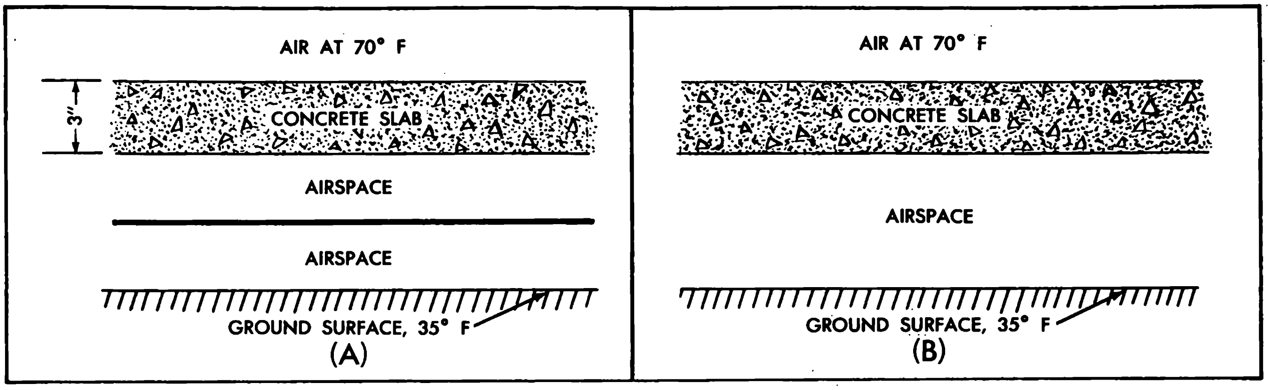


FIGURE 2A8-19

Airspace Insulation Under Floor

With a double airspace having a partition of very high conductivity (assumed ∞)

$$U = \frac{1}{\frac{1}{1.21} + \frac{3/12}{0.4} + \frac{2}{0.94}} = 0.279$$

$$Q = 0.279 \times 35° \text{ F} = 9.75 \text{ Btu/hr/sq ft}$$

Example 1B

A more detailed and somewhat different calculation is given below for a single airspace. Assume the emissivity of concrete and earth's surface is 0.85 and the surface conductance for the upper surface of concrete is 1.21 Btu/hr/sq ft/°F.

From Table 2A8-7, B = 0.89 for use in equation (2A8-20). For a more accurate treatment, equation (2A8-20) or Table 2A8-8 might also have been used here to calculate the conductance from the air to the concrete floor.

T_u = temperature of bottom of concrete
T_f = fluid temperature

For conduction through concrete, the overall coefficient of heat transfer

$$U = \frac{1}{\frac{1}{1.21} + \frac{3/12}{0.4}} = 0.689$$

$$Q = 0.689(70° \text{ F} - T_u) \text{Btu/hr/sq ft}$$

Conduction across the airspace must also equal

$$Q = Q_{sa} (\text{or } Q_{as}) + Q_r \qquad \text{(2A8-21a)}$$

Q_{sa} = conductance from lower surface of concrete to air
Q_{as} = conductance from air to ground
Q_r = radiation from concrete to air

Using equation

$$Q_{sa} = 0.89 \left(\frac{1}{24}\right)^{0.2} \left(\frac{1}{T_{m_1}}\right)^{0.181} (T_u - T_f)^{1.266} \qquad \text{(2A8-21b)}$$

$$Q_{as} = 0.89 \left(\frac{1}{24}\right)^{0.2} \left(\frac{1}{T_{m_2}}\right)^{0.181} (T_f - 460 + 35)^{1.266} \qquad \text{(2A8-21c)}$$

$$F_e = \frac{1}{\frac{2}{0.85} - 1} = 0.741 \quad \text{(using Table 2A8-6)} \qquad \text{(2A8-21d)}$$

$$Q_r = 0.172 \times 0.741 \left[\left(\frac{460 + T_u}{100}\right)^4 - \left(\frac{460 + 35}{100}\right)^4 \right] \qquad \text{(2A8-21e)}$$

$$T_{m_1} = \frac{T_u + T_f}{2} \qquad \text{(2A8-21f)}$$

$$T_{m_2} = \frac{T_f + 495}{2} \qquad \text{(2A8-21g)}$$

$$Q_{sa} = Q_{as} \qquad \text{(2A8-21h)}$$

Thus, there are eight equations to be solved simultaneously with eight unknowns: Q, Q_{sa}, Q_{as}, Q_r, T_u, T_f, T_{m_1}, and T_{m_2}. When solved,

Q = 13.3 Btu/hr/sq ft
Q_r = 10.0 Btu/hr/sq ft
$Q_{sa} = Q_{as}$ = 3.3 Btu/hr/sq ft

These results are particularly significant because they show that a very large percentage of the heat is conducted by radiation. This may be materially reduced by coating the undersurface of the structure with a material of low emissivity. For example, a coating of aluminum paint may reduce the total heat transmission to 65 or 70 percent of the value without such a coating, and aluminum sheeting may reduce it to 35 or 40 percent of the value without it.

Example 2

Calculate the depth of thaw after three years under the building described in Example 1A, assuming the soil has a conductivity when thawed of 0.67, a moisture content of 40 percent, and a dry density of 81 lb/cu ft.

Assume, when the building is built, the permafrost cover has been removed and the upper 1 ft of permafrost thawed.

For approximate purposes a satisfactory (and conservative, that is, a maximum) estimate will be obtained if the heat used in raising soil temperatures is neglected.

The thermal resistance above the original 32° F isotherm

$$R_1 = \frac{1}{1.21} + \frac{3/12}{0.4} + \frac{1}{0.94} + \frac{1}{0.67} = 4.01$$

Using equation (2A8-14),

$$I = \frac{LZ}{24}\left[4.01 + \frac{Z}{2(0.67)}\right]$$

Z = depth of thaw below original 1-ft isotherm

After 3 years,

$$I = 3 \times 365(70 - 32) = 41{,}600$$

$$L = 1.434wp = 1.434 \times 40 \times 81 = 4{,}650$$

$$41{,}600 = \frac{4{,}650Z}{24}(4.01 + 0.747Z)$$

$$0.747Z^2 + 4.01Z - 215 = 0$$

$$Z = 14.5$$

or the total depth of the 32° F geo-isotherm after 3 years will be 15.5 ft.

The other equations given in par. 1 of 2A8.06 and 2A8.07 could also have been used for treating the heat transmission from the floor to the ground, as was done in Example 1B.

If the airspace is omitted, the same type of calculation gives 33½ months as the time required for thawing to 15.5 ft. Thus, an airspace without circulation of the air is not particularly desirable under circumstances such as those illustrated in the foregoing problem; this is because the thawed ground provides the principal insulation during most of the time.

The preceding calculations are all based on the supposition that the air under the structure is stagnant. It is, of course, possible to circulate the air under the structure naturally or by forced draft, and when the air temperatures are low, this will be desirable. The advantages are obvious when the air is at a temperature much lower than either the ground or building temperatures, for then heat will be removed from both (Figure 2A8-20). If the air temperature is the same as the average air temperature under the structure with no circulation, it is unwise to circulate air because the conduction coefficients will be increased by the velocity, and the heat leak will be greater than for no circulation. If air temperatures are higher than the stagnant temperature, it is even more disadvantageous to circulate air. For the case with the air temperature at a value lower than the stagnant temperature but higher than the ground temperature, there will be some optimum rate of circulation, depending on the size of the structure, the thickness of the airspace, and the air, ground, and building temperatures. Some sample approximate calculations follow.

Example 3

Assume a 1-ft airspace, a 50-ft building length, a ground-surface temperature of 35° F, and, as a first approximation, the temperature of the lower building surface as 50.7° F (Figure 2A8-20) and an air temperature of 40° F. The problem is to minimize the heat flow to the ground. No consideration is taken here of the desirability of also reducing the heat leak through the lower surface of the building to a minimum. This factor may be taken into account with an increase in the complexity of the calculations.

If T_u is 50.7° F and the ground temperature is

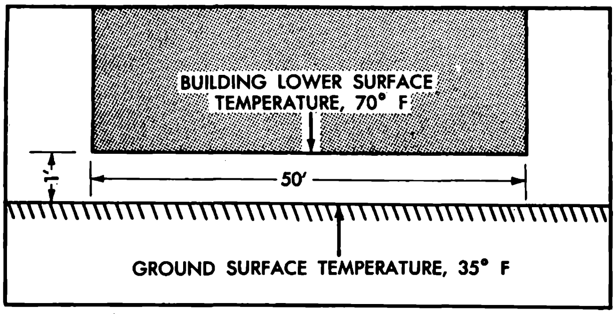


FIGURE 2A8-20

Airflow Under Foundation

35° F, the air temperature, if stagnant, will be approximately the average of these two values. Because the available air is at a lower temperature, circulation is desirable.

Regardless of the rate of air circulation, the rate of heat transmission by radiation will remain constant (assuming, of course, that the lower surface does remain at 50.7° F); it may be calculated easily, as in the previous Example.

For ordinary surfaces, such as concrete, the surface conductance, that is, the convection term, will be given very approximately by the equation

$$h = \left(1 + \frac{V}{4}\right) h_o \qquad \text{(2A8-22)}$$

h_o = conductance for still air, which may be approximated by using Table 2A8-8 or equation (2A8-20)
V = velocity of air motion in mph
h = conductance for moving air

Assume the air to be moving at 2 mph. Using equation (2A8-20) multiplied by 1.5, from equation (2A8-22), the calculations are

Q_{sa} = 4.62 Btu/hr/sq ft (conduction from lower surface of building to air)
Q_{as} = 1.77 Btu/hr/sq ft (conduction from air to ground)

The difference, 2.85 Btu/hr/sq ft, is absorbed, of course, by the air and raises the air temperature during passage. Thus, in a 50-ft path, 50 × 2.85 = 142 Btu/hr will be absorbed by the 1 × 2 × 5,280/cu ft of air that flows along a 1-ft channel under the structure. With the heat capacity taken as 0.0188 Btu/cu ft/°F, the air increases in temperature to a first approximation by

$$\frac{142}{2 \times 5{,}280 \times 0.0188} = 0.72° \text{ F}$$

To a second approximation, using the average air temperature just calculated, that is, 40 + 0.72/2 = 40.36° F, the heat transfer is again calculated.

Q_{sa} = 4.41 Btu/hr/sq ft
Q_{as} = 1.92 Btu/hr/sq ft
Difference = 2.49 Btu/hr/sq ft

The second approximation for the temperature increase is then

$$\frac{2.49 \times 50}{2 \times 5{,}280 \times 0.0188} = 0.63° \text{ F}$$

Further approximations may be taken as desired to improve the accuracy. Using this value, the heat leak to the ground at the outlet end of the building is calculated.

Air temperature = 40 + 0.63 = 40.63° F
Q_{as} = 2.05 Btu/hr/sq ft

If the calculation is repeated for rates of flow of 2, 1½, 1, and ½ mph, the results are:

Approximation	V, *mph*	T, *outlet*, °F	Q_{as}, *Btu/hr/sq ft*
2	2	40.63	2.05
2	1½	40.72	1.87
2	1	40.95	1.83
3	½	41.55	1.86

From the above it would seem that a velocity of about 1 mph is the optimum for minimum thawing at the outlet end of the building (where, of course, the thawing is at its worst). If the degrees of approximation are increased, this conclusion might be slightly altered.

The foregoing treatment has failed to consider certain factors. For example, as the air is warmed, it expands; thus, the velocity will increase and the heat capacity per cu ft will decrease. However, the errors introduced because of these approximations are negligible compared to those resulting because of the approximate nature of the equations used.

For actual problems encountered, the cooling effect of the cool air on the lower surface of the floor must be considered. Thus, if this were considered in the above example, the optimum velocity would be slightly higher than indicated by the foregoing calculations. The extent of this effect will depend strongly on the thermal resistance of the floor.

Experimental determinations of the optimum velocities can be made by adjusting the rate of airflow so that the minimum outlet ground temperature is obtained, other conditions being the same.

In Figure 2A6-6, an alternative method of refrigeration using air is illustrated. The calculation of the heat exchange between the air and pipe can be treated using equations given in par. 1 of 2A8.06. For a comparison of air, brine, pentane, and oil circulation reference should be made to the following paragraphs.

2. LIQUID CIRCULATION FOR REFRIGERATION. The circulation of liquid through closed systems for refrigerating purposes has been indicated in several of the Problems previously dis-

cussed. For the temperature range above 32° F, water is the most obvious medium. For lower temperatures, brine or different kinds of oil have generally been used. Compared below are the relative merits of air, brine, pentane, and petroleum circulation for the same problem. (See example in par. 4 of 2A8.03.)

Example

Here $q = 1{,}215$ Btu/hr or $\frac{q}{X} = 24.3$ Btu/hr/ft for pipe temperature of 32° F. Assume oil, brine, pentane, and air are all available at 30° F. First, calculate the rate at which each must be circulated to maintain a temperature of 32° F at the input end of the pipe. Second, calculate the temperature of each at discharge immediately after circulation starts.

Assume the following data (all at 30° F except μ_s).

Values	*Air*	*Brine*	*Oil*	*Pentane*
k in Btu/hr/ft/°F	0.0128	0.31	0.082	0.084
C_p	0.234	0.96	0.51	0.50
μ in lb/hr/ft	0.041	4.6	242	0.73
μ_s in lb/hr/ft at 32° F	0.041	4.4	236	0.72

D in ft = 2 in. = 0.167 ft

X in ft = 50 ft

$$\frac{X}{D} = 300$$

$$\frac{q}{X} = 24.3 \text{ Btu/hr/ft} = hA\Delta T = h\pi D\Delta T$$

$$= h\pi(0.167)(2)$$

$$h = \frac{24.3}{\pi(0.167)(2)} = 2.31$$

With these data to determine the values in the first four columns of the following tabulation, Figure 2A8-18 may be used to determine the values in column 5, and G may be calculated using D and μ from the preceding data.

	Air	*Brine*	*Oil*	*Pentane*
$\frac{hD}{k}$	300	12.5	47	46
$\frac{C_p\mu}{k}$	0.750	12.7	1,500	4.35
$\frac{DG}{\mu}$	127,000	2,700	2,200	8,200
$\frac{\mu_s}{\mu}$*	1	0.89	0.91	0.95
$\frac{\left(\frac{hD}{k}\right)\left(\frac{\mu_s}{\mu}\right)^{0.14}}{\left(\frac{C_p\mu}{k}\right)^{1/3}}$	330	5.36	4.04	27.6
G	31,000	74,000	3,210,000	35,800

* For small temperature differences, $\left(\frac{\mu_s}{\mu}\right)^{0.14}$ is so close to 1 that using 1 causes only negligible change in the final answer.

To calculate increase in fluid temperature during passage (first approximation),

$$\Delta T = \frac{1{,}215 \text{ Btu/hr}}{G \text{ lb/sq ft/hr}\left(\frac{\pi D^2 \text{ ft}^2}{4}\right) C_p \text{ Btu/lb/°F}}$$

$$\Delta T = \frac{55{,}500}{G\,C_p}$$

= 7.65° F (air), 0.78° F (brine), 0.034° F (oil), 3.1° F (pentane)

Thus, the increase in fluid temperature is negligible for oil but is quite large for air and pentane. The calculated increases are excessive, however, because the rate of heat flow will decrease to a value lower than was assumed when the pipe temperature rises appreciably above 32° F at any point along its length. To take this into account, equations (2A8-23a), (2A8-23b), and (2A8-23c) may be solved simultaneously. The three unknowns are q, T_p, and T_f.

For any increment, dx, along the length, N, of the pipe,

$$dq = \frac{\Delta T}{R} = \frac{\dfrac{T_s - T_p}{\cosh^{-1}\frac{r_1}{r}}}{2\pi k dx} \qquad \text{(2A8-23a)}$$

T_s = surface temperature

T_p = pipe temperature (see par. 2A8.03)

$$dq = h^2\pi r(T_p - T_f)dx \qquad \text{(2A8-23b)}$$

T_f = fluid temperature

$$T_f - T_{f_i} = \frac{q}{3{,}600G\frac{\pi d^2}{4}C_p} \qquad \text{(2A8-23c)}$$

T_{f_i} = fluid temperature at input

This solution neglects heat flow within the ground parallel to the pipe. Such a flow does exist because in the steady state under the previous conditions the temperature of the pipe is a function of x, as are T_f and dq.

Referring to the values of G obtained in the previous example, the oil is clearly the least desirable medium for circulation because the rate of circulation is by far the greatest and the viscosity is also high. Thus, a much greater expenditure of energy will be required for its circulation. (In this case, the conversion of mechanical energy into heat because of frictional effects will cause a greater heating effect in the oil than the heat leak from the pipe to the oil. The change in oil temperature is still negligible, however.) The air would be the most desirable medium because of its low viscosity and because no recirculation would be necessary. To keep the output temperature at a reasonably low value, it might be necessary, for some purposes, to increase the rate to several times that calculated; pumping costs would still be less than for other media. In order to make a decision between the brine and pentane, a quantitative calculation of costs would be necessary. In making such a calculation, the power required for circulation, the cost of the medium, and the cost of appropriate heat exchangers would all have to be considered. In addition, possible corrosive effects of the brine and the fire hazard of working with pentane would have to be considered.

3. LIQUID CIRCULATION FOR HEATING OR THAWING. For thawing purposes the circulation problem differs considerably from that encountered in freezing and refrigeration, because it is usually most efficient to allow water to percolate through soil to as great an extent as possible. (See Problem 4 in par. 3 of 2A8.04.) Where this percolation is desirable, water is the only medium that has proved practicable. For heating not involving percolation, treatments similar to that used in the previous section may be used.

For thawing where recirculation of water is not used, every opportunity should be used to increase the water temperature, if it can be done economically. For example, it may prove desirable to sacrifice certain hydrodynamic advantages in bringing the water to the point of use in order to increase exposure to the sun and warm air.

The cost of thawing by cold-water circulation varies enormously, depending on water costs, depths required, and composition of the materials; in general, it has been the preferred method for very deep thawing.

4. STEAM THAWING. In the past, steam has frequently been used for thawing purposes. Its use offers, of course, tremendous thermodynamic advantages in that for every pound of steam put in the ground, a hundred times or so as much heat is supplied as by a pound of water at temperatures at which it may normally be obtained. However, principally because of high fuel costs, this method of thawing, while very rapid, does not in general compare favorably, particularly for large operations, with cold-water thawing from an economic point of view. It may be preferred for small operations.

5. HEATING OR COOLING BY CONDENSATION OR EVAPORATION. Except when steam has been used for thawing, there do not appear to have been instances in the Arctic where advantage has been taken of the heat of vaporization of various substances for thawing or freezing. For freezing segments of ground or for refrigeration purposes generally, the method would seem to offer very great advantages, if closed systems were used with liquids whose normal boiling points are within the range of ambient temperature variation.

6. ELECTRICAL HEATING. Electricity has been used, particularly in Scandinavia and the Soviet Union, to heat soil for agricultural purposes. Either buried cables or the internal resistance of the soil may be used. To thaw ground, however, electrical heating will be of value only where electrical power is very cheap and water is difficult to obtain. If the electrical resistance of the soil itself is used for heating, a serious disadvantage is encountered because the resistance of thawed soil is much less than that of the same frozen material. Consequently, once a thawed channel is opened up between two electrodes in the ground, most of the heat will be generated in that channel and must then diffuse into the permafrost. In addition, the resistance of permafrost is so high that very high voltages and comparatively close spacing of electrodes will be required; moreover, because of the great change in conductivity, voltage regulation must be made as thawing occurs. (See par. 4 of 3C1.02 for a discussion of electrical thawing using electrically heated points.) Neglecting any heating effect, the energy used for thawing frozen soil is

$$E = 27 \times \rho \times \frac{w}{100} \times 143.4 \times 2.930 \times 10^{-4} \text{ kwh/cu yd} \quad (2A8\text{-}24)$$

$$= 0.01133\, w\rho/\text{kwh/cu yd}$$

ρ = density in lb/cu ft
w = percent (of dry-weight) water

Thus, for soil with a density of 100 lb/cu ft and a water content of 25 percent, and even with electricity at \$0.01/kwh, cost will be \$0.28/cu yd.

Electrical heating does have more practical application in permafrost regions in keeping liquid in the thawed state. This is a problem particularly encountered in water supply and sewage disposal systems. Similarly, heating may also be valuable in keeping oil in pipelines at sufficiently high temperatures so that pumping costs are not prohibitive. External heating of the pipes, using the internal resistance of the pipe itself as a heating unit, or heating within the pipe may be used. The latter is the most efficient as far as electricity costs and electrical and thermal insulation are concerned.

Example 1

Standard apparatus is now available for keeping pipes heated by using an external heating circuit. (See Figure 2A8-21.) Assume a 6-in. water pipe is provided with an external heating element and covered with 1 in. of asbestos-felt insulation. If the ambient temperature is −20° F and the air is still, calculate the energy required to keep the water from freezing. Assume the asbestos felt has a k value of 0.05 Btu/hr/sq ft/° F.

To calculate the heat leak in the steady state, the heat leak through the asbestos felt is set equal to that conducted away from the cover. Because the thickness of the insulation is small compared to pipe thickness, its average radius, 3.5 in., may be used instead of the logarithmic value (see steady state) for the calculation of the heat leak through the asbestos cover. Thus, the leak is

$$q = kA\frac{\Delta T}{\Delta z} \qquad \text{(See par. 2A8.03.)}$$

X = length
r = radius
Δz = thickness
A = area = $2\pi r X$

$$\frac{q}{X} = 0.05(2\pi)\left(\frac{3.5}{12}\right)\left(\frac{T_s - 32}{\frac{1}{12}}\right) = 1.1(32 - T_s)$$

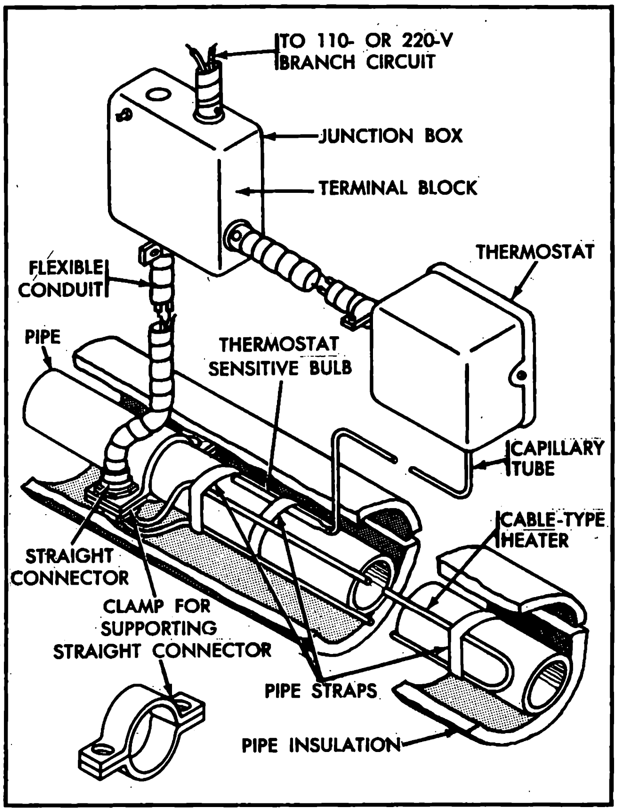


FIGURE 2A8-21

Cutaway Showing Single Length of Heating Cable Installed Parallel With Pipe (Ref. 44)

The heat leak by convection from the surface, q_c, is $h_c A \Delta T$.

Using Table 2A8-8,

$$\frac{q_c}{X} = 0.27\left[\frac{T_s - (-20)}{\frac{8}{12}}\right]^{0.25}\left(\pi\frac{8}{12}\right)[T_s - (-20)]$$

$$= 0.68(T_s + 20)^{1.25}$$

Equation (2A8-20) could also have been used instead of Table 2A8-8. The heat leak by radiation may be calculated using equation (2A8-19). Taking the emissivity factor with the asbestos-felt cover to be about 0.95,

$$\frac{q_r}{X} = 0.172\left(\pi\frac{8}{12}\right)\left[\left(\frac{460 + T_s}{100}\right)^4 - \left(\frac{460 - 20}{100}\right)^4\right]0.95$$

$$= 0.34\left[\left(\frac{460 + T_s}{100}\right)^4 - 4.4^4\right]$$

Since $q_c + q_r = q$,

$$1.1(32 - T_s) = 0.68(T_s + 20)^{1.25} + 0.34\left[\left(\frac{460 + T_s}{100}\right)^4 - 4.4^4\right]$$

Solving for T_s, $T_s = -4.5°$ F.

$$\frac{q}{X} = 1.1[32 - (-4.5)] = 40 \text{ Btu/hr/ft}$$
$$= 11.7 \text{ w/ft}$$

Example 2

A water supply pipe with a 6-in. OD and a 5.5-in. ID is covered with 1 in. of insulation; k value = 0.1 Btu/hr/°F/ft. The pipe is placed 3 ft below the ground surface; k for soil = 1.1 Btu/hr/°F/ft. Assume that the pipe has a heating element of negligible heat capacity centered in it and that the ground surface is 10° F. Calculate the electrical requirements to keep the water thawed when the rate of flow is 5 ft/sec and 0.5 ft/sec. Also, calculate the temperature of the outer surface of the insulation in both cases.

Using equation (2A8-7) (par. 2A8.03),

$$R \text{ soil} = \frac{\cosh^{-1}\frac{z}{r}}{2\pi k X}$$

$$= \frac{\cosh^{-1}\frac{36 \text{ in.}}{3 \text{ in.} + 1 \text{ in.}}}{2\pi(1.1)X} = \frac{\cosh^{-1} 9}{6.92X}$$

$$= \frac{2.88}{6.92X} = \frac{0.416}{X}$$

Using equations (2A8-4a) and (2A8-5) (par. 2A8.03),

$$A_{\log} \text{ insulation} = \frac{A_2 + A_1}{2} = X\frac{2\pi r_2 + 2\pi r_1}{2}$$
$$= \pi(r_2 + r_1)X$$
$$= \pi\frac{(4+3)}{12}X = 1.83X$$

$$R \text{ insulation} = \frac{\frac{1}{12}}{0.1(1.83X)} = \frac{0.455}{X}$$

From Table 2A8-10 for water at 32° F,

$k = 0.325$
$C_p = 1.01$
$\mu = 4.33$
$\rho = 62.5$
$\frac{C_p\mu}{k} = 13.4$
$D = \frac{5.5}{12} = 0.458$ ft

At 5 ft/sec flow rate,	At 0.5 ft/sec flow rate,
$G = 5(62.5)(3{,}600) = 1{,}123{,}000$ lb/sq ft/hr	$G = 112{,}300$ lb/sq ft/hr
$\frac{DG}{\mu} = 119{,}000$	$\frac{DG}{\mu} = 11{,}900$

Using Figure 2A8-18 and assuming $\left(\frac{\mu}{\mu_s}\right)^{0.14} = 1$,

$\frac{\left(\frac{hD}{k}\right)\left(\frac{\mu_s}{\mu}\right)^{0.14}}{\left(\frac{C_p\mu}{k}\right)^{1/3}} = 312$	$\frac{\left(\frac{hD}{k}\right)\left(\frac{\mu_s}{\mu}\right)^{0.14}}{\left(\frac{C_p\mu}{k}\right)^{1/3}} = 45$

(Assume effective pipe length of 50 ft, $\frac{X}{D}$, is 109.)

$\frac{hD}{k} = 742$	$\frac{hD}{k} = 107$
$h = 742\left(\frac{0.325}{0.458}\right) = 526$ Btu/hr/sq ft/°F	$h = 107\left(\frac{0.325}{0.458}\right) = 76$ Btu/hr/sq ft/°F
$R \text{ film} = \frac{1}{hA}$	$R \text{ film} = \frac{0.00914}{X}$

$$= \frac{1}{526\left(\pi\frac{5.5}{12}\right)X}$$
$$= \frac{0.00132}{X}$$

Thus, in both cases, the film resistance is nearly negligible compared to that of the insulation and the ground. The insulating value of the steel pipe will also be negligible and can be neglected. In view of the similarity in resistance factors, the calculation is continued only for the 5 ft/sec flow rate.

$$\Sigma R = \frac{0.416 + 0.445 + 0.001}{X} = \frac{0.862}{X}$$

$$q = \frac{\Delta T}{\Sigma R} = \frac{32 - 10}{0.862}X$$

$$\frac{q}{X} = 25.5 \text{ Btu/hr/ft} = 75 \text{ w/lin ft}$$

To calculate T insulation (outer surface), either resistance factor may be used with the value given above for $\frac{q}{X}$.

$$q = 25.5X = \frac{\Delta T}{\Sigma R} = \frac{\Delta T}{\frac{0.416}{X}}$$

$$\Delta T = 25.5(0.416) = 10.6° \text{ F}$$
$$T \text{ insulation} = 10.6° \text{ F} + 10° \text{ F} = 20.6° \text{ F}$$

TABLE 2A8-10

Approximate Thermal and Physical Properties of Selected Liquids

Liquid	°F	Conductivity, k Btu/hr/° F/ft	Heat capacity, C_p Btu/° F/lb.	Viscosity, μ		Density, lb./cu ft	Freezing point, °F
				Centipoises	lb./hr /ft		
Water	50 32	0.334 0.325	1.00 1.01	1.31 1.79	3.17 4.33	62.5	32
Ethyl alcohol	50 −30	0.107 0.110	0.54 0.37	1.5 3.8	3.6 9.2	49	−174.6
Pentane	50 −30	0.080 0.084	0.52 0.44	0.26 0.41	0.63 0.99	39	−202
Brine (25 percent NaCl)	50 14	0.266 0.237	0.79 0.78	2.8 4.3	6.8 10.4	74.5	13.2
Brine (25 percent $CaCl_2$)	50 −10	0.302 0.257	0.69 0.67	3.5 12	8.5 29	77.1	−18
Sea water (3.5 percent solids)	50 32	0.320 0.310	0.96 0.96	1.4 1.9	3.4 4.6	64	28.6
Average midcontinent fuel oil, 26.8° API	50 0	... ...	... ...	81 860	196 2,100	56	
Ventura, Calif., crude, 28.2° API	50 0	... ...	... ...	39 366	94 890	55	
Kerosene	50 −30	0.089 0.095	... ...	2.1 5.8	5.1 46	50	
Light diesel oil	50 −22	... ...	... ...	6.7 33	16.2 80	53	
SAE 20 (lubricating oil)	50 0	... ...	... ...	310 5,500	750 13,000	56	
SAE 40 (lubricating oil)	50 0	... ...	... ...	680 4,000	640 54,000	56	

Notes: Most of the values given for low temperatures are extrapolated. The properties of the last four liquids vary widely, and the values given should be considered only representative. For many oils a value of 0.079 may be used for the conductivity. Heat capacities of oils and kerosene are about 0.5. The densities are for ordinary temperatures. In all cases they are somewhat greater at lower temperatures. Viscosities may be interpolated or extrapolated approximately to other temperatures by using two given values to determine a and b in the empirical equation:
$\log \log (\gamma + 0.8) = a \log T + b$.

γ = viscosity in centistokes
η = viscosity in centipoises
ρ = density (g/cm)
T = absolute temperature (either Kelvin or Rankine).

$$\gamma = \frac{\eta}{\rho}$$

To convert viscosities in centipoises to lb/hr/ft, multiply by 2.42.

Thus, there is no danger of the permafrost being thawed by such circulation, and even an appreciable increase in the heating current may be allowed without thawing. A limited decrease in heating current will also be possible. In this case, a film of ice will form in the pipe, reducing the area of the channel but increasing the thermal resistance until equilibrium is again obtained.

For the transportation of oil or other fluid, the temperature of which is to be maintained appreciably above 32° F, special provisions must be made to prevent thawing of the permafrost. A possible installation is illustrated in Figure 2A8-22. (Applications to patent certain features of this arrangement are pending.)

With such an installation, automatic controls might well be used to regulate the rates of both current and airflow so that fluid temperatures will remain sufficiently high and outer pipe temperatures sufficiently low.

2A8.08 TEMPERATURE MEASUREMENT AND CONTROL

1. INTRODUCTION. Many of the problems involving permafrost require or are made easier by a knowledge of temperature distribution within the permafrost. In addition, temperature measurements in refrigerating or thawing systems may be important. For some purposes, standard liquid-filled glass thermometers are satisfactory; but, in general, electrical measurement of temperatures is to be preferred, the principal advantage being that the temperature-responsive element need not be close to the indicating element. For example, tem-

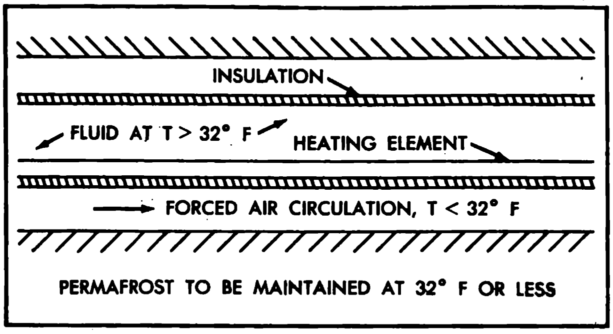


FIGURE 2A8-22

Method of Maintaining Fluid Above Freezing in Presence of Permafrost

peratures that may be desired from a series of wells may be obtained with thermocouples or other temperature-responsive elements, using a single potentiometer at a central location for temperature indication. Alternatively, portable potentiometers might be used to check the temperatures at the top of each well.

2. INSTRUMENTS. The favored temperature-responsive elements are the thermocouple, the resistance thermometer, and the thermistor. (Actually, thermistors are also resistance thermometers with elements whose resistance increases with decreasing temperatures.) For most of the applications within the scope of this technical publication, the thermocouple will probably be preferred.

A thermocouple consists simply of two dissimilar wires joined together, as indicated in Figure 2A8-23. When a temperature differential exists between points A and B, a potential difference exists between the two leads. This may conveniently be measured with either a millivoltmeter or potentiometer. The latter is much to be preferred because with it no consideration need be given to potential losses along the leads. Because the electromotive force measured depends on the difference in temperature between the two junctions, A and B, one must be maintained at a standard temperature. Usual procedure has been to use an ice-water bath in a thermos flask to maintain one junction at 32° F. In recent years, self-compensating elements have been built into potentiometers that correct for slight variations in the temperature of the standard junction so that no constant-temperature bath is required. There is evidence, however, that the performance of such a temperature compensating element is not entirely satisfactory, and for precision the ice-water junction is probably still to be preferred. Although any dissimilar metals may be used, the copper-constantan combination is the one most generally used for low temperatures, particularly for sub-freezing temperatures. Thermocouple wires and recording instruments that record temperatures directly are available from various instrument makers, as are potentiometers and millivoltmeters. Also, the standard handbooks contain tables for converting millivolts to temperatures. For a continuous record, recording potentiometers are available.

A Wheatstone bridge is the usual method for measuring with thermistors and resistance thermometers. In order to simplify the lead correction, circuits of the type illustrated in Figure 2A8-24 have been used.

If the test lead and the thermistor (or resistance thermometer) leads are from the same stock, their resistance will be very nearly the same. To correct a thermistor reading, therefore, the resistance of the test lead plus that of the common lead is subtracted from that read for the thermistor plus the common lead.

Each of the three types of elements has its own advantages and disadvantages. Some of these are summarized as follows.

(1) Thermocouples are easily reproducible, and for most purposes no individual calibration is required. Both thermistors and resistance thermometers require individual calibration, and for the former reproductibility is difficult.

(2) Resistance thermometers and thermistors are not particularly rugged, and the latter sometimes change in calibration with time. Thermocouples are rugged, and under ordinary circumstances corrosion does not occur and changes in calibration with time are negligible.

(3) Thermocouples are cheap and occupy

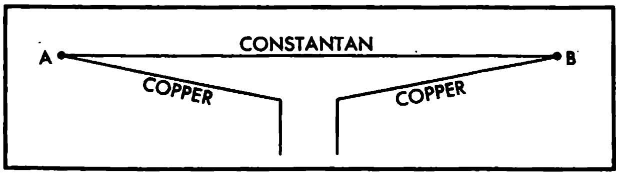


FIGURE 2A8-23

Diagram of Thermocouple

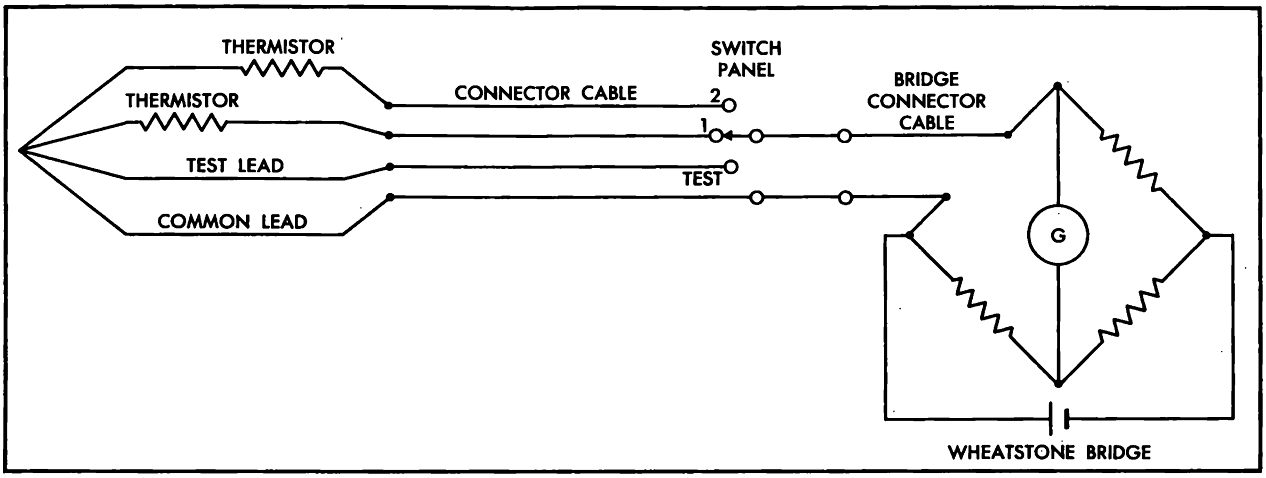


FIGURE 2A8-24

Wiring Diagram of Thermistor Circuit

little space, but thermistors and resistance thermometers are relatively expensive and are particularly bulky.

(4) Thermocouples are much more easily made and installed than either of the others; the two wires may be welded together at the junction, or simply soldered or even twisted together.

(5) When a thermocouple is used with a potentiometer, no correction need be made for the leads. For resistance thermometers and thermistors, such a correction is necessary as indicated in (1).

(6) The variation of resistance with temperature for the resistance thermometer is approximately linear, but for the thermistor the variation is far from linear. Thus, interpolation for thermistors is more cumbersome. The variation of electromotive force of the thermocouple with temperature approaches linearity sufficiently so that interpolation is easy.

(7) Thermistors have very high resistances and, consequently, heat up appreciably during measurement, particularly if the current is allowed to flow for any period of time. Precaution should be taken, therefore, to minimize the heating effect, and corrections may be necessary. Because thermistor resistances are usually much lower, this is not as serious a problem in resistance thermometers; on the other hand, because of the low resistance, the lead connections become much more serious for resistance thermometers than for thermistors.

(8) The resistances in the Wheatstone bridge are temperature sensitive, and therefore corrections may have to be made, particularly in portable use when the bridge may get very cold. Potentiometers have a similar disadvantage in that the voltage of the standard cell is also temperature dependent and therefore may require correction. Furthermore, the cell must be protected from extreme cold.

(9) With common installation, the degree of precision is least for the thermocouple and greatest for the thermistor. Precision of the order of 0.1° to 0.5° C (0.18° to 0.9° F) is available with thermocouples and standard equipment; with special potentiometers, shielded leads, and constant temperatures at the potentiometer, this precision may be improved. When properly used by skilled operators, precisions of at least 0.01° C (0.018° F) are obtainable with thermistors.

In recent years the techniques for using thermistors have been greatly advanced, and for very precise work thermistors are probably the preferred element. Where such precision is not required, and for general use, thermocouples are probably the most useful.

3. PLACEMENT AND OBSERVATION. For determination of fluid temperatures, the temperatures of refrigeration pipes, and so on, no special problems are likely to be encountered in placing thermally responsive elements. For very rapid response time, the element must have a small heat capacity, and for the determination of fluid tem-

peratures a relatively large surface in contact with the fluid.

For accurate gas measurement, the responsive element should be shielded from the surroundings if they are at a temperature different from that of the gas, to prevent heat transmissions by radiation. (See Figure 2A8-25.) Materials of low emissivity should, of course, be used for shielding.

For any type of measurement, heat leakage along the leads should also be sufficiently small so that the temperature at, for example, the thermocouple junction will not differ appreciably from the fluid or solid temperature. This last difficulty may be largely eliminated by allowing a foot or so of wire beyond the junction, depending on conditions, to come also in thermal but not electrical contact with the solid or fluid.

The accurate determination of ground temperatures is considerably more difficult because of the long time required for approximate attainment of equilibrium after an installation is made. For example, if attempts are made to determine ground temperatures by putting a string of thermocouples down a recently drilled well (Figure 2A8-26), a period of time must elapse before the heat generated in drilling the well has diffused sufficiently into the adjacent soil so that the readings are really characteristic of soil conditions. This time lapse may vary from a few days to one or two years, depending on the method of drilling and the soil characteristics. If accurate temperature measurements are desired, the amount of heat generated or transferred within the well should, of course, be as small as possible. Other slight difficulties are encountered, but for many purposes they will not be important. If the wells are left open or filled with water, oil, or some other fluid, convection currents may be sufficient to cause errors, particularly in large holes. In addition, because of differences in thermal properties between the filling fluid and the soil, the response to changes in temperature will not be exactly the same. Also, the addition of a fluid at a temperature above that of the ground results in a dissipation of heat into the ground, the diffusion of which requires some time. Finally, metal casings, if left in the ground, lead to inaccuracies. Perhaps the best results may be obtained by drilling small holes, removing casings, and allowing the thermocouples or resistance thermometer string to freeze in the ground. Experience has shown (Ref. 45) that, after drilling, the rate at which equilibrium is approached may be approximated empirically by a hyperbola so that extrapolation is possible.

As a rule, temperature-responsive elements will be installed so that they will actuate devices regulating the flow of refrigerating or heating media, or so that an observer may control the circulation

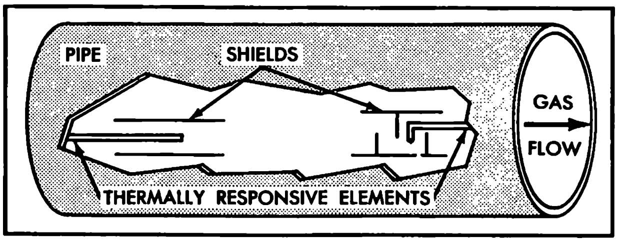


FIGURE 2A8-25

Protected Thermal Elements for Measuring Fluid Temperatures

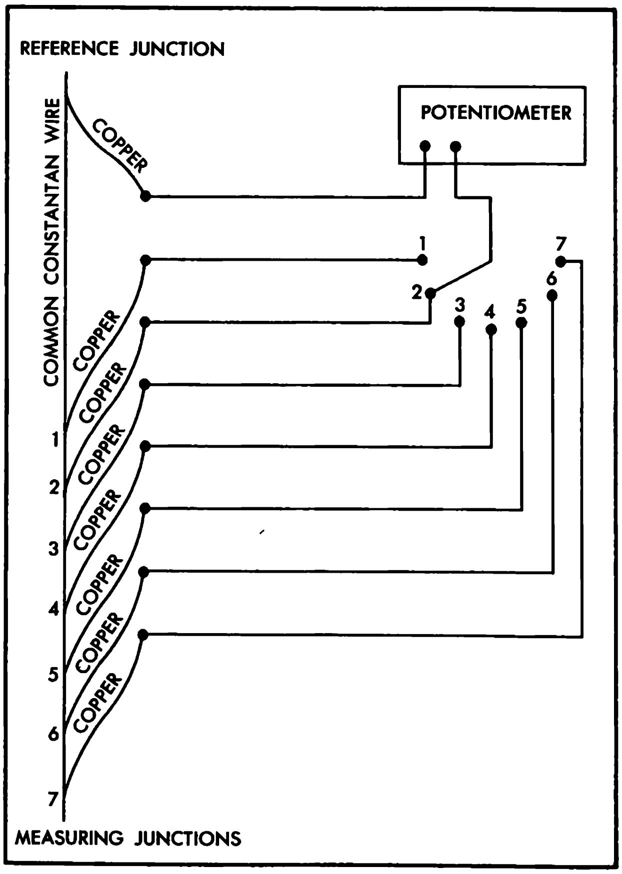


FIGURE 2A8-26

Wiring Diagram of Thermocouple String for Field Use

or make estimates of the expected lifetimes of projects and the preventive or precautionary measures that must be taken. When the problem is one of heat flow in soil, very serious difficulties may be encountered because of the large volumes and low diffusivities involved.

Figure 2A8-17 illustrates the nature of the problem. With reference to this example, the central hole acted as a heat source. The holes marked P were pilings, those marked R were refrigerating holes, and those marked T were temperature measurement holes. Observations at holes marked T could be used to determine whether or not refrigeration would be required in the holes marked R if thawing about the pilings was to be avoided. Assume that an observer decides that a temperature of 32° F at T 14, 15, and 16 should indicate circulation or refrigeration in the holes marked R. This decision would be adequate (with refrigeration reasonably available) to assure the stability of the pilings at the northeast and northwest corners of the foundation. Such action, however, may be delayed too much to save the other pilings because the 32° F isotherm may well reach these other pilings before the refrigeration at S has become sufficiently effective. (In this particular instance, the situation was not serious because provision had been made for refrigeration in the pilings themselves.) Clearly, in a circumstance of this kind, attempts should be made to extrapolate, by both theoretical and empirical results, the rate at which the 32° F isotherm will be moving so that refrigeration will not be delayed beyond the critical time. Careful placement of temperature observation points and study of temperatures at these points will be helpful. Needless to say, a generous margin of safety should be provided.

CAUTION: The point to be emphasized is that failure may be inevitable if preventive measures are delayed until the critical temperatures have almost been reached. In many cases, the preventive measures will have to be taken weeks or months in advance if they are to be effective.

4. EXTRAPOLATION. As previously indicated, extrapolation of the movement of isotherms may be of great importance. The thermal properties of the solids need not be explicitly determined before the equations given in previous sections can be used. Thus, a glance at equations (2A8-12b) and (2A8-13) shows that the depth of thaw in homogeneous material from surface heating is proportional to the square root of the thawing index. A more complicated example follows.

TABLE 2A8-11

Percent Freezable Water in Soil (After Bouyoucos) (Ref. 46)

Soils	When cooled to 29.3° F percent	When cooled to 24.8° F percent	When cooled to 24.8° F and also to 108.4° F twice, percent
Norfolk sand, Anne Arundel Co., Md.	1.39	1.39	
Plainfield fine sand, Wis.	2.94		
Miami silt loam, Ky.	5.27	...	5.07
Miami silt loam, Delaware Co., Ind.	7.05	4.62	
Vernon clay loam, Archer Co., Tex.	9.17	7.93	
Carrington silt loam, Wis.	11.36		9.85
Marshall silt loam, Ky.	14.25	...	9.95
Carrington loam, Goodline Co., Minn.	16.22	8.22	
Black clay loam, Ill.	19.76	...	13.41
Houston clay, Franklin Co., Tex.	21.88	12.50	

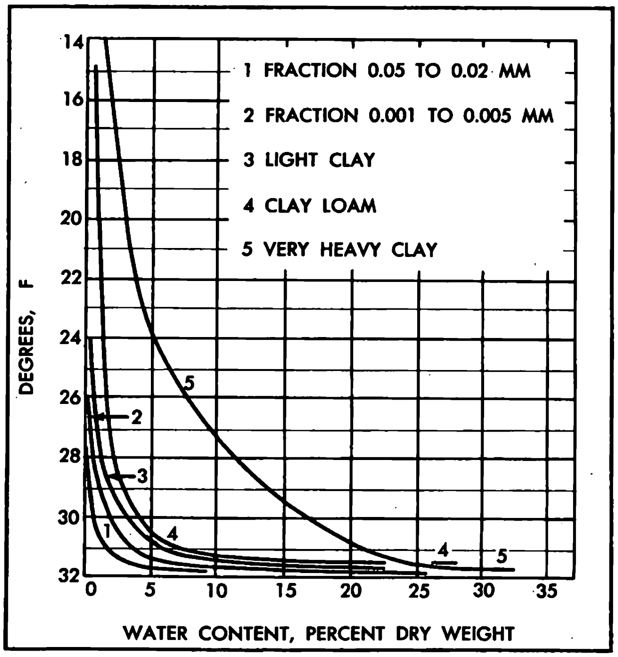


FIGURE 2A8-27

Relationship Between Freezing Temperature and Water Content for Different Soils (After Beskow) (Ref. 46)

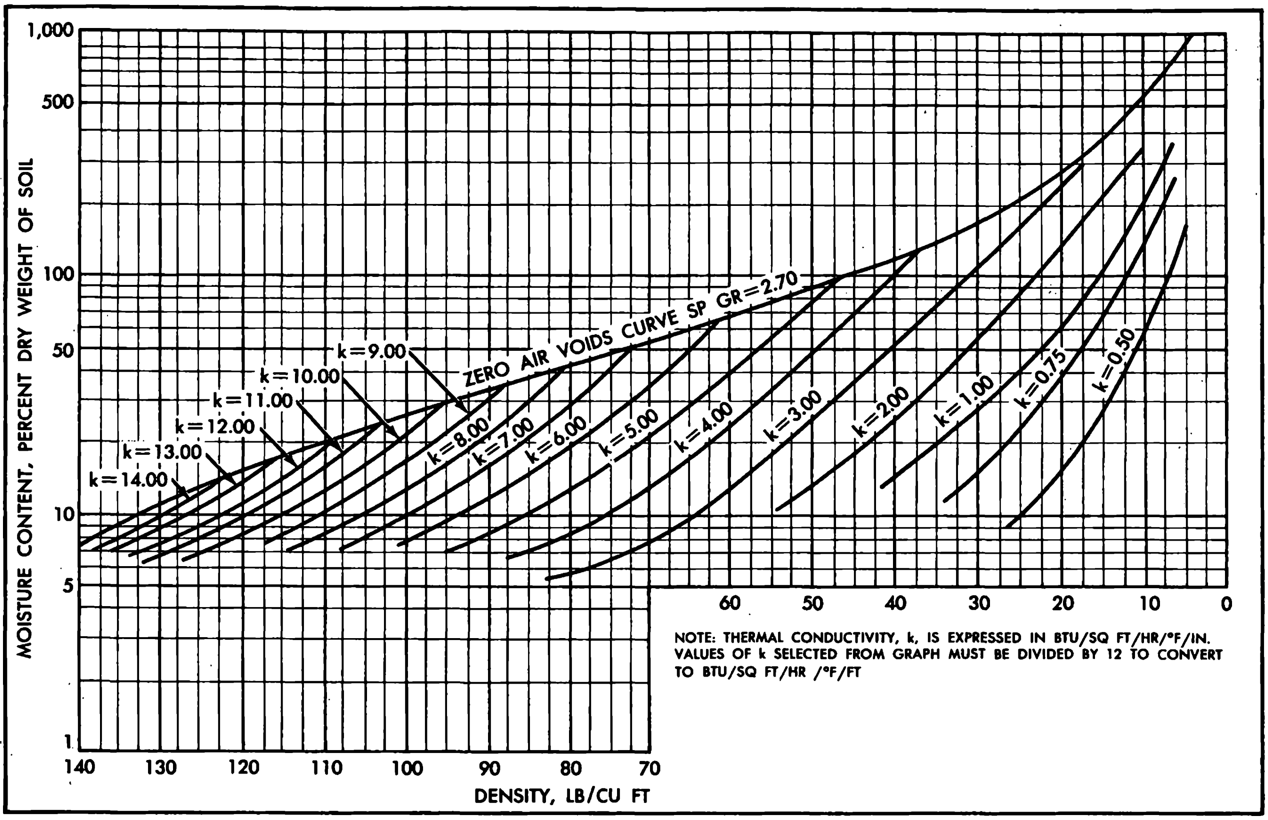


FIGURE 2A8-28

Average Thermal Conductivity for Silt, Clay, and Peat—Unfrozen, Mean Temperature 40° F (Ref. 35)

Example

An artesian flow of water occurs through a 4-in. well in a permafrost region. A thermocouple 2 ft from the pipe surface records a temperature of 32° F after 400 degree-days of flow. (The freezing point is to be taken as the reference for computing degree-days. For example, if the water has an average temperature of 40° F for 10 days, this would equal 80 degree-days of flow). Calculate the radius of the thawed zone after 2,000 degree-days, or using equation (2A8-16a) and assuming $y = y_o$,

$$\left(\frac{r_2}{r_1}\right)^2 = y_o$$

$r_1 = 2$ in.

$r_2 = 2$ in. $+$ 24 in. $=$ 26 in. at 400 degree-days

$$\left(\frac{r_2}{r_1}\right)^2 = \left(\frac{26}{2}\right)^2 = 169 = y_o$$

r_2 ft = radius at 2,000 degree-days

$$\left(\frac{r_2\ \text{ft}}{r_1}\right)^2 = y_o\ \text{ft}$$

From equation (2A8-16b),

$$\frac{F(y_o)}{F(y_o\ \text{ft})} = \frac{400}{2{,}000}$$

Using Figure 2A8-15,

$F(y_o) \quad = 690$

$F(y_o\ \text{ft}) = 690 \times \dfrac{2{,}000}{400} = 3{,}450$

Again using Figure 2A8-15,

y_o ft $= 635$

r_2 ft $= \sqrt{635} \times 2$ in. $= 50.4$ in.

The extrapolation need not be made under exactly equivalent conditions. For example, the data obtained in the one measurement given in the previous example could be applied to larger or smaller wells in permafrost believed to have the same properties. In this case,

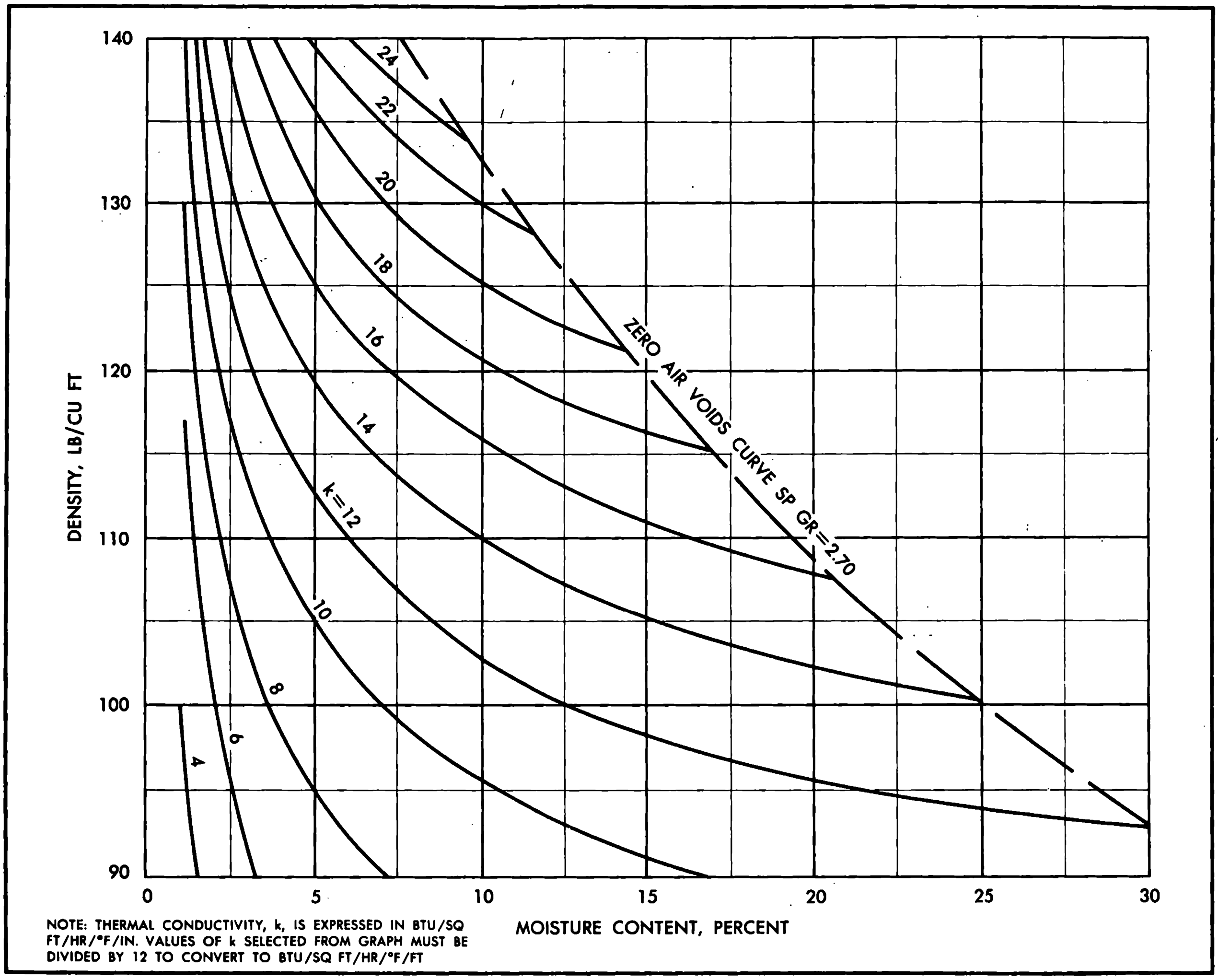


FIGURE 2A8-29

Average Thermal Conductivity for Sandy Soil—Unfrozen, Mean Temperature 40° F (Ref. 35)

$$\frac{F(y_o)}{F(y_o\ \mathrm{ft})} = \frac{r_1^2 400}{2^2 \int_o^t (T_1 - T_o)\,dt}$$

r_1 ft = radius of pipe larger or smaller than 2 in. pipe

$\int_o^t (T_1 - T_o)\,dt$ = thawing index in degree-days

5. FREEZING POINT OF PERMAFROST. In all of the foregoing discussions it has been assumed that the freezing point of moist or wet soil was constant and the same as that of pure water. This is not strictly true, and under certain circumstances the deviation must be considered. The deviation is negligible, for most purposes, for all soil except silt and clay of low moisture content. Figure 2A8-27 shows the relationship between freezing point and water content for different soils. From Table 2A8-11 it can be seen that not all of the water in some soil freezes at the same temperature. The water that does not freeze at −108.4° F has been classified as in loose chemical combination with the soil, and water that does freeze at these low temperatures but not at 29.3° F as capillary-absorbed water. These facts are of importance in the formation of ice in freezing soil. The relatively free water in large voids freezes first; then the water in the capillaries moves to the voids and freezes there. Thus, local concentrations of ice result.

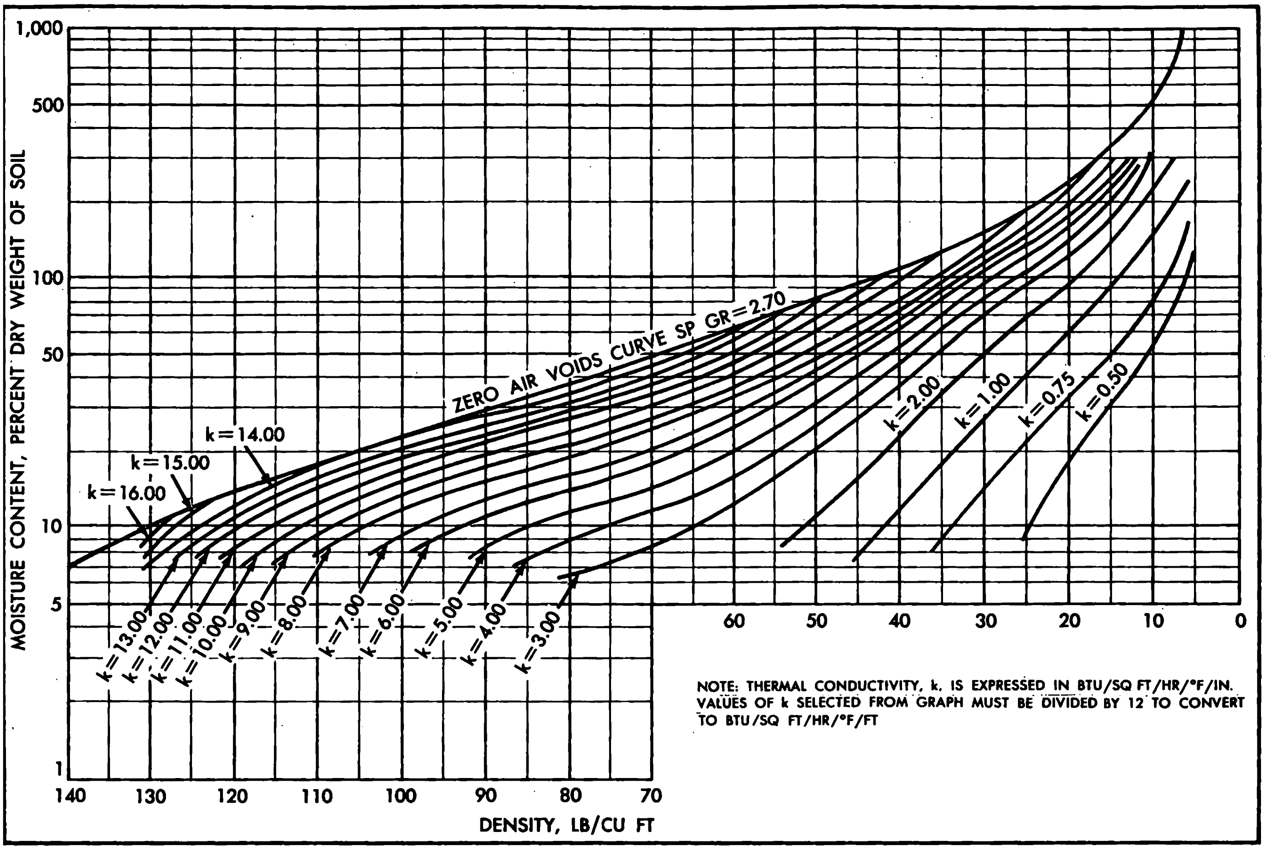


FIGURE 2A8-30

Average Thermal Conductivity for Silt, Clay, and Peat—Frozen, Mean Temperature 25° F (Ref. 35)

6. **THERMOCONDUCTIVITY OF SOIL.** Examination of Figures 2A8-28, 2A8-29, 2A8-30, and 2A8-31 shows that the conductivity of frozen soil, particularly that with a high water content, is much higher than for the same soil in a thawed state. As a consequence, freezing of soil is relatively easier than thawing (by conduction) because the heat flows more readily from a 32° F isotherm to a heat sink through frozen soil than from a 32° F isotherm to a heat source through thawed soil.

A corollary consequence is that the approximate calculations for freezing are more accurate than for thawing because these calculations neglect heat flow beyond the 32° F isotherm, and the error will be greater when the material beyond the 32° F isotherm is frozen because the heat flow then occurs more readily.

Densities given in the figures are dry densities.

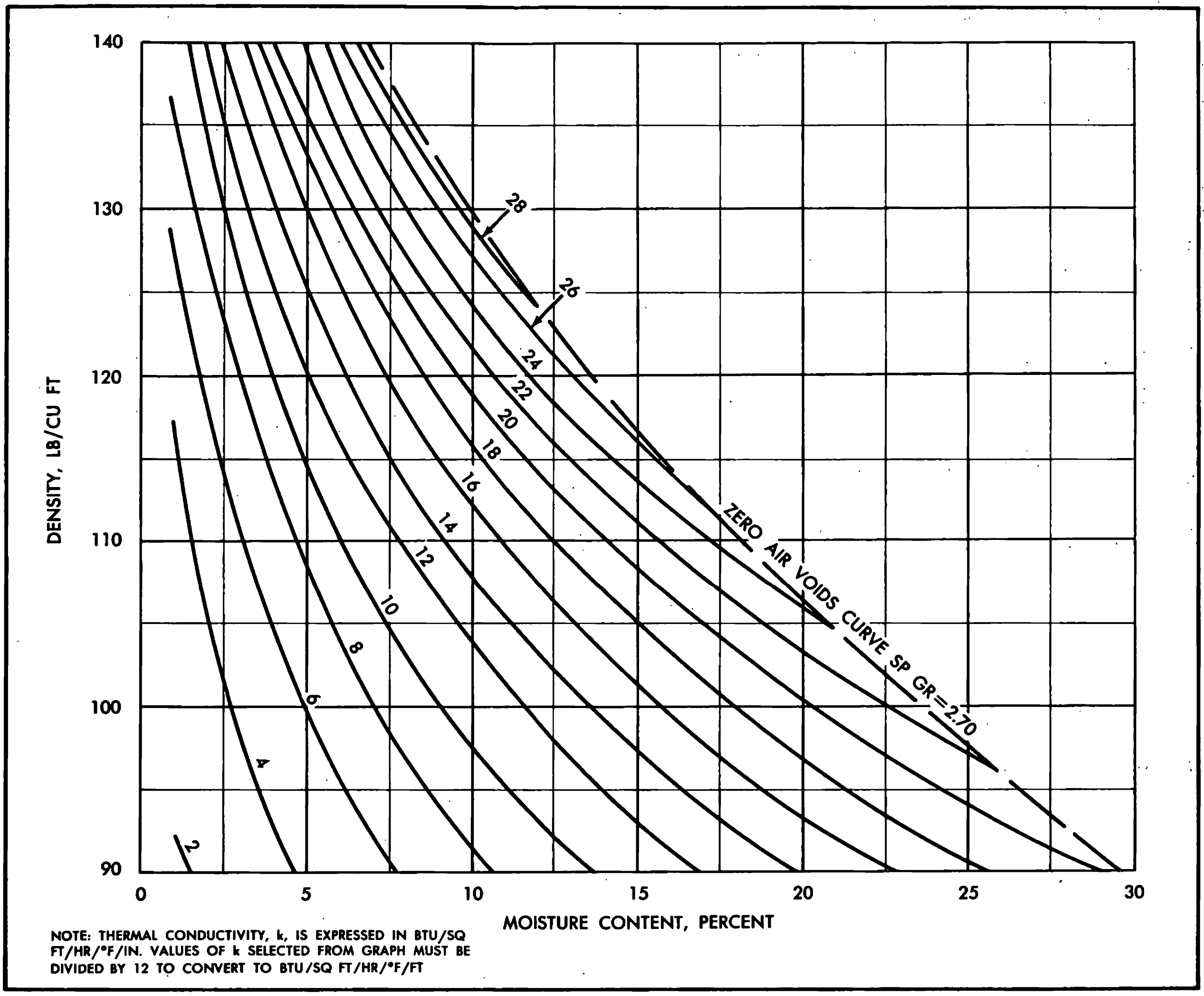


FIGURE 2A8-31

Average Thermal Conductivity for Sandy Soil—Frozen, Mean Temperature 25° F (Ref. 35)

Section 9. CONSTRUCTION MATERIALS

2A9.01 EFFECT OF EXTREME COLD ON MATERIALS

1. GENERAL. A knowledge of the effect of extreme cold on the structural properties of construction materials is of prime importance in designing facilities for use in the Cold Regions. Although considerable low-temperature research has been reported on many of the common types of construction materials, as well as on many that are comparatively new and appear to be potentially valuable, the conclusions reached can not always be evaluated so that they can be readily applied to the improvement of structural designs. In reviewing the available information, therefore, it appears advisable to emphasize only those materials that have had sufficient use under critical operating conditions to permit the formulation of reliable design criteria. Materials that have been reported promising but on which field information is lacking or inconclusive will be discussed to the extent of the information available.

2. FERROUS METALS.

a. *Classification.* The general classification of ferrous metals covers many important commercial forms of iron and can be broken down in accordance with the chemical elements that the metals contain. The amount and distribution of these elements depend on the method of manufacture and have considerable effect on the physical and mechanical properties of ferrous metals. (See Ref. 47, pp. 526-584.) Discussion of cold-weather effects on ferrous metals will be limited to: (a) carbon steel, (b) alloy steel, and (c) cast iron, including gray, white, and malleable cast iron, all of which react to low temperatures approximately the same.

The effect of low temperatures on stainless steel is discussed under chromium (par. 3e of 2A9.01).

b. *Carbon Steel* (Ref. 48). The general behavior of carbon steel under low-temperature service conditions may be summarized as follows (Ref. 49).

(1) Strength, as measured by standard static tests, increases to a marked degree over normal temperature values. The increase continues down to −320° F.

(2) Ductility decreases slightly down to −100° F, as measured by elongation and reduction of area or necking down during tension tests.

(3) There is a marked decrease in impact resistance, as measured by Charpy and Izod impact tests, and an increasing tendency toward notch brittleness and brittle-type fractures.

(4) Brinell hardness increases with decreasing temperatures through all ranges of temperature service.

For all temperature conditions experienced in the Cold Regions, steel is, generally speaking, a satisfactory construction material. For these temperatures and for most types of service the slightly lower ductility and increased hardness indicated for carbon steel would be of negligible importance. However, the loss of impact resistance and the tendency toward brittle-type fractures might influence the designer to select a steel of different composition and treatment than that chosen for a similar structure built for normal temperature service.

CAUTION: To meet low-temperature conditions and avoid embrittlement effect of these temperatures, especially on steel that is not heat-treated, the steel should have a relatively low carbon content. A good example is the Bailey bridge used by US Army Engineers. Probably the greatest tonnage used in this bridge was furnished by the US Steel Corporation and consisted of the following composition (by percent): C, 0.25 max; Mn, 1.50 max; Cu, 0.25 to 0.50; Ni, 0.50 to 1.00.

This steel retains its toughness at temperatures down to and below −50° F.

It has been customary for many years to use in structures designed for the Cold Regions the same design values that would be allowed for similar structures built in the Temperate Zone. Many standard ferrous metals, including structural low-carbon steels such as ASTM A-7 and low-alloy steels such as ASTM A-242, have had wide use in the Cold Regions for many years, with satisfactory results.

The Alaska Road Commission, in correspondence dated 18 July 1952, makes the following comment regarding the grades of steel used in its buildings and bridges.

> For most of our steel construction, both buildings and bridges, we use A.S.T.M. designation A-7 structural grade steel with an allowable working stress of 18,000 lbs. per square inch for design of our steel bridges and 20,000 lbs. per square inch for our building design. Prior to the present steel shortage, for our bridge work we used a considerable quantity of A.S.T.M. A-242 steel. For this grade steel we used the allowable working stresses shown in the A.A.S.H.O. Standard Specifications for Highway Bridges.

Table 2A9-1a lists other engineering structures of various types that have given satisfactory service in Alaska for a number of years. The ASTM designations for the steel used in each structure are indicated in Table 2A9-1b.

c. *Alloy Steel.* Among the many important effects of certain alloying elements on the properties of steel are a lowering of the temperature at which fracture changes from ductile to brittle (transition temperature) and an increase in impact resistance at low temperatures. Steels for various types of low-temperature service have been and are being developed. In many cases, however, the value of laboratory tests should be questioned until an evaluation can be made under service conditions. The effect of alloying materials on all properties of the metal that contribute to its serviceability should be considered, and detrimental

TABLE 2A9-1a

Engineering Structures Giving Satisfactory Service in Alaska

Project number	Type of structure	Satisfactory operation, years	Location
1	Water treatment plant	Under construction	Fairbanks
2	Pipeline and siphon system	25±	Chatanika
3	Beam highway bridge	2±	Haynes
4	Beam highway bridge	2±	Eklutna
5	Beam highway bridge	2±	Gulkana Creek
6	Beam highway bridge	2±	Darling Creek
7	Beam highway bridge	2±	Bear Creek
8	Through-truss highway bridge	2±	Gahona River
9	Through-truss highway bridge	2±	Matanuska River
10	Girder highway bridge	2±	Chena River
11	Girder highway bridge	2±	Noyes Slough
12	Railroad bridge	30±	Tanana River
13	Railroad iron and steel bridge	30±	Alaska Railroad

differences should be compensated for in the design. (Ref. 48.) (See also par. 3 of 2A9.01.)

d. *Cast Iron.* (See classifications in par. 2a of 2A9.01.) Gray iron, which is the most widely used cast metal, maintains or slightly increases its tensile strength and Brinell hardness down to −317° F. There is a slight decrease in impact value at −112° F and below. At −317° F there is no pronounced increase in brittleness or change in appearance of fracture. Figure 2A9-1 shows the tensile properties of malleable cast iron at various temperatures. (Ref. 51.)

3. NONFERROUS METALS (Ref. 48).

a. *General.* Most nonferrous metals (Ref. 47, pp. 586-631), in contrast to ferrous metals, become more resistant to impact with decreasing temperatures. Because of this and other beneficial effects at normal and low temperatures, including high strength and nearly constant ductility values, nonferrous metals are widely used as alloying elements. (See Ref. 47, Table 9, p. 604.)

b. *Aluminum and Aluminum Alloys.* These materials are particularly well suited for extremely low temperature service. Tensile, yield, and impact strength of all aluminum alloys increase at extremely low temperatures. Aluminum alloys retain ductility at these temperatures, corrosion resistance is enhanced, and there is no increase in brittleness. No special precautions regarding

TABLE 2A9-1b

Steel Specification for Structures Shown in Table 2A9-1a (Ref. 50)

Project number	Material	Specification
1	Structural steel Rivet steel Plate steel	ASTM A-7-49T ASTM A-141-49T ASTM A-30-24
2	Rivet steel Cast steel Structural steel	ASTM A-31-24 ASTM A-27-24 medium class B ASTM A-7-24
3	Structural steel	ASTM A-242-46
4	Structural steel	ASTM A-242-46
5	Structural steel	ASTM A-242-46
6	Structural steel	ASTM A-242-46
7	Structural steel	ASTM A-242-46
8	Structural steel	ASTM A-242-46
9	Structural steel	ASTM A-242-46
10	Structural steel	ASTM A-242-46
11	Structural steel	ASTM A-242-46
12	I-bars	ASTM A-8
13	Iron and steel	Committee 15, AREA[1]

[1]American Railroad Engineering Association

methods of handling at extremely low temperatures are required. (Ref. 52.)

A small amount of soluble aluminum is commonly used in steel manufacturing to secure grain refinement. Tests indicate that if the aluminum content is raised to a level approaching 0.20 percent, appreciable lowering of the transition temperature is possible. (See Figure 2A9-2.)

Although it has not been common practice to use so high an aluminum content, there do not appear to be any serious difficulties involved, and a significant saving in more strategically critical alloys is realized. (Ref. 49.)

Aluminum, because of its light weight, is worthy of consideration for many applications in the Cold Regions, where transportation is an especially important factor. (See Ref. 47, p. 595.)

c. *Nickel.* This material is widely used in steels as an alloying material because of its strong beneficial effect on toughness and transition temperature. Low-carbon 3.5-percent nickel steel meeting the requirements of ASTM A-203, grades D and E, has been used successfully in the unheat-treated condition in the form of plates, forgings, and castings at temperatures as low as −150° F.

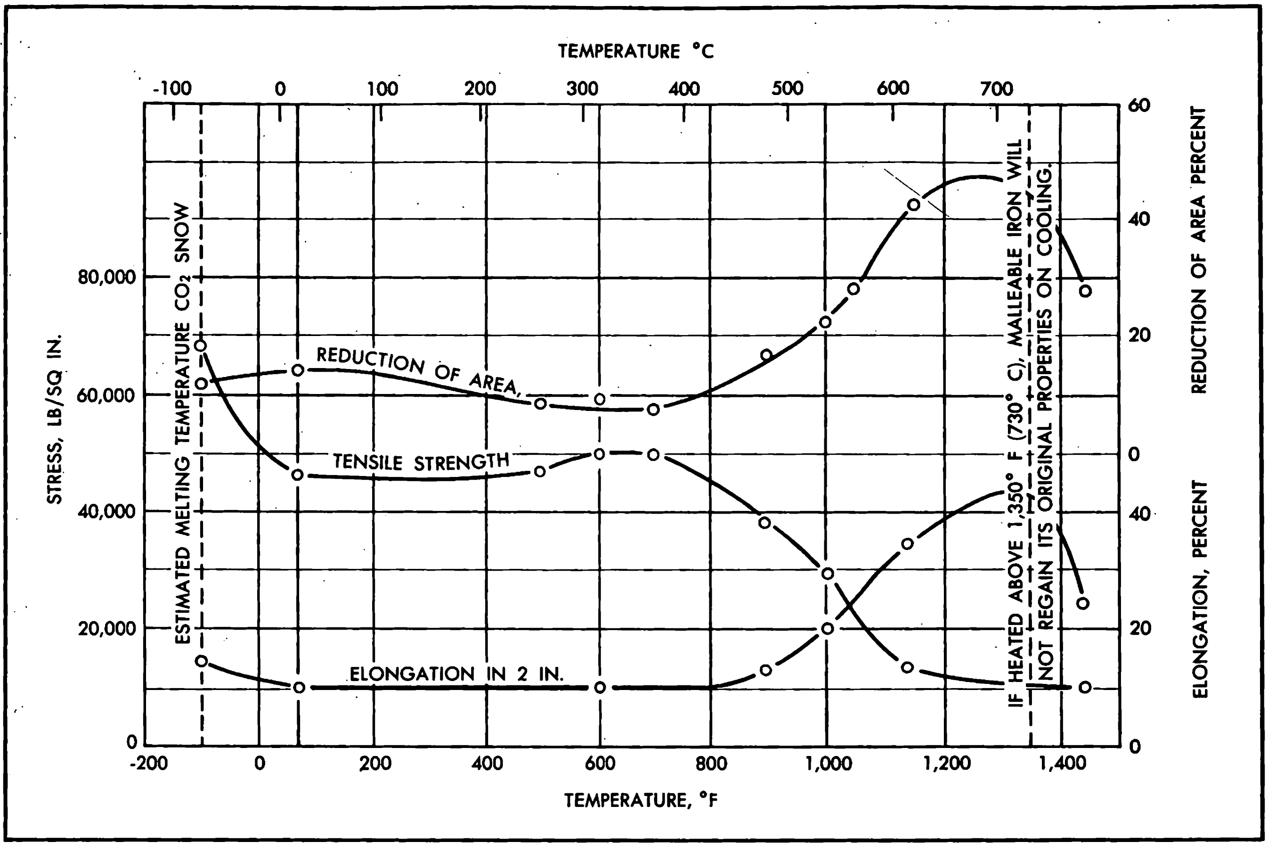


FIGURE 2A9-1

Tensile Properties of Malleable Cast Iron at Various Temperatures

Experience in mining operations in cold climates indicates that low-carbon 3.5-percent nickel or low-carbon 2-percent nickel steels can be expected to give good service at low temperatures in such applications as power shovels, trucks, and other equipment that must operate out-of-doors. One company, for its northern mining operations, specifies either low-carbon 2-percent nickel steel or high-strength low-alloy steel for unheat-treated parts such as dipper sticks, shovel booms, truck bodies, and frames.

Structural nickel steel conforming to ASTM A-8 has been successfully used in many highway or railroad bridges in the Temperate Zone. Its use, however, is not suggested as a means of combating the embrittling effects of low temperature because of its relatively high carbon content (0.43 to 0.45 percent maximum).

d. *Copper and Copper Alloys.* Copper and all its alloys show a uniform improvement in hardness, yield, and tensile strength as the temperature decreases from room temperature. Ductility of cold-worked alloys increases at low temperatures to a greater extent than does the annealed material, but that of castings of copper alloys decreases slightly. Impact properties are almost unaffected by low temperature. Although cases of failure of copper wire under tension at low temperature have been reported, it is possible that the large temperature range common to many sections of the Cold Regions was not allowed for. (Ref. 52.) (See par. 4d of 2B4.04.)

e. *Chromium.* This material is an important constituent of many alloy steels, including the complex group known as stainless steels. Each of the three general types of stainless steel (Ref. 47, pp. 560, 561, and 562) contains a relatively high percentage of chromium and has high resistance against weather, water, steam, and many organic and inorganic corrodents.

The chrome-nickel types are especially suitable for low-temperature applications because their

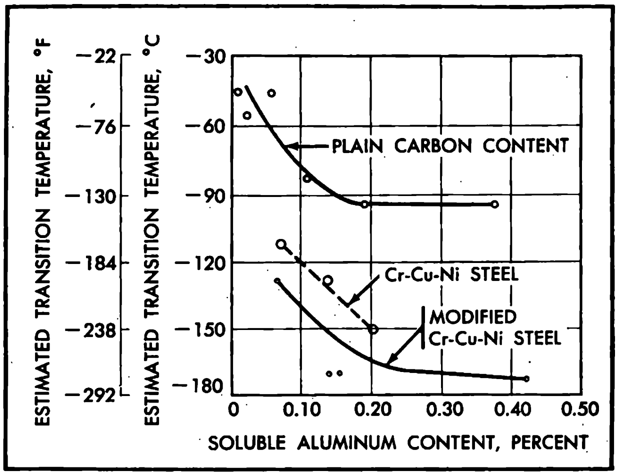


FIGURE 2A9-2

Lowering of Temperature in Aluminum Alloys (Ref. 49)

strength and toughness properties are improved at extremely low temperatures. (Ref. 52.)

Low-carbon, nonhardenable chromium types show marked loss of toughness at 0° F, but hardenable chromium types show moderate loss of toughness at extremely low temperatures. (Ref. 52.)

f. *Zinc and Zinc Alloys.* The strength and ductility values of extruded zinc show a marked reduction at subzero temperatures. This is in contrast to the characteristics of other nonferrous metals at these temperatures. (Ref. 51.)

For the same temperature service conditions, zinc alloys of copper, magnesium, and aluminum show improvements in these properties in comparison with the base metal. These improvements are sufficient in most cases to make them as satisfactory for use at subzero temperatures as at room temperatures. Impact strength, although seriously reduced at subnormal temperatures, is considered adequate for practical purposes. (Ref. 51.)

Galvanizing is one of the most common uses of zinc, and the results of tests performed on galvanized wire rope at −80° F showed a tendency toward cracking for heavy zinc coatings. This was not sufficient, however, to make the coating defective for most Arctic service. (Ref. 51.)

The New Jersey Zinc Sales Company commented as follows regarding the effect of low temperatures on zinc coatings, including sherardized products.

The effect of low temperatures on zinc coatings has not been considered important because it would only be observed if the zinc-coated articles were deformed, which is unlikely. We have no information with respect to sherardized coatings but would imagine that there would be little change because in properties at low temperatures these coatings usually are brittle initially. It should be borne in mind that changes in properties of zinc and zinc alloys, caused by exposure to unusually high or low temperatures, are not permanent but only maintained while the metal is at the temperature in question.

g. *Magnesium and Magnesium Alloys.* Magnesium is the lightest metal of structural importance and has many important applications in portable tools, aircraft, and other equipment used widely in the Cold Regions.

In general, for engineering uses, the mechanical behavior of magnesium and magnesium alloys at temperatures as low as −76° F is the same as at room temperature. Tensile strength and modulus of elasticity values increase with decreasing temperatures. Ductility decreases at subzero temperatures, but the decrease is negligible down to −76° F. Impact values show slight decrease, but tension impact resistance is improved at temperatures down to −76° F. Fatigue strength of magnesium alloys is noticeably increased at low temperatures. (Ref. 51.)

Thermal expansion of magnesium and magnesium alloys exhibits little change at subzero temperatures in comparison with room temperature.

h. *Lead.* Low temperatures within the range experienced in the Cold Regions do not affect the properties of lead in any detectable manner. Lead-base white-metal bearing alloys (Babbitt metal) will generally react to low temperatures in the same manner as pure lead, provided the alloy contains not over 15 percent tin. (Ref. 52.) (See par. 3i of 2A9.01.)

i. *Solders (Lead and Tin Alloys)* (Ref. 52). Soft or low-strength solders that contain a high percentage of lead (65 to 97.5 percent) retain their ductility and increase in impact strength at low temperatures. Tin contents up to 15 percent have no serious embrittling effect. When the percentage of tin becomes as high as 50, serious embrittlement and decrease in impact strength occur.

The increase in tensile strength of solder alloys and in breaking load of soldered joints is linear with decreasing temperature. High-strength solders, those containing the most tin (50 percent), show the greatest increase in tensile strength, and low-strength solders, those containing the most lead (97.5 percent), show the least increase in tensile strength as temperatures decrease below freezing.

Breaking loads of soldered copper tubing at low temperatures are nearly independent of the kind of lead-base solder used. Impact strength and ductility of such joints would probably be influenced by low temperatures, in view of the properties of individual solders.

4. WOOD PRODUCTS.

a. *General.* In general, wood is as satisfactory for construction purposes in the Cold Regions as it is in the Temperate Zone. Structures and a wide range of products made of wood have been used in areas subject to extremely low temperatures for many years without noticeable failure. Strength/temperature relationships for longtime exposure to low temperatures or to fluctuating temperatures have not been determined, but experience indicates that such exposure is not noticeably detrimental. There is a general agreement among the various investigators that, in most cases, strength properties are actually improved by comparatively shorttime exposure to below-freezing temperatures, a notable exception being impact strength, which was found to exhibit little change either way with changes in temperature for wood at 7.5 percent moisture content in the range from about 75° F down to −58° F. (Ref. 53.) The strength properties of wood at low temperatures are shown in Table 2A9-2 and Figures 2A9-3 through 2A9-6.

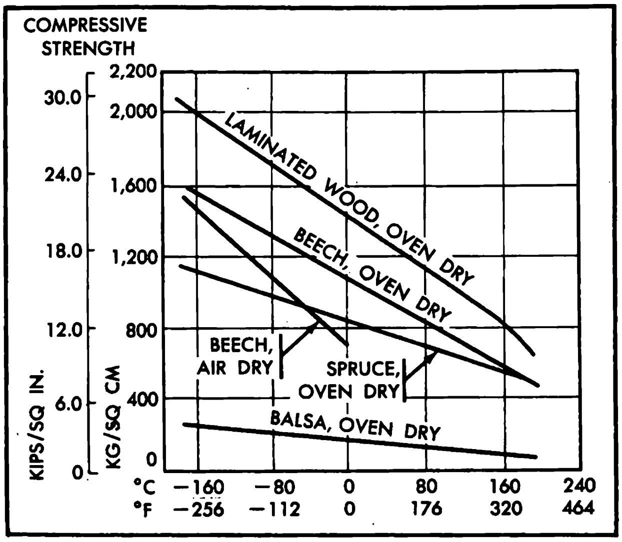


FIGURE 2A9-3

Effect of Temperature on Compressive Strength of Various Woods (Ref. 53)

b. *Moisture Content* (Ref. 52). There is a strong indication that below the fiber saturation content, properties representing toughness or shock resistance decrease at subfreezing temperatures with moisture content. If this is true, failure would not be so likely to occur with wood articles stored or used outside or in unheated sheds. Wood exposed to outdoor winter conditions at Fairbanks, Alaska, where the relative humidity averages about 83 percent during that season, should attain an equilibrium moisture content of about 17 percent. On the other hand, if wood articles are stored in heated buildings, they may be subjected to con-

TABLE 2A9-2

Toughness of Solid Wood and Plywood Specimens

Species	Average moisture content,[1] percent	Average toughness per specimen			Number of tests at each condition	Ratio of average values to control values	
		Control,[2] in.-lb	Frozen,[3] in.-lb	Cycle,[4] in.-lb		Frozen	Cycle
Southern yellow pine	10.4	126	152	141	30	1.21	1.12
White pine	12.3	88	100	88	28	1.14	1.00
Sweet gum	10.7	83	103	83	30	1.24	1.00
Douglas fir plywood	11.3	28	24	35	29	0.86	1.25
Gum and yellow poplar plywood	8.4	4.1	4.2	4.2	30	1.02	1.02

Note: Tested at three temperature exposure conditions at the Forest Products Laboratory for Air Materiel Command.

[1]Average moisture content is for control specimens.

[2]Control specimens were tested at 75° F after initial conditioning (75° F, 65 percent relative humidity).

[3]Frozen specimens were stored at −67° F for about 44 hours after initial conditioning (75° F, 65 percent relative humidity).

[4]Cycle specimens were conditioned initially (75° F, 65 percent relative humidity), frozen at −67° F (44 hr), reconditioned (75° F, 65 percent relative humidity), and tested at 75° F.

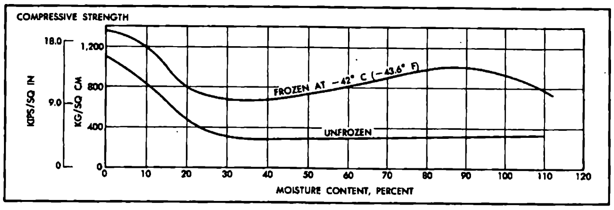


FIGURE 2A9-4

Effect of Moisture Content on Compressive Strength of Frozen and Unfrozen Beech (Ref. 53)

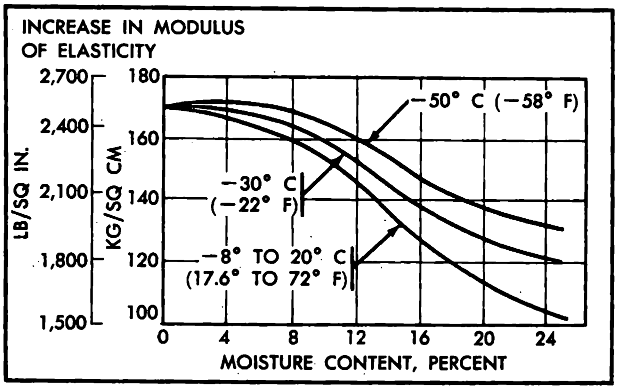


FIGURE 2A9-5

Effect of Moisture Content on Modulus of Elasticity at Various Temperatures (Ref. 53)

ditions that will result in extreme dryness, even less than 1 percent, if such exposure is continued for sufficient time. Consideration should be given to the possibility of reduced impact strength of wooden containers, tool handles, and other articles that have been removed from storage in heated buildings and are subsequently subjected to freezing temperatures.

Nailing and nail-holding qualities of wood are influenced by moisture content. Dry wood is harder to nail and splits more easily than green wood. If wood dries after the nail is driven, the nail-holding power is often seriously reduced. Thus, the serviceability of wood articles, such as wooden shipping containers, is materially affected

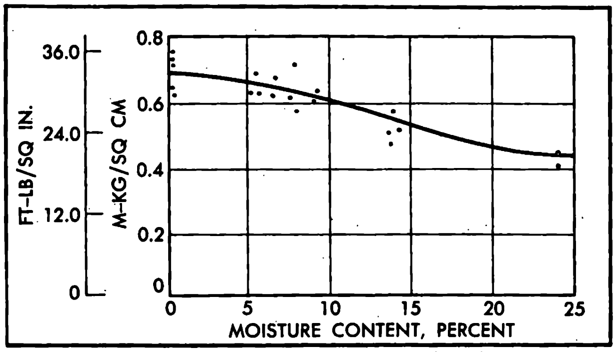


FIGURE 2A9-6

Breaking Energy Under Impact of Frozen (—58° F) Laminated Wood in Hygroscopic Range (Ref. 53)

by the moisture content or the change in moisture content of the wood in response to exposure conditions.

5. NONMETALLIC MATERIALS.

a. *Portland Cement and Concrete.* The use of portland cement and concrete at low temperatures is mainly a problem of (a) properly designing a durable mix from cement, aggregates, and water that satisfactorily complies with ASTM requirements, and (b) assuring satisfactory mixing, placing, and curing of concrete. (See Section 3E1.) Structural behavior of properly designed concrete is not materially changed by temperatures encountered in cold-weather service.

b. *Snowcrete* (Ref. 52). Snowcrete is a term used to describe the condition of snow resulting from compaction by natural or mechanical means. Except for some recent work, little has been done in the field of mechanical compaction of snow. However, naturally compacted drift snow has been used for a long time. Caves have been hollowed out of snowdrifts, and snow blocks have been carved out for building purposes. These blocks have been used primarily by Eskimos to build snow caves, igloos, shelters, and windbreaks. (See par. 2E2.05).

All the properties of compressed snow have not yet been determined by experimental work. The hardness of snow is based on the strength of the attachment of individual snow particles to each other. The mechanical value of compacted snow depends on its density, temperature, and texture. Uncompacted snow crystals enclose a great deal of air. If the snow is compacted, the crystals are crushed together and the air is practically eliminated, resulting in greater density. Tests indicate that compaction methods are more efficient at high temperatures and that intercrystalline cohesion and strength of snow crystals of the same form, size, and density increase greatly at low temperatures.

One of the notable properties of snowcrete is, therefore, that at temperatures below freezing its hardness continues to increase if left undisturbed after having been compacted. Temperatures following compaction are also important because the bearing capacity of snowcrete developed at very low temperatures will be highest and will decrease rapidly as the melting point of snow is approached.

Use of snowcrete is slowly being developed. Obviously, development is limited to periods when temperatures do not rise above freezing. During these periods compacted snow may be used for the construction of airstrips, roads, shelters, windbreaks, and limited military construction.

c. *Icecrete* (Ref. 52). Icecrete is a term applied to a material made from aggregates, with ice acting as the cementing agent. During periods of no thaw, icecrete may be used as a dependable substitute for concrete in regions of extreme cold. By mixing water and aggregate materials (sand and gravel) either by hand or in a concrete mixer, a plastic and flowable homogeneous mixture may be made. The mixture may be poured into forms in a manner similar to concrete and rodded or tamped to assure compaction. Forms may be built from snow or ice blocks or available brush or wood and may be left in place.

The presence of the aggregates makes icecrete darker in color than ice. Therefore, it will absorb more heat from the sun, which may cause melting. To minimize this action the icecrete structure or mass should be covered with snow, ice, or canvas.

Icecrete is generally tougher than ice, does not crack readily, and is comparatively shatter and impact resistant. It is excellent for construction of roads, protective barriers, foundations for structures to be used only in winter, deadmen for tiedowns, and as a substitute for mass concrete construction required during no-thaw periods.

d. *Lime, Mortar, and Plaster.* Low-temperature use of these materials is similar to that of portland cement and concrete. Proper mixing, placing, and curing temperatures must be provided. If used on outside areas, these materials should be made as durable and moisture resistant as possible to provide protection against the extreme cycles of freezing and thawing.

e. *Stone and Structural Clay Products.* Properties of these materials are included in most engineering handbooks. Their selection for low-temperature service can be made with respect to these properties, provided additional consideration to durability is given either by selecting a more durable material or by furnishing methods of protection and waterproofing.

6. GLASS MATERIALS (Ref. 52). Window glass has no visible reaction to cold. Thin sections are susceptible to sudden change in temperature, but the glass is designed to withstand the average thermal shock of 150° F.

Laminated safety glass (plate and sheet) has no visible reaction to cold. It is designed to withstand 150° F, the average thermal shock, and to meet minimum requirements of −65° F.

Structural glass also has no visible reaction to cold. It is designed to withstand the average thermal shock of 150° F.

7. FABRICS. Untreated and water-repellent fabrics are satisfactory for service down to −40° F. Canvas and heavy materials lose their pliability at low temperatures, and when frozen should be bent or stretched with caution. Loss of elasticity should not be mistaken for shrinkage. For flexibility and heat insulation, woolen blankets are much better than canvas. (Ref. 52.)

8. LEATHER. In low temperatures, leather becomes stiff and cracks, often tearing easily. When wet untreated leather becomes frozen, it will not stand tension, bending, or impact. Leather items to be subjected to extreme cold should be carefully tanned and then treated with a light coat of good shoe oil or lard. Tanned skins are less easily injured by wetting and subsequent freezing than untreated skins. Much has been said about the difference between Eskimo scraped and prepared skins and those tanned by commercial methods. In general, commercially tanned skins weigh more per square unit and as clothing are not as warm as those prepared by Eskimos. Commercially tanned items tend to stiffen, thereby reducing their utility. Because commercial tanning is cheaper, however, and better able to provide items in large numbers, commercially tanned items should be used. But, when leather and fur clothing are required to offset midwinter chill during operations on the

trail or away from main encampments, it is advisable to use clothing made from skins prepared by Eskimos. (Ref. 52.)

9. EXPLOSIVES. All modern explosives are the low-freezing variety and are designed to eliminate freezing under ordinary conditions of exposure at any temperature normally encountered. Gelatins and similar types of explosives become quite hard when subjected to low temperatures but do not freeze. Certain high explosives composed of a mixture, and mainly of ammonium nitrate, are absolutely nonfreezing. Some experience, however, has indicated that explosives become critically hazardous during freezing or thawing. Under these conditions, extreme care is therefore necessary in handling. Also, in the frozen state they seem to have no diminishing explosive effect, once set off. When frozen, they may be easily detonated by careless handling.

If an explosive is suspected of being frozen, using the simple pin test will readily determine if it is. An ordinary pin will not penetrate a frozen column of explosive but can be inserted quite easily into one that is merely very hard.

All explosives should be stored and transported in accordance with the standard precautions recommended by their principal manufacturers.

Blasting caps and electrical blasting caps have withstood satisfactory storage at laboratory temperatures as low as −110° F (−78.5° C). These tests reveal little or no change in characteristics at such low temperatures.

Safety fuzes show no appreciable change in performance after storage in extremely low temperatures except that the burning time may be slightly increased. Caution is required in the handling of safety fuzes after freezing, because the fuze covering, particularly the waterproofing, cracks at low temperatures. It is necessary, therefore, to uncoil the fuze and prepare the explosive devices at normal temperatures. Primacord detonating fuze performs satisfactorily at low temperatures, provided it has not been wet previous to freezing. Care must be taken, however, to prevent breaking or cracking. If detonating fuze becomes wet before freezing, it is difficult to initiate, and a booster is required to assure detonation. (Data on explosives are largely from Ref. 52.)

10. CERAMICS. Ceramics are not ordinarily affected by extremely cold temperatures. However, a warm blast of air or a sudden change of temperature may cause frozen material to shatter.

11. RUBBER AND RUBBERLIKE MATERIALS. For a discussion on the behavior of these materials under low-temperature conditions, reference should be made to par. 8a of 2B4.04. Many of the large rubber and chemical companies are working in cooperation with the Armed Services on the problem of providing satisfactory rubberlike materials that will retain their flexibility under conditions encountered in the Cold Regions. The objectives of the Arctic rubber research program are summarized as follows. (Ref. 54.)

(1) Development of general-purpose synthetic-rubber compounds for fabrication of tires, tubes, mechanical goods, cable insulation, and similar items for use at temperatures as low as −65° F in operation, as low as −80° F in storage, and as high as 125° F for longtime and 168° F for shorttime storage periods.

(2) Development of special-purpose synthetic rubber that can be used for oil hose, hose liners, and sealants, capable of performing within a temperature range of −65° F to 300° F. (Ref. 54.)

12. PLASTICS (Ref. 52). Most plastics contain a base material, the properties of which have been modified by the incorporation of plasticizers or fillers. Each base material is the foundation for a group of compositions related in general behavior but differing from one another in individual physical properties. Such basic groups of plastics are acrylics, cellulosics, nylons, ethylene polymers, vinylester polymers, polyvinyl acetals, phenolics, urea resins, casein, alkyds, neoprene, and others. Groups that contain several different compositions are divided into types. Each type represents one or more compositions, each of which is designed to give the superior value of some specific property, even at the expense of some other property. There are, for example, Type I—General, Type II—Temperature-resistant, Type III—Impact-resistant, Type IV—Moisture-resistant, and so on. When further subdivision is required, the types are subdivided into grades. Each grade represents, at the most, a very restricted number of common commercial materials, which are similar both chemically and physically. These groups, types, and grades usually correspond to those given in ASTM specifications.

The service success of an article of any plastic often depends as much on the design and fabrication processes as on the material itself. The importance of selecting items of good workmanship in both design and fabrication for cold-weather operations can not be overemphasized. The plastics industry has developed a background of practical experience in design, fabrication, and testing of plastics and should be consulted regarding specific cold-weather problems. It is important not only to select the proper material but to use it properly in the field. Too frequently, good plastics improperly handled in the field have failed solely because of misuse.

As an aid to the understanding of this field of material, a list of the important plastics by resin group and subgroup, trade names, available forms, and commercial uses is given in standard handbooks.

a. *Acrylics.* The acrylics are perfectly clear and transparent. They have the best resistance of all transparent plastics to sunlight and outdoor weathering and will tolerate years of exposure without significant loss of properties. They possess a good combination of flexibility with shatter resistance and rigidity. Their impact strength is lower than that of the celluloses, but the effect of extreme low temperatures upon this property is much less pronounced; hence, articles designed for use at ordinary temperatures will not show excessive embrittlement at −50° F.

b. *Cellulosics.* Cellulose nitrate is the toughest of all thermoplastics. It has low water absorption and is resistant to mild acids. At −50° F its impact strength is about 35 percent of its impact strength at normal temperatures (77° F). Cellulose nitrate is very flammable; it is not suited for prolonged service in outdoor sunlight, for it turns yellow and becomes brittle.

Cellulose acetate is comparatively tough. Its low-temperature impact strength and embrittlement characteristics are inferior to those of cellulose nitrate. Cellulose acetate is superior to cellulose nitrate in resistance to outdoor exposure and to burning. Sunlight has little effect. Because there are many commercial compositions of this material, it is advisable for a given application to indicate the application and desired properties—for example, for general use or for resistance to heat, cold, impact, or moisture.

Cellulose acetate butyrate material is tough and has dimensional stability. Fluctuation in dimension must be considered when articles are made of a combination of this material and glass or metal.

Ethyl cellulose material possesses toughness, high impact strength at low temperatures, and excellent dimensional stability. When the article is in combination with glass or steel, assurance must be made that the wall thickness of the plastic is sufficient to withstand the strain caused by temperature changes. Type II of this plastic is specifically designed for low-temperature resistance. At −50° F its impact strength is about 40 percent of its impact strength at normal temperatures.

c. *Nylons.* Nylon is a generic term for any long-chain synthetic polymeric amide that has recurring amide groups as an integral part of the main polymeric chain and that is capable of being formed into a filament whose structural elements are oriented in the direction of the axis. Nylon textile filament materials are noted for their toughness. The effect of extreme cold on the mechanical properties of cords and ropes is small; tensile strength increases and elongation decreases. Woven fabrics are not stiffened or embrittled by extreme cold but remain soft and pliable at −40° F. The effect of prolonged exposure to sunlight and outdoor weather is not enough to impair practical utility.

Several types of nylon plastics are involved here, and their properties are not identical. Impact strength is measurably decreased by extreme cold, but toughness and impact strength at low temperatures are still so good that nylon plastics have been successfully used at low temperatures. At −40° F the impact strength of nylon is about 55 percent of its impact strength at normal temperatures. The electrical properties of nylon plastics are better at low temperatures. Prolonged exposure of nylon plastics to sunlight and weathering is not recommended.

d. *Polyvinyl.* Polyvinyl acetal material provides a tough impact-resistant layer for safety glass over a wide range of temperatures down to about −40° F. It has stability under light and heat, is relatively insensitive to moisture, and has good adhesive qualities. It is an excellent thermoplastic adhesive for leather, rubber, paper, wood, canvas, laminated cellophane, and glass. It is also excellent for coating fabrics for raincoats, water-repellent garments, tentage, food and clothing bags, and so on.

e. *Vinylidene.* Vinylidene chloride material is tough, resistant to chemicals and prolonged immersion in water, nonflammable, and useful over a wide range of temperatures.

f. *Polystyrene.* Polystyrene has good electrical properties, good resistance to acids and solvents, excellent dimensional stability, low unit weight, and general stability satisfactory at extremely low temperatures (below −50° F). Many of the materials have good outdoor weathering properties.

Polystyrene expanded (foam type) has several outstanding properties. One is its low thermal conductivity (0.27 Btu/hr/sq ft/°F/in.). Another is its low water absorption and moisture transmission rate, which enhances its usage as an insulating material under extremely cold conditions. This material has good structural strength, is easy to handle, and may be bonded to itself, concrete, brick, wood, or metal. It has a minimum buoyancy of 55 lb/cu ft.

g. *Resin.*

(1) *Phenol-Formaldehyde.* These resins are thermosetting, and the molded types are shaped and hardened by heat and pressure. They are hard, strong, rigid, and light in weight. They are not readily flammable, and have good electrical insulating properties; but they are not suitable for prolonged outdoor exposure because the lighter colors fade, and the material may change water content, causing slight expansion and contraction. Types are made to provide general-purpose shock, electrical, heat, and chemical resistance. The shock-resistant types show the best combination of flexural and tensile strength at extreme Arctic temperatures. The cast phenolic resins are not recommended for outdoor use. The laminated phenolic products are some of the strongest materials in the plastic field.

(2) *Melamine-Formaldehyde.* These resins are thermosetting and rigid and possess a hard surface that resists wear. They have good electrical properties and their water absorption is low. Dimensional stability, with strength and shock resistance, is good. The laminated melamine products are used widely for electrical instrument panels.

(3) *Urea-Formaldehyde.* These resins are thermosetting. They are colorless, offer unlimited color possibilities, and have a high degree of translucency, as well as good mechanical and electrical properties. They have been widely used within a temperature range of −70° to 170° F.

h. *Neoprene.* All neoprene products, when exposed to temperatures in the range of 0° to −50° F, stiffen and lose some of their flexibility and resiliency. By proper compounding of neoprene, however, it is possible to make compositions that retain sufficient flexibility to be practical from −50° to −60° F.

13. LUBRICANTS, FUEL, AND ANTIFREEZE. Reference should be made to par. 4A3.03 for military specifications and list of Navy stock numbers of materials prescribed for servicing of construction equipment and automotive vehicles for operation at low ambient temperatures.

2A9.02 FROZEN SOIL

1. COMPRESSIVE STRENGTH. Frozen ground with pores completely filled with ice is susceptible to deformation, the extent varying with temperature and pressure. With the rise of temperature the deformation of ice becomes more intense, and its plasticity and flowage become more pronounced. When the ice begins to melt, the character of the ground is completely changed, and its deformation is greatly intensified even without application of additional load. The rise of temperature to the melting point may thus have a stronger effect on the stability of frozen ground than the increased load. (Ref. 55.)

The compressive strength of frozen ground increases with the lowering of temperature. Compressibility of sand varies with the amount of moisture (ice) and reaches a maximum when the pores are completely filled with ice. The compressive strength of clay decreases with the increase of moisture content. (Ref. 55.) (See Figures 2A9-7 and 2A9-8.)

Tables 2A9-3, 2A9-4, and 2A9-5 illustrate the behavior of different types of frozen ground under compression. The conditions under which the values were ascertained are not known. It is recommended, therefore, that they be used with caution, and that whenever practicable the compressive value of the material in place be determined for use in any important design.

As can be seen in Table 2A9-4, the compressive strength of water- (ice-) saturated frozen ground at the temperature not exceeding 28.40° F is relatively small, varying from 5 to 30 kg/sq cm.

The variations of strength of saturated frozen soil with temperature and time have not been

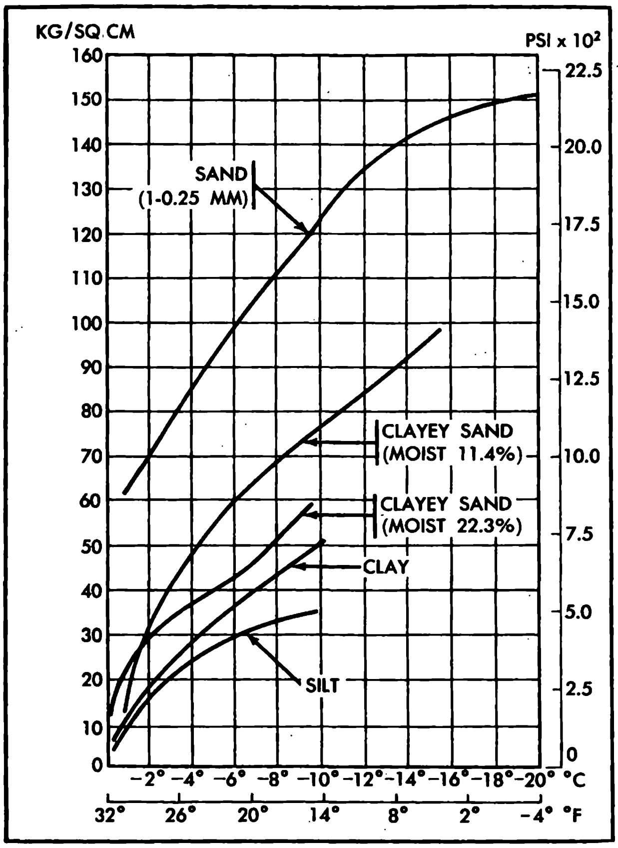


FIGURE 2A9-7

Compressive Strength of Frozen Ground in Relation to Temperature (Ref. 55)

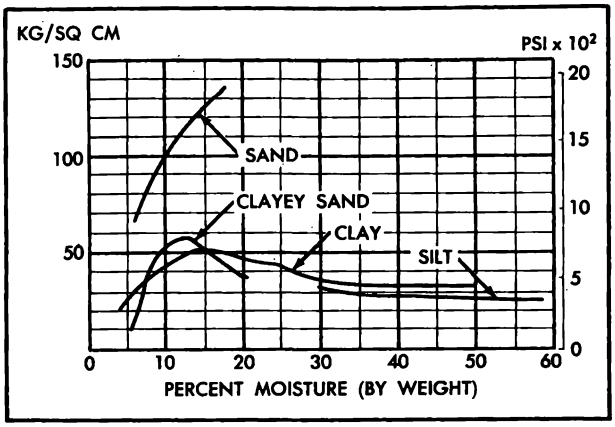


FIGURE 2A9-8

Compressive Strength of Frozen Ground in Relation to Amount of Moisture (Ref. 55)

determined, nor has the creep of such soil under moderate loads. (See Section 2A5.)

2. ADFREEZE.

a. *General.* Adfreezing strength of frozen ground is defined as the resistance to the force that is required to pull apart the frozen ground from the object to which it is frozen. In engineering practice, however, the tangential adfreezing strength is of greater importance. This is the resistance to the force that is required to shear off an object that is frozen to the ground and to overcome the friction along the plane of its contact with the ground. Care should be exercised in evaluating the tangential adfreezing strength as given in the original Russian reports, for in Russian permafrost literature the tangential adfreezing strength is generally referred to as *sila smerzania* or simply adfreezing strength. (Ref. 55.)

The tangential adfreezing strength of frozen ground varies with:

(1) Amount of moisture in the ground.

(2) Temperature of the ground.

(3) Texture and porosity of the ground.

(4) Nature of the surface of the building material used (smooth or rough).

(5) Porosity of the material near the surface.

(6) Degree of saturation.

The maximum adfreezing strength in most ground is reached at about the maximum saturation of ground with ice. Further increase in amount of ice, beyond the maximum saturation point, tends to decrease the adfreezing strength, gradually approaching that of pure ice.

The heaving force of ground in the process of freezing is proportional to the adfreezing strength of that ground with the material of the foundation. The tangential adfreezing strength varies with the texture of the ground and, in general, is greater in fine- and medium-grained sand than in the coarse-grained aggregates. Adfreezing strength in clay and silt is slightly less than in sand. (Ref. 55.)

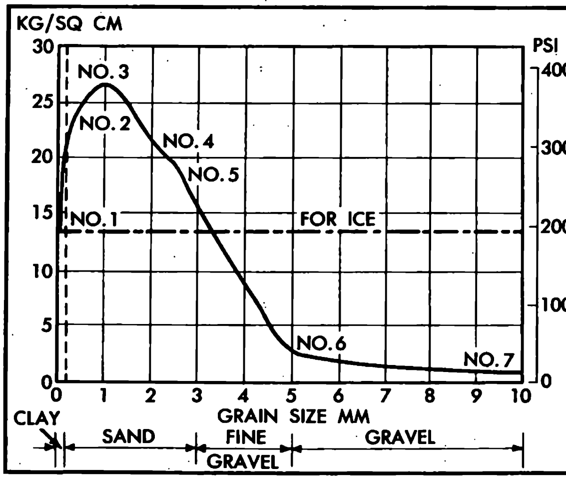
Tables 2A9-6, 2A9-7, and 2A9-8 and Figures 2A9-9, 2A9-10, 2A9-11, and 2A9-12 give the quantitative data on the adfreezing strength between different kinds of ground and wood and concrete under different conditions of temperature and amount of moisture (ice).

b. *Soil Tests.* In designing an important foundation in a permafrost area, it was deemed advisable to transfer the load, by piling, to a

TABLE 2A9-3

Elastic and Plastic Deformation of Frozen Ground Under Compression (Adapted from Tystovich and Sumgin) (Ref. 55)

Type of ground	Moisture (ice) content, percent	Temperature		Limits of load, kg/sq cm	Time in min from beginning of application of load	Relative deformation		Elastic deformation, percent of total deformation
		°C	°F			Elastic	Plastic	
Frozen clay	36.8	– 2.8	26.86	0.5—1.5	6.0	0.000066	0.000074	49
					7.0	0.000061	0.000129	32
		– 2.8	26.86	0.5—2.5	10.5	0.000127	0.000719	15
		– 2.8	26.86	0.5—2.5	11.5	0.000142	0.000562	20
		– 2.4	27.68	0.5—3.5	12.0	0.000220	0.001350	14
				0.5—3.5	13.5	0.000200	0.001250	14
	32.0	– 2.0	28.40	0.5—1.5	11.5	0.000110	0.000190	37
		– 1.9	28.58	0.5—2.5	12.5	0.000170	0.000845	17
		– 1.5	29.30	0.5—3.5	13.5	0.000220	0.002050	10
		– 1.4	29.48	0.5—3.5	14.5	0.000200	0.003560	5
	32.5	– 1.3	29.66	0.5—2.5	30.0	0.000055	0.006950	1
Frozen clayey sand	17.0	–12.2	10.40	0.5—1.5	11.0	0.000010	0.000010	50
		–10.4	13.18	0.5—2.5	12.0	0.000030	0.000020	60
		– 8.7	15.66	0.5—3.5	13.0	0.000055	0.000070	44
		– 7.0	17.50	0.5—4.5	14.0	0.000115	0.000205	36
	12.8	– 1.7	28.04	0.5—2.5	17.0	0.000042	0.000076	33
		– 1.1	30.02	0.5—3.5	18.0	0.000111	0.000231	32
	16.9	– 2.5	27.50	0.5—2.5	30.0	0.000180	0.000475	27
		– 1.7	28.04	0.5—3.5	30.0	0.000350	0.006670	5
Frozen silt	39.2	– 4.9	23.18	0.5—1.5	11.0	0.000035	0.000001	97
		– 3.5	25.70	0.5—2.5	12.0	0.000090	0.000045	67
		– 3.4	25.88	0.5—3.5	17.0	0.000190	0.000140	58
				0.5—5.0	34.5	0.000430	0.000730	37
		– 1.0	31.20	0.5—3.5	18.0	0.000335	0.000260	56
	38.9	– 0.8	30.56	0.5—5.0	19.5	0.000640	0.003030	17



Type of ground	Dominant grain size, mm	Temperature		Coefficient of saturation, per cwt.	Tangential adfreezing strength	
		°C	°F		Kg/cm²	Psi
Clay, No. 1	0.01	–10	14	77	15.3	217
Sand, fine No. 2	0.25	–10	14	76	23.3	331
Sand, medium No. 3	1.0	–10	14	78	26.8	381
Sand, coarse to fine, No. 4	3–0.25	–10	14	79	21.7	308
Sand, coarse No. 5	3–2	–10	14	97	19.1	271
Gravel, fine No. 6	5.0	–10	14	77	2.6	37
Gravel, No. 7	10.0	–10	14	79	0.9	13

FIGURE 2A9-9

Tangential Adfreezing Strength Between Wood and Frozen Ground of Different Textures (Ref. 55)

TABLE 2A9-4

Compressive Strength of Frozen Ground at Temperatures From —3.0° to —2° C (31.46° to 28.40° F) (Adapted from Tystovich and Sumgin) (Ref. 55)

Type of ground (granulometric composition)	Temperature		Moisture (ice), percent	Ultimate compressive strength	
	°C	°F		kg/sq cm	psi
Sand with rubble (gr > 1 mm = 85%)	-1.4	29.48	15	27	384
Sand (gr > 1 mm = 80%)	-0.8	30.56	18	28	398
Sand, arkosic (gr > 1 mm = 61%)	-1.6	29.12	15	43	611
Sand, arkosic (gr > 1 mm = 44%)	-1.7	28.94	20	30	426
Silty sand (gr < 0.005 mm = 4%)	-0.4	31.18	38	22	311
Silty, clayey sand (gr < 0.005 mm = 7%; > 1 mm = 0.5%)	-1.1	30.02	20	28	398
Clayey sand (gr < 0.005 mm = 10%)	-0.7	30.74	36	15	213
Clayey sand (gr < 0.005 mm = 10%)	-1.1	30.02	32	18	256
Clayey sand (gr < 0.005 mm = 10%)	-1.2	29.84	46	12	171
Clayey sand (gr < 0.005 mm = 8%; 0.05 to 1 mm = 68%)	-0.3	31.46	21	12	171
Clayey sand (gr < 0.005 mm = 8%; 0.05 to 1 mm = 68%)	-1.0 to -1.1	33.80 to 30.02	21	25	355
Clayey sand (gr < 0.005 mm = 10%; > 1 mm = 25%)	-0.4	31.18	17	10	142
Clayey sand (gr < 0.005 mm = 10%; > 1 mm = 5%)	-0.9	30.38	31	26	369
Clayey sand (gr < 0.005 mm = 9%; > 1 mm = 15%)	-1.5	29.30	48	23	327
Sandy, micaceous clay (gr <0.005 mm=13%; >1,mm=9%) 33.80	-0.6	30.92	32	19	270
Sandy clay with rubble (gr < 0.005 mm = 17%; > 1 mm = 12%)	-1.8	28.76	23	22	313
Sandy clay (gr < 0.005 mm = 23%)	-1.9	28.58	41	27	384
Sandy clay (gr < 0.005 mm = 22%)	-1.4	29.48	43	22	311
Sandy clay (gr < 0.005 mm = 17.5%)	-1.3	29.66	24	17	242
Sandy clay (gr < 0.005 mm = 15%)	-1.0	30.20	34	15	213
Sandy clay (gr < 0.005 mm = 14%)	-0.8	30.56	32	24	341
Sandy clay (gr < 0.005 mm = 14%)	-0.8	30.56	28	17	242
Sandy clay (gr < 0.005 mm = 20%; > 1 mm = 21%)	-0.6	30.92	37	22	311
Sandy clay (gr < 0.005 mm = 18%; > 1 mm = 14%)	-1.9	28.58	27	26	369
Sandy clay (gr < 0.005 mm = 17%; > 1 mm = 17%)	-1.6	29.12	29	24	341
Sandy clay (gr < 0.005 mm = 17%; > 1 mm = 16%)	-0.8	30.56	26	23	327
Sandy clay (gr < 0.005 mm = 15%; > 1 mm = 19%)	-1.3	29.66	21	20	284
Sandy clay (gr < 0.005 mm = 15%; > 1 mm = 3%)	-0.8	30.56	37	18	256
Sandy, silty clay (gr < 0.005 mm = 26%)	-2.0	28.40	52	29	412
Clay (gr < 0.005 mm = 45%)	-1.7	28.94	45	15	213
Clay (gr < 0.005 mm = 36%)	-0.3	31.46	43	6	85
Clay (gr < 0.005 mm = 36%)	-1.5	29.30	48	16	227
Clay (gr < 0.005 mm = 30%)	-1.7	28.94	34	20	284
Clay (gr < 0.005 mm = 26%)	-1.5	29.30	42	17	242
Silt (gr < 0.005 mm = 22%)	-1.6	29.12	52	24	341
Silt (gr < 0.005 mm = 14%)	-1.2	29.84	38	14	199
Silt (gr < 0.005 mm = 13%)	-1.0	30.20	70	22	313
Silt (gr < 0.005 mm = 12%)	-0.7	30.74	40	12	171
Silt (gr <0.005 mm=14%; 0.005 mm to 0.05=63%; organic matter=18%)	-0.3	31.46	59	5	71
Silt (gr <0.005 mm=14%; 0.005 mm to 0.05=63%; organic matter=18%)	-1.1	30.02	52	12	171

definite stratum. Piles similar to those shown in Figure 2A6-15 were used. To transfer the load effectively and use the piling to maximum advantage, adfreeze values for piling and permafrost were determined in a field laboratory operated by Arctic contractors (US Navy Contract NOy-13360). That portion of the final laboratory report (Ref. 56) summarizing the work on adfreeze is given in the following paragraphs.

Several mixtures and solutions were made up and tested for adfreeze to determine the best backfill for Oumalik piling. Fresh water, salt water, and fresh water with admixtures of Aquagel (drilling mud), Baroid (drilling mud), Aeroseal Q (drilling mud dispersing chemical), fibrous peat, silt, sawdust, dishwashing detergent, Tergitol (wetting agent), and trisodium phosphate (wetting agent) were tested.

In every case, the sample froze from the rod outward, producing an adfreeze bond formed of clear ice. Results showed that clean, fresh water provided the strongest bond. The other samples tested

TABLE 2A9-5

Mean Values of Compressive Strength of Water-Saturated Frozen Ground

Type of ground	At temperatures not lower than −0.5° C (31.10° F)		At temperatures from −0.5° to −1.5° C (31.10° to 29.30° F)		At temperatures from −1.5° to −2.0° C (29.30° to 28.40° F)	
	Kg/sq cm	Psi	Kg/sq cm	Psi	Kg/sq cm	Psi
Sand	22	313	27	384	30	426
Clayey sand	11	156	22	312		
Sandy clay	...	...	20	284	26	370
Clay	6	85	17	242		
Silt	5	71	15	213	23	327

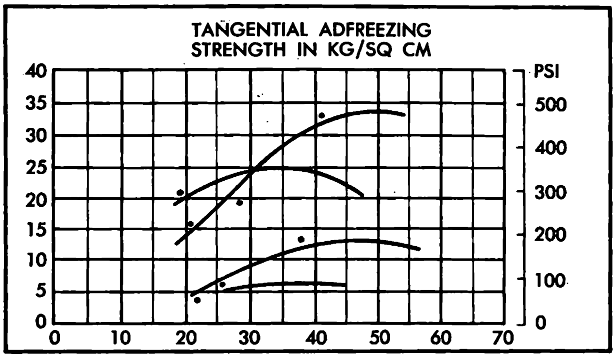


FIGURE 2A9-10

Effect of Moisture on Adfreezing Strength of Clayey Ground (Ref. 55)

TABLE 2A9-6

Effect of Temperature and Moisture Content on Tangential Adfreezing Strength Between Different Types of Ground and Water-Saturated Wood and Concrete (Adapted from Tystovich and Sumgin) (Ref. 55)

Temperature °C	Temperature °F	Type of ground (granulometric composition)	With water-saturated wood: Moisture, percent	Adfreezing strength Kg/sq cm	Adfreezing strength Psi	With water-saturated concrete: Moisture, percent	Adfreezing strength Kg/sq cm	Adfreezing strength Psi
−0.2	31.64	Silt (gr 0.05 to 0.005 mm = 63%)	29.9	3.6	51.2			
		Clay (gr < 0.005 mm = 36%)	27.1	2.9	41.2			
		Clayey sand (gr 1 to 0.05 mm = 68%)	12.1	1.3	18.5			
		Silt (gr 0.05 to 0.005 mm = 63%)	22.4 32.6 43.8 51.2	7.0 8.9 7.1 7.6	99.6 126.6 101.0 108.1	16.4 33.0 44.0 53.2	4.4 6.0 9.2 3.1	62.6 85.3 130.8 44.1
−1.2	29.84	Clay (gr < 0.005 mm = 36%)	22.4 26.4 37.3 56.5	3.2 5.9 13.0 11.8	45.5 83.9 184.9 167.7	17.8 26.3 36.2 43.9	7.8 4.8 6.4 5.8	110.9 68.2 91.0 82.4
		Clayey sand (gr 1 to 0.05 mm = 68%)	6.7 10.1 13.3 16.5	2.8 4.1 7.2 8.2	39.7 58.3 102.4 116.6	5.8 11.7 12.1 16.1	2.8 6.4 7.0 11.1	39.7 91.0 99.6 157.9
		Silt (gr 0.05 to 0.005 mm = 63%; < 0.005 mm = 14%; organic matter = 18%)	18.8 33.9 41.5 51.0 62.2	6.9 14.1 28.7 34.8 34.7	98.1 200.5 408.2 495.0 493.5	17.4 32.5 46.4 51.8 58.3	7.8 21.8 26.2 28.1 27.7	110.9 310.1 372.6 399.7 394.0
		Clay (gr < 0.005 mm = 36%)	18.4	12.8	182.0	18.9	20.6	293.0
−10.0	24.0	Clay (gr < 0.005 mm = 36%)	21.6 28.4 41.4 55.6	15.7 18.6 32.2 31.9	223.3 264.5 558.0 453.7	25.1 34.6 46.1	21.9 25.3 20.1	311.5 359.8 285.9
		Clayey sand (gr 1 to 0.05 mm = 68%; < 0.005 mm = 8%)	5.7 10.1 13.9 19.9 33.5	7.9 12.6 21.4 32.3 33.5	112.4 179.2 304.4 459.4 476.5	7.5 11.9 18.1 23.8	10.0 22.8 24.2 21.0	142.2 169.2 344.2 298.7

TABLE 2A9-7

Tangential Adfreezing Strength Between Different Types of Frozen Ground and Water-Saturated Wood (Adapted from Tystovich and Sumgin) (Ref. 55)

Type of ground	Granulometric composition		Temperature		Moisture, percent	Adfreezing strength	
	Percent of grains > 1 mm	Percent of grains < 0.005 mm	°C	°F		Kg/sq cm	Psi
	None	45	−1.5	29.30	41	5	71.1
	13	45	−1.0	30.20	39	6	85.3
Clay	...	41	−1.0	30.20	30	5	71.1
	6	31	−2.2	28.04	29	7	99.6
	2	30	−1.6	29.12	24	7.2	102.4
Sandy clay	None	27	−0.8	30.56	35	4	56.9
	None	25	−1.2	29.84	26	5	71.1
Silty, sandy clay	None	24.8	−1.5	29.30	40	6	85.3
Sandy clay with layers of ice	None	23.5	−0.8	30.56	39	4	56.9
Sandy clay	None	22	−1.8	28.76	39	6	85.3
	None	22	−1.6	29.12	34	4	56.9
Sandy, silty clay with layers of ice	None	22	−1.5	29.30	43	6	85.3
Sandy clay	None	20	−0.5	31.10	20	2	28.4
Sandy clay with layers of sand	None	18	−1.0	30.20	18	5	71.1
Silty, sandy clay	14	18	−2.0	28.40	25	7	99.6
	13	17	−1.1	30.02	31	4	56.9
	17	17	−2.2	28.04	25	10	142.2
	None	16	−0.6	30.92	27	4	56.9
Sandy clay	None	15	−1.6	29.12	28	7	99.6
	None	15	−0.7	30.74	25	3	42.7
	3	15	−0.5	31.10	25	2	28.4
	3	15	−4.0	24.80	26	4.3	61.1
	...	14	−1.2	29.84	24	6	85.3
Sandy clay	None	14	−0.8	30.56	36	3	42.7
	None	14	−2.0	28.40	33	5	71.1
Sandy clay, micaceous	1	14	−1.8	28.76	32	3	42.7
	9	13	−0.5	31.10	25	2	28.4
	25	13	−1.6	29.12	17	7	99.6
Sandy clay	...	11	−0.9	30.38	27	5	71.1
	23	10	−1.6	29.12	25	5	71.1
Sandy clay, micaceous	None	10	−1.0	30.20	39	3.3	46.9
Sandy clay	5	10	−1.8	28.76	23	7.2	102.4
Clayey sand with silt	...	9	−1.1	30.02	28	3.1	44.1
	0.5	7	−1.0	30.20	17	5.4	76.8
Clayey sand	41	7	−1.5	29.30	16	1.3	18.5
Silty, clayey sand with layers of ice	...	4	−1.6	29.12	27	3.3	46.9
Granitic arkose	61	?	−1.7	28.94	14	2	28.4
Gravel	80	3	−1.1	30.02	12	3.3	46.9

either produced no appreciable effect or showed a marked inferiority, as was the case with drilling mud. The solutions were not, as a rule, suitable because of the lower freezing points. Some samples were frozen slowly and others rapidly. No marked difference in strength was noted. The silt sample was the only one in which no large ice-crystal structure was evident.

Conditions under which the samples froze would correspond to winter installation of steel piling. Summer installation, when freezing would progress from the ground to the pile, might produce a slightly different effect, but should not change the strength figures noticeably.

A summary of average ultimate strengths under the conditions of loading used follows.

°F	°C	Lb/sq in.
30.2	−1	69
28.4	−2	108
26.6	−3	123
24.8	−4	157
21.2	−6	179
19.4	−7	200

Tests for repeated loading, or live loads, indicated that a considerable undetermined factor was involved. Time was a very important factor, due serious consideration if results were to be applied to more permanent structures than the drilling rigs. Another important factor was the length of time allowed for the ice to age before loading. After the solution was frozen, several days were required even at very low temperatures for full adfreeze strength to develop.

Tests at −5° C (23° F) indicated the maximum dead load for an extended length of time to be about 40 lb/sq in. At −5° C (23° F) an average deflection of 0.001 in. per 10 lb/sq in. load was recorded.

A critical temperature for good adfreeze strength appeared to be −3° C (26.6° F). Because of mechanical considerations connected with temperature control, tests at 0° to −2° C (32° to 28.4° F) were unreliable. Field testing must be resorted to for obtaining this critical information.

These careful and excellent studies of adfreeze made at Point Barrow, Alaska, resulted in using the ultimate strengths shown in the summary. It is now believed, however, that these values would have been too high for use in the design of a permanent structure.

TABLE 2A9-8

Effect of Temperature on Tangential Adfreezing Strength of Different Materials (Adapted from Tystovich and Sumgin) (Ref. 55)

Material	Temperature		Percent moisture by weight	Tangential adfreezing strength	
	°C	°F		Kg/sq cm	Psi
Ice and smooth-surfaced wood (wood placed in water in air-dry condition)	−1 −5 −7 −10 −20	30.20 23.0 19.40 14.0 −4.0	... ...	5.0 6.2 11.6 13.7 22.0	71.1 88.2 165.0 194.8 312.9
Ice and smooth concrete	−5 to −10	23.0 to 14.0	...	9.8	139.4
Clay (gr < 0.005 mm = 36%) and water saturated wood (moisture content of grounds about ½ of saturation)	−0.2 −1.5 −5.8 −10.8 −17.8	31.64 29.30 19.56 12.56 −0.04	27.1 26.4 28.4 28.4 25.8	2.9 5.9 11.1 18.6 29.4	41.2 83.9 157.9 264.5 366.9
Clayey sand (gr 1 to 0.005 mm = 68%; < 0.005 mm = 8%) and water-saturated wood	−0.2 −1.2 −2.7 −5.2 −5.6 −10.7 −17.4	31.64 29.40 27.14 22.64 21.92 11.74 0.68	12.1 13.0 10.1 14.8 12.9 14.1 12.8	1.3 7.0 11.0 19.6 20.8 24.7 27.4	18.5 99.6 156.4 278.8 295.8 351.3 289.7
Silt (gr < 0.005 mm = 14%; organic matter = 18%) and water-saturated wood	−0.2 −0.5 −5.7 −10.3 −12.3 −22.7	31.64 31.10 21.74 13.46 9.86 −8.86	29.5 33.4 34.3 33.1 33.2 34.9	3.6 6.1 10.6 14.3 19.9 25.9	51.2 86.8 150.8 203.4 283.0 368.4

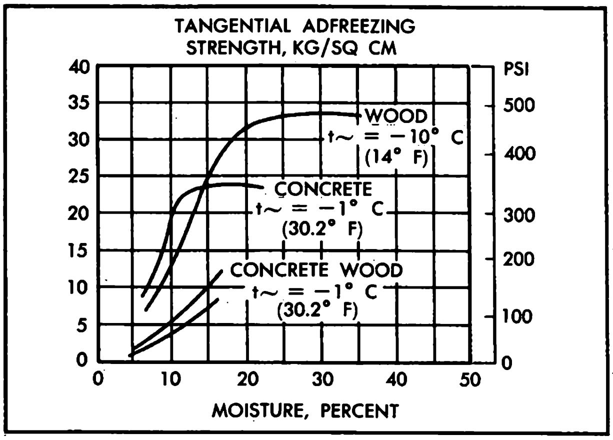


FIGURE 2A9-11

Effect of Moisture on Adfreezing Strength of Clayey, Sandy Ground (Ref. 55)

3. SHEAR. (Ref. 22.) Under the influence of concentrated loads, both thawed and frozen soil commonly fail by shear. According to Coulomb's classical concept, the resistance s per unit of area against failure by shear along a section through any material is

$$s = c + p \tan \phi \qquad \text{(2A9-1)}$$

c = cohesion (shearing resistance for $p = 0$)

p = unit pressure on surface of sliding

ϕ = angle of internal friction

The validity of this equation is subject to various limitations (Ref. 57, pp. 78-93), but in connection with the following discussions these limitations can be disregarded.

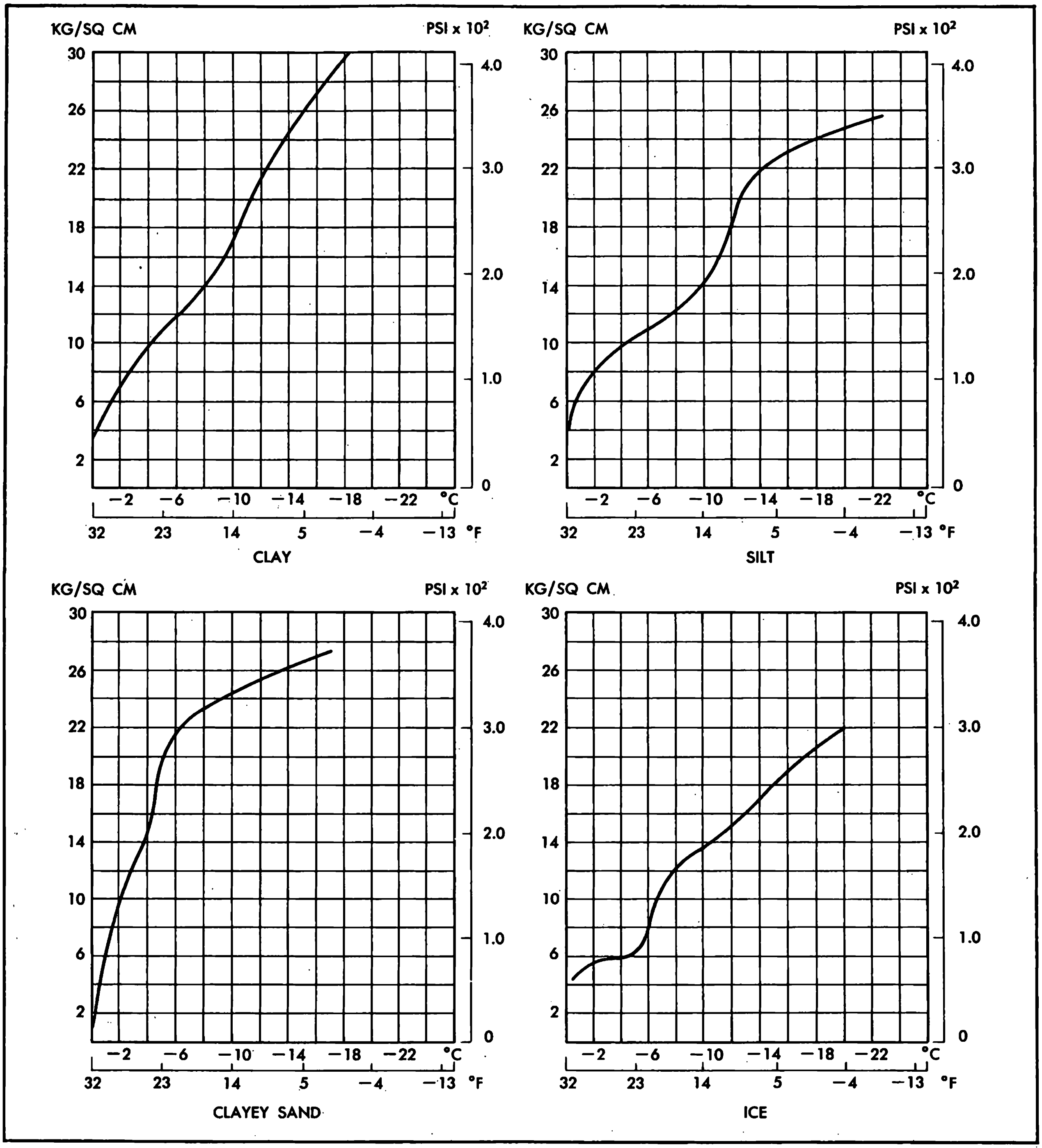


FIGURE 2A9-12

Effect of Temperature on Tangential Adfreezing Strength Between Various Materials (Ref. 55)

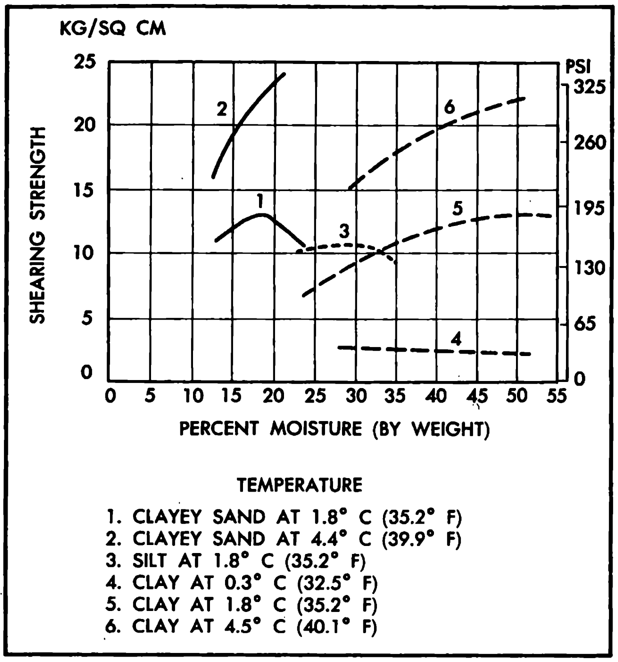


FIGURE 2A9-13

Shearing Strength of Frozen Ground in Relation to Amount of Moisture (Ref. 55)

TABLE 2A9-9

Effect of Temperature on Shearing Strength of Frozen Ground (Adapted from Tystovich and Sumgin) (Ref. 55)

Type of ground (granulometric composition)	Temperature		Percent moisture (ice) by weight	Ultimate shearing strength	
	°C	°F		Kg/sq cm	Psi
Clay (gr 0.01 to 0.005 mm = 50%; < 0.005 mm = 36%)	−0.4	31.28	45.5	3.7	52.5
	−1.8	28.76	50.6	17.2	244
	−3.0	26.60	49.8	20.9	297
	−4.9	23.18	44.0	24.3	345
	−6.3	20.66	42.0	28.5	405
	−8.8	16.16	45.9	33.5	476
Clayey sand (gr 1 to 0.05 mm = 68%; < 0.005 = 8%)	−0.4	31.28	18.4	4.9	69.5
	−0.9	30.38	17.8	10.6	151
	−3.1	26.42	19.1	21.8	310
	−3.9	23.18	16.9	24.8	352
	−6.7	19.94	19.0	44.2	628
	−8.5	16.70	16.2	47.5	675
	−9.3	15.26	19.0	48.5	688
Clean artificial ice	0.0	32.00	...	9.9	141
	−0.4	31.28	...	11.0	157
	−2.9	26.78	...	27.4	390
	−4.4	24.08	...	32.5	462
	−6.1	21.20	...	38.5	547
	−10.1	13.72	...	56.2	799

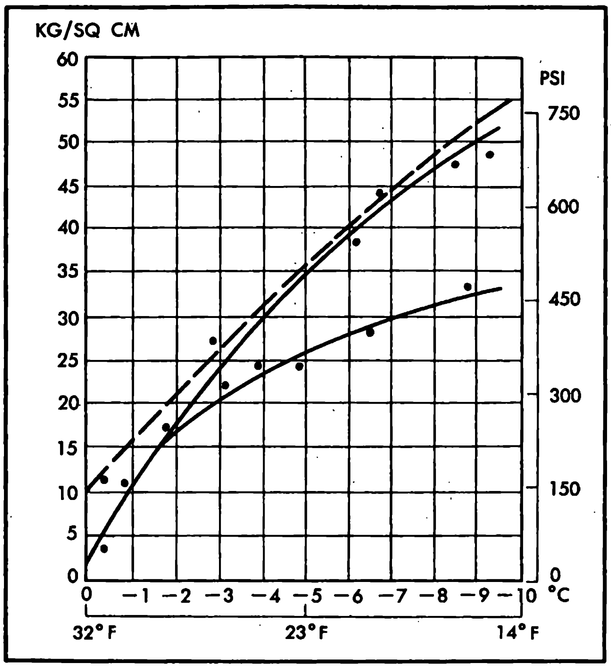


FIGURE 2A9-14

Shearing Strength in Relation to Temperature (Ref. 55)

If the shearing resistance of a material is determined by equation (2A9-1), the unconfined compressive strength q_u or the unit load under which a cylindrical specimen fails is equal to

$$q_u = 2c \tan\left(45 + \frac{\phi}{2}\right) \qquad (2A9\text{-}2)$$

For coarse-grained soil like clean sand or gravel in a dry or completely saturated but unfrozen state, $c = 0$ and $q_u = 0$. In other words, these types of soil owe their capacity to sustain concentrated loads exclusively to internal friction. The angle of their internal friction commonly lies between 35 and 45 degrees, and its value depends on the relative density and the shape of the grains. Fine sand and very fine sand in a moist state have a slight apparent cohesion that disappears as soon as the sand is submerged.

The compressive strength q_u of a saturated silt or clay depends on its geologic history and on the physical and chemical properties of the clay constituents. The q_u value determines the consistency of the clay, which is commonly designated by one of the following terms.

TABLE 2A9-10

Shearing Strength of Ice-Saturated Frozen Ground (Adapted from Tystovich and Sumgin) (Ref. 55)

Type of ground (granulometric composition)	Temperature		Percent moisture (ice) by weight	Ultimate shearing strength	
	°C	°F		Kg/sq cm	Psi
1. Rubble (weathered granite) (gr > 1 mm = 44%)	−1.8	28.76	23	11.0	157
2. Sand (gr < 0.005 mm = 3%; > 0.25 mm = 34%)	−0.8	30.56	36	12.2	174
3. Sand (gr > 0.25 mm = 51%)	−0.7	30.74	18	10.9	155
4. Silty, clayey sand (gr < 0.005 mm = 4%)	−1.6	29.12	26	10.0	142
5. Sandy clay with rubble (gr < 0.005 mm = 13%; > 1 mm = 25%)	−1.6	29.12	19	10.8	154
6. Sandy clay with rubble (gr < 0.005 mm = 9%; > 0.25 mm = 33%)	−1.1	30.02	49	15.0	213
7. Sandy clay (gr < 0.005 mm = 27%)	−1.9	28.80	28	8.9	127
8. Sandy clay (gr < 0.005 mm = 22%)	−1.9	28.80	34	9.0	128
9. Sandy clay (gr < 0.005 mm = 15%)	−1.6	29.12	29	7.0	99.5
10. Sandy clay (gr < 0.005 mm = 15%)	−1.9	28.80	23	10.0	142
11. Sandy clay (gr < 0.005 mm = 14%)	−1.7	28.94	24	8.0	114
12. Sandy clay (gr < 0.005 mm = 11%)	−1.7	28.94	34	8.9	127
13. Sandy clay (gr < 0.005 mm = 10%)	−2.0	28.40	39	9.5	135
14. Sandy clay (gr < 0.005 mm = 12%; > 0.25 mm = 13.6%)	−0.9	30.38	37	8.9	127
15. Sandy clay (gr < 0.005 mm = 17%; > 1 mm = 16%)	−1.8	28.70	27	8.0	114
16. Sandy clay (gr < 0.005 mm = 17%; > 1 mm = 13%)	−2.1	28.12	31	8.5	121
17. Sandy, silty clay (gr < 0.005 mm = 25%)	−2.0	28.40	36	8.0	114
18. Sandy, silty clay (gr < 0.005 mm = 15%)	−1.3	29.66	23	6.0	85.2
19. Sandy, silty clay (gr < 0.005 mm = 15%)	−2.8	26.96	23	14.0	199
20. Sandy, silty clay (gr < 0.005 mm = 14%)	−1.5	29.30	34	7.4	105
21. Sandy clay (slud) (gr < 0.005 mm = 14%; > 1 mm = 12%)	−1.7	28.94	17	10.3	147
22. Clay (gr < 0.005 mm = 45%)	−2.1	28.12	35	6.6	93.8
23. Clay (gr < 0.005 mm = 41%)	−1.8	28.76	33	8.0	114
24. Clay (gr < 0.005 mm = 31%; > 1 mm = 6%)	−1.9	28.80	29	9.0	128
25. Silt (gr < 0.005 mm = 14%; 0.01 to 0.005 mm = 68%)	−0.6	31.92	55	7.8	111

Consistency	*Very soft*	*Soft*	*Medium*	*Stiff*	*Very stiff*	*Extremely stiff*
q_u in kg/sq cm	0.25	0.25 to 0.5	0.5 to 1.0	1.0 to 2.0	2.0 to 4.0	4.0
q_u in psi	3.5	3.5 to 7.0	7.0 to 14.0	14.0 to 28.0	28.0 to 56.0	56.0

If soil is exposed to freezing temperatures, the free water contained in the voids of the soil freezes, whereupon the ice interconnects the soil particles. Therefore, the strength of the soil increases. The unconfined compressive strength q_u' of the frozen soil depends on the unconfined compressive strength q_i of the ice, on the degree of saturation S_r, and the angle of internal friction ϕ in equation (2A9-2).

The unconfined compressive strength q_i of ice depends on many factors. (See par. 2A4.07.)

Because frozen soil owes its cohesion chiefly or entirely to that of the ice, the behavior of frozen soil under stress must have at least some features in common with the behavior of pure ice under similar stress conditions. Because the angle of internal friction of ice is equal to zero, equation (2A9-2) requires that the cohesion c of ice be equal to $\frac{q_i}{2}$.

If the degree of saturation of soil is smaller than 100 percent, the freezing of the soil moisture imparts to the soil the character of a mild sandstone. The grains of this sandstonelike material are interconnected by minute patches of ice. On the other hand, if a saturated soil freezes, it turns into a block of ice, reinforced by a skeleton of solid soil particles. The strength q_u' of such a soil is likely to be approximately equal to

$$q_u' = q_i \tan\left(45 + \frac{\phi}{2}\right) \qquad (2A9\text{-}3)$$

q_i = unconfined compressive strength of ice

ϕ = angle of internal friction of soil

Equation (2A9-3) is identical with the equation for the confined compressive strength of crystalline rocks such as marble.

Figures 2A9-13 and 2A9-14 and Tables 2A9-9 and 2A9-10 show the shear-strength values obtained for soil and the variation in these values with temperature and moisture content.

PART B. DESIGN OF STRUCTURES

Section I. STRUCTURAL DESIGN CRITERIA

2B1.01 GENERAL

Each and every structure in the Cold Regions must be designed and constructed so that it will properly and adequately fulfill its mission under the conditions to which it will be subjected. Designs will be influenced by the materials and labor available, the temporary or permanent nature of the construction, the disciplines of the area in which the structure is to be built, and the probable changes in the existent thermal regime because of the structure, its occupancy, and its use.

Wind, snow, precipitation, temperature, and ice conditions of the area should be studied before any structural design is undertaken. The data presented in Chapter 1 and Appendix B are indicative of what can be expected at certain locations in the Cold Regions. When information is available, however, that indicates local variations, it should be used in conjunction with or in place of that given.

Although various specifications and details exist for structures in the Cold Regions, they should be reviewed and evaluated for their adequacy to accomplish the assigned mission under the disciplines of the area.

Exposure, in addition to its effect on foundations (Section 2A6) and heat transmission, refrigeration, and temperature measurements (Section 2A8), requires more attention than in the Temperate Zone. This applies to all types of structures —emergency, temporary, semipermanent, and permanent. Special consideration must also be given to probable icing on operations areas, heat loss, drifting snow, and portability (if required); possible damage from snowslides, avalanches, and high water (both surface and ground water); and ice jams and their breakup. The possibility of interference with the established drainage is extremely important. During storms, shore and near-shore installations may be subjected to the piling up of pack and offshore ice.

Designs for shore and near-shore installations will be influenced by the character of the shore ice and the possible effect of its vertical and horizontal movement on such installations. In constructing facilities of this type, both the active and passive methods of construction will often have to be used because, in many cases, the subsurface conditions may be the same as those illustrated by the borings at Churchill, Canada (Figure 2A5-16).

Many sections of the Cold Regions are subject to earth tremors. A seismic coefficient of 0.08 of gravity has been used in the design of some of the important buildings in the Fairbanks, Alaska, area, and it is believed that this factor is very conservative.

2B1.02 MATERIALS AND EQUIPMENT

Consideration must be given to the practicability of using construction materials that may be available in the area. Designs must be such that the materials and equipment to be used (a) can properly fulfill their function under the disciplines to which they will be subjected, (b) can be delivered to the site in accordance with the time schedule provided for by the mission, and (c) can be properly erected and installed in accordance with the time schedule by the labor available.

2B1.03 SETTLEMENT

Settlement of a structure is determined by the ability of the ground materials supporting the structure to resist change under the conditions to which they are subjected, including the superimposed load of the structure. Uniform settlement in moderate amounts, depending on the type of structure, should be provided for in the design. In talik areas, or when the supporting materials are thawed and remain thawed, the settlement problem is similar to such problems in more temperate zones where like materials are present under similar packing and ground-water conditions. Frequently, a disturbance of temperature equilibrium causes no serious settlement. However, serious differential settlement may occur, depending on the character and nature of the materials in place and on their confinement. For example, assume that the utilidors shown in Figure 2B2-2 have an effective diameter of 8 ft and are maintained at an average inside temperature of 40° F throughout the year; that they are buried several feet below the ground surface and supported on frozen materials whose conductivity is 1.5 Btu/hr/ft/°F, whose dry density is 100 lb/cu ft, and whose water content is 25 percent; and that the life expectancy of the structures is 15 years.

For an approximation, these utilidors may be considered cylindrical heat sources in an infinite medium. Thus, Figure 2A8-15 or equations (2A8-16b) and (2A8-16c), Problem 4 in par. 3 of 2A8.04, may be used to calculate approximately the radius of thawed zones around the utilidors at any time. Such a calculation indicates a thawed zone extending approximately 6 ft beyond the surface of the utilidor at the end of one year and 12 ft at the end of five years. NOTE: In a problem of this type, the surface effects become increasingly important as time progresses. Thus, values for one year and particularly for five years are only approximate because they neglect heat loss at the ground surface.

Now, assume that at a depth of 10 ft below the bottom of the structure there is a stratum or lens of frozen material that, when thawed, is unable to support properly the load coming to it. In this case, it is evident from the foregoing calculations that the expected life of the structure may be materially shortened because of the change in thermal regime of the supporting materials, unless provision has been made to arrest such settlement or unless the structure is designed to accommodate the anticipated settlement.

2B1.04 MISCELLANEOUS CONSIDERATIONS

All construction in the Cold Regions must fulfill certain basic requirements, which are discussed in pertinent sections of this publication. In addition, consideration should be given to the following.

(1) In areas of extremely high winds, special precautions are necessary to anchor structures and their component parts and to provide adequate rigidity. Eaves should not be used in these areas. Coverings on the leeward side of sloped roofs are particularly susceptible to the destructive effect of high winds. Metal roofs laid from the leeward side to windward and covered with hot asphalt make satisfactory roofs in windy areas, as do built-up roofs of bituminous-saturated felt nailed with large-head roofing nails and battened down with wood nailing strips.

(2) Insulation under built-up felt roofing should be rigid and strong and should not give underfoot, which causes breaks in the roofing felt. During extremely cold weather, felt roofs can be easily damaged if this precaution is not observed. Ice caused by melting and refreezing of snow on roofs can be very damaging to roof coverings. Removal of ice and snow, if necessary to minimize the roof load, should be carefully done.

(3) Vestibules are recommended for all buildings where frequent entrance and exit are necessary during cold or stormy weather. Double doors should be provided on entrances without vestibules. Storm windows should be used and should be adjustable to permit control of ventilation. Exterior doors should open inward because outward-opening doors may be blocked by snow or ice or be blown off by high winds.

(4) Adequate facilities, located close to sleeping quarters, must be provided for drying wet or damp clothing. When practicable, the warm air used for drying should be expelled from the building by an exhaust fan.

(5) Whenever concrete or metal sumps or pits are constructed in permafrost, their inside vertical surfaces should be battered so that, in the event of freezing, damage to the structure from the freezing process is minimized.

(6) It is recommended that as many windows as practicable be provided for all working or living quarters. Although additional heat loss will result, this practice will help in overcoming the feeling of confinement and isolation that is frequently prevalent among personnel working in bleak, isolated regions.

(7) Also, when interior painting is done, some thought should be given to using colors with sufficient tone to have a beneficial psychological effect.

(8) Positive ventilation and adequate circulation of air within buildings should be provided for in designs. Carbon monoxide is a constant threat during the winter months because of the wide use of coal, oil, and wood-burning heating units.

(9) Fire prevention and firefighting measures should be carefully considered in regard to all buildings and installations in the Cold Regions. The consequences of serious fires in such areas are, in general, much more severe than in temperate climates.

Section 2. DESIGN OF UTILITY DUCTS AND TUNNELS

2B2.01 UTILIDOR SYSTEMS

Placement of water distribution lines in heated conduits, or utilidors, has been used in many places. Continuous distribution can be maintained relatively easily by this method, but it is costly to install.

1. TYPES. Two general types of utilidors in use are (a) underground utilidors constructed of wood, metal, or concrete, some of which are insulated; and (b) aboveground utilidors constructed principally of wood or metal, practically all of which have special insulation, such as commercially prepared asbestos, rock wool, or similar insulators, or sawdust, fiberboard, paper, tar, felt, peat, or dead-air spaces.

There are several types of commercially made insulated conduits that may be purchased in standard sections or lengths and used as utilidors for transmission of one or more materials or services. Figure 2B2-1 illustrates one example of commercially built equipment that is available; Figure 2B2-2, four possible cross sections for utilidors; and Figure 2B2-3, some construction details for a concrete utilidor. (See Section 2A8 and par. 2B1.03.)

In all utilidor installations it is essential that the insulating materials be kept dry to maintain their insulating value. It is advisable to use and install insulating materials in such a manner that their packing, because of any vibration to which they may be subjected, will not be changed and thereby reduce their overall insulating properties.

Wood and/or concrete utilidors of rectangular cross section and constructed in place are the most common types. Their sizes range from those just large enough to convey the services carried through them to those almost 9 feet high by 7 feet wide, inside dimensions. Figures 2B2-2, 2B2-4, and 2B2-5 illustrate examples of possible constructed-in-place utilidors. Lightweight concrete has been employed in constructed-in-place types primarily as an insulating medium, as shown in Figure 2B2-6.

Little attempt has been made, in some instances, to provide the utilidors with any more insulation than that of the wood or concrete walls making the enclosures. Other utilidors have been insulated by gravel, fiberboard, sawdust, peat, and moss.

2. ADVANTAGES AND DISADVANTAGES. In February 1949, the National Research Council (Ref. 60) reported the following advantages concerning utilidors of the basic or tunnel type used in the Arctic.

(1) Pipes are accessible so that inspection and repair can be made easily and at any time.

(2) Communication between buildings is facilitated.

(3) Surface areas and traffic are not disturbed during repairs.

(4) Utilities enter the buildings at a single point.

(5) Heating system can be readily installed and operated.

(6) Special drainage system can be justified.

This type of installation, however, has the disadvantages associated with heavy unit construction.

(1) High initial cost in labor, time, and material.

(2) Possibility of failure of one utility, causing serious damage to other systems.

(3) Hazards associated with failure of all utilities at once.

(4) Foundation failures because of changes in soil brought about by excavation and placement.

(5) Increased depths required to give proper grade to domestic sewer.

(6) Rigidity and strength required to withstand earth pressures.

3. PRACTICAL CONSIDERATIONS. The National Research Council also reported that the foregoing difficulties have led to many modifications in basic utilidor installation. These changes in design have been largely characterized by reduction in size and weight, although the essential characteristics of an insulated conduit provided with artificial heat have usually been maintained. (Ref. 60.)

With a smaller utilidor the advantage of ready

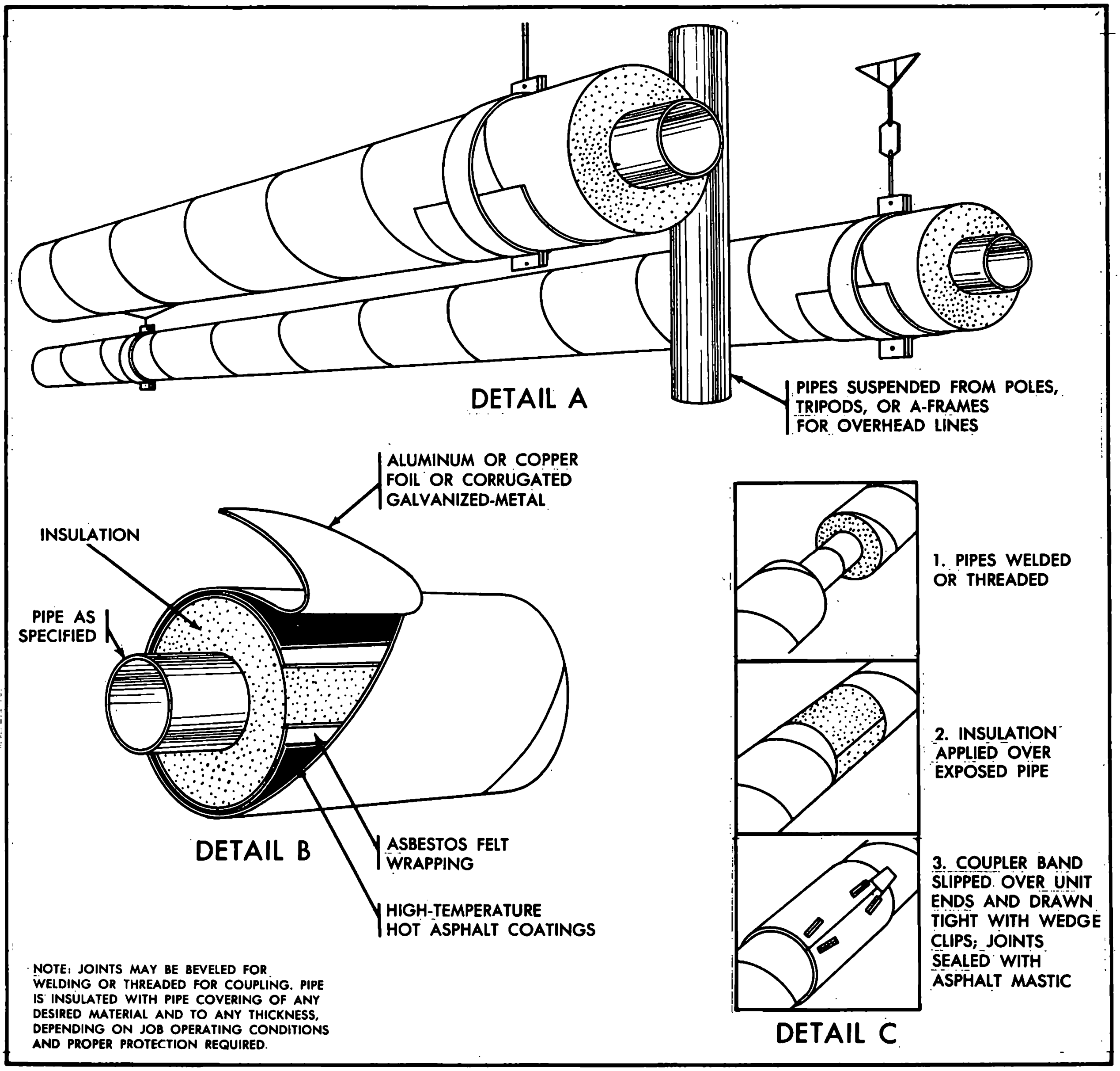


FIGURE 2B2-1

Details of Insulated Utilidor (Ref. 58)

access for inspection and repairs is necessarily sacrificed, and the heating problem is more difficult. This advantage is especially important when both water and sewer services are involved. Recognizing this difficulty, some designers have completely separated water and sewer mains from other utilities and others have gone still further and placed water and sewer mains in separate utilidors. Some systems are put on piling aboveground. When this is done, weight and foundation problems are materially simplified, but the amount of insulating materials and the quantity of artificial heat and consequent maintenance are increased. (Ref. 60.)

Hazards exist in utilidors when both water and sewer services are placed in the same duct. Leakage of sewage and negative heads in water mains may readily and seriously contaminate a water supply. Adequate drainage is necessary in all utilidors.

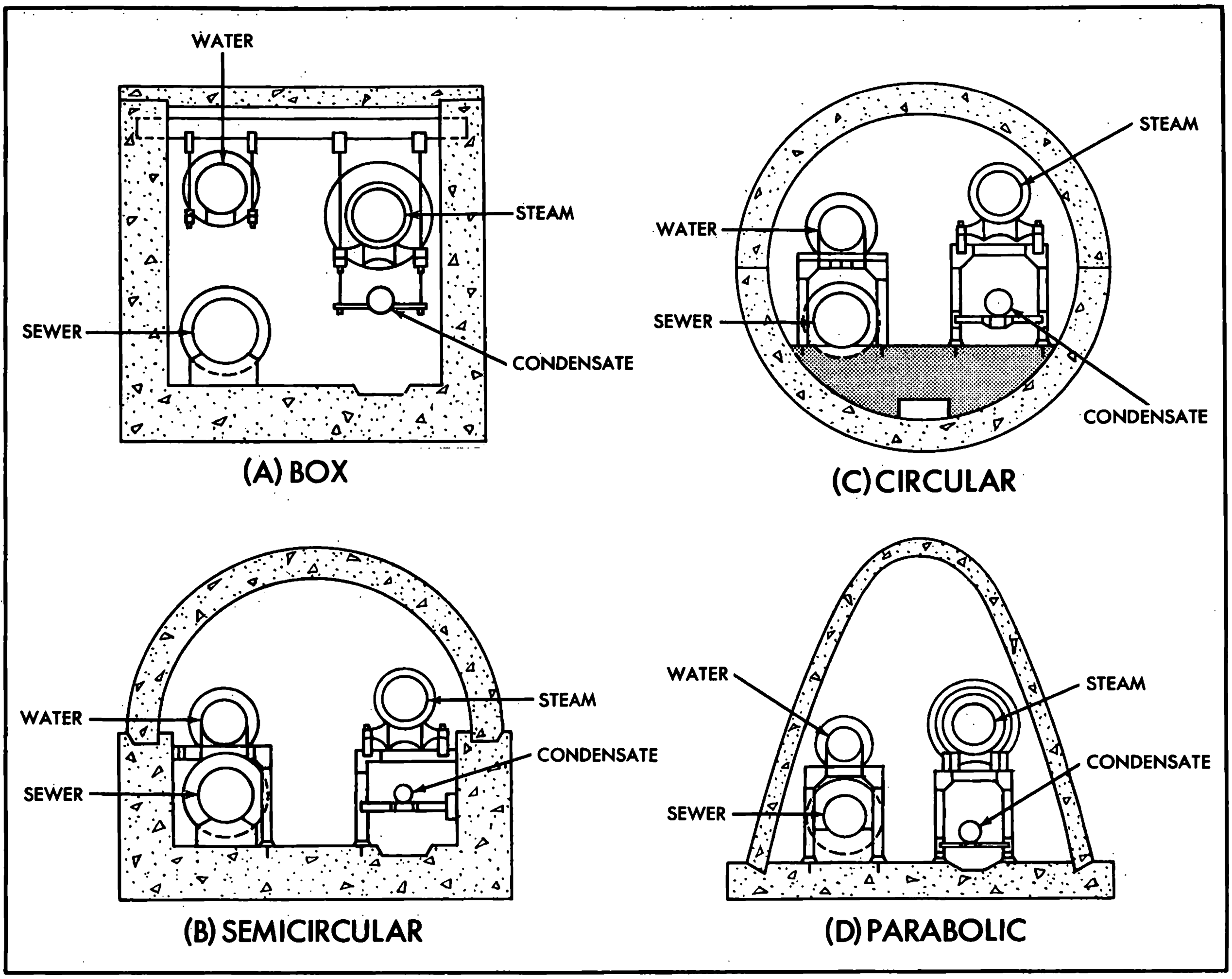


FIGURE 2B2-2

Utilidor Types

Rodentproof construction should be used for all utilidors. Improperly constructed utilidors may provide rodents with shelter and runways.

Service connections are difficult to operate unless the utilidor is extended all the way to each property served. This difficulty is most commonly overcome by providing heat as a utility along with sewer and water services. The heat service line from the heat main is connected to the premises through the same pipe gallery that is used for water service.

Underground utilidors, which extend down in the ground to a point below the water table or the permafrost table, must be constructed watertight or they will serve as an infiltration gallery (Figures 2B2-3 and 2B2-7) and collect ground-water flow from the surrounding ground. Even though the utilidor may not extend down to a point near or in the permafrost, it will, unless it is tight, collect ground water at any point where the ground water reaches an elevation above the floor of the duct. During the summer, tundra, peat, and similar soil prevalent in the Arctic are saturated with ground water almost to the ground surface.

Lost heat from the underground utilidor destroys the permafrost near it. Unless the soil characteristics where the utilidor is placed are such that its properties are not altered greatly by this change in state, differential settling may occur with resultant damaging effects on the utilidor and the enclosed services. Placing the utilidor on piling

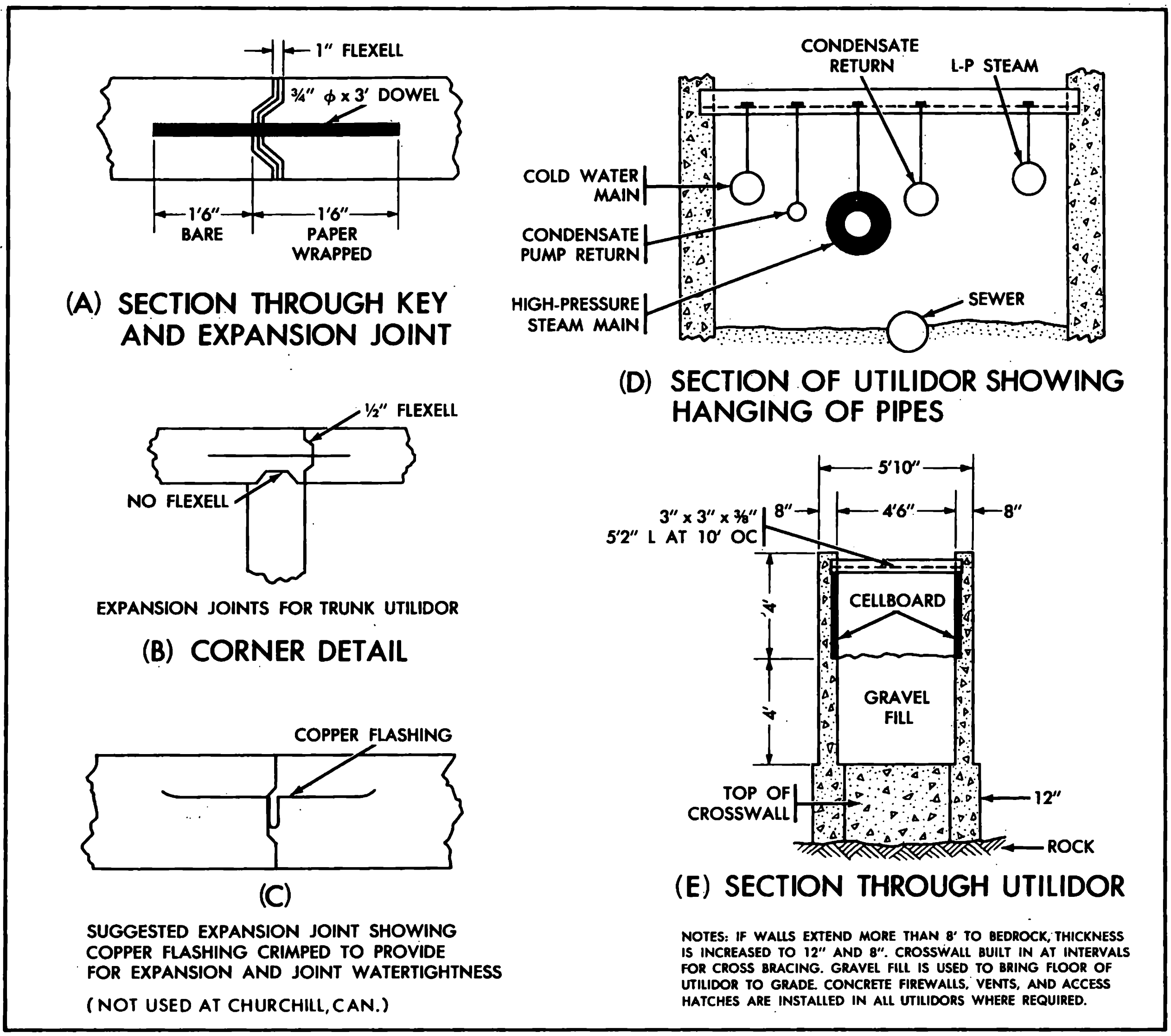


FIGURE 2B2-3

Construction Details for Concrete Utilidors, Churchill, Canada (Ref. 59)

properly driven into the permafrost will tend to reduce these effects. Proper insulation around the utilidor to protect the permafrost is necessary where the permafrost must not be disturbed. For small cast-in-place concrete utilidors, the top for the utilidor should be constructed so that it is readily removable and also so that it is tight enough to retain all heat possible in the duct. Tops for concrete utilidors may be cast in sections, and each section fitted with pulls so that it may be easily lifted. Such an arrangement may not be necessary or desirable for utilidors with a width and depth sufficient to permit adequate working space inside the duct.

Water distribution at Churchill is accomplished by pipes, which are (a) protected by moss insulation, as illustrated in Figure 2E1-6; (b) enclosed in 30-inch corrugated culvert pipe and insulated by loose rock wool; or (c) installed in utilidors, as illustrated in Figure 2B2-3.

Topography of the permafrost table, thermal regime of the ground, ground-water conditions, soil characteristics, and the minimum amount of utilidor required to serve a given area must be carefully studied in planning the installation of an

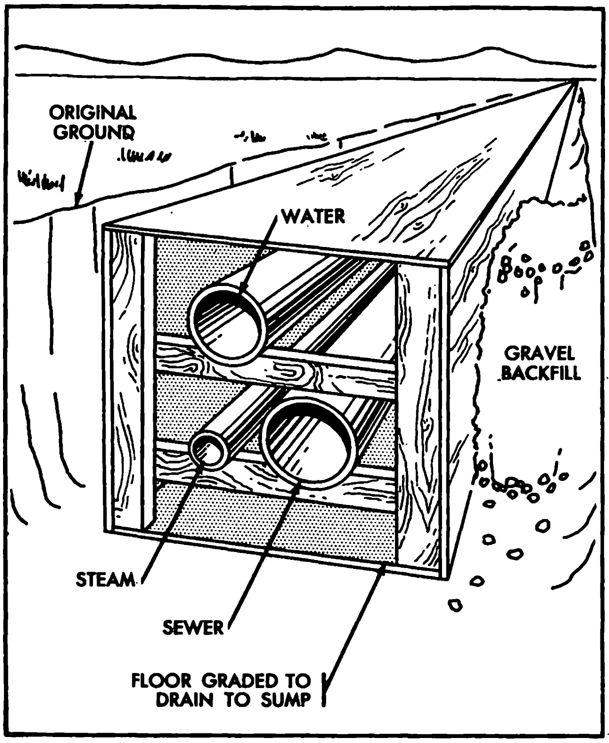


FIGURE 2B2-4

Small Wood Construction Utilidor

underground utilidor. The thermal regime of the ground will determine whether permafrost should or should not be thawed prior to installation of the systems. In parts of the Subarctic, if permafrost is destroyed it may not return, and it may be best to thaw it. The relatively high cost of utilidor construction necessitates careful study of the area to determine the absolute minimum length of utilidor necessary to provide service.

Heat for a utilidor may consist solely of that heat present in the service lines contained in the conduit or it may also come from sources other than service lines. A utilidor carrying steam lines is usually overheated. Warm air blown through the utilidor may also be used as a method for maintaining above-freezing temperatures.

4. CONCLUSIONS AND RECOMMENDATIONS. The February 1949 National Research Council report (Ref. 60) lists these conclusions concerning utilidors.

(1) The utilidor as it has been developed for use in The Arctic, when of adequate size, effectively protects utilities from extreme weather conditions.

(2) Potential sanitary hazards exist when these utilidors contain both water mains and sewers.

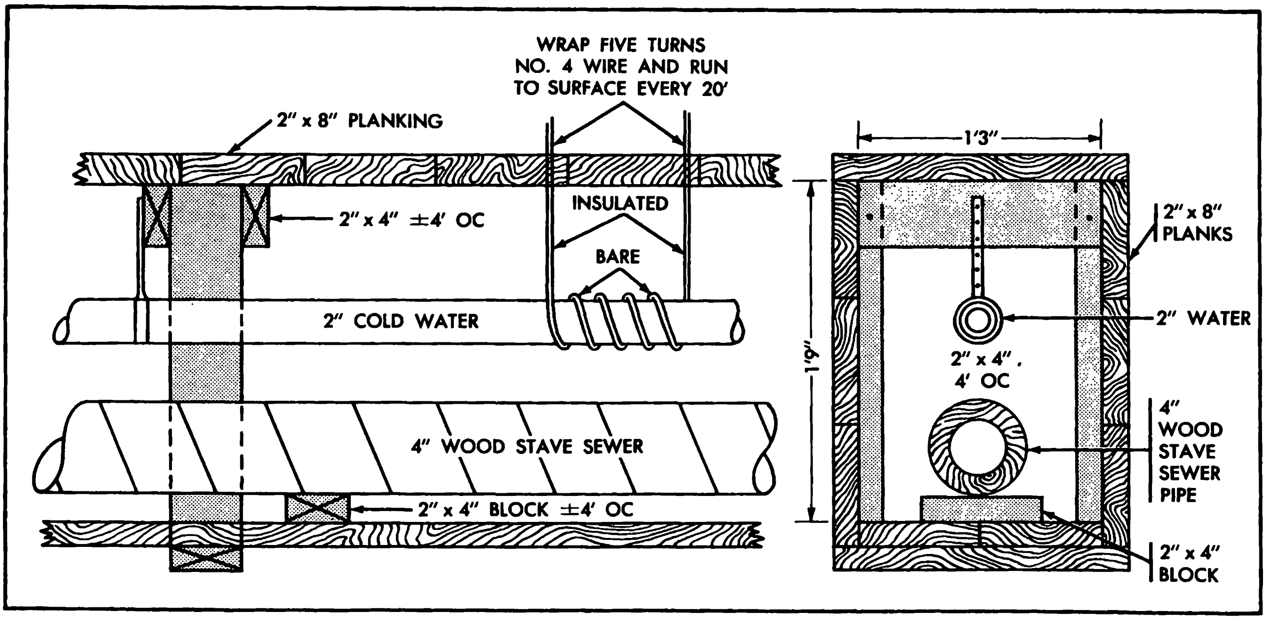


FIGURE 2B2-5

Wood Utilidor Detail

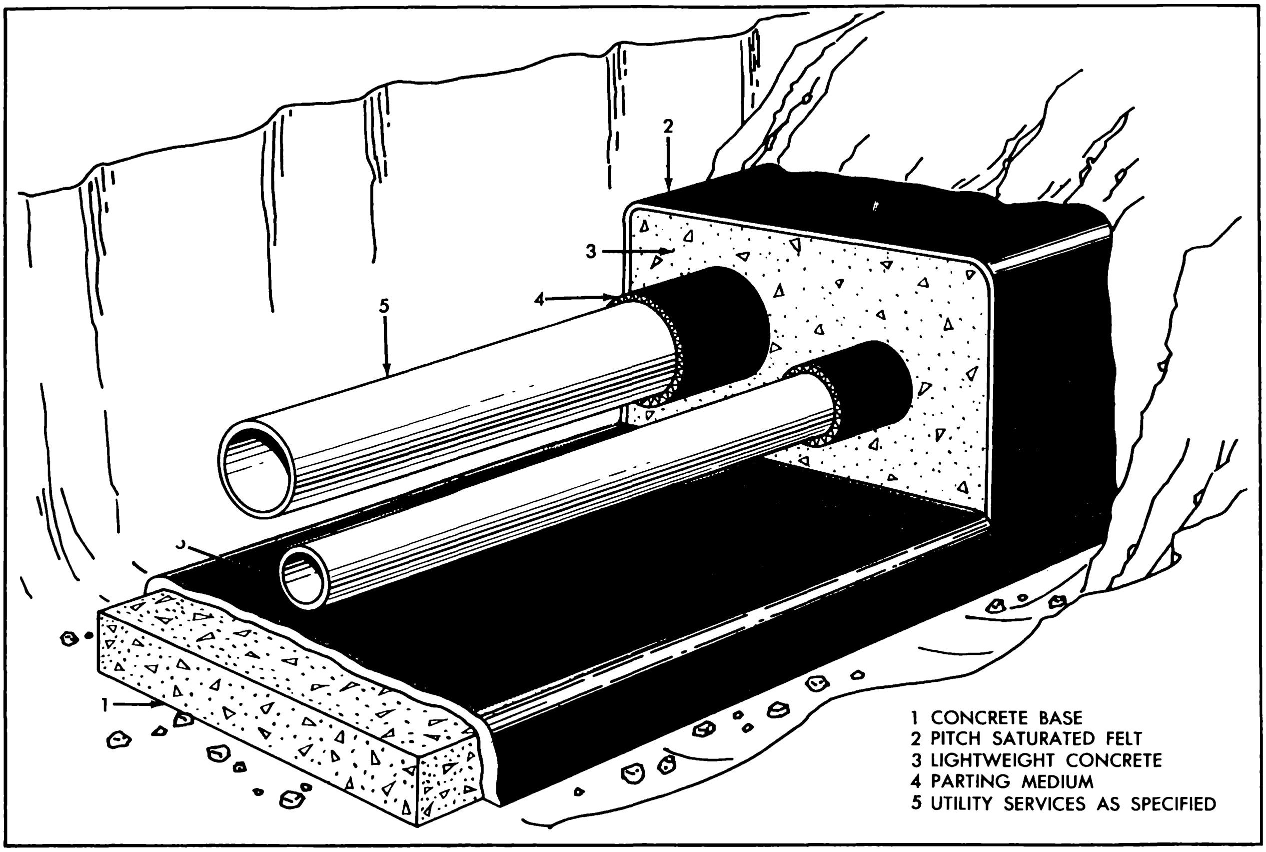


FIGURE 2B2-6

Patented Method for Insulating Service Lines With Lightweight Concrete

(3) These hazards are increased by modifications of the basic utilidor design, tending to reduce the size and weight, with consequent crowding of pipes. (Such conditions have caused serious outbreaks of disease in the United States.)

(4) Separate installation of sewer and water mains reduces sanitary hazards existing where sewer and water mains are laid close together, but creates many problems of design, especially for sewer systems.

(5) Satisfactory operation of separate water supply systems has been reported in both Canadian and Siberian communities.

(6) General information on existing sanitary sewers in Alaska and on the methods of installation used on existing water supply systems provides encouragement that improved designs can be developed for separate sanitary sewer systems that will reduce sanitary hazards associated with the modified type of utilidor design.

Recommendations are as follows.

(1) Utilidors containing both water and sewer systems should be designed to minimize sanitary hazards.

(2) In place of utilidors smaller than the walk-through (tunnel) type, consideration should be given to the separate installations of water and sewer systems.

In the design and construction of utilidor structures consideration should be given to fire prevention and protection. (See Figure 2B2-3.) NOTE: See also Sections 2A6 and 2A8, and par. 2B1.03.

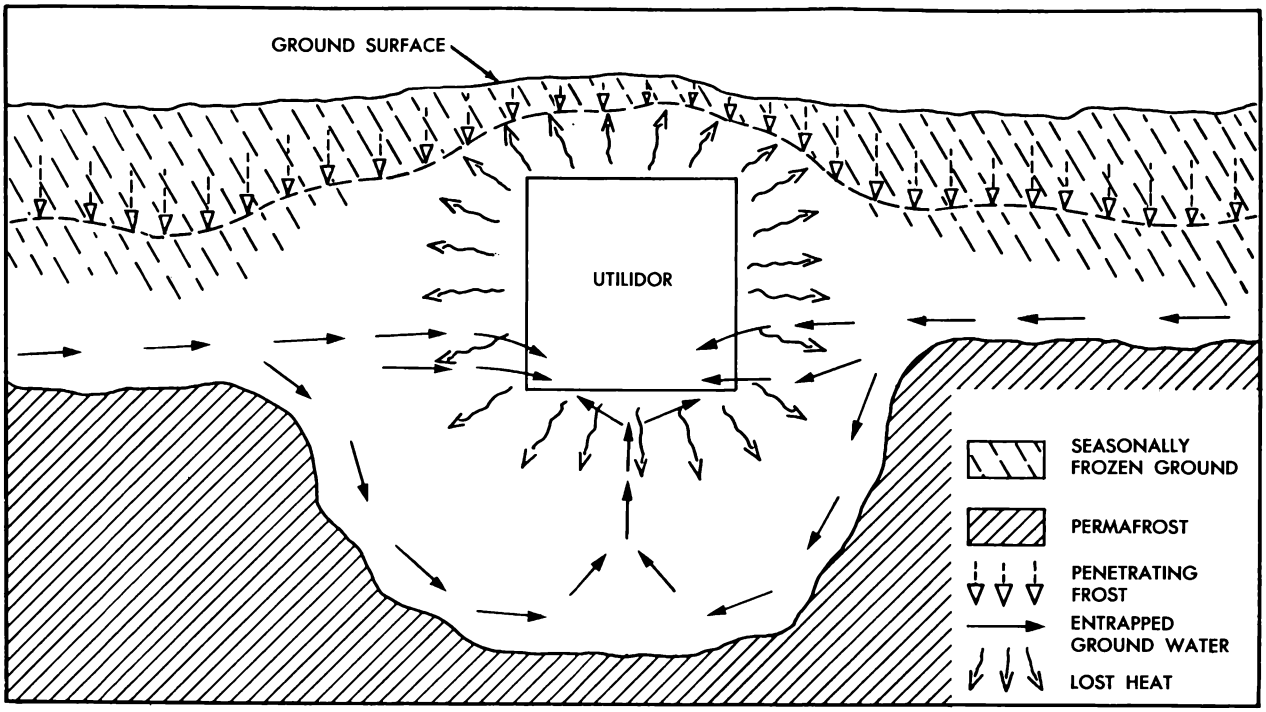


FIGURE 2B2-7

Drainage of Entrapped Water Into Improperly Sealed Utilidor

Section 3. HEATING, VENTILATING, AND AIR CONDITIONING

2B3.01 HEATING CAPACITY

As in other areas, heating plants in the Polar Regions should be able to produce sufficient heat to replace that lost through the confining surface of the structure, and lost to air that is admitted by infiltration or to produce ventilation. Ample additional capacity should be provided to compensate for unusual conditions of wind exposure and to make possible rapid heating of the building and contents after shutdowns. Also, because of the importance of fire prevention at advanced bases, the capacity of the heating plant should be sufficiently large so that operation at full capacity is never required. In buildings heated by stoves, two units operated at relatively low capacity may be safer and more economical than one unit that must be forced during severe weather.

2B3.02 HEATING PLANT DESIGN CRITERIA

1. DESIGN FOR OUTDOOR WEATHER CONDITIONS. The problem of selecting the design for outdoor weather conditions for heating load calculations in a given locality is to some extent a matter of judgment and experience. Theoretically, the most unfavorable combination of temperature and wind velocity for the particular area should be chosen, but the lowest temperature or even the lowest daily mean temperature ever recorded in a particular locality is rarely repeated in successive years. Also, the wind direction and velocity at the time of designing for outside conditions usually are quite different from those prevailing during the winter season. Designers generally do not feel that consideration of wind velocity is justified except when local wind conditions are particularly severe. In such cases, particular consideration should be given to the increased influence of wind velocity on buildings having relatively high infiltration losses.

The ASHVE Technical Advisory Committee on Weather Design Conditions recommends the adoption for heating load calculations of an outside design temperature equaled or exceeded during 97½ percent of the hours in December, January, February, and March. In the Cold Regions, November temperatures also should be considered. In areas where temperatures are not available, interpolation is suggested, with due consideration given to altitude and other local conditions. (Ref. 61.)

2. EFFECTIVE TEMPERATURE. Assuming adequate heating capacity, recommended inside design temperatures (Ref. 47, Table 1, p. 1594) and effective temperatures can be maintained if attention is given to the following: (a) proper heat distribution within buildings heated by stoves, (b) control of air movements during periods favorable to rapid infiltration, and (c) control of relative humidity.

The maintenance of proper relative humidity in the Cold Regions is most important because air at extremely cold temperatures contains only a small amount of water even at saturation. If saturated outdoor air at −60° F is brought indoors and heated to 65° F without the addition of any moisture, the resulting relative humidity would be less than 1 percent. It will be noted (Ref. 47, Figure 14, p. 1619) that the effective temperature of the room in this case would be less than 60° F. Such air should be humidified and, if this is done, the effective temperature will be increased.

3. HEAT TRANSMISSION LOSSES. Standards for buildings in the Cold Regions differ widely from those used in the Temperate Zone because they must meet certain basic requirements peculiar to the region.

Structures in permafrost areas have in common certain characteristics, mostly evident in the design of the floor, outer wall, and roof sections. In the calculation of heat losses through these sections, the value of heat transfer tables that list overall coefficients (air-to-air) of standard sections will be limited. Calculation of overall coefficients should be made from the heat conductivities and conductances of the individual building components (Ref. 62, Tables 1 and 2, pp. 13-37 through 13-43).

Certain common materials, not ordinarily considered for their thermal insulating value, are used in the Cold Regions to a considerable extent because of their favorable heat transfer coefficients, ready availability, and low cost. Table 2B3-1 may be used to supplement heat transfer coefficients obtained from other sources. (See also Table 2A8-1.)

TABLE 2B3-1

Thermal Properties of Construction Materials and Soil (Ref. 32)

Type of material	Description	Density, lb/cu ft	Conductivity, k[1]	Insulating value[2]
Loose-fill type	Redwood bark	3.00 to 5.00	0.31 to 0.26	E
	Glass wool fibers, 0.0003 to 0.0006 in. in diam	1.50	0.27	E
	Expanded vermiculite particles, fireproof	6.20	0.32	E
	Mineral wool, machine-blown	5.74	0.30	E
	Rock wool, fireproof	10.00	0.27	E
Slab insulation	Corkboard, no added binder	5.40 to 14.00	0.25 to 0.34	E
	Corkboard, asphaltic binder	14.50	0.32	E
	Sugarcane-fiber insulation blocks encased in asphalt membrane	13.80	0.30	E
	Made from shredded wood and cement	29.80	0.77	VG
Peat, near Fairbanks	Percent moisture 10.4	13.90	0.39	E
	Percent moisture 112.0	7.50	0.82	VG
	Percent moisture 277.0	17.80	3.26	F
Silt loam, near Fairbanks	Percent moisture 2.4	70.00	1.09	G
	Percent moisture 13.8	94.40	7.02	P
	Percent moisture 93.3	93.30	9.93	P
Sand, Northway airfield	Percent moisture 0.6	92.20	1.43	G
	Percent moisture 3.9	92.10	4.15	F
	Percent moisture 13.5	113.20	8.70	P
	Percent moisture 21.8	97.90	10.92	P
River gravel, Chena River, near Fairbanks	Percent moisture 0.2	119.50	4.23	F

[1]These constants are expressed in Btu/hr/sq ft/°F. Conductivities, k, are per inch thickness.

[2]E, excellent; VG, very good; G, good; F, fair; P, poor.

2B3.03 INFILTRATION AND VENTILATION

1. GENERAL. Buildings at bases in the Cold Regions are seldom over one story in height and are built as airtight as possible to reduce to a minimum the infiltration of cold air. During high winds the amount of air entering such a building may be considerable, but at other times it may be insufficient for proper ventilation. A dependable and adequate supply of air for ventilation and combustion should, therefore, be provided either by adjustable vents and storm sashes or in buildings by mechanical ventilation.

2. TOTAL AIR REQUIREMENTS. Tables of air requirements for ventilation (Ref. 47, Table 18, p. 1620) generally do not take into consideration the possible presence of heating appliances that require air for combustion. When such appliances are present, the theoretical quantity of additional air required for combustion can be calculated. For actual requirements, 25 to 50 percent should be added. (See Table 2B3-2.)

a. *Air Required for Combustion* (Ref. 61). The weight of air required for perfect combustion of one pound of fuel may be determined by using the ultimate analysis of the fuel as applied to equations (2B3-1) and (2B3-2). The various elements are expressed in percentages by weight.

TABLE 2B3-2

Approximate Theoretical Air Requirements (Ref. 61)

Solid fuel	Lb air/lb fuel
Anthracite	9.6
Semibituminous coal	11.2
Bituminous coal	10.3
Lignite	6.2
Coke	11.2
Fuel oil	**Lb air/gal fuel**
Commercial Standard No. 1—Federal Specification No. 1	102.6
Commercial Standard No. 2—Federal Specification No. 2	105.5
Commercial Standard No. 5—Federal Specification No. 5	112.0
Commercial Standard No. 6—Federal Specification No. 6	114.2
Gaseous fuel	**Cu ft air/cu ft gas**
Natural gas	10.0
Mixed natural and manufactured	8.0
Manufactured	5.2
Butane	31.0
Propane	23.8

Solid and Liquid Fuel

Pounds air required per pound fuel

$$= 34.56 \frac{C}{3} + H - \frac{O}{8} + \frac{S}{8} \qquad (2B3\text{-}1)$$

Gaseous Fuel

Pounds air required per pound fuel

$$= 2.47\,CO + 34.34\,H_2 + 17.27\,CH_4 + 16.12\,C_2H_6 + 15.70\,C_3H_8 + 15.49\,C_4H_{10} + 13.30\,C_2H_2 + 14.81\,C_2H_4 + 6.10\,H_2S - 4.32\,O_2 \qquad (2B3\text{-}2)$$

When the analysis is given on a volumetric basis, the equation is expressed as

Cubic feet air required per cubic foot gas

$$= 2.39\,(CO + H_2) + 9.53\,CH_4 + 16.68\,C_2H_6 + 23.82\,C_3H_8 + 30.97\,C_4H_{10} + 11.91\,C_2H_2 + 14.29\,C_2H_4 + 7.15\,H_2S - 4.78\,O_2 \qquad (2B3\text{-}3)$$

Equations (2B3-4) and (2B3-5) may be used as approximate methods of determining the theoretical air required for any fuel.

Pounds air required per pound fuel

$$= 0.755 \times (\text{Btu/lb}) \div 1{,}000 \qquad (2B3\text{-}4)$$

Cubic feet air required per unit fuel

$$= (\text{Btu/unit}) \div 100 \qquad (2B3\text{-}5)$$

b. *Recirculation.* In buildings or rooms where there are no heating appliances and danger from carbon monoxide poisoning is absent, intake openings may be dampered, and the need for air movement and good distribution may be satisfied by partial recirculation of inside air by small fans. During extremely cold weather this is frequently done.

c. *Mechanical Ventilation.* In crowded rooms, such as large offices, workshops, or auditoriums, the cubic space per person is less, and it may be impossible to admit sufficient untempered air without creating drafts. In such cases, mechanical ventilation is essential to remove the heat and moisture produced by the occupants. (Ref. 47, pp. 1620 through 1629.)

2B3.04 AIR CONDITIONING

1. GENERAL. The problem of providing human comfort within buildings located in the Cold Regions is not a complicated one. In winter the objective is usually the simultaneous control of temperature, humidity, and air motion. During summer months, little if any control of these

factors is considered necessary, except in special cases. The control of dust may be required in certain localities during high winds, and in such places the use of dust filters on ventilating fan intakes during summer months may be advisable. Screens at all openings to control insects are advisable.

2. HUMIDITY CONTROL. As has been pointed out, it is frequently desirable during winter months to raise the relative humidity inside buildings to conform to minimum comfort standards. Control of humidities at all seasons may also be required for various reasons, particularly in connection with hospitals, storage rooms for certain commodities, and other buildings in which a constant relative humidity is desirable.

The raising of relative humidities within buildings during the heating season will require a certain amount of heat to evaporate the amount of water vapor that must be added to the air within the building. The amount of heat required can be calculated from the following equation (Ref. 61). It is assumed that the latent heat of vapor at W_i is 1,060 Btu/lb.

$$H_1 = 79.5\, Q\, (W_i\, W_o)$$

H_1 = heat required to increase moisture content of air leaking into building from W_o to W_i, Btu/hr

Q = volume of outside air entering building, cu ft/hr

W_i = vapor density of inside air, lb/lb dry air

W_o = vapor density of outside air, lb/lb dry air

(See Ref. 10, Tables 15 and 16, pp. 949, 950, and 951, for vapor density values—grains/lb dry air—for temperatures between −45° and −95° F.)

Tabulated below are density values from −45° to −95° F.

t, °F	*Grains/lb dry air, saturated*
−45	0.40
−50	0.29
−55	0.22
−60	0.15
−65	0.10
−70	0.07
−75	0.05
−80	0.03
−85	0.02
−90	0.01
−95	0.01

2B3.05 VAPOR CONDENSATION

1. GENERAL. Buildings in the Cold Regions are particularly susceptible to vapor condensation and the formation of frost and ice on the inner surfaces of outer walls and roof sections. Low outside temperatures, lightweight construction materials, and uneven inside temperatures contribute to conditions favorable to condensation and accumulations of frost on inner surfaces, as do through structural members, which provide an unbroken line for frost penetration from outside to inside.

2. INSIDE SURFACE TEMPERATURE. During extremely cold weather the overall heat resistance of a wall may be insufficient to permit the maintenance of a desired relative humidity within the building without the formation of moisture on the inner surfaces. To avoid lowering the relative humidity of the room, more insulation will be required in the wall section to raise the surface temperature above the dewpoint. In designing wall and roof sections, consideration should be given to the inside surface temperature in relation to the dewpoint corresponding to the inside temperature and relative humidity. In all rooms where high relative humidities are maintained, double-glazed sash or storm windows are advisable.

3. HEAT DISTRIBUTION. The use of ordinary electric fans to evenly distribute heat produced by radiant heaters has been widely adopted and has proved quite effective. Proper distribution can best be accomplished, however, and more uniform room and surface temperatures will result if air circulation units designed to meet the specific requirements of each building are installed.

4. METHODS OF VAPOR CONTROL. The methods used in the Cold Regions to prevent or retard water vapor penetration through building sections are no different from those elsewhere. Vapor-retarding membranes and building materials of low moisture permeability are widely used. (See Table 2B3-3.)

2B3.06 HEATING METHODS

1. PRACTICAL CONSIDERATIONS. The type of heating system best suited for particular purposes depends on the size, function, and permanency of the buildings to be heated, the fuel available, and other circumstances. A careful review of all the facts is necessary to select the system that will most satisfactorily meet the requirements in

TABLE 2B3-3

Permeability of Various Materials to Water Vapor (Ref. 61)

Group	Material	Permeability, gr/sq.ft/ hr/in. Hg
1[1]	Plaster base and plaster, ¾ in.	14.7
	Fir sheathing, ¾ in.	2.9
	Waterproof paper[2]	49.1
	Pine-lap siding	4.9
	Paint film	3.4
	Sugarcane fiberboard, ¾ in.	12.5
	Brick masonry, 4 in.	1.1
2[3]	Foil-surfaced reflective insulation, double-faced	0.08 to 0.13
	Roll roofing, smooth, 40- to 65-lb roll, 108 sq ft	0.13 to 0.17
	Duplex or laminated papers, 30-30-30	1.37 to 2.58
	Duplex or laminated papers, 30-60-30	0.52 to 0.86
	Duplex paper coated with metallic oxides	0.52 to 1.29
	Insulation backup paper, treated	0.86 to 3.42
	Plaster, wood lath	11.00
	Plaster, 3 coats of lead and oil	3.68 to 3.84
	Plaster, fiberboard or gypsum lath	19.73 to 20.57
	Plaster, 2 coats of aluminum paint	1.15
	Plywood, ½ in., 5-ply Douglas fir	2.67 to 2.74
	Plywood, 2 coats of asphalt paint	0.43
	Plywood, 2 coats of aluminum paint	1.29
	Gypsum lath with metallic aluminum backing	0.09 to 0.39
	Insulating lath and sheathing, board type	25.68 to 34.27
	Insulating sheathing, surface-coated	3.03 to 4.36
	Insulating cork blocks, 1 in.	6.19
	Mineral wool, unprotected, 4 in.	29.07
	Sheathing paper, asphalt-impregnated, glossy	0.17 to 2.05

[1]"Calculating Vapor and Heat Transfer Through Walls," J. G. Miller, Heating and Ventilating, Vol. 35, Nos. 11 and 56, November 1938.

[2]Lightweight slater's felt to keep rain from dripping through. Not used as vapor barrier.

[3]"How To Overcome Condensation in Building Walls and Attics," L. V. Teesdale, Heating and Ventilating, Vol. 36, No. 4, April 1939.

each case and be consistent with the objectives of the mission.

Buildings can be heated either by separate units installed in each structure or from a central heating plant. Temporary and semipermanent facilities, especially those located in isolated sections of the Cold Regions, should have separate heating units. For permanent installations in which groups of buildings are involved, central heating may be feasible, but the possibility of loss or damage to the facilities by fire or from attack should be considered, as well as the time required for construction. Provisions must be made for temporary heat during the construction period. Radiant space heaters may be satisfactory for this purpose, but if the installation is a large one, packaged-type steam boilers, which can be placed in service quickly, should be considered. Such units can often be incorporated later into the permanent layout or used as a standby.

2B3.07 INDIVIDUAL SPACE HEATING

1. TRAIL EQUIPMENT. Wood-burning sheet-iron stoves, makeshift heaters constructed from oil drums, and standard US Army tent stoves, which can burn either oil or wood, are adequate for heating small tents and trail shelters and have the advantage of being easily transported. Diesel-operated tent stoves and gasoline-burning Yukon stoves have given satisfactory service in pyramidal tents as large as 16 feet x 16 feet during very cold weather.

2. RADIANT SPACE HEATER APPLICATIONS. Temporary and semipermanent structures of nominal dimensions, such as log cabins, Quonset huts, Jamesway huts, or their equivalent, can be maintained at comfortable temperature levels by one or more radiant heaters operated by whatever fuel is available. Such units, operated by fuel oil supplied by gravity from 55-gallon drums mounted on racks outside the building, are widely used in the Cold Regions. If properly operated and maintained, they give efficient and dependable service and are comparatively safe.

Heaters should be placed no closer than 36 inches from the wall and located to provide maximum comfort for all personnel. If closer spacing is necessary, the wall should be protected by a sheet-metal screen on a rigid metal frame that maintains an airspace of not less than 1 inch between the wall and the metal, or the wall should be covered with asbestos. Roof jacks should be provided at all places where stovepipes pass through the roof, and asbestos should be placed on all surfaces within 18 inches of the stovepipe.

Oil-operated heaters should not be placed over boxes of sand, because oil leaking from feed lines or the burner unit soaks into the sand and is not easily detected. Mountings over asbestos, concrete, or metal are satisfactory. A gravity fuel line from the storage tank or drum to the heater should be provided with a vertical condensate trap. The trap may consist of a 2-in. T and an 18-in. long 2-in. pipe with drawoff valve at the bottom made up with a close nipple at the drum to prevent any moisture from settling and freezing in the fuel line under the building (Figure 2B3-1).

The advantage of using fans to evenly distribute

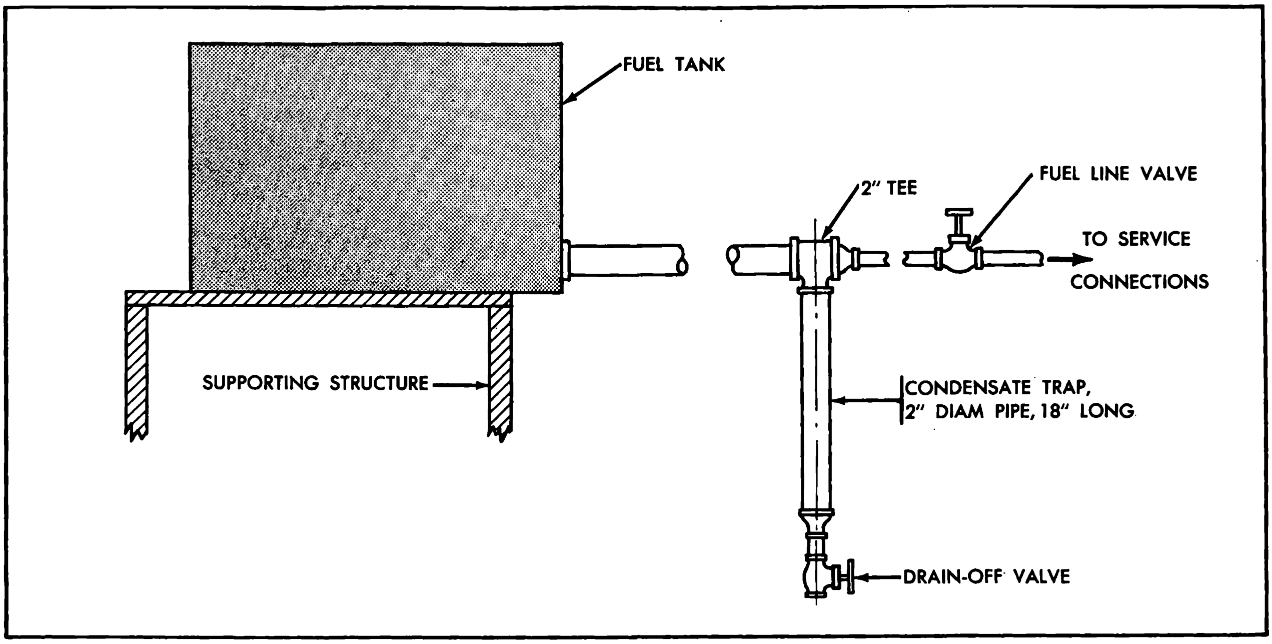


FIGURE 2B3-1

Condensate Trap for Fuel Oil Storage Tanks

heat produced by radiant heaters has been discussed elsewhere in this section.

Flue outlets of oil- and solid-fuel-burning heaters should be equipped with barometric dampers to prevent excessive flue drafts, which could impair combustion or blow the products of combustion into the space surrounding the appliance.

Small utility buildings containing pumping units, light plants, or other service equipment can be adequately heated by oil-operated radiant heaters. Heating units in such buildings, which are usually occupied only periodically, should have a capacity sufficient to produce adequate building temperatures when the unit is set at a relatively low operating position.

3. FLOOR FURNACES. Oil-burning floor furnaces have certain advantages over radiant heaters, among which are the following.

(1) They take up no floor space.

(2) Their flues are entirely outside the building.

(3) They make possible more uniform room temperatures because they expose relatively large volumes of air to moderate temperatures, whereas radiant heaters expose relatively low volumes to very high temperatures.

The disadvantages of floor furnaces are as follows.

(1) They require electricity for ignition and automatic temperature control, which limits their use to buildings having electric service.

(2) The heat radiated from the flues is not utilized.

(3) The section of flue underneath the building must be well insulated to prevent thawing of the permafrost.

4. FORCED HOT-AIR SPACE HEATERS. Oil-operated, forced hot-air, direct-fired space heaters have been successfully used for heating large buildings at advanced bases and have many advantages.

(1) They are shipped completely assembled with all but mechanical equipment and controls in place.

(2) Their shipping weights are moderate; for example, a 400,000-Btu heater equipped with 5,000-cfm blowers weighs less than a ton.

(3) They can be purchased with stainless-steel combustion chambers that require no refractory.

(4) They use fuel with a high degree of efficiency and require little or no attendance and maintenance.

(5) They cost less to install than steam or hot-water systems.

(6) They require no special foundation and can easily be moved from place to place.

(7) They can be conveniently connected to a duct distribution system or can operate as individual floor sets.

Although forced-air heaters of this type are particularly adaptable to hangars, shops, garages, and so on, they may be used with equal success for heating any type of building if attention is given to the prevention of drafts and the problem of noise.

5. INDIVIDUAL STEAM, HOT-WATER, AND WARM-AIR SYSTEMS. Conventional low-pressure heating systems for steam and hot-water and gravity or forced-circulation warm-air furnaces are widely used in the Cold Regions. Their use is generally confined to private residences and commercial, industrial, and service establishments in which central and district heating is not available. Warm-air systems are most frequently used in the smaller dwellings because of the difficulty, in permafrost areas, of obtaining a dependable source of makeup water. Larger establishments generally use hot-water and low-pressure steam systems of the same types used in the Temperate Zone. Inasmuch as water distribution systems do not exist in many sections of the Cold Regions, drilled wells usually supply makeup water for the boilers. This water is generally highly mineralized. The fuel used depends on what is available. Coal and oil, automatically fired, are the most common, but wood is frequently used in forested areas.

a. *Radiant and Panel Heating*. Radiant heating (Ref. 47, pp. 1613 through 1617) is a practical solution to many heating problems in the Cold Regions, and its use is increasing. The system can be used successfully in conjunction with hot-water or warm-air sources to heat permanent nose hangars, shops, and other such structures. Radiant heating systems using steam are not recommended. Radiant surfaces may be the ceiling, walls, or floors. Copper or ferrous coils are usually embedded in a gravel or stone fill overlaid with concrete, or are in contact with a plaster wall or ceiling. Hot air can be circulated through ducts formed of hollow tile cast into concrete floor slabs or through airspaces provided in paneled ceilings or walls. Heating with electric grids placed behind walls and ceilings or with heating cable properly installed in walls, ceilings, or floor panels should be considered for small utility buildings, nose hangars, or other structures of moderate dimensions.

Snow and ice can be melted from important operating areas, driveways, and sidewalks by embedding coils in the fill under the concrete. In out-of-door slab heating, hot water should contain an antifreeze solution. Electric heating cable embedded in a similar manner can be used for melting snow from operating areas or for space heating. In certain applications it may be more practical than any other method.

2B3.08 CENTRAL HEATING PLANTS

Reference should be made to par. 2B4.02.

2B3.09 STEAM DISTRIBUTION SYSTEMS

1. GENERAL. Central or district heating systems are feasible in the Cold Regions and should be considered at permanent installations whenever the heating problem involves a large group of buildings, the units of which are not unduly dispersed. Aside from special provisions necessitated by the disciplines of permafrost areas, the mechanical features of steam distribution systems are identical with those constructed in the Temperate Zone. High-pressure steam distribution is generally preferred to hot-water distribution because the former allows smaller mains to be used and makes steam available at various pressures for cooking or process work. If hot-water heating is particularly desired at any building, it can be made available by using steam for heating water, which is then circulated through the heating system by a pump or by gravity.

2. DESIGN FACTORS. Many factors must be known before the most economical pipe sizes for a steam main can be determined. It is common practice to transmit steam through mains at comparatively high pressures and velocities and to allow pressure drops sufficient to reduce pipe sizes to a minimum. Before designing the system, maximum steam demands and pressure requirements for each building and for each section of the line must be known on the basis of initial pressure available at the central station and the total length of the line. The pressure drop per unit of length along the line should be definitely decided upon only after a careful analysis has been made of all factors involved in the installation. Once these factors are known, flow formulas can be used to determine line sizes.

Vacuum return-line systems are commonly used to withdraw condensate from the various area loops. The particularly desirable features of such systems in permafrost areas are that leaks in their return lines can be detected by vacuum gage readings and repairs can be made before thawing and serious subsidence of the permafrost have taken place.

It is desirable and often practicable to place the loop vacuum pump and receiver tank in the manhole containing the reducing valve serving the particular area. The vacuum pump, which should be controlled by both vacuum regulator and float, creates a partial vacuum in the receiver and draws water and air from it, separating them and discharging the air to the atmosphere and the water to the hot pit. Separate pumps are frequently used to pump condensate from manhole hot pits to the feedwater tank at the central plant.

Condensate and vacuum pumps should be the duplex type, automatically controlled to interchange load and to supplement one another in case of mechanical failure. Experience in the Cold Regions has indicated the advisability of running separate powerlines from the pumping equipment to the powerplant so that pumps can be kept in operation by emergency equipment in the event of a power outage. In extremely cold weather such outages may be disastrous.

Safety valves, which protect low-pressure loops from high steam pressures carried in the mains, usually discharge outside of manholes and, in case of leaking valves, are subject to icing at the outlets. Icing can be prevented by installing a steam tracer line around the outlets or by other methods.

Manholes should be constructed at intervals, as required, along the route of the line. Concrete structures are preferable for permanent installations. Their sides should be battered to resist frost heaving, and they should be large enough to contain auxiliary equipment, such as pumps, control valves, and traps, and to provide working space for maintenance of equipment and lines that may pass through them. These usually include water and sewer lines as well as steam mains and return lines. Line anchors are usually provided at the manholes and are frequently incorporated in the walls of the structures, which should be designed to take the load imposed.

Expansion joints and anchors must, of course, be provided at specified intervals along the line. Properly designed loops, from a mechanical standpoint, are excellent to take up expansion. However, when lines must be heavily insulated and waterproofed or when they are carried in underground pipe galleries or utilidors, the accordion type of expansion joint is usually preferred.

Steam mains and return lines that are buried in the ground must be insulated to preserve heat and must be watertight. Also, they must be protected from damage by traffic or other loads that may be imposed. Several patented systems designed to accomplish this are available. In one such system, piping is laid on a supporting slab of concrete running the full length of the line. The pipe is completely connected, forms are built, and a material of high insulating value is poured around the pipes. After the forms are removed, a waterproof membrane is applied to the outside of the insulation. Special insulated and watertight structures are provided for expansion joints, loops, and other appurtenances. In another system the two lines are made up either as two individual units or as a single insulated unit surrounded by a corrugated metal jacket wrapped with asphalt-saturated asbestos felt to make it watertight and to combat corrosion. Sections are completely built up and prefabricated at the factory. Pipe and jacket sections, as received, are welded into the line, and closures between sections are insulated and waterproofed. Either expansion joints or loops may be used with this system. They are insulated and waterproofed in the same manner as piping. Anchoring of such lines is accomplished by enclosing special anchor sections in blocks of concrete.

Metal-jacketed lines are structurally strong and can be installed in shallow trenches with only a few feet of covering.

Both of these systems, if properly designed and installed, are satisfactory if there is no permafrost, provided waterproofing is adequate to prevent the entrance of moisture. Both have also given good service in sections of the Subarctic in ground that is not permanently frozen. Where permafrost does exist, lines should be placed overhead or in utilidors constructed underground, so designed and installed that the permafrost is not damaged structurally. (See Sections 2A8 and 2B2 and par. 2B1.03.)

2B3.10 FUEL CONSUMPTION

1. ESTIMATION OF REQUIREMENTS. Because logistic limitations are usually such that Polar operations must be self-sustaining for long

periods, it is important that the amount of fuel that the operation will require for a given period be estimated as accurately as possible.

There are several methods in common use by which fuel consumption can be estimated. Nearly all such methods will give trustworthy results over a full yearly heating period. Few estimates will give consistent results within themselves for monthly periods because, as the estimating period is shortened, there is more chance for discrepancy caused by some factor not allowed for in the estimating method.

a. *Degree-Days.* A method of estimating probable fuel consumption that has wide usage is based on degree-days (Ref. 10, p. 945), values for which are computed from mean temperature normals on record at most weather stations. Monthly averages and average yearly totals of degree-days, taken from US Weather Bureau records maintained at various locations in the Cold Regions, are given in Chapter 1. Monthly averages were obtained by adding daily degree-days for each month each year, dividing by the number of days involved, and then totaling the respective calendar monthly averages for the number of years indicated and dividing by the number of years. The total or long-term yearly average degree-days is the summation of the twelve monthly averages.

b. *Seasonal Efficiency.* In calculating the probable fuel consumption of buildings, a seasonal efficiency value must be assumed unless factors based on actual seasonal efficiency are available for conditions similar to those contemplated.

The input of heat to a building consists not only of the energy in the fuel but also of that from occupants, the sun, appliances, processes, and all other sources. In many cases these make up, over a period, an important percentage of the total heat required, and if they are not taken into account, a calculation of efficiency can show a figure over 100 percent. (Ref. 10.)

For this and other reasons the actual seasonal efficiency is difficult to determine. Published data are widely scattered and insufficient. From the available published material, it is found that the seasonal efficiency varies over a wide range, depending on the fuel used, and it varies widely even for a given fuel. For example, in a recent survey of 30 houses in one locality, a variation of 45 to 75 percent was found in the utilization efficiency, depending on the fuel. (Ref. 10.)

TABLE 2B3-4

Cooling-Water Heat Available for Recovery (Ref. 63)

Maximum water temperature, ° F	Number of cylinders	Horsepower	Heat in cooling water, Btu/hr	Circulation, gpm
Diesel engines				
190	1	5	15,600	2.5
190	2	10	31,200	5.0
180	1	10	33,500	5.0
180	2	20	67,000	10.0
180	3	30	100,500	15.0
180	4	40	134,000	20.0
180	6	60	201,000	30.0
180	8	80	268,000	40.0
160	4	60	235,000	30.0
160	6	90	353,000	45.0
160	8	120	470,000	60.0
160	6	225	630,000	112.5
160	8	300	840,000	150.0
160	1	60	106,000	30.0
160	2	120	212,000	60.0
160	3	180	318,000	90.0
160	1	75	128,000	37.5
160	2	150	256,000	75.0
160	3	225	384,000	112.5
160	4	300	512,000	150.0
160	5	375	640,000	187.5
160	6	450	768,000	225.0
160	3	35	98,400	17.5
160	2	60	128,700	30.0
160	3	90	193,000	45.0
160	1	55	157,900	27.5
160	2	110	315,600	55.0
160	1	75	145,000	37.5
160	2	150	290,000	75.0
160	3	90	193,000	45.0
160	4	120	256,700	60.0
160	5	150	322,000	75.0
160	6	180	385,000	90.0
160	4	160	312,500	80.0
160	5	200	390,000	100.0
160	6	240	469,000	120.0
160	8	320	625,000	160.0
160	5	375	691,000	187.5
160	6	450	830,000	225.0
160	5	250	451,000	125.0
160	6	300	541,000	150.0
160	5	500	741,000	250.0
160	6	600	888,000	300.0
160	7	700	1,036,000	350.0
160	5	575	782,000	287.0
160	6	690	938,000	345.0
160	7	805	1,092,000	402.0
160	4	700	1,008,000	350.0
160	5	875	1,259,000	437.0
160	6	1,050	1,510,000	525.0
160	7	1,225	1,760,000	612.0
160	8	1,400	2,016,000	700.0
160	10	1,750	2,518,000	875.0
Gas engines				
160	3	50	129,400	33.0
160	4	80	377,000	53.0
160	6	120	565,000	80.0
160	8	160	752,000	107.0
160	6	225	945,000	150.0
160	8	300	1,260,000	200.0
160	1	60	304,000	40.0
160	2	120	608,000	80.0

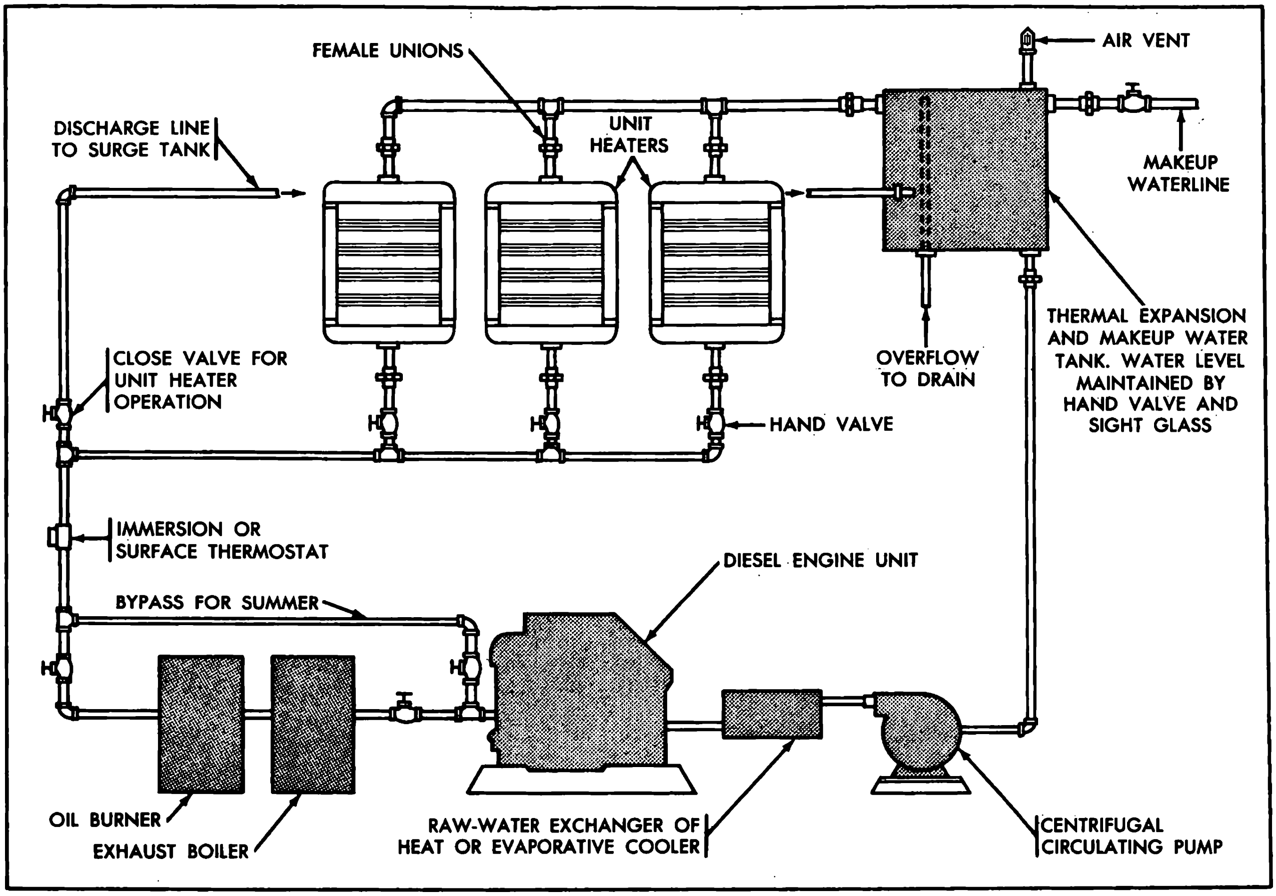


FIGURE 2B3-2

Cooling-Water Circulation System—Diesel Engine Unit Heaters (Ref. 63)

2. INPUT HEAT CONSIDERATIONS. In the Cold Regions, input heat from all sources is usually neglected, except in the case of machine shops, powerplants, laundries, and so on, where large quantities of heat may be released inside the building. This is true, provided input heat is always available during periods of human occupancy. (See Ref. 47, Table 5, p. 1643.) In the case of buildings such as theaters and assembly halls, the heating system should have sufficient capacity to bring the building up to the required room temperature before the audience arrives. During occupancy, the system should be properly adjusted to assure a comfortable temperature.

2B3.11 HEAT FROM INTERNAL COMBUSTION ENGINES

1. HEAT RECOVERY. Internal combustion engines are used extensively in the Cold Regions as prime movers for electric generators and for many other purposes. Inasmuch as a large proportion of their fuel input is ordinarily wasted as heat losses in the cooling water, exhaust gases, and radiant heat, manufacturers of such engines and related equipment have made accessory equipment of various types available. The function of the accessory equipment is to recover the waste engine heat for use in heating systems and for other purposes. Unit heaters or radiators are available that are designed to transfer heat from diesel engines to the air inside of buildings and to produce the correct engine and room temperatures under all conditions of operation. On diesel power-generating applications or comparable service in which engines are running for long periods of time, a recovery system using only jacket-water heat can often constitute the basic heat supply of a building in or near which the diesel unit is located. Such a system is com-

paratively simple and may be controlled either manually or automatically. If more heat than that supplied by the jacket water is required, an exhaust boiler can be installed in the engine circulating system. For needs beyond the engine jacket-water and exhaust heat supply, an oil burner may be installed as a component part of the system (Figure 2B3-2). Quantities of heat made available by a diesel engine recovery system are considerable. (See Table 2B3-4.) (Ref. 63.)

Section 4. POWER GENERATION AND DISTRIBUTION, AND LIGHTING

2B4.01 INTERNAL COMBUSTION POWERPLANTS

1. APPLICATIONS. Diesel engines, because of their high thermal efficiency, ruggedness, and great reliability, are widely used by the Armed Forces as prime movers of electric generators. Engine generators are portable and flexible and can be placed in operation soon after delivery. They are simple to operate and maintain. They use less water than steam plants and are not damaged, as are boiler tubes and other steam-plant components, by water having a high mineral content. At large permanent installations where district heating systems are installed, dual-service steam plants equipped with extraction-type steam turbines are practicable, but these installations are not common in the Cold Regions. Buildings in forward areas can be adequately heated by individual oil-burning systems, and steam for laundry, kitchen, and other services can be supplied by small local steam generators.

The low vapor pressure of diesel fuel, with attendant reduced fire hazard in comparison with gasoline, is an especially important advantage when fuel must be transported by ship.

2. PRACTICAL CONSIDERATIONS.

a. *Powerplant Structure.* Buildings housing engine-generator sets should be built in accordance with the principles set forth in Sections 2A6 and 2B1. If the foundations for the building and equipment are constructed in or on permafrost, it is important that the relationships discussed in Section 2A8 be recognized. Rooms housing internal combustion engines must be well ventilated.

b. *Location of Equipment.* It is common practice to place engine-generator units on parallel lines, leaving ample clearing for dismantling the engine, generator, and exciter. When so arranged, plants having two or more units can be almost square.

Switchboards and other control equipment vulnerable to moisture should be located well away from surfaces that may collect condensation during cold weather.

c. *Dispersal of Facilities.* (See par. 5 of 2B4.02.)

d. *Engine Foundations.* The engine manufacturer should be consulted for recommendations regarding design of foundations for diesel equipment. The mass of such foundations must be sufficient to absorb vibration. Modern equipment, however, has many features that contribute to light weight, good balance, and a reduction in size of foundations from those required by older equipment. Special precautions are necessary in constructing foundations for heavy engines in permafrost. (See Sections 2A5 and 2A6 and Chapter 3, Part C.)

e. *Cooling Systems.* Various types of conventional cooling systems for diesel engines, details of which are discussed in mechanical and electrical engineering handbooks, are applicable to cold-weather installations. Several types of cooling equipment are available that can be located in the engine room, where danger of freezing is minimized. If practicable, consideration should be given to heating the power station by transferring heat by unit heaters from the jacket circulating water to the air within the building (par. 2B3.11).

Figure 2B4-1 illustrates a proposed diesel engine cooling system consisting of a shell-and-tube heat exchanger using continuously recirculated water cooled by permafrost. It is suggested that such a system may be practicable in areas where the mean annual temperature is less than 32° F. The thermal characteristics of the soil should be carefully studied and evaluated in terms of the cooling requirements. (See Section 2A8.)

f. *Water Supply.* (See par. 4 of 2B4.02.)

g. *Maintenance and Repair.* Engine-generator sets pose no special maintenance or repair problems in the Cold Regions provided they operate within buildings in which above-freezing temperatures are maintained. If they are required to operate out-of-doors during winter months or in cold buildings, the equipment, including accessories

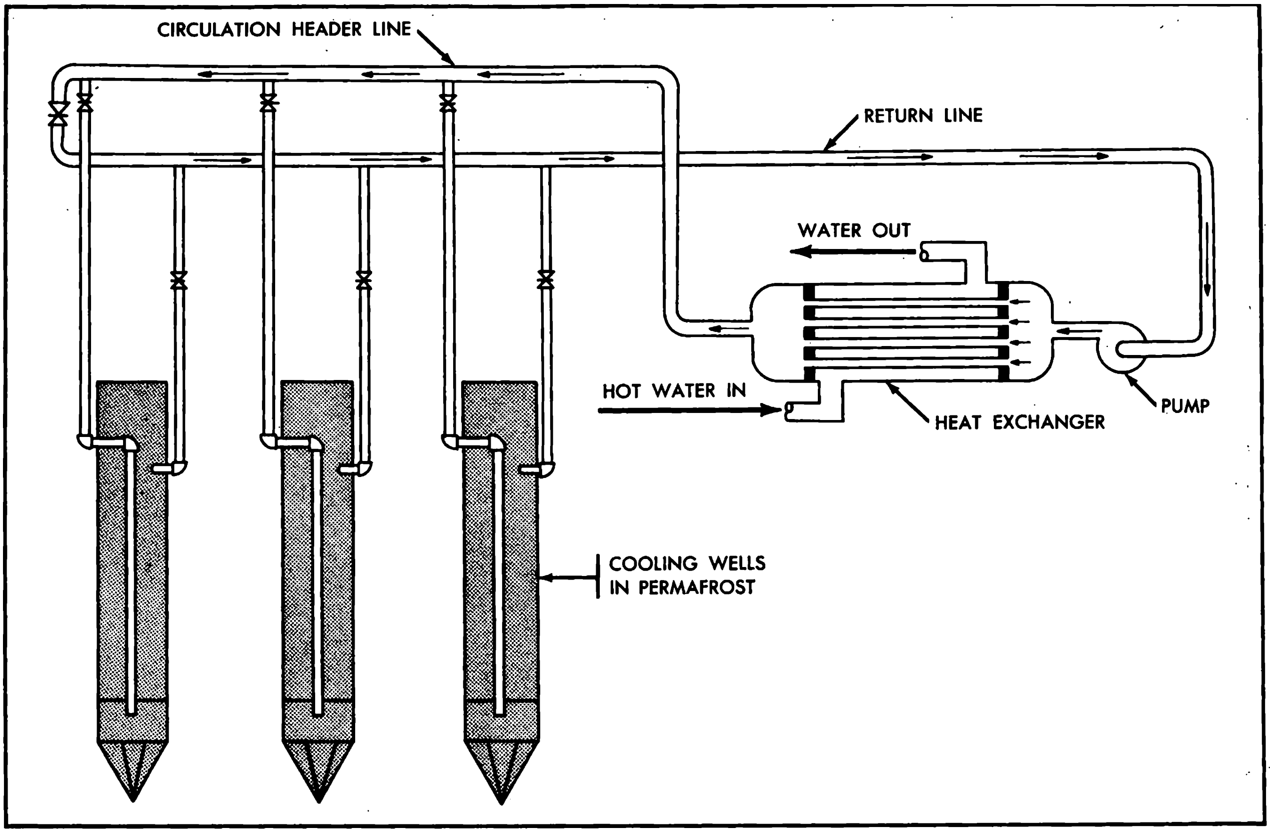


FIGURE 2B4-1

Cooling System Using Heat Exchanger and Circulation Wells in Permafrost

and auxiliaries, must be completely winterized, as discussed in par. h, following. An effective maintenance routine must be established, and sufficient operating repair equipment, supplies, and repair parts must be stocked to carry the operation through the season.

h. *Winterization of Equipment.*

(1) *Engines.* Large diesel engines used as prime movers for electric generators in central stations are usually housed in well-heated engine rooms if auxiliary power sources are available for starting the engine and if severe low-temperature conditions never occur. However, portable engine-generator sets, which generally are limited to engines of small and medium sizes, are important frontline equipment; they must be capable of going into operation on short notice even under the most severe temperature conditions. Internal combustion engines are not designed for starting and operating at extremely low temperatures, and their satisfactory operation under such conditions depends on certain necessary modifications. Instructions and procedures designed to facilitate cold-weather starting and operation of diesel, gasoline, and electric equipment are presented in Ref. 64. The instructions prescribed are applicable to all powered heavy-duty equipment, including their accessories and auxiliaries, for ambient temperatures down to −65° F.

(2) *Protection of Cooling Systems.* In winter, special measures are necessary to prevent heat exchangers and other auxiliary equipment from freezing during shutdowns or when standby units are housed in a separate building. The safest method is to provide adequate heat to the area in which the equipment is located. If this is impracticable, antifreeze solution should be added to the jacket water, or the circulating pump should be kept in operation during shutdown periods. When a battery of engines is installed in the same room, the waterlines of the separate cooling systems should be cross-connected so that hot water from

any or all of the engines may be pumped through any or all of the cooling systems. This should be provided for in the design. Additional precautions applicable to evaporative coolers and other equipment should be obtained from equipment manufacturers. Whenever practicable, provisions should be made so that the entire system or critical portions of it can be readily drained.

i. *Fuel, Lubricants, and Coolants.* Reference should be made to par. 4A3.03 for military specifications and a list of Navy stock numbers of fuel, lubricants, and coolants that are available for field use and are satisfactory for low ambient temperatures.

j. *Cold-Weather Starting.* Reference should be made to par. 1 of 4B1.03 for a discussion of auxiliary heat used to start engines at low ambient temperatures. Paragraph 2a of 4A2.02 describes the use of diethyl ether priming systems for lowering the temperature to the degree at which ignition can take place. Diethyl ether, because of its high volatility and low ignition temperature, combines with air to form a mixture that ignites much more readily on compression than do mixtures of diesel fuel and air. Most authorities agree that ether, if properly used, has no damaging effects on an internal combustion engine. There is some question, however, about using ether in two-cycle diesel engines in which the air is passed through the crankcase before it goes to the cylinders, because the presence of the air-ether mixture in the crankcase may cause a premature explosion.

As an alernative to ether injection for obtaining ignition at low ambient temperatures, spark ignition, in combination with a lowered compression ratio, and other methods have been tried. However, sufficient work has not been done at low temperatures to justify the inclusion of these methods in this publication.

To aid cold-weather starting, some work has been done on injecting fuel such as gasoline or petroleum naphtha under very high Reed vapor pressures into the manifold by a carburetor. As a safety measure, it has been suggested that the fuel be put into steel capsules, which would have to be much larger than ether capsules. Petroleum naphtha with a Reed vapor pressure of 20 psi at 100° F has been used as a starting aid in the Ranger aircraft engine for starts at −65° F. (Auxiliary heat was also employed.) Injection of high Reed vapor pressure fuel has merit, but the method has not been sufficiently tested to permit conclusions as to its practicability. (Ref. 54.)

k. *Handling and Storage of Fuel Oil.* Improper handling methods during shipment, storage, and transfer of fuel often result in rusty containers, icing, and other conditions that cause clogging of fuel lines and carburetor jets by ice, scale, or other material. Procedures for shipping, storage, and handling of petroleum supplies are presented in paragraphs 3A1.02, 3A1.06, and 4A3.04, and should be carefully followed. (See also Ref. 65.)

When bolted steel tanks are used aboveground for fuel oil storage, a nonmetallic sheathing of some kind is required on the sunny side of the tank; otherwise, failure of tanks will occur from long daily exposure to the sun's heat on one side and coolness on the opposite side. The unequal expansion causes bolt joints to separate, resulting in leakage.

l. *Combustion Air.* Extremely cold air drawn into engines directly from the outside often causes difficult starting and misfiring under light loads. Air supply to power station diesel equipment should be preheated by heating coils or other methods, as described in par. 8 of 2B4.02.

2B4.02 STEAM POWERPLANTS

1. GENERAL. Except for the influence of climate and other factors peculiar to permafrost areas, the design of steam powerplants in the Cold Regions does not differ from the design of similar plants in the Temperate Zone. In selecting a site for such a facility, the factors and procedures discussed in Section 2A2 should be considered, as well as such special conditions as may be applicable.

2. ICE FOG. The most carefully designed steam powerplants aggravate, to some degree, the ice fog condition in their immediate vicinity. When practicable, steam plants should be located to leeward of important operating areas and, if they burn coal, should be provided with automatic combustion control and with high-efficiency mechanical-type precipitators. The operation of the plant should be planned so that only a minimum amount of steam and vapor is discharged to the atmosphere during extremely cold weather. If low areas exist close to the plant, boiler blowoffs should be piped to them.

3. ELECTRICAL GROUNDS. A suitable ground grid connected to permanent moisture is

necessary in the operation of powerplants, and this requirement should be considered in locating the plant. Grounding of all nonlive metal objects and parts in the station and switchyard is necessary to the safety of personnel. Also, certain neutral points of circuits on generators and transformers are grounded solidly or through impedance to limit voltage rise under conditions of fault and to assist relaying. Although effective grounding in permafrost areas is often difficult to accomplish (par. 2B4.08), the special requirements of powerplants for an ample supply of boiler feed and condenser cooling water will usually offer an obvious solution to the problem.

4. WATER SUPPLY. Steam powerplants require an ample year-around supply of boiler feed and condenser cooling water. If the plant can be located near a river, lake, or pond from which such a supply is available, the problem is comparatively simple. If such a supply does not exist, test drilling should be done in the near vicinity to determine the possibility of obtaining sufficient water from wells. Several plants of moderate size (4,000 to 10,000 kw) in the Fairbanks, Alaska, area obtain their total water requirements from California-type wells, which are 18 to 24 inches in diameter. Electrically driven vertical turbine pumps, housed in well-insulated structures, pump water to the powerplant. Year-around water temperature is between 34° and 40° F. Several wells, usually at least three, are provided. Any two of the three wells are capable of supplying the total requirements during normal operation; thus, each well is operated periodically to obtain a fluctuating drawdown to minimize sanding and to prevent freezing inside the casing and in the zone of depletion. Caution should be observed in locating the wells to assure that their ranges of drawdown are not sufficient to have a detrimental effect on the plant's foundations or seriously interfere with each other's supply. Operation of the well pumps should be controlled from the powerplant. Serious trouble from freezing or sanding can often be prevented if a visible signal is installed inside the plant to indicate when the pumps are in operation. Supply lines should drain back to the wells so that no water will remain in the pipe when the pump is shut down. Supply lines, if laid aboveground, should be provided with some protection in extreme weather, although the velocity will usually be so great that little will be required. After passing through the condensers, the water is usually sufficiently warm so that the discharge line will require no insulation. Condenser circulating water should, if possible, be discharged into a natural drainage channel, where its thawing action will do no damage and where icing can be controlled. Heat picked up in the condensers can sometimes be utilized. At a powerplant in the Fairbanks area, the water, after picking up heat from the condensers, is piped to the adjacent water treatment plant and circulated through coils to produce optimum temperatures for chlorination.

a. *Reuse of Condenser Circulating Water.* When the supply of water from natural sources is limited, it may be necessary to reuse the condenser water. This is usually a serious problem in permafrost areas and, therefore, requires intensive study. Of the several methods in general use in the Temperate Zone (Ref. 47, pp. 1184 and 1185), none is presently entirely satisfactory for use in cold climates.

Construction of cooling or spray ponds over permafrost should not be attempted unless the type of material is such that it will maintain its stability in a thawed condition or unless positive measures are taken to preserve the permafrost. (See Sections 2A5, 2A6, and 2A8.) Cooling ponds require large surface areas, and their efficiency is independent of their depth. Under average conditions and assuming full condensing operation, every 1,000 kw of turbine capacity will require 150,000 sq ft of pond area. This ratio can, perhaps, be reduced during the winter months when steam is being extracted for heating purposes, although at such periods the electrical demand is also near its peak and the steam required for the production of electrical energy may overbalance that required for heating. Under usual conditions of operation, a cooling pond large enough for winter use would probably be adequate for summer operation if cooling sprays were installed. Sprays are not practicable at low temperatures. Ponds must be designed for proper protection against undue freezing and icing during cold weather. (See par. 2A7.05.)

Cooling condenser water by towers of the mechanical-draft type is usually an efficient process, but experience has indicated that the operation of such equipment at low temperatures is not entirely satisfactory because of icing difficulties. Where cooling towers are employed, design criteria must include consideration of environmental disciplines that cause icing.

5. DISPERSAL OF FACILITIES. Central power and heating plants are attractive military targets and should be constructed for ready camouflage. Also, consideration should be given to dispersal of the generating and heating facilities to reduce the possibility of complete loss of capacity in case of attack or fire. This can be accomplished by construction of a standby plant capable of carrying minimum load requirements and located at some distance from the main plant, or by construction at well-separated locations of two or more smaller plants, all operating in conjunction with each other and with the total load divided between them. From an operating standpoint the first method would probably be the more economical, but if war were in progress or seemed imminent, the second method might be the more practical. Packaged-type steam boilers and power-generating equipment can be placed in operation in a comparatively short time after delivery and should be considered for other than permanent service. Such equipment could be used during the construction of the permanent facilities and be incorporated into the completed system as an auxiliary or standby. Mobile types, which can be mounted on flatcars or motor trailers, have many useful applications.

6. FUEL AND FUEL STORAGE. The problems involved in connection with fuel utilized by powerplants located in the Cold Regions are concerned primarily with quality, unloading, and storage. In Alaska, practically all steam plants burn coal, and many of them do so efficiently, despite the generally poor quality of coal available locally. Although coal of the type most generally used in Alaska has a high ash and a low Btu content (less than 9,000 Btu/lb), it burns well on chain grate and spreader-type stokers. Boilers are operated at pressures up to 675 psi, and the most modern plants use flue gas economizers and hydraulic ash-handling equipment. Oil of the grades ordinarily used for steaming fuel is not yet available in Alaska in sufficient quantities to compete with coal.

It is difficult to unload coal that has frozen en route from the mine or in the storage pile, and many operators store such cars for a day or so in thawing sheds before attempting to empty them. Sheds built over the track hopper may contain one or several cars and are equipped with steam coils arranged along the walls parallel to the cars. The usual practice in Alaska is to build up coal stockpiles during the summer. Although coal in storage will freeze in winter, experience has indicated that it can be handled quite well in its frozen state with power equipment, unless it contains a large proportion of fines and was excessively wet when frozen. Such coal should not be stored outside if it must be used during winter.

The possibility of coal fires caused by spontaneous combustion is an ever-present hazard, and every precaution should be observed to minimize oxidation within the coal pile and to dissipate any heat produced. (See Ref. 47, p. 764.) For a discussion of handling and storage of fuel oil, refer to par. 2k of 2B4.01.

7. WATER COMPOSITION. Water in many sections of the Cold Regions is particularly high in magnesium, silica, calcium, and other natural impurities that cause scale, corrosion, caustic embrittlement, and other ill effects on boiler surfaces. It is important, therefore, that central plants be equipped with water-testing devices and whatever equipment is required to treat the boiler feedwater properly. (See Ref. 47, pp. 1116 through 1120.)

8. LOCATION OF FAN INTAKES. The location of intakes for forced-draft fans in powerplants should be given special consideration in climates subject to extremely low winter temperatures. In many installations, such intakes are located within the building so that comparatively warm air can be used for combustion purposes. The relative humidity within powerplants is usually high, and as the cold outside air is pulled into the building to replace the considerable volume of air used for combustion, frost and ice form in progressive layers around the inside of door and window openings. Rapid movement of air inside the building lowers the effective temperature and causes discomfort to operators. A better method that has been used successfully is to provide louvers in the outside building walls, from which air is conducted through a bank of nonfreeze heating coils into the duct leading to the fan intake. These coils can be designed to deliver air of uniform temperature regardless of outside air temperatures.

9. LOCATION OF HEAVY EQUIPMENT. In designing powerplants to be constructed over taliks, the location of heavy equipment such as boilers, turbogenerators, and auxiliaries is an important consideration. If improperly distributed, the weight of such equipment plus their live loads

can cause conditions favorable to differential settlement (par. 1d of 2A6.02).

10. RETENTION OF PERMAFROST. Basements of steam powerplants frequently contain surface condensers, hot pits, and other equipment that radiate a considerable amount of heat. When the passive method is used in construction over permafrost, a careful study is required in the development of floor designs for such basements to assure retention of the permafrost. (See Section 2A8.)

11. PRACTICAL CONSIDERATIONS. Construction of a steam powerplant of the size ordinarily required for a permanent establishment usually requires a period of several years for planning and construction. As previously mentioned (par. 5 of 2B4.02), temporary plants for generating power and steam for heating can be provided on short notice if packaged-type units are used and if boiler feedwater is available.

Permanent plants should be structurally and mechanically as simple and foolproof as possible. They must possess a degree of mechanical efficiency consistent with the purpose for which the plant is designed. In remote areas, the extremely high pressures common to modern plants in the Temperate Zone should be avoided because of the difficulty of obtaining qualified operating and service personnel. Standardization of equipment and parts permits interchange of equipment and personnel and reduces the spare parts required. Provision for comparatively rapid increase in capacity should be allowed for in the design. At most establishments in the Cold Regions, there is a heavy demand for electrical energy and steam for heating during winter and an unusually small demand during the long, warm days of summer. Provision should be made to handle plant auxiliary requirements and the reduced summer demand without operating large generating units at reduced capacity.

Steam plants in the Cold Regions generally serve the dual purpose of supplying electrical energy and steam for space heating. For such plants, extraction turbines are commonly used because of the high thermal efficiency usually obtained. With this type of equipment, partly expanded steam is extracted at one or more points at whatever pressure is desired in the heating system. Steam not required for heating or for other purposes passes to the surface condenser and is pumped back to the boilers as feedwater. Power is produced at high efficiency in plants equipped with extraction turbines because the only heat required in such a plant, aside from that required for heating purposes, is the heat equivalent of the power generated by the steam before extraction. If more heating steam is required than is available by extraction, it can be obtained at the required pressure by passing high-pressure steam from the boilers through a reducing valve. This is not, however, an economical procedure.

Backpressure turbines, in which the turbine exhausts directly into the heating system, have a high efficiency if all or most of the condensate is returned to the system. They are not practical for year-around use in areas that require no heating or process steam for several months of the year. (See also par. 2B3.06.)

2B4.03 HYDROELECTRIC POWERPLANT

1. SELECTION OF SITE.

a. *Available Power and Energy.* A thorough analysis of water supply, head, and storage conditions is necessary to determine the power and energy that a proposed hydroelectric development can provide during dry, wet, and average years. Appraisal of water supply is a problem that requires much study, particularly when adequate information on rainfall, runoff, streamflow, and other hydrological conditions is not available. In many sections of the Cold Regions there is a great lack of such information, and the situation is further complicated by peculiarities of runoff.

The head that can be developed, the amount and type of storage that can be provided, and the amount of installed capacity that can be justified are controlled usually by economic as well as physical limitations. (See Ref. 66, Section 13, pp. 14 through 34.) The extent to which such limitations are influenced by the disciplines of the area must be considered in determining the overall feasibility of a development at the proposed site.

b. *Physical Characteristics of the Site.* Each site should be considered for its practical advantages in construction, including those factors particularly applicable to the selection of building sites in the Cold Regions. (See Section 2A2.) Soil conditions, geology, and topography of the entire reservoir area should be carefully investigated to discover possible future sources of leakage to adjoining watersheds or around the dam to the stream below. Storage of water over permafrost or diversion of the stream during construction may result in detrimental disturbances in the thermal regime of the subsurface, which may increase the possibility of water leakage. (See Sections 2A5, 2A6, and 2A8.)

2. ICE PREVENTION. If adequate provision is made in the design, hydroelectric plants, except in extreme cases, can be kept operative during winter. Definite provision must be made for combating ice, and frequently this involves considerable expense and waste of water. Although conditions encountered in the Cold Regions are often more severe and of longer duration than those encountered in other cold climates, the problems imposed by ice and the methods of combating them are the same. (See Ref. 66, Section 13, pp. 32 and 33, which describe the methods of protecting facilities against sheet ice and frazil ice.)

3. SEDIMENT DISCHARGE AND GLACIAL DEBRIS. The problem of the sediment discharge of streams assumes major proportions in connection with streams draining glaciers. The channels of these streams are usually full of glacial debris, and construction of dams and reservoirs is complicated by dam foundation problems and possible early filling of reservoirs by sediment. The rock flour remaining in suspension, even after long periods of storage, as in lakes, may cause rapid wearing of waterwheels and turbines. To obtain appropriate basic facts for the study of these problems, the Corps of Engineers is collecting information on sediment discharge at a number of locations. (Ref. 67.)

2B4.04 POWER TRANSMISSION AND DISTRIBUTION

1. GENERAL. The basic factors that influence design of transmission lines and distribution circuits in temperate climates are applicable also to the design of such facilities in the Cold Regions. Electrical systems in these regions are usually not subjected to the frequency of violent electrical disturbances and usually benefit by the close proximity of the generating facilities to the load centers. They are subjected, however, to the disciplines of the area, which require that special consideration be given to the large variation between summer and winter demands, great differences in temperature, problems involved in the construction and operation of overhead and underground facilities in permafrost, and the difficulties frequently incurred in obtaining adequate electrical grounds. (See Ref. 66, Section 14, pp. 3 through 17.)

2. LINE LOSSES. Calculations of A-C voltage and power losses on many transmission and distribution lines designed for the Cold Regions can be accomplished with sufficiently accurate results by using approximate methods. For short-, low-, and medium-voltage distribution lines, the charging current can be neglected entirely, and the simple impedance method will give sufficiently accurate results. For all but the highest tension transmission lines, the charging current is taken into account by using the relatively simple end-condenser method. (See Ref. 66, Section 14, pp. 18 through 29 and p. 35.)

3. CORONA. Losses from corona effect on high-tension transmission lines in the Cold Regions may be estimated in the same manner as for such lines in the Temperate Zone. A line should not be operated at voltages higher than the disruptive critical voltage for the average barometer at summer temperatures. In winter, the critical voltage is higher because of lower temperatures and generally higher barometer. Power losses from corona effect, therefore, will generally be less in winter than in summer. The altitude at which the line is to be built should be considered because disruptive critical voltages vary directly with barometric pressures. Therefore, such voltages calculated for a general location should be multiplied by a corrective factor equal to the ratio of the barometric pressure at the given altitude to barometric pressure at sea level. (See Ref. 66, Section 14, Table 5, p. 32 and pp. 29 through 33.)

4. BASIC FACTORS IN MECHANICAL DESIGN. (See Ref. 66, Section 14, pp. 49 through 84.)

a. *Selection of Route.* Most of the usual factors influencing the location of transmission and distribution lines in urban areas in the Temperate Zone are applicable to the Cold Regions. Few restrictions for rural construction exist in permafrost areas other than those imposed by the disciplines of the region and topography, vegetation, and foundation conditions. The last is frequently the most important. Easements and right-of-way agreements may be necessary in certain regions of the Subarctic but generally will not be required in more isolated areas. Forests are practically nonexistent in the Polar Regions, and where they exist in the Subpolar Regions, the lines can usually be routed to avoid them.

b. *Ground Wires.* Lightning is infrequent in most parts of the Cold Regions, and overhead lines are generally not equipped with ground wires. Also, in permafrost areas proper grounding is often not readily accomplished because of the difficulty of contacting ground equipment with permanent earth moisture (par. 1 of 2B4.08).

c. *Clearances.* Because of the higher cost of properly preparing and maintaining foundations for pole-line structures in permafrost areas, spans longer than those ordinarily used may be justified. However, the greater sag resulting from a longer span and the relatively large sag necessitated by extreme temperature ranges common to the Cold Regions require careful consideration of the clearance that will be obtained in warm weather, as well as the tension to be expected during the worst conditions of wind, ice, and low temperatures. Longer spans and difficult transportation problems in isolated areas will warrant the consideration of conductors other than copper, such as aluminum, steel-core aluminum, and copper-weld. Both aluminum and steel-core aluminum are lighter than equivalent copper conductors, and sag values of aluminum compare favorably with those of copper. Both sag values and ultimate strength of steel-core aluminum cables are better than those of either aluminum or copper. Copper-weld has the highest ultimate strength and the best sag values of any, but it is also heavier than any of the others. For very long spans, copper-weld conductors should be considered.

d. *Calculation of Sag and Tension.* Data on the behavior of transmission line materials under extremely low-temperature service conditions are not as readily available as are such data for other types of service loadings, but once the service temperatures of the line have been determined, sag and tension values may be computed as required.

The true shape of the line between supports is a catenary, but because catenary equations are difficult to deal with, calculations are generally made by parabolic formulas, which are comparatively easy to handle using the fundamental relationships of stress and strain for the conductor material selected. The following example illustrates the method of solution, which is best done graphically (Figure 2B4-2). Curve CD shows the tension-sag relationship for the conductor. The maximum tension in the conductor will occur at the minimum design temperature and should be taken as 50 percent of the ultimate strength. In order that this tension will not be exceeded, all tension-sag relationships must be based on the length of the conductor at this temperature. For any temperature, the length of the conductor, and therefore the sag, will be proportional to the tension. This curve for 110° F is represented by curve EF. The intersection of curves CD and EF gives the value of sag and tension for 110° F. Values for the curves in Figure 2B4-2 were obtained from calculations similar to that given in the following example.

Example

Find the tension and sag at 110° F for Conductor No. 1. (See Table 2B4-1.) Span is 1,000 ft; minimum design temperature is −95° F.

E = Young's modulus, lb/sq in.
A = area of conductor, sq in.
c = temperature coefficient
t = temperature, °F
S = span, ft
W = weight of conductor, lb/ft
T = tension, lb
L = length of conductor, ft
d = sag, ft

(1) For curve CD,

$$d = \frac{S^2W}{8T} = \frac{(1{,}000)^2 \times 0.322}{8 \times 2{,}300} = 17.5 \text{ ft}$$

(2) Length at −95° F, 2,300-lb tension

$$L = S + \frac{8d^2}{3S} = 1{,}000 + \frac{8(17.5)^2}{3{,}000} = 1{,}000.818 \text{ ft}$$

(3) Length at −95° F, 0-lb tension

$$L = 1{,}000.818 \text{ ft} - \frac{TL}{EA}$$
$$= 1{,}000.818 - \frac{2{,}300 \times 1{,}000.818}{16 \times 10^6 \times 0.0829}$$
$$= 999.084 \text{ ft}$$

(4) Length at 110° F, 0-lb tension

$$L = 999.084 + cL\,(t - t_2) = 1{,}001.054 \text{ ft}$$

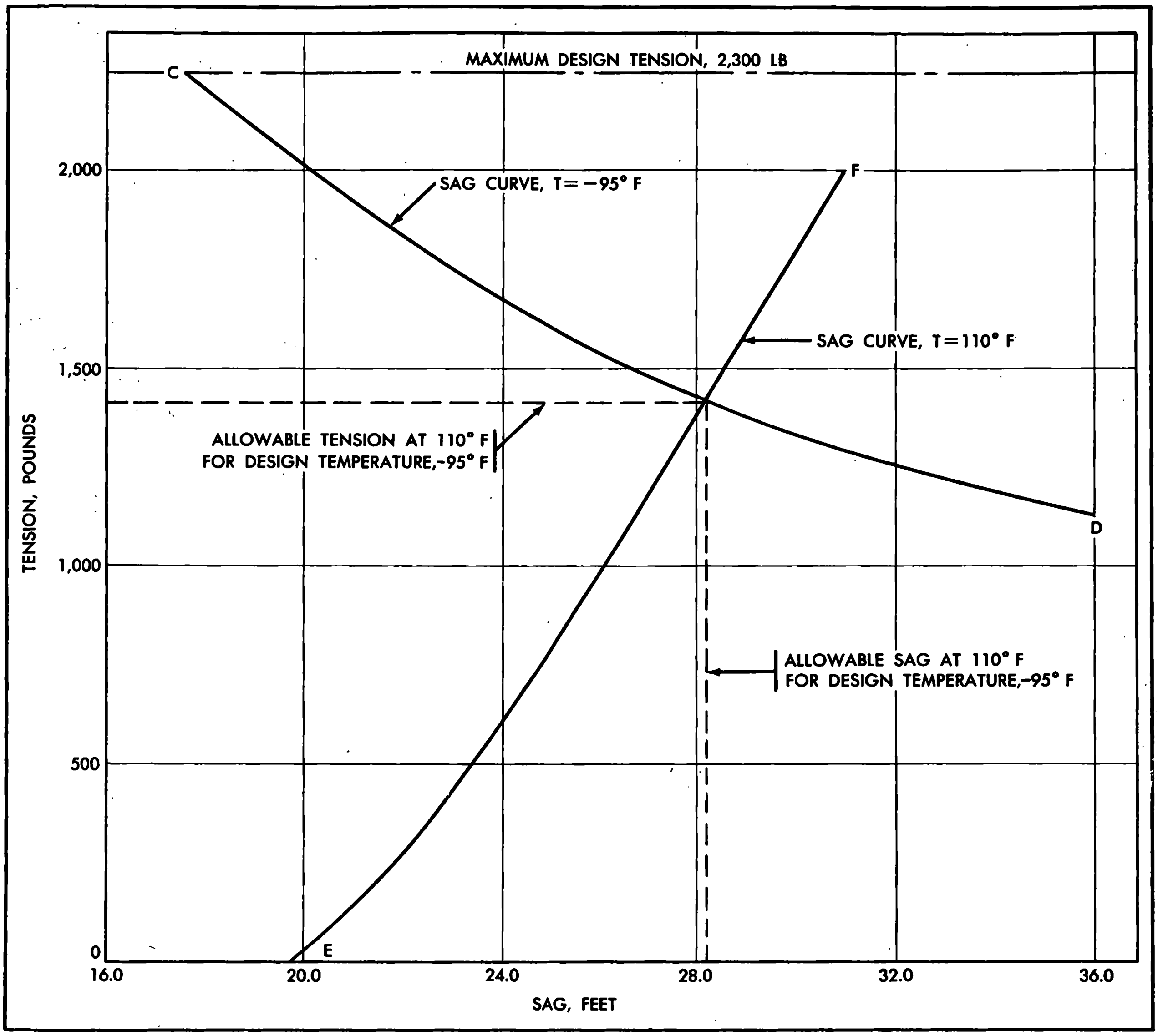


FIGURE 2B4-2

Sag-Tension Curves, 1,000-Foot Span, No. 0 Heavy-Duty Stranded Copper Wire

(5) Sag at 110° F, 0-lb tension

$$d = \frac{(3)\ (S)\ (L - S)^{1/2}}{8}$$

$$= \frac{3}{8} \times 1{,}000 \times (1{,}001.054 - 1{,}000)^{1/2}$$

$$= 19.6 \text{ ft}$$

By the foregoing method, sag-span and tension-span data for various temperatures can be built up. (See Figure 2B4-3.) In some cases of transmission line construction, clearance requirements may control the design. Figure 2B4-4 shows the sag-span curves for the four conductors whose properties are shown in Table 2B4-1. It will be noted that the sag for the equivalent steel-core cable is much less than for the equivalent aluminum or copper conductor under the same service temperatures. Copper-weld, although it has a slightly higher sag at the minimum temperature, has the lowest sag of all at temperatures near 100° F because of its low coefficient of expansion. On long spans where clearance is of major importance, copper-weld conductors should be considered.

It will be noted that in the foregoing Example

TABLE 2B4-1

Tension and Sag for Transmission Line Materials

Properties	Transmission-line materials			
	No. 1	No. 2	No. 3	No. 4
Maximum tension, lb[1]	2,300	1,600	3,300	5,500
EA, lb.	1.326×10^6	2.11×10^6	2.07×10^6	2.74×10^6
Area, sq in.	0.0829	0.132	0.197	0.1184
E (Young's mod), lb/sq in.	16.0×10^6	16.0×10^6	12.0×10^6	20.0×10^6
c, per °F	9.6×10^{-6}	12.8×10^{-6}	10.5×10^{-6}	7.2×10^{-6}
Weight, lb/ft	0.322	0.194	0.232	0.444
Copper equivalent	...	No. 0(AWG)	No. 0(AWG)	No. 0(AWG)

No. 1. No. 0 (AWG) HD stranded copper wire
No. 2. HD aluminum wire
No. 3. HD steel-core aluminum wire
No. 4. Copper-weld, type J
[1]Maximum tension is maximum tension design, = 50 percent of ultimate breaking strength.

the critical stress is assumed as that caused by temperature only. At extremely low temperatures, icing conditions are nonexistent, and wind velocity at such temperatures would rarely, if ever, be sufficient to create stresses equivalent to those incurred at temperatures of −95° F.

5. OVERHEAD STRUCTURES. (Ref. 66, Section 14, pp. 85 through 112.)

a. *Types.* The most common pole-line structure in the Cold Regions is the wood pole, although steel poles of the tubular or square-latticed type are occasionally used to support distribution lines or low- or medium-voltage transmission lines. The use of rigid steel towers on transmission lines may be justified in certain cases. However, the foundation problems involved in the construction of these towers in permafrost areas, as well as other factors, preclude their general use. Steel structures of any type, whether pole or tower, should not be considered on primary lines where good grounding is impossible because of possible creation of dangerous potential gradients at or near their bases during periods of power arcing.

b. *Local Timber.* Local timber may be used for line structures if it is available in the vicinity. Newly cut poles must be well seasoned before they can be properly treated with a preservative. This requirement, together with the difficulty of obtaining proper preservative treatment in the Cold Regions, makes their use advisable only on temporary lines. Imported poles are generally preferred, and their selection as to kind and quality should be based on the expected permanency of the line. Because of the expense of transporting these poles to isolated areas, inspection before shipment should be thorough and specifications enforced. Full-length preservative treatment is generally unnecessary because decay processes in the aboveground portions of the pole will be relatively slow in the semiarid areas common to the Cold Regions.

c. *Tripods.* Low-voltage distribution lines constructed on pole tripods have given satisfactory service in many applications. These structures consist of three comparatively small poles so lashed together at their tops as to allow for slight movement. It is advisable to weight the tripod with a rock or other weights suspended from the center of the structure or from each of its legs to help prevent overturning (Figure 2B4-5). Pole-line tripods are usually set on the tundra in cold weather when the surface is frozen. Their use should be limited to lines of low voltage.

d. *Design Factors.* Although high winds are infrequent in many sections of the Cold Regions, there are areas subject to winds of terrific velocities. Proper separation of line conductors, particularly on long spans of three-phase lines, may make advisable the use of H-frame sections rather than individual poles. In designing line structures (pole or tower) for locations in taliks, conventional methods may be used. However, in areas where permafrost is present, especially if the permafrost supports the pole or makes or nearly makes contact with the material immediately supporting the pole, additional factors other than those usually evaluated in the design of distribution and transmission lines should be given consideration. (See par. 2A6.05.)

e. *Crossarms and Hardware.* Conventional crossarms and pole hardware are used on pole lines just as in the Temperate Zone and are almost always imported.

6. INSULATORS FOR OVERHEAD LINES. (See Ref. 66, Section 14, pp. 112 through 121.) All the common types of standoff and strain insulators designed for pole-line construction are satisfactory in their proper applications in the Cold Regions. The materials ordinarily used in such service are glass and its compositions, pyrex, porcelain, and, to some extent, commercial plastics. All have excellent electrical and weathering properties and maintain good dimensional stability.

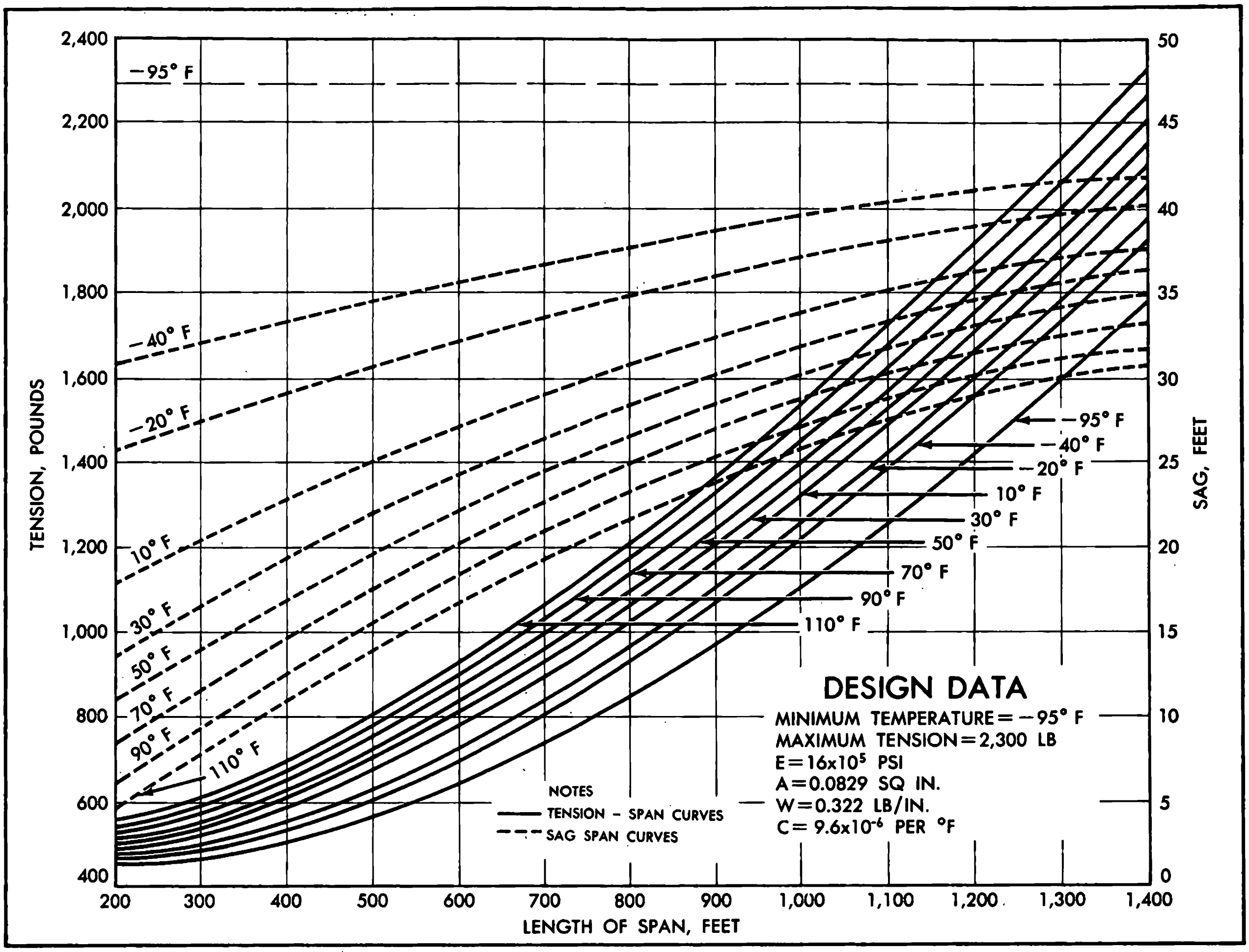


FIGURE 2B4-3

Sag-Span and Tension-Span Curves for No. 0 Heavy-Duty Stranded Copper Wire

a. *Materials.* The strength of certain compositions of glass is not significantly affected by temperature ranges from −95° to 100° F unless the temperature variation is nonuniform, with resulting thermally induced stresses. Porcelain, also, is not ordinarily affected by extremely low temperatures, but, as in the case of glass, a sudden change of temperature may cause the frozen material to shatter. Polystyrene, a thermoplastic, maintains stability at extremely low temperatures (below −50° F) (Ref. 52) and has wide use in certain electrical fields. If available, low-temperature plastics should be used instead of glass or porcelain. (Ref. 52.)

7. BARE WIRES AND CABLES. (See Ref. 66, Section 14, pp. 154 through 185 and par. 4 of 2B4.04.)

8. INSULATED WIRES AND CABLES. Particular care must be used in the selection of insulated wire because many of the common types of insulation will check and crack in extremely cold weather, a condition aggravated by bending and kinking during installation and by change in temperature. (See Ref. 66, Section 14, pp. 154 through 185 and par. 4 of 2B4.04.)

a. *Rubber and Rubberlike Materials.* Insulation made of new natural rubber is usable at temperatures approaching −50° F (Ref. 52), but in this range it loses its elasticity and becomes rigid and brittle. In this state it will not stand repeated bending and flexing without cracking and possibly shattering. For this reason it should not be installed during extremely cold weather. Experience has shown that if this insulation is installed at

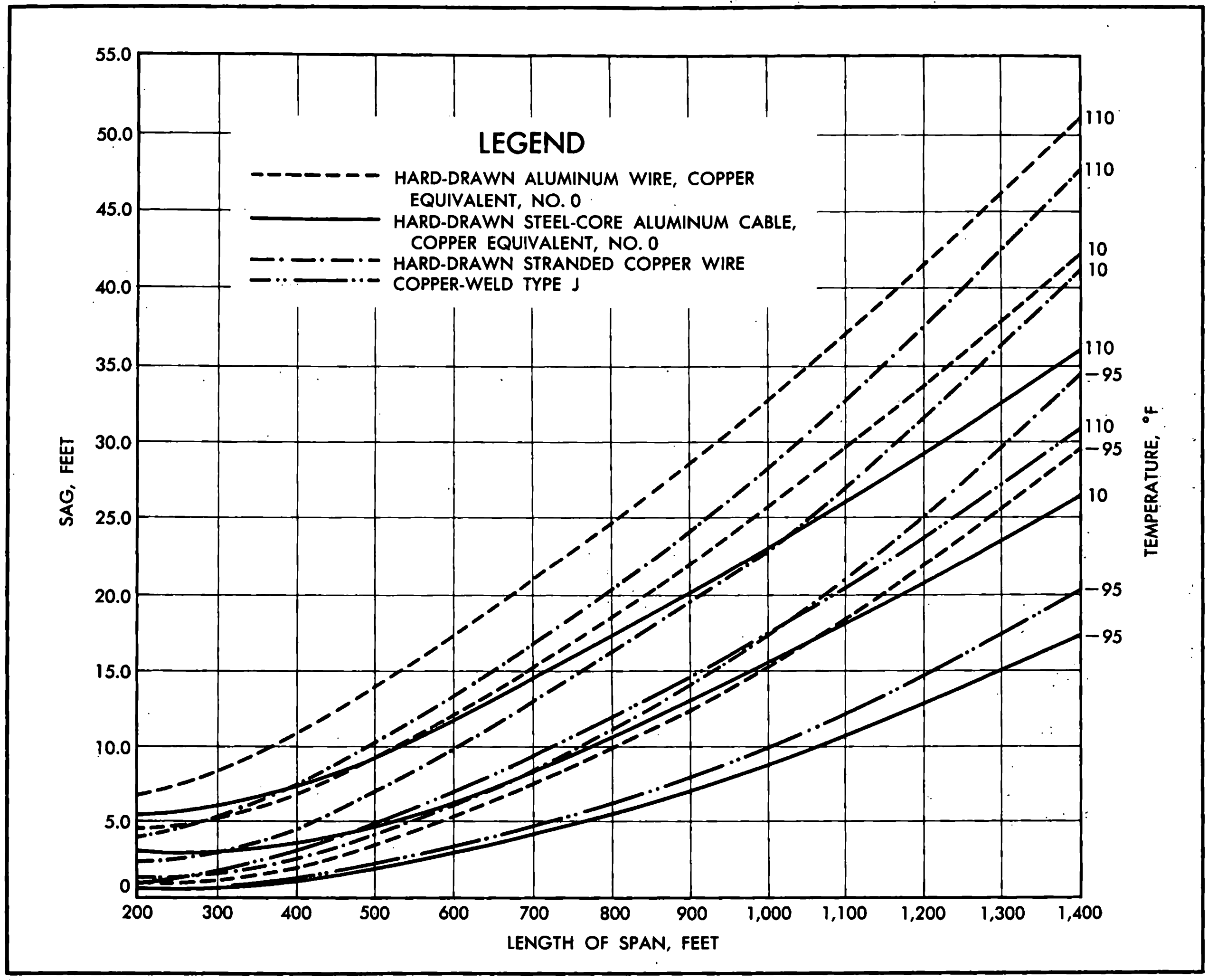


FIGURE 2B4-4

Sag-Span Curves for Four Conductor Materials

higher temperatures and is not moved when cold, the cold does not hurt its insulating qualities. Old rubber will lose its elasticity at much higher temperatures, and insulation made of this material is generally not reliable below −10° F. The material also does not show permanent injury if it is not flexed in extremely cold weather. A special rubberlike material made of natural rubber and butyl, a comparatively new and important synthetic elastomer, has been developed for use in temperatures as low as −70° F. (Ref. 52.) Neoprene has not been satisfactory at temperatures below −20° F because it loses flexibility and resiliency. Manufacturers indicate, however, that they have been able to make compositions of this material that are practical in the range of −50° to −60° F. (Ref. 52.) Careful consideration should be given to its characteristics if it is to be used. (Ref. 52.)

b. *Thermoplastics.* Thermoplastics have not been recommended for use at temperatures below −14° F because experience with some types has been unsuccessful in that range. Several materials of this group, however, have noteworthy properties and are worth consideration for use on electric power cables. (Ref. 47.)

Polyethylene is tough and durable, and its toughness is not affected by low temperatures. It stiffens slightly at −30° F, but does not become brittle until exposed to temperatures as low as −94° F.

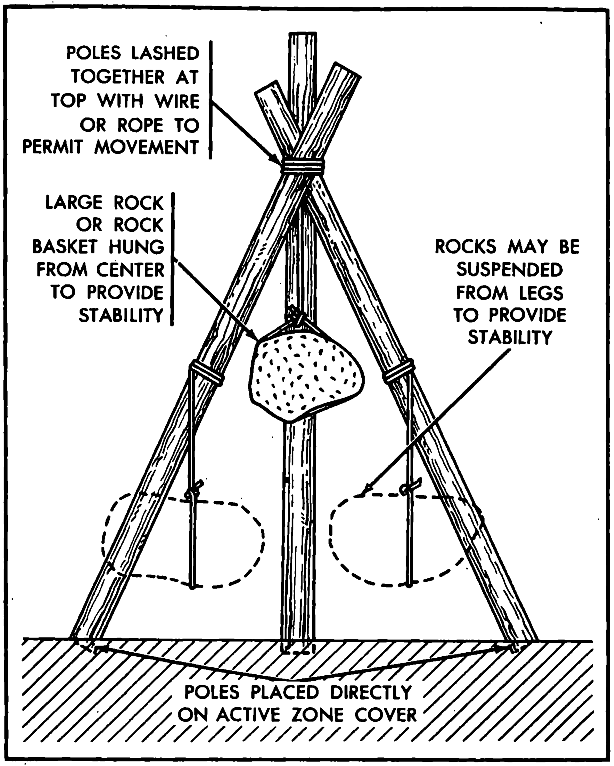


FIGURE 2B4-5

Powerline Tripod

(Ref. 52.) It has excellent electrical properties and extremely low vapor transfer qualities.

Polyvinyl chloride compositions are noteworthy for their heat resistance, exceptional toughness, and ability to withstand continued exposure to maximum temperature differences. Some have low-temperature brittleness approaching −40° and −50° F when subjected to bending. If this material were subjected to sudden shock, however, it would fail at higher temperatures, possibly approaching −30° F. Polytetrafluoroethylene has potential utility because of its excellent thermal stability, resistance to corrosive reagents, and low dielectric loss. It is not embrittled by extremely low temperatures. Films can be flexed at temperatures as low as −148° F without breaking. Its resistance to outdoor weathering is excellent. (Ref. 52.)

9. AERIAL CABLE AND CONDUCTOR INSTALLATION. Aerial cables are occasionally used in the Cold Regions when adequate clearances from other structures or isolation from contact by the public can not be obtained by open-wire construction. Because of their higher cost and the exacting insulation requirements necessitated by the disciplines of the area, their general use can not be justified as can low-voltage cables used in connection with communication. The greater weakness of high-voltage cables is the inability of their insulation at extremely low temperatures to withstand the almost constant flexing to which such cables are subjected by variable wind pressures and changes in temperature.

The installation of aerial cables and single conductors is accomplished in the usual manner by sagging to the predetermined amount calculated for the temperature prevailing at the time of stringing. Dynamometers should be used to measure the tension in messenger cable or conductor for approximate sagging, but surveying instruments should always be used in the final determination. Wind loads at the time of stringing should be taken into account if wind velocities are sufficient to affect the tension by even a slight degree. (See Ref. 66, Section 14, pp. 121 through 125 and par. 4d of 2B4.04.)

10. UNDERGROUND DUCTS. Power cables are placed underground in permafrost areas to a much lesser extent than in the Temperate Zone. Not only are underground structures in permafrost more difficult to construct and maintain (Section 2B2), but the usual reasons for placing cables underground often are not sufficient to justify the additional expense. Unsightliness is not an important factor. Also, the chances of injury to the public and damage to the line by external agencies are reduced because of lack of congested areas, violent electrical storms, and icing conditions. At large bases where service facilities such as steam, water, and sewer lines are placed in utilidors, electric power cables may also be placed, if necessary, in the structures. Further, it is often necessary to place cables underground at crossings, such as highways, railroad tracks, and airstrips, to avoid interference with traffic. (See Ref. 66, Section 14, pp. 128 through 143.)

Effective electrical insulation of cables installed in utilidors is, of course, mandatory. Ref. 66, Section 14, pp. 185 through 240, contains recommendations on the proper insulation and other protection for electric cables of various system voltages when placed in underground conduits and other locations. Wherever possible, however, electric power distribution lines in the Cold Regions should be placed aboveground. This is especially true for advanced bases.

The inability of cable installations to withstand repeated flexing is not an important consideration in underground cables because flexibility is required only at the time of installation.

Underground ducts, constructed solely for power cables, must be designed to accommodate frost heave if it is necessary to use them in areas where heave may occur. Piping made of galvanized steel or of asbestos cement heavy enough to be placed without a concrete envelope is preferred, although ducts of fiber, wood, and concrete are sometimes used. Fiber ducts are comparatively light and should be enclosed in an envelope of concrete. Lead-covered cables should not be installed in concrete ducts until at least six weeks after the concrete has been poured because of the corrosive effect of certain types of cement on lead. Manholes, service boxes, and other underground structures that are required in connection with the system should be designed with full recognition of the factors affecting these structures in permafrost areas.

2B4.05 TRANSFORMERS

The demand for electrical energy during summer in the Cold Regions is usually small compared to winter demand. Sufficient flexibility should therefore be incorporated into the design to assure that transformer losses during low-demand periods are kept to a minimum. Large transformers, designed for peak demand, should not be allowed to remain energized when only a fraction of their capacity is being utilized. (See Ref. 66, Section 10, pp. 2 through 73.)

1. SINGLE-PHASE TRANSFORMERS. Single-phase transformers, although costing more and weighing more per bank than a three-phase unit of equal rating, are more widely used than three-phase transformers because of the importance of flexibility and dependability of the electric system at advanced bases. Installation of numerous types of motors and other equipment of varying electrical characteristics is often required, and it is important that sufficient energy of the proper phase and voltage be available at all times. Frequently, emergency changes or temporary use of equipment will require corresponding voltage and phase changes in the supply lines; this is especially true on a construction project where contractors frequently import construction equipment with electrical characteristics other than those of the energy that is normally supplied. Under such conditions, spare transformers of various voltages, capacities, and types are excellent assurance against delays. Under such conditions also, single-phase transformers are especially valuable because of the convenience of interchangeability, with one single-phase transformer acting as a spare for several banks of three similar transformers. Also, when using single-phase transformers, any one of a three-phase bank can be cut out of service and the other two continue operation in open delta, giving about 56 percent of the bank capacity.

2. THREE-PHASE TRANSFORMERS. Three-phase transformers, however, have many useful applications, particularly in capacities of 500 kva or over, where their shortcomings with respect to flexibility may be outweighed by savings in initial cost, weight, space, and oil requirements. Recently it has become quite common practice to use two three-phase transformers, each one-half the size of the total bank capacity desired, with proper switches on both the primary and secondary side of each transformer. Thus, in case of trouble in one transformer, the switches on each side of it are opened and the bank put back into operation at 50 percent capacity in much less time than is required to cut out a single-phase transformer for open-delta operation. This scheme can also be used where there is a two-to-one ratio between winter and summer load, in order to keep losses at a minimum during light load periods.

3. DRY-TYPE TRANSFORMERS. Dry-type transformers can safely be used indoors because, if properly designed, they contain no oil or other flammable materials. They are lighter and smaller than liquid-filled transformers of equal rating but do not have as high an impulse strength. Their cost is about the same as nonflammable, liquid-filled transformers.

4. PRECAUTIONS AGAINST FIRE. Sections of the National Electric Code governing the location of transformers are not in all respects sufficiently rigid for the Cold Regions. Fires are very difficult to handle during extremely cold weather, and it is during such periods that transformer overloads sufficiently heavy and prolonged to ignite the cooling oil are most likely to occur. Oil-filled transformers should be installed only outside or in separate fireproof enclosures away from other

buildings. Transformers should be installed on a concrete pad only when placed in an enclosure and should have a curb high enough to contain all oil in all transformers.

5. PRECAUTIONS AGAINST GAS. Transformers containing nonflammable liquid have the same high impulse level as oil-filled transformers and can be used safely indoors. The gas given off, however, in case of an arc under the liquid, is disagreeable, though not dangerous, and the room in which the transformers are installed should be well ventilated and located away from other buildings.

2B4.06 SWITCHGEAR, CONTROL, AND PROTECTIVE EQUIPMENT

(See Ref. 66, Section 12, pp. 2 through 82.)

1. GROUNDING. Conventional control apparatus for electrical systems is satisfactory for use in the Cold Regions, but the difficulty of obtaining satisfactory grounding in permafrost areas often poses serious problems in connection with the operation of protective devices. Grounding is an important feature of switching, substation, and distribution system design. In most cases the maintenance of service continuity and the safeguarding of personnel depend on grounding effectiveness, and every means should be employed to obtain it. (See par. 2B4.08.)

2. DAMAGE BY BLOWING SNOW. Much trouble has been encountered from dry, finely powdered snow sifting into electrical equipment. Snow melting on vital components may cause short circuits and corrosion, and sufficient moisture, if it subsequently freezes, may cause other failures. Exposed equipment susceptible to damage by snow should be covered with canvas or moved to a less exposed location.

3. FUSING. In fusing, consideration must be given during winter to low ambient temperatures around control equipment.

4. PROTECTION OF RURAL LINES. Patrol of rural lines under extreme temperature conditions is difficult; therefore, devices that will clear momentary shorts or overloads without manual attention should be incorporated in these lines. Repeater fuses are valuable in this respect; their slow-burning characteristics, which often make possible the clearing of transitory faults before the fuse has had time to blow, are advantageous. The protection of isolated branch lines can be accomplished by oil-circuit reclosers that take care of momentary overloads before the fuses on the feeder line react to the overload. (Ref. 68.)

2B4.07 SYSTEM STABILITY AND REGULATION

Most power systems in the Cold Regions are characterized by stable operating conditions. The ultimate capacity requirements are generally predictable, and an emergency load suddenly applied or other transient-state condition is rare. The average composite load is generally beneficial to system performance, although regulation is often better in winter than in summer because of the preponderance in winter of heating and lighting loads. (See Ref. 66, Section 3, pp. 60 through 83.)

2B4.08 GROUNDING OF ELECTRIC CIRCUITS

(See Ref. 66, Section 14, pp. 290 through 298.)

1. GENERAL. Effective grounding of electric circuits and equipment in permafrost areas is not easily accomplished because of the extremely high resistivity of frozen soil and the consequent difficulty of making good contact with permanent earth moisture. Often the only solution is to extend ground buses to areas in which good grounding is possible, such as nearby streams or other bodies of water or to driven wells. The amount of expenditure justified in specific cases will depend on the purpose for which the grounding is to be used, as well as the ground resistance required. Soil of high resistivity, for example, can be utilized in the grounding of overhead transmission lines if expulsion gaps are used at each line structure in conjunction with low-cost pole, butt-wrapped grounds. However, grounding of overhead transmission lines in the Cold Regions is seldom necessary.

The possibility of obtaining satisfactory grounding conditions should be an important consideration in the selection of sites for switching stations, substations, and generating plants, all of which require an effective grounding for their successful operation. For such facilities some choice of site is usually possible, and the least desirable locations from a construction standpoint are often areas in which soil resistivity is unusually high. In such facilities, maximum effectiveness and least expense will be realized by the interconnection of all grounds to a common all-purpose ground bus.

2. MULTIGROUNDING. The grounding effi-

ciency on distribution lines is increased by multi-grounding and by using a common primary and secondary neutral in conjunction with common grounding facilities. In high resistance areas the pooling of ground facilities by interconnection of individual grounds at services, transformers, and other equipment to distribution circuit neutrals is an important aid to grounding system effectiveness and protection of equipment and personnel. In urban areas, multigrounded networks usually involve a large number of grounds, many of which can be made effective by connection to water-piping systems. In isolated districts, these means may not be available, and low-resistance grounds must be obtained by other methods, which may involve drilling wells to permanent moisture or extension of ground buses to satisfactory grounding beds.

3. TRANSFORMER VAULTS AND SUBSTATIONS. All equipment at transformer vaults and substations should be thoroughly grounded to a common ground bus.

4. GROUNDING AT POINTS OF UTILIZATION. Considerable expense for the procurement of satisfactory grounding at the point of utilization is sometimes not justified. In such cases, equipment and exposed metallic parts of the wiring system should be protected by insulation to assure the safety of personnel.

5. GROUNDING OF CABLES. Many power transmission and distribution applications involve the use of insulated cables that may be laid in buildings, in underground conduits, on pole lines, on the surface of the ground or in the ground, or under water. The outer coverings of these cables usually consist of tapes, braids, rubber jackets, or lead sheaths. Grounding is required for lead sheaths and static shielding tapes to control voltage gradients along the line and to protect personnel. On long single-conductor lines, sheaths should be sectionalized by insulating sleeves, and each section should be grounded at one point only. In general, standard shielding practice should be followed (Ref. 66, Section 14, pp. 201 through 203, and Section 13, p. 50), except that in particularly high-resistance areas it may be advisable to shield below the voltage limits recommended. Bare ground wires are often laid alongside cables carrying over 2 kv when installations are made in soil of alternately high and low resistivity. Experience at Kodiak, Alaska, has shown that bare copper ground wires, installed in some ducts with lead-sheathed cables under wet conditions, will cause corrosion and subsequent failure of lead sheaths.

6. EFFECT OF DEEP SNOW ON RESISTIVITY. It is believed that a deep snow cover affects resistivity only to the extent that it may change the state of matrix in the permanently frozen materials.

2B4.09 WIRING OF BUILDINGS

(See Ref. 66, Section 14, pp. 241 through 289.)

1. GENERAL. General requirements pertaining to wiring systems in the Temperate Zone are applicable to installations in the Cold Regions. Although many areas in which installations will be made are not subject to municipal or other regulation, practical consideration of fire hazard, accident prevention, and dependability make advisable practices more rigid than those required by any regulating agency or the National Electric Code.

2. WIRING SYSTEMS. At very small establishments equipped with isolated generating plants (either direct current or single-phase alternating current), 2-wire systems will usually be adequate. On combined lighting and power circuits where the motor load is small (5 kw or less), the system may be a DC or single-phase AC 3-wire system capable of delivering energy either at 115 or 230 v. At larger establishments, 3-phase 3-wire systems are most common because they are the most efficient for power distribution and for mixed power and lighting loads. However, where the lighting load predominates, 3-phase 4-wire systems should be used. General Navy practice calls for all wiring to larger establishments to be 120/208-v 4-wire 3-phase systems, 120-v for lighting systems and 208-v for 3-phase.

3. CIRCUIT CAPACITY. For wiring systems, it is often difficult in the Cold Regions to determine the design criteria that will result in the most efficient and satisfactory layouts. Minimum requirements of the National Electric Code are seldom adequate. Lighting and small appliance loads can be anticipated fairly accurately, but demands from heavy appliances, such as oil burners, pumps, water heaters, and so on are often greater than anticipated, and generous estimates should be made in determining the branch circuits and feeder capacities.

4. TYPICAL LOADS. In the Cold Regions, there is generally wide seasonal difference in electrical demands. Because of the long hours of sunlight or twilight during summer, the lighting load is almost negligible, the only artificial light required indoors being in areas to which no natural light is supplied. The energy demand at this period comes from appliances and from motor-driven equipment such as pumps, air compressors, and machine tools. The load is very small from 7 p.m. to 7 a.m. In winter, lighting and heating loads usually predominate and are fairly constant during all hours of the day and night. Although the high cost of energy, in most cases, makes electric central heating systems impractical, household heating and cooking appliances, motor-driven oil burners, stokers, and immersion heaters are widely used.

2B4.10 LAMPS AND ILLUMINATION

(See Ref. 66, Section 15, pp. 2 through 51.)

1. PRACTICAL CONSIDERATIONS. Currently recognized standards of illumination may be used in preparing specifications for lighting systems in the Cold Regions. The disciplines of the area should be considered in relation to the probable life of the type of lamps selected for various outdoor services because at extremely low temperatures thermal cracks are likely to occur more frequently in gas-filled lamps than in vacuum types, which operate at much lower bulb temperatures. In certain instances, long lamp life may be the primary consideration; but in lamps serving as obstruction lights, airstrip markers, and street lamps, high lumen output may be a more important factor than the inconvenience of replacement. In all services the possibility of a compromise between optimum lamp life and high operating efficiency should be considered.

2. FLUORESCENT LIGHTS. Standard fluorescent lamps and starters do not give satisfactory service at temperatures below 40° F. Considerable work is being done in an attempt to get better operation of fluorescent equipment at lower temperatures, but at present filament-type lamps should be used for buildings that may be unheated during cold weather and for all outdoor lighting in the Cold Regions. Fluorescent fixtures should not be used near electronic equipment; they are a source of bad radio interference.

PART C. DESIGN OF ROADS, RUNWAYS, AND RAILROADS

Section I. GENERAL CONSIDERATIONS

2C1.01 GENERAL

In many respects the principles of design and construction of roads, airstrips, and railroads on sites underlain by permanently frozen ground are identical. On all such facilities the type and thickness of the base course or fill, the weight and concentration of traffic, and the climate, ground water, and subgrade soil are, individually and collectively, factors that determine the nature and degree of damage that may result from frost action.

As long as permafrost remains frozen, it has a high bearing power regardless of the elements of its composition. If, because of some change in its thermal balance, permafrost thaws, its bearing power will revert to that of its original soil components and may be further affected by the presence of free water. The supporting power of a subgrade under these conditions can be seriously reduced and can vary greatly even within small areas. Further reduction of subgrade strength may result from the application of traffic during the thaw period, which may cause remolding or develop hydrostatic pressures within the pores of the soil during the period of weakening. The degree to which soil loses strength during frost-melting periods and the length of periods during which strength is reduced depend on the type of soil, amount and type of traffic during the frost-melting periods, temperature conditions, drainage conditions, and availability of water during critical periods. On refreezing and in the presence of free water, heaving may take place, producing structural stresses commensurate with those caused by melting and subsidence. (See Section 2A5 and par. 4 of B2.01 in *Airfield Pavement*, NAVDOCKS TP-Pw-4.)

The processes of freezing and thawing in permafrost areas are more intense than in the Temperate Zone, and their detrimental effects are more clearly emphasized. In runways and along roads and railroads, they result in hazardous operational conditions, excessive maintenance, and traffic interference. To avoid complications resulting from frost action, facilities of the above type should, wherever practicable, be constructed on bases of preserved permafrost or on taliks sufficiently large and structurally adequate to function properly as a base. (Ref. 31, 35.)

2C1.02 SITE SELECTION

1. ROAD LOCATION.

a. *Location Criteria.* Road planning in the Cold Regions usually involves location through virgin country, and the road is therefore not appreciably influenced by factors other than construction and maintenance. In addition to the usual location criteria of shortest route, standard alinement and grades, reasonably economical design, and safety of traffic, certain important requirements imposed by the disciplines of the region must be considered. Successful roads in permafrost areas are located to take advantage of favorable foundation and drainage conditions rather than directness of route. Areas are avoided where a receding permafrost table may produce an unstable foundation or where there may be evidence of creeping or swelling of the active layer. Wet side hills or slopes, which indicate possible effluent seepages, are avoided because spalling of slopes and major slides are to be expected and winter ground icing will normally result. Likewise, the location must be kept sufficiently above the known icing elevations of all streams and rivers, including stacked breakup or pack ice that is either marginal to or crossing the roadway. Wherever possible, roads are located parallel rather than perpendicular to the ground-water movement. If practicable, locations should be made on the south rather than the north slopes of hills and mountain ranges because of the greater benefits that south-facing slopes derive from the heat of the sun. The ground on such slopes is more likely to be free of permafrost, and construction operations will have the advantage on such slopes of an earlier spring thaw and later fall freezeup. Also, subsequent maintenance problems are likely to be reduced by less slippery surfaces, less winter ground-ice formation, and earlier spring thaws. (Ref. 33.)

Other precautions essential to minimize winter maintenance problems include avoidance of through cuts, which induce drifting, and construction of slightly raised or fill sections, which tend to be swept clear of snow. Such construction usually makes impractical the balancing of cuts and fills. Minimum grades and curvatures are utilized to reduce winter maintenance and increase safety of winter traffic. (Ref. 33.)

(1) *Bridges.* Bridges require the additional consideration of winter overflow icing possibilities, stream ice breakup and flow, and the channel-shifting to be expected of most glacial streams. In addition, glacial streams and rivers in the Cold Regions are often subject to heavy flash floods from the bursting of glacier-dammed lakes or streams. Glacial floods in many large rivers often raise those rivers as much as 20 feet, causing serious ice flow, bank erosion, and drift problems. Floods may occur in summer or in winter, and in the latter case may cause considerable damage by carrying not only heavy broken river ice against the bridge but also ice brought down by glaciers and ordinary drift composed of trees, stumps, and other debris. (Ref. 33.)

Bridge locations to minimize these conditions are preferably chosen well in advance of the road locations and act as control points for the route. A narrow crossing where the river is confined by geographical features is preferable, and a high, level crossing supported by geographical features is similarly desirable. Locations like these eliminate many troublesome maintenance problems caused by the foregoing conditions. In actual practice, however, it is usually necessary to accept less than the ideal crossing because the economics of the overall route location seldom allow the bridge crossing to control the location of the line. (Ref. 33.)

b. *Map Reconnaissance and Aerial Photographs.* A thorough study of all available maps of the region will aid in selecting one or more possible routes to be checked later by ground reconnaissance. The study may include photogrammetric maps and aerial photographs, either mosaic or strips of stereopairs. Aerial photographs can provide much information on road location and elimination of unpromising routes more quickly than from any other source. At the same time they make possible a stereoscopic study of surface phenomena, such as land forms, drainage, and vegetation along those routes that appear to be the most practicable. (Ref. 31.)

c. *Ground Reconnaissance.* A thorough and detailed ground reconnaissance by a qualified party is necessary to decide if the route tentatively selected by previous studies is practicable. This work usually begins in the early spring before the thaw takes place so that construction equipment and supplies can be transported while the ground is still frozen. Also from the standpoint of planning, the period before the spring thaw is an ideal time to make a study of snow cover, the depth of freezing under conditions of varying moisture and vegetation, winter outlets of springs, types and locations of frost mounds, freezing of water basins, and other features influencing construction. (Ref. 29.) (See Section 2A2.)

The following considerations are of importance in selecting a location for facilities in the Cold Regions.

(1) Estimate the amount and type of clearing required.

(2) Study the surface and ground water thoroughly, with respect to quantity, direction of flow, rate of movement, and source. Note weather conditions, snow depth, and probable runoff. Watch for evidence of icing (Section 2A7).

(3) Thoroughly investigate soil characteristics. Note the presence or absence of permafrost, including depths and soil types involved. Foundation design and thickness of base course will depend on the quality of the soil at the site. Avoid areas of fine-grained soil, if possible, because these are the major cause of construction and maintenance defects. (See also Section 2A2.)

(4) Note evidence of detrimental frost action.

(5) Carefully note the topography of the area. Locations on high, well-drained ground with a reasonably smooth surface will require a minimum of grading. Estimate the grades to be encountered and the amount of fill required. In rough terrain in permafrost areas, avoid cuts wherever possible.

(6) Note availability of local materials. Because construction in permafrost areas is accomplished primarily by hauled-in fills rather than by balancing cuts and fills, large quantities of granular materials are necessary.

(7) Note the transportation requirements of the various sites. Compare the accessibility of possible routes and estimate the maintenance required for continuity of supply.

(8) Note possible location for borrow pits. It is essential that pits be located in full recognition of the disciplines of the area, character of the active layer and its cover, the present and future horizon of permafrost, and surface and subsurface drainage.

(9) Note stream conditions at prospective crossing sites including icing conditions, width, depth, and velocity of the stream, condition of banks, stream bed, and high-water marks.

(10) Look for major discrepancies in map, photographic, or other data on which the tentative location was based. (Ref. 31.)

d. *Preliminary Survey and Final Location.* The preliminary survey should be started as soon as possible after the ground reconnaissance so that early and correct decisions can be made concerning the various sections of the line, including bridges, pits and quarries for building materials, and buildings and other special structures. Conventional methods for conducting this survey, as well as making the final location, are applicable (Ref. 10, pp. 553-589) except in cases of hasty location work where instructions given in various military technical orders should be followed. Test holes and soil studies supplementing those made during the ground reconnaissance should be made, if required, along the route and at the site of buildings, bridge crossings, pits and quarries, and at the following locations at or adjacent to proposed construction areas.

(1) Slopes with different exposures.

(2) Breaks in slopes.

(3) Areas to be excavated.

(4) Areas in which differences in soil, vegetation, and minor features are indicated.

(5) Areas to be covered by fill sections.

(6) Swampy hollows and depressions.

(7) Sites of springs and fields of surface ice.

(8) Areas where landslides or slips are indicated.

(9) Areas of ground ice.

(10) Along gulleys and canyons.

(11) Near lakes and rivers. (Ref. 29.) (See Sections 2A2 and 2A8.)

Efforts made during the survey to obtain adequate and reliable information on all sections of the route traversed by the line will be justified by safer and more rapid travel, fewer traffic interruptions, and simpler maintenance problems.

2. RAILROAD LOCATION. The same factors that influence the selection of routes for highways in permafrost areas are applicable to railroad location. Also, surveys for the purpose of fixing the line and grade for the two types of facilities are essentially the same in principle. Although greater latitude is ordinarily permissible in specifying alinement and profile requirements for highways than for railroads, the difference is less in permafrost areas because of the important consideration of minimum grade and curvatures. (See Ref. 10, Section 11.)

3. AIRFIELD LOCATION. Selection of a site for an airfield is usually a compromise among engineering, strategic, and operational requirements. Factors of major importance, from a construction standpoint, in selecting a satisfactory site for a facility in permafrost areas are presented in Section 2A2. The exact location of the runway is of first importance, for it determines the rest of the airfield layout. In making the final runway location, one or more of the factors referred to in Section 2A2 may outweigh operational considerations because these factors will determine the amount of effort, equipment, materials, and time required to construct the airfield. In many sections of the Cold Regions, particularly in rough terrain, it is frequently impracticable to follow normal procedure and orient runways in accordance with the prevailing winds of the area. Operational requirements, however, can not be ignored to the extent that operation of aircraft from the proposed site will be excessively hazardous. Meteorological conditions, such as gusty winds of high velocity, cross-currents, downdrafts, haze, fog, ice fog, and precipitation, must be considered; and potential sites, particularly those located near prominent topographical features, should be flight-tested by an experienced pilot to disclose the existence and extent of hazardous air eddies and other detrimental local conditions that may be present. Glide angles along the projection of both ends of the runway must be suited to the landing and takeoff requirements of the using aircraft. Locations meeting glide angle requirements but offering mental hazards that cause pilots to fail to use the available length of the runway should, when practicable, be

avoided. The selection of the best site from a construction standpoint, however, will often require the acceptance of mental hazards.

For basic location and layout criteria, for standards applicable to emergency minimum operational and full operational airfields, and for information on strategic and tactical considerations, reference should be made to pertinent manuals and special instructions of engineering services. (Ref. 31.)

2C1.03 DRAINAGE—ROADS AND RAILROADS

1. GENERAL. Every section of the route will present an individual drainage problem, and trial layouts should be made on the contour maps (or aerial-mosaic overlays) on which are first traced the natural drainage pattern, ridges, and valley lines of the various areas along the route. After an acceptable drainage scheme has been evolved, it is checked for hydraulic accuracy by a series of trial computations. These cover estimates of the quality of the surface runoff water to be carried by the system at each location and of the hydraulic capacity of each system and its component parts. Drainage systems should be constructed in accordance with the general principles outlined in Section 2A7. However, inasmuch as more drainage problems are usually involved in road construction than any other type of facility, because of the many types of terrain encountered, the basic considerations specifically applicable to drainage of roads and railroads are briefly reviewed in this paragraph.

2. SURFACE DRAINAGE. In planning for drainage of surface water, the following procedure is recommended.

(1) Reduce the possibility of fields of surface water by providing an adequate number of structures discharging into natural drains away from the road. Natural drains should preferably be on the low side of the roadway so that spring melt water from the icefield will not be required to pass through the drainage structures.

(2) Construct ditches to intercept sidehill drainage.

(3) Locate side ditches as far from the crown of the road as is practicable. The shoulder between the edge of the road and the ditch should be wide enough for storing snow.

(4) Use deep, narrow ditches in preference to wide, shallow ones. The thickness of surface ice will be the same for both, but the depth of the narrow ditch allows free flow of water for a longer period than does the shallow ditch.

(5) Locate drainage ditches and related facilities, when practicable, including haul roads, on the side of the road least vulnerable to damage from construction activity. Disturbance of the ground during construction often results in an irreparable altering of the thermal regime.

(6) Provide adequate checks to prevent erosion in side ditches.

(7) Include in specifications the requirement that all excavations made near the roadbed, such as borrow pits, be drained.

(8) Make culvert sections deep and narrow rather than square. For ground drainage, deep, narrow sections are preferable. (Ref. 29.)

3. SUBSURFACE DRAINAGE. In planning for drainage of subsurface water the following procedure is recommended.

(1) Anticipate the effect of cuts and fills on flows of ground water by providing for construction of French or other types of drains.

(2) Give special attention to drainage of road surfaces that are subject to heavy traffic and that may be particularly subject to frost boils during the spring thaw.

(3) Provide for thawing of underground drains and culverts that are susceptible to icing by installation of small pipes that can be connected to portable boilers when icing occurs.

(See Ref. 10, pp. 259-278, for laws governing flows of water in pipes and open channels.)

4. SURFACE ICING. Because effluent ground-seepage icing frequently varies with the weather conditions and other factors, its control is more often a maintenance rather than a design problem. Sometimes, however, the possible formation can be forecast and preventive measures specified. (See par. 2A7.05.) As previously stated, it is preferable, when locating a line, to avoid areas that appear susceptible to seepage icing unless it seems practicable to prevent or control it.

5. STREAM AND RIVER ICING. An ice problem that is relatively easy to predict and to design for is that of stream and river icing formed when the stream freezes to its bed and then continually overflows and freezes, which builds up successive ice layers that in many cases reach to heights of more than 20 feet. This type of icing occurs when the stream flows over permafrost; it is relatively predictable because it occurs year after

year in the same locations. Bridges crossing these streams must be kept sufficiently high to prevent overflows from reaching deck level, building heavy ice loads onto the structure, and endangering traffic. Besides planning high, level bridges for stream crossings susceptible to icing, it is important that wherever possible a clear span be used. Trestle-type structures should be avoided because removal of ice formations from the trestle supports is extremely difficult without endangering the bridge. Where icing streams and rivers parallel highways, the principal preventive measure is to build a road sufficiently high to avoid overflows, which require continual attention to maintain traffic and to protect a road from subsequent washouts during the spring thaw and runoff. (Ref. 33.)

2C1.04 DRAINAGE—AIRFIELDS

1. GENERAL. The degree of protection to be provided by drainage facilities primarily depends on the class and volume of traffic to be accommodated by the particular airfield, the necessity for uninterrupted service, and similar factors. In general, the degree of protection should increase with the importance of the field, but minimum requirements must be adequate to avoid serious hazards of operation. The drainage system and structures should be designed and installed to drain properly all surface and subsurface water that may cause damage to the airfield facilities, property, or adjoining land, and to conduct such water to the designated point of disposal.

2. SURFACE DRAINAGE.

a. *Design Objectives.* To the extent that it is economically feasible, considering the purposes and importance of the particular airfield, the design objectives of the surface drainage system should be adequate to accomplish the following results.

(1) Disposal of surface runoff that would result from the selected design storm, without damage to field facilities, undue saturation of the subsoil, or serious interruption to traffic.

(2) Disposal of surface runoff from storms greater than the design storm, with minimum damage to field facilities and minimum interruption to traffic.

(3) Maximum reliability and minimum maintenance under the disciplines existent in the area.

(4) Adaptability to future extension of drainage facilities, with minimum expense and interruption to traffic. (Ref. 31.)

b. *Design Storm Frequency.* The design storm frequency (Ref. 69, par. B2.01) is selected on the basis of the operational importance and monetary value of the airfield and its facilities. The Navy bases frequencies on 2, 5, and sometimes 10 years. For the average naval activity, the runoff should be based on a minimum design storm frequency of 2 years. However, in locations where flooding and subsequent damage to vital installations or interruption to traffic may occur, or serious erosion of naval or adjoining property may result, a design storm frequency greater than 2 years should be used. In virtually all cases, the classification of drainage requirements of a given naval airfield will be specified by the Bureau of Aeronautics.

c. *Disposal of Surface Water.* Design criteria, including transfer slopes for the removal of water from runways and taxiways, will depend on the operational classification of the airfield and on limitations of time, materials, and terrain. Transfer slopes will usually vary between 1 and 3 percent, but the requirements of the Bureau of Aeronautics should be consulted regarding layout criteria of this nature. (Ref. 31.) (See par. 2A7.02.)

d. *Design Considerations.* To calculate the cross sections required at critical points along the drainage channels, the amount of water the drainage system has to handle must be determined. The usual methods of determining design discharge from areas to be drained involve approximations that are not desirable in airfield design for the reasons noted in par. 1 of 2A7.02. Methods that tend toward overdesign are therefore commonly used and can usually be justified, particularly at forward airfields in permafrost areas where reliable information on rainfall intensity and frequency and surface runoff is often lacking. Also, such fields are usually originally designed for minimum operational requirements, and substantial overdesign may be no more than adequate if later improvements to the field are made.

e. *Design Factors.*

(1) *Design Storm.* Although it is important to know the annual amount of rainfall to design a surface drainage system, a knowledge of seasonal variations and data on typical intense

rainstorms is of more importance from the standpoint of the drainage problem. The design storm frequency is not in itself a reliable criterion of the adequacy of surface drainage facilities. Intense storms usually cover only a small area and are of short duration. They ordinarily determine the design capacity of the drainage facilities, but storms of longer duration and moderate intensity may cause a greater runoff. Consideration should be given to the possibility of storms of greater frequency than the design storm, as well as melting snow and ice, which may be responsible for flooding and severe damage, particularly if melting occurs at the same time as rain. (See Ref. 69, par. B2.05.)

A detailed analysis of local rainfall conditions is desirable in the particular area where an airfield is required. If an analysis can not be made, sufficient accuracy is obtained by estimating the 1-hour maximum rainfall as 0.4 of the 24-hour maximum rainfall (Ref. 31). The 1-hour rainfall corresponding to the design storm frequency adopted for a particular station is then used in selecting the suitable standard supply curve. (See Ref. 69, par. 3 of B2.01.)

(2) *Infiltration.* The 1-hour infiltration is used as an index for losses caused by absorption of rainfall by the ground during the design storm. Because of many varying factors, it is difficult in the Cold Regions to determine specific applicable rates. It is therefore recommended that infiltration be considered zero in the Arctic and 0.4 in. per hour in the Subarctic. The infiltration rate of pavement is considered to be zero. (See Ref. 69, par. B2.02.)

(3) *Rate of Supply.* Rate of supply is the difference between the rainfall intensity and the infiltration capacity at the time of a particular storm. Both of these factors are assumed to be constant during a given storm. Supply rates are averaged where various surfaces make up the drainage area, and averages must be weighted in proportion to the areas of the surface involved. (Ref. 70.)

(4) *Rate of Runoff.* Rate of runoff for any rate of supply is determined primarily by the length of overland and channel flow, the slope of the ground and drainage channels, and the retarding characteristics of the surface cover and channel linings (Ref. 70). Typical values of the retardance coefficient *n* to determine the effective length of overland flow are shown in Table 2C1-1.

The upper value of *n* for the Arctic should be 0.1 because the surface may be frozen or covered with sleet when the rain falls. In the Subarctic, *n* may be very high but generally should not exceed 0.3 for design purposes. The coefficients should not be confused with Manning's *n*. (Ref. 70.)

TABLE 2C1-1

Retardance Coefficient for Overland Flow (Ref. 70)

Surface	Value of n
Smooth pavement	0.02
Bare, packed soil, free of stone	0.10
Poor grass cover, or moderately rough, bare surface	0.20[1]
Average grass cover	0.40
Dense grass cover	0.80

[1]Changed from 0.30 to agree with Hathaway value.

For drainage areas consisting of combinations of paved and unpaved surfaces having different infiltration capacities, computations will be simplified if weighted rates of runoff are estimated for composite drainage areas with each type of area proportional to the whole. Computation of runoff may then be made in accordance with instructions given in Ref. 69, par. 3 of B2.03.

f. *Method of Computing Drainage Capacities.* Paragraph B2.04 and other sections of Ref. 70 describe in detail Bureau of Yards and Docks practice in computing capacities of drainage facilities and should be consulted. Also, to assure successful design of drainage facilities in the Cold Regions, all features related to such facilities in permafrost areas should be considered. (See Section 2A7.) All phases of site reconnaissance should have been completed and information regarding topography, soil characteristics, groundwater movement, seasonal frost levels, and permafrost levels should be available. Liberal allowances should be made for possible flow retardation caused by ice formation in drainage structures.

g. *Ponding.* Ponding should be avoided in permafrost areas. The saturation of fine-textured, frost-susceptible soil shortly before freezing in the fall may cause heaving and swelling, which can not be confined to ponding areas. (Ref. 70.)

h. *Drainage Structures and Computation of Capacity.* The size and gradient of pipes and open channels required to discharge design storm water are determined by Manning's formula. Liberal allowances should be made for possible flow retardation caused by ice formation in drainage structures. (See discussion on drainage structures, including open channels, culverts, and storm drains, in Section 2A7.)

Section 2. ROADS AND RUNWAYS

2C2.01 GENERAL

1. DESIGN CRITERIA. In designing pavement over permanently frozen, frost-susceptible subgrades, preventive measures against frost action are quite different from those used in pavement design over frost-susceptible materials in areas subject only to seasonal freezing. In the latter areas there are two acceptable methods. The first is to prevent freezing of the subgrade and thereby prevent pavement heave and subgrade weakening. The second method is to allow freezing of the subgrade and to design on the basis of anticipated reduced strength during the frost-melting period. In permafrost areas, designs of road and airfield surfaces must provide for insulation and preservation of the permafrost in its frozen state (par. 2 of 2A6.02) or provide for uniform settlement when the permafrost thaws.

a. *Insulation of Permafrost.* The problem of insulating permafrost under roads, runways, taxiways, and aprons from changes in temperature, breaks down into two fundamental considerations—heat penetration and frost penetration, both of which arise in connection with the relative insulating properties of natural materials. (Ref. 71.)

(1) *Heat Penetration.* When heat penetrates through an operating surface, it may thaw a frozen, fine-grained subsoil, causing saturation and loss of stability. An example is a typical runway site from which the natural vegetation has been stripped, drainage structures installed, grading operations completed, and the base and surface materials placed. Heat will penetrate faster and deeper through the construction materials than through the natural insulation materials that made up the original cover. (See Section 2A8.) To preserve the existent permafrost horizon, therefore, the surfacing material and insulation course should provide insulation equal to the natural cover. (Ref. 71.)

(2) *Surface Icing.* When winter freezing penetrates an operating area deep enough to interrupt the normal flow of ground water, surface icing may occur. (See par. 1 and 2 of 2A7.05.) Sufficient subsurface data must be obtained so that the fluctuation in depth of the ground-water table is known and possible damage to the structure or interruptions to operations by surface icing are prevented.

2C2.02 RUNWAY PAVEMENT DESIGN

Airfield pavement will be designed and constructed in accordance with the procedures and recommendations in *Airfield Pavement,* NAVDOCKS TP-Pw-4. The recommendations of this publication are to be applied in full recognition of the disciplines of the area and the existent and future thermal regime to which the materials involved will be subjected. (See also Sections 2A5 and 2A8.)

Soil studies and sampling recommended in the publication should be supplemented by subsurface temperature measurements and in-place diffusivity studies. This information should be used to determine the present and future horizon of permafrost in the materials involved in the project.

Compaction of the subgrade may cause aggradation of permafrost, which, if uniformly distributed, would improve the modulus E_2; if not uniformly distributed, however, such change may detrimentally affect the surface of the pavement, unless a subbase course is designed to take care of such change.

CAUTION: Changes in the permafrost may materially affect the value of E_2.

Density studies of permanently frozen materials should preferably be made from undisturbed samples. (See Section 2A2.) When the sand method is used, the sand must be dry and cold enough so that its contact with the frozen materials will not cause it to freeze and adhere to the side of the hole.

The settlement values determined when the plate method is used in developing the modulus E_2 for the subbase material must be interpreted in terms of the existent thermal regime when the measurements are made. These values must then be corrected for the thermal regime existent in the materials involved during the construction and operation of the project.

Ditches and borrow pits in the immediate vicinity of an airport development may result in changes to the subdrainage and thermal regime of a portion of the foundation materials.

The possible effect of adfreeze must be evaluated in estimating the frictional resistance to horizontal movement of a concrete slab upon its support.

2C2.03 APRON AND RUNWAY FACILITIES

Detailed information regarding the type and location of apron and runway facilities and services must be incorporated in pavement designs or specifications so that in-pavement and under-pavement appurtenances, such as anchors, conduits, ducts, pipes, and service outlets, can be installed before the pavement is laid. The general standards for apron and runway facilities and services at naval shore activities are prescribed by the Bureau of Yards and Docks and are amended from time to time as dictated by changes in aircraft design and maintenance methods. These standards, therefore, are not discussed in this publication.

The services that should ordinarily be considered in designing runways and related surfaced areas are as follows.

(1) Runway and taxiway markers
(2) Lighting
(3) Cable ducts
(4) Tiedown anchors
(5) Static grounds
(6) Electrical utility conduits and outlets
(7) Radiant heating piping (if involved)
(8) Water service piping and outlets
(9) Wash racks and wash drains (Ref. 31)

2C2.04 ROADS

1. SELECTION OF ROAD CROSS SECTIONS (Ref. 10, Section 12). The selection and design of road cross sections in the Cold Regions depends on many factors, including traffic and drainage conditions, the nature and state of the subgrade (frozen or unfrozen), materials available, construction time, and personnel and equipment available. The design of all-weather road surfaces of heavy section gravel or broken stone and high-type flexible or rigid structure must be based on the fundamental principles of continuous stable support furnished by the subgrade and adequate drainage and proper load distribution by the surface and base courses. All of these factors are discussed elsewhere in this Section. Reduced importance can be placed on these factors in the construction of public and private service roads designed for light traffic or temporary haul roads in construction areas where high maintenance for a limited period is expected. Expedient and military roads are built primarily to satisfy minimum needs, and their design should be simple and practicable in order to use local materials and whatever personnel and equipment is available. The objective of designs for such roads should be a facility that can carry the required volume and weight of traffic with the least expenditure of time, labor, equipment, and materials. If it is to be an all-weather road, drainage and subgrade conditions are of primary importance as well as the structural design of its components. Earthwork should be held to a minimum, but grades and alinements should permit traffic to move speedily and safely. Future traffic conditions should be considered and stage construction principles followed to permit later modification without excessive grade and alinement adjustments.

a. *Earth and Earth-Gravel Roads.* In the Cold Regions, natural earth roads constructed of the material that exists along the right-of-way are, for obvious reasons, confined to nonpermafrost areas. Their use is limited to dry weather and light traffic. For such service over permafrost, it is common practice to place just enough gravel over the tundra to protect the moss from damage and to distribute to some extent the induced stresses from the wheel loads. Although considerable expense may be required, such roads are often satisfactory for limited traffic conditions and for providing a base for later-stage, intermediate-type construction. These roads are extremely susceptible to subsidence and frost heave.

b. *Intermediate-Type Roads.* The intermediate type of road surface is considered to include all-weather flexible-surface structures such as heavy-section gravel and broken stone, treated or untreated, and the bituminous retread, road-mix, and penetration-macadam types. (See Ref. 10, pp. 621-633.) Subgrade stability, drainage, and base-course thickness are of primary importance in the construction of roads in this class. All intermediate-type roads can be constructed rapidly even in cold weather and can be readily converted to high-type construction. In permafrost or heavy frost-action areas, it is usually advisable to restrict the movement of traffic during critical periods to minimize damage to the road and to promote safety.

c. *High-Type Roads.* High-type roads represent the heavier and more durable roads with paved surfaces. In the Cold Regions the most common type is asphaltic concrete, although rigid concrete surfaces from a structural standpoint are satisfactory if the subgrade is uniform and if the cost can be justified. As previously mentioned, roads with a flexible surface are usually preferred in permafrost areas because the minimum requirements of rigid surfaces under varying permafrost conditions can not usually be attained.

(1) *Pavement.* Pavement for roads will be designed and constructed in the same manner as that given for runways in *Airfield Pavement,* NAVDOCKS TP-Pw-4. (See also par. 2C2.02.)

d. *Expedient Roads.* Corduroy, fascine corduroy, plank, plank-tread, and log-tread roads are practicable in swampy areas underlain with fine-grained materials. When a satisfactory fill is scarce, these types of roads should be considered if the materials required for their construction are available. Metal landing mats can often be used in conjunction with corduroy to cross short sections of ground. In the Cold Regions, designs for these roads will differ from conventional practice only to the extent that ground should be disturbed as little as possible during and after construction to reduce the thawing and pumping action of fine-grained soil. Ordinarily, corduroy construction, in which traffic vibrations are transmitted directly to the ground, is probably not as practicable as sleeper and stringer construction. If sleepers and stringers are used, ground contact is minimized by the sleepers, and a considerable amount of vibration should be absorbed by the surface cross logs and stringers. (Ref. 31.)

2C2.05 BRIDGE DESIGN

1. GENERAL. Bridge design must provide a minimum of restriction to river flow and sufficient height to clear floods, ice flow, and winter ground and stream icing formations. As a rule, clear spans are more satisfactory than trestle-type structures, and midchannel piers are undesirable because special icebreakers and protective structures must nearly always be provided. On wide, flat, glacier stream crossings, where channel shifting is prevalent, the overall bridge length can often be reduced by using dikes, wing dams, and other channel control structures to restrict the flow to a single opening. These bank protective measures are costly and require continual maintenance, but they are often economical because of the decreased length of required bridge structure. (Ref. 33.)

2. STEEL BRIDGES. Standard steel bridges have been widely employed for roads in the Cold Regions. These bridges are mostly simple truss and girder spans, though arches, suspension bridges, and cantilever designs are freely used for special crossings. (See Tables 2A9-1a and 2A9-1b.) Timber trestles and truss spans have been used extensively in the past but are being replaced with steel as rapidly as possible. The timber trestle is used for small crossings and on secondary roads. (Ref. 33.)

3. CONCRETE CONSTRUCTION. Concrete is used for bridge seats, footings, and some abutments, but is seldom used for spans or piers because of the comparatively high costs involved. No cement is produced in the Cold Regions, and the freight costs for this bulky material amount to several times its value. Most gravel and sand available for concrete aggregate require extensive washing and screening to remove glacial silt that predominates in the deposits. In the isolated locations common to most bridge construction in the Cold Regions, these factors, together with the additional plant and the skilled labor required for aggregate preparation, form erection, concrete mixing and placing, and heating during cold-weather placing, make concrete construction exceptionally costly. By comparison, steel structures can be easily handled, freighted, and erected with a relatively small plant setup. Steel structures in the Cold Regions do not deteriorate appreciably compared to similar structures in the Temperate Zone. Concrete, on the other hand, deteriorates faster because of the numerous cycles of extreme freezing and thawing. (Ref. 33.)

4. PIERS. Piers for bridges in the Cold Regions are predominantly the steel H-piling bent type. Developed by the Alaska Road Commission, they have proved very satisfactory. Their cost is considerably less than comparable concrete piers, their permanence is of equal duration, and their comparatively simple handling and erection facilitates use in isolated locations. Their cost is relatively low because they require none of the expensive ex-

cavation, formwork, cofferdam or caisson construction, or underwater work common to concrete piers. In addition, they are well adapted to use in frozen ground and can be placed as easily in winter as in summer. This factor is important in the Cold Regions, where most bridgework is accomplished in the winter, a time when concrete operations require costly heating measures. (Ref. 33.)

5. STRUCTURAL DESIGN. See Ref. 10, Section 7, and Section 2A9 of this publication.

2C2.06 PLANNING STRUCTURAL DESIGN OF AIRFIELD INSTALLATIONS

General and detailed instructions and standards relating to all phases of planning runways, parking aprons, and taxiways, as well as housing, utility, and other functional areas of naval airfield installations of all operational classifications are contained in various NAVDOCKS publications. No attempt has been made to incorporate such information in this or other Sections of this publication. It is assumed, however, that overall planning for installations in permafrost areas will consider the particular dangers present where permanently frozen ground exists, and that designs and construction procedures will reflect the basic and guiding principles discussed herein, which, if followed, will aid in avoiding or minimizing operational difficulties.

Section 3. RAILROADS

2C3.01 GENERAL

As noted in Section 2C1, the design of railroads in areas underlain by permafrost follows the same basic principles as those for roads and, to a lesser extent, airstrips. All are concerned with preserving the permanently frozen ground over which they are constructed, or preventing or minimizing differential heaving where thawing and refreezing of the permafrost can not be prevented. All use the same methods in accomplishing these objectives. (See Section 2C1 and par. 2C2.01.)

2C3.02 HEAVING TRACK

1. GENERAL. Railroads, like highways, traverse many miles of country in which widely varying conditions of soil, ground water, vegetation, climate, and other elements affecting frost phenomena are encountered. If, in all sections of the line underlain by permafrost, the permafrost could be preserved or if thawed subgrades could be maintained in a thawed state, the maintenance problems would be greatly simplified. On new lines, designed after adequate soil data have been obtained, roadbeds can be constructed over practically any type of subgrade, with reasonable assurance that maintenance, despite increasing loads and more concentrated traffic, will be kept to a minimum. (See Sections 2C1 and 2C2.) Economic considerations, however, are often paramount, and modification of designs that are technically adequate may be advisable where there is an extensive occurrence of fine-grained soil.

2. MEASURES AGAINST FROST HEAVING. The common methods of combating destructive frost heaving are drainage, lifting of track (on proper ballast or by shimming or both), and soil replacement.

a. *Drainage.* The drainage methods discussed in par. 2A7.03 are applicable to railroad subgrades. Very often, however, the soil involved is such that the level of ground water in and/or adjacent to the subgrade can be sufficiently drained to prevent heaving in frost-susceptible materials of the subgrade.

b. *Lifting Rails.* Raising the track by increasing the depth of ballast will assist in draining the roadbed and will distribute the effect of a heaving subgrade so that the use of shims under the rails can be reduced or even eliminated.

c. *Soil Replacement.* The most effective but also the most expensive method of preventing heaving of operating surfaces is to replace frost-susceptible soil with materials that will not heave when frozen. Gravel and broken stone are materials most commonly used as soil replacement. Peat and cinders, however, have also been used with good results, the latter on lines already in operation. The Norwegian State Railways, to overcome surface frost heaving on their lines, has found that the most effective soil replacement materials are a layer of pressed peat blocks topped with gravel, crushed stone, or cinders.

So effective has this expedient proved in eliminating heaving that plans are under way to pave the subgrade over approximately 300 km (186 miles), which will require approximately 1,600,000 peat blocks, 1.0 m x 0.5 m in plan and from 0.3 to 0.5 m thick. (Ref. 72.) (See Figures 2C3-1 and 2C3-2.)

2C3.03 STANDARDS AND REQUIREMENTS

Railroad construction in American-controlled sections of the Cold Regions is accomplished in accordance with AREA standards for comparable facilities, except where local conditions indicate the advisability of modifications. Criteria pertaining to requirements of layout, design, and construction are issued by the AREA and by sponsoring agents and are not discussed in this publication. Standard specifications for trackage and auxiliaries, including rails, ties, splice bars, and tie plates, are applicable to track construction in the Cold Regions. Construction methods and procedures and information regarding the effects of low temperatures on construction materials are presented in other Sections of this publication.

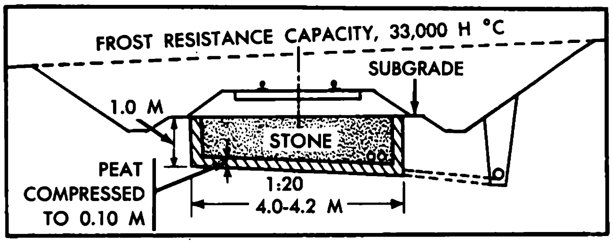


FIGURE 2C3-1

Normal Replacement Section Used in New Construction Before World War II, Showing Lining of Compressed Peat and Backfill of Crushed Stone (Ref. 72)

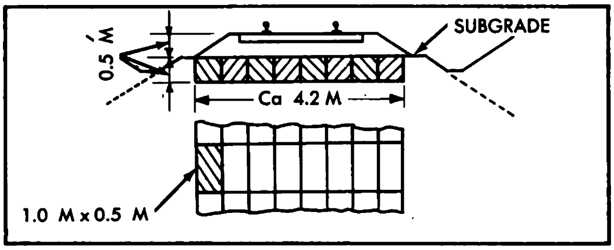


FIGURE 2C3-2

Sketch Plan and Section of Track, Showing Location and Arrangement of Pressed Peat Blocks (Ref. 72)

PART D. SANITARY ENGINEERING

Section I. GENERAL

2D1.01 INTRODUCTION

Safe and adequate water supply and sewage and waste disposal systems are as essential in low-temperature regions as elsewhere. Frozen ground and snow cover make it difficult to always dispose of body wastes and garbage and to collect drinking water from areas that are entirely separated. Rigid discipline must be followed in selecting water supply and waste disposal sites. In general, water supply should be taken only from ice, snow, or water from the largest fresh-water rivers and lakes in any given area. Wastes should be deposited only in confined areas as far as possible up the watersheds of only the smallest rivulets or streams; waste should not be placed in a lake or watercourse. Whenever possible, oil should be poured over the discharged wastes to make their detection easier in the immediate discharge area and yet not reveal their presence to persons outside the immediate area.

Publications that offer excellent information on sanitary engineering in the Cold Regions are: *Bulletin*, Committee on Sanitary Engineering and Environment, National Research Council, National Academy of Science, 1950; *Study of the Mechanical Engineering Features of Polar Water Supply*, Hostrup, Lyons & Associates, Contract NOy-27491, US Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, August 1953; and *Sanitation and Water Treatment in the Arctic*, Lloyd K. Clark, Report of Proceedings for Symposium on Advance Base Water Supply and Sanitation, US Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, 7-9 October 1953.

2D1.02 SANITARY ENGINEERING LOW-TEMPERATURE PRINCIPLES

1. EFFECT OF TEMPERATURE. Initially, temperature is the principal variant distinguishing sanitary engineering for Arctic installations from that used in other regions. Low prevailing temperature results in a changed exhibition of certain common engineering, physical, chemical, and biological principles. Biological and chemical reactions are retarded and the physical state of fluid, soil, metal, plastics, and other materials is appreciably different. Heat conservation, humidity, light, construction and operation costs, and the efficient use of materials and resources assume positions of great importance in Arctic sanitary engineering. Planning must be thorough, workmanship good, and tolerances small, and safety factors must allow for all the resultant effects of the disciplines of the area.

2. CHEMICAL REACTIONS. In general, all chemical reactions utilized in environmental control, such as oxidation, reduction, coagulation, solubility, vaporization, and precipitation, are retarded by lowering the temperature. At low temperatures, the oxidation of organic material is slowed appreciably. Temperature has an effect on coagulation, filtration, and precipitation in water and sewage treatment. Most solids and liquids decrease in solubility with decreasing temperatures. Vaporization occurs less readily at low temperatures.

3. TREATMENT ADAPTATIONS. All treatment of water or sewage must be conducted in shelters, with heating equipment adapted to maintain the temperature above 32° F throughout the treatment enclosure. Heated shelter for sanitary engineering operations assumes major significance because drinking water and water in sewage freeze. The simplest pump or Lyster bag is useless if the water is frozen.

The details of operation, maintenance, or overhaul found in appropriate technical manuals or manufacturers' handbooks have not been repeated in this publication nor has any specific technical or general engineering information given elsewhere in this publication or in standard engineering handbooks.

2D1.03 SANITARY ENGINEERING INSTALLATIONS

Water supply and waste disposal disciplines are equally applicable to individuals, small detachments, and larger units during emergency, temporary, semipermanent, or permanent stages of operation. The methods employed differ, depending on the size of the group, stage of the operation, and climatic and geographic conditions imposed at the site. Quality and quantity of equipment and supplies, suitability of equipment and supplies for use under low-temperature conditions, training and care in the handling of equipment under these conditions, a general understanding of the basic concepts of cold-weather engineering, and ingenuity—all govern the success of operations under low-temperature conditions.

Groups of from 1 to 25 men are dependent upon equipment and kits prepared for individuals and small detachments. Supply and equipment for such groups satisfy requirements for a 3-day period. Groups of from 25 to 500 men are dependent upon portable units for small and medium-sized detachments, such units consisting of semipermanent-type equipment. Expendable supplies are provided for a 90-day period. Semiportable units are used for large detachments (1,000 men or more) and for special requirements. Engineering design for fixed installation utilizes conventional equipment modified for adaptation to use under the disciplines of the area.

Water supply, sewage disposal, and garbage disposal plans for fixed-base installations should be carefully reviewed for the effect of low temperature on all units of such sanitary engineering facilities. Basically, the same commercial units and methods of water supply and waste treatment used in temperate climates are employed under low-temperature conditions. Modification of reaction times, thermal characteristics of units, ventilation, and simplification of operational requirements constitute the principal changes from temperate-climate practice.

Section 2. WATER SUPPLY

2D2.01 SOURCES OF WATER

Continuous and readily usable sources of water supply are not numerous in low-temperature regions. Most of the myriads of shallow lakes and ponds that may be found in flat areas are too shallow for year-around use. Ground water is found only in small amounts, particularly at shallow depths. Low precipitation does not provide adequate recharge of ground water, and permafrost interferes with its storage. Runoff is rapid where slopes permit.

1. ICE AND SNOW. The principal source of water supply used by the natives of the Arctic is melted ice and snow.

a. *Fresh-Water Ice.* Ice is cut from fresh-water lakes and rivers in the fall, when it is about 10 to 12 inches thick, and stored either in cellars in the permafrost or on the ground surface in a convenient spot. Improper handling of ice may contaminate it and make it unsafe for human consumption. Although uncommon, it is possible that freezing may not have excluded all impurities, including pathogenic bacteria present in the contaminated water, and ice cut from such a supply may be unsafe for human consumption without disinfection.

b. *Salt-Water Ice.* Old sea ice is a source of fresh water that is purer than the water from some springs and streams. Old sea ice, as well as icebergs, is frequently used as a source of water in coastal areas during summer months. Sea ice loses most of its saltiness in one year, and after two years it can be considered salt free. Fresh water can be dipped from pools in the ice or obtained by melting it. Old sea ice is recognized by its bluish color, rounded corners, smooth and glossy surface containing pits, standing pools of water, and the ease with which it can be splintered. Salt ice, on the other hand, has angular corners, milky appearance, and a tough texture, which is difficult to splinter. (Ref. 73.)

In native practice, harvested ice is taken a block at a time and placed in a container in a heated room. There it is allowed to melt at room temperature for general use. These methods of handling and melting ice are questionable, and it is doubted if the resultant water is safe for general use without disinfection. Ice should not be cut from a surface that has partially thawed and accumulated waste and organic material and then refrozen. Ice from a pond in which the ice surface has been flooded with surface water and refrozen should not be used. Natural exclusion of filth from the refrozen portion of the ice does not occur under such conditions.

c. *Snow.* Snow may be melted and used for water supply. (See Figure 2D2-1.) This method, however, requires more effort than melting ice and is less desirable. The quantity of snow in many places is relatively small except where snow has drifted. Barricades may be placed so as to cause drifting and accumulation of snow for water supply. There is usually dirt, silt, and organic material mixed in with the snow where it has drifted.

d. *Surface Water Supply Intake Facilities.* Special provisions must be made to protect intake works for surface water supplies in the Arctic. Frazil ice and solid ice will form and completely choke intake works if adequate protection is not provided to retain the heat of the water or if facilities are not provided to keep the water thawed at the intake. Water at several Alaskan surface sources has been found to be 32° F during winter and not more than 37° F during summer. Location of an intake at a point 10 or 12 feet below the minimum level of the surface of the source body of water facilitates protection of the intake. Such an arrangement does not give complete protection for the intake works, because turbulence created at the entrance of the intake may cause unnecessary cooling of water at the intake and the formation of anchor or frazil ice, particularly

FIGURE 2D2-1

Snow Melter, 75-Gal/Hr

during the early freezing stages of the winter. Intakes are sometimes fitted with steam lines and jets arranged so that water at the intake may be heated and the formation of frazil ice prevented.

Where water-bearing soil, sand, or gravel exists under the body of water from which the supply is to be taken, it is possible to use a subsurface intake works. Anchor ice and accumulated organic material at the bottom of a lake may necessitate special means for opening up the bottom of the body of water so that a subbottom perforated intake may be used to utilize stored water as well as underground flow to the lake. Deposits of organic material, mud, and similar matter in the bottom of bodies of water sometimes act as a check valve, which permits ground-water inflow but not outflow from the body of water into the aquifer or an underground collection system. Intake openings should not be placed directly on the bottom of a lake or other body of water, because freezing of the upper portion, as well as normal settling, concentrate foreign material at this point. Because most of the lakes and ponds in the Arctic are shallow, special intake facilities must be constructed that are not affected by low temperature and that also do not collect foreign material from the bottom of the lake or pond.

2. SURFACE WATER. Rivers receiving water from subpermafrost sources and entrapped water from extensive areas may flow continuously at points where the depth of channel, flow characteristics, and quantity of flow are sufficient to offset tendencies to freeze. There are comparatively few rivers that are large enough to maintain an appreciable flow throughout the year. Utilization of water from rivers in the permafrost region is complicated not only by such bodies of water freezing solid in some places but also by the formation of frazil or anchor ice.

Shallow surface sources are not practical when a continuous supply of water is needed. Seasonal ice is rarely, if ever, more than 6 to 8 feet deep in surface water; the majority of surface sources are only a few feet deep and many of them freeze solid. Moreover, they may be physically unsatisfactory without treatment.

In helping to locate appreciable quantities of subpermafrost water flowing into a watercourse (Figure 2D2-2), checks can be made at intervals downstream on the temperature and general physical and chemical characteristics of the water.

The latent heat of fusion from entrapped ground water may be sufficient to prevent a river source freezing. The quantity of entrapped water, however, may be quite limited, and in this case the river source can not be depended on unless there is also subpermafrost or spring water flowing into it.

Relatively deep lakes, which do not freeze to the bottom, usually receive a considerable amount of entrapped water and frequently receive subpermafrost or artesian water. They can serve as a continuous source. Shallow lakes receiving a large supply of entrapped water (Figure 2D2-3) can be used as a limited source. The great proportion of ice to unfrozen water in a pond or lake not fed with considerable quantities of entrapped water or from subpermafrost sources may make the quantity of stored water under the ice insufficient for supplying demands for an extended period.

3. SEA WATER.

a. *Distillation.* In coastal areas, sea water can be made usable during the summer months by normal distillation methods. Winterization of this equipment would make the source available during the winter. (Ref. 73.)

b. *Fresh-Water Layers on Salt Water.* In summer, if conditions are favorable, fresh water may be found in open leads in the sea ice. This fresh water, consisting of a layer up to 10 feet thick on top of the denser salt water, is found when the surface of the sea is mostly frozen so that winds can not cause wave action. The water in the leads stays fresh until after the freezing starts; it is then possible to cut through 12 to 18 inches of new ice and get fresh water. As winter advances, the movement of ice causes the fresh water and salt water to mix, but the ice formed on these leads in the fall is still a source of fresh water. Fresh-water creeks at the heads of inlets sometimes discharge enough fresh water to maintain a layer on top of the salt water in the inlets. This fresh water freezes first, with the result that in winter the ice in the inlet consists of an upper layer of fresh-water ice and a lower layer of salt-water ice. Additional fresh water is formed whenever the creek floods the frozen inlet. (Ref. 73.)

4. GROUND WATER. The following points of natural topography are indicative of the possible availability of ground water.

(1) Wide, shallow, exposed channels, glacial streams, or alluvial fans.

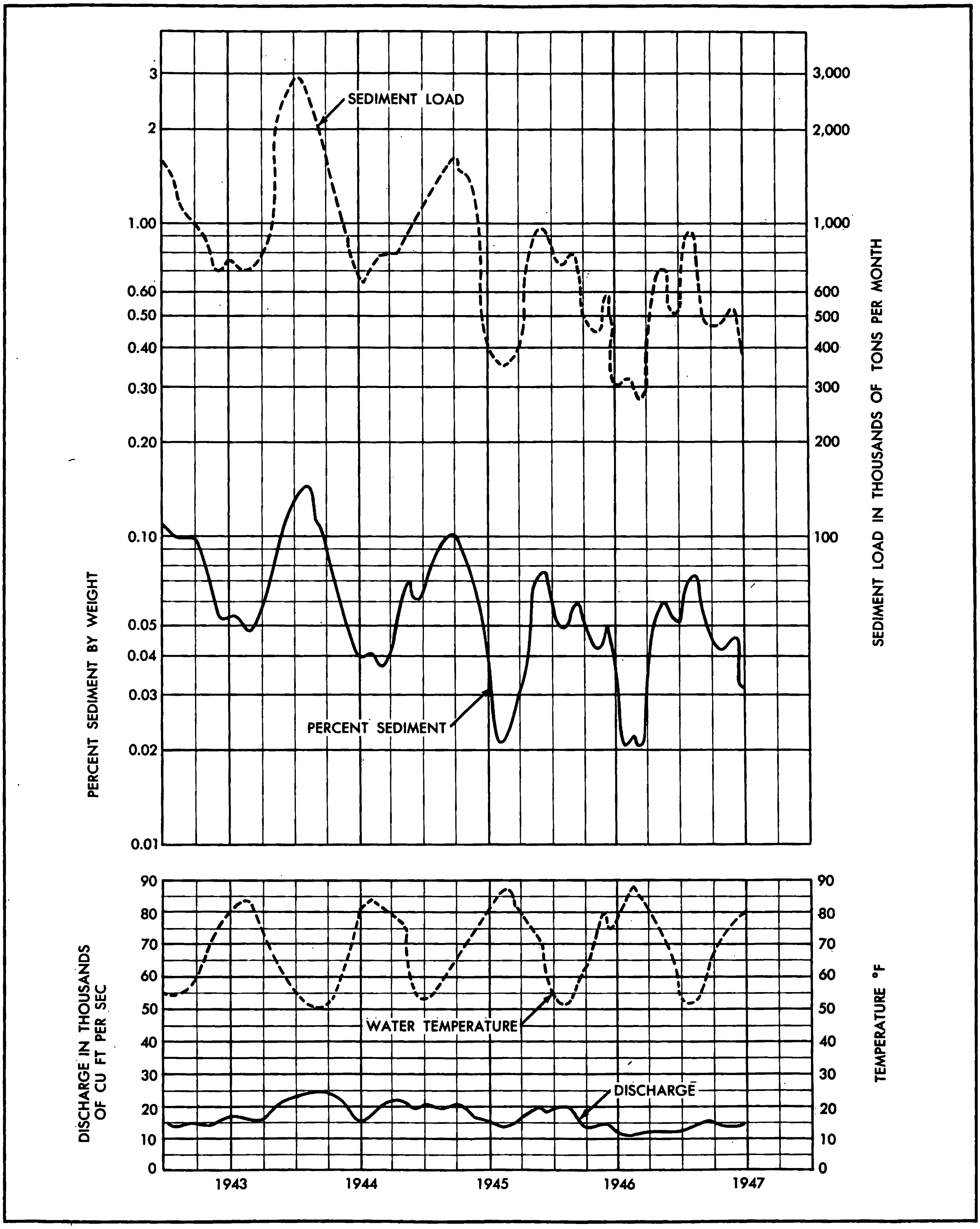


FIGURE 2D2-2

River Temperature, Sediment, and Discharge

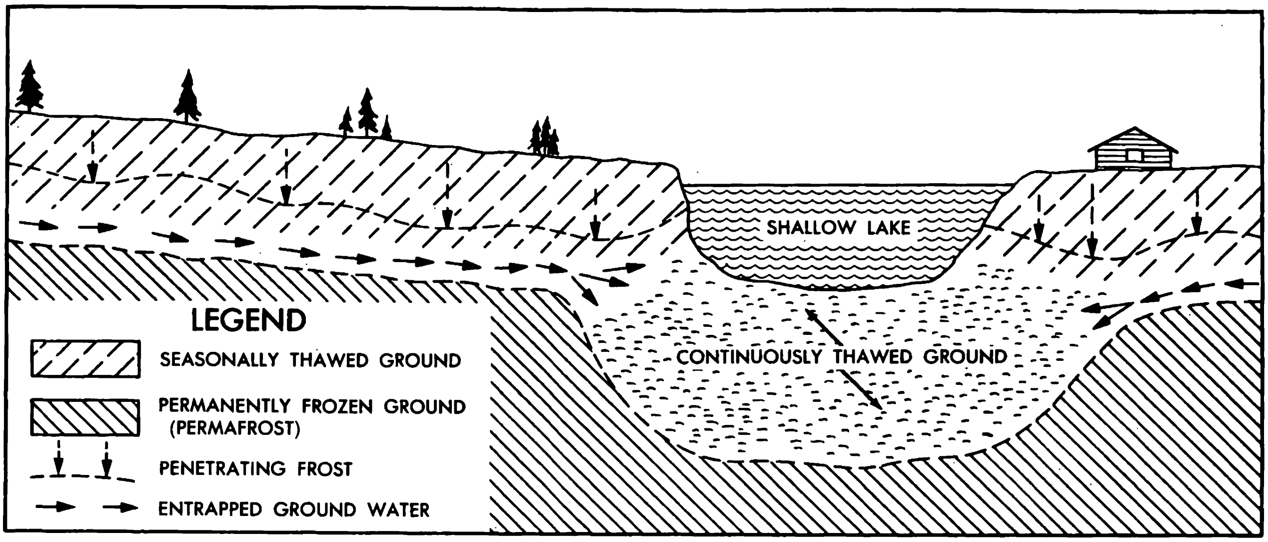


FIGURE 2D2-3

Entrapped Water in Permafrost

(2) Slopes at or near the foot of a mountain or hill where movement of ground water down the slope may be intercepted.

(3) Locations immediately downstream from poorly drained areas, such as muskeg swamps, which, because of heavy vegetative cover, may continue draining throughout the winter.

(4) Any sudden reduction in natural channel gradient and breadth in such a way that the constriction would tend to accumulate ground water.

a. *Salt-Water Infiltration.* Wells located on islands and near coastal areas may be sources of salt water only, or they may yield salt water as a result of excessive pumping that lowers the ground-water table and allows infiltration of sea water. Salt water has been found in exploratory oil wells in the interior of Canada near Great Slave Lake. (Ref. 73.)

b. *Drilling for Ground Water.* Ground-water investigative work has been carried on recently in Alaska by the US Geological Survey. O. J. Cedarstrom of the Geological Survey has made the following comments concerning this work.

(1) *Permafrost Drilling.* The Geological Survey has considered the techniques and problems of permafrost drilling since 1947 at which time detailed studies in the Fairbanks area were initiated. In that area we eventually drilled several test holes in frozen ground and developed water from them. Subsequent years we drilled a deep test hole at Kotzebue where the frost was colder and thicker than it is at Fairbanks.

Drilling by the cable tool method in permafrost presents no difficult problem and, in fact, many drillers in the gold fields claim that drilling in frozen ground is easier and permits more rapid progress than drilling in thawed ground. Alluvial material is referred to by these drillers and I believe that if consolidated rock material were considered, little or no difference between frozen and unfrozen ground would be experienced.

(2) *Open Hole Drilling.* In drilling frozen alluvium, drillers make open hole ordinarily for many tens of feet before setting casing. Thus the process is speeded up. Where frost temperatures are only a little below freezing, or at the freezing point, some difficulty is experienced with the sides of the hole melting and sloughing in, and in such instances a hole must be cased as progress is made. Another difficulty in making open hole is that drilling is done using a minimum of water (in order to minimize melting) and when thawed ground is reached there is a distinct tendency for water and sand to rush in and fill up the hole to static water level.

This could be avoided by casing and drilling with a hole full of water as the thawed zone is approached. In many instances thawing of the walls is retarded by using snow instead of water in the hole. The snow offsets the heat generated by drilling and inhibits wall melting.

In drilling frozen sandy ground, the wear of bits is very high and heavy drilling projects in frozen alluvium must have good facilities for frequent bit dressings.

(3) *Freezing of Casing.* Where the frost is appreciably colder than 32° F, there may be real difficulty in the tendency of the casing to freeze to the walls. At Kotzebue we introduced steam to melt the side walls (circulating hot water in smaller diameter lines would have been easier and more successful, I believe) but it was found later that the better technique was to keep the job operating as nearly continuously as possible and to keep the casing moving at frequent intervals. By so doing the casing tends to remain free and there is only a little tendency for freezing in to occur. To move casing either up or down after a period of idleness, even when the frost is not very cold, a pre-thawing is almost certainly necessary to free the casing from the walls. After the pre-thawing, presumably the casing should be kept in motion pretty much and further heat should not be introduced.

(4) *Freezing of Sludge.* In drilling the colder permafrost there will be a tendency for the sludge to freeze. This tendency can be avoided by introducing common salt with the drilling water. At Kotzebue we introduced hot water with our bailer.

Where water is encountered below very cold permafrost and rises in the hole, freezing of the water inside the casing will occur in a very short time. After a short period of idleness this ice can be drilled out rather quickly with only a little loss of time. It might be better technique in such instances to make the water very saline by introducing rock salt or whole packages of salt to the bottom of the hole during the course of drilling.

At Fairbanks, where the frost is not very cold, only a little difficulty is experienced with production wells freezing. It is generally found that using the well regularly, and this applies even to two-inch diameter wells, is sufficient to keep the well open. When such wells do freeze, they can be thawed out by introducing salt, by steaming, or by introducing hot water. Steam out with a boiler for a period of 8 hours or so is generally sufficient to keep the well from freezing for a period of years.

Where the frost is colder, real difficulties may be experienced in keeping wells from freezing. We know little or nothing about this problem. It is suggested that use of resistance wires, continuously operated steam lines, or continuous pumping may be necessary in order to maintain the wells. Probably it would be desirable to steam out such a very cold well very thoroughly by boiler or otherwise for a period of weeks or even months to drive the frost back from the casing. In such an operation there would be a tendency for the area around the casing to slump unless the material was hard rock or something like gravel having very little free ice or organic content. Presumably it would be most desirable to thaw before building a permanent pump house. In Fairbanks there are a large number of small-diameter wells that have been drilled by a drive jet process . . . . The drive pipe consists of two-inch pipe with a cone-shaped point. Just above the point the two-inch pipe is perforated with 10 to 20 holes about one-eighth inch in diameter. The point is ground off to permit passage of a one-half inch thaw line. During the course of drilling in frozen ground, the thaw line is worked ahead of the drive point and melts out an area big enough to permit subsequent driving of the two-inch line. During the driving of the two-inch line, the one-half inch thaw line is retracted. [See Figure 2D2-4.]

(5) *Drive-Jet Method.* Holes to a depth of almost 200 feet, passing through as much as 160 feet of frozen ground, have been constructed by drive-jet. Progress is fast for the first 75 feet or so, but at greater depth as little as two or three feet a day may be made. Pounding of a two-inch line with a light weight is a severe strain and is possible only because the couplings are reamed and the pipe ends form butt joints as invariably used in cable tool drilling.

Drive-jet methods are not satisfactory in ground containing boulders, but such methods are economical and easy when used in fine alluvium. NOTE: For the rotary drill method, see par. 9 of 2A2.03.

c. *Suprapermafrost Sources.* Suprapermafrost water supply or ground water from above

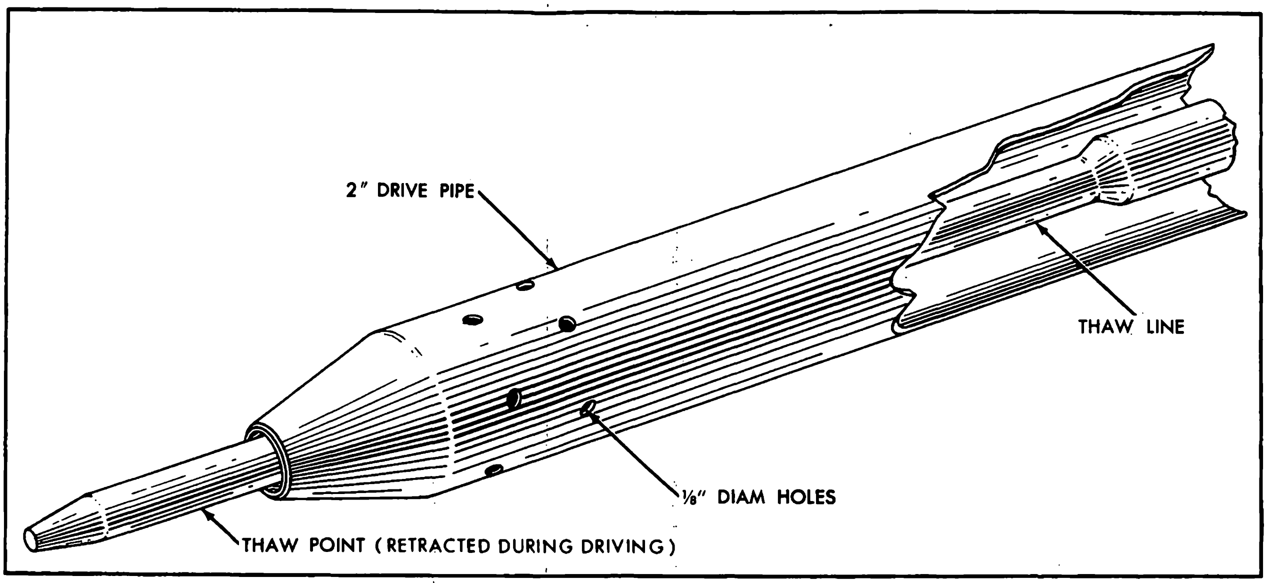


FIGURE 2D2-4

Drive-Jet Assembly for Driving Small-Diameter Wells in Frozen Ground

the permafrost is irregular, and quite often such sources disappear altogether before the end of winter. This is particularly true in areas where the seasonal frost extends down to the permafrost. In the Subarctic and southern sections of the permafrost region, shallow layers of thawed ground may exist continuously above the permafrost, and with appropriate soil type these layers serve as an aquifer for suprapermafrost water supplies. These supplies are generally poor producers and can not be depended on when any great amount of water is needed.

For several reasons, the safety of suprapermafrost supplies is highly questionable. They are rarely more than 10 to 20 feet deep and receive water from the contaminated zone of the subsoil. Cesspools and other waste disposal facilities are usually placed at about this same depth to avoid seasonal frost and yet not be in permafrost. Heat losses from houses tend to thaw the permafrost under them and cause formation of a sump in the top of the permafrost. [See Figure 2D2-5.]

Ground water from above the permafrost is usually obtained by bored, dug, and driven wells or by infiltration galleries.

d. *Intrapermafrost Water*. Entrapped water or artesian water found within the permafrost is called intrapermafrost water. Intrapermafrost water supplies are rare except in the southern portion of the area of permanently frozen ground. Figure 2D2-6 illustrates diagrammatically the different occurrences of subsurface ground water in a permafrost region. In the foothills of mountain ranges, where geological formations and permafrost exist in such a fashion that subpermafrost water may be forced up into the permafrost by hydrostatic pressure, intrapermafrost water may be found in fault zones of the permafrost. This water is not stable, and in time the supply may be exhausted or may come through the permafrost and appear as suprapermafrost or subpermafrost water. Intrapermafrost supplies, which can be tapped by using drilled or thawed and jetted wells, may be likened to water supplies in fissured limestone. They differ greatly in quantity and safety.

e. *Subpermafrost Water Supplies*. Subpermafrost water, although it is the most promising for continuous Arctic water supply, is difficult to locate, costly to develop, and may be highly mineralized. The supply will probably be comparatively warm because of the depth at which it is found; it is, therefore, less liable to freeze in the supply system. The four types of subpermafrost water are alluvial, bedrock aquifer, fissure, and karst. (Ref. 73.)

(1) *Alluvial*. Alluvial water may be found below the permafrost in broad river valleys where the alluvial deposit is very thick and the

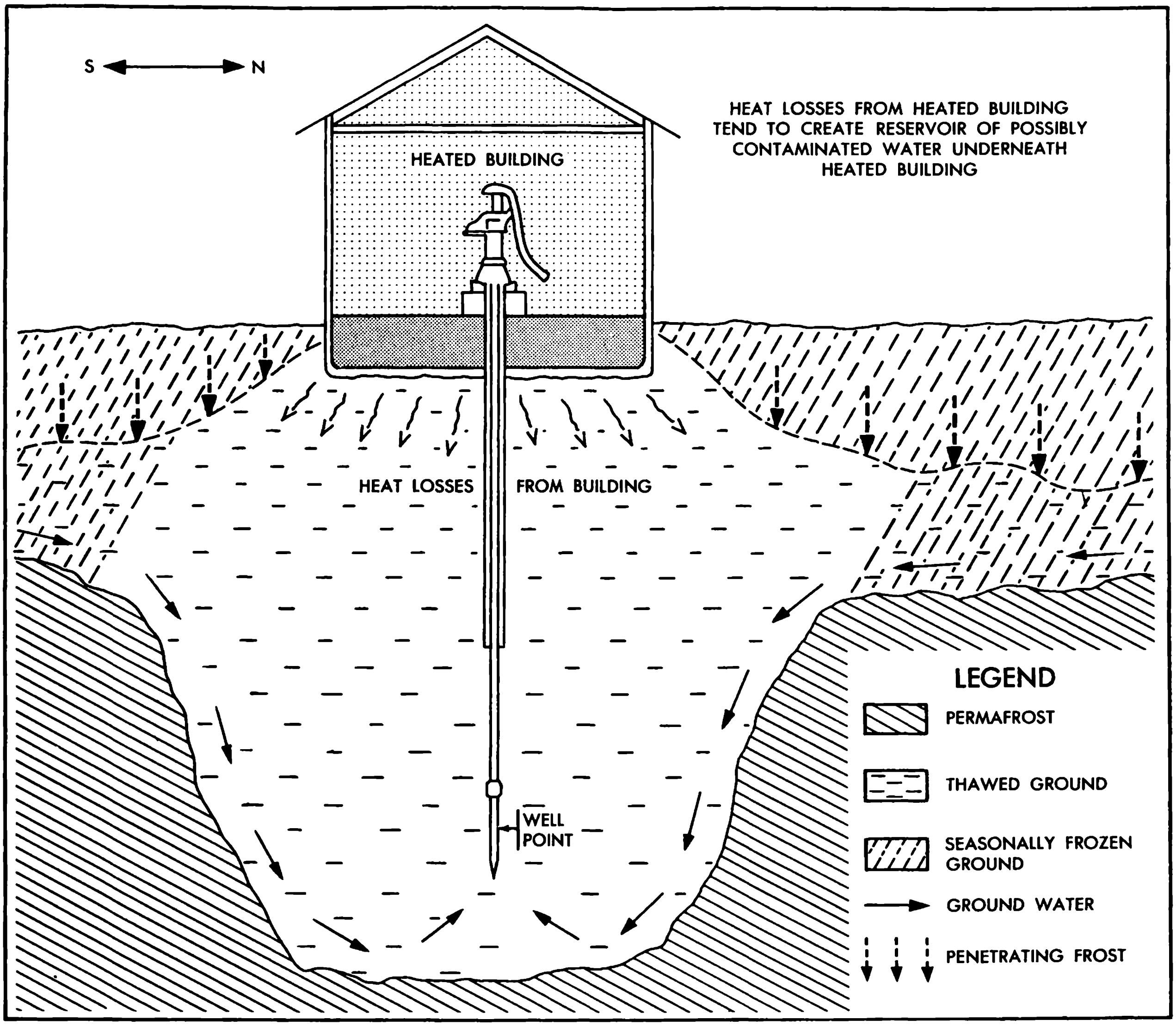


FIGURE 2D2-5

Unsafe Ground-Water Supply in Permafrost

depth of the deposit extends below the permafrost. It is found at the foot of river valley slopes that face south or are so alined that they receive considerable solar heat. (Ref. 73.)

(2) *Bedrock Aquifer*. A bedrock aquifer tapped by a well may be used as a water source. The best location is generally the center of a structural depression. The well should be drilled deep enough to tap the water-bearing strata below the permafrost and produce reasonably warm water. The probable yield of a well drilled in an aquifer should be estimated carefully, because the supply of water percolating into the water-bearing strata may be decreased by the action of the permafrost. (Ref. 73.)

(3) *Fissure*. Water in ordinary fissures produced by weathering, or in the deeper fissures produced by tectonic action, can be obtained by sinking wells. Before a well is sunk, a careful study must be made of the natural seepages and springs, as well as of the structural and geomorphic features of the area. Favorable locations for fissure water are found along fault zones, dikes, intrusions, and stratigraphic contacts. The bases of slopes in fissured areas, especially those with south-

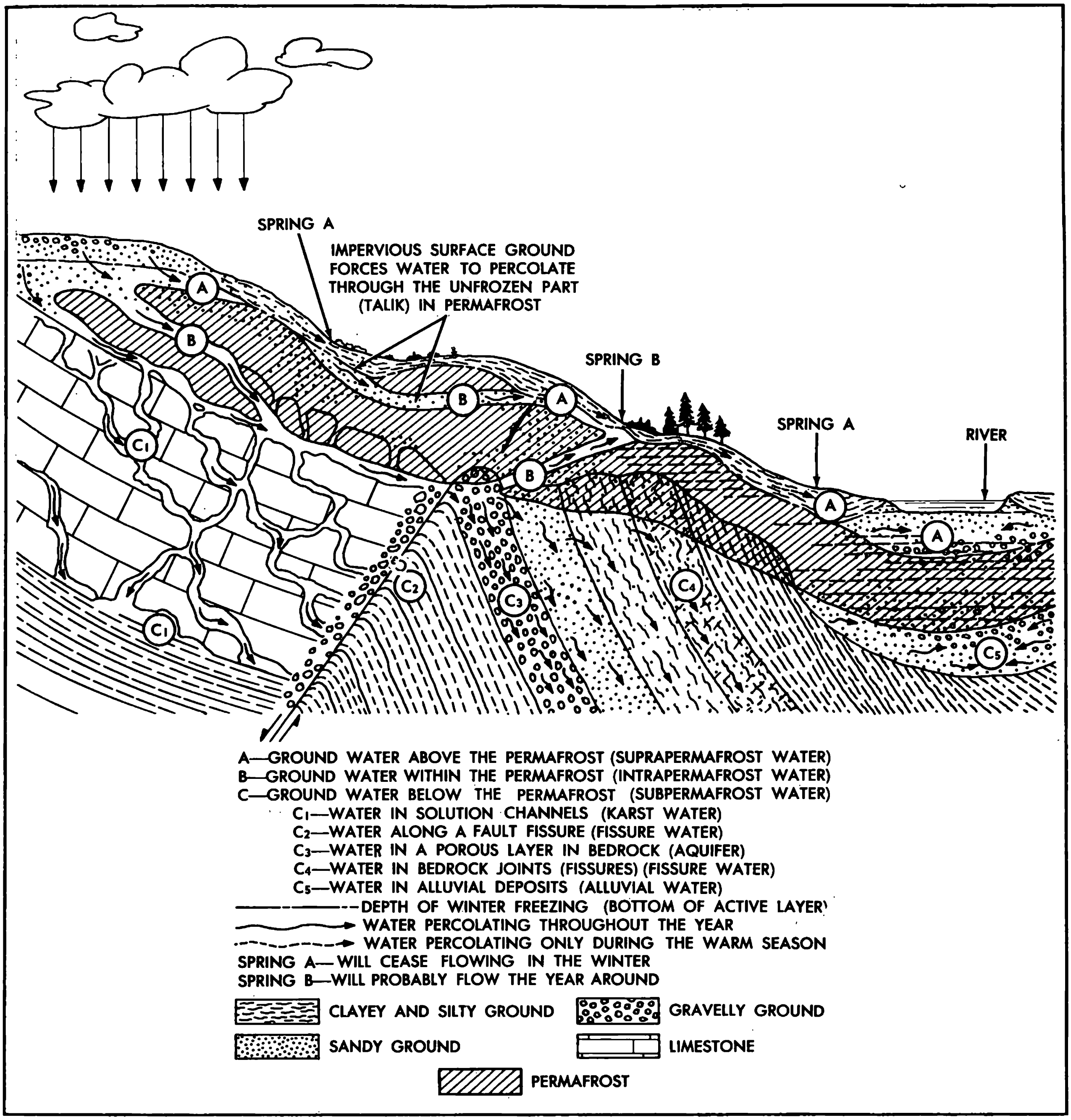


FIGURE 2D2-6

Occurrences of Ground Water in Permafrost Region (Ref. 21)

ern exposures, are the most common locations for sources of this type. (Ref. 73.)

(4) *Karst.* Karst water is found in areas of limestone and dolomite. The water-bearing channels may be very irregular and may occur at any depth below the permafrost. A careful study should be made to determine the source of replenishment of the supply and its ultimate constancy as a water source. (Ref. 73.)

Permafrost has been reported to extend to a depth of well over 1,000 feet at some points in the Arctic, and pervious strata below this point are not readily charged with ground water. Several satisfactory subpermafrost test wells have been drilled at Fairbanks, Alaska. The warmest water may be found some distance below the lower limit of permafrost, and such sources should be utilized wherever possible.

Overpumping or underpumping a well in permafrost may result in freezing. Excessive pumpage may freeze the aquifer and possibly change local hydrology; insufficient pumping permits water to freeze in the casing. The US Geological Survey *Water Supply Paper 140* discusses the effect of temperature on percolation. Movement of ground water through a water-bearing stratum is slower at low temperatures than at moderate temperatures, and the yield from a given type of aquifer may be appreciably less under low-temperature conditions.

Well casings should be firmly anchored in permafrost and constructed so that seasonal freezing of the surrounding soil does not disjoint, crush, or otherwise destroy the casing.

It has been recommended that fill around casings be sand or gravel to minimize cohesion of the seasonally frozen soil around it. Puddled clay may freeze to the casing and damage it. This type of construction enhances the possibility of contamination of the well by surface drainage. Wells should be located in a heated structure to minimize seasonal frost damage and to prevent damage caused by cold air. However, wells should not be placed in pits because such an arrangement may disturb the thermal regime of the ground excessively, as well as increase the possibility of contamination. A large-diameter casing and continuous moderate pumping are helpful in preventing freezing of a well through permafrost.

2D2.02 WATER SUPPLY NEEDS

Although water supply needs for individuals and small detachments may be slightly higher under Arctic conditions, water supply for medium-sized and large detachments at advanced bases will not materially differ from needs in temperate climates. Improperly designed or operated systems may result in excessive use of water through bleeding of outlets to prevent freezing. This practice is wasteful and unnecessary if facilities are designed, constructed, and operated properly. The following figures are sufficiently accurate to give general approximation of water supply needs at advanced bases in low-temperature regions.

(1) Individuals and small detachments—1 gal/man/day during combat periods not to exceed 3 days.

(2) Individuals and small detachments—3 gal/man/day in bivouac.

(3) Temporary or semipermanent camps—25 gal/man/day.

In addition to the distillation and purification units provided for small and medium-sized detachments, for operations under low-temperature conditions, snow-melting units should be provided. Consideration must also be given to the necessity for proper shelter for all units, which must be designed and constructed for use under low-temperature conditions. Water purification units, for example, which are designed for water treatment under temperate climate conditions, are not suitable for operation or storage under low-temperature conditions. Porous tubes are damaged by extremely low storage temperatures, and moving metal parts must remain usable even though they are subjected to direct flame during thawing.

Water supply needs for large detachments are accomplished in a similar manner except that more and larger units of equipment, such as the diatomite filter, distillation unit, hypochlorination unit, and snow-melting unit, are used. Water supply for fixed installations should be planned and constructed to utilize semipermanent or permanent-type sources and methods. Snow melters and distillation units are generally not the most efficient means for permanent solution of water supply.

2D2.03 CHARACTERISTICS OF WATER

1. PHYSICAL. Thorough understanding of certain physical characteristics of water at a temperature near the freezing point is necessary for full appreciation of precautionary measures necessitated in planning, constructing, and operating water and sewage works in low-temperature regions. Figure 2D2-7 shows the relation between temperature and viscosity in water. For this discussion, it is assumed that low-temperature characteristics of water are equally applicable to water and sewage, although it is recognized that dissolved salts, solids, and organic material, as well as some other items, may have a slight effect on the characteristics of the fluid.

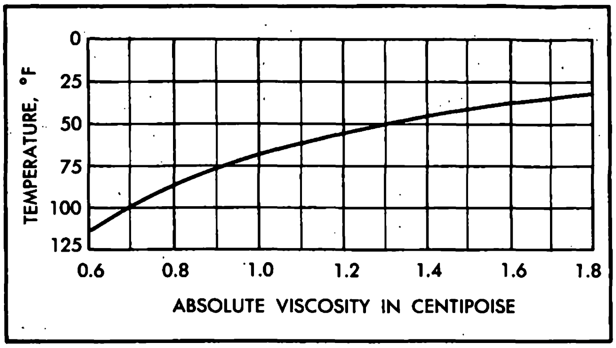


FIGURE 2D2-7

Relation Between Temperature and Viscosity in Water (After Bingham and Jackson)

Proper precautions must be taken to minimize supercooling of both water and sewage under low-temperature conditions, and adequate provision must be made for control of frazil ice if it forms. Figure 2D2-2 shows the effect of temperature on the load of suspended material that may be carried by water. Although these data relate to the silt load of water, they are indicative of glacial silt loads that may be found in some Subarctic waters.

2. CHEMICAL. A large amount of data on the analysis of Arctic water has been gathered and collated in this paragraph. It has been assumed that these data are reasonably representative of the water found in the specified regions; without such an assumption no conclusions could be drawn. The validity of this assumption can not be determined by the data at hand, but a fair consistency within the regions is noted.

It must be remembered that the data are selected, that is, they represent for the most part water found to be suitable as water supplies without treatment or with only the more usual forms of treatment. There are many water areas so obviously unsuited for water supply that no analyses have ever been made. Also, for example, there are numerous hot springs in southern and central Alaska for which analyses are available but are not included. These springs are of no interest as potential water supplies because of high temperature and mineralization.

With these limitations in mind, the following general conclusions are drawn. (Ref. 74.)

(1) Surface water of the northwest Canadian Arctic and northern and central Alaska differs from the supplies usually selected in the continental United States by only one feature, the possession of rather high pH values.

(2) This fact, together with the low temperatures of such water, tends to reduce the efficiency of disinfection procedures using chlorine and its compounds, and presumably most other disinfecting agents that might be employed. The difficulty is not an insurmountable one, but it is obvious that greater care must be taken in disinfection procedures.

(3) Considerable silt may be present in the larger Arctic rivers during the warm months, necessitating coagulation and filtration if they are to be used as water supplies.

(4) Ground water of the northwest Canadian Arctic is rather unsatisfactory; that of northern Alaska appears to be somewhat better but is not entirely satisfactory in all cases.

2D2.04 WATER TREATMENT

The need for appropriate treatment of Arctic water supplies to render them physically and bacteriologically satisfactory is comparable to such needs in temperate climates. Although the principles involved appear to be the same in the Arctic as elsewhere, the physical features of water treatment under low-temperature conditions may differ slightly at several points.

1. AERATION. Under low-temperature conditions, the viscosity of water is relatively high, and aeration is more difficult and not as effective as it is with water at higher temperatures. The aerator should be constructed as compactly as possible, and provision should be made for heating the air as required. Diffusion-type aeration may have some advantage in Arctic installations.

2. MIXING OF CHEMICALS. Mixing chambers and mixing are affected by temperature, and design and operation must take this into consideration for satisfactory results. Presumably, a change in electrochemical phenomena under low-temperature conditions causes more rapid formation of small floc. However, additional mixing beyond what is normally required is necessary to consolidate the floc and to secure its proper settling (Figure 2D2-8). It is recommended that the normal mixing time of from 10 to 30 minutes be almost tripled when water at temperatures from 32° to 38° F is being treated. Both rapid and slow mixing should be increased for best results. In cer-

tain instances, it may be desirable to increase the quantity of coagulant to secure proper floc formation in minimum time, but efficient design should make this unnecessary.

Arctic water treatment deals with water at approximately its maximum density, and the ease with which complete mixing is obtained is somewhat different from that for temperate climate operation.

3. SEDIMENTATION. Sedimentation in Arctic water treatment theoretically is slowed greatly by the increased viscosity of the water at low temperatures (Figure 2D2-9). Aside from unusual circumstances, sedimentation chambers should be designed for operation at 32° to 35° F and probably should provide capacities of from 1½ to 2 times that provided for operation in temperate climates.

4. USE OF CHEMICALS IN ARCTIC REGIONS. Use of chemicals, under Arctic conditions, requires a knowledge of certain changes that occur at low temperatures. In general, practically all chemicals react much slower at temperatures near freezing than they do at normal temperatures. Better mixing and longer reaction times are necessary for proper effect. Frequently, chemicals must be added in excess to procure the desired results within a reasonable period of time. Jar tests and laboratory tests are highly desirable for efficient operation under most conditions; they are even more desirable under Arctic conditions.

Certain difficulties are experienced with chlorine in cold water and under low-temperature conditions. From 32° to slightly over 49° F, chlorine hydrate forms, removing the chlorine from solution. At 32° F there is practically no chlorine in solution. Gaseous chlorine containers should be located in an isolated room that is heated to a uniformly warm temperature to keep the chlorination apparatus working properly. The gasing rate is reduced with temperature lowering, but great care must be taken to prevent overheating gaseous chlorine containers.

The application of chlorine to overheated water

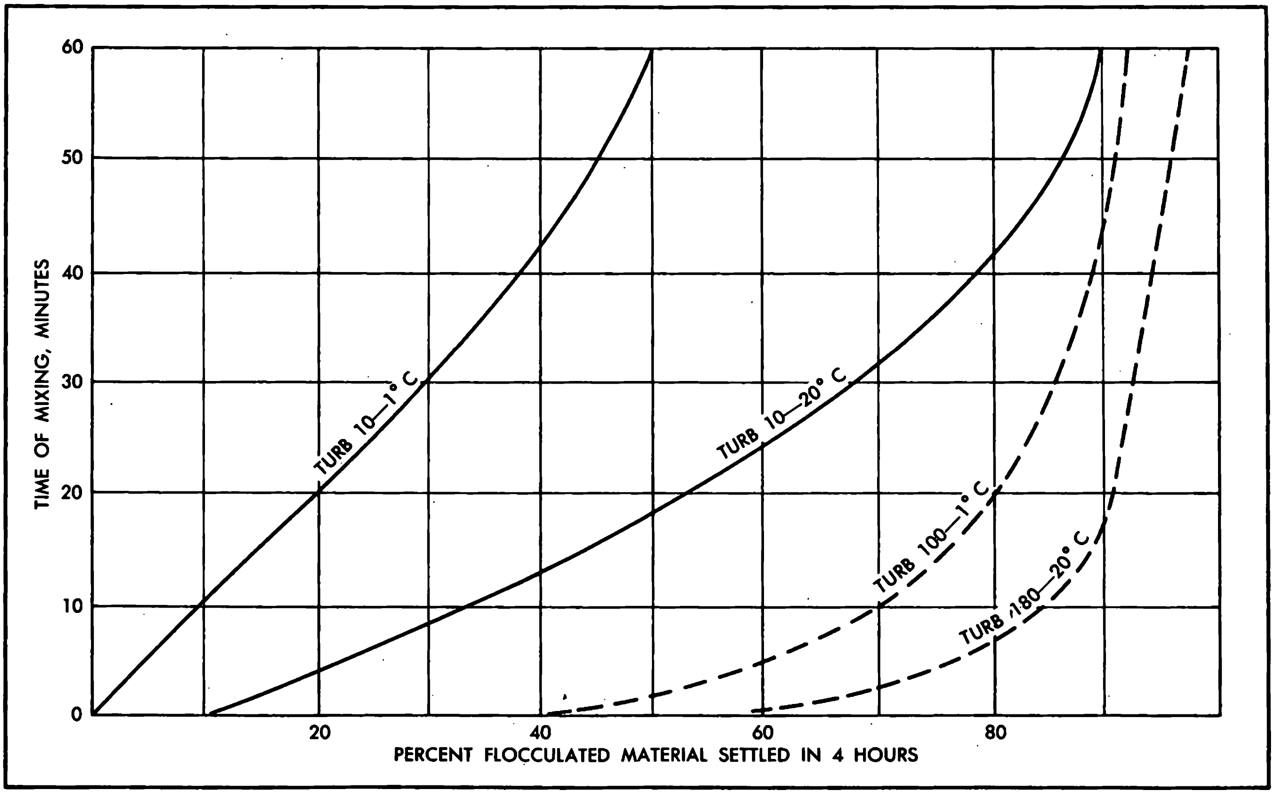


FIGURE 2D2-8

Relation Between Time of Mixing, Temperature, and Rate of Settling (After Baylis)

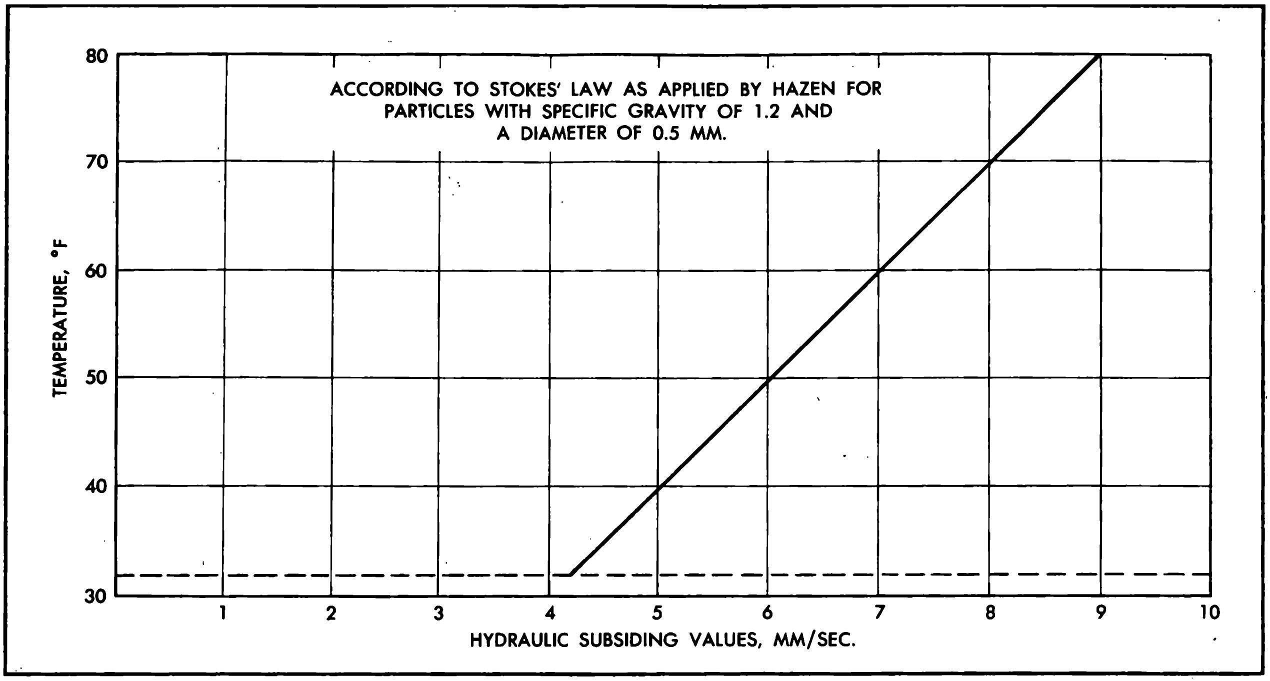


FIGURE 2D2-9

Theoretical Relation of Hydraulic Subsiding Values to Temperature

results in inefficient use of the chlorine, and care must be taken to prevent the introduction of chlorine near a condensate line or other heating means that may raise the temperature of the water considerably above normal. For the most effective use of chlorine, the water to be treated should be about 50° F.

5. RAPID-SAND AND DIATOMACEOUS EARTH FILTRATION. Rapid-sand filters, or diatomaceous earth filters, appear to be the most practical filtering means for low-temperature operation. Rapid-sand filters may be relatively easily enclosed and heated. Theoretically, the rates of filtration may be lowered as much as 30 percent at temperatures from 32° to 35° F (Figure 2D2-10). Filter design should take this reduction in efficiency into consideration. Diatomaceous earth filtering rates may also be reduced somewhat at low temperatures. Filters constructed of materials with unequal rates of expansion and contraction may present operating difficulties under low-temperature conditions.

6. WATER SOFTENING. Conventional water softening in the Arctic is affected by slowed reaction times for chemicals and longer mixing and settling times. Zeolite softeners are common on small ground-water supplies. It appears that lowered temperatures may tend to reduce the maximum rate of softening to somewhat below the usual 75 to 120 gallons per square foot of zeolite surface. Temperature is very important in lime softening. Less calcium and magnesium stay in solution at high temperatures than at low temperatures.

7. CORROSION CONTROL. Corrosion control in recirculating water distribution systems would not normally present a serious problem. The systems are usually designed and constructed to utilize insulating nonferrous materials not readily attacked by corrosive water. Chemical action is also retarded by low temperatures.

Metal piping, however, is usually used in utilidor systems, and under such conditions corrosion problems in the Arctic do not differ from similar problems elsewhere.

8. OTHER METHODS OF WATER TREATMENT. The hand-pumping kit-type purification unit (Figure 2D2-11) is suitable only at temperatures above freezing; the filter becomes clogged with ice and the entire unit will freeze at low temperatures. It must be remembered that chemicals are most effective in warm water and the Lyster bag (Figure 2D2-12) must be used in a

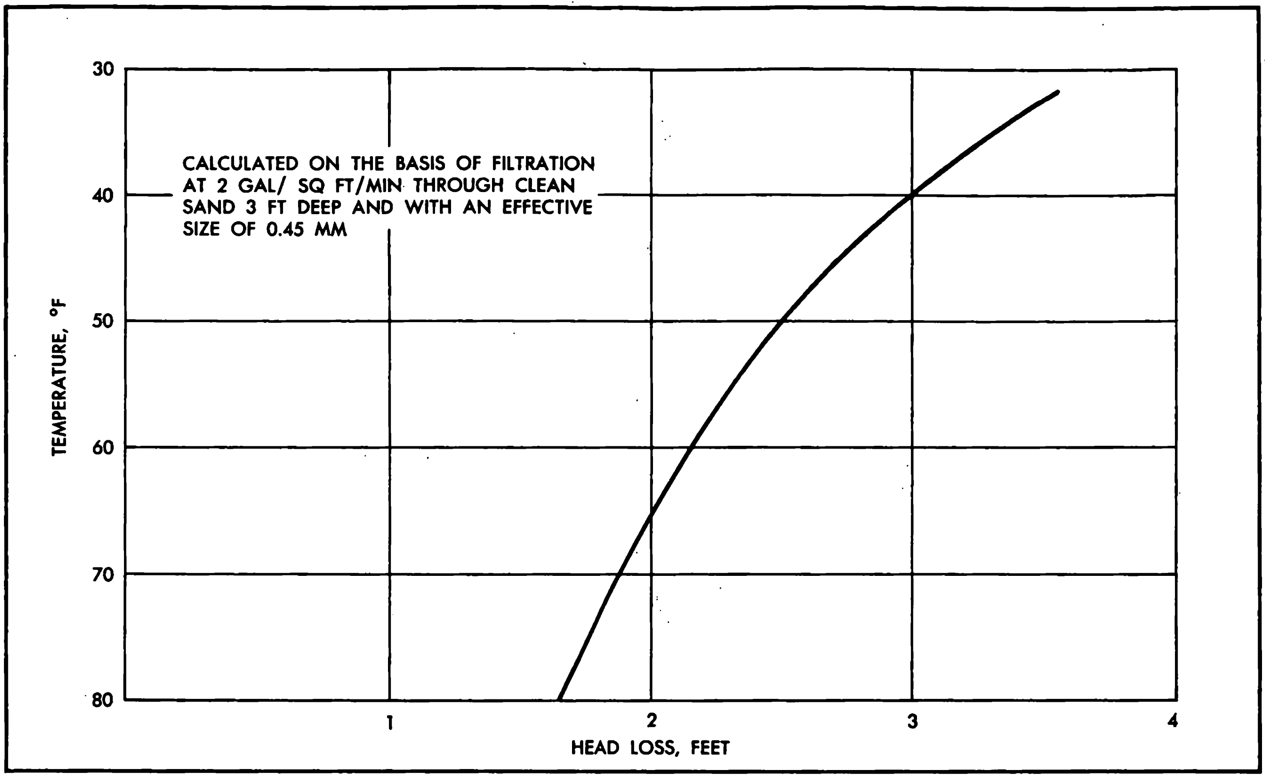


FIGURE 2D2-10

Relationship Between Temperature and Loss of Head in Sand Filter (After Flinn, Weston, and Bogert)

heated shelter. The bag must also be thoroughly dried before packing.

9. SALT WATER. Distillation units may be used to treat salt water. Energy requirements are less if the water is provided by distillation rather than by melting salt ice and distilling the resulting water. For a discussion of desalting of sea water, consult Ref. 75.

10. SNOW AND ICE TREATMENT. Water may be obtained by melting snow or ice. Glacial water is suitable if the sediment is settled out. If only ice and snow are available, ice is the preferred source because it yields the most water with the least effort. Wet or frozen snow is better than powdered snow. Small quantities of snow or ice may be eaten when persons are on the move or warm, but it should never be eaten in large quantities or lumps. It is better to eat a little snow often than to wait until thirst causes a person to eat too much. Sucking ice or snow without putting it entirely into the mouth causes chapped lips and discomfort. Tired, hot, or cold persons should not eat snow.

Improper melting of snow in a container may burn the bottom of the container. About half an inch should first be melted, and then small quantities may be added from time to time, keeping the mixture a slush. The water should be purified by boiling or using iodine whenever there is any question of its cleanliness or purity. Iodine tablets are most effective when the water is warm. Canteens should only be filled about three-quarters full when water is carried, so that they will not be damaged by freezing. A small stove, candles, improvised oil stoves, or other light, compact heat sources must be kept available for melting ice and snow. Solid fuel or a primer-type gasoline stove are most desirable under low-temperature conditions.

2D2.05 WATER SUPPLY STRUCTURES AND APPURTENANCES

1. GENERAL. Proper housing, insulation, and protection must be provided for all equipment and processes. Due regard must be taken to protect all

FIGURE 2D2-11

Hand-Pumping Kit-Type Purification Unit

units from the destructive forces of seasonal frost. The effect of permafrost must be evaluated before pumping stations, distribution systems, treatment facilities, and water towers are constructed.

Suggested methods for building a foundation construction are covered in other Sections of this publication, and only the peculiarities of construction of water and sewage works are discussed in this paragraph.

2. PRACTICAL CONSIDERATIONS. Annually repeated displacement of foundations, walls, and other parts of a structure causes leaks in reservoirs, cracks in walls, and breaks in foundations, and threatens stability. Long-term change in permafrost conditions at the site may also bring about the same effects.

Thawing of ground under pumphouse floors must be prevented. Pipes passing through a pumphouse floor and under buildings must be properly insulated to prevent frost destruction. Pipes placed under continuous foundations may cause damage to the foundation if they are not properly insulated.

Foundations and walls should be finished smoothly, which decreases the cohesiveness of frozen ground with the wall and tends to prevent raising of foundations. It is also desirable to give foundations a trapezoidal profile. The surrounding

FIGURE 2D2-12

Lyster Bag

excavation should be filled with coarse sand or gravel, and water should be led off by a drain. Clay or asphalt berms may be necessary to lead off surface water. Location of settling basins, mixing chambers, and other units of a treatment plant aboveground facilitates housing and protection of the units from unequal forces of freezing and thawing ground and affords better opportunity to prevent permafrost destruction.

Unequal expansion and contraction of dissimilar materials used in equipment may result in damage to the unit. All piping must be installed with steep slope so that rapid drainage may be accomplished, and all drain ports must be sufficiently large to permit rapid drainage. All water-lubricated equipment is subject to rapid freezing immediately on stopping, unless heated. Water-lubricated equipment may be considered unsatisfactory in some instances for Arctic use. Pumps, even though they are not water lubricated, may frequently freeze when they are stopped. Prompt drainage may leave enough moisture in a centrifugal pump to permit freezing of the impeller blades to the housing.

Hydraulically operated control equipment employing water is not well adapted for operation under low-temperature conditions. Elevated storage must be properly insulated and heated with a recirculating heater system. For rapid-sand filter plants, washwater pumps are sometimes preferable to elevated storage for backwashing filters. It is desirable to provide for proper reuse of filter washwater and to take advantage of other water conservation possibilities in Arctic water treatment.

Radiant heating and ventilating fans to maintain even heat distribution are highly desirable in providing appropriate heating facilities for enclosures containing treatment units. Appropriate provision must be made for using heated outside air for ventilation of enclosures in which exposed water surfaces or other vapor sources may exist, which tends to cause excessive condensation of moisture on the cold surfaces of the enclosing structure. Appropriate vapor barriers must be provided over all the insulating walls in these enclosures to prevent soaking and damage of insulating materials from excessive condensation.

2D2.06 WATER DISTRIBUTION

1. METHODS. Several means have been employed to distribute water under low-temperature conditions. The most common is by tank truck. Preheated water, distributed by a recirculating system, and heated pipe galleries are also used in water distribution.

Permafrost complicates the laying and operation of a water distribution system. Only a shallow layer of top soil thaws in summer and then only in an insignificant amount. Permafrost extends down into the ground so deep that it is impractical to attempt to lay water mains below it. Laying mains at usual depths may cause freezing of the water.

In North America, difficulties of water distribution by pipe placed in permafrost have been predominantly overcome by using heated distribution galleries called utilidors, but in the Soviet Union the predominant method is reported to be by using recirculating systems, with the water preheated.

2. TANK TRUCK DISTRIBUTION. Distribution by tank truck and carboy, the most common methods employed, leaves much to be desired because the water is subjected to excessive handling and exposed to many opportunities for contamination. A residual of disinfecting agent must be maintained in the water at all times. It is difficult to maintain a properly effective residual with low water temperature, frequent handling, pumping, jostling, heating to relatively high temperature to prevent freezing, aeration, and so on. Hoses are contaminated by dragging on the ground and by handling. Carboys, tanks, and hoses are difficult to clean and keep clean. Filling facilities are often makeshift and may introduce contamination.

All valves, controls, drains, hinges, seals, close-fitting edges, and movable equipment must be designed and constructed for operation at $-80°$ F. This same equipment must also serve its purpose at normal temperatures. Dusttight gaskets are necessary during dusty periods. Hoses, pails, and carboys, as well as tanks, must be kept free from dust and filth during all periods of operation.

Tanks must be insulated and constructed of materials that prevent freezing of the water. With a temperature differential of 100° F between water in a well-insulated truck and the temperature of the air, heat losses of from 2 to 3 degrees per hour may be expected when the water is not being jostled.

3. SEASONAL DISTRIBUTION SYSTEMS. Seasonal distribution systems are used in some places. Water pipes that may be disjointed and drained during cold weather are laid on the surface of the ground and used in the warm months. Distribution by tank truck or carboy for domestic use is also practiced in both winter and summer. In addition to interrupted service, the pipe distribution system is usually unfit for carrying water for human consumption. Pipes that are left open and exposed on the ground for several months accumulate whatever contamination may be found on the street. Complete collection, storage, and relaying of the pipe each season is costly and considered impracticable. Hasty assembly and the use of worn and damaged fittings and pipe make the system subject to contamination whenever negative heads occur in the system. Water distribution, during a lengthy portion of the year, must be entirely by tank truck or carboy.

4. UTILIDOR SYSTEMS. Reference should be made to Sections 2A1, 2A8, and 2B2.

5. PREHEATING AND RECIRCULATING DISTRIBUTION SYSTEM. Heating the water to be distributed and recirculating it to a pumping station and heating plant through a system designed and constructed to make the most efficient use of all available heat is, in many instances, the most economical solution to water distribution. It presents, however, many problems of design and satisfactory operation.

a. *Russian Methods.* According to Kojinov (Ref. 76), in 1933 the Moscow Scientific Research Institute of Water Supply worked out detailed technical specifications for laying water pipes in the permafrost region. The Russians have rejected the use of utilidors, and the following recommendations are quoted from Kojinov.

> The pipes are laid directly into the ground about 10 feet deep, i.e., at a depth at which temperature fluctuations are insignificant, and the temperature does not sink below 26.5° F. The foundation under the pipes is made of gravel or sand. The pipe is surrounded for a distance of two diameters by loose earth. This is covered from above by a layer of dry peat eight inches thick. The rest of the trench is filled up with local ground which had been taken out in its digging.
>
> The purpose of the peat layer is to speed up the warming through of the ground around the pipes, this being important only in the beginning of the pipe's functioning. Therefore, if the preliminary heating of the ground has been made in summer, the peat cover is not necessary.
>
> If the pipes are laid in a forest clearing, the longitudinal axis of the latter must not coincide with the longitudinal axis of the pipe. In other words, the main must not be laid along the middle of the clearing, but along its sunny border. The width of the clearing is to be equal to 1½ times the height of trees.
>
> The artificial heating of the water is an indispensable peculiarity of the water supply in the perpetually frozen areas. It is usually car-

ried out in the vicinity of the pump at the beginning of the discharge line. The method of heating chosen is dependent on the kind of engines used for driving the pumps. When steam engines are installed their waste steam and the waste gases of the boilers must be utilized. If electric motors drive the pumps, the heating of the water may be done by means of the electric current or with the help of a special heating boiler. At present, steam heaters utilizing the waste steam are almost exclusively employed.

In concluding, we must state that all expenses for these special measures are quite justified, as they preclude the expenses for continuous repairs of the building, which would be unavoidable if the peculiarities of water supply construction in the perpetually frozen region were not taken into consideration in the design of structures for such areas.

b. *Types of Systems.* The recirculating system consists of a distribution main, a water return main, circulation pumps, and a water heating system. The distribution and return mains may be looped in one continuous line starting and ending at the recirculation pump, or they may be a dual piping system with high- and low-pressure lines placed side by side (see Figures 2D2-13 and 2D2-14).

c. *Service Connections.*

(1) *Single-Main System.* Service connections for the single main are kept operative by one or more of the following methods: (a) good insulation, (b) short service connection utilidors, (c) electrical resistance tape that, when energized, warms the service connection, (d) dual pipe service connection using a scoop-type tap pointed against flow in the street main for the incoming portion of the dual service lines and a return tap with elbow pointed downstream for the return tap, or (e) dual pipe service connection with a small electrically operated recirculating pump in the service line.

Short service connection utilidors may be heated by the heating system at the premises they serve. Heating may be accomplished by forced air or by steam or hot-water lines placed in the service connection utilidor. Figure 2D2-15 shows a typical electrical resistance tape installation. (See also Figures 2A8-21 and 2A8-22.) The scoop-type tap

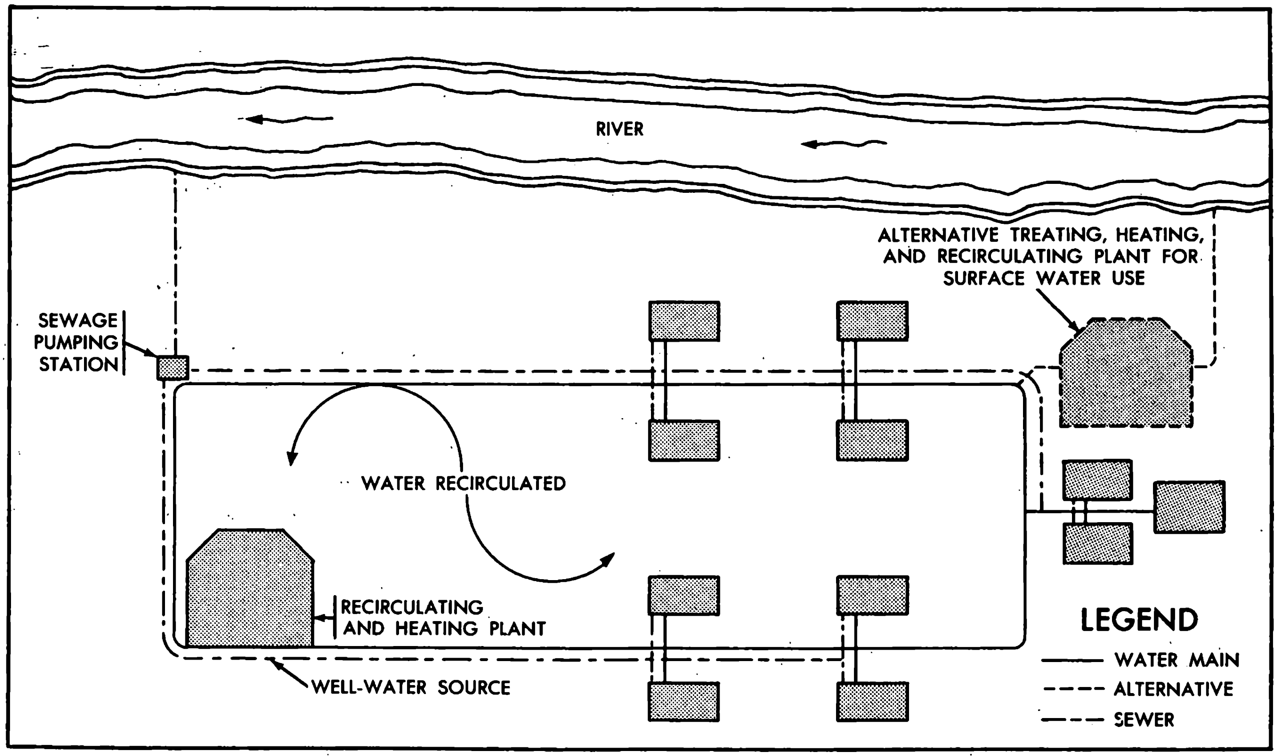


FIGURE 2D2-13

Single-Main Recirculating and Distribution System

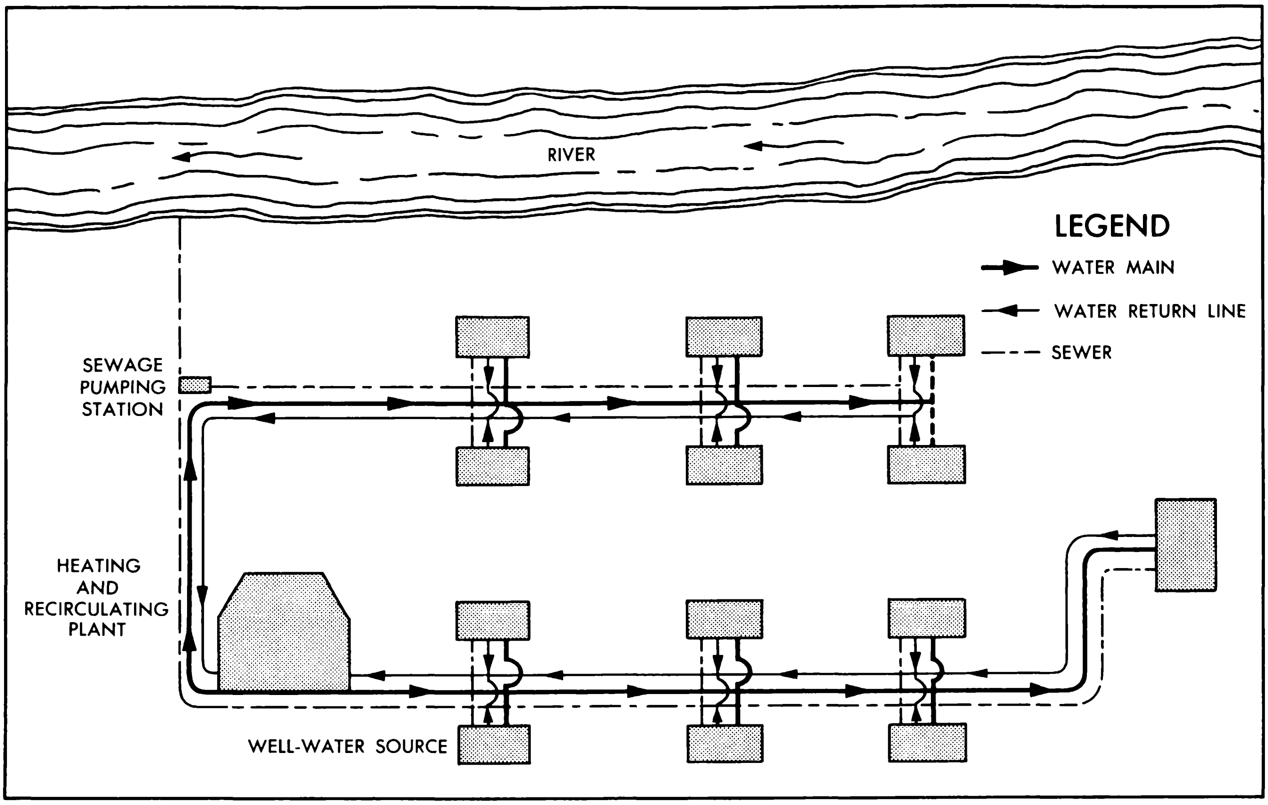


FIGURE 2D2-14

Dual-Main Recirculating and Distribution System

is only effective during periods when there is appreciable water velocity in the street main. During periods of maximum flow, velocity head causes circulation in the service connection line. Small recirculating pumps placed on each service connection use a small amount of electricity to maintain circulation but introduce the additional problem of mechanical as well as electrical maintenance.

(2) *Dual-Main System.* The dual piping system affords positive means for complete recirculation. Service connections to the premises are made by tapping the high-pressure main and serving the property from this main; the unused water, which has cooled, is returned to the distribution system by tapping the return line from the premises to the low-pressure line (Figure 2D2-16). The low-pressure line returns the unused water to the recirculating pump and heating unit.

d. *Preheating.* In recirculating systems the water is usually heated only a few degrees above freezing or to a temperature that just permits the unused water to return to the recirculating pump and heating plant slightly above freezing. It is very difficult to start operating such a system during cold weather. Only small sections of the system should be started at a time, and intensive pumping with continuous waste is necessary until the entire system and the ground around it have been warmed.

Heat conservation and the most efficient use of available heat are necessary for sound engineering design and operation of the recirculating distribution system. Heat losses for the distribution system should be computed for various types of construction, and the most efficient and economical type of main should be selected. Conduction and convection heat losses from the distribution system vary with the type of materials used for the main. These losses also vary with the flow characteristics of the water; greater turbulence dissipates heat faster than it is dissipated from still water.

e. *Location of Pipe.* Location of the distribution system aboveground, on the surface, or

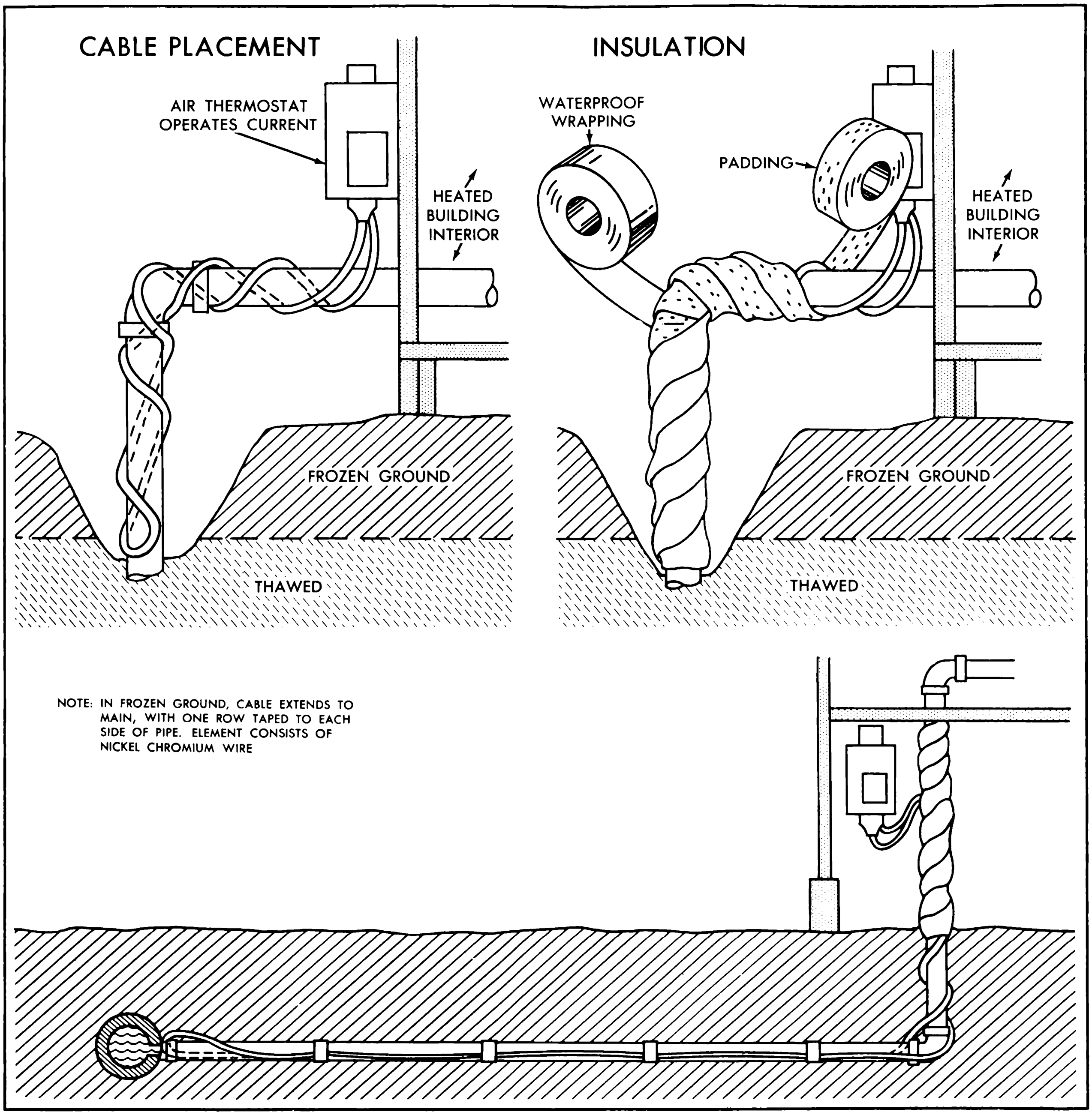


FIGURE 2D2-15

Commercial-Type Resistance Heater for Pipe Protection

underground has been practiced. A careful study of the heat losses involved in each method and the relation of construction, operation, and maintenance costs should be made and evaluated in each instance. In locating pipe underground, careful consideration should be given to determine whether the pipe should be placed at the top of the permafrost table, in the permafrost, or in the seasonally thawed area. If the distribution system is placed aboveground rather than underground, winter temperatures around the system are lower but summer temperatures are higher. If the distribution system is in the permafrost, low temperatures prevail throughout the year, but at no time are

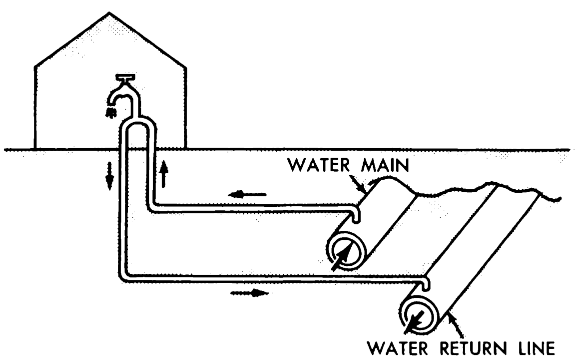


FIGURE 2D2-16

Dual-Main Service Connection

they as extreme as when the pipe is placed on the surface. If the distribution system is placed at the top of the permafrost table, advantage may be taken of the latent heat of fusion of entrapped water. However, when the system is placed at this point, and if insulation is used, it may be damaged or rendered almost useless by ground water.

f. *Other Factors.* Intermittent circulation of water in the system conserves heat. Turbulence is reduced to a minimum when the water is static. Exhaust steam or other waste heat sources should be used in heating the water prior to circulation. Insulation of the distribution system should be done with economical materials. Peat, moss, gravel, and other similar insulating materials may be found readily in many places in the Arctic.

g. *Control of Plumbing.* Rigid control of plumbing is of prime importance on a recirculating system. Cross-connections and backsiphonage conditions must not be tolerated. It is desirable, if possible, to eliminate dead ends and to arrange the distribution system so that the largest users are located at the points of maximum distance for water flow. On large systems, several heating points may have to be established. Location of water mains near sewer mains may help to keep the water mains from freezing, but this is a dangerous practice. Frost action may damage both the waterlines and the sewer lines, with resultant leakage and possibility of contamination of the water supply.

6. HEAT LOSS FROM WATER MAINS. Water pipes located directly in permafrost or within the zone of seasonal frost may be protected from freezing by introducing heat into the system at the beginning of circulation. Excessive amounts of heat should not be added, but enough heat must be added to keep the water just above the freezing point. The quantity of heat required depends on: (a) the difference in temperature of the water in the pipe and the temperature of the soil around it, (b) the thermal characteristics of both the pipe and the surrounding soil, (c) the length and size of the pipe, and (d) the time during which the water in the system is exposed to a cooling effect.

a. *Introduction.* Various approaches have been used in mathematically and physically relating these factors so that the heat balance of a distribution system may be approximated and the effect on the temperature equilibrium of the surrounding materials may be anticipated in terms of time of operation of the system. (See Section 2A8, especially paragraphs 3 and 4 of 2A8.02 and Problem 5, par. 2 of 2A8.03.)

b. *Occurrence of Heat Losses.* The loss of heat in a water system depends to a considerable degree on the operation of the system. The most intensive loss of heat is observed during the flow of the water when the transfer of heat takes place through convection. A very small amount of heat is lost during the static period when water does not move through the pipe, at which time the transfer of heat takes place through conduction through the peripheral layers of water. (Ref. 23.)

Figure 2D2-17 is a nomogram that may be used to determine relationships of pipe size and length, velocity of flow, K values, temperature differences, and length of time the water may remain static in the system. Values of K were empirically determined.

c. *Normal Operating Conditions.* The values of the coefficients K_1 and K_2 given in Figure 2D2-17 correspond to the normal operating conditions of a system that is kept in operation with a regular daily flow of water. Under these conditions the consumption of water should not be less than 8 times the volume of pipes of the entire system. (Ref. 23.)

d. *Initial Operating Condition.* In addition to the computation of heat values for normal operation of a water system, it is necessary to calculate the heat exchange during the initial stage of a system when water is turned on for the first time.

When water is turned on at the completion of the installation, after a prolonged period of inactivity, or after the pipes have been drained, the ground surrounding the pipes attains the lowest temperature, and the pipes are appreciably chilled. It follows that, when water is turned on again, there is considerable absorption of heat by the pipes and by the immediately adjacent frozen ground, resulting in a substantially higher coefficient of the loss of heat, K, than during normal operation. In every water system, therefore, one should take into account the need of additional heating of water during the period when the system is first put into operation. The coefficient K is as yet based on only a few experiments and is given in the table in Figure 2D2-17. (Ref. 23.)

e. *Terminal Point Temperature.* When water is turned on in a newly constructed water system, it is safe enough to allow the temperature T_2 at the terminus of the system to drop to between 1° and 2° C (34° and 36° F). This temperature will prevail only during the initial stage of operation of the system. With the passage of water through the system, this temperature will gradually rise and after a time will attain a certain stability. After that the water system may be allowed to remain static for a duration in accordance with the computed values for such a condition. (Ref. 23.)

f. *Distribution System Temperature Control.* The temperature of a distribution system generally becomes more or less stabilized after the volume of water that has passed through the system is about twenty times the volume of the entire pipe system. To speed up the warming of the pipes during the initial stage of operation, the water is generally forced to flow through the pipes at a higher velocity or, if facilities are available, the water at the starting point is warmed up more than is required for the normal operation. It should be borne in mind, however, that water warmed to a temperature above 20° C (68° F) may cause some damage to the pipeline by excessive expansion, particularly at the joints. Under normal operation of a distribution system the temperature of water T'' at the terminal point during the static (nonflow) period is generally maintained between 3° and 5° C (37° and 41° F). (Ref. 23.)

g. *Principles for Calculating Heat Values.* Two fundamental principles should be used for calculating heat values in a water distribution system.

(1) To determine the temperature at the terminal point of the system, the temperature in the component sections should be calculated in consecutive order in the direction from the terminal point toward the intake where the water is being warmed.

(2) Knowing the available amount of heat from the heating unit, the temperature of water T_1 is determined after the water leaves the heating unit. Then the temperature of water is verified in consecutive order at all the distribution centers down to the terminus of the system. The terminal temperature should never be allowed to drop below the computed permissible minimum. (Ref. 23.)

CAUTION: It is recommended that, for sections of a water distribution system in critical permafrost, careful investigation be made of the extent of thaw resulting from the operation of the system during its estimated useful life. (See Section 2A8.)

Example

Given
$L = 16{,}400$ ft
$d = 6$ in.
$v = 2$ ft/sec
Temperature of water τ at starting point of system $= 50°$ F
Average temperature of ground t during static period $= 26.6°$ F

Determine temperature of water τ_2 at terminus of the system, and the maximum duration of static period Z for the temperature of water at the end of the static period; $\tau'' = 35.6°$ F.

To find τ_2 with

$$T_1 = 50° \text{ F} - 26.6° \text{ F} = 23.4° \text{ F}$$

$$K_1 = 3.7$$

start from the left-hand nomograph with the given value of L and follow the dotted line to the given value of v, then upward to the given value of d and horizontally to the value of K_1; drop a perpendicular from K_1. The intersection of this line with the value of T_1 gives the value of T_2. T_2 for this problem is approximately 13° F.

VALUE OF COEFFICIENTS

OPERATION OF SYSTEM	KIND OF PIPE	K_1 DURING FLOW OF WATER	K AT START OF OPERATION	K_2 DURING NONFLOW PERIOD	K AT START OF NONFLOW PERIOD
WITH DAILY INTERRUPTION IN FLOW OF WATER	CAST-IRON	3.7	7.4	0.37—0.74	1.5
	WOOD-STAVE	1.33	2.2	0.37—0.74	1.29
WITH CONTINUAL FLOW OF WATER	CAST-IRON	1.1	7.4	—	—

VALUES OF k FOR PIPES BURIED IN CLAYGROUND ONLY

LEGEND

ON LEFT HALF OF GRAPH

L LENGTH OF WATER SYSTEM, FT
d DIAM OF PIPES, IN.
v VELOCITY OF FLOW OF WATER FT/SEC
Z DURATION OF STATIC PERIOD OF WATER IN PIPES, HR

ON RIGHT HALF OF GRAPH

K COEFFICIENT OF HEAT LOSS BTU/SQ FT/HR
T_1 DIFFERENCE IN TEMPERATURE BETWEEN FLOWING WATER AND GROUND AT STARTING POINT OF SYSTEM
T_2 DIFFERENCE IN TEMPERATURE BETWEEN FLOWING WATER AND GROUND AT TERMINUS OF SYSTEM
T_2' DIFFERENCE IN TEMPERATURE BETWEEN STANDING WATER AND GROUND AT STARTING POINT OF SYSTEM
T_2'' DIFFERENCE IN TEMPERATURE BETWEEN STANDING WATER AND GROUND AT TERMINUS OF SYSTEM

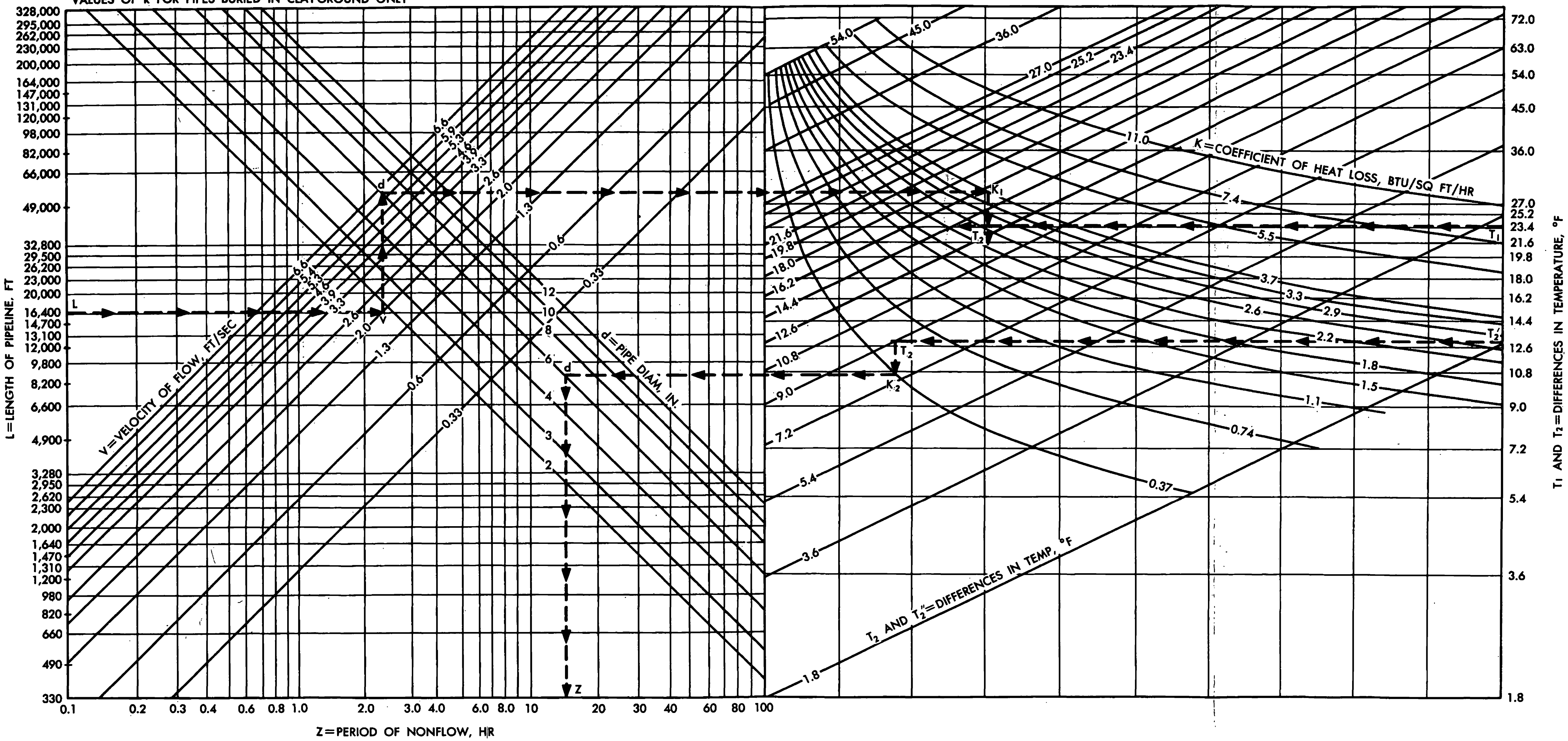


FIGURE 2D2-17

Nomogram To Determine Water Temperature in Pipes

Therefore,

$$\tau_2 = T_2 + t = 13^\circ \text{ F} + 26.6^\circ \text{ F} = 39.6^\circ \text{ F}$$

To find Z with

$T_2 = T_2'$ (par. 6e of 2D2.06)

$T_2'' = \tau'' - t = 35.6^\circ \text{ F} - 26.6^\circ \text{ F} = 9^\circ \text{ F}$

$K_2 = 0.37$

start from the right-hand nomograph with the given value of T_2' and follow the lower dotted line until it intersects the computed value of T_2'', then drop a perpendicular from this value to intersect the curved line representing assigned values of K_2. From this value of K_2, project a horizontal line to intersect the diagonal of the given pipe diameter (in the left-hand nomograph). From this intersection, project a perpendicular to obtain the value of Z. Z for this example is approximately 14 hours.

Section 3. SEWAGE AND WASTE DISPOSAL

2D3.01 GENERAL

The need for proper disposal of sewage wastes under low-temperature conditions is as important as it is in temperate climates. A long record of the occurrence of typhoid fever and dysentery in the Cold Regions establishes this fact. The degree of treatment and care in sewage disposal must, as in temperate climates, be predicated upon concentration of population, water uses, and availability of water for dilution of wastes. Table 2D3-1 gives an indication of the quantity of sewage to be treated from a 22-man barracks.

TABLE 2D3-1

Daily Human Wastes From 22-Man Barracks

Waste	Weight, lb/day	Water content, percent	Volume, gal/day
Fecal	7.26	75 to 80	
Urine	48.4 to 87.1	95 to 96	5.8 to 10.6
Combined	55.9 to 94.6	93.3 to 94.4	6.7 to 11.3

Note: For Arctic use, a 40-percent overloading factor is advisable.

2D3.02 SEWAGE TREATMENT (Ref. 77)

On cold-weather difficulties involved in sewage treatment plant design and operation, the Subcommittee on Waste Disposal of the Committee on Sanitary Engineering and Environment, National Research Council, reported as follows.

1. GENERAL.

Winter-borne difficulties in a plant are likely to be cumulative. A defect at one point in a plant caused by cold or storm is apt to have consequences the effect of which will spread progressively to interfere with the performance of other plant units. For example, sludge drying beds that have become overloaded during the winter as a result of inadequate capacity or insufficient attention on the part of the operator may result in overloaded sludge digesters; these in turn may result in a deterioration in the quality of supernatant returned to the primary settling tanks; these units are apt thereby to perform with impaired efficiency, with the result that secondary units become overloaded. Solids in the primary effluent coupled with freezing may put the filter distribution system partly out of service. With poor distribution and heavy loading, the effluent will deteriorate and the entire plant may go out of kilter.

Winter difficulties may be attributed to sources that fall into two categories, as follows: (A) Minor deficiencies of design or operation, such as control valves sited in positions exposed to cold winds, lack of screens to protect filter nozzles, lack of provision for draining tanks, and lack of suitable lighting for nocturnal inspection; and (B) Major defects in design, such as inadequate capacity of or means for maintaining heat in important plant units.

Especially important among the points of design that fall in category (A) are those that pertain to the safety and comfort of operating personnel. To provide men with facilities for walking in safety, working without unreasonable exposure, and seeing with ease is to make a real contribution toward elimination of cold-weather trouble. It is certain that with forethought on the part of the designer and ingenuity and resourcefulness on the part of the operator, many of the problems that beset sewage plants during cold periods may successfully be encountered.

2. EFFECT OF COLD.

In order to evaluate more comprehensively the requirements for weatherproofing and heating of sewage plants in the low-temperature areas of the North, it is pertinent to consider the effect of cold on the organic content of raw sewage and on the physical and biochemical processes of stabilization, both within plants and in receiving waters.

a. *Organic loading.*

Higher amounts of BOD and SS per capita in northern plants may be anticipated as a result of two factors: (1) Lower temperatures of water (less treatment in sewers, if not heated); and (2) less bivouacking (non-contributory population)—field maneuvers will be more restricted during colder portions of the year. The first factor is a relatively minor one, and at most, probably would cause an increase in organic loading of the order of ten percent above that usual in sewage plants at military posts in temperate climates. The second factor may exert a sizable effect. The proportion of contributory (sewered) population to nominal population of ten decreases at military posts during warm months in which field maneuvers are practiced; this is generally accompanied by a substantial reduction in per capita loading at sewage plants.

b. *Pretreatment units.*

Universal experience in sewage plants in the northern U.S. and Canada with screens, bar racks, shredders, comminutors, detritus tanks, and grit chambers has been that these units, which must be frequently inspected and cleaned, may be subjected to icing to such an extent as to render maintenance difficult or impossible unless covering or housing is provided. It would appear that in plants designed for operation in the far North, housing is a necessity for pretreatment units, together with pumps and flow-measuring equipment.

c. *Settling Tanks.*

Of all sewage treatment devices in common use, settling tanks appear to be least vulnerable to cold.

The chief difficulties that have been experienced in the operation of settling tanks during intervals of low temperature have resulted from the interference of ice with sludge and scum removal mechanisms. These devices now seem for the most part to have been successfully adapted to function properly despite the rigor of the climate in the northern U.S. and Canada.

Two factors, however, militate against the use of open settling tanks in the extreme cold of the far North: (i) the loss of heat needed for proper action in secondary oxidizing units and in outfall lines; and (ii) the formation of sheet ice of sufficient thickness to endanger tanks structurally. While the thin ice sheets that have been described may have no particular deleterious effect on operation, sheets of several inches in thickness that theoretically could form under Arctic conditions could easily muster sufficient compressive strength to break tanks if the operating staff did not persist in breaking up the formation. These factors are especially significant in sewage plants at military posts, where periods of inactivity may result in low flows and long detention periods.

The influence of temperature on the performance of settling tanks has been the subject of a number of investigations. The main conclusion is that no pronounced deleterious effect of cold *per se* on efficiency is manifest. Particles settle more slowly in cold fluids because of increased viscosity. The time for a sewage particle to settle a given distance at 60° F is increased by a factor of 40 percent when the temperature drops to 40° F. On the other hand, particles in sewage tend to be somewhat larger and heavier during cold weather. Low temperatures affect the stability of colloids adversely and agglomeration rates are increased. In cold weather, moreover, gas-buoying of sludge particles is reduced.

It would appear that most settling tanks perform more efficiently on the whole during warm weather if maintained in aerobic condition.

Grit chamber design should provide for almost 50 percent more required time for settling of mineral solids in the Cold Regions. Increased viscosity and load of silt in sewage at temperatures of from 32° to 35° F lessen efficiency of the grit chamber.

d. *Trickling Filters.*

Despite their merits in other respects, trickling filters have always been found to be one of the sewage treatment devices most vulnerable to cold weather. In many parts of the Midwest it has become almost standard practice to provide cover for filter units; this has increased the cost of construction, but the justification has been in the fact that little operational trouble has been experienced, even in severe climates, with housed filters. There can be little doubt that housing is indicated for trickling filters in the Far North, except perhaps under unusual mitigating circumstances (for example, seasonal operation).

Results of several investigations indicate that trickling filters generally have lower efficiencies in cold weather. While the observed differences are not often found to be large, the problem is one of considerable importance in the design of filters for low-temperature regions.

In this connection (efficiency) it is of interest to estimate the increase in volume of media of a filter that would be required in winter in order to retain summertime efficiency. Such an estimate is made in the following computation, which is based on the filter formula developed by the NRC Subcommittee on Military Sewage Treatment:

$$y = \frac{100}{1 + 0.0085\sqrt{x}}$$

where

y = the BOD efficiency (percent) of filter and secondary settling tanks

x = the filter loading of applied BOD, lb/acre ft/day

If x is taken as the median value of the summer loadings, i.e., 372 lb/afd, then the average summer efficiency, y_s, may be calculated by substitution in the formula:

$$y_s = \frac{100}{1 + 0.0085\sqrt{372}} = 86.0 \text{ percent}$$

The corresponding winter efficiency, y_w, using an assumed average difference of 2.93 would be

$$y_w = 86.0 - 2.93 = 83.07 \text{ percent}$$

The BOD loading, x_w, corresponding to this figure may be evaluated from the relation

$$83.07 = \frac{100}{1 + 0.0085\sqrt{x_w}}$$

or

$$x_w = 576 \text{ lb/afd}$$

Hence, a difference in BOD efficiency of 2.93 percent corresponds to a difference in volume of

$$\frac{2(576 - 372)}{(576 + 372)} 100 = 43 \text{ percent}$$

That is, in winter the volume of a filter must be 43 percent larger to attain the same degree of treatment it attains in summer. The Army Engineering Manual of the Office of the Chief of Engineers specifies that filters in the northern states be designed 25 percent larger than in southern states. This is in line with the foregoing figure when account is taken of the difference in the average annual temperatures of the two sections of the country.

Filters in the Arctic would operate at temperatures lower on the average than those analyzed, and an allowance greater than 25 percent for temperature is therefore required. Since the average annual temperature in northern Alaska is about 8° F, an allowance of the order of 50-60 percent appears to be indicated.

There is, of course, the question of the economic justification for such substantial increases in volume to attain such seemingly small increases in efficiency. This is the crux of the comparison of the relative merits of the high-rate and standard trickling filters, and the former certainly serve a useful function. The last fraction of organic load is expensive to treat. Whether its removal is worthwhile depends upon the local situation. In some streams it may represent the difference between effective and ineffective treatment; in others it may be unimportant.

e. *Activated-Sludge Aeration Basins.*

Cold-weather difficulties with activated sludge units have generally been less serious than with open trickling filters. Troubles due to freezing and snowing up have rarely been reported. The process inherently entails less exposure of sewage to cold dry winds; moreover, units are relatively compact and more easily protected by covers and windbreakers. Such troubles as have been reported are usually caused by improper functioning of other plant units—e.g., overloading by bad primary tank effluents. Some difficulties have been described in mechanical aeration plants due to icing of emerging paddles; such devices, however, are not common in North American practice.

The extensive use of the activated sludge process in Canada is indicative of its ability to function during periods of low temperature. Insofar as military plants are concerned, however, this advantage is offset to a certain extent by the somewhat disappointing experience with the process during World War II. The high volatile and grease content of military sewage, the rapid variation in diurnal flow, and the frequent changes in loading due to shifts in contributory population were, no doubt, important factors in the failure of the process to produce the degree of treatment commonly attained in municipal activated sludge plants.

A number of investigators have examined the effect of cold weather upon activated sludge operation. In general, it may be said that the adverse effect of cold on the performance of activated sludge plants is less than it is on trickling filter plants.

Bloodgood, in analyzing records at the Indianapolis plant for several years, found that lower temperatures in the aeration basins caused a reduction in the quality of the effluent unless compensating measures, such as increasing the retention time, were taken. At the Indianapolis plant the secondary treatment units were not large enough to give complete treatment to the entire flow of sewage. The plant was operating by treating the maximum amount possible in the activated sludge units and the balance by plain aeration. The proportion of sewage routed through each unit was such as to give the best combined effluent. With applied sewages of BOD concentrations ranging from 165 to 226 ppm, it was found that when temperatures decreased from 79° to 57° F, the detention period had to be increased about 45 percent in order to achieve the same degree of treatment.

Aeration takes place more slowly when temperatures are low because of increased viscosity of sewage. It is possible that heating the air used in the aerating process may be desirable under extremely low temperature conditions.

There would appear to be no inherent limitation in the activated sludge process that would interfere with its adaptation for use in the Far North. Designs should provide for ample detention periods and for large volumes of activated sludge. Digestion facilities should be proportioned accordingly.

f. *Sludge Digestion and Disposal.*

The chief problem with heated sludge digesters engendered by cold weather is the added heat requirement to maintain adiabatic digestion. Other difficulties that have been reported include the freezing of liquid seals on gas domes, maintenance of waste gas burners, and icing and uneven weighting by snow of floating covers. Most winter complaints, however, stem from inadequate sludge storage capacity rather than from difficulties with cold.

Figure 2D3-1 shows the relationship between digestion tank capacity and temperature.

Reports of unsatisfactory Imhoff tank performance during cold weather have not been uncommon. The causes have usually been overloading, lack of attention (cleaning, skimming, etc.), and insufficient heat in sludge storage compartment.

Difficulties with sludge disposal during intervals of low temperature have been almost universal. The problems have been manifest in particular at small plants, where mechanical methods (conditioning, dewatering, incineration, etc.) are not practicable. The complaints have usually related to inability to remove sludge during inclement weather. The literature on the pros and cons of open versus glass-covered sludge drying beds is extensive and indicates that the question is one of economics, at least insofar as treatment in temperate zones is concerned. In practically all cases, cold-weather difficulties derive from beds that are inadequate as to size or as to drainage characteristics. Nearly every experienced operator knows that there is no easy solution to the problem of overloading sludge beds. If repeated applications of sludge are made on top of semi-dry sludge, trouble is piled up for the future. Sludge is thereby deprived of effective drainage at the bottom, and evaporation is limited because of the excessive depth. The accumulated sludge may require such a long time to attain a spadable condition that it may happen the next cold period must be met with an even more unfavorable situation as to sludge bed capacity.

All such difficulties, it may be expected, will be markedly increased in the Arctic. On the basis of the relative duration of periods of warm weather, it may be estimated that sludge beds in the North should have capacities from three to six times larger than those common in conservative practice in the States.

The relative costs of constructing, insulating, and heating of sludge digesters in the Arctic may be expected to be different from those in the States. Accordingly, it may be found that the

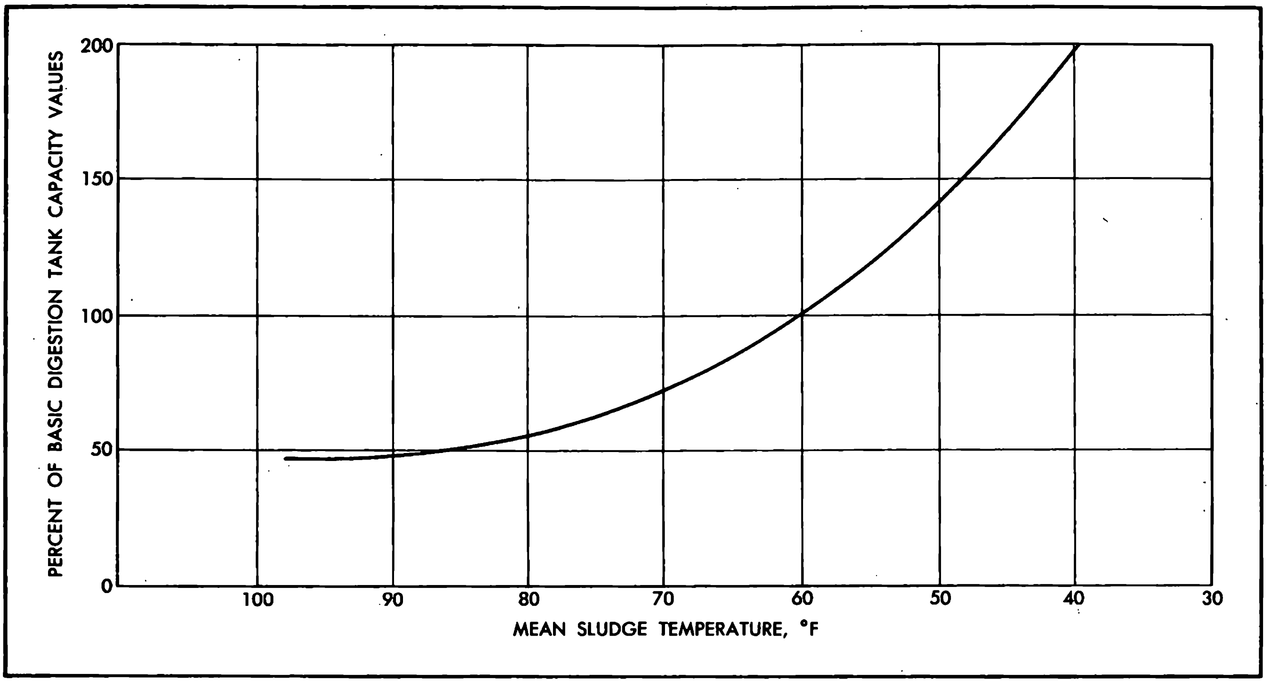


FIGURE 2D3-1

Relation of Digestion Tank Capacities to Mean Sludge Temperature (After Imhoff and Fair)

optimum temperature for Northern digesters will not be in the range of 85°-95° F that is common in temperate zones. A sufficient amount of operational data are available to anticipate with a fair degree of precision the performance of digestion tanks operated at any temperature and with any loading within reason.

Available data indicate that considerably longer periods are needed at low temperatures to effect a given degree of compaction of sludge than are necessary at higher temperatures.

g. *Effect of Temperature on Self-Purification in Receiving Waters.*

Rates of biochemical stabilization and bacterial die-away in streams are markedly lower at near-freezing temperatures than at higher ones. This has much significance in the design of Arctic sewage plants. The organic material and bacteria in the effluent of sewage plants will persist for much greater distances and longer times in the cold streams of the North than in the warmer streams of the continental U.S. An indication of the time required in the self-purification process is given by the BOD reaction-velocity constant, k, in the first-order equation

$$y = L(1 - 10^{-kt})$$

which approximately expresses the time-rate of biochemical oxidation. In this equation y is the amount of BOD remaining after time, t, starting with the initial (ultimate) BOD, L. The reciprocal of the reaction-velocity constant, $\frac{1}{k}$, gives the time necessary to effect a 90 percent reduction of the initial BOD.

It may be concluded that purification periods 3 to 5 times longer are required at near-freezing temperatures. The effect of temperature on the ultimate oxygen demand, L, is less pronounced. The die-away rates of such pathogenic bacteria as *Eberthella typhosa, Salmonella schottmuelleri,* and *Entamoeba histolytica* decrease by a factor of 2 to 3 for each 50° F decrease in temperature.

In view of the retarding effect of low temperatures on bacterial die-away, it would appear essential that at many sites facilities for chlorination be provided in Arctic sewage plants discharging into waters that are used for water supply.

Stream reaeration rates are lower in cold water than in warm water. Adeney found a decrease in the reoxygenation rate of about 17 percent with each decrease of 50° F. This figure applies to open streams; reaeration in ice-covered streams may be negligible.

It is evident from all of the foregoing considerations that requirements as to the degree of treatment in a sewage plant in a region where the mean temperature is less than 10° F during a large part of the year may differ materially from those that suffice in temperate zones.

3. WEATHERPROOFING AND HEATING.

The importance of proper siting of sewage plants in the Arctic can hardly be over emphasized. Marked differences in the degree of exposure of buildings to wind and cold are created by relatively minor features of topography. Local mean temperatures differ considerably at different sites in Northern areas where long shadows are cast by the sun during a large portion of the year. The average wind velocity increases about in proportion to the cube root of the height of a structure above the mean local elevation.

A warm zone of soil and melted frost exists around heated tanks and other sewage treatment devices that are maintained in frozen ground. This zone aids in insulating against cold air. The volume of the zone varies from approximately one to two times the volume of the structure, depending upon the temperature differential. During a period of extreme cold the volume of the unfrozen zone slowly decreases—measurements show that the lag in response to new conditions is of the order of a month, since the heat capacity is large and the conductivity is small. The warm zone under and around a tank acts as a heat reservoir that effectively buffers the structure against extreme cold periods of short duration such as are usual in the States. If the cold period is prolonged to the duration of extreme cold that occurs in the Arctic, the buffering action may fail, and unless the structure is well insulated and heated, it can not continue to operate. For this reason it can not be inferred that a design that has been successful at, say, −30° F in the northern U.S. will perforce be satisfactory in the Arctic.

a. *Design Criteria.*

In the economical design of the various units of a sewage plant, it is of key importance to strike an optimum balance between expenditure for insulation and that for heating. Relevant data include (1) the degree-days of cold based upon the operating temperature of the unit (40° F for a settling tank, 90° for a digester) rather than the conventional 65° F used in the common definition of degree-day; (2) the availability and feasibility of the use of different types of insulation; and (3) the physical properties of the soil at the site.

A summary of heat transfer data for sewage, sludge, and sewage plant construction materials is presented in the following outline. [See also Section 2A8.]

$$q = \left(\frac{k}{x}\right) A (T_2 - T_1)$$

where

q = heat flow, Btu/hr

k = thermal conductivity, Btu/hr/sq ft/°F/1 in.

x = thickness of the material in inches, measured in the direction of heat flow

A = area of the material normal to the direction of heat flow, square feet

T_1, T_2 = boundary temperature, °F

Conductivity of fluids
(k, Btu/hr/sq ft/°F/1 in.)

Water	4.0
Sewage	4.0 to 4.1
Raw sludge	4.5
Partly digested sludge	5.0
Digested sludge	5.1
Ice	13.0 to 17.0

The over-all coefficient of heat transfer, U (Btu/hr/°F/sq ft), for compound walls of several materials (including airspaces) shall be selected or computed as indicated in the ASHVE *Guide.*

Heat flow may be computed from the following relation:

$$q = U A (T_2 - T_1)$$

The over-all transfer coefficients for concrete tanks containing sewage or sludge vary markedly with the moisture of the surrounding soil. Typical values are as follows:

Condition	*U (Btu/hr/sq ft/°F)*
Concrete tank in dry soil, top covered and flush with surface	0.10

Condition	*U(Btu/hr/sq ft/°F)*
Concrete tank in dry soil, top covered, with ¼ of structure aboveground	0.20
Concrete tank in wet soil, top covered, with ¼ of structure aboveground	0.40 to 0.75
Concrete tank in wet soil, top open, with ½ of structure aboveground [1]	1.0 to 2.5
Housed trickling filters	0.5 to 2.0
Open trickling filters	2.0 to 6.0

[1] Heat loss variable, depending on wind, humidity, and rate of flow.

The heat maintenance problem in Arctic plants is of sufficient importance to justify some compromise between the shaping of units for efficiency in settling or in ventilation and the shaping for maximum heat conditions.

The cooling of still water (in a tank) proceeds with the transfer of heat to the atmosphere. The upper layers of water become more dense and sink to the bottom, forcing warmer water upward. The process continues until the body of fluid becomes isothermal at 39.2° F. As the cooling progresses, the density of the upper layers is decreased; they remain at the top and are rapidly cooled to the freezing point. Freezing begins (usually at the edges of the tank) after an amount of heat equal to the latent heat of fusion (144 Btu/lb) has been abstracted. As the ice sheet is built up, the rate of heat transfer is reduced by the insulating action of the ice itself.

The heat, H (Btu/hr), necessary to maintain the temperature drop, $T_i - T_o$, (°F), at any desired amount in a sewage treatment device with a surface area A (square feet) and an over-all heat transfer coefficient, U(Btu/hr/sq ft), and carrying a discharge of Q (mgd) may be computed approximately from the following heat balance equation:

$$H = U\,A\left[\left(\frac{T_i + T_o}{2}\right) - T_a\right] - \frac{1}{24}\left(8\frac{1}{3}\right)(10)^6\,Q(T_i - T_o)$$

$$= U\,A\left[\left(\frac{T_i + T_o}{2}\right) - T_a\right] - 347{,}000\,Q(T_i - T_o)$$

If no heat is added to the structure, the inlet temperature may be calculated from the other quantities, if these are known, by the following relation:

$$T_i = \frac{(694{,}000\,Q + U\,A)T_o - 2U\,A\,T_a}{694{,}000\,Q - U\,A}$$

Likewise, the outlet temperature may be calculated from the equation

$$T_o = \frac{(694{,}000\,Q - U\,A)T_i + 2U\,A\,T_a}{694{,}000\,Q + U\,A}$$

if the other variables are known.

b. *Planning.* According to the National Research Council committee report, the following points are important in planning and operating heating facilities for sewage works.

(1) It is advantageous to use the same basic plan for heating sewage, sludge, buildings, and equipment. This simplifies operation, maintenance, and repair.

(2) Internal heat exchanges with hot water coils or external heat exchangers may be used for heating facilities, and a selection of the type should be made after consideration of all the advantages and disadvantages for the particular type in question at the installation under consideration. Figure 2D3-2 shows possible arrangements for external heat exchangers.

The following advantages and disadvantages for heat exchangers are listed from Ref. 77.

A. Internal Heat Exchangers: Hot Water Coils in Tank

1. Types: vertical and horizontal. Vertical less prone to collect sludge and form scale, but are more likely to induce high-velocity thermal current. Accessibility is chief advantage pertaining to vertical. Coils embedded in walls do not accumulate scale or corrode on the outside, but have a lower over-all heat transfer coefficient.
2. Advantages.
   a. Simplicity.
   b. Easy to combine with sludge digester heating arrangement if common method of heating is used in latter.
   c. Scale formation less with relatively large area of coils (as compared with small area of transfer used in other heating methods).

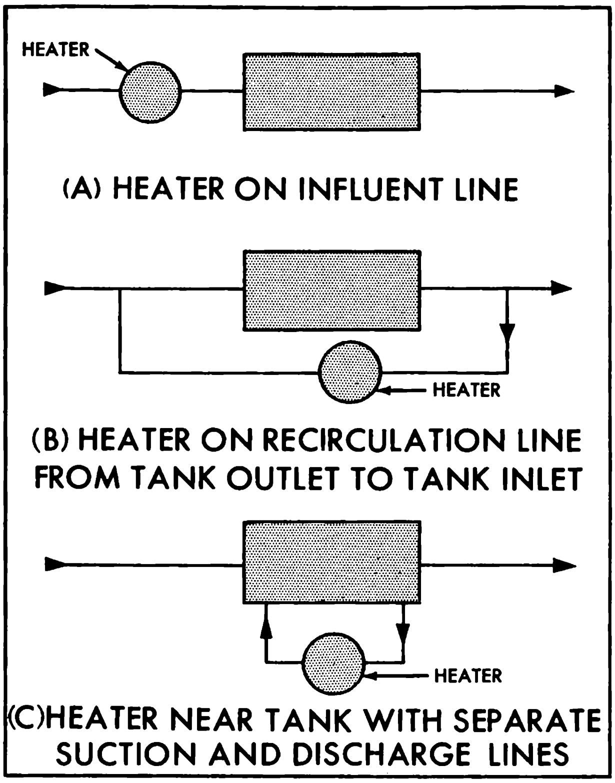


FIGURE 2D3-2

Arrangement of External Heat Exchangers (Ref. 77)

3. Disadvantages.
   a. Temperature nonuniform in tank and thermal currents may impair settling efficiency.
   b. High local temperatures may cause sludge flotation; anaerobic biological activity may cause odors. Gases coming out of solution on and near coils may interfere with settling.
   c. Waste heat.
      (1) In flue gas from boiler.
      (2) In transmission line from boiler to digester.
   d. Settling tank out of service during repair of horizontal coils.

B. External Heat Exchangers

1. Location.
   a. On influent line [(A) of Figure 2D3-2].
   b. On recirculation line from tank outlet to tank inlet [(B) of Figure 2D3-2]. When recirculated flow is heated, tank temperature may be controlled two ways: (i) by varying the rate of recirculation and (ii) by varying the temperature gradient in the exchanger. Without recirculation, only the latter method of control is available. Hence B 1 b and B 1 c afford more positive control—temperature may be maintained even when the plant inflow is low or zero.
   c. Near tank with separate suction and discharge lines [(C) of Figure 2D3-2]. Not so satisfactory as b because of thermal currents resulting from nonuniform distribution of heat in tank.
2. Advantages.
   a. Readily accessible for repair.
   b. Settling tank need not be taken out of service to repair heat exchanger, since it may be heated by another heat exchanger.
   c. High velocities in exchanger bring about higher heat transfer coefficients.
   d. Much developmental work has already been done on external heat exchangers for sludge heating in small plants. Commercial heaters using gas and gas-oil burners with automatic thermostatic control are available. [Figure 2D3-3.]
   e. Heat may be applied to flow in inlet pipe (B 1 a and b), avoiding sharp thermal gradients in tank that may interfere with settling. However, if inflowing fluid is considerably warmer than average temperature in the tank, it may ride over tank fluid directly to the outlet. Short-circuiting of this nature may result in inadequate treatment. Moreover, the lower portion of the fluid may develop objectionable odors if circulation is inadequate.
3. Disadvantages.
   a. Large temperature gradients in exchanger tend to accelerate the rate of build-up of scale.
   b. Wastes heat.
      (1) In flue gas.
      (2) In transmission to digester.
   c. If recirculation fluid heated (B 1 b and c), then tank volumes must be increased to provide necessary detention period. (This would, of course, not be disadvantageous if recirculation were otherwise necessary, as in high-rate filtration.)

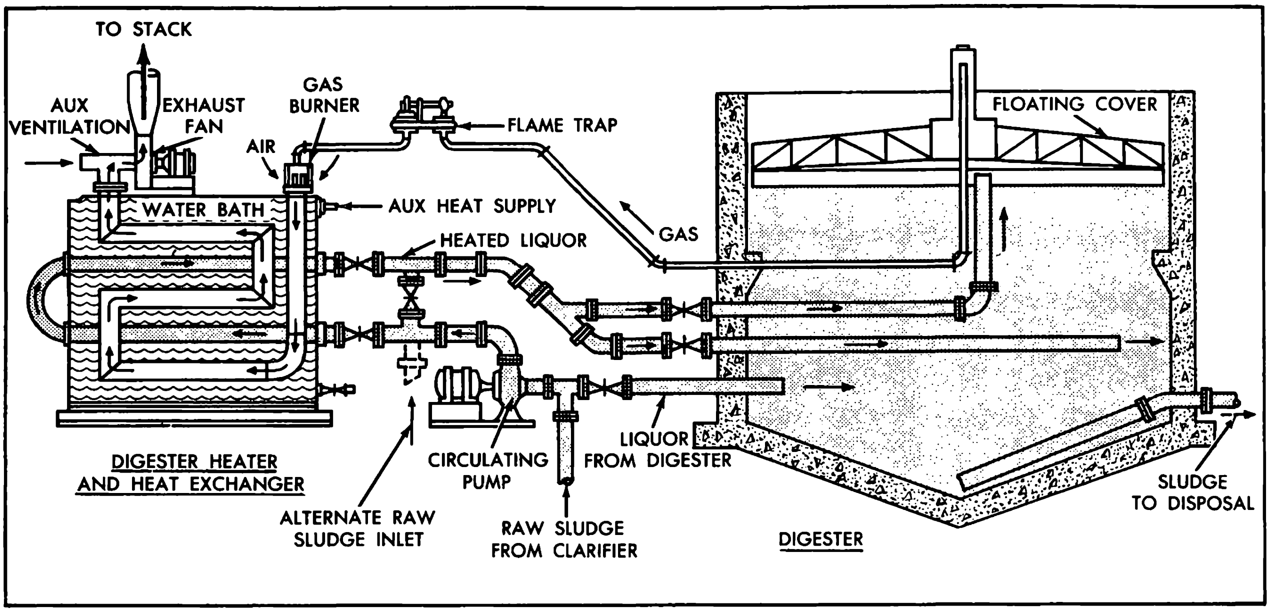


FIGURE 2D3-3

Circulation Diagram of Gas- and Oil-Burning Heat Exchanger System (Ref. 77)

C. Submerged Gas Burners

1. Similar in design to types developed for sludge heating. In application to settling tank heat, no gas hazard entailed. Many problems of design have already been worked out for submerged burners in other applications.
2. Advantage: 100 percent efficient use of fuel —no losses in flue gas or in transmission.
3. Possible disadvantage: odors caused by very high local temperatures (not a problem in the closed digester system).

D. Direct Addition of Hot Water

1. Advantages.
   a. Saves cost of coils.
   b. May be added to sewage flow in a manner such that sharp temperature gradients in tank do not occur (multiple outlets).
2. Disadvantages.
   a. Water costs may be high.
   b. Possibility for cross-connection with potable supply. (However, protection against such a cross-connection may easily be provided.)
   c. Tank would have to be made larger to handle increased flow at the requisite detention period.
   d. Dilution likely to impair sedimentation efficiency.

E. Direct Addition of Steam

1. Point of injection.
   a. On suction side of pump (if raw sewage pumped at plant). Would require low-pressure, heat-type boiler.
   b. On pressure side of pump. Would require high-pressure, power-type boiler. Possibility that design might utilize propelling power of steam jet.
   c. Directly into settling tank. Disadvantage: additional baffling might be necessary to prevent excessive turbulence. Advantage: uniform distribution of heat —short-circuiting possible with a and b.
2. Advantages.
   a. Considerable experience available (California) with sludge heating by direct addition of steam. A number of design problems (e.g., noise and vibration of jet) have been solved.
   b. Amount of dilution by condensate not large. (At one installation: 1 gal condensate/10° F temperature rise for every 110 gal of sludge heated.)

c. Flexibility of operation; simplicity of installation.

d. Steam available at military posts for heating buildings and utilidors.

3. Disadvantages.

a. Waste heat:

(1) In flue gas.

(2) In transmission (not, however, if routed through utilidor).

b. High local temperatures in vicinity of jet may release gases from solution: small bubbles may interfere with settling by buoying particles to surface.

c. *Summary.*

A substantial part of heat needed in Arctic sewage plant operation may be supplied by heating the water supply or the sewers, utilidors, and pumping stations. Indeed, in some cases this amount may be sufficiently large so that no additional heat will be needed at the sewage plant. The proportion of heat supplied in the sewerage system relative to that supplied at the plant will differ at different posts depending upon local conditions, size, and percent occupancy. Heating at the plant may be necessary during severe cold (a) with water supply or sewage systems that are unheated or heated insufficiently to prevent freezing at the plant, and (b) when the heating system in the sewer fails. The objectives of plant heating are to prevent (a) interruption or impairment of treatment by freezing or cold, (b) damage to treatment devices by ice, and (c) excessive ice formation in the outfall and in the vicinity of the point of discharge.

Foremost among the various considerations that are important in the design of sewage treatment plants in the Far North are the following:

1. Plant units should be designed in replicate wherever possible. By retaining the proper number of units of each type in service, prolonged detention periods that increase freezing hazards may be avoided.
2. All major plant units should be covered or housed.
3. Tanks should be designed so that they may be rapidly and completely drained.
4. Provision should be made for emergency heating of important treatment devices.
5. The capacities of tanks and filters should be determined with due regard to the adverse effect of low temperature upon treatment efficiencies and upon the rate of self-purification in receiving waters.

2D3.03 SEWERAGE SYSTEMS

1. DESIGN FACTORS. Strength and flow of sewage from military installations vary somewhat from strength and flow for civilian communities. Military sewage is more concentrated, and flow more closely equals water consumption. Figure 2D3-4 shows normal flow characteristics for sewage wastes from fixed installations.

Factors most affecting design and operation are the intensity and duration of cold. Because water is only slightly above the freezing point, sewage is colder than usually found in temperate climates unless sewers carrying the wastes are located in steam-heated utilidors. Under such conditions, the sewage may be found to be abnormally warm. Retarded biochemical reactions lessen the ability of receiving water for self-purification and lessen the bacterial die-away rate.

Conventional design of sewage works makes them particularly subject to adversity during cold weather. Sewer venting to the open atmosphere, large open basins, widely dispersed treatment units, and similar features of conventional design enhance the problems of freezing. Many operational inconveniences and even complete breakdown may occur under the most critical climatic conditions.

Collecting-sewers systems are feasible in the Cold Regions. They must be constructed, however, so that they can be maintained operative by added heat and/or by retention of maximum sewage heat by insulation and appropriate design. At fixed installations where utilidors are used for water distribution, sewers usually have been placed in the utilidor for protection from low temperatures. In some places, sewers may also be operated satisfactorily by placing them directly in the ground without using a utilidor.

2. SEWERAGE SYSTEMS IN UTILIDORS. Utilidors constructed in a manner similar to those discussed in Section 2B2 have been used for carrying sewer services. Utilidors have been used just for protection of sewers or for transmission of both water mains and sewers. The latter arrangement presents undesirable conditions that may lead to contamination of the water supply. The salient features in construction of utilidors for water distribution must also be considered in planning and constructing utilidors for sewers. Sewers placed

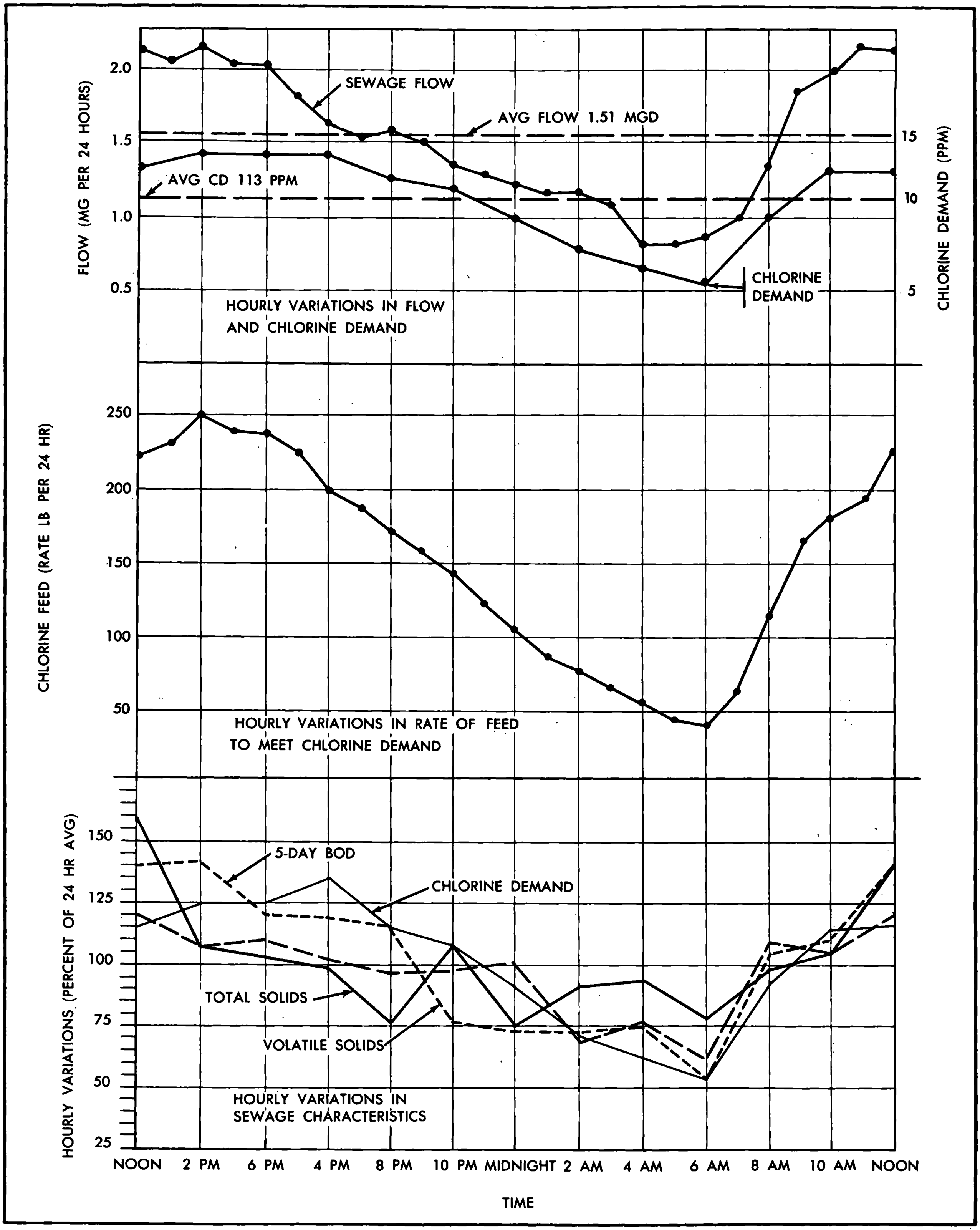


FIGURE 2D3-4

Curves Showing Variation in Sewage Flow, Chlorine Demand, and Rate of Feed

in utilidors are much more expensive to construct than sewers installed directly in the ground; maintenance, however, is less expensive, and the certainties of operation during all periods are greater. The underground type of utilidor is more practical for use in established communities than the aboveground utilidor because of the difficulty of making connections to the latter. Sewers laid in utilidors govern the slope of the utilidor to a great degree. Sewers placed in utilidors that do not also carry steam lines for transmission of heat from a central heating plant should be heated either by a steam tracer line placed in the utilidor or by circulation of warmed air.

3. SEWERS PLACED DIRECTLY IN GROUND. In constructing sewerage systems placed directly in the ground, care must be taken to use sewers whose materials have a relatively high insulation value, and insulation such as peat, moss, gravel, and so on, must be placed around the sewer in the ground. Masonry, concrete, vitreous, and iron sewers conduct heat relatively rapidly. Conduction losses may be excessively high in these sewers if proper insulation is not provided.

a. *Utilization of Natural Heat.* Sewers should be located to avoid compaction of the soil over them. Compaction occurs in the center of a street. They should be located preferably in alleys or other places where snow cover will be the greatest and vegetative cover may be utilized. They should also be located so that they are not in shadow when the sun is shining. By following these methods most efficient use is made of the natural heat.

Special arrangements for heat conservation in venting the sewerage system are necessary. Standard venting of manholes, with openings to the Arctic air, is not practical. Large exposed openings at outfall points should be designed and constructed to minimize heat losses by drafts of cold air into the system.

Sewers may be placed to take full advantage of latent heat of fusion of entrapped ground water where such heat is of significant value. In this location, however, it is difficult to keep infiltration at a minimum.

b. *Stability.* Sewers placed in soil that loses its stability when the permafrost is disturbed must be designed and constructed with adequate supports and foundations to maintain proper alinement under all conditions. Original construction and slopes must be exact, and piling anchored in permafrost may be required to maintain grades in some soil (Figure 2D3-5). (See Sections 2A6 and 2A8.)

c. *Maintaining Flow.* Each section of a sewerage system has certain static, or fixed, heat losses under a given condition of flow and ground temperature; flow and temperature at any given time in a sewer must be sufficient to satisfy the fixed heat losses of the system and yet prevent freezing of the sewage. In many instances, it may be simpler to regulate flow of sewage in the system or air temperature within the sewer than to attempt to heat all of the sewage to prevent freezing. Sewage may be diluted to maintain the desired flow, or by using pumps and pumping wells it may be possible to maintain a somewhat continuous minimum flow in the system. Steam condensate should be used wherever available to keep sewer installations from freezing.

4. PUMPING STATIONS POSSIBLY NECESSARY. Because of the generally flat terrain in many Arctic communities, it may be necessary to install sewage pumping stations at one or more points in the collection and disposal system. These stations are particularly necessary in systems designed to operate through utilidors or as nearly as possible at some fixed depth in relation to the permafrost table.

a. *Problems Encountered.* The Subcommittee on Waste Disposal of the Committee on Sanitary Engineering and Environment, National Research Council, reported as follows. (Ref. 78.)

> The chief difficulties associated with operation of these stations in the northern United States have been:
>
> 1. Operating failures, caused by
>   a. Clogging of pumps
>   b. Loss of power
>   c. Stoppage of automatic controls
> 2. Insufficient ventilation, causing
>   a. Explosion hazards
>   b. Health hazards to employees
>   c. Excessive condensation and corrosion of equipment
>   d. Excessive odors
> 3. Flooding of the station, caused by
>   a. Surface water
>   b. Pump failure without overflow
>   c. Backing up of sewers
> 4. Unsatisfactory maintenance, caused by

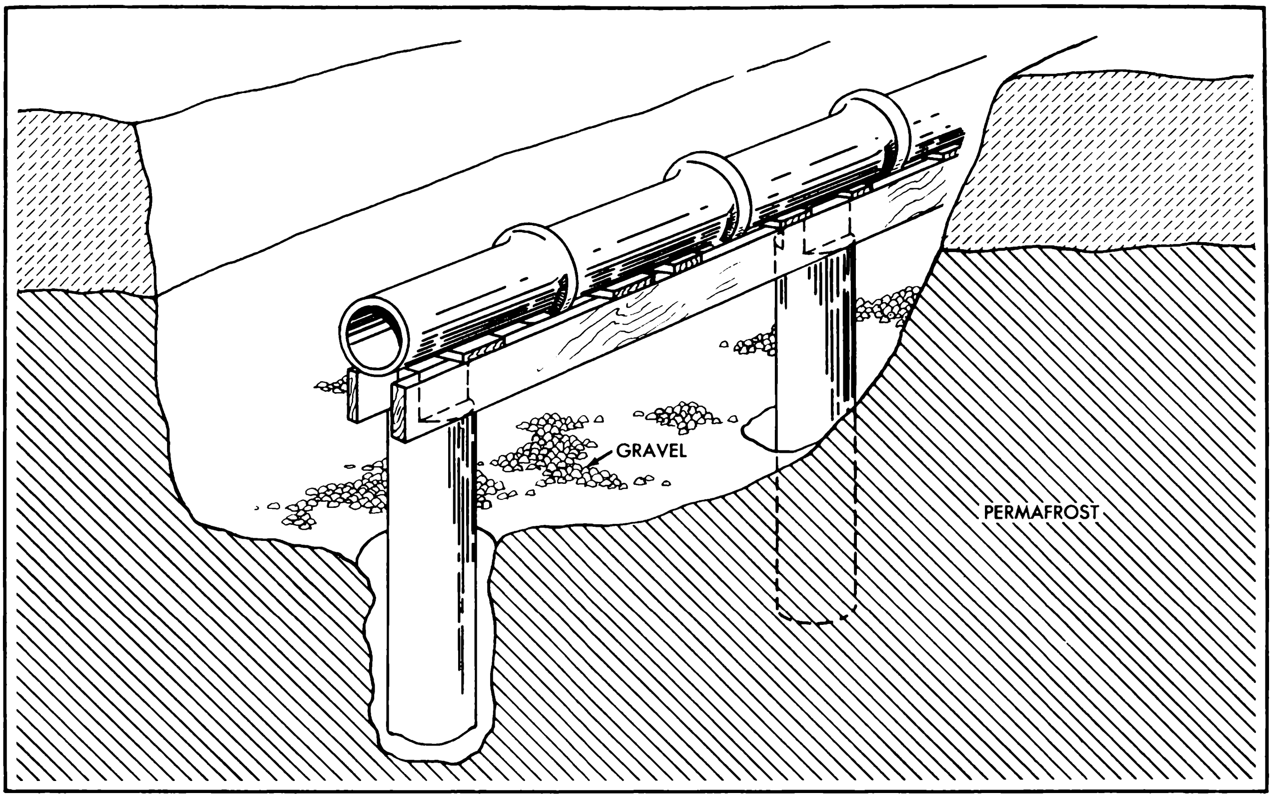


FIGURE 2D3-5

Vertical Alinement Support for Sewer in Permafrost That Becomes Unstable When Thawed

a. Insufficient room to provide working space around the equipment
b. Hazardous working conditions in the station
c. Insufficient methods of removal of screenings
d. Difficult access through heavy manhole covers and exposed ladderways.

It is apparent that the foregoing problems encountered in temperate areas are intensified in installations made in permafrost areas, where air temperatures are much lower for longer periods and wind velocities are critical.

Additional requirements for design of pump stations created by these conditions include the following [Ref. 78]:

1. Need for conservation of heat in all ways possible, especially the heat in the sewage, to protect against lowering of temperature and freezing in sewer system or treatment plant.

2. Need for minimum heat loss to the surrounding soil from the structure to avoid thawing of the permafrost and possible foundation failures. [See Section 2A8.]

3. Need for provision of sufficient source of heat in the structure to assure against freezing of sewage or inoperation of the equipment.

b. *Disadvantages of Wet-Well and Dry-Well Types.* The National Research Council report also lists the following disadvantages in conventional wet-well and dry-well design for pump stations. (Ref. 78.)

1. The storage in the wet well facilitates loss of heat from the sewage and into the adjacent ground.

2. The open discharge permits release of entrained and volatile gases.

3. The large excavation and the exposed wall area facilitate loss of heat to the surrounding ground and possible foundation failures.

4. The ventilation problem is difficult.

Disadvantages of the single-chamber, two-story type of station (Figure 2D3-6) with a wet well in the bottom are similar to disadvantages of the wet-and dry-well types. In the two-story type the size of the excavation is reduced, but the overall depth is increased and ventilation and maintenance problems are much more difficult.

c. *Advantages of Enclosed Storage Single-Chamber Type.* In reference to a pump station with enclosed storage in a single chamber (Figures 2D3-7, 2D3-8, and 2D3-9) the National Research Council report gives the following advantages and comments. (Ref. 78.)

1. Sewage is stored a shorter period of time.
2. Gas and ventilation problems caused by sewage are minimized.
3. Underground stations are more easily constructed.
4. Storage unit can be readily insulated.

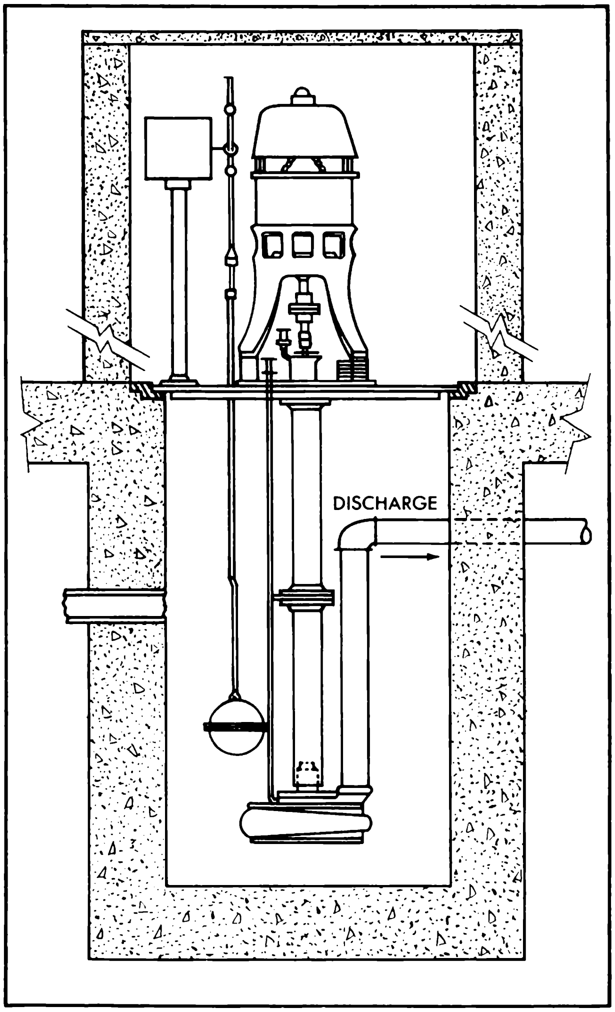


FIGURE 2D3-6

Submerged Sewage Pump (Ref. 78)

NOTE: Details of design and construction of pump stations should be in accordance with recommendations presented in Section 2A6.

d. *Pumps* (Ref. 78).

The selection of pumps for this type of station can be made from several special types of sewage pumps available. [Figures 2D3-8 and 2D3-9] show examples of special types of pumps which do not require removal of screenings. The ejector type [Figure 2D3-9] may be operated by either steam or compressed air which permits remote source of power. Additional types are available and are being developed to overcome problems associated with clogging of pumps. Grinders or cutting equipment which are entirely enclosed can be used ahead of the pumps. Where flooding is a possibility, waterproof motors can be used.

e. *Access Ways.* Wherever possible, pump stations should be located in heated structures. If such an arrangement is not possible, access ways to pump stations should be constructed to minimize heat losses and to make them readily accessible. Drifted snow, ice, and strong winds necessitate orientation and design suited for ready use even during the worst weather.

2D3.04 WASTE DISPOSAL METHODS

1. PROBLEM. Numerous methods are employed to dispose of sewage in the Arctic, but the effectiveness and safety of most of them are greatly impaired by low temperatures. Usual processes of decomposition do not appear to occur within permafrost. Organic materials exposed on the surface of the ground, or placed within shallow top layers of seasonally thawed ground, decompose slowly. An abundance of psychrophilic organisms apparently accomplish the process along with frost and chemical action.

2. BURIAL. When it is practical and when a suitable active zone can be relied upon, wastes should be placed underground, wholly within the active zone. The forces of nature that break down and destroy such wastes are most effective just at the ground surface, under suitable temperature conditions. However, wastes must not be thrown indiscriminately on the ground surface. Improvised burners for disposal of burnable wastes and refuse may be constructed from abandoned fuel containers, such as those shown in Figures

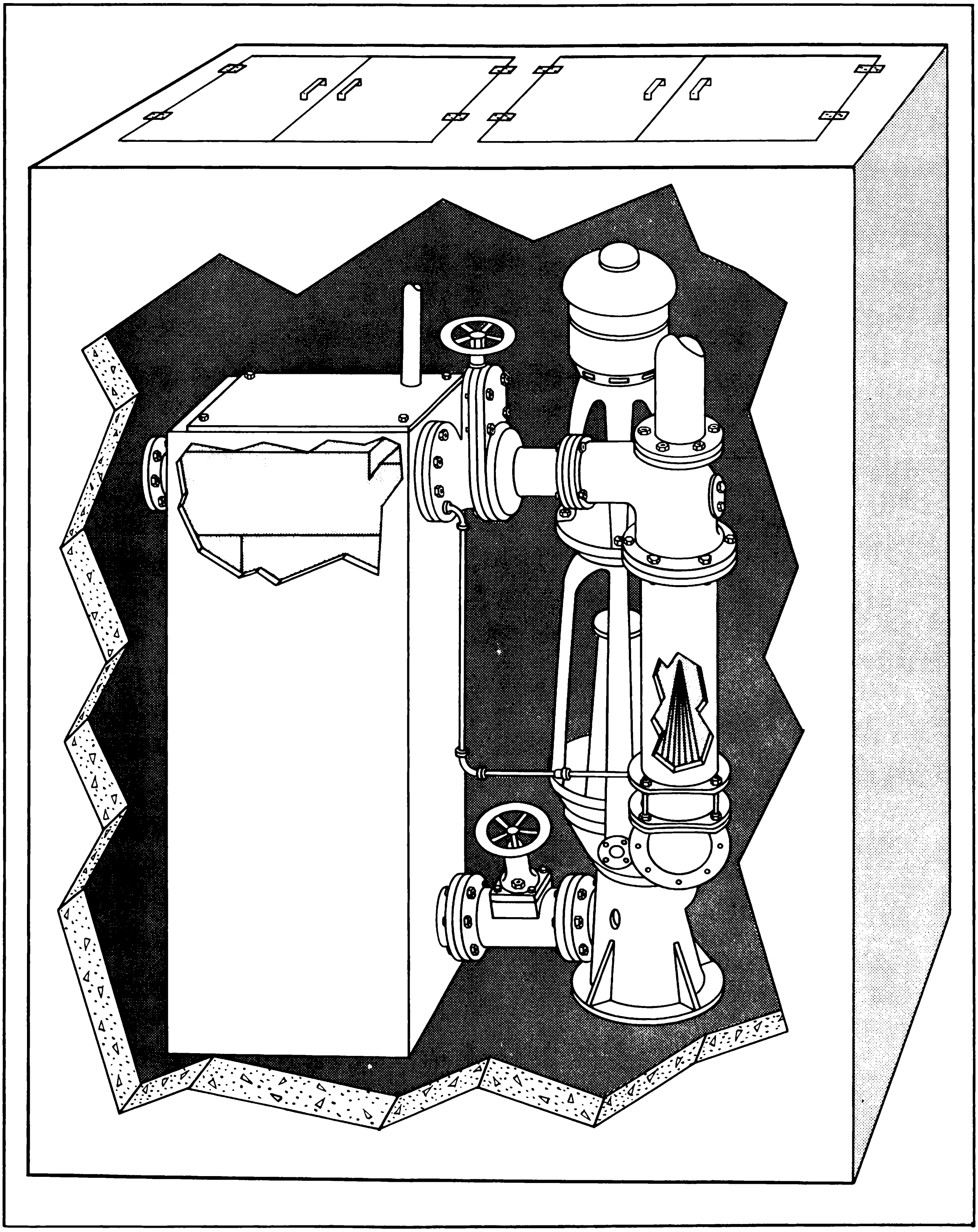


FIGURE 2D3-7

Sewage Lift Station, Single Chamber and Pump (Ref. 78)

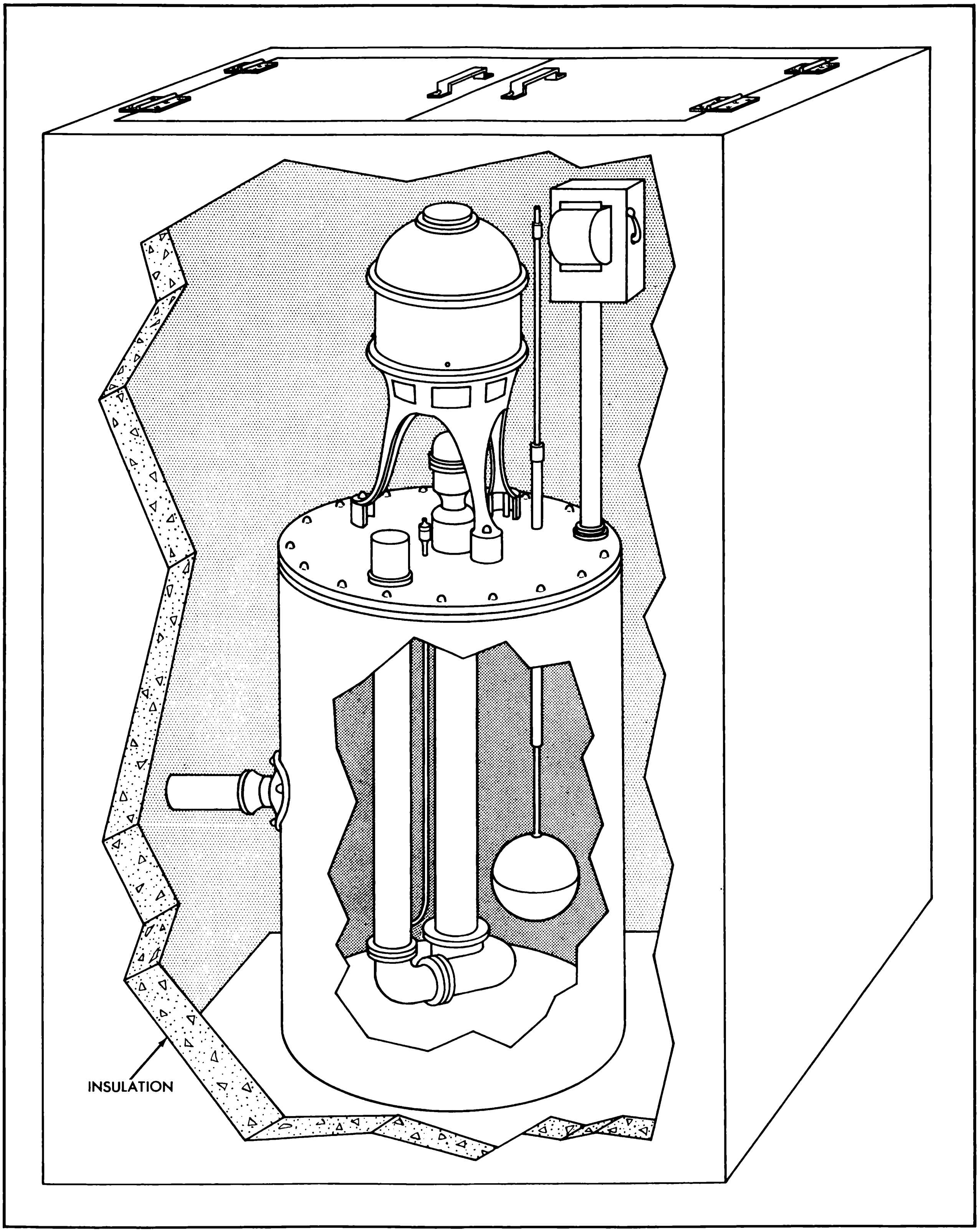


FIGURE 2D3-8

Sewage Lift Station, Submerged Vertical Pump (Ref. 78)

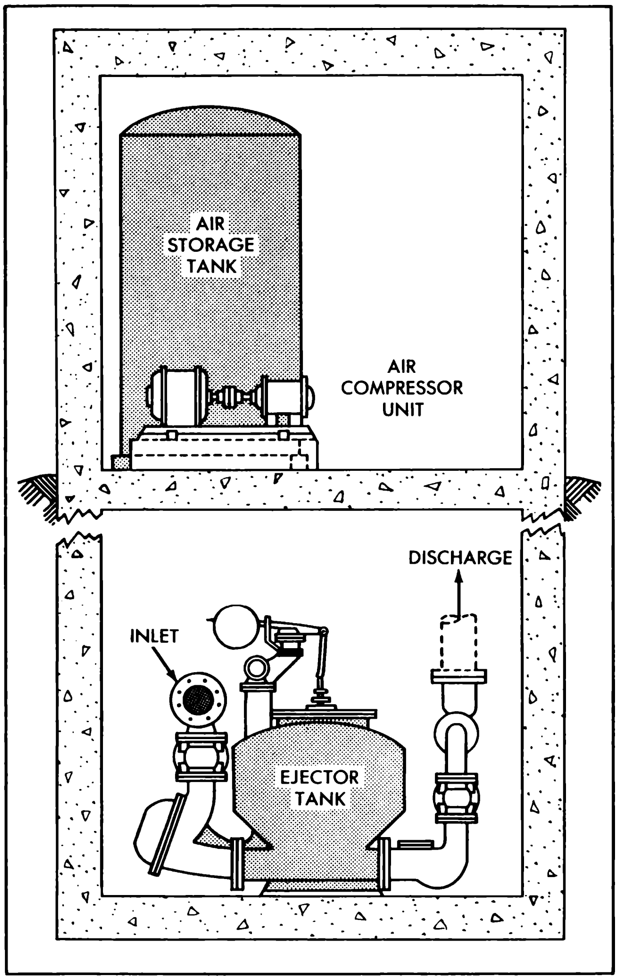


FIGURE 2D3-9

Sewage Lift Station, Ejector-Type (Ref. 78)

2D3-10 and 2D3-11. Fecal material does not readily burn and creates a serious odor nuisance during the burning process unless properly designed equipment is used for incineration.

3. BOX AND CAN SYSTEM. The chamber pot and box and can systems of sewage disposal are by far the most common methods for waste disposal in the Cold Regions. Ultimate disposal of collected wastes by indiscriminate dumping should not be tolerated. Figure 2D3-12 shows a typical modification of the standard latrine box for use with cans. Emptied fuel barrels may be used for collecting the contents of cans. Filled barrels may, under some conditions, be placed in fill at isolated points where there is no possibility of contaminating a water supply and where there is adequate material for fill.

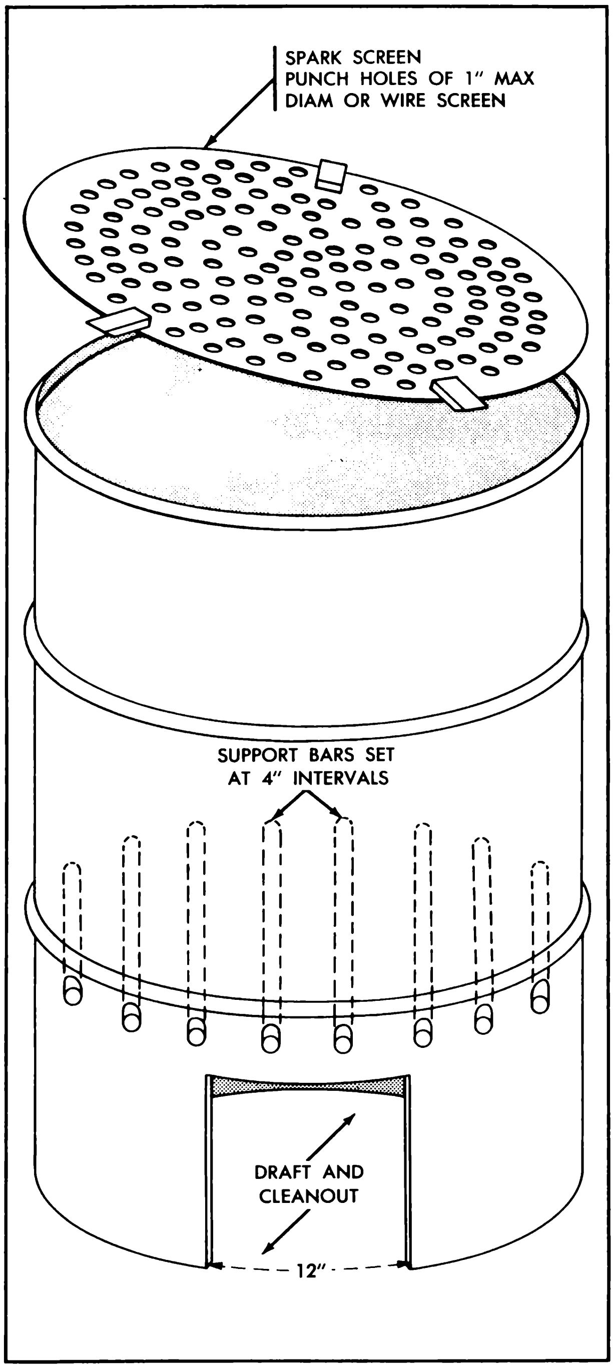


FIGURE 2D3-10

Oil Drum Incinerator, 55-Gallon

4. INCINERATION. An experimental waste incinerator has been developed for use where other sewage disposal means are unsatisfactory. A skid-mounted portable unit, it will satisfactorily in-

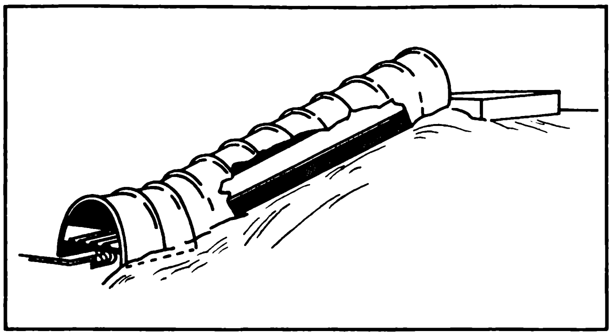


FIGURE 2D3-11

Diagram of Improvised Inclined-Plane Garbage Incinerator

cinerate human wastes without serious odor nuisance. Ninety pounds of human waste may be incinerated at one charge and within 2 hours. Twice daily operation for a total period of 3 hours permits incineration of the 40-percent greater amount of waste anticipated for Arctic installations.

Under the transient conditions of military field operations, incineration is the most expedient means of human waste disposal. Incineration can be readily adapted to field use with a minimum weight, space, and installation time, but the auxiliary fuel necessary requires adequate planning for fuel supply. Approximately 1¾ pounds of diesel oil or gasoline per man per day must be provided as fuel supply for presently designed units. Although disposal by a field-type portable incinerating unit is extremely mobile and meets health requirements, it should only be used by advance units that can not employ other suitable means. Waste incineration for a 250-man unit can be combined in one facility for garbage disposal, fecal waste, space heating, and possibly water heating, provided adequate care is taken to prevent contamination of water by fecal matter.

Specially adapted trays may be used in the incinerator for burning garbage. The efficiency of the unit, however, is much less for this kind of operation.

Figure 2D3-13 shows a recently developed commercial toilet-incinerator unit designed for temporary and semipermanent housing not having conventional sewerage systems. It consists primarily of a toilet and an attached incinerator with a manually operated conveyor between the two for carrying human waste from the toilet to the incinerator. The incinerator chamber, made of stainless steel, is heated by a continuous-burning 100,000-Btu/hr, oil- or gasoline-burning heater of conventional design similar to blower-type air heaters. The burner flame is directed at the incinerator chamber so that fecal matter is burned

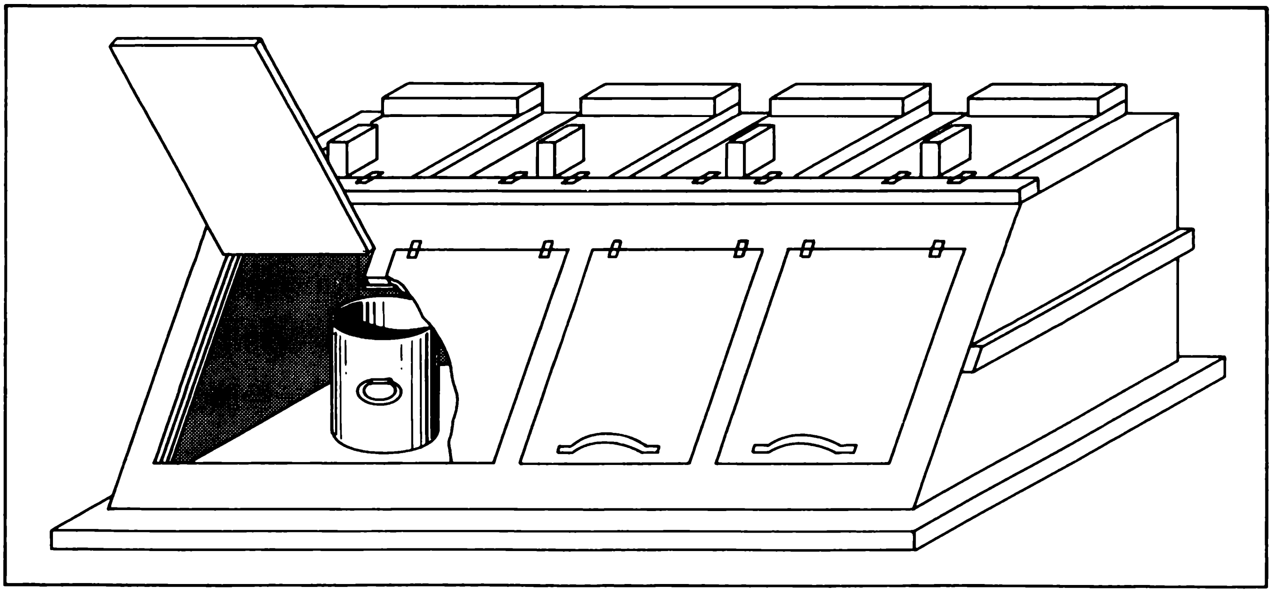


FIGURE 2D3-12

Method of Adapting Standard Latrine Box for Use as Pail Latrine

completely with practically no odor or ash. Fumes are carried outside through the heater exhaust stack. Because the incinerator burner is a continuous-burning type, its 60,000 Btu/hr of heated uncontaminated air and 40,000 Btu/hr of contaminated air can be utilized to provide heat for the building itself. The illustration shows only one toilet unit; possibly two or three units could be readily handled by the 100,000-Btu/hr incinerator or a smaller incinerator used for only one toilet. Fuel consumption ranged from 0.4 to 0.8 gal/hr at continuous burning for the unit shown.

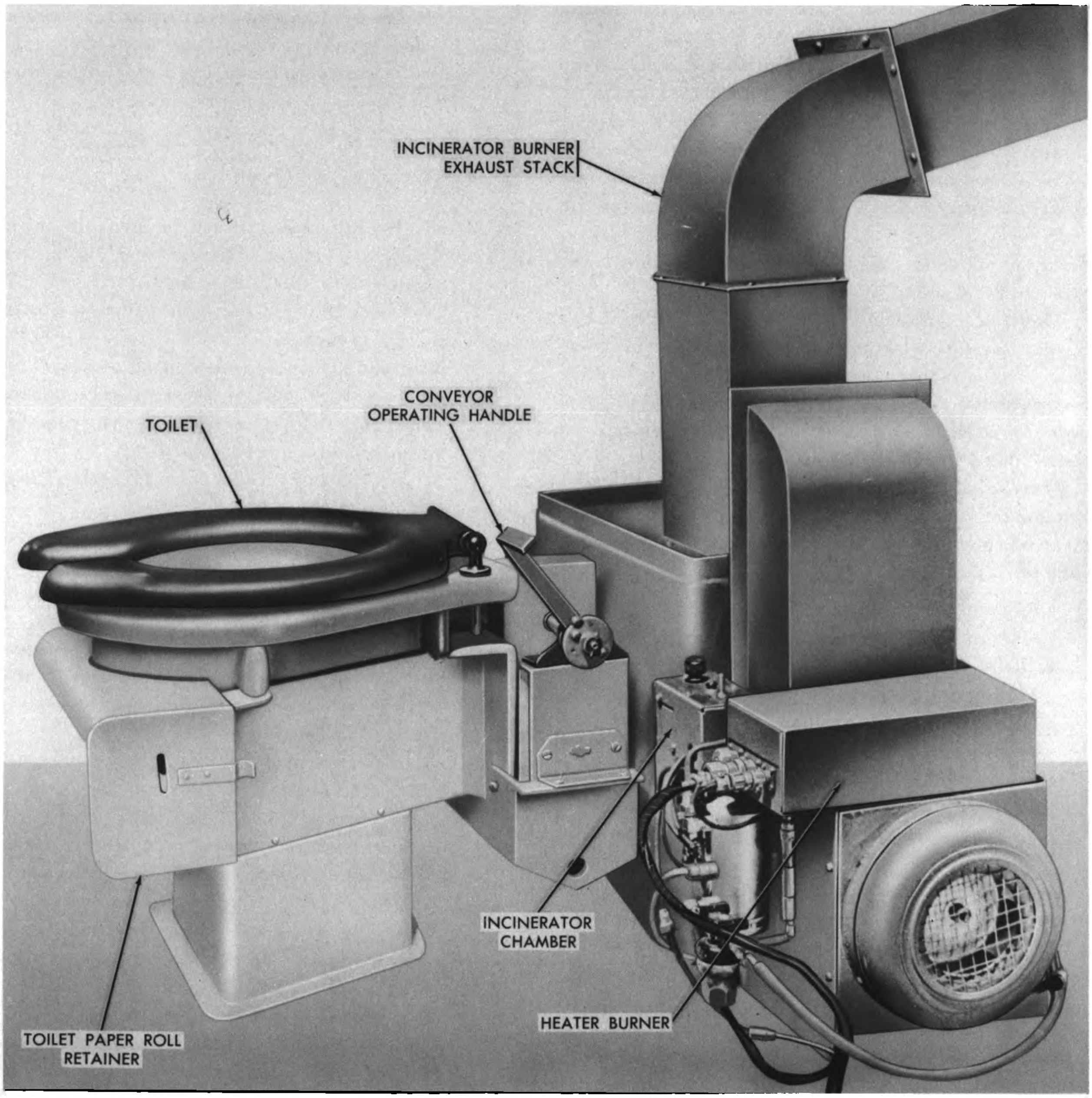


FIGURE 2D3-13

Self-Contained, Dry-Flush, Incinerator-Type Toilet

OR THE "HOT SEAT"
OR THE "SINGE CRAPPER"

Section 4. GARBAGE AND REFUSE DISPOSAL

2D4.01 LOW-TEMPERATURE FACTORS

In the Cold Regions, permanently frozen ground and prevailing low temperature necessitate modification of normal garbage disposal practices. Normal decomposition that occurs in controlled fills is seriously retarded in permafrost, and the mechanics of garbage burial in these difficult areas is also an impediment to such practice. Lack of outlets for sewage, relatively high fuel costs, and rigorous climatic conditions complicate disposal by other methods. However, these factors do not erase the importance of proper disposal even in the Cold Regions. Filth is conducive to the spread of disease, and wastes must be removed beyond sight and smell.

There are many insects in the Cold Regions at certain seasons, although the housefly is not common. Rodents are also prevalent in some Arctic communities. Where garbage and waste are accessible to rodents and insects, problems similar to those found in temperate climates may arise.

The Subcommittee on Waste Disposal of the Committee on Sanitary Engineering and Environment of the National Research Council reported as follows. (Ref. 79.)

> Regardless of climate, soil conditions, or the size or mobility of the group, garbage disposal methods are predicated upon:
>
> 1. Getting wastes out of sight, way, and smell of the individual or group.
> 2. Convenience in disposal.
> 3. Economy.
> 4. Indirect effect upon public health.
> 5. And, possibly, direct effect upon public health.
>
> All present-day garbage disposal methods except promiscuous dumping are dependent upon volumetric reduction or dilution of wastes with water to a degree which is satisfactory for the material and area concerned. All disposal methods ultimately depend upon dumping of either bulk or concentrated wastes. Some processes stabilize all organic or putrescible material contained in the garbage; however, either method leaves a noisome, unstable material. *In regions where soil is insufficient to cover garbage or where it is impossible to keep the wastes out of ground water used for domestic water supply, (a) bulk or concentrated wastes must be reduced to a stable, noninfectious condition prior to ultimate disposal, or (b) they must be adequately removed from the area.* Removal of waste to a point beyond the flight range of flies and other insects and placement in such a fashion that it does not constitute food and harborage for vermin or contaminate ground and surface waters makes disposal inconvenient.

2D4.02 SELECTION OF GARBAGE DISPOSAL METHODS (Ref. 79)

The following points must be kept in mind in selecting a garbage disposal method which will be suitable in difficult areas:

1. Is there a beneficial use for garbage wastes in this region?
2. Will the disposal method under consideration prevent unsightly and malodorous conditions to an extent unobjectionable to individuals or the group?
3. Is the method under consideration convenient to the group?
4. Will the method under consideration prevent occurrence of food, harborage, and/or breeding places for insects, rodents, or wild animals common to the region?
5. Will this method prevent the transmission of parasites through domestic animals which are later to be used for human food?
6. Will this method prevent the contamination or pollution of surface or ground waters which must be kept clean for domestic water supply, wild life, agricultural, recreational or industrial purposes?
7. What special equipment, patented processes, and/or special operating skills will be needed in this method?
8. Is this the most inexpensive method possible in this region?
9. Is the method of garbage disposal under consideration economically sound for the group in question?
10. Is this method suitable for use under prevailing climatic conditions in the region considered?

The following generally recognized methods for garbage disposal have been considered:

Dumping
Dumping in water or on ice
Dumping on land
Burial
Reduction
Incineration
Burning on open dump
Burning in incinerator
Fermentation
Private premise composting
Beccari system
Indore process
Verdier process
Frazer process
Earp-Thomas process
Dano process
Filling
Sanitary land fill (controlled tipping)
  Trench fill method
  Area method
Feeding
Dilution
Grinding and disposal to the sea, lakes or water courses.
Grinding and disposal through sewers and sewage treatment plants.
Miscellaneous Methods
Garchey system
Chemical disintegration
Repellents

At the present time the subcommittee reports, in summary, incineration and composting offer the most suitable means for garbage disposal for small groups under difficult conditions, namely, in areas where rock outcrop, permanently frozen soil, or high ground water prevent burial or sanitary fill such as may normally be used by small groups. In certain areas accelerated reduction and stabilization may be accomplished or use of repellents and plain dumping in a non-objectionable spot may prove adequate upon further investigation. Grinding and dilution, in conjunction with plain dumping or incineration of non-putrescible material is adequate for individual homes or small groups where the wastes may be adequately treated in the sewage works or where suitable power and maintenance facilities are available.

2D4.03 COLLECTION PRACTICE

Special equipment, suitable for operation under low temperatures and designed for travel over tundra, is needed for collection and hauling by other than dog teams. Refuse and garbage collection in cans, which must usually be stored outside heated structures, is complicated by the freezing of waste in the cans. In the past this has been combated by using nonuniform containers for collection and disposal of the container with the garbage. Emptied oil barrels, with tops removed, have been used for collection because present economy does not permit their reuse as oil containers. These containers do not have fitted covers and are subject to depredation and spillage. In some instances, garbage may be encased in ice to prevent depredation.

Where possible, garbage-can storage should be provided in a heated area. Buildings in which garbage may be expected to originate should include heated space for this purpose in the design.

It is highly desirable that can-washing facilities, including steam or hot-water services, be provided at each building where garbage originates. If this is not possible, however, a minimum provision of central garbage-can washing facilities is necessary. Operating complications make can-washing facilities located on the collecting vehicle impractical. The collected garbage should be buried near the surface of the ground if possible. All disposal sites for garbage or other waste should be covered with brush, if available, and the site plainly marked to avoid subsequent personnel unknowingly disturbing area.

2D4.04 REFUSE DISPOSAL

Refuse and trash such as empty containers, crates, cans, paper, and so on, present no low-temperature disposal problem because they can be readily collected and burned. Because of the extreme difficulty of fire control in low-temperature regions, when refuse is burned separately from garbage, the burning site should be selected some distance from the camp area. This is essential to avoid camp fire hazards from prevalent strong winds, which carry sparks to structures that are easily ignited because of the dry atmosphere. The importance of fire prevention in the Cold Regions (par. 2F1.01) should be considered at all times.

PART E. EXAMPLES OF ARCTIC STRUCTURES

Section I. UNDERGROUND

Presented in this Section are examples of Arctic structures or principles that experience has indicated as adequate or useful in coping with the disciplines of the area. No attempt has been made to treat the various examples in detail; rather, they have been included only to illustrate certain aspects of cold-weather problems.

2E1.01 AGGRADATION OF PERMAFROST

The development of a large mining operation near Fairbanks, Alaska (mean annual temperature 26° F), required water for thawing permafrost preparatory to excavation. Investigation of one of the valleys in the region indicated that the river in the valley was flowing over thawed sand and gravel through which a much needed quantity of water was moving. This sand and gravel was underlain with a schist bedrock, a portion of which was frozen. To obtain the water moving in the subsurface gravel, as well as the water in the river, a diversion dam was constructed (Figure 2E1-1). (Figure 2E1-2 shows the dam during construction.) Interlocking steel sheet piling was driven well into the bedrock to intercept the considerable amount of water moving through the subsurface gravel. Timber piles were driven to support the dam superstructure.

Because of the interference of the subsurface water and the disciplines existent, this type of construction caused aggradation of permafrost in the materials around the piling and in the area around the dam site.

FIGURE 2E1-1

Diversion Dam Near Fairbanks, Alaska

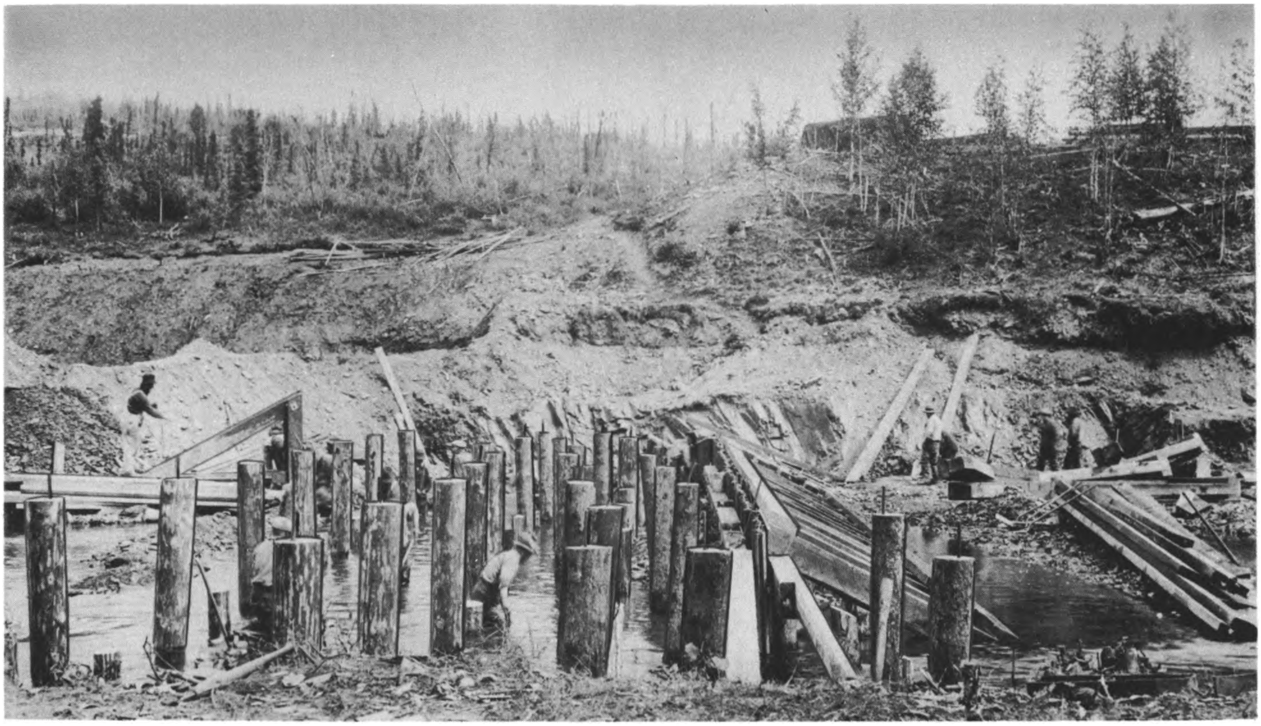


FIGURE 2E1-2

Construction of Diversion Dam Shown in Figure 2E1-1

2E1.02 PRESERVATION OF PERMAFROST BY COLD AIR

The permafrost subgrade under the structure shown in Figure 2E1-3 is maintained in its frozen state by circulating air beneath the structure. Two large adjustable louvers, located at each end of the structure, provide for intake and discharge of air during the winter months. Circulation can be maintained by fans if necessary. The louvers are closed during warm weather. (See also Figure 2A8-20.)

2E1.03 REMOVAL OF SURPLUS HEAT BY GROUND WATER

Figure 2E1-4 is a map of a permafrost area near Fairbanks, Alaska, on which are indicated by arrows the ground-water movements and gradients that predominate in the area. In 1926-1927, a 6,500-kva steam powerplant was constructed on a large kidney of permafrost at the location shown on Figure 2E1-4. The structure was reinforced concrete and steel and had a basement with surface condensers, boiler feed pumps, heat wells, and other equipment that radiated a considerable amount of heat. The bottom of the concrete slab that supported the structure was approximately 10 ft below the ground surface, at which elevation permafrost was encountered. The ground-water table varied, rising at times to within a few feet of the surface.

The permafrost kidney was composed of sand and gravel relatively closely packed compared to the adjacent materials, through which water was moving.

Provision was made to thaw the permafrost with steam points to a depth 30 ft greater than the bottom of the concrete slab and to use the thawed, confined sand and gravel to support and distribute the load to the permanently frozen materials of the kidney, which surrounded them on all four sides and below. Also, the thawed area was extended about 100 ft farther in each horizontal direction than the size of the structure.

After excavation, careful load-bearing tests were made of the sand and gravel in their thawed state. No piles were driven or other methods taken to secure better consolidation of the soil than its *in situ* condition, which resulted from steam thawing. After the bearing tests, the load-

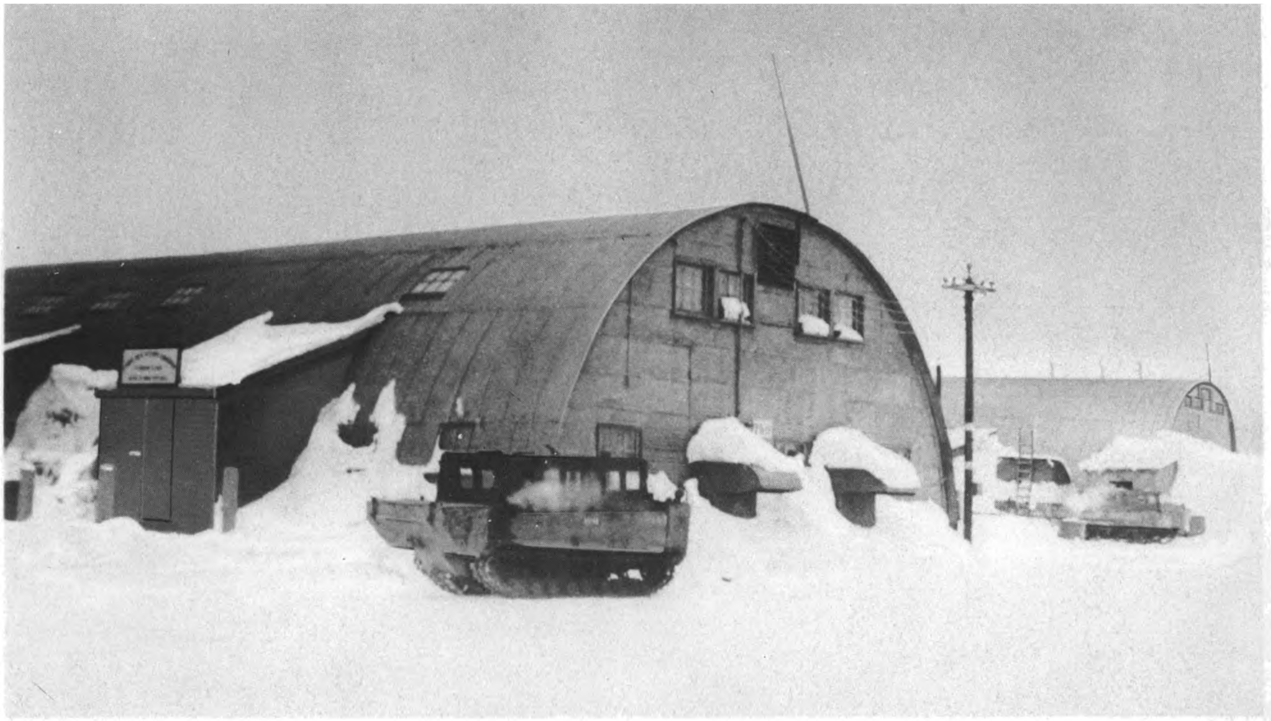


FIGURE 2E1-3

Quonset Structure, Point Barrow, Alaska

bearing capacity of the thawed materials was estimated and the foundation designed accordingly.

Temperature wells were established at each corner of the powerplant to measure subsurface temperatures. Temperature readings were taken over a period of many years. No aggradation of permafrost has been indicated and no measurable settlement has occurred.

From observations made since the plant was built, it is believed that the temperature equilibrium is here maintained by removal of surplus heat from the powerplant foundations by the relatively large volume of ground water continuously moving in the area adjacent to the foundations.

2E1.04 PRESERVATION OF PERMAFROST BY INSULATION (Ref. 80)

1. GENERAL. An example of a foundation constructed by the passive method is shown in Figure 2E1-5. This foundation is for one leg of a 200-ton, four-legged steel tower constructed by the Bureau of Yards and Docks in northern Alaska. The soil at this site was unstable black muck typical of northern Alaskan tundra. The main features of the foundation are steel pipe piles frozen into permafrost and insulation to prevent thawing of the permafrost.

2. EXCAVATION AND DRILLING. Excavation and drilling methods were specified that would disturb the thermal regime as little as possible. Excavation to within one foot of finish grade was done by blasting and by using a dragline. Pile holes were located with a template and drilled with a portable rotary rig. Steel pipe piles were placed and, after the drill mud had been pumped out, were filled with clean sand. The timing of these operations was such that when the piling for the fourth foundation had been placed, the piling of the first foundation was frozen in sufficiently to proceed with the footing construction.

3. FOOTING CONSTRUCTION. The excavation was carried to finish grade by jackhammers and hand shovels. Insulation layers were placed as shown in Figure 2E1-5, and prefabricated forms and reinforcing steel were placed and anchored to the pipe piles by welding. The footing slab was poured in three lifts, adequate bond being assured by reinforcing steel and a roughened but clean sur-

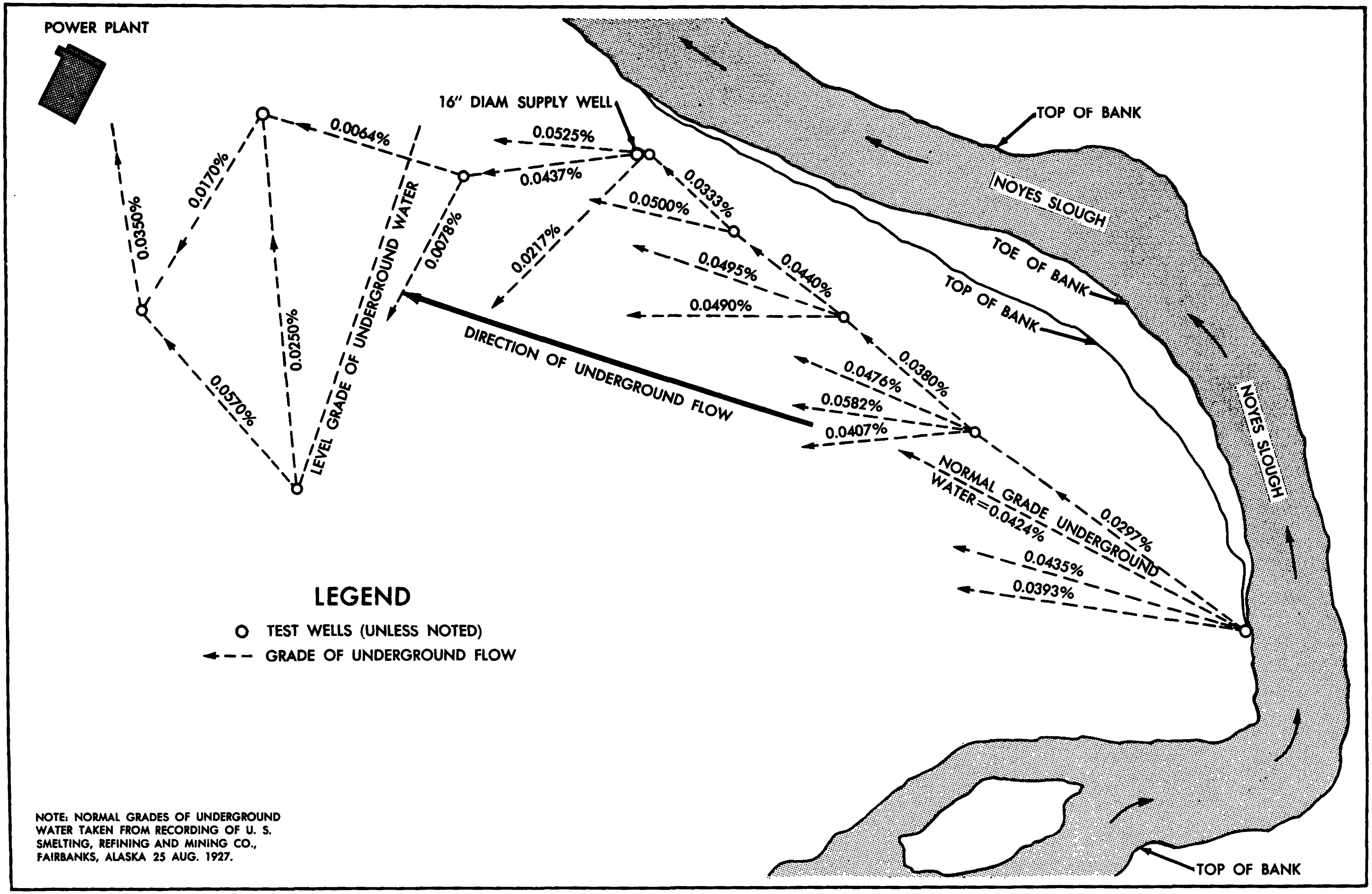


FIGURE 2E1-4

Ground-Water Movements and Gradients in Area Near Fairbanks, Alaska

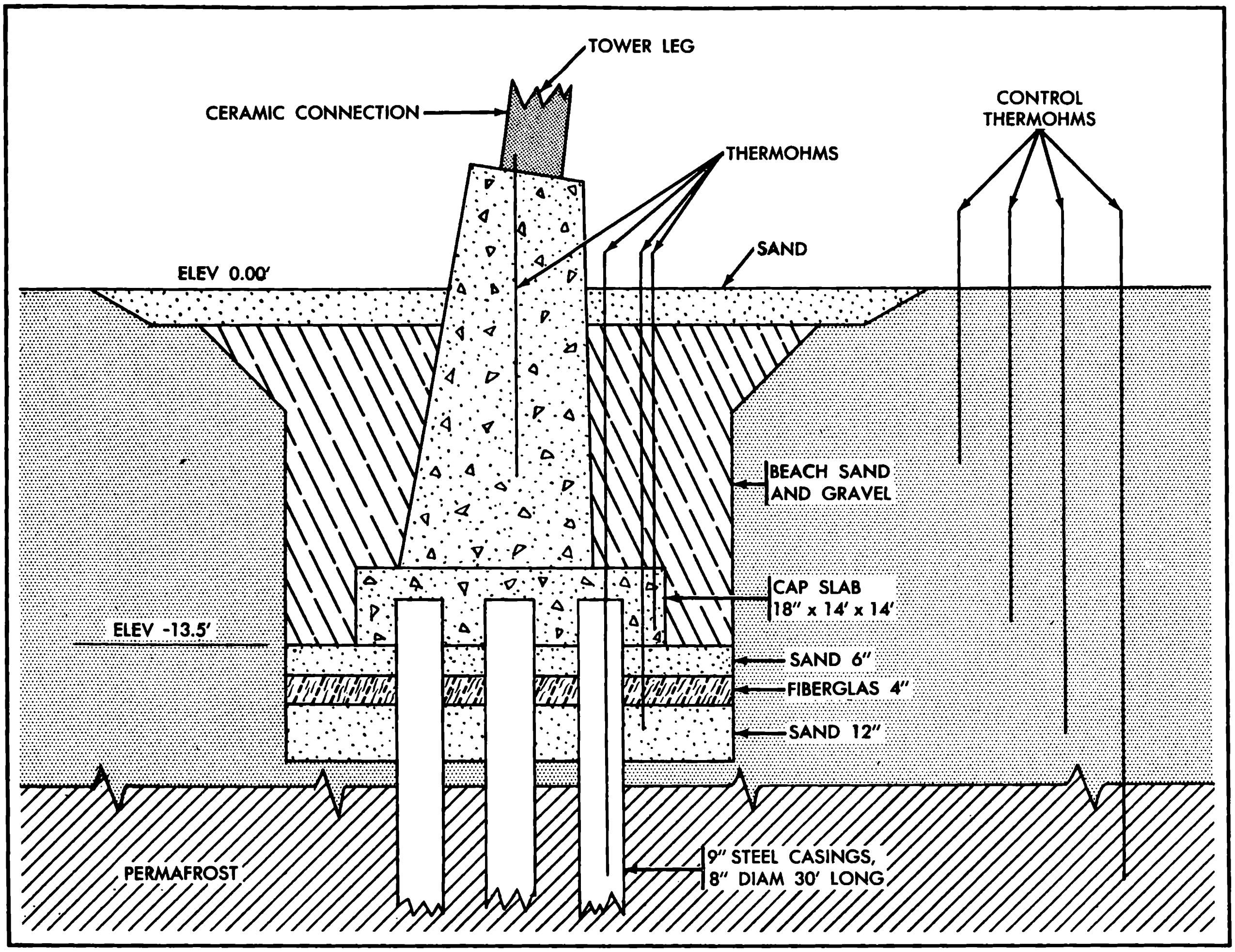


FIGURE 2E1-5

Tower Foundation in Northern Alaska (Ref. 80)

face at the time of pouring each lift. On completion of pouring, the foundation was backfilled to elevation 0.00 feet with beach sand and gravel.

4. TEMPERATURE CONTROL. During the construction of this foundation, temperature pipes were placed at various locations within the foundation. The purpose of this was to take temperature readings during the curing period of the concrete and to compare them with readings taken outside the foundation area, thus recording any changes in the permafrost caused by the curing concrete.

5. WELLPOINTS. Despite the care taken in placing insulating backfill, water began to accumulate around the footings, which indicated melting of the permafrost. To prevent this water from causing ground heaving and differential settlement to the foundations, wellpoints were placed around the footing and the water pumped off by continuously operating pumps.

6. PERFORMANCE. According to the latest information available, this structure has given satisfactory performance for two years. This means that differential settlement has been kept below ½ inch, preventing damage to the ceramic connection details. Knowledge of the adfreeze bond developed by the piling and permafrost to maintain these conditions is difficult to evaluate. At the time of design, a laboratory value of 75 psi was used, which gave a value of adfreeze force thirty times that required. In any case, the force developed has been sufficient to assure satisfactory performance of the structure.

2E1.05 PERMAFROST STORAGE LOCKERS (Ref. 81)

Cold-storage lockers built in permafrost are common in many sections of the Cold Regions. Usual practice is to sink a vertical shaft to around 20 feet and then either drift horizontally to form vaults or gradually widen the shaft as it is excavated so that at the bottom a storage space is formed. Positive flow of cold air is maintained in cellars with vertical shafts because the greater density of cold air causes movement downward and removal of the warmer air upward. A vent at the top of the shaft is therefore necessary. Horizontal tunnels excavated in sidehills ordinarily do not make satisfactory cold-storage vaults because it is impossible to prevent the escape of cold air in summer. The best location for storage vaults is in areas where the permafrost table is close to the surface. The best materials are good heat conductors, such as frozen silt, fine gravel, and sand with a high ice content.

Excavation is usually done during winter when the frozen silt can be removed without danger of cave-in or of surface water interfering with the work. Also, low winter temperatures prevent melting inside the shafts or tunnel.

Excavation is usually accomplished by thawing the materials with steam points and hoisting the muck out of the shaft with a windlass or power winch. Several other methods of excavation are also applicable. (See Chapter 3, Part C.)

Proper protection of the shaft entrance to keep out moisture and heat is most important. Common practice is to raise the elevation of the shaft entrance above that of the surrounding ground and to place moss for insulation over the surface around the entrance. If practicable, a small building should be constructed over the entrance to the shaft as a precaution against rain and to shade the entrance from direct rays of the sun. The building should be well banked with moss or peat.

Cold air is sometimes circulated freely through the storage rooms in midwinter, by which practice, according to some reports, summer average temperatures within the rooms can be considerably lowered. Even near the southern limit of permafrost, it is considered that judicious chilling during winter will permit the maintenance during summer of a temperature that varies only between 14° and 18° F below freezing.

Permafrost storage lockers are extremely easy to maintain. If small repairs to the walls are needed, slushy snow can be applied like mortar and will freeze hard, or cold water can be sprayed on and will glaze the surface with ice. (See also par. 2 of 3A1.07.)

Section 2. ABOVEGROUND

2E2.01 ICE BRIDGES (Ref. 21)

Where it is necessary to transport heavy loads on ice that contains many cracks or is not thick enough to bear up under the load imposed, ice bridges may be constructed to overcome the deficiency (Figure 2E1-6). These structures may take a simple form, such as merely increasing the thickness of the ice at the place desired by pumping water from underneath and flooding the intended area with one or more ice layers to achieve the desired thickness; or, if greater strengths are required, by freezing timber into the flooded area if timber is available.

To construct an ice bridge, it is usually desirable to remove all snow from the ice surface and lay the longitudinal and wearing courses of logs from which all loose snow has been removed. Snow removed from the courses is thrown up as windrows on either side and sprayed with water, which is pumped from beneath the ice. The windrows act as dams between which the water is flooded, covering the logs. At temperatures below 0° F, the cold water should not be added in thin layers because a good bond is not secured. The layers will tend to flake off. The quantity of water that may be added depends on the pumping capacity available and the temperature.

2E2.02 WATER SUPPLY, CHURCHILL, CANADA (Ref. 73)

Churchill has a Subarctic climate (mean annual temperature 17.7° F) and is underlain by permafrost that in some places lies 16 to 20 inches below the ground surface. Water for the Churchill settlement and harbor facilities is obtained from a reservoir made by deepening and extending a small lake. Because the excavated material was predominantly clay, the sides and bottom of the

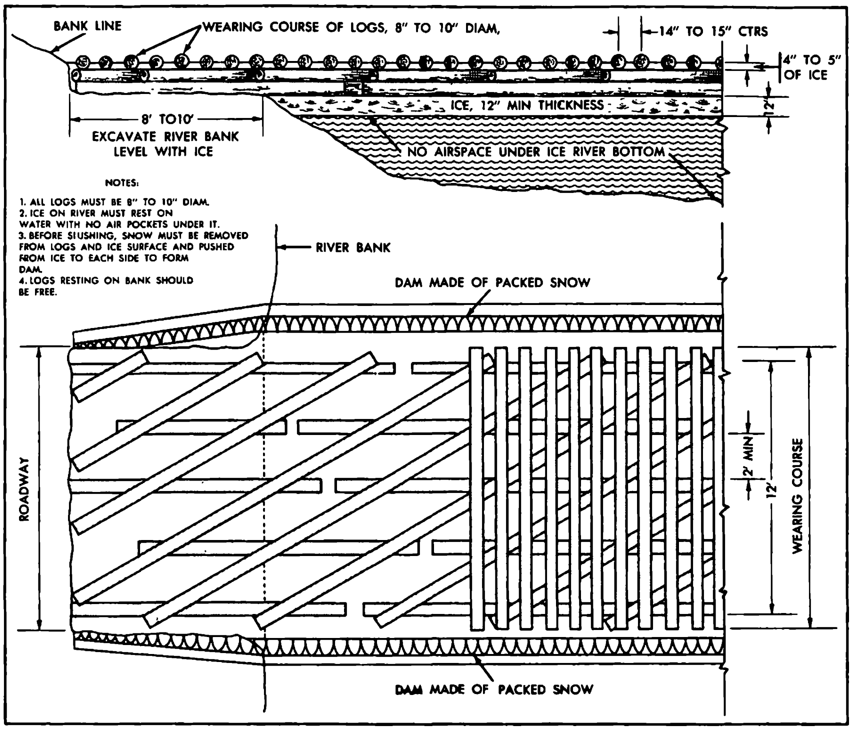


FIGURE 2E1-6

Ice Bridge Construction (Ref. 21)

reservoir were lined with gravel to avoid muddy water. Water from small lakes in the area is conducted to the reservoir by ditches. Capacity of the reservoir is 13,000,000 gallons.

1. RESERVOIR AND PUMPS. Two elevated 60,000-gallon insulated tanks were erected as part of the town system; one is located at the reservoir, the other close to town. Temperature of the water in the reservoir tank is maintained at 76° to 78° F by injecting steam into the water at the pump intake. Water in the town tank is about 15° F lower. A smaller, third tank is used by the railroad. The town tank supplies water to the railroad tank, wharf area, powerhouse, and town. Pumps at the town tank are electrically driven. One of the pumps at the reservoir tank is diesel driven and the other is a reciprocating steam pump. These pumps can, if necessary, fill the town tank as well as the reservoir tank.

2. ARRANGEMENT OF SYSTEM. All facilities are so arranged that they can be quickly and thoroughly drained. They are also arranged so that brine and other solutions can be pumped back and forth through the system to raise the temperature of the lines above that of the surrounding ground (24° to 25° F).

3. PIPELINES. The water main from the reservoir to the town tank is 14,500 ft long and is wrought-iron pipe 10 in. in diameter. Two branch lines of 8-in. wrought-iron pipe connect the town tank to the railroad tank and to the powerhouse at the elevator and wharf area. Some sections of the waterlines are insulated with rock wool and placed in 30-in. culvert pipe; others have moss insulation, as shown in Figure 2E1-7, and a portion of the water distribution system and other services have been installed in utilidors, as illustrated in Figure 2B2-3. (Ref. 59.) (See also par. 3 of 2B2.01.)

2E2.03 WATER SUPPLY, FLIN FLON, CANADA (Ref. 73)

The mining town of Flin Flon is located at about lat 55° N and has a climate that is typically Subarctic. The design of the water system is unique in that circulation of water in the mains and the house service lines is continuous. (See Figures 2E1-8 and 2D2-15.)

The distribution system is laid out with supply

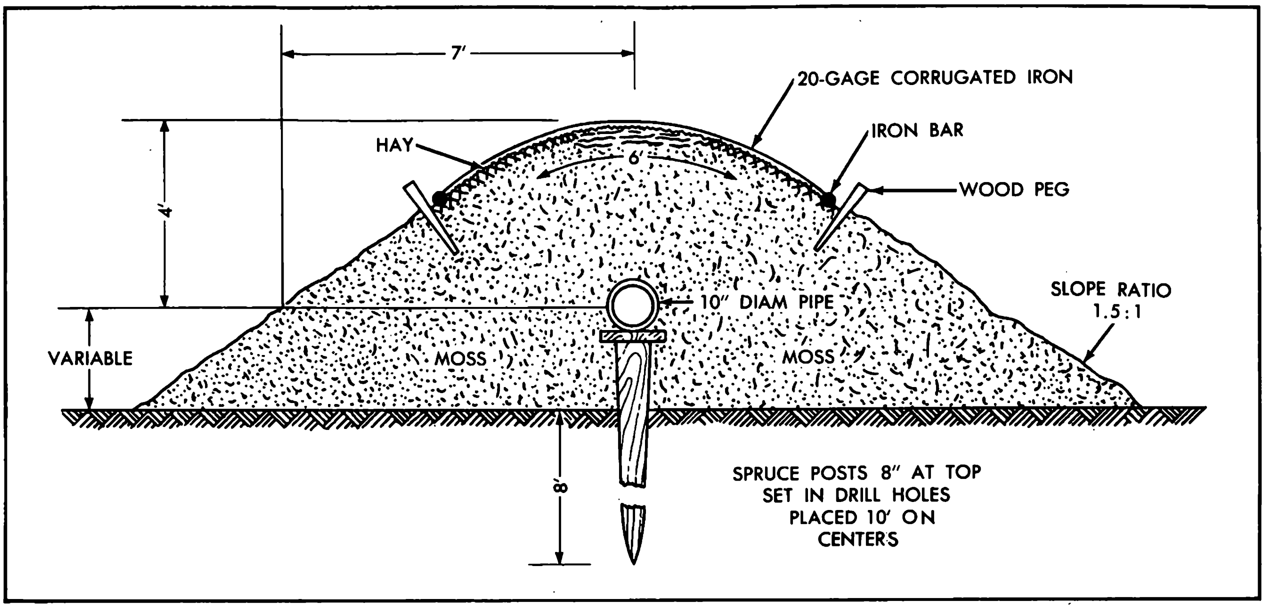


FIGURE 2E1-7

Cross Section Showing Insulation of Waterline, Churchill, Canada (Ref. 73)

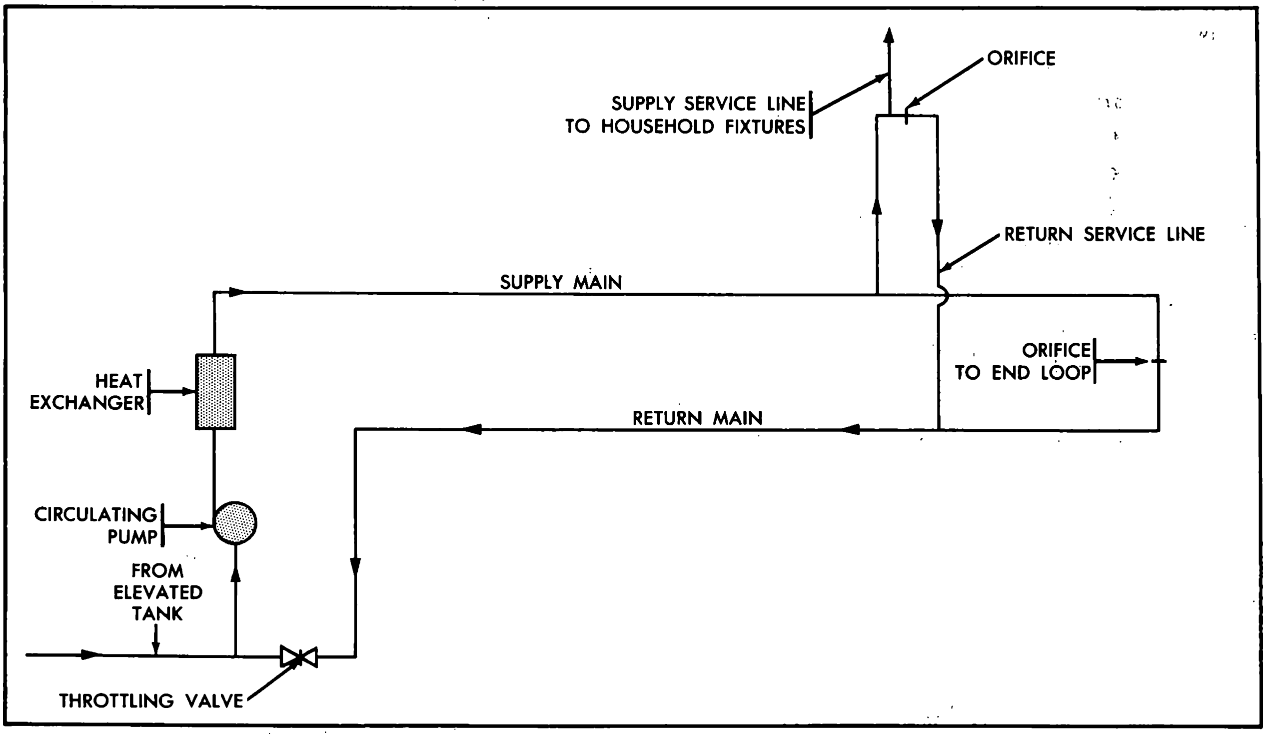


FIGURE 2E1-8

Diagrammatic Layout of Circulating System, Flin Flon, Canada

and return mains on streets and a service line from the main to every consumer. Mains are supplied from the high-pressure header of circulating pumps that take suction from the header into which the return mains discharge. Water consumed is made up from an elevated tank that feeds into the return header. By running the circulating pumps, water is circulated through all the mains and through every connected premise. Water from the circulating pumps passes through heat exchangers before entering the supply mains. This raises the temperature sufficiently so that water in the return mains will be well above freezing. Heat for the heat exchangers is supplied by oil-fired steam boilers. Inside the premises, where the supply and return lines are joined together, an orifice is placed. The waterline to the household fixtures is taken off the supply side of the orifice. At Flin Flon the orifice has 1/32-inch holes drilled in it that restrict the circulation to just the amount required to prevent freezing. (Figure 2D2-14 does not show an orifice in the loop to the premises.) Without such orifices the circulating pumps at Flin Flon would not have sufficient capacity to maintain a pressure differential between the supply and the return mains.

2E2.04 PROBLEMS OF WATER TREATMENT PLANT DESIGN, FAIRBANKS, ALASKA

The design of a water treatment plant for Arctic conditions is typified by the plant designed for Fairbanks, Alaska. Special consideration of Arctic conditions entered into the functional design, structural design, and air-conditioning system of this plant. (Ref. 82.) (See Figure 2E1-9.)

The raw water for the plant comes from 24-inch California-type wells driven in a talik of sand and gravel. The wells are approximately 150 feet deep and are perforated at various horizons. A report (Ref. 82) on water treatment plant design is quoted as follows.

> The temperature of the raw water is low (35° F) and the mineral content (iron and manganese) of the water is high.
>
> To permit the most economical plant design, the raw water temperature is raised to approximately 55° F. The warmed water is oil-free and waste-free spent condenser cooling water from the adjacent powerhouse. With the tempered water, normal design bases for chemical coagulation, sedimentation and filter rates were used. If unheated water were to be treated, the size of units would have been two to four times larger.
>
> Treatment consists of provisions for preaeration, coagulation with iron salts, pH adjustment with lime, mixing in the presence of a highly concentrated slurry, settling and filtration. Greater filter efficiency is anticipated through the use of anthracite filter media.
>
> After treatment and disinfection filtered water is cooled to palatable and suitable distribution temperatures by means of a heat exchanger utilizing raw water as a cooling medium. A clear well allows additional chlorine contact detention for disinfection.
>
> In the structural design of the plant special consideration was given to the location of the plant in order to insure satisfactory foundation conditions. The location selected is not in a permafrost zone and foundations are in river gravel material. Foundation design is based upon equalizing or securing a minimum of variation in soil bearing values, for both loaded and unloaded conditions.
>
> Insulating materials were used in the building structure to counteract exterior temperatures expected to vary from −66° to 95° F. Exterior walls above ground consist of a structural steel frame with insulated wall panels. Roof construction consists of a steel ribbed deck and 3-inch thick fiberglass insulation with structural steel frame. Exterior windows are provided with storm sash.
>
> Extended use of air conditioning for the protection of plant and equipment is included. The air conditioning installation provides for heating, cooling and humidity control as required to meet the range of temperature and humidity conditions existing during the different seasons. Winter air conditioning must take care of temperatures which average −10° F during January and have reached a minimum of −66° F. This cold air contains very little actual moisture. When heated to building temperatures of 65° to 70° F the addition of sufficient moisture to raise the relative humidity to 20%-30% for health and comfort conditions is required. Summer air conditioning, on the other hand, must take care of 80° to 90° F temperatures with relative humidity of 65% and dew point temperatures which often exceed 60° F.

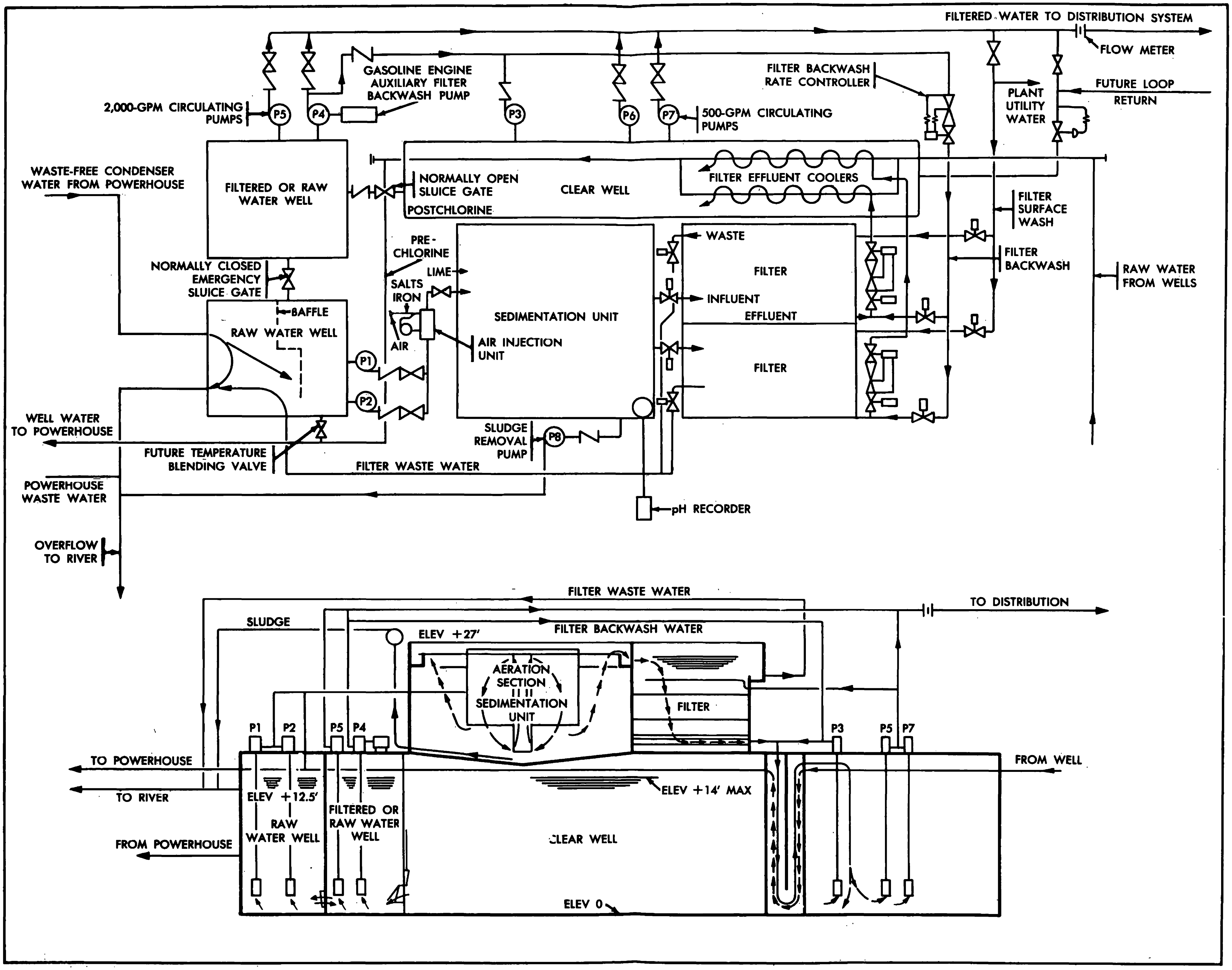


FIGURE 2E1-9

Flow Diagram and Profile of Water Treatment Plant, Fairbanks, Alaska (Ref. 83)

In order to prevent condensation on surfaces of water lines and tanks containing water at temperatures of 35° F to 65° F provision is made to insulate cold surfaces and to lower the dew point within the building to approximately 45° F to 50° F. This is accomplished by chilling building air, condensing out excess moisture, and reheating to optimum temperatures.

Air conditioning equipment consists of a unit conditioner with steam coils, chilling coils and live steam humidifier arranged with centrifugal blower, filters and dampers for adjusting fresh air and recirculated air mixtures with a minimum of 10% fresh air at all times. Ventilation of the building is accomplished by a duct system with additional wall fans and unit heaters to provide positive circulation throughout the building. The building windows are non-operating sash. The ventilating system provides positive internal pressures to minimize air leakage and infiltration.

Steam for heating and humidification is provided from the municipal steam distribution system and power plant located adjacent to the water treatment plant. Cooling water for the air chilling coils is provided from the raw well water at 35° F temperature.

2E2.05 SNOW SHELTERS (Ref. 84)

1. SNOW CAVE. A snow cave (Figure 2E1-10) is one of the simplest shelters and can be built in one or two hours. Only a shovel is required in its construction. The site selected is usually a fairly steep slope where the snow has lain in place long enough to be compacted. A working shelf is cut into the snowdrift, and a small cave about 2 ft x 2 ft is excavated back for several feet. This opening becomes a doorway. Excavation can then continue on the cave proper, the easiest way being to cut the snow into blocks and push them out the door. The floor of the cave should be sloped upward away from the doorway, with the sleeping platform at the top of the slope. The ceiling should be shaped like a dome to strengthen the shelter and to allow condensate to run down the walls. To accommodate three or four occupants, the final cave size should be about 9 x 8 ft. Such a cave is usually about 5 ft high at the highest point. Immediately inside the door are several feet of working area with the upper side about a foot above the floor elevation at the door. The bed platform is usually a foot above the highest point of the working area or at the same elevation as the top of the door. This keeps cold drafts away from the sleeping area unless there is a strong wind. A ventilating hole is cut upward through the roof on the side of the cave farthest from the door. Cold air, being heavy, remains at the lower level as long as the upper parts of the cave are filled with warm air. No artificial lighting is needed in the daytime because enough filters through from overhead. At night, a single candle

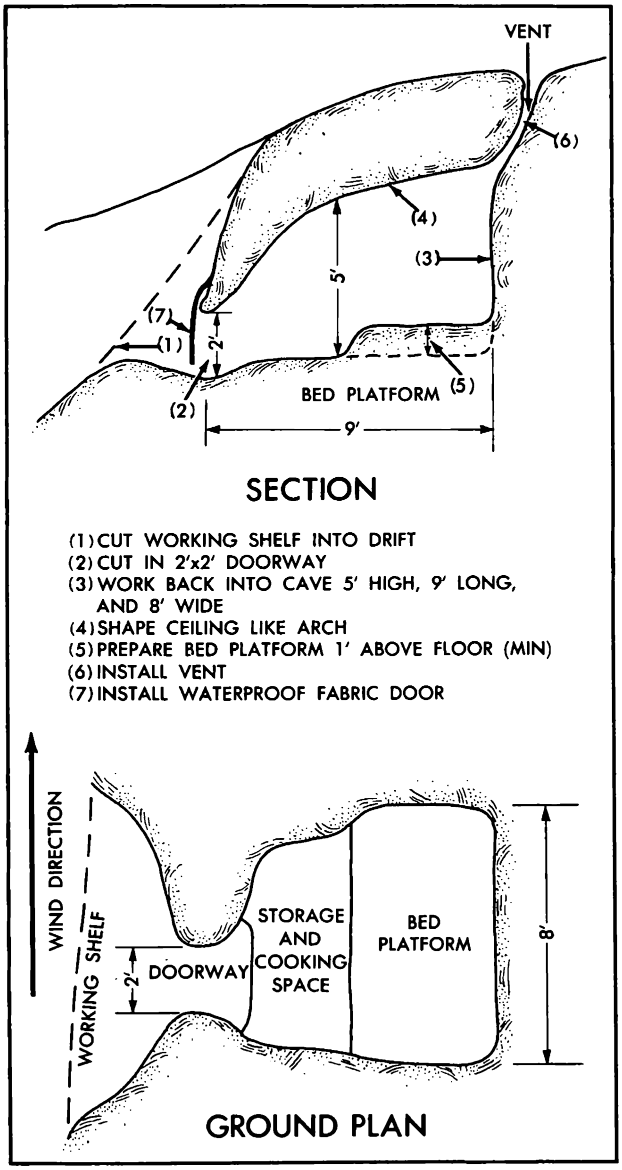


FIGURE 2E1-10

Steps in Building Snow Cave (Ref. 84)

is usually sufficient because of the high reflecting qualities of ceiling and walls.

2. IGLOO. An igloo is built of snow blocks 4 to 6 in. thick, 12 to 20 in. wide, and 20 to 40 in. long. Depending on the density of the snow, the blocks weigh from 50 to 100 lb and are strong enough to support their own weight and that of the blocks resting on them. To build an igloo the snow must be the proper consistency. This can be determined by sinking a slender, blunt rod into a snowbank. If it sinks in slowly with an even pressure on the rod, the snow is the proper consistency for construction. Snow that is too soft will crumble when handled; if layers of snow have different consistencies, the blocks may split; and if the snow is too hard, its insulating qualities are poor.

Tools required in building an igloo are a knife with a blade 14 to 20 in. long and a shovel for piling snow on the completed igloo. If the snow is quite hard, a carpenter's saw may be used. Three men make an efficient building team; one cuts the blocks, the second carries them, and the third places them. Cracks should be chinked, but only after the blocks have cured for a few hours.

The best location for building an igloo is on a level, well-compacted drift where the snow is over 3 ft deep. This depth permits tunneling the entrance under the walls to a well in the floor, which is the preferred type of entrance.

An igloo is usually dome shaped, with a 5- to 7-ft ceiling and with a diameter equal to twice its height. Several people can be comfortably sheltered in an igloo of this size.

To start construction the blocks are placed on edge and fitted snugly together on the line of the circle that has been previously laid out to the desired diameter. (See Figure 2E1-11.) They should be tilted slightly inward; the top of the first course is then cut with a knife and tapered in height. Succeeding blocks are then laid in a continuous spiral, each course tilting farther and farther inward until there is only a small opening left at the top of the door. The last block, or king block, is then carved, and the builder on the inside thrusts it through the aperture edgewise, levels it, and lets it fall back into place. The openings between the blocks are then carefully chinked from the outside with loose snow, which soon sets into snowcrete. The protruding exterior edges of the blocks should be left rough to provide a key for the snow cover. The interior edges should be smoothed down. After all blocks are in place, loose snow is thrown against the house and allowed to slide back to its natural angle of repose. On completion, there may be around the house a bank of snow several feet thick at the base and thinning upward. A tunnel is then dug under the wall to connect with an entrance well dug in the floor of the house.

A bed platform is built of snow at an elevation at least 18 in. above the top of the entrance tunnel. This elevation relationship is very important because it is about the minimum required for gravity control of the temperature within the house. The snow sleeping platform should be protected from thawing by blankets or skins.

Heat for the house is provided by a lamp or small oil stove. To glaze the inner wall surface, the temperature in the house is raised high enough to make the inner surface spongy; then the fire is put out and the wall is allowed to freeze, which may be hastened by cutting a hole in the roof. Glazing in this manner provides a hard protective inner surface that increases the strength of the dome and protects the wall from crumbling when touched by occupants. Ventilation is obtained by a hole cut in the roof near the top. If available, a metal vent can be placed in the hole. When the lamp or stove is in use, the vent is opened as required. When there is no fire, the vent can be closed by stuffing it with cloth. The upward movement of warm air through the vent allows cold air to enter from below through the entrance passage. In this manner the rate of air change and the temperature of the room are controlled.

2E2.06 PREFABRICATED SHELTERS AND BUILDINGS

In the following paragraphs, brief descriptions are given of various types of structures used to provide housing for personnel or equipment in regions of extremely low temperatures. The structures described are prefabricated types that can be transported by air or by tractor train and can be quickly erected by whatever labor is available. Many new building designs for the Cold Regions are now in the experimental stages of development and research, but conclusions regarding their feasibility are not yet available.

1. ARCTIC HUT. (Ref. 21.) This is a prefabricated structure designed to serve as a 16-

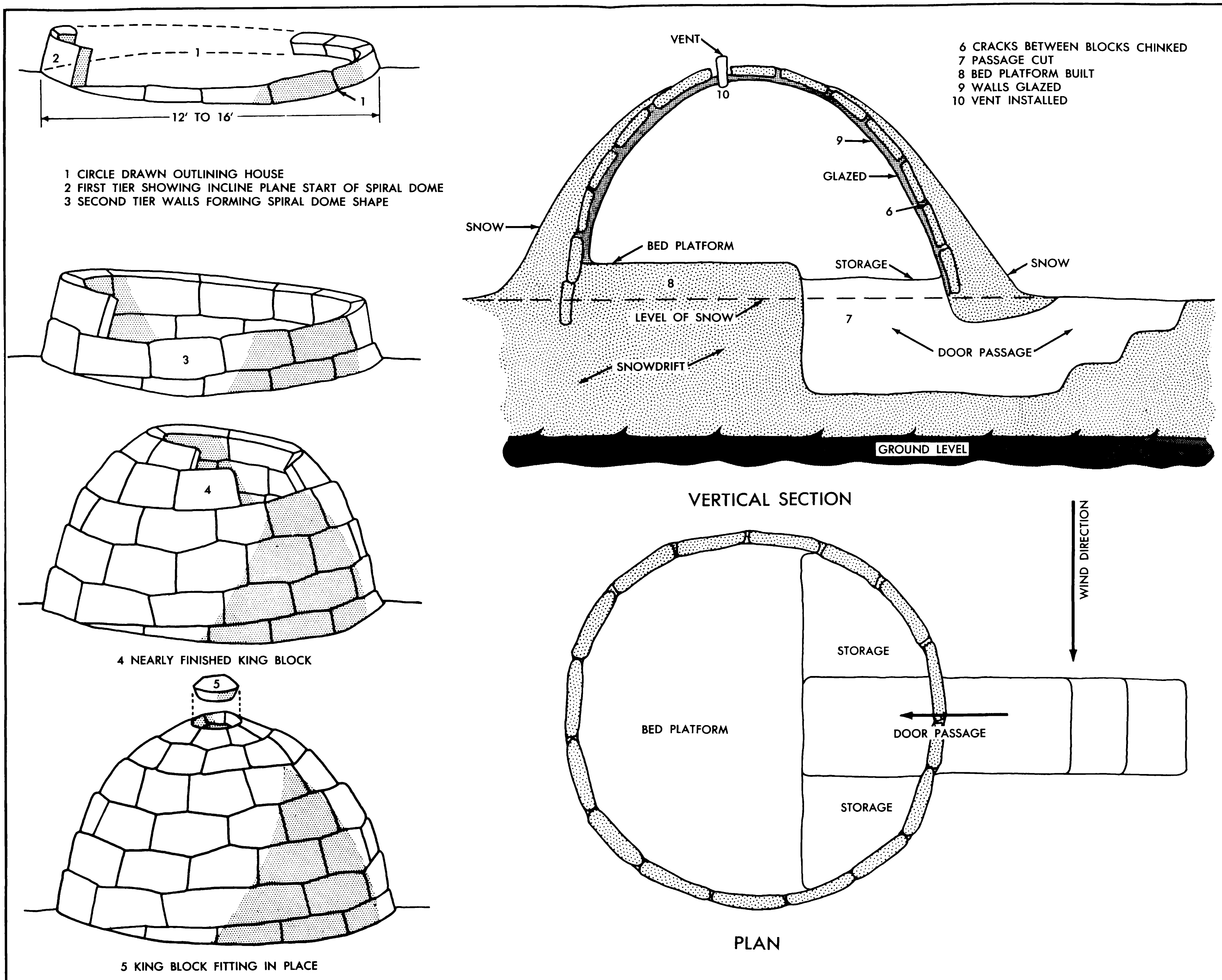


FIGURE 2E1-11

Steps in Building an Igloo (Ref. 84)

nan barracks or for equipment storage in frigid areas. At −65° F an inside temperature of 70° F can be maintained with only a small fuel consumption. Even under low-temperature conditions it can be erected by 12 men in 4 hr or less. The hut is made up of panels consisting of a resin-impregnated paper honeycomb core sandwiched between two thin aluminum skins. Wall panels are 3 in. thick; the roof and floor panels, 5 in. thick. Panel edges are plastic fiberglass laminate, and the shiplap joints are fastened with pins approximately 6 in. long and ⅞ in. in diameter. Pins are plastic, reinforced with fiberglass, to prevent condensation of heat. They are held in place by metal wedges. Twelve 4- x 8-ft panels form each side of the hut, which is 12 ft x 18 ft. The weight of the structure is 5 tons.

The roof is slightly pitched. There is a door at each end, one for entrance, the other for emergency only. Each panel, except the two center end ones, contains a round window 16 in. in diameter consisting of 2 panes of plexiglass separated by a 1-in. airspace.

A bulkhead may be installed at any of several points within the building. If installed close to the entrance, it acts as a vestibule. Framework of the building is of structural aluminum. The structure rests on 2-ft high foundation beams in which large holes have been cut to allow air to circulate. The heaviest piece to handle weighs 147 lb. Only a mallet and socket wrench are required for erection.

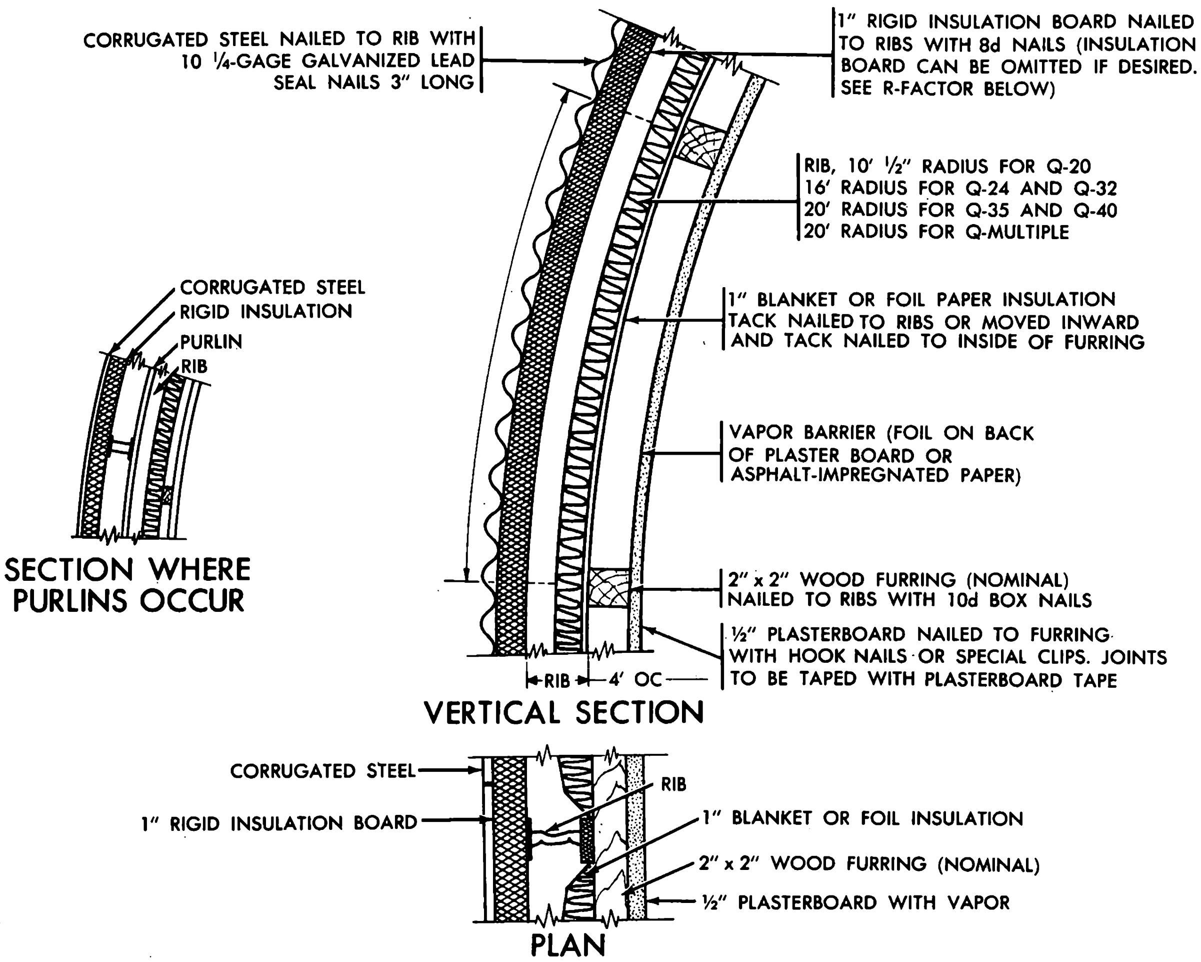
2. QUONSET HUT. (Ref. 84.) This is a prefabricated metal structure composed of corrugated-iron sheets supported by curved steel ribs. The basic unit is 20 ft x 48 ft, interior size, with a 4-ft vestibule extension on each end of the building. Endwalls are entirely steel. The unit is provided with inner insulated walls, the thermal resistance value of which may be controlled to meet the design dictated by the disciplines. A typical section in use in northern Alaska is shown in Figure 2E1-12a. The floor consists of 4- x 8-ft plywood double panels separated by insulation. All doors, windows, vents, adjustable louvers, and other appurtenances, including erection materials, are supplied with each building. A 20- x 48-ft basic unit requires about 100 man-hours to erect the bare structure, with additional time required for the foundation and insulation under the building. The building may be placed on any type of foundation, and larger buildings of the arch-rib design are available.

Figure 2E1-12b shows a cross section and construction details for a Quonset-type hut that is presently being developed by the Navy for Arctic adaptation.

3. JAMESWAY HUT. This is one of the most flexible and satisfactory prefabricated units developed to date. It is light in weight, easy to erect, and comfortable. The basic unit size is either 16 ft x 16 ft or 24 ft x 24 ft, and each can be erected in any length that is a multiple of 8 ft. The framework consists of a series of laminated wood ribs, which are covered by blanket strips 8 ft wide and the correct length to extend in a continuous covering over the full arch from the base on one side of the building to the base at the opposite side. Blanket strips for roof and end sections consist of two layers of heavy canvas with approximately 1½ in. of fireproofed rock wool or fiberglass insulation between them. The outside layer of canvas is treated with rubber to make it waterproof and windproof. Floor sections consist of plywood panels faced on the underside with a blanket of insulation usually 1½ in. thick. In extreme cold a double thickness of floor is required. Hard maple or steel stakes are used to anchor the building to the ground. The outside canvas is lashed to the floor and the connection insulated with snow or other material. Vestibules and storm doors are required at the entrances during extremely cold weather. At low temperatures the outside cover should be placed in a warming shed before placing; otherwise it becomes stiff and hard to erect. Jamesway huts are generally used for living quarters, mess halls, and administration buildings. (Ref. 84.)

4. WANIGANS. (Ref. 84.) These are small, mobile structures mounted on sleds or go-devils and towed by a tractor or other prime mover. They are commonly used by reconnaissance and initial construction crews operating away from their base, and comprise the greater part of a tractor train, aside from cargo units. (See par. 3B2.02.) They may serve as galleys, repair shops, water and fuel carriers, sleeping quarters, offices, and warming shelters for either mobile or static situations.

Wanigans are very rigidly constructed to enable them to withstand the twisting and vibration of the sled unit on which they are mounted. They usually are about 8 x 20 ft, have a minimum ceil-



HEAT TRANSMISSION DATA

ITEM	MATERIAL RESISTIVITY FACTOR R.	
OUTSIDE SURFACE	0.17	0.17
CORRUGATED STEEL	0.10	0.10
AIRSPACE (AVG. ⅜")	0.64	—
1" INSULATION BOARD	3.03	—
AIRSPACE	0.91	0.91
1" BLANKET-TYPE INSULATION	3.03	3.03
AIRSPACE	0.91	0.91
½" PLASTERBOARD	0.23	0.23
INSIDE SURFACE	0.61	0.61
TOTAL RESISTANCE Σr	9.63	5.96
TOTAL CONDUCTIVITY FACTOR (1/r)=U	0.103	0.168

CONDUCTANCE FACTOR, U, GIVES HEAT LOSS PER SQ FT OF SURFACE THROUGH CONSTRUCTION IN BTU/HR/°F DIFFERENCE BETWEEN INSIDE AND OUTSIDE TEMPERATURES.

FIGURE 2E1-12a

Typical Section of Quonset Hut, Point Barrow, Alaska (Ref. 84)

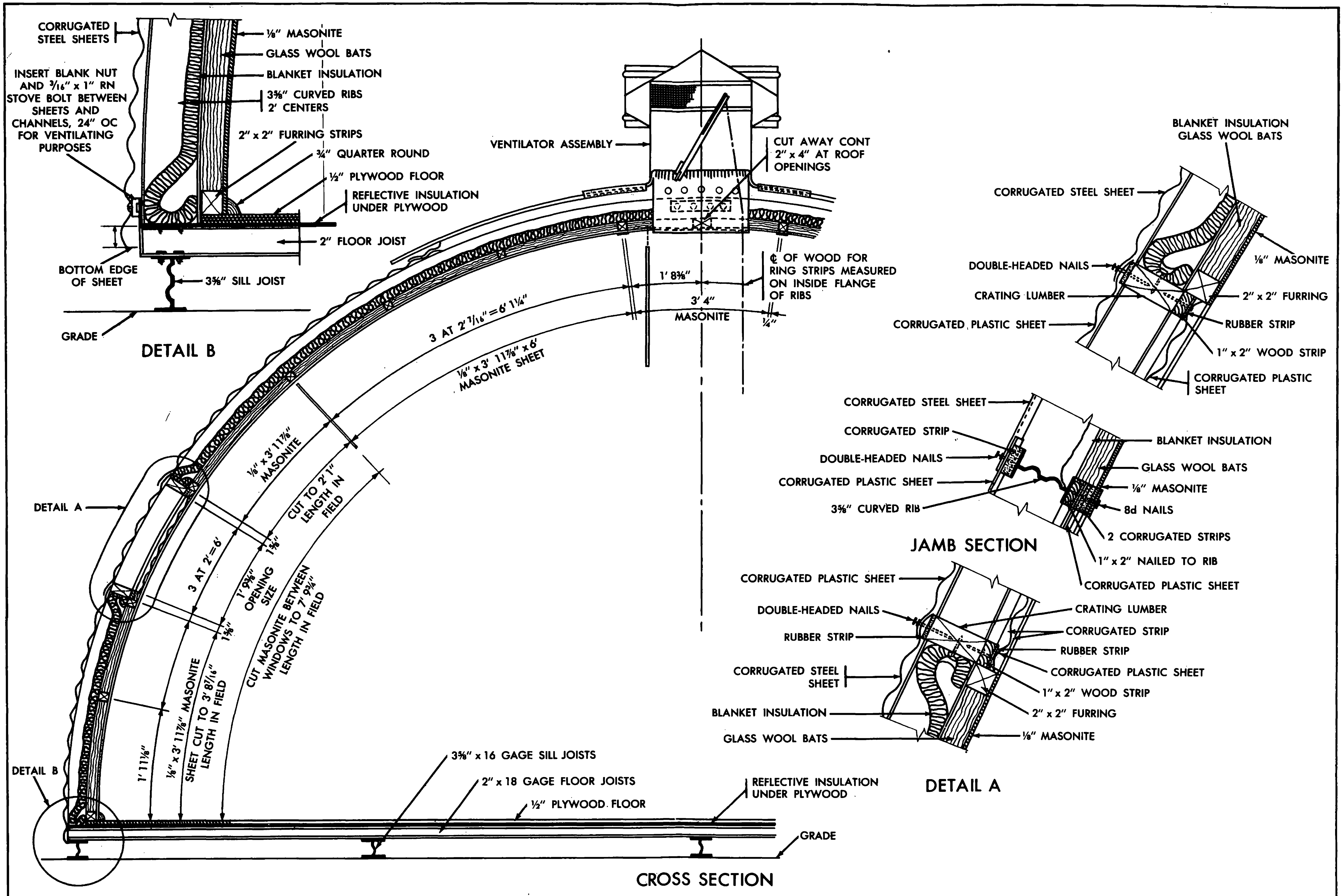


FIGURE 2E1-12b

Arctic Adaptation Kit for Northern Design, Q-20 x 48 Feet

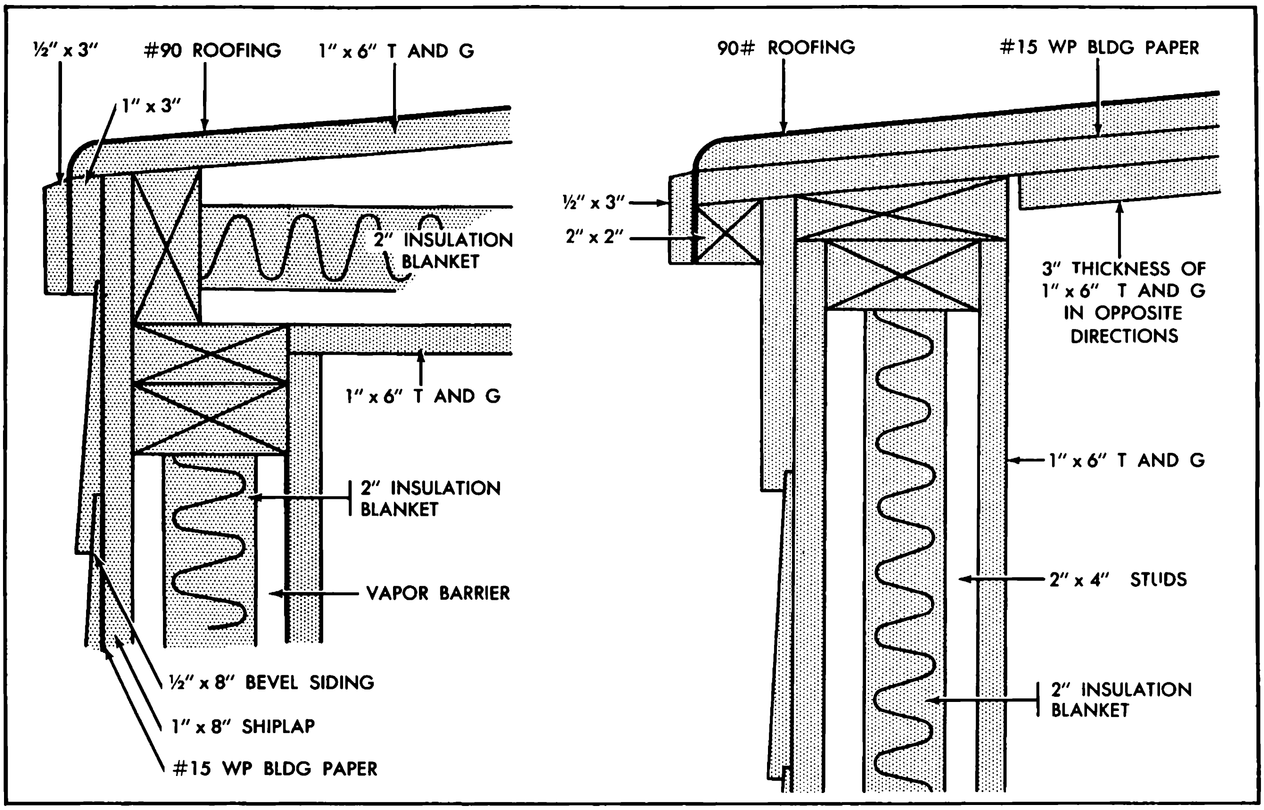


FIGURE 2E1-13

Arctic Wellhouse Weatherproofing Detail (Ref. 85)

ing height of 7 ft, and can be built of frame or prefabricated materials. Usual construction is ⅝-in. plywood or sheet metal on a strong, well-braced frame. The roof is a flat arch and is the same material as the walls, with a sublayer of roofing paper. The interior is insulated with wall-board. For tractor-train service, heavy protective screens should be put over the windows as protection against branches.

Doors should be located at the ends to allow egress for personnel in case the unit tips over. Also, doors should open inward to permit close coupling of units.

Wanigans are the heaviest of the small shelters generally used in forward areas of the Cold Regions. The rectangular sections of the prefabricated types can be packed well for efficient cubage.

5. STOUT HOUSE. A Stout house is a shed-type structure erected by using flat panels of wood to which insulating material has been nailed. The basic building unit is 16 x 16 ft. Next to the Jamesway, it is the easiest to transport by air or tractor train because it is light and because the rectangular sections can be efficiently packed. Floors should be laid double thickness, with an intermediate layer of insulation. Tar or asphalt roofing paper is usually applied to the outside for further protection. Roof maintenance is usually considerable, and in areas of high winds the roofs must be lashed down. Because of the shape of the house, more headspace is available per square foot of floorspace than in curved-roof structures. The Stout house is convenient for quarters, mess halls, administration buildings, and bath houses. (Ref. 21.)

6. STRESSED-SKIN PLYWOOD BUILDING. (Ref. 84.) This structure is prefabricated throughout and consists of floor, wall, and roof panels, each highly insulated, which are nailed and screwed together to form a rigid frame. The building panels consist of a frame of studding on

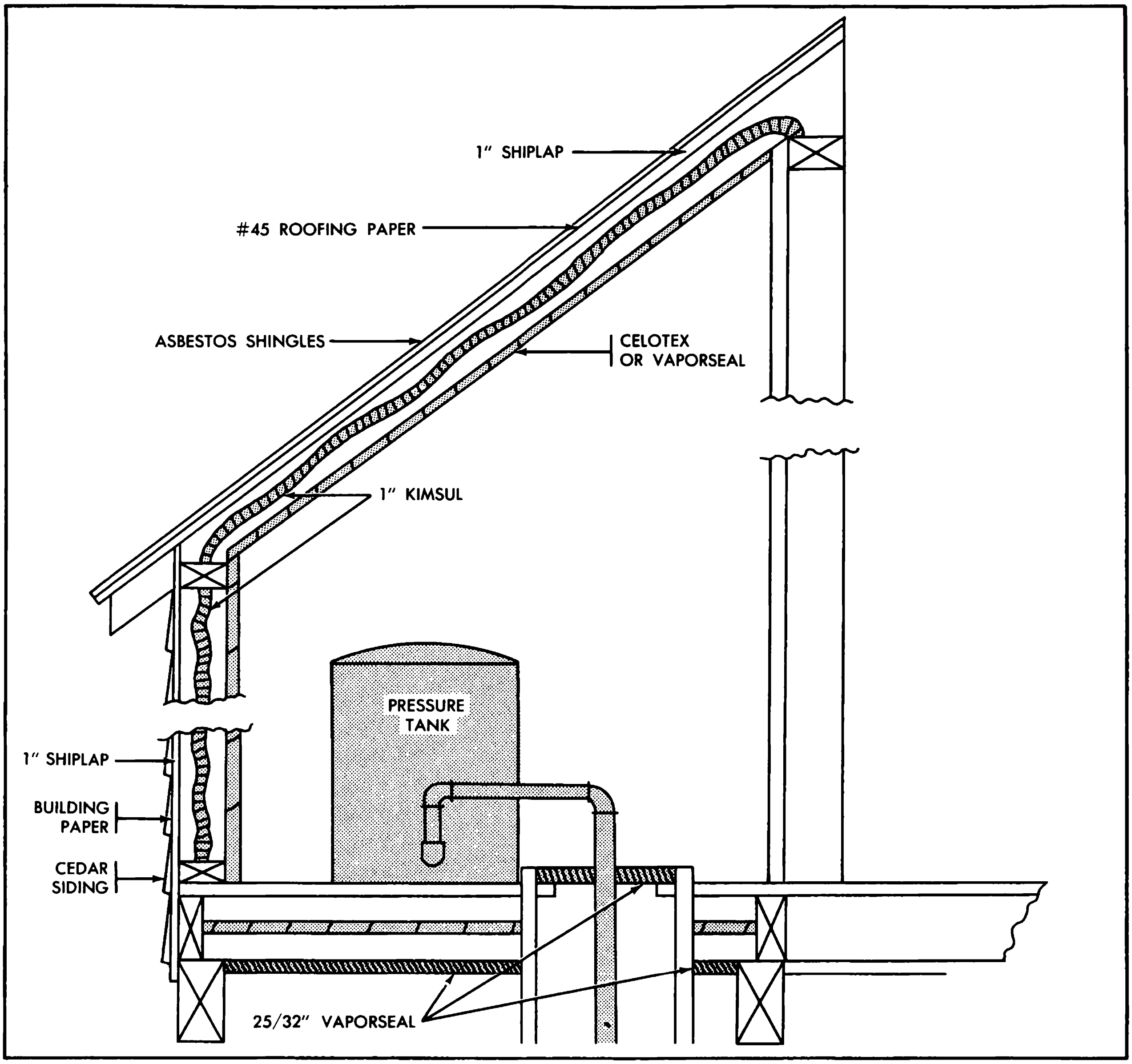


FIGURE 2E1-14

Insulation and Vaporseal, Moses Point, Alaska (Ref. 85)

which plywood layers are glued and nailed. Between the outer layers is a sandwich of triple insulation of fiberglass aluminum foil and fibercard. The panels are joined by separate connectors. All joints are covered on the outside with felt-lined strips. Standard sizes of the panels are 4 ft x 8 ft. They can be easily handled by two men. In special cases, when only small bush planes were available to fly the building components to the site, the panels were made 2 ft x 8 ft. On this type of building all overhangs or sharp corners are avoided to prevent lift action by the wind. Gable ends and corners have special flashings to keep the building snowtight. Aluminum sheet roofing covers the roof. The outside is painted with high-grade aluminum paint, which has proved resistant to weather action in the Arctic. Because of its smooth exterior, the building withstands storms up to 65 mph without having to be tied down. At locations where higher winds are expected, tie rods with

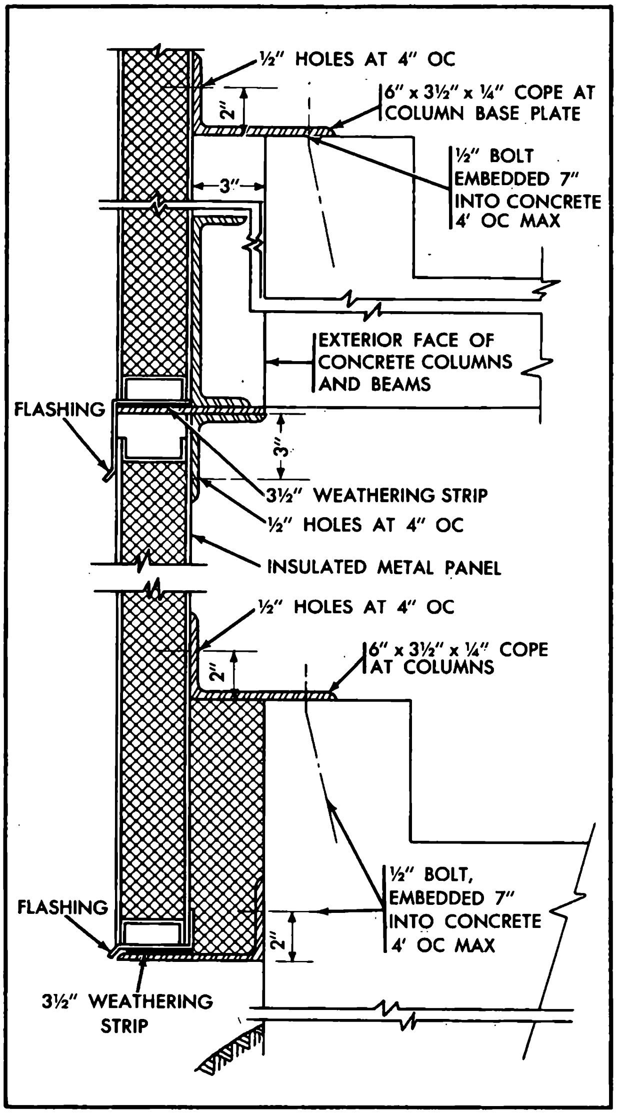


FIGURE 2E1-15

Typical Wall Section, Water Treatment Plant, Fairbanks, Alaska (Ref. 83)

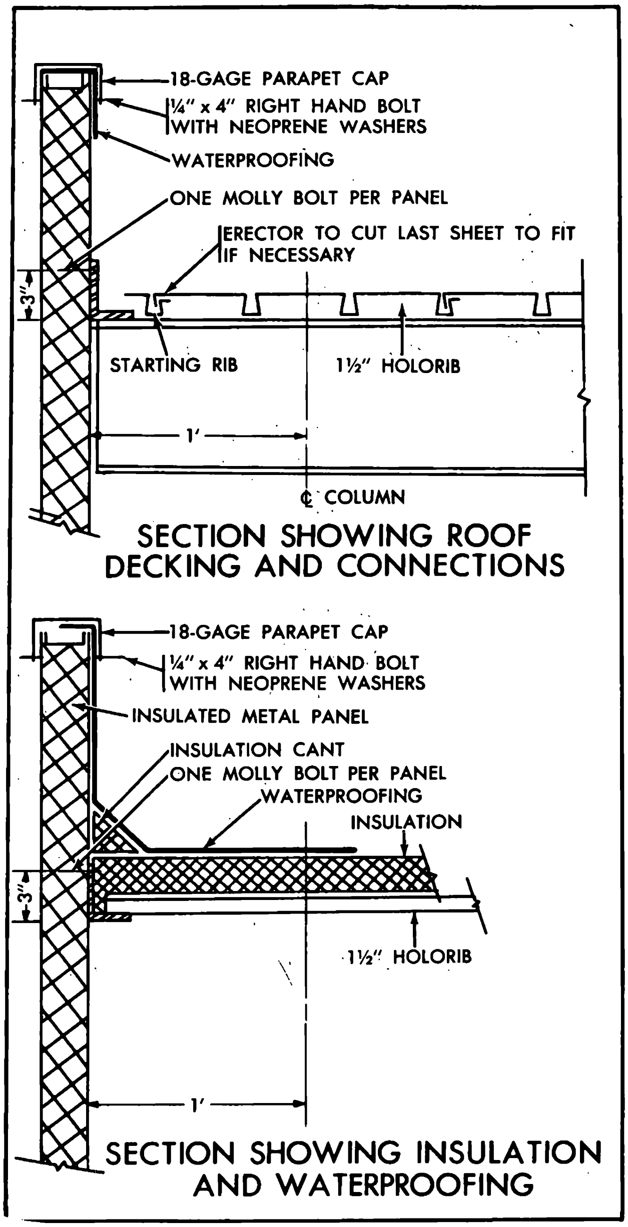


FIGURE 2E1-16

Roof Sections, Municipal Powerplant, Fairbanks, Alaska

turnbuckles are used to anchor the building to the ground.

Windows are triple-glazed and can not be opened.

On larger structures of this type, such as power-houses, garages, and warehouses, the insulated panel floors are not used. In such cases, whenever possible, a reinforced concrete slab should be used as a floor to replace the rigidity provided by the frames of the floor panels. If a concrete floor is not practicable, the gravel fill may be used as a floor, provided ballasted outriggers are spaced alongside the building to prevent it from being moved by the wind. The outriggers consist of heavy timbers properly braced against the building. At the bottom they are connected with horizontal beams to the wall panels and interbraced by tie rods. The bottom members are then ballasted with gravel. During the winter, outriggers catch the snow, which adds warmth and stability to the building.

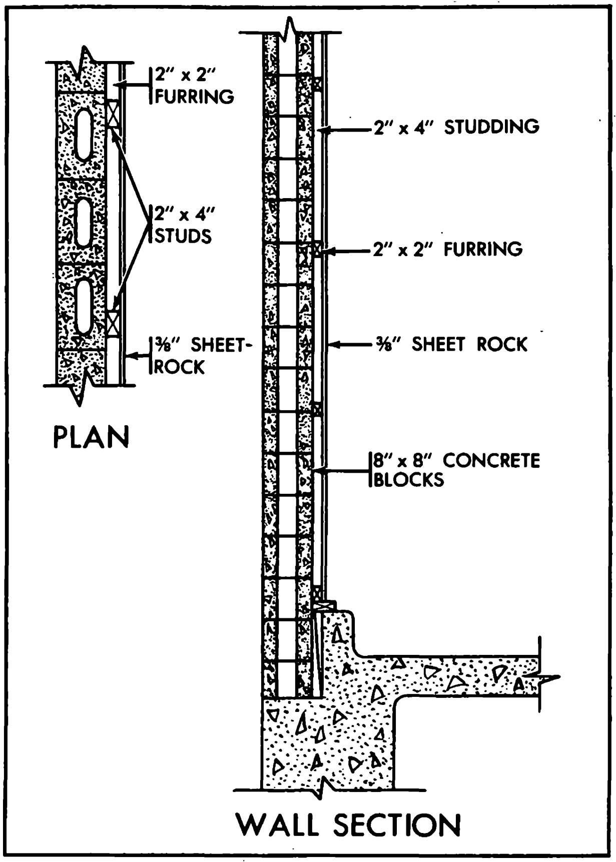


FIGURE 2E1-17

Typical Wall Section, Telephone Exchange Building, Fairbanks, Alaska

7. OTHER TYPES. Several other types of shelters, including the Cowan hut, Pacific hut, and Army standard theater-of-operations hut, have been successfully used in the Cold Regions. All are similar in many details to one or more of the types of shelters previously described. Some modification is usually required on all these structures to make them adequate for the severe conditions frequently encountered.

2E2.07 WALL AND ROOF SECTIONS, OTHER STRUCTURES

Figures 2E1-13 through 2E1-18 illustrate several types of wall and roof sections used in the Cold Regions.

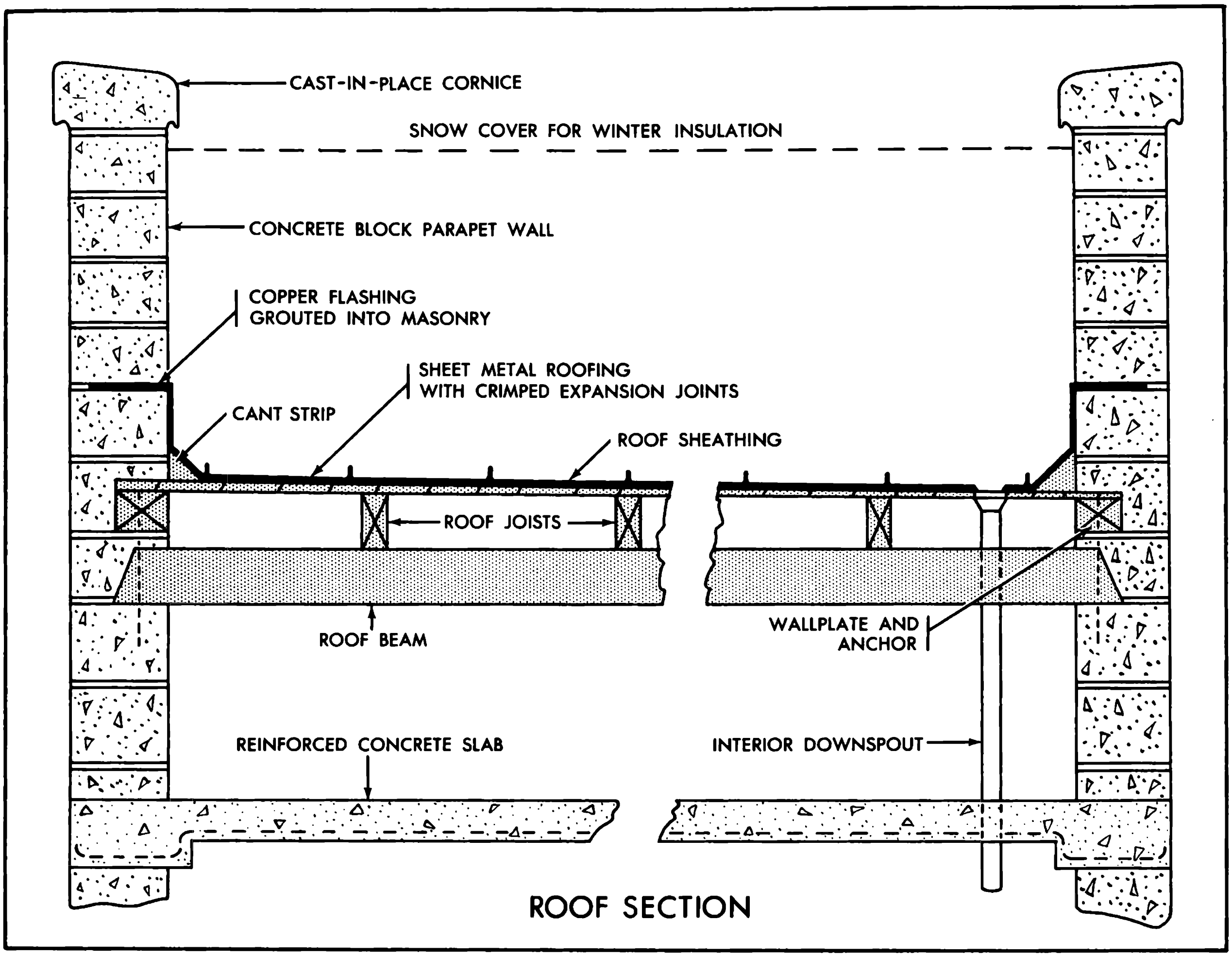


FIGURE 2E1-18

Roof Section, U. S. Smelting, Refining, and Mining Co., Fairbanks, Alaska

PART F. FIRE PROBLEMS IN THE COLD REGIONS

Section I. FIRE PREVENTION

2FI.01 CHARACTERISTICS

Prevention of fires in the Cold Regions is many times more important than in the Temperate Zone for the following basic reasons.

(1) Present firefighting equipment and techniques in the Cold Regions are far from satisfactory, and fires, once having gained headway, are practically uncontrollable.

(2) Loss of facilities during extreme temperatures may threaten the survival of personnel.

(3) Facilities are presumed to be of strategic importance and should therefore remain operative until no longer practicable.

(4) Logistics is extremely difficult in remote sections of the Cold Regions.

A basic element of fire prevention is the maintenance of a high standard of cleanliness and order. It is important, therefore, that safeguards, procedures, and routines be established that will minimize the probability of fires and make possible the confinement or rapid extinguishment of a blaze once it has started.

2FI.02 PLANNING

To obtain the maximum degree of protectibility from damage, consistent with economic utilization, fire safety must be considered in all stages of planning and design. In general, fire protection in building construction is obtained by adequate separation between buildings, limitation of individual areas in accordance with the type of construction, subdivision of individual fire areas, protection of exposures to fire (including all openings), provisions for adequate exit and evacuation, and provisions for fire detection and extinguishment.

1. DESIGN. Design requirements for the type of construction selected are covered, in most cases, by standards and regulations of the Bureau of Yards and Docks. Special designs are necessary for buildings erected in the Cold Regions. The difficulty of transporting bulky or heavy materials to isolated regions generally necessitates the use of lighter and less fire-resistive construction than is customary in more temperate climates. (Ref. 86.)

2. SPACING OF BUILDINGS AND OTHER FACILITIES. Adequate separation of structures, limitation in size of built-up areas, and open storage and warehousing areas are of prime importance from the standpoint of reducing the probability of conflagration and the spread of fire to other buildings and areas. This is especially true where frame construction predominates, as it usually does in forward areas. Minimum standard spacings are usually established at each camp according to construction type and utilization. Special spacings are usually established for hazardous materials such as paint, oil, dope, chemicals, flammable liquid, gas, and liquefied gas. (Ref. 86.) Installations should, where possible, be placed in relation to natural or artificial terrain features to conceal or disguise them from recognition by enemy aerial or ground observers. If possible, sites should be chosen in broken terrain with small hills, streams, rock outcroppings, and timber stands. Concealment is especially difficult in the Arctic in winter because the sun is low and all objects cast long shadows, which are conspicuous. The natural texture of the snow is difficult to duplicate, and camouflage nets or drapes show up readily unless they are well installed.

An irregular arrangement is desirable to protect facilities such as fuel oil tanks from bombing and often fits the natural, irregular contour lines. Spacing is the most successful measure for conflagration control or fire area limitation at advanced bases. (Ref. 65.)

3. FIREBREAKS. Adequate firebreak areas should be maintained at all posts, camps, and stations and should, at all times, be kept clear of buildings, brush, timber, and other combustible material.

2F2.01 GENERAL

Modification of standard firefighting equipment and techniques is necessary in sections of the Cold Regions subject to extremely low winter temperatures. Inasmuch as most areas do not have adequate water supply and distribution systems, expedient equipment must be used. Where a dependable water supply is available, special methods are required to maintain circulation in the lines and to protect hydrants and fire apparatus from freezing. (See par. 2D2.05 and 2D2.06 and par. 3 of 4C2.01.)

2F2.02 FACTORS NECESSARY FOR FIRE

Fire can continue only where fuel, oxygen (or other oxidizing agent) from the air or other source, and a sufficiently high temperature to maintain combustion are present. Extinguishment can be accomplished by the elimination of any one of three factors: (a) removing the fuel, (b) excluding oxygen (smothering), or (c) reducing the temperature (cooling by water or other means).

In the burning of most substances the actual combustion takes place only after the solid or liquid fuel has been vaporized or decomposed by heat to produce a gas, and the visible flame is the burning gas. However, in the case of solid fuel, which does not evaporate or decompose to form gas at ordinary fire temperatures, combustion also takes place by direct combination of the fuel with oxygen, particularly in the case of the glowing combustion of charcoal or of charred wood remaining after combustible gases have burned. (Ref. 87.)

2F2.03 FIRE EXTINGUISHERS

1. CLASSIFICATION OF FIRES. Underwriters' Laboratories, Inc., to express the relative values of first-aid fire extinguishers, developed the following fire classification plan, which has been adopted by the National Fire Protection Association (NFPA). (Ref. 87.)

Class A—Fires in ordinary combustible material, where the quenching and cooling effects of quantities of water, or solutions containing large percentages of water, are of first importance.

Class B—Fires in flammable liquid, grease, and so on, where a blanketing effect is essential.

Class C—Fires in electrical equipment, where the use of a nonconducting extinguishing agent is of first importance.

2. TYPES OF FIRE EXTINGUISHERS. Firefighting under low-temperature conditions presents two widely different problems. For outdoor use, low-temperature characteristics of equipment and material must be considered; but indoors, and to a lesser extent outdoors as well, the toxic effects of firefighting chemicals are important. The following general types of fire extinguishers are suitable in the Cold Regions.

a. *Water Types* (*for Class A*). (Ref. 87.)

(1) *Pump Tanks*. The 2½-gallon floor type is recommended by this Bureau. The equipment can be used for both normal and low-temperature service. Containers are provided with a built-in pump with attached hose and nozzle. The container is equipped with a handle, which permits carrying the pump tank to a fire. For low-temperature use, calcium chloride potassium dichromate antifreeze charges are used. Common salt or chemicals other than those recommended by this Bureau should not be used in these extinguishers for any purpose, because they may cause corrosion and render the extinguisher inoperative.

(2) *Chemical Pressured*. These extinguishers are furnished in the standard soda and acid type, tilt-bottle soda and acid type, and the break-bottle soda and acid type. The soda-acid extinguisher is the most common water solution extinguisher in which pressure is used to expel water. Although satisfactory at normal temperatures, it is not practicable at low temperatures because any antifreeze agent may cause corrosion, interfere with chemical reaction, or, if the antifreeze agent is combustible, reduce the extinguishing action. Also, even if an otherwise suitable antifreeze were available, soda-acid extinguishers would be of questionable value at low temperatures because of the retarding of the chemical action by cold. To protect these extinguishers from freezing, they are usually stored in an insulated cabinet heated by an electric bulb or strip heater.

(3) *Cartridge Pressured*. These extinguishers are usually furnished in a 2½-gallon capacity. The extinguishing agent is water, and the pressure for expelling the water is carbon dioxide gas released from a cartridge by inverting the extinguisher and bumping it on the floor to

puncture the gas-retaining seal. These extinguishers can be used at freezing temperatures by charging them with calcium chloride solution.

b. *Carbon Dioxide Squeeze-Grip Type (for Classes B and C)*. Because carbon dioxide is essentially nonconducting, these extinguishers are suitable for fires in electric equipment if they are provided with horns made of nonconducting material. The most effective extinguishing results are obtained by applying the discharge as close to the fire as possible, preferably between 3 and 8 feet maximum, depending on the size. Carbon dioxide is slightly toxic and may suffocate persons exposed to high concentrations for long periods. There is no residue from carbon dioxide, which makes these extinguishers especially useful in kitchens, hospitals, and other areas in which contamination is an important factor. (Ref. 87.)

c. *Dry-Chemical Type (for Classes B and C)*. This extinguisher is the most recently developed, and the design has not yet been stabilized. The extinguishing agent is a dry-chemical mixture expelled in powder form by a carbon dioxide cartridge and from wheeled extinguishers by nitrogen from cylinders. One design uses as a standard nozzle one that discharges the dry chemical at a relatively low velocity in a wide, fan-shaped stream to give maximum coverage of a fire. Another nozzle design, available as special equipment, delivers a high-velocity stream of dry chemical in a narrow fan shape. It is accordingly effective in the wind or on fires that must be attacked from a distance. Types have been developed for use at extremely low temperatures and for all conditions of exposure. (Ref. 87.)

d. *Wheeled Units*. Wheeled extinguishers are available in all of the types mentioned above. With their greater capacity, they furnish considerably more protection than hand-portable sizes. In that part of the Cold Regions, however, where terrain presents a mobility factor, wheeled extinguishers are difficult to handle and frequently are impracticable.

e. *Supplementary First-Aid Equipment*. To supplement fire extinguishers within buildings, boxes of dry sand and water barrels should be placed at convenient locations both inside and outside the buildings. Water, if placed outside or in unheated buildings, should be protected from freezing by adding an antifreeze compound. Sand and water containers placed outside must be sheltered to protect them from drifting snow and should be inspected daily and cleared of snow and ice to assure that the sand (and scoop) and water will be quickly available. Fire pails should be hung on hangers or set on shelves close to fire barrels at a convenient height from the floor. Fine, dry sand is an efficient medium to suppress spill fires involving small quantities of flammable liquid, but it is of no value on fires of flammable liquid in pans or vats or on Class A fires in ordinary combustibles. Sand can be used effectively in preventing fires of flammable liquid by covering and absorbing the spilled material.

f. *Effectiveness of Snow*. Snow is *not* effective as a first-aid measure in suppressing a blaze. Snow, because of its physical structure, retains oxygen, which aids combustion rather than suppresses it unless the snow is extremely wet and dense. Further, melted snow forms a crust to prevent additional melting at the base of the blaze, and the fire continues to smolder under the snow. Such an incident occurred during a tractor train expedition when several hundred gallons of aviation gasoline had to be dumped. Personnel were unaware that the fuel had spread over a wide area under the snow. When they sank through it, making holes that let in oxygen, flames shot up and burned vigorously, endangering the entire train and its complement.

2F2.04 EXPEDIENT FIREFIGHTING EQUIPMENT

1. STATIONARY WATER TANKS. Large, heated buildings, such as shops, warehouses, powerplants, and hospitals, can be given some degree of protection by installing a large tank, such as a pontoon, which is filled with water and connected through a pump to a fire hose. This system is especially practicable in boiler rooms and laundries, which usually store considerable quantities of water. In buildings that are not heated sufficiently to prevent the water in the tank from freezing, a calcium chloride solution should be added. In equipment of this type, the hose should be long enough to reach any part of the building and, if practicable, adjoining buildings.

2. WATER FOG EQUIPMENT. The water tank and pump combination described above can be used effectively in conjunction with water fog, supplied either from hose cabinets or hose carts. Water fog is valuable in handling nearly any type of fire. Combination nozzles capable of producing

either fog or straight stream are standard equipment. On Class A fires, excellent results are obtained both with fog and straight stream. Water fog is effective on Class B fires, particularly on kerosene and heavy petroleum. On light petroleum, initial control can usually be effected to the extent that fires can then be extinguished by dry chemicals.

On Class C fires, electric circuits should be shut off if possible. Fog may be used on live electrical equipment if the operator remains at least 10 feet from the equipment. (Ref. 88.)

The tank pump should have sufficient capacity to give a fog range of 10 to 20 feet. Straight streams should be effective at 40 to 50 feet.

3. MOBILE WATER TANKS. Much development work is presently under way by the Services to produce more satisfactory mobile equipment for transporting water for fighting fires. Trucks lack the ability to traverse heavy snowdrifts; present water tanks, fittings, pumps, and hoses need modifications for extremely low temperatures. A reasonably satisfactory immersion heater for mobile water tanks has been developed. One type of equipment, which is used in some areas, consists of a large insulated water tank equipped with a water pump and hose storage compartment and mounted on a sled or tracked vehicle and towed by a tractor. If roads within the area are kept clear of drifts, such a tank may be mounted on a truck. The equipment should be stored in a heated building to prevent the water in the tank from freezing and to assure that the vehicle is capable of starting quickly in cold weather. Antifreeze may be used in insulated tanks, but the toxic effect of any fumes generated when the mixture is thrown on a fire must be given consideration.

2F2.05 PORTABLE FOAM EQUIPMENT

Foam is produced at the time of the fire by various means, depending on the degree of control as to proportions and quality required. Foam is excellent for extinguishing many types of flammable liquid but is not suitable for protection of tanks of alcohol, acetone, or other liquid more volatile than gasoline. Special foam, however, is available for protection of such materials. Foam should not be used on metal fires or on live electrical equipment. If terrain conditions make access by truck possible, small crash units equipped with foam, carbon dioxide, and water fog combinations are valuable for handling vehicle and small aircraft rescue work. No equipment is available that has sufficient fire-extinguishing ability to handle successfully, under all conditions of terrain and weather, every type of crash-fire emergency involving large aircraft. Portable versions of fixed foam systems are available for areas in which wheeled vehicles have sufficient cross-country mobility to warrant their use. These areas, however, are not typical of the environments with which this publication is concerned.

2F2.06 FIREFIGHTING AND RELATED EQUIPMENT, WITH ADEQUATE WATER SUPPLY

1. GENERAL. The problems of fire protection in the Cold Regions are, of course, simplified when an adequate and reliable supply of water from a central distribution system is available. Conventional mobile fire apparatus and brigade methods of fighting fires can then be used if roads are kept operative and if equipment is modified for low-temperature service. Fixed fire protection equipment, such as automatic sprinklers, water fog, and foam systems, can be installed if their use can be justified. It should be borne in mind, however, that in permafrost areas where a central water system exists, it often meets only minimum requirements and may lack elevated tanks and other forms of storage capacity. Also, difficulties from supply lines and related facilities freezing during low-temperature periods may be expected.

2. DISTRIBUTION SYSTEMS. Criteria of the Bureau of Yards and Docks should be used in all phases of design, layout, and construction of the water distribution system. In laying out protection it is important to consider the probable development of the facility and to plan, at least in a general way, protection for the ultimate plant. Pipe systems serving hydrants and fixed protection systems should, wherever practicable, be arranged in loops.

3. HYDRANTS. Special methods are required to keep hydrants from freezing. In many areas, hydrants are boxed during the winter months to prevent freezing and still provide easy access. (See Figures 2F2-1 and 2F2-2.) Using salt or salt solutions in hydrant barrels to prevent freezing is not recommended because of their corrosive effect and limited usefulness. The most satisfactory method of thawing frozen hydrants is by steam hose.

Portable boilers, in which steam may be produced rapidly, should be standard equipment for Polar firefighting organizations. (Ref. 87.)

4. FIRE HOSE. Ordinary fire hose gives adequate service at temperatures as low as −65° F. It becomes stiff and brittle at low temperatures, however, and particular care must be taken in handling. Loss of hose is high when fighting fires at low temperatures because it often freezes to the ground, particularly in wet areas near the hydrants and the fire, where there may be spillage. The hose should be thawed loose as quickly as possible, drained immediately on stoppage of water flow, and dried. Freezing of cotton hose causes cracking and breaking of the cotton webbing. A practical way of drying hose is to direct warm exhaust from vehicle engines through it. Firm rules for hanging and caring for hose when not in use are essential if hose is always to be ready to combat fires.

5. SPRINKLER SYSTEMS. Sprinkler systems should be designed in accordance with Bureau of Yards and Docks standards.

6. OIL STORAGE. The design of storage facilities for stationary, vehicular, and aircraft engine fuel, lubricating oil, and heating oil is accomplished in accordance with Bureau policy and standards. Deviations from accepted standards and procedures are often necessary in the Cold Regions because of the disciplines encountered. In permafrost areas fuel oil storage tanks are located underground to a much lesser extent than in temperate climates. This necessitates considerable modification of handling systems and layouts, which are normally based on underground storage. (See Ref. 65.)

This Bureau recommends subsurface application of foam to fuel tanks by a method developed by the Navy that is presently regarded as standard for large fuel tanks. By this method, foam is pumped into the tank below the oil surface, extinguishment being accomplished by the foam floating up and covering the oil surface. This method re-

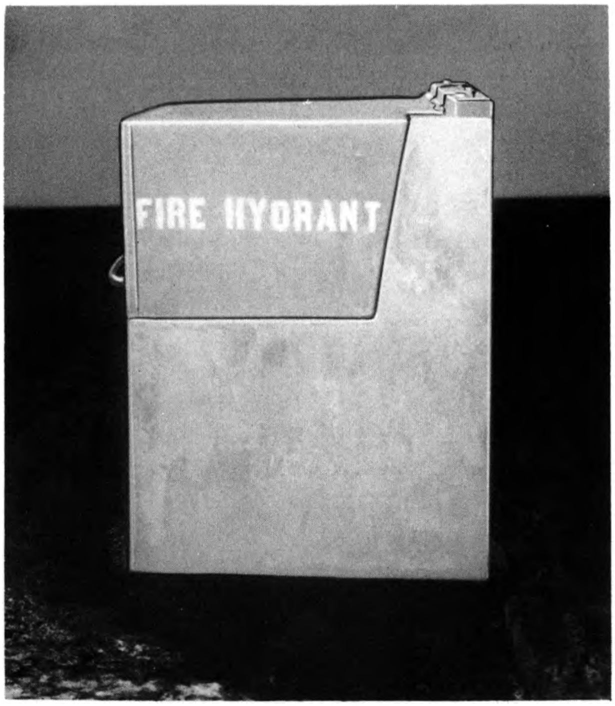


FIGURE 2F2-1

Hydrant Box, Fairbanks, Alaska

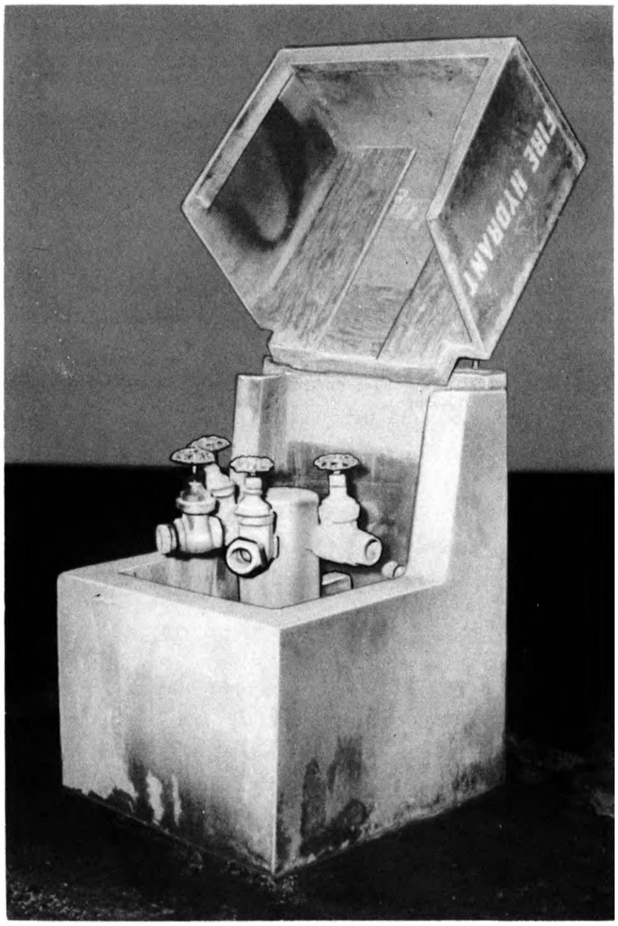


FIGURE 2F2-2

Hydrant Box Opened To Show Hose Connections

quires that mechanical foam be produced under pressure and with closely controlled proportions and quality.

Bureau standards require that each aboveground tank be enclosed by an individual dike with a maximum height of 5 feet (nominal) and with a minimum 1-foot freeboard. The necessity of obtaining adequate quantities of stable fill for dike construction should be considered in planning the project.

2F2.07 STATIC

Particular attention must be given to static ignition hazards in the Cold Regions, especially inside buildings that may have an extremely low humidity if very cold air is brought into the building and heated to room temperature without the addition of moisture. All potential gaps should be bonded unless generation of static can be eliminated.

Section 3. FIRE DETECTION

2F3.01 CLASSES OF DEVICES

There are three distinct classes of fire detecting devices, all of which operate satisfactorily in the Cold Regions if properly installed.

(1) Fixed-temperature, designed to operate when the temperature rises to or exceeds a certain value.

(2) Rate-of-rise, designed to operate when the temperature rises faster than a predetermined rate.

(3) Smoke detector, actuated when smoke interrupts a light beam to a photoelectric cell.

There are available also numerous devices embodying both the fixed-temperature and rate-of-rise features.

2F3.02 THERMOSTATIC DEVICES

Thermostatic devices (Ref. 87) are grouped as:

a. Spot devices in which the thermally sensitive elements are "spotted" at specified distances apart on the ceiling or roof.

b. Continuous line type, in which the thermally sensitive element is continuous along the line.

They are subdivided (Ref. 78) into:

a. Devices which are capable of repeated operation without replacement (unless damaged or thrown out of adjustment by heat).

b. Devices which must be replaced when they have once been operated.

Proper location of thermostats, thermostatic wire, air chambers, tubing, and other heat-actuated devices is particularly important in the Cold Regions. Strong drafts may introduce serious delays of operation, which may also be adversely affected by installation near cold surfaces, such as poorly insulated walls and ceilings. The stability of the fusible elements on wire systems should be investigated to determine that these elements will provide dependable protection under extreme low-temperature conditions.

ARCTIC ENGINEERING

CHAPTERS 1 and 2

CONTENTS

EDGE INDEX

INSTRUCTIONS

1. Bend the handbook with the Edge Index on the outside.
2. Locate the desired subject in Edge Index and place left thumb on the single- or double-line mark opposite that subject.
3. Riffle the edges of the pages to the corresponding mark on the edge of the page and open to the subject.

CHAPTER 3. CONSTRUCTION

PART A. PLANNING FOR POLAR CONSTRUCTION

Section 1. PACKING, HANDLING, AND STORAGE OF CONSTRUCTION MATERIALS AND EQUIPMENT

3A1.01 GENERAL

Operations incident to service of supply in the more remote areas of the Cold Regions must be precisely planned so that work may be performed quickly and efficiently and with a minimum of hazard to personnel. Difficulties of transportation and nonexistence of accessible resupply points may necessitate maintenance of the operation without reinforcements over an extensive period and require strict accountability for fuel and other consumable supplies. The disciplines of the area and the contingencies that may occur because of them should receive the utmost consideration. This will require emphasis on factors that, in the Temperate Zone, are not involved or are of minimum importance.

1. MATERIALS SUPPLY. Plans for materials supply are dictated by the location of areas in which work is to be accomplished and the types of transport that will serve. If water transport is involved, planning will be governed by the limitations of ship service and related facilities. In many sections of the Cold Regions, supply by ship must be limited to only a few weeks during the year, and it requires a well-arranged and efficient operation to unload sufficient bulk cargo to supply the project for the period required. In such cases, materials must generally be ordered two years in advance of construction. If delivered dockside at the shipping port in late June or early July, they would ordinarily be delivered to the beachhead during August or September. Scheduling from that point depends on the nature of the consignment and its final destination. August and September are generally too late for excavation in the same year in the northern Cold Regions. If the site is located inland from the coast, transport overland must be made the following winter to the construction site, and construction work begun the following spring; or if the shipment involves materials for inside construction, work can start on arrival.

2. SEQUENCE OF SHIPMENT. Materials and equipment for construction in the Cold Regions should be ordered and shipped in the following sequence.

(1) Beach unloading equipment, if required.

(2) Temporary housing.

(3) Excavation and grading equipment.

(4) Pipe, cement, reinforcing steel, and exterior framing materials.

(5) Interior finish materials and equipment.

(6) Heating and electrical equipment.

3. MAINTENANCE OF SCHEDULE. It is imperative that all work be scheduled to coincide with the season that is most favorable to its accomplishment (Section 3A2) and that construction schedules be rigidly maintained. A year can easily be lost if schedules lag, particularly during the early part of the construction plan.

4. ICE-FREE PORTS. Advance planning for construction in interior areas where transport is by rail or highway from ice-free ports can proceed in a manner comparable to that in temperate climates, except that earth handling and concrete work should be completed before freezeup. Buildings should be enclosed, and at least temporary heat installed, before the advent of extremely cold weather. Materials shipped by ocean transport should be shipped as many months ahead of construction as possible because of unpredictable ship sailings, which are frequently interrupted by strikes of longshoremen and ships' crews.

3A1.02 PREPARATION AND HANDLING OF CARGOES

Preparation of cargoes consigned to projects in the Cold Regions, including marking, packing, handling, stowage, and determination of weight limitations, dimensions, and other details, are accomplished in accordance with the pertinent directives and instructions of sponsoring Services. The following procedures are recommended to facilitate loading, stowage, transportation discharge, and rehandling and to minimize damage or loss from water and rough handling.

(1) Drummed oil products need be marked only for description of contents. Gasoline should be shipped in new drums. Use of reconditioned drums is limited to lubricating and diesel oil. All drums must be inspected for tightness of plugs, presence of leaks, and secure stowage in holds and must be loaded on end with plugged ends up.

(2) Beach area, weight, cubage, contents, and vendor must be stenciled on each container. This does not apply to petroleum products, except as noted in (1).

(3) All cargo should be properly export packed and, insofar as practicable, palletized to facilitate handling in the ships and on the beaches.

(4) Palletized materials should be securely strapped with metal strapping, using corner plates when the straps are necessary to eliminate damage to materials.

(5) Flour and sugar should be packaged in waterproof containers and boxed; metal containers are preferable, if available.

(6) Commissary supplies should be packaged in waterproof containers and securely boxed.

(7) Machinery and spare parts should be treated with corrosion-resistive materials and preservative and packaged in export boxing.

(8) Drilling mud, sand, cement, and like materials should be packed in metal containers holding four sacks each. If metal containers are not available, the materials should be placed in waterproof bags and export boxed or sealed in watertight barrels.

(9) Lumber should be metal strapped in sling-load lots, and pieces should be of equal length.

(10) Plywood, wallboard, and insulation materials should be waterproof wrapped and well crated with weights not exceeding the predetermined maximum.

(11) Prefabricated housing for workmen should be shipped so that the construction camp can be quickly erected and should be designed so that workmen can handle individual sections in spite of heavy gloves and bulky clothing.

(12) Beach unloading and construction equipment should be loaded aboard ships so that it can be unloaded without undue delay in accordance with the predetermined sequence.

(13) When supply operations for an expedition involve several ships traveling in convoy, each category of goods necessary to survival of personnel and continuity of operations should be divided among the several ships so that in case of loss or delay of one or more ships the expedition can still function with a minimum of delay and inconvenience.

(14) Maximum weights and dimensions of individual pieces of equipment and materials should be limited to the capacity of the transportation and handling that will be available en route. (Ref. 89.)

3A1.03 ECONOMIC CONSIDERATIONS

Consideration should be given to the economic aspects of the service of supply, particularly if commercial carriers and related organizations are involved. Full information should be obtained on the following for each part involved.

(1) Terminal charges, including penalty cargo unloading and heavy lift charges, wharfage, and rehandling.

(2) Tariffs, commodity classifications, and surcharges.

(3) Cargo-handling equipment and stevedore services.

(4) Tug service, taking- and releasing-line service, and lighterage.

(5) Boiler and drinking water service.

(6) Berthage.

(7) Ferry or taxi service to ships at anchor.

(8) Port regulations regarding the handling of special materials such as vehicles, explosives, bulk petroleum, bulk asphalt, bulk cement, lumber, and others.

3A1.04 UNLOADING AND RELOADING

1. GENERAL. The unloading of supplies and equipment on beachheads or landing strips and the reloading of these materials for cross-country transportation to the construction site are among the most important tasks to be undertaken in con-

nection with the establishment of a facility in remote areas. Sufficient personnel must be assigned to this phase of the operation to assure that the work of providing shelter and maintenance for men and equipment and for operation of the weight-handling equipment is conducted efficiently in spite of contingencies that may arise.

2. BEACHHEAD OPERATIONS. Ships are usually involved in transporting supplies to large operations in the Cold Regions. Although thousands of tons of supplies have been moved in these regions by air and by tractor train, it is obvious that the nearer to the eventual site that ships can bring bulk cargoes and heavy construction equipment the more efficient will be the employment of men and machines. (Ref. 21.) (See Section 3B1.)

Customarily, the beach is divided into zones marked for various classes of cargo. By a previously devised loading plan, a balanced unloading operation is obtained that permits the simultaneous working of a ship's hatches for delivery of cargo at all beach points. Pallets are usually loaded not to exceed 4,000 pounds, with flour, sugar, cement, calcium chloride, and so on, protected by waterproof coverings. A crew should be available to handle cargo after it has reached the beach areas, to operate weight-lifting equipment, and to move the cargo from the beach to the storage areas, as well as to assist in the maintenance and repair of all equipment, including the small craft used in the unloading operations. Because weight-lifting equipment is available usually in limited quantities, it must be utilized to the highest degree of its capacity. Moving of supply equipment from one beach area to another should be avoided. Working areas should be kept clear to avoid congestion and consequent slowing down of unloading and lighterage operations. (Ref. 89.)

If the cargo has previously been properly marked and packaged for maximum protection against loss, water damage, and rough handling, field handling and storage operations will be greatly simplified. Beachhead operations require aircraft to supply perishables, emergency parts, and personnel. A temporary winter airfield can be constructed rather quickly, even though the all-year airfield may not have been completed before freezeup, by leveling off the muck or gravel with a drag and allowing it to freeze. (See also Section 3D3.) Even sites for temporary landing strips, housing, and storage areas must be carefully chosen to minimize construction time and maintenance. (See Section 2A2.)

3. SUPPLIES BY AIR. Thousands of tons of supplies and equipment are regularly transported each year by air in the Cold Regions. During winter, when the ground is frozen, planes can be landed on either skis or wheels, depending on snow conditions at the landing strip. In summer, landings are on airstrips, on gravel or sandspits, or on lakes or other bodies of water. Regardless of the type of landing area, unloading operations involve the same general principles regarding classification of supplies as unloading from ships or barges. Prompt and efficient handling and early release of the carrier is particularly important when temperatures are low or when air operations are hazardous. (See Section 3B3.)

4. WEIGHT - HANDLING EQUIPMENT. Equipment for handling cargo after its arrival at the unloading site, whether beachhead or airstrip, consists generally of cranes, A-frames, forklifts, crawler tractors, sleds, go-devils, toboggans, and Athey wagons. Personnel carriers, fuel and water carriers, and other special service vehicles for fire-fighting and other purposes supplement the unloading and transportation vehicles. Truck cranes are much faster than tractor cranes, but because of the terrain features of the Cold Regions and the absence of roads, wheeled vehicles are generally unsatisfactory except in the immediate camp area, where a few roads may have been constructed. Track equipment has been most successful. The presence of many streams and lakes during the summer season requires that personnel and light utility vehicles be amphibious in order to provide year-around service. (Ref. 89.)

5. RELOADING. Once the supplies are unloaded on the beach or landing strip there still remains the task of reloading them for transportation to the job site. In the remote areas of the Cold Regions there are few roads, and the most effective and dependable means of cross-country transportation of materials and equipment is by tractor trains composed of go-devils or sleds towed by a crawler tractor. (See par. 3B2.02.) The terrain is usually rugged, and the loading must be efficiently accomplished to avoid overturning and shifting of loads.

Experience and a knowledge of the route to be traveled is of great help in determining the maximum allowable height and weight of loads.

Most manufacturers mark the load capacity on the sled. Allowance for age and condition of sleds should be made. Because sled platforms are generally constructed in the field and vary in length according to the distance between the front and rear sets of runners, the load they carry will depend on the maximum allowable unit stress in the longitudinal members.

The height of the load is generally governed by its tipping tendency rather than its weight. For any but old, smooth trails, the height from the ground to the top of the load should not exceed the width. This last measurement should be kept under 10 feet because of obstructions along twisting routes. Wide loads require breaking a trail wider than the dozer blade, which causes excessive work and delay.

Loads should be secured before the train starts. A shifting load not only wastes precious traveling time on the trail, but it distracts the operator when he should be concentrating on running the tractor. Loose loads should be boxed in with flat lumber at the sides, and open loads, such as wire on spools or a landing mat, should be spiked to the platform and secured by stakes driven through the openings. (Ref. 21.)

3A1.05 SHELTERS

Adequate housing of personnel and equipment is necessary during all phases of operations in the Cold Regions. Wanigans, Jamesway huts, tents, or similar shelters are provided for this purpose. The housing area should be laid out carefully, with consideration given to exposure, foundation conditions, and fire protection. (See Sections 2A2, 2A6, and 2F2.) All buildings that are to be moved during winter should be blocked up from the ground because they may freeze to the mud or gravel and be pulled apart when heavy equipment hooks onto them. Substantial timber skids placed under temporary housing at the time of erection will facilitate moving the structure to other locations. For details regarding the various types of structures commonly used to provide housing for personnel or equipment in the Cold Regions, refer to Section 2E2.

3A1.06 STORAGE OF SUPPLIES

1. GENERAL. For the great bulk of common construction materials and supplies, storage methods in the Cold Regions are the same as those used in the Temperate Zone. Modification of the common storage factors is necessary primarily because of the effect of low temperatures on certain materials (par. 2A9.01) and because of moisture condensation when cold equipment is brought into warm rooms. The outdoor storage area should be carefully selected with respect to its vulnerability to floods, icing, drifting snow, and other hazards. (See Section 2A2.) Sites in which stored materials will cause interference to surface or subsurface drainage should be avoided. Exposed sites are generally preferable to lee positions, which are subject to drifting snow. Each general type of material should be segregated, and the location of each area well charted with long flag stakes to facilitate identification under drifting snow and during storms. Photographs of the area, made prior to the advent of snow, are very useful when it is required to move materials during winter. All materials should be piled in orderly fashion, with adequate firebreaks provided. Each pile should be carefully inventoried and withdrawals recorded. Piles should be so spaced that carryall scrapers can remove snow that may drift around them.

2. PETROLEUM.

a. *Bulk Storage.* Bulk storage tanks provide a reserve and/or operating supply of liquid petroleum, such as motor vehicle gasoline, aviation gasoline, jet fuel, diesel oil, fuel oil, and engine oil. The selection of the proper type of storage to be installed for each commodity depends on a number of factors, including permanency of installation, ground conditions, comparative costs, location and characteristics of the site, protection required, and amount of oil being stored. The issuance of plans and specifications regarding oil storage and dispensing facilities is a function of the using agency. Manuals prepared by the Corps of Engineers, Department of the Army, contain information and instructions covering the major requirements in the design of vehicular and aircraft engine fuel and engine oil storage and dispensing systems for all Services. (See par. 6 of 2F2.06.)

b. *Storage of Oil Drums.* Drums of gasoline and oil should be carefully inspected at the unloading point for tightness of plugs and possible leaks. Drums should be stored with the plug end up and marked for description of contents. Spillage of fuel and gasoline into the snow around the storage area should be avoided because this snow will not compact but will remain soft and slushy throughout the winter. In laying out the oil storage area, consideration should be given to the possibility of contaminating the drainage shed of the water supply. Adequate firebreaks are, of course, important in the oil storage area. (Ref. 89.)

WARNING

When handling drums or other metals at extremely low temperatures, personnel should be careful not to contact the metal with unprotected hands or other uncovered parts of the body. Perspiration of the skin affords sufficient moisture to freeze the hands to the metal. Forcible removal of the part may cause removal of the skin, resulting in painful injury.

c. *Separation of Hazardous Materials.* Fire is an ever-present menace, and the most rigid precautionary measures must be observed to prevent its occurrence. Caches of explosives, fuel, lubricating oils, and bituminous materials should be located remote from buildings and should be well separated by firebreaks within their own storage area. Asphalt and tar, particularly when cut back with naphtha or kerosene, are highly flammable.

3A1.07 REFRIGERATED STORAGE

1. MECHANICAL SYSTEMS. Refrigeration is, of course, as important in the Cold Regions as in the Temperate Zone. The basic factors affecting design of mechanical refrigeration systems are the same, and the usual procedures for storage and care of products apply. In the Cold Regions the uncertainty of transportation facilities and the fact that practically all food must be imported require that emphasis be placed on quantity storage and space requirements. Several types of portable refrigerating units have been developed by the armed services for advanced bases. These include walk-in types of 150-cu-ft capacity, 25-cu-ft chest type, 50-cu-ft reach-in field refrigerators, prefabricated refrigerated warehouses of various capacities, and portable ice plants. All of these were designed for maximum ruggedness combined with light weight and maximum adaptability to field service. Such refrigerators can be designed to meet all ordinary refrigeration requirements and can be erected and placed in operation in a matter of days. During extremely cold weather, auxiliary heating facilities may be required to prevent freezing temperatures within cooler rooms.

2. NATURAL COLD STORAGE. In an area of permanently frozen ground, natural refrigeration for year-around use may be obtained by excavating pits in permafrost. The Eskimos have used lockers in permafrost for storing oil and some foodstuffs for many years. Larger storage chambers in permafrost have been used successfully by the Lomen Commercial Company along the Arctic coast and by the Navy at Point Barrow. The usual method of building such lockers is to sink a vertical shaft into permafrost and, at the bottom, drift horizontally to form a tunnel or vault. The Navy locker at Point Barrow was 22 ft x 18 ft x 7 ft high. The shaft was 8 ft x 8 ft x 21 ft deep. At the top of the shaft was a 3- x 4-ft trapdoor with a 2-in. curved vent pipe. A report on the operation of this locker states:

On 6 September 1946, 1,500 cu ft of frozen boneless boxed beef, pork loins, pork ribs, chicken, turkey, liver, bacon, and butter were placed in the locker, which was then sealed. The locker was not opened until 12 April 1947, when the first items were withdrawn for use. At that time the cellar temperature was −6° F and the outside aboveground temperature was 20° F. This indicates that the cold had penetrated into the locker during the winter months and had lowered the temperature of the locker below the surrounding formation. (Permafrost has a year-around temperature of 16° to 22° F.) At the time of withdrawal, the food had been in storage 7 months, was frozen solid, and was in good condition. The containers were in the original state, and there was no moisture or mold present. The locker was then sealed and no extractions were made until 13 June 1947, when the remaining items were removed. At that time the locker temperature was 9° F and the outside aboveground temperature was 32° F. These last items had been in storage for 9½ months, were completely frozen, and the containers, of wood and paper construction, were in the original condition. (Ref. 90.) (See also par. 2E1.05.)

a. *Storage Procedure in Natural Cold-Storage Lockers.* Fresh fruits, vegetables, and eggs can be kept frozen in fairly good condition for long periods, but they will deteriorate rapidly if allowed to thaw and freeze repeatedly. (Ref. 21.)

Most canned foods can be frozen without loss of food value, though the flavor of some products may be affected. Occasionally a can may burst in freezing, and in such cases the contents should not be eaten unless it is certain that they have remained continuously frozen. The cans may have been weakened by rust, caused by the can coming into contact with salt water or salt spray during shipment. Experience has indicated that even salt present in the air at beach sites makes cans rust if exposure has been sufficiently long. (Ref. 21.)

When perishables are stored in icehouses, the various kinds of food should be segregated and piled warehouse fashion, permitting ready access to each sort of commodity. Vertical stocks must be firmly based and should be as nearly the same height as possible, with sufficient space left beneath the ceiling to permit air movement. Products should be kept at least 12 in. from outside walls and at least 6 in. from walls of inside rooms, if any. Carcasses must be hung on rails or hooks; hams, bacon slabs, sausages, and so on, must be either hung or stacked on wire shelves. The more delicate commodities should be stored away from the door, where warm air does not readily penetrate. Kegs or buckets containing brined products should be placed on the floor so that leaking brine can be cleaned up more easily.

3. ICEHOUSES. In locations near lakes, rivers, and the seacoast, where ice is readily available, icehouses may be used in the conventional manner. Icehouses are commonly built with double walls on the surface or, if ground conditions are favorable, underground.

3A1.08 EQUIPMENT STORAGE

Equipment that is detrimentally affected by condensation should, if practicable, be stored during winter in unheated buildings. Certain equipment is subject to rapid rusting from condensation following exposure to low temperatures and introduction into warm buildings or space. Materials and equipment coming in contact with salt water or salt spray may be seriously affected, and even the salt present in the air at beach sites can cause rusting. If warm storage is necessary, small equipment, after reaching room temperature, should be disassembled and the parts wiped dry and thoroughly cleaned and oiled. This procedure should be repeated each time the equipment is brought from a cold to a warm temperature. Corrosion of electrical equipment caused by condensation is particularly detrimental. Electronic equipment, generating equipment, relay contacts, switches, spark plugs, magnetos, ignition harnesses, and electrical leads are only a few of the many items of equipment that are susceptible to the ill effects of condensation. Storage of chemicals, storage batteries, rubber goods, instruments, and other equipment involved in operations in the Cold Regions is the subject of preventive maintenance instructions and precautions set forth in applicable technical manuals and publications pertaining to specific equipment. These instructions must be strictly adhered to. (Ref. 89.)

Section 2. WORK FEASIBILITY

3A2.01 PRINCIPAL FACTORS

1. CLIMATIC CONDITIONS. The scheduling of operations in the Cold Regions is influenced primarily by climatic conditions, particularly wind, temperature, precipitation, amount of daylight, ceiling, visibility, and ice thickness. A careful analysis of climatic conditions to be expected at the area of the proposed site for all periods of the year is necessary in order to meet operational and logistical requirements successfully.

a. *Wind Chill.* The sensation of chilling is caused by the cooling of the body surface faster than heat can be produced from within the body. This sensation is not alone attributed to low temperature or to wind, but usually to a combination of the two. Under conditions where the temperatures are continually below freezing, the cooling or chilling effect of wind and low temperature is very noticeable and at times dangerous. Moving air greatly accelerates the sensation of chill because body heat is dissipated more rapidly in the wind. (Ref. 90.)

This effect has been called wind chill by P. A. Siple, who has proposed a system he calls the Wind Chill Index. This index provides a definite means of describing the climatic conditions caused by wind and temperature variations. In this system each factor is obtained by multiplying the temperature in degrees centrigrade by the wind velocity in meters per second. Curves showing the relationships of the factors involved are shown in Figure 3A2-1.

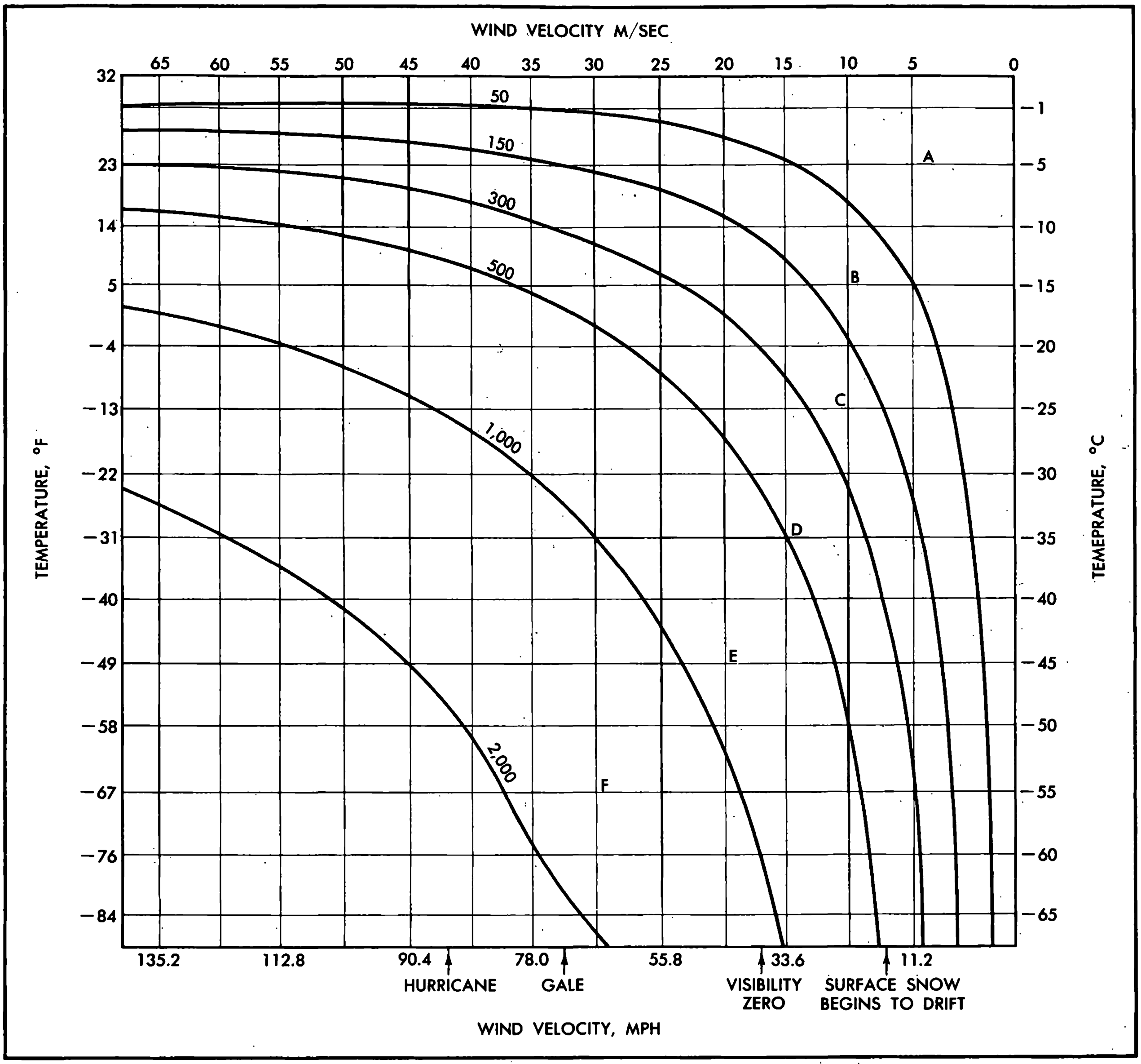


FIGURE 3A2-1

Wind Chill Index (Ref. 90)

3A2.02 GRAPHIC EVALUATION

1. WORK FEASIBILITY CHART. (Ref. 90.) A chart of the type illustrated in Figure 3A2-2, developed for the Point Barrow area, is an aid in evaluating climatic factors for determining the most favorable months in which to conduct field operations with effectiveness. Similar charts can be drawn for all sections of the Cold Regions, provided necessary data are available.

The factors of climate and the work involved in the mission to be accomplished, such as transportation, construction, and water supply, are shown on the chart. In February, for example:

Daylight	3 hr increasing to 9 during the month, with an additional 1½ hr of twilight per day
Ceiling	1,000 ft or lower 19 percent of the month
Visibility	1 mile or less 14 percent of the month

Temperature	Absolute maximum	35° F
	Mean maximum	−15° F
	Mean	−20° F
	Mean minimum	−25° F
	Absolute minimum	−56° F
Wind	Maximum recorded	71 mph
	Average	10 mph
	Direction SW	43 percent
	NE	15 percent
Wind chill	Varying from B, fair for traveling, to E, extreme for operations	
Precipitation	4 in. of snow; trace of rain	
New ice thickness	Ocean, 40 in. increasing to 50 Rivers and lakes, 48 in. increasing to 54	

Reviewing these factors, it is noted that freighting over ice with tractors and sleds can be conducted. Ground surface will support wheeled vehicles, tractors, and sleds. Planes can operate on skis throughout the area and on wheels from prepared strips, but the number of flying hours per day is limited by light. Shallow lakes and rivers are frozen, but water can be taken from deeper lakes or obtained from melting ice or snow. Because of poor visibility and cold, surveying is not recommended. Earth work is not possible, and foundation work is accomplished by using explosives or by thawing methods. For outside construction, floodlighting is required. February can be used to repair equipment in shops and accomplish inside construction. All equipment will require complete winterization, Arctic lubricants and fuels, and heated inside storage; and personnel will require adequate protection.

This same procedure can be followed for each month of the year, or for a longer period, to analyze the climatic and operating factors.

3A2.03 PRACTICAL CONSIDERATIONS

It is often possible, of course, to accomplish work without excessive cost before or after the time indicated by the feasibility chart as the most favorable for the particular type of work. This may be because of the yearly variations in freezeup and thaw dates, or, as in the case of tractor transport, measures may be taken on the job that will enable work to start earlier or later in the season than is normal for the area. Figure 3A2-2, for example, indicates that by January 15 in the Point Barrow area, river and ocean ice is normally sufficiently thick to permit freighting over ice on a limited basis. Actually, by December 15, rivers in the area can be crossed by tractors weighing up to 30 tons, if ice bridges are constructed by spreading water on the ice surface and allowing it to freeze in 3- to 4-in. layers. Also, although not indicated by the chart, shallow thaw depths along the Arctic coast allow heavy tractors to operate on land throughout the year. One hundred miles inland from Point Barrow, however, thaw depths may reach 20 in., which almost eliminates the possibility of tractor transport in these areas.

Local conditions, which can not be reflected on feasibility charts that were originally developed for a particular area, often cause modification of job scheduling. At Point Barrow, although there is little snow, constant winds keep the air full of snow, often reducing visibility so much that transport equipment can not travel safely. Early snow affects transport by slowing up freezeback on thawed ground and retarding ice formation on lakes, rivers, and ocean lagoons. Smooth ice accumulates drifts with mean depths up to 2 ft, which is sufficient to make the movement of smooth-wheeled vehicles difficult and often impracticable. Drifted snow on the Arctic slope generally blows in again within a few hours after being removed.

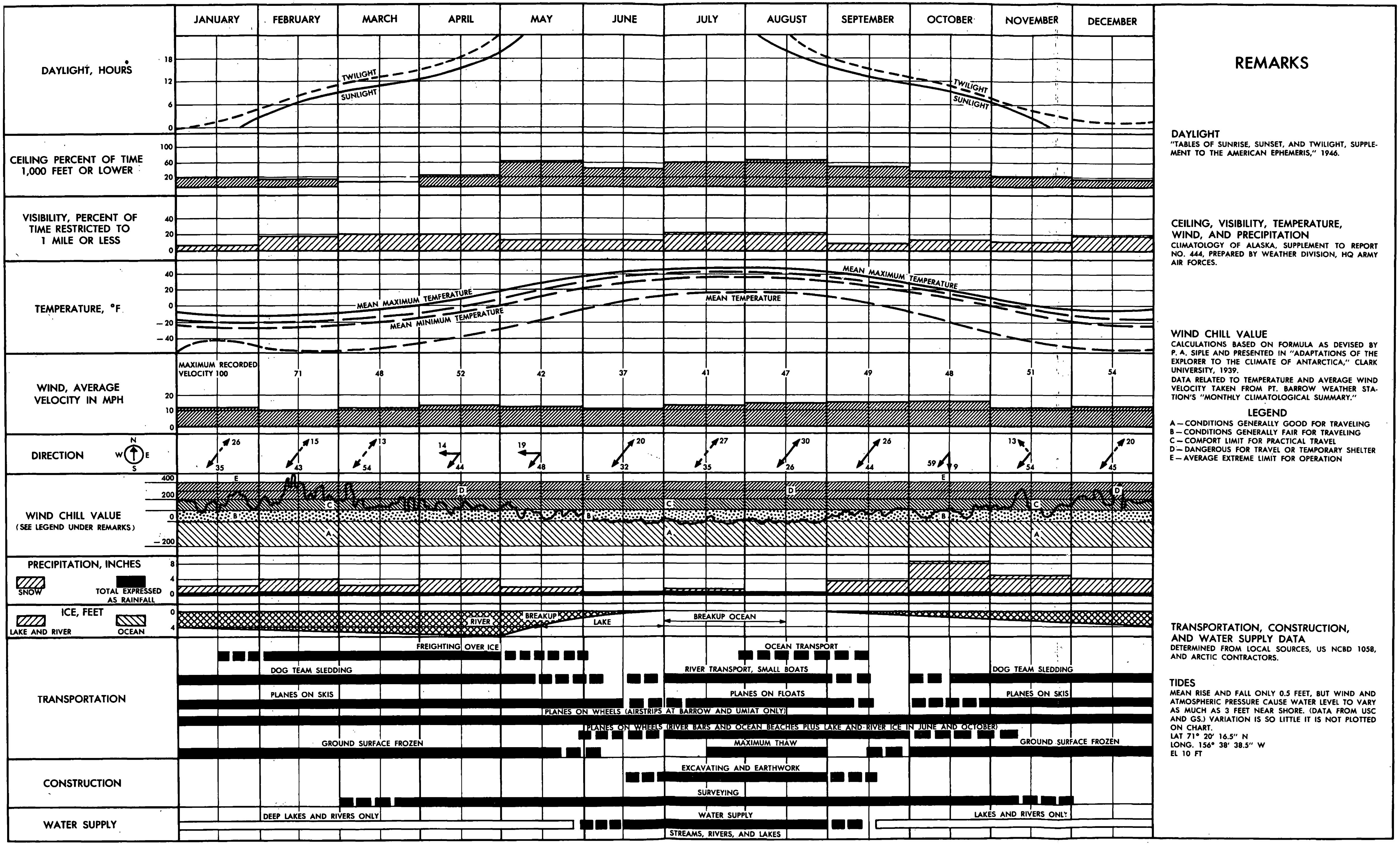


FIGURE 3A2-2

Work Feasibility Chart, Point Barrow, Alaska (Ref. 90)

Section 3. LABOR EFFICIENCY

3A3.01 GENERAL

The efficiency of labor on construction projects in the Cold Regions varies, as it does elsewhere, with the skill and mental attitude of the workmen as well as with working conditions on the particular job. Contractors and others with wide experience in construction work in Alaska report that during the months of May through September labor productivity on jobs within the Territory compares favorably with that obtained in the United States. In many sections of the interior, swarms of mosquitoes appear early in June, requiring workmen to wear headnets and gloves, which cause some annoyance; offsetting the insects, however, is the generally cool weather, which promotes greater vigor in all individuals.

In most sections of the Cold Regions, the number of skilled workmen is comparatively small, and men must usually be imported for work on the larger projects. Sufficient unskilled labor is generally available locally in all except the most remote areas.

During the winter season, productivity of labor on out-of-door construction operations is greatly reduced because of wind chill (par. 1a of 3A2.01) and other factors. The degree of acclimation of the workman and his adaptability to cold are extremely important in all classes of labor and, other factors being equal, directly affect his output.

1. NATIVE LABOR. Native Alaskans, either white or Eskimo, or men with five or more years of experience in the country are capable of producing with high efficiency under winter conditions. Indians, although skilled with boats and dog teams, generally have little enthusiasm for construction work. Eskimos have a natural instinct for working with their hands and make good equipment operators, carpenters, oilers, and mechanics, but require close supervision because of their inherent tendency to disregard upkeep of tools and equipment. Their ability to work efficiently in low temperatures and high winds makes them preferable to white men as laborers during winter. The tuberculosis rate is very high (70 to 90 percent) among Eskimos, which suggests the advisability of careful screening before hiring. Also, the natural preference of Eskimos for seal oil as a food often makes them, as a class, undesirable as messmates or barracks companions.

2. EFFICIENCY OF CRAFTS.

a. *Carpenters.* Experience has indicated that carpenters, as a craft, work at about 75 percent efficiency at 32° F, 50 percent at 0° F, and 25 percent at −30° F. Below this temperature, efficiency drops off rapidly to about −40° F, below which only emergency work should be done. Reasons for reduced efficiency are bulky gloves, mittens, and other clothing, occasional trips to the fire, and an increased sense of caution. Also, frozen lumber with a high moisture content is difficult to work.

b. *Electricians.* Outside electricians work at efficiencies between 25 and 50 percent of normal at temperatures below 0° F, depending on the wind velocity. Emergency work is often accomplished by trained crews at temperatures below −50° F, but line construction is not practicable from an economic standpoint at temperatures much below −30° F.

c. *Ironworkers.* Many structural steel buildings, bridges, and pipelines have been erected in Alaska at temperatures below −25° F with reasonable efficiency, but this temperature is probably the practicable minimum because of the difficulty of starting and maintaining compressors and other construction equipment. Personnel whose work is usually out-of-doors at all seasons are less prone to lay off or intentionally work at reduced efficiency during cold weather than are those whose work takes them both indoors and out.

d. *Equipment Operators.* Trained operators employed in housed machines work at an efficiency comparable to that attained during normal temperatures. During periods of blowing snow, restricted visibility may require that the machines be shut down. One or two years of experience in operating and maintaining equipment during cold weather is necessary to achieve consistently high efficiency.

e. *Tractor-Train Operators.* Tractor-train operators should have from 2 to 4 years experience in winter operations before being made regular crew members on cross-country work, because the travel time of the entire train depends on the speed of the slowest tractor.

f. *Masons and Concrete Workers.* Because the nature of their employment requires that they work only within heated buildings or enclosures,

TABLE 3A3-1

Excavation and Backfill, Interior Alaska

Type of work	Type of soil	Method used		Volume, cu yd		Man-hours/cu yd	
		Excavation	Backfill	Excavation	Backfill	Excavation	Backfill
Power plant	Steam thawed silt and gravel (wet)	Hand shovel	Shovel and tamp	1,000	200	2.00	1.01
Diversion dam and gates	Coarse gravel, mica schist, bedrock, and quartz stringers	Hand shovel and blasting	None	547	...	3.62	
Water tower	Heavy gravel (partly frozen)	Jackhammer, hand shovel	Shovel and tamp	41	25	3.16	0.40
Warehouse No. 1	Heavy gravel, coarse sand, and silt (partly frozen)	Jackhammer, hand shovel	Shovel and tamp	230	150	3.32	1.12
Steam lines	Silt, sand, and gravel (frozen)	Steam thawing and jackhammer	Shovel and tamp	660	585	4.55	1.33
Sewer mains and laterals	Silt, sand, and gravel	Hand shovel	Shovel and tamp	900	880	1.94	0.41
Garage and repair shop and pits	Light sand (some fine)	Hand shovel	Shovel and tamp	300	82	1.07	0.50

masons and concrete workers function with little decrease in efficiency during cold weather.

g. *Supervision.* Work in the Cold Regions at all seasons requires alert supervision by men who can lead rather than push. A very high labor turnover can be expected unless applicants are carefully screened before hiring. This is particularly true if the job is in a remote area that lacks the usual forms of social activities.

Reference is made to Tables 3A3-1 through 3A3-11, which indicate man-hour performance obtained on some typical projects in Alaska. No data are shown for the output of power equipment because such information is shown in the catalogs of manufacturers and other sources.

3A3.02 COST OF LABOR

1. GENERAL. Labor costs vary with the kinds of work involved as well as with the different classes of workmen needed (skilled or unskilled) and with the prevailing hourly wages. Wages for various classes of labor will vary in different localities and often in the same locality from season to season. Union regulations, and frequently local customs, require certain classes of labor and set the wages for certain work. It is impossible, therefore, to generalize regarding the cost of performing construction work in the Cold Regions compared to the cost of performing similar work in the Temperate Zone. It is undoubtedly true, however,

TABLE 3A3-2

Form Work—Assemble, Erect, Strip, and Clean, Fairbanks Area, Alaska

Type of work	Approximate area, squares	Man-hours/100 sq ft of form surface		
		Assemble and erect	Strip and clean	Assemble, erect, strip, and clean
Contractor A, footings and piers	Season average	No breakdown	No breakdown	10 to 15
Contractor A, floors and flat slabs	Season average	No breakdown	No breakdown	15 to 20
Power plant A, footings and piers	50	11.0	3.0	14.0
Power plant A, walls	153	9.0	3.0	12.0
Power plant A, floors and flat slabs	95	13.0	3.0	16.0
Power plant A, columns, including caps	20	17.0	3.0	20.0
Power plant B, all classes	165	18.0	8.0	26.0
Warehouse, footings, piers, and walls	15	9.2	1.5	10.7
Central heating plant, footings, walls, and cornices	45	9.8	2.0	11.8
Garage and repair shop, footings and piers	14	10.2	See note	
Office building, footings, piers walls, and beams	200	7.9	1.6	9.5
Office building, floors, columns, caps, and beams	119	8.6	1.1	9.7

Note: Forms below surface left on piers to break bond in case of heaving ground.

that in all sections of the Cold Regions the cost of doing construction work is greater than for similar work in the Temperate Zone. Workmen must nearly always be transported to such regions, wages are generally higher, and in many cases the men's subsistence must be paid while they are working on the job.

a. *Wage Rates.* An analysis of 1952 wage rates in the Seattle-Tacoma area indicates that the arithmetical average of hourly rates received by 14 representative union building crafts was $2.69. In Alaska, for the same period and the same crafts, the hourly rate averaged $3.52, 31 percent more than the average Seattle-Tacoma rate. The average first-shift workweek for the building trades in the Seattle-Tacoma area during 1952 was 40 hr, or five 8-hr days, with specified rates for overtime when overtime was worked. In Fairbanks, Alaska, in 1952 the average first-shift workweek was 54 hr, or six 9-hr days, with overtime at specified rates over 8 hr per day or 40 hr per week. The workman in Seattle, receiving the average base rate of $2.69 per hr for the average workweek of 40 hr, earned $107.60. The Fairbanks workman, receiving the average base rate of $3.52 per hr for 40 hr and an overtime rate of $5.28 (one and a half times the base rate) for 14 hr, earned $214.72, an average of $3.97 per hr for the 54 hr. Hour for

TABLE 3A3-3

Wood Construction, Interior Alaska

Type of work	Unit	Qty	Man-hours		
			per M fbm	per 100 sq ft	per opening
Garage and repair shop					
Framing	M fbm	5.5	24.8		
Sheathing	M fbm	16.5	13.9		
Four dwellings					
Framing	M fbm	37.1	37.7		
Sheathing	M fbm	37.6	20.0		
Wallboard	sq	204.0	...	2.6	
Rough flooring	M fbm	6.4	17.2		
Finished flooring (wide, including sanding)	sq	23.0	...	4.6	
Exterior finishing	M fbm	10.4	32.9		
Exterior millwork (double doors and windows)	openings	56.0	...	...	10.5
Exterior millwork (screens)	openings	56.0	...	...	1.9
Warehouse					
Framing	M fbm	52.9	33.4		
Sheathing	M fbm	30.0	23.8		
Rough flooring	M fbm	23.0	11.6		
Exterior millwork	openings	41.0	...	...	3.4
Office building					
Rough flooring	M fbm	9.3	16.5		
Finished flooring (narrow, including sanding)	sq	66.0	...	9.5	
Exterior millwork	openings	63.0	...	...	2.1
Wallboard (including furring)	sq	185.0	...	2.1	
Sheathing	M fbm	21.0	20.0		
Penstocks (flumes and pressure boxes) 2,000 lin ft, 7 to 17 ft wide x 6 ft high, framing and double-ply fir sheeting with tar-soaked insulation	M fbm	535.0	32.2		

TABLE 3A3-4

Structural Steel Erection, Alaska Area

Type of work	Unit	Quantity	Man-hours/unit
Apartment building	tons	500	10.0[1]
Office building	tons	20	19.5[2]
Power plant	tons	415	26.5[2]
Power plant	tons	300	18.5[2]
Gold dredge			
Hull	tons	465	26.8
Superstructure	tons	289	25.0
Stacker	tons	65	42.4
Buckets	tons	137	3.6
Rivets, ⅝ in.	...	95,000	145.0
Rivets, ¾ in.	...	34,000	153.0

[1]Includes field welding.
[2]Includes field riveting.

TABLE 3A3-5

Reinforcing Steel—Bending and Placing, Fairbanks Area, Alaska

Type of work	Size of bars (round), in.	Length of bars, ft	Quantity, 100 bars	Man-hours/100 bars
Power plant A	⅜ to 1	20 to 30	119	17.6
Power plant B	⅜ to 1	20 to 30	137	18.2
Warehouse	⅜ to 1	20 to 30	118	15.9
Office building A	⅜ to ¾	30	17	49.2[1]
Office building B	⅜ to ¾	30	10	58.4[1]
Contractor A (avg of many jobs considered typical of area)	¾[2]	10 to 20[2]	...	10.66

[1]All hand bending and cutting.
[2]Considered by contractor A to be optimum diameter and length for best labor performance.

TABLE 3A3-6

Concrete Mixing and Placing, Fairbanks Area, Alaska

Type of work	Approximate volume, cu yd	Man-hours/cu yd			
		Mix only	Place only	Mix, place, and cure (ordinary weather)	Mix, place, and cure (cold weather)
Contractor A[1]	Season average	...	1.0		
Contractor B, central mix plant	Season average	0.3			
Contractor B[2]	22	...	...	...	2.0[5]
Power plant[1,2]	1,360	...	...	1.9	
Power plant[1,2]	341	...	...	...	3.2
Power plant[1,2]	1,500	...	0.9		
Water tower[1]	26	...	...	...	4.8
Central heating plant[1,2,4]	95	...	...		3.5
Manholes[1]	17	...	...		4.9
Manholes[1]	30	...	...		4.1
Manholes[1]	120	...	1.7		
Warehouse[1]	105	...	...	3.3	
Well House[1]	11	...	...	3.4	
Garage and repair shop[1,2]	40	...	...	1.9	
Office building[1]	46	...	...	3.35	
Office building[3,4]	206	...	...	3.44	
Office building[3,4]	124	...	...	3.90	

[1]Footings, piers, and thick walls.
[2]Floors and slabs.
[3]Columns, beams, and thin walls.
[4]Cornices.
[5]Does not include curing.

TABLE 3A3-7

Concrete Block Laying, Fairbanks Area, Alaska

Type of work	Quantity, 100 blocks	Man-hours/100 blocks
Warehouse[1]	11.8	26.0
Central heating plant[1]	20.0	22.0
Office building A[1]	40.5	15.2
Office building B[1]	25.6	12.0
Power plant[2]	11.8	38.4

[1]Superstructure with many openings.
[2]Partition with many openings.

TABLE 3A3-8

Concrete Surface Finishing, Fairbanks Area, Alaska

Type of work (hand tools only, trowel finish)	Area involved, squares of 100 sq ft	Man-hours/ 100 sq ft
Contractor A, floor slabs	Season total	1.2 avg
Contractor B, floor slabs	Season total	1.4 avg
Power plant	125	2.4
Central heating plant	10	3.2
Garage building	3	2.0

TABLE 3A3-9

Test Well Drilling, Fairbanks Area, Alaska

Item	Man-hours/ft		Cost in percent of total	
	6-in.	18-in.	6-in.	18-in.
Supervision and engineering	...	...	1.35	2.62
Drilling labor	1.85	7.90	23.99	27.00
Mess	...	...	4.91	5.31
Camp	...	...	0.63	0.65
Materials and supplies[2]	...	...	54.91	45.71
Fuel for camp	...	...	2.74	4.27
Maintenance and repairs	...	...	3.94	5.04
Transportation	...	...	7.53	9.40
Total			100.00[3]	100.00[3]

[1]Average experience for thirty-five 6-in. wells (average depth 200 ft) and eight 18-in. wells (average depth 225 ft).
[2]Includes casing.
[3]6-in. casing is recoverable. Its cost amounts to 40.7 percent of this total.

TABLE 3A3-10

Pile Driving, Interior Alaska

Type of work	Unit	Quantity	Wood piling, man-hours/ unit	Sheet piling,[1] man-hours/ unit	3-pile bents[2] man-hours/ unit
Wing dam and spillway seal	100 sq ft	116	...	29.5	
Diversion dam, weir and apron	lin ft	2,000	0.36		
Supports for steel siphons	bent	1,130	...	...	15.6

[1]Interlocking steel.
[2]Includes labor for capping. Thawing labor is not included. Penetration of piles varies from 6 to 10 ft. Figure 3A3-3 shows typical pile bents including capping.

hour, therefore, on the basis of the customary workweeks in the respective areas, the Fairbanks workman received approximately 48 percent more than the Seattle workman. Of the increase, 31 percent is due to the straight-time rate differential, and 17 percent is the result of overtime pay.

b. *Workweek.* In remote areas, when construction activity is great and the season short, many building contractors believe that a long workweek is a necessity. In such areas a standard workweek, such as the 54-hour week in the Fairbanks area agreed to by a majority of the building contractors, minimizes raiding of workmen, who will, in general, prefer to work on those jobs on which they can accumulate the greatest number of overtime hours during the construction season. It is probable, however, that many employers could meet their construction schedules and benefit economically by a 40-hour week if they could retain their men. In isolated areas, where competition for men is not an important factor, the respective advantages of a long workweek, involving overtime pay, and a shorter workweek, which may require a greater number of men, should be evaluated. Consideration should be given to the cost of transporting such men to and from the job as well as their subsistence and other requirements incidental to their employment.

TABLE 3A3-11

Miscellaneous Labor Performance, Fairbanks Area, Alaska

Type of work	Unit	Quantity	Corrugated siding, man-hours/unit	Roofing, man-hours/unit			Painting, man-hours/unit	
				Standing seam	Corrugated	Composition	Int	Ext
Garage and repair shop								
Corrugated siding	Squares	22	2.7					
Exterior painting	Squares	58	...				...	3.5 (two coats)
Four dwellings								
Exterior painting	Squares	520				...	...	1.0
Interior painting	Squares	160				...	2.2	
Office building A								
Roofing, comp 3-ply, 4-coat	Squares	36		...		3.9		
Office building B								
Roofing, metal, standing seam	Squares	36		6.1[1]				
Roof flashing and trim	100 lin ft	10						
Central heating plant								
Roofing, metal, standing seam	Squares	85		5.9[1]				
Plastering	Sq yd	134						
Exterior painting	Squares	28	...				...	0.7
Interior painting	Squares	39	...				1.0	
Warehouse A								
Corrugated siding	Squares	60	5.0					
Roofing, metal, standing seam	Squares	85	...	5.7[1]				
Roof flashing and trim	100 lin ft	11						
Exterior painting	Squares	129	...				...	3.5 (two coats)
Warehouse B								
Corrugated siding	Squares	17	4.1					
Corrugated roofing	Squares	19	...		3.6			
Power plant								
Interior painting	Squares	390	...	...	...	...	1.8	

[1]Metal sheets, 14 x 20 in.

PART B. TRANSPORTATION OF CONSTRUCTION MATERIALS

Section I. WATER TRANSPORTATION

3B1.01 GENERAL

Ships are usually necessary to transport supplies to large operations in the Cold Regions. Although thousands of tons of supplies have been moved in these regions by air and by tractor train, it is obvious that the nearer to the site of operations that ships can bring bulk cargoes and heavy construction equipment the more efficient will be the employment of men and machines. (Ref. 21.)

There are few sheltered anchorages on Polar coastlines, and supply ships must anchor offshore. Supplies are then unloaded into smaller craft, which transport them to the beach. Because of the uncertainty of weather and ice conditions, unloading must be planned for accomplishment in a minimum time consistent with safety to personnel and materials. There is always the attendant threat of pack ice moving in to the shoreline to endanger ships and terminate the supply operations. At points along Arctic coasts, ice-laden water permits ship discharge operations for periods of 3 to 5 weeks only during the summer season, with navigation often closed as much as 50 percent of this time because of weather or ice conditions. Where docking facilities are not available, amphibious techniques are used, and work is accomplished in accordance with a previously devised unloading plan that permits simultaneous working of all the ship's hatches during the 24 hr of daylight on a 6-hr watch-and-watch system. If beach facilities do not permit simultaneous unloading of all ships in a convoy, ships are required to tie up to wait their turn outside the ice-covered waters. Adequate and safe mooring facilities are required in these cases or when it is necessary to wait for favorable weather or ice conditions. Ships in Polar waters are usually not allowed to proceed to the cargo-unloading area unless cargo can be immediately moved to the beach and the ship released. Amphibious unloading operations in World War II showed longer turnaround time at the beach than for loading barges or loading craft at ship's side. (Ref. 21.)

Single ships can navigate Polar waters if great care is taken, but icebreakers and the convoy system are preferable.

1. CARGO DISCHARGE. Rate of discharge of cargo is governed by the unloading capacity of the beach cargo-handling equipment. Ordering ships into the cargo-unloading area by echelon exposes fewer ships to possible contact with ice floes and shortens the time in which each ship is within the forward unloading area, thus increasing manpower efficiency in both ship and beach working details. (Ref. 21.)

2. MOORING. Supply ships and their protecting vessels must be moored in open roadsteads in a manner that reduces their swinging radius and provides for a quick getaway in case of emergency. These conditions usually require some type of mooring other than the ship's own mooring tackle. Because of meager past experience with moorings in the Polar Regions, the basic principles of mooring in the Temperate Zone are generally used, with such modifications as increasing experience in Polar waters indicates are advisable. The chapters cited in Ref. 21 contain a comprehensive discussion on moorings.

3. LIGHTERAGE EQUIPMENT. Small craft, such as the Navy LCM-3, LCVP, LVT-3C, and LVT-5, and the Army DUKW and M29C, supplemented by ice skiffs, motor launches, pontoon barges, motor whaleboats, and surfboats, are very successful in Polar beachhead supply operations. (See Table 3B1-1.) These craft should be winterized before use and, because of hazards from unfavorable wind and ice movements, should be manned only by experienced and dependable crews who are familiar with the equipment's capabilities and limitations. Shallow-draft barge transportation along Polar coasts is possible only during periods of favorable wind and ice.

TABLE 3B1-1

Small Craft Polar Operations—Physical and Performance Characteristics (Ref. 89)

	Type of craft	Physical characteristics						Performance characteristics					
		Length	Beam	Draft	Weight, empty, lb	Height	Hull	Speed, mph: Land	Speed, mph: Water	Capacity: Lb	Capacity: Men	Power plant (bhp)	Usual employment
Navy	LCM-3	50′	14′6″	3′6″	52,000	...	Steel	...	12	50,000	80[1]	Twin diesel, 225 each	Cargo, passenger
Navy	LCVP	36′	10′6″	3′4″	18,000	...	Steel	...	10	8,000[2]	36	Diesel, 225	Cargo, passenger
Navy	40-ft motor launch	40′2″	11′4″	2′4″	16,000	...	Wood	...	9	14,850	90 (open) 22	Diesel, DB 50	Cargo, passenger
Navy	26-ft motor whaleboat	25′11½″	7′3⅜″	...	5,066	...	Wood	...	...	3,600	20 (hood)	Diesel, Da	Cargo
Coast Guard	Motorboat (cabin) Greenland cruiser[3]	36′8″	11′1¼″	3′3″	21,255	...	Wood	...	9	3,300	25	Diesel, 85 (Buda Lanova)	Passenger
Coast Guard	Motor launch (special) GIG[4]	26′6″	7′10″	2′7″	7,450		Wood	...	9	...	18	Diesel, 35 (Buda Lanova)	Passenger
Coast Guard	Self-bailing motor surfboat[5]	25′10″	7′4″ (wood fenders) 7′11″ (cork fenders)	2′9″	6,000	...	Wood with metal sheathing	...	8	...	16	Diesel, 30	Rescue, passenger
Coast Guard	26-ft Monomoy surfboat[6]	26′3″	7′4″	...	2,100	...	Wood	...	...	...	14	Pulling	Rescue, passenger
Coast Guard	Ice ski	15′6″	3′8½″	...	510	...	Wood	...	...	...	4	Pulling	Passenger
Amphibious	M29C weasel	10′5¾″	5′1″ (old track) 5′7¼″ (new track)	3′5 11/16″	4,771	Overall 5′13/16″ (top up) 4′5 11/16″ (top down)	Steel	32	4	...	4	Gasoline, 65 (Studebaker)	Passenger
Amphibious	LVT-3C	25′1½″	11′2½″		36,400	9′11¼″	Steel	25	6	5,000	25	Twin gasoline, 110 (Cadillac)	Cargo, passenger
Amphibious	LVT-5			...	66,818		Steel	...	...	18,000		Twin gasoline, 110 (Cadillac)	Cargo, passenger
Amphibious	DUKW	31′	8′4″	Loaded 3′6″ (front wheels) 4′3″ (rear wheels)	14,880	9′2¼″	Steel	50	6.5	5,000	25	Gasoline, 90	Cargo, passenger

[1]Dimensions limit capacity to 80; normally, however, boat capacities assume 10 cu-ft internal volume per man and man weighing 165 lb.

[2]Has carried 10,000-lb T-9 tractor without difficulty.

[3]486-mile cruising radius, 330-gal tank, 4 berths, 4 heavy chains for lifting built on 36-ft motor surfboat hull.

[4]95-mile cruising radius.

[5]75-mile cruising radius. High engine hatch with Buda. Low engine hatch with Kermath. (Buda has fresh-water cooling tank above.)

[6]Usually equipped with sails.

LST Navy craft have proved very successful in making beach landings at several points on the northwest and northeast Arctic coasts. These ships are most satisfactory for handling Arctic cargo, but their thin skin makes them extremely vulnerable to ice damage. The advantage of the LST is the bow opening so that cargo can be delivered right on shore. Present marine laws do not allow these ships to be used for commercial cargo unless bow doors are sealed, which eliminates one of their greatest advantages. This limitation applies, however, to commercial cargo only.

Section 2. SURFACE TRANSPORTATION

3B2.01 HIGHWAYS

In many sections of the Cold Regions there are no year-around roads because materials with which to build them are not available. Year-around roads are confined to Subpolar areas that may or may not provide for transportation during winter, depending on the amount of traffic over them. Wheeled vehicles are not practical in summer in tundra areas except in the immediate vicinity of the camp, where roads for trucks and other wheeled equipment may be maintained. Recent tests have indicated that trafficable snow surfaces suitable for heavy-wheeled vehicles can be produced. However, extensive traffic testing of compacted snow surfaces and evaluation of compacting techniques and equipment in areas of both shallow and deep natural snow cover is necessary before the feasibility of extensive construction of snow roads can be established. (See also Sections 2C2 and 3D2.)

3B2.02 TRACTOR TRAINS

Tractor trains operating in winter have proved to be the most satisfactory and cheapest overland transportation method on the Arctic slope. Lack of timber, early freezeup, and thick ice make ideal conditions. Trains must be organized and equipped to be completely self-sustaining for as long as two weeks and for distances up to 400 miles. Operations require that the heaviest types of tractors and sleds be utilized and all equipment be kept in the finest operating condition possible. A mechanical breakdown of any unit on the trail can delay the entire train.

Winter freighting normally starts as soon as ice is thick enough for equipment to cross (Section 3A2); 24 to 30 inches of ice is considered a safe thickness for river crossings by 30-ton tractors. (See Table 2A4-5.) Ocean ice should be 30 to 36 inches thick for such equipment. Any thickness is unsafe if the underlying water does not fully support the ice sheet. Water levels in rivers sometimes recede after the ice has obtained considerable thickness, leaving suspended gaps near the riverbanks that are unsupported by the water beneath. Ice bridges (par. 2E2.01) are often necessary at river crossings. In traversing ice, care must be taken to avoid tension cracks.

In Naval Petroleum Reserve (NPR-4) operations in northern Alaska during the winter of 1950-1951, four tractor trains hauled 3,700,000 ton-miles at a cost of 30 to 35 cents per ton-mile. Hauling costs are lower on ice trails but quite high in mountainous terrain.

1. TRAIL STAKING. Routes to be followed by the trains must be laid out and carefully staked prior to the actual freighting operation. Staking must be performed by experienced persons to avoid bad ice, rough terrain, and adverse grades and to pick the shortest routes. Trails are staked over ice and marsh wherever possible. Train travel is roughly four times as fast over such terrain as over rough, ice-hummocked areas; distance, therefore, can be sacrificed for level ground conditions. The general route is marked by dropping from an airplane weighted flag stakes whose color contrasts with the surroundings. The stakes act as a guide to the trail-staking crew, which later comes along with a completely self-sufficient outfit and light equipment to stake the final route with flags at quarter-mile intervals.

The lack of discernibility in the Arctic during twilight in January and February adds greatly to the difficulty of this operation. Discernibility is used here to express the inability of the eye to see objects because of the lack of contrast. The combination of a milky overcast and snow of the same color makes it impossible at times to discern the terrain or even to see snowdrifts 6 inches high underfoot. This condition can arise when visibility of a black object might be unlimited.

Two-way radio equipment is required for each operating unit. Trail-staking crews require the best compass available. No compass yet devised is entirely satisfactory because of the low horizontal component of the earth's magnetic field and the rough usage inherent in the operation of vehicles over the Arctic terrain. The best compass developed to date is the Sperry gyrosyn unit, followed, in order of preference, by the magnesyn type and finally the regular magnetic needle type. Wind direction and snowdrift pattern are used extensively for navigation by Arctic trail-staking crews.

a. *Trail-Scouting Equipment.* On the NPR-4 operations, conventional trail-scouting equipment consisted of R4D (C-47, DC-3) and Norseman aircraft and two LVT-M29C combinations. A small hatch placed in the cargo door of the R4D permitted this plane to be easily used for much of the trail-staking work; its advantages over the smaller craft (Norseman) include greater range, carrying capacity, and personnel comfort.

The scouting force in these operations consisted of two 3-man crews. Equipment makeup of each of the crews was as follows.

(1) One each trail-type LVT, completely enclosed, containing compass, cooking and sleeping gear, hand tools and miscellaneous spare parts, approximately 800 gallons of gasoline, 60 man-days food supply, and enough trail flags to stake 50 to 300 miles.

(2) One each trail-type weasel with extralarge plywood cab, outfitted with gyro compass and repeater and 50-watt radio transmitter and receiver.

By these parties, 1,284 miles of trail were staked between headquarters and various field locations between mid-December 1950 and 10 May 1951.

All machines were, of course, completely winterized for operations in subzero weather and equipped with escape hatches in the roofs of the cabs.

Ground staking has been accomplished by two men in an M29C pulling an M-19 trailer loaded with auxiliary gasoline. The weasel was winterized with a windproof, insulated plywood cab fitted with windows. Complete trail equipment and fur clothing was carried.

In trail scouting it is usually necessary to navigate the course by following compass traverse of direction and distance conforming to those previously laid out on maps and previously staked from the air. Also, it is usually advantageous to cease work during twilight but to work at night by spotlights and floodlights when it is easier to outline the trail by the light contrast.

The personnel comprising the scouting party are forced to live under the most rugged conditions, and men for this work must be carefully chosen for their ability to live in the open under Arctic conditions. They must also have a good knowledge of the country to be traversed.

2. FREIGHTING EQUIPMENT. The best tractors found to date are Class V crawler tractors equipped with all standard winter equipment and a specially heated cab constructed for maximum visibility and housing of all controls. Escape hatches are provided in the roof of each cab. Towing winches are standard on all units. Belly hooks, radiator guards, and radiator covers are utilized. The lead tractor of each train is equipped with a V-type snowplow. Other units have angle dozer blades, straight blades, or no grading attachments, as required. Perforated grouser shoes with ice lugs of narrow width provide maximum penetration on frozen surfaces. Sprockets are the standard snow type, and skid blocks are inserted in place of top idlers to support the tracks. Cable-operated snowplows and dozer blades are preferred by some operators to the hydraulic type because experience has indicated that they require less maintenance and give more trouble-free operation. The best operation has resulted when tractors are kept running 24 hours a day to maintain the heat and when usual winter lubricants are used. One tire company has developed a special low-temperature hose for tractor-train operations. Ordinary fueling hose is useless because it breaks when flexed at temperatures below −35° F. Tractor trains have operated on the Arctic slope at −65° F without difficulty. Breakage of drawchains and highly stressed steel parts increases below −30° F and becomes a problem at −65° F.

Storm conditions, encountered an average of three times each winter in northern Alaska, shut down the tractor trains for a period of one to four days because flying snow reduces visibility to zero and tractor drivers can not see to operate. These and lesser storms make it imperative that several tractors with their loads operate together as a unit, with complete messing, sleeping, and repair facilities with them at all times. The balance between this facility requirement and the unwieldy operation of too many tractors has resulted in trains being standardized at 6 tractors, 5 of which pull 3 to 4 sleds loaded with 15 to 30 tons each, depending on trail conditions. The lead tractor plows the trail and pulls the cookhouse, sleeping wanigan, and repair wanigan, which is equipped with lightplant, electric refueling pump, electric welder, gas welding equipment, handtools, spare rigging, and spare lubricants for each tractor.

The No. 9 Michler sled, modified to eliminate the high center of gravity and the instability inherent in the original design, is the standard hauling outfit. A short go-devil type of sled is used to transport certain concentrated loads such as draglines, cranes, and other heavy units difficult to load on the higher sleds. Each tractor operator performs his own oiling and greasing. Grease guns are carried in the tractor cabs to maintain fluidity of grease. The train is supervised by the train foreman, who uses an M29C for scouting ahead of the train and for inspecting train equipment. Heavier loads may be pulled during the early spring as temperatures moderate. The coefficient of friction of snow varies greatly with temperature. Approximately one-sixth of the tractive effort required to pull a load at −50 to −60° F is required at 20° F. Trains usually are operated on a basis of 15 hours per day. Refueling, lubricating, and so on is done during stops at noon and evening mealtime. A typical train starts at 6:30 a.m., and shuts down at 9:30 p.m.; tractors then idle while the crew sleeps. Using drivers on shifts, for continuous traveling, has been found impractical because crews do not get proper rest in wanigans traveling over the usual Arctic terrain. A man can stand such conditions for about one week only.

a. *Typical Train Composition.* The basic components of a typical tractor train (four trains operated) in the NPR-4 1950-1951 operations were as follows.

(1) One each weasel (train foreman) equipped with plywood cab and gyro compass.

(2) One each Class IV tractor equipped with Balderson cable-operated snowplow and Hyster towing winch.

(3) Four each bald-faced D-8 tractors equipped with Hyster towing winches.

(4) One each D-8 tractor equipped with Le Tourneau cable dozer and Hyster towing winch.

(5) One 10- x 24-ft trail-type sleeper wanigan mounted on No. 9 Michler freighting sled, containing 50-watt radio transmitter and receiver.

(6) One 8- x 24-ft trail-type galley mounted on Michler No. 9 sled.

(7) One 8- x 12-ft trail-type shop mounted on Michler go-devil, containing a Hobart 300-amp gasoline engine welder, a Witte 8-kw 110/220-v 3-phase 60-cycle diesel-electric generator set, a Herman-Nelson heater, a 2-hp electric centrifugal train fuel pump, and miscellaneous tools, spare parts, and equipment.

(8) One fuel tanker (4 each T-6 pontoons mounted on Michler No. 9 sled).

(9) One each 8- x 12-ft Michler go-devil.

(10) Thirteen each Michler No. 9, 8- x 24-ft flat-bed cargo sleds.

(11) Two each Michler No. 9, 8- x 36-ft flat-bed cargo sleds.

(12) One each Michler No. 9, 8- x 24-ft boxed flat-bed cargo sled.

(13) One each 18- x 36-ft trail drag.

b. *Personnel.* Four complete train crews of 9 men each were employed during the freighting season; only personnel having prior experience in winter equipment operation in NPR-4 were used. Personnel makeup of a typical train crew was as follows.

(1) One each foreman
(2) Six each skinners
(3) One each heavy-duty mechanic
(4) One each cook

c. *Lubricating Oil, Fuel, and Antifreeze.* Reference should be made to par. 4A3.03 for MIL-STD and list of Navy Stock numbers of materials prescribed for servicing construction equipment and automotive vehicles for operation at low ambient temperature.

3B2.03 LIGHT SURFACE TRANSPORTATION

1. DOG TEAMS. The dog team has long been used for Arctic transportation. For many years, transportation was required for only light loads and personnel with time available for slow movement. The dog team admirably filled this need. To maintain the dogs, a food supply was readily available in the fish that abound in all northern streams. Dog-team transportation is limited in force and speed by its effective working radius from a food supply. Rarely could much payload be carried if the distance between food caches ex-

ceeded 100 miles. On the well-broken trails as much as 100 pounds per dog can be transported on the sled; in Alaska, under methods developed by Europeans, the team normally used 9 to 13 dogs per team. If the trails were not well traveled, the slow, laborious work of breaking the trail by the driver on snowshoes ahead of the dogs made 10 miles of travel a hard day's work. This factor is not so important on the northern Alaska slope because the snow usually blows into a hard surface. The fish supply for the dogs is usually caught in the rivers during summer and dried and stored for winter. Inability to obtain dried fish at some locations when needed often precludes working in certain areas.

2. MECHANICAL VEHICLES. To overcome the limitations of the dog team, mechanical vehicles were introduced shortly before the airplane, making it possible to haul greater loads for longer distances without depending on an uncertain food supply. The machines generally consisted of an automobile-type engine in a chassis mounted on skis at the front end and propelled by a track drive at the rear. These machines have been improved to the present snowmobile, which operates with good efficiency and fair reliability.

Because the snowmobiles were restricted in operation to winter, and because they lacked the amphibious qualities necessary for summer operations, when the frozen lakes, rivers, and swamps turn into mud and water, the M29C was introduced by the Navy in northern Alaska in 1944 (Figure 3B2-1). With this machine it has been possible to transport personnel and light loads throughout the year, and it may be said that without it large-scale exploration could not be carried out. The weasel transports personnel and loads up to 1,500 lb. In winter a ski-equipped trailer may be added behind and an additional 1,000 lb towed successfully if favorable snow conditions exist. Fuel consumption averages approximately 2 to 4 miles per gallon at speeds of 5 to 10 mph. The working radius is 60 to 100 miles, which has been extended to 400 miles during winter by carrying additional fuel in the weasel and the towed trailer. This practice, however, results in practically no

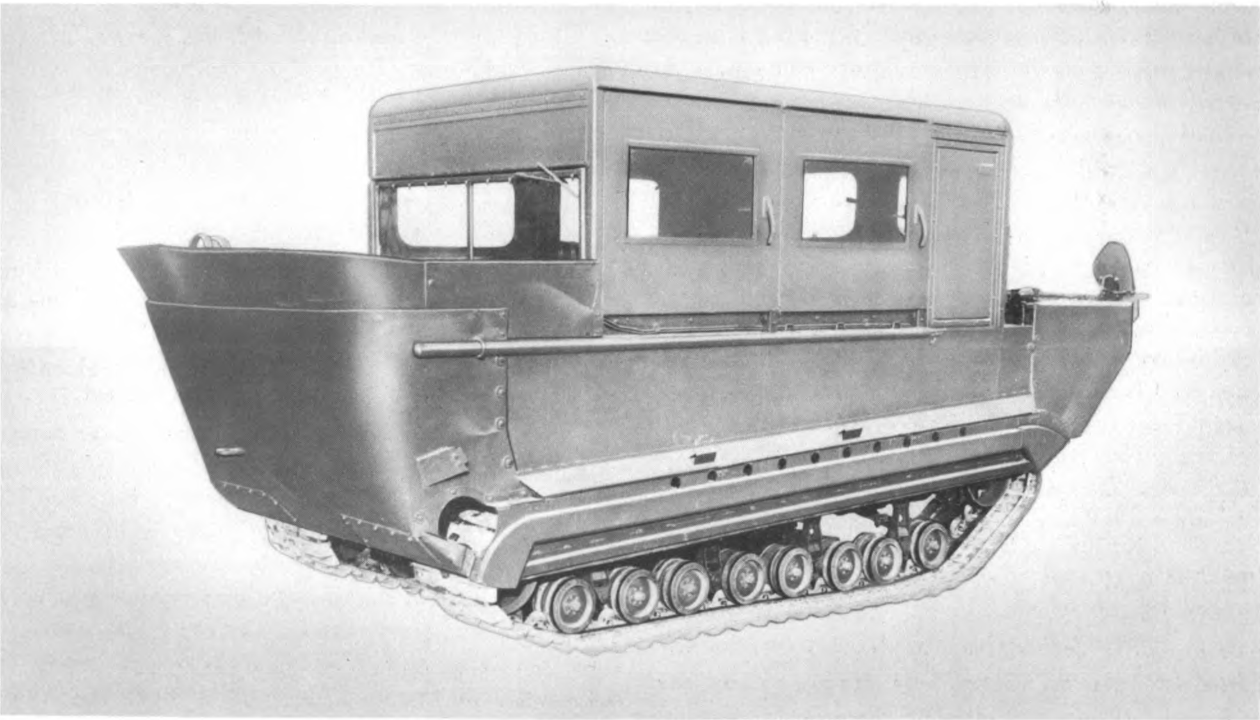


FIGURE 3B2-1

M29C Personnel and Cargo Carrier, Winterized (1951 standardized version with enclosed cab, personnel heater, engine preheater and fuel primer, and reinforced wide tracks)

useful payload, and the net accomplishment is only the transportation of the driver and one passenger. A war product, the weasel has many inherent weaknesses and a short operating life. Track life varies from 800 to 1,500 miles per set. Bogie wheels, sprockets, and idlers wear out in approximately 500 miles. Complete motor overhauling is required at 1,000- to 1,500-mile intervals, and transmissions last for only 200 to 500 miles. The hull itself generally fails from fatigue cracks any time after 3,000 miles. Careful operation and slower speed raise these limitations somewhat, but a definite need exists for a comparable vehicle of greater dependability.

To obtain an amphibious vehicle to transport greater loads, the Navy amphibious forces' landing vehicle tracked (LVT) was tried out and found superior for some types of work. The LVT can transport 5,000 lb over land or water and has a fuel consumption of ½ to 1 mile per gallon and a working range from 70 to 140 miles. By the addition of auxiliary fuel tanks, this radius can be extended to 300 miles. The vehicle weighs approximately 36,000 lb. Like the weasel, but to a somewhat greater extent, it can become stuck in mud of certain viscosities and depths and also in deep snow during early winter before the snow has been packed into hard drifts. It is a ponderous vehicle to extract from a mudhole or snowdrift, but in spite of these drawbacks it has performed during all months of the year if the ground over which it operated has been carefully chosen.

Mechanically, the LVT is much more durably constructed than the weasel, but the gasoline engines do not stand up to continuous working with full loads. The track is admirably suited for frozen ground, light snow, and water operations. It is well suited for deep mud and soft snow. The hull and transmission system are adequate, but the universal joints are inherently weak and failure is common. Track and bogie-wheel life varies widely with ground surface conditions. The average life of tracks thus far has been 3,000 miles; bogie wheels last about 1,000 miles. The basic LVT is easily modified to include a suitable cab to cover the complete vehicle and additional gas tanks. The larger interior gives room for construction of bunks and other utility facilities for housing and adequate space for hauling bulky freight. This construction requires additional ventilator systems. Odometers must be installed for accurate navigating. Because there are no overnight facilities in most areas, a vehicle having room in which men may sleep and prepare their meals is almost a necessity during long trips, the only alternative in winter being to build a snowhouse or erect a tent during stops.

Section 3. AERIAL TRANSPORTATION

3B3.01 GENERAL

Aircraft must be relied on as the sole means of transport in some remote areas. All sizes of planes are used for such work, and each type has a specific usefulness for certain jobs. Where large tonnages of freight are to be handled, economy dictates that large aircraft be used, which, with present planes, requires a landing strip with a minimum length of 5,000 feet. Strips for year-around use must be located where there is sufficient gravel for their construction (Section 2C2). Suitable winter airstrips can be constructed on the larger lakes (Section 3F1) or on fields made of compacted snow (Section 3D1). Medium-weight and small-weight planes use skis in winter and may be loaded, if necessary, without field preparation in nearly any area. During summer, bush-type planes are often equipped with pontoons, which enable them to land and take off from the lakes and rivers that occupy so much of the Cold Regions. Larger flying boats are often used in summer and are operated from the larger lakes. The period of breakup is a short time during which neither skis nor floats can be used. Shallow Arctic lakes freeze to the bottom and thaw out rapidly because of heat absorption from the sun by water overlying the ice. The larger, deeper lakes usually have a floating ice sheet, which remains thick enough during the breakup period for ski-equipped bush planes to land on. It is not unusual to have one lake suitable for pontoons and, nearby, another on which ski landings can be made during the breakup period.

The freezeup period offers much more difficulty to air operations. During this period all lakes begin to freeze and pontoons can no longer be used after air temperatures reach 25° F, even though the lake itself has not accumulated an ice sheet.

The young ice, which forms at temperatures above 15° F, does not have sufficient strength to support the larger bush planes until the thickness exceeds 14 in. Ice 10 to 12 in. thick will support plane landings if it has been subjected to air temperatures below 15° F for longer than one week. Emergency landings and takeoffs may be made on skis from smooth grassy swamps that do not have more than 1 in. of water in the sod. Only light loads can be transported under these conditions, being limited to one or two persons with their baggage.

The helicopter would have a distinct advantage in Arctic operations if it could operate during this period, because it does not require an extensive runway. To date, however, it has not proved dependable enough mechanically nor can it combat light icing conditions.

To base large aircraft satisfactorily in the Cold Regions, hangars are necessary. Smaller planes based in these regions can operate if simple nose hangars and portable gasoline heaters are provided. Major repairs, such as engine changes, performed in the open during extremely cold weather are difficult and time consuming.

Adequate unloading equipment and maintenance crews are essential at Polar air bases to assure the fast service and quick turnaround necessary for these operations during extreme cold. Particular attention must be paid to parking procedures on Polar airfields. Planes parked near runways during high winds may cause serious drifting across runways if they are located on the upwind side. Also, blowing snow will fill parts of the parked plane with a solid block of very hard snow that enters through small holes in the outer skin.

3B3.02 PLANE TYPES

The DC-4 (20,000-lb payload) has proved the best commercial type for carrying heavy loads over long distances.

The Air Force C-124 (50,000-lb payload) is the best freighting airplane yet used in Arctic operations. Its huge capacity and ability to take off and land from 5,000-ft airstrips are especially desirable. This plane can haul the heaviest type of tractor.

The twin-engine C-46 (9,000-lb payload) is efficient for flights of 1 to 1½ hr duration.

The R4D (4,000-lb payload and ability to operate from 2,500 ft airstrips) makes an excellent bush plane, especially when equipped with skis for winter operations. This plane can make maximum use of all navigational aids and operates in tougher weather than any other plane now in use.

The Norseman bush plane (900- to 1,200-lb payload, with 5-hr gas supply) is operated on floats, wheels, or skis. It is the largest of the present strictly bush-type aircraft now used.

Small planes that have a use because of their particular size, range, and horsepower are the Stinson, Cessna, and Super Cub. The Super Cub, equipped with tandem landing wheels, can carry one passenger or the equivalent in mail and emergency parts. It can land at 35 mph in a distance of 150 ft. It can take off or land from very soft ground surface conditions. Satisfactory landings and takeoffs have been performed on moss in summer if the moss is first compacted with tractor or heavily loaded weasel. The plane has good characteristics on floats or skis.

PART C. EXCAVATION AND GRADING

Section 1. PRELIMINARY OPERATIONS

3C1.01 GENERAL

In permafrost areas the exact location of a building or other structure is selected only after thorough surface and subsurface investigations have been made and the findings carefully evaluated (Section 2A2). The conclusions reached from these studies will influence the establishment of design criteria and indicate the phases and scope of the construction operations and the type of equipment that will be required.

The presence of permanently frozen ground makes excavation and grading operations very difficult and costly. Before excavation the frozen materials must be thawed by steam, water, electricity, or solar heat or broken up by blasting, pneumatic chisels, or mechanical equipment such as dozers, rooters, or rippers. In certain cases a combination of two or more methods may be advisable.

In general, summer is the most favorable season for excavation and grading operations. Gravel may be recovered from borrow pits, and large volumes of frozen silt may be economically excavated during this season, if time permits, by regularly removing thin layers of soil thawed by solar heat (par. 1 of 3C2.01). Cold-water thawing operations (par. 2 of 3C1.02) usually start as soon as thawing water is available in the spring and may continue until the freezeup. Steam thawing (par. 1 of 3C1.02) can be accomplished as effectively in winter as in summer, but winter operations with steam are usually limited to comparatively small excavations because condensate and melt water rise to the surface and freeze to create a difficult icing problem. Thawing ground by electricity or shattering it by blasting, pneumatic chisels, or mechanical equipment can be done as efficiently in winter as in summer.

Excavation during the winter season by blasting or other means is often advantageous in locations where water would seriously retard summer excavation (par. 5 of 3C2.01.)

3C1.02 THAWING METHODS

When abundant water under sufficient static pressure is available at reasonable cost, frozen gravel can be thawed more economically by cold water (par. 2 of 3C1.02) than by any other method. Steam thawing is effective in fine-grained materials such as silt and in relatively small gravel when the materials are packed tightly enough to allow the heat to be utilized efficiently. The coarser the frozen materials, the greater is the possibility that the steam and resulting condensate and melt water will be piped through the voids and be uselessly dissipated. This may also occur in thawing shallow frozen strata underlain by taliks or when steam points penetrate zones that are not completely frozen. In such cases, steam will quickly find its way to the thawed area and will have little or no effect on the frozen materials adjacent to them. Power equipment, such as dozers, rippers, and rooters, is useful in breaking up shallow layers of frozen materials; it is least effective in frozen muck and in sand containing a considerable amount of silt. Ice can easily be broken up with large rippers towed by one or two Class V crawler tractors. Blasting is often the most practical method of breaking frozen ground. A combination of methods may be advisable when the frozen materials are not homogeneous.

1. STEAM THAWING. The most commonly used method of thawing the frozen soil of a building site is by steam points. The standard steam point consists of a ¾-in. wrought-iron pipe of the required length, the lower end of which is shaped to form a point tip (Figure 3C1-1). A ¼-in. or ⅜-in. diam hole is punched in the square end of the tip. A driving head (Figure 3C1-2) is welded to the top of the point pipe and connected to the source of steam by a hose. Point pipes larger than ¾-in. are sometimes used for deep thawing. Water points (Figure 3C1-3), designed primarily for cold-water thawing, are often used in place of conventional steam points even though they are con-

sidered by experienced operators to waste steam.

In operation, the thawing point is slowly worked into the ground by turning the point pipe by the twisting bar in the driving head and by tapping the head occasionally with a hammer. Staging is necessary when long point pipes are used for deep thawing (Figure 3C1-4).

a. *Boilers.* Prospectors' lightweight boilers, burning either wood, coal, or oil and capable of being hauled from place to place on a sled or go-devil, can handle one steam point and are usually sufficient for thawing small machinery foundations, excavations for piling, and other such operations. When large volumes must be thawed, boilers capable of handling many steam points will be required (Figures 3C1-5 and 3C1-6).

b. *Steam Pressures.* Pressures between 60 and 90 psi at the boiler are commonly used in steam thawing. Lines between the boiler and thawing points should be sufficiently large to keep pressure losses to a minimum. During cold weather it may be advisable to wrap the main line and distribution pipes with an insulating material to reduce heat loss.

c. *Effectiveness of Steam* (Ref. 21). The heat required to thaw 1 cu ft of frozen ground

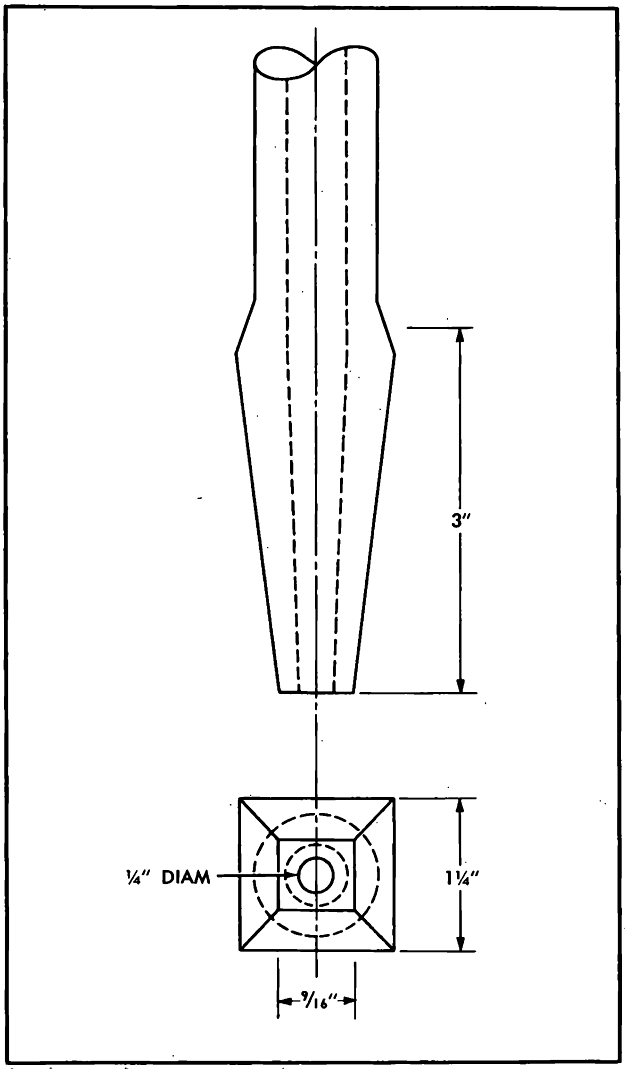


FIGURE 3C1-1

Steam Thawing Point Tip

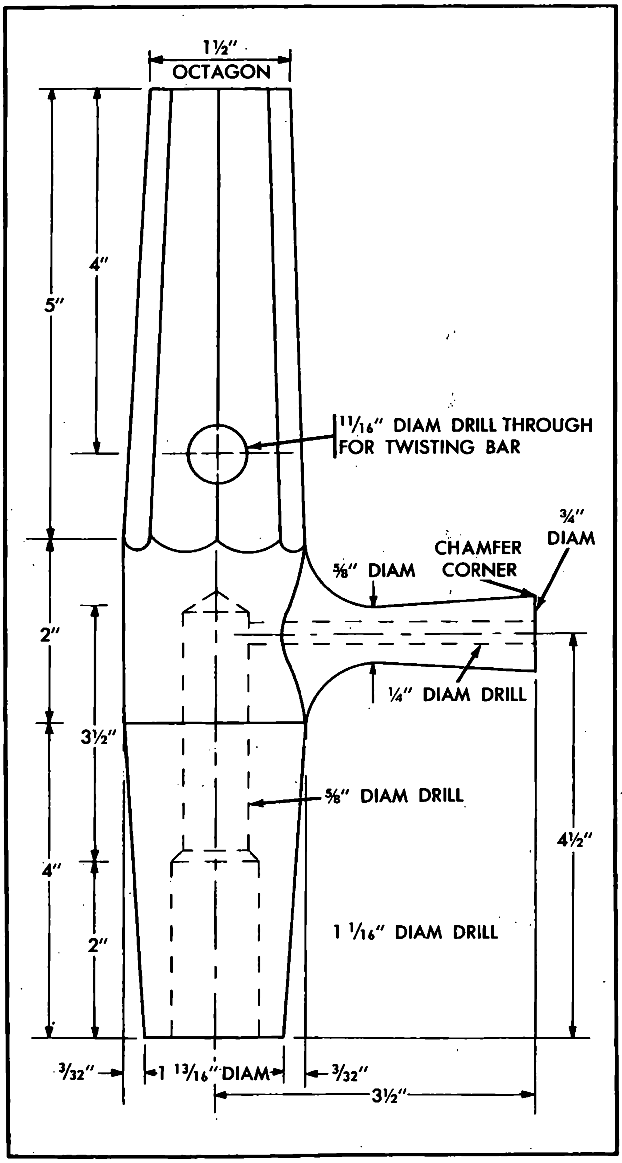


FIGURE 3C1-2

Steam Point Driving Head

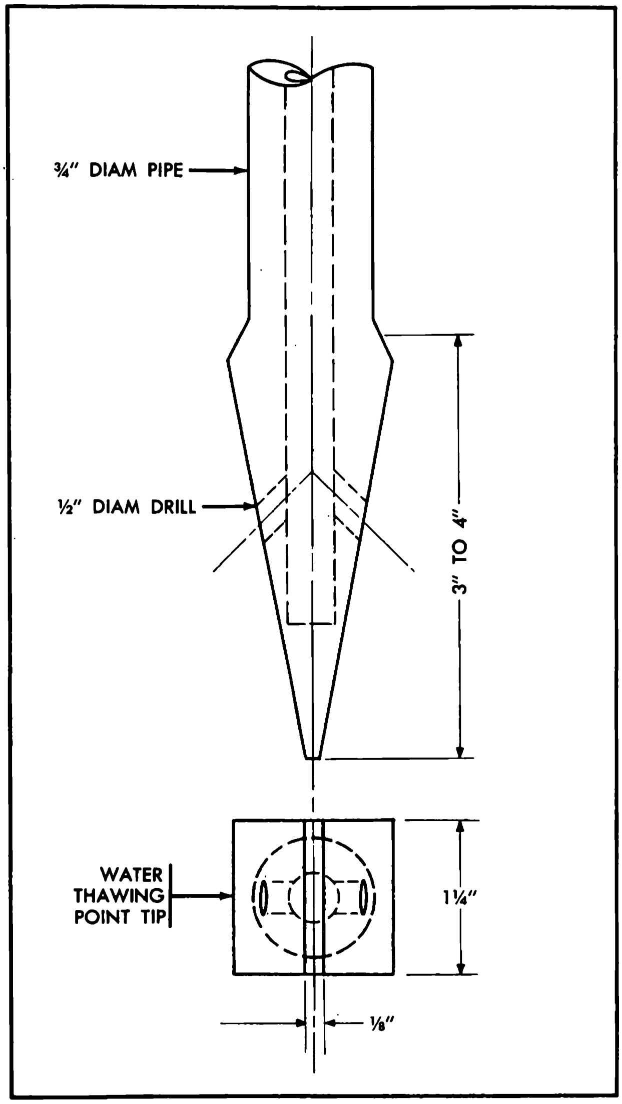


FIGURE 3C1-3

Chisel-Pointed Water Point Tip

varies with the unit weight of the soil, the void content, the amount of ice in the voids, and the soil temperature. No two soils have exactly the same characteristics, but for estimating the capacity of equipment required, the effectiveness of steam (assuming 60 psi at the point pipe) may be assumed at 8 lb per cu ft of soil thawed.

Rate of thawing penetration, when thawing holes for piling in average soil, is reported to be about 6 ft per hr. Such figures are not significant except for excavations of very small cross sections. As the steam point thaws its way into the ground, the frozen materials within close radius of the point thaw quickly, but more distant materials are not thawed until much later. After the desired depths have been reached by the thawing points, the points are left in the ground for a period of time to allow the steam condensate and melt water to percolate through the voids outward and upward from the point tip. Length of steaming time depends on the type of ground, its depth, and the spacing of the points (Section 2A8). With close spacing (6 to 10 ft) in depths up to 20 ft, 3 to 6 hours steaming time may be sufficient for fine-grained soil. The heat stored in the ground will continue to thaw adjacent materials for some time after the jets have been removed. Spacing of points in most cases is a matter of economics. If deep ground is involved and driving is difficult, it may be better to widen the point spacing. One operator reports a steaming time of 144 hours with 24-ft point spacing at 40- to 60-ft depths. In this case the lower gravels were very tight, and the ground immediately surrounding the points and above the frozen strata was water saturated, so the steam condensed rapidly.

2. COLD-WATER THAWING. Thawing frozen gravel with water instead of steam may be worth consideration on a project in which large volumes are involved. In this method, surface water is introduced under pressure into frozen gravel through ¾- or 1-in. extraheavy pipes, each equipped with a driving device and point tip somewhat similar to those used in steam thawing. Water is directed through a chisel-bit water point (Figure 3C1-3) welded to the driven end of the pipe, and thawing occurs ahead of the point. Spacing of points is usually 16 ft, but it may vary with the type and depth of the ground to be thawed. It is customary in Alaska to locate thawing holes at the apexes of equilateral triangles because this arrangement has proved the most satisfactory. Rocky soil or other soil in which driving is difficult, may justify larger spacing of points. Hand driving is usually difficult at depths over 40 ft, and it is customary in larger operations to use electric point-driving machines at greater depths. At one location in interior Alaska, a large area was thawed to depths between 80 and 150 ft in three summer seasons. Holes for points were drilled with Keystone drills (par. 6 of 2A2.03) modified for electric drive. The spacing of points in this case was 32 ft; 1¼- and 1½-in. point pipes were used with no point tips.

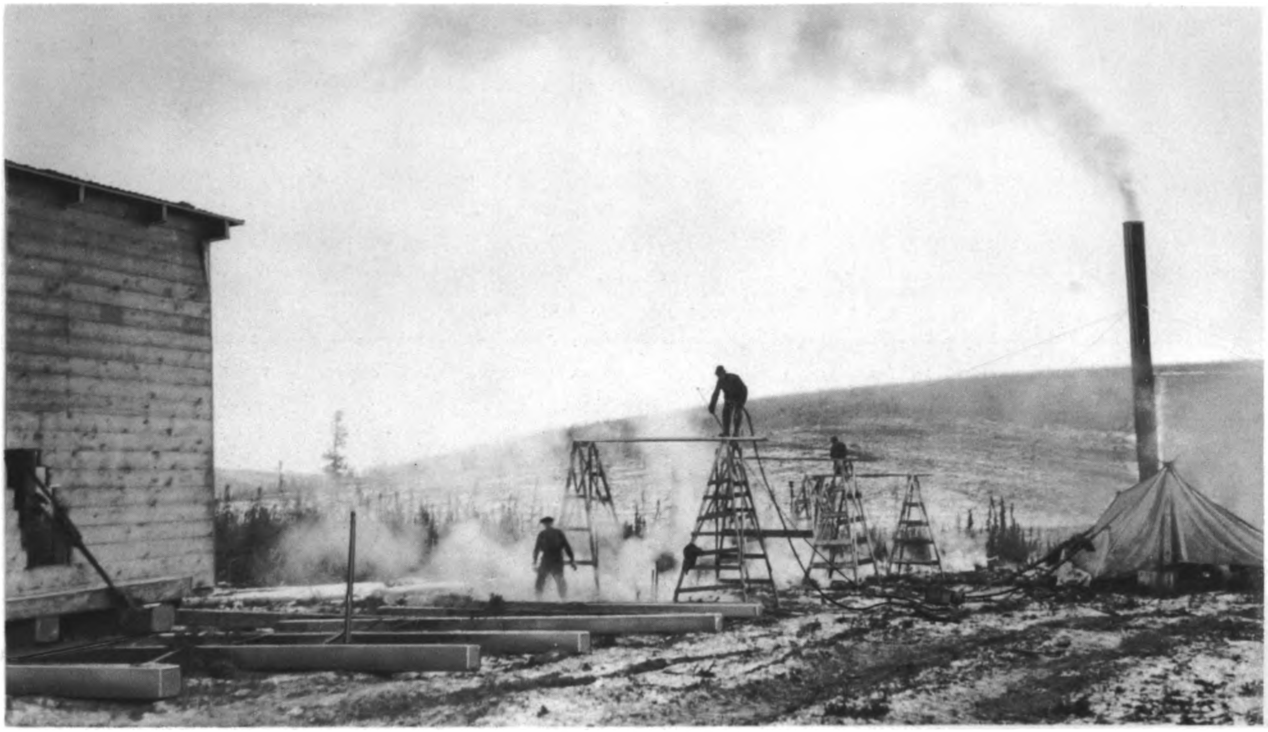


FIGURE 3C1-4

Staging Platforms for Driving Long-Point Pipes

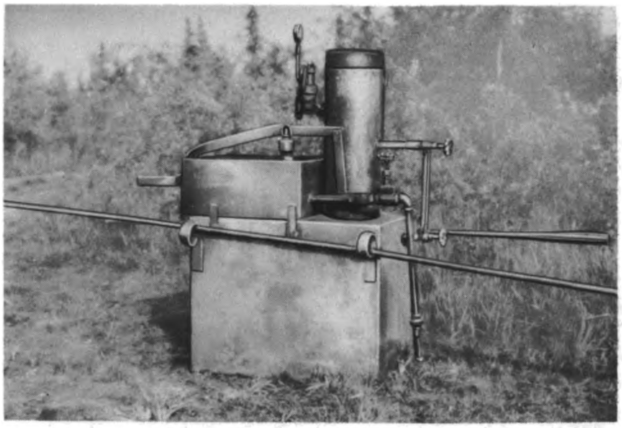


FIGURE 3C1-5

Prospector Boiler

a. *Effectiveness of Water.* Assuming the most efficient point spacing for a particular soil and depth of thawing, the effectiveness of water varies with the temperature of the water and the soil, including its packing and the amount of ice it contains. Water temperature is affected by the day-to-day air temperatures as well as the area of the pump pond because a large pond absorbs more heat than a small one. Cleanliness of the thawing water is important because it reduces the maintenance required on thawing points. When the water is dirty, points must be constantly doctored to keep them running freely. Continuous probing must be done or soil temperatures of the various strata must be read frequently to assure that no more water than necessary is pumped into the ground.

Tables 3C1-1a and 3C1-1b indicate the effectiveness of water in thawing frozen gravel, as recorded at various locations in the interior of Alaska. Table 3C1-1a represents cumulative experience per year over 13 years. Column 5 reflects the average yearly temperatures of the thawing water, as does Column 4 of Table 3C1-1b.

3. SOLAR THAWING. See par. 1 of 3C2.01.

4. ELECTRIC THAWING. Electricity for thawing has been used to some extent. The cost of this method, however, is apparently greater than that for thawing by steam. Average demand for various types of soil is approximately 2 kwhr per cu ft, according to available experience records.

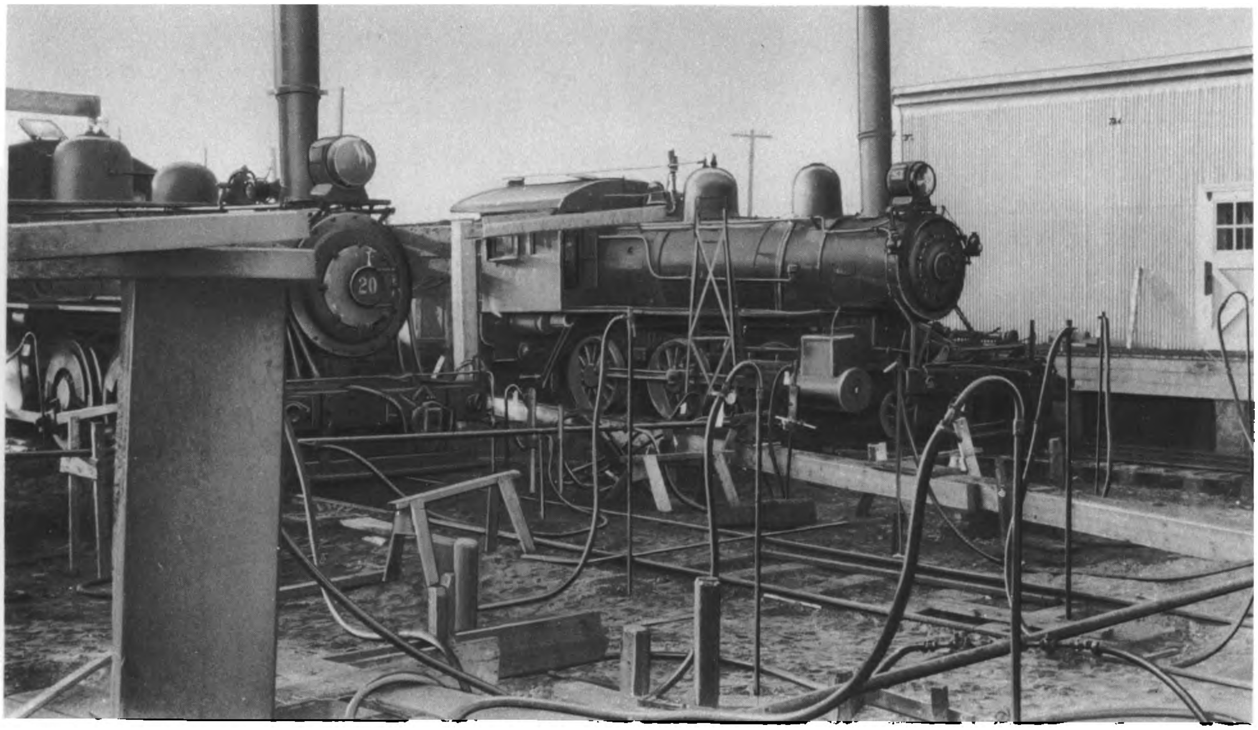


FIGURE 3C1-6

Locomotive Boilers Used for Thawing, Fairbanks, Alaska

In this method of thawing, a steel pipe containing an asbestos-packed resistance wire wound on a steel bar is used in the same manner as a steam point. The method is advantageous in certain winter applications where it is desired to keep surface ice to a minimum. (Ref. 21.)

3C1.03 BREAKING FROZEN GROUND

In certain cases it may be more practical to break up frozen ground than to thaw it.

1. PNEUMATIC CHISELS. Pneumatic paving-breaker chisel points do good work in shallow frozen strata if the equipment first works in a very small area and breaks through to the thawed material. Enough thawed material is then removed with hand shovels to undermine sections of the frozen ground. Pneumatic points can then readily break off sections of the frozen layer, and excavation of both thawed and frozen material can proceed. Frozen strata up to 2 ft in thickness can be broken in this manner. In solid permafrost, however, this equipment is not productive because most frozen materials are too resilient to be easily shattered by pneumatic equipment.

2. BLASTING. Blasting is commonly used in breaking up permafrost for shallow excavations, and although it is a costly procedure, in certain applications it is cheaper than other methods. As in the case of pneumatic equipment, blasting is most productive in frozen strata up to 2 ft thick, although many deeper excavations have been made by this method. Active-zone frost layers have been shattered by placing blastholes at 3-ft centers on lines 4 ft apart with one-half stick of 40-percent dynamite in each hole.

Blastholes may be either drilled or thawed, the latter method being preferable in materials not subject to sloughing. In certain soils, ice may foul up drill bits to such an extent that drilling may be impracticable.

Slow-burning powder is the most effective explosive for blasting frozen silt and fine sand. Frozen gravel of high moisture content requires the shattering effect of 40 to 60 percent dynamite or TNT. Close spacing of holes is required, but trial shots are necessary to determine the most effective spacing. Most Alaskan operators appear to prefer electric priming with delay electric blasting caps

TABLE 3C1-1a

Effectiveness of Thawing Water, Interior Alaska

Location	Year	Cu yd,MID[1]	MID,cu yd	MIDD,cu yd[2]
Areas 1 through 7	1927	10.02	0.100	1.970
Areas 1 and 2	1929	...	0.074	0.860
Areas 1 and 2	1930	...	0.109	0.932
Areas 1 and 2	1931	...	0.118	1.331
Areas 1 through 7	1932	8.89	0.112	1.569
Areas 1 through 7	1933	9.06	0.110	1.475
Areas 1 through 7	1934	11.27	0.089	1.377
Areas 1 through 7	1935	10.76	0.093	1.296
Areas 1 through 7	1937	11.70	0.085	1.408
Areas 1 through 7	1938	10.01	0.100	1.613
Areas 1 through 7	1939	10.90	0.092	1.514
Areas 1 through 7	1940	11.30	0.089	1.581
Areas 1 through 7	1941	12.67	0.079	1.099

[1]MID = miner's inch flowing for 24 hours or miner's inch-day. One MI = 1/40 cfs = 1.5 cfm or 1 cfs = 40 MI.

[2]MIDD = miner's inch-day degrees. If the average water temperature to points in one day is 48° F and there are 100 MID, then MIDD = (48-32) 100 = 1,600 MIDD.

TABLE 3C1-1b

Effectiveness of Thawing Water, Interior Alaska, 1940

Location	Cu yd,MID[1]	MID,cu yd	MIDD,cu yd[2]
Area 1	12.14	0.082	1.638
Area 2	13.51	0.074	1.501
Area 3	6.33	0.158	2.673
Area 4	13.65	0.073	1.334
Area 5	13.43	0.072	1.550
Area 6	6.10	0.166	2.241
Area 7	10.60	0.094	1.500
Weighted average, all areas	11.30	0.089	1.581

[1]MID = miner's inch flowing for 24 hours or miner's inch-day. One MI = 1/40 cfs = 1.5 cfm or 1 cfs = 40 MI.

[2]MIDD = miner's inch-day degrees. If the average water temperature to points in one day is 48° F and there are 100 MID, then MIDD = (48-32) 100 = 1,600 MIDD.

and rotation firing. The effectiveness of explosives in permafrost has been reported to be about the same as in fine-grained sandstone. Permafrost that has been blasted has a tendency to break into large, heavy pieces. Power shovels and forklifts should be used to load the broken materials into dump trucks. Also, bulldozers may be used to push the chunks up ramps onto lowboy trailers.

3. ROOTERS. Single-tooth rooters, towed by tractors, are useful in breaking up comparatively thin layers of frozen materials on fairly smooth surfaces where there is sufficient area for free movement of the equipment. When towed by heavy tractors, this equipment can break ground frozen down to 12 to 18 in. On this type of work it is helpful if, at the start of the operation, a hole is blasted through the frost layer so that the tooth can work from the bottom edge in the frost layer, forcing it upward in the direction of travel. By making parallel passes 5 ft apart, 20,000 sq ft of 18-in. frost have been broken up in an 8-hr day by one unit of such equipment. Two Class V crawler tractors may be necessary to tow a single-tooth rooter. Tooth mortality of rooters in permafrost is very high and must be taken into consideration. Broken frost layer slabs resulting from such an operation often weigh a ton or more, and power equipment is required to load them onto dump trucks.

The foregoing method has been used successfully in excavation work after the freezeup but before the active layer has become frozen to its full depth.

4. BACK RIPPERS. Back-rip scarifiers or hinged teeth for bulldozers that rip while backing up have been used recently in breaking up ice and permafrost. Because the teeth are mounted on the back of bulldozer moldboards, the tractor operator has excellent control and can make effective short-coupled pulls in a manner that is impossible when the tractor is pulling a rooter or ripper. Such equipment was first used in Alaska at Livengood in 1951. A reliable source indicates that by using this equipment, mounted on a Class V bulldozer, a cut 120 ft x 40 ft was cleared of 4 ft of solid ice in 6 hr. From the same source it was reported that a drainage area 600 ft x 12 ft was cleared of 4 ft of ice in 5½ hr.

Reports of the efficiency of the equipment in permafrost are not as encouraging. The short distance that the multiple-hinged teeth extend below the cutting edge of bulldozer blades limits the depth of scarifying with back rippers. This depth may often be too shallow to get below the active layer effectively. The back ripper, therefore, tends to ride upward unless considerable downward pressure forces the rippers down to the permafrost. For this reason it is doubtful if present back rippers are adequately designed for much usefulness in breaking up permafrost.

Section 2. REMOVAL OF MATERIALS

3C2.01 GENERAL

Designs for certain types of facilities often make use of fill sections and specify only the removal of fine-grained materials in the active layer that will be subject to destructive frost action. Occasionally such excavation may be quite deep, but more often only several feet of the material need be removed.

Stripping and excavation of such areas are usually accomplished by hydraulic dozer equipment and carryall scrapers, and the work should be confined to the area within the construction lines. Operation of heavy equipment over the surface of the active zone, removal of the vegetative cover, and making cuts in the subgrade materials may alter the flow of subsurface water and cause adjustments in the thermal condition of the active layer. Once the vegetative cover is removed, the exposed frost areas thaw rapidly and produce surface water in the disturbed areas. In certain parts of the Cold Regions, undisturbed moss-covered ground may thaw during summer to depths of 12 to 18 in., but the same area stripped of moss may thaw to depths of 4 to 6 ft.

Materials of fine texture often contain ice, either as minute grains or as ice lenses or wedges, which when thawed produce excessive wetting and plasticity and are susceptible to settling and caving. Removal of the materials should therefore start immediately after the moss has been removed; otherwise, the area will soon become a quagmire in which equipment will become inoperative.

1. SYSTEMATIC REMOVAL OF THAWED MATERIALS. In moss-covered areas, where the thaw of fine-grained materials ranges from 12 to 18 in. each season, 3 to 5 in. of thawed materials may be removed each day during the warm months; and if the materials are continually removed as they thaw, 25 ft may be excavated in a 100-day summer operation. The advantage of making it possible for the construction equipment to work always on the frozen ground table is a considerable one.

a. *Abrasiveness of Silt.* The fine hard-grained particles of silt or sand agitated by equipment working in wet areas will cause excessive wear of rails, pins, wheels, sprockets, and plates of tractors and lead to early failure of the running gear. Records of equipment used in construction of northern airstrips indicate the necessity of having available a supply of replacement parts for tractors working in wet fine silt. (Ref. 21.)

2. STOCKPILING GRAVEL. If the material is continually removed as it thaws, frozen gravel in a borrow pit may be excavated by dozers and carryalls and stockpiled to allow the gravel to drain out and dry for future use as coarse base material.

3. DEVELOPING DRAINAGE FACILITIES. The exposure and thawing of fine-grained frost-action materials produces much water, which may present a serious drainage problem, especially in flatlands. The problem may be complicated by the interception of subsurface water during excavation, which, if not properly drained, may break through to the surface during the winter and form a field of ice on the operating area. It is important that proper drainage facilities be developed before the start of the stripping and excavating operations (Section 2A7). This is in contrast to the construction of these facilities in the Temperate Zone, where in many instances the final drainage facilities are not installed until after the wearing surfaces of roadways, landing strips, parking areas, and taxiways have been put down.

4. REMOVING FROZEN ACTIVE-ZONE MATERIALS. Tractor-mounted draglines and shovels are frequently used in handling broken or shocked frost layers. So also are road scrapers equipped with offset frost-blade sections and hydraulic dozers that utilize the downward-powered force of their blades to cut into the frozen materials. Mechanical breakage of equipment on this type of service is apt to be excessive because it is often impossible to anticipate erratic ground conditions. In many cases, however, the methods are faster and less costly than thawing. A mining company in the Fairbanks, Alaska, area constructed a mile-long drainage canal, 3 to 6 ft deep and 10 to 12 ft wide at the bottom, by blasting the frozen ground and excavating the materials with a dragline. The work was done in March. The materials excavated were frozen silt with a high moisture content, ice lenses of various thicknesses, and a fibrous peat occurring at various depths throughout the channel line. Because of the characteristics of the materials, thawing would have turned the right-of-way into a plastic flowing mass that would have been extremely difficult to excavate. (Ref. 21.)

5. ADVANTAGE OF WINTER EXCAVATION. After thawing or breaking the frozen materials, deep outfalls for sewer or drainage lines discharging into natural water channels can often be more easily excavated in winter when the water level of the stream is low.

6. HYDRAULIC STRIPPING. Hydraulic stripping of frozen fine-grained soil is used extensively by mining companies operating in the Arctic and Subarctic Regions and consists of intermittently playing high-velocity streams of water from Monitors, or Giants, onto the frozen materials. The combined washing and thawing action of the water and warm air makes possible rapid stripping and removal of fine-grained materials, which are carried in suspension from the working area. The best efficiency is obtained when several Monitors are installed within range of each other and operated in rotation, each unit washing off the thaw of all ground within its working radius. Continuous nozzling of frozen muck, particularly when the water is very cold, is an inefficient operation. Hydraulic stripping is faster than mechanical, but is seldom practical on construction projects because of the necessity of having available large quantities of water under pressure. In such operations proper drainage must be provided so that the soil-laden water will be deposited away from the building site.

7. WALKING DEVICES. In excavation operations involving large-capacity shovels or draglines, consideration should be given to mounting such equipment on walking devices such as Monaghans. Experience with this type of equipment in Alaska indicates that its greater bearing area and lower unit-bearing pressure is advantageous in soft, level ground and that the tundra is disturbed much less by walking equipment than by the treads of heavy tractors. For the most efficient operation, uneven surfaces to be traversed by heavy walking devices should first be leveled by bulldozers or other equipment.

8. GRUBBING AND STRIPPING. Grubbing and stripping construction sites in permafrost areas is ordinarily accomplished by bulldozers and drags and should be started in the early spring as soon as the snow has disappeared. Blasting stumps and cutting down trees is seldom required in areas where permafrost is close to the surface.

Section 3. BANKS AND FILLS

3C3.01 MAINTENANCE OF BANKS

In excavating for foundations that are to be supported on permafrost and confined for at least a portion of their depth by permafrost, it is important that the stability of the frozen sides of the excavation be preserved.

If the ground is broken by blasting, care should be taken that the thermal condition of the area outside the limits of the excavation is not disturbed as a result of the blasting operations.

Sidewalls should be protected from high summer temperatures by lining the sides of the excavation with insulating materials, such as layers of dry tundra, which is plentiful in some permafrost regions. In special cases it may be desirable to refrigerate the excavated surfaces by circulating a refrigerant through double pipes. This has been accomplished by putting down a series of these pipes, of required sizes, in a perimeter larger than the required excavation and by circulating a refrigerant down the inside pipe and letting it rise through the outside pipe. Widely different applications of refrigerants are possible, and the specific method used depends on the circumstances in each case (par. 2 of 2A8.07).

3C3.02 FILLS

1. STOCKPILING. Stockpiling of fill materials should begin as early as possible in the spring so that they will be well drained before placing. Frequently this work has been carried on during winter by bailing gravel from rivers by draglines through holes in the ice. Stockpile areas should be located in the vicinity of the construction operations, with consideration given to the route and the possible condition of the haul road after seasonal frost has left the ground.

a. *Separation of Materials*. Care should be taken in the stockpiling operations to separate the types of granular materials available. Although there may be little choice in the type of well-graded materials available in the region, it is usually possible to obtain and separate clean sand or densely graded sand-gravel and coarse gravel.

Each of these has important applications in most construction operations.

2. PLACING FILLS. In placing fills on saturated fine-grained subgrades, it is important that the first course be densely graded sand-gravel or clean sand because fine-grained soil when wet and under load is likely to ooze up through coarse materials into the base course. On such subgrades it is important that drainage be provided so that excess water can escape as the fill is placed and compacted. Fill materials should be placed and compacted in 6-in layers to the elevation required. Every effort should be made to create uniform soil conditions in embankments so that differential settlement will be avoided. Pockets of unsatisfactory materials over which embankments are to be placed should be replaced with materials comparable to the adjacent subgrade materials.

Before making fills in frozen ground, the possibility of slippage of the new fill should be investigated. Blasting the permafrost to form a rough surface will improve the bond between the new fill and the subgrade when the conditions are such that no thawing of the contact materials between the fill and the subgrade will occur during any portion of the year. If the materials and the disciplines are such that the contact plane may thaw, any previous rough permafrost surface may become plastic and flat. Slippage may then occur if the weight of the fill is sufficiently great to overcome the coefficient of sliding friction between the permafrost and the superimposed load, whether thawed or frozen.

Backfilling operations should begin immediately after excavation of the fine-grained frost-action materials in order to preserve the permafrost.

3. DRAINAGE. The importance of good drainage in subgrades under fills can not be overemphasized. A high subgrade moisture content will result in poor compaction of the completed embankment and increase the possibility of settlement. (See Section 2A7.)

Fills should be constructed sufficiently high to provide adequate surface drainage and to insulate the underlying permafrost. (See par. 2 of 2A6.02 and par. 2A7.02.)

4. COMPACTION. Requirements prior to fill construction include the placement of all necessary trenches, culverts, and other drainage structures.

If French drains are used, the backfill must be placed and compacted in layers to reduce subsequent settlement in areas where the drain is subject to loads from traffic. Either hand or air tampers may be used. The top portions of these drains may be compacted by running a loaded truck back and forth with wheels in the trench, but care should be taken that soil or other fine material is not deposited in the trench by the wheels.

Where perforated pipes are laid, a selected backfill must be used and carefully compacted to prevent silting and obstruction of perforations.

Culverts should be laid on well-tamped materials, and backfill should be placed simultaneously on both sides of the culvert in approximately 3-in. lifts throughout its entire length. Sidefills should be hand tamped. Machine compaction may be used after at least 12 in. of fill have been placed over the top of the culvert.

Compaction of base course or embankment fills is generally comparatively easy to accomplish in the Cold Regions. These fills are almost always nonplastic and are satisfactorily compacted by tractors, trucks, and road rollers. Clean gravel is usually compacted to a dense state by such methods; sand, however, is more difficult to compact because it is usually moist when placed. A slight amount of moisture in sand may hold the grains together by capillary forces to the extent that they are incapable of being moved to a denser packing. Such a condition can be improved by completely drying the sand or by completely saturating it. The latter method is generally the more practical.

PART D. SNOW COMPACTION FOR ROADS AND LANDING FIELDS

Section I. COMPACTION EQUIPMENT

3D1.01 GENERAL

The most important property of a snow surface from a trafficability standpoint appears to be hardness. Hardness may be defined as the ratio of intensity of pressure to depth of penetration and may be characterized by the resistance of the surface to the penetrating effects of wheels and skis. Tests indicate that under the proper conditions of temperature, snow covers having the higher density also have the higher hardness. Snow is a crystalline material, and its strength near its melting point is fixed by the number and strength of the intercrystalline bindings. The crystals, themselves, are stronger than the boundary layers, and to spread stress on as many boundary bindings as possible, it is necessary to consolidate the snow. The nearer snow is to the melting point, the more the crystal boundaries become liquid in form and the more unstable the crystals become. Also, milling the coarse-grained crystals and packing them together results in an ever more unstable condition. Compaction methods are therefore more efficient at high temperatures after the ice crystals have been milled and before they have developed a stable form. Intercrystalline cohesion and strength of snow crystals of the same form, size, and density increase greatly at low temperatures. Snow should therefore be used for traffic at low temperatures. (Ref. 91, 92.)

Snow, immediately after it falls, may have a density as low as 0.05 g/cc (3.1 lb/cu ft), although the average density is more often about 0.1 g/cc (6.3 lb/cu ft). With natural pressure and age it will seldom attain a density of more than 0.3 or 0.4 g/cc (18.7 or 25.0 lb/cu ft). The density and hardness required to support and endure the traffic of heavy-wheeled vehicles can be determined, at present, only by traffic testing. Therefore, until representative loads have been imposed on snow surfaces of various densities and subgrade conditions, and the densities themselves have been produced under all the various atmospheric conditions expected, it is impossible to predict whether present snow-packing techniques and equipment, available or contemplated, will satisfy all the requirements of future operations. (Ref. 91, 93.)

3D1.02 RESEARCH

A considerable amount of research has been undertaken in recent years to develop techniques and equipment to improve a natural snow cover so that it is capable of supporting heavy traffic. Some work that has been programed has not been completed, but sufficient research has been done to allow at least tentative conclusions as to the effectiveness of certain snow stabilization techniques and equipment in producing trafficable snow surfaces. More extensive research and traffic testing are necessary before conclusive evaluations are possible. No practicable means has yet been developed to predict the suitability of a given snow surface for any particular vehicle, but valuable groundwork in this direction has been accomplished. (Ref. 93.)

3D1.03 MEASUREMENT OF COMPACTION

Adequate instrumentation to evaluate natural or processed snow has not yet been developed. Also, the common instruments used to measure the results of compaction have not been correlated one to the other nor with regard to ultimate traction loading. Tests indicate that it appears desirable to keep instrument field testing to a minimum and as simple as possible. Snow classification, density, hardness, and tire penetration are considered the most essential. (Ref. 91, 92.)

3D1.04 SNOW SURFACE PROCESSING EQUIPMENT

In general, two types of equipment are required to increase the density and hardness of snow. These are (a) those that pulverize, scarify, or otherwise depth-process the snow, and (b) those that compress and compact it. Application of heat to the snow while it is in the maximum state of disaggregation is very desirable. However, no practical and economical method of accomplishing this has been reported. Flame, steam, water, and admixture have been added to agitated snow surfaces during tests, but the results have so far been ineffective. In certain areas, such as those of the Arctic coastal plain, where snowfall is comparatively light and ground surfaces are frozen prior to any appreciable amount of snowfall, compacting methods and equipment are comparatively simple. All that is necessary ordinarily is to utilize the snow as a fill material for final grading purposes, elevating the fill periodically to keep its elevation slightly above that of the uncompacted area. Continuous Arctic winds then keep unwanted snow off the compacted surface. In such areas compacted surfaces constructed only with a bulldozer and a steel drag have accommodated C-46 and C-54 aircraft. For this reason construction criteria can best be established in localities having a deep snow cover, although the same basic principles are involved in any locality. (Ref. 91.)

1. DEPTH PROCESSING. Pulvimixers, tooth harrows, and disk harrows are the most commonly used equipment for depth processing.

a. *Pulvimixers.* A pulvimixer is a machine that scoops a layer of snow (usually 1 foot or less) into a closed compartment where it is pulverized by a chain or hammer flail into fine particles before being redistributed on the snow surface. It may be self-propelled or towed by a tractor. If towed, it is usually ski mounted. The self-propelled type, to be effective in deep snow, should be track equipped. This equipment is often used in conjunction with some form of dry-heat apparatus by which heat is applied directly to the agitated snow surface. Pulvimixers preceded and followed by a proper pressure device are the most satisfactory equipment yet developed for producing trafficable surfaces. (Ref. 91, 92.)

b. *Tooth Harrows.* Tooth harrows are simple and easy to maintain, because they have no moving parts. Usually, for snow consolidation, they are specially constructed of structural steel sections with steel bar teeth of various spacing and projection, depending on snow conditions. This equipment is difficult to maneuver in deep snow; lighter construction would probably overcome the difficulty, and weights could then be added as required. Another disadvantage of tooth harrows is the fact that there is no vertical intermixing of snow from different levels and therefore no mixing of snow of different temperatures. Tooth harrows do not leave a smooth surface and must always be used in conjunction with rollers. (Ref. 92.)

c. *Disk Harrows.* Disk harrows have been inadequate, primarily because of insufficient flotation or supporting devices. Test results are based on the use of gang harrows with 24-inch disks, which were so small that the drawbar and axles were always well down in the snow and plowed up the snow ahead. Had they been equipped with large-area support shoes, runners, or plates, the harrows would not have sunk into the snow. On a hardened strip the equipment was found to be quite effective in chopping up the surface. (Ref. 92.)

2. APPLICATION OF PRESSURE. Pressure for compaction is generally applied with some type of roller or drag. Satisfactory compaction has been accomplished by bolting wooden track extensions to tractor plates and utilizing the weight and vibration of the tractor unit in the same manner as compacting earthfills. Modified sheepsfoot rollers, slat rollers, and an air-driven vibrator mounted on a steel plate shaped like a toboggan have been used to a limited extent in snow compaction tests. Results are not conclusive, but they indicate that further investigation of such equipment is justified. (Ref. 91, 92.)

a. *Rollers.* Snow can best be compacted in a series of thin layers, but it must be compacted as found in the field, where the depth is often 5 ft or more. On the icecaps it may well be 30 ft deep. Compacting snow depths of this magnitude requires a roller of large diameter (6 to 8 ft) and relatively light weight (9,000 lb unballasted). This is to prevent the roller from sinking deeply and becoming, in reality, a plow. As the snow density increases from reworking, it is capable of supporting greater unit loads. Thus, heavier (1,500 lb unballasted) rollers having small diameters (2 to 4 ft) or high angles of approach are satisfactory.

Indications are that the compacting effectiveness of large-diameter rollers does not decrease as the snow becomes denser. Additional weight or roller ballast does not appreciably alter results. This indicates that the angle of approach or radius of the roller influences the compaction. It is analogous to the angle of approach of the runners on snow. Conclusions from recent tests indicate that 8-ft-diameter, variable-weight snow rollers in combination with pulvimixers were most effective in the particular tests in producing suitable snow surfaces, and that rollers when ballasted are more effective than when unballasted. It has been found that the multiple-pass procedure, done on one continuous operation, is more effective than the single-pass procedure; the continuous procedure, however, becomes impractical beyond 3 or 4 passes. Rollers should be able to be coupled in line or tandem and should be provided with snow-cleaning scrapers.

b. *Drags*. Various types of drags have been used in snow compaction investigations and in the construction and maintenance of snow roads and airfields. When snowfall is light, steel drags are very effective in compacting thin layers of snow and are particularly effective when used during storm periods to keep snow moving and to prevent drifting. Pontoon drags are more difficult for tractors to handle in deep snow than are rollers and are not as effective as rollers. (Ref. 92.)

3D1.05 CURING INTERVAL

A notable property of snow is that its hardness continues to increase if it is left undisturbed after having been mechanically treated. After the absorbed air has been eliminated, the crystals in contact with each other continue to grow together, a process that continues for 10 to 12 or more hours after compaction. Tests have indicated that after progressive passes with a roller over a snow surface, the hardness measured 1 hour after completing the compaction was twice as great as that after a single pass and that a further increase in hardness of 8 to 10 times the value obtained after a single pass took place 12 hours after completing the rolling. Attempts to work hard, dry snow continuously without allowing for a curing interval will result only in a churning of the snow with no increase in compaction. (Ref. 21, 92.)

Section 2. SNOW ROADS

3D2.01 TESTS AT CHURCHILL, CANADA (Ref. 92)

Practical field trials consisting of actual construction and maintenance of a 12-mile section of road 45 miles from Churchill and 2 miles from the shore of Hudson Bay were conducted by the Royal Canadian Engineers in 1951. Winds here are common and of high velocity, and snow conditions are analogous to those occurring on flat, exposed Arctic coasts and for some considerable distance inland. The equipment consisted primarily of a Seaman pulvimixer and low-pressure roller. The pulvimixer was equipped with a chain flail consisting of 120 chains, 15 in. in length (chain diam, ⅝ in.). It was mounted on skis and towed by a tractor; the roller was 6 ft in diam and 8 ft in width, and its weight could be varied between 3,175 and 5,800 lb in 75-lb increments.

No difficulty was encountered in compacting snow in these tests when the atmospheric temperature was below 5° F, and no trouble was experienced with traffic on the road while the temperature was below 10° F. Temperatures during the test period ranged from −30° to 15° F. Compacted snow densities achieved were between 0.4 and 0.5. Traffic tests involved using 3-ton trucks loaded to a gross weight of 9 tons, developing axle loads of 11,500 lb.

No satisfactory answer was obtained to the question of optimum number of passes of equipment. A long interval between passes appeared to be definitely detrimental. A 4-hr period caused trafficability failures every time it was tried. A treatment interval of less than 1 hr produced good results from which the conclusion is apparent that with this equipment the time interval between passes should be kept to a minimum and in no case should be allowed to become greater than 2 hr. A recommended curing period for the treated snow, prior to its being opened to traffic, ranged from 19 to 24 hr.

When these road-making materials were used, the rate of construction of snow roads amounted to 3 miles during a 24-hr working day with the equipment at hand and under favorable conditions. Favorable conditions are defined as terrain open and flat, snow depth under 3 ft, wind chill factor less than 2,100, and visibility at least half a mile.

In these tests, the road surface was raised above the surrounding snowfield by a snowfill. Therefore, wind and drift swept over it, and snow fences were unnecessary. Equipment included a pulvimixer, 3 rollers, and 5 tractors.

The buildup process was attained by spacing the initial passage of the tractors 45 ft apart, across the proposed centerline. After dragging the snow in toward the centerline, it was roughly leveled by the tracked tractors. The treatment with the pulvimixer and, in turn, the rollers, followed. A built-up roadway was constructed having about a 15-ft surface width, usually raising the road surface about 1 ft above the surrounding snow surface.

Great care was taken in smoothing off the snow-fill slopes, which were made no steeper than 1:5, with the shoulder corners smoothly rounded off. The buildup process was accomplished at the rate of 7 miles a day, but the progress on the road finishing depended entirely on the single pulvimixer unit. By using 2 such units, therefore, the construction progress could have been doubled.

The buildup process in detail was accomplished by starting 2 tractors on opposite sides of the centerline with blades angled toward each other, continuing forward a distance of half a mile. The two tractors were then reversed in direction, continuing to windrow the snow toward the center until they made their third and last pass in the direction of forward movement. The crests of the two final windrows were 10 to 13 ft apart. During this windrowing process the contraction in the snow volume, starting with a snow density of 0.3 g/cc (18.7 lb/cu ft), amounted to 40 or 50 percent. The windrows were then smoothed over the road surface and in turn followed by five passes with the pulvimixer-roller combination.

Within 36 hr the road was subjected to traffic, including 3-ton loaded trucks, 20-ton loaded sleds (moving at 25 mph), and tracked tractors. One section of the road, a crossing, was subjected to 50 tractor passes a day over a 5-week period without ill effects. No failures occurred over any part of the road. Traffic wore down the corrugations made by the rollers, the only evidence occurring on the surface.

The speed at which vehicles could move over the road was governed only by vehicle performance. No difficulty was experienced at 40 mph, and there was no indication of either sidesway or skidding. No evidence of deterioration of the road surface was visible at temperatures up to 20° F, which prevailed late in the season. The road was built in mid-February and, with temperatures as high as 30° F, up to 8 April had suffered no permanent damage. The effect of the heavy traffic to which it was subjected, if anything, appeared to have improved the road and its surface.

3D2.02 TESTS AT POINT BARROW, ALASKA (Ref. 94)

During the 1950-51 winter season, the Arctic Test Station at Point Barrow constructed 19 test strips built with various combinations of snow stabilization equipment. From these tests the most effective combinations were selected and used in the construction of a 5,000-ft snow road. The road was maintained at the same time that it was subjected to testing by wheeled traffic. Construction operations were on two parallel sites 75 ft apart, each 2,500 ft long by 31 ft wide, which were covered with drifted snow 6 to 18 in. deep. More snow was hauled to the sites so that the overall depth averaged 18 in.

Each of the 2,500-ft sites was divided into two 1,250-ft sections, and each of the four sections was stabilized by one best method established in the test strip studies. The four methods were:

Section I: Pulvimixer followed immediately by 8-ft roller.

Section II: Pulvimixer followed immediately by snow surface heater and sheepsfoot roller.

Section III: Pulvimixer followed immediately by water carrier and 8-ft roller, with the water carrier discharging water at the rate of 50 gal/lin ft or 0.5 lb/sq ft through a spray bar 8 ft long and 2½ in. in diam.

Section IV: Pulvimixer followed immediately by pontoon barge with a 6,300-lb load.

Each combination of equipment made 5 stabilization passes, and all equipment except the water carrier and the snow surface heater was towed at approximately 1.5 mph. The snow surface heater was towed at a speed of 0.85 mph and the water carrier at a speed of 1.0 mph. In making an 18-ft wide roadway, 3 equipment lanes were used for the pulvimixer, snow surface heater, 8-ft roller, and sheepsfoot roller, whereas only 2 equipment lanes were used for the water carrier and pontoon barge drag.

Passes with equipment combinations were made at 2-hr intervals on Sections I and II, except when the end of the workday intervened, causing a lengthening of the time interval. The time interval between passes with the equipment combinations used on Sections III and IV was increased to 15 hr and 24 hr, respectively, in an attempt to compensate for relatively high ambient temperatures present during the stabilization of these strips.

Test data were collected on each section 2 hr after each pass with the equipment combinations and 24 hr, 1 week, and 2 weeks after completion of the snow roads. The data included ambient air temperatures; snow temperature; type of snow; depth of snow; snow density at the surface and the ground; hardness of the snow surface using the hand penetrometer, CBR field testing apparatus, and the bearing test frame; and Mark II soil truss readings. Data were as follows for tests on the various sections.

(1) Section I—Pulvimixer and 8-Ft Roller: The pulvimixer operated with ease, cutting about 12 in. into the snow on each pass, and a good traffic-bearing surface was produced by following each pass immediately with the 8-ft roller. Tests indicated that the density of the entire depth of snow was increased uniformly, and no stratification was observed in the test cores. The surfaces were subjected to hardness tests with the hand-operated penetrometer, CBR field testing apparatus, and field bearing test frame; but insufficient data were obtained for correlation.

The fact that the stabilization method produced a good traffic-bearing surface was proved when, after 20 continuous trips with a jeep and 10 with an empty GMC 2½-ton 6 x 6 cargo truck, the surface was only slightly marred; good condition was quickly restored with a single pass of the steel snow drag. For greater wheel loadings, a Caterpillar Model-12 motor grader, towing a loaded low-bed trailer with a gross weight of 26 tons, was moved over the roadway. This caused only shallow tire depressions along the line of travel, which were quickly removed with the wooden snow drag and 8-ft roller.

(2) Section II—Pulvimixer, Surface Heater, and Sheepsfoot Roller: The surface produced on this section was hard and stable, and a marked increase was observed in the density of the entire snow cover over that obtained in Section I, with greatest increase near the surface. The density of the section continued to increase with age. Several objections to using the snow surface heater as a piece of stabilization equipment were observed. Towing speed was slightly more than half as fast as the speed for most other pieces of stabilization equipment; constant operator attention was necessary to assure a maximum output of heat; and continual repair and modification were necessary for successful operation.

Ten trips with a jeep and 10 with an empty GMC 2½-ton 6 x 6 truck were made over Section II before a maintenance pass with the steel snow drag was necessary to restore the surface to good condition. In a single pass over the section, the motor grader and loaded 26-ton-gross low-bed trailer caused very shallow tire marks on the road.

(3) Section III—Pulvimixer, Water Carrier, and 8-Ft Roller: The surface density on the finished roadway was very high because of the added water, but the low density near the ground indicated that even with the aid of a pulvimixer the water did not penetrate the snow completely. The toboggan on which the water carrier was mounted provided a smooth surface to receive the water, and the pass with the roller was started 30 minutes behind the carrier to allow for freezing. This delay prevented adherence of the surface material to the roller. This section was stabilized in unusually warm weather and the traffic tests were inconclusive.

(4) Section IV—Pulvimixer and Pontoon Barge Drag: The density of this section was increased uniformly with each additional pass of the combination of equipment. During the construction of the test strips it was found necessary to load the barge with 6,300 lb for good compaction. This load, which did not cause the barge to plow into the processed surface, at times stalled the International T-9 towing tractor.

This section was stabilized in unusually warm weather, and traffic tests were inconclusive. The surface held up well under limited jeep traffic, but the unloaded GMC 2½-ton 6 x 6 truck and the motor grader bogged down. Maintenance with the pontoon barge drag was not at all satisfactory because of its bulk and lack of maneuverability.

From all these data it is apparent that a combination of agitation and rolling appears to be the most practical and effective means of stabilizing a snow road on the Arctic coastal plain. The best results were attained during the 1950-51 winter test season with a pulvimixer followed by an 8-ft roller. The pulvimixer proved to be an excellent device for preparing a surface, and the ratio of the diameter of the roller to the weight permitted free rolling without plowing.

Using heat to increase the density of a snow road is considered inefficient because of the large quantity of heat lost to the atmosphere and the increased stabilization time. An actual evaluation of the benefits gained by using a surface heater is not possible with the data available; the benefits, however, are believed to be small.

Adding water to the surface has some effect, but in practice the test road was no better than the one built with only the pulvimixer and the roller. Further, water is at a premium on the Arctic plains.

The pontoon drag is unsatisfactory as a piece of snow stabilization equipment because of its size and weight. Moreover, these same factors, which affect its maneuverability, are also reasons for objecting to its use as a piece of maintenance equipment.

The best method of maintaining a snow road is with a weighted steel or wood frame drag. Either drag followed by the 8-ft roller is very effective in restoring the surface to good condition.

3D2.03 TESTS AT CAMP HALE, COLORADO

In 1950 the Bureau of Yards and Docks undertook a series of tests, as part of a snow compaction program, at Camp Hale. The purpose of the tests was to develop techniques and equipment that could be used to improve the natural snow cover so that it would become capable of supporting heavy-wheeled traffic. Camp Hale is on Eagle River, 4½ miles west of the Continental Divide. The snow depths and temperature data for the test period (late January, 1950, to mid-March, 1951) follow.

Average snow depth	17 in.
Maximum snow depth	30 in.
Average temperature	17° F
Maximum temperature	64° F
Minimum temperature	−28° F

The following equipment was used.

(1) 8-ft-diam, variable-weight snow roller
(2) Pontoon barge drag
(3) Seaman's 6-ft-wide pulvimixer
(4) Disk harrow
(5) 250,000-Btu/hr gasoline heater

The pulvimixer, harrow, and heater were either ski or toboggan mounted, exerting a maximum intensity of pressure of 2 psi. Of this equipment, the roller and pulvimixer were the most effective in producing suitable snow surfaces.

The conclusions that can be drawn from these tests resolve themselves into a discussion of the effects of the multiple-pass procedure, a discussion of the relative merits of the different categories of compaction techniques, and a discussion of the instrumentation used. It can be said that the multiple-pass procedure is more effective than the single-pass for increasing the density and in most cases for increasing the hardness. It appears that the use of the multiple-pass beyond the third or fourth pass is impractical.

A comparison of the density results obtained by the numerous techniques tried shows that the various techniques rank in the following order.

(1) Drag, pulvimixer, roller
(2) Roller, disk harrow, drag
(3) Roller (ballasted)
(4) Pulvimixer, roller
(5) Roller
(6) Pulvimixer, drag
(7) Pulvimixer
(8) Pulvimixer, heater
(9) Drag
(10) Disk harrow

The first two techniques successfully withstood limited traffic of a 4-ton 6 x 6 Army wrecking truck. Strips constructed by the other methods were not tested by subjection to traffic.

Section 3. SNOW AIRFIELDS

3D3.01 CONSIDERATIONS

1. GENERAL. Snow on airfields must either be removed at once, compacted and then removed, or compacted and preserved. In areas where snowfalls are very heavy, snow may be compacted or removed completely from the runways. If removed, removal is usually begun as soon as the snow can be picked up by a blade (par. 1 of 4C2.03). Attempts at compaction are useless in areas of fast and complete breakup by sudden thaw, because slush does not compact. In areas where one or more snowfalls may prove too heavy for complete removal at once, the snow is often compacted to keep the facility in operation, and as soon as possible after the storm it is removed. In areas where temperatures are low enough to maintain a compacted surface, newly fallen snow is preserved and compacted as it falls. Initial compaction should be done by rolling only, preferably in increments of 2 to 3 in. of snow. If the surface of the snow is drifted and uneven, it should be worked with a light drag before rolling. After each successive layer of new snow has been completely rolled, the compacted surface should be allowed to set for 10 to 20 hours before being used, although often this curing interval can not be allowed because of frequency of traffic.

It is advisable to compact the airfield initially to the width of the runway, then compact for some distance on either side of the runway with a gradual feathering out at the edges. Continuous dragging and rolling are necessary to maintain hard, level surfaces and prevent drifting in areas where snow is light and steady winds prevail. At temperatures above 21° F, snow may adhere to the roller and tractor plate surfaces. A coating of shellac helps prevent this condition. Experience at NPR-4, Point Barrow, indicated that the most satisfactory drags for northern coastal areas of light snow are built on the principal of a land leveler and should be from 20 to 30 ft long. Large tractors can handle drags with a width of 16 ft. This type of drag is equipped with runners at its four corners. A vertical blade plate is mounted at the middle of the drag for the full width. The bottom of the plate should be at the same elevation as the runners.

As mentioned in par. 3D1.04, compaction equipment and techniques differ in areas where snow is used as a fill material, as it is on the Arctic coastal plains, from those used in areas of deeper snow where snow is processed in its natural position. Compaction in the latter areas involves much more work and equipment than it does in the former and provides more information on the factors that govern snow compaction.

2. VISIBILITY. Good lighting, good marking of runways and approaches, and good navigational aids are of utmost importance on snow-covered landing fields, particularly in sections of light snow and extreme cold. In such areas, winds of 10 to 15 mph are sufficient to move snow and cause very limited visibility forward, but winds of 35 to 40 mph will cover the landing field to a height of 50 ft with flying snow and reduce visibility over the field to zero.

3. HEATED SHELTERS. Warm shelters that make possible the maintenance of aircraft during prolonged stays at the airfield are most important. Aircraft, if left out in extreme cold for an extended period, are very apt to develop unforeseen failures in important components after taking off, particularly in hydraulic, electronic, and electrical systems. Such equipment should be maintained at near-normal temperatures at all times.

PART E. CONCRETE PRACTICE

Section I. LOW-TEMPERATURE CHARACTERISTICS

3E1.01 GENERAL

The placing and curing of concrete in the Cold Regions presents the same basic problems as the accomplishment of similar work in the colder sections of the Temperate Zone. (Ref. 10, Section 8.) If adequate preparations are made, concrete can be successfully placed and cured at extremely low atmospheric temperatures, and it is probable that under such conditions harmful influences to the ultimate strength of the concrete are caused more often by overheating, during the pouring and curing period, than by low temperature. Experience indicates that damage from freezing is most likely to occur during the early fall when sudden freezing temperatures may not be anticipated and when freshly poured concrete is allowed to remain unprotected for a sufficient length of time to cause permanent loss of strength.

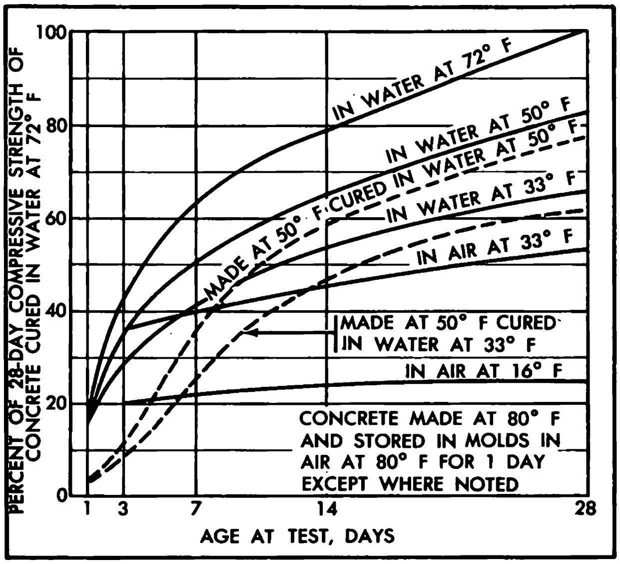


FIGURE 3E1-1

Effect of Curing Temperatures (Ref. 96)

3E1.02 EFFECT OF FREEZING ON STRENGTH OF CONCRETE

When fresh concrete freezes, the expansion resulting from the water freezing causes separation of the solid particles and reduction of their bond. If concrete is frozen immediately after placing but is later exposed to favorable curing temperatures, the concrete may attain a strength of 50 percent of that of unfrozen concrete of the same age. The fact that concrete may have remained frozen for 1 day, or for 7 days, seems to make little difference in the strength it ultimately attains. Dry concrete when frozen suffers less damage than wet concrete. There is little difference in resistance to freezing between a rich mix and a lean mix. Concrete that is relatively dry (2-in. slump) may be frozen solid with only a small loss of strength if cured at 80° F for 24 hours before freezing, followed by 3 weeks of curing at the same temperature. Concrete of higher slumps requires a longer curing period before it can be frozen without harmful loss of strength. If it is found that poured

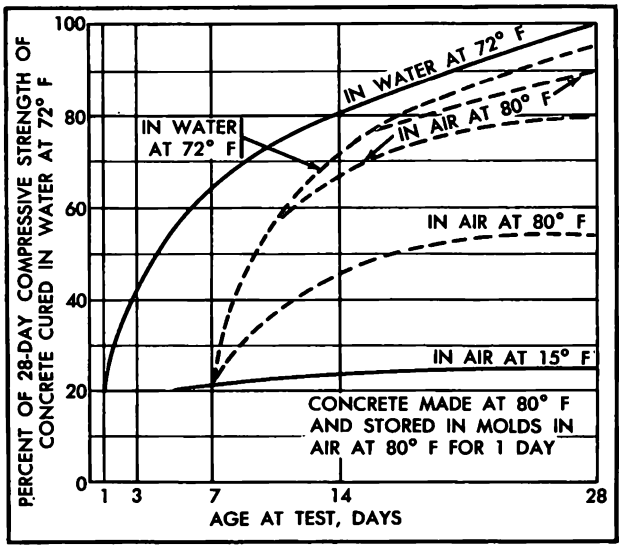


FIGURE 3E1-2

Gain in Strength After Freezing (Ref. 96)

concrete is frozen, and if time will permit, it is advisable to subject the concrete to high curing temperatures for 3 weeks or more, taking care to prevent evaporation during the curing period. The ultimate strength attained will depend primarily on the amount of moisture in the concrete and the amount of set it had attained prior to freezing. (See Figures 3E1-1 and 3E1-2.) In general, it is not safe to expose concrete to freezing temperatures at early periods. (Ref. 95.) When such freezing does occur, the damage must be carefully assessed in terms of strength requirements.

3E1.03 RECOGNITION OF FROZEN CONCRETE

Fresh concrete that has been frozen usually turns white, but concrete that is one or two days old and not frozen will retain its dark gray color in cold weather for several days. Older concrete, however, may have the appearance of adequate strength when in reality it may be frozen. Concrete that has been exposed to freezing temperatures should be tested by placing a sample in hot water or over a stove. If it is frozen, it will quickly disintegrate; if not frozen, the heat will cause no change. (Ref. 96.)

Section 2. PROTECTIVE PRACTICES

3E2.01 ENCLOSURES

1. TYPES. Rapid temperature changes and extreme temperatures should be anticipated in preparing for concrete operations during fall and winter. The working area should be enclosed so that air surrounding the forms and exposed concrete may be heated to proper curing temperatures. Temporary enclosures may consist of tarpaulins attached to wood framework constructed to allow ample working space, or they may be built of plywood panels fabricated for easy erection and dismantling for use at other locations. Extensive foundations were recently constructed at Fairbanks, Alaska, inside an enclosure consisting of double panels of ⅜-in. plywood separated by one ply of heavy building paper. Concrete was admitted to the working area by lowering a bucket by crane through a slide door in the roof. Although the outside temperature was $-50°$ F on the day of pouring and for some time thereafter, the temperature inside the enclosure was easily maintained at 50° F by oil-burning salamanders supplemented by three gasoline-burning hot-air heaters of 250,000-Btu/hr capacity. Panels of this type are not as susceptible to destruction by fire or wind as are tarpaulins; their insulating value is much better, and the air temperature can be much more closely controlled. (See Figures 3E2-1 and 3E2-2.)

2. HEATING. Enclosures are usually heated by oil- or coke-burning salamanders, portable hot-air heaters, or steam. When salamanders or gasoline heaters are used, ample ventilation must be provided. Vents must be carefully located to prevent wide variation in temperature. Heating units should not be located so close to the forms that they cause rapid drying, are a fire hazard to forms or canvas, or cause discoloration from the smoke. Legs of salamanders should be set over sheet metal with several inches of wet sand under the metal. Temperature variation within the enclosure will endanger the concrete, particularly during extremely cold weather. Wide spaces between the concrete and the walls of the enclosure are advisable, and heating units must be carefully placed and of sufficient capacity to protect the concrete nearest the outside walls. Additional heat should be added on the windy side.

Steam is a preferred source of heat for concrete operations. It provides no fire hazard; control of temperature within the enclosure is easier; moisture can be supplied to the air as required; and steam jets can quickly remove frost from forms, reinforcement, and the ground. Heaters should be placed horizontally so that vertical lines can be coupled to them as necessary. Live steam, if allowed to escape into the enclosure, will provide warm, humid air, which is excellent for curing.

3. HEAT FROM HYDRATION. Frequently the heat generated by hydration of the cement is sufficient to prevent freezing of concrete without artificial heat. Heavy footings placed at 70° F and protected by the surrounding earth, except on top, will usually be safe from freezing at temperatures as low as 15° F if a tarpaulin is placed over the top with an airspace between the tarpaulin and the concrete. Mass concrete placed at 70° F can be protected, by wood forms of ⅞-in. sheathing, down to about 20° F if the corners, edges, and exposed surfaces are protected by double sheathing, insulation board, or tarpaulins. In tundra areas moss can

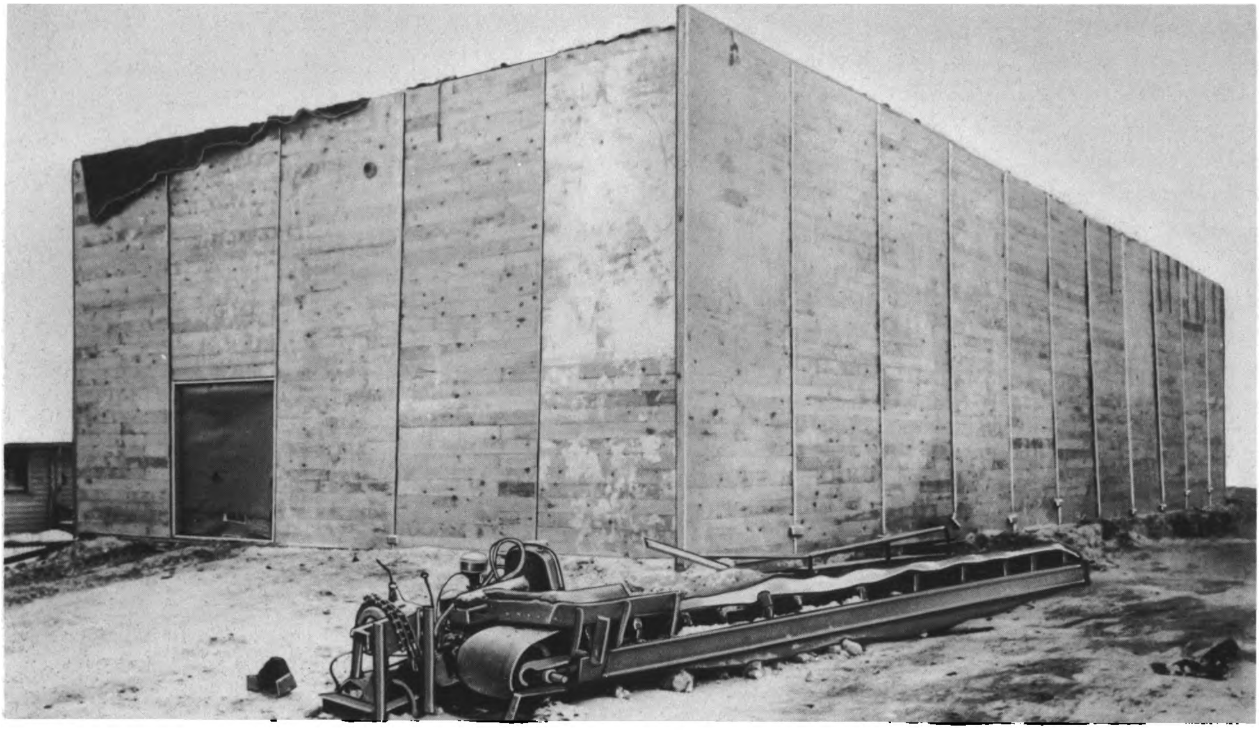


FIGURE 3E2-1

Plywood Panels Protecting Construction of Telephone Exchange Building, Fairbanks, Alaska (Concrete poured and block wall erected at —50° F)

be used to retain the heat resulting from hydration. Protective coverings should be ready for placement immediately after the concrete is poured to reduce heat losses to a minimum. (Ref. 96.)

3E2.02 HEATING THE MATERIALS

1. TEMPERATURE OF CONCRETE AT TIME OF PLACING. Because aggregates usually contain moisture, they must be heated after exposure to freezing temperatures. Materials should be thawed, even at air temperatures above freezing, if the aggregates have been exposed to low temperatures for an extended period immediately prior to their use in concrete. Coarse aggregate is frequently dry and at moderate temperatures often need not be heated; if, however, it has been stored for some time at low temperatures, it is advisable to heat the coarse aggregate as well as the sand. Concrete when placed should have a temperature of not less than 70° F or more than 80° F. Many specifications allow a maximum temperature of 100° F at the time of placing; the upper limit of 80° F, however, is recommended because tests show that temperatures higher than this result in lower strengths. There is a wide tendency to overheat the aggregates, and this often results in concrete temperatures that at the time of placement are too high.

Temperatures above 100° F accelerate the early hydration of a cement and produce concrete of high strength at early stages. However, upon cooling, such concrete may have a tendency to crack, and in some cases it suffers loss of strength at later stages. (Ref. 95.)

2. TEMPERATURE OF AGGREGATES AND WATER. Many specifications require that aggregates be heated to temperatures between 70° and 150° F and that water be heated to temperatures between 130° and 150° F. The Portland Cement Association, in its bulletin No. St 21, recommends a maximum water temperature of 175° F, a limit that is placed because of the danger of causing a quick or flash set of the cement. This bulletin suggests the following formula, which may be used for estimating the temperature of mixed concrete.

FIGURE 3E2-2

Interior of Building Shown in Figure 3E2-1 (Temporary covering removed for erection of steel roof deck and later replaced for pouring concrete roof slab)

$$X = \frac{Wt + 0.22W't'}{W + 0.22W'}$$

W = weight of water (lb)
W' = weight of solids (cement and aggregates, lb)
t = temperature of water (°F)
t' = temperature of solids (°F)
X = temperature of mixed concrete (°F)

The average specific heat of the solid materials may be assumed to be 0.22, and the weight of one sack of cement 94 lb. An example indicating the use of the formula follows (Ref. 96).

Assume a mix with 210 lb sand, 320 lb gravel, and 50 lb (6 gal) total of water, 10 lb of which is introduced with the sand. Assume temperature of materials equals 45° F, and that of water 170° F; water added equals 50 − 10, or 40 lb. Then

$$X = \frac{40 \times 170 + 10 \times 45 + 0.22(94 + 210 + 320)45}{50 + 0.22 \times 624}$$

$$= 72° \text{ F}$$

It will be noted that only the water added was heated to 170° F. The water in the aggregates had the same temperature as the aggregates themselves.

3. HEATING AGGREGATES WITH STEAM. Aggregates can be heated efficiently by steam points of the type used in thawing frozen ground (par. 1 of 3C1.02) or by placing perforated or loosely covered pipes under the aggregate piles. These coils should be placed at closer centers under the sand than under the coarse aggregates. The amount of steam required depends on the atmospheric temperatures, the methods of storing the aggregates, and the rate of concrete required per hr. A minimum boiler capacity of 50 hp is usually necessary on jobs where the pouring rate approaches 20 cu yd per hr. Steam pressures between 60 psi and 100 psi are customary. Portable thawing boilers are satisfactory for small jobs.

4. HEATING AGGREGATES WITH WOOD FIRES. Aggregates are often heated by piling them over large-diameter pipes in which wood fires have been built. When materials are heated in this manner, there is a tendency to overheat some portions and neglect others, producing wide

variations in temperature of the concrete. Care must be exercised that materials in the pile are shifted frequently. Aggregates should be heated the day before they are to be used and should be protected overnight. Tarpaulins placed over the aggregates help in conserving heat.

5. HEATING MIXING WATER. Mixing water is preferably heated by injecting live steam into the auxiliary tank connected to the water-measuring tank. When steam for this purpose is not available, water may be circulated through pipe coils heated by wood fires.

6. OIL-BURNING HEATERS. Oil-burning heaters are sometimes used to heat water or to heat concrete by directing an open flame into the concrete mixer. This method is not recommended except in mild weather when it is not necessary to heat the aggregates.

3E2.03 CURING

Responsible supervision is required during the curing period to keep the heating units in operation and to provide fire protection. A permanent record should be kept that should show for each hour the outside temperature and temperatures at various locations within the enclosure. Immersion thermometers placed in the concrete at critical points close to horizontal and vertical surfaces are helpful in obtaining proper heat distribution. Temperatures within the enclosure should be maintained between 70° and 80° F for the first 3 days, or above 50° F for the first 5 days after placing the concrete, which should not be exposed to freezing temperatures until it has obtained 80 percent of the strength for which it was designed. If high-early-strength cement is used, a temperature of 70° to 80° F for 2 days or 50° F for 3 days should be maintained; however, the concrete should be protected from freezing temperatures for a longer period, as in the case of normal concrete. Application of wet fabrics or sprinkling of the concrete surfaces and forms within heated enclosures is frequently not practicable. The forms are effective in preserving moisture within the concrete and should be left on as long as possible. Exposed surfaces of the concrete should be sealed with an impervious curing compound. If a boiler is available, a favorable humidity within the enclosure can be maintained with steam jets.

3E2.04 DEFROSTING

Flame-throwing oil heaters or a steam jet may be used to defrost the reinforcement and the interior of forms before placing concrete. A steam jet is preferable because all sections of the forms can be reached and the steam provides moisture as well as heat. Open-flame heaters must be carefully handled to avoid setting fire to the forms.

3E2.05 ANTIFREEZE COMPOUNDS AND ADMIXTURES

Using salts, chemicals, or other foreign materials to lower the freezing point of concrete is not recommended. The amount of any of these materials required for appreciable temperature reduction is so large that the strength of the concrete is seriously reduced and flash set may result. Calcium chloride can often be used advantageously to reduce the curing time. If it is used, quantities should be limited to 2 pounds of calcium chloride per sack of cement. Crystals may be added to the batch with the aggregates, or the materials may be dissolved in the mixing water before placing. It should be noted that heating the water speeds the rate of set of concrete, and care should be taken that acceleration due to the combination of calcium chloride and heat is not so rapid that the concrete can not be properly handled. There is no conclusive evidence to indicate that a small addition of calcium chloride to concrete has any corrosive effect on steel reinforcement. Concrete in the Cold Regions is subject to very severe cycles of alternate freezing and thawing and should, therefore, be as durable and watertight as possible. Using air-entraining agents to increase durability is usually desirable; the proper placement, however, and the use of low water/cement ratios is equally important. (Ref. 96.)

3E3.01 PLANNING

If winter concrete operations are planned, the type of enclosure and the locations of openings for concrete placement should be determined in advance so that the aggregate piles and other components of the mixing plant can be properly placed. In cold weather an efficient, well-balanced operation is extremely important to keep delays to a minimum. The mixer-charging and concrete-handling facilities should be adequate to keep the mixer going at its full capacity, and the pouring schedule should be carefully planned. The size of the mixer should be adequate to provide the yardage required in the time available.

3E3.02 PLACING

Concrete barrows and buggies are difficult to wheel in extremely cold weather, and ample additional labor to assist in pulling these vehicles, particularly on inclines, should be provided. Inclined ramps should be kept clear of snow and ice and should be sanded. All components of mechanical placing systems (including hoppers, buckets, chutes, and spouts) should be kept free of ice during placing operations, and entrances to the enclosure should be provided with easily operated doors to avoid delay in placing.

Cableways, belt conveyors, chutes, and concrete pumps are not recommended for out-of-door use in cold-weather operations. The best placing system under such conditions, if the size of the job will justify it, is a truck- or tractor-mounted crane that can rapidly transfer the concrete bucket from the mixer to the pouring area. Such a bucket should preferably be lowered into the enclosure and discharged directly into portable hoppers placed over the forms or into wheelbarrows or buggies for distribution of the concrete.

3E3.03 MIXING CYCLE

A mixing cycle of 3 min, assuming a minimum mixing time of 1 min, is average for summer operations, but it is difficult to attain in cold weather because of reduction in efficiency of men and equipment and additional work involved in heating the materials and performing other tasks necessitated by the circumstances.

3E3.04 LIGHTING

Adequate lighting of the outside operational area should be provided in winter because of the long hours of daytime darkness during this period.

3E3.05 STOCKPILING AND STORING MATERIALS

When possible, the coarse aggregate should be stockpiled closer to the mixer than the sand because more coarse aggregate than sand must be handled for each mixing cycle. Cement should be stored in a weathertight shed until transported to the mixing plant immediately prior to pouring.

If the aggregates are stored in a central materials yard and hauled in batch trucks to the mixer, advance measurements are advisable to assure that the truck bed is sufficiently high to discharge directly into the mixer hopper. In cold weather, if batcher bins are used, heat should be provided in them by placing steampipe coils in the bins or by placing pipes on the outside of the bins connected to steam jets extending into the interior of the bins.

3E3.06 CONCRETE FROM CENTRAL MIXING PLANT

If concrete is obtained from a central mixing plant by transit-mix trucks, provision for heating the aggregates at the plant and the water on the truck must be made. Efficient receiving facilities at the site are required to avoid delay in transferring concrete from the mixer truck. Certain types of transit-mix vehicles can not discharge directly into large-capacity concrete buckets, except from ramps, unless holes for the buckets are dug at the receiving points. Dimensions of all types of trucks to be used on particular pouring jobs should be ascertained and receiving points determined far enough in advance of the operation so that proper preparations can be made for rapid discharge from the trucks to the receiving bucket. Particular care must be taken, in using concrete from a central mixing plant, to avoid segregation of materials in the batch and to place concrete in the forms before it has attained initial set.

3E3.07 VIBRATION

Using vibratory equipment is particularly advisable when pouring concrete under cold-weather conditions, because it allows the use of drier mixes, which are less subject to freezing. The mix, however, should not be so dry that it can not be handled properly in the equipment and forms. Spare vibratory equipment should be provided for emergency. In cold weather, electric equipment is preferable, although gas equipment is often used and may be advisable for standby service in case of power failure.

3E3.08 TEST CYLINDERS

Field control cylinders, taken during the pour, should be cured under conditions representative of the concrete that has been placed.

3E3.09 FORMS AND REINFORCEMENT

When possible, forms are usually fabricated at the carpenter shop and hauled in trucks to the site for erection. Reinforcing steel is usually shipped to the job in long lengths (40 to 60 ft) and bent on the job. At isolated areas the length of reinforcing bars is usually limited to 40 ft unless they must be transported by plane, in which case they are cut into shorter lengths. Construction of complicated forms and placement of reinforcing steel in extremely cold weather is difficult, and it is often advisable to construct the enclosure, which will protect the concrete, early enough to make possible its use during the construction of the forms. Ample light as well as sufficient heat to maintain a comfortable working temperature should be provided within the enclosure.

Forms, when prefabricated in a warm shop from lumber that has been stored out-of-doors during cold weather, should be returned to cold storage after fabrication. Under such conditions, if lumber is allowed to remain in a warm room, it often dries to less than one percent moisture (par. 4 of 2A9.01). If wood dries after the nails are driven, the nail-holding power is often seriously reduced.

For forms, it is a common practice to use lumber that has been purchased for other purposes in the construction of the building. Boards that will be used for underflooring and roof or wall sheeting may be used for formboards. Studding ordered for partitions is used as form studs, and material ordered for form rangers or walers is often used for studding or for scaffold supports. Form studs seldom have to be of uniform height, and to save waste they should be left at random lengths. It may be necessary to cut an occasional stud if it interferes with pouring operations. Square-edged boards are preferable, when lumber must be salvaged, because forms built of such material can be dismantled with little breakage. The boards seal nicely and a good concrete surface can be secured. Tongue-and-groove sheeting is hard to dismantle without breakage, but such boards are relatively cheap and hold together well if sections must be reused. Narrow boards, 6 to 8 in. wide and ⅞ in. thick, are preferable to wide boards because they have less tendency to warp.

Plywood panels are widely used in urban areas where appearance is an important factor, but their high cost for use in forms is often not warranted in isolated sections. Double-headed nails used in form construction make dismantling possible with a minimum of loss. Reuse of lumber for forms or other purposes is always advisable. In winter concrete operations, however, it is frequently advantageous to construct at one time all of the required forms, even at the sacrifice of some form lumber, so that all concrete can be poured and cured in one operating period.

Form construction, hardware, and reinforcement bending and placing methods are the same as those used in the Temperate Zone. Power equipment for fabricating forms and for cutting and bending reinforcement is usually advisable in all except the smallest jobs. Care should be taken that the electrical characteristics of such equipment are the same as those of the power available.

3E3.10 MASONRY

Foundations constructed of masonry, as well as those built of concrete, do not have wide application in the Cold Regions because of their inability to resist tension and shear. Masonry superstructure and concrete block are widely used because of their good insulating and fire-resistive qualities. Clay bricks are seldom used, because they must be imported at considerable expense; concrete block, brick, and tile ordinarily can be manufactured locally. The usual masonry construction in the Cold Regions consists of 7¾″ x 8″ x 16″ concrete blocks laid up with cement mortar to which hydrated lime, in proportion of 5 to 10 lb per sack of cement, has been added to improve workability. Masonry construction can be accomplished during cold weather within heated enclosures of the type used in protecting concrete. The sand should be completely thawed, and the temperature inside the enclosure should be maintained at a minimum of 50° F for at least 5 days after the masonry has been laid. Exposed mortar joints on the side facing the enclosure wall will be in danger of freezing in extremely cold weather if additional heat in that area is not provided. With an average temperature of 50° F inside the enclosure and an outside temperature of −20° F, mortar in masonry within 2 ft of the enclosure wall may be exposed to temperatures below freezing. When constructing masonry walls within enclosures, masons usually lay up from the inside where more working space is available. Properly pointing all joints on outside walls under these circumstances is difficult. A wide, well-lighted, and well-heated area between the work and the enclosure wall usually results in a better pointing job and reduces the danger of the mortar freezing.

PART F. ICE AIRFIELDS

Section I. ICE CHARACTERISTICS

3F1.01 GENERAL

Airstrips on ice are highly desirable, from the standpoint of military strategy, for increasing the versatility and mobility of aircraft in the Cold Regions. The feasibility of these airstrips has been established by the combined experience of various air operations and scientific investigations that have been conducted in Polar areas within the past thirty years. A landing strip on ice must be so located as to satisfy certain tactical and operational requirements, and the ice must be smooth and have sufficient strength to support the using aircraft.

3F1.02 ICE FORMATIONS

1. TYPES. Three general types of ice offer suitable locations for airstrips:

(1) Salt-water ice
(2) Lake and river ice
(3) Land ice

Each occurs in different areas, has widely different characteristics, and presents different problems. According to its concentration, salt-water ice may be broken down into:

(1) Polar pack ice
(2) Drift ice
(3) Fast ice
(4) Ice foot

2. SUITABILITY FOR LANDING STRIPS.

a. *Polar Pack Ice.* The Arctic pack ice is a floating icecap occupying about 70 percent of the Arctic Ocean. Along the edges of the pack and for 20 to 50 miles inward the ice is more broken and hummocky than in the central regions. Pressures on the pack ice are highest near the shore, and peaks may pile up to 60 or 70 ft above sea level. Far from land these peaks probably do not exceed 40 ft. In the central part of the Polar icecap, years of weathering of old ice, which has not recently been subjected to pressure sufficient to cause hummocks, have rounded the original rough surfaces and flattened the small jagged ridges into areas that are gently rolling or possibly sufficiently smooth to permit, with some leveling, aircraft landings. It has been estimated that areas in the Arctic pack that are suitable as airstrip sites for light- and medium-weight planes compose approximately 5 percent of the pack ice. Surface areas suitable for airstrips for heavy planes represent a much smaller percentage. (Ref. 21.)

In Antarctica, sea ice surrounds the continent. The ice moves around and outward and gathers in a belt formed by the meeting of southwesterly and northwesterly winds in the vicinity of the 60th parallel. In the Antarctic it is unusual for sea ice to be more than one or two years old. The drift in both the Weddell and Ross Seas carries the pack out into the open oceans in a little over a year. (Ref. 97.)

Ice• pools on pack ice are usually relatively young, formed many miles from the margin of the pack, and frequently suitable for landing sites. Such areas usually have maximum stability, and the pools can be readily distinguished from the air.

Pack ice, under the influence of various forces, is constantly being fractured, opening cracks or leads. Such areas of open water may exist even in the vicinity of the North Pole, but new ice in leads of sufficient area to land planes is usually found only south of the 80th parallel. (Ref. 21.)

b. *Drift Ice.* Loose ice floes fringing the Polar pack are called drift ice, which differs from the pack itself only in the degree of compaction. Landings may often be made on floes of drift ice, but it is not suitable for an airstrip because of the probability of drifting into open water, disintegration, or the development of pressure hummocks during storms. (Ref. 21.)

c. *Fast Ice.* Fast or landfast ice is sea ice that is attached to the shore or is otherwise confined so that it does not drift. It may include bay ice or lagoon ice. One edge of the fast ice may be firmly attached to the shore or there may be a crack between it and the so-called ice foot, the fast ice rising and falling with the tide and the ice foot remaining fast to shore. If the fast ice borders on the open sea, the outer or sea edge may terminate on the moving pack ice, and the border may be a rampart of ice heaps. (Ref. 21.)

(1) *Bay and Lagoon Ice.* Bay and lagoon ice and fast ice bordering directly on the sea are generally suitable for airstrip locations. Bay and lagoon ice are usually smooth because of lack of wind and wave movement and because they have no contact with moving pack ice. However, on a wide or only partially sheltered bay or lagoon there may be some motion. Also, river currents may break up young ice, or pack ice may drift in from the open sea. Generally, however, a site can be selected that requires little or no smoothing of the ice.

(2) *Fast Ice Bordering on the Sea.* The seats of fast ice are the broad continental shelves and their spacious embayments. The most striking example is the Siberian Shelf, which has a mean width of 400 miles and a depth of 12 to 50 fathoms (72 to 300 ft), its outer edge falling abruptly to the greater depths of the Arctic Ocean. These regions produce a vast amount of fast ice because the shallow depths favor early chilling, and the salinity of the sea has been lessened by the discharge of numerous large rivers. The Arctic coast of Eurasia, especially the shore of the East Siberian Sea, has more extensive shallow water than is found elsewhere in the Arctic Ocean. Here fast ice attains its greatest width, amounting to 270 miles at its widest place off the mouth of the Yana. It has an average thickness of 6½ ft and at times reaches a maximum thickness of 9 ft. (Ref. 97.)

Another large area of fast ice, second only to that off Siberia, is the sheet covering the labyrinthine waterways of the Canadian Arctic Archipelago. (Ref. 97.)

Landfast ice bordering directly on the open sea is apt to be rougher than bay or lagoon ice because of increased wind action and pressure of the moving pack ice. Most of the fast ice, however, is young, and its roughness is not comparable to that of heavy pack ice and may not pose any considerable problem to an experienced party properly equipped for preparing an airstrip surface. Airstrips should, in general, be located as near to shore as possible. The farther from shore the site is, the greater the danger of breaking up or drifting away. Heavily grounded pressure ridges forming on the seaward edge of landfast ice offer much protection to an airstrip near shore; also, in such a location hangars, quarters, and other structures can be established on the shore where they can be permanent. (Ref. 21.)

d. *Ice Foot.* The ice foot, that part of the fast ice directly attached to the shore, is unaffected by tides. It forms from thin ice frozen fast to the shore and grows from the end of summer through autumn as long as the ice or water along the shoreline is in motion and particularly during rising tides. In areas where tides are great, ice foot may grow to a height of 6 ft or more. It can also form from foam thrown onto the shore and refrozen. At present, portions along the coastline of Greenland are the only known places where foot ice formations are pronounced. Although no record of plane landings on ice foot is available, there is no apparent reason why an ice foot can not be used as a landing area, and such a strip would have the advantage of increased bearing power because the ice rests on the bottom. The surface of an ice foot is generally rough, and preliminary smoothing would be necessary; also, landings in most cases would have to be made parallel to the shore, which would be a distinct disadvantage where prevailing winds were at right angles to the shore. (Ref. 21.)

e. *Lake and River Ice.* Lakes provide innumerable landing surfaces for planes. They generally freeze with a smooth surface except for ridges and depressions caused by pressures resulting from expansion. Also, open cracks may be formed from contraction resulting from very cold weather, particularly on large lakes where separation of the ice sheet may occur and where refreezing may be delayed by a snow cover. Drifting snow on airstrips on lake ice often causes a difficult maintenance problem.

Rivers have been used extensively as landing surfaces, but generally are not as suitable as lakes. The current often breaks up the first ice of the season, creating a rough surface and later eating away ice and creating a generally treacherous condition, which will not be apparent if the ice is covered with snow. Also, rivers break up much more rapidly than lakes because of the mechanical effects of currents, changes in water level, and rapid changes in the water temperature.

f. *Land Ice.* Greenland and Antarctica have the greatest concentrations of mountain glaciers and icecaps, which vary in thickness from a few hundred to several thousand feet. Mountain glaciers generally have rough surfaces with numerous crevasses, especially at lower altitudes. Comparatively smooth stretches suitable for landing strips may exist on the larger slow-moving glaciers near their source and in the valley areas (Ref. 21). Icecaps offer many suitable sites for permanent landing strips, particularly in far inland areas where the high winds experienced on the marginal areas seldom occur. Emergency sites may be located within the marginal area of icecaps, but such areas generally present more difficulties from both an operational and maintenance standpoint than do interior sites.

g. *Ice Islands.* Ice islands originate from land ice such as glaciers and shelf ice and can at present be divided into two groups: (a) those that have found their way into the channels of the Canadian Arctic Archipelago and (b) those that are drifting in the Arctic Ocean. Ice islands can readily be distinguished from pack ice by their homogeneous surfaces and regular surface patterns. Surfaces are ridged or rolling, with wide troughs. They have a striking ability to keep their shapes over a period of years, which indicates great thickness and hardness. Quite a large number of ice islands are known to exist, the smaller ones varying in size from ¼ to 7 or 8 miles across, although many fragments are much smaller. Three large ice islands, the largest having an area of some 300 square miles, that are drifting in the Arctic Ocean have been of particular interest recently. They are quite smooth, and pilots who have made low-level flights over them are almost unanimous in stating that landings can be safely made on all of them. Landings have been made on at least one of the three. Ice islands move and it is well known that they move with ocean currents rather than with wind, which moves pack ice. Because they are so easily seen and recognized, their movement would presumably be of valuable assistance in determining the direction and rate of subsurface currents. (Ref. 98.)

Section 2. SITE SELECTION

3F2.01 AERIAL OBSERVATIONS (Ref. 21)

1. AIRCRAFT TYPES. Aircraft with relatively low flying speeds, such as the C-47 or Norseman, are the types best suited for reconnaissance because the ice surface can be carefully scrutinized. Skis are preferable to wheels for safety. Fully retractable aluminum skis are highly valuable because they provide greater safety and reduce the drag. The helicopter would be ideal if sufficient range could be developed, for it can make a close, deliberate inspection of possible airstrip sites.

2. TERRAIN IDENTIFICATION. In selecting a site for an airfield, reconnaissance of the ice surface is usually made from the air. Relatively light planes are ordinarily used, and it is essential that only experienced pilots be assigned. A reconnaissance pilot should have experience in making landings on ice, as well as a theoretical and practical knowledge of the various kinds of Polar ice. He must have experience in traveling over ice and snow and judging them from the ground; it is extremely difficult for an inexperienced pilot to interpret ice and snow patterns from the air. Variations in elevation on a white surface are most readily discerned if the sky is clear and the sun is low enough to cast shadows. A full moon throws even more effective shadows. If possible, therefore, the selection should be made at these times. Sites on pack ice are more difficult to select than others because relatively smooth areas 2 or 3 miles in diameter and reasonably free from hummocks, depressions, and pressure ridges are often not readily located. Also, initial landings may be on rough ice.

An experienced observer can judge fairly accurately the thickness and character of sea ice by its color and general appearance. When thick ice has been freshly broken, it resembles masses of rock in a quarry just after a blast, or if it is thin it resembles broken bottle glass on top of a stone wall. During thaw periods the sharp outlines of broken ice are softened. At the end of the first summer they appear about as jagged as a typical mountain range, but at the end of two or three years the ice resembles the rolling hills of a western prairie.

Black ice, which may appear blue or green under certain light conditions and angles, is unsafe and so are the various shades of gray, the ice being safer the lighter the gray. If it is desired to land a plane on a lead, even a grayish lead may be strong enough if there has been no snow since the pressure broke the ice and produced the lead. This rule applies only to light planes because the thickness required for heavy planes will take longer to develop.

Differences in the coloring of ice floes indicate hardness or strength. In both summer and winter, sea ice that possesses average normal properties is distinctly light green. When a light-gray-blue floe is encountered in such ice, it definitely indicates desalted, and therefore stronger, ice. So-called dirty ice may be of varying strength. As a general rule, the many-years-old ice is hardier and dirtier and is brown; younger ice is more pinkish. Ice that is at the same time very dirty and very crumbly, caused by thawing lumps of crushed ice being frozen over, can easily be distinguished from older ice.

The foregoing paragraphs are for winter observations. The coloring of icefields in summer is exactly contrary to coloring prevailing in winter. Pools on sea ice are a characteristic feature, principally because of color, from which a good measure of the ice thicknesses beneath may be obtained. For young ice the color of the pools varies from steel-gray blue for sheets some 6 ft thick to gray green for 3 to 4 ft to brownish green for thinner stuff. For old, thick ice the pools are clear blue. For thin, soft ice the pools vary from gray green to brownish yellow and seem to give a distinct impression of rotting, as differentiated from melting.

Stability and drift of an area in the pack ice may be determined by spreading lampblack or other suitable material in a continuous strip on the ice and returning at regular intervals to observe whether the strip is in one piece or whether parts of it have shifted or been broken up. Snowfalls between observations make it necessary to re-mark the strip.

3F2.02 USABILITY OF ICE

It is, of course, of paramount importance to know the earliest date on which ice may be utilized for an airstrip and the useful period of operations. Many ice maps, charts, tables, and isopleths give seemingly definite dates of ice formation within the Polar Regions but should be used only as a general guide. Icing conditions vary so widely from year to year, and even within a season, that definite information can be obtained only at the proposed site.

Section 3. UTILIZATION OF ICE STRUCTURES

3F3.01 GENERAL

Constructing an airstrip on smooth, level ice usually requires only a small bulldozer to clear obstructions. On pack ice or on landfast ice much more equipment is required because the ice is generally rough. Hummocks must be removed with light equipment carried in the first planes so that cargo planes can land with major construction equipment. Depressions and holes are filled by pumping water into them and allowing it to freeze or by filling with well-compacted snow. Construction of an airfield on an icecap requires a minimum of equipment because, as with lakes or bays, the main problem is to compact the snow sufficiently to enable wheeled planes or heavy skiplanes to land. The initial landing on an icecap may be hazardous because the loose, soft snow may make an underlying hard-drifted rough surface difficult to detect from the air. (Ref. 21.)

3F3.02 SNOW COVER TREATMENT AND DRIFT CONTROL

Drifting snow may cause wheeled planes to ground-loop. As mentioned previously, skiplanes are more practical than wheeled planes for landing on snow. Gliders are effective because of their low landing speed. The only power equipment normally needed to clear drifts is a bulldozer. Snow cover treatment, however, is often a major problem and thorough investigation is usually required before definite procedures can be outlined. (See Chapter 3, Part D.) Compacted snow on ice retards thawing of the ice in the spring and lessens trouble from slush and standing water. Also, ice formed by compression of successive layers of compacted snow does not candle. On lake, river, or bay ice it is best to compact the snow as hard as possible. On sea ice the snow can either be compacted or removed completely. On land ice, snow may be quite deep and the only solution usually is to compact the snow as hard as possible.

3F3.03 HANGARS AND STRUCTURES (Ref. 21)

On lake, river, bay, or lagoon ice, hangars and other structures are usually located on shore. Construction of such facilities on icecaps or floating ice is difficult. Housing for personnel would probably consist of double-walled tents or light, fully insulated prefabricated huts that could also be developed as repair shops. Specially rigged gliders could be used for quarters or repair shops and could be easily moved if it were necessary to change the location of the airfield. Hangars are a special problem on land ice or floating ice, and no really good workable model has been developed. Some type of light, portable, heated nose hangar is necessary so that mechanics can work on a plane without using gloves.

It is absolutely necessary that all heated structures on ice have adequate insulation under the floor to prevent them from thawing the ice and then freezing to it. A structure frozen into the ice would not be portable if it were necessary to make a quick change in location. Also, it is preferable to have structures move as a unit so that they will not be torn apart in case the ice cracks or shifts under them.

Because ice bends gradually under a static load, it may be necessary to provide wood or metal platforms in the parking areas in order to distribute the load to better advantage.

Wheels and skis may freeze to the snow or ice; therefore, planes should be taxied up on a rest or cradle that will prevent them from freezing in. Some sort of anchor is, of course, necessary to tie down the planes on ice airstrips.

3F3.04 MAINTENANCE OF AIRSTRIPS ON ICE

All that is usually required to maintain an airstrip on ice is to drag or roll the snow cover continually. If drifts form, they should be spread out by a scraper or bulldozer or removed. Cracking of the ice often makes it difficult to maintain an airstrip, particularly when cracks go entirely through from top to bottom. Sections of ice adjacent to such cracks should not be used until the cracks freeze over, because their bearing power is greatly reduced. Sites should, if possible, be selected where an alternate airstrip can be prepared in case large cracks appear on the main runway.

3F3.05 MEASURING ICE THICKNESS

The thickness of floating ice should be carefully measured at regular intervals. Frequent measurements are particularly important near the beginning and end of the usable seasons. Various devices have been used for this purpose. One type is illustrated in Figure 3F3-1. Currently, efforts are being made to develop a measuring device that will not require drilling a hole in the ice. An electronic ice gage has been tested recently on various types of ice. Its principle is the transmission of an ultrasonic wave downward into the ice to be reflected from the bottom surface and detected on its return to the top surface. Measurement of ice thickness is obtained from the elapsed time for the passage of the ultrasonic wave through the ice layer. Conclusions drawn from the tests indicate that the device, as presently designed, is not a satisfactory device for ice measurement but that additional study of the problem, using ultrasonic techniques, is desirable. (Ref. 99.)

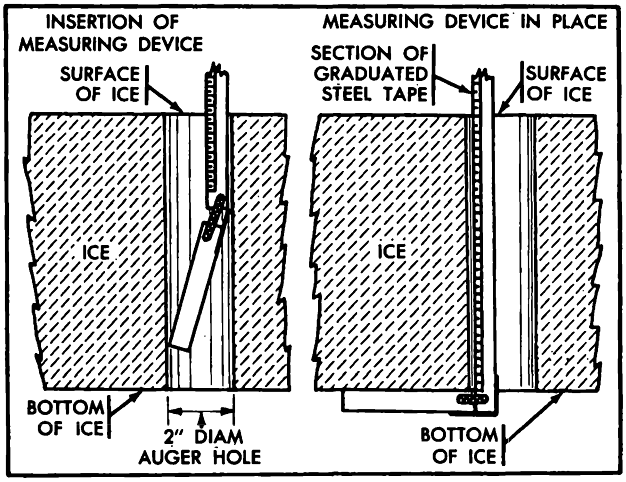


FIGURE 3F3-1

Device To Measure Ice Thickness (Ref. 21)

CHAPTER 4. OPERATION

PART A. CONSTRUCTION EQUIPMENT

Section I. LOW-TEMPERATURE PERFORMANCE

4A1.01 MILITARY REQUIREMENTS

1. OPERATION. The Armed Services have adopted −65° F as the lower temperature limit at which equipment must be capable of continuous satisfactory functioning to be acceptable for military use. In addition, the Bureau of Yards and Docks in its interim standard specifies that the equipment must function under conditions of a 10-knot wind and no solar radiation. (See Ref. 100.) Low-temperature fuel, lubricants, antifreezes, hydraulic fluids, and the like may be used. Military and commercial design refinement and development have advanced so that it is entirely feasible for transportation and construction equipment to meet the military requirement.

2. STARTING. The Armed Services have also prescribed that powered equipment be capable of internal combustion engine starting at −25° F ambient temperature without engine preheating. The Bureau of Yards and Docks interim standard (Ref. 100) further states that this performance must be met under conditions of a 40-knot wind and no solar radiation. Fuel primers, ether-type priming fuel, and low-temperature batteries are permissible as permanent aids to meet the requirement. Engine preheating may be used, in addition to the above aids, to facilitate engine starting at ambient temperatures below −25° F.

3. STORAGE. Military requirements for storage are that equipment must satisfactorily withstand, without damage, storage at an ambient temperature of −80° F for three days of continuous exposure. The Bureau of Yards and Docks interim standard (Ref. 100) has added that this requirement be met with no wind and no solar radiation.

4. EXCEPTIONS. It is realized, of course, that because of increased cost and limited use of the equipment, it is impracticable to meet the military requirements for all equipment. The Armed Services, therefore, permit exceptions when it is apparent that the requirements result in an impracticable end item based on current engineering development. Equipment that normally requires shelter does not actually function under the extreme temperature and wind conditions required of exposed equipment. In many instances, therefore, the military requirements may not need to be met for stationary units, such as powerplants, shop equipment, water treatment units, and the like.

4A1.02 PERFORMANCE EFFICIENCY

1. FIELD OPERATING CONDITIONS. The performance of most equipment is adversely affected by subzero temperatures; loose, fine, blowing snow; ice; frozen terrain during winter; and mud of the thawed, undrained, active layer of permafrost during summer in the higher latitudes. The coefficient of friction of snow and ice increases with a decrease in temperature. For instance, the coefficient of friction for snow is approximately one-sixth higher at −60° F than at 20° F. Moderate-temperature months, such as April, therefore, are periods when tractor-sled trains can haul maximum loads most economically. The performance of equipment under these conditions should be considered when estimating required logistics and workloads.

2. MECHANICAL PERFORMANCE. Contraction of machine parts and sluggishness of lubricants at low temperatures produce a high internal frictional drag in equipment. With smaller clearances, there is a tendency for parts to seize. Low temperatures, even when low-temperature lubricants are used (par. 2 of 4A3.03), cause a somewhat slower initial circulation and penetration of

lubricants until friction raises the temperature of machine parts. Thus, a slightly decreased overall mechanical efficiency of equipment and stiffness of controls and actuating mechanisms may be expected at subzero temperatures.

Track and drive-wheel slippage of prime movers operating on snow, ice, and mud is inevitable. The reduced tractive efficiency is reflected by high fuel consumption or waste of fuel.

3. ENGINE PERFORMANCE. Engine fuel combustion efficiency depends on atmospheric conditions within cylinders, fuel/air mixtures, and heat available for combustion. Even during short intervals of engine inoperation at low ambient temperatures, air in cylinders chills sufficiently to condense moisture, producing conditions nonconducive to combustion. Diesel engines are particularly difficult to start in extreme cold because fuel combustion depends entirely on the heat of compression. For spark-ignition engines, the fuel/air mixture entering cylinder combustion chambers is sometimes chilled to the icing point because it expands when flowing through carburetor Venturi. Frequently, icing of fuel occurs in fuel lines exposed to the weather, which hampers proper fuel flow to carburetors or fuel injection pumps. Wax in paraffin-base diesel fuel congeals when cold, clogging fuel lines and transfer and injection pumps.

Subzero, snow-laden air sucked through oil-bath air cleaners tends to increase the viscosity of oil droplets adhering to the filter element. This restricts airflow so that a higher intake manifold vacuum must be produced by the engine. In diesel engines, excess air is always present for efficient fuel combustion. In spark-ignition engines, however, the air restriction may cause too lean a fuel/air mixture for efficient combustion. In such cases, carburetors must be readjusted and air cleaners operated dry or with a lightweight engine oil.

On cold starting, internal engine friction is high and fuel combustion inefficient. This necessitates using more than the average of unburned fuel, longer engine starting time, and more frequent idling, contributing to a higher fuel consumption even though engine performance is satisfactory at normal operating temperature.

4. STORAGE BATTERY PERFORMANCE. The electrolytic strength or specific gravity of standard storage (wet-cell) batteries decreases with temperature. Battery current, therefore, delivered at subzero temperatures is appreciably less for a given charge than the battery rating. For instance, battery current (fully charged) at 15° F is one-half and at −30° F about one-tenth the rated current output at 80° F. At −40° F the current requirement to start cold engines reaches a peak.

The capability of a battery to absorb a charge is also adversely affected by a decrease in temperature. Below 35° F, standard storage batteries will not receive an adequate charge from generators.

The diminishing electrolytic specific gravity increases the possibility of electrolyte freezing. Table 4A1-1 gives electrolyte freezing temperatures at various specific gravities corrected to 80° F. (Correction factor is 4 points or 0.004 added to specific gravity for every 10 degrees of electrolytic temperature above 80° F, and 4 points or 0.004 subtracted from the specific gravity for every 10 degrees of electrolytic temperature below 80° F.) The table shows that a fully charged battery will not freeze at extremely low temperature, but a discharged battery (specific gravity 1.130) will freeze at 10° F. It is mandatory, therefore, that the specific gravity of batteries be maintained at 1.275 or better (corrected to 80° F) at all times to avoid ruptured battery cases caused by freezing of electrolyte.

Special low-temperature automotive-type storage batteries have been developed in recent years with improved low-temperature performance characteristics.

4A1.03 EQUIPMENT DURABILITY

1. SERVICE CONDITIONS. The severity of climate and terrain of the high latitudes naturally impose above-average wear and tear on equipment. An understanding of the type and cause of failure of parts is therefore helpful in planning logistics

TABLE 4A1-1

Relationship Between Temperature and Battery Freezing

State of charge	Specific gravity of electrolyte (temperature corrected)	Freezing temperature, °F
Fully charged	1.275 to 1.300	-85 to -95
75 percent	1.250	-62
50 percent	1.220	-31
25 percent	1.160	1
Discharged	1.130	10
Fully discharged	1.000 (water)	32

and stocking adequate high-mortality spare parts in the field. Otherwise, because of general isolation and inaccessibility and because of deadlining equipment for lack of spare parts, operations in these forward areas may well fail.

2. METALLIC MACHINE PARTS. Not too much investigation has been made on the physical properties of engineering materials at subzero temperatures. In many cases, field observations seem to indicate that the metals undergo a pronounced transition of internal structure at approximately $-25°$ F. The result is an increase in brittleness so that there is less ductility or resistance to the sudden shock loads prevalent in subzero environments. Consequently, a higher-than-normal rate of brittleness in structural machine parts, shafts, gears, cables, chains, tow hooks, tools, drilling bits, cutting edges of blades, and ripper and shovel dipper teeth is to be anticipated.

The rate of failure can be held to a minimum by selecting whenever possible equipment that has critical parts built of low-carbon steels, with alloys giving the necessary hardness, instead of plain carbon steels. Also, wire cables with Manila rope cores have superior flexibility to withstand flexing at low temperatures.

Normal service is obtained from aluminum and copper alloy parts because low temperatures do not adversely affect their strength properties.

3. NONMETALLIC MACHINE PARTS. Breakage of nonmetallic parts made of natural and synthetic rubber, plastics, glass, and leather (such as hoses, tires, distributor housing, windshield, and drive belts) may be frequent for standard grades. Special grades now commercially available, however, have reduced their low-temperature failure considerably. Rubber parts, such as boots, guards, electric cables, and hydraulic hoses, become hard and brittle at reduced temperatures so that they break easily when flexed or struck. This is especially true for parts made from synthetic rubber materials like neoprene. Tire walls stiffen and check extensively. The stiffness increases tread wear because of a line ground contact during use and flat spots during nonuse. Synthetic rubber does not give as good mileage as natural rubber in tires and tubes. Condensed moisture freezing in tire valves requires a higher-than-normal replacement of valves.

Tarpaulins, tents, and other canvas parts may break if folded or unfolded without care at subzero temperatures. Plastic and leather parts and glass also withstand very little impact, bending, or abusive handling when cold. Leather lubricant seals may leak if frozen or cracked from cold. Wood parts subjected to shock or bending loads break readily.

4. ENGINE FAILURES. Even though engines may be winterized and serviced with low-temperature engine oil, the difficulty of rapidly heating and maintaining them at normal operating temperature throughout and excessive idling tend to cause crankcase sludge formation and gumming of valve stems. Sludge may not cause immediate failures but certainly will adversely affect the mechanical condition of the engine and shorten its life. Valve failures may be greater than average because of heavy carbon deposit from poor combustion, sticking valve stems from gumming lubricant, and burning of valve face or seal as the result of hot spots caused by poor cooling or semifrozen or sluggish coolant circulation. Insufficient penetration of lubricant to clutch pilot bearings during initial cold starting causes many of these bearings to burn out. The frequent clutching and stiffness of clutches are reflected in abnormal clutch-facing wear. Woven-type clutch facings seem to give better wear and, therefore, are preferred.

Low-temperature difficulties that may be encountered with the electrical systems of engines are:

(1) Oxidation of distributor breaker points, forming a high resistance between contacting surfaces and thereby restricting adequate flow of current.

(2) Freezing of breaker contact arm bushing on its pivot, causing failure of breaker arm to function properly.

(3) Unsatisfactory automatic spark advance unless spark advance is clean and properly oiled.

(4) Ice on spark plugs, which deteriorates electrical insulation so that insufficient spark is available for starting engine.

(5) Failure of drive mechanism of starting motors. Sluggish lubrication causes improper meshing of gears and excessive drag on the armature and binding of solenoid plungers. Postwar introduction of 12- and 24-volt electrical systems on military vehicles and many industrial and construction types of equipment has provided starting motors with more torque to crank stiff engines.

5. SNOW-CAUSED FAILURES. Equipment operated on snow-covered terrain shows an above-average life for structural and running gear parts because of the cushioning effect that snow gives to rough terrain and to sudden starts and stops. Failure, therefore, of spring and structural parts, driving mechanism shafts, gears, tracks, and so on is low. The absence of the abrasive action of fine dust also lengthens their life. However, unless packing of snow between track links is prevented, excessive track chain tension develops and breaks track links and track tension members.

Blowing snow finds its way underneath enclosures such as engine compartments and control boxes. When it accumulates around the engine, snow enters the air filters, thereby restricting the intake airflow, also causing short circuits of electrical systems. Melted snow refreezes and sometimes cracks the insulation on ignition harnesses. Melted snow and condensed air frequently freeze around spark plug insulations so that starting the engine is difficult. Blowing snow also accumulates and hardens in the joints of exposed mechanisms, such as brakes, steering gears, winches, cable and hydraulic attachments, power controls, and so on, binding working parts so that the mechanisms require thawing before becoming operable.

6. TERRAIN-CAUSED FAILURES. Frozen soil causes excessive vibrations within mobile equipment traveling over it. These shaking forces and the additional high-frequency vibrations of tracked equipment quickly loosen bolted and poorly welded sheet metal parts. Therefore, lightweight and poorly mounted accessories, cabs, lights, and so on are to be avoided, or sufficient spares should be provided. Because of the low-temperature brittleness of metal, breakage of suspension springs may result when equipment is severely jolted in moving over frozen ground. Track-shoe wear will be above normal when equipment is operated on frozen soil or in silt of the thawed active layer of permafrost. Track-roller and track-guide wear is usually severe.

4A1.04 ADAPTABILITY OF SPECIFIC TYPES OF EQUIPMENT

Lack of road networks in high latitudes necessitates mostly cross-country use of mobile equipment. Consequently, this equipment must have the stamina and power/payload ratios common to heavy-duty models. High ground clearance is demanded to avoid bogging and frequent miring in snow and thawed active zones of permafrost. Dangerous side-slope slippage can be prevented by selecting equipment that has inherently good stability and by loading payloads properly.

1. TRANSPORTATION. Wheeled equipment is limited almost solely to base use because of the high traction and flotation required to traverse cross-country winter and summer terrain in the Polar Regions. This is usually reflected in equipment allowance lists specifying a higher percentage of track-type than wheeled-type equipment. Class IV and Class V crawler tractors are indispensable for both winter and summer operations because of their heavy weight and good traction. Smaller sizes are less effective but often desirable when extremely low ground pressures are required for crossing river and lake ice. Track-type trailers such as the Athey wagon, which has a payload capacity of 25 tons, give excellent service at moderate speeds (15 mph). Higher speed vibrations shake them apart.

a. *Sleds.* Tractor-drawn sleds have been universally adopted as the best means of transporting personnel and cargo in the Far North. Sled sizes range from ½-ton to 100-ton capacities, with body types ranging from platforms, for general bulk cargo hauling, to enclosed and special bodies such as wanigans for personnel transportation and housing. Running-gear designs commonly employed are the bobsled type, toboggans or come-alongs, and go-devils.

(1) *Bobsleds.* Bobsleds (Figure 4A1-1) consist essentially of two sets of runners joined by cross chains, which make the rear runners track with those in the front. Each set of runners is connected by a low stationary bolster; an upper movable bolster pivots on the stationary bolster about a kingpin. In this manner, runners can swing without interfering with the payload. They are attached to the tractor by a tongue. Bobsleds are extremely rugged and have good stability.

(2) *Toboggans.* Toboggans or come-alongs (Figure 4A1-2) are flat-bottomed sleds. They are fabricated of wood or steel and are useful for hauling bulk loads, such as fuel and oil drums.

(3) *Go-Devils.* Go-devils (Figure 4A1-3) consist mainly of a single pair of runners carrying a low platform. Because their center of gravity is extremely low, payload capacity is limited by bulk rather than by weight. They are, therefore,

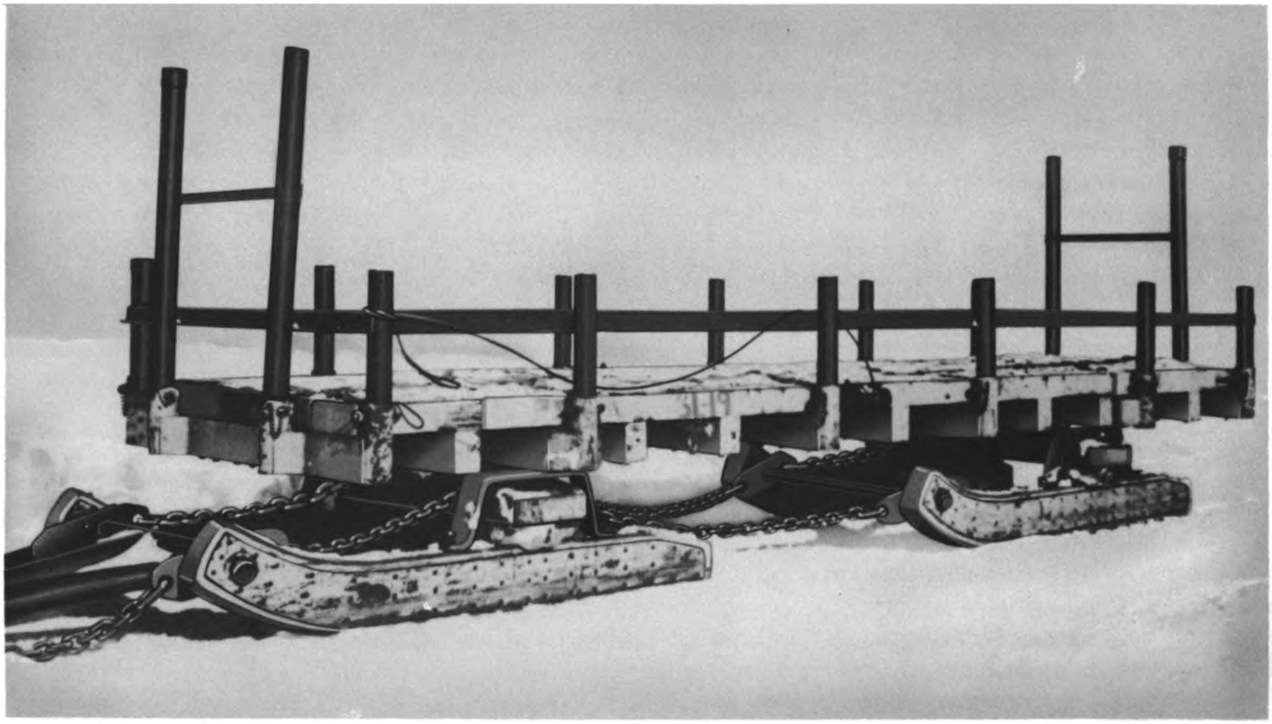


FIGURE 4A1-1
Bobsled, 20-Ton Payload Capacity

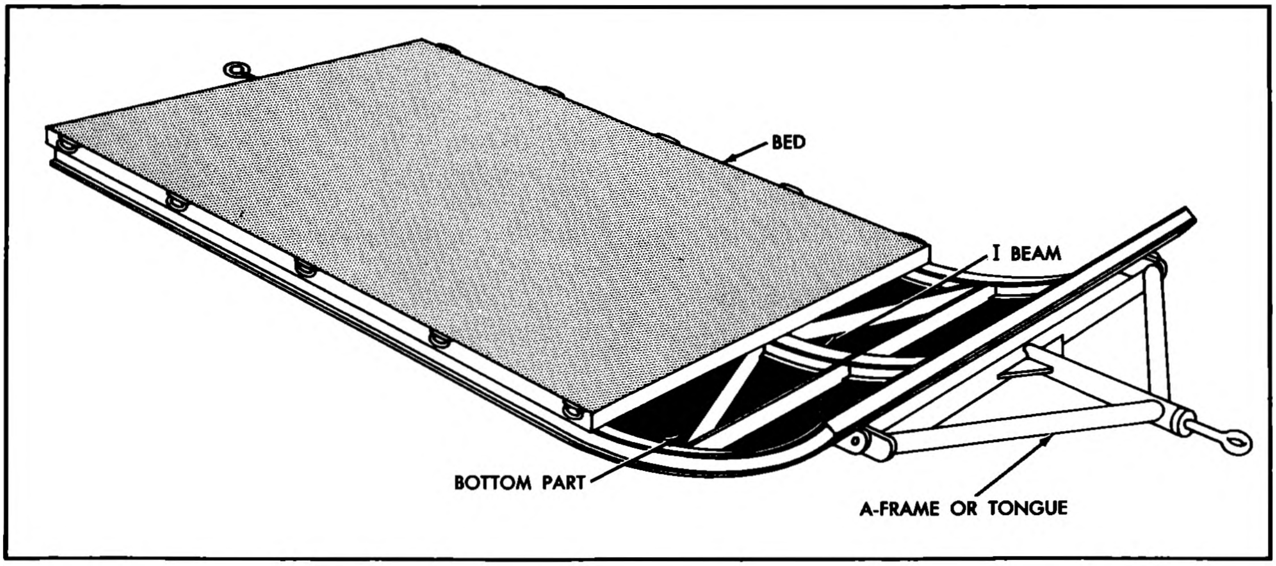


FIGURE 4A1-2
Tractor Toboggan

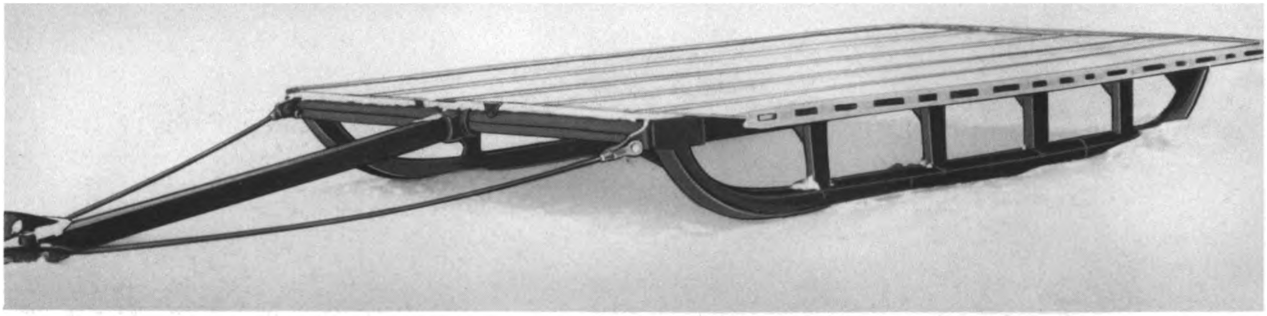


FIGURE 4A1-3

Go-Devil Sled

well adapted to the transportation of concentrated loads, such as draglines, cranes, shovels, engine-generator sets, and other heavy equipment difficult to load on other types of sleds. Go-devils are ordinarily built on the job by blacksmiths and carpenters in 50 to 150 man-hours.

b. *Special Carriers.* Special personnel and cargo carriers have been developed to meet the military requirements of Arctic environments. These include the US Army M29C and T46E1, US Navy landing vehicles tracked (LVT), and the commercial 4-track snow-cat.

(1) *M29C.* The M29C (Figure 3B2-1) has a limited life of about 1,000 hours. However, its comparatively low cost, maneuverability, and excellent flotation and traction give it a high degree of usability in northern climates as a reconnaissance vehicle, personnel carrier, cargo carrier, and prime mover for towing. It has seating space for 3 passengers and driver, plus their luggage. With seats removed, it is capable of carrying 1,200 lb of cargo. As a prime mover, it can tow a 1,200-lb load, such as a sled, plus a 500-lb payload of its own. Being amphibious, it is usable over varied terrain during all seasons.

(2) *T46E1.* The T46E1 (Figure 4A1-4) is a full-track amphibious vehicle especially designed for Arctic terrain. It has a personnel or cargo payload capacity of 3,000 lb. Loading may be either by rear door or by hatch.

(3) *LVT.* The LVT is also a full-track amphibious vehicle capable of year-around use in the Polar Regions, provided it is properly winterized. It transports personnel and cargo. The LVT-3C (Figures 4A1-5 and 4A1-6) has a maximum payload capacity of 5,000 lb, with a ground pressure of 11.5 psi. A later model, the LVT-5 (Figure 4A1-7), has an increased payload capacity of 9,000 lb, with a unit ground pressure of 8 psi. Both models may be loaded through a ramp or hatch.

(4) *Snow-Cat.* A commercial type of 4-track-drive automotive vehicle called the snow-cat (Figure 4A1-8) has a personnel or cargo payload capacity of 3,000 lb. The track/pontoon principle gives good over-snow flotation and traction characteristics applicable to both transportation and construction prime movers.

2. CONSTRUCTION. Single-tooth rooters drawn by 3 Class IV crawler tractors have been found the most efficient equipment for breaking up the concrete-like hard permafrost. Shovel and dragline dipper teeth, as well as the cutting edges of tractor dozer and grader blades, quickly wear and break in permafrost. Tractor-drawn graders are of little if any use in the Polar Regions, but heavy-duty motor graders can be used extensively. Tractor dozers are useful and almost mandatory because of the variety of tasks they can accomplish. Although both cable- and hydraulic-actuated dozers can be used successfully, hydraulic dozers have the advantage of the positive downward pressure almost always necessary for blade penetration into frozen soil. Further, hydraulic dozers are not subject to destructive vibration, snow-clogged sheaves, and the cable breakage common to cable dozers.

Tractor-drawn scrapers can be satisfactorily employed for earthfill work and snow hauling if the distances are not too great. The limited traction and flotation of motorized scrapers preclude much use for them in snow and in thawed permafrost, where they quickly mire. Scraper failures, besides cutting edges, involve cables that become

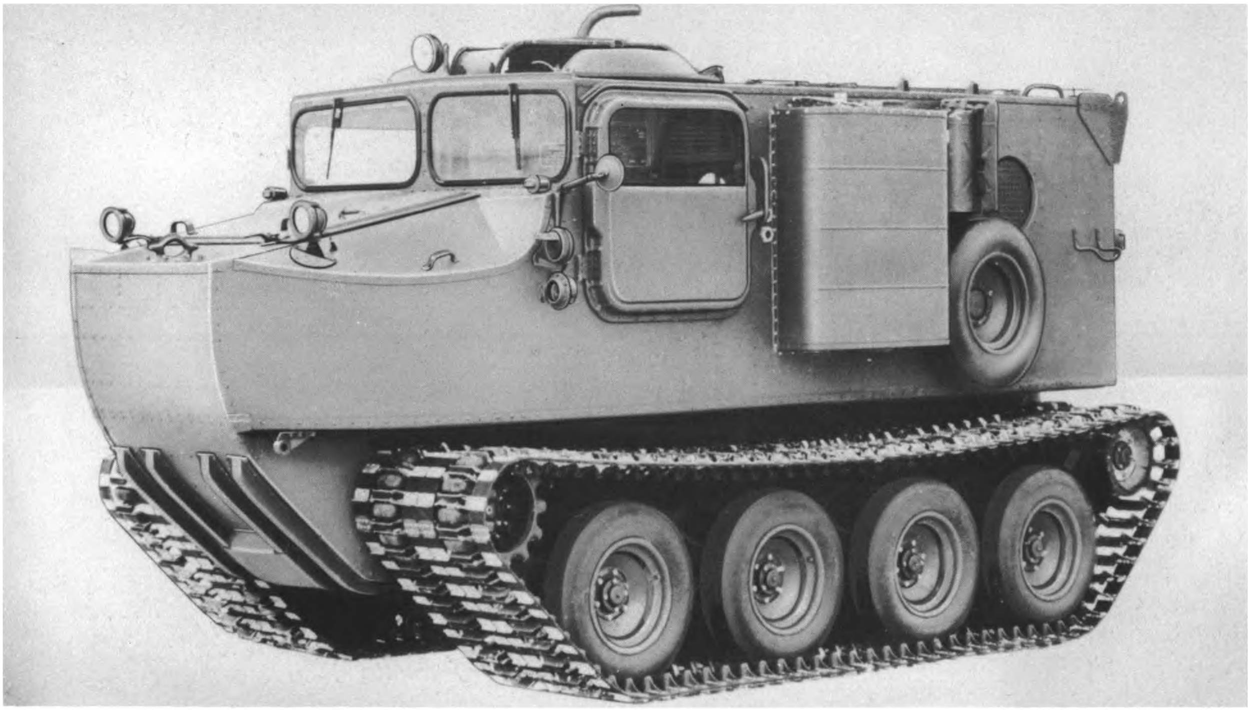


FIGURE 4A1-4

T46E1 Cargo Carrier, Amphibious, 1½-Ton Payload Capacity

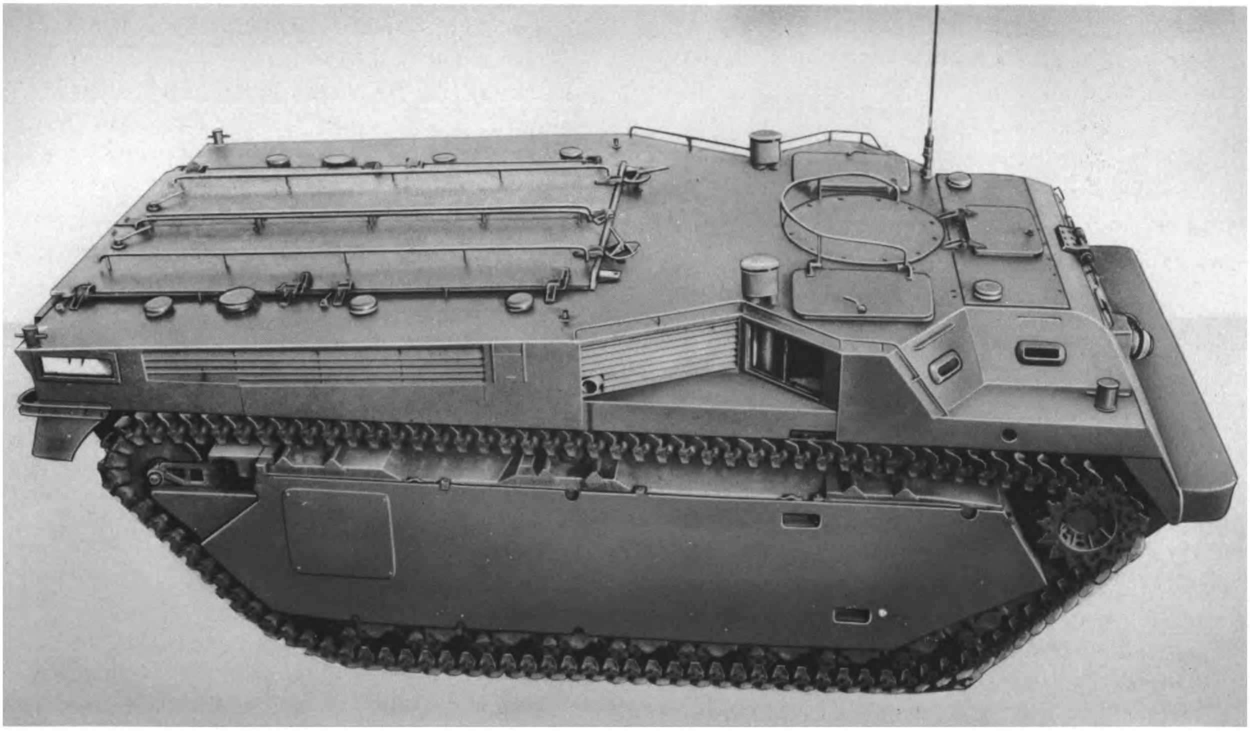


FIGURE 4A1-5

Landing Vehicle Tracked, LVT-3(C), 2½-Ton Payload Capacity, Side View, Loading Hatches and Ramp Closed

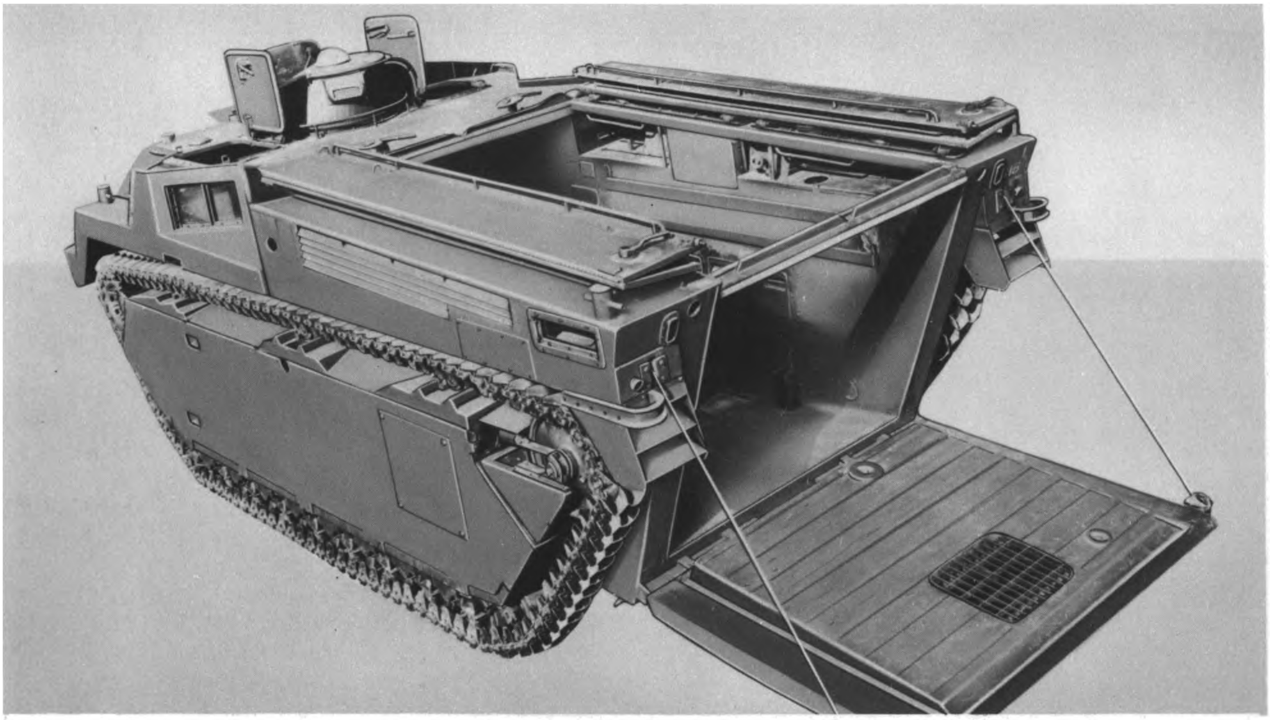


FIGURE 4A1-6

Landing Vehicle Tracked, LVT-3(C), 2½-Ton Payload Capacity, Rear View, Loading Hatches and Ramp Open

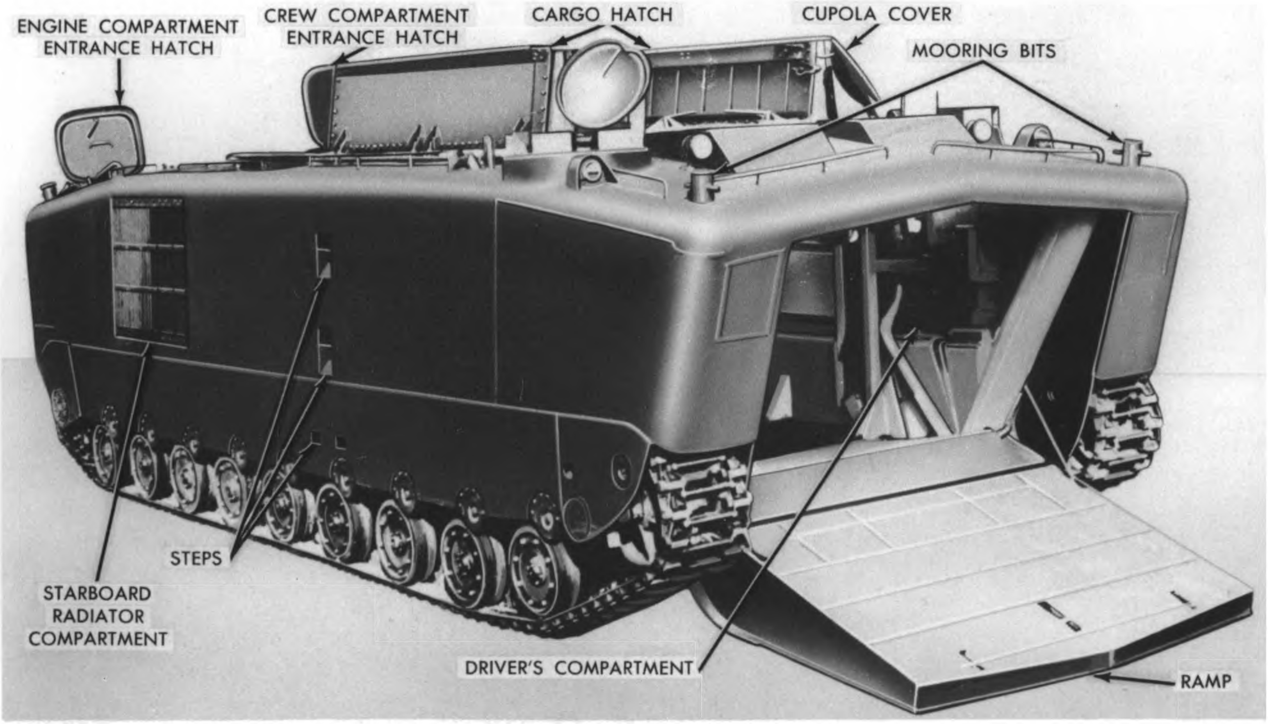


FIGURE 4A1-7

Personnel Carrier, LVT-5, 4½-Ton Payload Capacity

FIGURE 4A1-8

Commercial Cargo and Personnel Carrier (Snow-Cat), 4-Track-Drive, 1½-Ton Payload Capacity

FIGURE 4A1-9

Wheel-Type Bucket Snow Loader

brittle when cold, and body cracking because of apparent cold-temperature fatigue. Severe scuffing and wear of tires is also prevalent because of the rough and frozen terrain. For rock, quarry, or permafrost excavation, 4 x 4 and 6 x 6 military or 4 x 2 conventional heavy-duty dump trucks, such as Euclids, are useful for hauling when roadways can be maintained.

Power shovels, draglines, and cranes should be mostly crawler type because of the cross-country movement difficulties that may be encountered with truck-mounted types. Crawler types are transportable by tractor sleds if it is necessary to move them from one location to another. Around camp, where roadways exist, truck-mounted equipment has the advantage of quicker movement.

3. MATERIALS HANDLING. Crawler-mounted forklifts, mobile boom cranes (cherry pickers), and material loaders are extremely efficient on snow, ice, and tundra. Wheeled equipment is generally confined to storage areas, piers, or loading areas. Several wheel-type loaders, both bucket (Figure 4A1-9) and conveyor (Figure 4A1-10), commercially available, are practical for snow and gravel handling under Arctic conditions.

4. POWER TOOLS. Pneumatic equipment can be used under the environmental conditions of the Arctic and Subarctic. Condensation of moisture in air lines and fittings, however, is apt to freeze and cause trouble. Electrically operated power tools may overcome this difficulty.

5. NAVIGATION AND SURVEYING INSTRUMENTS. Navigation and surveying instruments include altimeters, tactometers, theodolites, sextants, and transits. Fairly satisfactory operation has been obtained by using dry graphitic lubricants and weather-protecting shields. None of these instruments has yet been adapted, however, to overcome the low horizontal component of the earth's magnetic field in the Arctic, nor to withstand rough use when mounted on cross-country vehicles. Perhaps the best compass so far for Arctic use is the Sperry Gyrosyn, next the magnesium type, and then the needle type.

6. DIESEL ENGINES. There are two advantages of diesel-powered equipment in Polar operations: (a) less volumetric fuel consumption than gasoline engines and (b) absence of ignition harness failures. The first eases logistics and the second cuts down deadlining.

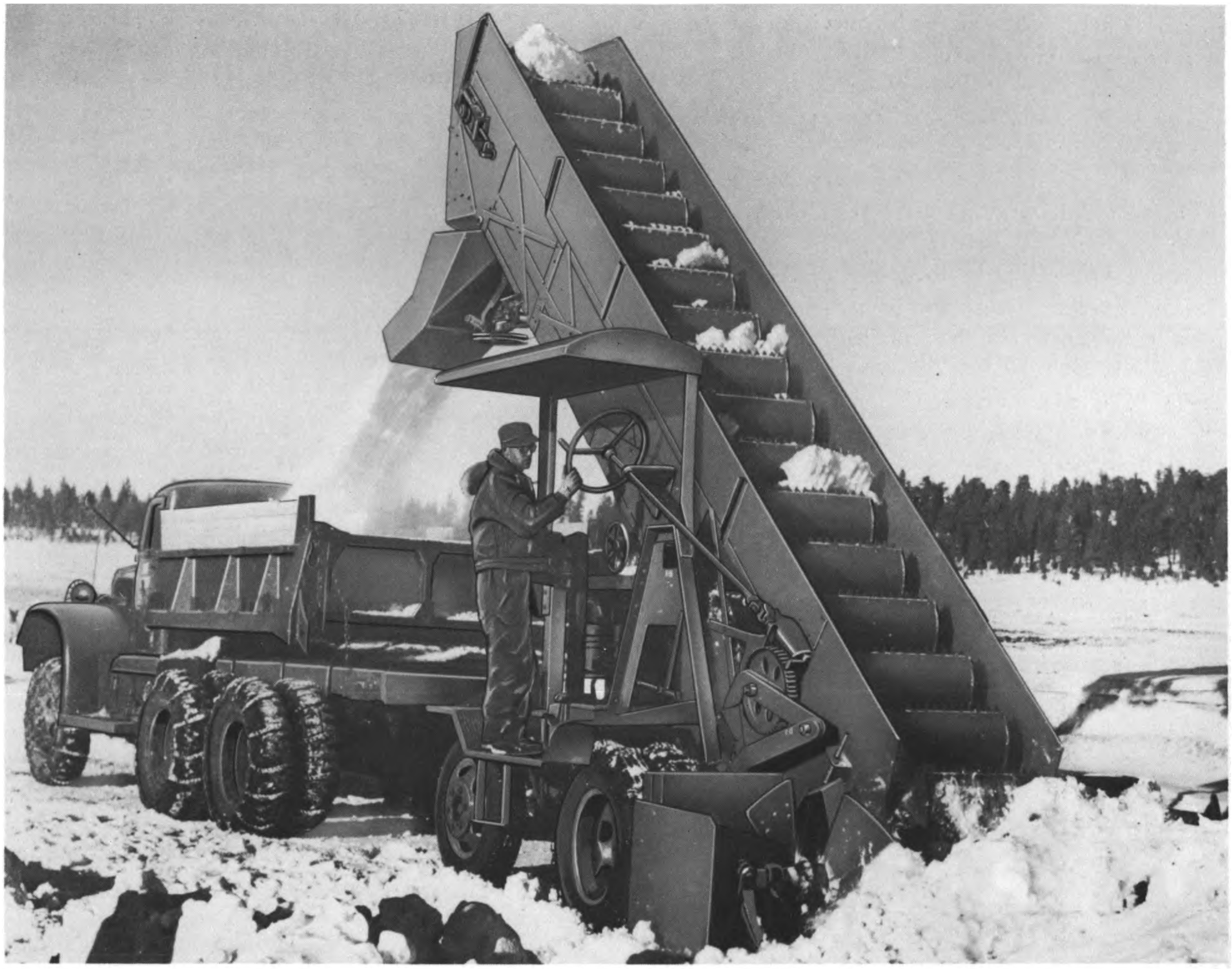


FIGURE 4A1-10

Wheel-Type Conveyor Snow Loader

Section 2. EQUIPMENT WINTERIZATION

4A2.01 INTRODUCTION

1. ADAPTATION OF WINTERIZATION. The basic functional differences between automotive, construction, and utility equipment, plus variations in size and individual manufacturer's design within each of these groups, preclude much standardization of equipment winterization. It is therefore usually specified only in terms of type of winterization and low-temperature performance requirements. From such specifications, actual winterization is mostly tailored to each specific item.

2. LOCALE OF WINTERIZATION. Equipment to be winterized at the factory in accordance with specifications presents no difficult problem. Standard equipment drawn from stock, however, frequently must be winterized at depots or other field installations not acquainted with winterization. In such instances, the field activities should be furnished with winterization specifications, bills of material, and typical winterization installation plans on the specific item. This is emphasized to avoid faulty performance of equipment after it arrives at the site of operations.

4A2.02 WINTERIZATION CATEGORIES

Equipment winterization may be conveniently classified into four categories: (a) adjustment, (b) cold-engine starting aids, (c) winterization kits, and (d) modification. Information on auxiliary starting aids is contained in par. 1 of 4B1.03. The practices explained in the following subordinate paragraphs are those accepted as satisfactory by the Armed Services and are applicable to automotive, construction, and utility equipment.

1. ADJUSTMENTS. Detailed instructions for adjusting powered equipment for cold-weather operation will be found in most equipment operational manuals. Only a few general cold-weather adjustments applicable to a wide range of equipment are mentioned here.

a. *Engines.*

(1) *Generator Regulator.* Generator regulator voltage should be adjusted for subzero voltage setting as follows:

12-volt system

	Minimum	*Maximum*
Open circuit	14.3	15.3
Closed circuit	14.2	15.0

6-volt system

	Minimum	*Maximum*
Open or closed circuit	7.3	7.8

These settings are for −40° F and are satisfactory for temperatures as low as −65° F. No adjustments are required on regulators having automatic voltage variation.

(2) *Magneto or Distributor.* Magneto or distributor interrupter point gaps should be reduced 20 to 25 percent (while at an ambient temperature of 70° F) relative to the adjustment recommended by the engine manufacturer for temperate climate operation.

(3) *Ignition Timing.* Ignition timing should be retarded 3 degrees from the engine manufacturer's recommendation. The condenser should be replaced by one of lower capacitance to avoid pitting during low-temperature use. Capacity of condensers is usually set by engine manufacturers as a range, for example, 0.18 to 0.26 microfarad. In this case, a condenser of 0.25 microfarad capacitance should be replaced with a 0.17 to 0.21 capacity condenser.

(4) *Spark Plugs.* Spark plug air gaps recommended for temperate climates will prove to be excessive at the reduced voltages of ignition systems that may prevail at subzero temperatures. Gaps, therefore, should be reduced 0.005 in. from the specification for temperate climatic conditions. Spark plugs of the next hottest range to that recommended for temperate climates ordinarily give better low-temperature results.

(5) *Carburetors.* Carburetors should be set at COLD position, and the manually operated engine manifold heat controls adjusted to cold or winter setting.

(6) *Oil-Bath Air Cleaners.* Oil-bath air cleaners should be emptied and cleaned. When it is known that equipment is to be operated in cold areas where dust is not a problem, cleaners are to be left dry. This prevents blowing snow mixing with oil and clogging cleaner filter elements. Oil, hydraulic, aircraft (petroleum base), Military Specification MIL-O-5606, has performed well at low temperatures when dust conditions have precluded using wet-type cleaners dry.

(7) *Thermostat.* Thermostat openings should be raised to 180° F so that engine coolant circulation through radiators is delayed. This accelerates heating of the engine block and thereby facilitates engine starting and maintains normal engine operating temperature.

(8) *Batteries.* Batteries must be capable of absorbing full charge to deliver maximum current and prevent rupture by freezing. The mechanical condition, electrolytic strength, and charging temperature are controlling factors. Battery case and electrolytic temperatures must be from 60° to 100° F while the battery is being filled with electrolyte. Battery temperature during charging should be above 35° F. The electrolytic strength or hydrometer readings should be in accordance with Table 4A2-1, corrected to 80° F. (See par. 4 of 4A1.02.)

TABLE 4A2-1

Battery Temperature Correction Chart

Temperature, °F	Specific gravity (hydrometer reading)		Approximate state of charge, percent
	Actual	Temperature corrected	
80	1.280	1.280	100
0	1.280	1.248	75
−10	1.280	1.244	70
−20	1.280	1.240	65
−40	1.280	1.232	60
−65	1.280	1.222	50

(9) *Instruments.* All instruments such as temperature and oil-pressure gages, ammeters, and viscometers should be calibrated for temperature deviations down to $-65°$ F. Bourdon-tube-type oil-pressure gages should be disconnected at the gage when engine oil is hot, to assure a clean tube. It is better, if possible, to replace the Bourdon-tube type with electrical types.

b. *Running Gear.*

(1) *Tire Pressures.* Tire pressures should be reduced approximately 10 percent to increase flotation and traction on snow and ice.

(2) *Tracks.* Tracks break easily at subzero temperatures. For this reason track tension should be adjusted to allow 50 percent greater slack than that specified for temperate climates. Adjustments should be made at temperatures above freezing to avoid possible breakages.

c. *Auxiliary Equipment.*

(1) *Winches.* Caution plates on winch housings indicate maximum safe loads. These load markings should be changed to read 25 percent less than the original safe load. Such a reduction prevents hazardous winch and cable failures at low temperatures.

(2) *Compressors.* Oil-bath air cleaners on compressors should be emptied, cleaned, and operated dry. An alcohol evaporator should be installed, especially on airbrake systems. The alcohol evaporator permits denatured alcohol, Grade 2, to be drawn into the airbrake system and thus guards against moisture freezing in the system. The evaporator set consists of a Mason jar (1 pint capacity), a jar top with fittings, necessary tubing, and an adapter plate, which is attached to the air-compressor manifold. The jar must be kept filled with alcohol. (See Figure 4A2-1.)

2. COLD-ENGINE STARTING AIDS. Cold-engine starting aids include factory built-in or permanently installed devices or accessories that enable internal combustion engines to start at temperatures down to $-25°$ F. The aids are used in

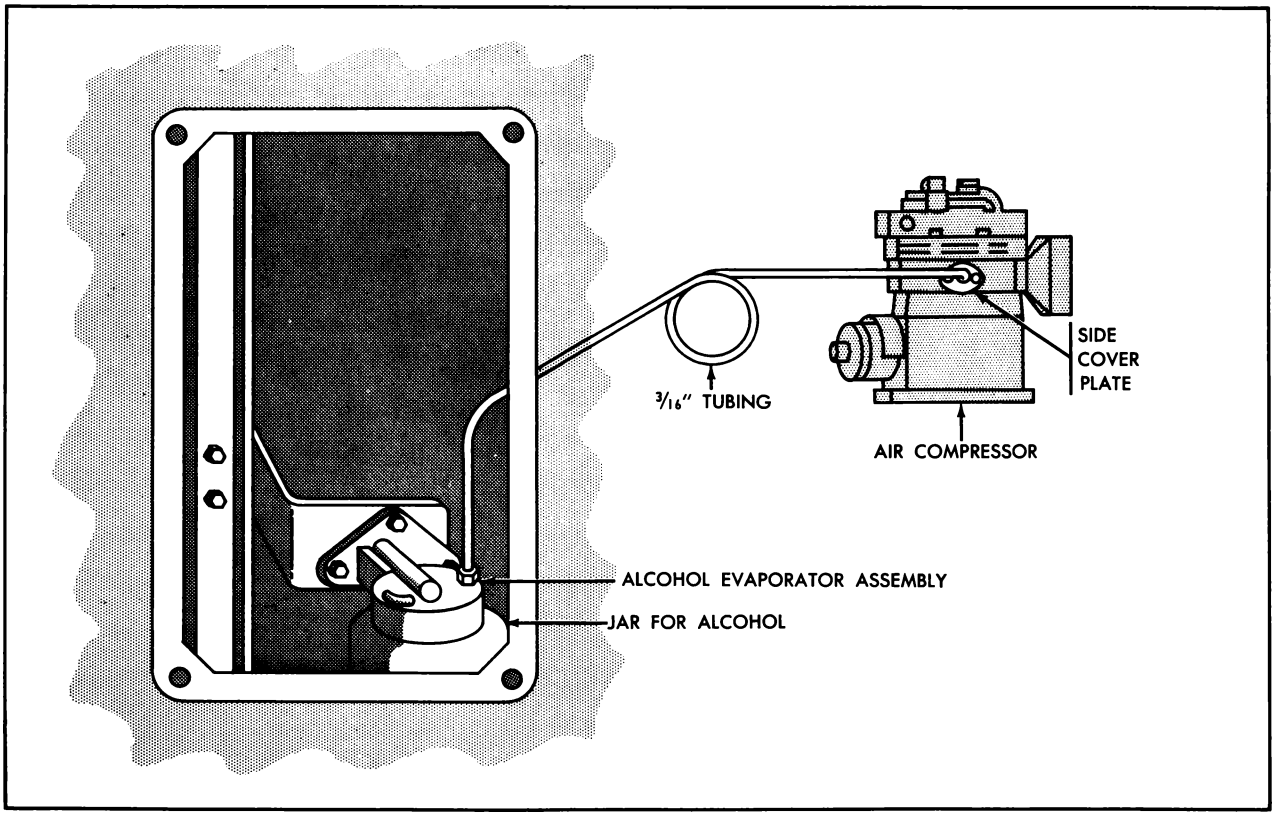


FIGURE 4A2-1

Alcohol Evaporator for Compressed Air Systems

conjunction with winterized engine adjustments (par. 1 of 4A2.02) and prescribed low-temperature fuel and lubricants (par. 4A3.03). Because the aids are permanently part of the engine, they ordinarily do not interfere with equipment operation under normal operating and under other than cold conditions.

a. *Fuel Primers.* Priming with a high volatile fuel is now the generally accepted practice, commercially and militarily, to effect cold starting of engines. The priming is merely injecting diethyl ether into the engine intake manifold. The priming fuel, having a much wider flammability range than pure hydrocarbons, ignites and burns much more readily than the regular fuel under the adverse combustion chamber atmospheric conditions prevalent in cold engines. Other ingredients of the priming fuel provide initial top-cylinder lubrication and improve the fluid's storage stability. The priming fuel is contained in small steel capsules partially filled with pressurized nitrogen gas so that when the capsule is pierced the internal pressure forces the fuel out.

Commonly used priming systems (Figure 4A2-2) consist of a dispenser assembly for holding and puncturing the capsule, tubing, and a pump for forcing the fuel through a nozzle into the engine intake manifold. Priming systems are satisfactory for both gasoline and diesel engines.

b. *Low-Temperature Batteries.* Special automotive-type lead-acid batteries have been developed that are satisfactory for operational use at temperatures down to −40° F without heat. The 6-volt size, available in four types, is covered by US Army Specification 91-88A, and the 12-volt size is a lightweight battery covered by Military Specification MIL-B-11188 (ORD). Both batteries are intended for cold-engine starting, lighting, and

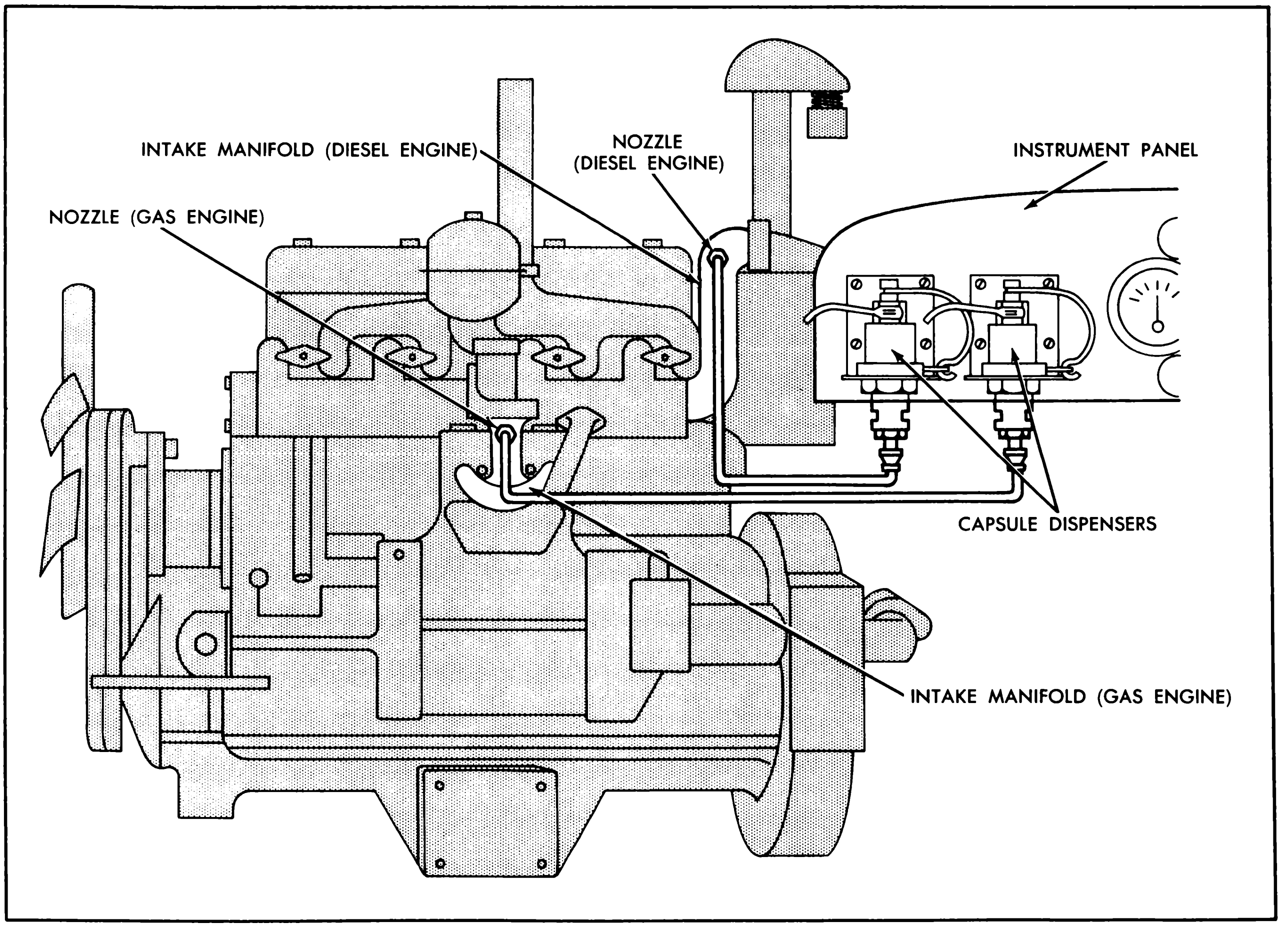


FIGURE 4A2-2

Pressure-Priming System on Engine Using Separate Gasoline Starting Engine

ignition service. They may be obtained from Navy stock by requisition.

3. WINTERIZATION KITS.

a. *General.* Winterization kits are special auxiliary units mounted on equipment to assure satisfactory performance of the equipment and to provide adequate personnel protection at temperatures from −25° to −65° F. They consist mainly of a heat source and an enclosure for retaining heat. Winterization kits are used in conjunction with low-temperature servicing materials (par. 4A3.03), winterized equipment adjustments (par. 1 of 4A2.02), and cold-engine starting aids (par. 2 of 4A2.02). Figure 4A2-3 illustrates a typical winterization kit installed on a 30-kw engine-generator set.

Winterization kits are fabricated separately from the basic equipment and mounted on it during manufacture, or they are stocked for future mountings by depots or in the field. To avoid unnecessary reworking of kits stocked for specific items, complete bills of material and a plan drawing showing method of installing the kit on the specific item should be a part of the complete winterization kit. Because winterization kits are not integral components, they are removable and thus may be detached and restocked when the equipment is no longer operated in areas of extremely low temperatures.

b. *Engine Kits.*

(1) *Auxiliary Heating Methods.* There are three methods commonly employed in winterization kits for preheating cold engines: (a) circulation of heated engine coolant, (b) warming engine internally by electrical heating elements in the cylinder block and crankcase, and (c) circulation of heated air around the engine exterior. The first two methods are heating by conduction; the third is heating by convection. Heating by radiation, using reflected heat from light-painted surfaces or infrared heat, is also possible. Radiant heat, although tried experimentally, has not yet been adopted as standard practice.

(2) *Preheating Requirements.* Engine preheating is usually either continuous during shutdown, called standby heating, or quick-start heating for use during a short time prior to engine starting. As a consequence, preheaters used for any of the three methods outlined in (1) preceding are classed as either standby or quick-start

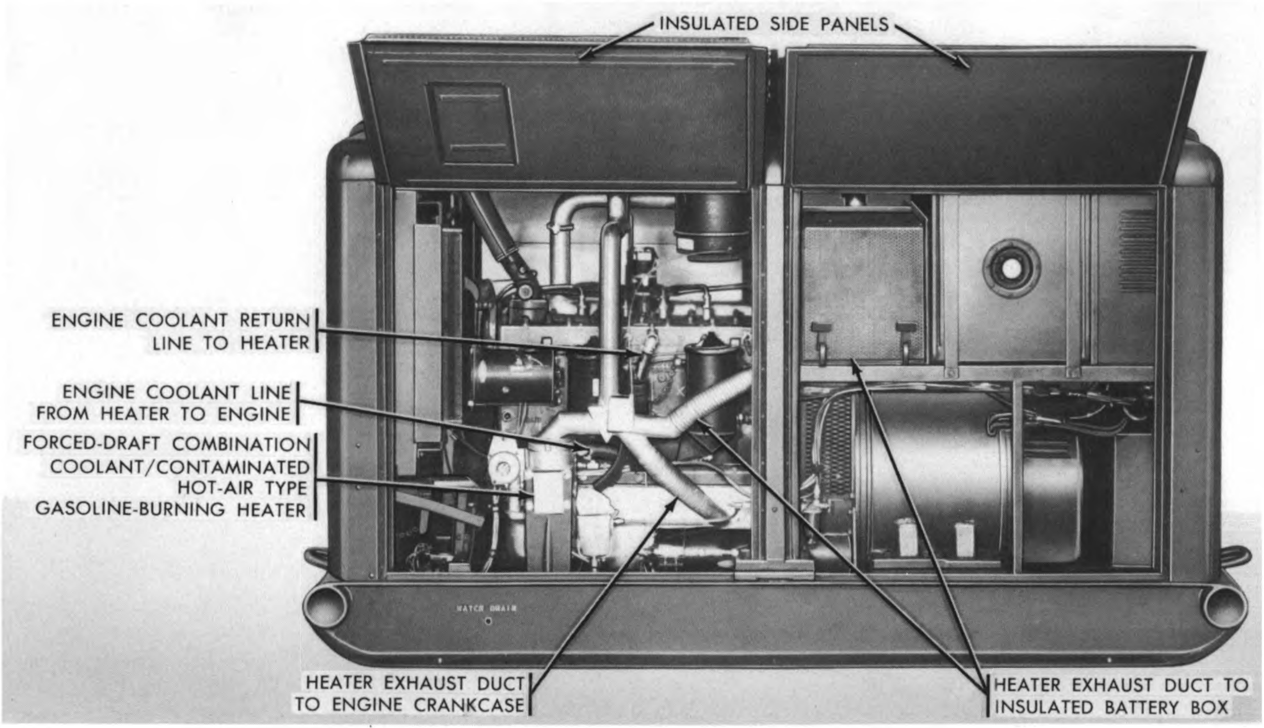


FIGURE 4A2-3

Winterization Kit Installed on 30-Kw Engine-Generator Set

heaters, the main difference being the heat output. Standby heaters are in continuous operation while engines are not operating and are often manually or automatically turned on immediately on engine stoppage. They maintain engines, therefore, only at approximately normal operating temperature. Their output ranges from 20,000 to 30,000 Btu/hr. Quick-start heaters must have a much greater output, for example, 200,000 Btu/hr, because they must heat a cold-soaked engine to normal operating temperature within a given time. The shortest possible time is preferred, but because of the size of heater required and the damaging effect of raising the temperature of engine parts too rapidly, time for heating is limited to a period of 15 minutes to 1 hour at −65° F ambient temperature, depending on engine mass.

(3) *Engine Coolant Heaters.* Because coolant heaters employ a liquid heat-exchange medium, they are applicable only to liquid-cooled engines. Circulation of the heated engine coolant is either by thermosiphon action or by a small electric pump on the heater. A typical heater is shown in Figure 4A2-4. Coolant heaters commonly used in military engine winterization kits are rated at 21,000 Btu/hr; 9,000 Btu are circulated through the coolant to the engine and heating pad of an insulated battery box, and the remaining 12,000 Btu,

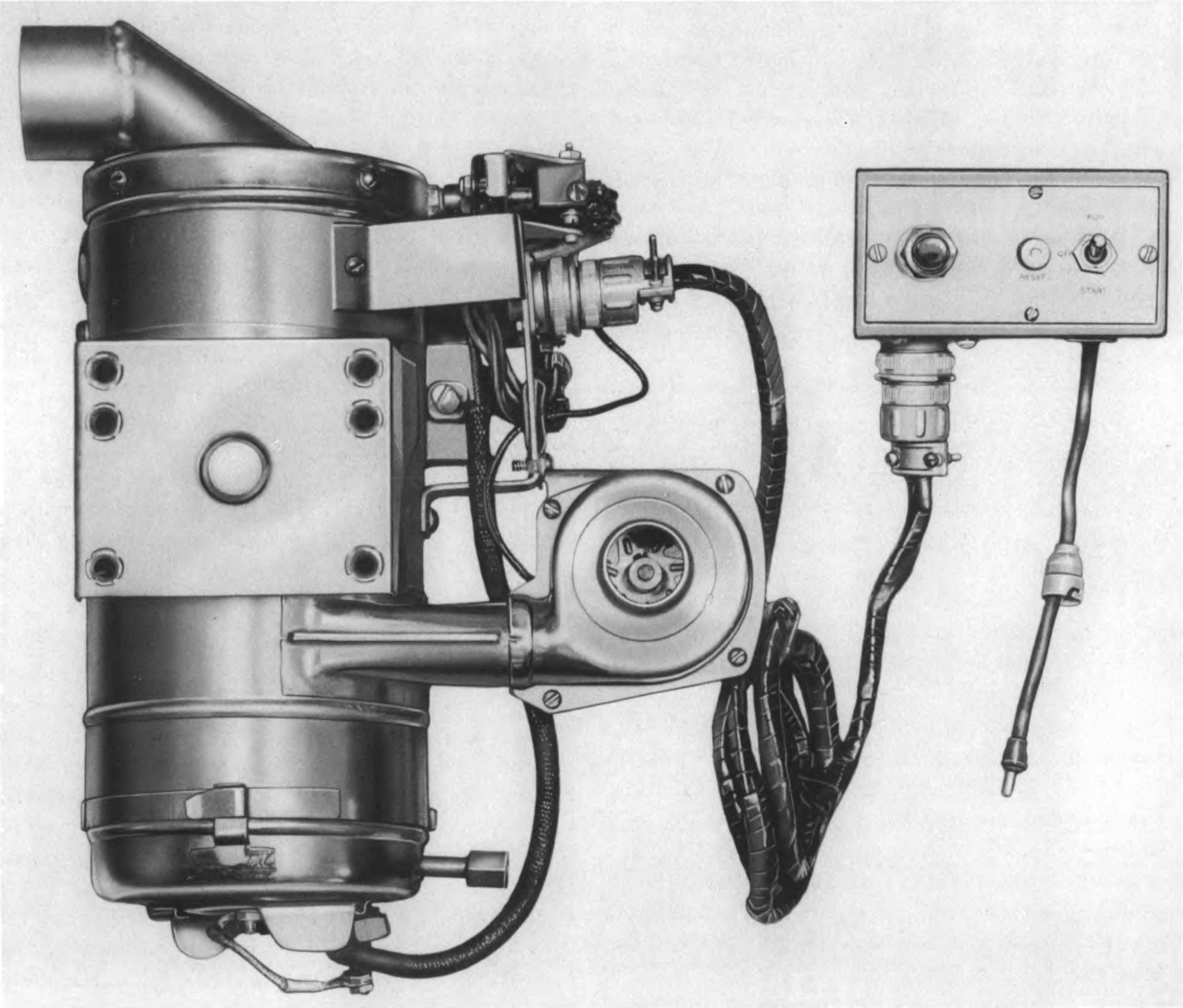


FIGURE 4A2-4

Engine Coolant Heater, 20,000 Btu/Hr

in the heater exhaust gas, are directed around the engine accessories, engine oilpan, clutch housing, and so on. These heaters are gasoline-burning, forced-draft heaters, with an electric fuel pump operating on 6, 12, or 24 volts, depending on the equipment's electrical system. Maximum fuel consumption is 0.19 gal/hr.

(4) *Contaminated-Air Heaters.* Air-cooled engines can be heated directly by combustion products from a heater or by such products diluted with fresh air. Batteries are enclosed in an insulated box through which the contaminated air circulates. Heaters of this type are built with burners that have high excess air (low CO_2) to produce a large volume of comparatively low-temperature exhaust gases. Batteries are heated rapidly, but the system must be equipped with thermostatic valves to cut off the heat supply before the battery case reaches a temperature at which it may be damaged.

(5) *Radiant Heating.* A modification of the contaminated-air system carries the products of combustion through ducts and heat radiators located adjacent to the points to be heated so that engine parts are protected from contact with the combustion products. A combination of radiators and direct heating using exhaust gases can be designed to obtain fairly high heating efficiency with protection for personnel and all delicate parts of the equipment.

(6) *Fresh-Air Heaters.* Air-cooled engines can be heated with fresh hot air blown to the points to be heated. This system involves the design of a heater with a large heat exchange surface and a powerful blower to propel fresh air over the surface, then through ducts to the point of application.

(7) *Engine Enclosures.*

(a) *Side Panels.* Special engine compartment side panels of both wood and metal have been tested under cold conditions. The tests indicated that wood panels presented a fire hazard and were too difficult to remove to be practicable, and that the metal types, as designed, were also impracticable. A commercial type of side panel and hood assembly was indicated to be preferable to the special types tested.

(b) *Blankets.* Hood blankets, commonly used in Arctic service, have usually been fabricated of heavy canvas and are sometimes filled with kapok or other insulating material to protect the engine and help retain engine heat during shutdown periods. Because of their bulkiness, however, canvas hoods are difficult to handle and install, and because they accumulate dirt and grease, they become a fire hazard. Also, while the engine is operating, the blankets absorb moisture from melted snow, and during shutdown periods they shrink and become stiff. They can be improved by being made water repellent. For flexibility and heat insulation, woolen blankets are much better than canvas. Nylon, also, is unaffected at $-40°$ F and below and would probably be better than canvas in this application. Further investigation is necessary to provide engine compartment insulation that is waterproof, fireproof, lightweight, and satisfactory in thermal qualities. (Ref. 101, 102.)

(c) *Winterfronts.* Canvas winterfront blankets and radiator curtains have been the type most commonly used. They are, however, difficult to roll and unroll because of absorption and freezing of moisture. Results of tests indicate that a commercial winterfront, controllable from within the cab, has been developed that is satisfactory for Arctic service. The chief disadvantage of some commercial types has been their inability to withstand severe vibration. (Ref. 101, 102.) A simple winterfront for radiators developed by the Army Corps of Engineers, shown in Figure 4A2-5, consists of a movable and a stationary aluminum sheet perforated with 1½-inch holes. This type is rugged enough for construction equipment and is cleaned easily simply by lifting the outer sheet.

4. MODIFICATION.

a. *Tracks.* Wide track shoes are preferred over standard shoes to increase flotation by reduction of unit ground pressure. Snow and ice shoes and snow sprocket wheels, or their equivalent, are required on crawler tractor equipment for winter operations. If snow and ice shoes are not available, standard track shoes can be altered by cutting 3-inch-square holes in each track plate over the line of the drive sprocket. Snow can then clear itself from the sprocket instead of becoming packed inside. The squares that have been cut out of the tractor plates may be cut in half and welded in a staggered pattern to the existing cleats to form ice grousers. These grousers are effective for operations on marshy tundra and in mud, as well as on snow and ice.

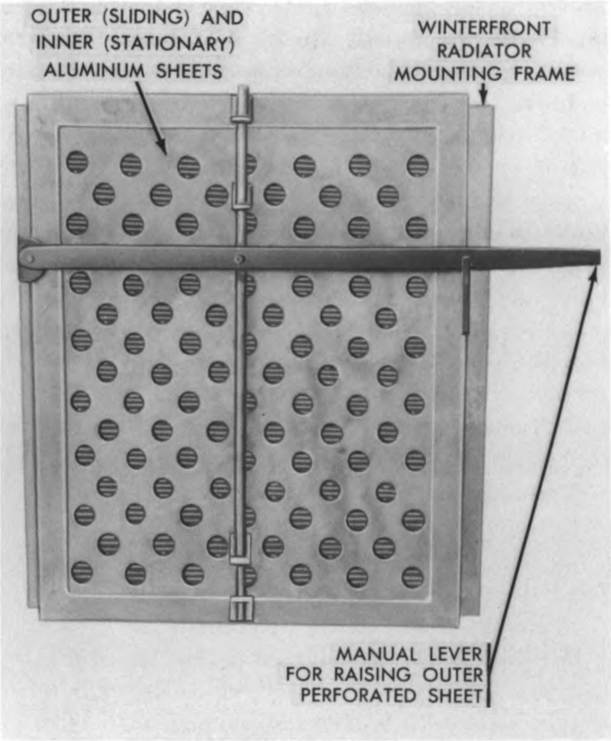


FIGURE 4A2-5

Perforated-Aluminum Sheet-Type Radiator Winterfront

When operating in snow, idler rollers become clogged and will not revolve. They should be replaced with hardwood skid blocks shaped to carry the upper tracks. An elongated slot should be provided in the skid blocks over the front axle to allow track release action. Roller guards, made of heavy steel plates, should be installed on both sides of the roller frames to keep out snow, ice, gravel, and silt. Canvas socks should be installed around the springs.

b. *Engine Exhaust.* Engine exhaust should be directed away from the operator's line of vision. In cold weather, steam formed from condensed exhaust gases reduces visibility and is thus a hazard to safe and efficient operation.

c. *Lights and Storage Battery Locations.* Lights should be carefully located to avoid their restricting the vision of the operator and becoming packed with snow thrown by the tracks. The storage battery should be housed in a box insulated with a material that will withstand the vibration of the equipment. The box should have a heating pad connected to the coolant heating system and should be equipped with battery lifting handles. It is recommended that the battery box be located within the cab, preferably under the right seat, to reduce exposure to wind chill, prevent damage to the coolant lines, and avoid interference with controls. (Ref. 102.)

d. *Air Intakes.* To prevent snow from being sucked in with the engine air, the air intake should be located inside the cab or in some other sheltered part of the prime mover. (Ref. 103.)

e. *Fuel Systems.* A bleeder valve or drain cock should be inserted in an accessible location near the lowest point of the fuel system. This allows easy drainage of any fuel remaining in the fuel tubing system after engine stoppage and thus avoids possible ice clogging.

f. *Safety Features.* Many equipment accidents caused by the operator's foot or hand slipping when wearing Arctic clothing can be avoided by providing nonskid walking or standing surfaces and oversized handles on the equipment. Grated types of platforms, running boards, and walkways are self-cleaning for snow and ice. Standard equipment can also be made nonskid by applying paint mixed with emery dust to all foot surfaces. Oversized door handles and similar fixtures are required so that operators wearing bulky gloves can obtain good grips. A further safety feature is the coating of control handles with a cold-resistant or nonconducting paint so that bare hands will not freeze to the handles.

4A2.03 EQUIPMENT OPERATOR PROTECTION

An enclosure of some type to shield the operator from the weather is necessary during winter on every type of construction equipment. Enclosures may range in type from canvas, installed around foot controls and seat to protect the operator's feet from cold and snow, to fully equipped cabs. Rough frozen terrain makes it preferable to use three-point cushion (coiled spring or rubber block) suspension for tractor cabs. Also, a quick-escape hatch should be located in the roof just over the driver's seat of tractor cabs to avoid the possibility of the driver being trapped if the tractor should break through ice. Insulation should be provided behind all solid panels of the cab, and the cab should be protected on the inside by canvas or other suitable lining. Double glass, or single glass and frost shields, should be installed in all doors and windows. Tinted windshields reduce snow glare.

Plastic windows are not satisfactory because they filter out some light and scratch easily if frost is brushed from the surface. The windshield should be equipped with defrosters or a frost shield and manually operated windshield wipers. Canvas boots should be placed over control openings to prevent cold blasts from entering the cab. If practicable, cabs should be designed so that the operator has ready access to the controls of winches and other auxiliary equipment without being required to open windows.

Engine heat can be used for cab heating by installing a louver, adjustable from inside the cab, in the lower portion just above the controls. Special care must be exercised to keep exhaust gaskets tight to prevent gases entering the cab. Figure 4A2-6 shows a 20,000-Btu/hr, 100-cfm forced-draft uncontaminated-air heater commonly used in cabs of military equipment to supply adequate heat for personnel at ambient temperatures of −65° F. It is gasoline burning and has an electric fuel pump and blower operating on 6, 12, or 24 volts, depending on the equipment's electrical system. Maximum fuel consumption is ¼ gal/hr.

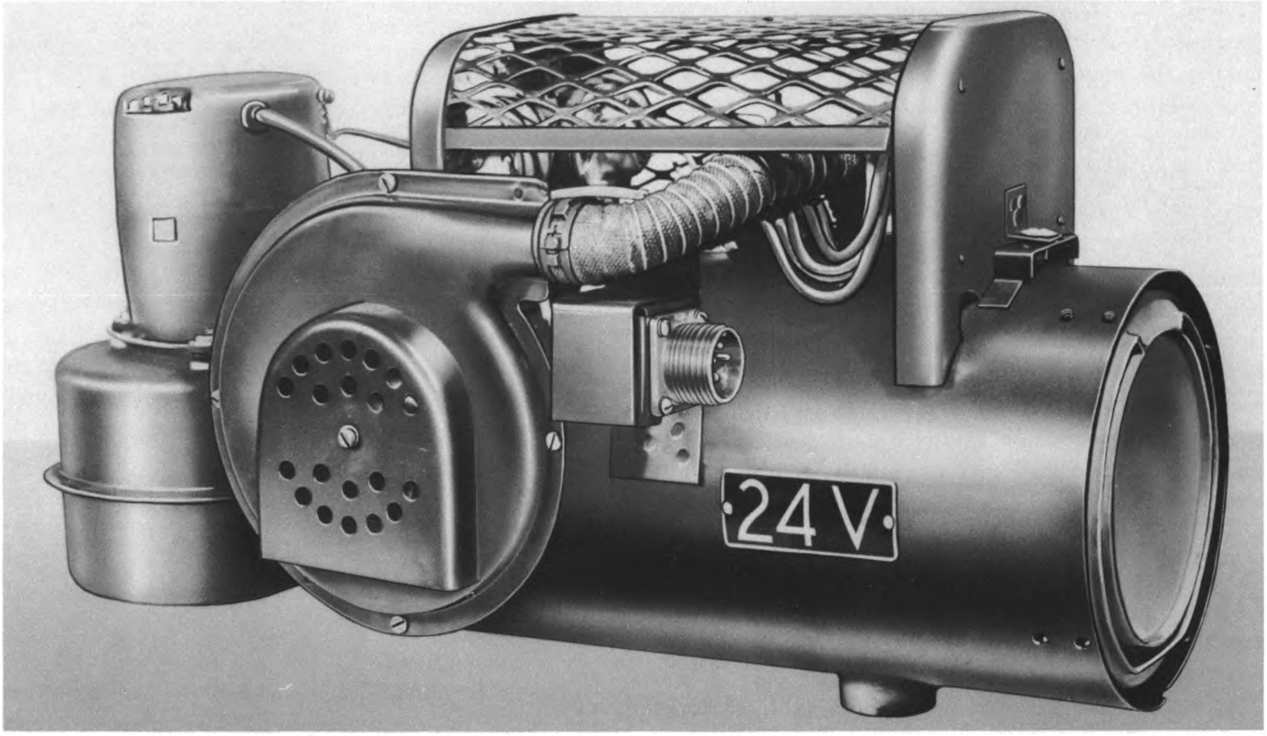


FIGURE 4A2-6

Forced-Draft Uncontaminated-Air Cab Heater, 20,000 Btu/Hr

Section 3. PREPARATION OF EQUIPMENT FOR COLD-WEATHER OPERATIONS

4A3.01 INTRODUCTION

This Section deals with the initial adjustments and the fuels, lubricants, antifreezes, hydraulic fluids, preservatives, and the like for low-temperature operation of automotive, construction, and powered utility equipment. The practices and materials are common to all the Services. They are the result of experience gained from extensive laboratory and field tests as well as in-service use. They are applicable to winterized and nonwinterized equipment.

Detailed instructions on the preparation and servicing of diesel-, gasoline-, steam-, and electric-powered automotive and construction equipment and the accessory equipment will be provided by this Bureau on request. The instructions that follow are for intended use of equipment at prevailing ambient temperatures below 0° F.

4A3.02 COLD-WEATHER PREPARATION

1. PREINSPECTION. Equipment efficiency in any climate depends on mechanical or working condition. This is particularly true if the equipment is to withstand added difficulties and failures during low-temperature operation. It is of utmost importance, therefore, that all equipment be thoroughly inspected and properly readied before being serviced for low-temperature use. If at all possible, this should be done stateside or at depots where equipment or component parts not in first-rate mechanical condition can be replaced. Although the following recommendations may appear as unnecessary duplication in some respects, low-temperature field experience has shown that such preparation of equipment has prevented many mechanical failures.

2. DEFECTIVE PARTS. To conduct a thorough inspection that will reveal broken, cracked, worn, corroded, deteriorated, or loose parts, preservative coatings should be removed and the equipment completely steam-cleaned and drained of all lubricants. Visual inspection should be made of seals, linkages, drive belts and chains, the electrical system, adjustments and condition of control devices, winch cables, and so on. Defective parts should be replaced or repaired so that the equipment is mechanically in a first-rate condition.

3. NORMAL PERFORMANCE. The equipment should then be serviced and adjusted for temperate climate conditions as prescribed by the manufacturer's or Service operation manual. The equipment should be operated sufficiently to assure that it is satisfactory in regard to its normal temperature-rated performance capacity and safety.

4. READJUSTMENT. When it is satisfactory, the equipment should be drained and flushed of all lubricants, hydraulic fluids, coolants, and fuel. Winterization should be installed and the equipment repainted as necessary. It should be properly readjusted for low-temperature operation in accordance with par. 4A2.02 and the manufacturer's or Service instructions and replenished with cold-weather materials (par. 4A3.03).

5. WINTERIZATION PERFORMANCE. The equipment (including winterization, accessories, and attachments) should again be operated sufficiently to circulate the cold-weather materials thoroughly and to indicate any malfunctioning requiring correction. This operation can be performed without equipment damage, even though ambient temperatures are comparatively high, if indicators (pressure, temperature, and others) are carefully observed so that the equipment is not overheated or overloaded.

4A3.03 COLD-WEATHER SERVICING MATERIALS

Materials prescribed for cold-weather servicing of automotive, construction, and utility equipment are listed in the following subordinate paragraphs. They may be requisitioned from Navy stock.

1. FUEL.

a. *Gasoline Engines and Burners.* Fuel for all gasoline engines and gasoline-burning heaters and stoves is as follows.

(1) *Within Continental Limits.* M, Class C motor fuel, Federal Specification VV-M-561, (Reid vapor pressure, 12 to 14 lb).

(2) *Outside Continental Limits.* Type C automotive combat gasoline, Military Specification MIL-G-3056.

b. *Diesel Engines and Oil Burners.* Fuel for all diesel engines and fuel oil burning heaters and stoves is Class 3 diesel fuel oil, Military Specification MIL-F-896.

c. *Kerosene Burners.* Fuel wherever kerosene is specified is commercial grade kerosene, Federal Specification VV-K-211. NOTE: Kerosene has a pour point of −40° F and a freezing point of −60° F.

2. LUBRICANTS.

a. *Crankcase Oil.* Crankcase oil for gasoline and diesel engines, compressors, hydraulic couplings, and other component parts when engine oil is normally prescribed as a lubricant is as follows.

(1) *At Ambient Temperatures of 32° F to −10° F.* Lubricating oil, internal combustion engine, diesel, Military Specification MIL-L-9000.

(2) *At Ambient Temperatures Below −10° F.* Subzero engine oil, Military Specification MIL-O-10295.

b. *Gear Oil.* Lubricant for gearboxes, such as transmission, transfer cases, power takeoff, winch, fluid-lubricated universal joints, and similar equipment is subzero universal gear lubricant, Military Specification MIL-L-10324.

c. *Transmission Fluid.* Fluid for automatic fluid-type transmission is subzero engine oil, Military Specification MIL-O-10295.

d. *Torque Converter.* Lubricant for torque converters is Class III diesel fuel oil, Military Specification MIL-F-896.

e. *Winch Cables.* For winch cables and all oilcan points where engine oil is normally prescribed and for lubricating and preserving internal machine surfaces, the lubricant is preservative (special) lubricating oil, Military Specification MIL-L-644.

f. *Water Pumps.* Water-repellent lubricant for water pumps and similar equipment is No. 4 water-pump grease, Type A, Grade 4, Federal Specification VV-G-632.

g. *Chassis Grease.* Chassis grease for all grease fittings, wheel bearings, track rollers, driving sprockets, steering-gear joints, and slip joints, and whenever general purpose grease No. 0, 1, or 2 is prescribed for temperate climates, is automotive and artillery grease, Military Specification MIL-G-10924.

h. *Lubricating Instruments.* Fluid for lubricating instruments at all temperatures, and sealing bearings of engine generators, starting motors, and similar components is instrument grease, Military Specification MIL-G-3278.

3. HYDRAULIC FLUIDS. The following fluids are used for hydraulic and hydrovac brake systems and all shock absorbers except Houdaille type.

CAUTION: These fluids are not to be used as brake fluid.

(1) Petroleum-base aircraft hydraulic oil, Military Specification MIL-O-5606.

(2) Fluid for hydraulic braking systems, Arctic hydraulic brake fluid, US Army Specification 2-138.

4. COMPRESSED-AIR SYSTEMS. For compressed-air systems, such as airbrakes, Grade III denatured alcohol, Federal Specification O-A-396(1), is used.

5. ENGINE COOLANT, ANTIFREEZE. Antifreeze for liquid-cooled engines and compressors is as follows.

a. *Ambient Temperatures Above —40° F.* Ethylene-glycol-type antifreeze compound, US Army ORD Specification 4-1116. NOTE: Dilute 60 parts compound with 40 parts water.

b. *Ambient Temperatures Below —40° F.* Arctic winter-grade antifreeze compound, US Army Development Specification. NOTE: Compound is premixed. Do not dilute with water or other substance.

6. WASHING AND CLEANING SOLUTIONS. The solution for washing and cleaning machine parts is Stoddard-solution dry-cleaning solvent, Federal Specification P-S-661a(1).

4A3.04 COLD-WEATHER HANDLING AND STORAGE OF FUEL

As temperatures drop, moisture from the air condenses to form water in fuel tanks, storage drums, and containers. The water freezes below 32° F, forming ice crystals that subsequently clog fuel lines and carburetor jets. Observance of the following precautions will overcome this fault.

(1) Use ICC types 17C and 17E, 5-gallon steel drum, single-trip containers for handling fuel. (See Federal Specification RR-D-760.)

(2) Thoroughly clean all fuel containers of rust, sediment, or foreign matter before storing fuel in them.

(3) If possible, after filling or moving a fuel container, allow the fuel to settle 24 hours before filling fuel tanks from containers.

(4) Tighten all closures of containers to prevent snow, ice, dirt, or other foreign matter from entering.

(5) Wipe all snow or ice from dispensing equipment and from around the fuel tank filler cap before removing cap to refuel equipment. After refueling, secure filler cap tightly.

(6) Avoid dragging fuel-dispensing hose nozzle over snow.

(7) Strain the fuel when transferring it from one container to another or when refueling equipment, to prevent passage of water. A wire mesh filter over chamois skin is recommended.

CAUTION: Gasoline flowing over a surface generates static electricity that will cause a spark unless means are provided to ground the electricity. An effective ground is the metallic contact of the container or dispensing hose nozzle held firmly against the tank or container being filled.

(8) Keep fuel tank full, if possible. The more fuel in a tank, the less volume of air is left to condense into moisture to freeze or form in crystals.

(9) Refuel equipment, whenever possible, at

the end of the day's operation so as to leave less airspace in the fuel tank and to permit any water to settle out during nonoperating time.

(10) Bleed the drain valve located at the lowest point of the fuel system (if equipment is winterized in this manner) at the beginning and end of the day. This eliminates any water that has collected in the fuel system.

PART B. EQUIPMENT MAINTENANCE AND REPAIR

Section I. MAINTENANCE AND REPAIR

4B1.01 GENERAL

The effect of the severity of subzero operational conditions on equipment emphasizes the necessity for effective preventive maintenance and adequate repair facilities to avoid costly breakdowns and to obtain maximum life and use. Advanced planning on type and number of repair parts to be stocked must be given prime consideration. Replacements must be sufficient to carry the project over until the next season.

Extreme cold aggravates any maintenance task through physiological and psychological personnel factors. For instance, experiments have proved that the time required to screw a big nut on a large bolt was twice as long when men wore mittens instead of using bare hands. Also, manual dexterity and fine discrimination by sense of touch are lost at low temperatures.

4B1.02 SHELTERS

Generally, shelters may be thought of as semipermanent or portable. They are essential in maintenance and repair to retain adequate heat for personnel and equipment operation and to prevent interference from blowing snow.

Easily transportable and quickly erected rigid and semirigid structures, such as the Quonset and Jamesway huts, are commonly used as semipermanent maintenance and repair shelters. Other knockdown temporary buildings, both arch and straight-side designs, have been developed since World War II but as yet have not been widely adopted primarily because of high initial cost.

Factors of importance in selecting semipermanent maintenance shelters are size, flooring, heating and insulation, and ventilation. The 40- x 100-ft Quonset or Jamesway huts are adequate in size and ceiling height to accommodate a Class IV tractor with cab. Flooring of concrete or wood planking must be capable of supporting heavy equipment. Attention should be given to main end doors to prevent snow drifting and subsequent melting and ice formation in front of the doors. Sometimes this is done by windbreaks or by locating shelters so that doors are kept snow-free by blowing winds. Because a great tendency exists to ignore engine exhaust dangers at subzero temperatures to conserve heat, it is mandatory that all maintenance shelters have adequate ventilating systems. A 40- x 100-ft shelter requires about 400,000 Btu/hr at $-65°$ F to be comfortable for mechanics. This heat is usually provided by a 200,000-Btu/hr uncontaminated-air space heater located at each end of the shelter.

Portable shelters are lightweight collapsible enclosures usually only large enough to enclose one item of equipment, such as a tractor. Tents have been used but do not withstand high winds. Some experimental work has been done on air-inflated tents, which assume a definite shape and rigidity and have the advantage of air insulation to retain heat. Air cells are contained between two linings.

FIGURE 4B1-1

Mobile Field Repair Shelter

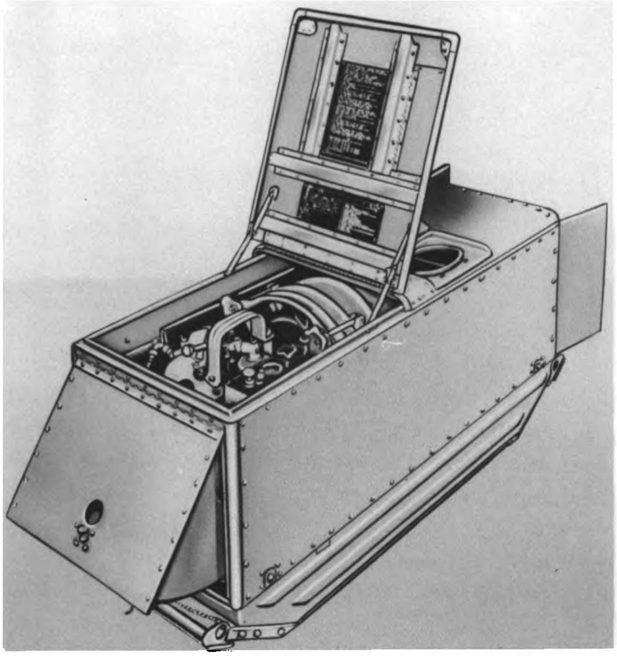


FIGURE 4B1-2

Portable Uncontaminated-Air Heater, 40,000 to 400,000 Btu/Hr Variable Output, Skid-Mounted

Air pressures are only slightly above atmospheric so that they may be pumped up manually if necessary. A fabricated portable field shelter consisting of a tubular frame with canvas covering is shown in Figure 4B1-1.

4B1.03 EQUIPMENT

1. AUXILIARY STARTING AIDS. Portable heaters are employed to supplement winterization kit heaters in facilitating cold starting of equipment and to aid cold servicing, maintenance, and repair of the equipment. They range in heat output from 10,000 to 500,000 Btu/hr. Available commercial types include heated uncontaminated- or contaminated-air and heated-liquid circulators. Depending on their size and design, they may be used to heat individual items of equipment, a group of items simultaneously, provide concentrated heat on a particular component of equipment, or warm the inside of a portable shelter. Figure 4B1-2 shows a portable military uncontaminated-air heater, skid-mounted to facilitate moving it over snow. It has a variable heat output from 40,000 to 400,000 Btu/hr, with an adjustable ventilating air delivery of 485 to 970 cfm. It is gasoline burn-

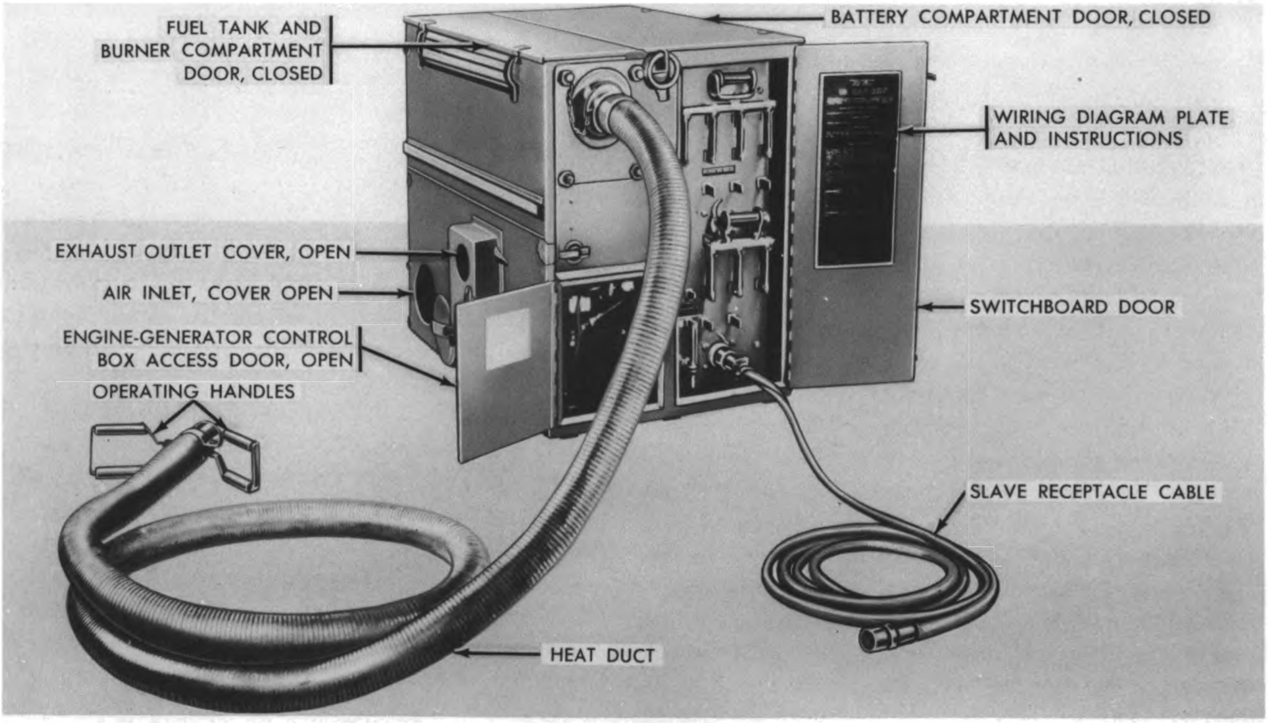


FIGURE 4B1-3

Portable Slave Kit for Sled or Trailer Mounting

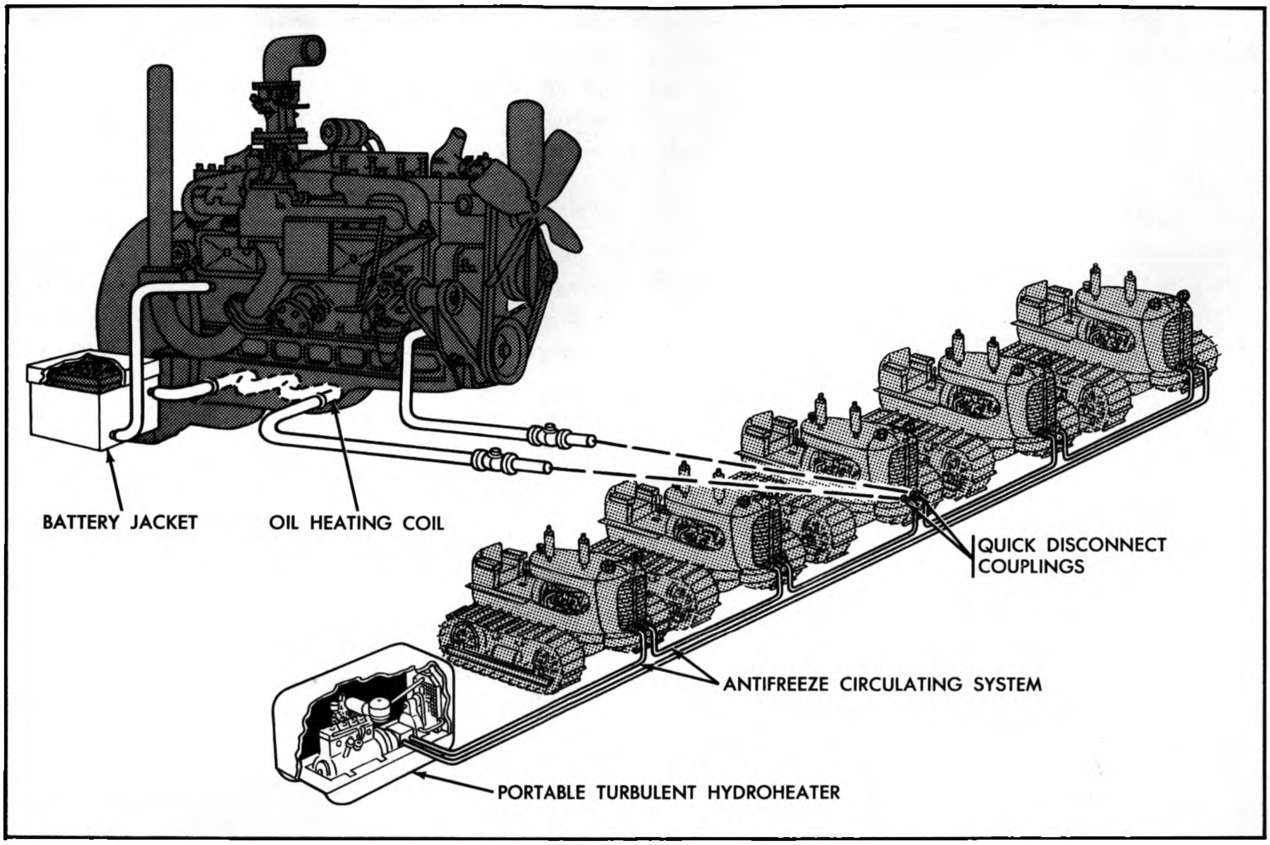


FIGURE 4B1-4

Portable Hydroheater Slave Kit, Sled-Mounted, Used To Warm a Group of Tractors

ing and is either engine or electric-motor driven.

The portable, hand-cranked, blower-type contaminated-air heater has an output of 8,000 Btu/hr. Its light weight and small size make it useful to warm prime-mover starting engines, transmissions, and similar equipment.

A much more satisfactory portable heating system, a so-called slave kit, employs an auxiliary heater along with an auxiliary battery, as shown in Figure 4B1-3. (Ref. 104.) The kit includes a 24-volt battery system, with taps and switches permitting it to be connected as a booster to the electrical system of a vehicle or other piece of equipment operating on 6, 12, or 24 volts. It also includes a gasoline-engine-driven battery-charging generator and a gasoline burner for supplying a large volume of heat as an aid for quick starting.

The slave kit is generally mounted on a ¼-ton truck, small trailer, or sled so that it can be brought close to any item of equipment to be started. The auxiliary battery is plugged into a slave receptacle on the equipment (when provided) or clamped to the battery posts of the equipment by a flexible power cable. Most winterized military vehicles are provided with these slave receptacles for connecting outside batteries. A flexible tube connects the exhaust outlet of the heater to the engine compartment, warming and drying engine accessories.

Because the auxiliary battery has a high capacity when fully charged and warmed, and because the heater has a high enough output to warm the engine crankcase, inlet manifold, and cylinder walls rapidly, starts on average-size vehicles can be obtained within five minutes. If the slave kit itself is cold, the self-contained heater can be started and used to warm the slave kit batteries and engine generator, as well as the vehicle parts.

One slave kit should be provided for each group of 5 to 10 items of transportation and construction equipment. It is useful, of course, for quick starting only those powerplants located nearby.

An important advantage in having at least one slave kit wherever vehicles are stationed is that all vehicles or other kinds of equipment can be warmed for starting even though they do not have any self-contained starting aids. Another advantage is that the slave kit can also be used to recharge run-down batteries or to start equipment whose batteries are discharged.

A commercial type of slave kit, trailer- or sled-mounted (Figure 4B1-4), uses the available heat of an internal combustion engine as a heat source. It is equipped with inlet and outlet coolant hoses that have quick-disconnect fittings. The fittings enable the heating or slave kit engine coolant system to be easily connected with the cooling system of the equipment, which also has quick-disconnect fittings. In this manner, heated engine coolant from the slave kit engine is circulated through the engine being warmed up for cold starting. The unit also utilizes frictional heat from an engine-driven generator used as a Prony brake.

The principal drawback to general use of slave kits instead of starting aids built into the equipment is that vehicles and powerplants in the field may be parked in remote areas or other locations where slave kits are not available. Self-contained heating units, on the other hand, are always present on the equipment.

2. LUBRICATORS. Low temperature and blowing snow impose difficulty in routine outdoor field lubrication because of icing around grease fittings and stiffened lubricant in the equipment. In addition, difficulty is experienced in handling grease guns, hoses, valves, and similar items. It is best, therefore, to winterize portable lubricators to be used in the field to assure that adequate fluidity and pressure of a new lubricant is obtained and that some heat is provided to open frozen grease fittings. The lubricator unit should be mounted on a ski-equipped trailer or sled mounted to increase cross-country mobility.

3. FIELD REPAIR SHOPS. Field repair shops for the Cold Regions consist of the same basic hand and power tools, hydraulic presses, and welding and gas cutting equipment that are furnished with motorized military field repair shops for vehicle and construction equipment. Because of environmental conditions, however, the shop is usually mounted on a sled for mobility. Special provisions are also made for heating the shop interior for the

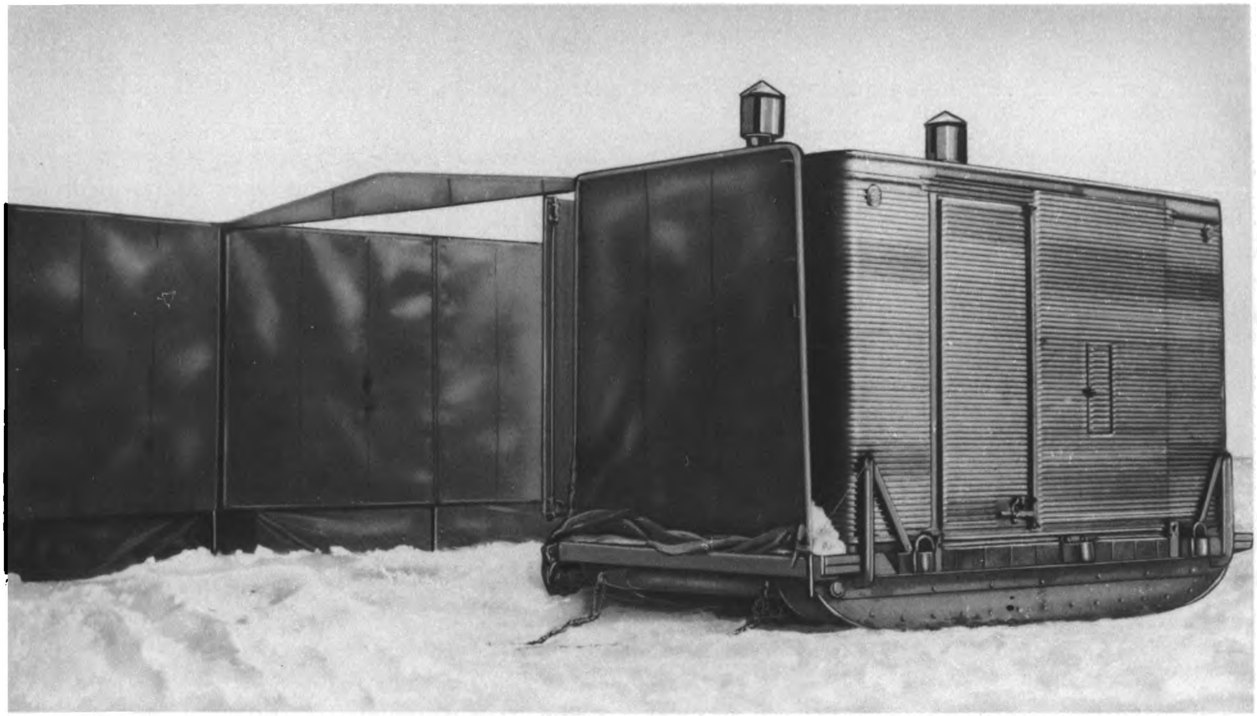


FIGURE 4B1-5

Winterized Field Repair Shop, Sled-Mounted, Showing Folding Side Extensions in Use

comfort of the mechanics. Lightweight lean-tos or folding side extensions, covered or uncovered, enclose equipment to be repaired. An additional portable air heater that has ducts to direct hot air around the equipment component being repaired is part of the winterization of the repair shop. A typical northern or winterized mobile repair shop is shown in Figure 4B1-5.

4. PORTABLE FLOODLIGHTS. Portable floodlights are necessary for outside construction and field maintenance and repair because of the long season of short days in the Far North. Standard 1,000-watt reflectors mounted either on tripods or field repair shops are suitable for outdoor use. Their serviceability under Arctic environment is good, although consideration must be given to obtain firm tripod footing and/or mounting to withstand high winds and to avoid rough handling of lamps because of their greater fragility when cold.

Section 2. COLD-WEATHER WELDING

4B2.01 LOW-TEMPERATURE WELD PROPERTIES

1. THEORETICAL ASPECTS. Research on the properties of fusion welds at low temperatures has been quite limited and has, in general, been confined to welded test pieces that have been machined. In view of the extreme sensitivity of certain ferritic steels to surface imperfections when subject even to static loading at low temperatures, the characteristics of the weld metal of unmachined welds may be quite different from that of machined welds. In practice, the surface of a weld, particularly if it was made in a vertical or overhead position, is very rough in comparison with that of the plate in which it occurs, and it is possible that the flow notch might decrease the impact resistance of the weld over that of the plate. In weld research, attention has been given to the gaseous constituents of the weld and the metal in its vicinity, the most common of which are nitrogen and hydrogen. Modern welding techniques reduce the pickup of either gas, but when pickup occurs, its detrimental effects (mostly increased notch sensitivity) can be reduced by postheating the welded part to a temperature and for a period that are governed by the thickness of the weld. After postheating, the weld should be allowed to cool slowly. Additional information is given in Robert D. Stout's paper, "The Properties of Weldments at Low Temperatures," presented at Symposium on Effects of Low Temperatures on the Properties of Materials, March 19, 1946, by the Philadelphia District of the American Society of Testing Materials.

2. CARBON STEELS. With decreasing temperatures, welded specimens of carbon steels show a definite tendency to increase in ultimate stress, yield, and elastic moduli. Ductility of carbon steels decreases at lower temperatures. High-manganese/carbon-ratio mild-steel welds that are low in nitrogen and hydrogen and are subsequently heat treated and machined have good notched-bar impact resistance in comparison with that of the plate in which they occur. On the other hand, machined but unstress-relieved welds made with covered electrodes have at least as low a transition temperature as that of the plate. Therefore, when the highest possible low-temperature impact resistance is required in a welded part made of as-rolled or normalized mild or slightly alloyed steel, particular attention must be given to the chemical composition of the weld and base metal and to the welding technique adopted. The manganese/carbon ratio should be high, and the welding should be done by a process that tends to reduce the nitrogen and hydrogen pickup. After welding, a stress-relieving and gas-expelling heat treatment should be given and, if practicable, the weld should be machined to remove all surface roughnesses that might act as centers of crack propagation. (Ref. 48.)

3. FERRITIC ALLOY STEELS. The static mechanical properties of low-alloy welded steels at low temperatures behave much like those of carbon steels. But if the alloying constituents are such that the steel becomes an air-hardening one, then there will be a zone adjacent to the weld whose characteristics greatly differ from those possessed before welding. If the part in question is structurally important and may be exposed to low temperatures, a postwelding heat treatment should be carried out.

4. AUSTENITIC STEELS. Welded steels of the 18/8 class (18 Cr, 8 Ni) appear to preserve, at low temperatures, approximately the same relationship to unwelded metal as to their own static mechanical properties at room temperatures. If, however, the weld is to be exposed to very low

temperatures and machining is not practicable, the characteristics of the unmachined weld metal under both static and dynamic loads can be much improved by using an austenite steel welding rod. An argon or helium arc technique is recommended for making such a weld, although a submerged arc weld would probably be equally satisfactory. (Ref. 48.)

4B2.02 LOW-TEMPERATURE WELDING PRACTICE

1. TECHNIQUES. Arc welding under cold-weather conditions involves few changes from conventional techniques. There are, however, certain recommended precautions.

(1) Preheat the work. (Some steels require preheat under any conditions.) The chemical composition of the steel and the thickness of the section being known, the degree of preheat required can be determined.

(2) Use a welding procedure that gradually increases the temperature of the entire assembly; for example, stagger welds when possible. (See Figure 4B2-1.)

(3) Use low-hydrogen electrodes to minimize occurrence of underbead cracking.

(4) Make slow, thick beads rather than fast, stringer beads.

(5) Make welds slightly convex rather than concave. Weld uphill rather than downhill.

(6) Use techniques and plate preparation designed to reduce combinations of alloys and high-carbon base metals. High-carbon steels are difficult to weld under any conditions. They require thorough preheating in and near the welded zone and should be subsequently annealed at 1,350° to 1,450° F.

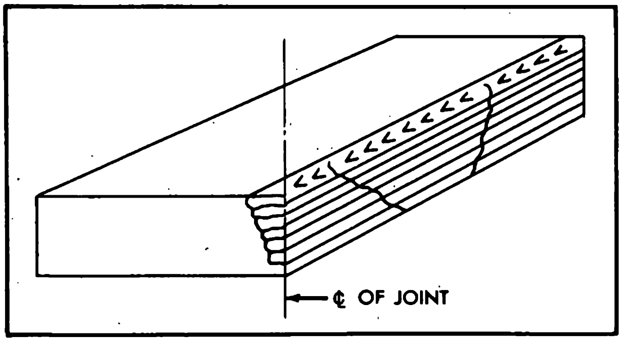


FIGURE 4B2-1

Block Sequence of Welding

2. RECOMMENDED ELECTRODES. Electrodes used successfully by the Bureau of Yards and Docks at Point Barrow, Alaska, are given in the following table.

Type of steel	*Type of electrode and welding procedures*
Open-hearth, hot-rolled low-carbon SAE 1020 structural steel, ASTM-A-7-46 (C, 0.18 to 0.23; Mn, 0.30 to 0.60).	(1) AWS E-6012 (Lincoln Fleet No. 7). Used on low-alloy steels in the higher carbon content varieties, it must be stress-relieved. Heat heavy sections to just below critical range, 1 hr per in., and cool slowly. (2) AWS E-6010 (Lincoln Fleet No. 5). Used on low-alloy steels in the lower carbon varieties. Light sections used as welded; heavy sections stress-relieved at 1,050° F.
Medium-carbon content SAE 1040; hot-rolled, cold-rolled. NOTE: Weld fully annealed only. Heat-treat after welding to not over 280 Brinell scale. (Higher hardness will not stand up on plain carbon steel.)	Preheat heavy sections to 300° to 500° F before welding.
Standard line pipe (for construction use), API specification grade x 42 and drill pipe, API specification grade D (C, 0.42; Mn, 1.35; P, 0.017; S, 0.019; Si, 0.20).	AWS E-7010 (Lincoln Fleet No. 85). Preheat to 600° F; stress-anneal at 850° F.
API high-strength casing, grade J-55 and grade N-80.	AWS E-6016 (USN BuShips Specification 46E8, grade 2) low-hydrogen (Lincoln LH 70). Preheat to 600° F; stress-anneal at 850° F.
SAE 3140; SAE 4140; weld-annealed or tempered to not over 285 Brinell scale.	AWS E-7010; AWS E-6016 (low-hydrogen). Preheat to 650° F; stress-relieve at 800° F.
Tractor rollers and idlers rebuilding and hard-surfacing.	Automatic application, submerged arc, alternating current. For buildup, use high-carbon wire (C, 0.60 to 0.70; Mn, 1.00; Si, 0.14). NOTE: Stoody high-carbon used on idlers without hard-surfacing. No preheat required; stress-relieve at 1,150° to 1,200° F; cool slowly. To hard-surface built-up rollers (submerged arc as above), 2 passes Stoody 105. No preheating or stress-relieving required.

PART C. SITE MAINTENANCE

Section I. SUMMER MAINTENANCE OPERATIONS

4C1.01 CAMP FACILITIES

1. DRAINAGE. In the Cold Regions the ice breakup or thaw period preceding summer and the freezeup period following summer are the most critical times in the maintenance of pavement and other traffic areas. As soon as a thaw begins, ditches, drains, culverts, and other critical points in the drainage system should be opened, if necessary, with thawing equipment in preparation for spring floods. Portable boilers should be provided for this purpose. Attention must be given to compacted snow on shoulders and other areas, which may melt and refreeze, and to places where its presence would interfere with drainage. Abnormal traffic loads during the breakup period should not be permitted because they may cause subgrade pumping of concrete surfaces and breakthrough of bituminous and gravel surfaces. Melting ice and snow, spring rains, and frost leaving the ground all have a tendency to saturate permeable surfaces, raise the water table, and make subbases unstable. Particular attention should be given during this period to protecting the drainage shed of the water supply. Any evidence of winter contamination should be noted and corrected.

2. UTILITIES. Utilities and their component parts should be carefully checked and overhauled in accordance with normal winter preparation procedures. Grades on pipelines with critical slopes should be checked. Dead-end lines, hydrants, and other risers should be examined to see that they drain properly. All systems should be checked for leaks, and proper insulation and repairs should be made if required. Sewer lines should be flushed out. Water pressures should be checked, and if chlorine is used to purify drinking water, its quality should be carefully checked. Repairs to underground mains should be made preferably in the early fall just prior to the freezeup, when thaw penetration is at its maximum. All trenches, however, must be backfilled and compacted before the freezeup occurs because frozen chunks in the backfill cause subsequent settlement.

3. STRUCTURES. Painting and repairs to all structures should be made during the warm season. Interior painting should be accomplished with the doors and windows open and with the heat turned on. Airspaces underneath the buildings constructed on permafrost should be closed off before the spring thaw, to retard the entrance of atmospheric heat into the frozen subsoil.

4. CAMP AREA. Every area of the camp should be thoroughly cleaned and put in orderly arrangement before the freezeup. Containers of materials, and equipment and buildings that are to be moved in the winter should be placed on blocks to prevent freezing to the ground. Figure 4C1-1 shows how a dry, snow- and ice-free camp fuel-dispensing station can be made by mounting standard T6B pontoons, as storage tanks, 4 or 5 feet above the ground on timbers. Beachheads, roads, airstrips, and base areas should be leveled and graveled, and drain ditches recut as necessary. Tripods and poles supporting overhead power and communication lines, as well as surface supports for utilidors, should be raised to upright positions. Maintenance operations involving excavation or grading should be completed before the freezeup, and areas that have been roughened by construction activities should be dragged level.

4C1.02 EQUIPMENT AND SUPPLIES

Winter transportation equipment, snow compaction and removal equipment, snow fences, tackle, rigging, small tools, and other maintenance equipment used primarily during winter should be put in first-class mechanical condition so that it will perform without additional repair during the winter. Stocks of spare parts, lubricants, fuel oil, antifreeze, chlorine, firefighting materials, and other consumable supplies should be stockpiled and inventoried. Material in outside storage areas

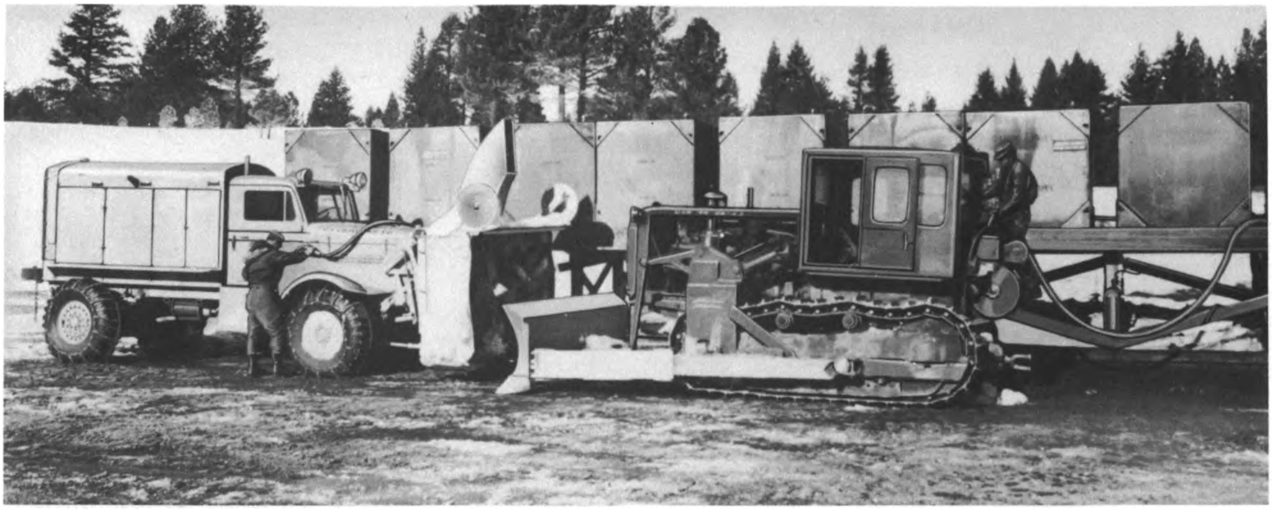


FIGURE 4C1-1

Fuel Dispensing Station Constructed of T6B Pontoons Mounted on Timber Framework

should be stacked in an orderly fashion in an arrangement permitting operation of snow removal equipment between the material and with provisions for proper surface and subsurface drainage to minimize possibility of winter icing. The stacks should be carefully marked and, if practicable, their arrangement should be recorded by photographs to facilitate identification when the area is blanketed with snow.

4C1.03 INSECT CONTROL

1. ARRIVAL. In the Arctic the spring thaw is followed by a sudden emergence of swarms of mosquitoes and other insects. The latter include horseflies, botflies, and blueflies, which are troublesome but present no serious problem. The arrival of the mosquitoes coincides with the mildest weather, which is the period of greatest possible human activity; personnel, therefore, may be handicapped by these pests. Control meaures may be required in the vicinity of bases and permanent camps. (Ref. 90.) A report (Ref. 105) on Arctic mosquitoes is quoted as follows.

> Studies on the biology and control of Arctic mosquitoes were made at Umiat, Alaska, in 1946 and 1947. Larvae were found in grassy sloughs, mossy pools, frost ditches and willow-alder pools, but not in waters subjected to wind or wave action. A species selectivity for these habitats was observed. Associated rearings were made of three species: *Aedes punctor* (Kirby), *A. communis* (DeGeer), and *A. nearcticus* (Dyar). One-third instar larva of an unidentified fourth species was found.
>
> There is only one generation of mosquitoes annually and the Arctic *Aedes* apparently overwinter in the egg stage. Larvae emerge as soon as the ice thaws from around the eggs. Larval development requires almost a month, pupal about five days and the adult female persists until the first heavy frost. The adults do not fly when winds exceed ten miles per hour, or when the temperature is less than 45° or greater than 80° F.

2. CONTROL. An effective control program consists of 5- and 10-percent solutions of DDT in fuel oil applied aerially in a dosage of 0.2 and 0.4 lb of DDT per acre, sprayed every 5 days. Field parties should be provided with repellents, headnets, and aerosol bombs.

Section 2. WINTER MAINTENANCE OPERATIONS

4C2.01 PREPARATION FOR WINTER OPERATIONS

1. PERSONNEL TRAINING. The highest possible standards should be set for winter maintenance operations. Careful planning and adequate preparations before the freezeup can help greatly in simplifying operations after winter arrives. Camp routines should have been well established and daily tasks performed thoroughly and on schedule. Snowplow operators and truck drivers should have been trained by competent instructors and have practiced snow removal techniques on dry runs at every opportunity. This training should have included those personnel who are to assist the drivers in manipulating the plow controls. All operators should have studied manufacturers' instruction books and service manuals pertaining to the equipment they are certified to operate. Considerable practice by operators of specialized snow equipment is necessary if it is to be used to full capacity and adaptability. Much more speed and throw can be obtained if operators are sensitive to the limitations and capacities of each piece of equipment and are continually endeavoring to become more skillful in the many possible methods of operation to meet the various conditions to be encountered.

2. AREA WINTER READINESS. A thorough cleanup of the camp area should have been made before the first snowfall. Roads and paths should be clearly outlined with flags on high marker poles. In areas subject to severe blizzards men can become lost during storms even when very close to their quarters if they do not have some marker to guide them. All materials should have been neatly stacked in their storage areas, and all areas should be well marked to identify the type of material stored. Containers or other objects left around outside and not in their proper storage place will become covered with snow and may be damaged by snow removal or other equipment. Rubbish should be properly disposed of and not thrown in the snow where it may interfere with winter operations and become an unsightly mess in the spring thaw. Oil drums and other containers should not be stored closely upwind from airstrips, where they may cause drifting across the strip, nor in locations where they may cause icing or interference with drainage.

3. FIRE PREVENTION. The most rigid fire prevention precautions and disciplines must be maintained, for lack of large quantities of water combined with low temperature and wind usually result in complete loss of a structure if a fire starts during winter. Frequent and thorough inspections should be made by trained men. Stoves should be checked periodically for mechanical defects and cleaned daily during winter months by fire watchmen specifically assigned to this work. Each stovepipe outlet should be equipped with a vane exhaust or other device to prevent downdrafts in the stovepipe. Such drafts can be severe enough to blow out an oil fire or spread flame out of the stove to flammable material nearby. An adequate supply of fire extinguishers and other first-aid firefighting equipment should be readily available and maintained in satisfactory operating condition. (See also Section 2F1.)

4. REFUSE DISPOSAL. Garbage and rubbish can best be disposed of by burning either on an open dump, carefully located in relation to prevailing wind and at a safe distance from the base, or in an incinerator.

5. TOOLS AND EQUIPMENT. At the start of the winter season, all tools, rigging, and equipment to be used for maintenance, transportation, and construction operations, as well as service equipment, utility systems, and their component parts, should have been inspected for mechanical condition and, if necessary, completely overhauled and placed in their best state of repair. Spare parts should have been carefully selected and should be on hand in sufficient quantity to assure continuity of operations through the season, with a minimum of equipment deadlines. An adequate supply of extra tools and rigging should be provided for storm periods or other emergency work. All hand tools and other maintenance equipment should be stored in a definite location when not in use and should be maintained in good working order.

4C2.02 SNOW AND ICE CONTROL EQUIPMENT

1. GENERAL. Snow and ice control requirements and problems vary at every location, and techniques and equipment must vary accordingly. No ironclad procedure regarding either can be established, but it appears at present that advanced

ideas in mobile equipment offer, and will continue to offer, the quickest approach to a possible solution to all snow and ice control problems. The control equipment selected for any facility must be capable of keeping traffic lanes operative and of accomplishing this mission within the time limit allowed. The operational requirements of the traffic lanes of close-in post, camp, or station areas will vary with the type of traffic lanes and with the activity in the area. The requirements of a highway, railroad, or airfield must be geared to the urgency of passage of vehicular or airborne traffic. The equipment should be durable and simple to operate and maintain and should provide adequate comfort and vision to the operator. The equipment and its attachments should be capable of satisfactory performance under the environment of the area. If the equipment is for an airfield, it must be capable of immediate clearance from the runway to permit emergency landing of aircraft. It should function without damage to operating surfaces or installed equipment adjacent to operating areas. (Ref. 93.) For further information on equipment, reference should be made to *Snow Removal*, NAVDOCKS TP-Pw-29.

2. SNOW REMOVAL. Snow removal equipment should be tailored to meet specific needs, depending on climatic information pertaining to average snowfall, frequency and type of snow, and terrain and wind conditions encountered. In isolated forward areas of the Cold Regions more reliance must be placed on crawler equipment than is necessary in northern areas where there is no lack of established roads. The *Catalog of Navy Material*, Part C, lists typical Bureau of Yards and Docks components of snow removal equipment to clear and maintain a one-strip airfield and relating taxiways, ramps, aprons, and roads in Arctic and northern areas. It is expected that local environments may require that the components be modified to meet field requirements.

a. *Blade Plows*. The ability of a blade plow to handle snow depends on the weight and quantity of snow; the size, type, and design of the plow; and the weight, traction, and speed of the unit pushing the plow. Especially designed high-speed displacement plows are capable of dispersing snow over distances of 20 feet, which reduces the number of times the snow must be handled. Speeds of 20 to 30 mph are necessary to obtain this dispersion; and to reach these speeds, powerful special-purpose 4-wheel-drive prime movers are necessary. Blade equipment generally used for fast traffic lane clearing is not affected by adverse winds to the same degree as blower-type equipment. The selection of the snowplows for a given area is a matter of judgment, which is affected by numerous variables. For work involving long, wide areas, such as an airstrip that must be cleared within limited time, a well-balanced operation usually includes many types of plows and various techniques. Generally speaking, techniques resolve into windrowing the snow by using truck-mounted straight blades and V-blades and then removing the snow by rotary plows or blowers. (Ref. 93.)

(1) *V-Plows*. V-shaped plows are more effective than other types in breaking through heavy drifts. In packed and crusted snow, however, the blade should be mounted on a crawler tractor rather than on a wheeled vehicle. V-plows are commonly used by railroads for single-track snow clearance and by highway networks and airfields. In heavy snow areas, plow groups usually include at least one V-plow equipped with sand hopper and a mechanical spreader, a combination that is used for making the initial cut after severe drifting has occurred. (Ref. 31.)

(2) *One-Way Plows*. One-way plows, usually hydraulically controlled, may be mounted on either truck or tractor. They are of various widths, depending on the size of the prime mover. When in use, the plows are set at an angle so that the snow slides off the end of the plow. Medium one-way blades are best adapted for speed work on runways, roads, and other large continuous areas; the heavy one-way blade units should be used when there is a heavy accumulation from removal of great widths. Reversible blades are best adapted to roadway and parking areas.

Modern plows have been designed to give the best possible visibility and protection against snow spray. Because of this, plowing speeds of 25 mph are possible and generally safe. At speeds over 20 mph the dispersion and spread of especially designed displacement plows are excellent. Over 25 mph there is little gain in dispersion and spread. At less than 20 mph the dispersion and spread fall off noticeably, and at 10 mph there is practically no spread or dispersion, but only displacement. (Ref. 106.)

(3) *Side Wings*. Both V-shaped and straight-blade plows may be equipped with side

wings to widen the length of the cut. Side-wing units when used in conjunction with other blade plows are particularly useful in adding increased width on runways beyond that which is possible with plain blades. On fast runway clearance it is frequently the case that the depth or resistance of the snow is such that efficient plowing speeds can not be maintained with the full cutting width of the front plow and wing. In such cases, the outer end of the wing can be raised to permit proper plowing speeds. Also, in very deep snow it may be necessary to pull in the wing completely on the first or opening pass. On widening cuts, the unit may be steered so that only a narrow width of cut is taken by the front plow. The wing should be raised at the outer end to give proper snow flow. In extreme cases it may be necessary to raise the front end of the wing, leaving a bank or windrow that must be cut down or shaped on the next trip. The usefulness of side wings depends to a large extent on the skill of the driver and the wing operator. Side wings mounted on railroad plows have many useful applications and are widely used. (Ref. 106.)

(4) *Grader Blades.* Motorized graders are not effective in drifts or heavy snow, but are excellent for plowing light snow and for removing ice and clearing snow and ice ruts. Power graders equipped with large, strong scarifier teeth can rip up hard snow and ice down close to the pavement surface. Compacted airfields can be cleared quickly in the spring by ripping the surface with grader scarifier blades, gathering the broken material into ridges with blade plows, and removing the ridges with snow blowers.

b. *Rotary Plows.* Several types of rotary plows, one of which is shown in Figure 4C2-1, are acceptable for advanced base use. One of these in a test run moved snow weighing 26.2 lb/cu ft at the rate of 1,536 tons/hr and discharged it a distance of 60 to 85 ft. Another rotary removed the same weight of snow and discharged it 125 ft at the outer arc in calm weather. The capacity of a rotary plow depends on the horsepower of the engine employed by the rotors. Reports indicate that unless a rotary is capable of pulverizing all snow directly in its path, the vehicle on which it is mounted must have sufficient traction to force the unit into the unbroken snow. During operation, snow passes to the rotary turbine and is driven up and out through the chute and is discharged. The efficiency of a rotary plow depends to a considerable extent on the skill of the operator. The capacity of the rotary must be synchronized with the speed of the truck, otherwise the blower becomes clogged if the speed of the truck is too great, or the blower operates at only part capacity if the speed of the truck is too slow. Under ideal conditions of synchronized truck speed and blower capacity, the discharge will show a distinct pattern of blade pulsations of compressed snow.

c. *Prime Movers.*

(1) *Trucks.* The weight, traction, and speed of the prime mover are extremely important in obtaining maximum efficiency from snow control equipment. Two- to five-ton trucks with one-way blades mounted in front have many useful applications in clearing moderate depths of snow. However, in obtaining the speeds necessary for proper dispersion and spread on displacement plows and the power and maneuverability required by snow blowers, all-wheel-drive-steer trucks of 6 tons or over are superior to all other types.

(2) *Motor Graders.* Figure 4C2-2 shows a conventional heavy-duty motor grader equipped with an 8-ft V-blade and a blower-type side wing. Both V-blade and side wing are hydraulically raised and lowered. Only heavy-duty motor graders of the 12-ft moldboard size have the power and stamina necessary for snow removal.

(3) *Tractors.* Crawler tractor equipment is a necessity in forward areas of the Cold Regions where there are few established roads. Tractors should be fully winterized and equipped with a hydraulically controlled blade and power winch.

d. *Miscellaneous Equipment.*

(1) *Loaders.* Snow blowers are often used for loading dump trucks at taxiway and runway intersections and at other locations. Tractor-drawn carryalls, when available, can also be used advantageously for this work. They are particularly useful in removing snow from lanes of storage areas and from the outer edges of loading and hangar aprons after a severe storm. Small conveyor and front-end loaders mounted on crawler tractors have many useful applications.

(2) *Sweepers.* Rubber-tired tractor-mounted rotary brooms and gang-type towed sweepers are useful in sweeping sand from runways, taxiways, and other paved areas.

(3) *Hand Tools.* Hand tools for snow

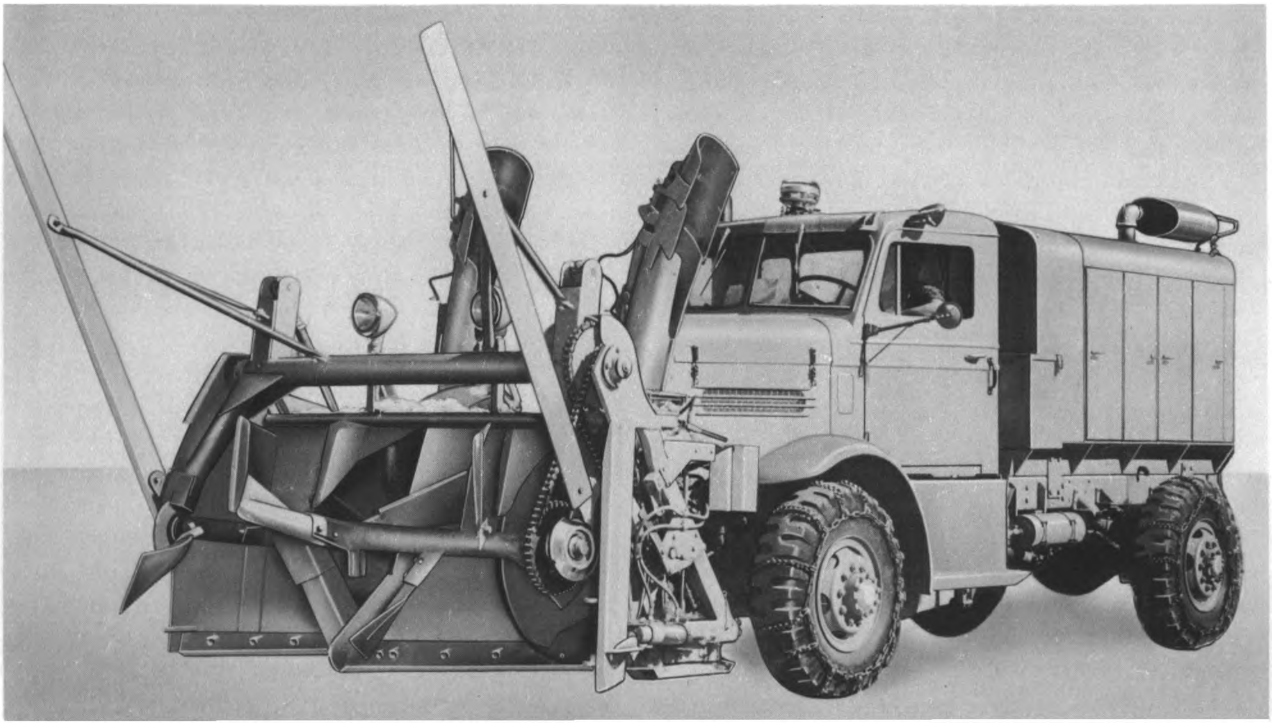


FIGURE 4C2-1

Rotary Snowplow, Truck-Mounted

and ice control should include an adequate supply of general-purpose shovels, scoops, snow pushers, ice choppers, heavy street brooms, and hand thawing equipment such as the weed-burner flame thrower.

3. SNOW FENCES. Snow fences create an artificial obstruction that lessens the velocity of windborne snow and deposits it on the lee side in a selected location. There is a wide variety in use. Common commercial types consist of metal posts and wooden laths or metal pickets about 5 ft long and woven together with wire. Fences 10 to 12 ft high are not unusual. Fencing of this kind is portable and easily erected and removed and may be rolled for compact storage. Expedient fences can be made of brush, branches, or other such material anchored in place by wire or wood. Permanent snow fences are often built of heavy posts embedded in the ground with horizontal boards nailed to them. Semipermanent metal fences using corrugated metal plates have given excellent service and have the advantage of strength and elimination of fire hazard. Heavy sisalboard fences have been used in northern States. The material seems to have advantages in cost and lack of bulkiness, but no conclusive report is available on their ability to withstand heavy winds.

4. ICE REMOVAL.

a. *Materials.* Calcium chloride has been used with success on roadways, but it is not suitable for runways because it causes excessive corrosion on surfaces and running gear of planes. If used on walks, it is tracked into buildings where it damages floor surfaces, shoes, and clothing. Efforts are being made by the chemical industry to find a neutralizer for calcium chloride. (Ref. 93.)

Rock salt crystals also are widely used on roadways and small operating areas and, in special cases, on airstrips. Salt is corrosive and, when used on airstrips, hazardous to personnel and equipment because of flying salt particles.

Calcium chloride, in the proportion of 2 percent by weight, is effective to −55° F in preventing sand stockpiles from freezing. Salt in the same proportion loses its effectiveness at −5° F. (Ref. 93.)

Thermo lead-sheathed cables have been used in many locations to prevent icing. A common ap-

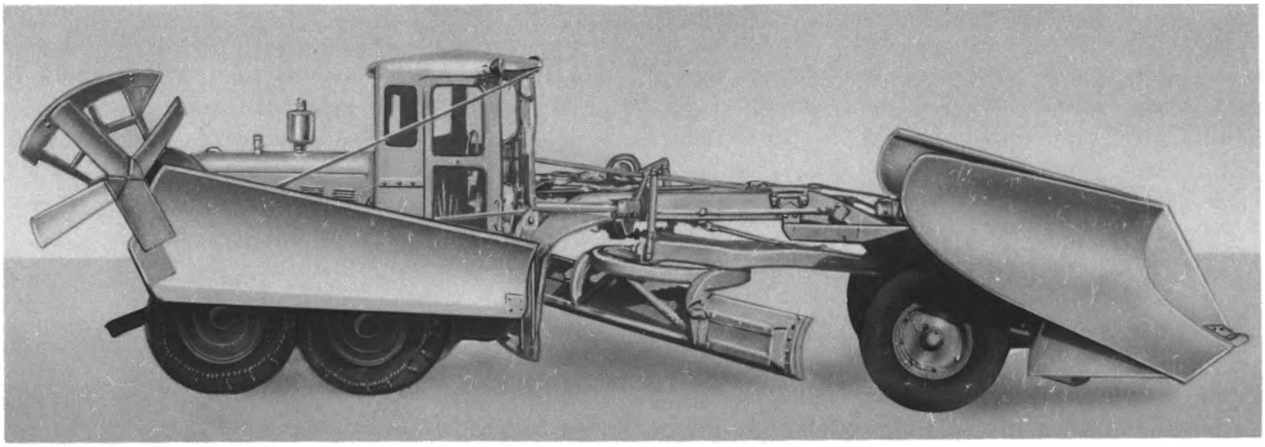


FIGURE 4C2-2

V-Plow With Roto-Wing Attachment, Grader-Mounted

plication that has been successful is under the eaves and downspouts of heated buildings.

b. *Distribution Equipment.* Tests on sand spreaders indicate that friction-drive and independent-drive trailer-mounted sanders are unsatisfactory because they are difficult to maneuver. A disk type with gasoline motor for truck mounting is recommended.

5. MARKERS. Roads and airfields should be suitably marked to guide crews and prevent damage or obstruction to lights, hydrants, catch basins, inlets, curbs, and similar appurtenances. Advance markers should be placed to delineate runway, taxiway, hardstand, and roadway outlines and intersections and should have high visibility and appropriate marking for easy identification. (Ref. 106.)

4C2.03 SNOW AND ICE CONTROL METHODS

Information supplementary to the following is contained in Part F of *Snow Removal*, NAVDOCKS TP-Pw-29.

1. SNOW REMOVAL. Complete removal of snow is required in regions where climatic conditions do not permit compaction or where snowfall is in excess of that which can be compacted. Light snowfalls are removed with angle dozers, tractor-mounted one-way blades, truck-mounted plows, and rotary snowplows. Drifts are usually opened by tractors or trucks with V-blades or by a rotary snowplow. An effective cutter for high drifts is a rotary consisting of 3 horizontal light spiral blades mounted one above the other. The action is similar to that of a disk harrow turned vertically. V-blades on wheeled vehicles are generally ineffective in packed and crusted snow. Large crawler tractors operating as bulldozers in parallel, tandem, or echelon should be used under such conditions. Dozers are quite effective in pulling down steep snowbanks so that rotary plows can operate. The efficiency of displacement plows decreases rapidly as new windrows increase in depth. In general, rotary plows or blowers should be used to remove windrows over 10 inches high. (Ref. 31.)

a. *Roads.* Snow should be removed from the road surface as soon as possible after it falls. Equipment should, when practicable, be stored along the roads and, with its operators, should be ready to move promptly when a snowstorm occurs. Sections of the road subject to drifting should be patrolled in windy weather with drags or plows. Two and one-half to five-ton trucks with one-way blades are best adapted for clearing moderate depths of snow on long stretches of roads. They usually operate at from 15 to 25 mph. For heavier snowfalls or to widen traffic lanes, heavy 4-wheel-drive special-purpose displacement plows are best, although standard 5- to 10-ton trucks equipped with straight or V-blades are used on many highway networks. Standard equipment operates usually on heavy drifts at about 15 mph. Special-purpose equipment should be designed for 20 to 30 mph. V-shaped plows are more effective than other types in breaking through heavy drifts. Either V-shaped or straight-blade plows equipped with side wings are used to push the snow beyond the shoulder line and to provide room for additional snow storage. Abrasives for better traction and as ballast are usually carried by plowing trucks. Tractors are sometimes required for heavy snowfalls and deep drifts. Motorized graders are satisfactory for light snow. (Ref. 31.)

b. *Bases.* Snow removal from storage and service areas, driveways, and parking lots can be economically handled by truck- or caterpillar-mounted straight blades and V-blades to accumulate and windrow the snow. The windrow is then loaded into dump trucks by snow blowers or snow loaders, available in many types. Certain types of conveyor or front-end loaders are effective, but all available types are not suitable for advanced base use. Carryall scrapers are often used to remove snow from around buildings and from parking and material storage areas. Material piles should be so spaced that carryall scrapers can remove snow that drifts around them. In areas where the snow is dry and crystalline, snow should be disposed of in flat spoil piles on the downwind side of the camp area. Whenever possible, advantage should be taken of high wind to blow snow clear of operating areas. Often winds of even 10 to 20 mph are sufficient to blow light snow long distances. Constant operation of drags during periods of moderate winds prevents snow drifting on traffic lanes. In many areas rotary brushes have been effective in keeping loading platforms clear of snow. Several types of brushes and sweepers are available as standard equipment, but tests have indicated that all types are not suitable for advanced base use.

c. *Airfields.*

(1) *Runways and Taxiways.* Snow removal from airfields is started as soon as possible after the first snow falls, preferably after only 2 or 3 in. have accumulated on the runway. Equipment is then kept in operation until the storm is over. Ordinarily, runways into the wind are cleared first and, if conditions warrant, all access taxiways thereto. At the same time, snow should be loaded and hauled away from taxiway and parking areas. Because it requires some time (depending on area, weight, and depth of snow) to prepare a runway for blower operations, the rotary plows should be used on the ramp and taxiways until they are required on the runways. All taxiways should be plowed to their full width. Each storm presents special snow removal problems at taxiways and parking aprons. Frequently, immediate removal may be impracticable, in which case windrows should be spaced far enough apart to permit aircraft and vehicular movement. Openings in the plow windrows should be cut as required, pending their complete removal. When parked planes are encountered, operators should use extreme caution to avoid damaging the aircraft by crowding snow or ice against them. To aid pilots to land during whiteouts, windrows should not obscure airstrip marker lights, and the thin layer of snow remaining on the airstrip should be marked with dye or carbon black along the centerline of the runway.

At one airfield, which may be considered typical, several heavy all-wheel-drive trucks with hydraulically controlled one-way plows mounted on front are started along the edges of the runway next to the lights. They plow the snow from the runway edges toward the center for 10 to 15 ft. The trucks are driven between 20 and 25 mph and each plows a swath 8 to 10 ft wide. Plows then start down the center of the runway and plow from the center toward the sides, adding snow to the windrows already established 10 to 15 ft from the edges of the runway. When the plowing is completed, there will have been formed two ridges of snow well out from the runway lighting. Snow blowers are then brought into operation, picking up the windrowed snow and blowing it to either side over and past the runway lights. If there is no convenient place to deposit the snow, it must be loaded into dump trucks and hauled away. Loading and hauling must usually be done at runway intersections, parking areas, and around buildings. In these areas a snow blower or other suitable loader loads the snow into dump trucks, which haul it to a selected location. The snow storage area should be closely accessible and of adequate size.

Another common method is to start truck-mounted snowplows at the center of the runway, operating in echelon and moving the snow progressively to the sides with each lengthwise trip. The windrows are then picked up and blown over the lights by a rotary blower or, if necessary, removed by loaders and dump trucks. Snow left around landing lights and other obstructions must often be removed by small mechanical loaders or by hand. (Ref. 93.)

In working runways or taxiways that are situated crosswind, plowing should be done so as to take advantage of the wind in throwing snow and to maintain a minimum height of snow to the windward. (Ref. 106.)

When wet snow is encountered, every effort should be made to clear it entirely before the windrow freezes and causes serious difficulties.

Calcium chloride and rock salt should not be used on any portion of the runways, taxiways, or aprons. These materials should be confined to local and service roadways because of their detrimental effect on aircraft.

(2) *Adjoining Areas.* Snow-covered areas adjoining runways and taxiways should be dragged and rolled to prevent the snow blowing and drifting on operating areas and building up too high. Banks should not be more than 24 in. high, and their slopes should be graduated. No snowbanks should be permitted close to the sides of the runway. At one airfield, for example, the minimum distance allowed is 100 feet. (Ref. 93.)

(3) *Camouflage.* From the standpoint of camouflage, it is desirable to leave some snow on the runway when the surrounding terrain is covered with snow. However, a thin layer of snow next to the pavement often turns into ice and is difficult to remove.

(4) *Personnel Safety.* Safety to all personnel concerned should be the first consideration in airfield snow removal. If truck drivers and equipment operators have been well trained in their duties at the airfield and are kept under close supervision, all operations can be accomplished with a minimum of accidents. Arrangement of equipment into operating groups simplifies the coordination of snow removal operations with the control tower. If practicable, a radio-equipped car should patrol the areas at all times while removal operations are in progress. The patrol vehicle should carry truck-servicing tools, tow cable, jacks, tire chains, oil, gasoline, antifreeze, and other emergency equipment. Some easily recognized signal, such as the flashing off and on of runway lights, should be established to warn all concerned that the runway must be immediately cleared of all vehicles. Vehicles should then move at least 100 ft off the nearest edge of the runway and the tower should be notified of their locations before a landing is made. (Ref. 106.)

d. *Railroads.* When possible, snow from railroad tracks is removed as it falls, before it has had time to accumulate and drift. Before snow builds up to any degree, high-speed operation of plows is possible and a lot of territory can be covered in a short time. Intense and prolonged storms, however, frequently make it impossible to follow this policy.

(1) *Clearance Problems.* The problems of railroad snow clearance vary greatly with line cross sections, particularly the shape of berms, cut slopes, and the amount of snow storage area, as well as with the quantity and type of snow involved. Whenever possible, fill embankments are used through areas where snowfall is heavy and subject to drifting.

In mountainous areas, where winds are turbulent and snow movements are of great magnitude, snow fences are often of little or no value. Snowslides that follow approximately the same course each winter can be controlled by construction of snowsheds, which carry avalanches over the tracks. Frequently, however, slide patterns are erratic and their location or occurrence can not be predicted accurately. They often complicate removal by gathering trees and loose rocks that happen to be in their paths and depositing the mass in huge piles on the tracks. Rotary plows can not remove such material. The heaviest bulldozers are the most efficient equipment for clearing snowslides containing timber or rocks.

(2) *Track Clearance.* When heavy drifts are involved, the rotary plow is the mainstay of railroad snow removal equipment. A new type, consisting basically of two rotors, one mounted above the other, was developed some years ago and showed enough promise to justify further work, which has been done under railroad sponsorship. The new model has not been fully tested. Drifts 18 ft high can be fed into the rotors of this machine. (Ref. 93.)

Some plows are supplied with side wings, which can fold back against the plow or can be extended to clear snow on both sides of the train usually a total of 6 ft beyond the width cleared by the plow. The wings are operated by compressed air from the cab and can be snapped open and shut quickly. The Canadian Pacific Railroad uses this equipment and has had considerable success. (Ref. 93.)

There are several types of wedge plows. The full V-wedge is used for single-track operation. Right- and left-hand wedge plows are used for double-track operation. A third type is the spreader or wide-winged dozer, which is used by practically all railroads for yard and terminal clearance. Wings that can be attached to spreaders are being developed to give additional width of cut, which is desirable in yards containing many tracks. These wings extend 16 ft beyond the sides of the spreader when it is in the open position, making possible a total overall cut of 42 to 45 ft. Windrows left by a spreader are blown out with a rotary or loaded and hauled away. On-track snow-melting equipment is sometimes used when it is necessary to load snow from terminal trackage and when there is a lack of clear area for snow storage. These machines pick up the snow at the front and blow or convey it into a hot-water tank which must be dumped periodically.

(3) *Switch Clearance.* There has recently been developed an automatic snow-blowing mechanism to keep railroad switches free from snow during storms. The equipment consists of a small compressor that charges a receiving tank. Intermittently the tank discharges and blows the snow away from the critical locations.

There are several types of automatic heating devices available for switch and interlocking point clearance. They are not, however, effective when the temperature gets much below freezing. Below freezing, manually operated open heaters are usually required.

2. SNOW FENCES.

a. *Purpose.* Drifted snow obstructs traffic more than an equal depth of freshly fallen snow because it is finely divided and compacts into a dense mass. Drifts form when windborne snow loses velocity and is deposited in sheltered places. Drifts form in the lee of buildings and other obstructions, on roads at ground level, or in cuts adjacent to large open areas. High snowbanks left close to a traffic lane furnish ideal conditions for heavy drifting across the traffic area.

b. *Placement.* Snow fences are usually placed 100 to 150 ft to the windward of the protected area but may be placed as far out as 300 ft in unusual cases. No set distance can be prescribed, because wind velocity, shape of ground, height of fence, and other factors influence location. If fences are set too close in, the drift to the leeward of the fence falls on the protected area. If they are set too far out, they have little or no effect in reducing drifts. Two or more parallel lines may be necessary in severe locations, additional lines being added to provide additional storage capacity as required. Along existing traffic lanes, locations can best be determined by the experience of the men who patrol the right-of-way.

In territory that is subject to drifting snow, cuts should be provided with the flattest possible slopes to permit snow to blow free. To produce this result, slopes not greater than 8:1 are required. When it is not possible to maintain this kind of slope, it is then desirable to erect snow barriers. Experience in the North Central States has indicated that to keep the accumulation of snow clear of the tracks the distance the barrier should be from the track is approximately 8 times the height of the barrier and in no case less than 100 ft.

c. *Erection.* Snow fences should be erected before the ground is frozen. Metal or wooden posts are driven into the ground and the fencing attached with annealed wire to the windward side. In areas of heavy snow, posts should be long so that the fencing may be raised on the posts as the season progresses to increase snow storage to leeward. One end of the post should be a chisel point and the other end without flare or burr to permit using the driving tool. Fencing should be initially in-

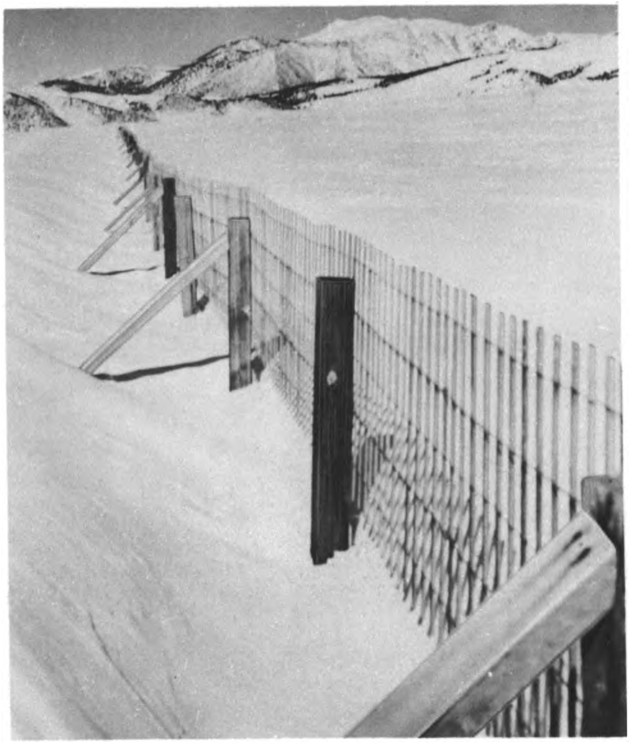


FIGURE 4C2-3

Snow Fence

stalled with the bottom raised above the ground level to prevent its freezing to the ground. Intermediate posts should be cross-braced diagonally as required by anticipated wind velocities, and end posts should be securely guyed. Wire stretchers should be used in the erection of slat fences or other types involving wire bracing or guys. (Ref. 31.) Figure 4C2-3 shows a typical method of snow fence erection.

d. *Maintenance.* Snow fences should be inspected after heavy storms and the necessary repairs made to blown-down sections or to broken ties, guys, and braces. They should be kept raised to exceed the height of snow that has accumulated to the leeward. Lowering of fences may also be required after long periods of settling or after sudden thaws. (Ref. 31.)

3. SNOW COMPACTION. Snow compaction is the compacting of snow where it has fallen on runways and other traffic areas. Ordinarily, compaction is practicable in areas where there is a minimum annual snowfall of 2 ft and a continuous cold season with temperatures below 20° F for at least 3 months. The various techniques and equipment used in compacting snow are discussed at length in Section 3D1. All techniques involve agitating the snow to get the air out of it, leveling it at the same time by drags, then rolling it to press the snow solidly together without any voids, as shown in Figures 4C2-4, 4C2-5, and 4C2-6, respectively. Initial compaction is a most important process. The first 2 inches or so of snow must be solidly cemented to the runway or road surface to form a compacted base on which to build subsequent layers of compacted snow. To do this, drags and rollers must be put to work immediately after the first few inches of snow have fallen, and rolling must be kept up continuously until a satisfactory surface is obtained. The large roller shown in Figure 4C2-6 is preferable to a smaller roller because of the plowing effect of the latter. Approximately 12 inches can be compacted to 3 inches of firm, solid snow. Layer after layer may be built up in this manner until by spring there may be a considerable depth of solidly compacted snow.

The towing tractor should be powerful enough to tow a set of snow rollers behind the snow drag or pulvimixer. (See Section 3D1.) Corrugated

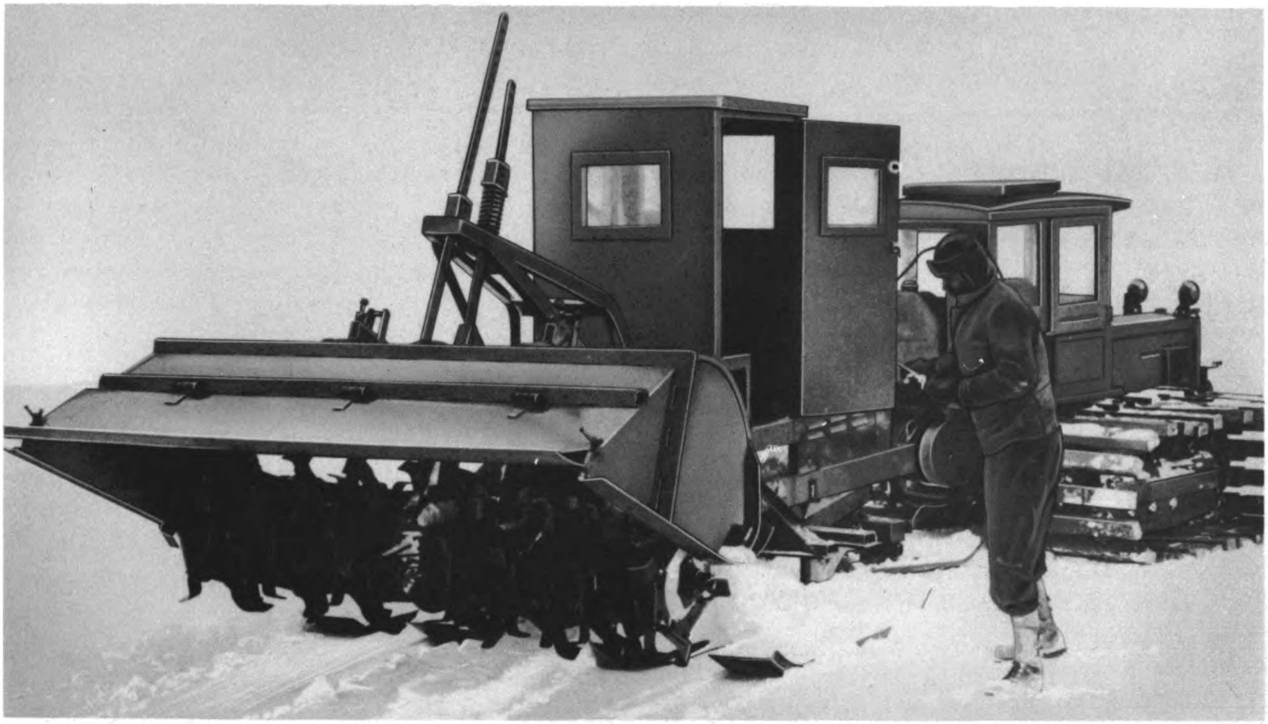


FIGURE 4C2-4

Pulvimixer, Runner-Mounted, Towed by Class I Tractor

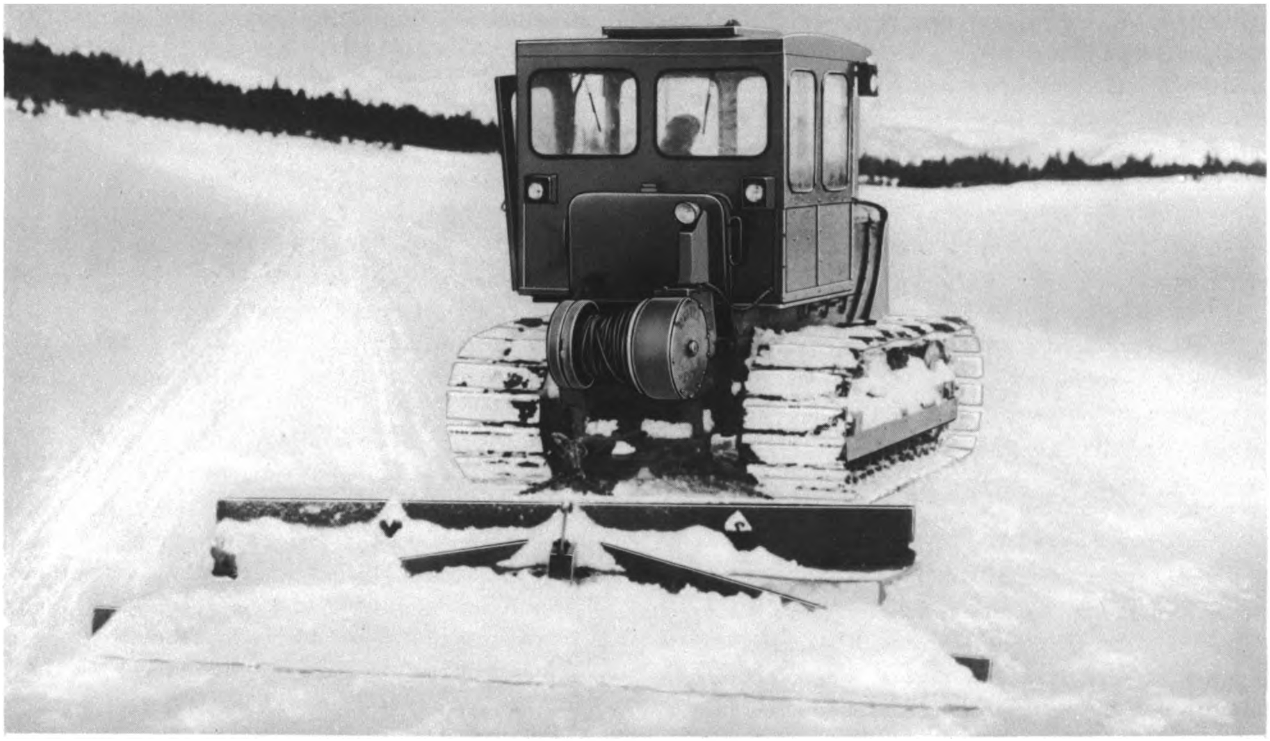


FIGURE 4C2-5

Snow Drag Leveling Snow

rollers make a slight impression on the snow and give depth perception to a pilot when landing. (Ref. 93.)

Thaws may make the surface of the compacted snow icy. Scarifier teeth attached to adjustable drag blades remedy this by providing a scratch surface that, if sanded, gives good braking action. (Ref. 93.)

4. DRAINAGE PRECAUTIONS.

a. *Compacted Snow.* At airfields on which layer after layer of snow has been compacted there may be, by spring, 2 or more feet of solidly compacted snow. During the spring breakup, the snow should be slowly reduced by using scarifiers to scrape the surface, allowing it to melt and evaporate during the heat of the day. Even if this is done, however, there may be a period when the thaw is so rapid that drainage facilities can not handle the melt water, and the field becomes a lake on which aircraft can not land with safety.

To avoid the necessity for closing the airfield to traffic, a system of combined compaction and removal is adopted that keeps the snow at a constant compacted depth of approximately 5 inches; any snow in excess of this is gathered in windrows by blade plows and blown away. In the spring, the compacted surface may be broken by using a heavy power grader equipped with strong scarifier teeth that rip up the hard snow and ice down close to the pavement surface. The blade plows then quickly gather the broken material into windrows and the snow blowers grind into it and blow it into dump trucks or to infield areas. By using this method, stoppage of flying operations in the spring is avoided and there is no serious drainage problem. (Ref. 93.)

b. *Snow Windrows.* Windrows should not be left where they will obstruct catch basins or other drainage inlets or drainage channels. If windrows are allowed to remain and freeze in such locations, full advantage can not be taken of the drainage facilities that have been provided, and portions of the field may become inoperative during critical periods.

5. SANDING.

a. *Hot Sand and Wet Sand.* The last thin layer of snow on an operating surface is difficult to

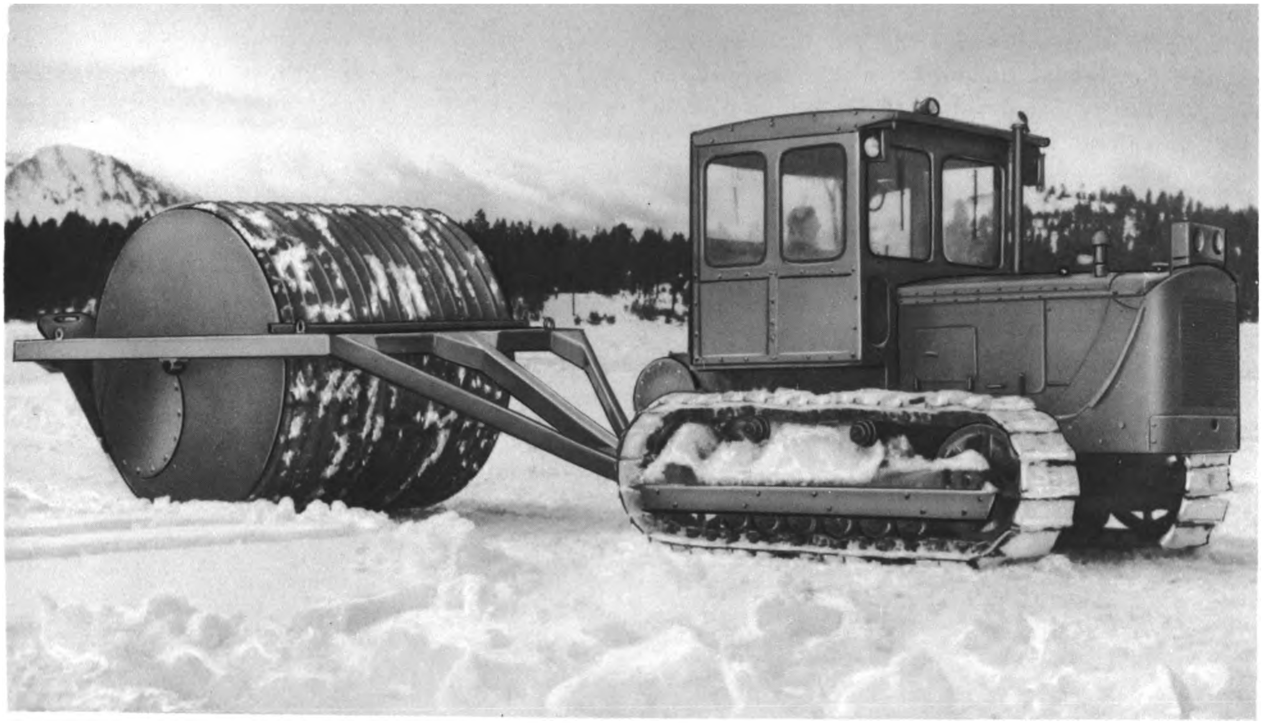


FIGURE 4C2-6

Roller Compacting Snow

remove, and if a thaw occurs, an icy condition develops. To create a good braking surface for the wheels of aircraft and other vehicles, sanding is resorted to. It is difficult, however, to keep sand on pavements because it is easily blown away by the wind, and on runways by the slipstream of aircraft as well. If the sand is heated, it will embed itself in the ice and be less easily blown away; hot sand, however, usually penetrates the ice so deeply that no abrasive action results. A method that has been used with success in some areas is to sprinkle water on the ice immediately before sanding to freeze the sand to the ice.

b. *Spreading*. Sand and other loose abrasive materials are unacceptable at military airfields because of possible damage to jet turbines. (Ref. 31.) If sand is allowed on the airstrip, it is often laid down in 2 strips about the width of the aircraft running gear, each strip being 6 to 10 ft wide. Sanding operations are usually required until the snow reaches a depth of 2 in. or less or until a freezing rain occurs. Also, if necessary, a compacted snow surface may be sanded to provide good braking action for aircraft wheels. Sanding operations should begin on all paved surfaces as soon as hazardous conditions are noted.

c. *Ice Control on Road Surfaces*. A variety of conditions causes icing on roads. Poor drainage (Section 2A7), midday thawing and night freezing, or rain, sleet, or wet snow falling on cold pavement are common causes. Often films of ice are too thin to be removed by mechanical means and cause hazardous sections that are particularly dangerous on high-crowned roads and on grades and curves.

Wet snow and sleet can be kept from sticking to the surface by applying sodium chloride at the beginning of a storm. Icy pavement is treated with abrasives to minimize slipping and skidding. Sand, cinders, and other materials, such as crushed rock, slag screenings, pea gravel, and coal and coke screenings, may be used if available. Sharp, angular material embeds itself readily; dark-colored materials absorb heat from the sun and aid melting and embedding. For most effective use, calcium chloride is mixed with abrasive material, which causes the abrasive to embed in the ice and improve tractive qualities. The usual proportion is 40 to 75 lb of calcium chloride per cubic yard of abrasive for stockpiling and 25 to 50 lb more added upon application. Sodium chloride may be used in place of calcium chloride but is not effective, as previously noted, at temperatures lower than −5° F. Stockpiles of abrasive materials should be established at critical locations, such as steep grades and curves or other known dangerous areas. (Ref. 31.)

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APPENDIX A

GLOSSARY

ACTIVE CONSTRUCTION: method of construction in which permanently frozen soil is thawed and kept thawed, particularly in areas of relatively thin permafrost where the soil (sand and gravel) has sufficient bearing strength in a thawed state.

ACTIVE ZONE: the entire layer of ground, most of which freezes and thaws every year, above the upper surface of permafrost.

ADFREEZE: adhesion of frozen soil to contiguous objects by the binding action of ice resulting from water freezing.

AGGRADATION. See Permafrost.

ANCHOR ICE. See Ice.

BARRENS: level, treeless, and inland Arctic and Subarctic areas of muskeg or light sandy soil interspersed with floating bogs and sloughs.

BREAKUP: the melting time at which (a) ice on rivers breaks and starts moving with the current, (b) lakes can no longer be crossed on foot, and (c) frozen mud is soft and most of the snow is gone.

CALVING: breaking away of ice from a berg, a glacier, or shelf ice.

CANDLE ICE. See Ice.

COASTAL ICE. See Ice.

CONTRAIL. See Vapor Cloud.

DEGRADATION. See Permafrost.

EVAPORATION: process by which water (liquid or frozen) is changed to vapor.

FAST ICE. See Ice.

FIBROUS ICE. See Ice.

FIRN. See Névé.

FRAZIL ICE. See Ice.

FREEZEUP: the time when hardened mud no longer sticks to boots, a traveler can cross rivers and lakes on ice, and sleds can be used.

FROST BATTER: an inclined surface that helps to overcome the effects of changes in volume of confined materials when they freeze.

FROST MOUND: seasonal upwarp of land surface.

FROST SMOKE: mist or thick fog rising from the sea when the relatively warmer water is exposed to subzero ambient temperatures.

FROST TABLE: a more or less irregular surface representing the penetration of seasonal thawing. It is not to be confused with permafrost table.

GLACIER: field or body of ice formed from recrystallized snow that moves because of gravity to an elevation lower than that at which it originated.

GLACIER ICE. See Ice.

GLACIERING. See Icing.

GRISSEL: grains of snow less than 1 mm (0.04 in.) in diameter.

GROUND ICE. See Ice.

HORST: tract or mass of the earth's crust separated by faults from surrounding tracts that have been relatively depressed.

HUMMOCKED ICE. See Ice.

ICE.

- ANCHOR (BOTTOM): ice formed on the bottoms of rivers and lakes.
- CANDLE: long crystals formed in fresh-water ice or in salt ice that has become fresh.
- COASTAL: formations that, regardless of origin, exist between land and sea on the coast.
- FAST: stretches of broken or unbroken sea ice attached on one or more sides to land or to stranded hummocks or bergs.
- FIBROUS (ACICULAR): formed at the bottom of the ice near its contact with water. It consists of numerous long crystals and hollow tubes of variable form having a layered arrangement and containing bubbles of air.
- FRAZIL: a mush of ice spicules and water, resembling slush, that forms when turbulent water freezes.
- GLACIER: ice of glacial origin found under old moraines or outwash deposits.
- GROUND: bodies of ice in frozen ground, excluding ice of glacial origin.
- HUMMOCKED: ice piled haphazardly in short ridges or hillocks.
- PACK: any large area of floating sea ice driven closely together.
- PANCAKE: pieces of newly formed sea ice each about 1 to 6 ft in diameter.
- PRESSURE: a general term for ice displaced vertically by pressure resulting from wind, tide, temperature change, and so on.
- SEA: a general term for all forms of salt-water ice encountered on the surface of the sea.
- SHELF: thick glacial ice extending out from the land but attached to it.
- YOUNG: newly formed ice in transition from ice crust to winter ice.

ICEBERG: huge mass of ice calved from a glacier.

ICECAP AND ICE SHEET: perennial mantle of ice and snow covering a tract and moving in all or several directions from the center. An ice sheet, or continenal glacier, is a very large icecap, such as that covering Antarctica or Greenland. The latter, however, is commonly called the Greenland Icecap.

ICEFIELD: extensive sheet of sea ice.

ICE FOG: supercooled fine droplets of water caused by condensation during cloudless periods of low temperature, high relative humidity, and calms or light wind.

ICING: mass of surface ice formed by successive freezing of sheets of water that may seep from the ground, a river, or a spring. When the ice is thick and localized, it may be called an icing mound. In Alaska, it is frequently called glaciering.

INFILTRATION: process by which water or another element passes through material.

INSOLATION: absorption of heat from the sun's rays.

INTRAPERMAFROST WATER. See Water.

KARST. See Thermokarst.

LEAD: long, narrow navigable water passage through pack ice that is too wide for men and dog teams to cross. (See also Shore Lead.)

MUCK: mixture of decayed vegetable matter and siltlike material that forms the surface layer of the ground in permafrost areas.

MUSKEG: a *Sphagnum* bog, especially one with tussocks. Muskeg moss is any of the various mosses of the *Sphagnum*, *Hypnum*, and similar genera.

NÉVÉ (FIRN): recrystallized snow, in transition from snow to ice, that is compacted and hardened by wind and thermal variation.

NUNATAK: isolated hill or mountain of bare rock rising above the surrounding ice sheet.

PACK ICE. See Ice.

PANCAKE ICE. See Ice.

PASSIVE CONSTRUCTION: method of construction that preserves permafrost for its structural value.

PERMAFROST: permanently frozen subsurface material not subject to seasonal freezing and thawing.

AGGRADATION: growth of permafrost under the disciplines (natural or artificial) existent in the area.

AREA: specific section where all or only a part of the material below the earth's surface is permafrost.

DEGRADATION: disappearance of permafrost through natural or artificial causes.

DRY: permafrost whose ice matrix is insufficient to fill the voids existent in the remaining solid material.

SUPRAPERMAFROST LAYER: thickness of ground above the permafrost consisting of the active layer, talik, and any isolated lenses of permafrost wherever present.

TABLE: irregular surface representing the upper limit of permafrost. (See also Frost Table.)

PINGO: large mound in a permafrost area.

POLYGONAL SOIL: polygonal pattern of the ground surface produced by a more or less marked segregation of textural constituents of the ground and indicated also by a slight relief.

POLYNYA: any enclosed water area, other than a crack or lead, among fields and floes of pack ice.

PRESSURE ICE. See Ice.

REGELATION: fusion of pieces of ice under pressure.

RIME: ice crystals precipitated from moist air.

RUNOFF: precipitation that has escaped the actions of interception, evaporation, transpiration, and deep seepage.

SASTRUGI (ZASTRUGI): wavelike ridges of hard snow formed by the action of the wind on a level surface, with the axes of the ridges at right angles to the prevailing wind direction.

SEA ICE. See Ice.

SERACS: ice pinnacles on a glacier.

SHELF ICE. See Ice.

SHORE LEAD: lead between floating ice and the shore or between floating ice and fast ice. (See also Lead.)

SIKUSSAK: very old ice that does not drift because it is located in areas (fiords, for example) that seldom become clear of ice.

SKY MAP: mirroring of land, snow, or ice in the clouds that approaches perfection as the clouds on an overcast day approach uniformity.

SOLIFLUCTION: process of denudation caused by slow gravitational flowing (creep) on slopes of saturated soil masses that alternately freeze and thaw.

SNOWCRETE OR SNOW CONCRETE: snow, hardened at low temperatures by mechanical compaction and aging, used as a construction material.

SUBPERMAFROST WATER. See Water.

SUPRAPERMAFROST LAYER. See Permafrost.

SUPRAPERMAFROST WATER. See Water.

TAIGA: cold, swampy, forested regions of the north, particularly in Siberia, which begin where the tundra ends.

TALIK: layer of unfrozen ground between the seasonal frozen ground (active layer) and the permanently frozen ground (permafrost). It also applies to any unfrozen zones within the permafrost as well as to the unfrozen ground beneath the permafrost.

THAWING INDEX: summation of the number of degree-days of thaw during the thawing season. For corrections to this factor, see Problem 2, par. 3 of 2A8.04.

THERMOKARST: uneven topographic features produced by melting of ground ice and subsequent settling or caving of the ground. It is characterized by short ravines, sinkholes, funnels, and caverns similar to those produced in limestone terrain (karst) by the solvent action of water.

TRANSPIRATION: exhalation of vapor from plant tissues.

TUNDRA: level or undulating treeless plain characteristic of northern Arctic regions in both the Eastern and Western Hemispheres. Generally, the tundra marks the limit of arborescent vegetation, but supports a dense growth of grass, moss, lichen, and shrub.

TUSSOCK: tuft or clump of grass or sedge.

UTILIDOR: conduit placed in the ground or supported on the ground to protect electrical or telephone cables, water, steam, and/or sewer pipes.

VAPOR CLOUD: fog or mist formed by condensation of moisture from relatively warm gases, such as breath from animals or humans and engine exhaust, expelled into low ambient temperatures and visible as trailing clouds above persons, animals, and heat-producing objects.

WANIGAN: small shed or houselike structure mounted on sleds and used for sleeping, working, eating, or storage.

WATER.

- INTRAPERMAFROST: ground water within permafrost.
- KARST: ground water flowing through karst formations. (See also Thermokarst.)
- SUBPERMAFROST: ground water beneath permafrost.
- SUPRAPERMAFROST: ground water above permafrost, called the suprapermafrost layer.

WIND CHILL: combined cooling effect of wind and air on the temperature of heated bodies. It is expressed in kilogram calories per square meter per hour (kg cal/sq m/hr).

YOUNG ICE. See Ice.

APPENDIX B

THE ARCTIC

Section I. GEOGRAPHY AND TOPOGRAPHY

XB1.01 ALASKA

1. ARCTIC. Much of Alaska is not Arctic but Subarctic. What might truly be called Arctic Alaska is the broad belt that extends northeast along the coast from Seward Peninsula to Point Barrow and east to the Canadian boundary at Demarcation Point. The larger topographical features of this belt are Brooks Range and Seward Peninsula, whose tip, Cape Prince of Wales, is only about 60 miles from Siberia across Bering Strait.

Brooks Range is one of the great mountain chains of North America. Actually, it is not a single range but a series of ranges, some of whose peaks are between 8,000 and 8,500 feet high. The range has an east-west trend, with the western end near Cape Lisburne and the eastern near Demarcation Point.

The coast, with the exception of Seward Peninsula and the vicinity of Cape Lisburne, is generally flat and low. Shaped like a wide triangular plateau, it reaches its greatest width near Point Barrow.

2. SUBARCTIC. The territory south of Seward Peninsula includes the broad deltas and alluvial plains of the Yukon and Kuskokwim Rivers. The Yukon, rising in northwestern Canada and flowing from east to west across central Alaska, is a major feature of the interior.

The Aleutian Islands, stretching in a chain across the northern part of the Pacific Ocean to Kamchatka Peninsula, Siberia, form an almost perfect arc. Most of the Aleutians are active or only recently dormant volcanoes. They are a continuation of a volcanic belt that begins in Alaska at Mt. Edgecumbe on Kruzof Island near Sitka, continues north to the south coast, swings west to the Alaska Peninsula, and then southwest to join the great arc that extends to the American end of the chain at Attu, a distance of about 2,500 miles. The entire chain, therefore, is shaped like a giant S. Many of the peaks in this active volcanic belt are 8,000 to 11,000 ft above sea level. Glaciers descend from a large number of the extinct volcanoes.

The south coast of Alaska has no recent volcanoes, but it is even more mountainous and contains some large glaciers, notably Hubbard and Malaspina. The higher mountains are Marcus Baker (13,250 ft), St. Elias (18,008 ft), and Logan (19,850 ft), which is just over the Canadian border. This group continues into the interior, forming the Alaska Range. Mt. McKinley, 20,270 ft high, is the crowning summit and is the loftiest peak in North America.

XB1.02 CANADA

Arctic Canada includes almost all of the north coast and the Canadian Arctic Archipelago. The two topographical areas as a unit have been conveniently divided into Western and Eastern Canadian Arctic, with the division based chiefly on topographical differences. There is almost no travel back and forth, and usually both areas are approached from different directions.

1. WESTERN ARCTIC. The Western Canadian Arctic consists of the coastal mainland from Demarcation Point to Boothia Peninsula, including the islands of the archipelago to the north. Except for the region of the Mackenzie River, the mainland, which is part of the Canadian Shield, is rocky, composed of granite and gneiss. The islands are also part of the Canadian Shield but are overlain by sedimentary rocks. The largest, Victoria, is the second largest in the entire archipelago. Banks and Melville are other large and important islands in the group. On the whole, the region is low lying, but there are a few mountains with perennial snowbanks.

2. EASTERN ARCTIC. The Eastern Canadian Arctic comprises most of the mainland from Boothia Peninsula to Labrador and includes the islands to the north and northeast. Of this group, Baffin, with an area 2½ times that of Great Britain (or nearly 200,000 square miles), is the largest island in the entire archipelago and fifth largest in the world. Ellesmere is third largest in the archipelago. The east coast of Baffin and the eastern and northern parts of Ellesmere are rugged and mountainous, with peaks approximately 8,000 ft high on Baffin and 11,000 ft on Ellesmere. Both islands have small icecaps and valley glaciers. Other important islands in the group are Bylot, Devon, and Axel Heiberg, all of which are high enough to carry glaciers. Deeply indented fiords and glacial sculpturing are the characteristic features of most of the island coasts, especially Baffin and Ellesmere.

On the whole, the Eastern Canadian Arctic is higher and more rugged than the Western, although low tundras do occur. Parts of the island interiors and practically all of the west coast of Hudson Bay on the mainland are low lying and flat and in most places covered by tundra.

3. SUBARCTIC. South of the Western and Eastern Canadian Arctic, the principal natural regions (partly Arctic but mostly Subarctic in character) are the western mountains and interior lowland. The mountains, of which the Mackenzies are part, represent the northward extension of the Rocky Mountains of the United States and southern Canada. Some of the peaks reach 7,000 and 8,000 ft and a few have snowbanks the year around.

The interior lowland comprises the rich valley of the Mackenzie River and a broad expanse of generally flat country. Gigantic Great Bear Lake is separated from the Mackenzie Valley by a low range. Countless smaller lakes, a notable feature of the region, are scattered throughout the valley. Eastward lies a broad plain, which slopes gently to sea level at Hudson Bay.

XB1.03 LABRADOR

Labrador, between the 60th and 50th parallels, lies far south of the Arctic Circle. Only the northeastern part is truly Arctic, and this is chiefly because of the cold Labrador Current. Like the Eastern Canadian Arctic, northeastern Labrador is mountainous and dissected by many fiords. The Torngat Mountains, which carry a few cirque-type glaciers, exceed 5,000 ft. In the southern part there are only a few fiords; but one, Hamilton Inlet, penetrates many miles into the interior and is several times as large as any other in Labrador.

XB1.04 GREENLAND

Greenland (840,000 square miles) is not only the largest of the Arctic islands but also the largest island in the world. About 85 percent is covered by an ice sheet, more commonly referred to as the Greenland Icecap, which leaves only a relatively narrow ice-free border along the coasts. Much of the coastal zone is mountainous, the east coast more so; Watkins (Gunnbjorn) Mountain, the highest, is 12,139 ft.

Excluding the icecap and descending valley glaciers, which discharge huge bergs into the sea, the fiords, many of which have glaciers at their heads, are the most characteristic topographical feature. They penetrate deeply into the coast and lend unsurpassing grandeur to the landscape. The East Greenland fiord system, of which Scoresby Sound and Franz Josef Fiord are the most spectacular and best known, is one of the most imposing in the world. Scoresby Sound cuts inland for some 150 miles; Franz Josef Fiord has sheer, multihued walls.

The Greenland Icecap, nearly 1,500 miles long and 200 to 500 miles wide, has an area of about 714,000 square miles. Observations indicate that it has not been in equilibrium for more than a century; it is steadily shrinking. Ablation exceeds precipitation, that is, the icecap is suffering considerable loss from calving of icebergs.

Over the vast central area the slopes are quite moderate, 5 to 50 ft per mile. Nevertheless, the Icecap, estimated at between 7,000 and 8,000 ft thick, rises in at least three known domes, the highest of which exceeds 11,000 ft. Whether the domes are the topographical expression of highland areas or simply thousands of feet of ice is not known and will not be known until the nature of the subglacier floor has been determined.

The Icecap is not the only type of glacier in Greenland; there are hundreds of valley glaciers and small icecaps occupying the coastal belt in both East and West Greenland. Even the piedmont glacier, such as the Frederickshaal, is represented on the west coast. Undoubtedly there are more, as yet unreported.

The margin of the Icecap is extremely irregular (Figure XB1-1) because of the ruggedness of the coastal mountains through whose valleys the ice descends in tonguelike outlet glaciers. These tongues, with clifflike termini and intricate crevasses, finally reach the sea on fronts that may be several miles in width. All year they calve icebergs of immense size into the deep water. Humboldt Glacier on the west coast is the largest of the outlets—60 miles wide at its terminus. The Icecap produces by far and away the greater number of bergs, somewhere between 10,000 and 15,000 annually, with east and west coasts sharing equally in the total. The majority are calved from glaciers located between the 65th and 80th parallels.

XB1.05 SPITSBERGEN

Spitsbergen, an archipelago, is part of the Norwegian possession of Svalbard, which includes several other islands between the Greenland and Barents Seas. The archipelago (about 24,000 square miles in area) consists of the following islands: West Spitsbergen, Northeast Land, Edge, Barents,

FIGURE XB1-1

Surface of Greenland Icecap Near Its Edge

and Prince Charles Foreland. Despite its high northern latitudes (76° 25′ to 80° 50′), Spitsbergen has been the cynosure of many nations for at least four centuries. The basic reasons are (a) the Gulf Stream keeps the seas open for more than half the year, and (b) minerals, particularly coal, are extensive.

West Spitsbergen Island (about 15,000 square miles in area) is wedge shaped, with the apex pointing south. (See Figure 1B2-7.) Its coastline, especially the western, is indented by many fiords.

The west coast is a folded belt marked by sharp peaks and valleys through which glaciers reach the sea. Eastward are faulted plateaus whose beds, although affected by folding, are in general nearly horizontal. Interspersed among these contrasting structural forms are basal platforms composed of ancient crystalline rocks, the largest exposure of which is at the northwestern corner. It parallels Wijde Bay and reaches 5,633 ft in Mt. Newton. *Roches moutonnées*, or bosses of bedrock smoothed and polished by glacial abrasion, occur frequently in these basal platforms. Locally, eruptive rocks and volcanic cones of ashes, lapilli, and scoria have furnished additional features to the topography. Along some of the fiords, there are wide and long coastal plains from 60 to 90 ft above sea level, and above them are raised beaches, some of which are 400 ft high or more.

XB1.06 SOVIET UNION

The major divisions of the Soviet Arctic are the Eurasian and Eastern Asiatic Arctics. The geographical boundaries, however, do not follow the generally accepted southern latitudinal boundary of the Arctic as the region having a mean temperature of 9° C (48.2° F) in the warmest month of the year. The Soviets have defined the Soviet Arctic in terms of administrative jurisdiction as set forth in the Decrees of 1926 and 1936 on the Territorial Rights of the Soviet Union in the Arctic and the Central Administration of the Northern Sea Route. This jurisdictional boundary follows a line most of which is considerably south of the Arctic Circle (lat 66° 30′ N). Reading from west to east, the line runs from the Finnish border on Kola Peninsula along the coast to a point west of Pechora River, where it angles southeast and south, crosses the river, and then turns south and southwest to cross the Arctic Circle. From here it swings across the rest of the Eurasian Arctic and all of the Eastern Asiatic Arctic to Bering Strait.

1. EURASIAN ARCTIC. The Eurasian Arctic includes islands, seas, and mainland. It lies between the Finnish border and Anabar River, which is east of Taimyr Peninsula in Siberia.

a. *Islands*. The islands, separated by Barents and Kara Seas, consist of three archipelagoes —Franz Josef Land (also called Fridtjof Nansen Land), Novaya Zemlya, and Severnaya Zemlya.

(1) *Franz Josef Land*. Franz Josef Land consists of 85 islands with a combined area of about 8,000 square miles. The British and Austrian Sounds divide the archipelago into three sections. The two largest islands, Aleksandra and Prince George, are on the west. The middle section is occupied by numerous small islands. East of Austrian Sound are two relatively large islands, Wilczek and Graham Bell, and northeast of them is Prince Rudolph Island. The islands are predominantly low plateaus averaging 1,000 ft in elevation. Wilczek is the highest (2,410 ft).

(2) *Novaya Zemlya*. Novaya Zemlya (New Land in Russian), with Vaigach Island, is the next archipelago (36,500 square miles) to the east. Novaya Zemlya itself is a double island broken by Matochkin Shar Strait. The western coastline is a low foreland at the base of the steep flanks of the central north-south mountain ridge, which rises to between 3,000 and 3,500 ft. Goose Land, Dry Headline, and Admiralty Peninsula are prominent projections of the forelands. The east coast is low and flat; around Matochkin Shar the coast is rocky. The archipelago is a continuation of the Ural and Pai-Khoi Mountains of the mainland.

(3) *Severnaya Zemlya*. Severnaya Zemlya (North Land in Russian) consists of four large islands (Komsomolets, Pioneer, October Revolution, and Bolshevik) and several smaller islands. The total area is about 14,300 square miles. The Red Army Strait separates Komsomolets from October Revolution. It is a narrow fiord-type strait dotted with islets and reefs that make navigation impracticable. Shokalski Strait separates October Revolution from Bolshevik. Wide and deep, it may become an important passage for ships going from Kara Sea to the east. Boris Vilkitski Strait, also wide and deep, separates Severnaya Zemlya from Taimyr Peninsula. No special characteristic distinguishes these islands. None exceeds 1,500 ft in elevation, and all are more or less dome shaped and dissected by fiords, with the exception of the east coast of October Revolution, which has no fiords.

b. *Mainland*. The mainland of the Eurasian Arctic is subdivided into European Arctic and Western Siberian Arctic.

(1) *European Arctic*. The European Arctic extends from the Finnish border to the Ural Mountains. It consists of Kola and Kanin Peninsulas and Malozemelskaya and Bolshezemelskaya Tundras (Little and Great Lands, respectively, in Russian).

The topography has no special characteristics. The Murman coast of Kola Peninsula, except the southeastern extremity, has few Arctic characteristics because of the influence of the Gulf Stream. The harbors are open all year. The coast of the Kanin Peninsula has low cliffs and terraces from 180 to 280 ft high; the northern extremity is the highest. The terraces are postglacial raised beaches.

The maximum altitude of the coastal belt of Malozemelskaya Tundra, east of Chesha Bay, is about 600 ft, which is much higher than the highest part of the Kanin Peninsula coast. Actually, the belt in this part constitutes the foothills of the Timan Ridge, which accounts for the increased elevation. From here on, the coast flattens out and maintains its low altitude through the Pechora region and the Bolshezemelskaya Tundra until it reaches the Pai-Khoi Mountains, a tectonic extension of the Urals that rises to 1,560 ft. The rest of the coast as far as the Urals resembles that of Kanin Peninsula, with low cliffs and terraces. The Urals themselves, as they approach the Kara Sea, slope down from their general elevations (3,000 to 6,000 ft) to about 1,500 ft and merge into the tundra, which is much lower and forms a narrow belt along the coast.

(2) *Western Siberian Arctic.* The Western Siberian Arctic includes the region between the Urals and Anabar River. It is a succession of peninsulas—Yamal, Gyda, and Taimyr. The first two are topographically inconsequential; both are flat and low. The coast is also low except in a few places where it rises 90 to 100 ft.

The Taimyr Peninsula is much higher, especially in the north, where Bryanga Ridge to the west and Northeastern Ridge to the east rise 1,000 to 1,500 ft. South of them the land is lower, seldom reaching 600 ft. The coastline also differs in that it is much more indented, although there are no sizable bays except those at the mouths of the Piasina and Taimyr Rivers. The coast is sheer in many parts. Offshore there are numerous groups of rocky crags and islets, of which the Nordenskjöld are the largest.

2. EASTERN ASIATIC ARCTIC. The Eastern Asiatic Arctic is also divided into islands, including Laptev, East Siberian, and Chukchi Seas, and mainland. It lies between Anabar River and Bering Strait.

a. *Islands.* The islands include New Siberian Islands and Wrangel.

(1) *New Siberian Islands.* The New Siberian Islands are made up of three groups that have a combined area of about 11,000 square miles. Great and Little Lyakhov Islands form the southern group; Koltelny, Faddei, Novaya Siber (New Siberia), Belkovski, Figurin, and Zheleznyakov the central; and Bennett, Henrietta, and Jeanette the northeastern. The last group is also known as DeLong Islands. Those in the central group are the largest and highest in the archipelago. On the whole, elevation is slight; the highest is Koltelny (1,150 ft). The coastlines are even and regular.

(2) *Wrangel Island.* With the exception of Herald, the easternmost island is Wrangel (about 1,740 square miles in area). The northern portion, called the Academy Tundra, is practically unknown; the southern consists of high plateaus, traversed by two longitudinal ridges, and deep valleys. The eastern part of the plateaus is higher, ranging from 600 to 1,200 ft, and has steeper coasts. On the south, where the highlands descend to the shore, the slope is more gradual.

Wrangel is an extremely difficult island to reach. Almost always enveloped by fog, the island is surrounded by icefields practically all year. Rogers Bay (lat 70° 57′ N, long. 178° 10′ E) is one of the few places that may be found free of impassable ice, generally from mid-August to September.

b. *Mainland.* The mainland of the Eastern Asiatic Arctic is subdivided into the Western and Eastern Sections.

(1) *Western Section.* The coastal belt of Yakutia, stretching between Anabar River and Kolyma Estuary, is the Western Section. Because of numerous projections and indentations, the coastline changes direction frequently. Between Anabar and Lena Rivers, the belt averages 300 ft in elevation; eastward to Kolyma the altitude decreases sharply. Cape Svyatoi Nos is the highest point (over 1,200 ft). The characteristic feature is not so much the relief of the land or the configuration of the coastline, but the sandy foreshore and shallow coastal waters and the estuaries and deltas of the rivers.

(2) *Eastern Section.* The Chukchi Peninsula constitutes the Eastern Section. It extends from the mouth of the Kolyma to Cape Dezhnev on Bering Strait. The coastline has not nearly as many projections and indentations as the Western Section. The major indentation is Chaun Bay; a lesser one is the long, narrow Kolyuchin Bay at long. 175° E. The shore, in contrast to the Yakutia coast, is more abrupt; the cliffs are sheer, often reaching considerable heights, as on Cape Shmidt and Cape Dezhnev. Stretches of sandy flats, however, are not uncommon, especially in the northeast. The most striking feature of the region is that the land rises from the shore to hilly tundra, becoming more and more mountainous as it recedes farther inland.

XB2.01 MINERALS

1. ALASKA. Alaska, on the whole, is relatively rich in mineral resources. Arctic Alaska, however, has not yet shown a corresponding yield, although placer gold and platinum, tin, nickel, silver, antimony, tungsten, jade, and asbestos have been found. Coal has been mined at Chichagof Creek on Seward Peninsula and in several places in northern Alaska at Corwin, Cape Lisburne, and along Meade River south of Point Barrow. An oil reserve of 37,000 square miles has been set aside in the vicinity of Point Barrow north of Brooks Range. The coastal plain and foothills of Brooks Range are believed to be the most promising areas for oil and other valuable minerals.

2. CANADA.

a. *Mainland*. The mineral resources of the Arctic mainland of Canada, if judged on the basis of those existing farther south, must be considerable. Radium and uranium deposits at Great Bear Lake, oil at Norman Wells, gold at Yellow Knife, and iron ore at Burnt Creek and Leaf Lake are outstanding examples that indicate what may be the mineral potential of the Canadian Shield farther north. One of the most promising regions is along the west coast of Hudson Bay between Eskimo Point and Chesterfield and around the upper Kazan River and Padlei areas. Nickel, copper, platinum, gold, silver, and iron have been reported.

b. *Islands*. The Arctic islands of Canada (over 525,000 square miles) are another vast area whose terrain indicates favorable development of mineral resources. Various mineral occurrences have been observed in areas underlain by Pre-Cambrian rocks, and numerous coal deposits of late Paleozoic and Tertiary times have been reported. Coal may play an important part in a land devoid of wood and waterpower. Small amounts of Tertiary lignite have been mined near Pond Inlet at Salmon River for the last quarter of a century and used for the post settlement.

Some of the islands (northern Ellesmere, Sverdrup, Cape Grinnell Peninsula on Devon Island, Bathurst, Melville, Borden, and northern Banks), containing flat or gently folded beds of epeiric sea sediments, offer structural conditions for oil accumulation. Actual seepage has been reported on northern Melville Island.

All in all, despite potentialities, development of the Canadian Arctic is at present limited; at least, it is not comparable to cryolite mining in Greenland or coal mining in Spitsbergen.

3. GREENLAND. Cryolite, used as a flux in the electrolytic production of aluminum, occurs in a great pegmatite vein cutting through granite near Ivigtut. It is now produced synthetically, with the result that in its natural form it has lost much of its value. Minerals associated with cryolite in the pegmatite vein are siderite, galena, chalcopyrite, pyrite, fluorite, topaz, and a few rare minerals. Graphite is mined at Amitsok and near Upernavik. North of Nagsuak Peninsula at Kaerssvarsuk, bituminous coal of Tertiary age is mined for local use. Coal also occurs on Disko Island.

4. SPITSBERGEN. Coal, which is mined extensively, is the principal resource of Spitsbergen. Marble, gypsum, mica, and phosphate rock are of lesser import. High-grade iron ore exists on Prince Charles Foreland, but it is almost inaccessible because of glaciers.

5. EURASIA. From the standpoint of industrial exploitation, the most important deposits that are mined or could be mined with profit in Eurasia are coal in the four large basins around Pechora, Tungus, Lena, and Kolyma River areas; oil in the Ukhta-Pechora belt and on Taimyr Peninsula; fluorite at Anderma; copper and nickel at Norilsk; graphite at Kureika; silver and lead in the western part of Verkoian Range; and rock salt at Nordvik. The largest nickel deposit (nickel-copper sulfide) in northern Europe is near Pechenga (Petsamo) in northern Finland, and the largest deposit of high-grade iron ore (magnetite) presently known in the world is at Kiruna, 100 miles within the Arctic Circle.

XB2.02 VEGETATION

1. THERMAL REGIME.

a. *Interaction of Permafrost and Plant Growth*. Permafrost affects plant growth. For example, (a) plants may be subjected to severe water loss, perhaps to the extent of permanent damage, by exposure to drying winds while the roots are encased in frozen soil and can not absorb water, and (b) slopes modified by intensive frost processes are remarkable for the lateral and vertical uniformity of the covering vegetation.

Plants affect soil frost phenomena most significantly through controls exercised on the thermal regime of the soil. These controls and their effects are probably different for all natural sites. Vegetation shields the soil from maximum penetration of heat by shading, by decreasing air circulation, by retaining moisture in and just above the soil, and by intercepting rain. Another cooling effect, the evaporation of moisture on plant surfaces, may also be significant. Moss plays an important part in this effect because it has not only a low thermal conductivity, especially when dry, but also a large water-holding capacity. Moss is strongly hygroscopic. It is common knowledge in Alaska that thawing of frozen ground is greatly hastened by removing moss, a term loosely used for moss carpets, thick turf, and surface peat. Accumulations of vegetal matter are effective insulators during thawing and good conductors when frozen in a water-saturated condition.

Although vegetation dominantly favors the accumulation of a cold reserve in the ground, it also contributes to the opposite effect. Vegetal cover decreases air-current velocities within its stratum and, therefore, impedes heat radiation from the soil to the cold air.

The ground permitting the greatest degree of water penetration usually thaws to the greatest depth. Extensive root systems impede downward percolation and thus restrict thaw. On the other hand, roots, especially when dead or decaying, may provide channels for water penetration and may sometimes become loci for the growth of granules and small stringers of ice. Uprooting and other disturbances to roots of larger plants over a high permafrost table can initiate thaw and sinks.

Plant roots and underground stems have certain mechanical roles in the genesis of soil frost features. These organs serve as binding and anchoring agents in the turf and upper soil layers and may show remarkable strength and resilience against frost action. Roots and underground stems hold the turf wall together on the front scarp of turf-banked terraces, and anchoring roots hold back great heavy mats of turf on slopes that have unstable soil.

Frost in the soil and the associated vegetal cover thus exert a dynamic influence on each other. In many situations this interaction engenders cyclic

TABLE XB2-1

Appearance of Vegetation in Aerial Photographs (Ref. 107)

Name	Description
Alaska birch	The bright green foliage appears light to medium gray. Crowns of multiple-boled trees, often 25 feet in diameter, resemble billowy fluffs of cotton. Shadows, more dense than those of aspen, have a feathery texture.
Balsam poplar	Balsam poplar registers medium gray, darker than birch and about the same tone as aspen. Unlike the round-topped shadow cast by mature aspen, the shadow of this species has a pointed, tapering crown that is more dense than aspen. The feathery shadows of balsam poplar are usually less flimsy than those cast by Alaska birch, except in situations where birch grows in clusters of five or more stems.
Black spruce	It is extremely difficult to differentiate between stunted white spruce and black spruce established on poorly drained sites. When viewed from the air at low altitudes, this species appears nearly black. In open stands, solid black, narrow shadows cast on light-hued sedges and heaths are conspicuous. Compared to white spruce, trees are uneven in height and usually sparse.
Felt leaf willow	Dense young stands register nearly solid, light gray, but older stands with fairly open canopies have a medium-gray, pebble-grain pattern. In marshes and muskegs, the individual light-gray, rounded willow clumps are readily identified.
Mountain alder	Because alder is nearly always overtopped by associated species in areas generally covered by forests, it is only rarely that it can be identified. In muskegs and swampy sites having little or no tree growth, the dark-gray, globose clumps are readily discernible. Alder registers considerably darker than willow.
Quaking aspen	Young aspen stands appear medium gray, darker than Alaska birch but lighter than alder. The canopy is quite dense, with few openings. Immature stands cast open, feathery shadows that are pyramidal in shape. Old stands are open, with only 50 percent or less crown closure. The rounded crowns, up to 20 feet in diameter, have a light-gray tone. The long, slender branchless trunk casts a readily resolved shadow. From low-flying aircraft, a young stand of aspen is identified by a solid canopy, which is medium green in color. The ever-fluttering leaves and swaying slender branchlets cause a blurred or fuzzy texture. The white boles of old aspen can be mistaken for Alaska birch, but branches usually clothe birch trunks over one half of the total height.
Tamarack (larch)	Tamarack has a fuzzy, light- to medium-gray tone, which is easily mistaken for Alaska birch. Tamarack, however, casts a less dense shadow, which is effused, feathery, and more narrow than birch. The crown of this species is rarely over 15 feet in diameter, but multiple-boled Alaska birch are frequently double that size. During the summer months, tamarack appears much lighter in color than other coniferous trees in Alaska.
White spruce	White spruce registers as a dark gray to black spire, which casts a solid black, narrow triangular shadow. From the air, slender, uniformly shaped conical crowns of white spruce are readily identified. Compared to black spruce, stands are uneven in height and quite dense.
Tundra	On large scale photographs, sparse tundra on well-drained sites registers a solid, light-gray tone. Well-developed, sedge-heath tundra on poorly drained sites has fine, pebble-grained, medium-gray to black pattern.

changes that are especially prominent in vegetation-permafrost relationships.

b. *Effect of Surface Disturbances.* Disturbances to the vegetation, such as burning and clearing, in regions of severe frost do much more than initiate plant succession that may culminate in the return of the original type of stand. Because of soil frost changes following disturbance, the affected surface and the local environment may be so greatly modified that entirely different communities will occupy the site for unknown periods. Land clearance has a beneficial influence on the thermal regime of the upper layers of soil during the warm months of the year. Changes, however, in the water relations may result and should be anticipated. Due allowance should be made for the soil becoming colder during winter.

Construction on soil actively disturbed by frost and on soil with permafrost requires special stabilization and drainage measures. Treatment of the vegetal cover necessitates careful planning. Preservation of forests helps to prevent a rise in the water table, which tends to form bogs and marshes when underlain by permafrost. Brush should be cleared from forests because it retains moisture and hinders drying air from reaching the surface. Large trees, on the other hand, retain a considerable amount of moisture around their roots; but they also transfer a great deal by transpiration. They help, therefore, to dry the soil. Attention to these considerations during planning stages will pay dividends both during construction and throughout the ensuing maintenance period.

2. APPEARANCE IN AERIAL PHOTOGRAPHS. Table XB2-1 describes how vegetation looks in aerial photographs.

XB2.03 ANIMALS AND INSECTS

The fauna of the Cold Regions (bear, caribou, fox, wolf, dog, ermine, duck, ptarmigan, salmon, seal, and similar species) depends either directly or indirectly on vegetal resources. The primary interest in fauna is in terms of the survival needs of man. Dogs and reindeer, however, are used as beasts of burden. Rodent and insect life is a nuisance factor and demands special attention from persons working in the field.

1. RODENTS. Recently, in some communities, there have been instances when rodents have been present in large enough numbers to present sanitation problems. Of primary importance in this classification is the Norwegian rat.

2. INSECTS. The biting pests in Alaska are, in order of their importance, mosquitoes, black flies, punkies or nosee-ums, snipe flies, and horseflies (Ref. 108). Generally, they are distributed throughout the Arctic and Subarctic Regions, but in different areas different species dominate. The insects may cause miserable living conditions for the inhabitants. There are many hours of sunshine during the summer months when insects are active.

Section 3. CLIMATOLOGICAL SUMMARIES

Table XB3-1 gives weather data for Arctic and Subarctic stations in the North Polar Region. In many instances, the information has been gathered during a very short period; the reliability of the figures, therefore, must be questioned. Differences exist in some cases among the results reported because different times were used in accumulating the data.

TABLE XB3-1

Weather Data for Arctic and Subarctic Stations (Ref. 6a)

Station	Lat	Long.	Elevation, ft	Years of record	Mean temperature, °F Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Record temperature Max	Min
Alaska																			
Adak	51° 57′ N	176° 36′ W	...	4	31	32	33	37	40	44	49	51	48	42	37	33	40	75	12
Attu	52° 54′ N	173° 20′ E	13	1 to 4	31	29	31	34	39	43	51	53	47	42	36	31	39	71	12
Barter Island	70° 80′ N	143° 50′ W	50	1	−15	−10	−12	5	19	33	41	38	28	13	1	−15	8	61	−51
Dutch Harbor	53° 54′ N	166° 32′ W	13	24 to 26	31.9	31.7	33.9	36.1	40.8	46.1	51.3	52.9	48.7	42.1	36.5	33.2	40.4	80	8
Galena	64° 48′ N	156° 54′ W	120	3	−4.7	−12.3	10.7	20.8	41.3	54.9	60.2	54.3	44.3	25.6	4.3	−9.6	26	87	−51
Kodiak	57° 48′ N	152° 24′ W	152	36 to 42	30.1	31.8	33.4	36.9	43.2	49.9	54.3	54.7	50.1	42.3	35.2	31.3	41.1	85	−12
McGrath	62° 58′ N	155° 37′ W	334	10	−6.7	0.8	8.3	24.7	43.3	55.7	58.7	53.4	44.1	27.6	3.2	−7.2	25.5	89	−64
Wales	65° 37′ N	168° 03′ W	9	7	0.5	−0.1	−2.7	13.1	26.1	37.4	45.9	44.9	39.9	29.7	17.8	3.7	21.4	71	−41
Wiseman	67° 26′ N	150° 13′ W	675	7 to 8	−11.4	−6.9	1.2	20.6	39.7	56.6	55.9	52	40.6	21.8	−0.3	−7.1	21.9	89	−62
Canada																			
Aklavik	68° 14′ N	134° 50′ W	30	21 to 26	−19	−16.2	−10.4	8.7	31.1	49.2	56.4	50.2	38	20.4	−3.6	−17	15.6	88	−56
Arctic Bay	73° 00′ N	85° 18′ W	36	9 to 12	−21	−27	−16	−4	19	36	44	42	30	15	−4	−16	8	75	−57
Churchill	58° 47′ N	94° 11′ W	43	54	−19	−16.7	−6.1	14	29.6	42.6	53.7	52.4	41.8	26.7	5.9	−11	17.8	96	−57
Clyde River	70° 25′ N	68° 17′ W	26	8	−16	−19	−13	−2	19	34	41	40	32	21	4	−11	11	71	−47
Coppermine	67° 49′ N	115° 10′ W	13	13	−19	−19	−16	0	22	38	50	46	36	18	−6	−16	11	87	−54
Coral Harbour	64° 11′ N	83° 17′ W	193	8	−25	−21	−13	1	19	35	46	46	33	19	8	−12	11	79	−58
Dawson	64° 04′ N	139° 29′ W	1,062	...	−21	−12.1	4.4	28.6	46.3	56.8	59.6	54.6	42.1	26	1.4	−13.7	22.9	95	−73
Fort Chimo	58° 05′ N	68° 25′ W	112	3	−8	−11	2	14	31	43	54	51	45	31	16	−3	22	87	−46
Fort Simpson	61° 52′ N	121° 21′ W	415	...	−18.3	−10.7	1	26	44.7	56.1	61.7	57.2	46.1	28.6	4.3	−12.1	23.7	95	−69
Isachsen	78° 47′ N	103° 32′ W	83	3	−37	−33	−26	−20	10	30	38	33	16	−5	−22	−31	4	64	−60
Mould Bay	76° 16′ N	119° 50′ W	50	3	−32	−31	−21	−11	12	30	38	34	19	−2	−16	−26	−1	57	−63
Norman Wells[1]	65° 17′ N	126° 47′ W	290	31 to 35	−19.4	−12.8	−2.4	19.1	40.6	54.6	59.2	53.8	41.8	24.6	−1.1	−14.8	20.3	94	−65
Pangnirtung	66° 09′ N	65° 30′ W	43	13	−15.8	−16.4	−6.8	7.8	25.4	36.9	45.4	44.1	37	24.8	11.2	−8.4	15.4	70	−52
Port Harrison	58° 25′ N	78° 08′ W	66	18	−18.1	−18.5	−6.6	11.2	29.3	38.6	46.9	46.6	40.6	30.6	17	−1.5	18	78	−57
Greenland																			
Angmagssalik	65° 37′ N	37° 33′ W	95	30	17	14	18	24	33	41	44	42	37	30	23	19	29	77	−26
Godthaab	64° 11′ N	51° 43′ W	66	50	14	14	19	25	33	40	44	43	38	31	24	18	29	76	−20
Ivigtut	61° 12′ N	48° 10′ W	82	45	19	19	24	31	40	46	50	47	41	34	27	21	33	86	−20
Scoresby Sound	70° 30′ N	23° 00′ W	55	5	0.6	1.6	1.7	9.6	24.1	35.2	40.1	38	31.6	19.4	9.1	4.1	17.6	...	...
Upernavik	72° 47′ N	56° 07′ W	59	52	−7	−10	−7	7	25	35	41	41	33	25	15	2	17	69	−44
Iceland																			
Stykkisholmur	65° 05′ N	22° 46′ W	82	47	29	28	28	33	40	47	50	49	45	39	33	29	38	73	−21
Finland																			
Kittila	68° 01′ N	24° 09′ E	...	30	9.9	9.1	15.6	26.6	36.7	48.7	55.9	51.6	42.6	30.6	15.8	10.9	29.5	...	...
Pechenga (Petsamo)	69° 33′ N	31° 13′ E	43	7	17.8	10.4	16.9	28.8	39	48.2	55.6	53.2	43	33.6	27.5	19.6	32.7	86.4	−39.5
Utsjoki	70° 05′ N	27° 52′ E	66	30	9.9	11.5	16.2	24.3	34.5	45	51.8	49.5	41.7	29.8	19.4	13.1	28.9	86.7	−34.6
Norway																			
Bear Island	74° 28′ N	19° 17′ E	95	14	18	17.1	14.7	19	28	34.7	40.1	39.2	36	29.7	23.2	20.1	26.6	65.3	−24.9
Fagernes	68° 27′ N	17° 25′ E	26	26	26.1	24.8	26.4	33.1	40.8	49.1	54.1	52.7	45.3	37.2	30.7	26.4	37.2	80.6	−2.4
Green Harbour	78° 02′ N	14° 15′ E	13	15	3	−2.4	−1.3	7.7	23.4	35.6	41.7	40.3	32.2	21.6	10.8	6.3	18.3	60.4	−56.6
Jan Mayen	70° 59′ N	8° 18′ E	75	12	22.8	21.9	20.7	25.2	29.7	36.1	40.5	41.7	38.1	31.8	27	23.5	29.8	59	−1.7
Karasjok	69° 25′ N	25° 35′ E	420	60	3.7	4.6	12.4	25.3	36.9	49.3	55	51.1	41.7	28.4	13.6	5.2	27.3	90.3	−60.5
Vardo	70° 22′ N	31° 06′ E	33	60	22.1	21.4	23.5	29.5	35.1	42.3	47.7	47.8	43.2	34.9	28.2	24.1	33.3	80.1	−10.7
Soviet Union																			
Anadyr	64° 47′ N	177° 34′ E	16	7	−9.6	−7.6	−4.4	6.6	24.4	40.1	51.1	50	39.2	22.8	6.1	−5.6	17.8	79.7	−44.9
Archangel	64° 35′ N	40° 30′ E	...	...	...	...	...	...	...	...	...	...	...	...	...	...	32.3	94	−49
Berezovo	63° 56′ N	65° 04′ E	131	35	−10.5	−1.1	8.8	22.5	36.5	50.5	60.3	55.4	43.2	25.9	5.7	−4.9	24.4	...	...
Cape Chelyuskin	77° 43′ N	104° 17′ E	20	11	−13.9	−13.2	−19.3	−4.9	14.9	29.8	34.7	32.5	27.1	12.7	−6.5	−14.6	6.6	67	−50
Cape Deznev	66° 02′ N	169° 52′ W	50	6	−6.5	−9.6	−2.2	9.3	22.1	34.5	41.7	41	36.3	24.4	9.5	1.2	16.9	...	...
Cape Shmidt	68° 55′ N	179° 29′ E	23	3	−19.9	−15.2	−10.2	−3.8	18.2	34	39.4	37	30.4	17.4	−0.8	−8.3	10.1	75	−46
Chita	52° 03′ N	113° 29′ E	2,221	26	−17.3	−8.1	9.7	32	46.2	60.3	65.7	59.7	46.8	28.9	5.9	−11.4	26.5	100	−57
Dickson Island	73° 30′ N	80° 23′ E	79	11	−18.4	−14.4	−13.9	−0.8	16.9	30.7	37.8	39.7	32.5	16.9	−4.5	−11	9.1	73.4	−55.3
Dudinka	69° 24′ N	86° 04′ E	66	17	−22.4	−14.4	−9.6	3	20.3	39	54.9	50.5	36.3	14.7	−7.8	−16.1	12.4	84	−70
Irkutsk	52° 16′ N	104° 19′ E	1,532	35	−5.6	−1.3	13.5	32.7	46.4	57.9	63	58.8	46.2	31.5	12.7	−0.8	29.7	98	−58
Kolguyev Island	69° 32′ N	49° 08′ E	23	7	14	8.8	12	19.9	26.6	39.7	43.3	45.9	40.6	32	23	14.4	26.6	75.6	−30.1
Krasnoyarsk	56° 02′ N	92° 45′ E	885	30	−0.8	4.5	16.9	33.6	48.9	61.2	66.7	61.5	49.6	33.3	15.8	5.5	33.1	103	−56
Markovo	64° 45′ N	170° 56′ E	85	21	−19.8	−13.9	−9.4	5.2	30.2	50.9	58.1	50.7	37.8	15.8	−3.1	−15.3	15.6	84	−75

Station	Years of record	Average precipitation, in. Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Alaska														
Adak	4 to 5	7.87	6.21	5.98	3.92	4.22	2.13	3.13	5.24	6.01	7.45	8.03	9.63	69.82
Attu	4	5.50	2.70	7.00	3.30	5.50	8.20	5.70	5.00	6.20	10.80	10.10	5.80	75.80
Barter Island	0 to 1	...	...	...	...	0.05	0.20	0.40	1.70	0.90	0.50	0.10	0.20	...
Dutch Harbor	19 to 23	6.32	6.12	4.92	4.19	4.33	2.82	1.89	2.45	5.45	7.39	5.81	6.92	58.61
Galena	3	0.90	0.38	0.69	0.47	0.48	1.74	2.35	2.53	1.56	0.36	0.64	0.94	13.04
Kodiak	46 to 52	4.82	4.88	3.94	4.20	5.94	4.86	3.56	5.04	5.48	7.45	5.60	6.17	61.94
McGrath	12	1.18	1.19	1.04	0.42	0.98	2.12	2.42	3.52	2.40	1.74	1.08	1.28	19.37
Wales	7	0.33	0.37	0.24	0.20	0.37	0.53	1.44	2.52	1.76	1.18	0.53	0.29	9.76
Wiseman	6 to 8	0.56	0.24	0.20	0.45	0.57	0.70	1.50	0.93	1.83	0.81	0.59	0.64	8.82
Canada														
Aklavik	21	0.58	0.53	0.43	0.50	0.56	0.78	1.35	1.29	0.94	0.80	0.81	0.48	9.05
Arctic Bay	12	0.31	0.18	0.29	0.24	0.31	0.46	0.68	1.27	0.93	0.70	0.31	0.23	5.91
Churchill	54	0.48	0.61	0.87	0.89	0.93	1.85	2.19	2.69	2.33	1.43	1.03	0.66	15.96
Clyde River	8	0.35	0.33	0.24	0.24	0.44	0.37	0.94	1.17	0.86	1.29	1.13	0.21	7.57
Coppermine	13	0.57	0.44	0.63	0.84	0.55	0.84	1.33	1.86	1.03	1.16	0.84	0.63	10.72
Coral Harbour	8	0.29	0.32	0.32	0.60	0.46	0.97	1.47	1.36	1.03	1.14	0.71	0.42	9.09
Dawson	...	0.87	0.70	0.52	0.51	1.01	1.18	1.53	1.55	1.41	1.17	1.13	1.03	12.61
Fort Chimo	3	0.76	0.30	0.33	0.34	1.29	0.61	3.45	2.64	2.12	0.76	1.02	0.72	14.34
Fort Simpson	...	0.72	0.70	0.48	0.70	1.37	1.46	1.99	1.47	1.31	1.07	0.85	0.84	12.96
Isachsen	3	0.07	0.06	0.06	0.05	0.32	0.14	0.73	0.49	0.64	0.14	0.20	0.05	2.95
Mould Bay	2 to 3	0.04	0.05	0.12	0.02	0.15	0.28	0.96	0.34	0.49	0.08	0.08	0.03	2.64
Norman Wells[1]	31	0.46	0.49	0.42	0.43	1.15	1.34	2.02	1.94	1.06	0.85	0.61	0.45	11.22
Pangnirtung	13	1.00	1.24	0.98	1.55	0.70	0.95	1.39	2.14	1.24	1.83	1.94	1.22	16.18
Port Harrison	18	0.71	0.28	0.72	0.84	0.79	0.97	1.19	1.62	2.11	2.45	3.38	1.24	16.30
Greenland														
Angmagssalik	30	3.30	2.00	2.40	2.40	2.40	2.10	1.90	2.40	3.70	5.70	3.30	2.80	34.40
Godthaab	45	1.38	1.69	1.61	1.18	1.69	1.42	2.24	3.11	3.35	2.52	1.89	1.46	23.54
Ivigtut	50	3.27	2.60	3.35	2.50	3.46	3.22	3.11	3.74	5.87	5.71	4.64	3.15	44.61
Scoresby Sound	4	1.80	1.70	0.60	1.50	0.30	1.00	0.60	0.40	1.10	1.10	1.00	1.50	12.60
Upernavik	50	0.43	0.47	0.68	0.59	0.59	0.51	0.94	1.14	1.06	1.10	1.06	0.55	9.13
Iceland														
Stykkisholmur	50	3.00	2.50	1.90	1.50	1.30	1.50	1.40	1.60	2.70	3.00	2.80	2.40	25.60
Finland														
Kittila	50	0.9	0.7	0.7	0.9	1.3	1.9	2.8	2.7	1.9	1.5	1.3	1.0	17.6
Pechenga (Petsamo)	10	0.7	0.8	1.2	0.8	1.2	1.9	1.5	1.8	2.4	1.9	1.2	1.2	16.6
Utsjoki	8	0.9	1.0	0.9	0.9	1.1	1.3	2.9	2.4	1.7	1.1	1.3	0.9	16.4
Norway														
Bear Island	7	1.1	1.4	1.2	0.7	0.7	0.8	0.7	0.9	1.6	1.3	1.0	1.1	12.5
Fagernes	27	1.4	1.3	1.1	0.9	1.1	1.6	2.1	2.7	2.5	1.9	1.5	1.2	19.3
Green Harbour	15	1.4	1.5	1.1	0.9	0.5	0.4	0.6	0.9	1.0	1.1	0.9	1.5	11.8
Jan Mayen	7	1.5	1.7	1.1	0.9	0.5	0.6	0.8	1.1	2.5	2.2	1.4	1.0	15.3
Karasjok	46	0.7	0.7	0.5	0.5	0.9	1.7	2.4	2.1	1.8	1.2	1.0	0.7	14.3
Vardo	33	2.6	2.8	2.1	1.6	1.4	1.6	1.7	2.0	2.4	2.5	2.5	2.6	25.9
Soviet Union														
Anadyr	4	0.2	0.1	0.2	0.3	0.4	0.5	1.4	1.6	1.1	0.3	0.2	0.1	6.4
Archangel	...	...	...	...	...	...	...	4.1	4.1	...	...	...	...	16.8
Berezovo	27	0.6	0.4	0.5	0.6	1.3	2.0	2.2	2.3	1.6	0.9	0.7	0.5	13.6
Cape Chelyuskin	7	0.2	0.1	0.0	0.1	0.1	0.5	1.0	0.9	0.3	0.3	0.2	0.1	3.8
Cape Deznev	6	0.1	0.2	0.1	0.1	0.2	0.5	0.7	...	...	1.3	0.2	0.1	...
Cape Shmidt	3	0.1	0.4	0.5	0.5	0.2	0.4	0.8	1.8	0.8	0.7	0.2	0.2	6.6
Chita	22	0.1	0.1	0.2	0.4	1.1	2.0	3.7	3.7	1.4	0.4	0.3	0.1	13.5
Dickson Island	11	0.3	0.2	0.1	0.3	0.3	0.7	0.9	1.5	1.1	0.5	0.4	0.2	6.5
Dudinka	17	0.2	0.2	0.2	0.3	0.4	1.2	1.3	1.7	1.7	0.7	0.3	0.2	8.4
Irkutsk	35	0.4	0.3	0.3	0.2	1.5	2.2	3.5	3.1	1.7	0.7	0.7	0.6	15.2
Kolguyev Island	4	0.2	0.2	0.1	0.3	0.4	0.8	1.4	0.9	1.6	1.2	0.9	0.8	8.8
Krasnoyarsk	21	0.2	0.2	0.3	0.4	1.3	1.7	2.0	2.6	1.4	0.9	0.7	0.5	12.2
Markovo	21	0.3	0.2	0.3	0.1	0.3	0.8	1.5	1.9	1.0	0.5	0.4	0.3	7.6

[1] Because the records for Norman Wells only go back to 1944, temperature and precipitation data have been taken from the records for Fort Norman, about 50 miles to the southeast.

TABLE XB3-1 (cont.)

Weather Data for Arctic and Subarctic Stations

Station	Lat	Long.	Eleva-tion, ft	Years of record	Mean temperature, °F													Record temperature		Years of record	Average precipitation, in.												
					Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Max	Min		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Soviet Union (cont)																																	
Matochkin Shar	73° 16′ N	56° 24′ E	59	7	3.6	3.2	−3.3	8.2	22.3	33.8	41.7	42.1	35.4	26.6	15.8	6.4	19.6	63.3	−41.3	16	0.4	0.3	0.2	0.3	0.3	0.6	1.3	0.9	1.5	0.6	0.6	0.4	7.4
Okhotsk	59° 21′ N	143° 17′ E	20	32	−10.5	−7.2	6.4	21	34.9	44.4	54.3	55	46.4	26.6	5.4	−7.4	22.4	78	−50	20	0.1	0.1	0.2	0.3	0.8	1.7	2.3	2.4	2.1	1.0	0.1	0.1	11.2
Olekminsk	60° 22′ N	120° 26′ E	663	25	−31.9	−18.8	−0.6	23.2	43.2	59.9	66.9	58.1	44.4	23	−5.6	−25.6	19.8	95	−76	26	0.4	0.3	0.2	0.4	0.9	1.6	1.6	2.1	1.2	0.7	0.7	0.5	10.6
Russkaya Gavan	76° 14′ N	62° 39′ E	29	7	11.1	7.7	3.6	10.9	21.9	32.7	38.1	39	33.1	26.2	15.4	8.8	20.7	60.4	−33.9	7	0.3	0.2	0.3	0.4	0.4	0.7	0.9	1.6	1.3	0.8	0.5	0.4	7.8
Salekhard	66° 31′ N	66° 35′ E	86	33	−14.1	−7.8	−0.4	13.1	28	44.8	56.8	52	41	23.5	2.1	−7.4	19.2	85	−65	30	0.3	0.3	0.2	0.3	0.7	1.3	1.8	2.0	1.5	0.7	0.5	0.4	10.0
Sredne-Kolymsk	67° 10′ N	157° 10′ E	98	13	−39.8	−32.8	−16.8	5	30.2	54.7	57.2	49.5	36.5	11.8	−18.2	−34.1	8.6	94	−72	13	0.3	0.3	0.2	0.2	0.2	0.9	1.3	1.2	0.8	0.5	0.5	0.4	6.8
Surgut	61° 17′ N	72° 30′ E	138	24	−11	−2.2	9.7	23.7	38.5	54.3	63.5	58.1	46.4	28.2	6.8	−5.1	25.9	90	−67	28	0.6	0.4	0.5	0.5	1.3	2.5	2.4	3.2	1.9	1.3	0.8	0.7	16.1
Tikhaya Bay (Franz Josef Land)	80° 20′ N	52° 48′ E	20	7	1.6	−1.5	−7.1	2.5	18.1	30.2	34.3	33.4	27.7	17.4	7.3	2.5	13.8	52.5	−39.3	10	0.2	0.3	0.2	0.2	0.2	0.3	0.7	1.1	0.7	0.3	0.3	0.2	4.7
Tiksi Bay	71° 35′ N	128° 55′ E	23	7	−19.5	−18	−20.2	−0.8	24.4	38.5	48.2	46.8	36	13.5	−9.6	−15.9	10.3	91	−57	7	0.1	0.1	0.1	0.1	0.1	1.2	1.3	1.1	0.8	0.2	0.2	0.1	5.4
Turukhansk	65° 55′ N	87° 37′ E	131	46	−19.1	−10.2	0.5	14	30.4	47.7	60.6	54.3	40.6	19.2	−5.4	−17.5	18	91	−78	40	0.5	0.4	0.4	0.5	1.0	1.6	2.0	2.3	2.0	1.1	0.8	0.5	13.1
Vaigach Island	70° 24′ N	58° 48′ E	36	7	3.2	1.9	−0.1	10.4	22.3	34.5	41.9	42.3	38.3	29.3	18.9	7.5	20.8	62.8	−44.5	13	0.3	0.2	0.2	0.2	0.3	0.8	1.0	1.3	1.3	0.9	0.7	0.4	7.6
Verkhoyansk	67° 33′ N	133° 24′ E	400	38	−58.2	−48.1	−23.8	9.3	36.3	56.1	59.9	51.6	36.1	5.7	−34.1	−51.3	3.3	94	−94	31	0.2	0.1	0.1	0.2	0.3	0.9	1.0	1.0	0.5	0.3	0.3	0.1	5.0
Vladivostok	43° 07′ N	131° 54′ E	95	35	7.3	13.8	26.4	39.9	49.1	56.5	64.6	69.1	61.7	48.7	31.1	14.7	40.3	96	−22	49	0.3	0.4	0.8	1.2	2.1	2.9	3.3	4.8	4.5	1.9	1.2	0.6	24.0
Wrangel Island	70° 58′ N	178° 23′ W	10	11	−10.7	−12.8	−9.8	1.2	17.2	32.9	36.5	35.4	29.1	18.1	3.9	−5.3	11.3	65	−50	11	0.2	0.2	0.2	0.2	0.2	0.3	0.6	0.9	0.5	0.4	0.1	0.2	4.1
Yakutsk	62° 01′ N	129° 43′ E	354	77	−45.9	−33.2	−9.2	16.7	41.4	59.5	66.4	58.8	42.6	16.7	−19.7	−40.4	13.3	100	−84	35	0.2	0.2	0.1	0.2	0.5	1.1	1.3	1.6	0.9	0.5	0.4	0.3	7.3
Yurievo	59° 58′ N	108° 00′ E	1,079	3	−24.2	−10.3	4.3	23.7	40.5	56.8	62.1	55.4	41.5	23.2	−2.2	−17.5	21.2	...	...	6	0.4	0.4	0.3	0.4	1.3	1.5	1.9	2.4	1.5	1.0	0.8	0.5	12.4
Outer Mongolia																																	
Ulan Bator	47° 55′ N	106° 50′ E	4,347	26	−10.7	−2.6	11.7	33.3	46.4	58.3	62.8	59.5	46.6	30.6	8.2	−6.3	28.2	97	−48	5	0.0	0.0	0.1	0.2	0.3	1.0	2.9	1.9	0.8	0.2	0.1	0.1	7.7

APPENDIX C

PHYSICAL CONSTANTS AND CONVERSION FACTORS

PHYSICAL CONSTANTS				Reference
π	$= 3.1415926536$			
ϵ	$= 2.7182818285$		Base of natural logarithms	
G	$= (6.673 \pm 0.003) \times 10^{-8}$ cm^3/(gm sec^2)		Gravitational constant	B
e	$= (4.80288 \pm 0.00021) \times 10^{-10}$ esu		Electronic charge	A
$e' = e/c$	$= (1.60207 \pm 0.00007) \times 10^{-20}$ emu			A
h	$= (6.6252 \pm 0.0005) \times 10^{-27}$ erg sec		Planck's constant	A
c	$= (299792.9 \pm 0.8)$ km/sec		Velocity of light	A
m	$= (9.1085 \pm 0.0006) \times 10^{-28}$ gm		Electron rest mass	A
m_p	$= 1.007593 \pm 0.000003$ AMU	(phys.)	Proton rest mass	A
m_H	$= 1.008142 \pm 0.000003$ AMU	(phys.)	Hydrogen atom rest mass	A
m_n	$= 1.008982 \pm 0.000003$ AMU	(phys.)	Neutron rest mass	A
m_α	$= 4.002775 \pm 0.000015$ AMU	(phys.)	Alpha particle rest mass	D
m_p/m	$= 1836.13 \pm 0.04$		Ratio: proton mass/electron mass	A
e/m	$= (5.27299 \pm 0.00016) \times 10^{17}$ esu/gm		Specific charge of electron	A
e/mc	$= (1.75888 \pm 0.00005) \times 10^{7}$ emu/gm			A
$\hbar$	$= h/2\pi = (1.05444 \pm 0.00009) \times 10^{-27}$ erg sec		Unit of angular momentum	A
α	$= 2\pi e^2/(hc) = (7.29726 \pm 0.00008) \times 10^{-3}$		Fine structure constant	A
α^{-1}	$= hc/(2\pi e^2) = 137.0377 \pm 0.0016$			A
a_o	$= h^2/(4\pi^2 me^2) = (5.29171 \pm 0.00006) \times 10^{-9}$ cm		First Bohr radius	A
λ_{ce}	$= h/(2\pi mc) = a_o\alpha = (3.86150 \pm 0.00009) \times 10^{-11}$ cm		Compton wavelength of the electron	A
r_o	$= e^2/(mc^2) = a_o\alpha^2 = (2.81784 \pm 0.00010) \times 10^{-13}$ cm		Classical radius of the electron	A
μ_o	$= he/(4\pi mc) = (0.92732 \pm 0.00006) \times 10^{-20}$ erg/gauss		Bohr magneton	A
R_∞	$= 2\pi^2 me^4/(ch^3) = 109{,}737.309 \pm 0.012$ cm^{-1}		Rydberg for infinite mass	A
N	$= (6.02472 \pm 0.00036) \times 10^{23}$ (gm-mol)$^{-1}$	(phys.)	Avogadro's number	A
1/N	$= (1.65983 \pm 0.00010) \times 10^{-24}$ gm	(phys.)	Atomic mass unit (AMU)	A
R_o	$= (8.31662 \pm 0.00038) \times 10^{7}$ erg/(gm-mol °C)	(phys.)	Gas constant per mol	A
R_o	$= 1{,}545$ ft-lb/(lb-mol °F)			
k	$= R_o/N = (1.38042 \pm 0.00010) \times 10^{-16}$ erg/deg		Boltzmann's constant	A
0° K	$= -273.16$°C $= -459.69$° F		Absolute zero	
F	$= Ne = (2.89360 \pm 0.00007) \times 10^{14}$ esu/gm-mol	(phys.)	Faraday constant	A
F′	$= Ne/c = (9652.01 \pm 0.25)$emu/(gm-mol)	(phys.)		A
σ	$= 2\pi^5 R_o^4/(15c^2h^3N^4) = (5.6686 \pm 0.0005) \times 10^{-5}$ erg/(cm^{2}deg^{4}sec)		Stefan-Boltzmann constant	A

THE GREEK ALPHABET

Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ϵ	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	o	omicron
Π	π	pi
Ρ	ρ	rho
Σ	σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	ϕ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

PROPERTIES OF THE STANDARD ATMOSPHERE
(Based on NACA Technical Note No. 1428)

Altitude (ft)	Pressure		Velocity of sound (ft/sec)
	(psi)	(cm Hg)	
0	14.696	76.000	1,117
1,000	14.173	73.295	1,113
5,000	12.228	63.236	1,098
10,000	10.107	52.268	1,078
15,000	8.2937	42.891	1,058
20,000	6.754	34.93	1,037
25,000	5.453	28.20	1,017
30,000	4.365	22.57	995
35,000	3.458	17.88	973
40,000	2.721	14.07	971
50,000	1.682	8.698	971
60,000	1.048	5.420	971
70,000	0.649	3.36	971
80,000	0.403	2.08	971
90,000	0.250	1.29	971
100,000	0.156	0.807	971
200,000	0.004615	0.02387	1,220

CONVERSION FACTORS

Angular measure

1 degree = 0.017453 radian
1 radian = 57.29578 degrees
1 mil = $\tan^{-1}$ 0.001 = 3.4377 minutes

Length (L)

1 cm = 0.39370 in.
1 km = 3,280.8 ft = 0.62137 mile = 0.53961 nautical mile
1 in. = 2.540005 cm
1 ft = 30.48006 cm
1 mile = 1,760 yd = 5,280 ft = 1.60935 km
1 meter = 0.5468 fathom
1 nautical mile = 1.1516 miles = 2,026.8 yd = 6,080.2 ft
1 micron (μ) = 10^{-6} m = 10^{-3} mm = 10^{4} Å
1 Angstrom Unit (Å) = 10^{-10} m = 10^{-8} cm
λ_g/λ_s = 1.002063 ± 0.000034 (conversion factor from Siegbahn x-units to milliangstroms) Ref. A
1 sidereal light year = 9.46090 × 10^{12} km = 5.8787 × 10^{12} miles
1 parsec = 30.82 × 10^{12} km = 19.15 × 10^{12} miles = 3.258 light years

Area (L^2)

1 cm^2 = 0.15500 $in.^2$
1 $in.^2$ = 6.4516258 cm^2
1 $mile^2$ = 3,097,600 yd^2 = 2,589,998 m^2 = 640 acres
1 circular mil = 7.854 × 10^{-7} $in.^2$ = area of circle 0.001 inches in diameter
1 barn = 1 × 10^{-24} cm^2

Volume (L^3)

1 cm^3 = 0.061023 $in.^3$
1 liter = 1,000.027 cm^3 = 1.056710 liq qt = 0.26417762 gal
1 $in.^3$ = 16.387162 cm^3
1 ft^3 = 7.481 gal
1 liq qt = 946.333 ml
1 gal = 3.7853 liters = 231.00 $in.^3$
volume/mol of ideal gas (STP) = (22.4207 ± 0.0006) × 10^3 cm^3 (phys.) Ref. A
1 meter = 1.0936 yd

Time (T)

1 mean solar day = 1,440 min = 86,400 sec
1 calendar year = 8,760 hr = 525,600 min = 31,536,000 sec
1 sidereal year = 365.256 days

Velocity (L/T)

1 mi/hr = 1.4667 ft/sec = 0.86836 knots
60 mi/hr = 88 ft/sec
1 knot = 1.1516 mi/hr

Mass (M)

1 gm = 15.4324 grains
1 kg = 35.273957 oz avdp = 2.2046223 lb avdp
1 oz avdp = 28.349527 gm = 437.5 grains
1 lb avdp = 453.59243 gm = 16 oz avdp

Density (M/L^3)

1 gm/cm^3 = 0.03613 $lb/in.^3$ = 62.43 lb/ft^3 = 1,000 kg/m^3

Force (ML/T^2)

1 newton = 10^5 dynes = 0.22481 lb
Kgm/m = lb/lin ft

Pressure (M/LT^2)

1 gm/cm^2 = 0.014223 $lb/in.^2$
1 bar = 1.000 × 10^6 $dynes/cm^2$
1 $dyne/cm^2$ = 1.4504 × 10^{-5} $lb/in.^2$ = 0.1 $newton/m^2$
1 $lb/in.^2$ = 2.3066 ft of H_2O (39.1° F) = 2.0360 in. Hg (32° F)
1 atmosphere = 1.01325 bars = 1,033.2 gm/cm^2 = 1.0332 × 10^4 kg/m^2
= 14.696 $lb/in.^2$ = 760 mm Hg (0° C)
= 29.921 in. Hg (0° C) = 33.904 ft H_2O (0° C)

Work and energy (ML^2/T^2)

1 erg = 1 dyne-cm = 1 × 10^{-7} joule
= 2.3901 × 10^{-8} defined calorie
1 defined calorie = 4.1833 international joules
= 4.1840 absolute joules
1 absolute joule = 1 newton-meter = 10^7 ergs
= 0.23901 defined calories
= 2.778 × 10^{-7} kilowatt-hour
= 3.725 × 10^{-7} horsepower-hour
1 Btu = 252 calories = 1,055 joules = 778 ft-lb
1 calorie = 3.9683 Btu
1 horsepower-hour = 1.98 × 10^6 ft-lb = 2,545 Btu = 0.7457 kw-hr
1 electron volt = (1.60207 ± 0.00007) × 10^{-12} erg, Ref. A
Wavelength associated with 1 ev = (12,397.8 ± 0.5) × 10^{-8} cm, Ref. A
Wave number associated with 1 ev = 8,065.98 ± 0.30 cm^{-1}, Ref. A
1 AMU = 931.162 ± 0.024 Mev (phys.), Ref. A
1 gm = (5.60999 ± 0.00025) × 10^{26} Mev, Ref. A

Power (ML^2/T^3)

1 hp = 550 ft-lb/sec = 745.70 watts = 2,545 Btu/hr
1 kw = 1.341 hp = 239 Cal/sec = 3,413 Btu/hr
Under standard conditions, 60° F and 29.92 in. Hg (University of Nebraska Tractor Test Codes),

$$bhp_c = bhp_o \times \frac{P_s}{P_o}\sqrt{\frac{T_o}{T_s}}$$

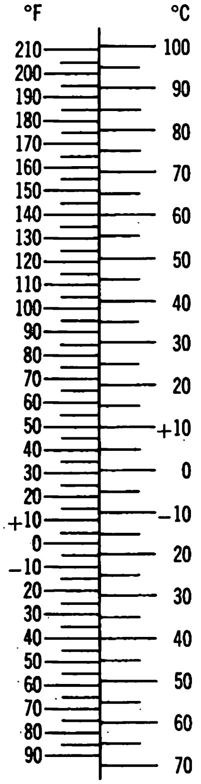
bhp_c = corrected brake horsepower
bhp_o = observed brake horsepower
P_o = observed barometric pressure in in. Hg
P_s = standard barometric pressure in in. Hg
T_o = observed absolute temperature in °F
T_s = standard absolute temperature in °F
Corrected belt horsepower = 0.85 × bhp_c
Corrected drawbar horsepower = 0.75 × bhp_c

Electricity and magnetism

1 ampere = 0.1 abampere = 3 × 10^9 statampere
1 ohm = 10^9 abohm = 1/9 × 10^{-11} statohm
1 volt = 10^8 abvolt = 1/300 statvolt
1 coulomb = 0.1 abcoulomb = 3 × 10^9 statcoulomb
1 henry = 10^9 abhenry = 1/9 × 10^{-11} stathenry
1 farad = 10^{-9} abfarad = 9 × 10^{11} statfarad
1 statvolt × 1 statcoulomb = 1 erg
1 abvolt × 1 abcoulomb = 1 erg
1 volt × 1 coulomb = 1 joule
permittivity in vacuum = ϵ_o = $1/36\pi \times 10^{-9}$ farad/meter
permeability in vacuum = μ_o = $4\pi \times 10^{-7}$ henry/meter

The above conversion factors are approximate on the assumption that C, the velocity of light, is given by C = 3 × 10^{10} cm/sec. Strictly, the numbers 3 and 9 above should be replaced by 2.99793 and 8.98758 respectively in the above formulae and 1/300 should be replaced by 1/299.793 in order to use the more accurate value of C in the conversion factors.

COMPARISON BETWEEN DEGREES FAHRENHEIT AND DEGREES CENTIGRADE



MISCELLANEOUS DATA

Wavelength of red Cd line = 6,438.4696 Å (in air, 1 atm., 15° C)

Wavelength of green Hg 198 line = 5,460.7532 Å (in air, 1 atm., 0° C) — Ref. C

Acceleration due to gravity g = 32.174 ft/sec² = 980.665 cm/sec² (standard value)

Velocity of sound in dry air = 331.36 m/sec = 1,087.1 ft/sec (0° C)

Velocity of sound in distilled H_2O = 1,404 m/sec = 4,605 ft/sec (0° C)

Density of Hg = 13.59509 gm/cm³ (0° C)

Density of dry air = 0.001293 gm/cm³ (0° C, 760 mm)

Normal boiling points:

He =	4.26° K =	−268.9° C
H_2 =	20.36° K =	−252.8° C
N_2 =	77.36° K =	−195.8° C
O_2 =	90.16° K =	−183.0° C
CO_2 =	194.65° K =	− 78.5° C
H_2O =	373.16° K =	100.0° C

Normal heat of fusion of H_2O = 79.71 (15° C cal)/gm

Normal heat of vaporization of H_2O = 539.55 (15° C cal)/gm (100° C)

1 curie = 3.700×10^{10} disintegrations/sec

REFERENCES

A. Least-Squares Adjusted Values of the Atomic Constants—November 1952. Special Technical Report No. 1 Prepared under Contract with the Atomic Energy Commission. Jesse W. M. DuMond and E. Richard Cohen. (The precision measures quoted on this chart from Reference A are standard errors, σ, as distinguished from "probable errors," P. E.: P. E. = 0.6745 σ. For a more extensive list of atomic constants, together with a thorough discussion of the entire problem of determining the values and standard errors of these constants, see this excellent report or the abridged version which appears in Revs. Modern Phys. 25, 691 and 709 (1953).)

B. P. R. Heyl and P. Chrzanowski, J. Research NBS 29, 1 (1942).

C. Wm. F. Meggers and F. O. Westfall, J. Research NBS 44, 447 (1950).

D. Private communication from Professor Jesse W. M. DuMond.

NOTE: The physical scale of atomic weights on which O^{16} isotope of oxygen has by definition the exact weight 16 is the one used throughout these tables.

ARCTIC ENGINEERING

CHAPTERS 3 and 4

U. S. Patent No. 2680630

Machol Edge Index

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1. Bend the handbook with the Edge Index on the outside.
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3. Riffle the edges of the pages to the corresponding mark on the edge of the page and open to the subject.