DEPARTMENTS OF THE ARMY AND THE AIR FORCE

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ARCTIC AND SUBARCTIC CONSTRUCTION GENERAL PROVISIONS

CCB Application Notes:

1. Character(s) preceded & followed by these symbols (+ +) or (+ +) are super- or subscripted, respectively.
   EXAMPLES: 42m+3+ = 42 cubic meters
   CO+2+ = carbon dioxide
2. All degree symbols have been replaced with the word deg.
3. All plus or minus symbols have been replaced with the symbol +/-. In turn, all greater than or equal to and less than or equal to symbols are replaced with > / =, < / = respectively.
4. All table note letters and numbers have been enclosed in square brackets in both the table and below the table. The same is true for footnotes.
5. Whenever possible, mathematical symbols have been replaced with their proper name and are enclosed in square brackets.
6. An asterisk placed before a letter indicates that it is cursive in the original document.

TECHNICAL MANUAL

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This manual supersedes TM 5-852-1/AFM 88-19, Chap. 1, dated 25 February 1966.

ARCTIC AND SUBARCTIC CONSTRUCTION--GENERAL PROVISIONS

LIST OF FIGURES

CHAPTER 1

GENERAL

1-1. Purpose

This manual contains general criteria and information for considering frost action, permafrost and other factors in the design of military facilities in arctic and subarctic regions.

1-2. Scope

The contents of this manual are applicable to both Army and Air Force construction. This manual provides basic background data for the detailed criteria pertaining to the various elements of arctic and subarctic facility design presented in the other manuals of the Arctic and Subarctic Construction series, TM 5-852-2 through 7, and 9/AFR 88-19, Volume 2, 5 and 6/AFM 88-19, Chap. 3, 4, 7, and 9.

1-3. Need for special approaches

In the design, construction and maintenance of facilities such as roads, utilities and buildings in arctic and subarctic regions, many problems are encountered that do not exist, or are not present in the same degree, in more temperate regions. These problems arise, for example, from the presence of permafrost over vast areas, with its potential for thaw and thaw-settlement; from the special properties of frozen soil, frozen rock and ice; from the effects of frost heave and other phenomena in soil, rock, paving and other materials subject to intense annual cycles of freezing and thawing temperatures; from drainage, water supply and sewerage problems peculiar to those regions; and from such factors as the shortness of the above-freezing summer season, the limited amount of daylight in fall and winter, environmental aspects, and often difficult conditions of transportation, access and communications. Special design, construction and maintenance approaches, and management of construction are often required to cope with such problems and to meet stability and operational requirements for facilities.

1-4. Definitions

Certain specialized terms used in current literature on frost and permafrost and in the Arctic and Subarctic Construction manuals are defined below. Additional terms pertinent to heat transfer calculations are defined in TM 5-852-6/AFR 88-19, Volume 6.

a. Regions.

(1) Arctic. The northern region in which the mean temperature for the warmest month is less than 50 deg. F and the mean annual temperature is below 32 deg. F. In general, the arctic land areas coincide approximately with the tundra region north of the limit of trees.

(2) Subarctic. The region adjacent to the Arctic in which the mean temperature for the coldest month is below 32 deg. F, the mean temperature for the warmest month is above 50 deg. F, and in which there are less than 4 months having a mean temperature above 50 deg. F. In general, subarctic land areas coincide with the circumpolar belt of dominant coniferous forest.

(3) Seasonal frost areas. Those areas of the earth in which there is significant freezing during the winter but without development of permafrost.

b. Soil and frost terms.

(1) Active layer. A commonly used term in permafrost areas for the annual frost zone.

(2) Aggradation. Progressive raising of the permafrost table, taking place over a period of years.

(3) Annual frost zone. The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, the active layer, suprapermafrost and the annual frost zone are identical.

(4) Closed system. A condition in which no source of free water is available during the freezing process beyond that contained originally in the voids of soil.

(5) Creep. Extremely slow, continuing strain deformation of material under stress, at rates so slow as to usually be imperceptible except by observations of high precision or of extended duration.

(6) Degradation. Progressive lowering of the permafrost table, occurring over a period of years.

(7) Excess ice. Ice in excess of the fraction that would be retained as water in the soil voids upon thawing.

(8) Frost action. A general term for freezing and thawing of moisture in materials. It also covers the effects on these materials and on structures of which they are a part or with which they are in contact. The term "frost" is often used to refer to frost action in general.

(9) Frost boil. The breaking of a limited section of a highway or airfield pavement under traffic and ejection of soft, semi-liquid subgrade soil. This is caused by the melting of the segregated ice formed by frost action.

(10) Frost creep. The ratchetlike downslope movement of particles as a result of frost heaving and subsequent ground settling upon thawing. The heaving is predominantly normal to the slope and the settling more nearly vertical.

(11) Frost heave. The raising of a surface because of ice formation in the underlying soil

(12) Frost slough. A shallow slide that occurs when the stability of frost-loosened and moisture-saturated fine-grained soils on slopes is reduced during thaw.

(13) Frost-susceptible soil. Soil that will experience significant ice segregation when the requisite moisture and freezing conditions are present. Such soils are further defined in TM 5-818-2/AFM 88-6, Chap. 4.

(14) Frost table. The surface, usually irregular, that represents the level, at any time in spring and summer, to which thawing of seasonal frozen ground has penetrated.

(15) Frost thrust. A force due to frost action.

(16) Frozen zone. A range of depth within which the soil is frozen. (17) Ground ice. A body of more or less soil-free ice within frozen ground.

(18) Heterogeneously frozen soil. A soil with part of its water frozen as macroscopic ice occupying space in excess of the original voids in the soil.

(19) Homogeneously frozen soil. A soil in which water is frozen within the material voids without macroscopic segregation of ice.

(20) Ice segregation. The growth of ice within soil in excess of the amount that would be produced by the in-place conversion of the original void moisture to ice. Ice segregation occurs most often as distinct lenses, layers, veins and masses, commonly, but not always, oriented normal to the direction of heat loss.

(21) Ice wedge. A wedge-shaped ice mass in permafrost, usually associated with fissures on trough-type polygons.

(22) Non-frost-susceptible materials. Cohesionless materials such as crushed rock, gravel, sand, slag and cinders in which there is no significant ice segregation under normal freezing conditions (see TM 5-818-2/AFM 88-6, Chap. 4).

(23) Normal period. The time of the year when there is no alteration in

strength of foundation materials because of frost action. In seasonal frost areas, it generally extends from mid- or late spring to mid- or late fall.

(24) Open system. A condition where free water in excess of that contained originally in the voids of the soil is available to be moved to the surface of freezing to form segregated ice in frost-susceptible soil.

(25) Percent heave. The ratio, expressed as a percentage, of the amount of heave to the depth of frozen soil.

(26) Permafrost. Perennially frozen ground. It may be defined more specifically as a thermal condition in soil or rock in which temperatures below 32 deg. F persist over at least two consecutive winters and the intervening summer.

(27) Permafrost base. The lower boundary of permafrost.

(28) Permafrost, continuous. Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region, with the exception of widely scattered locations.

(29) Permafrost, discontinuous. Permafrost occurring in some areas beneath the ground surface throughout a geographic region where other areas are free of permafrost.

(30) Permafrost table. An irregular surface within the ground that represents the upper boundary of permafrost.

(31) Residual thaw layer. A layer of unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost (active layer) extends to permafrost.

(32) Solifluction. The perceptible slow downslope flow of saturated unfrozen soil over a base of impervious or frozen material. Movement takes place primarily when melting of segregated ice or infiltration of surface runoff concentrates excess water in the surface soil, which then behaves like a viscous fluid.

(33) Suprapermafrost. The entire layer of ground above the permafrost table.

(34) Tangential adfreeze shear. Tangential shear between frozen ground or ice and another material to which it is bonded by freezing.

(35) Thaw-stable frozen soils. Frozen soils that do not, on thawing, show loss of strength below normal, long-time thawed values nor produce detrimental settlement.

(36) Thaw-unstable frozen soils. Frozen soils that show, on thawing, significant loss of strength below normal, long-time thawed values or significant settlement, as a direct result of the melting of excess ice in the soil.

c. Temperature-related terms.

(1) Average annual temperature. The average of the average daily temperatures for a particular year.

(2) Average daily temperature. The average of the maximum and minimum temperatures for one day or the average of several temperature readings taken at equal time intervals during one day, generally hourly.

(3) Average monthly temperature. The average of the average daily temperatures for a particular month.

(4) Breakup period. The period of the spring thaw during which the ground surface is excessively wet and soft, and ice is disappearing from streams and lakes. Duration of the breakup period varies usually from 1 to 6 weeks, depending on region or local climatic conditions.

(5) Degree-days. The degree-days for any one day equal the difference between the average daily air temperature and 32 deg. F. The degree-days are negative when the average daily temperature is below 32 deg. F (freezing degreedays) and positive when above (thawing degree-days). Degree-days may be computed in either Fahrenheit or Celsius units; in this manual, Fahrenheit degree-days are used. Figure 1-1 shows a typical curve obtained by plotting cumulative degree-days versus time.

(6) Design freezing index. For design of permanent pavements, the design freezing index

should be the average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the air freezing index for the coldest winter in a 10-year period may be substituted. For design of foundations for average permanent structures, the design freezing index should be computed for the coldest winter in 30 years of record or should be estimated to correspond with this frequency if the number of years of record is limited. Periods of record used should be the latest available. To avoid the necessity for adopting a new and only slightly different freezing index each year, the design index at a site with continuing construction need not be changed more than once in 5 years, unless the more recent temperature records indicate a significant change. A design freezing index for pavements is illustrated in figure 1-1.

(7) Design thawing index. The design thawing index is computed on the same frequency and other bases as the design freezing index, except that summer thaw conditions are used.

(8) Freezeup period. The period during which the ground surface freezes and an ice cover is forming on streams and lakes. The duration of the freezeup period varies from 1 to 3 months, depending on regional or local climatic conditions.

(9) Freezing index. The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of belowfreezing temperatures

[retrieve Figure 1-1. Determination of freezing and thawing indexes.]

occurring during any given freezing season. The index determined for air temperatures at approximately 4.5 feet above the ground is commonly designated as the air, freezing index, while that determined for temperatures immediately below a surface is known as the surface freezing index.

(10) Freezing season. That period of time during which the average daily temperature is generally below 32 deg. F. Figure 1-2 shows mean dates for beginning of the freezing season in the Northern Hemisphere.

(11) Frost-melting period. An interval of the year during which ice in the ground is returning to a liquid state. It ends when all of the ice in the ground is melted or when freezing starts again. Although in the generalized case there is only one frost-melting period, beginning during the general rise of air temperatures in the spring, one or more significant frost melting intervals may take place during a winter season.

(12) Geothermal gradient. The temperature gradient in the ground below the zone of annual temperature fluctuations, produced by the continuous flow of heat from the Earth's hot interior toward the relatively cool Earth's surface.

(13) Mean annual temperature. The average of the average annual temperatures for several years.

(14) Mean daily temperatures. The average of the average daily temperatures for a given day for several years.

(15) Mean freezing index. The freezing index determined on the basis of mean temperatures. A mean freezing index is illustrated in figure 1-1.

(16) Mean monthly temperature. The average of the average monthly temperatures for a given month for several years.

(17) Mean thawing index. The thawing index determined on the basis of mean temperatures. A mean thawing index is illustrated in figure 1-1.

(18) n-factor. The ratio of surface index to air index for either freezing or thawing. Surface index equals air index multiplied by the n factor.

(19) Period of weakening. An interval of the year that starts at the beginning of the frost-melting period and ends when the subgrade strength has returned to normal period values or when freezing starts again. In seasonal frost areas, the period of weakening may be

substantially longer than the frostmelting period, but in permafrost areas the periods coincide.

(20) Thawing index. The number of degree-days between the lowest and highest points on a curve of cumulative degree-days versus time for one thawing season. It is used as a measure of the combined duration and magnitude of abovefreezing temperatures during any given thawing season. The index determined for air temperatures at 4.5 feet above the ground is commonly called the air thawing index, while that determined for temperatures immediately below a surface is known as the surface thawing index. A thawing index is shown in figure 1-1.

(21) Thawing season. That period of time during which the average daily temperature is generally above 32 deg. F. Figure 1-3 shows mean dates for beginning of the thawing season in the Northern Hemisphere.

(22) Thermal regime. The pattern of temperature variations found in the ground with time and with depth from the surface.

(23) Wind chill. The excess rate of removal of body heat from exposed skin by moving air compared to still air at low temperatures. It is often expressed as a lower equivalent air temperature that is a function of actual air temperature and wind speed.

d. Terrain terms.

(1) Frost mound. A localized upwarp of land surface caused by frost action with or without hydrostatic pressure.

(2) Icing. A surface ice mass formed by freezing of successive sheets of water.

(3) Muskeg. Poorly drained organic terrain consisting of a mat of living vegetation overlying an extremely compressible mixture of partially decomposed peat, varying in thickness from a few inches to many feet.

(4) Patterned ground. A general term describing ground patterns that result from frost action, such as polygons, circles and nets, stripes, and solifluction features.

(5) Pingo (hydrolaccolith). A large ice-cored frost mound, often 100 feet high or more.

(6) Thermokarst. The irregular topography resulting from the process of differential thaw settlement or caving of the ground because of the melting of excess ice in thaw-unstable permafrost.

(7) Tundra. A treeless region of grasses and shrubs characteristic of the Arctic.

[retrieve Figure 1-2. Mean date of the beginning of the freezing season.]

[retrieve Figure 1-3. Mean date of the beginning of the thawing season.]

CHAPTER 2

ARCTIC AND SUBARCTIC REGIONS

2-1. Introduction

a. The Arctic and Subarctic may be defined in several different ways, depending on whether they are looked at from the point of view of astronomy, botany, physics, climatology, ocean navigation or other specialized field. For engineering, the Arctic and Subarctic are best defined on basis of the prevailing air temperature conditions. Definitions based on air temperature are given in paragraphs 1-4a(1) and 1-4a(2). Figure 2-1 shows the limits of the Arctic and Subarctic in accordance with these definitions, together with the northern limit of trees.

b. Climatic data for all stations that report to the U.S. National Weather Service are available from the U.S. Department of Commerce, National Weather Records Center, Asheville, North Carolina. In addition, climatic data for a large number of sites are given in TM 5-785/NAVFAC P-89/AFM 88-29. For foreign countries, attempts should be made to obtain climatic data from their respective national climatic centers. Department of Defense agencies should request additional climatic information through the U. S. Air Force Environmental Technical Applications Center (ETAC), Scott Air Force Base, Illinois. Included in data obtainable through ETAC are weather records for all military airfields.

c. Climatological, ground temperature and soil data have been obtained from the 21 locations in Alaska and Canada that are shown in figure 2-2.

d. Detailed records for Canadian observation stations are available from Atmospheric Environment Service, Department of the Environment Canada, Toronto.

e. Some specific features of these regions of significance to engineering are outlined in the remainder of this chapter.

2-2. Temperature conditions

a. As may be seen in figures 2-3 and 2-4, temperatures decrease generally from south to north, although not strictly according to latitude. On both continents, the lowest mean annual temperature is about 5 deg. F. Appendix A presents some general information about freezing and thawing index data from the two continents.

b. Air temperature records for some arctic and subarctic stations may not be of sufficient duration to permit determination of design freezing or thawing indexes on the basis of 30 years of record. For pavement design, as explained in paragraphs 1-4c(6) and 14c(7), the extreme values in 10 years of record may be used. For foundations of average permanent structures, the ratios of design to mean indexes determined at the closest stations that do have 30 years of record may usually be employed for estimating such design indexes at stations that have means based on at least 10 years of record.

2-3. Precipitation, snow cover and snow loads

a. Annual precipitation is mostly very light in the Arctic, much of it falling as snow. Considerably heavier precipitation falls in certain parts of the Subarctic that are under the influence of maritime storm paths. TM 5-852-7/AFM 88-19, Chap. 7 presents hydrologic criteria, together with general information on icing and special design considerations, for arctic and subarctic conditions. Figure 2-5 shows mean monthly and annual precipitation at selected stations.

b. Icing on structures, vehicles and aircraft can be a serious problem in some parts of the Arctic and Subarctic, particularly in coastal areas near open water. c. Snow cover may be a factor in planning field activities. Figures 2-6 and 2-7 provide measures of the snow cover season. Over large areas of the Arctic and Subarctic the mean depth of snow at the end of the month with maximum seasonal snow depth may not exceed about 2 to 2-1/2 feet. For some areas the value may be as little as about 10 inches, and for others it may be several feet. Absolute maximum values may exceed the mean by about half.

d. Extreme local variations precluded state-wide mapping of ground snow loads for Alaska. Design snow loads for specific sites should only be adopted after consideration of local conditions. Maximum snow loads may vary not only with snow cover depths but also with regional and seasonal variations in snow cover density. The general variation of maximum snow load on the ground in Canada is illustrated in figure 2-8. Differences in elevation and in topographic position, as well as details of the engineering feature itself, can produce substantial differences in effective maximum snow loads.

2-4. Ice cover

The freezing of lakes, rivers and coastal waters in winter can be a major controlling factor in the scheduling and effectiveness of field activities in the Arctic and Subarctic. Waterways that can be used for boats or float-equipped aircraft in the summer become unusable for these vehicles when freezeup starts in the period of September to November. Several weeks are then required before the ice becomes thick enough to support other types of vehicles. During the winter, ice surfaces can often be extremely valuable as aircraft

[retrieve Figure 2-1. Northern cold regions: polar limits and zones.]

landing areas and as smooth, obstruction-free surfaces for tractor-trains and other forms of surface transportation. Ice may be between 4 and 8 feet thick approximately between 1 April and 1 June and may remain capable of carrying loads for as many as 3 weeks after the start of surface thaw before becoming unsafe. Then there is another period of up to several weeks when the water body cannot be used for any form of transportation until the ice has melted or broken up and disappeared. Ice bearing capacity is affected by many variables such as ice thickness, temperature and quality; snow cover; type, speed, spacing and number of repetitions of moving loads; length of time of stationary loading; depth of water; presence of open cracks or zones of pressure buckling; and presence of springs, seepage inflow and currents. There is an approximate boundary between failure and safety for these conditions. For example, to ensure safe movement of single vehicles crossing freshwater (lake or river) ice at temperatures below 32 deg. F, the formula P = h+2+/16 can be used as a rough guide (P is in tons and h is in inches of solid, clear ice). Table 2-1 is a slight refinement over the above formula for shortterm loading. Solid, clear, freshwater ice has no air bubbles that might reduce strength. Ice containing air bubbles ("snow ice," often formed by the freezing of water-soaked snow) is not as strong as clear ice. To account for the reduced strength of snow ice, 1 inch of snow ice is equivalent to only 1/2 inch of clear ice. If any substantial operation involving loading of floating ice is contemplated, guidance should be requested from the U.S. Army Cold Regions Research

[retrieve Figure 2-2. Locations of observation stations in Alaska and Canada.]

[retrieve Figure 2-3. Distribution of mean annual air temperature (deg. F) in

[retrieve Figure 2-4. Distribution of mean annual air temperature (deg. F) in

[retrieve Figure 2-5a. Mean monthly and annual precipitation at selected

[retrieve Figure 2-5b. Location of stations.]

[retrieve Figure 2-6a. Snow cover of 1 inch or more in Canada--Mean annual date

[retrieve Figure 2-6b. Snow cover of 1 inch or more in Canada--Mean annual date

[retrieve Figure 2-7a. Stable snow cover, USSR--Average dates of formation.]

[retrieve Figure 2-7b. Stable snow cover, USSR--Average dates of destruction.]

[retrieve Figure 2-8. General variation in maximum snow load (lb/ft+2+) on the

and Engineering Laboratory in Hanover, New Hampshire.
[retrieve Table 2-1. Approximate short term or moving load-carrying capacity of

NOTE: When the air temperature has been 32 deg. F or higher for a few days, the ice should be considered unsafe for any load.

2-5. Wind and wind chill

In many parts of the Arctic and Subarctic, where pressure gradients tend to be weak and temperature inversions are common, surface winds may normally be fairly low. Where pressure gradients are more marked, however, as in areas near seacoasts, and in and near mountains, strong winds may be quite common and wind speeds can attain hurricane velocities. For example, a maximum estimated wind gust in winter of 130 miles per hour has been reported for Kotzebue, Alaska. The possibility of strong katabatic winds that may be concentrated in valley outlets should be considered in site selection. If strong winds are possible, they may especially affect outdoor activities during the colder months. Worker efficiency decreases with lowering of air temperatures (about 2 percent per degree below O deg. F), but wind significantly increases this effect, as shown by the windchill chart, figure 2-9. Distribution of January wind-chill values in North America is shown in figure 2-10. Information on the effects of various levels of wind-chill upon persons working outdoors is given in table 2-2.

[retrieve Figure 2-9. Dry-shade atmospheric cooling (wind-chill values).]

[retrieve Figure 2-10. Typical January wind-chill values for North America.]

Table 2-2. Stages of relative human comfort and the environmental effects of atmospheric cooling.

Wind-chill factor		
Btu/ft+2+hr	Kg cal/m+2+ hr	Relative comfort
220	600	Conditions considered as comfortable when people are dressed in wool underwear, socks, mitts, ski boots, ski headband and thin cotton windbreaker suits, and while skiing over snow at about 3 mph (metabolic output about 200 kg cal/m+2+ hr).
370	1000	Pleasant conditions for travel cease on foggy and overcast days.
440	1200	Pleasant conditions for travel cease on clear sunlit days.
520	1400	Freezing of human flesh begins, depending upon the degree of activity, the amount of solar radiation, and the character of the skin and circulation. Average maximum limit of cooling during November, December and January. At temperatures above 5 deg. F these conditions are

		accompanied by winds approaching blizzard force.
590	1600	Travel and life in temporary shelter very disagreeable.
700	1900	Conditions reached in the darkness of mid-winter. Exposed areas of face freeze in less than a minute for the average individual. Travel dangerous.
850	2300	Exposed areas of the face freeze less than 1/2 minute for the average individual. ---------------

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2-6. Visibility and natural illumination

Care should be taken in siting projects to take into account the possibility of local adverse weather conditions. Visibility problems may arise, for example, from local fogs that form over nearby bodies of water. Ice fog and blowing snow can cause severe reductions in visibility in the winter months, compounded by the shortage of natural illumination at that time. A "white-out," a condition where there is a lack of contrast between the sky and the snow surface, can hinder visibility considerably. Long hours of daylight and twilight provide maximum illumination for field activities during spring and summer, but in fall and winter the sun is very low or below the horizon. Figure 2-11 shows that at the North Pole the number of days in the year with continuous daylight is double the number with continuous darkness. Thus, the annual light conditions in these regions are not as poor as they are sometimes pictured to be. The consistently low elevation of the sun above the horizon when it is shining reduces its energy effectiveness but does help in judging surface conditions from the air because of the shadows cast by knolls, ridges and vegetation. During dark periods, the light of the full moon may be of help for some activities. The number of hours of daylight or of daylight plus twilight can be estimated from figure 2-12 or 2-13.

2-7. Vegetation

The three major types of vegetative cover in arctic and subarctic areas are tundra, muskeg and forest. Each of these represents a natural selection of species and the adaptation of vegetation to environmental factors such as soil and air temperatures, soil type, drainage, depth of active layer over permafrost, etc. Vegetation can be of particular value in arctic and subarctic areas as an aid, in conjunction with other information, in interpretation of subsurface conditions. Because relationships between vegetation and subsurface conditions determined in one geographical area do not necessarily apply in an environmentally different area, a specific correlation should be established, verified, or known in any substantially different geographical area in which such information may be used.

[retrieve Figure 2-11. Solar illumination in the Arctic.]

[retrieve Figure 2-12. Hours of sunlight.]

[retrieve Figure 2-13. Hours from dawn to dark--twilight and sunlight.]

2-8. Special surficial features and markings

Characteristic features and markings are produced on the ground in northern regions by permafrost degradation, frost action, mass wasting (i.e. creep, frost creep and frost sloughing) and other natural phenomena. These features include solifluction markings, pingos, thermokarst depressions and patterned ground. They can serve as important indicators of ground conditions, including the likelihood of the presence of permafrost and ground ice.

2-9. Seismic activity

Construction in the Arctic and Subarctic should be designed for seismic forces where required by the probability, in severity, frequency and potential damage, of seismic ground shaking or tsunamis (seismic sea waves). This is in addition to design for dead, live, snow and wind structural loads. Though risk from earthquake-generated forces is not very high over much of the Arctic and Subarctic, risk of major or great damage exists in certain areas, such as in Alaska, south of about Fairbanks. TM 5-809-10/NAVFAC P-355/AFM 88-3, Chap. 13 provides criteria and guidance for seismic design.

2-10. Graphic summaries

a. To aid in understanding the environmental conditions at specific locations and their variations through the seasons, graphic summaries such as the one for Barrow, Alaska, shown in figure 2-14 (fold-out located in back of manual), are useful.

b. Seismic probability, snow load and other design data may also be summarized on a regional basis to provide engineers with values to be adopted in design work.

CHAPTER 3

ENVIRONMENTAL IMPACT CONSIDERATIONS

3-1. National environmental policy

The National Environmental Policy Act of 1969 (NEPA) sets forth the policy of the Federal Government, in cooperation with State and local governments and other concerned public and private organizations, to protect and enhance environmental quality. All Federal agencies, in response to NEPA, must be concerned not only with the technical and economic aspects of their activities but also with the impact on the environment (CFR 40, 1500-1508).

3-2. U.S. Army environmental quality program

AR 200-1 outlines the Army's fundamental environmental policies, management of its program, and its various types of activities. The overall goal is to "plan, initiate, and carry out all actions and programs in a manner that will minimize or avoid adverse effects on the quality of the human environment without impairment of the Army mission."

3-3. U.S. Air Force environmental quality program

AFR 19-1 enunciates Air Force policy in compliance with the above-stated NEPA, executive orders and Department of Defense directives. Procedures outlined are similar to those described for Army installations. AFR 19-2 establishes policies, assigns responsibilities and provides guidance for preparation of environmental assessments and statements for Air Force facilities.

3-4. Environmental effects

Arctic and subarctic military facilities could have either beneficial or adverse environmental impacts, affecting the air, the water, the land, the local ecology and the socio-economic environment. Despite low population density and minimal development, the fragile nature of the ecology of the Arctic and Subarctic has attracted the attention of environmental groups interested in protecting these unique assets. For Army projects, guidance in preparing required Environmental Impact Assessments (EIA) and

Environmental Impact Statements (EIS) can be requested from the U.S. Army Construction Engineering Research Laboratory in Champaign, Illinois. Air Force installations can obtain guidance in preparing the required EIA or EIS, or both, from the Major Command Environmental Coordinator or from HQ USAF/LEEV, Washington, D.C.

CHAPTER 4

DEEP SEASONAL FROST AND PERMAFROST

4-1. Distribution

a. Areas of deep seasonal frost penetration may be defined arbitrarily for engineering as seasonal frost areas with design air freezing indexes of 1500 Fahrenheit degree-days or more. An air freezing index of 1500 Fahrenheit degreedays corresponds to a depth of seasonal frost penetration of about 7 feet into very well drained clean gravel under a bituminous surface kept clear of snow and ice. The actual frost penetration at a given point will depend on soil and surface conditions, and other factors as discussed in chapter 5. If the soil is saturated silt, the frost penetration may be about half of that in a very well drained clean gravel for otherwise identical conditions. Design freezing indexes of 1500 Fahrenheit degree-days exist well south of the Subarctic in the northern temperate zone. However, there are also lower values in a few locations within the Subarctic, such as in northern Iceland. As the freezing index increases with increasing latitude, or increasingly cold geographic location or topographic position, the depth of seasonal freezing increases; it may reach as much as about 20 feet in very well drained clean gravel under a bituminous surface kept clear of snow and ice, without development of permafrost. When a point is reached, however, where the depth of winter freezing exceeds the depth of summer thaw, permafrost results if frozen ground persists over at least two consecutive winters and the intervening summer. As one travels northward, permafrost, which in the more southerly part of the permafrost zone is discontinuous, becomes gradually continuous, except under some large water bodies that are deep enough to prevent freezing temperatures from reaching the bottom, and the depth of summer thaw becomes progressively smaller. In areas of continuous permafrost, lateral heat flow may cause permafrost to extend partly or entirely under bodies of water, even though there is a layer of unfrozen soil immediately below the water. Along the seacoast, permafrost may extend for a substantial distance offshore, either as relic permafrost or as permafrost formed as a result of seawater temperatures below 32 deg. F.

b. Figures 4-1 and 4-2 show the approximate extent of permafrost areas in North America and Eurasia respectively. Islands of permafrost are also found in mountains south of the Subarctic.

4-2. Characteristics of permafrost

The following summary of the characteristics of permafrost should be considered merely introductory.

a. Structure. Depending on local conditions, permafrost may exist as (see figure 4-3):

-- A continuous layer with its upper surface at the bottom of the annual frost zone (active layer). This is common in arctic regions.

-- A continuous layer with its upper surface separated from the annual frost zone (active layer) by a residual thaw layer. If the permafrost table is lowering progressively, this is a degrading condition.

-- Frozen layers separated by layers of unfrozen material.

-- Inclusions of remnants of permafrost in unfrozen ground.

b. Depth to surface. The depth to the permafrost table is dependent primarily on the magnitude of the air thawing index, the amount of solar radiation that reaches the surface, the surface cover conditions that have existed for the previous several years, and the water content and dry unit weight of the soil. See table 4-1 for typical depths to the permafrost layer. For comparison, in a subarctic area without permafrost, a well-graded sandy gravel that is relatively dry (w = 5%) and seasonally frozen would have an annual thaw penetration of about 16 feet. Methods for estimating depths of freeze and thaw penetration are discussed in TM 5-852-4/AFM 88-19, Chap. 4 and TM 5-852-6/AFR 88-19, Volume 6.

c. Factors affecting existence and distribution. Under natural, undisturbed ground cover conditions, the mean annual air temperature must usually be 21 deg. to 30 deg. F for permafrost to exist, although exceptions are possible on either side of this range. If temperatures at the ground surface could be used, more precise correlation could be obtained. However, surface temperatures have not been generally available in the past from meteorological records. The existence of ground temperatures perennially below freezing is a function of many factors other than air temperatures as discussed in chapter 5, including solar radiation, surface cover, snow cover, wind, soil type, soil moisture content, groundwater flow and presence of stationary or moving surface water. Forest fires or meandering of streams may cause alterations of permafrost conditions extending over many years.

[retrieve Figure 4-1. Approximate distribution of permafrost in North America.]

[retrieve Figure 4-2. Approximate distribution of permafrost in Eurasia.]

[retrieve Figure 4-3. Typical sections through ground containing permafrost.]

[retrieve Table 4-1. Depths to the permafrost layer at the end of the thawing

d. Thickness. The thickness of the permafrost layer generally increases with increasing latitude, being greater in arctic than in subarctic regions. The greatest depths of permafrost occur in the nonglaciated areas of the continuous zone. In Siberia, a record depth of 4900 feet to the permafrost base has been reported. It has been estimated that the maximum thickness of permafrost in arctic Canada may exceed 3000 feet, and in arctic Alaska it may be over 2000 feet. The greatest depth so far measured in Canada is about 1700 feet at Winter Harbour, Melville Island. A depth of 1600 feet has been estimated at Thule, Greenland. Other observed depths are about 1300 feet south of Barrow, Alaska, and at Resolute, Northwest Territories; about 920 feet at Umiat, Alaska; and about 170 feet at Northway, Alaska.

e. Soil factors. As a rule, the characteristics of permafrost will depend upon the texture, water content and temperature of the soil. Relatively clean sands and gravels located in well-drained positions may not present serious engineering construction problems if they do not contain appreciable amounts of excess ice. Conversely, permafrost consisting of fine-textured soils such as silt often contains large formations of ice in lenses, layers, wedges, veins or other shapes. TM 5-852-4/AFM 88-19, Chap. 4 presents information on the strength and other properties of frozen soils. MIL-STD-619B presents a standard system for classification of frozen soils.

CHAPTER 5

FACILITIES ENGINEERING IN AREAS OF DEEP SEASONAL FROST AND PERMAFROST

5-1. General

a. In the Arctic and Subarctic, engineering features such as pavements, foundations of structures, walls, utilities and pipelines, underground facilities, excavations and embankments, and drainage facilities must be designed and constructed with proper consideration for the special conditions prevailing in those areas, as described in chapters 2 and 4. Guidance and criteria for the design and construction of facilities in the Arctic and Subarctic are given in the remainder of the manuals in the Arctic and Subarctic Construction series,
TM 5-852-2 through 7, and 9/AFR 88-19, Volume 2, 5 and 6/AFM 88-19, Chap. 3, 4, 7 and 9.

b. One of the most important things in any civil engineering work in the Arctic and Subarctic is the effect of surface conditions upon the thermal regime in the ground. Transfer of heat at the air-ground interface is dependent on such time-varying factors as the thermal properties of the soil, the albedo (reflectivity) and insulating properties of the ground cover at the surface, the amount of solar radiation reaching the surface, the wind structure and velocity above the surface and the surface roughness, the air temperature and humidity as a function of height above the surface, precipitation, snow cover, and evapotranspiration from vegetation. Geothermal heat flow toward the surface from below is also a factor. These factors are further discussed in TM 5-8526/AFR 88-19, Volume 6. Stripping away, compressing, or otherwise changing the existing vegetative ground cover and erecting structures or constructing pavements, pipelines or other features will alter the thermal balance in the ground. The depth of annual freeze and thaw will change, and in permafrost areas the depth to the permafrost table will be altered. Permafrost degradation or aggradation may occur. Figure 5-1 shows permafrost degradation measured under different surface conditions over a 26-year period at Fairbanks, Alaska. Permafrost remained stable under the undisturbed, tree-covered area throughout the period.

[retrieve Figure 5-1. Permafrost degradation under different surface treatments

c. Surface index-air index ratios or n-factors provide measures of the effects of different surface conditions. A table of such values is given in TM 5 852-4/AFM 88-19, Chap. 4. Calculation methods for prediction of depths of freeze and thaw in soils are presented in TM 5-852-6/AFR 88-19, Volume 6.

d. Changes in the thermal regime may in turn affect the frost heave, seasonal thaw-settlement, or thaw-weakening behavior of the supporting soils. In permafrost areas, degradation will produce progressive settlement if thawunstable soils containing excess ice are present. Such potential effects should be anticipated and taken into account during design.

5-2. Site selection and development

a. All design for construction in arctic and subarctic regions must be preceded by thorough site or route investigations to obtain any existing information on the proposed location plus new field data on surface and subsurface features, drainage, permafrost and other conditions as needed. Environmental impact must be considered as discussed in chapter 3. The importance of thorough site investigations before construction cannot be overemphasized. Sites with non-frost-susceptible foundations are much easier to develop than those having frost-susceptible materials.

b. Site selection and development in the Arctic and Subarctic may often be much more complex than in the temperate regions because of the relative lack of existing information, the large areas and distances sometimes involved, the limited support facilities, and the seasonal and environmental constraints on field activities. Over large areas of the Arctic and Subarctic, specific terrain or local climatic information may be limited or nonexistent. Heavy reliance on air reconnaissance and air-photo studies may be required. Access to proposed site or route locations may be difficult and expensive, may require careful seasonal scheduling, and may involve severe restraints on sizes and weights of survey equipment that can be brought in. Field working conditions may sometimes be difficult. Safety aspects of field activities may be significant considerations. Costs of site selection and development studies may be high but cost should not be allowed to serve as justification for inadequate investigations. Procedures for site selection and development studies are presented in TM 5-852-2/AFR 88-19, Volume 2.

5-3. Airfield pavements and roads

The following detrimental effects, which may occur in airfield pavements and roads in the Arctic and Subarctic, should be considered in design:

-- Seasonal frost heave and settlement, commonly differential.
-- Reduction of bearing capacity during and after thaw.
-- Pavement pumping.
-- Pavement cracking.
-- Deterioration of pavement surfacing.
-- Progressive increase of pavement roughness.
-- Loss of compaction.
-- Restriction of subsurface drainage by frozen ground.
-- Wintertime surface drainage problems.
-- Snow removal and icing problems.
-- Degradation settlement from thawing of permafrost, commonly differential. -- Adverse surface drainage effects from permafrost degradation.

All but the last two effects may also be observed in temperate zone frost areas, but in the Arctic and Subarctic freezing is more intense and more prolonged. The thawing and thaw-weakening periods are also longer and in permafrost areas last until freezing starts again after the summer. The most difficult conditions are in the area near the boundary between permafrost and unfrozen soils where depth of seasonal freezing is maximum and permafrost, where present, is the least thermally stable. The detrimental effects of seasonal frost action on pavements are discussed in TM 5-818-2/AFM 88-6, Chap. 4. In permafrost regions, the change of surface conditions caused by construction may begin permafrost degradation, particularly in the discontinuous permafrost zone. This degradation will result in settlement. If the permafrost contains excess ice, the settlement will invariably be differential. Criteria and guidance for runway and road design in arctic and subarctic areas are presented in TM 5-852-3/AFM 88-19, Chap. 3.

5-4. Foundations for structures

a. The following principles must be considered for foundation design in areas of permafrost:

Foundation supporting conditions not adversely affected by thaw

Foundation supporting conditions adversely affected by thaw

-- Use normal temperate

Consider following op-

zone approach

tions:

1. Maintenance of existing thermal regime.
2. Acceptance of the changes in the thermal regime to be caused by the construction and facility, and allowance for these in design.
3. Modification of foundation

conditions prior to construction.

These alternatives are discussed in TM 5-852-4/AFM 88-19, Chap. 4.

b. For areas of deep frost penetration without permafrost, design options for stable foundations for subsurface conditions adversely affected by freeze and thaw are similar to those in seasonal frost areas of the temperate zone, namely:

-- Support foundation below the annual frost zone, with protection as needed against uplift acting in tangential adfreeze shear and against frost overturning or sliding produced by frost thrust.

-- Support structure on a compacted non-frost-susceptible fill capable of adequately limiting freeze and thaw effects.

-- Employ thermal insulation, foundation loading, foundation soil replacement, heat or combinations of these.

c. Detailed criteria and guidance for design of foundations for structures, including basic considerations, site investigations for foundations, construction considerations and monitoring of performance, are presented in TM 5-852-4/AFM 8819, Chap. 4.

5-5. Utilities

Utilities include water supply, sewerage, fire protection, central heating, fuel, electrical and communication systems. Many elements of these systems, such as electric generators and water treatment mechanical equipment, are standard items that require no modification for use in the Arctic and Subarctic. However, other items may require special approaches. For example, water distribution pipes in the Arctic are commonly placed in insulated above-ground utilidors or, if the soil conditions permit laying pipes directly in the ground, the water is heated before it enters the system and it may be continuously recirculated. Consideration should be given, whenever possible, to use of heat recovery systems to conserve energy. Utility poles must be protected against being pushed out of the ground by frost heave when they are placed in frost-susceptible soil. This can be done by anchoring them firmly in permafrost or by supporting them above ground in rock-filled cribs. Fuel storage tanks supported over thaw-unstable permafrost require ventilated foundations to prevent thaw-settlement if they will contain fuel at above-freezing temperatures. Sewage treatment facilities must be designed to be safe from frost heave or thaw-settlement damage to pipes, tanks and other structural elements; possible adverse effects of low temperatures on treatment processes must also be taken carefully into account. Insulation on wires and electrical equipment exposed to outdoor temperatures, which may drop to close to -70 deg. F, must not become brittle and crack under such conditions. Criteria and guidance for utilities in the Arctic and Subarctic are presented in TM 5-852-5/AFR 88-19, Volume 5. Connections of utilities to buildings are discussed in TM 5-852-4/AFM 88-19, Chap. 4.

5-6. Drainage and groundwater

a. Although annual precipitation intensity rates are relatively light in much of the Arctic and Subarctic, except in regions near coasts, the frozen condition of the ground during much of year makes it necessary to assume that the rate of infiltration in the Arctic, for surface drainage design, is zero. A frequent cause of damaging floods in these regions is the temporary damming of rivers by ice jams; however, floods caused by heavy precipitation are not unknown, the Fairbanks, Alaska, flood of 1967 being an example.

b. Egress of groundwater may result in icing, which is undesirable near buildings or other structures. Icing caused by groundwater may be a serious problem when it interferes with road travel or drainage. Ground icing effects can ordinarily be circumvented by inducing the icing at a place where it will do no harm. Drainage structures like culverts should be constructed so that they can be readily opened or kept open by steam thawing or other methods.

c. The flow of water, both surface and subsurface, is an important source of heat in permafrost thawing, particularly when the flow is concentrated in channels. In subarctic regions such channels, once formed, may continue to thaw and deepen year after year. In fine-grained soils containing excess ice, progressive differential settlement may result. Thaw of ice and frozen fine-grained soil in fractures and fissures of bedrock may cause open joints or cavities (sink holes). The possibility of subsurface groundwater during construction should be considered in project planning. Concentrated drainage flow or discharge near structures that are built over fine-grained foundation soils should be eliminated or diverted. Lake levels must not be allowed to rise if they might induce detrimental subsurface flow of warm surface water. It may be possible to exert some control over the directions of summer drainage flow in the active layer by modifying surface conditions so as to selectively control depth of thaw. Even the most minor leaks from water, sewer or steam pipes can seriously degrade permafrost and must be prevented. Drainage ditches cut into ice-rich permafrost should be avoided. Subsurface drains are usually not practical in the Arctic and Subarctic. When wells drilled through permafrost encounter water under artesian pressure, great care is necessary to avoid loss of control of the well by thawing and piping in thaw-unstable soil around the casing.

d. TM 5-852-7/AFM 88-9, Chap. 7 provides criteria and guidance for surface drainage design and for control of icing in arctic and subarctic regions. Criteria

and guidance for drainage around structures are presented in TM 5-852-4/AFM 88-19, Chap. 4.

5-7. Building design practices

a. Buildings generally should be designed and constructed in accordance with standard practice for arctic and subarctic regions. Special attention should be given to foundations, exposure and adaptation to the environmental conditions. Factors affecting the morale of the occupants are also important considerations in isolated arctic locations, and thus habitability criteria (e.g., security, comfort, privacy, aesthetics, socialization, mobility, etc.) should be carefully considered during the design of physical facilities. Structure design should be closely linked with foundation design concepts in order that these two will be compatible with one another in interface, cost and other aspects.

b. In a cold regions environment, building type and materials should be selected for ease and speed of erection and resistance to fire, high winds and low temperatures. Building geometry and layout, the effects of low temperatures on the structural properties of materials, and problems of vapor condensation, energy conservation, snow infiltration, and snow and ice accumulation and removal should be examined.

c. Prefabricated panels or complete buildings designed for the Arctic are excellent for use at remote arctic sites. Lightweight materials are important in regions where native supplies are scarce and transportation is difficult. Highearly-strength cement is good for cold-weather concreting, but precast concrete is better than cast-in-place construction. The buildings should be located on well-drained sites where practicable. The sites should be where snow drifting will be low. The layout of utilities should be considered. Wind and snow load design assumptions should be based on long-term weather records wherever possible.

d. Precautions should be taken to minimize probable icing resulting from the freezing of water from snow melting on roofs and nearby drifts. This is especially true at eaves, in front of doors, and around fire hydrants and other critical service and utility areas. Ducts from the building's heating system may be installed in the eaves to prevent the dangerous growth of large icicles. Drifting of snow, possible damage from snow slides, avalanches, high winds, ice jams and high water will in some instances require consideration in the placement and orientation of buildings and in location of services. Latrines and washrooms should be located at the lee end of living quarters. Where wind directions are consistent, the orientation of buildings with the direction of the strongest winds may reduce stresses on wind-bracing elements of the structures.

e. Metal, conventional built-up and protected membrane roofs have been found satisfactory if properly constructed. Precautions that must be taken are outlined in TM 5-852-9/AFM 88-19, Chap. 9. Since removal of ice and snow during cold weather is often necessary, the insulation and roof covering should be able to withstand such treatment. Personnel doors should open inward so that they can't be blocked by drifted snow or damaged by high winds. Vestibules or storm entrances should be used if needed. If doors must open outward because of fire regulations, an apron should be provided that is resistant to the effects of freeze-thaw cycles. The wide temperature range, causing large thermal expansions and contractions, should be considered in spacing of expansion joints.

f. Adequate facilities for drying wet or damp clothing must be provided near sleeping quarters. When practical, the warm air used for drying should be expelled from the building by an exhaust fan. Since it is not advisable to bring metal equipment into warm buildings for overnight storage, a special place, protected from the weather, for storing such equipment should be provided. The psychological effect of window size and spacing (and, where the interior is to be painted, of the various colors used) should be given consideration to help overcome the feeling of confinement and isolation that sometimes affects personnel who work in bleak, isolated regions of the far north. Fire protection, prevention and fire-fighting measures should be very carefully considered in regard to all buildings and installations. The consequences of a serious fire in the cold regions are in general much more serious than in temperate zones.

g. Where the use of a building results in an atmosphere of relatively high humidity within the building, such as in power and water-treatment plants, special care should be exercised in the design to reduce to a practical minimum the condensate that may form on cold walls, windows and ceilings within the buildings. Provisions should be made to avoid water dripping onto personnel and critical equipment within the structure. No condensate should be allowed to drip on the floors within the structures, particularly in front of doors that open to the outside. Vapor barriers that are properly designed and installed should be provided.

h. During winter in the far north it may be necessary to humidify the air of living quarters. This arises from the low humidity of the air in such regions of very low precipitation as well as the usual low relative humidity associated with heated structures. Whether building interiors are humidified or not, the water vapor pressure differentials between interior and exterior spaces in the winter are normally very large in the cold regions. The resulting very steep pressure gradients indicate the great importance of properly designed and installed vapor barriers.

i. For most structures simple designs are best. Continuity in design is not usually worthwhile for weight and cost reduction, and the effects of differential movements are so serious that the "rigid" type structure should not be used unless conditions are such that differential movements cannot occur. Multistoried concrete frame buildings and other buildings with considerable structural rigidity should be separated into independent units, by expansion joints and double columns, at locations where differential movement can be anticipated, such as at connections of wings to the central section of a building and at intervals along a long rectangular building. Control joints should be employed to prevent or minimize unsightly cracking of exterior facing. The principle of resisting differential movements by extreme rigidity is not recommended because the costs are high, the forces cannot be estimated very closely and failure is common.

j. Specialized building design criteria and guidance are given in TM 5-852-9/AFM 88-19, Chap. 9, and design criteria and guidance pertinent to foundations for buildings are presented in TM 5-852-4/AFM 88-19, Chap. 4.

5-8. Construction management and practices

a. General. Construction management and procedures in arctic and subarctic regions differ from those in temperate regions because of deep seasonal frost, permafrost and climate. The environment and short construction season critically affect field operation schedules. Remote, isolated construction sites served by long and difficult supply lines mean that mistakes in planning are time-consuming and costly. A highly competent management team, possibly having decentralized authority with centralized support, must carefully plan and organize field activities, and conduct an intensive field inspection effort. Designs and cost estimates are strongly influenced by the construction procedures and schedules that are feasible in the arctic and subarctic regions.

b. Methods of transportation.

(1) Air transport is one of the principal modes of transport to arctic and subarctic field sites. If a landing strip does not exist near the site, helicopters or float-, ski- or wheel-equipped small planes may be used in initial project stages, depending upon the available surface conditions. In winter, fairly heavy wheel-equipped planes can use ice landing surfaces. With construction of a serviceable conventional runway, heavy planes can operate more permanently.

(2) Where a suitable road or waterway is present, or where an access road, even of an expedient nature, can be constructed, construction materials and equipment can be brought to the construction site by this route. However, rivers and the arctic coastal waters have only limited ice-free periods during which they can be used for water transport. Sometimes a north-flowing river may be open for upstream navigation before its mouth becomes sufficiently ice-free in the breakup period to permit entrance from the sea. Low ground-pressure tractor trains may be used to transport men, materials and equipment over frozen, snowcovered terrain in winter. Frozen lakes and rivers are frequently used very effectively for such transportation. Ice bridges can be used for crossing rivers and lakes by wheeled, tracked or sled equipment. Materials can often be stockpiled at convenient locations during the summer for surface transport to the site in the winter. For protection of the terrain, operations on the natural tundra surface in summer are generally prohibited in Alaska. Vehicles with rubber tires of very low ground pressure (1 to 2 pounds per square inch) are an exception. In some areas, such as natural preserves, various other restrictions or permit requirements may apply. Other countries also have land-entry and landuse regulations for northern regions.

c. Construction equipment. Heavy equipment is essential in arctic and subarctic construction. The severity of construction and climatic conditions usually makes the use of tractors weighing at least 30,000 pounds, of 10-cubicyard dump trucks, of 2-cubic-yard or larger shovels, of heavy ripping equipment, etc., very important. All motorized equipment should be winterized, including insulated cabs and facilities, fire retardant engine shrouds, and heaters to protect personnel from severe cold, wind and snow. Removable cleats on tracked vehicles (i.e., grousers) or other special traction devices and winches are frequently necessary. Preventive maintenance plays a key role in equipment operation, and a strict lubrication schedule should be maintained on all pieces of equipment. Cold weather pre-operation, starting, warm-up and operating procedures should be adhered to by equipment operators. "Cold-soaked" hydraulic systems not being used are especially vulnerable to failure upon start-up at about -30 deg. F or lower. Tires in extremely low temperatures become brittle and are easily punctured. Brittle fracture of metal parts at temperatures around -40 deg. F or lower is a potential problem, and all equipment should be inspected regularly to locate cracks and breaks. All cracks should be repaired when first observed by pre-heating before welding, and broken parts should be replaced. Statistics on one U.S. Army Corps of Engineers project in Alaska showed that the availability of equipment was reduced 2 percent for every degree lower than -20 deg. F.

d. Cold and the worker. The efficiency of labor on construction projects in the Arctic and Subarctic varies with the experience, attitude and morale of the workmen as well as working conditions on the job. Cold and darkness during the winter months combine to create safety and operational problems that directly limit productivity. The degree of acclimation of the worker and how adaptable the worker is to cold are very important in all classes of labor and they directly affect output. For example, Alaskan contractors report that at -20 deg. F, labor productivity was about 25 percent of that obtained in the summer. The efficiency of surveyors, mechanics and other outside personnel was reduced to near zero at -35 deg. F or lower. Such temperatures had little effect on equipment operators housed in heated cabs.

5-9. Construction operations

All aspects of construction, such as excavation of frozen soil or frozen rock, placement of embankments and backfill, placement of concrete, and protection of the work, are affected by the special conditions that prevail in the Arctic and Subarctic. Among the factors that may give special difficulty and may require careful consideration are the following:

-- Difficulty of excavating frozen materials.
-- Difficulty of handling wet, thawed material in summer.
-- Adherence of ice-filled frozen materials to equipment at low temperatures.
-- Direct effects of low temperatures upon equipment, including brittle fracture of metal.
-- Shortness of the above-freezing summer season.
-- Shortness of daylight hours in fall and winter.
-- Difficulty of achieving satisfactory fills and backfills when temperatures are below freezing.
-- Problem of placing concrete and achieving adequate strength gain without thaw of underlying permafrost.
-- Problem of protection of work from cold, heat, drying, dust, wind and precipitation.
-- Enclosure of work to maintain worker efficiency.
-- Fire safety and fire protection.

Detailed discussion of these and other factors pertaining to construction operations in the Arctic and Subarctic is presented in TM 5-852-4/AFM 88-19, Chap. 4.

APPENDIX A
GENERAL AIR INDEX INFORMATION FOR NORTH AMERICA AND EURASIA

A-1. The freezing and thawing index data presented here are for general information only and are not sufficiently precise in local detail for use in selecting values to be employed in design at a particular site. Such values should be computed directly from meteorological records of weather observation stations nearest to the proposed site.

A-2. Figure A-1 shows the mean air freezing indexes for North America and northern Eurasia, and figure A-2 shows the mean air thawing indexes. The largest mean air freezing indexes in Siberia, about 12,500 Fahrenheit degree-days, are of the same magnitudes as the largest in North America, about 13,000 Fahrenheit degree-days. On the other hand, air thawing indexes in much of the same coldest areas of Siberia are larger than in northern Canada and Greenland.

A-3. Figures A-3 and A-4 show design air freezing index and design air thawing index values, in North America, computed for pavement design in accordance with the definitions in paragraphs 1-4c(6) and 1-4c(7).

[retrieve Figure A-1a. Distribution of mean air freezing indexes (deg.

[retrieve Figure A-1b. Distribution of mean air freezing indexes (deg.

[retrieve Figure A-2a. Distribution of mean air thawing indexes (deg.

[retrieve Figure A-2b. Distribution of mean air thawing indexes (deg.

[retrieve Figure A-3. Distribution of design air freezing indexes values for pavements in North America (deg. F).]

[retrieve Figure A-4. Distribution of design air thawing indexes values for pavements in North America (deg. F).]

APPENDIX B
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Figure 2-14. Work feasibility chart, Point Barrow, Alaska. FOLD-OUT NOT INCLUDED