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 5-852-6/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.

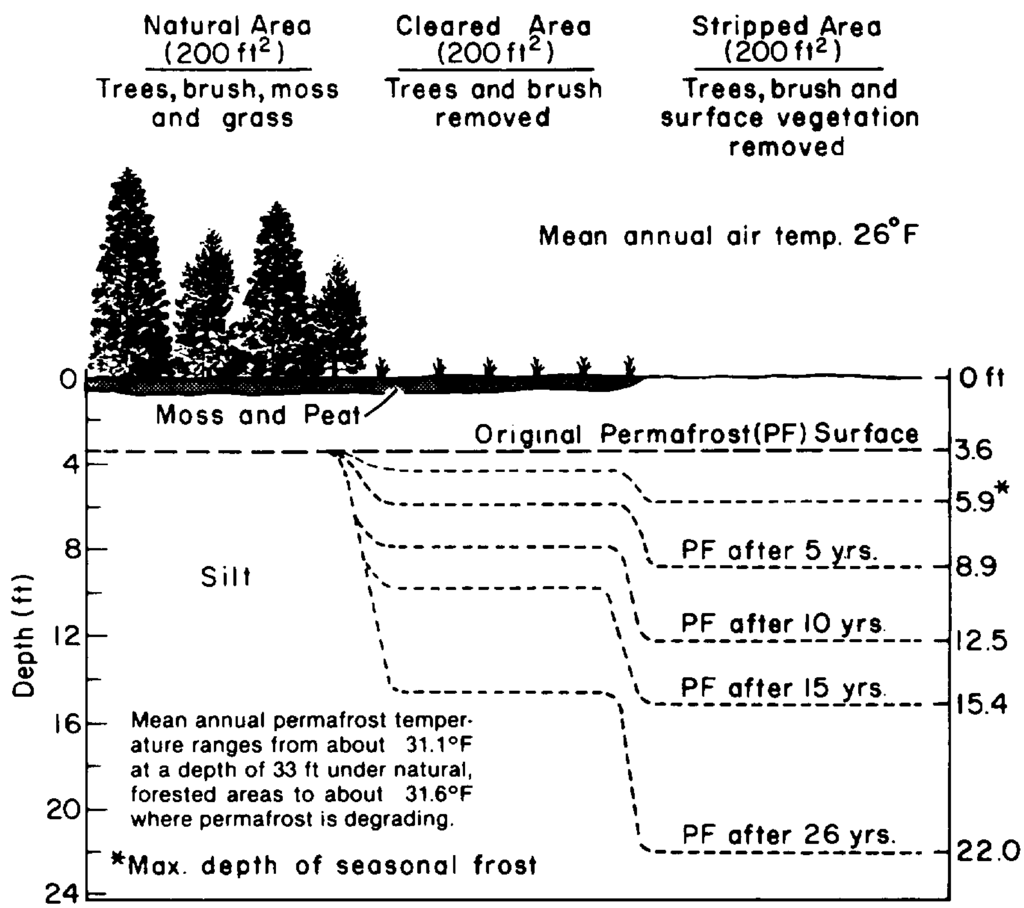

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Figure 5-1. Permafrost degradation under different surface treatments over a 26-year period at Fairbanks, Alaska.

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 5852-4/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 thaw-unstable 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 5-8522/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 runwav and road design in arctic and subarctic areas are presented in TM 5-852-/AFM 8S19, 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 zone approach	Consider following options 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 88-19, 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 utilitdors 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. Con-sideration 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°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 finegrained 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 88-19, 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. High-early-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 6-852-9/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, snow-covered 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 land-use 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-cubic-yard 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°F or lower. Tires in extremely low temperatures become brittle and are easily punctured. Brittle fracture of metal parts at temperatures around 40°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°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 re port that at -20°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°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.