PDH & Professional Training
An Introduction to Foundations in Areas of Significant Frost Penetration

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1. INTRODUCTION.

1.1 TYPES OF AREAS. For purposes of this manual, areas of significant frost penetration may be defined as those in which freezing temperatures occur in the ground to sufficient depth to be a significant factor in foundation design. Areas of significant frost penetration may be subdivided as follows:

1.1.1 SEASONAL FROST AREAS.

1.1.1.1 SIGNIFICANT GROUND FREEZING OCCURS in these areas during the winter season, but without development of permafrost. In northern Texas, significant seasonal frost occurs about 1 year in 10. A little farther north it is experienced every year. Depth of seasonal freezing increases northward with decreasing mean annual and winter air temperatures until permafrost is encountered. With still further decrease of air temperatures, the depth of annual freezing and thawing becomes progressively thinner.

1.1.1.2 THE LAYER EXTENDING THROUGH both seasonal frost and permafrost areas in which annual freeze-thaw cycles occur is called the annual frost zone. In permafrost areas, it is also called the active layer. It is usually not more than 10 feet thick, but it may exceed 20 feet. Under conditions of natural cover in very cold permafrost areas, it may be as little as 1 foot thick. Its thickness may vary over a wide range even within a small area. Seasonal changes in soil properties in this layer are caused principally by the freezing and thawing of water contained in the soil. The water may be permanently in the annual frost zone or may be drawn into it during the freezing process and released during thawing. Seasonal changes are also produced by shrinkage and expansion caused by temperature changes.

1.1.2 PERMAFROST AREAS.
1.1.2.1 IN THESE AREAS, perennially frozen ground is found below the annual frost zone. In North America, permafrost is found principally north of latitudes 55 to 65 degrees, although patches of permafrost are found much farther south on mountains where the temperature conditions are sufficiently low, including some mountains in the contiguous 48 States. In areas of continuous permafrost, perennially frozen ground is absent only at a few widely scattered locations, as at the bottoms of rivers and lakes. In areas of discontinuous permafrost, permafrost is found intermittently in various degrees. There may be discontinuities in both horizontal and vertical extent. Sporadic permafrost is permafrost occurring in the form of scattered permafrost islands. In the coldest parts of the Arctic, the ground may be frozen as deep as 2000 feet.

1.1.2.2 THE GEOGRAPHICAL BOUNDARIES between zones of continuous permafrost, discontinuous permafrost, and seasonal frost without permafrost are poorly defined but are represented approximately in figure 1.

1.2 GENERAL NATURE OF DESIGN PROBLEMS. Generally, the design of foundations in areas of only seasonal frost follows the same procedure as where frost is insignificant or absent, except that precautions are taken to avoid winter damage from frost heave or thrust. In the spring, thaw and settlement of frost heaved material in the annual frost zone may occur differentially, and a very wet, poorly drained ground condition with temporary but substantial loss of shear strength is typical.

1.2.1 IN PERMAFROST AREAS, the same annual frost zone phenomena occur, but the presence of the underlying permafrost introduces additional potentially complex problems. In permafrost areas, heat flow from buildings is a fundamental consideration, complicating the design of all but the simplest buildings. Any change from natural conditions that results in a warming of the ground beneath a structure can result in progressive lowering of the permafrost table over a period of years that is known as degradation. If the permafrost contains ice in excess of the natural void or fissure space of the material when unfrozen, progressive downward thaw may result in extreme settlements of overlying soil and structures. This condition can be very serious because
such subsidence is almost invariably differential and hence very damaging to a structure. Degradation may occur not only from building heat but also from solar heating, as under pavements, from surface water and groundwater flow, and from underground utility lines. Proper insulation will prevent degradation in some situations, but where a continuous source of heat is available, thaw will in most cases eventually occur.

1.2.2.2 THE MORE INTENSE THE WINTER COOLING of the frozen layer in the annual frost zone and the more rapid the rate of frost heave, the greater the intensity of uplift forces in piles and foundation walls. The lower the temperature of permafrost, the higher the bearing capacity and adfreeze strength that can be developed, the lower the creep deformation rate under footings and in tunnels and shafts, and the faster the freeze-back of slurried piles. Dynamic response characteristics of foundations are also a function of temperature. Both natural and manufactured construction materials experience significant linear and volumetric changes and may fracture with changes in temperature. Shrinkage cracking of flexible pavements is experienced in all cold regions. In arctic areas, patterned ground is widespread, with vertical ice wedges formed in the polygon boundaries. When underground pipes, power cables, or foundation elements cross shrinkage cracks, rupture may occur during winter contraction. During summer and fall, expansion of the warming ground may cause substantial horizontal forces if the cracks have become filled with soil or ice.

1.2.2.3 ENGINEERING PROBLEMS may also arise from such factors as the difficulty of excavating and handling ground when it is frozen; soft and wet ground conditions during thaw periods; surface and subsurface drainage problems; special behavior and handling requirements for natural and manufactured materials at low temperatures and under freeze-thaw action; possible ice uplift and thrust action on foundations; condensation on cold floors; adverse conditions of weather, cost, and sometimes accessibility; in the more remote locations, limited local availability of materials, support facilities, and labor; and reduced labor efficiency at low temperatures.
1.2.2.4 PROGRESSIVE FREEZING AND FROST HEAVE of foundations may also develop under refrigerated warehouses and other facilities where sustained interior
below-freezing temperatures are maintained. The design procedures and technical guidance outlined in this publication may be adapted to the solution of these design problems.
2.. FACTORS AFFECTING DESIGN OF FOUNDATIONS.

2.1 PHYSIOGRAPHY AND GEOLOGY. Physiographic and geologic details in the area of the proposed construction are a major factor determining the degree of difficulty that may be encountered in achieving a stable foundation. For example, pervious layers in fine-grained alluvial deposits in combination with copious groundwater supplies from adjacent higher terrain may produce very high frost-heave potential, but clean, freedraining sand and gravel terrace formations of great depth, free of excess ice, can provide virtually troublefree foundation conditions.

2.2 TEMPERATURE. The most important factors contributing to the existence of adverse foundation conditions in seasonal frost and permafrost regions are cold air temperatures and the continual changes of temperature between summer and winter. Mean annual air temperatures usually have to be 2º to 8ºF below freezing for permafrost to be present, although exceptions may be encountered both above and below this range. Ground temperatures, depths of freeze and thaw, and thickness of permafrost are the product of many variables including weather, radiation, surface conditions, exposure, snow and vegetative cover, and insulating or other special courses. The properties of earth materials that determine the depths to which freezing-and-thawing temperatures will penetrate below the ground surface under given temperature differentials over a given time are the thermal conductivity, the volumetric specific heat capacity, and the volumetric latent heat of fusion. These factors in turn vary with the type of material, density, and moisture content. Figure 2 shows how ground temperatures vary during the freezing season in an area of substantial seasonal freezing having a mean annual temperature of 37ºF (Limestone, Maine), and figure 3 shows similar data for a permafrost area having a mean annual temperature of 26ºF (Fairbanks, Alaska).

2.2.1 FOR THE COMPUTATION OF SEASONAL FREEZE OR THAW PENETRATION, freezing-and-thawing indexes are used based upon degree-days
relative to 32 F. For the average permanent structure, the design indexes should be
of record. This
is important to note
above the ground; the
values, are usually
for thawing where
index determined for
index, where n is the
corrected n value
and hence give less
less freeze or thaw penetration for the same air freezing or thawing index. Values of n for a

2.2.2  MORE DETAILED INFORMATION ON INDEXES
and their computation is
presented elsewhere in the technical literature, including maps showing distribution of

2.3  FOUNDATION MATERIALS.
The foundation design decisions may be critically
affect by the foundation soil, ice, and rock conditions.

2.3.1  SOILS.
2.3.1.1  THE MOST IMPORTANT PROPERTIES
of soils affecting the performance of engineering structures under seasonal freeze-thaw action are their frost-heaving
ccharacteristics and their shear strengths on thawing. Criteria for frost susceptibility
based on percentage by weight finer than 0.02 millimeter are presented in the technical
literature. These criteria have also been developed for pavements. Heave potential at
the lower limits of frost susceptibility determined by these criteria is not zero, although it
is generally low to negligible from the point of view of pavement applications.
Applicability of these criteria to foundation design will vary, depending upon the nature