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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000844
Canadian Building Digest, 1965-04

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 64

Permafrost and Foundations

Originally published April 1965

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Please note

Problems associated with seasonal freezing of ground in southern Canada are well known. Frost heaving of building foundations, roads, driveways and porches is a common occurrence. The physical processes involved in ground freezing and frost heaving have been described in **CBD 26**. Serious difficulties resulting from differential heaving of freezing ground have also been experienced in ice rinks and cold storage buildings, and these problems and the methods employed to avoid or alleviate them have been discussed in **CBD 61**.

There are additional problems to be considered when construction work is undertaken in northern Canada. About one half of the total land area of Canada is underlain by perennially frozen ground, more commonly known as permafrost, and as development moves northward consideration must be given to this feature of the terrain. This Digest briefly describes permafrost and its characteristics and discusses problems related to foundation design in permafrost areas.

Permafrost

The term *permafrost* refers to the thermal condition of earth materials under which their temperature remains below 32°F continuously for a number of years. Permafrost is defined on the basis of temperature alone, and any material, whether sand, gravel, silt, peat, refuse piles or bedrock, that has been below freezing continuously for more than one year is called permafrost. Although it is generally considered a northern terrain condition, permafrost,strictly speaking, can also exist artificially under cold storage plants (located in southern areas) that are operated continuously at sub-freezing temperatures.

The origin of permafrost, although not well understood, is commonly attributed to present climates. In far northern areas, however, it probably existed for a long time in equilibrium with the climate and hence was initially a product of the past, possibly first appearing during the cold period at the beginning of the Pleistocene Era. During subsequent climatic fluctuations, corresponding changes have occurred in its extent and thickness. It is known to be diminishing in some areas at present and increasing in others.

The formation of perennially frozen ground is direct result of an imbalance in the heat exchange at the ground surface whereby annual heat losses are greater than annual heat gains. The factors that determine the annual heat exchange at the ground surface can be grouped broadly under climate and terrain, the latter referring to surface conditions and including the thermal properties of the ground itself. Prediction of the occurrence and distribution (both areally and in thickness) of permafrost is difficult because of the complex interaction of the various components of these factors, the more important of which are air temperature, relief (slope and aspect), vegetation, drainage, snow cover and soil type.

The region of permafrost is normally divided into two principal zones, the discontinuous in the south and the continuous to the north. Within the discontinuous zone perennially frozen areas exist together with unfrozen areas; distribution varies considerably from the southern extremity, where unfrozen areas predominate and frozen ground occurs mainly as scattered patches or islands, to the northern reaches where permafrost is extensive and frozen ground predominates. This distribution varies not only in areal extent but also vertically, that is, in thickness. Thus, permafrost may be only a few feet thick in the southern fringe area or extend to considerable depth, perhaps 200 ft. in the more northerly areas. In the continuous zone, on the other hand, permafrost is found everywhere under the ground surface and may extend to depths exceeding 1,000 ft.

Permafrost Characteristics

Above the permafrost table, that is, the upper surface of permafrost, there is a layer of soil or rock called the active layer which freezes in winter and thaws in summer. Its thickness may vary regionally from several feet in the southern fringe area to only a few inches in the north of the continuous zone and is dependent on the same climatic and terrain factors as affect the permafrost. Local variations in terrain factors may cause the active layer to vary in thickness from less than one or two feet to several feet within any one area.

Permafrost exists as a result of a thermal condition that is reflected in ground temperatures never exceeding 32°F. Fluctuations in air temperature during the year produce corresponding fluctuations in ground temperature, although their magnitude is reduced with increasing depth by the effect of the surface cover (moss and snow) as well as the thermal characteristics of the soil. In addition, a time lag is introduced with increase in depth. The depth at which fluctuations become imperceptible (between 20 and 50 ft) is called the level of zero annual amplitude" (Figure 1). Below this, ground temperatures change only in response to long-term climate changes extending over centuries.

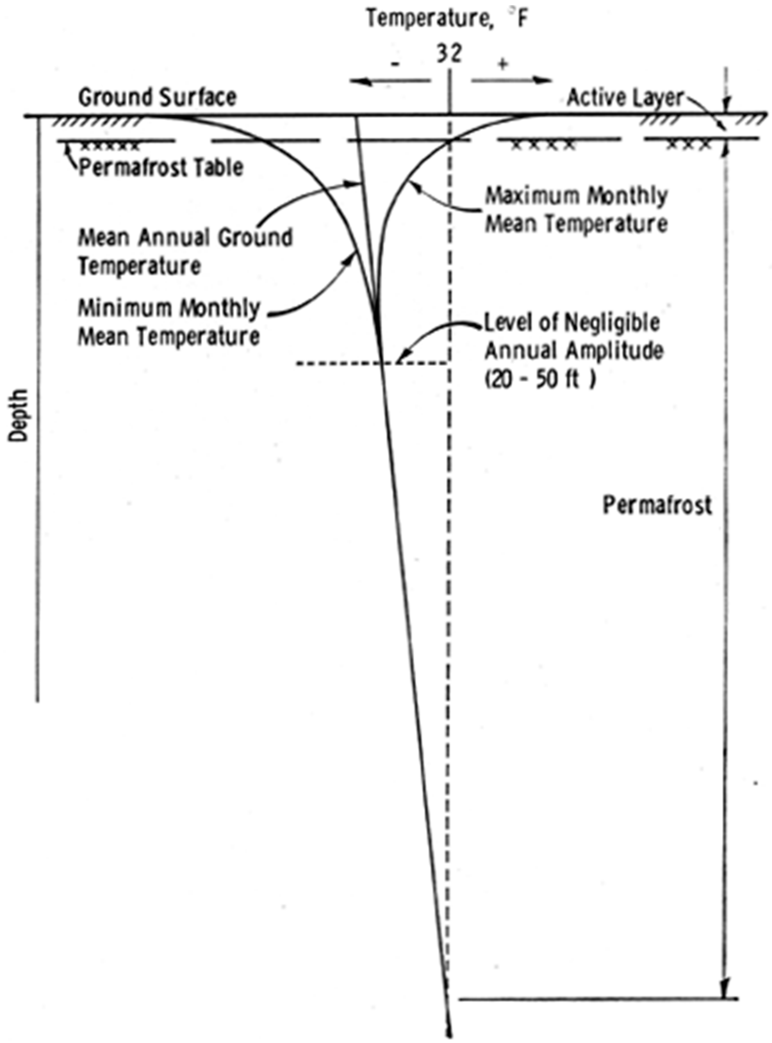

Figure 1. Typical ground temperature regime in permafrost

Mean ground temperature can vary appreciably under the influence of a number of factors, but in general it decreases with increase in latitude. In the southern fringe area the mean ground temperature of permafrost is slightly below 32°F (between 30 and 32°F); further north, but still in the discontinuous zone where permafrost is thicker and more widespread, it may range between 23 and 30°F, in the continuous zone it is usually less than 23°F.

There is a broad relationship between mean annual air temperature and mean annual ground temperature. Observations have indicated that the mean annual air temperature is about 3 to 10°F lower than the mean annual ground temperature, depending on local conditions; the over-all average is about 5°F.

Perennially frozen ground may contain a great deal of ice. Ice segregation can occur in a number of ways ranging from coatings or films on individual soil particles and minute hairline lenses scarcely visible to the naked eye to large inclusions up to several feet thick. All forms of ice segregation can occur in the same material. Extremely high ice contents are prevalent in fine-grained materials but may be difficult to discern; in some cases, silty soils for example, the volume of ice may be as much as six times that of the soil.

Permafrost normally exhibits rock-like qualities; but its strength is dependent on its composition, texture, ice content and temperature. Its relatively high strength can be attributed in part to the cementing action of the ice, which binds the soil particles into a solid mass. The mechanical properties of frozen ground, in which ice fills some or all of the interstitial space between soil grains, therefore tend to approach those of ice. The strength of frozen ground increases with decrease in temperature and, in general, with increase in moisture (ice) content. For some soils, e.g. clays the increase in strength is relatively small at temperatures just below freezing, due mainly to the amount of unfrozen water in the material. Frozen sands that are well cemented by ice usually have considerably greater strength than fine-grained materials, particularly at temperatures near thawing.

Engineering Considerations

Most of northern Canada was glaciated, and as a result fine-grained soils such as silts clays and fine sands, or combinations of these predominate. Organic materials also occur extensively, usually overlying the mineral soil. These soils are generally frost susceptible and when perennially frozen, contain large quantities of ice.

A major factor to be considered by the northern builder is frost action in the active layer, which freezes and thaws seasonally. The active layer often consists of frost susceptible soils and, in addition, is saturated with moisture. A ready supply of water, which is a prerequisite for frost heaving, is thus provided. Differential heaving as a result of frost action can and does cause serious damage to foundations and buildings.

Permafrost is particularly sensitive to thermal changes. Any natural or man-made change, however slight, in the environmental conditions under which permafrost exists will greatly affect the delicate natural thermal equilibrium. For example, the clearing of an area or the erection of a building may result in thawing of the frozen ground or a raising of the permafrost table. Care must be taken, Therefore, in all construction operations that detrimental conditions are not produced by changes in or disturbance of the original environment existing at the site.

Although frozen soil provides excellent bearing for a structure, its strength properties are greatly reduced with increase in temperature and, if thawed, may be lost to such an extent that it will not support even light loads. The most serious difficulties arise with those soils, usually fine-grained, that have large moisture (ice) contents. When thawed these materials turn to a slurry with little or no strength and large settlements and perhaps failure of a structure may occur.

In northern areas surface water is conspicuous in the summer despite the generally low precipitation. Because permafrost is relatively impermeable, drainage is generally poor and movement of water can only occur above it. For this reason materials in the active layer are often saturated.

Accumulation of water on the ground surface can be a serious problem because of its thawing effect. Drainage is therefore vital. If natural drainage is impeded or proper drainage structures are not provided, construction operations can be seriously complicated by intensified frost action during the winter and accelerated thawing during the summer.

From the preceding brief outline it is evident that adequate site investigations are essential prior to engineering design and construction in permafrost areas. Information must be obtained not only on the distribution of permafrost but also on sub-surface conditions, including data on the physical and mechanical properties of the soils and the thermal regime of the ground.

Foundation Design

The results of site investigations will indicate the approach to be taken in the design of foundations and the construction techniques to be used. Selection of suitable foundation designs is normally based on one of the following four approaches.

1. Permafrost conditions can be neglected when structures are sited on well-drained granular soils or solid rock. These materials usually contain little or no ice in the frozen condition and changes in the ground temperature regime will have little influence on their properties. Thus conventional design and construction methods are possible.

2. The frozen condition can be preserved and utilized to support a structure. In the continuous permafrost zone, particularly when fine-grained materials with high ice content are encountered, every effort must be made to preserve permafrost. This is usually accomplished by either ventilation or insulation construction techniques the former is commonly used with heated buildings. Foundations are well embedded in the permafrost and the structure is raised above the ground surface to permit air circulation beneath and to minimize or prevent heat flow to the ground. Pile foundations placed in steamed or drilled holes to depths of from 15 to 30 ft. depending on the foundation material and building and heat loads, have proved well suited to this method and have been used extensively.

   Where pile placing may be difficult as in very stony soils, alternative foundation designs may prove more economical. Insulation to prevent thawing of the underlying frozen material may be achieved by placing a gravel blanket on the ground surface. Depending on the structure and the heat load, the gravel fill may range in thickness from 1 to 2 ft for small unheated buildings, which can tolerate some movement, to 10 ft or more for larger heated structures.

3. When foundation soils contain excessive amounts of ice and it is not possible to preserve the frozen condition it may be convenient to thaw and then consolidate this material prior to construction. It may be advantageous in some cases, to remove and replace it with compacted, well drained, non-frost-susceptible material. The depth to which pre-construction thawing is carried out will depend on the estimated rate of subsidence that will result from further thawing when the structure has been completed. This method may be adopted in both the continuous and discontinuous zones but it is probably more applicable in the latter particularly if a suitable load bearing stratum is at relatively shallow depth. Frozen materials are more readily thawed and excavated in areas where ground temperatures are close to 32°F. Normal design and construction methods can then be employed.
4. At some locations foundation designs must take into account anticipated settlement. This is particularly true in the southern fringe area (but also in the continuous zone) where considerable consolidation of the foundation material is to be expected and thawing of the ground is inevitable during the life of the structure. "Flexible" foundations, which can be adjusted to eliminate structural deformation as differential settlement occurs, can be used. Special settlement joints that permit individual sections of the building to move (settle) without producing deformations in adjacent sections can also be employed to ensure stability.
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   Care should be taken to avoid close spacing of structures erected by different methods, particularly when the construction of one building may affect the thermal regime of the foundation soils of another. If at all possible sites underlain by materials containing large masses of ice or where thawing is anticipated should be avoided. Building sites, irrespective of the construction method, should be thoroughly prepared and graded to ensure drainage of surface water away from the structure and the site as a whole. Although construction in northern areas is complicated by the presence of perennially frozen ground, problems concerned with foundation design and construction can be reduced to a minimum if care is taken in the selection of suitable sites.