Frost action and foundations

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Frost Action and Foundations

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Please note

In most parts of Canada the ground freezes during the winter months to depths varying from a few inches in mild areas to several feet in colder regions. Such ground freezing can lead to heaving of buildings located above or adjacent to it. The forces involved can be very destructive to lightly-loaded structures and cause serious problems in major ones. This Digest outlines the causes of frost action, some of the construction problems it presents, and the steps that may be taken to control it. Previous Digests (**CBD 26**,**CBD 61**, and **CBD 128**) have dealt with related problems and may be referred to for more complete explanation of the mechanism of frost action, frost-heave in cold storage buildings, and adfreezing.

Frost Action

The volume increase that occurs when water changes to ice was at first thought to be the cause of frost heave, but it is now recognized that the phenomenon known as ice segregation is the basic mechanism. Water is drawn from unfrozen soil to the freezing zone where it attaches to form layers of ice, forcing soil particles apart and causing the soil surface to heave. without physical restraint there is no apparent limit to the amount of heaving that may occur. (Movements in excess of 4 in. (100 mm), developing under basement floors in only three weeks, have been recorded.) Where restraint in the form of a building load is present, heaving pressures may or may not overcome the restraint, but they can be very high: 19 tons/sq ft (1820 kPa) has been measured, and a seven-storey reinforced concrete frame building on a raft foundation was observed to heave more than 2 in. (50 mm).

A different form of frost action, called "adfreezing," occurs when soil freezes to the surface of a foundation (**CBD 128**). Heaving pressures developing at the base of the freezing zone are transmitted through the adfreezing bond to the foundation, producing uplift forces capable of appreciable vertical displacements. If constructed of concrete block a basement wall may fail under tension and part at a horizontal mortar joint near the depth of frost penetration. Relatively little is known of the magnitude of the forces that may be generated, but bond strengths of adfreezing of about 15 lb/sq in. (100 kPa) for steel surfaces and 10 lb/sq in. (70 kPa) for wood and concrete have been measured.

Controlling Factors

For frost action to occur three basic conditions must be satisfied: the soil must be frost-susceptible; water must be available in sufficient quantities; and cooling conditions must cause soil and water to freeze. If one of these conditions can be eliminated, frost heaving will not occur.

Frost-susceptibility is related to size distribution of soil particles. In general, coarse-grained soils such as sands and gravels do not heave, whereas clays, silts and very fine sands will support the growth of ice lenses even when present in small proportions in coarse soils. If frost-susceptible soils located where they will affect foundations can be removed and replaced by coarser material, frost heaving will not occur.

Water must be available in the unfrozen soil for movement to the freezing plane where the growth of ice lenses occurs. A high groundwater table with respect to the location of the ice lenses will therefore favour frost action. Where proper drainage is prescribed water can be prevented from reaching the freezing zone in frost-susceptible soils.

Depth of freezing is largely determined by the rate of heat loss from the soil surface. Besides the thermal properties of the soil, this heat loss depends upon such climatic variables as solar radiation, snow cover, wind, and air temperature, which is the most significant. If loss of heat can be prevented or reduced, frost-susceptible soils may not experience freezing temperatures.

Freezing Index and Frost Depth

Air temperature records can be used to gauge the severity of ground freezing by using the degree-day concept. (If the daily mean air temperature is 31°F this will be one degree-day.) The "Freezing Index" is simply the accumulated total of degree-days of freezing for a given winter.

Figure 1 is a map of Canada showing normal values of Freezing Index (Boyd, 1973). These vary from less than 100 degree days Fahrenheit (55 degree days Celsius) in southwestern British Columbia to 7500 degree days F (4150 degree days C) in northern Manitoba and northern Quebec, and up to 14000 degree days F in the Arctic Archipelago.

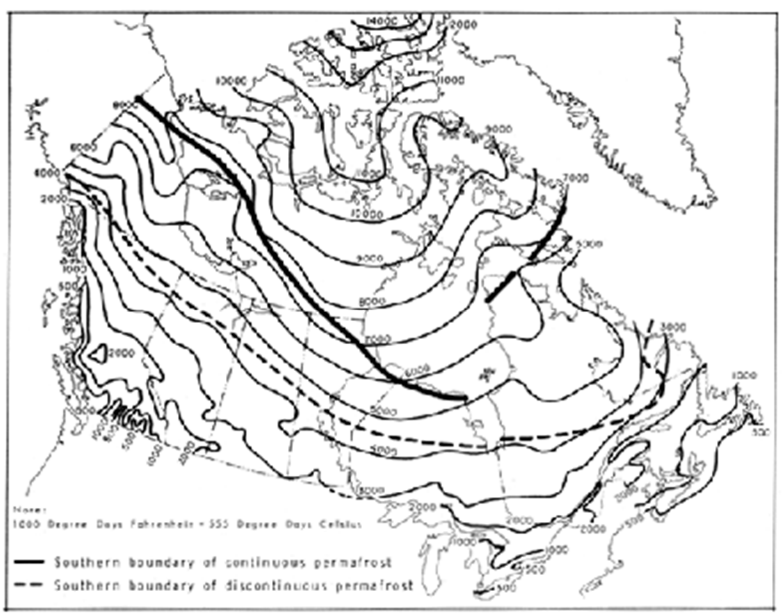

Figure 1. Normal Freezing Index for Canada in degree days Fahrenheit based on the period 1931 to 1960 (Boyd, 1973).

Correlations between frost depth and Freezing Index can be useful as guides for estimating total frost depth. That shown in Figure 2 is based on both field records and theory, but it should be recognized that all measurements were made in test areas kept clear of snow and that differences in soil thermal properties were not distinguished. Both these factors influence the depth of frost penetration.

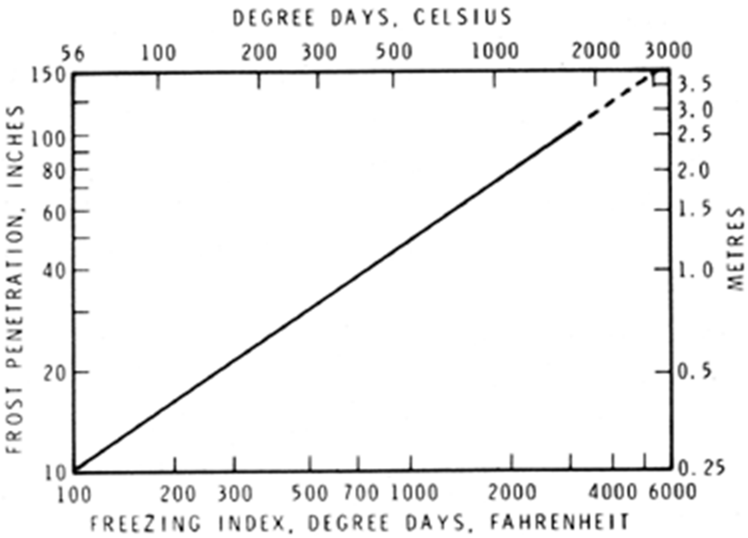

Figure 2. Relation between Freezing Index and depth of frost penetration (Brown, 1946).

The curve may be extended to encompass areas in which the Freezing Index exceeds the range of the original data, but such extrapolation should be limited to regions south of the southern boundary of discontinuous permafrost where the Freezing Index does not exceed 4500 degree days F (2500 degree days C). Because the provision of foundations in permafrost regions poses special problems beyond the scope of this Digest the reader is referred to **CBD 64**, "Permafrost and Foundations," for pertinent information.

Frost Action and Foundations

The conventional approach to the design of foundations to prevent frost damage is to place the foundation beyond the depth of expected maximum frost penetration so that the soil beneath the bearing surface will not freeze. This measure alone, however, does not necessarily prevent frost damage; if the excavation is backfilled with frost-susceptible soil it may lead to damage from adfreezing. Depths at which foundations should be placed are normally determined by local experience, as incorporated in building bylaws, but in the absence of such information the correlation shown on Figure 2 can be used.

By their very nature frost-susceptible soils do not drain well, and though inflow of groundwater may be prevented the quantity of water available in the unfrozen soil is often sufficient to produce significant heaving. Where possible it is good practice to remove frost-susceptible soil and replace it with coarse granular material that is easy to drain. Good drainage practice should also be followed, including the provision of drainage tile around the perimeter of the foundations (**CBD 156**).

Control by Thermal Insulation

In recent years, lightweight plastic insulation has been used extensively to reduce ground heat loss and hence depth of frost penetration. With the installation of the right thicknesses of insulation on the appropriate surfaces of the foundation or in the soil, soil temperatures can be kept above the freezing point. Insulation for this purpose, however, should only be used after careful examination of the pertinent conditions to ensure a thorough understanding of the effect it will have on heat flow at the soil-foundation interface. Insulation is of particular advantage in unheated buildings such as warehouses and garages, and in special facilities for food storage and ice surfaces for winter sports where inside temperatures must be kept several degrees below freezing.

Insulation that has relatively high compressive strength can be placed as boards directly below the bearing surfaces of foundations. Substantial economic advantage accrues where such designs are used because it is possible to place foundations closer to the ground surface, reducing the costs of excavation and transportation of granular fill to replace frost-susceptible soil (Robinsky and Bespflug, 1973).

Basements in Heated Buildings

Loss of heat from basement spaces through the surrounding soil reduces the depth to which frost penetrates in the immediate vicinity of a building. Consequently, foundations can be and are placed at levels above the depth of maximum frost penetration. In recent years, however, the need to reduce energy costs has led to increased use of insulation on foundation walls of existing buildings. This, while reducing heat loss, can cause deeper ground freezing than previously, particularly where insulation is applied to the interior surfaces of the basement space. Safe depths for footings on the perimeter of a building should therefore be determined from the maximum depth of frost penetration; interior footings are generally shallower.

Garages

Garages are frequently provided in basement spaces, but because corrosion of vehicle bodies is accelerated at higher temperatures such spaces are often maintained just above the freezing point. Frost heaving can occur if inadequate heat is supplied during cold snaps or if garage doors are left open. Concrete floors may be lifted and shallow foundations heaved, causing damage to the structure and interior finish of the building (**CBD 128**). Where such conditions are anticipated the foundations beneath all the walls of basement garages should be placed at depths beyond maximum frost penetration, properly backfilled and drained or protected from freezing by the use of insulation.

Small unheated structures such as garages and storage facilities, which may be expected to heave when erected on frost-susceptible soil, should not be attached to other structures designed not to heave. If they are, the resulting differential movements could damage connecting walls and roofs and present continual maintenance problems.

Frost Action during Construction in Winter

Frost heaving and damage frequently occur on construction sites in early winter because temporary heating is not begun sufficiently early. Special attention must be given to prevent frost action from affecting foundations during this period.

Interior footings, which are often placed only a few inches below basement floors, are particularly vulnerable to frost action at such times. The walls and floors of a partially completed structure act like cooling fins to accelerate the extraction of heat from the ground. This effect is most pronounced immediately beneath the footings. If the soil is frost-susceptible, severe heaving of the structural frame may result. Under the same conditions concrete floors on grade may be heaved, resulting in the crushing of lightweight partitions or distortion of the building frame and subsequent structural damage if the partitions are sufficiently strong to transfer stresses. Straw is sometimes used effectively as temporary insulation over the floors but during sub-freezing weather it cannot prevent heat losses from beneath the footings supporting walls and columns. For buildings designed to be heated, therefore, it is important that foundations at shallow depths and floors on grade be adequately protected against frost during construction in cold weather by either temporary heating or properly placed and suitable insulation.

Buildings in which crawl spaces are provided between the foundations and the first floor level are also vulnerable to frost action. Temporary heating is often installed only above the first floor, with no provision made for the crawl space, and in freezing weather frost heaving can result.

Excavation Walls and Supports

Dangerous conditions may develop in the walls of excavations supported by sheet piling or soldier pile and lagging systems during winter construction. Cold air is more dense than warm air and flows into the spaces below ground level, accelerating the extraction of heat from the soil behind the retaining structures. Under these conditions heat flow is primarily horizontal and ice lensing occurs parallel to the walls. This results in large pressures against the walls, causing considerable increases in the horizontal components of the supporting structural members. Horizontal struts spanning wall to wall will be subject to stress increases with contributions from both walls. It is imperative, if potentially dangerous conditions are suspected, to monitor walls and supporting systems to detect movements and stress increases associated with frost action. If such observations indicate that excessive heaving pressures are developing, preventive measures can be taken. These include continuous adjustment of the support systems to relieve excessive stresses and installation of heating systems.

Soil beneath the footing for a raker (sloping strut) cannot be permitted to freeze. Besides producing increased stresses on the supporting member, unstable conditions can develop if the soil is thawed rapidly, with subsequent loss of the shear strength upon which stability depends. The result may be complete failure of the footing and loss of support of the wall.

Summary

Designing buildings against potential frost-heave problems entails the avoidance of conditions that would lead to ice segregation in frost-susceptible soils. Frost action can be controlled through understanding of the problems it can produce and implementation of appropriate preventive measures.

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