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Please note

Frost damage to building foundations, retaining walls, driveways, walks and similar structures is common throughout Canada, and although it is not equally serious in all areas the resultant cost each year is high. This Digest contains a brief description of the physical processes involved in ground freezing and frost heaving and some suggestions on ways to prevent or diminish frost damage to various structures.

The results of frost heaving have been observed from earliest times. Swedish literature dating back to the 17th century indicates that the uplifting of boulders in the field and the breaking of plant roots in the winter were associated with frost heaving. At first, frost heaving of the soil was thought to result from the expansion of water on freezing. The present concept is that growing ice crystals draw water from the surrounding soil and develop into ice lenses.

Ground Freezing and Frost Penetration

When wet soil freezes, the main process is the physical change of soil water from liquid to solid that turns the soil into a hard mass resembling concrete. Its relatively high strength can be attributed in part to the binding together of soil particles with ice. In a porous body like soil, water exists in a network of inter-connecting pores; when it freezes, this network becomes rigid and encloses the soil particles in a solid block. If the soil is dry it cannot "freeze" in the accepted sense although its temperature may be well below 32°

It has been found that all the water in soil does not freeze at the same temperature. In studies with a saturated silty clay half the water remained unfrozen at 28°F; 1/6 was still unfrozen at -4°F. Because all soils have a similar freezing pattern, it is not surprising that the strength of frozen soil increases as the temperature is lowered and more water freezes. It bas been shown recently that the strength of heavy-textured soils increases 3 or 4 times as the temperature is lowered from 18 to 0°F.

The rate at which soil freezes is dependent upon its thermal properties, moisture content, and the ambient air temperature. Of these, probably the most important is the amount of water to be frozen, since it requires 144 heat units (Btu) to freeze each pound of water and by comparison only about 0.20 heat units to change the temperature of a pound of dry soil by 1°F. The density, conductivity of the soil particles and water content all influence the over-all thermal conductivity of soil. Because clay particles have a higher insulation value than silt or sand particles and since clay soils normally hold more moisture than silts and sands, the depth of frost penetration is usually greater in silt and sandy soils (light-textured soils) than in clays and silty clays (heavy-textured soils).

There are other factors that influence the depth of freezing. The insulating effect of snow deserves special mention. It bas been shown that each foot of undisturbed snow reduces the depth of soil freezing by approximately the same amount. Among meteorological factors such as air temperature, sunshine, precipitation, and wind velocity, air temperature is probably the most significant.

The use of "degree-days of freezing" as a guide in calculating frost depth for a given area illustrates the strong influence air temperature has on soil temperature. A degree-day of freezing results when the mean outside air temperature for one day is 1F deg. below 32°F. For example, if the average air temperature for a given day it 31°F this is one degree-day of freezing. The "freezing index" is simply the total number of degree-days of freezing for a given winter.

The use of the freezing index to predict the depth of frost penetration must be used with caution since it is based only on air temperature and does not take into consideration other factors such as soil type, snow cover and local climatic differences. In areas where no actual frost penetration information is available, the freezing index is a useful guide. Figure 1 shows the freezing index plotted against depth of frost penetration as determined from an analysis of many records of frost penetration in the northern United States. This design curve was developed by the U.S. Corps of Engineers and is used as a guide to the depth of frost penetration in the design of airport pavements. A "freezing indices" map of Canada has been prepared by the Department of Transport and may be obtained from the Division of Building Research in a paper describing its use (NRC 3573).

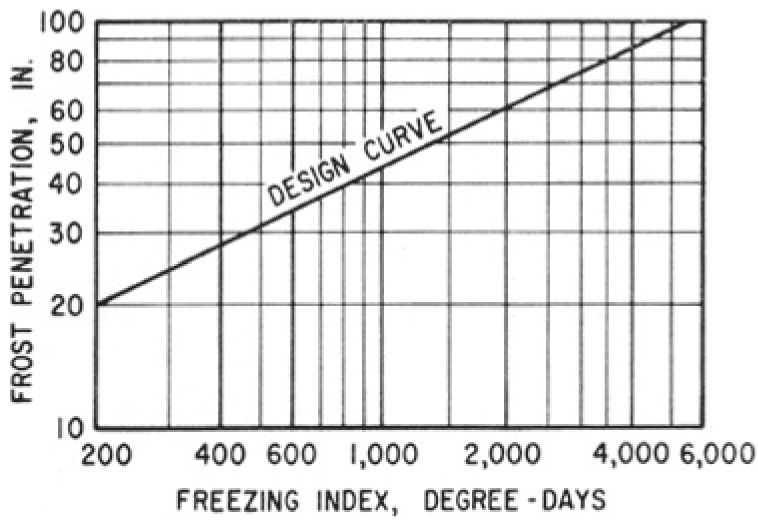

Figure 1. "Design Curve" of observed frost penetration in excavations.

Frost Heaving

In many cases where ground freezes no outward change is visible, although as indicated earlier the strength of the soil will be increased. In other cases, however, the ground heaves and the resultant displacement of the soil may cause considerable damage. The actual vertical displacement is far in excess of the expansion that occurs when water freezes. Heaving occurs when the right combination of fine grain soil, soil moisture and soil temperature exists.

As the mean air temperature drops in the fall of the year, the surface of the ground will freeze. With the lower air temperatures of approaching winter, the freezing plane slowly penetrates the soil. In a fine-grained moist soil a peculiar phenomenon occurs. At the freezing plane, the water in the soil turns to ice. This is, in effect, a drying action and water in the unfrozen soil beneath moves toward the freezing plane in the same way that water will move from moist soil to dry soil. This water, on reaching the freezing plane, is able to flow through and around the soil particles there and to join the ice crystals above, thus adding to the growth of a lens or layer of pure ice. Pressure is developed so that the ice and soil above it are lifted.

When there is an adequate supply of water to the freezing plane in soil of the proper type the ice lens can grow almost indefinitely. At the same time the freezing plane is prevented from penetrating further into the unfrozen soil because of the heat made available from the water as it freezes.

In practice, the freezing plane seldom remains stationary for any prolonged period; the supply of water may decrease or the rate of heat loss may increase due to a change in conditions. The balance between the heat from freezing of the water and the heat loss to the surface is then disturbed, and the freezing plane advances until the conditions for growth of a new ice lens are restored. This results in the formation of a series of ice lenses separated by layers of frozen soil, and is the most common situation in nature.

Ice lenses frequently develop in the soil under road surfaces and cause them to heave. As thawing proceeds downward from the surface in the spring, these ice lenses thaw and contribute water to the soil. In some cases the water that has accumulated as a result of the ice lens formation and subsequent melting is sufficient to cause the soil to lose strength, and the action of traffic may cause the paved road surface to break, through loss of support.

The expansion of soil from the formation of ice lenses varies over a wide range, but vertical movements of 4 to 8 in. are not unusual and as much as 24 in. has been reported.

Heaving pressures also vary over quite wide limits and depend mainly on the type of soil and its moisture content. A saturated soil will develop the maximum heaving pressure; as the moisture content drops, heaving pressure drops also and is reduced to zero in a soil with low moisture content. The type of soil has an influence, with clay soils developing higher pressures than silts. Pressures in excess of 14 psi have been measured, and in a laboratory experiment a pressure of 213 psi was developed in a clay soil. Pressures of this order are much in excess of the pressures found under roadways or under the footings of most buildings, so that these structures can be heaved quite readily when conditions are appropriate for ice lens formation. No heaving can take place, however, unless the heaving pressure exceeds the load on the soil.

The three basic requirements for frost heaving are: 1) a freezing plane in the soil; 2) a fine grain soil through which moisture can move; and 3) a supply of water. If any one of these factors can be controlled, frost heaving can be prevented. Since it is seldom economically possible to control soil temperature, frost heaving is usually prevented by replacing the fine grain soil with a coarse granular material. Soil moisture can also be controlled by careful attention to drainage, so that the extent of frost heaving is greatly reduced.

The Nature of Frost Heaving Soils

In a site investigation for a building project it is often necessary to determine whether ice lenses will form in the soil. This may be very difficult to determine if the soil is at the borderline between frost-heaving and non-frost-heaving material. The characteristics of a soil with extensive frost heaving ability are well known, as are those of a non-frost-heaving soil. The difficulty arises where there is a blending of both frost-heaving and non-frost-heaving soils.

The size of the particles in a soil has a marked influence on its properties, and this characteristic is often used to assess the heaving potential. The determination of particle size is relatively easy since most testing laboratories have facilities for making this analysis.

While a prediction of ice lensing based on the particle size of the soil is widely used, there are many cases where frost heaving has occurred in soils considered safe after an examination of particle size. Attempts have been made to use some other property, such as the height-of-capillary-rise, that more adequately describes the frost-heaving ability of a soil. Although this type of test is more difficult, the results provide a more realistic indication of frost heaving characteristics, giving an indirect measure of the size and distribution of soil pores.

A theory now held, based on the correlations between pore size and heaving pressures, is that the smaller the pore size the, greater the pressure. The way in which pore size distribution affects the heaving pressure is being investigated.

In general it can be said that coarse sands and clean gravels do not heave, while fine sand and silts are very susceptible to heaving. Clays also are very susceptible although they normally heave slowly but often with tremendous pressures. Silts show a high rate of heave but have much lower heaving pressures. When silts, sands or gravels are contaminated with clay, however, heaving ability is usually much enhanced and becomes less predictable.

At present the most reliable method of spotting a frost-heaving soil is to carry out a laboratory freezing test, although soils that show frost heaving in the laboratory do not always do so in the field. The test is therefore apparently on the safe side, but further research is required before completely reliable predictions can be made.

Prevention of Frost Damage

Frost heaving is not usually a problem in heated structures since the heat loss from the building keeps the temperature in the soil adjacent to the foundation above the freezing point. Difficulties often arise, however, in unheated detached buildings or in unheated additions to heated buildings. Damage also occurs to roads, sidewalks and shallow underground service lines.

A detached unheated building located on frost heaving soil may show no signs of distress owing to the fact that the foundation has been raised uniformly so that no stresses have been induced in the structure. Because of the non-uniformity of soil and other factors such as variable snow cover, it is more usual, however, to have differential heaving. This may also occur where the building has supports carried on footings located inside the structure. Due to the protection provided by the building, the penetration of frost under the interior column footings may be less than that under the perimeter footings. Under these circumstances there is a possibility that differential movement will occur.

If conventional foundation walls and footings are used for detached unheated buildings, the footings should be located below the level of maximum frost penetration. In such cases the backfill should be carefully selected and well drained. If this is not done, frost heaving in the backfill may occur that will lift the foundation wall because of the adhesion of the soil to the wall.

Where a detached building is located on a concrete slab on grade, protection will be provided by placing the slab on a mat of coarse granular material, which will act as a buffer against any movement of the soil under the mat. A mat 12 to 18 in. in thickness is usually adequate.

Unheated additions to buildings located on frost heaving soils are often damaged if their foundations do not extend below the frost level. This is due to the fact that some or all of the foundation of the addition is beyond the influence of the heated structure. In such cases frost penetrating below the shallow foundations will cause heaving that will result in a racking of the addition. Because of this danger, additions should have foundations extending below frost line with suitable backfill to prevent lifting of the foundation walls.

Retaining walls can be protected from being forced out of line by backfilling behind the wall with clean granular fill material and providing weep holes for drainage at the bottom of the exposed wall.

While driveways can tolerate some differential movement, particularly when a flexible covering such as asphaltic concrete is used, this movement should be kept to a minimum to avoid cracking and subsequent entry of water into the subgrade. Normally it is desirable to have a uniform subgrade to reduce differential heaving. This will often require a special mixing of the soil at the site. An addition of 6 in. of clean granular fill will provide added support for the covering during the thawing period if subgrade softening occurs in the spring from the melting of the ice lenses.

Run-off water from buildings should be directed away from critical areas by proper landscaping around the building. This will, at the same time, provide better subgrade drainage, which. is particularly important for driveways when only a thin layer of granular subbase material is used.

Frost heaving can be prevented if the soil temperature or the soil moisture content or the soil type can be controlled. Where differential movement cannot be tolerated, it is usual practice to replace the soil. Good drainage will reduce the extent of frost heaving, but it is usually not possible to lower the soil moisture content by drainage alone to a point where heaving is entirely eliminated.

While heated structures have little to fear from frost action, this does not mean that the depth of their foundations should be decreased. A foundation located below the frost line will also, in most parts of Canada be in a region of uniform soil moisture content throughout the year. This can be as important a consideration in the design of a building as are the provisions to prevent frost heaving.