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Adfreezing and Frost Heaving of Foundations

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Placing foundation footings below the frost line in frost susceptible soil does not necessarily ensure that a structure will be protected from damage from frost heaving. Movements in the soil resulting from ice lens growth can be transmitted to the structure if soil freezes to the foundation walls or supporting columns. The process is called adfreezing.

This Digest is intended to draw attention to the problem of foundation heave resulting from adfreezing for such structures as attached garages and carports, basement garages, separate garages, unheated warehouses, cottages and mechanical and electrical service units sensitive to differential movements.

The change of soil water to ice when the ground freezes greatly increases the strength of soil, but this same strengthening process is also responsible for the strong bond (adfreezing) that may develop between the foundation unit and the soil. During ice lens growth at the frost line most of the volume change results in an upward displacement of the frozen layer. The upward thrust of the growing ice lens is transmitted to the foundation unit to which the frozen soil is bonded by adfreezing. This places stresses on such units, and displacements occur unless the dead load of the building or other resisting forces exceed the uplift force (Figure 1).

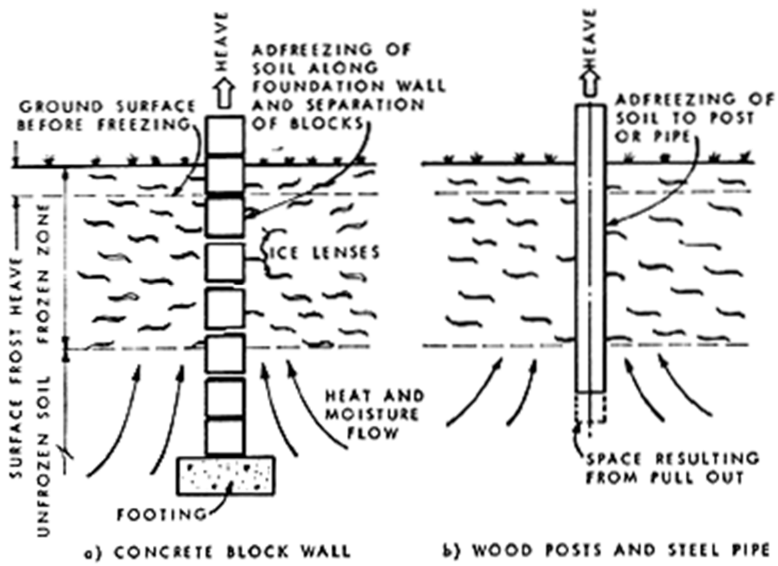

Figure 1. Behaviour of concrete block walls and posts in frost heaving soils.

Adfreezing by itself is not undesirable; it becomes destructive only when it occurs in frost susceptible (frost heaving) soils and the heaving displacements are transmitted to the structure. In most cases the amount is not uniform over the whole structure and distortion occurs. Frequently, also, soil material drops into the cavities produced by the heaving process so that the structure cannot settle back into its original position. Thus, the problem may get progressively worse from year to year, increasing the damage to both the foundation and the superstructure. It is necessary, therefore, to consider the probability of adfreezing and frost heaving when designing foundations for structures that are not protected from seasonal frost.

Assessment of the probability of encountering such difficulties with a particular structure and soil requires some appreciation of the frost heaving process (**CBD 26**). With this understanding and a means of identifying frost susceptible soils measures can usually be taken during the planning stage to avoid later trouble.

Adfreeze Strengths and Uplift Forces

Sufficient adfreeze strength studies have not been carried out to give precise field values for all foundation materials (e.g. concrete, wood, steel) in various soil types. The limited number that have been determined are used as a general guide only. Adfreeze strengths were determined by dividing the heaving force measured in the field by the area of contact between the foundation unit and the frozen soil. The heaving force on 3 ½ -inch diameter steel posts placed in clay had a maximum value of about 6,000 pounds for two consecutive winters for 3 ½ feet of frost penetration. This was equivalent to an average adfreeze strength in shear of about 12.5 psi and was a little lower than values determined elsewhere under different soil and climatic conditions. The maximum adfreeze measured on a concrete block wall was about 10 psi at the same site.

Information in the literature indicates that adfreeze strength values for wood and concrete are somewhat less than those for steel, and there is thought to be some dependence on foundation size and geometry. These factors are currently under study at the Division of Building Research. At this stage, and to allow for some factor of safety, an adfreeze strength of 18 psi is used to estimate whether the upward thrust on the foundation will be high enough to lift and distort the structure. For practical purposes the same adfreeze strength values may be applied for the various commonly used foundation materials until more detailed information becomes available. Methods of calculating uplift force and of preventing heave are given in the following section.

Foundations for Unheated Structures to Prevent Frost Heaving by Adfreezing

Heaving of unheated structures can be avoided by proper foundation design. Different principles can provide the designer with different methods and the opportunity to select the most suitable design for a particular structure. Necessarily, it must be consistent with the primary purpose of sustaining the load of the structure.

The method best understood is based on the principle of separating the foundation wall or column from the surrounding soil with a drained zone of granular material such as gravel or crushed stone (Figure 2). In this way the uplift forces generated in the frost heaving soil are not transmitted to the foundation but lost in shear in the granular zone. This zone must be well drained or the granular material will freeze into a solid mass. If this occurs any heaving forces outside the granular layer will be transmitted to the foundation and cause uplift and distortion of the structure.

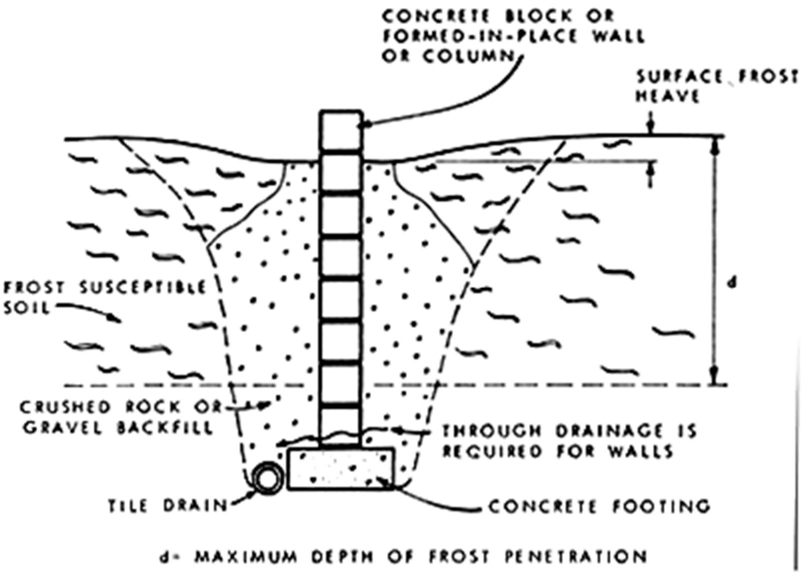

Figure 2. Drained gravel backfill around column or foundation wall.

A second method uses anchored columns or walls to resist the uplift forces generated by frost heaving of soil that is bonded by adfreezing to the sides of the foundation. A schematic drawing illustrates this principle (Figure 3). Uplift force may be estimated from adfreeze strength, expected depth of frost penetration, and the perimeter of the column or wall as follows:

U= d x p x f
where= uplift force,
U= depth of frost,
d= perimeter of
pcolumn or wall,
f= adfreeze
strength.

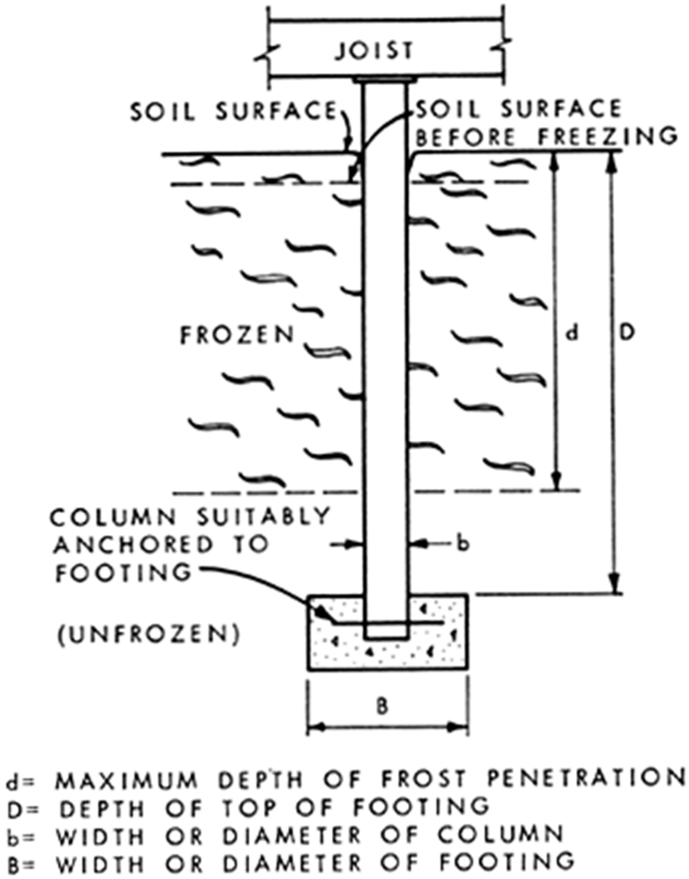

Figure 3. Anchored column (e.g. wood, steel, concrete).

The uplift force, U, will place the layer of unfrozen soil, D - d, between the frost line and the top of the footing in compression. From load-compressibility characteristics of the backfill at the density at which it is replaced, and from depth of frost penetration, depth of footing and permissible heave (upward movement) of the column or wall for a given structure an estimate can be made of the footing area required to give satisfactory anchorage.

Several aspects of this method should be emphasized.

1. For isolated supports, the more slender the column in the frozen layer the smaller the area of adfreezing and hence the lower the uplift force.
2. Good compaction of the backfill will reduce compression of the unfrozen layer and accompanying heave.
3. The soil must not freeze down to the top of the footing. Should this occur there would be no resistance to heave.

Experimental foundations in Leda clay at Ottawa, consisting of 3 ½ -inch diameter steel piles anchored to reinforced concrete footings 2 feet by 2 feet by ¾ foot and placed at a depth of 5-¾ feet, have heaved only 0.02 feet for a measured heave force of 6,000 pounds. The depth of frost was about 3-¾ feet. The maximum compressive stress placed on the unfrozen layer by frost heaving was calculated to be approximately ¾ ton/foot^2. This stress would normally cause little compression in well compacted, unfrozen backfill.

A third method makes use of non-wettable insulation such as foamed polystyrene board to prevent freezing of the frost susceptible soil in contact with the column or foundation wall. For best protection, the insulation should be placed horizontally, adjacent to the foundation. It should be buried a sufficient depth below the ground surface to prevent crushing by traffic, but shallow enough to avoid adfreezing problems above it.

The thickness of the required insulation depends on the severity of the climate. For insulation with a thermal conductivity of 0.25 Btu in./ft ^{2} hr °F, 1 inch thickness of insulation per 1,000 degree-days of freezing is normally sufficient in snow-cleared areas. On this basis, for example, about 2 inches would be required in Ottawa, ¾ inch in Halifax, and 3 ½ inches in Saskatoon. The width of the insulated strip next to the foundation wall or column should be approximately equal to the expected depth of frost penetration. Exposed foundation walls might also have to be insulated to prevent frost entry and to obtain maximum protection.

Other methods of preventing frost grip on foundation units have been investigated: applying a lubricant to columns, or applying lubricant and wrapping columns with building paper. These are temporary measures only, and usually require extensive maintenance after a few winters.

Heated Basements

Adfreezing of soil rarely occurs on uninsulated foundation walls of heated basements because of heat losses to the surrounding soil. Figure 4 shows the thermal regime around such a structure. Even under severe winter conditions the 32 °F isotherm does not intercept the foundation wall if the basement temperature is sufficiently high. Difficulties of frost heaving are avoided, even though the soil used for backfill may be potentially frost susceptible. If heat loss from the basement area is reduced to the point where the soil in contact with the wall freezes, difficulties may be encountered. Adfreezing may be induced if an excessive thickness of insulation is applied to the inside of exterior foundation walls, or if heat is excluded from certain areas of the basement, as for cold cellars.

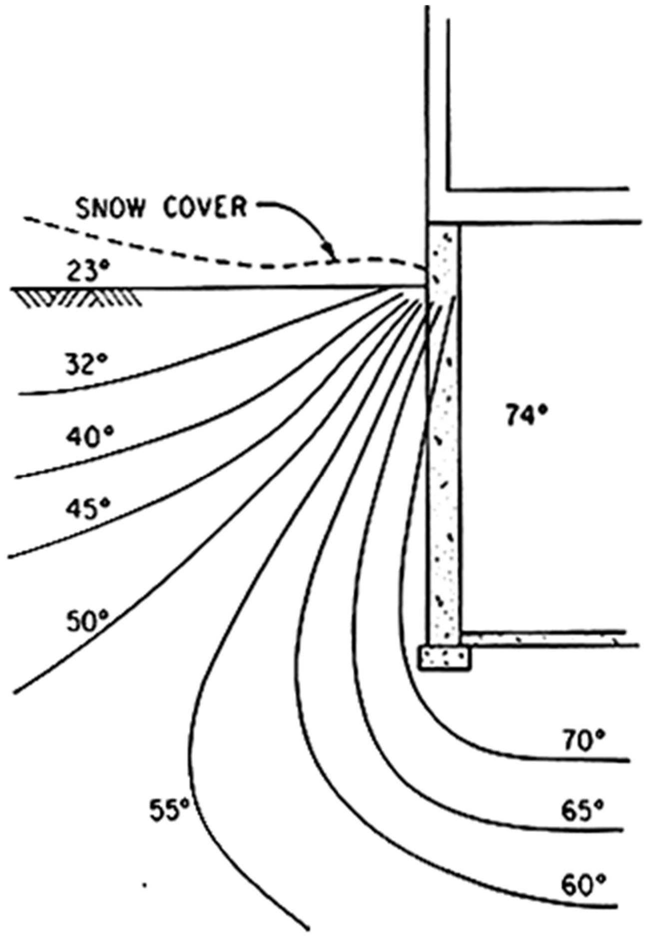

Figure 4. Measured ground temperature isotherms for 27 January 1956 at Prairie Regional Station, Saskatoon, Saskatchewan.

Drive-Down Basement Garages

Frost heaving of the sill across the entrance of drive-down garages is frequently encountered where the soils are frost susceptible, even when footings are placed below frost depth. This situation is given special attention because it is such a common problem. Causes of damage vary with differences in design detail, but they can usually be traced to a combination of the following factors:

1. a readily available water supply; the entrance is below street level and thus closer to the water table or below it:
2. frost susceptible soils used as backfill, both inside and outside the foundation wall at the garage entrance;
3. maximum frost penetration because the driveway is snow cleared:
4. gravel backfill not drained properly and uplift of adjacent soil transmitted to the foundation wall;
5. garage temperatures too low to keep soils from freezing around the entrance.

Figure 5 shows frost susceptible soil next to the foundation wall under the sill and heaving difficulties encountered because of adfreezing. The design and construction principles recommended under these conditions are given in the schematic drawing in Figure 6. It is important that clean gravel or crushed rock backfill be used on both sides of the foundation wall at the garage entrance.

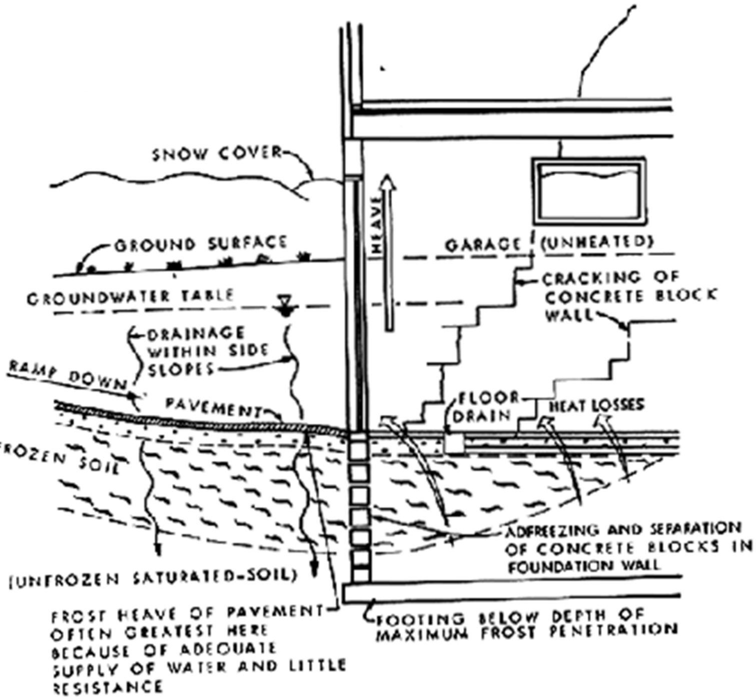

Figure 5. Frost heave and damage around entrance of basement garage.

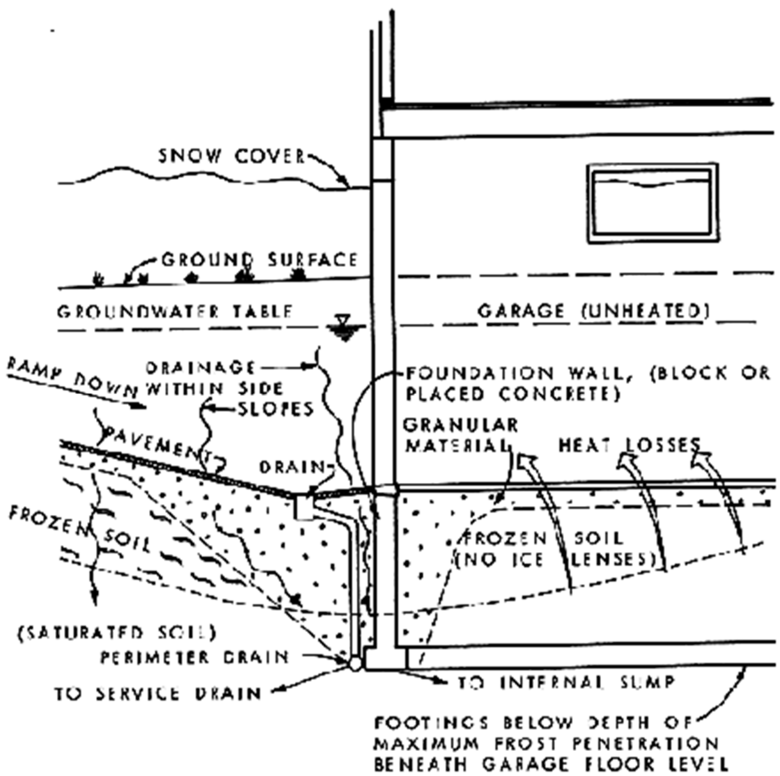

Figure 6. Suggested method of preventing frost damage to basement garage.

The footing depth must be lower than the expected frost penetration and drain tiles should be placed adjacent to the footings. Where the footing below the garage door is lower than the remainder of the foundation, special arrangements should be made for draining water away from it. This is absolutely necessary if heaving problems are to be avoided.