

How to prevent frost heave

Reduce frost penetration or keep water or frost-prone soil out of the frost zone

Frost can damage pavements and building structures in two ways: heaving of the frozen ground, caused by ice lenses forming in the soil, and collapse of the ground, caused by the thaw of these same ice lenses. In the winter, as frost penetrates the ground, water in the pores of the soil freezes, leaving the soil near the frost line dry. Because water flows from wet to dry regions by capillary action, water from below the frost line is drawn up. When it reaches the frost line, it freezes, too. The ice lenses grow thicker much as the ice on a pond thickens from the bottom side. As the frost line penetrates deeper into the soil, new ice lenses form below the first ones. The expansion caused by the water freezing heaves the ground a distance equal to the total thickness of all the ice lenses (Reference 1).

The amount of frost heave can be tremendous. In one case, a seven-

story building heaved 2 to 3 inches (Reference 2). Vertical ground movements of 4 to 8 inches are common and as much as 24 inches have been reported (Reference 3). Variations in the amount of heave, due to different soil and water conditions, can crack structures easily. Walls, slabs, footings, and pavements all can be damaged.

In early spring, the frozen soil begins to thaw—from both the top and bottom. For a while, a layer of frozen soil remains below the ground surface. Unable to drain through this frozen layer of soil, the water-laden surface layer loses practically all of its bearing capacity. The pavement or other structure built over it sinks and may break up, especially if it is heavily loaded.

Three conditions required for frost heave

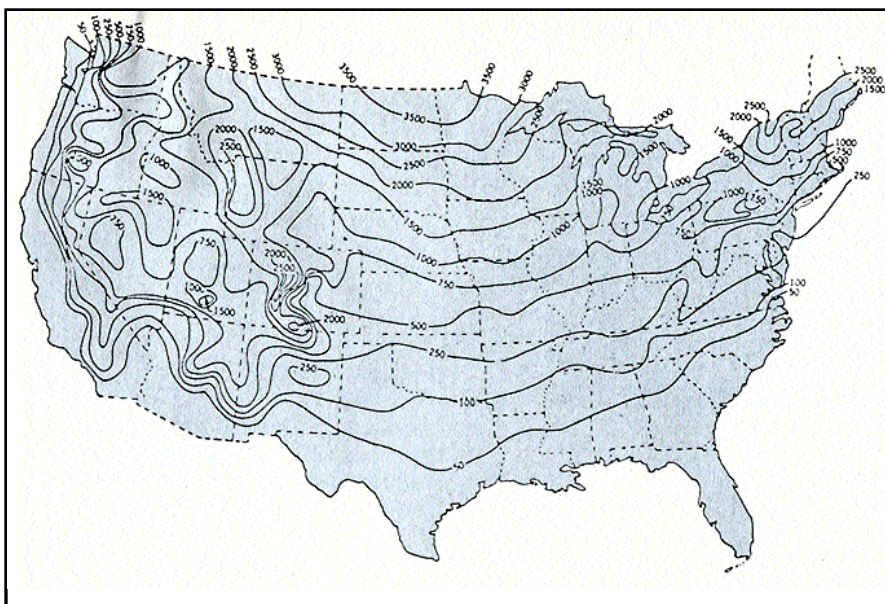
For frost heave to occur, three things must be present:

- Freezing temperatures
- Water
- Frost-susceptible soil

If any one of these three conditions is not present, the soil will not be subject to frost heave.

Freezing temperatures. The depth of frost penetration (and the amount of frost heave) depends on the intensity and duration of the winter freeze. Frost penetrates deeper in areas with colder, longer winters (Figure 1). Frost heave also is more severe when temperatures drop gradually, instead of suddenly. Thicker ice lenses form during a gradual freeze because capillary water has more time to rise from the water table.

Water. Water can come from the water table or surface infiltration, but a high water table causes the greatest frost heave. If surface infiltration is the only source of water, only the water in the pores of the soil freezes. When a high water table is present, capillary water drawn



Total Degree-Days for Coldest Year in 10 Years (from map)	Frost Penetration of Pavement Foundation (inches)
50	10
100	14
250	22
500	31
750	38
1000	44
1500	54
2000	62
2500	70
3000	77
3500	83

Figure 1. Frost penetrates deeper in areas with colder, longer winters. This map shows total degree-days below freezing for the coldest year in a 10-year period. It does not show local variations, which may be large, particularly in mountainous areas. The table shows how deep frost may penetrate a pavement foundation made of well-drained material that's not frost prone. You can calculate degree-days for one day, by subtracting the average temperature for that day from 32 degrees F (Reference 4).

from the water table also freezes. More water freezes, so more frost heave occurs.

Frost-susceptible soil. The frost heave potential of different soils is shown in Figure 2. Silty soils are the most prone to frost heave. Their pores are small enough to draw moisture through capillary action and large enough to allow this moisture to move through the soil quickly. In a way, they soak up moisture and hold it like a sponge.

Capillary rise for clays is high also, but permeability is low so water moves through the soil slowly. Winter may end before ice lenses grow thick enough to cause harmful heaving. Compacting clay reduces its permeability and frost heave potential even more.

Gravel is the soil least susceptible to frost heave. Water can't rise through it by capillary action, and because it's highly permeable it won't hold water. Free-draining gravel is thus an excellent base material for foundations.

How do you determine if the soil is silty and prone to frost heave? A soil test conducted by a materials testing laboratory is the most reliable way. No more than 10 percent of the particles of a uniformly graded soil should be smaller than 0.02 millimeter (passing the No. 200 sieve). Fairly well-graded soils should not contain more than 3 percent of this size (References 1 and 4). These are useful rules of thumb but they are not exact tests for frost susceptibility. Although rarely required, a slow laboratory freezing test can be performed. The test measures the rate of heave in a cylindrical soil specimen with one end set in water and the other end exposed to cooling.

You also may be able to get information about areas with frost-susceptible soils from local building code authorities, highway departments, geological survey offices, agricultural extension agents, or consulting engineers.

FROST HEAVE POTENTIAL OF DIFFERENT SOIL TYPES			
Soil Type	Capillary Rise (feet)	Permeability	Frost Heave Potential
Clay	Greater than 8	Low	Medium
Silt	Greater than 8	High	High
Fine Sand	3 to 8	Medium	Medium
Coarse Sand	1 to 3	High	Low
Gravel	0	High	Low

Figure 2. Permeable soils that exhibit strong capillary forces are the most prone to frost heave. Silty soil is thus very frost prone, and gravel is not.

Three ways of preventing frost heave

Because of heat loss to the surrounding soil, heated buildings rarely suffer frost heave damage. Frost heave also is avoided by extending footings below the frost line. Pavements, driveways, sidewalks, and floor slabs of unheated buildings are not supported by footings, however. To protect these structures, you must eliminate or minimize at least one of the three conditions that lead to frost heave:

- Reduce frost penetration.
- Keep water out of the freezing zone.
- Make sure soil in the freezing zone is not susceptible to frost.

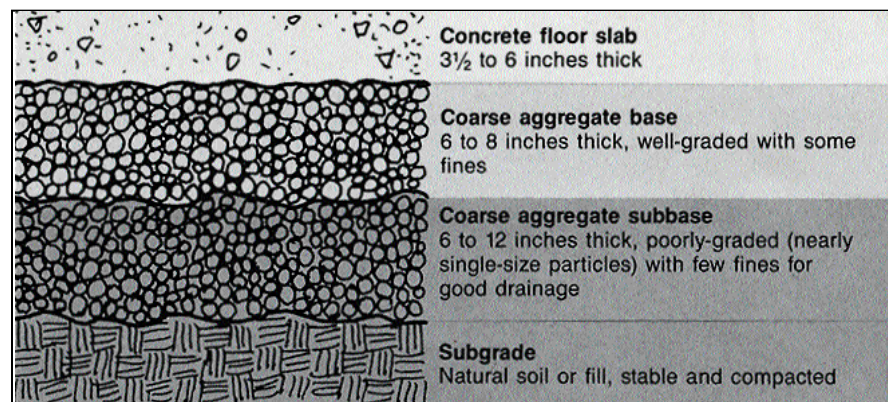
Reduce the depth of frost penetration. Clean sand and gravel are commonly used for bases under floor slabs and pavements. They also provide some insulating value, but usually not enough to adequately reduce frost penetration. A few years ago, however, the Portland Ce-

ment Association (PCA) experimented with a mortar containing expanded polystyrene beads (Reference 5). Placed under asphalt and concrete pavement sections, the material reduced pavement stresses, deflections, and depth of frost penetration. One inch reduced frost penetration as much as 3 inches of granular base did.

Keep water out of the freezing zone. You can keep water out of the freezing zone by lowering the water table, blocking the rise of water from the water table, or removing surface water before or after it enters the soil.

Lowering the water table slows the growth of ice lenses by increasing the distance that water must climb to reach a frost line. In many cases, doubling the distance to the water table can cut the amount of

Figure 3. Floor slabs for unheated buildings should be built with a coarse-grained base and subbase that are not frost susceptible (Reference 6).



frost heave in half. This usually is not economical, but it can be done by adding fill to raise the grade line of the slab in relation to the water table. Unless the soil is more than 70 percent saturated, frost heave usually does not occur if the water table is more than 10 feet deep year-round (Reference 4).

In some cases, you can block capillary rise or slow it to a tolerable level. Water cannot rise by capillary action through a layer of gravel or crushed stone installed between the water table and freezing zone. A blanket of nonswelling clay under the slab is effective, too. Clay has strong capillary forces but its low permeability prevents much water from passing through it.

Good drainage reduces the extent of frost heaving, but usually it doesn't dry the soil enough to eliminate heaving entirely. In pavement construction, try to prevent surface water from entering the base or subgrade. Seal joints and cracks, especially joints at the pavement edge. Install drain tile or build open side ditches to intercept water from higher ground nearby. In construction of retaining walls, provide weep holes for drainage at the foot of the exposed wall. Elevate building slabs at least 3 to 4 inches above the normal surface water drainage plane (which is not the same as the water

table). Direct runoff water away from the building with proper landscaping.

Make sure soil in the freezing zone is not susceptible to frost. Gravel or crushed stone drains surface water quickly and does not draw water from the water table. This makes these materials good replacements for frost-susceptible soil in the freezing zone. Coarse aggregate with all particles about the same size is best; it should be free of fines which might fill voids and provide capillary channels around large particles. Figure 3 shows a good floor design for unheated buildings.

Replacing all the frost-prone soil in the freezing zone often is impractical in northern regions, however. Frost in these areas may penetrate more than 4 feet. The cost of removing and disposing of that much soil and replacing it with gravel or crushed stone usually is too great. Even so, replacing some of the frost-susceptible soil reduces frost heave.

Use a granular backfill that's not frost prone around footings and foundation walls, too. In some cases, even if the foundation extends below the frost line, frost-susceptible soil that sticks to the foundation walls may lift the foundation if it undergoes frost heave.



—by Mark Wallace

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PUBLICATION #C870369

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