Frost-Susceptible Soils

Frost heave may be a concern in northern climates, but frost action can be reliably mitigated by utilizing one or more specific design techniques.

In northern or cold climates, the influence of frost and freezing of the roadbed is an important consideration. Certain subgrade soils are particularly susceptible to frost action, which raises the foundation and concrete pavement layer(s) vertically during freezing periods (commonly referred to as heaving or frost heaving). Generally, frost heave is limited to areas of freezing climates with silty soils. If the heaving is uniform along a pavement section it is not detrimental, but if heaving is localized, it upsets the uniformity of support provided to the surface pavement. Removing or treating these materials will be necessary to ensure that the pavement performs as desired. Thus, the potential for frost heaving of subgrade materials must be assessed by the engineer during the design phase. More on this topic is available in ACPA's **EB204P**, "*Subgrades and Subbases for Concrete Pavements*."

Frost Action and Heave

Frost action is a phenomenon that occurs in the winter and early spring in northern climates. Practically all surface soils in cold climates undergo some frost action, the magnitude of which is dependent upon the locally prevailing climate and precipitation and soil type. Frost action divides into two phases:

- freezing of the soil water and
- thawing of the soil water.

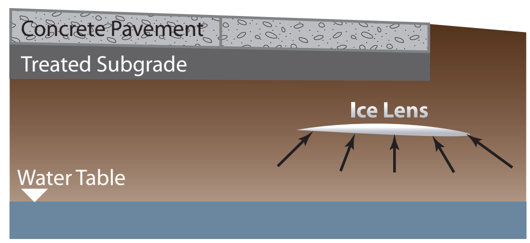
Heaving of the road from frost action is termed "frost heave." Frost heave, particularly when in isolated areas, induces uneven support of a pavement. When heavy loads pass over the area of uneven support, a crack may form in the pavement surface layer.

Frost heave is caused by the formation of ice lenses in the soil below the pavement (Figure 1). Water expands roughly 9 percent by volume when frozen. When freezing temperatures penetrate a subgrade soil, water from the unfrozen portion of the subgrade is drawn towards the frozen zone. If the soil is susceptible to capillary action, the water migrates to previously formed ice crystals and freezes. The size of the ice lens depends upon the quantity of free water available within the soil and from the water table, and time.

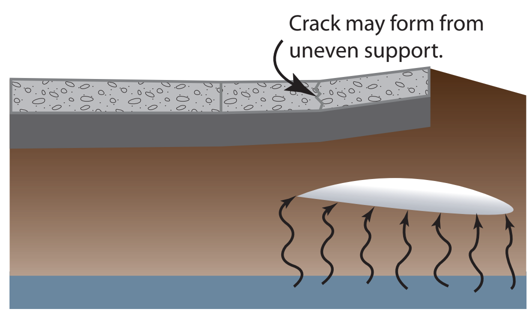
There are at least three conditions that must exist before frost heaving can occur. They are:

- A sufficiently cold climate to allow freezing temperatures to penetrate below the road surface and into the subbase and subgrade.
- A supply of water from below, above and/or laterally into the freezing zone.
- A soil material that is frost susceptible and is lying within the freezing zone.

The areas of the United States most susceptible to frost heave are those identified as wet-freeze (WF) in Figure 2, because two of the three conditions listed above (cold climate and supply of water) are common during the winter in these areas.



(a) Ice lens begins to form from free moisture in the soil.



(b) Ice lens grows as it is fed from water by capillary movement through frost-susceptible soil causing the pavement to heave and sometimes crack.

Figure 1. Formation of an ice lens, causing frost heave.

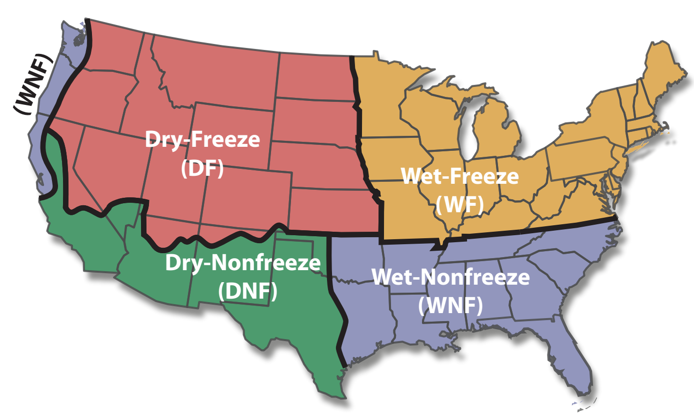


Figure 2. Four climatic zones as identified in the Long-Term Pavement Performance Program.

Frost-Susceptible Soils

Criteria and soil classifications for identifying frost-susceptible soils usually reflect susceptibility to softening on thaw as well as to heaving. For a concrete pavement, the major concern is to reduce heaving; control of spring softening is not as much of a consideration. Thus, differentiation between soils susceptible to heave and those susceptible to thaw softening may be useful to consider during the design of any concrete pavement.

There is a wide diversity in frost susceptibility determination methods; almost all of the methods are unique for individual state, provincial, and federal agencies. However, these methods seldom differentiate between frost heave and thaw softening. One method that does differentiate between the two factors is the freeze-thaw test of the U.S. Army Corps of Engineers, but the test and equipment are much more complex than most other frost-susceptibility tests.

In general, the degree of frost susceptibility can be explained by two hydraulic properties of soils:

- Capillarity — the soil's ability to pull moisture by capillary forces. The smaller the pore size distribution of a pore network, the greater the driving force (capillary action) and the greater the capillarity.
- Permeability — the soil's ability to transmit water through its voids. The permeability of any material is heavily dependent on the connectivity of its pore network. For example, if a material contains many tortuous pores that abruptly end, it will have less permeability than a material with very open pores that pass completely and directly through the material. The more connected and the larger the pore network is, the greater the permeability.

The relation of these properties to frost susceptibility is visualized in Figure 3.

Control of Frost Heave

The performance of older concrete pavements in frost-susceptible areas under today's increasingly heavy traffic shows that extensive, costly controls are not necessary to prevent frost damage. Surveys of these pavements indicate that control is needed only to reduce excessive heave and, more critically, to prevent differential heave by achieving reasonably uniform subgrade conditions. A large degree of frost heave control is attained most economically by appropriate grading operations and by controlling subgrade compaction and moisture.
Generally speaking, however, frost heave can be controlled

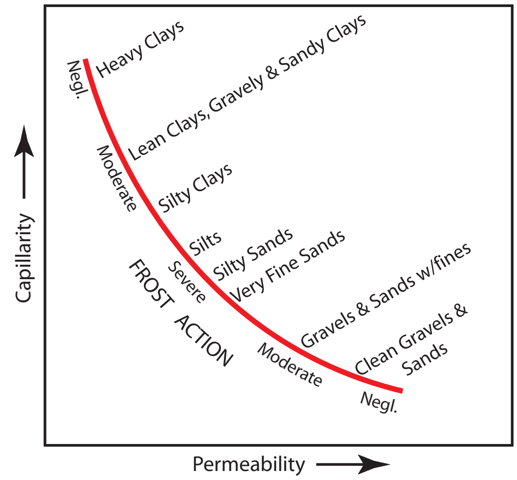


Figure 3. The relationship between frost action and hydraulic properties of soils.

by using one or more of the following mitigation techniques:

Non-Frost-Susceptible Cover - Layers of clean gravel and sand will reduce frost heave, but they are not required for this purpose if frost heave can be mitigated by proper grading operations.

Grade and Water Table Elevation - The most fundamental design aspect of controlling frost heave potential is to set the grade lines high enough and construct side ditches deep enough so that highly frost-susceptible soils are always above the capillary range of groundwater tables.

Selective Grading and Mixing - Selective grading operations are beneficial to place highly frost-susceptible soils in the lower portions of embankments, and to cross-haul less frost-susceptible soils form the lower portion of the subgrade towards the top.

Removal of Silt Pockets - When the grade includes only a few pockets of silt or other frost-susceptible soils, the best option is to excavate and backfill these pockets with soils similar to the surrounding subgrade.

Drainage - Where elevating the pavement grade is impractical, underdrains may be used.

Compaction and Moisture Control - Once reasonable soil uniformity is created through grading operations, compaction at controlled moisture levels will further improve the subgrade.

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