FROST HEAVE

The temperature of soils near the ground surface reflects the recent air temperatures. Thus, when the air temperature falls below 0˚C (32˚F) for extended periods, the soil temperature drops to a comparable level and the pore water turns to ice.

GROUND FREEZING and FROST HEAVE

The depth of freezing in the ground depends on:

• How far the air temperature falls below freezing,

• How long it remains there, and other factors.

- The depth is negligible in warm climates.
- But can extend to depths of 2 m or more when the winters are very cold.

In arctic and sub-arctic regions, the depth of freezing is even greater.

For geotechnical engineers, the most significant consequence of ground freezing is FROST HEAVE, which is an upward movement in the ground due to the formation of underground ice.

Due to frost heave, the pore water expands about 9 percent in volume when it freezes.

If the groundwater table is relatively shallow, capillary action can draw water up to the frozen zone where it forms ice lenses.

In some situations, this mechanism can move large quantities of water, so it is not unusual for these lenses to produce ground surface heaves of 300 mm or more.

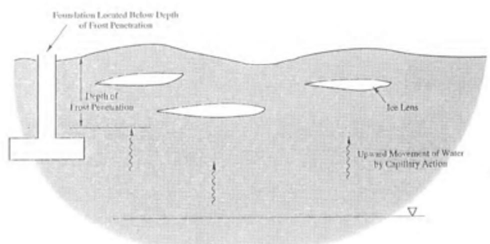

Figure 18.2 Formation of ice lenses. Water is drawn up by capillary action and freezes when it reaches the frozen soil, which is located within the depth of frost penetration. The frozen water forms ice lenses that cause heaving at the ground surface. Foundations placed below the depth for frost penetration are not subject to heaving.

In some situations, this mechanism can move large quantities of water, so it is not unusual for these lenses to produce ground surface heaves of 300 mm (12 in) or more.

Additional damage can occur when the frozen ground begins to thaw, especially if ice lenses are present.

As the upper soil and ice lenses thaw, the resulting soil has a much greater moisture content than it originally had.

However, the deeper soils have not yet thawed, so this excess water can not drain away, resulting in a

very soft and

weak soil.

- This condition is especially troublesome when it occurs beneath highways,

  and is often the cause of ruts and potholes.

- Once the soil completely thaws, the excess water drains down and the soil regains much of its original strength.

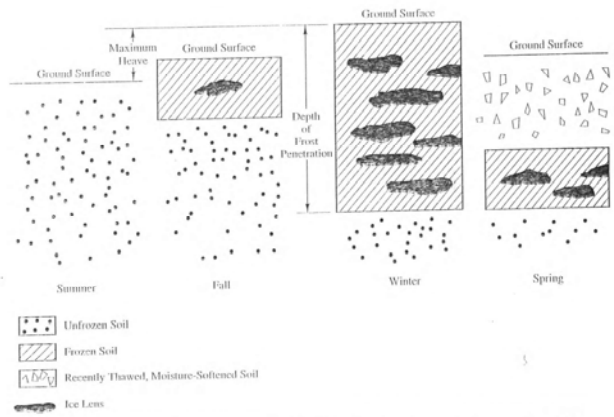

Figure 18.3 Idealized freeze–thaw cycle in temperate climates. During the summer, none of the ground is frozen. Then, during the fall and winter it progressively freezes from the ground surface downward. Finally, in the spring, it progressively thaws from the ground surface downward.

To evaluate the potential for frost heave at a given site, geotechnical engineers consider the following factors:

- The potential depth of freezing
- The frost susceptibility of the soil
- The proximity (closeness) of potential sources of groundwater.

To be considered frost-susceptible, a soil must be capable of drawing significant quantities of water up to the frozen zone through capillary action.

- Clean sand and gravels are not frost-susceptible because they are not capable of significant capillary rise.
- Conversely, clays are capable of raising water through capillary rise, but they have a low hydraulic conductivity, so they are unable to deliver large quantities of water.

Therefore, clays are capable of only limited frost heave.

- However, intermediate soils, such as

silts and fine sands,

Have both characteristics:

They are capable of substantial capillary rise and have a high hydraulic conductivity.

Large ice lenses are able to form in these soils, so they are considered to be very frost-susceptible.

TABLE 18.6 FROST SUSCEPTIBILITY OF VARIOUS SOILS ACCORDING TO THE U.S. ARMY CORPS OF ENGINEERS (Adapted from Johnston, 1981)

Group	Soil Types	USCS Group Symbols
F1 (least susceptible)	Gravels with 3 - 10% finer than 0.02 mm	GW, GP, GW-GM, GP-GM
F2	a. Gravels with 10 - 20% finer than 0.02 mm	GM, GW-GM, GP-GM
	b. Sands with 3 - 15% finer than 0.02 mm	SW, SP, SM, SW-SM, SP-SM
F3	a. Gravels with more than 20% finer than 0.02 mm	GM, GC
	b. Sands, except very fine silty sands, with more than 15% finer than 0.02 mm	SM, SC
	c. Clays with $PI > 12$, except varved clays	CL, CH
F4 (most susceptible)	a. Silts and sandy silts	ML, MH
	b. Fine silty sands with more than 15% finer than 0.02 mm	SM
	c. Lean clays with $PI < 12$	CL, CL-ML
	d. Varved clays and other fine-grained, banded sediments	

Highways and Other Pavements

- Highways,
- parking lots,
- airports, and
- other paved areas

are specially susceptible to damage from frost heave.

Some of these damage occurs during the winter as a result of differential heaving associated with ice lenses,

But more damage often occurs in the spring when the soils have partially thawed and contain trapped water.

Heavy wheel loads from trucks or large aircraft are especially troublesome during the spring thaw

because they produce bearing capacity failures in the weak soil,

which then causes the overlying pavement to sink into the ground.

Highways and Other Pavements

Highways, parking lots, airports, and other paved areas are especially susceptible to damage from frost heave. Some of this damage occurs during the winter as a result of differential heaving associated with ice lenses, but more damage often occurs in the spring when the soils have partially thawed and contain trapped water. Heavy wheel loads from trucks or large aircraft are especially troublesome during the spring thaw because they produce bearing capacity failures in the weak soil, which then causes the overlying pavement to sink into the ground. Figure 18.4 shows such a failure.

Figure 18.4 The soils beneath this asphaltic concrete pavement in New York became wet and soft during the spring thaws. As a result, these soils failed under the weight of the heavy trucks that use this site. The pavement is now in very poor condition, with extensive alligator cracks and potholes.

Preventive Design Measures:

- Excavating the upper soils and replacing them with non-frost-susceptible soils.
- Providing gradual transition sections between frost-susceptible and non-frost-susceptible subgrade soils.
- Restricting heavy traffic during the spring thaw.

- Installing thermal insulation between the pavement and the underlying soils (this method reduces the depth of frost penetration, but can enhance the formation of ice on the pavement surface, creating dangerous driving conditions).
- Increasing the thickness of aggregate base courses to spread out the wheel loads and provide greater overburden pressure on the subgrade soil.
- Treating the subgrade soils with cement or lime.

Unfortunately, these preventive measures are often very expensive and may not be cost effective for all pavements.

In addition, they are not always completely effective.

Thus, maintenance crews are usually busy through the summer to repairing these problems.