CHAPTER 12

Special Soil Problems

Misunderstanding soils and their properties can lead to construction errors that are costly in effort and material. The suitability of a soil for a particular use should be determined based on its engineering characteristics and not on visual inspection or apparent similarity to other soils. The considerations presented in the following paragraphs will help reduce the chances of selecting the wrong soil.

AGGREGATE BEHAVIOR

Gravel, broken stone, and crushed rock are commonly used to provide a stable layer, such as for a road base. These aggregate materials have large particles that are not separated or lubricated by moisture; thus, there is not a severe loss of strength with the addition of water. They remain stable even in the presence of rain or pending within the layer. As a result, these soils can be compacted underwater, such as in the construction of a river ford.

SOIL-AGGREGATE MIXTURES

Construction problems can arise with certain mixtures of soil and aggregate. These include dirty gravel, pit-run broken stone from talus slopes, clays used in fills, and others. If there are enough coarse particles present to retain grain-to-grain contact in a soil-aggregate mixture, the fine material between these coarse particles often has only a minor effect. Strength often remains high even in the presence of water. On the other hand, mixtures of soil and aggregate in which the coarse particles are not continuously in on tact with one another will lose strength with the addition of water as though no aggregate particles were present. High plasticity clays (PI > 15)in sand and gravel fills can expand on wetting to reduce grain-to-grain contact, so that strength is reduced and differential movement is increased. The change in texture from stable to unstable soil-aggregate mixtures can be rather subtle, often occurring between two locations in a single borrow pit. To assure a stable material, usually the mixture should contain no more than about 12 to 15 percent by weight of particles passing a Number 200 sieve; the finer fraction should ideally show low plasticity (PI < 5).

LATEITES AND LATERITIC SOILS

Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-g-rained residual soils of light texture as well as nodular gravels and cemented soils. They may vary from a loose material to a massive rock. They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the colors to the soils. For engineering purposes, the term "laterite" is confined to the coarse-grained vermicular concrete material, including massive laterite. The term "lateritic soils" refers to materials with lower concentrations of oxides.

Laterization is the removal of silicone through hydrolysis and oxidation that results in the formation of laterites and lateritic soils. The degree of laterization is estimated by the silica-sesquioxide (S-S) ratio ($SiO_2/(Fe_2O_3 + Al_2O_3)$). Soils are classed by the S-S ratios. The conclusion is—

- An S-S ratio of 1.33 = laterite.
- An S-S ratio of 1.33 to 20 = lateritic soil.
- An S-S ratio of 20 = nonlateritic, tropical soil.

Laterites

Most laterites are encountered in an already hardened state. In some areas of the world, natural laterite deposits that have not been exposed to drying are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. When the laterite is exposed to air or dried out by lowering the ground water table, irreversible hardening often occurs, producing a material suitable for use as a building or road stone.

Frequently, laterite is gravel-sized, ranging from pea-sized gravel to 3 inches minus, although larger cemented masses are possible. A specific form of laterite rock, known as plinthite, is noteworthy for its potential use as a brick. In place, plinthite is soft enough to cut with a metal tool, but it hardens irreversibly when removed from the ground and dried.

Lateritic Soils

The lateritic soils behave more like fine-grained sands, gravels, and soft rocks. The laterite typically has a porous or vesicular appearance. Some particles of laterite tend to crush easily under impact, disintegrating into a soil material that may be plastic. Lateritic soils maybe self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel.

Location

Laterites and lateritic materials occur frequently throughout the tropics and subtropics. They tend to occur on level or gently sloping terrain that is subject to very little mechanical erosion. Laterite country is usually infertile. However, lateritic soils may develop on slopes in undulating topography (from residual soils), on alluvial soils that have been uplifted.

Profiles

There are many variations of laterites and lateritic profiles, depending on factors such as the—

- Mode of soil formation.
- Cycles of weathering and erosion.
- Geologic history.
- Climate.

Engineering Classification

The usual methods of soil classification, involving grain-size distribution and Atterberg limits, should be performed on laterites or suspected laterites that are anticipated for use as fill, base-course, or surface-course materials. Consideration should be given to the previously stated fact that some particles of laterite crush easily; therefore, the results obtained depend on such factors as the—

- Treatment of the sample.
- Amount of breakdown.
- Method of preparing the minus Number 40 sieve material.

The more the soil's structure is handled and disturbed, the finer the aggregates become in grading and the higher the Atterberg limit. While recognizing the disadvantage of these tests, it is still interesting to note the large spread and range of results for both laterites and lateritic soils.

Compacted Soil Characteristics

Particularly with some laterites, breakdown of the coarser particles will occur under laboratory test conditions. This breakdown is not necessarily similar to that occurring under conditions of field rolling; therefore, the prediction of density, shear, and CBR characteristics for remolded laboratory specimens is not reliable. Strength under field conditions tends to be much higher than is indicated by the laboratory tests, provided the material is not given excessive rolling. Field tests would be justified for supplying data necessary for pavement design. The laboratory CBR results for laterite show higher values after soaking than initially found after compaction, indicating a tendency for recementation. For lateritic soils, the presence of cementation in the grain structure also gives the same effect. In addition, the field strengths may be higher than those in the laboratory, although in a much less pronounced fashion. If the soil is handled with a minimum of disturbance and remolding, laboratory tests do furnish a usable basis for design; however, lesser disturbance and higher strengths may be achieved under field conditions.

Pavement Construction

The laterized soils work well in pavement construction in the uses described in the following paragraphs, particularly when their special characteristics are carefully recognized. While the AASHTO and the Corps of Engineers classification systems and specifications are the basis for laterite material specification, experience by highway agencies in countries where laterites are found indicates that excellent performance from lateritic soils can be achieved by modifying the temperate zone specifications. The modified specifications are less exacting than either the AASHTO or the Corps of Engineers specifications, but they have proven satisfactory under tropical conditions.

Subgrade. The laterites, because of their structural strength, can be very suitable subgrades. Care should be taken to provide drainage and also to avoid particle breakdown from overcompaction. Subsurface investigation should be made with holes at relatively close spacing, since the deposits tend to be erratic in location and thickness. In the case of the lateritic soils, subgrade compaction is important because the leaching action associated with their formation tends to leave behind a loose structure. Drainage characteristics, however, are reduced when these soils are disturbed.

Base Course. The harder types of laterite should make good base courses, Some are even suitable for good quality airfield pavements. The softer laterites and the better lateritic soils should serve adequately for subbase layers. Although laterites are resistant to the effects of moisture, there is a need for good drainage to prevent softening and breakdown of the structure under repeated loadings. Base-course specifications for lateritic soils are based on the following soil use classifications:

- Class I (CBR 100).
- Class II (CBR 70 to 100).
- Class III (CBR 50 to 70).

Gradation requirements for laterite and laterite gravel soils used for base courses and subbases are listed in *Table 12-1.* Atterberg limits and other test criteria for laterite base course materials are listed in *Table 12-2, page 12-4.*

Subbase. Subbase criteria are listed in *Table 12-1, and Table 12-3, page 12-4.* These criteria are less stringent than those found in *TW 5-330,* which limits subbase soil materials

Table 12-1. Gradation requirements for laterite and laterite gravels.

Sieve	Class I	Class II	Class III	Subbase
2 inch	100	100	100	---
1½ inch	82-100	82-100	90-100	100
¾ inch	51-100	51-100	69-100	85-100
⅜ inch	30-90	30-90	47-75	70-95
3⁄16 inch or No 4	19-73	19-73	36-59	55-76
No 8	8-51	8-51	24-43	40-57
No 30	4-31	4-31	20-35	35-48
No 200	0-15	0-15	15-25	25-42

to a maximum of 15 percent fines, a LL of 25, and a PI of 5.

Surfacing. Laterite can provide a suitable low-grade wearing course when it can be compacted to give a dense, mechanically stable material; however, it tends to corrugate under road traffic and becomes dusty during dry weather. In wet weather, it scours and tends to clog the drainage system. To prevent corrugating, which is associated with loss of fines, a surface dressing maybe used. Alternatively, as a temporary expedient, regular brushing helps. The lateritic soils, being weaker than the laterites, are not suitable for a wearing course. Their use for surfacing would be restricted to—

- Emergencies.
- Use under landing mats.
- Other limited purposes.

Stabilization. The laterite and lateritic soils can be effectively stabilized to improve their properties for particular uses. However, because of the wide range in lateritic soil characteristics, no one stabilizing agent has been found successful for all lateritic materials. Laboratory studies, or preferably field tests, must be performed to determine which stabilizing agent, in what quantity, performs adequately on a particular soil. Some that have been used successfully are—

- Cement.
- Asphalt.
- Lime.
- Mechanical stabilization.

Laterite and lateritic soils can still perform satisfactorily in a low-cost, unsurfaced road, even though the percent of fines is higher than is usual in the continental United States. This is believed to be due to the cementing action of the iron oxide content. Cement and asphalt work best with material of a lower fines content. When fines are quite plastic, adding lime reduces the plasticity to produce a stable material. Field trials make it possible to determine the most suitable compaction method, which gives sufficient density without destroying the granule structure and cementation. Generally, vibratory compaction is best. Laboratory test programs for tropical conditions do not ordinarily include freeze-thaw tests but should check the influence of wetting and drying. The finer-grained lateritic soils may contain enough

Table 12-2. Criteria for laterite base course materials.

Criteria	Class I	Class II	Class III
CBR	100 min	80 min	50 min
LL	35 max	40 max	--
(LL) x (% Passing No 200)	600 max	900 max	1,250 max
PI	10 max	12 max	--
(PI) x (% Passing No 200)	200 max	400 max	600 max
Aggregate Crushing Value	< 35	35-40	40-50
Los Angeles Abrasion	< 65%	< 65%	--

Table 12-3. Criteria for laterite subbase materials.

CBR	Gradation	Maximum Values		
		PI	LL	No 200
≥ 20	See *Table 12-1, page 12-3*	25	40	40

active clay to swell and shrink, thus tending to destroy both the natural cementation and the effect of stabilization.

Slopes

The stiff natural structure of the laterites allows very steep or vertical cuts in the harder varieties, perhaps to depths of 15 to 20 feet. The softer laterites and the lateritic soils should be excavated on flatter than vertical slopes but appreciably steeper than would be indicated by the frictional characteristics of the remolded material. It is important to prevent access of water at the top of the slope.

CORAL

"Coral" is a broad term applied to a wide variety of construction materials derived from the accumulation of skeletal residues of coral like marine plants and animals. It is found in various forms depending on the degree of exposure and weathering and may vary from a hard limestone like rock to a coarse sand. Coral develops in tropical ocean waters primarily in the form of coral reefs, but many of the South Pacific islands and atolls are comprised of large coral deposits. As a general rule, living colonies of coral are bright-colored, ranging from reds through yellows. Once these organisms die, they usually become either translucent or assume various shades of white, gray, and brown.

Types

The three principal types of coral used in military construction are—

- Pit run coral.
- Coral rock.
- Coral sand.

Pit-Run Coral. Pit-run coral usually consists of fragmented coral in conjunction with sands and marine shells. At best, it classifies as a soft rock even in its most cemented form. The CBR values for this material may vary between 5 and 70. This material seldom shows any cohesive properties. In general, pit-run coral tends to be well graded, but densities above 120 pcf are seldom achieved.

Coral Rock. Coral rock is commonly found in massive formations. The white type is very hard, while the gray type tends to be soft, brittle, and extremely porous. The CBR values for this material vary from 50 to 100. Densities above 120 pcf are common except in some of the soft rock.

Coral Sand. Coral sand consists of decomposed coral rock that may be combined with washed and sorted beach sands. Generally, it classifies as a poorly graded sand and seldom will more than 20 percent of the soil particles pass a Number 200 sieve. The CBR values for this material vary between 15 and 50. Because of the lack of fines, compaction is difficult and densities above 120 pcf are uncommon.

Sources

Coral may be obtained from—

- Construction site cuts.
- Quarries.
- Wet or dry borrow pits worked in benches.

Rooters should be used to loosen the softer deposits, and the loosened material should be moved with bulldozers to power shovels for loading into trucks or other transport equipment. Rooting and panning are preferable in soft coral pits or shallow lagoons. Where coral requires little loosening, draglines and carryall scrapers can be used. Occasionally, coral from fringing reefs and lagoons can be dug by draglines or shovels, piled as a causeway, and then trucked away progressively from the seaward end. Hard coral rock in cuts or aggregate quarries requires considerable blasting. In both pit and quarry operations, hard coral "heads" are often found embedded in the softer deposits, presenting a hazard to equipment and requiring blasting.

Blasting hard coral rock differs somewhat from ordinary rock quarrying since coral formations contain innumerable fissures in varying directions and many large voids. The porosity of the coral structure itself decreases blasting efficiency. Conventional use of low-percent dynamite in tamped holes produces the most satisfactory results.

Shaped charges are ineffective, especially when used underwater; cratering charges, although effective, are uneconomical. Usually holes 8 to 12 feet deep on 4- to 8-foot centers are required to get adequate blasting efficiency.

Uses

Coral may be used as—

- Fills, subgrades, and base courses.
- Surfacing.
- Concrete aggregate.

Fills, Subgrades, and Base Courses. When properly placed, selected coral that is stripped from lagoon or beach floors or quarried from sidehills is excellent for fills, subgrades, and base courses.

Surfacing. White or nearly white coral with properly proportioned granular sizes compacted at OMC creates a concrete like surface. The wearing surface requires considerable care and heavy maintenance since coral breaks down and abrades easily under heavy traffic. Conversely, coral surfaces are extremely abrasive, and tire durability is greatly reduced.

Concrete Aggregate. Hard coral rock, when properly graded, is a good aggregate for concrete. Soft coral rock makes an inferior concrete, which is low in strength, difficult to place, and often of honeycomb structure.

Construction

Construction with coral presents some special problems, even though the uses are almost the same as for standard rock and soil materials. Since coral is derived from living organisms, its engineering characteristics are unique. Use the steps discussed in the following paragraphs to help minimize construction problems:

- Whenever coral is quarried from reefs or pits containing living coral deposits, allow the material to aerate and dry for a period of 6 days, if possible, but not less than 72 hours. Living coral organisms can remain alive in stockpiles for periods of up to 72 hours in the presence of water. If "live" coral is used in construction, the material exhibits high swell characteristics with accompanying loss of density and strength.
- Carefully control moisture content when constructing with coral. Increases of even 1 percent above OMC can cause reductions of 20 percent or more in densities achieved in certain types of coral. For best results, compaction should take place between the OMC and 2 percent below the OMC. Maintenance on coral roads is best performed when the coral is wet.
- When added to coral materials, salt water gives higher densities, with the same compactive effort, than fresh water. Use salt water in compaction whenever possible.
- Hard coral rock should not be used as a wearing surface. This rock tends to break with sharp edges when crushed and easily cuts pneumatic tires. When constructing with hard coral rock, use tracked equipment as much as possible.

DESERT SOILS

Deserts are very arid regions of the earth. Desert terrain varies widely as do the soils that compose the desert floor. The desert climate has a pronounced effect on the development of desert soils and greatly impacts on the engineering properties of these soils. Engineering methods effective for road or airfield construction in temperate or tropical regions of the world are often ineffective when applied to desert soils.

Because of wind erosion, desert soils tend to be of granular material, such as—

- Rock.
- Gravel.
- Sand.

Stabilization of the granular material is required to increase the bearing capacity of the soil. The options available for stabilizing desert soils are more limited. The primary means of stabilizing desert soils are—

- Soil blending.
- Geotextiles.
- Bituminous stabilization.

Chemical admixtures generally perform poorly under desert conditions because they cease hydration or "set up" too quickiy and therefore do not gain adequate strength.

If a source of fines is located, the fines may be blended with the in-place soil, improving the engineering characteristics of the resultant soil. However, before using the fine material for blending, perform a complete soil analysis on the material. Also, consider unusual climatic conditions that may occur during the design life of the pavement structure. During Operation Desert Storm, many roads in Saudi Arabia were stabilized with fine material known as marl. The roads performed well until seasonal rains occurred; then they failed.

Geotextiles can be used alone, such as the sand grid, or in combination with bituminous surfacing. The latter is the most effective.

Bituminous treatment is the most effective method of stabilizing desert soils for temporary road and airfield use.

ARCTIC AND SUBARCTIC SOILS

Construction in arctic and subarctic soils in permafrost areas is more difficult than in temperate regions. The impervious nature of the underlying permafrost produces poor soil drainage conditions. Cuts cause changes to the subsurface thermal regime. Stability and drainage problems result when cuts are made. If the soil contains visible ice, or if when a sample of the frozen soil is thawed it becomes unstable, it is termed thaw-unstable. Cuts into these types of frozen soils should be avoided; however, if this is not possible, substantial and frequent maintenance will undoubtedly be required. Cuts can generally be made into dry frozen (for example, thaw-stable) soils without major problems. Thaw-stable soils are generally sandy or gravelly materials.

Road and runway design over frost-susceptible soils must consider both frost effects and permafrost conditions. Adjustments to the flexible pavement design maybe required to counter the effects of frost and permafrost.

Depths of freeze and thaw are usually significantly altered by construction. *Figure 12-1, page 12-8,* illustrates the effect of clearing and stripping on the depth to permafrost after 5 years. The total depth of thaw is strongly influenced by the surface material and its characteristics (see *Table 12-4, page 12-8).*

Increasing the depth of the nonfrost-susceptible base course material can prevent subgrade thawing. The required base thickness may be determined from *Figure 12-2, page 12-9.* The thawing index is determined locally by calculating the degree days of thawing that take place. Thawing degree days data is usually available from local weather stations or highway departments. If thawing degree days data is unavailable, they can be estimated from information contained in *Figures 12-3 through 12-5, pages 12-10 through 12-12.*

Surface-Thawing Index

The surface-thawing index may be computed by multiplying the thawing index based on air temperature by a correction factor for the type of surface. For bituminous surfaces, multiply by a factor of 1.65; for concrete, multiply by a factor of 1.5.

For example, design a road over a permafrost region to preclude thawing of the permafrost. The mean air thawing index is 1,500 degree days (Fahrenheit). Base course material moisture content is 7 percent. Bituminous surface is to be used.

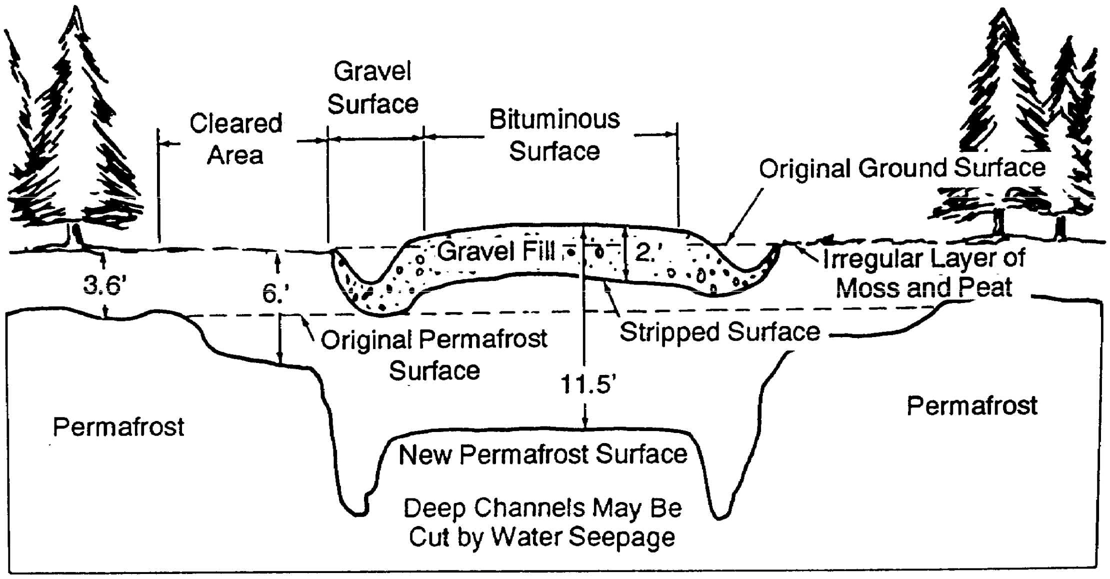


Figure 12-1. Maximum depth to permafrost below a road after 5 years in a subarctic region.

Table 12-4. Measured depth of thaw below various surfaces in the subarctic after 5 years. (Fairbanks, Alaska, mean annual temperature 26 degrees Fahrenheit).

Type of Surface	Color of Surface	Thickness of Pavement (ft)	Nature of Base Course	Thickness of Base Course (ft)	Approximate Elevation of Water Table	Observed Total Depth of Thaw (ft)	Depth of Thaw into Silt Subgrade (ft)
Gravel	Natural		Sand and gravel	4.0	Bottom of base course	8.0 – 10.5	4.0 – 6.5
Concrete	Natural	0.5	Sand and gravel	4.0	Bottom of base course	8.5 – 9.5	4.0 – 5.0
Concrete	Natural	0.5	Sand	4.0	Bottom of base course	8.5 – 9.5	4.0 – 5.0
Asphalt	Black	0.4	Sand and gravel	4.0	Bottom of base course	8.5 – 10.0	4.0 – 5.5
Trees, brush, grass, and moss	Natural vegetation				Surface	3.0 – 4.0	3.0 – 4.0
Grass and moss	Natural minus trees and brush				Surface	5.0 – 6.0	5.0 – 6.0
Grass without moss	Natural grass				Surface	8.0 – 9.0	8.0 – 9.0

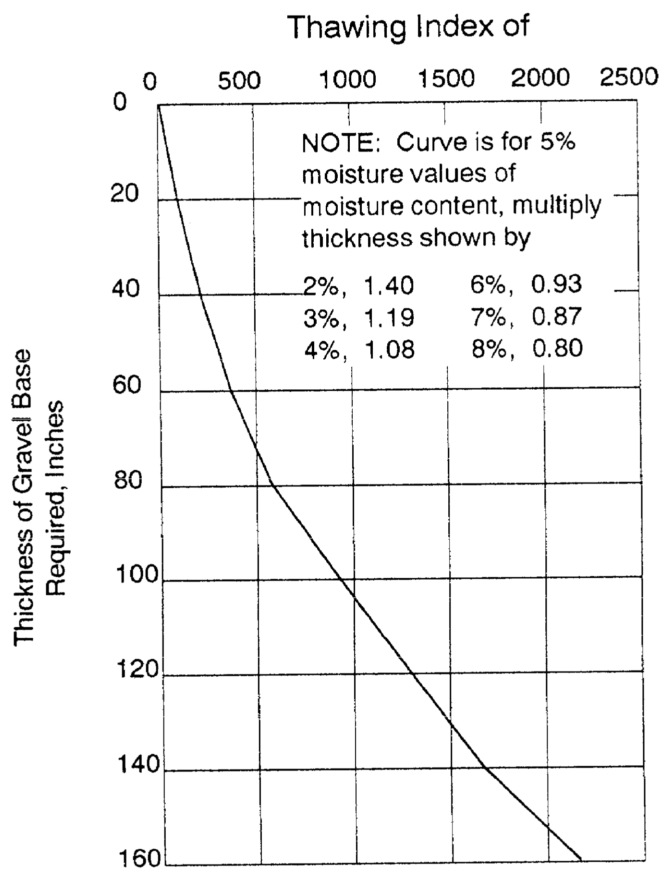


Figure 12-2. Thickness of base required to prevent thawing of subgrade.

1,200 degree days (Fahrenheit) x 1.6 = 1,920 surface-thawing index (air-thawing index) x bituminous correction factor)

What is the thickness of the base course material required to prevent thawing of the permafrost? (See *Figure 12-2).*

150 inches of the base at 5 percent moisture; adjust for moisture difference

150 x 0,87 = 130.5 inches

Therefore, for this example, permafrost thawing can be prevented by constructing a 130.5-inch base-course layer.

If the subgrade is thaw-stable, a soil that does not exhibit loss of strength or settlement when thawed may accept some subgrade thawing because little settlement is expected. If the subgrade is thaw-unstable, a granular embankment 4 to 5 feet thick is generally adequate to carry all but the heaviest traffic. Considerable and frequent regrading is required to maintain a relatively smooth surface. Embankments only 2 to 3 feet thick have been used over geotextile layers that prevent the underlying fine-grained subgrade from contaminating the granular fill. Additional fill may be necessary as thawing and settlement progress. It is usually desirable to leave the surface organic layer intact. If small trees and brush cover the site, they should be cut and placed beneath the embankment. They serve as a barrier to prevent mixing of the subgrade with the embankment material. *Figure 12-6, page 12-13, and Figure 12-7, page 12-14,* assist the flexible pavement designer in determining the depth of thaw and freeze, respectively,

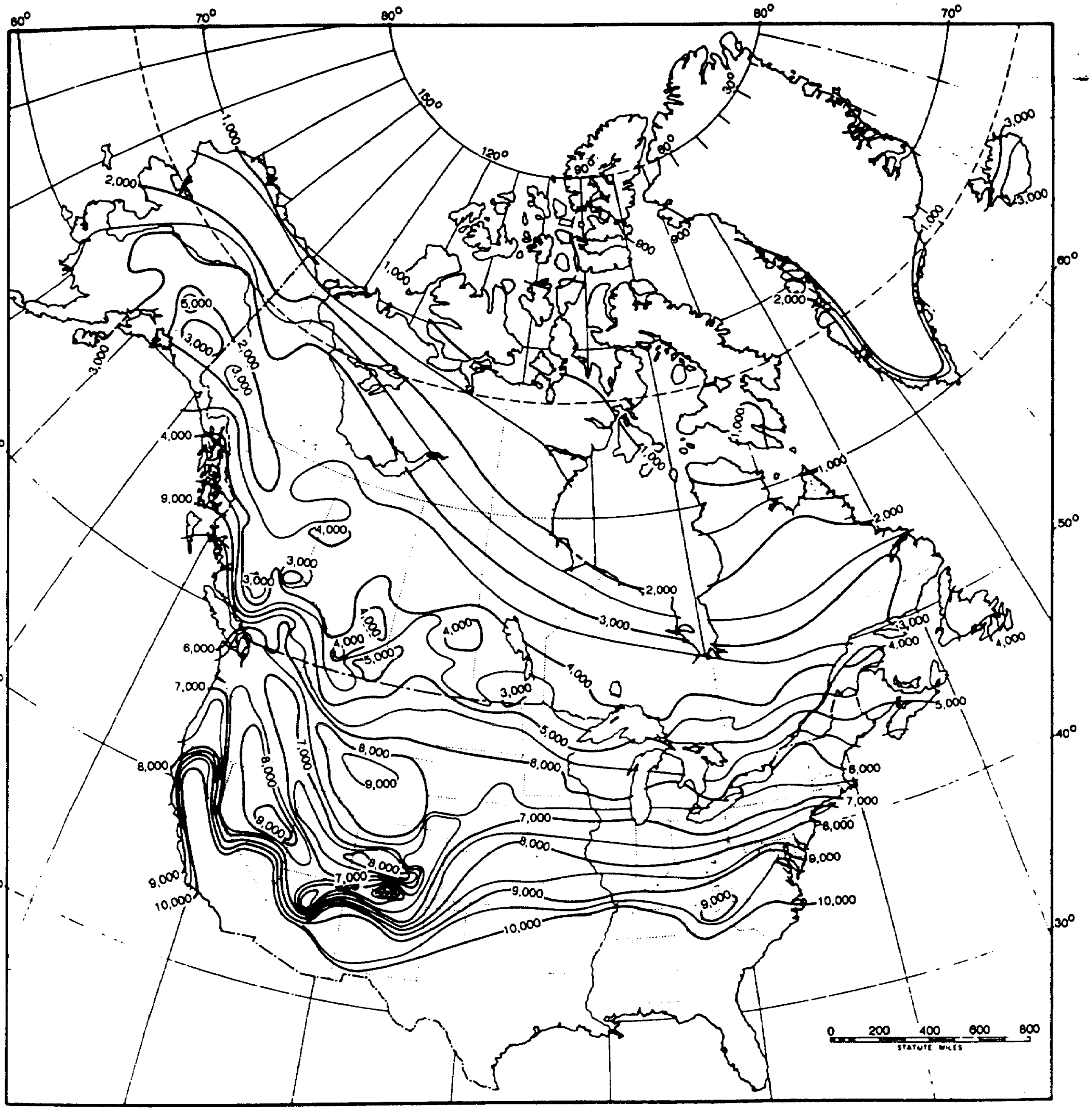


Figure 12-3. Distribution of mean air thawing indexes (0)—North America.

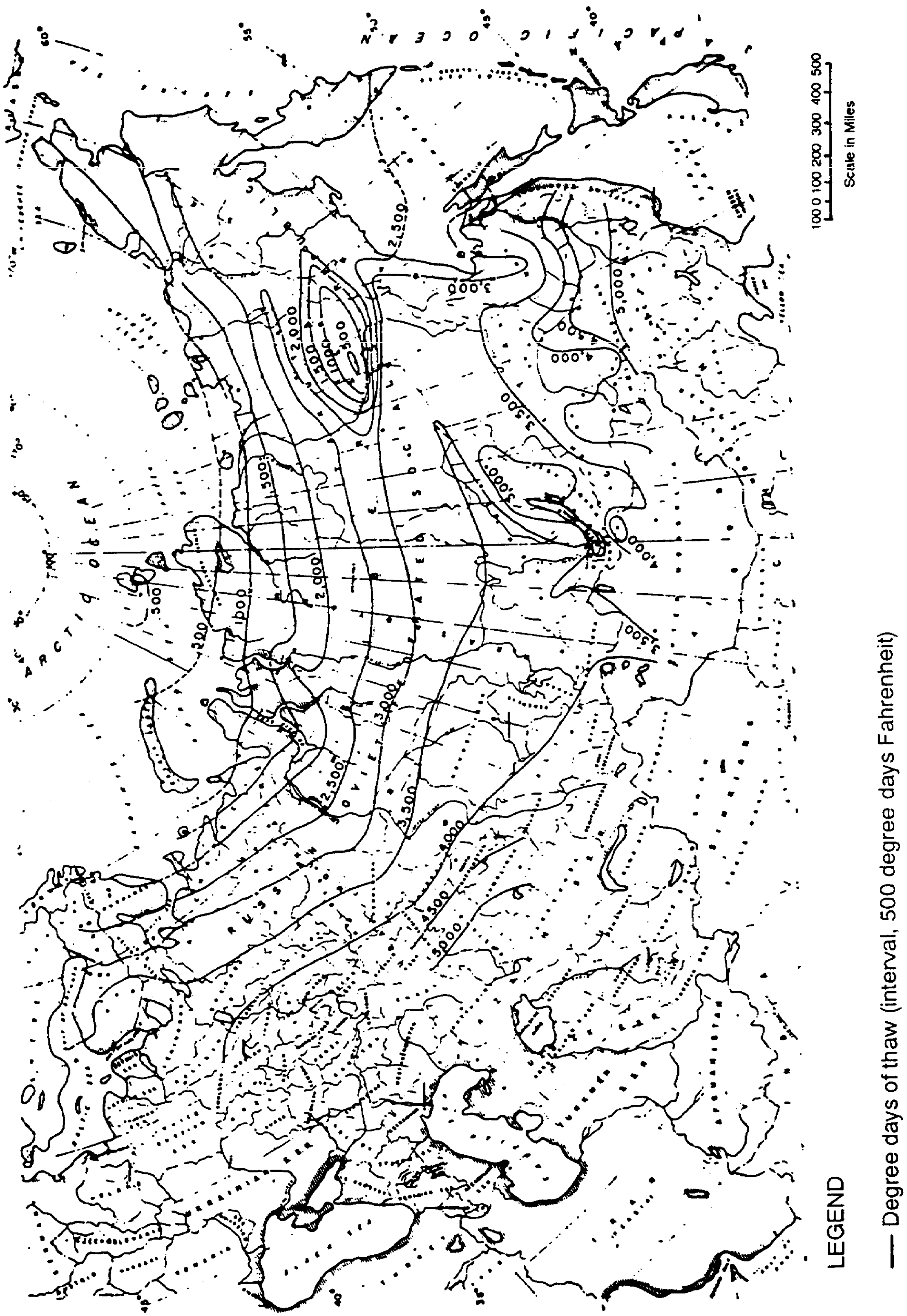


Figure 12-4. Distribution of mean air thawing indexes (θ)—Northern Eurasia.

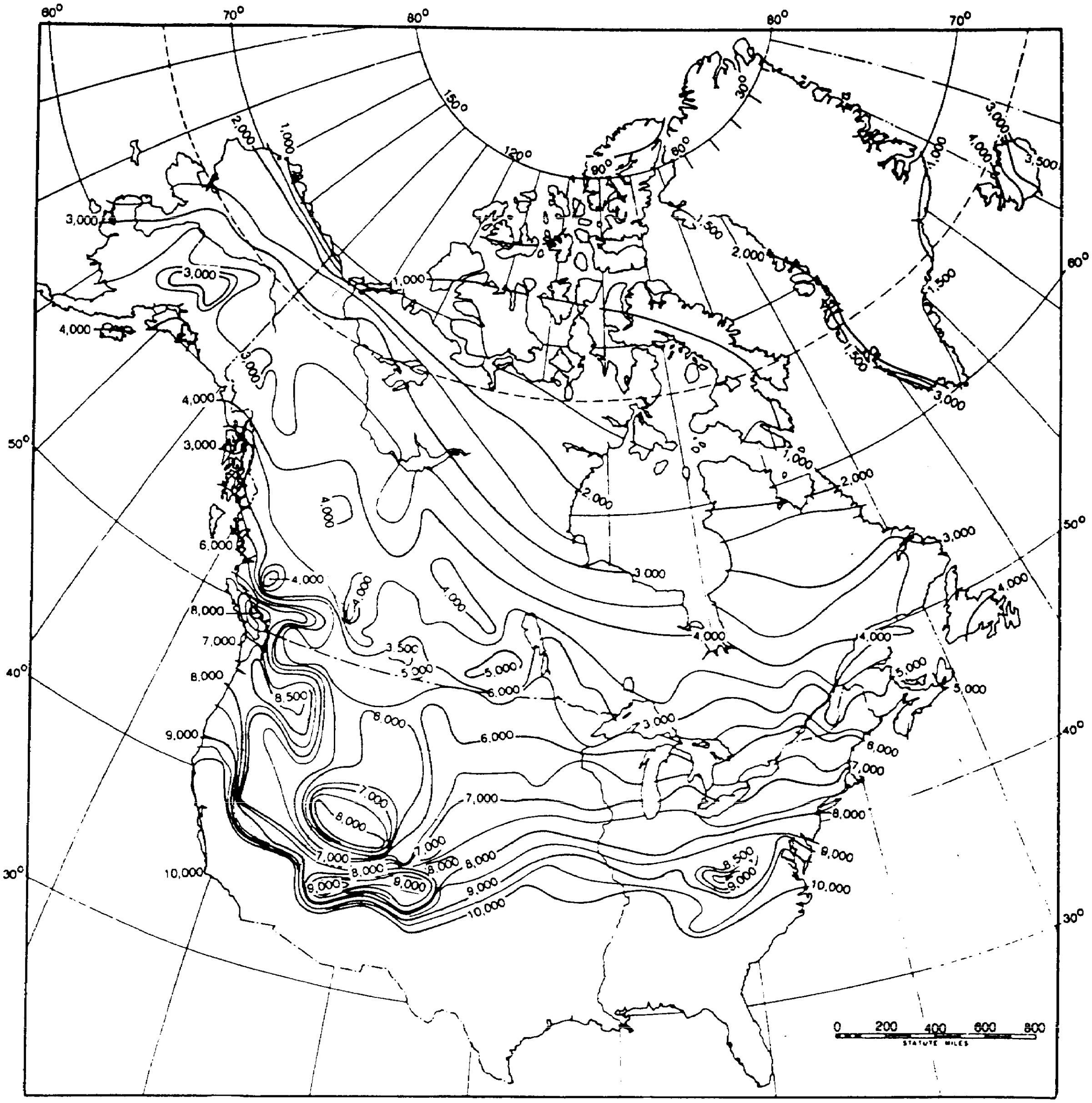


Figure 12-5. Distribution of mean air thawing index values for pavements in North America (0).

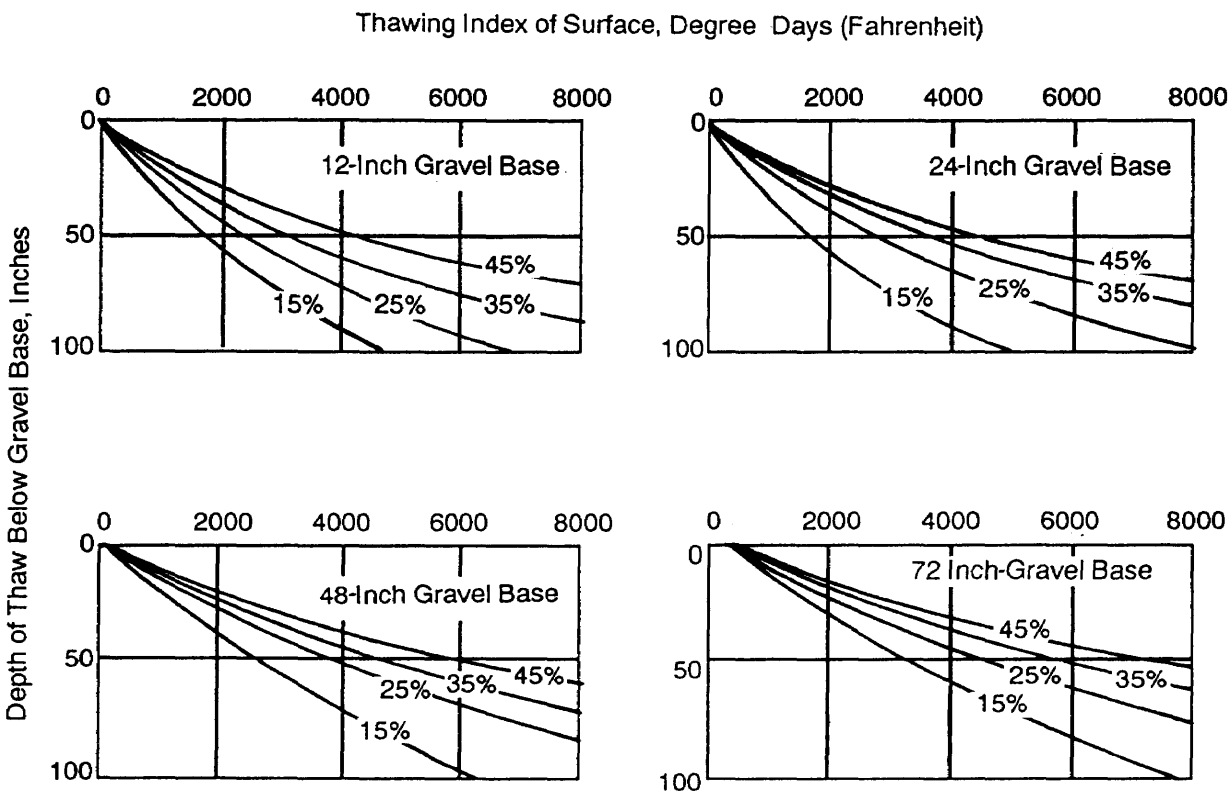
beneath pavements with gravel bases. The curves are based on the moisture content of the subgrade soil.

Ecological Impact of Construction

The arctic and subarctic ecosystems are fragile; therefore, considerable thought must be given to the impact that construction activities will have on them, *Figure12-8, page 12-15,* shows the long-term (26 years) ecological impacts of construction activities in Fairbanks, Alaska. Stripping, compacting, or otherwise changing the existing ground cover alters the thermal balance of the soil.

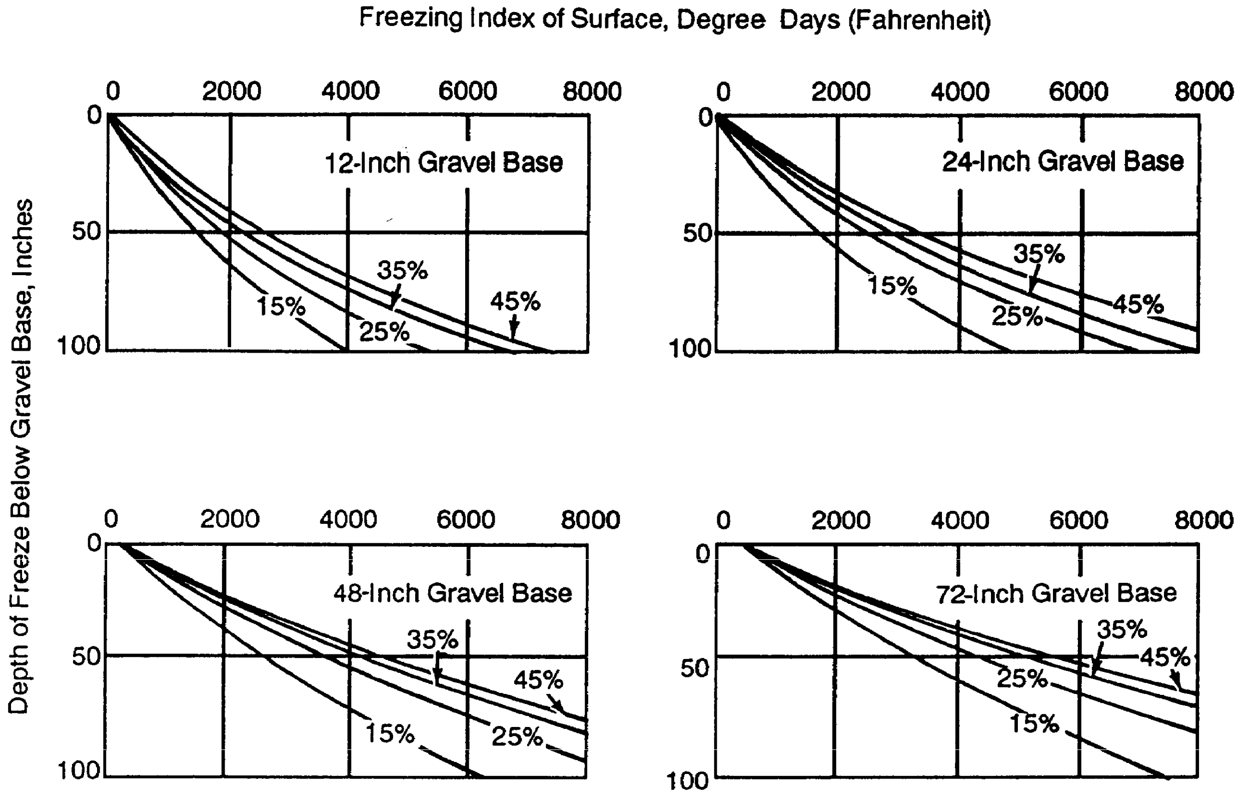
Unlike temperate ecosystems that can recover from most construction activities in a relatively short period of time, the arctic and subarctic ecosystems do not recover quickly. In fact, once disturbed, the arctic and subarctic ecosystems can continue to undergo degradation for decades following the disturbance.

The project engineer must consider these long-term environmental impacts, from the perspective of a steward of the environment, and the effects such environmental degradation may have on the structure's useful life.



NOTE: The values on the curves are the moisture content of frost-suseptible subgrade pavement surface, either bituminous or concrete. The depths are from the top of the subgrade.

Figure 12-6. Determining the depth of thaw beneath pavements with gravel bases.



NOTE: The values on the curves are the moisture content of frost-suseptible subgrade pavement surface, either bituminous or concrete. The depths are from the top of the subgrade.

Figure 12-7. Determining the depth of freeze beneath pavements with gravel bases.

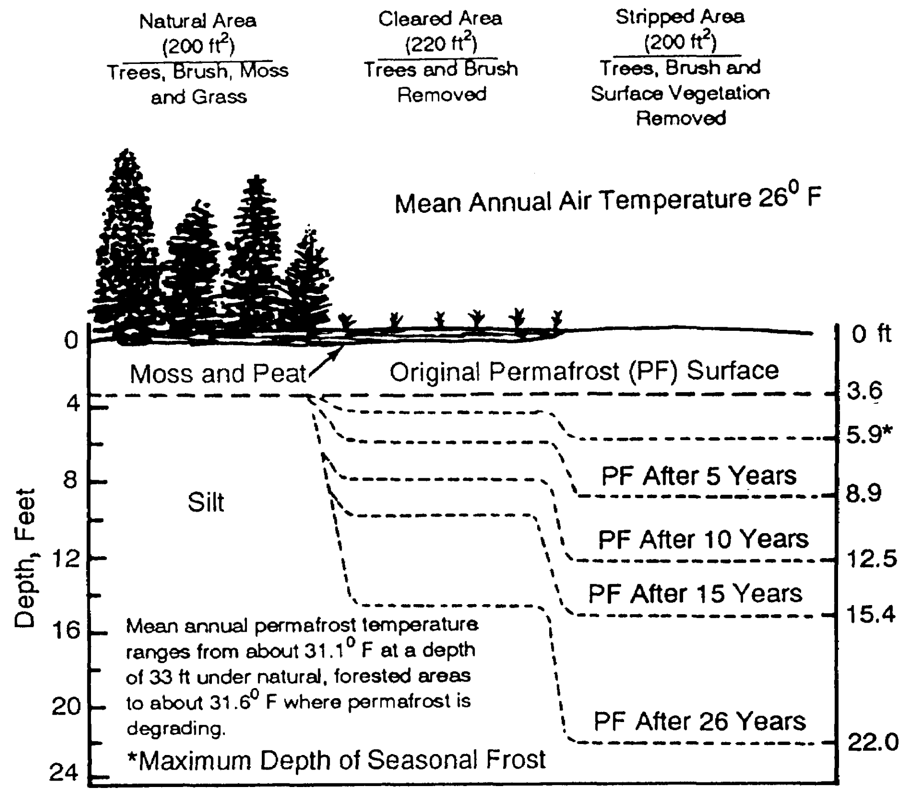


Figure 12-8. Permafrost degradation under different surface treatments.