5.4.2 Insulation

In locations where there is insufficient gravel or where it is impractical to provide a fill thick enough to protect the permafrost, manufactured insulation may be used. Any material that maintains its integrity and insulating character when wet is useful. However, the most commonly used material is high-density expanded polystyrene that is extruded in boards 0.61 m × 2.44 m (2 ft by 8 ft) in area and thicknesses from 25 mm to 100 mm (1 to 4 in.). High-density polystyrene has a compressive strength of about 415 kPa (60 psi) at a density of 6.4 kg/m^3 (4 lb/ft^3). The thermal properties are to be found in Chapter 4.

Enough insulation is provided to insure that thaw does not reach thaw-sensitive material. The modified Berggren equations and procedures given in Chapter 4 are appropriate for making the necessary calculations. In most circumstances the best results are obtained when the layer of insulation is placed as high as possible in the embankment.

Since the insulation is a relatively weak material, it must be placed at a depth that will prevent it being crushed by the applied wheel loads. A satisfactory rule is to limit the vertical stress from the combined dead and live loads to not more than one-third of the compressive strength of the insulating material. This will usually result in 450 to 750 mm (18 to 30 in.) of gravel over the insulation. The stress due to the wheel load can be calculated by the methods described in section 5.1.2.

McDougall (1977) proposed that the depth of good gravel cover over a layer of insulation can be estimated by means of an adaptation of the Boussinesq equation and the assumption that the contact pressure under a vehicle tire load can be approximated by the inflation pressure. His equation is

$$Z = \left[\frac{W/\pi p}{(1 - \sigma_a/p)^{-2/3} - 1}\right]^{1/2} \tag{5.3}$$

where Z = depth of cover; W = wheel load; p = tire inflation pressure; and σ_a = allowable compression stress in the insulation.

When the fill has reached the height for the insulation, the boards are laid on the compacted and shaped fill surface in two or more layers with successive layers arranged to stagger the joints. To keep the fill beneath the insulation layer as dry as possible, a slight crown is built in and the insulation is covered with an impermeable membrane. Construction is completed by end dumping of gravel on top of the insulation. This must be done carefully to avoid displacing or damaging the insulation. The first lift should be about 300 to 400 mm (12 to 15 in.) thick to prevent the construction equipment from damaging the insulation boards. The final grade should be slightly higher than the requirement in order to allow for loss due to future grader maintenance. A representative example of an insulated airfield cross-section is shown on Figure 5.15.

Peat Insulation. Peat is the partially decomposed residue of mosses and grasses. It is abundant in muskegs and bogs and is a component surface material in much of the Arctic terrain. The thermal conductivity of peat is much greater when frozen than when it is thawed. This characteristic of a peat ground cover allows heat to leave the ground comparatively easily in winter, but to reenter less readily during summer. The net result is that under a peat cover, the active layer is relatively small (Esch 1988). This property, coupled with low cost and desirable environmental characteristics, make peat and similar organic residues attractive for stabilizing and revegetating sideslopes at construction sites in permafrost terrain.

5.4.3 Reduced Subgrade Strength

For some instances of pavements over permafrost, especially warm and discontinuous permafrost, it is necessary to design on the basis of reduced subgrade strength in the active layer. The limited subgrade thaw penetration method is not practical in areas of warm or discontinuous permafrost because the thickness requirements are excessive.

The thickness of the pavement and non-frost-susceptible base are determined using thawed soil support index values in the same manner as described earlier for seasonal frost (section 5.3.3). However, since the design thicknesses do not prevent either seasonal frost heave or thaw degradation, it is necessary to anticipate large differential movements due to these seasonal changes. It is important to

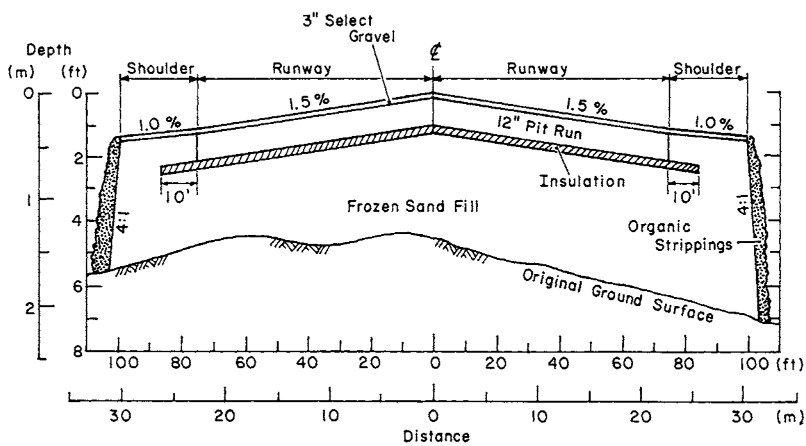

FIG. 5.15 Cross Section of an Insulated Gravel Airfield at Inigok, AK. (from Crory 1991)

learn as much as possible about the amount, type, and distribution of ice in that depth of the frozen subgrade that will thaw as a result of the construction and will probably refreeze seasonally. It is this section of the subgrade that is potentially the source of the largest distortions and the magnitudes can only be estimated.

Some possible solutions include excavation of the frozen soils, or allowing the frozen layer to be exposed long enough to melt to an adequate depth and then excavating before final construction with select backfill materials. If the ground ice is not abundant and the soil is reasonably uniform, it may be satisfactory to simply construct the pavement structure and plan on resurfacing after the distortions have stabilized.

The U.S. Army Corps of Engineers recommendations state that the reduced subgrade strength method "may be used for flexible pavements on subgrade soils of groups F1, F2, and F3 and rigid pavements over group F1 and F2 soils when subgrade conditions are sufficiently uniform to assure that objectionable differential heaving or subsidence will not occur." Also the method may be used "where subgrade variations are correctable . . . by removal and replacement of pockets of more highly frost-susceptible or high-ice-content soils." The method may also be used "for design of minor or slow-speed flexible pavements over all subgrades when appreciable nonuniform heave or subsidence can be tolerated." The reduction in strength method of design should be avoided, if at all possible, for rigid pavements over F3 and particularly over F4 soils. "Thickness requirements for the reduced subgrade strength method of design . . . provide adequate carrying capacity during the period of weakening but may result in objectionable surface roughness and cracking due to heaving or subsidence."

5.4.4 Unsurfaced Roads and Airfields

In the cold regions, especially on permafrost, maintenance costs of paved roads and airfields are quite high. Traffic frequency and quality demands usually are not sufficient to warrant the expenditure. Unsurfaced roads and airfields are the cheapest means of providing a durable, high-volume road. These facilities are unsurfaced in the sense that they do not have an uppermost layer of asphalt or portland cement. The final surface layer is of select unbound gravel or crushed rock (Oglesby and Hicks 1982, Crory 1991) often referred to as an aggregate surface. Unsurfaced roads do not require as much precision in design and construction as paved systems. The embankment is built with the idea that, as the roadway and subgrade deform from the effects of the annual freeze-thaw cycle, the distortions can be smoothed and repaired where needed. After some years of service most problems will have been attended to and, if traffic warrants, the surface can be paved.

Unsurfaced roads require almost continuous maintenance. A compacted gravel or crushed rock surface layer must possess very special characteristics. The ideal surface would shed water during a rain, maintain some moisture during dry periods to alleviate dust and to bind the particles together, and be strong enough to resist being displaced by traffic. While the ideal can never be achieved, the specifications in AASHTO M147 provide good guidance for material selection (Table 5.4).

Generally, the materials are well-graded with some fines to provide some cohesive strength. For use in cold regions, the material should tend toward smaller amounts of fines and should avoid any portion finer than 0.02 mm.

Problems encountered with aggregate surfaces are these. At locations where vehicles must apply extra torque to climb a grade or to brake, the surface material tends to develop shallow waves as a result of the shear forces. These will propagate with continued traffic to form a "washboard" or "corrugated" surface. If water is allowed to stand on the surface, the passing traffic will quickly splash it away along with the fines in the layer. If not refilled and smoothed, a pothole will soon appear. In dry weather, dust is inevitable and it can be alleviated only by continuous effort. Chemical surface treatments can be used, but they have very limited cost effectiveness. A problem unique to the permafrost regions is longitudinal cracking and sideslope failures. This will be described in section 5.8.

An unsurfaced road or airfield is designed to have a sufficient thickness of non-frost-susceptible or group F1 or F2 soil to limit the depth of thaw to an acceptable level. Fill depths of about 1.5 to 2.0 m (5 to 7 ft) are about the maximum feasible. In very cold locations, this is sufficient to limit the thaw penetration to the base of the gravel fill. Where cold is less severe, thaw may be permitted to progress to the original permafrost. In this case the design must be based on a

TABLE 5.4 Recommended Gradation of Soil Aggregates for Surface Courses (AASHTO M147)

	Percent Passing U.S. Standard Sieve			
Sieve size (1)	Gradation C (2)	Gradation D (3)	Gradation E (4)	Gradation F (5)
50 mm (1 in.)	100	100	100	100
25 mm (3/8 in.)	50–85	60–100	—	—
9.5 mm (#4)	35–65	50–85	55–100	70–100
2.00 mm (#10)	25–50	40–70	40–100	55–100
0.43 mm (#40)	15–30	25–45	20–50	30–70
0.075 mm (#200)	5–15	5–20	6–20	8–25

reduced subgrade strength. With no pavement, there need be less concern for non-uniformity in the subgrade but any obvious discontinuities should be removed and replaced with more uniform materials. In all cases there should be planning for regular inspection and maintenance. Whenever a section shows a pattern of frequent distress there should be consideration of reconstruction of that portion.

5.4.5 Drainage

In permafrost regions it is particularly important that surface runoff be controlled effectively. Water flowing over or standing on permafrost will accelerate melting of the ice and cause progressive degradation. Every effort must be made to avoid the flow of water along the toe of an embankment. Open ditches with adequate gradients are the most effective means of moving water but over ice-rich permafrost they should be used only if absolutely necessary. Then, they should be located well away from the embankment. Ditches cut into ice-rich permafrost are certain to cause continued melting and subsidence. Subsurface drains usually are not practical in very cold climates. They freeze up easily and remain frozen during the melt season when the need is the greatest.

At some point the drain water must cross a road. It is best to use natural drainage paths when ever possible. The volume of flowing water at any point along the roadway can be minimized by using frequent small culverts rather than accumulating large flows and using large openings. Culverts are chosen to be 2 to 3 times the size that would be used in a temperate climate to allow for inaccuracies in estimating the runoff and to account for the probability of ice and snow accumulations reducing the effective size (Lobacz and Eff 1981). Culverts frequently become blocked by ice, snow, or sediment. They require constant maintenance and should be used only when absolutely necessary.

Icings are a major problem in cold regions. They occur when ground water reaches the surface at times when the air temperature remains below freezing for periods of days and weeks. The water continues to seep out and freeze to accumulate a thick layer of ice on the surface. The presence of a cut or a frozen embankment is often the cause of the ground water exiting to the surface. This creates an icing along the toe of the embankment where it is least desired.

To some extent the location of an icing can be controlled. Earth dikes and snow banks can be used to divert the accumulation from a critical area. Some of the causes and remedies for icing occurrences are discussed in Chapter 8.

5.5 BASE COURSE COMPOSITION

A base course is an important and integral part of any road or airfield. All agencies' design procedures include specifications that cover such things as gradation limits, compaction requirements, durability, etc. In cold regions the requirement of frost resistance must be added. A base that is free-draining is desirable in most climatic zones but it is a requisite in cold regions. Water plays such an important part in frost heave that every effort must be made to keep it from accumulating under a paved surface. Therefore, the design of pavements against frost effects must include consideration of drainage layers as well as degree of frost-susceptibility.

Base courses usually are composed of granular unbound materials. Recently there has been an increasing use of materials bound by some type of cementing agent. Bound bases can be very effective load-carrying layers if properly designed and located but they are a special topic that cannot be considered in this introduction. The discussion that follows will be about unbound bases made of crushed rock or natural soil materials.

The portion of the base immediately below the paving, whether flexible or rigid, should be a layer of free-draining material at least 100 mm (4 in.) thick. The purpose is to allow water to drain from the section without penetrating into the lower layers. To be free draining the material should have no more than 2.0% of the grains finer than 0.075 mm (passing the #200 sieve). It must also meet other requirements for base courses such as gradation and strength. A screened and washed gravel is the best type of material for this purpose.

There is a trend to seek very rapid drainage of water beyond that resulting from a free-draining base. This is especially desirable when the pavement is permeable, the ground water table tends to be high, or there are large quantities of runoff such as during spring melt of snow banks along the pavement sides. To achieve high drainage rates, coarser base gradations have been allowed. Two additional classes of drain materials, the rapid-draining base and the open-graded base have been specified (Allen 1991). The gradations of the three general classes of base are given in Table 5.5.

If the design requires more than 100 mm (4 in.) of base course, the remaining thickness does not have to be free draining but it should be non-frost-susceptible, if feasible. If cost and availability are critical, substitution of an S1 or S2 material in the lower half of the base thickness is not likely to result in serious frost heave. If some risk of frost heave is tolerable, the lower half of the base may be an F1 or F2 material. In no case should a layer in the base be of lesser quality than the layer just below it.

Experience has shown that if a base layer is too dissimilar in gradation from the material over which it is placed, the kneading effect of traffic will cause the two layers to blend together thus degrading the quality of the coarser layer. To prevent this occurrence a "filter" is needed between them. A filter can be 100 mm (4 in.) of granular material of appropriate gradation or a cloth of synthetic non-biodegradable fabric.

TABLE 5.5 Gradation Ranges for Free-Draining, Rapid-Draining, and Open-Graded Bases (U.S. Army Engineer Guide Specification)

Sieve size (1)	Percent Passing U.S. Standard Sieve		
	Free-draining (2)	Rapid-draining (3)	Open-graded (4)
37.5 mm (1 1/2 in.)	70–100	100	100
25 mm (1 in.)	45–80	70–100	100
19 mm (3/4 in.)	—	55–100	90–100
13 mm (1/2 in.)	–60	40–80	40–80
9.5 mm (3/8 in.)	—	30–65	30–50
4.8 mm (#4)	20–50	10–50	–5
2.4 mm (#8)	—	0–25	0–2
2.0 mm (#10)	16–40	—	—
1.2 mm (#16)	—	0–5	—
0.42 mm (#40)	5–25	—	—
0.15 mm (#100)	0–10	—	—
0.075 mm (#200)	0–2	—	—

Filter cloth is produced as pervious sheets of nylon, polyester, or polypropylene, and is manufactured to meet specified characteristics. Criteria for porosity and strength have been developed by using agencies. A representative set is contained in AASHTO 1986.

The most commonly used filter material is sand processed to have a proper gradation. The sand must be fine enough to prevent the finest portion of the underlying subgrade from working up into the filter. It must also be coarse enough that it does not work into the layer above. The criteria given below will provide the desired gradation.

$$D_{15}(\text{filter})/D_{15}(\text{subsoil}) < 5 \qquad (5.4)$$

$$D_{15}(\text{filter})/D_{85}(\text{subsoil}) > 5 \qquad (5.5)$$

In addition, of course, the material must be non-frost-susceptible or of groups S1 or S2. A sand that meets the gradation requirements for a fine aggregate for portland cement concrete will normally meet all these requirements.

5.6 SUBGRADE PREPARATION

5.6.1 Soil Blending

Any natural subgrade soil that is expected to become frozen must be specially prepared to achieve uniformity of soil properties. This will minimize the amount of differential frost heave that is likely to occur but will not eliminate it. Fill sections should be built up with the most frost-susceptible soils in the lower layers and the least frost-susceptible soil reserved for the uppermost layers. In cut sections, the subsoil must be excavated, blended thoroughly, and compacted.

The depth of subgrade preparation should be great enough to ensure that at least two-thirds of the anticipated frost penetration is in pavement, base or processed subgrade. For lesser quality pavements this portion may be reduced to one half. Transitions from cut to fill and from one type of soil to another should be introduced gradually over a distance of about one station.

5.6.2 Boulder Removal

Any object buried in a soil mass that is subject to freeze-thaw cycles will tend to migrate toward the surface. Stones and rock fragments larger than about 150 mm (6 in.) in diameter will be jacked upward with sufficient force to penetrate a layer of asphalt concrete or to crack a rigid pavement slab. Therefore, removal of all large stones must be part of the soil blending process for material to be used within the probable depth of freezing.

5.6.3 Drains and Culverts

Culverts, drains, and other construction details under or near a pavement will usually experience frost heave to a different degree than the basic pavement structure. They are marked discontinuities with very different thermal conductivities. The U.S. Army Corps of Engineers offers the following guidelines to minimize the disruption that may be caused by these facilities.

"Wherever possible, the placing of such facilities beneath pavements should be avoided. Where this cannot be avoided, construction of drains should be in accordance with the 'correct' method indicated in Figure 5.13, while treatment of culverts and large ducts should conform with Figure 5.16. All drains or similar features should be placed first and the base and subbase course materials carried across them without break so as to obtain maximum uniformity of pavement support. The practice of constructing the base and subbase course and then excavating back through them to lay drains, pipes, etc., is unsatisfactory as a marked discontinuity in support will result. It is almost impossible to compact material in a trench to the same degree as the surrounding base and subbase course materials. Also, the amount of fines in the excavated and backfilled material may be increased by incorporation of subgrade soil during the trench excavation or by manufacture of fines by the added handling. The poor experience record of combination drains—those intercepting both surface and subsurface water—indicates that the filter material should never be carried to the surface as illustrated in the 'incorrect'

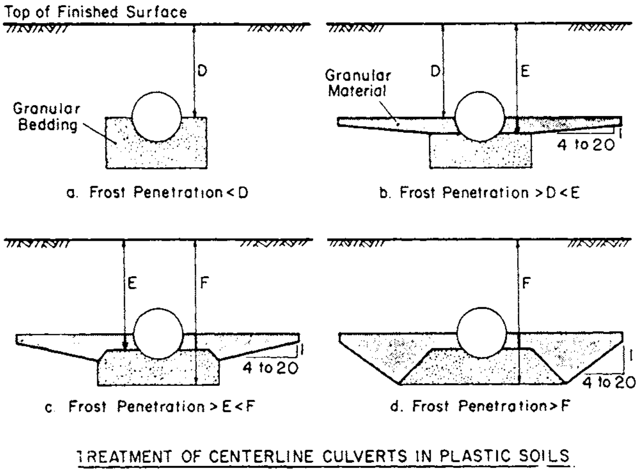

FIG. 5.16 Details for Culvert Installation under Pavements (from U.S. Army 1985)

column in Figure 5.13. Under winter conditions, this detail may allow thaw water accumulating at the edge of the pavement to feed into the base course. This detail is also undesirable because the filter is a poor surface and is subject to clogging, and the drain is located too close to the pavement to permit easy repair. Recommended practice is shown in the 'correct' column in Figure 5.13.

"Experience has shown that drain inlets, fueling hydrants, and pavement lighting systems, which have different thermal properties than the pavements in which they are inserted, are likely to be locations of abrupt differential heave. Usually, the roughness results from progressive movement of the inserted items. To prevent these damaging movements, the pavement section beneath the inserts and extending at least 1$^1/_2$ m (5 ft) radially from them should be designed to prevent freezing of frost-susceptible materials by use of an adequate thickness of non-frost-susceptible base course and by use of insulation. Consideration should also be given to anchoring footings with spread bases at appropriate depths. Gradual transitions are required to surrounding pavements that are subject to frost heave."

5.7 ASPHALT SELECTION

5.7.1 Asphalt Properties

Asphalt cements vary considerably in their properties depending on the source of the crude from which they are produced and the distillation process. Those asphalts that retain adequate ductility at low temperatures help minimize the occurrence of cracking of asphalt concrete pavements in the winter. At the same time, the asphalt must not become so soft during the summer that traffic of heavily loaded trucks and airplanes will create ruts in the pavement surface. Selection criteria based on the work of McLeod (1972), have been developed to assist in the identification of asphalts that have appropriate characteristics. The usual asphalt grade numbers based on viscosity at 135°C (275°F) are supplemented by the pen-vis number (PVN) which indicates the relative temperature sensitivity of the asphalt.

The PVN is derived from viscosity and penetration data commonly provided for all asphalts, thereby avoiding the need to conduct any special tests. The number represents the slope of the line connecting the penetration test value, which is run at 25°C (77°F) with the kinematic viscosity value, obtained at 135°C (275°F), on a log-log plot as shown in Figure 5.17. The PVN can also be approximated by the empirical equation given by Janoo (1990):

$$PVN = 11.300 + 1.629 \log (PEN) + 2.981 \log (VIS) \qquad (5.6)$$

where PEN = penetration at 25°C (77°F); and VIS = kinematic viscosity in centistokes at 135°C (275°F).

U.S. Army Corps of Engineers specifications for asphalt to be used in the sub-arctic require a PVN of not lower than −0.5 and in the severely cold parts of the arctic, not lower of −0.2. The dividing line between these two regions is considered to be the 1,670°C-day (3,000°F-day) freezing index.

5.7.2 Asphalt Selection Guide

A chart to guide in the selection of an asphalt with the desired combination of viscosity and PVN has been developed for use by the

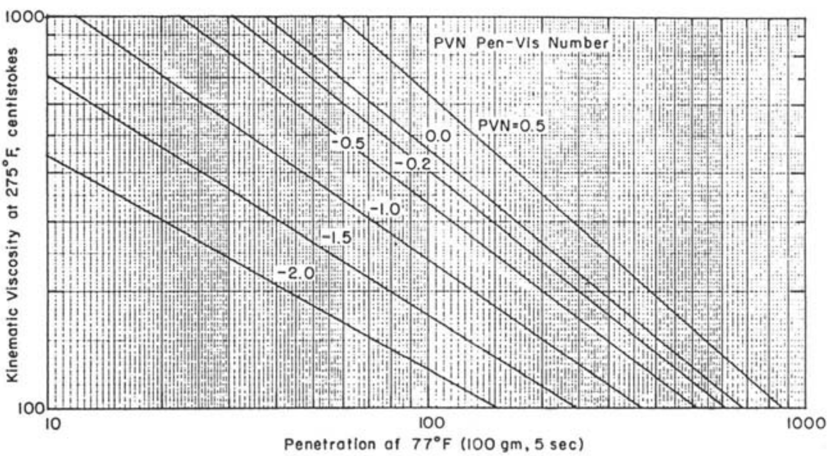

FIG. 5.17 Pen-Vis Numbers for Asphalt Cement (U.S. Army 1985)