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An Introduction to Pavement Design in Seasonal Frost Conditions

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The Figures, Tables and Symbols in this document are in some cases a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS COURSE IF THE FIGURES, TABLES AND SYMBOLS ARE NOT ACCEPTABLE TO YOU.**

1. GENERAL. This publication presents criteria and procedures for the design and construction of pavements placed on subgrade or base course materials subject to seasonal frost action. The most prevalent modes of distress in pavements and their causes are listed in table 1. The detrimental effects of frost action in subsurface materials are manifested by nonuniform heave of pavements during the winter and by loss of strength of affected soils during the ensuing thaw period. This is accompanied by a corresponding increase in damage accumulation and a more rapid rate of pavement deterioration during the period of weakening; other related detrimental effects of frost and low temperatures are possible loss of compaction, development of permanent roughness, restriction of drainage by the frozen strata, and cracking and deterioration of the pavement surface. Hazardous operating conditions, excessive maintenance, or pavement destruction may result. Except in cases where other criteria are specifically established, pavements should be designed so that there will be no interruption of traffic at any time due to differential heave or to reduction in load supporting capacity. Pavements should also he designed so that the rate of deterioration during critical periods of thaw weakening and during cold periods causing low-temperature cracking will not be so high that the useful life of the pavements will be less than that assumed as the design objective.

Distress mode	General cause	Specific causative factor
Cracking	Traffic-load associated	Repeated loading (fatigue) Slippage (resulting from braking stresses)
	Non-traffic-associated	Thermal changes Moisture changes Shrinkage of underlying materials (reflection cracking, which may also be accelerated by traffic loading)
Distortion (may also lead to cracking)	Traffic-load associated	Rutting, or pumping and faulting (from repetitive loading) Plastic flow or creep (from single or comparatively few excessive loads)
	Non-traffic-associated	Differential heave Swelling of expansive clays in subgrade Frost action in subgrades or bases Differential settlement Permanent, from long-term consolidation in subgrade Transient, from reconsolidation after heave (may be accelerated by traffic) Curling of rigid slabs, from moisture and temperature differentials
Disintegration	May be advanced stage of cracking mode of distress or may result from detrimental effects of certain materials contained within the layered system or from abrasion by traffic. May also be triggered by freeze-thaw effects.	

Table 1

Modes of distress in pavements

2. DEFINITIONS. The following frost terms are used in this publication.

2.1 FROST, SOIL, AND PAVEMENT TERMS.

2.1.1 BASE OR SUBBASE COURSE contains all granular unbound, or chemical- or bituminous-stabilized material between the pavement surfacing layer and the untreated, or chemical- or bituminous-stabilized subgrade.

2.1.2 BOUND BASE is a chemical- or bituminous-stabilized soil used in the base and subbase course, consisting of a mixture of mineral aggregates and/ or soil with one or more commercial stabilizing additives. Bound base is characterized by a significant increase in compressive strength of the stabilized soil compared with the untreated soil. In frost areas bound base usually is placed directly beneath the pavement surfacing layer where its high strength and low deformability make possible a reduction in the required thickness of the pavement surfacing layer or the total thickness of pavement and base, or both. If the stabilizing additive is portland cement, lime, or lime-cement-flyash (LCF), the term bound base is applicable only if the mixture meets the requirements for cement-stabilized, lime-stabilized, or LCF-stabilized soil set forth herein and in other technical literature.

2.1.3 BOULDER HEAVE is the progressive upward migration of a large stone present within the frost zone in a frost-susceptible subgrade or base course. This is caused by adhesion of the stone to the frozen soil surrounding it while the frozen soil is undergoing frost heave; the stone will be kept from an equal, subsequent subsidence by soil that will have tumbled into the cavity formed beneath the stone. Boulders heaved toward the surface cause extreme pavement roughness and may eventually break through the surface, necessitating repair or reconstruction.

2.1.4 CUMULATIVE DAMAGE is the process by which each application of traffic load or each cycle of climatic change produces a certain irreversible damage to the pavement. When this is added to previous damage, the pavement deteriorates continuously under successive load applications or climatic cycles.

2.1.5 FROST ACTION is a general term for freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part, or with which they are in contact.

2.1.6 FROST BOIL is the breaking of a small section of a highway or airfield pavement under traffic with ejection of soft, semi-liquid subgrade soil. This is caused by the melting of the segregated ice formed by the frost action. This type of failure is limited to pavements with extreme deficiencies of total thickness of pavement and base over frost susceptible subgrades, or pavements having a highly frost-susceptible base course.

2.1.7 FROST HEAVE is the raising of a surface due to formation of ice in the underlying soil.

2.1.8 FROST-MELTING PERIOD is an interval of the year when the ice in base, subbase, or subgrade materials is returning to a liquid state. It ends when all the ice in the ground has melted or when freezing is resumed. In some cases there may he only one frost-melting period, beginning during the general rise of air temperatures in the spring, but one or more significant frost-melting intervals often occur during a winter season.

2.1.9 FROST-SUSCEPTIBLE SOIL is soil in which significant detrimental ice segregation will occur when the requisite moisture and freezing conditions are present.

2.1.10 GRANULAR UNBOUND BASE COURSE is base course containing no agents that impart higher cohesion by cementing action. Mixtures of granular soil with portland cement, lime, or flyash, in which the chemical agents have merely altered certain properties of the soil such as plasticity and gradation without imparting significant strength increase, also are classified as granular unbound base. However, these must meet the requirements for cement-modified, lime-modified, or LCF-modifled soil set forth in this publication and other technical literature, and they must also meet the base course composition requirements set forth below.

2.1.11 ICE SEGREGATION is the growth of ice as distinct lenses, layers, veins and masses in soils, commonly but not always oriented normal to the direction of heat loss.

2.1.12 NONFROST-SUSCEPTIBLE MATERIALS are cohesionless materials such as crushed rock, gravel, sand, slag, and cinders that do not experience significant detrimental ice segregation under normal freezing conditions. Nonfrost-susceptible materials also include cemented or otherwise stabilized materials that do not evidence detrimental ice segregation, loss of strength upon thawing, or freezethaw degradation.

2.1.13 PAVEMENT PUMPING is the ejection of water and soil through joints, cracks, and along edges of pavements caused by downward movements of sections of the pavement. This is actuated by the passage of heavy axle loads over the pavement after free water has accumulated beneath it.

2.1.14 PERIOD OF WEAKENING is an interval of the year that starts at the beginning of a frost-melting period and ends when the subgrade strength has returned to normal summer values, or when the subgrade has again become frozen.

2.2 TEMPERATURE TERMS.

2.2.1 AVERAGE DAILY TEMPERATURE is the average of the maximum and minimum temperatures for a day, or the average of several temperature readings taken at equal time intervals, generally hourly, during a day.

2.2.2 MEAN DAILY TEMPERATURE is the mean of the average daily temperatures for a given day in each of several years.

2.2.3 DEGREE-DAYS are the Fahrenheit degree-days for any given day equal to the difference between the average daily air temperature and 32 degrees Fahrenheit. The degree-days are minus when the average daily temperature is below 32 degrees Fahrenheit (freezing degree-days) and plus when above (thawing degree-days). Figure 1 shows curves obtained by plotting cumulative degree-days against time.

2.2.4 FREEZING INDEX is the number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperature approximately 4.5 feet above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately temperatures are averaged is usually a minimum of below a surface is known as the surface freezing index.

2.2.5 DESIGN FREEZING INDEX is the average freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the air freezing index for the coldest winter in the latest 10-year period may be used. To avoid the necessity of adopting a new and only slightly different freezing index each year, the design freezing index at a site with continuing construction need not be changed more than once in 5 years unless the more recent temperature records indicate a significant change in thickness design requirements for frost. The design freezing index is illustrated in figure 181.

2.2.6 MEAN FREEZING INDEX is the freezing index determined on the basis of mean temperatures. The period of record over which10 years, preferably 30, and should be the latest available. The mean freezing index is illustrated in air figure 1.

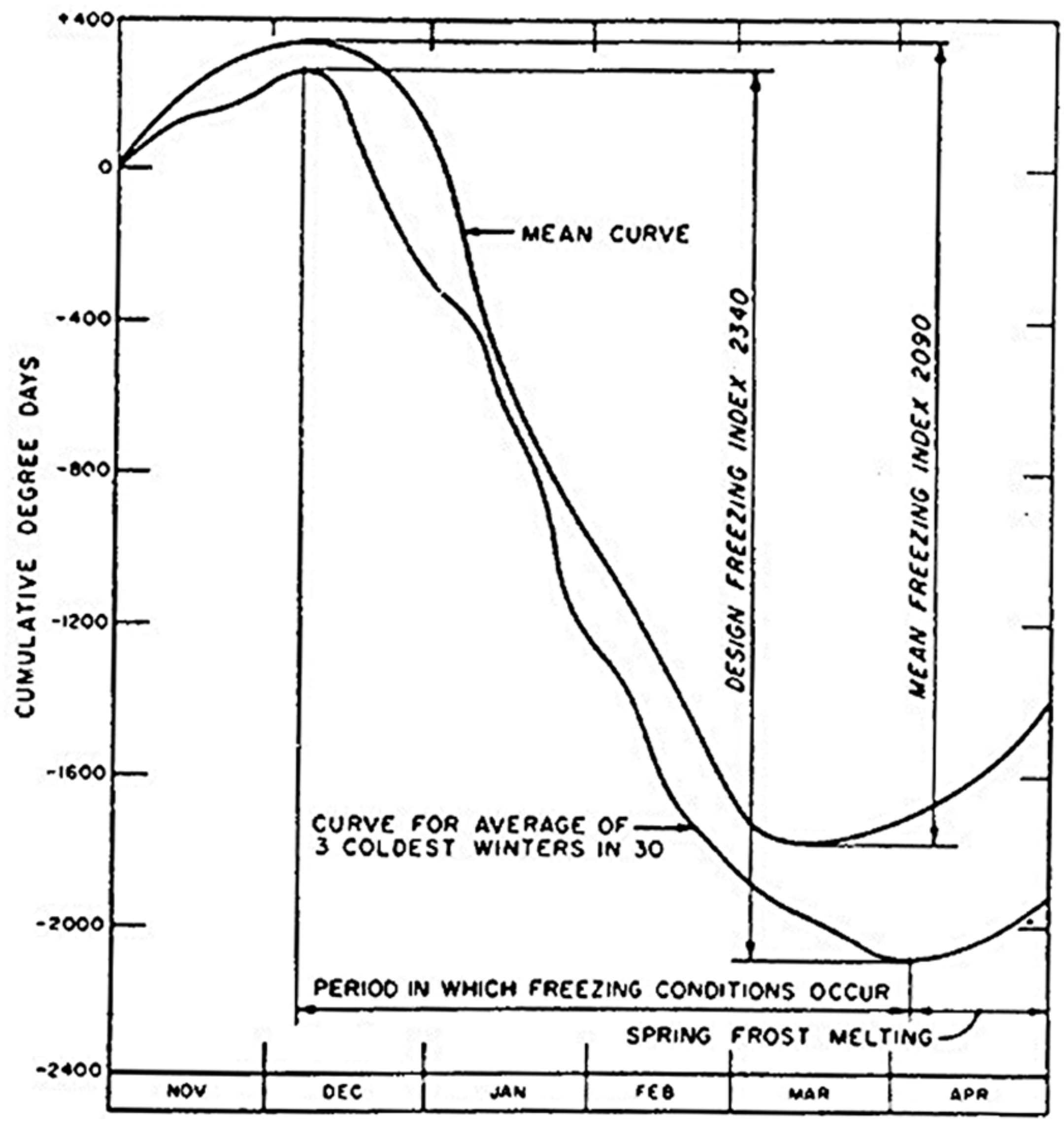

Figure 1

Determination of freezing index

3. FROST-SUSCEPTIBILITY CLASSIFICATION. For frost design purposes, soils are divided into eight groups as shown in table 2. The first four groups are generally suitable for base course and subbase course materials, and any of the eight groups may be encountered as subgrade soils. Soils are listed in approximate order of decreasing bearing capacity during periods of thaw. There is also a tendency for the order of the listing of groups to coincide with increasing order of susceptibility to frost heave, although the low coefficients of permeability of most clays restrict their heaving propensity. The order of listing of subgroups under groups F3 and F4 does not necessarily indicate the order of susceptibility to frost heave of these subgroups. There is some overlapping of frost susceptibility between groups. Soils in group F4 are of especially high frost susceptibility.

Frost group		Kind of soil	Percentage finer than 0.02 mm by weight	Typical soil types under Unified Soil Classification system
NFS*	(a)	Gravels Crushed stone Crushed rock	0-15	GW, GP
	(b)	Sands	0-3	SW, SP
PFS**	(a)	Gravels Crushed stone Crushed rock	1.5-3	GW, GP
	(b)	Sands	3-10	SW, SP
S1		Gravelly soils	3-6	GW, GP, GW-GM, GP-GM
S2		Sandy soils	3-6	SW, SP, SW-SM, SP-SM
F1		Gravelly soils	6 to 10	GM, GW-GM, GP-GM
F2	(a)	Gravelly soils	10 to 20	GM, GW-GM, GP-GM
	(b)	Sands	6 to 15	SM, SW-SM, SP-SM
F3	(a)	Gravelly soils	Over 20	GM, GC
	(b)	Sands, except very fine silty sands	Over 15	SM, SC
	(c)	Clays, PI > 12	--	CL, CH
F4	(a)	All silts	--	ML, MH
	(b)	Very fine silty sands	Over 15	SM
	(c)	Clays, PI > 12	--	CL, CL-ML
	(d)	Varved clays and other fine-grained, banded sediments	--	CL, CL-ML CL and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML and SM

*Non-frost-susceptible.
**Possibly frost-susceptible, but requires laboratory test to determine frost design soils classification.

Table 2

Frost design soil classification

3.1 S1 AND S2 GROUPS. The S1 group includes gravelly soils with very low to medium frost-susceptibility classifications that are considered suitable for subbase materials. They will generally exhibit less frost heave and higher strength after freeze-thaw cycles than similar Fl group subgrade soils. The S2 group includes sandy soils with very low to medium frost-susceptibility classifications that are considered suitable for subbase materials. Due to their lower percentages of finer-than-0.02- millimeter grains than similar F2 groups subgrade soils, they will generally exhibit less frost heave and higher strength after freeze-thaw cycles.

3.2 FL AND F2 GROUPS. The F1 group is intended to include frost-susceptible gravelly soils that in the normal unfrozen condition have traffic performance normal unfrozen condition have traffic performance characteristics of GM-, GW-GM-, and GP-GM-type materials with the noted percentage of fines. The F group is intended to include frost-susceptible soils that in the normal unfrozen condition have traffic performance characteristics of GM-, GW- GM-, GP-GM-, SM-, SW-SM-, or SP- SM-type materials with fines within the stated limits. Occasionally, GC or SC materials may occur within the F. group, although they will normally fall into the F3 category. The basis for division between the Fl and F. groups is that Fl materials may be expected to show higher hearing capacity than F. materials during thaw, even though both may have experienced equal ice segregation.

3.3 VARVED CLAYS. Varved clays consisting of alternating layers of silts and clays are likely to combine the undesirable properties of both silts and clays. These and other stratified fine-grained sediments may be hard to classify for frost design. Since such soils are likely to heave and soften more readily than homogeneous soils with equal average water thickness of pavement, base, and subbase that will contents, the classification of the material of highest frost susceptibility should be adopted for design. Usually, this will place the overall deposit in the F4 category.

3.4 SPECIAL CONDITIONS. Under special conditions the frost group classification adopted for design may be permitted to differ from that obtained by application of the above frost group definitions. This will, however, be subject to the specific approval of the design engineer.

4. ALTERNATIVE METHODS OF THICKNESS DESIGN. The thickness design process is the determination of the required thickness for each layer of a pavement system and of the combined thickness of all layers above the subgrade. Its objective is determining the lowest-cost pavement system whose rate of deterioration under traffic loads and environmental conditions will be acceptably low. In seasonal frost areas the thickness design process must include the effects of frost action. Two methods are prescribed for determining the thickness design of a pavement that will have adequate resistance to distortion by frost heave and cracking and distortion under traffic loads as affected by seasonal variation of supporting capacity, including possible severe weakening during frost-melting periods.

4.1 LIMITED SUBGRADE FROST PENETRATION METHOD. The first method is directed specifically to the control of pavement distortion caused by frost heave. It requires a sufficient thickness of pavement, base, and subbase to limit the penetration of frost into the frost-susceptible subgrade to an acceptable amount. Included also in this method is a design approach which determines the thickness of pavement, base, and subbase necessary to prevent the penetration of frost into the subgrade. Prevention of frost penetration into the subgrade is nearly always uneconomical and unnecessary, and will not be used to design pavements to serve conventional traffic, except when approved by the design engineer.

4.2 REDUCED SUBGRADE STRENGTH METHOD. The second method does not seek to limit the penetration of frost into the subgrade, but it determines the adequately carry traffic loads over the design period of years, each of which includes one or more periods during which the subgrade supporting capacity is sharply reduced by frost melting. This approach relies on uniform subgrade conditions, adequate subgrade preparation techniques, and transitions for adequate control of pavement roughness resulting from differential frost heave.

5. SELECTION OF DESIGN METHOD. In most cases the choice of the pavement design method will he made in favor of the one that gives the lower cost. Exceptions dictating the choice of the limited subgrade frost penetration method, even at higher cost, include pavements in locations where subgrade soils are so extremely variable (as, for example, in some glaciated areas) that the required subgrade preparation techniques could not be expected to provide sufficient protection against differential frost heave. In other cases special operational demands on the pavement might dictate unusually severe restrictions on tolerable pavement roughness, requiring that subgrade frost penetration be strictly limited or even prevented. If the use of limited subgrade frost penetration method is not required, tentative designs must be prepared by both methods for comparison of costs. Also, a tentative design must he prepared following the nonfrost-design criteria, since the thickness requirements under nonfrost-criteria must be met in addition to the frost design requirements.

6. LIMITED SUBGRADE FROST PENETRATION. This method of design for seasonal frost conditions should he used where it requires less thickness than the reduced subgrade strength method. Its use is likely to he economical only in regions of low design freezing index.

6.1 AIR FREEZING INDEX*.* Air freezing index values should he based on actual air temperatures obtained from the meteorological station closest to the construction site. This is desirable because differences in elevation or topographical position, or nearness to bodies of water, cities, or other sources of heat may cause considerable variation in air freezing indexes over short distances. These variations are of greater relative importance in areas of design freezing index of less than 1,000 degree Fahrenheit days (i.e. mean air freezing index of less than about 500 degree Fahrenheit days) than they are in colder climates. The daily maximum and minimum and mean monthly air temperature records for all stations that report to the U.S. National Weather Service are available from Weather Service Centers. One of these centers is generally located in each state. The mean air freezing index may based on mean monthly air temperatures, but computation of values for the design adopted that uses the average air freezing desired cycle. These years may be selected from the tabulation of average monthly temperatures for the nearest first-order weather station. (A local climatological data summary containing this tabulation for the period of record is published annually by the National Weather Service for each of the approximately 350 U.S. first-order stations.) If the temperature record of the station closest to the construction site is not long enough to determine the mean or design freezing index values, the available data should be related, for the same period, to that of the nearest station or stations of adequate record. Site air freezing index values can then be computed based on this established relation and the indexes for the more distant station or stations.

6.2 DESIGN FREEZING INDEX. The design freezing index should he used in determining the combined thickness of pavement, base, and subbase required to limit subgrade frost penetration. As with any natural climatic phenomenon, winters that are colder than average occur with a frequency that decreases as the degree of departure from average becomes greater. A mean freezing index cannot be computed where temperatures in some of the winters do not fall below freezing. A design method has been adopted that uses the average air freezing index for the three coldest years in a 30-year period (or for the coldest winter in 10 years of record) as the design freezing index to determine the thickness of protection that will he provided. A distribution of design freezing index for North America is shown in figure 2 and is to be used as a guide only.

Figure 2

Distribution of design freezing index for North America

6.3 DESIGN METHOD. The design method permits a small amount of frost penetration into frost susceptible subgrades for the design freezing index year. The procedure is described in the following subparagraphs.

6.3.1 Estimate average moisture contents in the base course and subgrade at start of freezing period, and estimate the dry unit weight of base. The moisture content of the base is generally affected by the moisture content of the subgrade, drainage, precipitation, and depth to water table. As the base course may, in some cases, comprise successive layers containing substantially different fine contents, the average moisture content and dry unit weight should he weighted in proportion to the thickness of the various layers. Alternatively, if layers of bound base course and granular unbound base course are used in the pavement, the average may be assumed to be equal to the moisture content and dry unit weight of the material in the granular unbound base course.

6.3.2 From figure 3, determine frost penetration into frost-susceptible soil penetration depth (a). These frost penetration depths are based on modified Berggren formula and computational procedures outlined elsewhere in the technical literature. Frost penetration depths are measured from pavement surface. Depths are computed on a 12- inch rigid pavement kept free of snow and ice, and are good approximations for bituminous pavements over 6 to 9 inches of high-quality base. Computations also assume that all soil beneath pavements within depths of frost penetration are granular and non-frost susceptible. It was assumed in computations that all soil moisture freezes at 32 degrees Fahrenheit. Use straight line interpolation where necessary. For rigid pavements greater than12 inches thick, deduct 10 degree-days for each inch of pavement exceeding 12 inches from the design freezing index before entering figure 18-3 to determine frost penetration depth. Then add determine frost penetration depth (a). Then add extra concrete pavement thickness to the determined frost penetration.

6.3.3 Compute thickness of unbound base C (figure 4) required for zero frost penetration into the subgrade as follows:

$$C = a - p$$

where

a = frost penetration depth

p = thickness of portland cement concrete or bituminous concrete

6.3.4 Compute ration r = (water content of subgrade)/(water conent of base)

6.3.5 Enter figure 4 with C as the absicca and, at the applicable value of r, find on the left scale the design base thickness b that will result in the allowable subgrade frost penetration s shown on the right scale. If r is greater than 3.0, use 3.0.

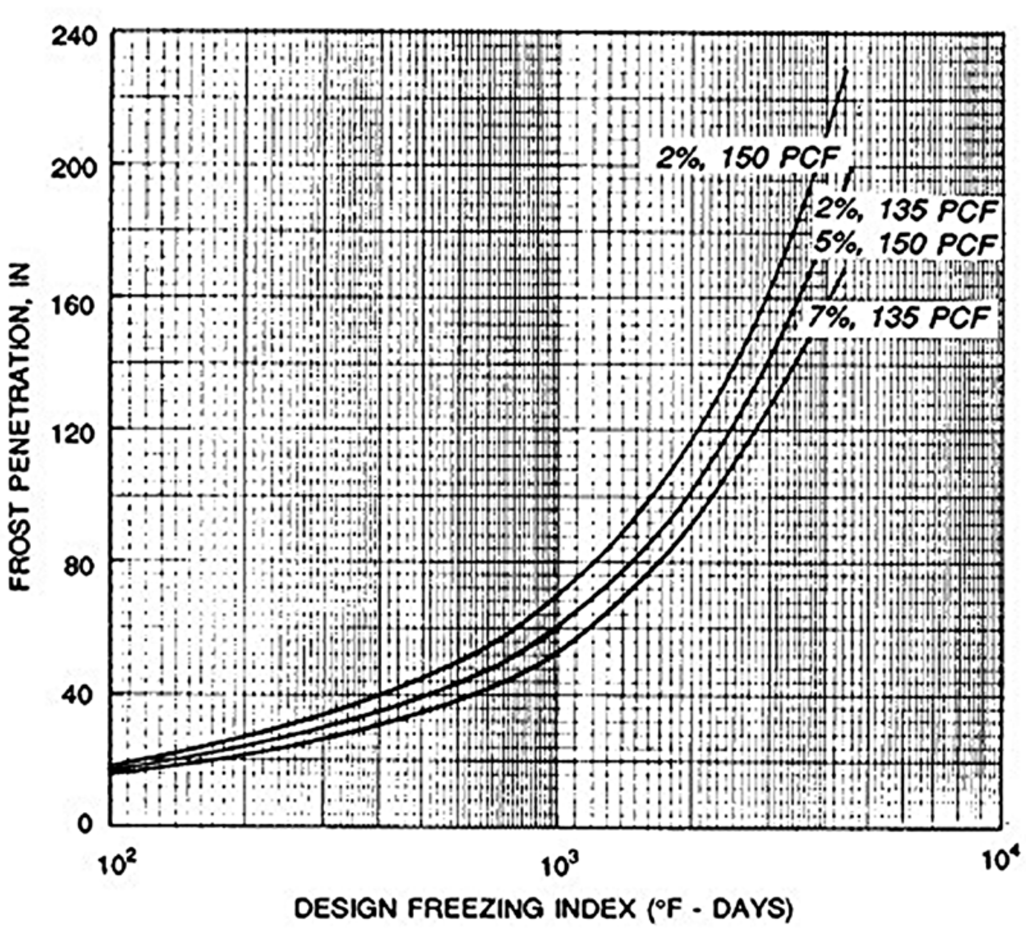

Figure 3

Frost penetration beneath pavements

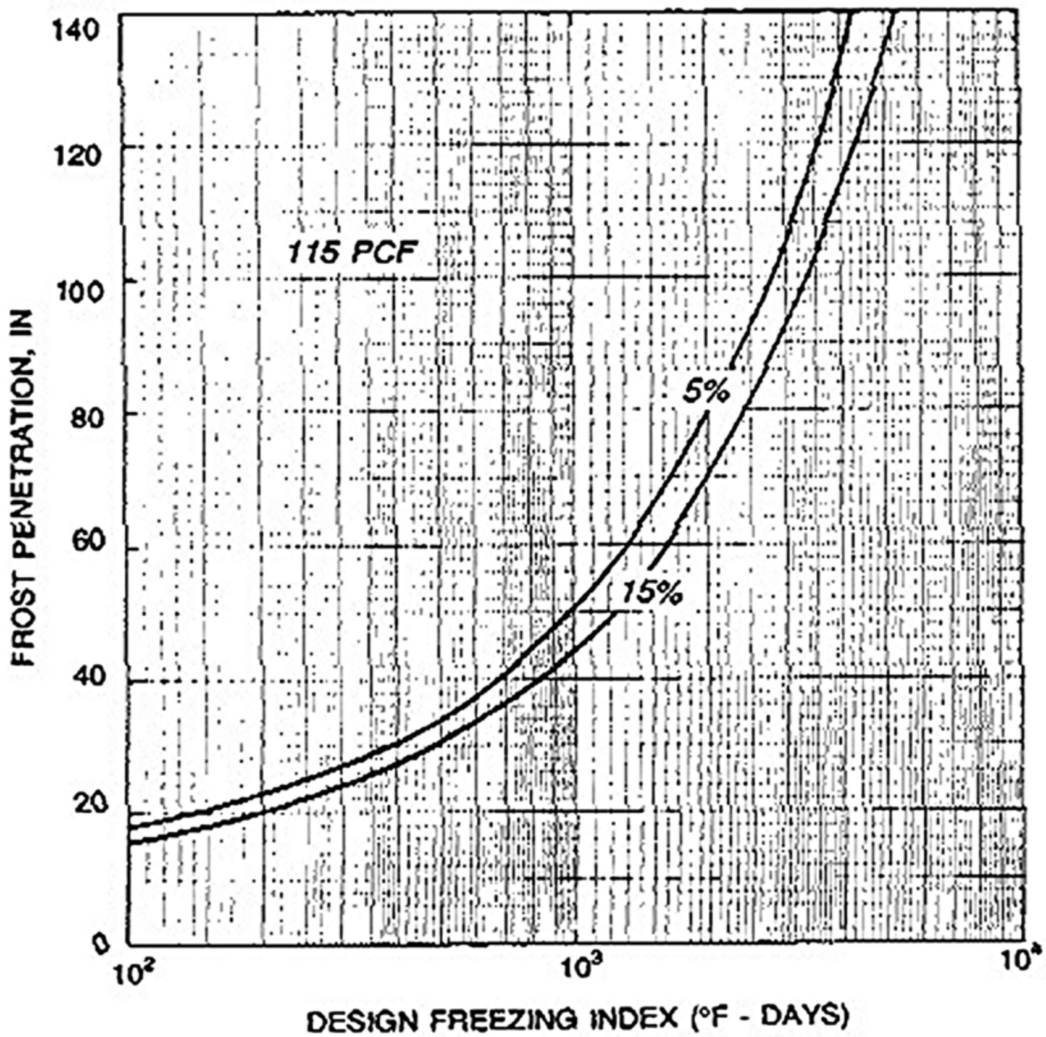

Figure 3 (continued)

Frost penetration beneath pavements

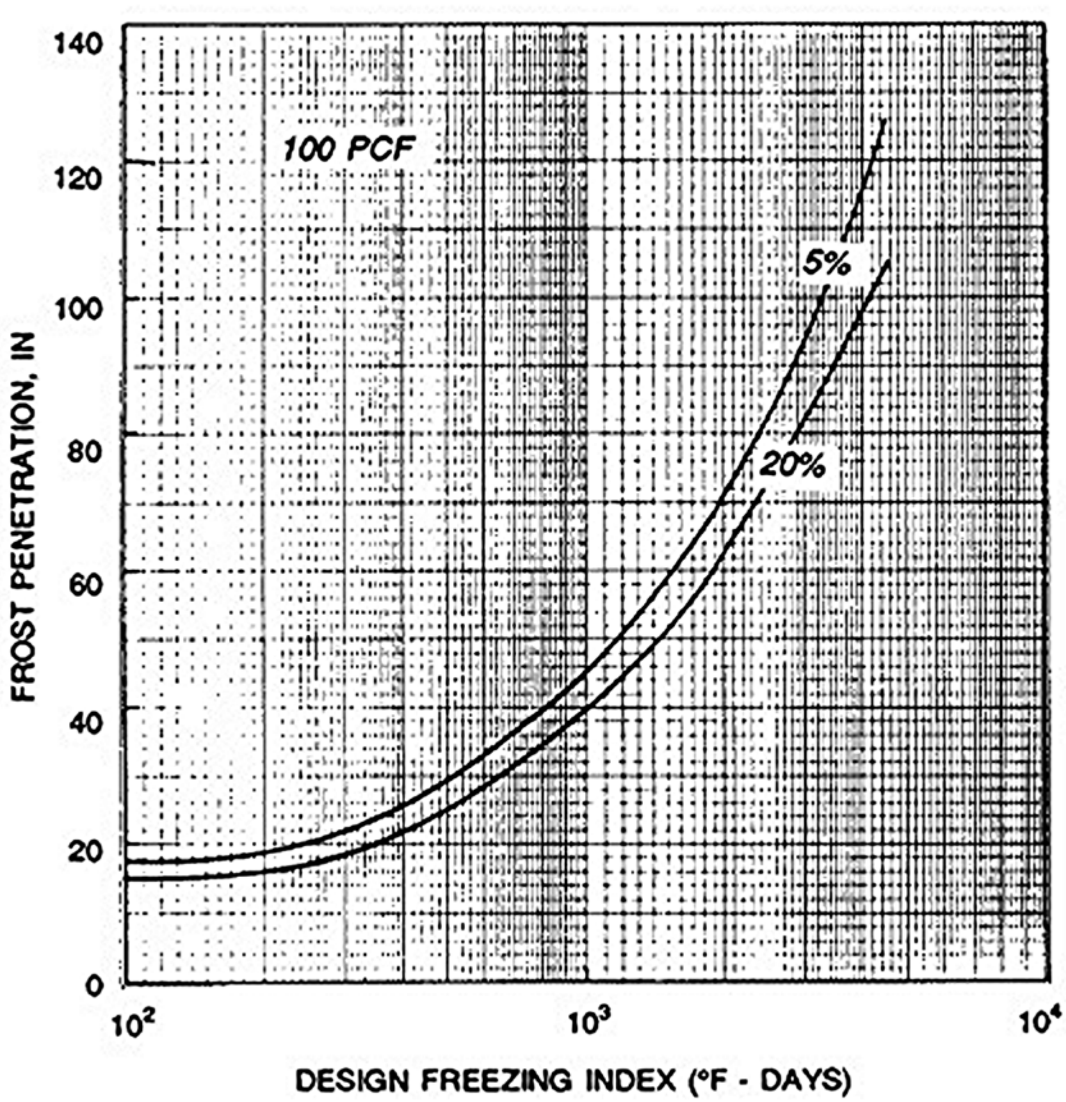

Figure 3 (continued)

Frost penetration beneath pavements

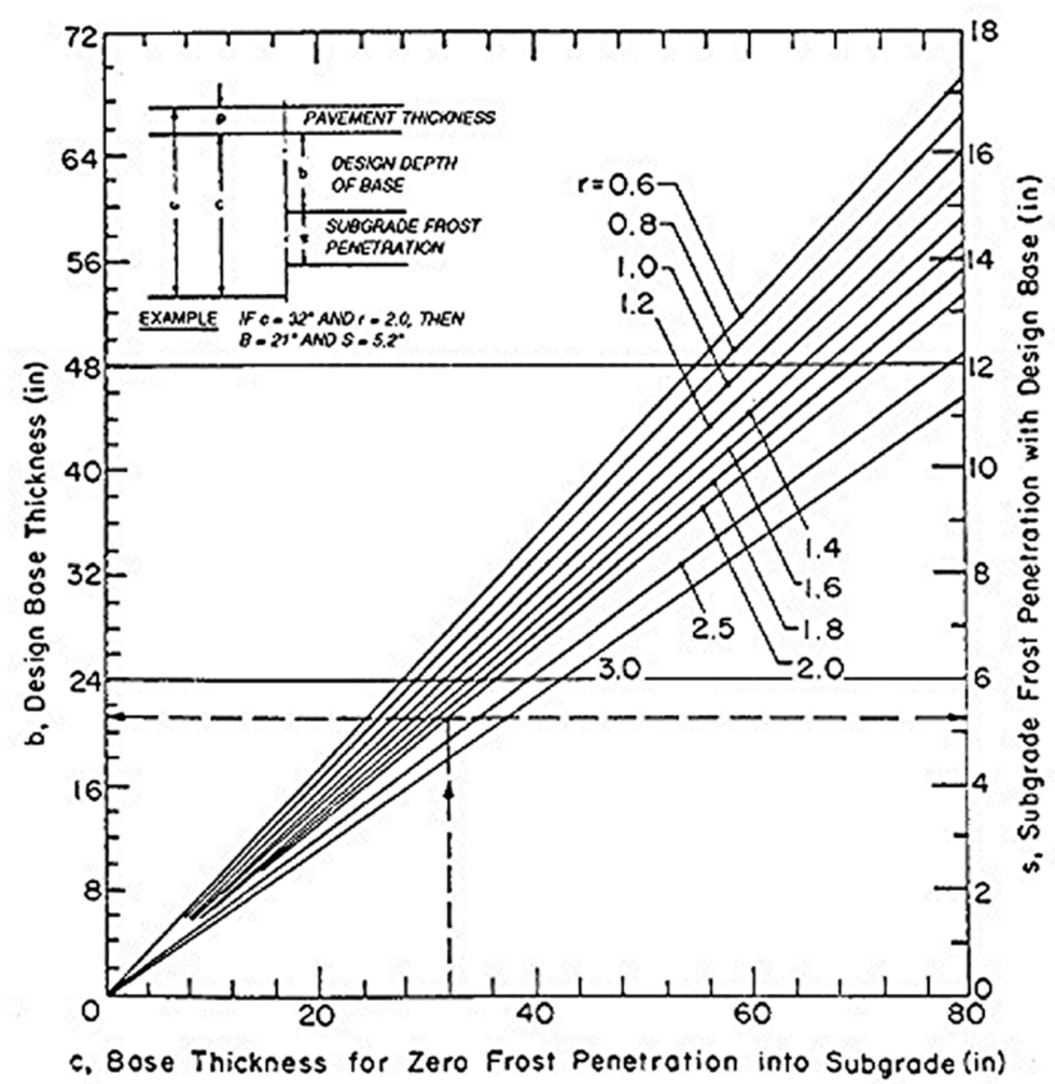

Figure 4

Design depth of non-frost susceptible base for limited subgrade frost penetration

6.4 THICKNESS. The above procedure will result in a thickness of material between the frost-susceptible subgrade and the pavement so that for average field conditions subgrade frost penetration of the amounts should not cause excessive differential heave of the pavement surface during the design freezing index year.

6.5 CONTROLLING THICKNESS. If the combined thickness of pavement and base required by the non-frost criteria exceeds the thickness given by the limited subgrade frost penetration procedure of design, the greater thickness given by the nonfrost-criteria will be adopted as the design thickness.

6.6 EFFECTS OF NONFROST CRITERIA. The base course composition requirements of this discussion should be rigorously followed. The design base thickness is the total thickness of filter layers, granular unbound base and subbase, and any bound base. For flexible pavements, the thickness of the asphalt surfacing layer and of any bound base, as well as the CBR (California Bearing Ratio) requirements of each layer of granular unbound base, will be determined using nonfrost criteria. The thickness of rigid pavement slab will also be determined from nonfrost criteria.

7. REDUCED SUBGRADE STRENGTH. Thickness design may also be based on the seasonally varying subgrade support that includes sharply reduced values during thawing of soils that have been affected by frost action. Excepting pavement projects that are located in regions of low design freezing index, this design procedure usually requires less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for both flexible and rigid pavements wherever the subgrade is reasonably uniform or can be made reasonably horizontally uniform by the required techniques of subgrade preparation. This will prevent or minimize significant or objectionable differential heaving and resultant cracking of pavements. When the reduced subgrade strength method is used for F4 subgrade soils, unusually rigorous control of subgrade preparation must be required. When a thickness determined by the reduced subgrade strength procedure exceeds that determined for limited subgrade frost penetration, the latter smaller value shall be used, provided it is at least equal to the thickness required for nonfrost conditions. In situations where use of the reduced subgrade strength procedure might result in objectionable frost heave, but use of the greater thickness of base course indicated by the limited subgrade frost penetration design procedure is not considered necessary, intermediate design thickness may be used. However, these must be justified on the basis of frost heaving experience developed from existing pavements where climatic and soil conditions are comparable.

Frost group of subgrade soil	Frost-area soil support index
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

Table 3

Frost-area soil support indexes for sub-grade soils for flexible pavement design

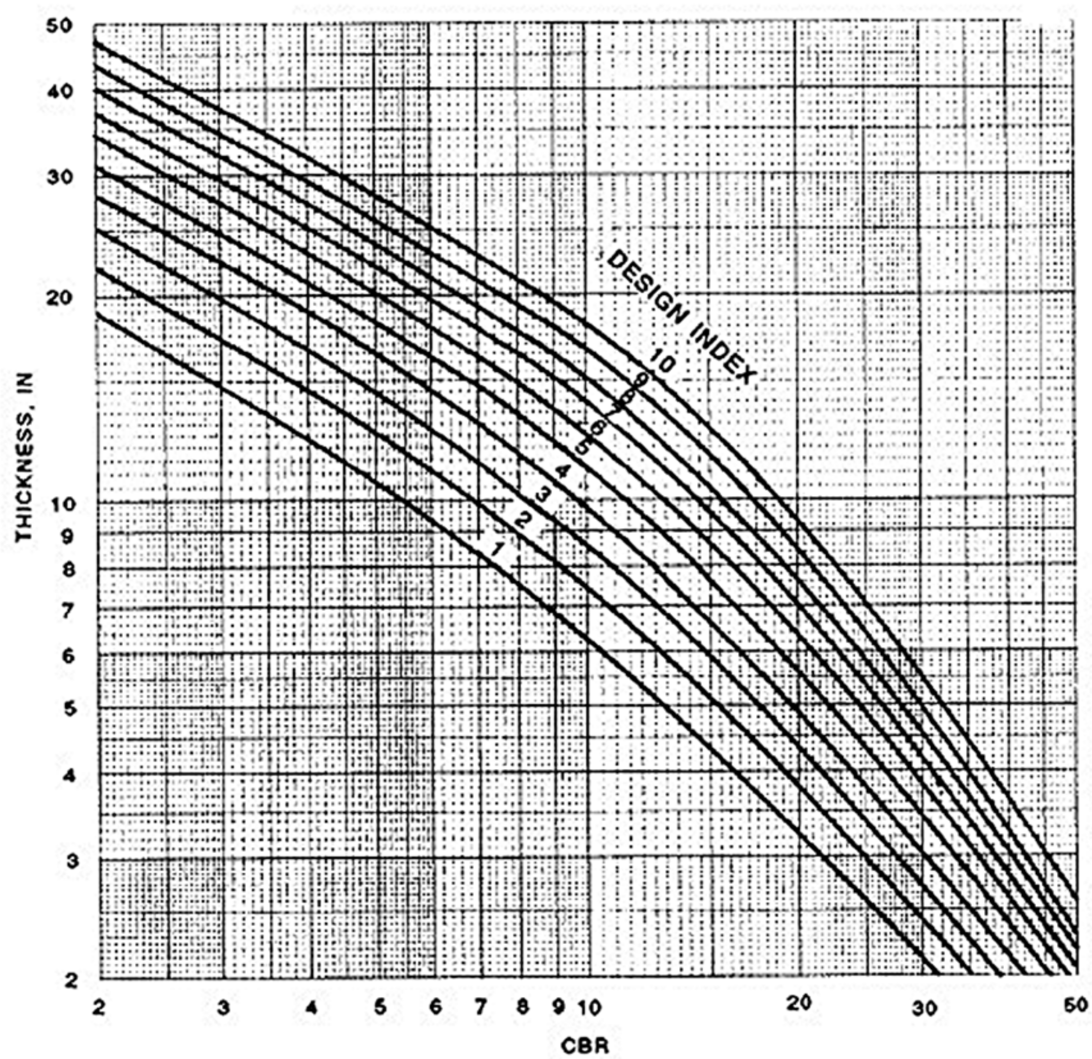

Figure 5

Flexible Pavement Design Curve for Roads and Streets

7.1 THICKNESS OF FLEXIBLE PAVEMENTS. In the reduced subgrade strength procedure for design, the design curves herein (fig 5) should be used for road, street, and parking area design. The curves should not be entered with subgrade CBR values determined by tests or estimates, but instead with the applicable frost-area soil support index from table 3. Frost-area soil support indexes are used as if they were CBR values; the term CBR is not applied to them, however, because being weighted average values for an annual cycle, their value cannot be determined by CBR tests. The soil support index for Si or S2 material meeting current specifications for base or subbase will be determined by conventional CBR tests in the unfrozen state.

7.1.1 GENERAL FIELD DATA and experience indicate that on the relatively narrow embankments of roads and streets, reduction in strength of sub-grades during frost melting may be less in substantial fills than in cuts because of better drainage conditions and less intense ice segregation. If local field data and experience show this to be the case, then a reduction in combined thickness of pavement and base for frost conditions of up to 10 percent may be permitted for substantial fills.

7.1.2 FLEXIBLE PAVEMENT CRITERIA for nonfrost design should also be used to determine the thickness of individual layers in the pavement system, and to ascertain whether it will be advantageous to include one or more layers of bound base in the system. The base course composition requirements set forth must be followed rigorously.

7.2 THICKNESS OF RIGID PAVEMENTS*.* Where frost is expected to penetrate into a frost-susceptible subgrade beneath a rigid pavement, it is good practice to use a nonfrost-susceptible base course at least equal in thickness to the slab. Experience has shown, however, that rigid pavements with only a 4-inch base have performed well in cold environments with relatively uniform subgrade conditions. Accordingly, where subgrade soils can be made reasonably uniform by the required procedures of subgrade preparation, the minimum thickness of granular unbound base may be reduced to a minimum of 4 inches. The material shall meet the requirements set forth below for free-draining material as well as the criteria for filter under pavement slab. If it does not also meet the criteria for filter over subgrade, a second 4-inch layer meeting that criteria shall be provided.

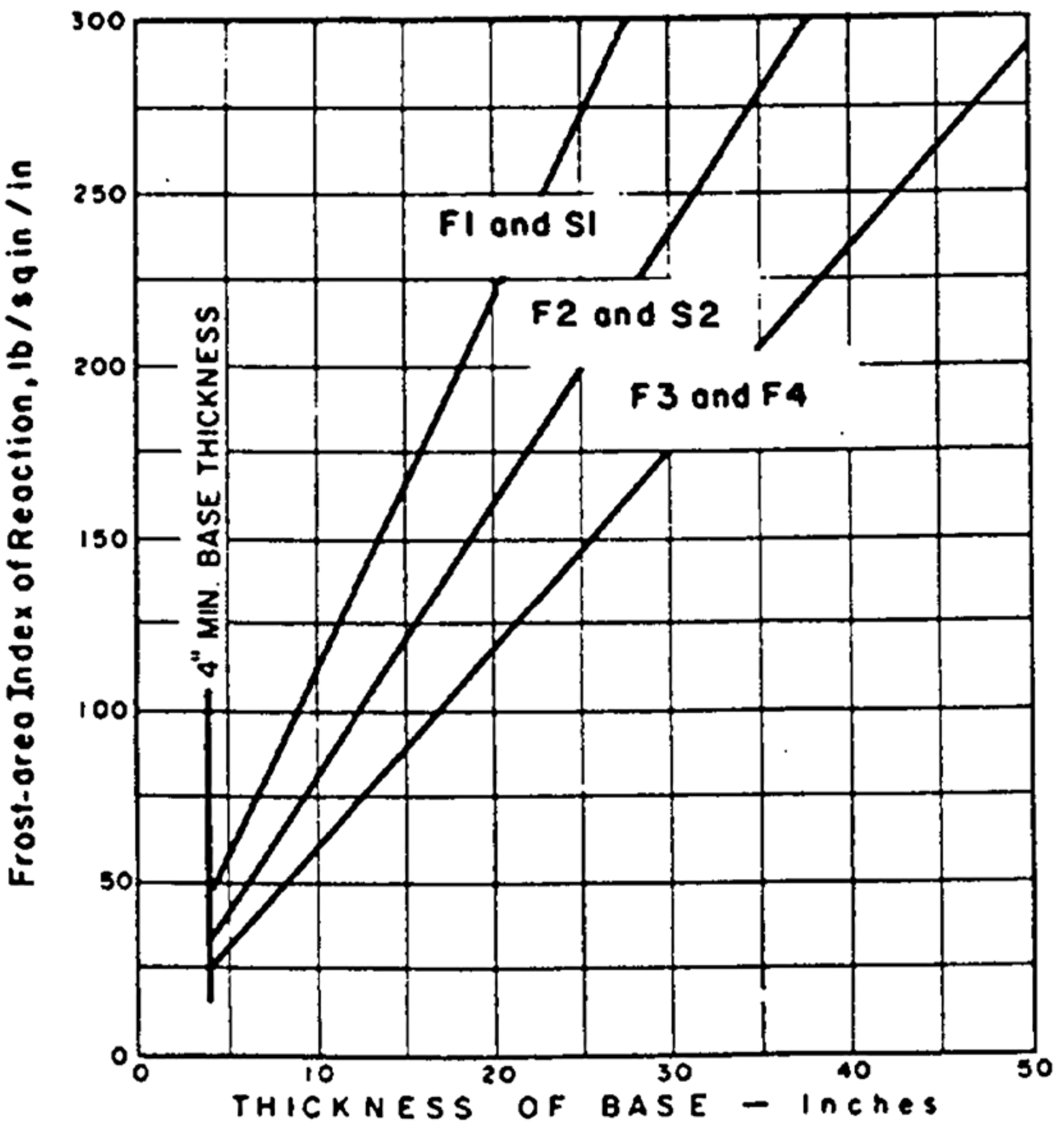

Figure 6

Frost-area index of reaction for design of rigid roads, streets and open storage areas

7.2.1 ADDITIONAL GRANULAR UNBOUND BASE COURSE, giving a thickness greater than the minimum specified above, will improve pavement performance, giving a higher frost-area index of reaction on the surface of the unbound base (fig. 6) and permitting a pavement slab of less thickness. Bound base also has significant structural value, and may be used to effect a further reduction in the required thickness of rigid pavement slab. Criteria for determining the required thickness of rigid pavement slabs in combination with a bound base course are contained in chapter 12. The requirements for granular unbound base as drainage and filter layers will still be applicable.

7.2.2 THE THICKNESS OF CONCRETE PAVEMENT will be determined using the frost-area index of reaction determined from figure 6. This figure shows the equivalent weighted average index of reaction values for an annual cycle that includes a period of thaw-wakening in relation to the thickness base. Frost-area indexes of reaction are used as if they were moduli of reaction, k, and have the same units. The term modulus of reaction is not applied to them because being weighted average values for an annual cycle, they cannot be determined by a plate-bearing test. If the modulus of reaction, k, determined from tests on the equivalent base course and subgrade, but without frost melting, is numerically smaller than the index of reaction obtained from figure 18-5, the test value shall govern the design.

8. USE OF STATE HIGHWAY REQUIREMENTS. To provide further flexibility in design options, and to exploit economical local materials and related experience, state highway requirements may be used for pavements with a design index less than 4. The decision to use local state highway requirements will be based on demonstrated satisfactory performance of pavements in that state as determined by observation and experience. If state requirements are used, the entire pavement should conform in every detail to the applicable state criteria.

9. FREE-DRAINING MATERIAL DIRECTLY BENEATH BOUND BASE OR SURFACING LAYER. Base courses may consist of either granular unbound materials or bound base materials or a combination of the two. However, a cement- or lime-bound base should not be placed directly beneath bituminous pavement without approval from the design engineer. Also, an unbound course will not be placed between two relatively impervious bound layers. If the combined thickness, in inches, of pavement and contiguous bound base courses is less than 0.09 multiplied by the design air freezing index (this calculation limits the design freezing index at the bottom of the bound base to about 20 degree-days), not less than 4 inches of free-draining material shall be placed directly beneath the lower layer of bound base or, if there is no bound base, directly beneath the pavement slab or surface course. The free-draining material shall contain 2.0 percent or less, by weight, of grains that can pass the no. 200 sieve, and to meet this requirement, it probably will have to be screened and washed. If the structural criteria for design of the pavement do not require granular unbound base other than the 4 inches of free-draining material, then the material in the 4-inch layer must be checked for conformance with the filter requirements below. If it fails the test for conformance, an additional layer meeting those requirements must be provided. When using a drainage layer, the drainage layer must extend to an open ditch or subdrains must be used.

10. OTHER GRANULAR UNBOUND BASE COURSE. If the structural criteria for design of the pavement require more granular unbound base than the 4 inches of free drainage material, the material shall meet the applicable requirements of current guide specifications for base of subbase materials. In addition, the top 50 percent of the total thickness of granular unbound base must be nonfrost susceptible and must contain not more than 5 percent by weight of particles passing the no. 200 sieve. The lower 50 percent of the total thickness of granular unbound base may be either non-frost-susceptible material, SI material, or S2 material. If the subgrade soil is SI or S2 material meeting the requirements of current guide specifications for base or subbase, the lower 50 percent of granular base will be omitted. An additional requirement, if subgrade freezing will occur, is that the bottom 4-inch layer in contact with the subgrade must meet the filter requirements, or a geotextile meeting the filter requirements must be placed in contact with the subgrade. The dimensions and permeability of the base should satisfy the base course drainage criteria as well as the thickness requirements for frost design. Thicknesses indicated by frost criteria should be increased, if necessary, to meet subsurface drainage criteria. Base course materials of borderline quality should be tested frequently after compaction to ensure that the materials meet these design criteria. When placed and compacted, subbase and base materials must meet the applicable compaction requirements.

11. USE OF FL AND F2 SOILS FOR BASE MATERIALS. An alternative to the use of SI and S2 base materials is permitted for roads and vehicle parking areas. Materials of frost groups Fl and F2 may be used in the lower part of the base over F3 and F4 subgrade soils. Fl materials may be used in the lower part of the base over F2 subgrades. The thickness of F2 base material should not exceed the difference between the reduced-subgrade strength thickness requirements over F3 and F2 subgrades. The thickness of Fl base should not exceed the difference between the thickness requirements over F2 and Fl subgrades. Any Fl or F2 material used in the base must meet the applicable requirements of the guide specifications for base or subbase materials. The thickness of Fl and F2 materials and the thickness of pavement and base above the Fl and F2 materials must meet the nonfrost criteria.

12. FILTER OR DRAINAGE REQUIREMENTS. For pavements under which subgrade freezing will occur, a filter or drainage layer meeting approved requirements will be provided.

13. STABILIZERS AND STABILIZED LAYERS.

13.1 ADDITIVES. Asphalt, portland cement, lime, and LCF are the most common additives used in stabilized soils. Other stabilizers may be used for pavement construction in frost areas only with the approval of the design engineer. The limitations of use, the basic requirements for mixture design, and the stabilization procedures using bituminous and chemical stabilizers must be observed.

13.2 LIMITATIONS OF USE. In frost areas, stabilized soil in most cases will be used only in a layer or layers making up one of the upper elements of a pavement system and only when using the reduced subgrade strength method. Usually, it will be placed directly beneath the pavement surfacing layer, where the added cost of stabilization is compensated for by its structural advantage in effecting a reduction in the required thickness of the pavement system. However, a cement, lime, or LCF-stabilized base should not be placed directly beneath bituminous pavements because cracking and faulting will be significantly increased. Treatment with a lower degree of chemical stabilization in layers placed at lower levels within the pavement system should be used in frost areas only with caution and after intensive tests. This is because weakly cemented material usually has less capacity to endure repeated freezing and thawing without degradation than firmly cemented material.

13.3 CONSTRUCTION CUT-OFF DATES. For materials stabilized with cement, lime, or LCF whose strength increases with length of curing time, it is essential that the stabilized layer be constructed sufficiently early in the season to allow development of adequate strength before the first freezing cycle begins. Research has shown that the rate of strength gain is substantially lower at 50 degree Fahrenheit than at 70 or 80 degree Fahrenheit. Accordingly, in frost areas it is not always enough to protect the mixture from freezing during a 7 day curing period as required by the applicable guide specifications. A construction cut-off date well in advance of the onset of freezing may be essential.

14. STABILIZATION WITH LIME AND WITH LCF.

14.1 BOUND BASE. Soils containing only lime as the stabilizer are generally unsuitable for use as base course layers in the upper layers of pavement systems in frost areas. Lime, cement, and a pozzolanic material such as flyash may be used in some cases to produce a cemented material of high quality that is suitable for upper base course and that has adequate durability and resistance to freeze-thaw action. The procedures in ASTM D 560 should be followed for freeze-thaw testing, except that the specimens should be compacted in a 6-inch diameter mold in five layers with a 10-pound hammer having an 18-inch drop, and that the preparation and curing of the specimens should follow the procedures for unconfined compression tests on line-stabilized soil.

14.2 LIME-STABILIZED SOIL. If it is economical to use lime-stabilized or lime-modified soil in lower layers of a pavement system, a mixture of adequate durability and resistance to frost action is still necessary. In addition to the requirements for mixture design of lime-stabilized and lime-modified subbase and subgrade materials, cured specimens should be subjected to the 12 freeze-thaw cycles in ASTM D 560 (but omitting wire-brushing) or other applicable freeze-thaw procedures. This should be followed by determination of frost-design soil classification by means of standard laboratory freezing tests. For lime-stabilized or lime-modified soil used in lower layers of the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for base course by the design engineer. If lime-stabilized or lime-modified soil is used as subgrade, its frost susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade strength design method is applied.

15. STABILIZATION WITH PORTLAND CEMENT. Cement-stabilized soil meeting the requirements set forth by the design engineer, including freeze-thaw effects tested under ASTM D 560, may be used in frost areas as base course or as stabilized subgrade. Cement-modified soil conforming with the requirements of the design engineer also may be used in frost areas. However, in addition to the procedures for mixture design specified by the design engineer, cured specimens of cement-modified soil should be subjected to the 12 freeze-thaw cycles in ASTM D 560 (but omitting wire-brushing) or other applicable freeze-thaw procedures. This should be followed by determination of frost design soil classification by means of standard laboratory freezing tests. For cement-modified soil used in the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for base course by the design engineer. If cement-modified soil is used as subgrade, its frost susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade design method is applied.

16. STABILIZATION WITH BITUMEN. Many different types of soils and aggregates can be successfully stabilized to produce a high-quality bound base with a variety of types of bituminous material. In frost areas the use of tar as a binder should be avoided because of its high temperature susceptibility. Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climate conditions should be selected. Excepting these special conditions affecting the suitability of particular types of bitumen, the procedures for mixture design should ensure that the asphalt-stabilized base will have adequate durability and resistance to moisture and freeze-thaw cycles.

17. SUBGRADE REQUIREMENTS. It is a basic requirement for all pavements constructed in frost areas, that subgrades in which freezing will occur, shall be prepared to achieve uniformity of soil conditions by mixing stratified soils, eliminating isolated pockets of soil of higher or lower frost susceptibility, and blending the various types of soils into a single, relatively homogeneous mass. It is not intended to eliminate from the subgrade those soils in which detrimental frost action will occur, but to produce a subgrade of uniform frost susceptibility and thus create conditions tending to make both surface heave and subgrade thaw-weakening as uniform as possible over the paved area. In fill sections the least frost-susceptible soils shall be placed in the upper portion of the subgrade by temporarily stockpiling the better materials, cross-hauling, and selective grading. If the upper layers of fill contain frost-susceptible soils, and the completed fill section shall be subjected to the subgrade preparation procedures required for cut sections. In cut sections the subgrade shall be scarified and excavated to a prescribed depth, and the excavated material shall be windrowed and bladed successively until thoroughly blended, then relaid and compacted. The depth of subgrade preparation, measured downward from the top of the subgrade, shall be the lesser of 24 inches; two- thirds of the frost penetration for class A, B, and C same subgrade preparation procedures prescribed roads, streets, and open storage areas or one-half of the frost penetration for roads, streets, and open storage areas of class D, E, and F less the actual combined thickness of pavement, base course, and subbase course. The prepared subgrade must meet the designated compaction requirements for non-frost areas. The construction inspection personnel should be alert to verify that the processing of the subgrade will yield uniform soil conditions throughout the section. To achieve uniformity in some cases, it will be necessary to remove highly frost susceptible soils or soils of low frost susceptibility. In that case the pockets of soil to be removed should be excavated to the full depth of frost penetration and replaced with material surrounding the frost-susceptible soil being removed.

17.1 EXCEPTIONS CONDITIONS. Exceptions to the basic requirement for subgrade preparation are sub-grades known to be nonfrost susceptible to the depth prescribed for subgrade preparation and known to contain no frost-susceptible layers or lenses, as demonstrated and verified by extensive and thorough subsurface investigations and by the performance of nearby existing pavements. Also, fine-grained subgrades containing moisture well in excess of the optimum for compaction, with no feasible means of drainage nor of otherwise reducing the moisture content, and which consequently it is not feasible to scarify and recompact, are also exceptions.

17.2 TREATMENT OF WET FINE-GRAINED SUBGRADES. If wet fine-grained subgrades exist at the site, it will be necessary to achieve frost protection with fill material. This may be done by raising the grade by an amount equal to the depth of subgrade preparation that otherwise would be prescribed, or by undercutting and replacing the wet fine-grained subgrade to that same depth. In either case the fill or backfill material may be nonfrost-susceptible material or frost-susceptible material meeting specified requirements. If the fill or backfill material is frost susceptible, it should be subjected to the above.

17.3 COBBLES OR BOULDERS. A critical condition requiring the attention of inspection personnel is the presence of cobbles or boulders in the subgrades. All stones larger than about 6 inches in diameter should be removed from fill materials for the full depth of frost penetration, either at the source or as the material is spread in the embankments. Any such large stones exposed during the sub-grade preparation work also must be removed, down to the full depth to which subgrade preparation is required. Failure to remove stones or large roots can result in increasingly severe pavement roughness as the stones or roots are heaved gradually upward toward the pavement surface. They eventually break through the surface in extreme cases, necessitating complete reconstruction.

17.4 CHANGES IN SOIL CONDITIONS. Abrupt changes in soil conditions must not be permitted. Where the subgrade changes from a cut to a fill section, a wedge of subgrade soil in the cut section with the dimensions shown in figure 7 should be removed and replaced with fill material. Tapered transitions also are needed at culverts beneath paved areas, but in such cases the transition material should be clean, nonfrost-susceptible granular fill. Other under pavement pipes should be similarly treated, and perforated-pipe underdrains should be constructed. These and any other discontinuities in subgrade conditions require the most careful attention of construction inspection personnel, as failure to enforce strict compliance with the requirements for transitions may result in serious pavement distress.

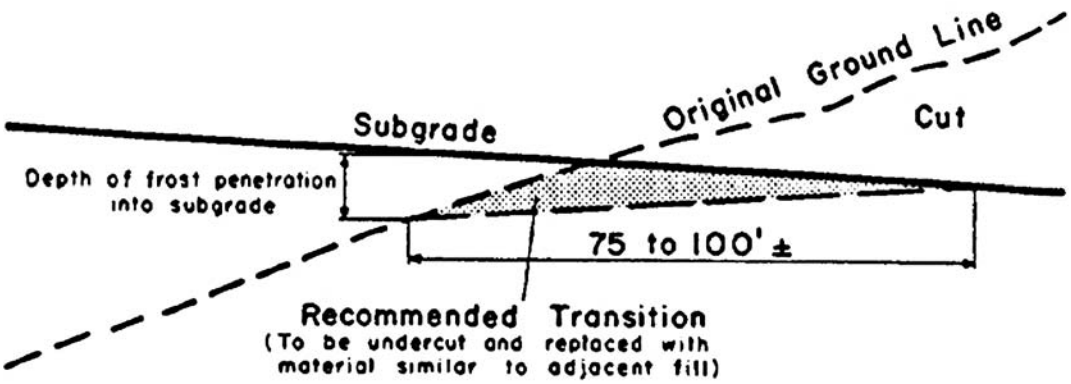

Figure 7
Tapered transition used where embankment material differs from natural subgrade in cut

17.5 WET AREAS. Careful attention should be given to wet areas in the subgrade, and special drainage measures should be installed as required. The need for such measures arises most frequently in road construction, where it may be necessary to provide intercepting drains to prevent infiltration into the subgrade from higher ground adjacent to the road.

17.6 ROCK EXCAVATION. In areas where rock excavation is required, the character of the rock and seepage conditions should be considered. In any case, the excavations should be made so that positive transverse drainage is provided, and no pockets are left on the rock surface that will permit ponding of water within the depth of freezing. The irregular groundwater availability created by such conditions may result in markedly irregular heaving under freezing conditions. It may be necessary to fill drainage pockets with lean concrete. At intersections of fills with rock cuts, the tapered transitions mentioned above (fig 7) are essential. Rock subgrades where large quantities of seepage are involved should be blanketed with a highly pervious material to permit the escape of water. Frequently, the fractures and joints in the rock contain frost-susceptible soils. These materials should be cleaned out of the joints to the depth of frost penetration and replaced with nonfrost susceptible material. If this is impractical, it may be necessary to remove the rock to the full depth of frost penetration.

17.7 ROCK SUBGRADES. An alternative method of treatment of rock subgrades, in-place fragmentation, has been used effectively in road construction. Blast holes 3 to 6 feet deep are commonly used. They are spaced suitably for achieving thorough fragmentation of the rock to permit effective drainage of water through the shattered rock and out of the zone of freezing in the subgrade. A tapered transition should be provided between the shattered rock cut and the adjacent fill.

18. OTHER MEASURES TO REDUCE HEAVE. Other possible measures to reduce the effects of heave are the use of insulation to control depth of frost penetration and the use of steel reinforcement to improve the continuity of rigid pavements that may become distorted by frost heave. Reinforcement will not reduce heave nor prevent the cracking resulting from it, but it will help to hold cracks tightly closed and thus reduce pumping through these cracks. Transitions between cut and fill and culverts and drains change in character or stratification of subgrade soils. Subgrade preparation and boulder removal should also receive special attention in field construction control.

19. PAVEMENT CRACKING ASSOCIATED WITH FROST HEAVE. One of the most detrimental effects of frost action on a pavement is surface distortion as the result of differential frost heave or differential loss of strength. These may also lead to random cracking. Deterioration and spalling of the edges of working cracks are causes of uneven surface conditions and sources of debris. Cracking may be reduced by control of such elements as base composition, uniformity and thickness, slab dimensions, subbase and subgrade materials, uniformity of subsurface moisture conditions, and, in special situations, by use of reinforcement and by limitation of pavement type. The importance of uniformity cannot be overemphasized. Where unavoidable discontinuities in subgrade conditions exist, gradual transitions are essential.

20. CONTROL OF SUBGRADE AND BASE COURSE CONSTRUCTION. Personnel responsible for field control of pavement construction in areas of seasonal freezing should give specific consideration to conditions and materials that will result in detrimental frost action. The contract plans and specifications should require the subgrade preparation work established for nonfrost areas in this manual in frost areas. They also should provide for special treatments such as removal of unsuitable materials encountered with sufficient information included to identify those materials and specify necessary corrective measures. However, construction operations quite frequently expose frost-susceptible conditions at isolated locations a degree and character not revealed by even the most thorough subsurface exploration program. It is essential, therefore, that personnel assigned to field construction control be alert to recognize situations that require special treatment, whether or not anticipated by the design engineer. They must also be aware of their responsibility for such recognition.

21. BASE COURSE CONSTRUCTION. Where the available base course materials are well within the limiting percentages of fine material set forth above, the base course construction control should be in accordance with normal practice. In instances where the material selected for use in the top 50 percent of the total thickness of granular unbound base is borderline with respect to percentage of fine material passing the no. 200 sieve, or is of borderline frost susceptibility (usually materials having 11/2 to 3 percent of grains finer than 0.02 millimeters by weight), frequent gradation checks should be made to ensure that the materials meet the design criteria. If it is necessary for the contractor to be selective in the pit in order to obtain suitable materials, his operations should be inspected at the pit. It is more feasible to reject unsuitable materials at the source when large volumes of base course are being placed. It may be desirable to stipulate thorough mixing at the pit and, if necessary, stockpiling, mixing in windrows, and spreading the material in compacted thin lifts in order to ensure uniformity. Complete surface stripping of pits should be enforced to prevent mixing of detrimental fine soil particles or lumps in the base material.

21.1 GRADATION OF BASE COURSE MATERIALS. The gradation of base course materials after compaction should be determined frequently, particularly at the start of the job, to learn whether or not fines are being manufactured in the base under the passage of the compaction equipment. For base course materials exhibiting serious degradation characteristics, a test embankment may be needed to study the formation of fines by the proposed compaction process. Mixing of base course materials with frost-susceptible subgrade soils should be avoided by making certain that the subgrade is properly graded and compacted prior to placement of base course, by ensuring that the first layer of base course filters out subgrade fines under traffic, and by eliminating the kneading caused by over compaction or insufficient thickness of the first layer of base course. Excessive rutting tends to cause mixing of subgrade and base materials. This of can be greatly minimized by frequent rerouting of material-hauling equipment.

21.2 VISUAL INSPECTION. After completion of each layer of base course, a careful visual inspection should be made before permitting additional material placement to ensure that areas with high percentages of fines are not present. In many instances these areas may be recognized both by examination of the materials and by observation of their action materials are wet. The materials in any areas that do not meet the requirements of the specifications, which will reflect the requirements of this publication, should be removed and replaced with suitable material. A leveling course of fine-grained material should not be used as a construction expedient to choke open-graded base courses, to establish fine grade, or to prevent overrun of concrete. Since the base course receives high stresses from traffic, this prohibition is essential to minimize weakening during the frost-melting period. Action should be taken to vary the base course thickness so as to provide transition, when this is necessary, to avoid abrupt changes in pavement supporting conditions.

22. COMPACTION. Subgrade, subbase, and base course materials must meet the applicable compaction requirements for nonfrost materials.

23. USE OF INSULATION MATERIALS IN PAVEMENTS. The use of synthetic insulating material within a pavement cross section must have the written approval of the design engineer, who can also provide advice and assistance in regard to the structural analysis.