Introduction to Road Design for Cold Regions

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J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

An Introduction to Road Design for Cold Regions

Guyer Partners
44240 Clubhouse Drive
El Macero, CA 95618
(530)758-6637
jpguyer@pacbell.net

J. Paul Guyer, P.E., R.A.

Paul Guyer is a registered civil engineer, mechanical engineer, fire protection engineer, and architect with over 35 years experience in the design of buildings and related infrastructure. For an additional 9 years he was a senior advisor to the California Legislature on infrastructure and capital outlay issues. He is a graduate of Stanford University and has held numerous national, state and local positions with the American Society of Civil Engineers, National Society of Professional Engineers and Architectural Engineering Institute.

CONTENTS

1. GENERAL. The construction of satisfactory roads and runways in permafrost areas is normally more difficult than in temperate regions because the imperviousness of the underlying permafrost tends to produce poor soil drainage conditions, and because disturbance of the natural surface may set in motion adjustments in thermal regime, drainage, and slope stability which may have serious and progressive consequences. Cuts should be avoided if possible, and side slopes in fill composed of fine-grained materials should be kept to a 4 to 1 ratio or flatter.

1.1 EFFECT OF SUBGRADE SOIL CONDITIONS ON DESIGN. The design of pavement sections is very dependent upon the type of subgrade soils. Clean coarse-textured soils are subject to negligible heaving when frozen, and to only nominal consolidation when thawed. Permafrost in such soil deposits is normally homogeneous and normally contains no segregated ice. Design problems are simplified with such soils, as frost conditions do not alter their stability or bearing capacity.

The danger of loss in bearing capacity upon thawing, and of heaving action upon freezing, is greatest in fine- textured soils. Such action in a soil is dependent upon the availability of water, and to a large degree on void sizes, and may be expressed as an empirical function of grain size, as follows:

- Inorganic soils containing 3 percent or more of grains finer than 0.02 mm. in diameter by weight are generally frost-susceptible. Although uniform sandy soils may have as high as 10 percent of grains finer than 0.02 mm. by weight without being frost-susceptible, their tendency to occur interbedded with other soils makes it generally impractical to consider them separately.

Soils in which ice segregation generally occurs when favorable ground water and freezing temperatures are present have been classified in the following four groups, listed approximately in the order of increasing susceptibility to frost heaving and/or weakening as a result of frost melting. The order of listing of subgroups *under* groups F3 and F4 does not necessarily indicate the order of susceptibility to frost heaving or weakening of these subgroups. There is some overlapping of frost susceptibility between groups. The soils in group F4 are especially of high frost susceptibility. Soil names are as defined in the Unified Soil Classification System and indicated Table 1 below.

Group	Description
F1	Gravelly soils containing between 3 to 20 percent finer than 0.02 mm. by weight.
F2	Sands containing between 3 and 15 percent finer than 0.02 mm. by weight.
F3	(*a*) Gravelly soils containing more than 20 percent finer than 0.02 mm. by weight. (*b*) Sands, except very fine silty sands, containing more than 15 percent finer than 0.02 mm. by weight. (*c*) Clays with plasticity indexes of more than 12. (*d)* Varved clays existing with uniform subgrade conditions.
F4	(*a*) All silts including sandy silts. (*b*) Very fine silty sands containing more than 15 percent finer than 0.02 mm. by weight. (*c*) Clays with plasticity indexes of less than 12. (*d*) Varved clays existing with nonuniform subgrade conditions.

Table 1

Soil Classification

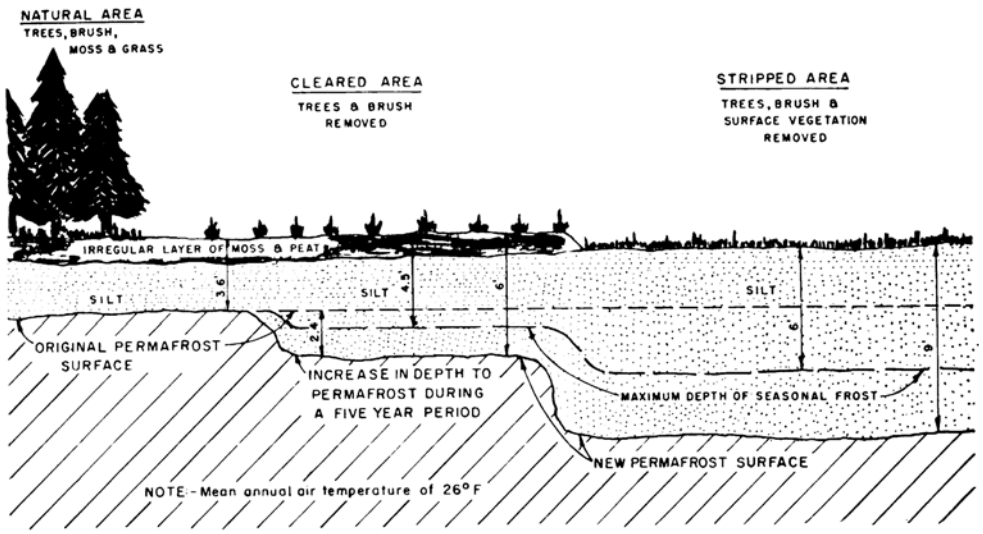
Varved clays consist of alternate layers of inorganic silts and clays and, in some instances, fine sand. The thickness of the layers rarely exceeds one-half inch, but occasionally very much thicker varves are encountered. They are likely to combine the undesirable properties of both silts and soft clays. Varved clays are likely to soften more readily than homogeneous clays with equal average water contents. However, local experience and conditions should be taken into account since under favorable conditions, as when insufficient moisture is available for significant ice segregation, there may be little or no detrimental frost action. There is some evidence that pavements constructed on varved clay subgrades, subject to freezing, in which tile deposit and depth to ground water are relatively uniform, have performed satisfactorily. When subgrade conditions are uniform and there is local evidence that the degree of heave is not exceptional, the varved clay subgrade soil should be assigned a group F3 frost susceptibility classification. Road and runway design over frost-susceptible soils must take into account frost and permafrost conditions. Soils information should be obtained from borings and test pits to at least the depths indicated for the final stage of site selection. The number of holes or pits required can only be determined from physical conditions and the experience of the engineer.

1.2 EFFECT OF FROST AND PERMAFROST CONDITIONS. Frost and permafrost conditions may be altered by changed surface conditions produced by construction. Such challenges have a considerable effect on the stability of roads and runways and must be considered in their design. Depths of freeze and thaw before and after construction may differ considerably. Figure 1 illustrates the effect of clearing and stripping on the depth to the permafrost table after a period of 5 years. Figure 2 shows an idealized sketch of the maximum thaw beneath a road and adjoining areas where thaw is caused by surface heat and the effect of running water in road ditches. The surface temperature for a given air temperature is strongly affected by a considerable variety of factors, and the mean annual surface temperature may differ considerably from that of the air. The effect of surface type on depth of thaw is illustrated in Table 2.

Type of surface	Color of surface	Thickness of pavement in feet	Nature of base course	Thickness of base course in feet	Approximate elevation of water table	Observed total depth of thaw in feet	Depth of thaw in feet into silt subgrade
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

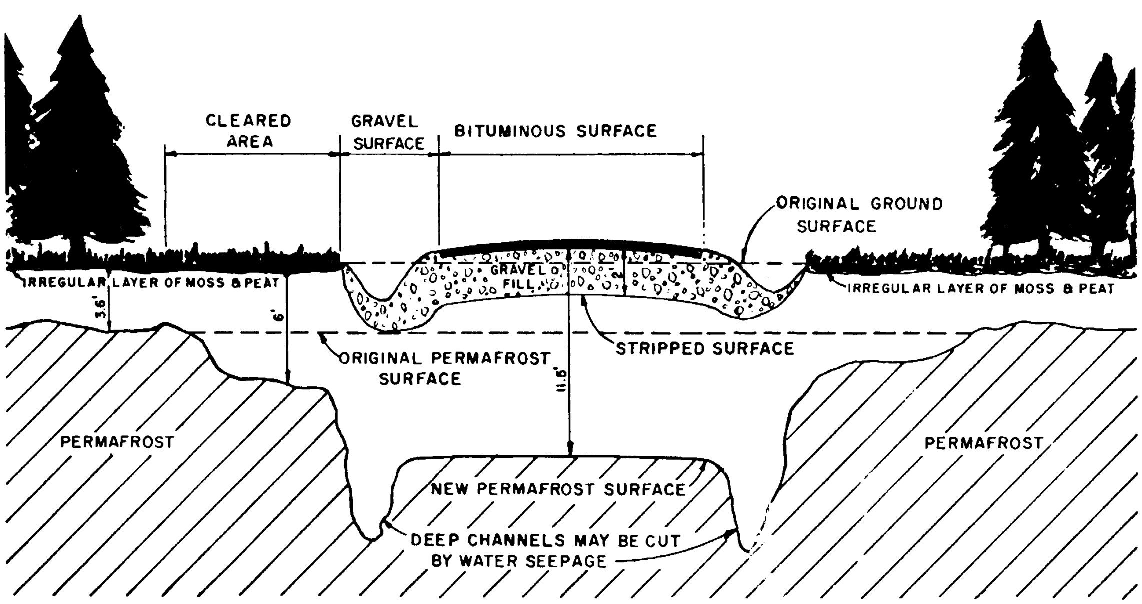
Table 2

Measured Depth of Thaw below Various Surfaces in the Subarctic After 5 Years
(Fairbanks, Alaska, Mean Annual Temperature 26° F.)



MEASURED DEGRADATION OF PERMAFROST IN FROST-SUSCEPTIBLE SOILS
BELOW DIFFERENT SURFACES IN A SUBARCTIC REGION
AFTER A FIVE YEAR PERIOD

Figure 1



MAXIMUM DEPTH TO PERMAFROST BELOW A ROAD AFTER FIVE YEARS
IN A SUBARCTIC REGION

Figure 2

The change of the level of the permafrost table after construction should be considered in the design. Construction may result in a degradation of the permafrost (a condition resulting if annual thaw exceeds annual freeze) or in a condition where thaw and annual freeze penetrate into soil which has previously existed as permafrost. Degradation of permafrost in cuts may lead to slides or sloughing, often difficult to stabilize. Where degradation is anticipated, soils should be investigated to a depth sufficient to determine the eventual effects of such progressive action. The depth of thaw and of freeze which will occur after construction may be calculated by methods given in the professional literature.

Thawing of previously unthawed subgrades which have a high ice content, such as with closely spaced thick ice lenses, buried ice masses, or ice-filled polygon fissures, will result in serious and abrupt surface subsidence. Thawing of such subgrades beneath completed pavements should be prevented by providing sufficient base-course thickness, or the effects of thawing should be anticipated in planning future maintenance requirements. Stage construction, where possible, such as for roads, should be considered so that final high-type surfacing is placed after completion of the greater portion of subsidence due to thawing. Where pavement construction is not going to result in a degrading condition, there may be an advantage in placing the base course directly on the existing vegetative cover. The settlement due to compressibility of surface materials, movement due to seasonal freezing and thawing of surface cover deposit, and soils in the active zone prior to construction will generally be much less serious than thawing of previously unthawed subgrade soils containing considerable segregated ice.

1.3 EFFECT OF GROUND WATER. In areas of permafrost the location of the ground water surface is greatly influenced by the existence of the underlying impervious permafrost layer. Surface infiltration and water released by the melting of frozen soil, supply water to the thawed zone above the permafrost layer during the summer period. Unless the soil is relatively pervious and the terrain has sufficient slope to permit lateral drainage, the water table may rise to, or near, the ground surface. During the early part of the freezing period, lack of precipitation, cessation of thawing of the permafrost layer and reduction in infiltration by freezing of the ground surface combine to restrict the entrance of water to the seasonally thawed layer. Where the terrain is sloping and the soil is relatively pervious (coefficient of permeability greater than approximately 1x 10^{-4} ft/min), the free water will tend to drain by gravity as freezing temperatures penetrate below the surface, and furthermore, water is drawn to the zone of freezing in frost-susceptible soils. As a result the ground water surface will approach the upper surface of the permafrost layer. However, where there is a considerable drainage area above a specific location, the water level may remain above the permafrost table for a considerable part of the freezing season due to the time-lag in the subsurface flow, and in addition to supplying water for ice segregation in the active zone, may cause the formation of surface icings and/or frost mounds. In evaluating probable ground water conditions during the freezing period at a particular site, observations and consideration of topographic position, slope of terrain, vegetative cover, and the soil type should be utilized. A potentially troublesome water supply for ice segregation is present if the uppermost ground water surface is within 5 feet of the plane of freezing, while if the ground water depth is in excess of 10 feet, appreciable ice segregation usually will not occur. However, fine-grained, frost-susceptible subgrade soils in permafrost regions will usually become sufficiently saturated to result in some ice segregation, even when the water table is remote. This applies to soils in groups CL, CH, OL, OH, MH and to a lesser extent ML. In such cases, the total depth of the thawed layer as well as the degree of saturation will influence the amount of ice segregation. Significant ice segregation will generally not occur in frost- susceptible soils with a remote water table, when the degree of saturation is less than approximately 70 percent.

Where water for ice segregation is extracted from the voids of the soil below the zone of freezing, the surface heaving generally will not be objectionable. When a frost-susceptible soil of group F3 or F4 is at or near full saturation, the movement of water from the bottom to the top of the soil layer during the freezing process will tend to result in weakening the soil at time of frost melting. In such cases the minimum base-course thickness should be determined by use of reduced strength of subgrade method described in the professional literature.

2. BASE COURSE AND PAVEMENT COMPOSITION.

2.1 RECOMMENDATIONS FOR BASE COURSES. All base-course materials lying within the depth of frost penetration should be non-frost-susceptible. Where the combined thickness of pavement and base over a frost-susceptible subgrade is less than the depth of seasonal freeze or thaw, the following additional design requirements apply:

2.1.1 For both flexible and rigid pavements a minimum of 4 inches of base between the subgrade soil and overlying base-course material should be designed as a filter consisting of any non-frost-susceptible gravel, sand, or crushed stone. The gradation of this filter material should be determined in accordance with criteria presented in the professional literature, with the added overriding limitation that the filter material should in no case have more than 3 percent by weight finer than 0.02 mm. Non-frost-susceptible sand is considered especially suitable for this filter course.

2.1.2 For rigid pavements a filter should also be placed immediately beneath the pavement. This filter should have a maximum of 85 percent by weight passing the 1/4-inch sieve.

2.1.3 The purpose of the filter courses is to prevent the mixing of the frost-susceptible subgrade with the base during the thaw period, and to prevent loss of support by pumping.

2.2 RECOMMENDATIONS FOR PAVEMENTS. Either flexible or rigid types of pavements may be used in arctic and subarctic regions. Rigid pavements should be used only where favorable subgrade conditions exist, such as over non-frost-susceptible subgrades and possibly uniform subgrade soils from groups F1 and F2. Even with the utmost care in soil investigation, design, and construction, differential movements may occur. Repairs in flexible pavements are simpler and more economical than those in rigid pavements. Hot plant-mix bituminous pavements are adapted for extremely cold climates as they may be constructed under relatively adverse weather conditions. Soft grades of asphalt are recommended for preparing hot-mix types of pavement subject to low temperatures. Asphalt cement grade AP 1 (pen. 120-150) conforming to Federal Specifications SS-A-706b is generally recommended. AP 2 (pen. 100-120) may be used in areas where temperatures are relatively higher and weather may be warm part of the year. Paving operations should be coordinated so that the temperature loss of the mixture during transporting and spreading is kept at a minimum. There is a tendency to over-heat the bituminous material when preparing mixtures in cold weather; this should be avoided as the resultant pavements are brittle and short-lived. The spread mixture should be compacted as rapidly as possible to prevent further loss of temperature and to obtain a dense pavement.

In order to ensure satisfactory results, concrete pavements must be protected from freezing during the placement and curing period and must be permitted to gain substantial tensile strength before exposure to very low temperatures to minimize cracking. High early-strength cement with air entrainment is recommended. Joints should be at much smaller spacing than usual because of exceptional expansion and contraction.

3. BASE COURSE DESIGN IN AREAS OF NON-FROST-SUSCEPTIBLE SOILS. In areas where the soils are non-frost-susceptible, or where the soils are frost-susceptible but ground water conditions preclude significant ice segregation, design principles are the same as in temperate zones. Airfield pavements and bases should be designed in accordance with guidelines in the professional literature. If pockets of frost-susceptible-soil exist within the construction area, they should be removed and replaced with non-frost-susceptible materials. The area of excavation of such a pocket should be large enough to allow feather-edging of the backfill. The depth of excavation should be not less than the estimated depth of frost penetration in the backfill material.

4. BASE COURSE DESIGN IN AREAS OF FROST-SUSCEPTIBLIE SUBGRADES. Two acceptable methods of design of base courses are available where frost-susceptible soils and frost-susceptible ground water conditions exist. One method is to restrict the depth of seasonal thaw to the pavement and base course, thereby preventing surface subsidence and subgrade weakening. The other method is to allow thawing to penetrate the subgrade and to design on the basis of anticipated reduced strength of the subgrade during the thawing period.

In order to use the minimum base-course thickness required to restrict the seasonal thaw to pavement and base depth, consideration should be given to using relatively high moisture retaining non-frost-susceptible soils, such as uniform sands in the lower base. After initial freezing such soils provide considerable resistance to thaw penetration because of the high latent heat required to melt them. The use of frost-susceptible soils of groups F1 and F2 in the lower base is also permissible if some heaving may be tolerated and these soils are covered with a thickness of non-frost-susceptible base determined by use of the reduced strength of subgrade method. The depth of thaw penetration into such a layered base may be estimated by methods presented in the professional literature. For pavements of lesser importance where considerable heaving is allowable, the use of a group F3 or F4 soil in the lower base is permissible in extreme instances where more suitable materials are not available to prevent initial thawing of a high ice content subgrade with large ice concentration. In such cases, the minimum thickness of the non-frost-susceptible base course over group F3 or F4 soils shall be determined by the reduction in strength method and some, possibly objectionable, heaving should be anticipated.

4.1 DESIGN TO RESTRICT SEASONAL THAW TO PAVEMENT AND BASE DEPTH. In arctic regions a design which will keep the seasonal thaw within the base-course depth, will keep the subgrade frozen and prevent frost heaving or damaging surface settling. The required gravel base thickness may be determined from Figure 3, utilizing the thawing index of the pavement surface and the 5 percent base moisture content for which the curve is computed, unless information on base materials indicates a different moisture content can be maintained. For base courses at other moisture contents, the thicknesses shown in Figure 3 may be multiplied by the appropriate factor given in the note.

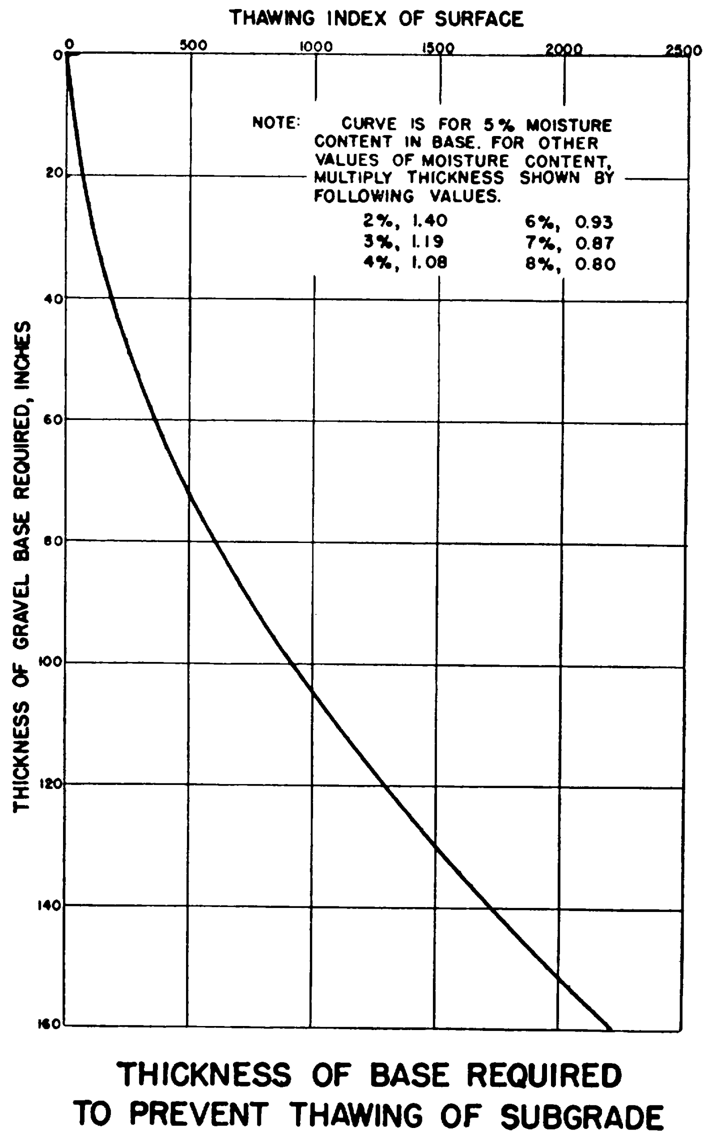


Figure 3.

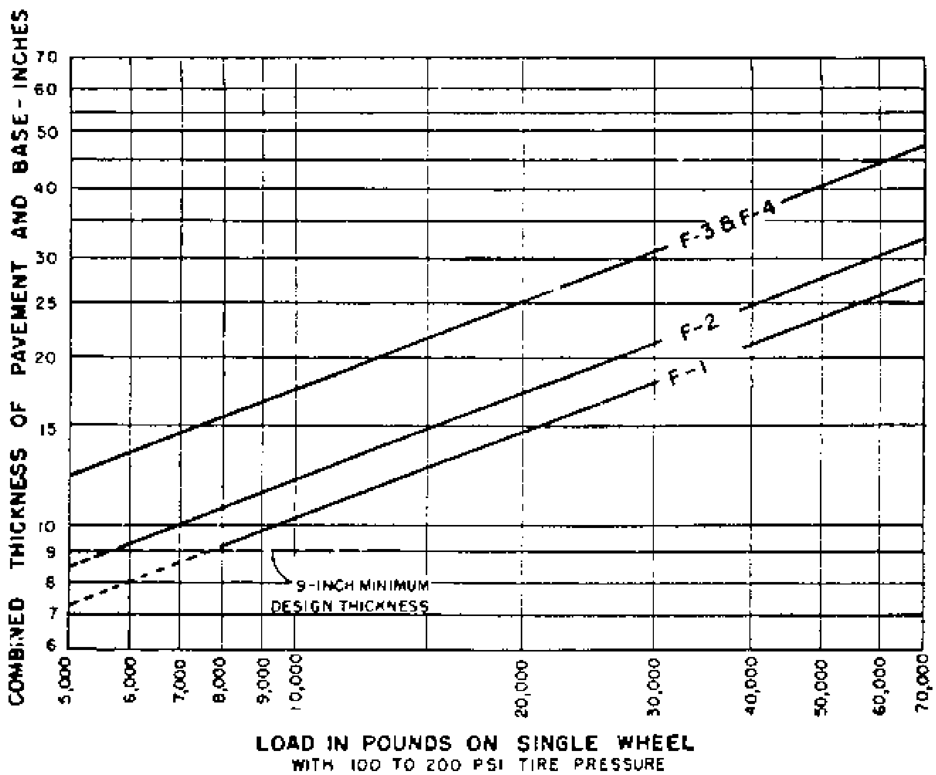
Observations have shown that a base consisting of non-frost-susceptible material normally has a moisture content between 3 and 6 percent. A completely saturated gravel base will only rarely contain more than 9 percent moisture. The surface thawing index may be computed by multiplying the thawing index based on air temperatures by a correction factor for the type of surface. This correction factor may be taken as 1.6 for bituminous pavements and 1.5 for portland cement concrete pavements. In each individual case the air thawing index should be computed with specific site data; however, order-of-magnitude values may be estimated from methods described in the professional literature. The thickness determined for Figure 3 is the thickness of the non-frost-susceptible base only and is not the combined thickness of pavement and base. Because of the fact that the surface course generally has a very small or negligible moisture content, it follows that little heat is lost in melting the frozen moisture therein. Thus, for determinations of this type, the thermal resistance of surface courses 6 inches thick, or less, may be neglected. It will be noted from Figure 3 that for a base thickness of 6 feet, the surface thawing index must be about 500 or less to restrict thawing to the gravel base course.

4.2 DESIGN BASED ON REDUCED STRENGTH OF SUBGRADE. Since the combined pavement and base thicknesses required to prevent thawing of the subgrade are commonly greater than 6 feet, except in extremely frigid areas, design must usually be based on the assumption that thawing and freezing will occur in the subgrade. This 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, or where subgrade variations are correctible to this condition by removal and replacement of pockets of more highly frost-susceptible or high ice content soils. This method may also be used for design of flexible pavements where appreciable non-uniform heave or subsidence can be tolerated in pavements of lesser importance (used for slow speed traffic) including pavements designed over group F4 subgrades. When the reduction in subgrade strength method is used for design of flexible pavements over subgrade soils of group F4, the combined pavement and base thickness should be determined using design curves for F3 and F4 soils shown on Figures 4 through 7. The use of the reduction for design of rigid pavements should be avoided if at all possible over group F3 soils and particularly over group F4 soils. If special needs or conditions dictate the use of rigid pavements over group F3 and F4 soils, a curve is included in Figure 10, so that the design can be made.

Use of the reduction in subgrade strength method for design of pavements for lightweight high-speed aircraft will give thicknesses adequate to carry traffic, but possibly may result in objectionable surface roughness due to heaving or subsidence. In such cases, design studies should include the compilation of frost heaving and settlement experience records from existing airfield or highway pavements in the vicinity where conditions are comparable. The amount, type, and distribution of ice formation in that portion of the existing frozen soil that will be thawed after pavement construction should be determined and an estimate made of the magnitude and probable unevenness that will result from future subsidence. Based on these design studies, the base-course thicknesses should be increased as necessary, over the thickness obtained *by the reduction in strength method*, to hold the differential surface heave or subsidence to a tolerable amount, or provisions made for resurfacing pavement periodically for a period of years to maintain a level surface. In order to accomplish this, base courses up to 6 feet in thickness may be required to reduce prohibitive differential heaving. Where the subgrade contains large, concentrated, buried ice masses, ice-filled polygon fissures and intense ice lens formations which will be subject to melting after pavement construction, the base thickness should be sufficient to prevent thawing of these ice masses or major maintenance anticipated.

In addition to the conditions stated above, it will be necessary to consider all reliable information concerning the performance of airfield and highway' pavements constructed in the area being investigated with a view toward modifying or increasing the design requirements. Local experience with soils of a particular frost-susceptible soil group may indicate that assigning the soils to the next highest or lowest grouping would best conform to actual behavior. Due regard should be given to freezing and ground water conditions in considering local experience with the soils.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F 2	SANDS CONTAINING BETWEEN 3 AND 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F 3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12. (d) VARVED CLAYS EXISTING WITH UNIFORM SUBGRADE CONDITIONS.
F 4	(a) ALL SILTS INCLUDING SANDY SILTS. (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12. (d) VARVED CLAYS EXISTING WITH NON-UNIFORM SUBGRADE CONDITIONS.



THE THICKNESS WILL BE REDUCED 10 PER CENT
FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT. SECTION AT EACH END)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS, ETC.
FOR
REDUCED STRENGTH OF SUBGRADE
ARCTIC AND SUBARCTIC REGIONS

Figure 4.

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F2	SANDS CONTAINING BETWEEN 3 AND 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
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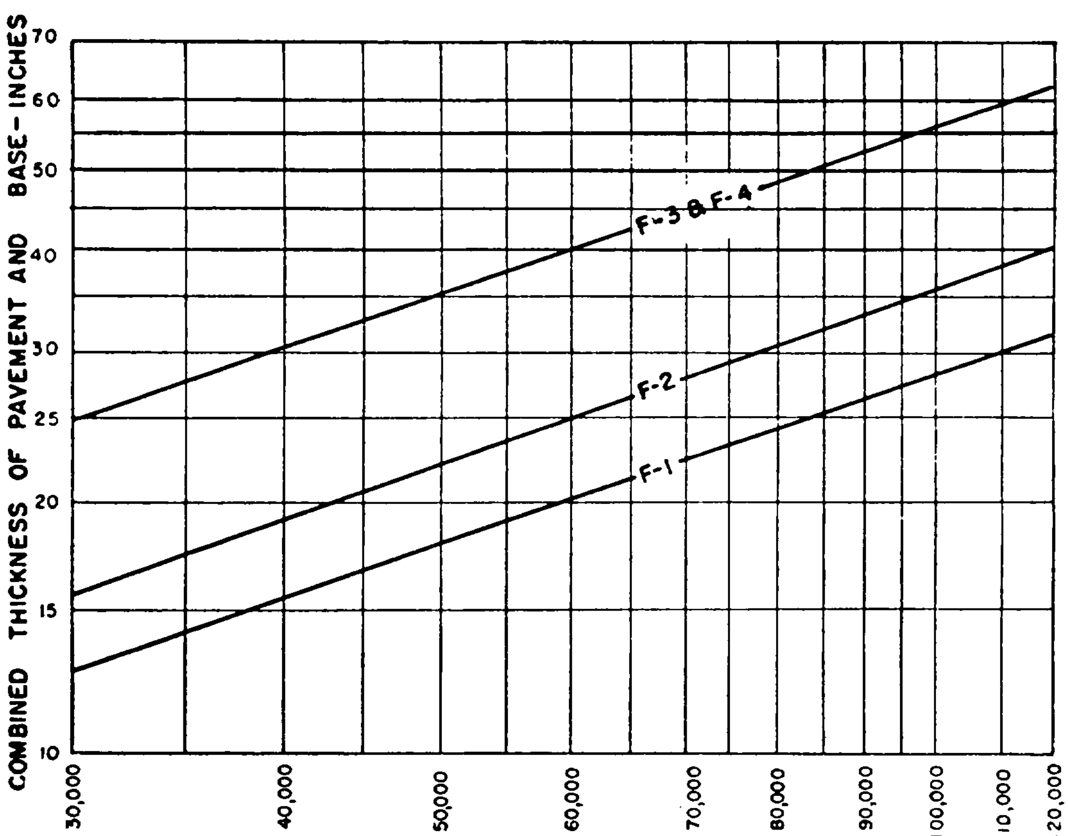

TOTAL LOAD IN POUNDS ON DUAL WHEELS 37.5" C.C.
267 SQ. IN. CONTACT AREA EACH WHEEL

THE THICKNESS WILL BE REDUCED 10 PER CENT
FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT. SECTION AT EACH END)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS, ETC.
FOR
REDUCED STRENGTH OF SUBGRADE
ARCTIC AND SUBARCTIC REGIONS

Figure 5.

GROUP	DESCRIPTION
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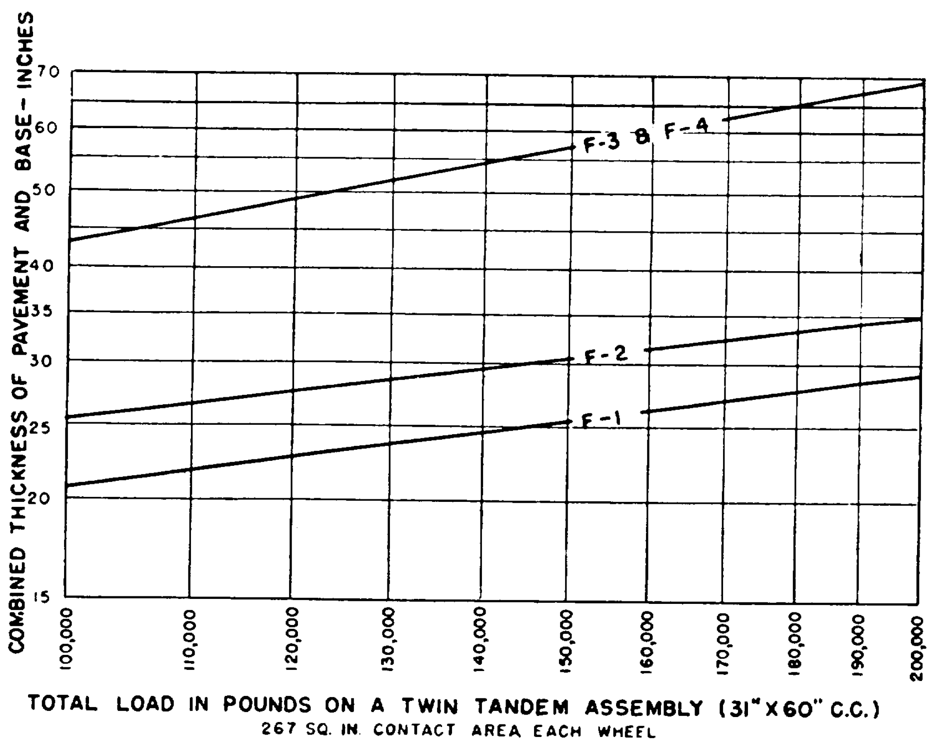

THE THICKNESS WILL BE REDUCED 10 PER CENT
FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT. SECTION AT EACH END)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS, ETC. -
FOR
REDUCED STRENGTH OF SUBGRADE
ARCTIC AND SUBARCTIC REGIONS

Figure 6.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
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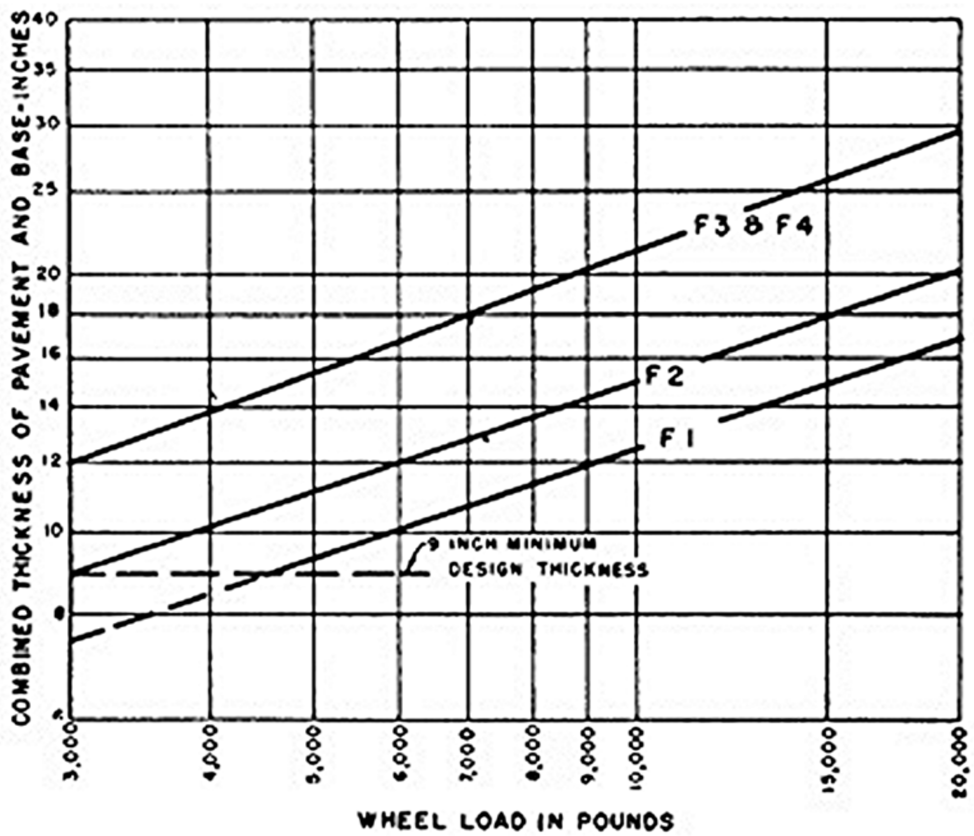


FLEXIBLE PAVEMENT DESIGN CURVES FOR HIGHWAYS, ETC.
FOR
REDUCED STRENGTH OF SUBGRADE
ARCTIC AND SUBARCTIC REGIONS

Figure 7.

4.2.1 FLEXIBLE PAVEMENTS. The curves of Figures 4, 5, and 6 should be used to determine the combined thickness of flexible pavement and non-frost-susceptible base required for various aircraft wheel loads and wheel assemblies, and Figure 7 should be used for highways. These curves reflect the reduction in strength of soil during the frost melting period.

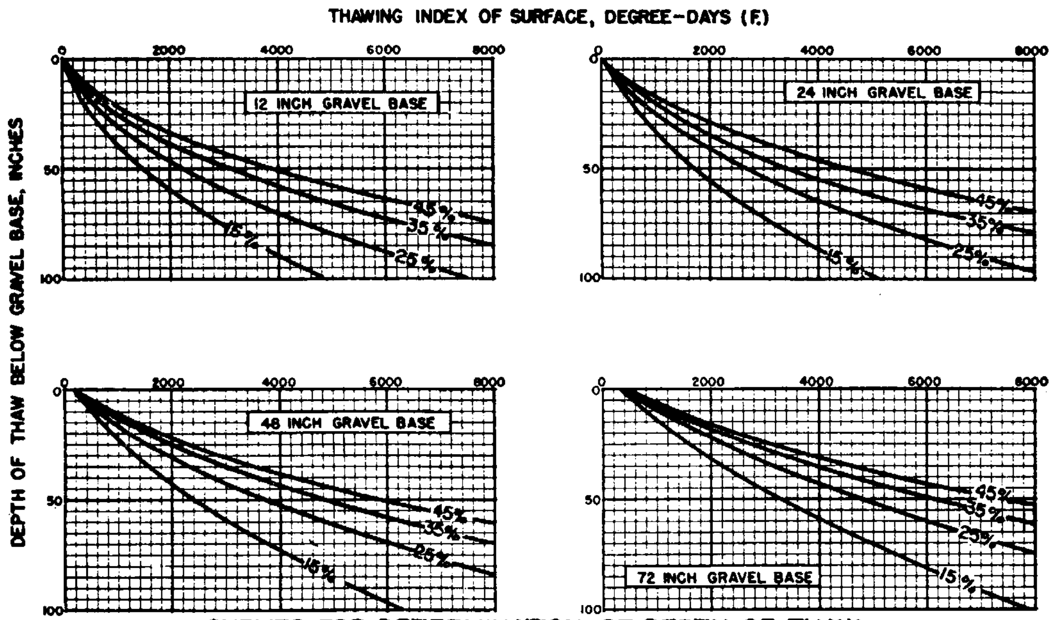
Since design thickness computed by this procedure does not prevent frost heaving, the annual depths of thaw and of freeze should be estimated from Figures 8 and 9. If subsoils are non-uniform or contain pockets of ice, differential surface movements may be expected which can be minimized by removal of such materials. The eventual development of abrupt surface irregularities in the finished pavement may be reduced by the tapering out of all excavations and backfills so as to ensure gradual transitions. If annual thaw is greater than freeze, the permafrost will degrade and the depth of thaw may become progressively greater. If the permafrost surface is at some depth beneath the designed pavement section, pockets of highly frost-susceptible soils within the depth of annual freeze should be removed.

In estimating the depth of annual freeze using Figure 9, the surface freezing index for bituminous surfaces (kept cleared of snow) may be computed by multiplying the freezing index based on air temperatures by a correction factor of 0.7.

4.2.2 RIGID PAVEMENTS. The thickness of concrete pavements should be determined in accordance with methods described in the professional literature for roads, using the subgrade modulus determined from Figure 10, which considers the reduced strength of the subgrade in conjunction with the modulus determined in the field. If the tested "k" value is smaller than the subgrade modulus obtained from Figure 10, the test value should govern the design. Where thawing and freezing are permitted in a frost-susceptible subgrade of group F1 or group F2 soil beneath a rigid pavement, the differential movement should be generally small.

Consequently, a non-frost-susceptible base course having a minimum thickness equal to that of the concrete slab should be used over these soils. In cases where rigid pavements are constructed over F3 soils, a non-frost-susceptible base course equal to a minimum of one and one-half times the concrete slab thickness should be used. In areas where a frost-susceptible subgrade soil of group F4 is present, appreciable total and differential movement may generally be expected. Therefore, a non-frost-susceptible base course of a thickness, equal to one-half the depth of the subgrade that will be subject to freezing and thawing, should be used over F4 soils. In the application of this criterion, the computed depth of freeze or thaw, whichever is less, will govern the depth of base course to be employed. In no case should the base-course thickness over an F4 soil be less than 24 inches or greater than 48 inches.

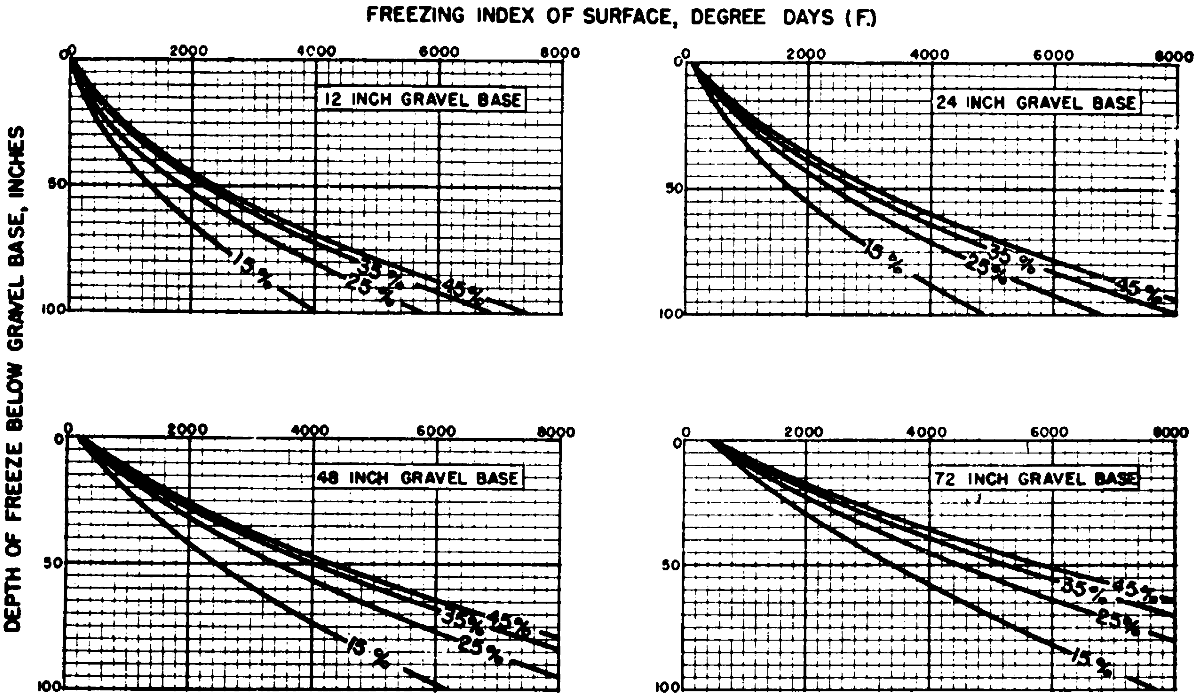
The annual depths of thaw and freeze can be estimated using Figures 8 and 9. The depths read from these curves can be considered as depths below the top of the subgrade. In calculations of depth of freeze, correction factor for portland cement concrete (kept clear of snow) may be taken as 0.6. If isolated pockets of ice or highly frost-susceptible materials exist to these depths of thaw and freeze, they should be replaced to minimize differential surface movements**.**



CURVES FOR DETERMINATION OF DEPTH OF THAW BENEATH PAVEMENTS WITH GRAVEL BASES

NOTE: VALUES ON CURVES ARE MOISTURE CONTENT OF FROST-SUSCEPTIBLE SUBGRADE
PAVEMENT SURFACE EITHER BITUMINOUS OR CONCRETE.
DEPTHS ARE FROM TOP OF SUBGRADE.

Figure 8.

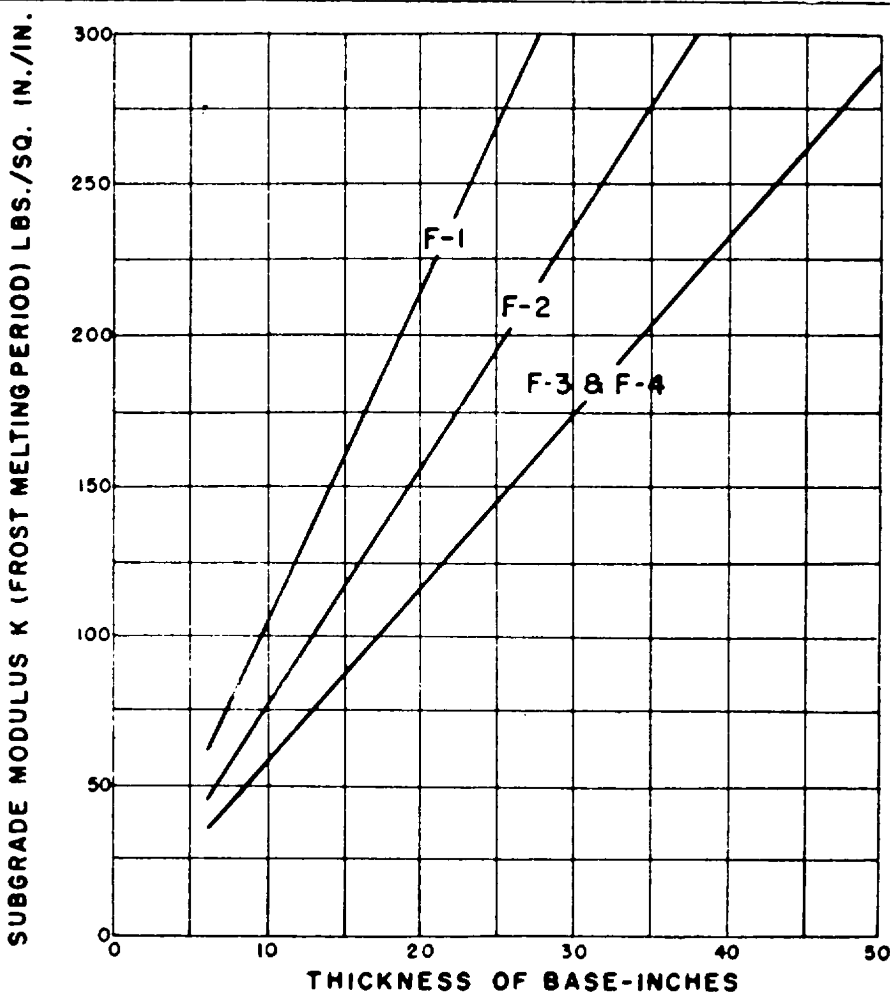


CURVES FOR DETERMINATION OF DEPTH OF FREEZE
BENEATH PAVEMENTS WITH GRAVEL BASES

NOTE: VALUES ON CURVES ARE MOISTURE CONTENT OF FROST-SUSCEPTABLE SUBGRADE
PAVEMENT SURFACE EITHER BITUMINOUS OR CONCRETE.
DEPTHS ARE FROM TOP OF SUBGRADE.

Figure 9.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F 2	SANDS CONTAINING BETWEEN 3 AND 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F 3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12. (d) VARVED CLAYS EXISTING WITH UNIFORM SUBGRADE CONDITIONS.
F 4	(a) ALL SILTS INCLUDING SANDY SILTS. (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS EXISTING WITH NON-UNIFORM SUBGRADE CONDITIONS.



RIGID PAVEMENT SUBGRADE MODULUS CURVES
FOR
REDUCED STRENGTH OF SUBGRADE
ARCTIC AND SUBARCTIC REGIONS

Figure 10.

5. BASE COURSE DESIGN IN AREAS OF HIGHLY ORGANIC SOILS. Every effort should be made to avoid construction on organic soils. However, because of the existence of extensive peat bogs and muskeg in the Arctic and Subarctic, it is occasionally necessary to construct roads on such areas because of the lack of an alternate route. In this case a thorough soil survey should be made to determine the depth and extent of the soft sediments in order that the best possible route may be determined. From field experience it is considered that in bogs having a surficial peat deposit less than 5 feet thick, the peat should be removed and replaced with granular fill. In deep peat bogs fill may be placed directly on the undisturbed cover. In either case the fill should be at least 5 feet thick regardless of surfacing and, in the latter instance, it may be found that great quantities of fill may be necessary as the underlying organic material is compressed or forced out to the sides. In any event continued differential settlement and almost constant maintenance may be expected.

6. DRAINAGE. Drainage ditches should be deep and narrow to minimize their surface area. They should preferably be lined to prevent seepage which would increase the depth of thaw, and prevent erosion which might cause blockage and ponding. Ponding must be avoided as it causes icing. Frequent culverts of double the normal capacity are valuable whereas subdrains are of little use. A steam pipe should be installed in every culvert to permit artificial thawing.

7. CORDUROY ROADS. Where standing timber is available, corduroy may be used for temporary roads and sometimes in permanent roads over poor soils, if better material is unobtainable. Corduroy must be protected by a sand, gravel, or stone cover.

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*Functions of the former Permafrost Division are now incorporated in the Arctic Construction and Frost Effects Laboratory, New England Division, Boston, Mass