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Frost Design Criteria for Pavements

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THE increases in traffic and wheel loadings on airfield and highway pavements in the past 10 to 15 years; the rising costs of pavement construction, maintenance, and repair; the greater need for maintaining pavements in fully serviceable condition at all times; and the increasing of operating speeds have made it necessary to consider frost action in greater detail in pavement design. This paper describes criteria formulated by the Corps of Engineers to meet the needs of its construction in areas of seasonal frost.

The variation of subgrade strength through the seasons is illustrated, and it is indicated that the frost-melting period is critical when conditions are conducive to active frost action. Methods for recognition of conditions of soil, temperature, and moisture which result in detrimental frost action are described. Base composition requirements are given. Load design charts for airfield and highway flexible pavements for various types of loadings are presented. Load-design criteria for rigid pavements are also given. The application of these methods is illustrated by means of design examples. Needed studies to further improve the present design criteria are discussed.

● THE detrimental effects of frost action in subsurface materials are manifested by heave of pavements or other structures during the winter and by loss of strength of affected soils with a corresponding reduction in load-supporting capacity during the period of weakening which ensues. In pavements, these effects may result in unsatisfactory riding qualities, excessive maintenance, hazardous operational conditions, or pavement breakup.

In highways, the great increases in traffic and wheel loads in the past decade may cause pavements which formerly appeared adequate to deteriorate in the spring. The interruption or slowing of traffic and damage to equipment which may result from frost action involves much more money value under the increased traffic conditions than in the past. The corresponding cost for maintenance, repair, and rebuilding of frost-damaged pavements is also increased.

On airfields, the great increases in wheel loadings have created problems not encountered on highways, because of deeper and more intense stressing of the subgrade. There must also be considered the possibility of damage or hazard to expensive present-day planes and their crews. This involves the necessity for maintaining smooth surfaces on runways where speeds may exceed 100 mph.

Thus, the detrimental effects of frost action must be taken into account in pavement design. At the same time, we must strive to avoid over design, since every extra inch of pavement structure will add enormously to the cost of pavements when multiplied over all highway and airfield pavements constructed over soils subject to the frost action.

The present paper describes frost design criteria developed by the Corps of Engineers to meet design needs in areas of seasonal frost action. The criteria are based on the assumption that permanent military pavements should be designed so that there will be no interruption of traffic at any time of the year due to differential heave, reduction in load-supporting capacity, or deterioration of the pavement resulting from frost action.

The criteria have been developed in the Frost Effects Laboratory, New England Division, Boston, Massachusetts, for the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers, U. S. Army. The studies are continuing, and it is anticipated that improvements will be made in the criteria from time to time in the future.

DEFINITIONS

The following specialized terms are used in this paper:

Degree-day is each degree in any one day that the average daily air temperature varies from 32 F. The difference between the average daily temperature and 32 F. equals the degree days for that day. The degree days are minus when the average daily temperature is below 32 F. and plus when above. A cumulative degree-days-time curve is obtained by plotting cumulative degree-days against time as illustrated in Figure 2.

Freezing index is the number of degree-days between the highest and lowest points on the cumulative degree-days-time curve for one freezing season (see Fig. 2). 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 temperatures at 4.5 ft. above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is known as surface freezing index.

Mean freezing index is the freezing index determined on the basis of mean temperatures.

Frost action is a general term used in reference to freezing and thawing of moisture in materials and the resultant effects on these materials and the structures of which they are a part or with which they are in contact.

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

Frost boil is the breaking of a highway or airfield surface under traffic and ejection of subgrade soils in a soft and soupy condition caused by the melting of the segregated ice formed by frost action.

Frost heave is the raising of a surface due to the formation of ice in the underlying soil.

Frost-melting period is an interval of the year during which the ice in the foundation materials is returning to a liquid state. It ends when all the ice in the ground has melted or when freezing is resumed. Although in the generalized

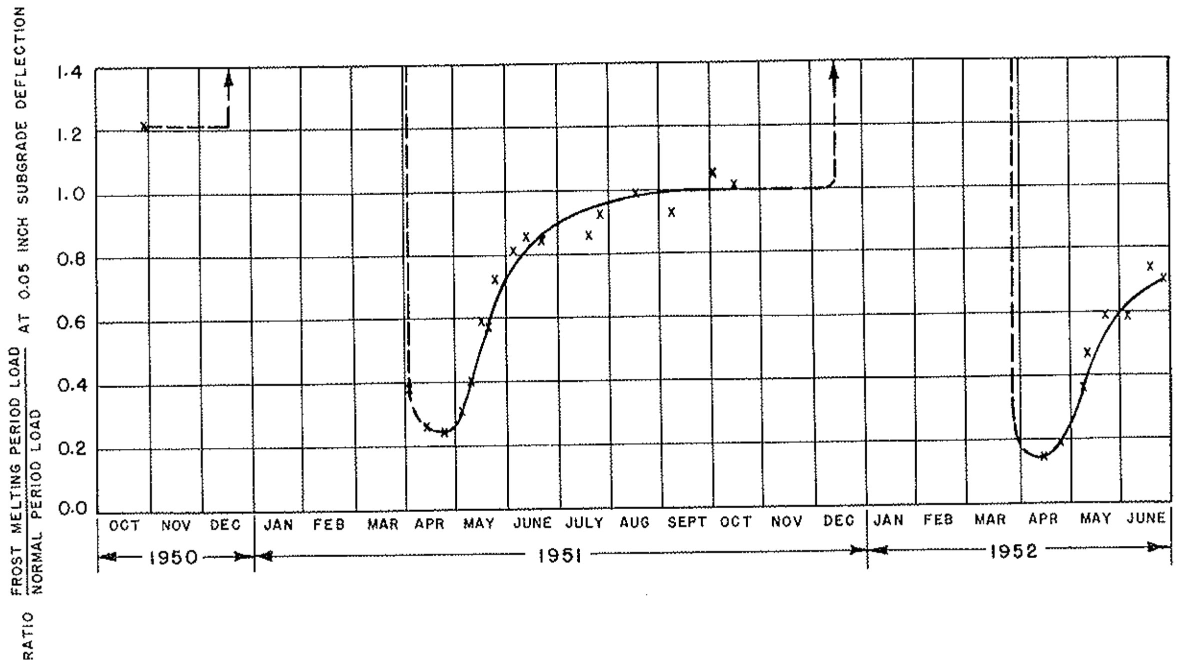


Figure 1. Results of static-load tests with 30-in.-diameter plate on 18-in. bituminous-surface-treated gravel base course for Limestone, Maine, frost test section, average of Positions 3 and 4.

case there is visualized only one frost-melting period, beginning during the general rise of air temperatures in the spring, one or more significant frost-melting intervals may occur during the winter season.

Frost-susceptible soils are those in which significant ice segregation will occur when the requisite moisture and freezing conditions are present.

Non-frost-susceptible materials are materials such as crushed rock, gravel, sand, slag, cinders, or any other cohesionless material in which ice segregation does not occur under natural freezing conditions.

Pavement pumping is the ejection of soil-water mixture from joints and cracks of rigid pavements under the action of traffic.

A coverage is one application of the wheel load over each point in the most heavily travelled area of the traffic lane. Four and 40 coverages are assumed here to correspond approximately to 30 and 300 landing and take-off cycles, respectively, on an airfield.

Frost capacity design is a pavement design which will be adequate under maximum traffic usage throughout the frost-melting period. For airfields, this usage corresponds to approximately 40 total coverages per day during the period of weakening due to frost, by the design wheel load and assembly. Greater frequencies of operation can be tolerated with loadings lighter than the design loading.

Frost limited design is design intended to be adequate under a definitely restricted number of coverages per day during the period of weakening due to frost, by the design wheel load and assembly. For airfields, this design corresponds to approximately four coverages per day. Greater frequencies of operation can be tolerated with loadings lighter than the design loading.

ICE SEGREGATION AND ITS EFFECTS

Evidence indicates that ice segregation will always occur in a frost-susceptible soil when it is frozen gradually, under conditions similar to those experienced in nature, with ample water available. A cross section through such a frozen soil will commonly show the segregated ice as lenses, layers, veins, and irregular masses. However, under some conditions and with some soils, the segregation may occur so uniformly through the soil mass that it may be difficult to determine visually the extent to which ice formation may have occurred.

In soils where appreciable water is drawn from below into the zone of freezing, pavement heave is the most obvious sign of ice segregation. However, in clays considerable ice segregation may occur without appreciable heave, the water to form ice lenses being obtained by pulling it out of the directly adjacent soil, which tends to be consolidated in the process. In this case, the only heave is that represented by the relatively small expansion resulting from change of a portion of the soil water from the liquid to the solid state. Spring breakup of pavements on fine-grained soils may sometimes be attributed erroneously to other phenomena than frost action simply because no heave has been noticed. Also, it is a normal tendency to dig an exploratory test pit only after the failure has become apparent; such an investigation may find no signs of ice segregation, the ice having, by that time, already melted.

Although pavement heave is definitely a problem in design, the subsequent weakening in the frost-melting period is more serious. As frost melting penetrates a frost-susceptible subgrade underlying a pavement, the melting of segregated ice releases an excess of water which must (1) escape upward to the surface of the subgrade or (2) be absorbed by the thawed soil. In either case, the thawed soil is loose, with a disrupted structure and an excess of moisture. Its shearing strength is therefore low. Even though ice segregation may have been weak, marked weakening of the load-supporting capacity may result if the soil conditions are such that a small increase in moisture content resulting from the frost action will cause appreciable loss of strength. The most critical period is usually from a few days to 3 week's duration, and as the excess water drains from the subgrade, the pavement gradually regains strength. The time during which strength continues to be regained varies from a few weeks to several months, depending upon the intensity of ice segregation, depth of frost penetration, rate of thawing, permeability of the soil, drainage, and traffic conditions.

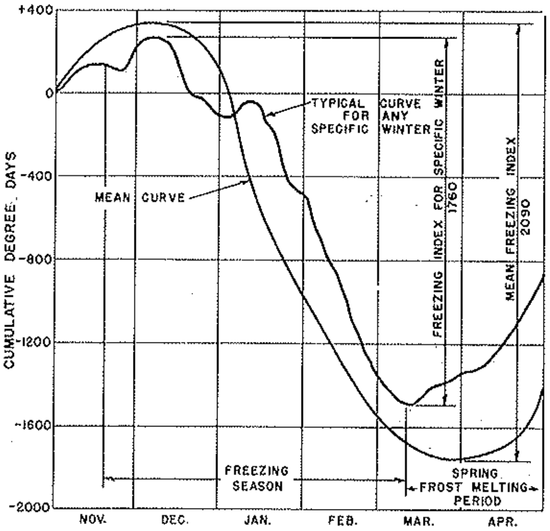
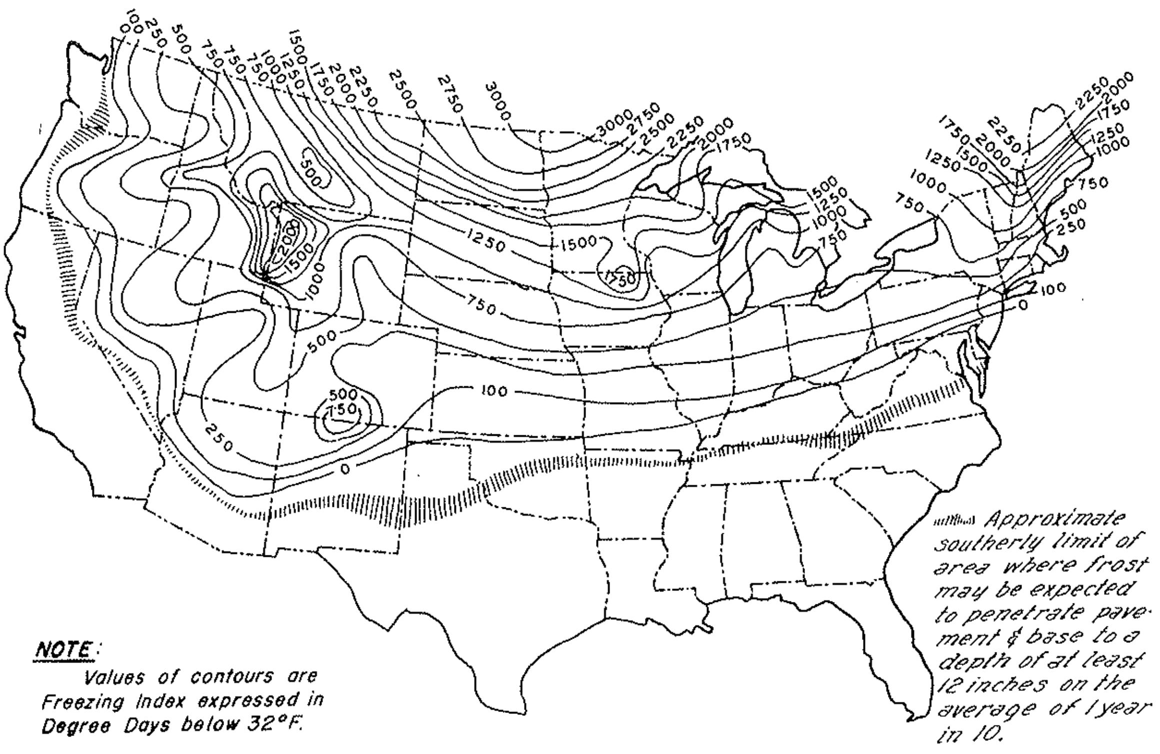


Figure 2. Determination of freezing index.

Figure 1 shows the variation of subgrade strength under a bituminous-surface-treated, 18-in. gravel base course at Limestone Air Force Base in Maine during 1950 to 1952, as measured by plate-bearing tests. A plate bearing test on a frost-softened subgrade is not considered a good measure of magnitude, of reduction in bearing capacity under traffic. However, it does provide a means of picturing (1) the relative change of strength through the season and (2) the duration of weakening. Conditions represented by the series of tests shown in Figure 1 are not atypical of many pavements on frost-susceptible soils, in areas subject to frost action. The regain of bearing capacity after the sudden drop during the spring frost-melting period is seen to be rapid at first, then somewhat slower. It is interesting to note that the loss of strength was apparently considerably greater in the spring of 1952 than in the spring of 1951. The test area did not receive traffic during the series of tests. If it had, the wheel loadings might have hastened the reconsolidation, but also the remolding effect of the traffic might have increased the degree of weakening.

It is obvious from Figure 1 that under seasonal frost conditions the bearing capacity of the pavement is not a fixed thing, but is something which is constantly changing. If our design is based on field soil tests and natural conditions, we are



NOTE:
Values of contours are Freezing Index expressed in Degree Days below 32°F.

Approximate southerly limit of area where frost may be expected to penetrate pavement & base to a depth of at least 12 inches on the average of 1 year in 10.

Figure 3. Mean freezing-index data influencing frost action.

likely to obtain different designs depending upon the particular time of year when we obtain our field data.' The strength in the frost-melting period is seen to be the critical value which must be considered in design. This spring weakening has long been recognized in the practice of limiting wheel loads to arbitrarily reduced values in the spring. On some airfields a comparable result has been obtained by limiting number of daily landings and take-offs during the weakened period. While such approaches are practical in many instances, they present an enforcement problem and are impractical for high-traffic-capacity roads or airfields.

Less conspicuous than either heave or weakening due to frost melt is the general roughening of an initially level pavement with time as a result of either differential changes in subgrade density as a result of frost action, or of overstressing during the frost-melting period, causing deterioration at a faster rate than otherwise would apply and which logically must be considered as an economic loss.

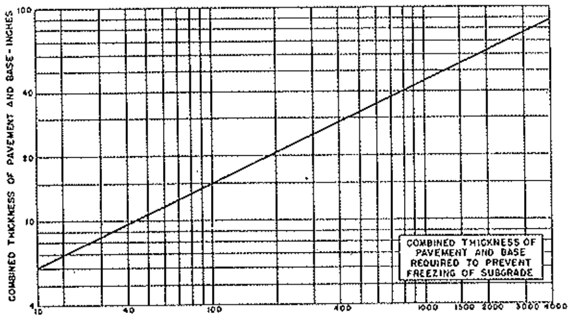


Figure 4. Combined thicknees of pavement and base required to prevent freezing of subgrade.

RECOGNITION OF FROST-SUSCEPTIBLE CONDITIONS

Direct evidence of the frost activity of the subgrade may not be unavailable or inadequate, or it may not be feasible to perform necessary field invesitgations during the freezing and frost-melting periods. Therfore, determination as to whether or not frost-evaluation criteria are applicable is usually based on the gradations of the base course and subgrade soils, and on ground-water conditions and air-temperature records. However, all reliable information on past performance of comparable pavements in the area during the freezing season and frost-melting period should be considered. Maintenance and traffic records may assist in confirming whether or not frost-susceptible conditions exist. Visible surface effects which may contribute to the picture and which are associated with frost action are pavement heave and surface cracking during the winter season, and alligator cracking, frost boils, noticeable weakening, shoving or deflection, and pumping in cracks and joints during the frost-melting period. When the presence of such defects, or the absence of them, is used as a guide in the design, the freezing index and moisture-condition data for the location during the actual years of record must be examined carefully to determine whether the severity of the frost conditions during the period of observation can be considered representative.

In order for ice segregation to occur, three conditions must exist simultaneously: the soil must be frost susceptible; freezing temperatures must penetrate the frost-susceptible soil, and a sufficient supply of water must be available.

Soil

The potential intensity of ice segregation in the soil is dependent to a large degree on its 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 considered generally frost susceptible. Certain sandy soils may have as high as three or four times this percentage of grains finer than 0.02 mm. without being frost susceptible; however, because of their tendency to occur interbedded with other soils, it has been considered generally impractical to consider them separately. Inorganic soils containing less than 3 percent of grains finer than 0.02 mm. in diameter by weight are generally not frost susceptible.

In borderline cases the Frost Effects Laboratory performs freezing tests on the soils to measure the relative frost susceptibility to ice segregation. This service has been performed on soils from government construction projects covering a wide range of geographical locations.

Frost-susceptible soils have been classified into four groups, listed in order of increasing susceptibility. Group F4 soils have particularly high frost susceptibility. Soil names correspond with those defined in the Department of the Army Uniform Soil Classification.

Group	Description
F1	Gravelly soils containing between 3 and 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 0.	(a) Gravelly soils, containing more than 20 percent finer than 0.02 mm. by weight, and sands, except fine silty sands, containing more than 15 percent finer than 0.02 mm. by weight. (b) Clays with plasticity indices of more than 12 except varved clays.
F4	(a) All silts including sandy silts. (b) Fine silty sands containing more than 15 percent finer than 0.02 mm. by weight. (c) Lean clays with plasticity indices of less than 12. (d) Varved clays.

Temperature

The depth to which frost will penetrate below the surface of the pavement kept clear of snow depends principally on the magnitude and duration of below-freezing air temperatures, of which the freezing index provides a measure, and on the amount of water which is frozen in the subgrade. Figure 2 illustrates the computation of the freezing index. An approximate value of the mean freezing index may be obtained from Figure 3, on which are plotted isograms of mean freezing index for the continental United States. However, it is prefereble to compute the freezing index from actual daily mean air temperatures measured at a weather observation station in the particular locality, based on a long period of record.

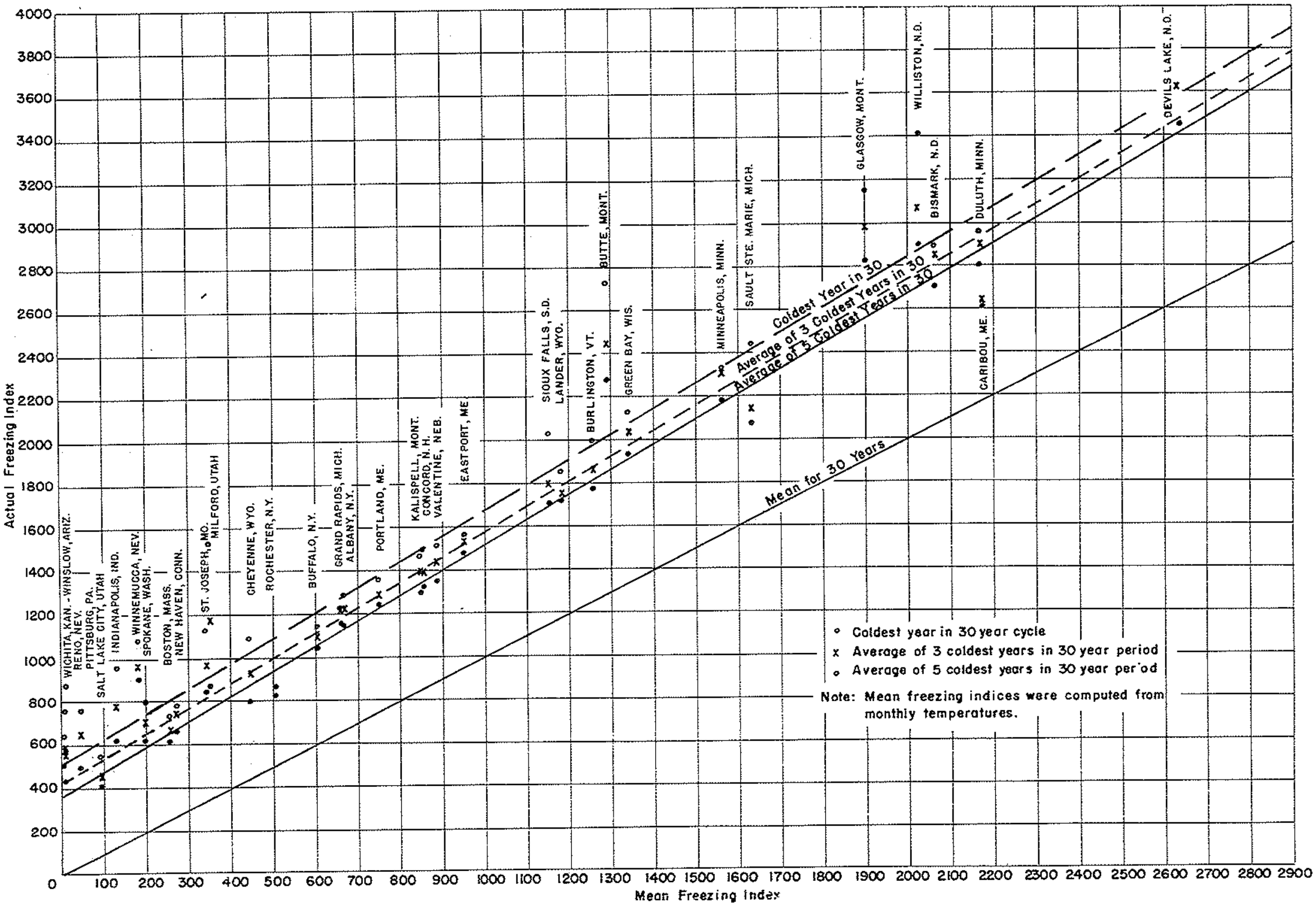


Figure 5. Relationship between mean freezing index and freezing indexes during colder years for 50 consecutive years.

An empirical chart showing the relationship between air freezing index and depth of frost penetration for the case of a drained, granular, non-frost-susceptible base course beneath a paved area kept free of snow, is shown on Figure 4. The relationship shown on this chart is an approximation, since it averages together the effects of such variables as pavement type and base-course density and moisture content. More comprehensive methods, which take these variables into account, have been studied in the Frost Effects Laboratory (1, 2) and the Permafrost Division, St. Paul District, Corps of Engineers. Carlson has described the Permafrost Division studies (3), in which emphasis is on calculation of depth of thaw. Improvement of these methods is still in progress. These methods should be used where detailed computations are required.

Fluctuations in the severity of winter freezing and in the rate of spring thawing, combined with fluctuations in seasonal ground-water conditions, cause wide variations in frost action from year to year and also between localities in any one year. Experience in the continental United States indicates that in 1 year out of perhaps every 5 to 10 years frost action conditions at any given locality are considerably more severe than the average. The results of a comparison between the mean freezing index and the freezing indices during the colder years, for a 30-year record from approximately 35 Weather Bureau Stations with a wide geographical distribution, is shown on Figure 5. It will be observed that in areas of relatively low mean freezing index the relative variation from mean temperature conditions may be very large. This condition also exists for some distance south of the zero mean freezing index isogram (see Fig. 3).

The design freezing index is, at present, usually based on the mean freezing index. However, the data on Figure 5 suggest that a more significant freezing index value would be obtained by selecting the value which occurs, let us say, about one year in ten, particularly in areas of low mean freezing index. On Figure 5 this would correspond to the average of the three highest freezing indices in the 30 years of record. In general, the magnitude of the freezing index value is not a measure of the intensity of ice segregation, but rather of the depth of frost penetration. Use of the one-year-in-ten freezing index in place of the mean freezing index would bring under the frost design criteria pavements and regions to which they would not otherwise apply. The greater depth of frost penetration would also correspond with longer critical weakened periods under traffic. The selection of design freezing index involves a balancing of the cumulative loss from frost damage over the life of the construction against the cost of protective measures. The proposal for use of a one-year-in-ten freezing index rather than the mean is tentative and is still under study.

Water

Moisture required for formation of segregated ice within the soil may be derived from an underlying ground-water table, from infiltration through the pavement or at the shoulders, from an aquifer, or from the water held within the voids of fine-grained soils adjacent to the freezing plane. A potentially troublesome water supply for ice segregation is considered to be present if the highest ground water at any time of the year is within 5 ft. of the proposed subgrade surface or of the top of any frost susceptible subbase materials used. When the depth to the uppermost water table is in excess of 10 ft. throughout the year, a condition of troublesome water supply is considered usually not present. However, these water-table criteria are not necessarily applicable for impervious clay soils if the water content is sufficiently high, since it has been found that ice segregation will occur in homogeneous clay soils at moisture contents down to approximately shrinkage limit of the clay, without any other water being available for freezing than that originally contained in the soil voids.

MAGNITUDE OF SUBGRADE WEAKENING DUE TO FROST ACTION

The degree to which the soil loses strength during the frost-melting period and the length of the period during which the strength of the soil is reduced depend on the type and condition of the soil, depth of frost penetration, temperature conditions during freezing and thawing periods, the amount and type of traffic during the frost-melting period, the availability of water during the freezing period, and drainage conditions. The application of traffic may cause remolding or develop hydrostatic pressures within the pores of the soil during the period of weakening, resulting in subgrade strength reduced appreciably below that measured by static tests. Traffic tests performed by the Corps of Engineers (4) have shown that the wheel-load-supporting capacity of a flexible pavement during the frost-melting period may be of the order of one third of the normal period wheel-load evaluation. Rigid pavements, on the other hand, have been found to retain about three quarters of their normal period wheel-load-supporting capacities. The smaller reduction in strength of rigid pavements due to frost action is attributed to the fact that the supporting capacities of rigid pavements are not influenced to as great a degree as flexible pavements by changes in the subgrade strength, and in addition, there is less loss in strength due to shearing deformation and remolding during the critical spring frost-melting period.

BASE COMPOSITION REQUIREMENTS

All base-course materials specified by the design criteria are required to be not frost susceptible, except for any portions which may extend below the predicted depth of frost penetration. Where the combined thickness of pavement and base over a frost-susceptible material is less than the predicted depth of frost penetration, the following additional design requirements apply:

1. For both flexible and rigid pavements, the bottom 4 in. of base course is required to be composed of any non-frost-susceptible gravel, sand, or crushed stone and is required to be designed as a filter between the subgrade soil and overlying base course, in order to prevent mixing of a frost-susceptible subgrade with the base during, and immediately following, the frost-melting period. The gradation of this filter material is determined in accordance with the filter criteria used in subsurface drainage design, with the added overriding limitation that the filter material shall, in no case, have more than 3 percent by weight finer than 0.02 mm.
2. For rigid pavements, the 85-percent size of the filter or regular base-course material placed directly beneath the pavement is required to be equal to or greater than a given diameter in order to prevent loss of support by pumping soil through the joints of the rigid pavement. This diameter is presently specified as ½ in., but study has indicated that this is probably too conservative under modern construction practices and consideration is now being given to reducing this 85-percent-size value.

LOAD DESIGN CRITERIA

Where the investigations of soil, temperature, and moisture conditions indicate that a frost-weakening problem does not exist, the pavement design is made in accordance with the standard methods for flexible or rigid pavements. However, if the investigations show that a frost problem does exist, then two alternate methods of design are available which will assure safe carrying of the design wheel load. First, enough thickness of pavement and base can be provided so that frost does not enter the susceptible soil. Second, we can base our design on the reduced strength of the frost-susceptible soil during the frost-melting period and provide sufficient thickness of pavement and non-frost-susceptible base above it to carry, during the most critical days of the frost-melting period, the anticipated rate of coverages of the design load.

Preventing Freezing of Subgrade

In this method the combined thickness of rigid or flexible pavement and base is chosen to be not less than the depth of frost penetration determined from Figure 4, using the design freezing index determined for the particular locality. This method is required (1) over the extremely frost-susceptible, type F4 soils or (2) wherever significant differential pavement heave will be detrimental to high-speed traffic. However, the method is not required in the case of flexible-pavement areas where appreciable differential heave may be tolerated, such as parking areas. Exception is also permitted when the causes of nonuniform heaving can be satisfactorily corrected by the removal of isolated pockets of highly frost-susceptible soils for the full depth of frost penetration or by providing gradual transitions at abrupt changes in subgrade conditions. In these cases, frost may be permitted to enter the subgrade and design is then based on reduction in subgrade strength.

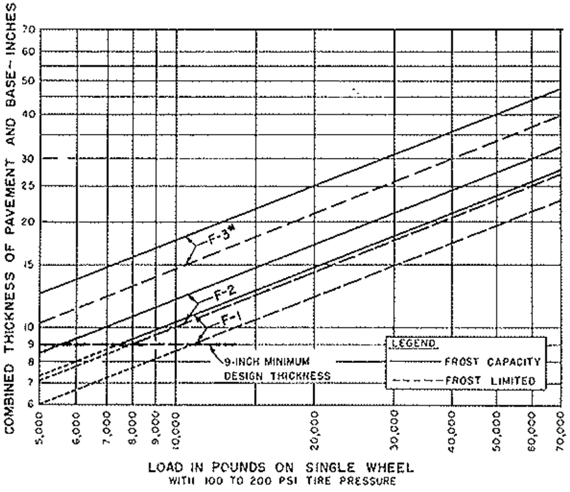
The full-protection-design method produces pavement-supporting characteristics which are fairly uniform through the year but which may be very conservative with respect to strength. The cost of this method rises with increase in depth of annual frost penetration. In regions of deep seasonal frost penetration the method is not feasible, even in cases where heavy wheel loadings would require heavy base courses in any event, and here arbitrary limits must be set upon the maximum thickness of base course. In extreme northerly areas the situation is reversed, and there full protection against thaw of the subgrade may be possible. The full-protection - design methods described should be considered limited to conditions comparable to those encountered within the continental limits of the United States.

Reduction in Subgrade Strength

Design based on the reduction in strength of the subgrade during the spring frost-melting period will frequently permit less depth of pavement and base than is required for prevention of freezing of the subgrade. This method is applicable for both flexible and rigid pavements on subgrade soils of Groups F1, F2, and F3, when subgrade conditions are sufficiently uniform to assure that objectionable differential heaving will not occur or where subgrade variations are correctible to this condition. As previously noted, the method may also be used where appreciable nonuniform heave can be tolerated, in flexible pavements of lesser importance not subject to high speed traffic. The design procedure provides a pavement which is just barely adequate during the frost-melting period but which necessarily has excess strength during the remainder of the year.

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 AND SANDS, EXCEPT FINE SILTY SANDS, CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (b) CLAYS WITH PLASTICITY INDICES OF MORE THAN 12, EXCEPT VARVED CLAYS.
F 4	(a) ALL SILTS INCLUDING SANDY SILTS. (b) FINE SILTY SANDS CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (c) LEAN CLAYS WITH PLASTICITY INDICES OF LESS THAN 12. (d) VARVED CLAYS.

* When frost is permitted to penetrate group F4 soils, use same design curve as for group F3 soils. Frost should be permitted to penetrate F4 soils only under flexible paved areas of lesser importance where appreciable non-uniform pavement heave may be tolerated.



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

Figure 6. Flexible-pavement design curves for taxiways, etc., for frost action in subgrade soil.

For airfield usage, two design categories have been chosen for design based on reduction in subgrade strength. Frost limited and frost capacity are used to denote approximately 4 and 40 total coverages per day, respectively, during the period of weakening due to frost, by airplane with weights equal to the design loadings. The frost-limited information represented here is tentative only. It is subject to revision and is presented only to illustrate the concepts involved in current studies. The frost-capacity category is normally used for design. The frost-limited category will normally be used only for evaluation of existing pavements to determine what loadings may be tolerated in the spring under a relatively small number of traffic operations. For flexible pavements, separate design curves have been prepared for the two operational conditions, the frost limited curves being tentative, as noted. No separate frost-limited design curves have been prepared for rigid pavements. However, where this condi-

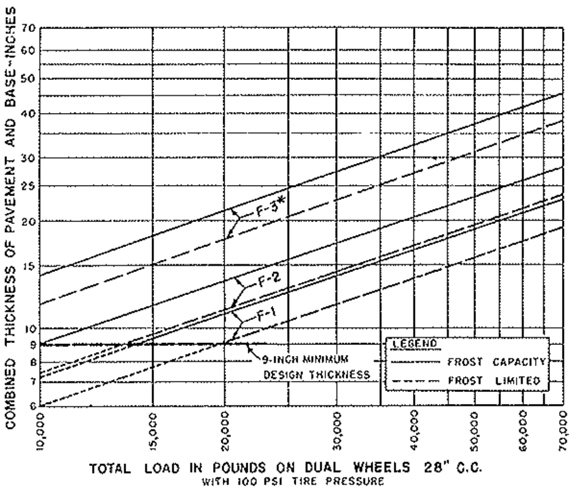


Figure 7.

tion must be considered, 10 percent less pavement thickness than that required for frost-capacity design is considered adequate for the frost-limited traffic.

1. Reduction in Strength Criteria for Flexible Pavements. When freezing is permitted in the subgrade, the combined thickness of flexible pavement and non-frost-susceptible base required for the design assembly and loading is determined from the applicable curve among Figures 6 through 10, Figure 10 being the highway design chart. The designs produced by these curves have previously been compared with the results of an extensive series of traffic tests in the frost-melting period, in a paper presented before the Highway Research Board in 1951 (4). However, since the referenced paper was presented, the curves have been adjusted to give approximately 10 percent less required pavement thickness and the frost-limited concept has been added.

The curves reflect the reduction in strength of the soil during the frost-melting period. It is considered that the reduction in strength of subgrades tends, generally, to be greater in cuts than in fills. If field data and experience definitely indicate that the reduction in strength in fill areas may be expected to be less, because of such factor as the greater depth to water table, a reduction in combined thickness of base and pavement for the fill area may be permitted. In no case is a combined thickness of pavement and non-frost-susceptible base less than 9 in. permitted in design, where frost action is a factor, although smaller combined thickness may have to be considered in evaluation of an existing pavement. Curves on Figures 6, 7 and 10 are therefore shown dotted below 9-in. thickness.

2. Reduction in Strength Criteria for Rigid Pavements. With certain exceptions, a non-frost-susceptible base course equal in thickness to the thickness of the concrete slab is required where frost penetration is permitted into a frost susceptible subgrade beneath a rigid pavement. The specific exceptions to this requirement are as follows:

A. Where soils of Groups F1, F2, and F3 occur under very uniform conditions of subgrade and the freezing index is less than 500, the thickness of the non-frost-susceptible base under a rigid pavement may be reduced to 4 in.; it is designed to meet filter requirements outlined previously under "Base Composition Requirements."

B. Where soils of Groups F1, F2, and F3 occur under uniform conditions and the depth to the uppermost water table is greater than 10 ft., the thickness of the non-frost-susceptible base under a rigid pavement may be reduced to 4 in., and the base is designed as a filter.

C. Over Group F4 soils the combined thickness of rigid pavement and base is determined according to the criteria for prevention of freezing of the subgrade.

The thickness of concrete pavement is determined on basis of anticipated flexural strengths and subgrade modulus using

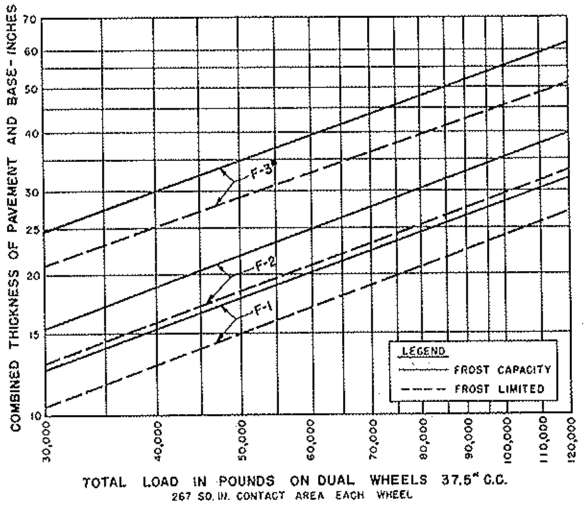


Figure 8.

standard Corps of Engineers rigid-pavement-design methods. Subgrade modulus values for use in these computations are determined from Figure 11, which allows for the reduced strength of the subgrade. Should actual field test subgrade modulus values prove to be lower than those obtained from Figure 11, the field test values govern the design.

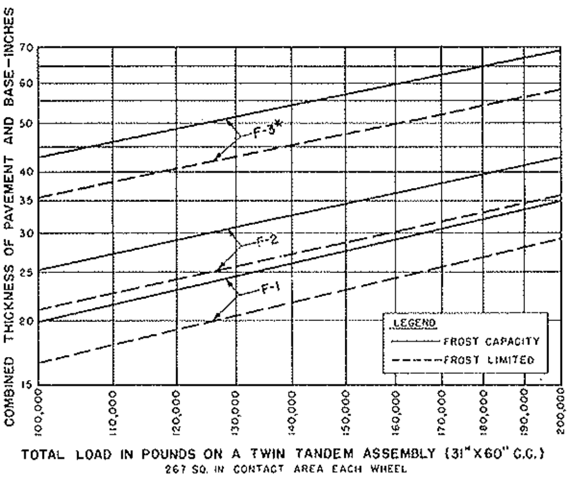


Figure 9.

EXAMPLES OF PAVEMENT DESIGN

Example 1

Design an access-road pavement for a flexible pavement to withstand a 12,000-lb. wheel load (24,000-lb. axle load) under maximum traffic conditions during the frost-melting period, for the following conditions:

Design freezing index, 700
Subgrade, silty sand 20 percent finer than 0.02 mm.
Highest ground water, 1 ft. below top of subgrade
Base CBR, 80 percent

1. Prevention of Freezing of Subgrade. From Figure 4 the combined thickness of pavement and base to prevent freezing of the subgrade for a design freezing index of 700 is 38 in.

2. Reduction in Subgrade Strength. From Figure 10, 23 in. combined thickness of pavement and base is required over the type F3 subgrade soil to provide sufficient supporting capacity during the weakened period in the spring. Since this thickness will still allow some frost penetration into the subgrade, some heave should be expected, but it should not be detrimental in this application provided it occurs uniformly, i. e., there are no abrupt changes in subgrade conditions.

Example 2

Design an airfield taxiway for both flexible and rigid pavements to withstand a 25,000-lb., single wheel load with 200-psi. tire pressure under maximum traffic conditions during the frost-melting period, for the following conditions.

Design freezing index, 300 degree-days
Subgrade, uniform lean clay and plasticity index 14.
Highest ground water, 2 ft. below surface of subgrade
Subgrade CBR, 8 percent (normal period)
Base CBR - 80 percent
Subgrade modulus, k - 100 lb. per sq. in. per in.
Concrete flexural strength, 650 lb. per sq. in.

1. Flexible Pavement. (a) Preventing freezing of subgrade: From Figure 4, the combined thickness of pavement and base to prevent freezing of the subgrade is 25 in.

(b) Reduction in subgrade strength: Soil is type F3. From Figure 6, the required total thickness of pavement and base for frost capacity operation is 28 in. This is greater than the depth of frost penetration; therfore, design on bases of reduction in subgrade strength is not applicable. Analysis by standard California Bearing Ratio procedures shows that a thickness of 22 in. is required for the normal period subgrade strength. Since the thickness of 25 in. required to prevent freezing of the subgrade is less than the value from Figure 6 and greater than the 22 in. required for the normal period, 25 in. would be selected as the combined thickness of pavement and base.

2. Rigid Pavement. (a) Preventing freezing of subgrade: From Figure 4 the minimum thickness of pavement and base required to protect the subgrade from frost action is 25 in. The required slab thickness from standard rigid-pavement-design charts, with no subgrade weakening, is 11.4 in. The Corps of Engineers' design manual specifies that when the thickness from the design curves indicates a

fractional value greater than 1/4 in., the next full-inch thickness is used for construction. The adopted slab thickness should therefore be 12 in., resulting in a base-course thickness of 25-12=13 in.

(b) Reduction in subgrade strength: Since subgrade conditions are uniform and freezing index is less than 500, exception to the rigid-pavement-base-course-design criterion is applicable. A minimum base course of 4 in. is required to protect against loss of support by pumping. The subgrade modulus during the frost-melting period is 25 lb. per sq. in. per in. as determined in Figure 11. The slab thickness required, from standard rigid-pavement-design charts, is 13 in. Cost comparison then indicates whether this design or the one obtained in the preceding paragraph should be used.

Example 3.

Design an airfield taxiway for both flexible and rigid pavements to withstand a 25,000-lb. single wheel load with 200-psi. tire pressure, under capacity operation during the frost-melting period, for the following conditions:

Design freezing index, 2000 degree-days

Subgrade, uniform lean clay and plasticity index 14

Highest ground water, 3 ft. below surface of subgrade

Subgrade CBR, 8 percent (normal period)

Base CBR, 80 percent

Subgrade modulus, k is 100 lb. per sq. in. per in.

Concrete flexural strength, 650 lb. per sq. in.

1. Flexible Pavement. (a) Preventing freezing of subgrade: From Figure 4 the combined thickness of pavement and base to prevent freezing of the subgrade, for the design freezing index, is 62 in.

(b) Reduction in subgrade strength: When allowing a reduction in strength of the subgrade due to frost action and allowing uniform heave of the pavement, a total thickness of 28 in. is required, according to Figure 6.

2. Rigid Pavement. (a) Preventing freezing of subgrade: From Figure 4 the minimum thickness of pavement and base required to protect subgrade from freezing is 62 in. The slab thickness according to standard rigid-pavement-design curves would be 11.4 in. A 12-in. slab thickness should be used in construction, thereby resulting in a base course of 50 in.

(b) Reduction in subgrade strength: Assuming a 12-in. base thickness, the subgrade modulus, as determined in Figure 11, is 65 lb. per sq. in. per in. Using this value, the required slab thickness, from standard rigid-pavement-design curves, is 12 in., which requires a 12-in. base thickness in accordance with the previously stated general criterion for base courses under rigid pavements. This confirms the original assumption of base thickness. For the uniform subgrade conditions, this would be the adopted design.

If, in this case, the ground-water-table depth should be in excess of 10 ft., with all other conditions the same, a 4-in.-minimum-thickness base would be permitted in accordance with exception previously outlined. The design subgrade modulus in accordance with Figure 11 would then be 25 lb. per sq. in. per in. Using this value of subgrade modulus, the required slab thickness, from standard rigid-pavement-design charts, would be 13.

NEEDED IMPROVEMENTS IN CRITERIA

Actual application of traffic on frost-susceptible areas is the only effective means we have at present of evaluating simultaneously all factors which influence weakening of frost-susceptible soils. The traffic method gives us, particularly, an evaluation of the remolding action of traffic and of any subtle changes in soil structure resulting from the frost action on the soil strength. Therefore, we should attempt to obtain additional fully correlated records of traffic experience on borderline designs during the frost-melting period. These should extend coverage over a full range of soil, temperature, and moisture conditions. Frost traffic tests to date have covered a fair variety of conditions, but much remains to be learned. It is essential that the surface observations be carefully correlated with data on the coverages, wheel loadings, soil mois-

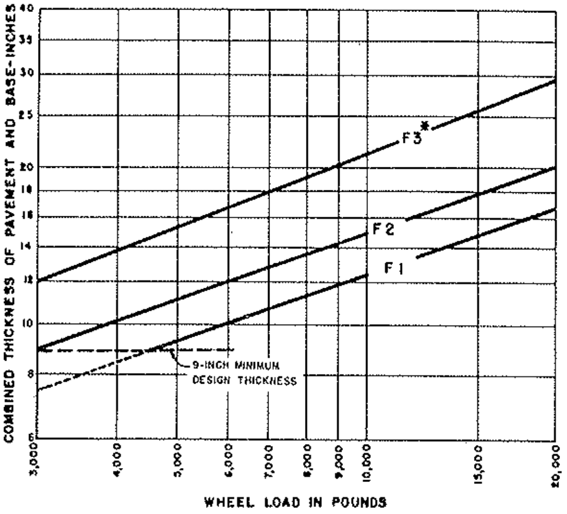


Figure 10.

ture, depth of freezing, soil density, and other basic soil information.

A thin base under a rigid pavement is believed to contribute relatively little structural effect, since the layer is so thin relative to the depth to which the material is stressed. However, a thin base course will definitely have some drainage function in distributing and removing infiltration through the pavement or excess melt water which emerges from the subgrade during the frost-melting period. This function will, of course, vary with the permeability of the subgrade, amount of ice segregation which has occurred, lateral drainage distance, rate of thaw. Also, it is assumed the thin base course will reduce or prevent pumping, if it is satisfactorily designed as a filter. Possibly conventional filter criteria may be too conservative for this special application. Much work needs to be done to crystallize design criteria in this field.

It may be that we should give greater attention to the difference in spreading effects of different base courses under pavements, as for example, between rounded natural gravels and angular crushed rocks. These effects possibly are of little consequence in relatively thin base courses but may be of distinct importance when base courses reach thicknesses of the order of 2 ft. or more.

The question of how much heave is permissible under a rigid pavement is also a thorny problem, not susceptible of theoretical analyses.

We need better methods of analyzing those combinations of precipitation, freezing and rate of thaw which are conducive to especially severe spring pavement weakening.

We need to obtain better information on the duration of the maximum weakening period in various soils. In relatively pervious frost-susceptible soils, the melt water may escape nearly as rapidly as it becomes available. In soils of lower permeability the effective time of drainage may be slower and the duration of the weakening may be greatly extended. We also need more information on the effective permeability of soils during the frost-melting period, which may not be the same as the permeability of a homogeneous sample, due to fissured structure.

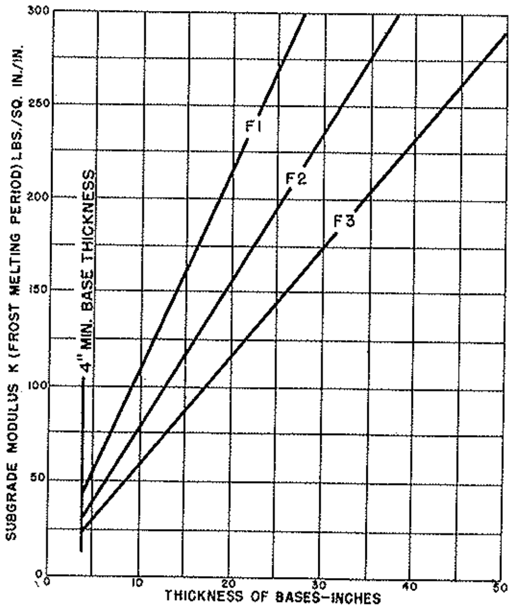

Frost shall not be permitted to penetrate group F4 soils beneath rigid pavements.

Figure 11. Rigid-pavement-subgrade modulus curves for frost action in subgrade soil.

Study is needed to determine whether the present rule, which states that a soil containing 3 percent or more of grains by weight finer than 0.02 mm. is generally frost susceptible, can be improved. Various possible methods of making use of borderline frost-susceptible base-course materials should be explored. More data are needed on the effects of depth to water table, degree of saturation, soil structure, surcharge, depth of cover and other variables. James F. Haley described in the previous paper cold-room studies presently being made in the Frost Effects Laboratory to investigate some of these effects with the objective of deriving improved design criteria (8). Actual field performance data and certain basic theoretical studies are needed in addition to the cold-room studies.

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Soil-Temperature Comparisons Under Varying Covers

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● THE Michigan Hydrologic Research Station was established at East Lansing in 1940 as a cooperative study between the Soil Conservation Service of the U. S. Department of Agriculture and the Michigan Agricultural Experiment Station to study the effect of land use on the hydrology of farm lands under varying types of snow cover and frozen soil. As additional objectives, it was planned for the station to: (1) determine the manner in which freezing and thawing of soils on watersheds with varying types of land use contribute to runoff, erosion, and flood flow under northern winter conditions, and (2) to determine the fundamental hydrologic relationships of typical Michigan soils under varying types of land use, with especial emphasis upon the movement of water through the soil profile during the fall and winter months. In order to accomplish these objectives, one of the most complete hydrologic instrumentations in this country was devised and installed on lands of Michigan State College and the Rose Lake Wildlife Experiment Station, near East Lansing (14).

The multiplicity of climatic and hydrologic factors working together to cause runoff, erosion and flood flow, and controlling the hydrologic relationships of soils requires a broad program of basic research to include investigations in many little known fields of climatology that are of considerable interest to highway engineers, agronomists, agricultural engineers, and many other specialists, as well as hydrologists. One set of relationships which interests both the hydrologist and the highway engineer is the air-soil temperature relationship.