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## **Roadway Design in Seasonal Frost Areas**

*An NCHRP staff digest of the essential findings from a report, "Roadway Design in Seasonal Frost Areas," by T. C. Johnson, R. L. Berg, K.W. Carey, and C.W. Kaplar, Cold Regions Research and Engineering Laboratory, U. S. Army Corps of Engineers, Hanover, N. H. The report was prepared under NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems."*

### THE PROBLEM AND ITS SOLUTION

In seasonal frost areas, defined as areas in which significant freezing occurs during the winter seasons without development of permafrost, the need for year-round roadway serviceability imposes special requirements on pavement design, construction, and maintenance. Damage to pavements, and thus pavement performance, is influenced greatly by low temperatures resulting in frost heaving and thaw-weakening. Uniform heaving, even several inches, is not noticeable to motorists and has little effect on the serviceability of pavements during the heaved condition. However, the undesirable effects of a uniformly heaved pavement can become evident during the spring when thaw-weakening may increase the rate of deterioration and adversely affect pavement performance due to the loss of bearing capacity. Differential heaving is indicated by the presence of surface irregularities, abrupt bumps, and general surface roughness, resulting in marked decrease in pavement serviceability during the frozen condition. Conditions conducive to differential heaving occur at locations where subgrades change from non-frost-susceptible materials to frost-susceptible materials, at transitions from cut to fill, and over culverts, drains, and other discontinuities in the pavement profile.

In the more southerly areas of the frost zone, several cycles of freeze and thaw may occur during the course of one winter season and cause much more damage than one longer period of freezing in a more northerly area. The usual pattern of

seasonal variation in subgrade support includes a sharp increase during the frozen period. Thawing produces an immediate decrease to levels well below the summer/fall value, followed by gradual recovery over a period of several weeks or months (Fig. 1).

The direct dependence of the rate of pavement deterioration on seasons is shown by Painter's analysis of AASHO Road Test data for asphaltic concrete pavements (Fig. 2); the deterioration rate was rather constant throughout the year except during the spring thaw period, when it increased to much higher rates. The permanent loss in serviceability during a brief period in the spring may equal or exceed the loss during the rest of the year.

Tensile stresses that build up when asphaltic pavements contract under extremely low temperatures cause low-temperature contraction cracks. The severity of low-temperature contraction cracking is directly related to the stiffness of the asphalt binder and significantly affects the serviceability of roads. Several highway agencies have adopted criteria for selection of softer grades of asphalt, and/or asphalt of lower temperature susceptibility, as a means of minimizing low-temperature contraction cracking.

Pavement design in the United States is largely an empirical process based on performance of test roads and local experience. As a result, the procedures for considering the effects of low temperatures and seasonal frost effects are quite variable. An NCHRP Synthesis of Highway Practice (in preparation) reviews and synthesizes current pavement design procedures in seasonal frost areas, as well as construction and maintenance practices, and identifies those that might be of greatest value to other road agencies. The study consisted of a literature review, a questionnaire survey of North American road design agencies, and visits to ten agencies for discussion of their practices.

## FINDINGS

The findings of the study are divided into the major categories of (1) factors fundamental to frost action, (2) the process of design, (3) construction and maintenance, and (4) research needs.

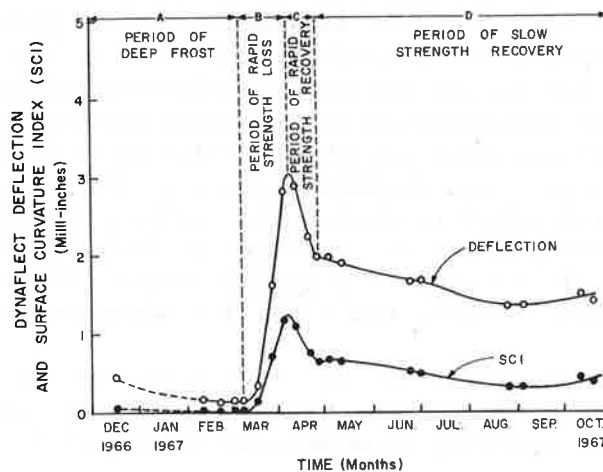


Figure 1. Typical seasonal variations in depth and curvature of the deflection basin. Note the four distinct periods: A (deep frost), B (rapid strength loss), C (rapid strength recovery), and D (slow strength recovery). (NCHRP Report 76, Fig. 26)

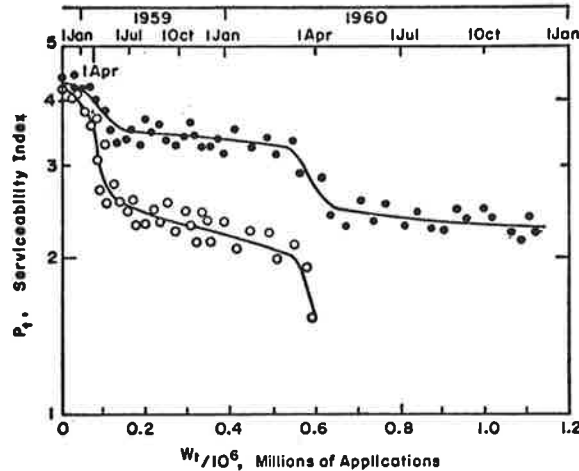


Figure 2. Typical performance data, AASHO Road Test (Painter, 1965).

This Digest concentrates on the portions of the report dealing with design, construction, and maintenance activities for minimizing the detrimental effects of frost action on pavements.

Freezing temperatures, frost-susceptible soils, and a source of water must be present simultaneously for detrimental frost action to occur. Accordingly, minimizing of frost heave and thaw-weakening in the subgrade and base courses of pavements can be accomplished effectively by dealing with one or more of these major factors during the design process. In seasonal frost areas, freezing temperatures cannot be eliminated; but experience has shown use of non-frost-susceptible materials in the frost zone and insulation of the subgrade to be useful in reducing their effects. It is practically impossible to eliminate the presence of water in subgrade soils; however, drainage is discussed as a means of reducing the effects of excessive water.

The primary approach for minimizing the detrimental effects of frost action in the subgrade is to deal with any frost-susceptible soils during the design and construction process. This can be accomplished by either (1) removal of frost-susceptible soils to below the level of frost penetration and replacement with non-frost-susceptible soils, or (2) accommodation of the frost action (heave and thaw-weakening) during the structural design process by eliminating discontinuities leading to differential heave and by strengthening the pavement structure. The first approach is more desirable, but usually is limited to relatively short sections that are identified at the time of final grade check during construction operations. This approach is particularly effective in preventing differential frost heave.

### Soils

A good share of the input data for the pavement design process in seasonal frost areas comes from the soils and materials surveys. This is certainly realistic when it is considered that all traffic loads must ultimately be carried by the subgrade soil and that a major portion of the pavement structure is composed of local materials. The methods used to acquire soils and materials information can be grouped into the following categories:

1. Methods largely reliant on pre-existent data, such as pedological and geological surveys.
2. Indirect assessment methods, such as airphoto interpretation and remote sensing.

3. Direct field contact approaches, such as geophysical surveys and direct sampling.

The methods vary greatly in accuracy and detail; thus, their applicability depends on the type of information needed. For example, several states have developed correlations between pedological information from agricultural soil maps and engineering considerations (such as drainage, gradeline establishment, construction provisions, and material needs) that are useful during preliminary design and route location. Most states use some type of direct field contact to obtain grain-size distribution of subgrade and paving materials. This is particularly important in frost areas with regard to the amount of fines in subgrade soils and base materials.

The frost-susceptibility classifications or criteria that are most widely used are based on the percentage finer than 0.02mm, the percentage passing the No. 200 sieve, and soil classification. The most accurate of these is the percentage finer than 0.02mm, but even this is not well documented in relation to observed frost heaves. Assessment of the relative worth of the various frost-susceptibility criteria requires examination of the performance of many pavements. The good performance of many pavements in seasonal frost areas, based on limiting the amount of fine material within the frost penetration zones, indicates that frost-susceptible soils are being identified and either excluded or effectively counteracted. Evidence that acceptable soils are not being excluded is lacking. Direct assessment of frost susceptibility by freezing tests is less likely to result in rejection of materials that would perform satisfactorily, but present freezing tests are difficult, time consuming, occasionally may reject suitable materials, and the criteria that have been proposed for application of these tests lack adequate field validation.

Frost action in soils involves both heaving and thaw-weakening. However, thaw-weakening is not necessarily proportional to heaving. Field experience indicates that thaw-weakened sandy gravel materials recover bearing strength quite rapidly, whereas clayey soils may show little heave but recover very slowly. The Corps of Engineers classification system was developed in the late 1940's to make use of the Casagrande criteria regarding frost susceptibility and also to account for the reduced stability of the various types of frost-susceptible soils during the thaw-weakening period. A laboratory freezing test has been used by the Corps since the early 1950's as a direct method of obtaining a relative measure of frost susceptibility for specific soils. Figure 3 shows composition envelopes developed from the average heave rate versus the percentage of particles finer than 0.02mm for all standard laboratory freezing tests made by the Corps from 1950 to 1970. There is no sharp dividing line between frost-susceptible and non-frost-susceptible soils, nor a well defined relationship with respect to percentage of particles finer than 0.02mm. The data confirm that frost susceptibility is generally related to the amount of fine material, but that other factors have a significant influence.

### Temperature

Characterization of the temperature regime in pavement structures affected by frost action includes such parameters as depth of frost penetration, number of freeze-thaw cycles, and duration of freezing and thawing periods. Many investigators seeking to calculate the depth of frost penetration have found it convenient to make use of a freezing index, which expresses the cumulative effect of intensity and duration of subfreezing air temperatures. The air-freezing index is the number of degree-days between the maximum and minimum points on a plot of cumulative degree-days of below freezing temperatures for one season, and can be calculated for a given site from average daily air temperature records from a station near the site.



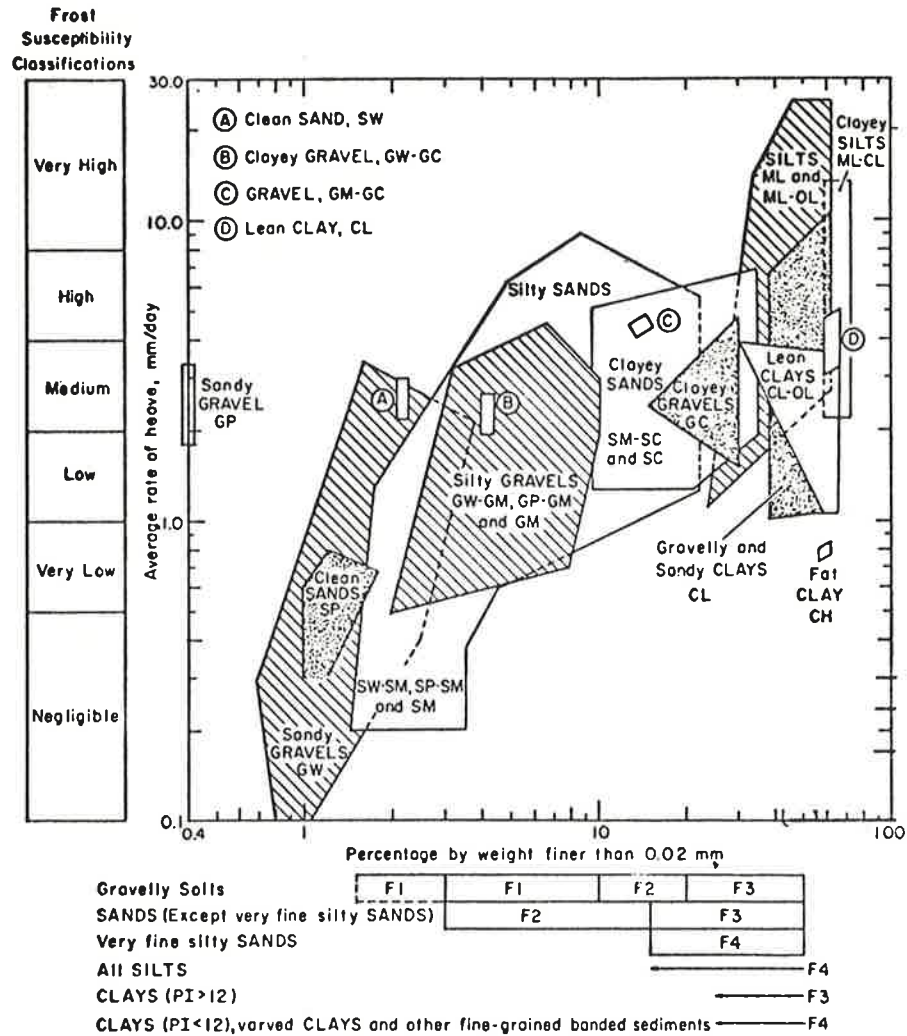


Figure 3. Summary envelopes of all standard laboratory freezing tests by Corps of Engineers, 1950-1970 (Kaplar, in preparation).

Selection of freezing index values, for design purposes, corresponding to years colder than normal provides a means of guarding against damage to pavements by unusually severe temperature conditions. The Corps of Engineers calculates the freezing index for the three coldest winters in the past 30 years of record, or the coldest winter in the latest 10-year period; when calculated on this basis, it is termed the "design freezing index." The relationship between "design freezing index" and "mean freezing index" is shown in Figure 4.

Frost penetration depends not only on the intensity and duration of subfreezing temperatures, but also on the type of soil or pavement substructure material, its density and moisture content, and the character of the surface. Frost penetration is considerably greater in paved areas underlain by granular materials with low moisture content. Snow cover acts as an insulating layer and reduces frost penetration. Depth of freezing can be measured by several methods, such as coring, test pits, temperature sensor installations, and frost tubes. The curves in Figure 5 were developed using the modified Berggren equation for predicting frost penetration, and can be used to estimate values for a variety of conditions.

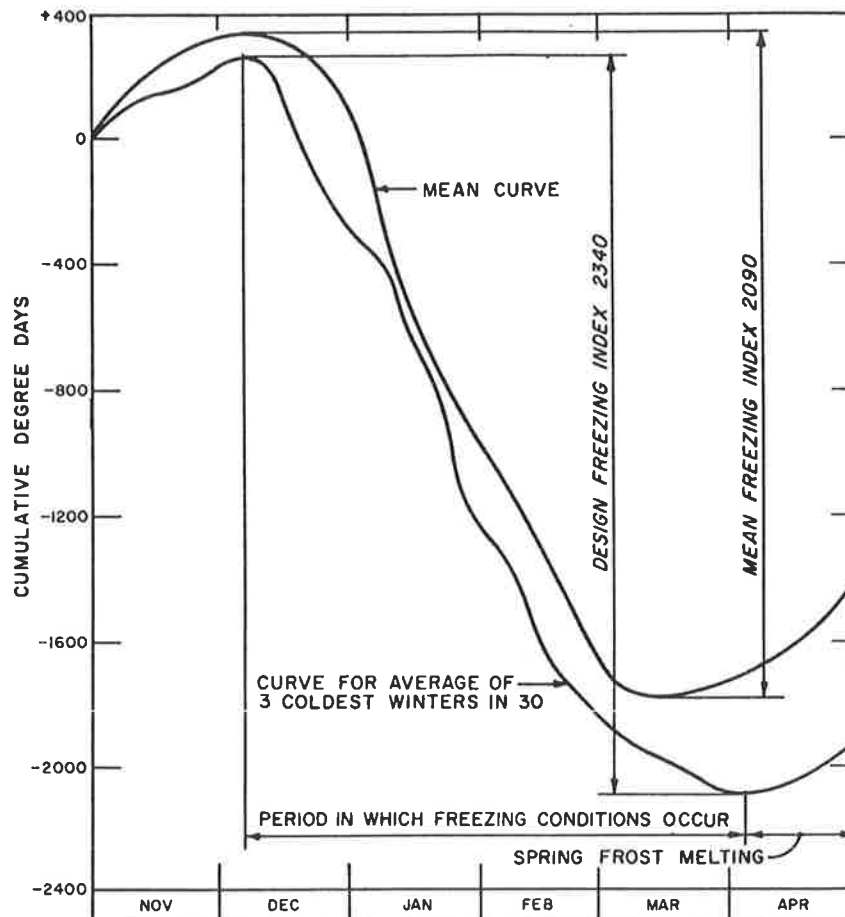


Figure 4. Determination of freezing index (Linell et al., 1963).

### Water

Sources of water contributing to frost problems in pavements can be separated into the two broad categories of surface water and subsurface water. Surface water enters the pavement structure by infiltration through cracks and joints, seepage through permeable pavements, and through unpaved adjacent surfaces. There are three primary sources of subsurface water: (1) groundwater table near the surface, (2) moisture held or drawn into soil voids by capillary action, and (3) seepage from external sources (such as springs).

Drainage is a fundamental feature of the pavement design process, particularly in areas of seasonal frost where water is a principal ingredient in the majority of the detrimental effects of freezing temperatures. The use of underdrains or interceptor drains is the most widely used technique for lowering of the water table. Alternatively, in many agencies the grade line is raised to provide greater separation between the water table and the subgrade. Some agencies specify a minimum height that the final grade shall be above the water table.

### Construction

Many potential frost problems can be identified by pre-design soil surveys and their severity reduced during design. Such conditions as variable subgrade soils conducive to differential frost heave are difficult to foresee during the design

process, but often can be recognized and corrected during construction. Specific locations along the route where such problems are likely to occur should be identified during design for more detailed investigation and correction during construction.

Selective grading is a construction technique for reducing frost action by placing the more highly frost-susceptible soils in the lower portions of embankments and the less frost-susceptible materials in the upper portion of the subgrade. Undesirable soils can be used in the outermost parts of the embankment rather than beneath the roadbed.

Cut sections frequently have been reported as sources of trouble because they alter the natural drainage and provide ample sources of water from adjoining higher ground. In some cases the problem can be eased by subsurface drainage or by undercutting and removal of the unstable materials.

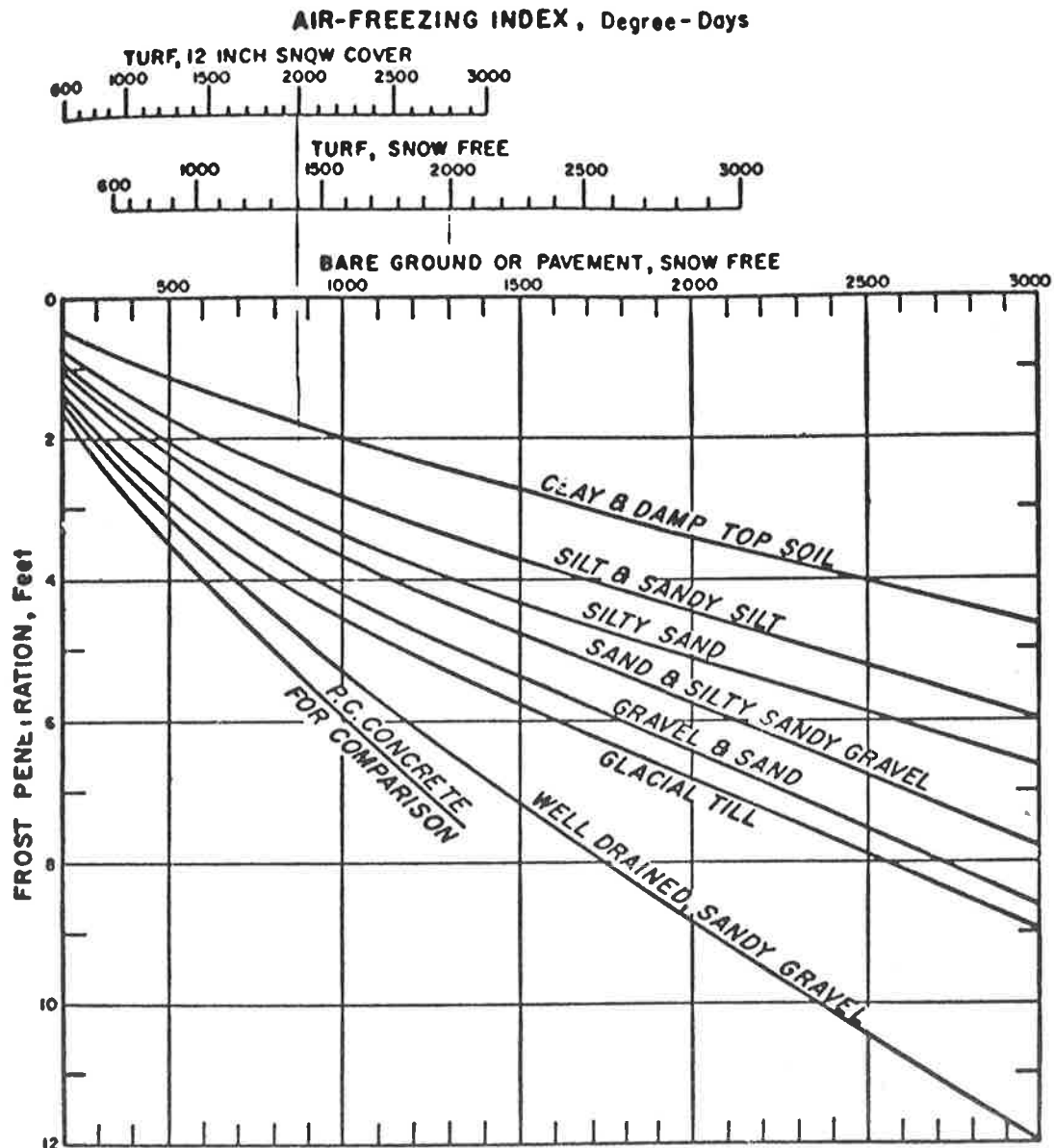


Figure 5. Relationship between air-freezing index, surface cover, and frost penetration into homogeneous soils (Sanger, 1963).

One of the first requirements during construction should be inspection of the subgrade to verify the validity of design assumptions and to locate silt pockets, frost-susceptible materials, seepage, ground or capillary water, logs, stumps, boulders, and other nonuniform subgrade conditions. Corrective measures include removal of unsuitable materials, mixing and blending of nonuniform materials, and installation of appropriate drainage.

The irregular surface in rock cuts forms basins and catchment areas for the collection of water, which can cause adverse frost action. Rock cuts also comprise a serious discontinuity in subgrade support compared with adjacent fills. To minimize adverse effects, current practice includes treatment of rock cuts by two alternative procedures to ease the abrupt change in subgrade conditions: (1) undercutting the rock subgrade and replacing with material similar to the adjacent fill, with tapered transitions at each extremity of the cut; and (2) in-place fragmentation of rock subgrades with blast holes 3 to 6 ft deep.

Achievement of the highest possible density of subgrade and base courses is essential to good pavement performance. Hauling equipment can be used to aid compaction and to identify weak spots of subgrade and base courses. However, there is a danger that soil fines from truck tires can contaminate a clean granular base course.

#### Other

Several additional methods are used experimentally and on a regular basis to reduce the effects of frost action, including soil stabilization, thermal barriers, and encapsulation. Stabilization is a method of processing (including the use of additives and binders) subgrade soils and base course materials to improve their performance under prevailing traffic and climatic conditions. Effective stabilization of a frost-susceptible material usually involves either (1) eliminating the effects of soil fines (by their removal or by cementitious bonding), or (2) reducing the effect of water by restricting its migration. Courses of action that do not involve additives are the removal of fines from base course materials and the blending of coarse-grained with local materials to reduce the percentage of fines. Binders added to subgrade and base course materials for greater strength and to reduce the effects of water include portland cement, lime, and bituminous materials. Pavements in which asphaltic mixtures are employed for all courses above the subgrade, generally referred to as full-depth asphaltic pavements, are extreme examples of reducing the effects of water within the pavement structure.

Thermal barriers can be used to reduce the effect of sub-freezing air temperatures on frost-susceptible soils. Extruded polystyrene boards have performed adequately in this regard, but several agencies have become concerned about the occurrence of occasional differential icing conditions on the pavement surface if the thermal barrier is not used continuously.

Several approaches to the use of moisture barriers to prevent the entrance of capillary water into the pavement structure have been used experimentally. They include sand layers to intercept the movement of water, and plastic membranes or complete plastic envelopes to cut off the migration of water into the freezing zone. The most successful experimental work of this type has been conducted by the Waterways Experiment Station and is known as "membrane-encapsulated soil layers" (MESL). In test sections not subjected to sub-freezing temperatures, MESL of fine-grained cohesive soils completely encapsulated in a moisture-proof barrier have performed better than granular materials in layers having the same thickness.



Spring load restrictions also may be considered preventive maintenance. Almost one-half of the polled agencies in seasonal frost areas indicated that load restrictions were applied to older secondary roads during the thaw-weakening period to reduce pavement damage. *NCHRP Report 76*, "Detecting Changes in Load-Carrying Capabilities of Flexible Pavement," describes procedures for determining the magnitude and duration of such restrictions.

#### APPLICATIONS

The pavement design procedures of most northern states and Canadian provinces are generally based on experience within the territory of each, and consequently account for frost action of the particular severity that each area experiences. Because the Corps of Engineers has responsibilities for construction in regions of widely differing geologic and climatic regimes, its design procedure has been developed to include soil properties and climatic conditions as basic parameters. Consequently, it can be applied anywhere within seasonal frost areas. The information on current practices gathered and synthesized during this study should be of value to all agencies that design and build pavements in frost areas.

It is recognized that the process of pavement design to accurately predict performance of pavements under a variety of traffic and environmental conditions in seasonal frost areas will ultimately require mechanistic techniques that analytically model the transmittal of traffic loads through the pavement layers to the subgrade soil. Progress is being made in this regard independent of the frost action problem and solutions are expected in the next few years. In the meantime, the best approach for minimizing detrimental effects of frost action (both differential heave and thaw-weakening) is to (a) exercise control over soil fines in the subgrade and base course layers within the zone of anticipated frost penetration, (b) provide good drainage, (c) design the pavement structure with adequate strength, and (d) eliminate abrupt discontinuities in support conditions that would lead to differential heave. The good performance of many pavements in seasonal frost areas, based on this general approach, indicates that the procedure is effective. Further research is needed to (1) develop and verify innovative procedures such as use of thermal barriers, encapsulation, and stabilization to more economically deal with frost action and reduce use of scarce high-quality materials, and (2) further advance mechanistic approaches to pavement design, including techniques for material characterization, assessment of environmental influences, and predicting cumulative damage.

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