Symposium Summary

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•IN SUMMARIZING Part II of this symposium, it is desirable to quote from the foreword of Part I: Basic Considerations:

> The objective of this symposium was to review, summarize and report the state of knowledge concerning the design of highway pavement in frost areas, treating individually the factors of temperatures, water, types of soil and materials, and the freezing mechanisms of soil-water systems; and relating these factors to the design problems associated with pavement surfaces, bases, subbases and subgrades, topography, highway cross-section and grade line, subsurface drainage, climate, and traffic weight and volume.
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> The purpose of the symposium was to provide for the practicing engineer, who is now confronted with the greatest highway program in history, a digest of current scientific knowledge that he may use as a guide in the solution of highway design problems in frost areas; and to provide for the research engineer and scientist information concerning practical highway design and construction problems in frost areas for use as a guide in experimental and investigational programs.

Part I of the symposium dealt with basic considerations; namely, water, temperature, soil, and the freezing mechanism of soil-water systems. Part II of the symposium was concerned with design considerations.

The reporting technique which was adopted for Part II of the symposium resulted in a wealth of practical information and a great amount of detailed information regarding design procedures. From an over-all point of view, it can be said that there is substantial agreement in the general approach to the problem, yet there is by no means a standardized design technique. The reports indicated that several agencies used experimental techniques for extending the results of observations on roads under service to the problem of designing new roads. As would be expected when reporting on a problem which covers such a wide geographic area, there were a variety of approaches. There were various points of emphasis and various definitions of what constituted a frost-susceptible soil. Some of these differences may be reconciled on the basis of differences in climatic factors and other environmental conditions, whereas others may be reconciled after a consideration of the predominant types of soils in any given area or lack of suitable granular materials.

One of the questions that this symposium should attempt to answer is "What basic knowledge of frost action do we have that we are not using in design practices?" Part of this summary will be directed towards an attempt to answer this question.

Some years ago, the frost problem was considered to be primarily that of frost heaving, especially differential heaving. More recently, greater recognition has been given to the problem of loss of stability of the pavement upon thawing. Some fairly elaborate field studies have been made for the purpose of quantitatively evaluating the damaging effects of frost action on roadways, or conversely, determining the necessary limitations of loadings to minimize or eliminate the damage to roadways during the

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thaw period (19). Still more recently, there has been a gradual increase in awareness of another problem resulting from frost action effects; namely, residual roughness. Recent designs have, in many cases, eliminated or minimized differential heaving and loss of stability upon thawing. However, the interest of the traveling public in high-speed transportation, regardless of season, has focused attention on residual roughness of pavements following one or more seasons of frost action.

SUMMARY OF DESIGN PROCEDURES

To design successfully, to minimize or eliminate differential heaving and the loss of stability upon thawing, and to minimize the effects of residual roughness, it is necessary to recognize the three requirements for detrimental frost action and the mechanism by which these three factors are combined to produce undesirable pavement conditions. It is not the purpose to review the findings of Part I of this symposium, but simply to restate these factors and to comment on them from the design point of view.

Temperature

The most general statement that could be made about temperatures is that for detrimental frost action to occur, there must be a sufficient duration of sub-freezing temperatures. This has been expressed quantitatively in terms of the freezing index or accumulation of degree-days of freezing temperatures. Some fairly good correlations have been established between frost phenomena and the design problems, especially concerning the anticipated depth of frost penetration which then becomes a guide to establishing the necessary depth of treatment.

Some agencies replace objectionable material with non-frost-susceptible soils to a depth equal to the depth of frost penetration. Other agencies do not attempt complete elimination of frost penetration into frost-susceptible soil, but provide for partial protection by covering frost-susceptible soils with a thickness of selected material equal to some arbitrary fraction of the frost penetration depth, such as one-half or three-quarters.

Some agencies are using freezing index data effectively, whereas others are reluctant to use this approach. It must be recognized that over the length of a given highway there may be considerable variations in the severity of freezing. Therefore the use of the freezing index approach becomes more difficult than in the case of a specific site such as an airfield.

During symposium discussions, the point has been made that although soil and moisture conditions can be modified to some extent, little can be done about the temperatures which occur in a given location. It is true that the temperature pattern is a phenomenon of nature, and more directly, a phenomenon that is not readily controlled by man. However, it is possible to control temperatures to a considerable extent if a different point of view is taken than that related to surface or air temperatures. For example, by placing non-frost-susceptible materials over frost-susceptible soils, the initial portion of the degree-day curve is neutralized. Alternately, this may be thought of as reducing the effective freezing index relative to the frost-susceptible soil.

Another approach that has been used in delaying the penetration of freezing into a frost-susceptible subgrade is that of the Corps of Engineers (5). This approach takes into consideration the quantity of heat which is stored in the water of a moist subbase. The higher the water content, the greater is the quantity of heat which must be removed from a given thickness of subbase before it will freeze, thus retarding the advance of freezing temperatures. Of course, the subbase must not exhibit detrimental frost action at this water content; therefore the moisture must be closely controlled.

Frost-Susceptible Soil Texture

There is essential agreement on the more general concepts of what constitutes a frost-susceptible soil. For example, silty soils are generally considered to be the poorest soils, whereas very clean sands and gravel give no trouble. Also, the so-called "dirty" sands and gravels often are troublesome. However, there are variations in the definition of frost-susceptible soils when a closer definition is attempted. Various criteria are used, such as the percent finer than the number 200 sieve, the percent finer than 0.02 millimeters, and the percent of clay sizes. For example, in some of the western states a non-frost-susceptible soil may have as much as 25 percent finer than the number 200 sieve (4). This high percentage of fines would be considered intolerable in the eastern and midwest areas. This difference points out the fact that frost susceptibility as it relates to actual damage to the pavement must be considered from more standpoints than the texture of the soil alone. In the case of the western states, it appears that the relative lack of moisture is an important consideration in determining the damage to be expected as a result of frost action.

Although there is difference of opinion as to what constitutes a frost-susceptible soil on the basis of texture, texture is used as the primary criterion for frost susceptibility in practically all cases. That is, the extent of frost damage anticipated is based on some measure of the texture, including the use of the Atterberg limits. A notable exception is that of British Columbia, where design is based primarily on the results of observed deflections under loading on selected observation sections of roadways in actual service (6). Although this procedure has not found general acceptance elsewhere, it is nevertheless an interesting approach and in many respects represents a more direct approach than that based on soil texture alone.

Another question that is raised and is discussed in several of the papers is whether frost susceptibility should be determined on the basis of frost heaving or on the basis of actual pavement damage. It seems to be implicit in many of the discussions that frost susceptibility is based on the relative amount of frost heaving. However, it has also been observed that some states are modifying this approach to account for the actual damage to the pavement, regardless of the amount of heaving.

Although not a direct contribution to this symposium, the studies of Csathy and Townsend (11) in Canada are of considerable interest in any discussion on frost susceptibility. These investigators concerned themselves with the distribution of pore sizes as a basis for the frost-susceptibility criteria. Because frost effects are concerned with the relationship of the moisture in the soil pores to the frost phenomena, this approach has much to commend itself.

Moisture in Soil

It is difficult to discuss soil moisture independently of soil texture because of the close relationship of moisture to texture. Generally, those soils which naturally hold relatively high contents of water will exhibit more severe frost action. For a given soil, however, differences in the environment as they affect the natural water content are significant. The previously mentioned criterion of 25 percent finer than the number 200 sieve, as used in some of the western states, is a clear example of the importance of over-all environmental effects.

Many approaches are used in an attempt to reduce the moisture content, and therefore to reduce the extent of detrimental frost action. One approach is to place the grade line as high as practical thereby increasing the distance from the pavement surface to the free water table. Another approach is to attempt to lower the free water table with subdrainage structures incorporated into the highway. The success of this design depends on the availability of a suitable outlet for the drainage facilities. In many cases, this requirement imposes a severe limitation on the effectiveness of this approach.

Another aspect of drainage concerns the dissipation of the excess moisture which is released by the subgrade soil when it thaws with the coming of spring. Because most of the thawing is from the surface downward rather than from the bottom of the frost layer upward, the problem is how to drain effectively this excess water. A number of design agencies have given a great deal of thought to the design of the base courses and subbases to serve the function of a filter. The fundamental approach is to have the base and subbase sufficiently permeable so as to permit drainage of the excess moisture from the subgrade as rapidly as it is formed by the thawing. Some of the states (4) mention the use of the generally accepted criteria for the design of filters. This approach is covered extensively in the paper from the Corps of Engineers (5).

The general concept of using bases and subbases as filters, although good, does have some limitations. Most of the discussions suggest that the moisture should first move upward from the subgrade into the base and/or subbase, from which it is then distributed laterally to the edges of the highway structures. If the base and subbase are sufficiently permeable and are sufficiently thick, this should result in an effective design. It is important that the designer recognize the possibility that the base and subbase may be weakened somewhat by the development of pore pressures. However, if the base and subbase are made sufficiently thick, this should not be a serious problem. What is of concern is whether or not the filter has a free outlet at the edges. Practically, this may be a severe limitation of the effectiveness of the filter principle because the outlet to the filter may be blocked by snow remaining in the ditches or by frozen soil remaining under the shoulders. Probably more attention needs to be given to this feature to insure effectiveness of transverse drainage.

Another factor that is frequently overlooked is that in many cases the longitudinal slope may exceed the transverse slope. In this case, the drainage water will be more likely to flow in the longitudinal direction rather than in the transverse direction, with the result that water may be accumulated to an intolerable degree at the low points in the highway profile in spite of satisfactory lateral drainage. If the lateral drainage were blocked, this problem would be accentuated. As a result of the longitudinal drainage, serious damage may occur at the low points or sags in the highway profile even though the design otherwise might be quite adequate.

From the foregoing, it can be seen that the application of the filter concept probably needs a more elaborate analysis than is obtained by considering only the typical cross-section. It may be necessary to increase the thickness of the base and subbase in the vicinity of the sag in the profile in order to develop sufficient hydraulic capacity for longitudinal flow through the filter.

ARE CURRENT DESIGNS UTILIZING AVAILABLE BASIC KNOWLEDGE?

As previously stated, one of the questions that this symposium should attempt to answer is: "What basic knowledge of frost action do we have that we are not using in design practices?" In general, it appears that in fact, design concepts are making use of nearly all of the basic information which is presently available and which is sufficiently developed to be used in design. This is especially true if one considers the many variables in the problem and the wide varieties of environmental conditions and availability of materials in various parts of this country, in Canada, and in Europe. An attempt will be made to answer this question somewhat more explicitly by considering in turn the mechanism of frost action and the three factors: moisture, temperature, and soils.

Mechanism of Soil Freezing

In recent years, and in particular in Part I of this symposium (14), a definite point was made regarding the importance of the unsaturated permeability of soils and the relationship between the moisture tension (or suction) and the movement of moisture. The design methods currently being used do not directly utilize these concepts. However, it must be recognized that these concepts are utilized indirectly in current design practices. Examples are the reduction of the unsaturated permeability by the use of selected coarse materials and the practice of elevating the grade line above the surrounding terrain to increase the moisture suction and thereby decrease the unsaturated permeability. Also in the same category is the lowering of the water table by subsurface drainage structures.

Another factor considered in the mechanism of soil freezing and the formation of ice lenses is the effect of the overburden pressure in reducing the magnitude of frost heaving. Again this is not utilized directly, but the effect is introduced automatically by the practice of placing a considerable thickness of non-frost-susceptible materials over the frost-susceptible subgrade.

Moisture

In the control of moisture it is generally accepted that the obvious approach is to provide better drainage. This is stated in the preceeding papers in Part II of the symposium, as well as in the part dealing with basic considerations. It is recognized that there are limitations on the effectiveness of drainage both from the standpoint of availability of suitable outfalls and the well-documented observation that many of the soils which are troublesome from a frost point of view do not drain by gravity to any great extent. It would appear that current design practices are making good use of all that is known about drainage.

Other methods for the control of moisture have been suggested by research, but these are not generally considered practical at least for conditions in the United States. One approach is to provide cut-off layers using either porous material such as sand to interrupt the capillary rise of the soil, or a layer of clay which would effectively serve as a moisture barrier (7). This has been tried in practice and is generally not considered feasible by those agencies within the United States, although this approach is used in Europe to some extent. Another variation of this scheme is to provide a membrane of film plastic to cut off the flow of moisture to the freezing zone. Not enough experience has been gained to know how this method will work out. Also, there are a number of practical problems associated with such an approach, such as a loss of effectiveness of the barrier if it becomes punctured.

Still another category of moisture control concerns the use of chemical additives to modify the wetting of the soil particles and water. This appears to be good on the basis of laboratory studies, but questions remain as to the relative permanency of the treatment and there is a serious question on the relative economy. One statement has been made to the effect that if dirty gravels are available in substantial supply it will probably be less expensive to wash the fines out of the gravel rather than to attempt treatment by chemical means (17). As time goes on and sources of suitable non-frost-susceptible materials are depleted and as water supplies for washing become increasingly more limited, this situation may change.

Temperature

Research has shown that the penetration of freezing temperatures into the soil can be predicted reasonably well on the basis of the freezing index which is developed from the degree-day curve. There remain, however, some questions as to the relationship between the freezing index and the soil characteristics which should be resolved (16). In spite of this, a fairly reliable estimate of the penetration depth can be made by this approach.

This approach is not universally adopted by the states and provinces. Instead, this approach is used mostly by the Corps of Engineers and other agencies whose operations extend over entire continents. It is possible that if more adequate temperature data were available for the determination of the freezing index in a greater variety of locations, this approach might gain more acceptance, especially as the supply of non-frost-susceptible materials becomes progressively more critical.

Definition of Frost-Susceptible Soils

Research has defined fairly well just what is meant by frost-susceptible soil when the frost susceptibility is judged on the basis of frost heaving. Most notable in this area is the work by the Corps of Engineers on the basis of laboratory freezing studies (17, 5). This information is generally available and should prove quite helpful. The extent to which this information is reflected in the design of highways by other agencies is not very clear, but it seems that it has influenced the decisions of several highway departments in establishing the frost-susceptibility criteria which they use even though they have not adopted the system in its entirety. It should be pointed out that the laboratory test utilized by the Corps of Engineers for this determination relates to the worst possible conditions that would likely occur in a highway.

One observation has been made which probably bears repeating, and that is that highway engineers could make more use of pedological soils data for the design of highways.

At present, this information is actively used by only a few states. Although other organizations do recognize the importance of it, the direct use of this source of information is not specifically in evidence. The importance of pedological data is that they reflect to a considerable extent the natural drainage condition of the soil and, therefore, probably would give valuable information regarding the relative frost hazard.

Chemical Additives

Chemical additives are treated separately here although they relate both to the control of moisture and to the modification of soils. Some additives are considered to have the effect of altering the particle size composition of the soil. These operate by lumping the finer particles together into collections of larger particles so that the net effect is an increase in the average size of the particles. Other chemicals tend to change the relationship between the surface of the soil particle and the included water in the soil. By reducing the wettability of the soil particles the transmission of moisture is reduced and as a consequence heaving and other detrimental effects of frost action are reduced.

It is presently considered that chemicals are too expensive for treating the soil. Also, certain chemicals are considered to be unpredictable, are non-uniform in their results and give only questionable permanence. However, there are certain chemicals which behave quite well as additives. Although it may be true that widespread use of chemical additives is not as yet practical or economical, it seems likely that in the near furture they may become increasingly important. This prediction is based on the known fact that the supply of suitably graded coarse material is running out and that it will be necessary to use materials which are now considered marginal. It is also to be expected that the chemical industry will continue to work on the problem and probably will, in the course of time, produce some form of chemical treatment which is reasonable in cost, easy to handle under construction operations, and is sufficiently permanent to find widespread use.

SUGGESTIONS FOR FURTHER RESEARCH

If it is true that designers are using all available knowledge of frost action, it follows that further research on frost action is needed if designs are to be improved. Some of the specific problems which warrant further study as suggested by this symposium are presented in the following paragraphs.

Use of Freezing Index Data

In general, highway departments have not used freezing index data very extensively. This may be partly due to the fact that there can be significant variations in the freezing index over a given length of highway. In the mountain states, freezing conditions change rapidly within a short horizontal distance as the altitude increases. Even in some areas of the midwest it can be visualized that the freezing index would change within a few miles for any given road in certain localities.

It is believed that freezing index data could be extended to cover these variations by considering differences in the degree of exposure to cooling, which would depend on topographic position, the relationship to the prevailing winds, and solar exposure. By taking these factors into account the freezing index obtained from a study of temperatures at regular weather stations could be corrected to develop the freezing index appropriate to any given remote point.

Another aspect is the relationship between the freezing index and the penetration of frost into different kinds of soils. The data reported in the literature indicate a considerable variation of penetration depth for a given freezing index (16). Apparently this variation is due to differences in soil and moisture conditions. It would be helpful if these relationships could be defined to the point that universal predictions of frost penetration could be made from the freezing index. If this concept could also be extended to frost heaving, it would be that much more valuable.

Increased Use of Pedological Soils Data

Some mention has been made in the discussion of use of pedological soils information. The application of this information has been largely based on a considerable length of experience with the system and with the soils and the observed behavior of highways. It is believed that if the logical relationship between this classification system and those factors governing the performance of highways could be established, the pedological system could be greatly extended. The pedological system is attractive because of the detailed mapping that has already been accomplished and the wealth of information that is already available.

Pedological soils data indicated the drainage characteristics of soils, their texture, and the relative natural water content for the undisturbed soil profile. When the soils are disturbed the situation is more complicated, of course, but nevertheless some useful correlations should be possible. Another problem that should be worked out is the effect of the boundary zone between adjacent series as it affects frost action. Adjacent series are often significantly different in their drainage characteristics so that they indicate a location of potential difficulty. Even within a single series, there may be significant differences at the boundaries between adjacent slope phases of the same soil series. Finally, it should be possible to use pedological soils data to determine the relative susceptibility to improvement of the soils by drainage.

Variations of Damage with Various Seasons

The paper by Kübler (9) reported some interesting observations in considerable detail. It emphasized or confirmed the general observations of highway engineers that the damage due to the frost is often more severe following a moderate winter than a winter of intense cold. It would appear that this subject could be explored further and eventually developed into such a form that it could be useful in predicting damage to pavements, or alternately, it could be used to estimate the load reduction necessary for that class of roads which for economic reasons could not be designed to be completely free of detrimental frost effects. It would be necessary to consider, in addition to the variation between seasons, different soil conditions and various moisture environments.

Moisture Tension Studies

Some research has already been conducted on the moisture tension developed during freezing and its relationship to frost action phenomena. It is clear that further work should be done in this area, again for the purpose of extending the knowledge to the stage where practical design decisions could be made. The importance of the relationship of moisture tension to the unsaturated permeability has been clearly demonstrated. Further research, including the correlation of unsaturated permeability to soil texture, is needed to make this concept useful.

Migration of Coarse Particles

The movement of coarse particles upward to the surface of the soil or through a pavement has been observed for some time. It is only recently, however, that any quantitative research has been accomplished in this area (13). It is believed that further studies should be made as a basis for establishing proper specifications governing large particles in a frost-susceptible subgrade. Furthermore, it is possible that such studies may lead to improvement in specifications and materials for base courses and subbase courses. The significance of particle movement is that it can lead to localized rough spots in the pavement because of the movement of large particles upward from the subgrade. It may lead to decreased density and to a change in the gradation of the material in the base and subbase.

Loss of Stability During Spring Thaw

The problem of loss of stability during and following the spring thaw is well recognized and a number of studies have been made to evaluate the significance of it. However, comparatively little has been done to study the fundamental nature of this problem. This phenomenon should be given intensive study to aid in designing pavements that will resist this loss of stability in frost-susceptible subgrades.

Design of the Base as a Filter

The reports in the present symposium have outlined the use of the filter approach to controlling loss of stability. One of the limitations that has been pointed out, however, is the possibility of the filter being blocked by retarded thawing of the shoulder zone of the highway. Effective methods of control need to be developed. Another problem is that of insuring that the filters drain to the side even when ice blocking is not a problem. It is believed that the filter could be made thicker near the shoulders in order to facilitate the drainage of the filter.

Thermal Insulation Layers

The use of the insulation layers has been proposed and has been used with some success in Europe, although this approach has not received general acceptance within the United States. One of the difficulties seems to be the provision of an insulation material that would have sufficient strength to withstand vehicle wheel loads. If insulation layers are to have an advantage over other materials, they must prevent freezing of the frost-susceptible subgrade. In areas where there is little or no granular material available, insulating materials may be more attractive. In either circumstance, the problem is to find a material that is a good thermal insulator, that is not subject to damage by moisture, that has adequate structural strength, and which is not excessive in cost.

Use of Nuclear By-Products

One of the problems of the nuclear age is the disposal of radioactive waste which involves, among other things, considerable quantities of heat. It has been suggested that it might be possible to utilize the radioactive materials to prevent frost-susceptible subgrades from freezing, thus controlling frost action. The feasibility of this will need to be established from the standpoint of highway economics, as well as from the standpoint of providing adequate protection against radiation damage or injury.

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