Highway Pavement Design in Frost Areas in Sweden

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After a short introduction about the climatic and geologic conditions in Sweden, the classification of the soils into groups differing in susceptibility to frost is described. The fundamental methods for protecting roads against harmful effects of soil freezing are summarized. The bearing capacity in the spring break-up varies from year to year. Consequently, a special bearing value cannot be determined that can be used for highway pavement designing. This must be founded on non-varying factors, especially the type of the subsoil. A table is given for pavement design for roads with traffic of more than 1,000 heavy vehicles daily. Finally, special frost damages, frost cracks, which are quite common in the northern parts of Sweden, are described.

• IN VIEW of the climatic and geologic conditions in Sweden, soil freezing is a very important factor in road construction. In autumn, the rainfall is rather heavy, and this contributes to raising the ground water table to a high level before the beginning of the winter. The winter is cold, particularly in the northern parts of Sweden where the depth of frost penetration on the snow-cleared roads is sometimes about 2.5 m or more. Figure 1 shows the mean freezing index in Sweden, expressed in degree-days (C^0-d).

By far the greatest part of the bedrock in Sweden consists of rocks having an average granitic-quartzitic composition (granites, gneisses, leptites, porphyries, etc.). Disintegrated rock soils are not met with in this country because the products of rock disintegration were removed by abrasive action of glaciation, which occurred in this region during a very late geologic epoch. At the same time, parts of the undisintegrated, sound bedrock were also crushed. These products of mechanical crushing and their restratified sediments constitute the present Swedish soils. On account of what has been said previously, these soils consist mainly of products formed by decay of rocks having a granitic composition.

In some parts of Sweden, however, the bedrock has a different composition where softer rocks (limestone, schist, sandstone) are preponderant. The soils in these areas exhibit corresponding changes in composition.

CLASSIFICATION OF SOILS

Inorganic soils are classified into two main groups, viz., assorted and unassorted soils. These soils are divided into subgroups in conformity with the following particle size scale:

Boulders		>20 cm
Stone	Large stones	20- 6 cm
	Small stones	6- 2 cm
Gravel	Coarse gravel	20- 6 mm
	Fine gravel	6- 2 mm

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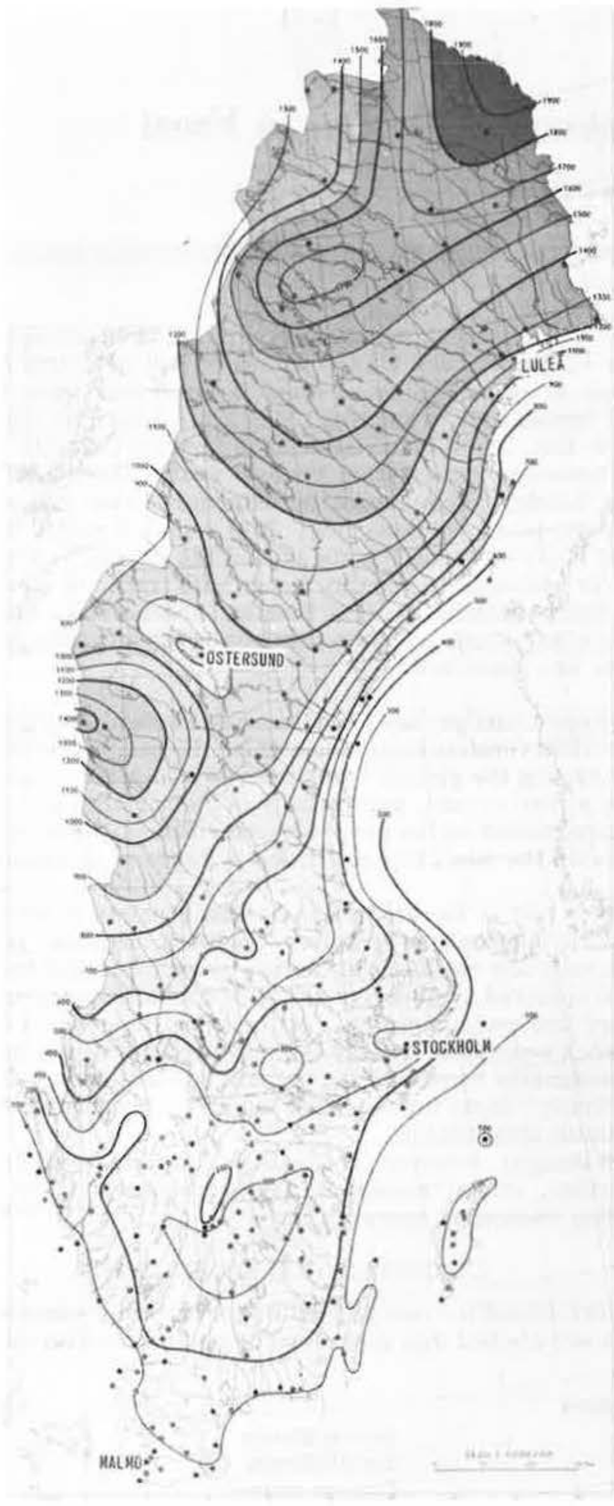

Figure 1. Mean freezing index, degree days (C°-d) for Sweden.

Sand	Coarse sand	2 -0.6	mm
	Medium sand	0.6 -0.2	mm
Mo	Coarse mo	0.2 -0.06	mm
	Fine mo	0.06 -0.02	mm
Silt	Coarse silt	0.02 -0.006	mm
	Fine silt	0.006-0.002	mm
Clay		<0.002	mm

The assorted soils are usually classified according to particle size distribution and clay content. This classification comprises the following distinct types of soils: gravel, sand, coarse mo, fine mo, silt, light clay, light medium clay, heavy medium clay, heavy clay, and very heavy clay.

The unassorted soils consist of moraines, which are classified according to the predominant particle size and clay content. This classification distinguishes between the following types: gravelly, sandy, moey, silty, clayey moraines, and moraine clays. In addition, there is a non-pronounced type, normal moraine, in which no particle size group is preponderant. The various types of moraines are classified on the basis of the clay content and the grading curve. The graphs shown in Figures 2 and 3 are used as an aid in classification.

FROST-SUSCEPTIBILITY OF SOILS

Soil freezing affects inorganic soils to a very high degree by causing a greater or smaller increase in the water content of the soil during the freezing process. This in turn gives rise to a greater or smaller reduction in the bearing capacity of the soil during thaw. However, a small number of soils are not affected in the aforementioned respect by freezing. In consideration of these characteristics, the inorganic soils can be classified according to their frost susceptibility.

I. Non-Frost-Susceptible Soils.

This group comprises the soils which are not liable to frost heaving in the course of the freezing process, and are therefore not softened during the thawing process.

II. Moderately Frost-Susceptible Soils.

This group comprises the soils which are normally subject to frost heaving in the course of the freezing process, and are exposed in this connection to moisture flow towards the boundary of the frozen zone, with the result that a certain quantity of excess water is fixed in the soil. However, these phenomena develop to a relatively great extent only when the rate of freezing is low or when the depth to the ground water table is small. During the thawing process, the soils belonging to this group are more or less softened by the liberated excess water according to the conditions under which the freezing process has taken place (high or low ground water table, slow or rapid soil freezing).

III. Highly Frost-Susceptible Soils.

This group comprises the soils in which the moisture flow towards the boundary of the frozen zone during the freezing process is considerable under normal conditions and very great if the ground water table is high. When the excess water fixed during this process is liberated in the course of thawing, it generally causes a great reduction in the bearing capacity of the soils belonging to this group. Because these soils are highly susceptible to conversion to a liquid condition, even a relatively small quantity of water can give rise to a considerable decrease in bearing capacity.

To sum up, the inorganic soils can be classified according to their frost susceptibility as follows:

Assorted soils	Frost-susceptibility group
Gravel Sand Coarse mo	I

Assorted soils	Frost-susceptibility group
Fine mo Silt Light clay Light medium clay	III
Heavy medium clay Heavy clay Very heavy clay	II

Unassorted soils	Frost-susceptibility group
Gravelly moraine	I (-II)
Sandy moraine	II (-I)
Normal moraine	II
Sandy moey moraine	II
Moey moraine	III
Silty moraine	III
Clayey moraine	II (-III)
Moraine clay	II

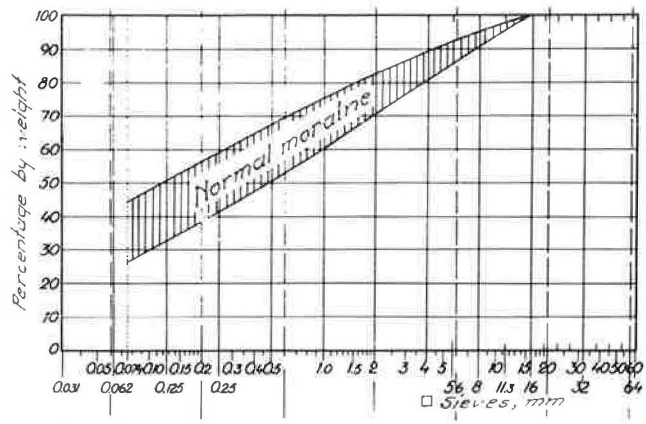

Figure 2. Grading of ordinary moraine soil (normal moraine) common in Swedish archaic rock areas. After G. Beskow.

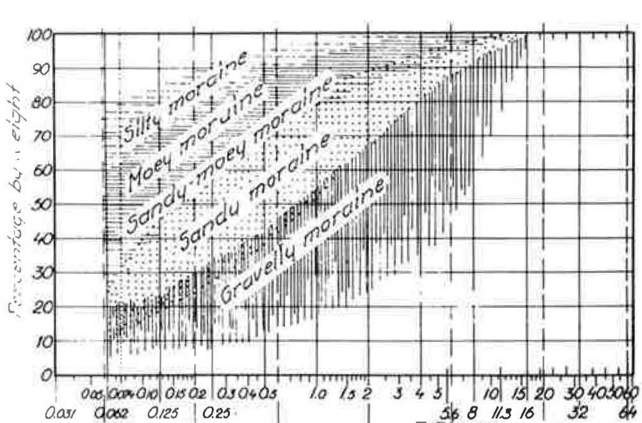

Figure 3. Grading of moraine types differing from the well-graded normal moraine by dominance of special fractions. After G. Beskow.

It follows that most inorganic soils in Sweden are frost-susceptible. Moreover, the geographic extent of the non-frost-susceptible soils in Sweden is relatively small. Therefore, soil freezing is of great importance in road construction.

PRINCIPAL METHODS FOR PROTECTING ROADS AGAINST HARMFUL EFFECTS OF SOIL FREEZING

The water absorption which takes place during the process of freezing results primarily in frost heaving, which can render a road surface so uneven as to cause trouble to traffic. This happens in areas where the soil conditions are non-uniform, chiefly in areas of transition from rock to frost-prone soil, and also at culverts. When thaw begins in the spring, the increased water content of the soil due to freezing gives rise to reduction in the bearing capacity of the road. Because the increase in the water content which takes place during soil freezing is the primary cause of the harmful effects produced by soil freezing on roads, various principal methods have been devised with a view to reducing or preventing the absorption of water due to moisture flow towards the frost line. These methods are briefly outlined (in the main according to G. Beskow) as follows:

I. Methods for Leveling Non-Uniform Frost Heave.
   A. Insertion of sand wedges in areas of transition from rock to frost-susceptible soil, and wedge-shaped tapering of culvert insulation.
   B. Insertion of V-shaped heat-insulating layer under the subbase of a road for the purpose of preventing frost cracks.

II. Methods for Reducing or Preventing Frost Heave.
   A. Methods for retarding or preventing the freezing of frost-susceptible soils.
      1. Spreading of non-frost-susceptible inorganic soil on top of the frost-susceptible subgrade. This method augments the thickness of the road construction, and hence increases the bearing capacity of the road.
      2. Spreading of heat-insulating materials (bark, peat) on top of the frost-susceptible subgrade. At the same time, this method reduces the depth of frost penetration.
      3. Replacement of frost-susceptible soil (excavation) with non-frost-susceptible soil.
   B. Methods for reducing or preventing water absorption from below during soil freezing.
      1. Breaking the capillary connection with the overlying backfill made of frost-susceptible soil by means of porous insulating layers (sand), and with the aid of impervious insulating layers (asphalted felt).
      2. Increase the depth of the ground water table below the carriageway by lowering the ground water table by deep drainage, and by raising the carriageway level by spreading materials on top of the existing road.
      3. Reduction of the thickness of the water films adsorbed on soil particles by load application (banking up), and by chemical stabilization.

III. Methods for Reducing or Preventing Harmful Effects of Excess Water Liberated During Thaw.
   A. Increase of the bearing capacity of the carriageway by augmenting the thickness of the base and the subbase. On gravel roads, this method can be supplemented with adjustment of the composition of the gravel course on the carriageway.
   B. Methods for removal of water.

Insulation by means of sand layers, which cut off the capillary flow, and lowering of the ground water table by deep drainage have formerly been used on a large scale, in addition to other methods, for prevention of damage due to soil freezing. For economic reasons, frost-susceptible soils from the subgrade were employed as backfill on the insulating sand layers.

In order to illustrate the efficiency of this method, it may be mentioned that a test road section (Fig. 4) was constructed in 1950 on National Main Road No. 13, which handles heavy and dense traffic. A layer of highly frost-susceptible silt (morainic soil

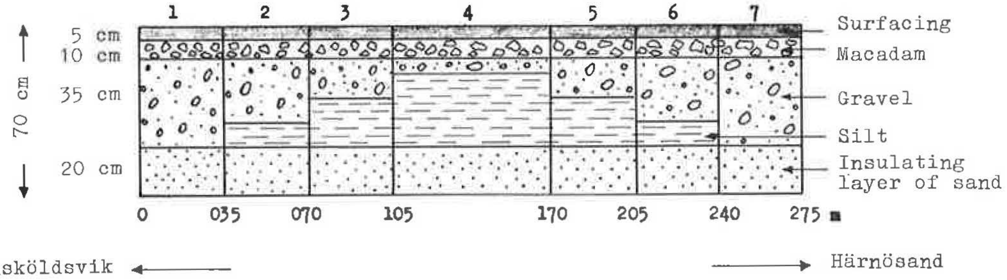

Figure 4. Road construction of the test road at Bjästa, Sweden.

was normally used) varying from 10 to 30 cm in thickness was placed as backfill on an insulating sand layer 20 cm in thickness. For the rest, the road construction comprises a gravel subbase, a broken stone base course 10 cm thick, and an asphalt surfacing 5 cm thick. The total thickness of the road construction is 70 cm. The insulating layer is made of sand with a well-assorted composition (Fig. 5). However, its content of fines varies within relatively wide limits. The subgrade of the test road section consists of silt.

After the construction of the test road section, samples have been taken at different times, distributed over several seasons, in order to check the water content of the

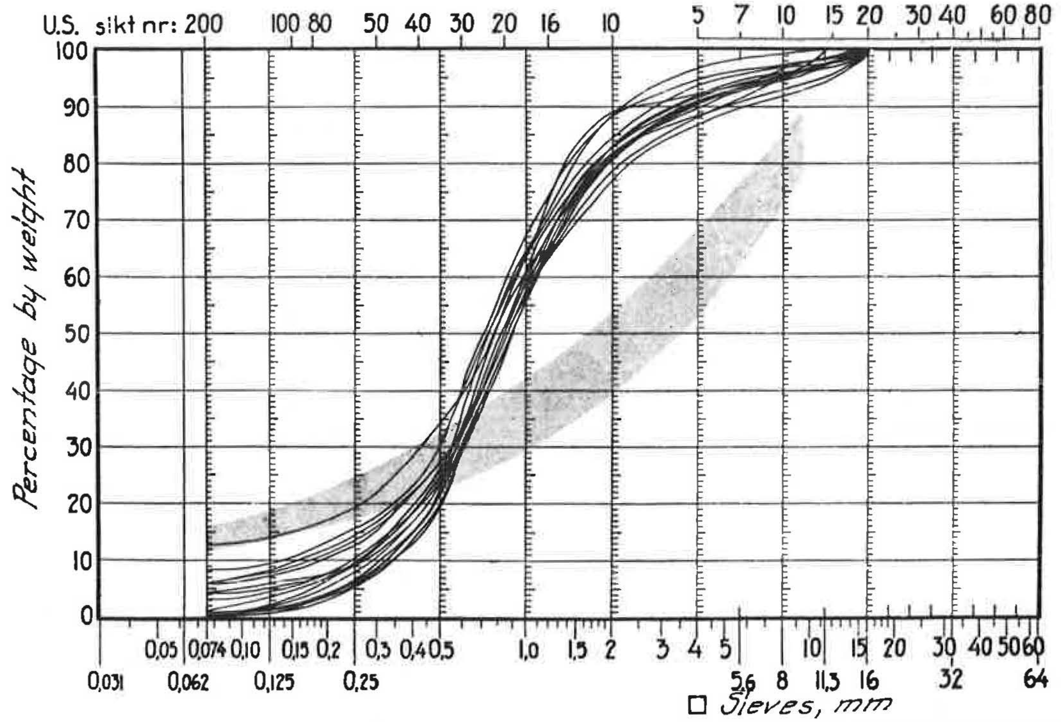

Figure 5. Grading curves for sand to the insulating layer in the bottom of the road construction of the test road at Bjästa.

insulating layer and the superposed silt layer employed as backfill. The water content of the insulating layer varied from 0.7 to 1.6 percent. The water content of the silt layer, which averages about 20 percent or slightly higher, has decreased in the course of several years by a few percent in comparison with the water content at the time of construction of this test road section. No increase in the water content was detected when these layers were frozen. The test road section had to carry heavy and dense traffic in the course of the past 12 years. Nevertheless, the test road section did not exhibit any frost damage. It may therefore be stated that the insulating layer used on this road has produced the intended effect of completely cutting off the capillary flow, with the result that the increase in the water content of the backfilled silt layer due to soil freezing was entirely prevented.

It is important to observe that the insulating sand layer should be placed on a certain definite level above the bottom of the side ditch so that the water cannot infiltrate the insulating layer. Some failures have occurred owing to soil flow solifluction from the slopes into the side ditches, with the result that water percolated into the insulating layer. Therefore, this method is now used on small roads only, whereas the base and subbase of other roads, particularly those which are surfaced, consist wholly of materials which are not frost-susceptible.

DETERMINATION OF TOTAL THICKNESS OF SURFACING, BASE, AND SUBBASE

The reduction in the bearing capacity of the frost-susceptible soils which takes place during thaw is dependent not only on the character and density of traffic, but also on many other factors, primarily on the type of soil, rate of freezing, ground water table, type of climate, heat insulation due to snow cover, and topographic conditions. Most of these factors can vary not only during the same freezing season, but also from one freezing season to another. The bearing capacity during the thawing period at the same point on a road or in the adjacent area can therefore vary considerably from one year to another, and also from time to time during the same period of thawing. Accordingly, it is difficult to obtain from measurements a correct actual value of the bearing capacity of a frost-susceptible soil which can be used as a basis for determining the total thickness of the surfacing, the base course, and the subbase. In particular, when new roads are to be constructed, the determination of the bearing capacity of a frost-susceptible subgrade is of little importance, because the value which is observed at that time will perhaps not agree with the bearing capacity of the soil at the time when the construction of the road is completed. Furthermore, the heat-insulating effect of snow cover can completely prevent freezing. The value of the bearing capacity observed under such conditions gives wholly misleading information on the true bearing capacity.

For practical purposes, it is therefore necessary to estimate the bearing capacity during the period of thawing on the basis of the non-varying factors, such as the type of soil and the features of the area where the road is to be built. On the basis of these factors and previous experiences concerning the requisite total thickness of the surfacing, the base, and the subbase on various soils, five different design tables have been prepared to take into account the traffic density and the type of wearing course. The requisite total thickness of the surfacing, the base, and the subbase is given in Table 1, which applies to roads with bituminous surfacings handling a traffic of at least 1,000 heavy vehicles (lorries and buses) per day during the period of thawing.

The total thickness of the base course and the bituminous surfacing should be 25 cm. The base course consists either of macadam or crushed gravel. If made of macadam, its surface is bound with bitumen as a rule. If made of gravel, its grading curve should run between, and conform to, two limiting curves. These limiting curves imply that 0 to 10 percent should pass the 0.074-mm sieve, 15 to 45 percent the 2-mm sieve, and 45 to 95 percent the 16-mm sieve.

The subbase consists of gravel, sand, or some other material which is not frost-susceptible. These materials should not lie nearer to the road surface than is indicated in the design table. Broken stone and the like may also be used, but in such cases a

TABLE 1

TOTAL THICKNESS OF SURFACING, BASE AND SUBBASE

Type of Soil (in subgrade or embankment)	Frost Suscep-tibility Group	Height of Road Surface Above Ground Level (cm)	Minimum Total Thickness of Surfacing, Base, and Subbase (cm)
Gravel Very gravelly moraine	I	–	–[1]
Sandy gravel Gravelly sand Very sandy moraine	I	–	25
Sand and coarse mo	I	–	35
Gravelly moraine Sandy moraine Normal moraine	II	Less than 30 or in cuts	60
		30 or more	40
Sandy moey moraine Clayey gravelly moraine Clayey sandy moraine Clayey normal moraine Moraine clay	II	Less than 40 or in cuts	70
		40 or more	50
(Clayey) moey moraine (Clayey) silty moraine Fine mo Silt Lighter clays	III	Less than 70 or in cuts	80
		70 or more	70
Heavier clays: Dry crust	II	Less than 40 or in cuts	70
		40 or more	50
Heavier clays: Very soft clay	II	–	90
Peat and mud	I	–	100

[1] The surfacing can be laid directly on this material if it meets the specifications for base courses.

filter layer of sand, 15 cm thick, should be inserted under the subbase if the subgrade consists of clay, peat, or some other highly frost-susceptible material.

FROST CRACKS

In recent years, longitudinal frost cracks (Fig. 6) have appeared mostly in new-built roads, especially in the northern parts of Sweden. These cracks are usually formed fairly early in the frost period, i.e., when the roads have a high bearing capacity. The cracks increase in width and length as the frost penetrates into the subgrade. Gen-

Figure 6. Frost crack in a road near Ersnäs.

erally, the cracks run along the approximate center line of the road or on either side of this center line.

As found from investigations, a necessary condition for the formation of frost cracks is that the road be built on a subgrade which is liable to frost heave and that the depth of frost penetration at the center of the road be greater than on the sides. As has also been shown, this uneven frost depth is due to the fact that the insulation due to snow cover at the center of the road is much less than on the sides. Consequently, the depth of frost penetration at the center of the road is greater than on the sides (Fig. 7). The depth of frost penetration at different times has been determined by the aid of a simple frost depth indicator (Fig. 8) described by R. Gandahl in the Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering. This indicator is filled with a blue-colored indicating solution. When the frost penetrates the ground, this instrument reacts so that the color of the solution changes to colorless and transparent in the frozen zone. The difference between the frozen and unfrozen parts is distinct (Fig. 8) and the depth of frost penetration is easily read from the graduated indicator tube.

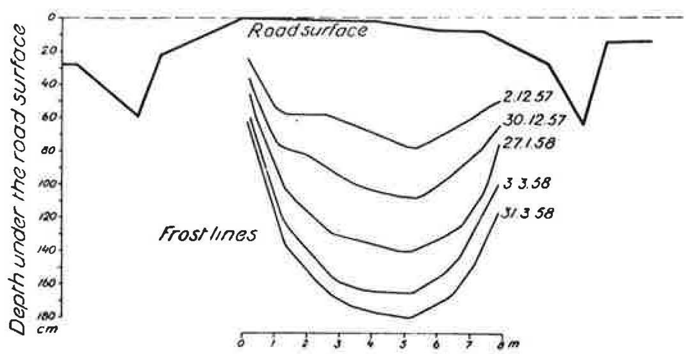

Figure 7. Frost lines at different dates during the freezing period 1957-58 in a road near Rutvik.

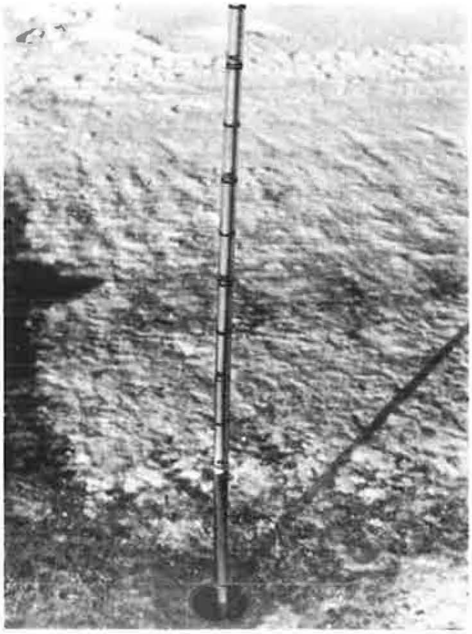

Figure 8. Frost indicator (model Gandahl) in the position of observation. In this case the frost depth is 141 cm.

A frost heave that is greater at the center of the road than on the sides may cause bending and tensile stresses in the road construction, and may thus involve the risk of cracking. This risk seems to be particularly great when the subbase consists of coarse-grained gravel, which does not retain any water in the pores, and therefore lacks adequate tensile strength in both frozen and unfrozen condition. In order to show this, the strength of some soil materials in frozen condition has been determined. The equipment used for this purpose is shown in Figure 9. The grading curves of the materials under test are reproduced in Figure 10, and the test results are given in Figure 11. It is seen from these graphs that the coarser material, Type 1, which did not contain any fine-grained particles, did not exhibit any strength in a frozen condition because no water was retained in the coarse pores, thus the material was not rendered cohesive during the freezing process.

In the tests on the other samples, the strength first increased with the increase in the water content up to a maximum and then decreased until it reached the strength of the ice itself. The maximum strength of the samples first increased as the content of fines became higher, and then decreased after the content of fines had reached a certain definite value. The highest maximum strength was observed in the case of Type III material, whose grading curve is in the main close to the ideal composition of gravel-wearing courses. For comparison, it may be mentioned that a test specimen made of concrete, whose composition corresponded to that of a concrete pavement mix, had a strength which was about half as high as that of Type III material.

In spite of the fact that a very high strength of soil materials in frozen condition can be obtained by adjusting their composition, this strength is probably not sufficient to prevent the formation of frost cracks in roads on account of the high stresses which are produced in the road construction when the frost heave is uneven. This adjustment of the composition can only reduce to some measure the liability to crack formation. To increase the total thickness of road construction to such an extent as to prevent frost crack formation is probably not recommendable for economic reasons (cracks have occurred in roads whose total thickness of construction was 1.6 m). Because frost crack formation is primarily due to the fact that the depth of frost penetration at the center of the road is greater than on the sides, it is possible to prevent crack formation by either increasing the depth of frost penetration on the sides by thorough snow clearing, or by reducing the depth of frost penetration at the center by using a heat-insulating layer. The latter method has proved to be particularly efficient.

On some Swedish test roads, a V-shaped layer of bark (or peat) has been provided under the subbase (Fig. 12). The thickness of the bark layer at the center of the road is 25 cm. During the frost season of 1960-61 when the freezing index at the time of maximum depth of frost penetration was 1,322 degree-days (C^0-d), the maximum depth of frost penetration on four road sections equipped with bark layers varied from 170 to 200 cm. On the other hand, the corresponding maximum depth of frost penetration on intermediate road sections, which are of a conventional type comprising a sand subbase and a gravel base course, varied from 230 to 260 cm. The difference in the maximum depth of frost penetration between the center and the edges of the road on the test sections with bark layers was negative. The greatest value of this difference was -13 cm.

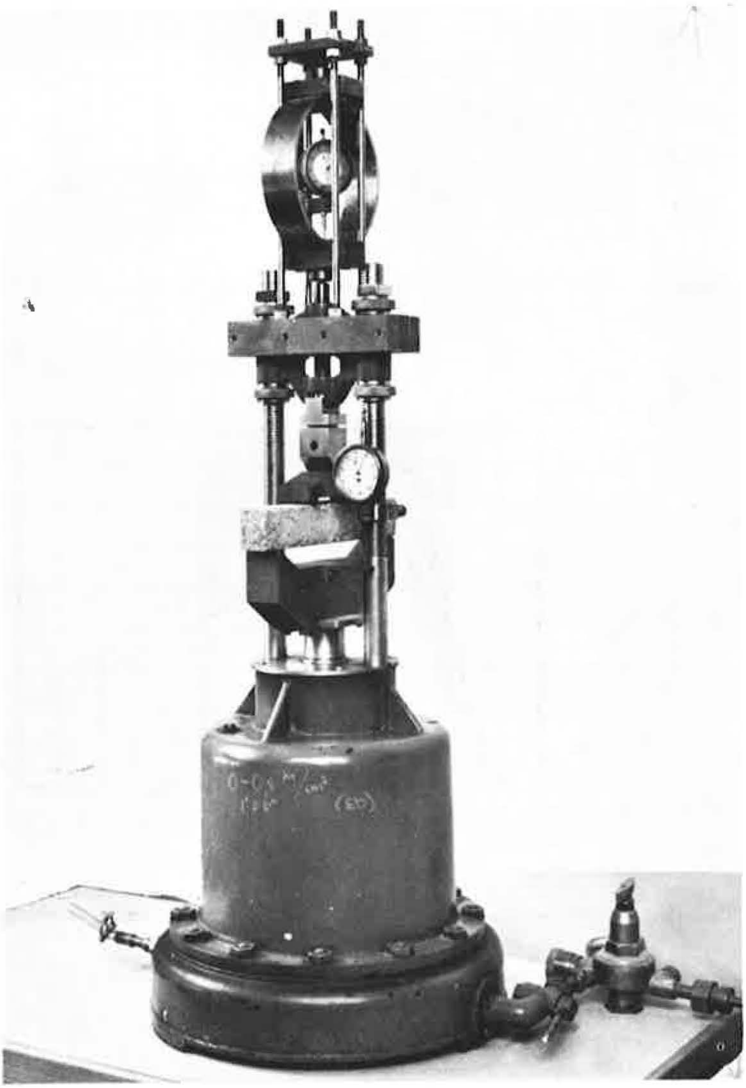

Figure 9. Pressure apparatus for determining the bending-tensile strength of soil samples in frozen conditions.

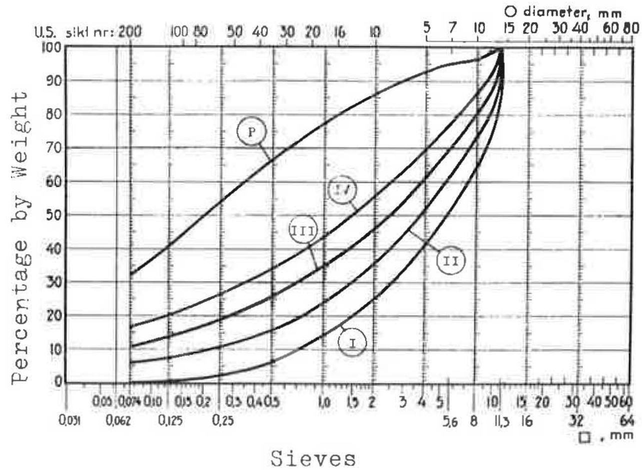

Figure 10. Grading curves for soils tested with respect to the bending-tensile strength in frozen condition.

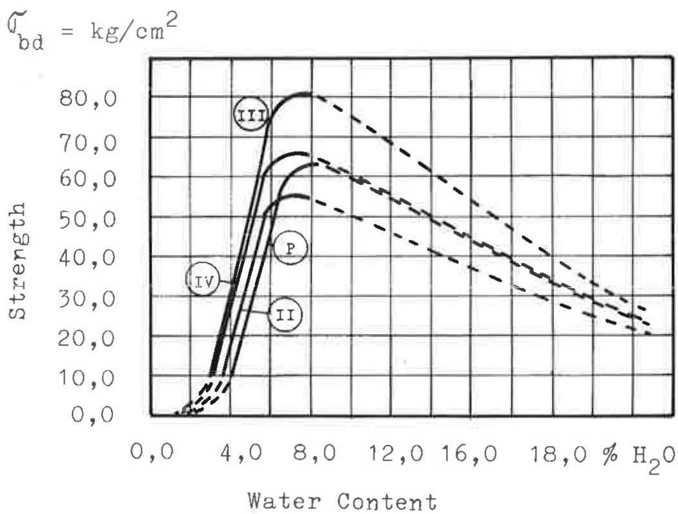

Figure 11. Bending-tensile strength for frozen soils in relation to moisture content.

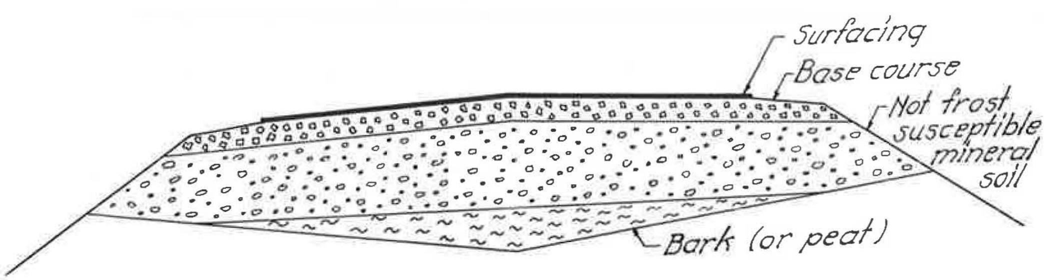

Figure 12. Road construction with V-formed layer of bark. In the center of the road, the thickness of the bark layer is 25 cm and the thickness of the remaining part of the road construction is 80 cm.

This means that the maximum depth of frost penetration at the center of the road in the present case was 13 cm smaller than at the edges of the road. The corresponding value for one of the test sections without bark layers was +20 cm, that is to say, the maximum depth of frost penetration at the center of the road was 20 cm greater than at the edges. It should be noted that no frost cracks have formed on the road sections with bark layers during the frost seasons of 1960-61 and 1961-62, whereas frost cracks have occurred during the latter frost season on road sections without bark layers.

Appendix

After the preceding paper was prepared the National Swedish Road Research Institute proposed the following new tables for pavement design.

	Type of wearing course		Gravel	Bituminous surfacing					Concrete
	Design table		1	2	3	4	5	6	7
	Daily traffic volume (no. of vehicles)								
	Heavy traffic (lorries and buses) during the period of thawing		<50	<50	<250	<1000	<3000	>3000	
	or								
	Total average daily traffic in summer (June - Aug.)		<500	<500	<2500	<10000	<30000	>30000	
	Type of soil (in subgrade and embankment)		Minimum total thickness of surfacing, base and subbase, cm						
A	Gravel Sandy gravel Gravelly moraine Sandy moraine	 I[1] I I	15	15	20	25	30	35	25
B	Gravelly sand Sand Coarse mo	I I I	20	25	30	35	40	45	25
C	Gravelly moraine Sandy moraine Normal moraine	II[2] II II	30	40	50	60	70	80	60
D	Sandy moey moraine Clayey moraine Moraine clay	II II II	40	50	60	70	80	90	70
E	Moey (silty) moraine Fine mo and silt Lighter clays Heavier clays (dry crust)	III[3] III III II	50	60	70	80	90	100	80
F	Heavier, very soft clays Peat and mud	II I	60	70	90	100	110	120	80[4]

[1] I = not frost-susceptible soil.
[2] II = moderately frost-susceptible soil.
[3] III = very frost-susceptible soil.
[4] Concrete is not recommended on peat and mud.

Discussion

I. C. MACFARLANE, Soil Mechanics Section, Division of Building Research, National Research Council, Ottawa, Canada.—One of the methods recommended by Mr. Rengmark for reducing or preventing frost heave is the spreading of heat-insulating materials, such as bark or peat, on top of the frost-susceptible subgrade. He points out that this also reduces the depth of frost penetration. It is interesting to observe that Skaven-Haug in his paper on protection against frost heaving on the Norwegian railways (1) also refers to this unusual use of peat. He shows very clearly that a layer of wet, compressed peat overlain by a dry bearing layer is extremely frost retarding. It also considerably reduced the depth of excavation required in the removal of frost-susceptible soil and subsequent replacement with non-frost-susceptible material. Miyakawa reports that this technique has also been followed in Japan with some success (2).

In Canada, this technique has rarely, if ever, been attempted. Rather, peat is generally considered to be somewhat of a liability, and great pains are usually taken to remove it from a proposed road right-of-way. The suggestion of deliberately incorporating a layer of peat into a roadway subgrade may be met with considerable scepticism by many engineers.

In the course of an investigation in northern Ontario to evaluate the performance of roads over muskeg (3), the writer observed that roads floated directly on the muskeg exhibited much less damage from the effects of frost action than did adjacent sections of road over clayey and silty soils. Even further north—in northern Alberta, British Columbia and the Territories—frost-susceptible soils and consequent difficulties are encountered to a considerable extent in the construction of the "roads to resources," which essentially are secondary roads designed for a low density of very heavy loads.

In many areas non-frost-susceptible soils are difficult to locate. One wonders if in cases such as this—and for secondary roads in general on frost-susceptible soils—it would not result in lower maintenance costs in the long run if the Scandinavian practice of incorporating a layer of wet, compressed peat into the roadway were followed. A corollary of this would be deliberately to site roads over muskeg areas where feasible rather than over inorganic frost-susceptible terrain.

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F. C. BROWNRIDGE, Special Assignments Engineer, Ontario Department of Highways.—Mr. Rengmark's report is interesting to highway engineers in Ontario because of the similar environment problems and his empirical approach to pavement design. He describes several experiments in highway construction in frost areas which have not been tried here.

Although Sweden lies entirely north of latitude 56^0, or approximately that of Hudson Bay, its temperature is decidedly moderated by its maritime character, its relatively low elevation and the influence of the Gulf Stream. The combination of these factors result in a freezing index for lower Sweden which compares with that of southern Ontario.

EMPIRICAL PAVEMENT DESIGN

In Table 1, Mr. Rengmark gives the minimum total thickness design for flexible pavements built on various types of subgrade soil, classified as to their frost susceptibility. Comparing this with the current Ontario design for the same conditions, the latter was from one to seven inches thicker with the greater depths required for the Group III soils. For Group I, the additional depth was from one to three inches, and for Group II, from three to six inches greater. When a crushed-rock subbase material is used in Sweden, an additional 5.9 in. of sand filter layer is employed where the subgrade is either clay, peat or silt. For these cases, the total pavement thicknesses would be approximately the same.

USE OF SAND-INSULATING LAYERS TO CUT OFF CAPILLARY FLOW

The use of cut-off sand layers for the test sections of National Main Road No. 13, (Fig. 4) appears to have been effective. There was concern over the possible saturation of the silt used for the embankment due to the entrance of surface run-off. On inquiry, Mr. Rengmark stated that the full width of the road surface was paved.

Unless granular material was very scarce we would hesitate to recommend this method of construction in frost areas. It is noted in his last paragraph that some failures have occurred and that present practice utilizes non-frost-susceptible bases except for minor roads.

FROST CRACKS

Mr. Rengmark refers to the recent occurrence of longitudinal frost cracks appearing mostly in new construction and especially in the northern parts of Sweden. His investigations show a necessary condition for their formation is a frost-susceptible subgrade with the frost penetration greater at the center than at the sides. The risk of cracking from unequal heaving appears greater when the subbase consists of coarse-grained gravel with little fines, and has low strengths in a frozen or unfrozen condition.

In northern Ontario, transverse cracking has occurred on new construction in a very irregular pattern. On the same contract and for the same design, cracks have been noted at 1, 500 to 2, 000 ft spacing for one area, while on another section they have been observed as close as 200 ft apart. Several years ago, adjoining Provinces and the more northern States were circularized in regard to transverse cracking in flexible pavements. Replies indicated that although these had been observed, they were not considered a serious enough problem to justify any concerted action, although all agreed they were related to severe frost conditions.

In Ontario, it is economically unfeasible to design for the full depth of frost penetration and the complete elimination of frost heaving. The general practice is to use non-frost-susceptible materials and sufficient depth so that the subgrade soil will not be over-stressed during the critical spring period. Frost heaving is, therefore, accepted with the design aimed at obtaining uniform heaving and preventing differential heaving as much as possible. Experience indicates that more effective and economical results can be obtained by the control of moisture through efficient drainage than by the removal of frost-susceptible soils or the use of increased depths of granular subbases.

FROST CRACK INVESTIGATION IN ONTARIO

Mr. Alex Rutka, Materials and Research Engineer, has furnished information on a long-term investigation of bituminous pavement cracking in Ontario which started in 1961. It identifies the specific conditions of pavement, granular bases, subgrade soil, moisture and temperature regime, frost-depth penetration, etc.

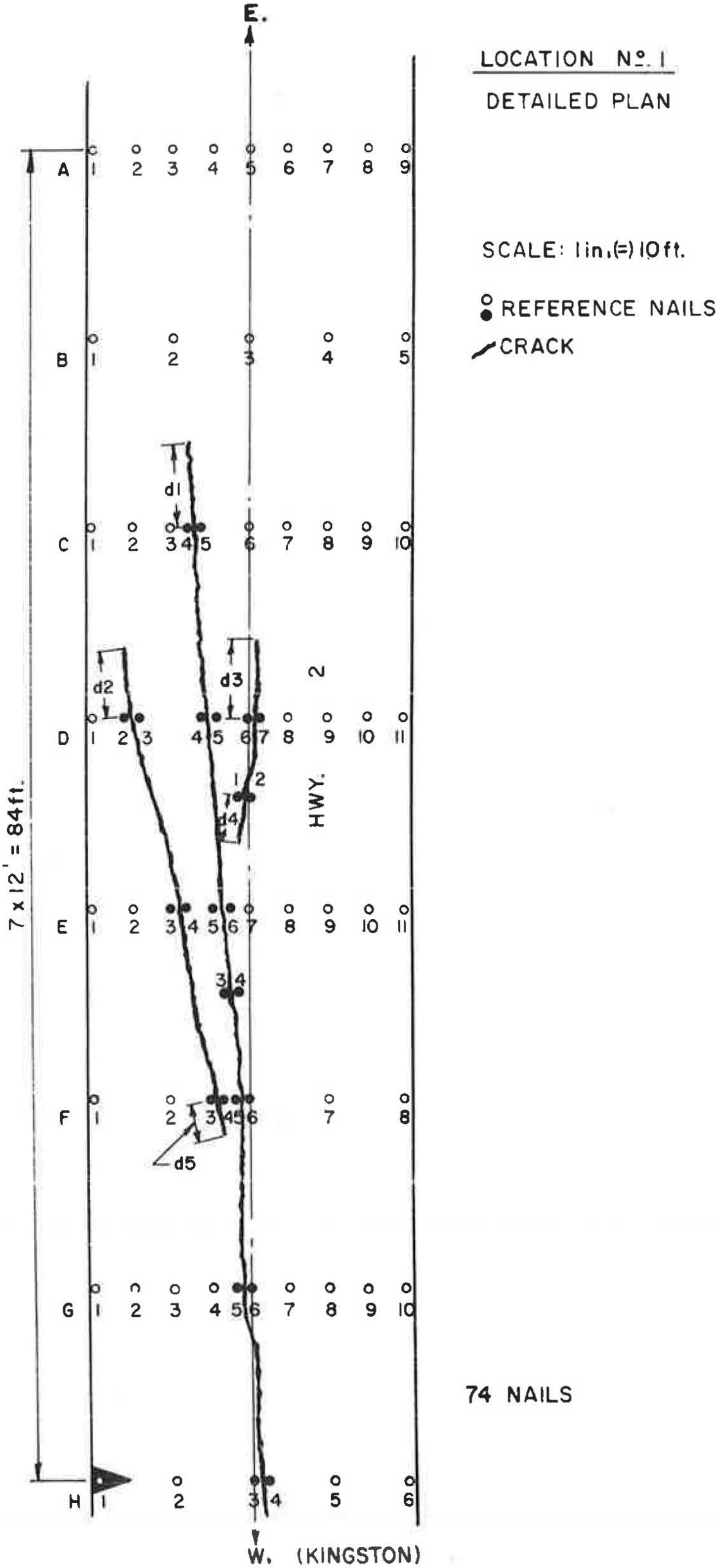

Figure 13. Typical installation of bench marks and reference nails.

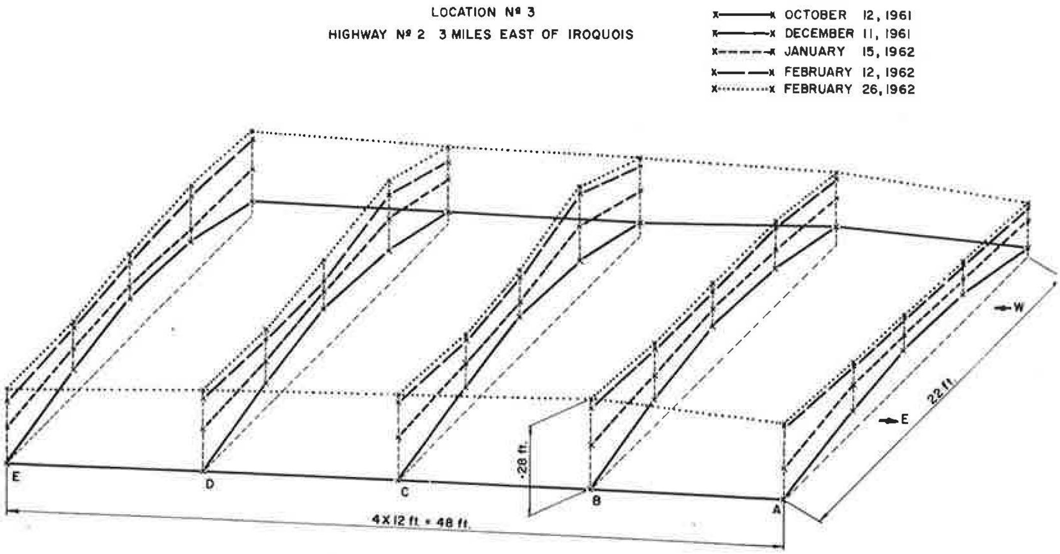

Figure 14. Vertical movements of pavement surface.

Twenty test sections, each of 100 ft length, were selected as representative of transverse, longitudinal, slippage, shrinkage and alligator cracking. The selection varied for geographic and topographic conditions, as well as sub-soil, moisture and traffic intensities. Permanent bench marks were installed and reference nails driven into the pavement in a pre-established pattern at each site (Fig. 13). The elevation of each reference nail and the distance between those shown as full black dots were taken on a weekly or fortnightly basis. The elevation records are plotted on a three-dimensional graph (Fig. 14).

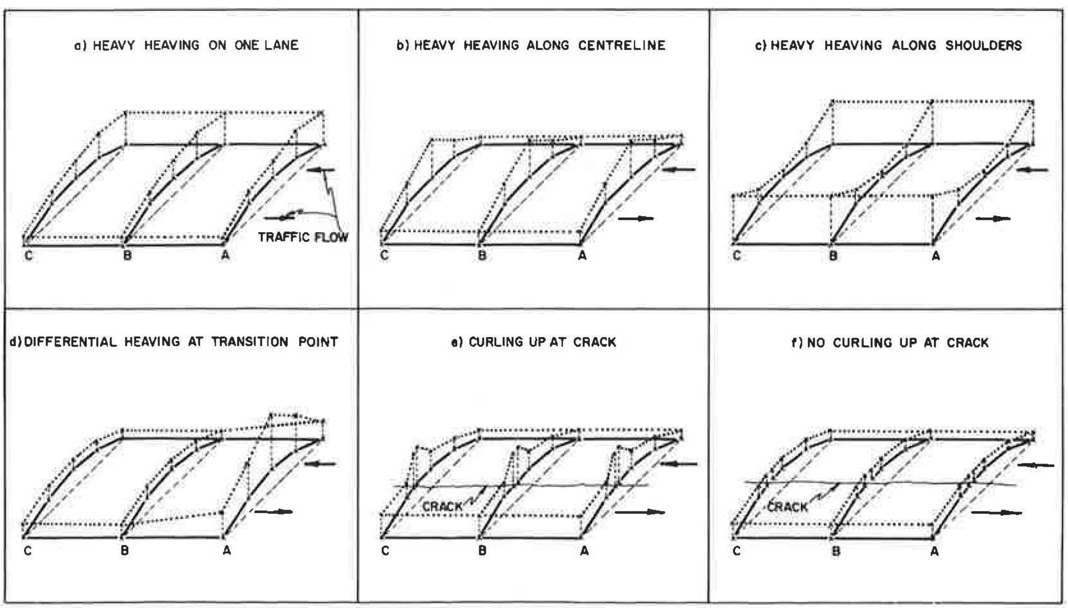

Figure 15. Patterns of vertical movement.

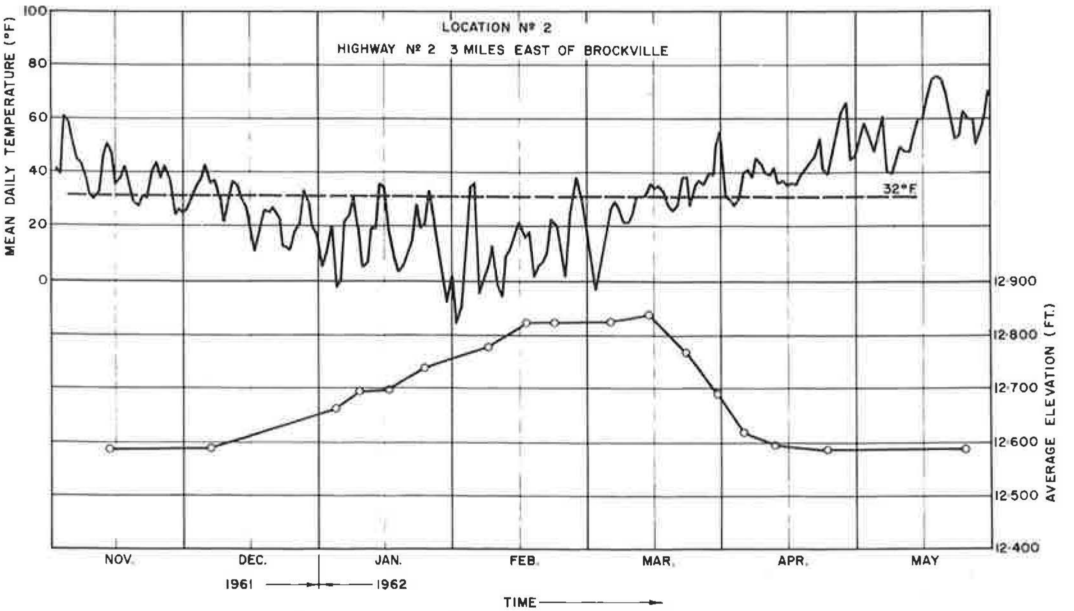

Figure 16. Average elevation vs daily mean temperature.

Although the investigation is not yet complete for all the test sites, characteristic patterns of surface movements have been observed. These patterns with the probable causes are shown in Figure 15.

Temperature and precipitation data are being obtained from weather stations in the vicinity of the test sections. An attempt will be made to analyze these data with observed surface movements. One such graph is shown in Figure 16. An analysis of graphs of this kind promises information on frost heaving concerning the role of temperature and the time-lag between temperature changes and the resulting vertical movements. The heaving process starts about two weeks after the temperature drops below the freezing point; is gradual in spite of significant temperature variations within the freezing range; is reversed at almost the same time the temperature again rises above 32 F in the spring; and the surface quickly settles down to its original level in about a month's time.

WILLIAM J. RAMSEY, Sr. Geologist, Division of Materials & Tests, Nebraska Department of Roads.—The report by Mr. Rengmark is an excellent summary of Sweden's highway design practices in frost areas, and this writer wishes to congratulate him for his endeavor. It was noted in his report that Sweden has experimented with the construction of an insulating layer of sand near the surface of a silt-clay subgrade. The result was the placement of a thin layer of silt-clay material over a sand material immediately below the base course. In Nebraska, a similar type of construction was detrimental to the performance of the flexible pavement.

A project of this nature, which is located on Nebraska Highway 44 between its junction with U. S. 6 and Kearney, Neb., is used as an illustration.

Prior to recent reconstruction, this road was last graded and surfaced in 1941. The flexible pavement surfacing consisted of a 3-in. × 27-ft soil stabilized base course and armor coat (Fig. 17).

In 1959 a subgrade survey was conducted. From this investigation, the project was divided into the following two sections of different soil types:

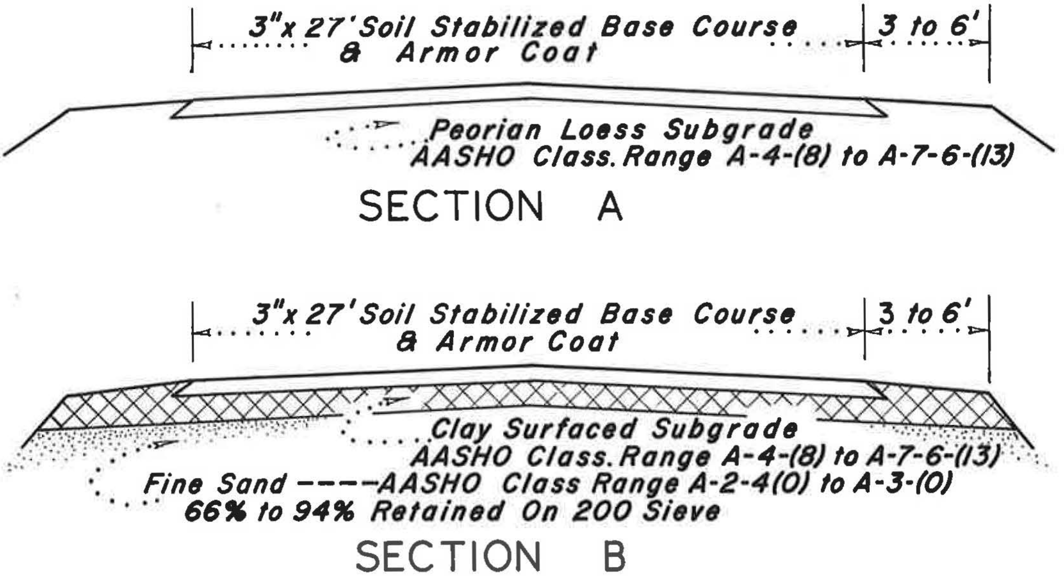

Figure 17. Typical cross-section of 1941 construction.

(A) The subgrade of the south 6½ miles consisted of silt-clay soils of Peorian loess origin (Fig. 1).

(B) The north 5 miles traversed a sandhill and alluvial sand section in which small pockets of Peorian loess and alluvial silts and clays were encountered. A layer of cohesive soil was used as a clay-surfacing material and had been placed over the sand subgrade (Fig. 1). This layer was approximately 4 in. thick.

Table 2 gives the minimum and maximum range of the engineering characteristics of the soils encountered during the subgrade survey. It should be noted that the Peorian loess subgrade material in section A and the material used as clay surfacing in section B have engineering characteristics that are similar.

TABLE 2

RANGE OF ENGINEERING CHARACTERISTICS OF SUBGRADE SOILS

Plasticity Index	Hydrometer Analysis		Sieve Analysis % Retained		AASHO Classification
	Silt 0.074-0.005	Clay -0.005	No. 10	No. 200	
		Section A (Peorian loess subgrade)			
7-21	36-53	18-41	0-7	1-23	A-4(8) to A-7-6(13)
		Section B (Clay-surfaced subgrade)			
5-21	38-59	14-28	0-3	2-27	A-4(8) to A-7-6(13)
		(Dune & alluvial sand)			
NP	3-20	2-8	0-10	66-94	A-2-4(0) to A-3(0)

During the field investigation, it was observed that considerably more maintenance was required in section B than section A. A review of the maintenance records which show the patching and repair accomplished between 1941-58 confirmed this.

From these records, Figure 18 was prepared. Note in section A that the length of patching per mile or portion thereof varies from approximately 700 ft (mile 1 to 2) to 4,700 ft (mile 6 to 6.5), or an average of slightly over 2,000 ft per mile. However, in section B the length of patching varies from about 7,400 ft between mile 11 and 11.5 to 13,700 ft between mile 8 and 9. This section has an average length of patching per mile of approximately 11,000 ft.

In the course of the field investigation, observations of the total thickness of the bituminous material were made (Fig. 19). These measurements include those sections where only an armor coat surfacing was encountered, as well as those sections which had bituminous patches applied. It is apparent that a thicker build-up of bituminous material has occurred in section B than section A. The average thickness of the bituminous material in section B is over 3 in., but the average thickness in section A is less than $1\frac{1}{2}$ in.

Admittedly, the 1941 design of this project was not adequate for today's traffic. However, because the flexible pavement design in both sections is the same, the following conclusions seem to be justified on the basis of the data presented:

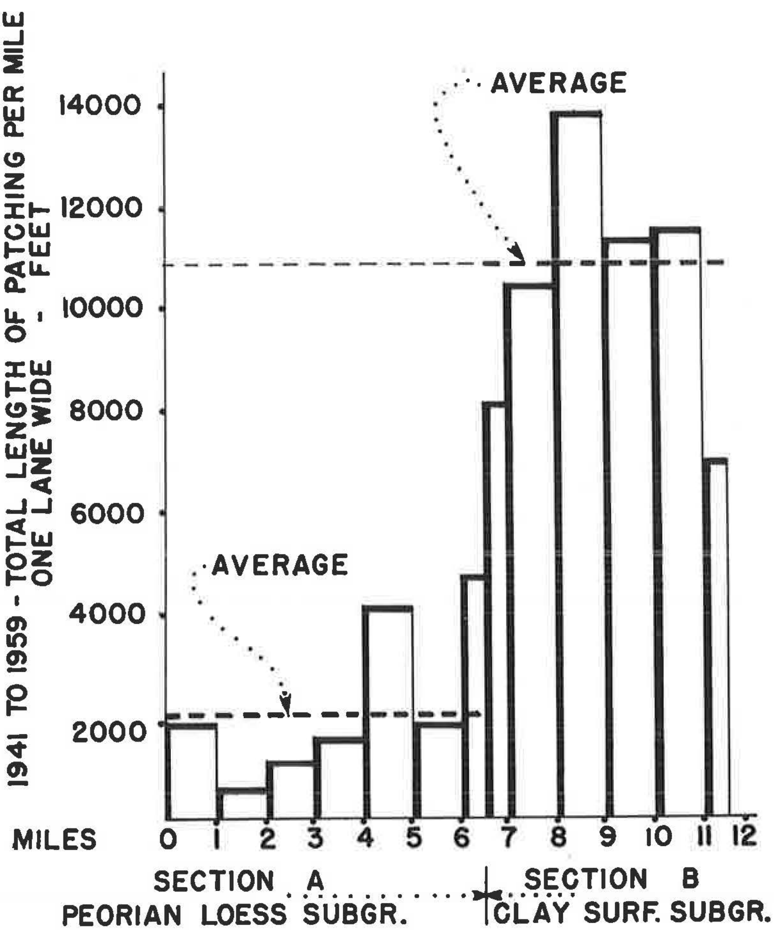

Figure 18. Total length of patching for each mile.

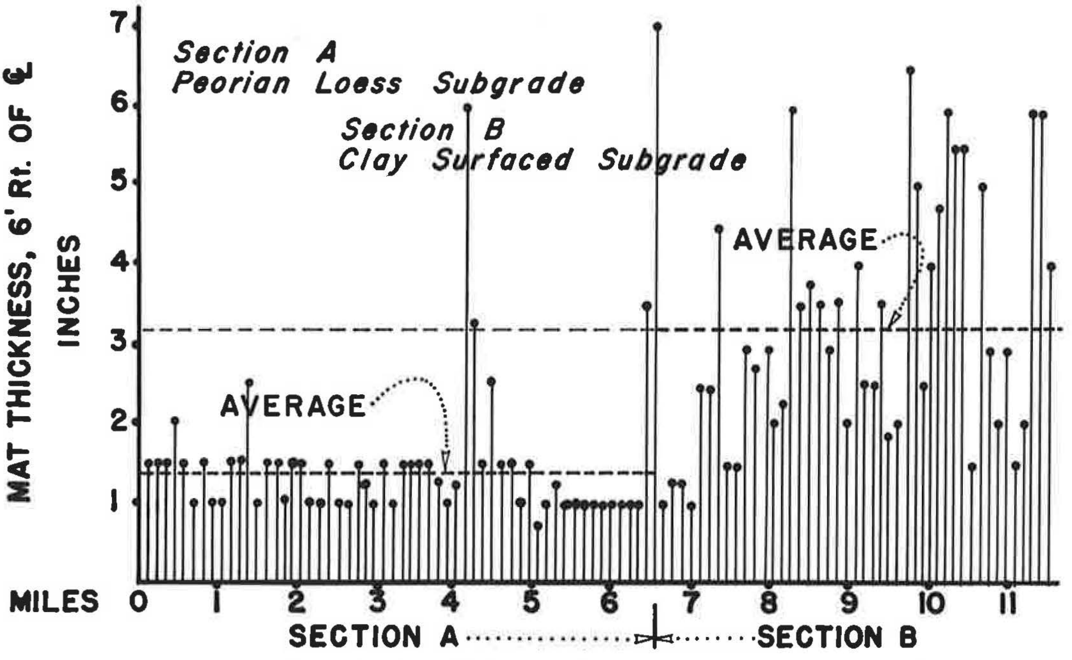

Figure 19. Borings showing thickness of bituminous surfacing in 1959.

(1) The placement of a silt-clay layer over a sand subgrade has a detrimental effect on the serviceability of the flexible pavement.

(2) Any given cohesive soil is less favorable for use in the subgrade if underlain by sand.

FOLKE RENGMARK, Closure—Ramsey reports on an investigation of Nebraska Highway 44 and on damages caused on this road. Considering the thickness of the road construction, it is surprising that no more serious damages have arisen. According to Table 1, the thickness of the road construction by Swedish standards along section A should be at least 70 cm, and 35 cm along section B.

The conclusions Ramsey draws are much too general. This is shown by the results reached at the experimental road at Bjästa. This road was built to try a method of breaking capillary connection with insulating sand layers. For this experiment, silt was used in the road construction to make the test harder. Of course, the purpose was not to test the silt for road-making purposes.

His statement that clay-surfacing materials have to be removed prior to construction of flexible pavements is completely in agreement with the opinion in Sweden.