Preventive Measures to Reduce Frost Action on Highways in Finland

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The report describes the methods used to diminish or prevent the detrimental effects of frost in Finland. The leveling of the non-uniform frost heaving came about by using wedges on the border of rock cuts, where embankments and cuts meet, where soil changes, and between both sides of culverts. Prevention or reduction of frost heaving was brought about by replacing the frost-susceptible soil with non-frost-susceptible soil or increasing the embankment on frost-susceptible soil. Absorption of the groundwater table into the base course was prevented by using an insulating course, lowering the groundwater table deep drainage, ditching of the road or by chemical stabilization. Vertical drain with gravel fill has also been used to reduce the suction of water into the border zone of freezing and to evaporate water from the base and subbase course. This report also describes some aspects to be considered in the construction of frost-resistant roads.

•CLIMATIC and geological conditions and the local circumstances in Finland, between the 60th and 70th latitude, are important factors to be considered when planning new highways and roads. The fall is usally very rainy so that the groundwater table is high when the frost begins. The winter is relatively long and cold. The mean freezing index is shown in Figure 1.

Finland belongs to the same primary granitic bedrock as the other Scandinavian countries. On top of the bedrock there are hard moraine or gravel ridges, but on lower places and on plains, sediments.

CLASSIFICATION OF SOILS

The Atterberg (Swedish) classification is used in Finland. The assorted soils are boulders, stone, gravel, sand, silt, and clay. The unassorted ones are in moraines.

The frost-susceptibility of the soils is almost the same as in Sweden. The soils are divided into three groups: non-frost-susceptible, moderately frost-susceptible, and highly frost-susceptible.

NATURE AND EXTENT OF FROST PROBLEM IN FINLAND

The climatic circumstances, the high groundwater table and the generally frost-sensitive soil all make the freezing problems difficult to handle throughout the country. The depth of the frozen earth layer is about 4 to 6 ft in South Finland and about 7 to 10 ft in North Finland. The old highways, which have only a thin base course, freeze badly every spring. About 65 percent of the highways and roads are frost-susceptible. In the spring the traffic must often be restricted. There have been restric-

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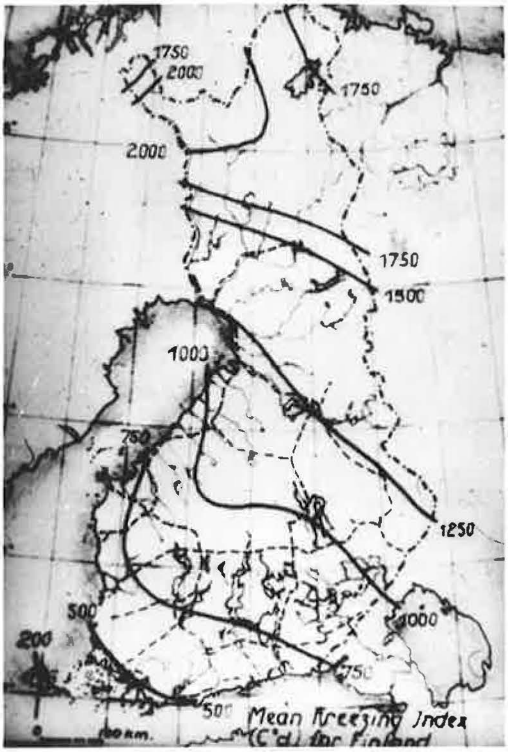

Figure 1. Mean freezing index for Finland. South, 500; Central, 1,000; and North, 1,250 to 2,000 degree-days (C x days).

tions on 25-40 percent of the highway routes. In 1955, during a very difficult spring, 47.3 percent of the roads were untrafficable. On these roads, there have been load restrictions to only 3, 6 or 8 tons. The greatest problem is the spring thaw in Central Finland, where about 80 percent of the roads were untrafficable some years ago. The most severe traffic restrictions (about 90 percent of the highways) were in the northernmost part of the country. Traffic has been restricted for periods of three weeks to two months, but some highway districts (in Central Finland) have had traffic restrictions until the end of June.

The frost heaving is of many different grades. On old highways, where the subbase is highly frost-susceptible soil, the heaving can be 2 ft or greater (Figs. 2 and 3). On the highways built during the last ten years, only non-frost-susceptible soils were used. On these roads, there were either no freezing problems, or only a few frost heavings of about 1 to 3 in.

In the spring, these new highways did not lose their capability to carry heavy traffic. From the viewpoint of the driver, the most difficult heavings appeared at the ends of rock cuttings or frost-susceptible earth cuttings, or when the frost heaving suddenly changed with respect to its quality or quantity.

PRESENT METHODS TO DIMINISH OR PREVENT DETRIMENTAL EFFECTS OF FROST

Frost heave is harmful to vehicles, causes breaks in the pavement, causes the subbase to soften, and reduces the bearing capacity of the road.

Use of Wedges

The methods of leveling the non-uniform frost heaving by using wedges are shown in Figures 4 through 9. Because the last few winters were mild, there was an opportunity to study the use of wedges for the first time. The author examined these few experiences with frost heaving due to the effect of the wedges and calculated the depth of the frost (according to Watzinger) using a surface correction factor, $\mu = 0.94$. The frost heaving was also calculated. The highest change of grade was assumed to be 0.3 percent. According to this study, the depth of the wedges was not sufficient to eliminate frost heaving greater than these maximum values more often than once every few years. The dimensions of the presently used wedges and those recommended are given in Table 1.

Use of Non-Frost-Susceptible Soil

The old road material was removed to a depth of 3 to 5 ft and replaced with gravel. On the new roads, the result was satisfactory, but on the older roads, it did not always improve the situation. During cold winters, the freezing may have penetrated even deeper into and below the base and subbase courses and caused larger cracks in pavement (about 2 in.) than before the soil was replaced. On old, narrow, steep sloping

Figure 2. Spring breakup on gravel roads in Central Finland.

TABLE 1

WEDGES AGAINST NON-UNIFORM FROST HEAVING

Type and Location of Section	Wedge Today					Wedge (After Taivainen)				
	Depth (m)	Top of Cut		Top of Earth Cut or Embankment		Depth (m)	Top of Cut		Top of Earth Cut or Embankment	
		Length (m)	Bottom Grade	Length (m)	Bottom Grade		Length (m)	Bottom Grade	Length (m)	Bottom Grade
Rock cut; highly-suscept. earth cut:										
S. Finland	1.7	5.8	1:4	18.0	1:20	1.7	5.8	1:4	27.0	1:30
N. Finland	1.7	5.8	1:4	18.0	1:20	2.25	8.0	1:4	43.5	1:30
Highly-suscept. earth cut; non-suscept. embankment:										
S. Finland	1.7	15.0	1:20	—	—	1.7	27.0	1:30	—	1:30*
N. Finland	1.7	15.0	1:20	—	—	2.25	43.5	1:30	—	1:30*
Highly-suscept. earth cut; frost suscept. embankment:										
S. Finland	1.2	5.0	1:10	8.0	1:20	1.2	15.0	1:30	15.0	1:30
N. Finland	1.2	5.0	1:10	8.0	1:20	1.2	15.0	1:30	15.0	1:30

*Down.

highways, which have been widened by soil filling on both edges, the part of the highway which was on top of the old road did not heave, but the edges of the road may have been raised to cause longitudinal cracks in the pavement.

Increasing Embankment on Frost-Susceptible Soil

Normal thickness of the base and subbase on frost-susceptible soil is now 0.80 m accord-

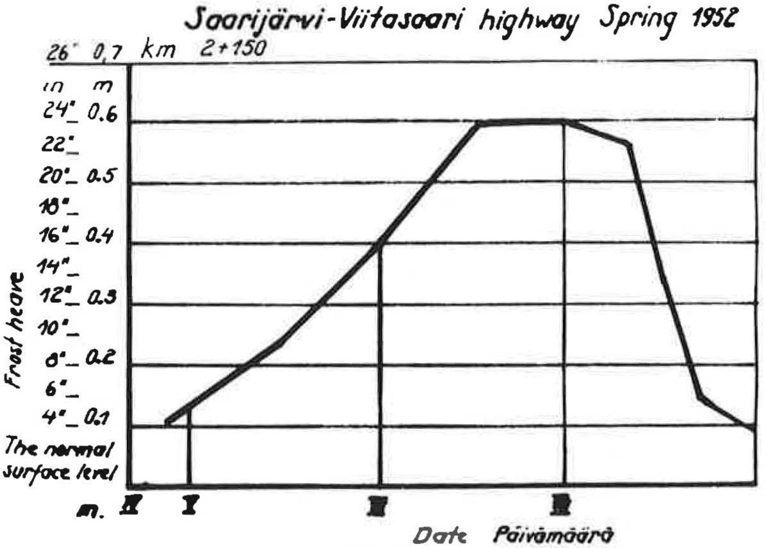

Figure 3. Frost heaving, Saarijärvi-Viitasaari highway, Spring 1952.

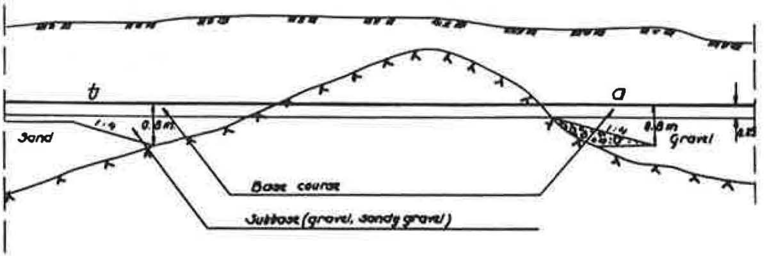

Figure 4. Wedge between rock cutting and non-frost-susceptible soil.

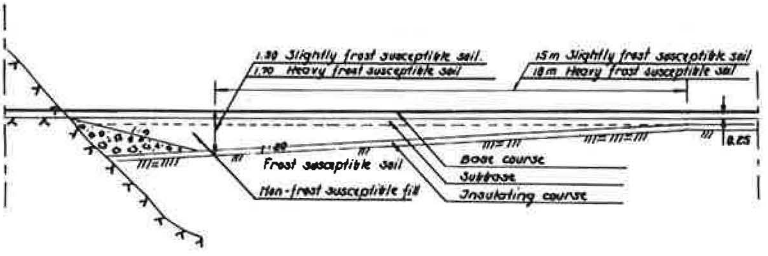

Figure 5. Wedge between rock cutting and frost-susceptible soil.

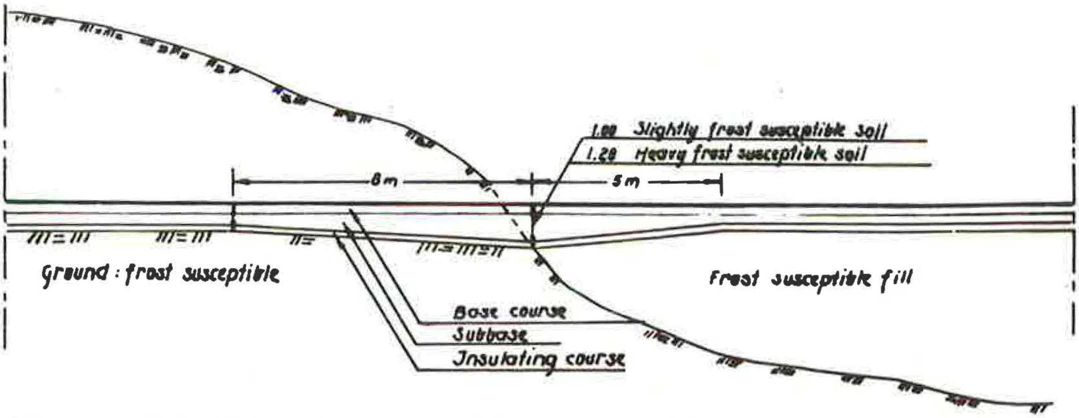

Figure 6. Wedge Between frost-susceptible earth cutting and frost-susceptible embankment.

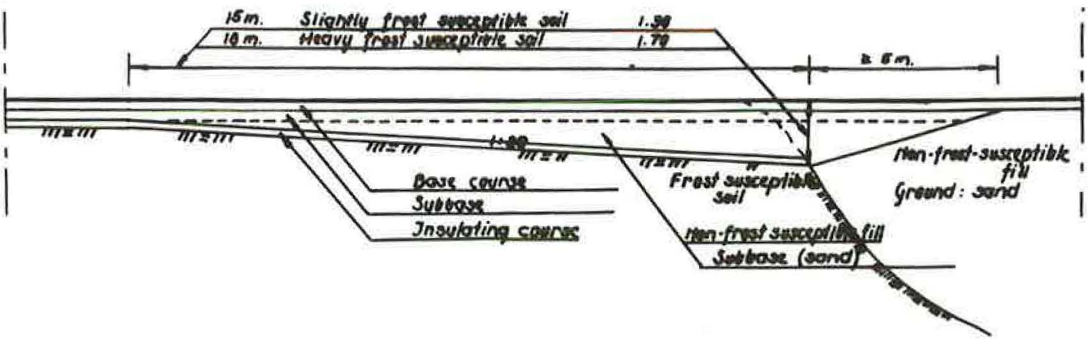

Figure 7. Wedge between frost-susceptible earth cutting and sand ground.

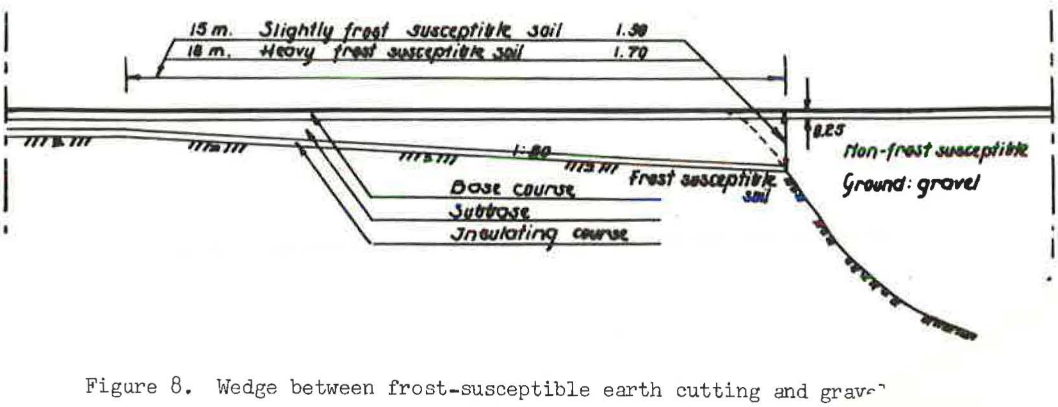

Figure 8. Wedge between frost-susceptible earth cutting and

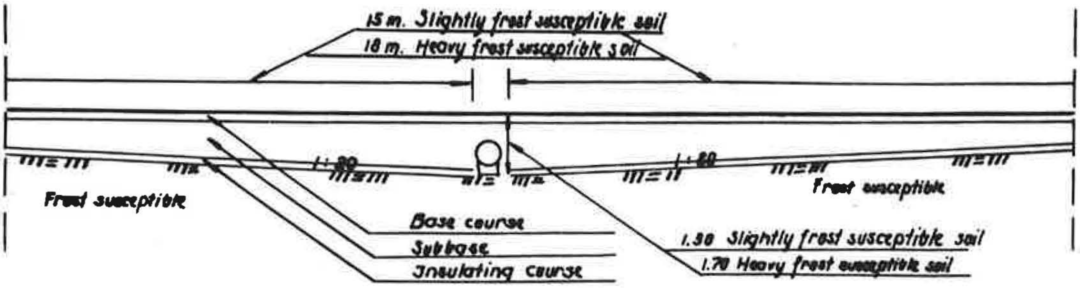

Figure 9. Wedge between both sides of a culvert.

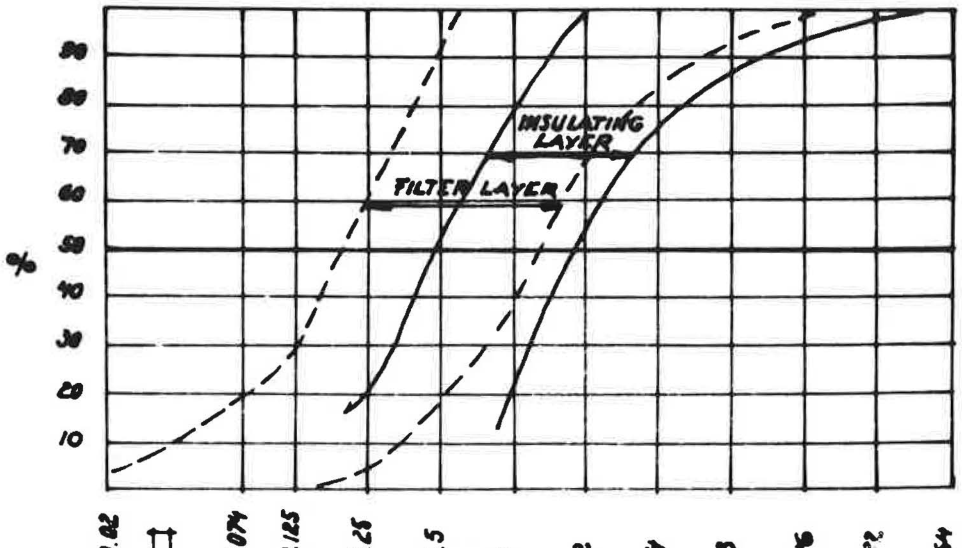

Figure 10. Use of insulating layer in highway.

ing to specified standards. However, the highways have generally been built to 1.0-meter thickness. Consequently, frost heaving and cracks due to the freezing have been lower and fewer. Frost heaving was studied on these roads and the conclusion was that, allowing frost heaving of 3 in., combined thickness of the base and subbase should be 2 ft, 8 in. (0.80 m) (F = 1,100 deg-days) in South Finland, 3 ft (90 cm) (F = 1,340 deg-days) in Central Finland, and about 5 ft (145 cm) (F = 2,100 deg-days) in North Finland. Under these conditions, large frost heaving will occur only once in every ten years.

Use of Insulating Layer

An insulating layer was used to interrupt the capillary contact in the base of the highway. The grain size distribution of the sand should be as shown in Figure 10, and it should not contain rocks bigger than 2 in. If such sand is not available, gravel may be used instead. A filler course containing 2-in. thick non-frost-susceptible moig sand (Figure 10) was made under the gravel course. The capillarity of the moig sand must not exceed 3 ft and should not contain rocks bigger than 2 in. The thickness of the insulating layer was 6 to 8 in. (15-20 cm), sometimes up to 16 in. (40 cm).

The insulating layer had a reducing and smoothing effect on frost heaving, and during the spring thaw, it increased the bearing capacity, but only if the layer was really dry and above the level of the water table. This layer was especially effective during mild winters.

Lowering Groundwater Table Through Deep Drainage

Drains were used to some extent to lower the water table. They were especially useful on roads built on slopes. Earlier, they were used under the open ditch but were clogged up in a few years. Drains have also been built under the shoulder. However, deformations occurred in the shoulder when the fill was not compacted enough. According to the instructions of the Administration of Roads and Waterways (1954), the drain has to be placed half-way between the edge of the road and the ditch (Fig. 11).

The depth of the drain is at least 5 to 8 ft (1.5-1.8 m) depending on the consistency of the soil, whether moderately or highly frost-susceptible.

The drains have reduced the frost damage to some extent, the frost heaving has been smaller, and the mutual differences have been evened out.

This is especially the case in mo soils. However, drains have not been successful in every case in avoiding frost heaving. If the ground soil is finer than 0.02 mm, drains have been used in some special cases under the road bed, but cracks in the pavement have generally occurred in these cases.

In planning drains, one must make arrangements for removing the water from underneath the road. In some cases, water remaining in the drains has caused frost heaving.

Ditching of Road

In ARW's instructions for dehydration of the water table, a depth of the roadside ditches of 1.0 to 1.1 m is required to dry the base and subbase courses and to avoid frost effects. On sloping roads an intercepting ditch is made on the upper side of the cutting. This leads the running surface water away. The absence of ditches in old roads caused strong freezing, and if traffic was maintained on the road in the spring, the road was completely untrafficable.

Chemical Stabilization

In South and Central Finland, experiments were made with lim zation of the ground. Use of these methods proved successful i water. This made the ground stronger and provided a better fou of the upper layers. The insulating layer became thicker and the reduced. Cement stabilization was used if more than 50 percent o finer than 0.02 mm.

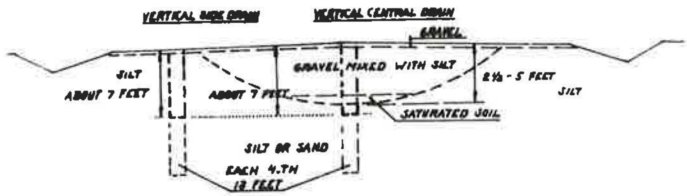

Figure 11. Placement of a drain.

Use of Vertical Drains

Badly freezing old highways were improved by building vertical drains. In the freezing spots of the highway, holes were drilled 8 in. in diameter and about 7 ft deep at a distance of 10 to 13 ft (3 to 4 m) from each other along the centerline of the road, or about 1 m from the road edge. The holes were filled with gravel or with a mixture of $CaCl_2$ or NaCl and gravel, in the ratio 1:1, 1:2, 1:3, and 1:4. A few of the holes terminated in the silt, but others penetrated to the region below it.

With vertical drains, Finland succeeded in keeping the frost heaving within only one-half of the value without drains. It was reduced to 8 to 16 in. (20 to 40 cm) from 20 to 32 in. (50 to 80 cm). Central vertical drains prevented the softening of the base course. Moving of the surface level as a result of the traffic and the slurry structure of the mo sand in the spring is also eliminated. Only one field was an exception. The drains were only 3 ft (90 cm) deep, and strong moving of the road surface due to traffic was observed in the spring. The frost heaving was 16 to 20 in. (40 to 60 cm).

The side vertical drains were also useful. The earlier commonly-occurring frost breaks were avoided when the holes were extended to the water-impervious layer. A few places were unsafe for traffic when the drains did not reach the water penetrating layer. The efficiency of the drains was decreased after a few years, because the silt often entered the gravel material. Gravel mixed with sodium chloride or calcium chloride, rather than gravel alone, has been proven to be a good material for filling the holes because it keeps the drains from freezing for a longer period of time. However, the practical significance of this difference is not clear. The primary importance of gravel filling is to provide the possibility for air to penetrate the subbase course. This reduces the suction of water into the border zone of freezing. Water can also evaporate from the base and subbase courses.

CONSIDERATIONS IN CONSTRUCTION OF FROST-RESISTANT ROADS

From experience it is known how harmful and dangerous the effect of the freezing of the base and subbase of the roads can be. The original road-ground must be absolutely level and sloping towards the sides. Longitudinal wheel tracks must be eliminated. If the ground is uneven and weak, it is advantageous to stabilize it with lime. The ground plane and the different beds can then be well compacted.

The water must not be allowed to run parallel to the road under the road bed. It has to be lead to the ditches.

If a road has to be constructed through frost-susceptible soil areas, the previously existing cross ditches should be filled with identical soil, not gravel or sand. The fill should be compacted effectively.

When an old road has to be widened and raised, the old embankment should be removed and planed over the total width of the new road. In North Finland, particularly, these have been harmful experiences with roads. Where only the edges of renewed roads were raised, longitudinal cracks appeared. Unusually steep edges are dangerous for the traffic.

Rocks in the ground below the road bed have been raised by frost heaving and cracked the pavement. The same condition resulted where pieces of telephone poles were left in or below the road bed.

When the rocks and other objects were removed unequal frost heaving, and a non-uniform surface level resulted. In those cases, the best way to repair the road, is to break the rocks and, if necessary, to fill the hole with gravel.

In the combined soil and rock cuts, harmful, uneven frost heaving and cracked pavements were observed. In such a case, normally the soil is replaced completely. If this is impossible, the soil is removed to a depth of 4 to 5 ft (1.3 to 1.5 m). This has already been shown to cause a great improvement.

Clay and other frost-susceptible soils often tend to accumulate on the bottom of rock cuts. Often, pits are found in which the water will gather. Frost heaving may have occurred in those places. To prevent this, the rock is blasted to a depth of about 3 ft (1.0 m) below the surface level of the road to be built. This method has given rather good results.

REFERENCE

1. "Specifications for the Building of the Transition Wedges." Administration of Roads and Waterways, Finland, Helsinki (1956).

Discussion

A. R. JUMIKIS, Professor of Civil Engineering, Rutgers, The State University, New Brunswick, N. J. —To characterize the severe conditions under which Finland must build its roads, a short recourse to the paper under discussion was felt to be desirable.

Frost Penetration and Heaves

In Finland, frost penetrates the glacial soils from about 4 to 6 ft in the southern part of the country, and from 7 to 10 ft in the northern part. Frost heaves have been observed 2 ft in magnitude and even greater.

Frost-Susceptibility of Soils

About 65 percent of Finland's so-called "old roads" are frost-susceptible, and during the spring thawing season, about 25 to 40 percent of the roads are closed to traffic to avoid "spring break-up" and to let the thawed soils dry out.

In severe years, 1955, for example, 47.3 percent of the roads were impassable. In certain years, about 80 percent of the roads in Central Finland were out of commission. Sometimes about 90 percent of the roads in Northern Finland had to be subjected to severe traffic restrictions time-wise, as well as load-wise.

Time-wise, depending on latitude; viz., severity of winter, roads had to be closed to traffic for a period of three weeks to two months to allow the roads to dry out. Sometimes roads were closed to traffic until the end of June.

This recourse obviously brings to the fore that coping with frost action on highways is a problem of national importance not only in Canada, the United States, or Europe in general, but in Finland in particular, especially if one considers Finland's relatively small population (estimated at 4,477,300 in 1960) and thus, the relatively small number of taxpayers as compared with the United States, for example. Everyone is aware that road-building is a very expensive enterprise.

REMEDIAL MEASURES

Sand Wedges

The paper describes the use of sand wedges in soil at transitions from cuts to fills, at contacts between various types of soil of different thermal properties, and at culverts. The experience with the sand wedges, however, is not wide. The author of the paper writes that the depth of frost penetration into the sand wedges was calculated theoretically, and finds on that basis that the wedges are somewhat too small (Table 1). However, it would also be desirable to measure the actual frost-penetration depths in these wedges and to check the performance of a series of variously sized wedges under similar climatic environment.

In the same connection, there are certain factors in highways and soil engineering which can be studied theoretically for the purpose of orientation in the various factors and frost-action phenomena. However, many things must be studied and verified experimentally in the laboratory as well as in the field. For example, in Table 1, Columns 6, 7 and 8, the wedges which are calculated by "using a surface correction factor μ = 0.94 in. may not be of the proper size after all. The size of the wedge and surface correction coefficients should be established from experiment, observations, and actual performance in the field.

However, no systematic data on the performance of sand wedges to remedy differential frost heaves on roads are presently available.

The wedge problem also points out the need in highway engineering for reliable thermal coefficients of soils, pavements and other highway materials. Some other questions also arise in this connection: what is the desired density, porosity, and permeability of such a heave-reducing wedge of soil? Likewise, it is of practical interest to know the moisture content and the porosity of the wedge before and after freezing, how to get rid of the excess moisture from the wedge, and how to restore the desired density and porosity after the spring thaw in order to be ready for the next fall and frost. Everyone knows that research costs time and money. It is hoped that in the future, after some severe winters, the Finns will have more actual qualitative and quantitative performance data on roads in frost areas than those given in the report under discussion.

Methods for Reducing Frost Heaves

The author lists several known methods which can be applied to reduce frost heaves. However, none of the described methods reflects a definite opinion on whether these methods are effective, or are the standard practice provided by the local specifications for building roads in that country, or whether they have been used as a sort of pilot field experiment. It would be interesting to know whether Figures 4 through 9 and Figure 11 are those reflecting the Finnish specifications for the construction.

Replacement of Frost-Susceptible Soil

One of the remedial methods mentioned in the paper is that of replacing frost-susceptible soil with a non-frost-susceptible one. This method essentially consists of removing the old material from the road by excavating it to a depth of 3 to 5 ft and replacing the excavated material with gravel. In discussing this method, the author makes an interesting but confirming remark; namely, that during cold winters, frost penetrated such a replaced soil deeper than before. This is in accordance with observations made by Austrian, Canadian and American highway engineers; namely, that frost in gravelly soils penetrates faster and deeper than in clayey soils, and that in spring, frost leaves gravelly soils sooner than clayey ones. Some engineers have even expressed concern over how deep one should go with backfilling gravelly soil. The deeper one goes, the deeper the frost penetrates (penetration governed by cold quantities in a given climatic condition, of course). However, such an increasingly gravelly backfill is expensive.

Does this not point out again that the thermal properties of soils would have to be studied, evaluated, and allowed to perform beneficially under freezing conditions?

Although thermal properties of soils have been studied to some extent in Sweden, the United States and Canada, it seems that more effort should be devoted to this subject. This problem is indeed a wide research topic in soil engineering.

Stabilization of earth roads by means of lime admixtures to surface material was also practiced in the Baltic States in the 1930's. The surfaces of such lime-stabilized roads were smoothed off in the spring and in the fall. In respect to service, these roads were satisfactory and relatively inexpensive.

Vertical Sand Drains

Relative to the use of vertical sand drains filled with gravel, mo (= silt) and salts, the following questions arise. Where does the water in such a drainage system go? Are the drains used as one-way or two-way drainage systems (relative to bottom and top)? Do calcium chloride and rock salt leach out? How long are chemicals efficient in the drains?

It seems that the description of the function of the drains does not satisfy some of the thermal aspects too well particularly if there is no lateral flux of heat in the soil underneath the road.

Further, if water can evaporate from the base and subbase courses, what has this to do with the vertical drain? According to the description, vapor would move upwards to the cold front and freeze, thus contributing to the formation of ice. Is vapor movement really a factor in soil moisture migration?

The writer's work on moisture-transfer mechanisms in silty soils on freezing shows that the vapor-transfer mechanism is an ineffective one for supplying soil moisture to the cold front (2).

Cracking of Pavements by Rocks

An interesting observation is made in the paper: upon freezing, rocks in the soil below pavements raise and bring about cracked pavements. Here the phenomenon of the effect of stress concentration underneath the pavement is brought clearly to the fore.

SUMMARY

The nature of frost damage to roads in Finland as described by the author is the same, for example, in Canada and the United States; namely, differential frost heaves in non-uniform soils at the contacts in cuts between two different types of soil with different thermal properties, at the transitions between cuts, fills, and at culverts; the breaking up of pavements; and spring break-ups during the seasons of thawing.

The report fulfills one definite function: it adds to the engineers' awareness of the damage factor to roads upon freezing.

The report also emphasizes, indirectly and directly, the need for more observations and knowledge on the complex freezing system soil-water-temperature.

Finally, the report under discussion may be characterized as supplemental information on how things are being done in Finland.

One should remember that in a country of very severe climatic conditions in respect to frost, highway construction and maintenance are expensive. For a country with a relatively small population, this is even a more difficult problem. One really has to look sympathetically on Finland's efforts to establish a good network of roads under very severe climatic conditions.

Reference

2. Jumikis, A. R., "Effective Soil Moisture Transfer Mechanisms Upon Freezing." HRB Bull. 317, pp. 1-8 (1962).

HAMILTON GRAY, Department of Civil Engineering, The Ohio State University, Coumbus, Ohio — The development of automotive transportation in Finland, as is true in other continental areas, has of course lagged somewhat behind that of the United States. The problems relative to frost action described in this paper recall to mind similar ones that have plagued American highway engineers working in the northern states for more than a generation. The similarity in analysis and treatment between Finnish and American practice is striking and indicates that the concepts of frost action as outlined by Beskow, Taber, and others are essentially sound and can form the basis for practical solutions.

It may be well to reassert the four conditions that must be fulfilled in order to bring about frost heaving in the soil. They are (1) a surface temperature below the freezing point; (2) the availability of water which can migrate toward the freezing zone; (3) the presence of a frost-susceptible soil, that is, one which will promote the growth of ice segregation and support the migration of water; and (4) a downward progression of the frost line which is compatible with the rate of moisture migration. Extremely rapid freezing in certain soils will result in reduced frost heave because of the inability of water to migrate rapidly toward the freezing zone.

Efforts to minimize the effect of frost action invoke modifications of the second and third conditions, because so long as no control can be exerted over climate, it appears impractical to alter the surface temperatures or to control the rate of freezing.

The restriction of traffic (up to 90 percent on occasion in the northern part of Finland) and the amount of untrafficability (amounting to as much as 80 percent in the center of Finland) represent figures which seem extreme to Americans who depend heavily on highway travel. On the other hand, the magnitude of the problem is reflected in the freezing index which amounts to as much as 3, 600 degree-days F in the northern part of the country, and except for the southwest coastal areas, the entire country seems to experience freezing indexes of the order of 1, 000 or more degree-days. The observation that old roads placed on highly frost-susceptible material have heaved as much as 2 ft also emphasizes the seriousness of the problem in Finland. Many other problems associated with frost action are encountered in Finland.

Figures 12-20 show some of the more common problem encountered in northern latitudes of the United States. Perhaps some of the situations appear to have little connection with roadways, but they do illustrate certain basic principles and demonstrate the omnipresence of frost action in high latitudes.

Engineers working in these northern latitudes have frequently observed that boundary markers are moved from their proper position. The phenomenon is essentially similar to the raising of rocks from below the road bed, which has proved bothersome in Finland. Similar frost action can be found very close to home. In Figure 12, a low set of front door steps, the outer edge of which rests on concrete cylinders embedded to a depth of 4 or 5 ft in the earth is raised. The opposite edge is hinged to the sill of the house. Adfreezing and associated expansion of the upper layers of the soil have lifted the concrete posts so that the steps tilt inward toward the house. As winter progresses, it may become impossible to open the storm door. This difficulty usually disappears with the advent of warm weather. However, many times the concrete posts do not settle back to their original positions, but retain a residual upward displacement after each winter. Consequently, after several years it may be impossible to open the storm door even in the summer! The only solution is to beat the tops off the concrete posts, or better, to pull them out of the ground altogether and set the outer edge of the steps on flat slabs which rise and fall with the surface. At least the steps will return to the initial position each time the ground thaws completely.

Figure 13, also taken close to home, shows the effect of lack of snow cover on the surface temperatures. In this case, the concrete sidewalk and adjacent turf were lifted 6 to 8 in. above the general surface of the surrounding lawn. This picture was taken in late March when the snow had disappeared, but the ground was still frozen almost completely. With the advent of warmer weather, the thawing permitted the sidewalk and adjacent turf to subside to a position commensurate with the general level of the surrounding lawn. Of course, the problem was introduced when the homeowner insisted on clearing the snow from the sidewalk. This allowed the frost to penetrate to greater depths because the surface was exposed to lower temperatures than the turf which was covered by several inches of insulating snow. Consequently, heaving beneath areas exposed to lower mean surface temperatures was pronounced.

The author indicated that most of the frost heave problems are concentrated near the ends of cuts made in rock or frost-susceptible materials. This, of course, reflects the

Figure 12. Frost action close to home.

Figure 13. Effect of lack of snow cover on a sidewalk.

Figure 14. Road surface raised due to freezing.

element of differential frost action accompanied by differential frost heaving.

The use of wedge-shaped volumes of frost-resistant material at the transitions between cuts and soils which are not frost-susceptible, or between rock cuts and frost-susceptible soils as well as in the vicinity of culverts, represents an economical means of reducing one of the most serious consequences of frost heave; namely, the uneven road surface which endangers vehicles moving at reasonable speeds.

Culverts have always given trouble because they provide an additional cold boundary to a part of the supporting structure of the roadway. This results in a more extensive zone of freezing with consequent differential heave.

A close inspection of the road surface (Fig. 14). should serve to convince an automobile driver that any effort to maintain a speed of 30 mph on this surface would provide a hair-raising experience, and be fraught with danger not only to the vehicle springs.

Figure 15 shows a low retaining wall which has obviously been thrown out of position, in this case, partly by the lateral freezing of earth against the vertical surface of the wall, and partly perhaps by greater penetration of frost on one side of the wall than on the other. Figure 16 shows a concrete headwall which was been cracked, presumably by forces accompanying differential heaving, and also perhaps by forces exerted by the culvert itself on the headwall. Figure 17 shows a similar headwall which has been shoved far out of its original position and the culvert has risen so that its upper surface projects above the level of the gravel shoulder. Many culverts exhibit a small annual increase in elevation and eventually appear at the road surface just like the rocks to which the author referred. At such times, it becomes necessary to dig out the culverts and replace them. However, long before they appear at the road surface, they lose most of their hydraulic function, because the elevation of the invert has become too great to discharge water at the proper time. The author did not indicate the depth to which the wedges should extend below the bottoms of his culverts. Circulation of cold air through the culverts, of course, produces freezing along the bottom as well as along the top of the culvert. It would be interesting to have figures which show

Figure 15. Low retaining wall thrown out of position because of freezing.

Figure 16. Concrete headwall cracked by differential heaving.

Figure 17. Headwall shoved from original position.

Figure 18. Shoulder elevated above pavement proper.

Figure 19. Damage caused by excessively heavy traffic.

Figure 20. Damage caused by excessively heavy traffic.

the necessary amount of frost-resistant material which should be placed beneath the culvert invert.

Finally, the desirability of continuing the frost-resistant base and subbase materials beyond the edges of the pavement and through the shoulders can be emphasized by Figure 18 in which it appears that the shoulders have been elevated to a greater extent than the pavement proper. This resulted in sags, or in some level sections, in the ponding of water on portions of the pavement. Obviously, at that time of year when daytime temperatures are above freezing but nighttime temperatures fall well below that point, the presence of this water will present a serious skid hazard for vehicular traffic in the evenings.

Figures 19 and 20 show the extent to which a road can be damaged when excessively heavy traffic is allowed to use it. The upheaved portions of the roadway are locally termed "mud volcanoes" and develop when excessive wheel loads squeeze the subbase material from the region beneath the load. Nothing short of complete rebuilding will remedy this type of situation. The damage resulted from illegal operation of heavy trucks after the road had been posted for limited loading.

It has long been realized that lowering the water table could more or less proportionally reduce the amount of frost action. Finnish experience seems to substantiate this, because generally the absence of side ditches which would serve to drain the base and subbase courses leads to unfavorable behavior. It is implied that the use of such ditches is invariably successful in diminishing the amount of frost action.

With buried side drains carried to depths approximating twice those of open ditches, success is not always attained. It is surmised that in some cases these drains may become clogged and fail to function, or that the groundwater table is so low the drains do not appreciably reduce its elevation. It is pertinent to point out that some people are so convinced of the efficaciousness of drainage that sub-drains have been installed to depths of several feet in situations where the groundwater table was actually a considerable distance below the drains. Therefore, the drains were unable to perform any useful function. It is not often that such a remedial measure is adopted without first ascertaining the prevailing conditions, but it has happened.

The use of circular vertical drains spaced at intervals is an interesting development, because in the majority of cases, the lower ends of these drains do not terminate within a stratum more permeable than the overlying soil. The explanation of their effectiveness is uncertain. Of course, if these vertical drains are filled with a salt as well as gravel, this will tend to leach into the surrounding soil and perhaps reduce the freezing effect. The author's suggestion that perhaps these drains serve to reduce the amount of soil suction above the water table may in effect represent the best available explanation of their value.

The paper finally emphasizes that uniform heave will result only when uniform conditions prevail; that is, when the soil conditions are uniform and the available water is present in a uniform way.

The significance of the paper would be enhanced if the author would provide a specific definition of "base course" and "subbase course" with particular reference to gradation of the materials.

Some clarification also appears to be warranted in connection with the need for wedges of frost-resistant material between rock cuts and non-susceptible soil.