The use of plastic foam insulation in roads

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Plastic foam used as a heat insulation layer in the road base protects the road from frost damage. For some years now this insulation method has been practised in Scandinavia and in other countries with a cold climate. A concentrated description is given of some of the insulation properties and effects. Particular aspects dealt with are the frost resistance capacity of the road base, partial insulation and frost heaving, special transitions with purposely arranged openings between the foam boards, icing problems, and construction economy.

Pour protéger les routes des dommages causés par le gel, on a employé des plastiques cellulaires formant une couche d'isolant thermique. On utilise déjà depuis un certain nombre d'années cette méthode en Scandinavie et dans d'autres pays froids. On décrit de façon condensée certains des effets et propriétés d'isolation. On traite en particulier de certains aspects de la résistance au gel de la couche de base de la route, de l'isolation partielle, du soulèvement par le gel, des transitions créées au moyen d'ouvertures entre les plaques de plastique cellulaire, des problèmes occasionnés par la formation d'aufeis et des économies réalisables dans la construction.

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Introduction

There are three layers which contribute to the frost resistance capacity of a road base insulated with plastic foam. The greatest contribution comes from the plastic foam layer itself and only a smaller amount from the overlaying bearing course. What sometimes is not considered is, however, the fact that the soil layers of non-frost susceptible material immediately beneath the plastic foam layer contribute to a degree.

When the road is not fully insulated there will be some heaving when the frost penetrates the frost susceptible subgrade. The magnitude of the heaving depends on the insulation properties of the road base.

An increased risk of early autumn icing is said to be a disadvantage of insulated roads. A three-year test at the Institute test site indicates that this risk can be minimized by an appropriate design.

Transitions from a fully insulated to a non-insulated part of the road in order to even out the insulation effect can be created by tapering off the plastic foam layer or by purposely arranging openings between the boards. In comparison to conventional road materials, plastic foam (polystyrene) is more expensive by cubic metre. Practical experience, on the other hand, indicates that a road, frost-protected by polystyrene foam, is often cheaper to construct than a road which is conventionally protected.

Frost Resistance Capacity

The frost resistance capacity is defined as the frost quantity (freezing index) which is required for freezing the road base totally. The frost resistance capacity is calculated by the formula of Skaven-Haug (1971) which is described below.

The calculation is based upon the model

[1] $F = \Sigma\Omega + E$, h·°C

where F is the frost resistance capacity.

The resistance to freezing from latent heat for a single soil layer is determined according to Watsinger (Gustavsson 1981):

[2] $$\Omega = \frac{q \cdot s^2}{2\lambda} + q \cdot s\Sigma \left(\frac{s_o}{\lambda_o}\right), \quad \text{h}\cdot{}^\circ\text{C}$$

where:

s = thickness of soil layer (m)
q = frost-accumulating ability of material (kcal/m^3)
λ = heat conductivity (kcal/m·h·°C) and
$\frac{s_o}{\lambda_o}$ = resistance to heat flow of frozen layers (m^2·h·°C/kcal).

The freezing resistance due to heat flow in the earth to the frost line (stored heat in unfrozen soil) can be expressed:

[3] $$E = kGT\lambda\Sigma \left(\frac{s_o}{\lambda_o}\right), \quad \text{h}\cdot{}^\circ\text{C}$$

k = a constant (usually 0.7)
G = temperature gradient below frozen zone of Feb. 1st (°C/m)
T = actual reference time (h) for stored heat.

The frost resistance capacity of a road base built up of layers of sand and gravel and of a road base insulated with polystyrene foam is plotted as a function of the thickness of the gravel-sand base and of the thickness of the polystyrene foam layer (Figure 1). The design freezing index is assumed to be 1000 degree Celsius days for most of the country. Where the

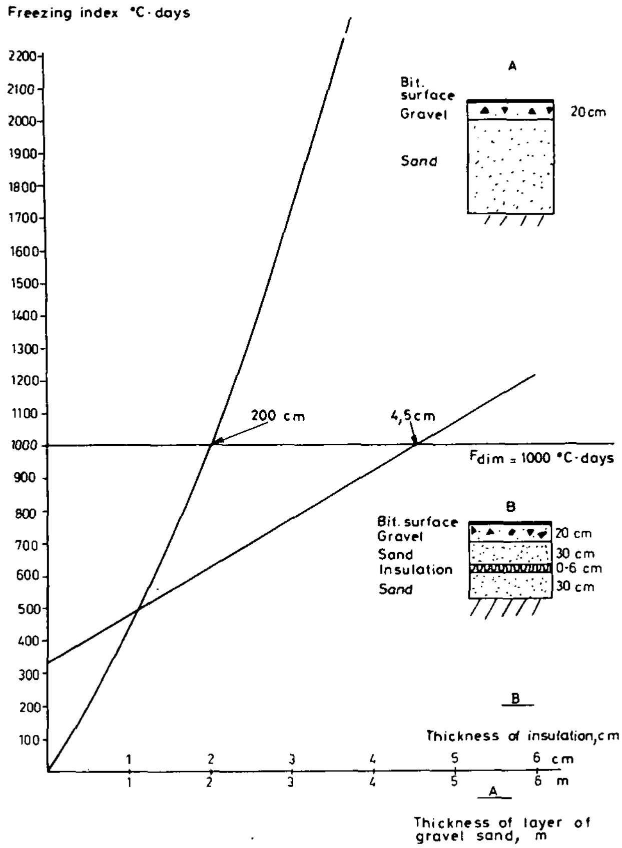

FIGURE 1. The calculated frost resistance capacity of a sand-gravel road base and a base frost protected with polystyrene foam. These capacity values are not to be generally used. By calculating the frost resistance capacity for any single base the appropriate input values have to be chosen.

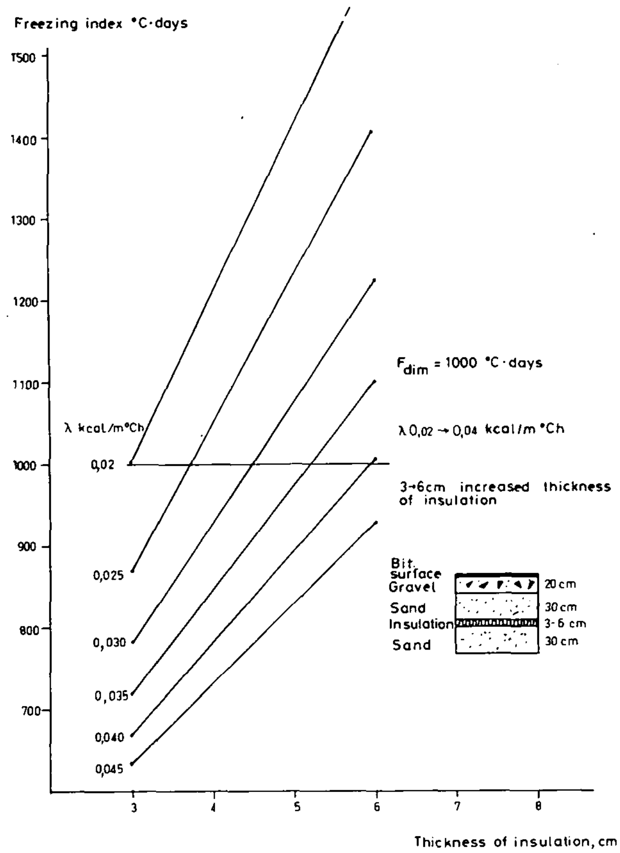

FIGURE 2. The frost resistance capacity of a road base with polystyrene foam expressed, for different values of the thermal conductivity, as a function of the thickness of the foam layer.

freezing index reaches the value of 1000 degree-days during one winter, the bases but not the subgrade will just freeze. Thus, using either a road base of gravel and sand 200 cm thick or a base insulated with 4.5 cm of polystyrene foam with a total base thickness of about 85 cm, either base will get 100 per cent frost protection.

The frost resistance capacity of the polystyrene foam insulated base is dependent mostly on the insulation properties of the polystyrene foam (thermal conductivity) and also of the water content of the layer of sand below. It is related to the thickness of the polystyrene foam for different thermal conductivity values of the foam (Figure 2).

The water content of the layers beneath the plastic foam is of significance in that the layer acts as a freezing resistance layer and is consequently more efficient the more water it contains (Figure 3). As old road bases often are built of fine-grained and moist material, it can be an advantage to insulate them with plastic foam by merely placing the foam boards directly upon the old road surface and constructing a new base on the plastic foam layer.

Partial Insulation and Frost Heaving

If the road base of sand-gravel or with polystyrene foam or other insulating materials is designed for a chosen freezing index, such as the mean freezing index, no frost heaving will take place provided that the winters are not colder than this critical freezing index.

The curves (*see* Figure 1) are based on the mean freezing index, which statistically will be reached in one of every two winters. Of interest now are the consequences of frost heaving when the winters are colder than the assumed winter. An attempt has been made by S. Fredén at the Institute to calculate the frost heaving when the assumed freezing index is exceeded.

The relation between freezing index and frost heaving has been calculated for three road bases with the

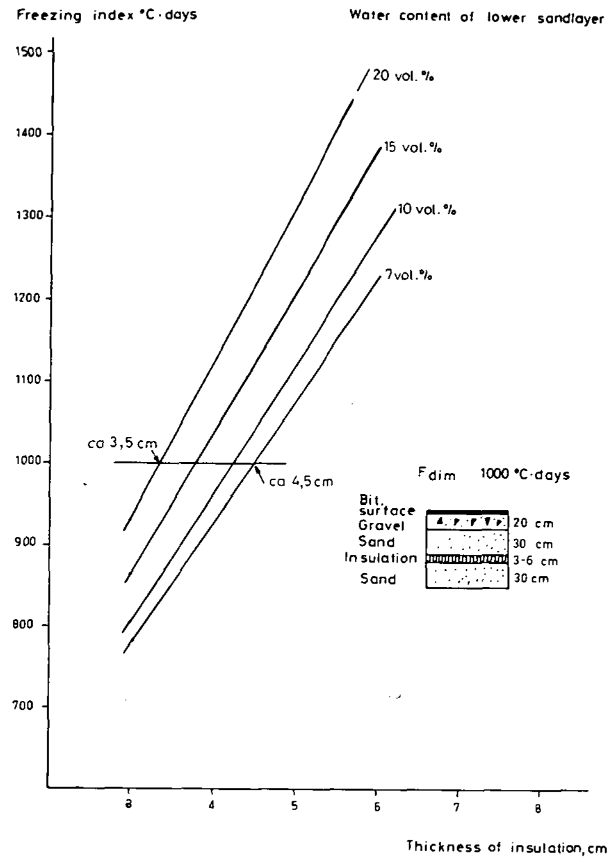

FIGURE 3. The frost resistance capacity of a road base with polystyréne foam for different values of the water content of the material in the layers just beneath the foam layer, expressed as a function of the thickness of the foam layer.

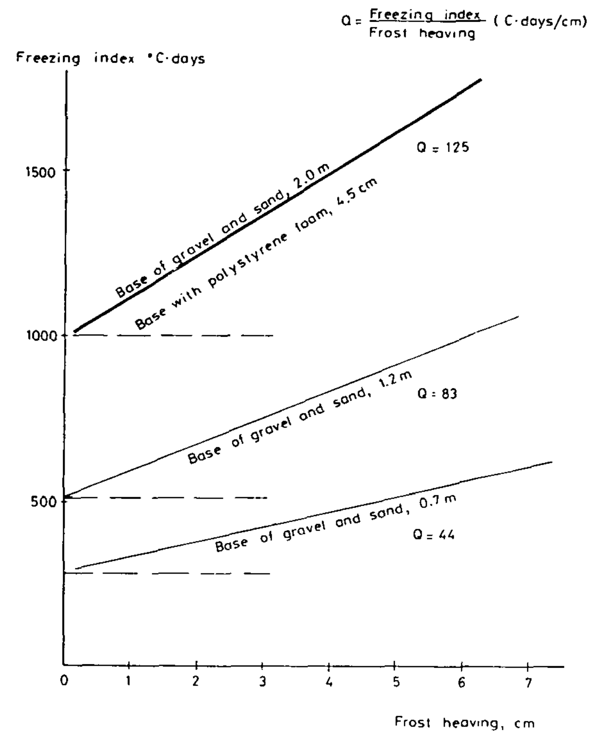

FIGURE 4. Calculated frost heaving in relation to freezing index (*after* S. Fredén: *Pers. Commun.* 1980).

frost resistance capacity of 1000, 500, and about 300°C days (Figure 4).

The calculations were made under the assumption that the frost heaving is proportional to the net heat flow from the freezing zone (i.e. the total heat flow from the freezing zone minus the heat flow through the soil under the frost line). It has also been supported that there is a steady flow of heat from the unfrozen soil to the freezing zone during the winter. The frost heaving characteristics of the soil have been defined as the quotient between the heat energy used for growing ice lenses and the total energy used for freezing the soil. In doing this calculation, no concern has been given to the changing load on the freezing front or to the distance to the groundwater table. The calculation has been done in short time steps, where it has been supposed that every step can be regarded as a stationary state (quasi stationary heat transport). The error introduced during this type of calculation has been computed and does not exceed 10 per cent; in most cases it is far less.

The upper curve (*see* Figure 4) describes the frost heaving when the freezing index exceeds the mean freezing index (1000 degree-days) for which the road base has been designed and it has been frozen through. The curve is nearly a straight line and the quotient, freezing index (degree Celsius days)/frost heaving (cm), is 125. The found quotient makes it possible to estimate the frost heaving for any realistic freezing index. If for example the freezing index for the 10 per cent winter is 1500 degree days, i.e. 500 degree days above the design freezing index the frost heaving will be 4 cm.

When designing for a lower freezing index than 1000 degree days, the resultant frost heaving after freezing of the base will be greater. The two lower curves exemplify this (*see* Figure 4). Thus, a sand–gravel base of 1.2 m thickness (frost resistance capacity 500 degree days) would give a frost heaving of 1000/83 cm = 12 cm at a freezing index 1500 degree days, while a base of only 0.7 m of sand and gravel (frost resistance around 300 degree days) would give a frost heaving of 1200/44 cm = 27 cm.

Field measurements give the same results as the calculated curves. In one such study, the frost heaving and the observed actual freezing index for a road base with morainic layer were measured (Figure 5).

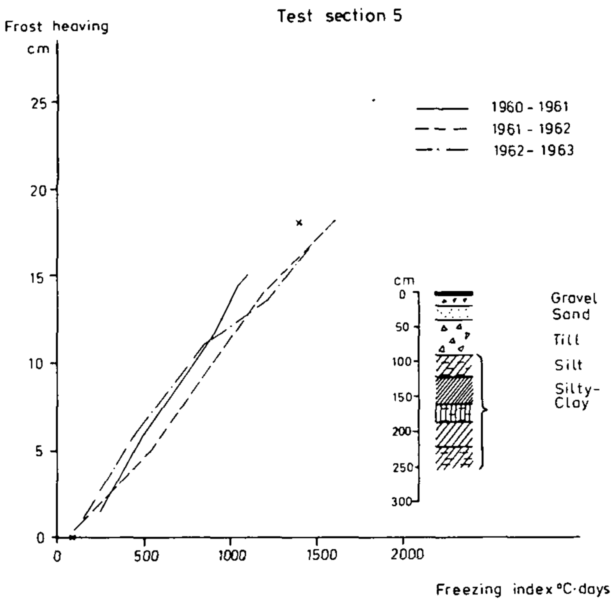

FIGURE 5. Frost heaving in relation to freezing index for the Test Road Öjebyn 1957 in the north of Sweden.

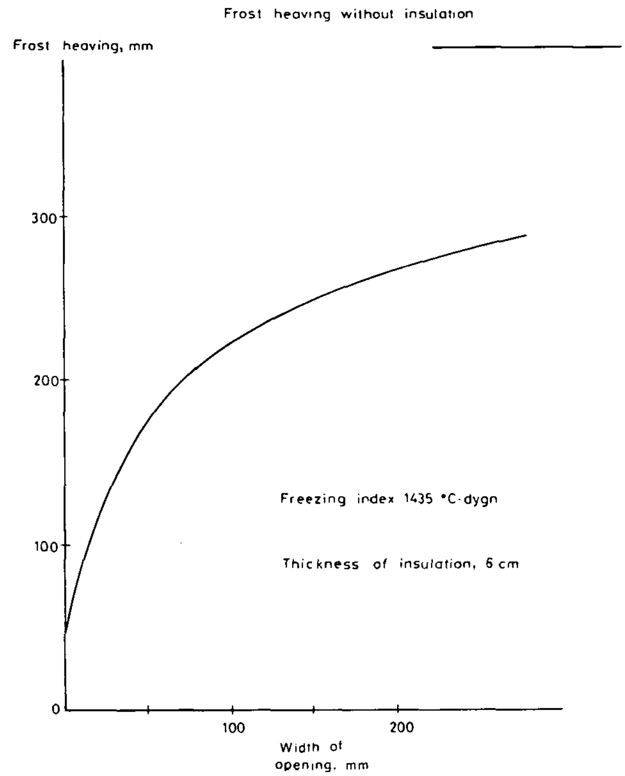

FIGURE 6. Frost heaving as a function of the width of parallel openings between plastic foam boards. The width of the boards is 60 cm and their thickness 6 cm, and the freezing index is 1435 °C · days.

The quotient freezing index in degree days to cm frost heaving for this base and sub-grade is around 100, which characterizes the conditions to be expected with an average risk of frost.

Special Transitions

By insulating a culvert with a plastic foam layer in a frost-susceptible subgrade a problem arises in flattening out the uneven frost heaving along the road, from the culvert area to the point where the plastic foam layer ends. The standard method is to taper off the insulation layer by using thinner boards towards the end of the insulation. Another method is now being tested, which takes advantage of the heat flow through openings arranged purposely between the single boards. The relation between the width of the openings and the resulting frost heaving is expressed as a function (Figure 6). A constant flow of heat is assumed up to the freezing zone. The curve was calculated by S. Fredén (*Pers. commun.* 1980) using a fast FEM-program in two dimensions. The program was constructed by the Mathematical Institution of the Technical University of Linköping. The physical basis for this calculation is the same as that used for the simpler one-dimensional frost-heaving program, presented earlier in this paper.

In a test road in North Sweden the polystyrene foam was laid with increasing width of the openings between the boards towards the end of the insulation. The openings are filled with sand which has a high thermal conductivity in comparison to the conductivity of the polystyrene foam. At this test road, the required width of the openings were not fully known and the test construction did not give the desired longitudinal curve of frost heaving (Figure 7).

The test road was reconstructed in 1980 according to the newly calculated curve (*see* Figure 6) and should theoretically give a better result. On February 19th, 1981, the longitudinal frost-heaving curve at a freezing index of 900 degree-days was measured and plotted (Figure 7). This heaving curve is much more even than the original "non insulated" curve, which also is plotted for comparison.

Icing Investigations

When a heat-insulating layer is inserted into the road base, the heat flow from the subgrade is retarded during winter. A possible consequence could be that, in early autumn, when the weather is clear at night and the net heat radiation from the road surface is great, the surface temperature would drop below 0°C and also below the dew point at insulated sections causing hoar frost on the road surface. This

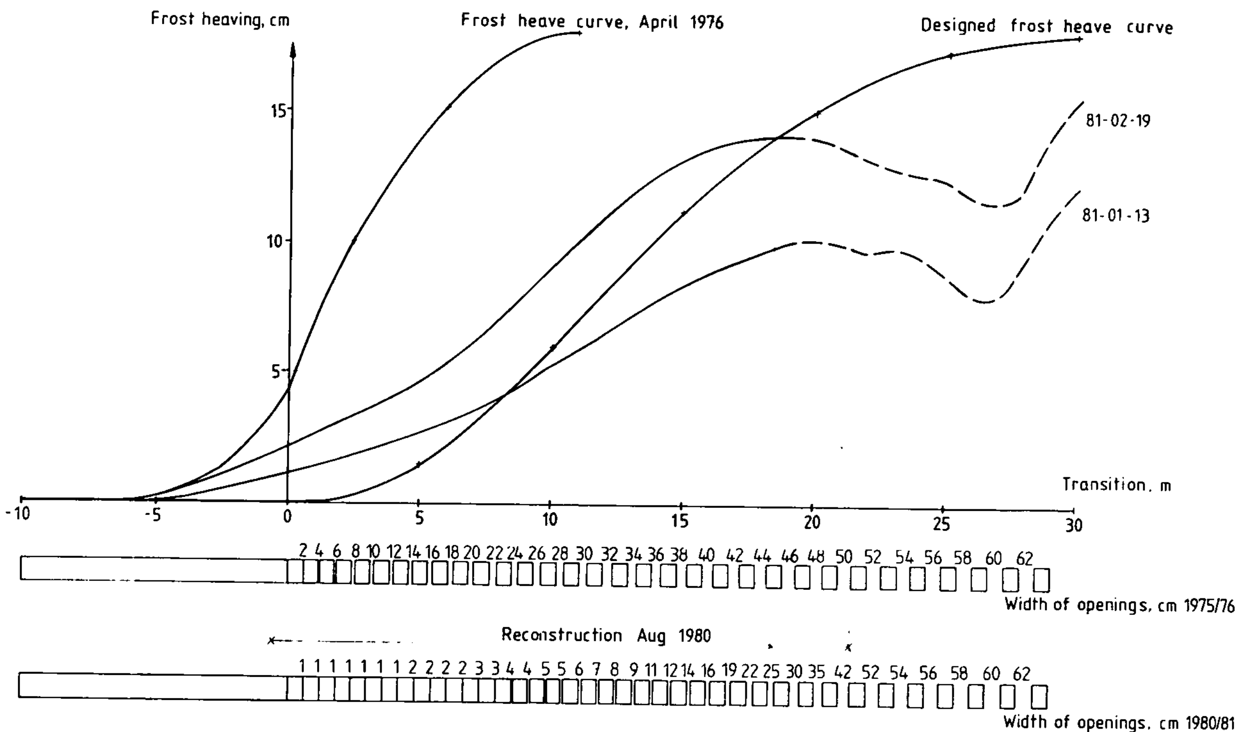

FIGURE 7. Frost heaving along a transition with successive widening of the openings between the plastic foam boards.

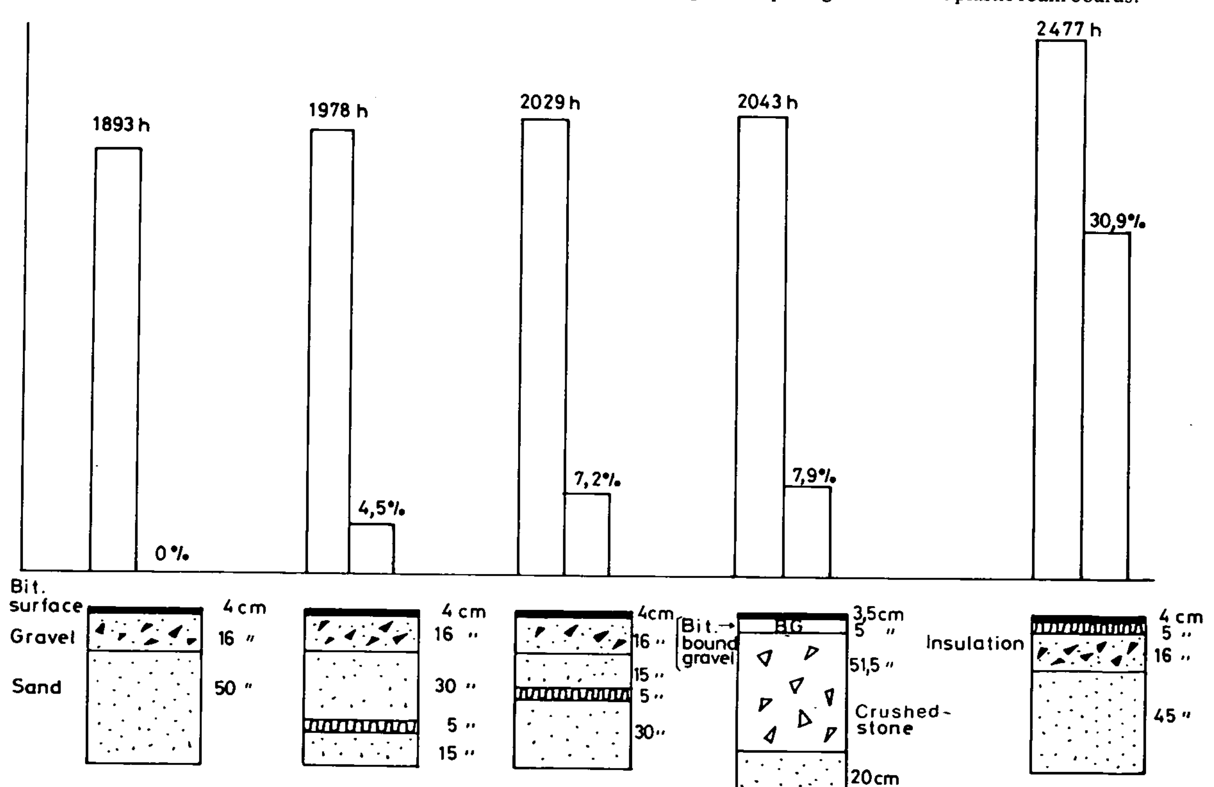

FIGURE 8. Duration of time with surface temperature below − 2°C for some road bases, indicating different degree of risk for surface icing (*from* Gustavsson 1981).

would not be the case at non-insulated sections. This problem has been thoroughly studied at a test site of the Institute by K. Gustavsson and the results of these investigations extracted (Figure 8).

Some of the investigated types of bases are illustrated, and the times in hours are given during which the surface temperature at these bases during three winters is measured to be lower than −2°C. A temperature of −2°C and lower could be critical for the formation of hoar frost on the road surface.

The sand-gravel base is the standard base and the other bases are compared with this base. It can be recognized that the base which is "top"-insulated is most critical to surface icing with the length of time during which the surface temperature is lower than −2°C being 30 per cent longer than that for the standard base.

Two bases, with insulation at a depth of 35 cm and a base with crushed stone, are critical to the same degree. The crushed-stone base is a conventional base in Sweden. According to the Swedish specification for designing bases insulated with polystyrene foam, the boards should be placed at least 50 cm below the road surface. The period with temperature lower than −2°C is 4.5 per cent longer than for a standard base, which is accepted.

Cost of Road Repair

Polystyrene foam is a comparatively expensive material per cubic metre. On the other hand, only thin layers are needed for an efficient frost protection, which will reduce the cost considerably. In fact, for the same protection, the base with polystyrene foam is cheaper to construct compared to the equivalent base of sand and gravel.

The construction costs have been calculated for two types of bases using the local cost figures for materials and transportation in north Sweden (mean freezing index 1000 degree-days). Comparing the two types of base (*see* Figure 1), the results of the cost calculations are given (Figure 9). The conditions are that the full insulation must be tapered off along a stretch of 22.5 m at each side, and that the polystyrene foam

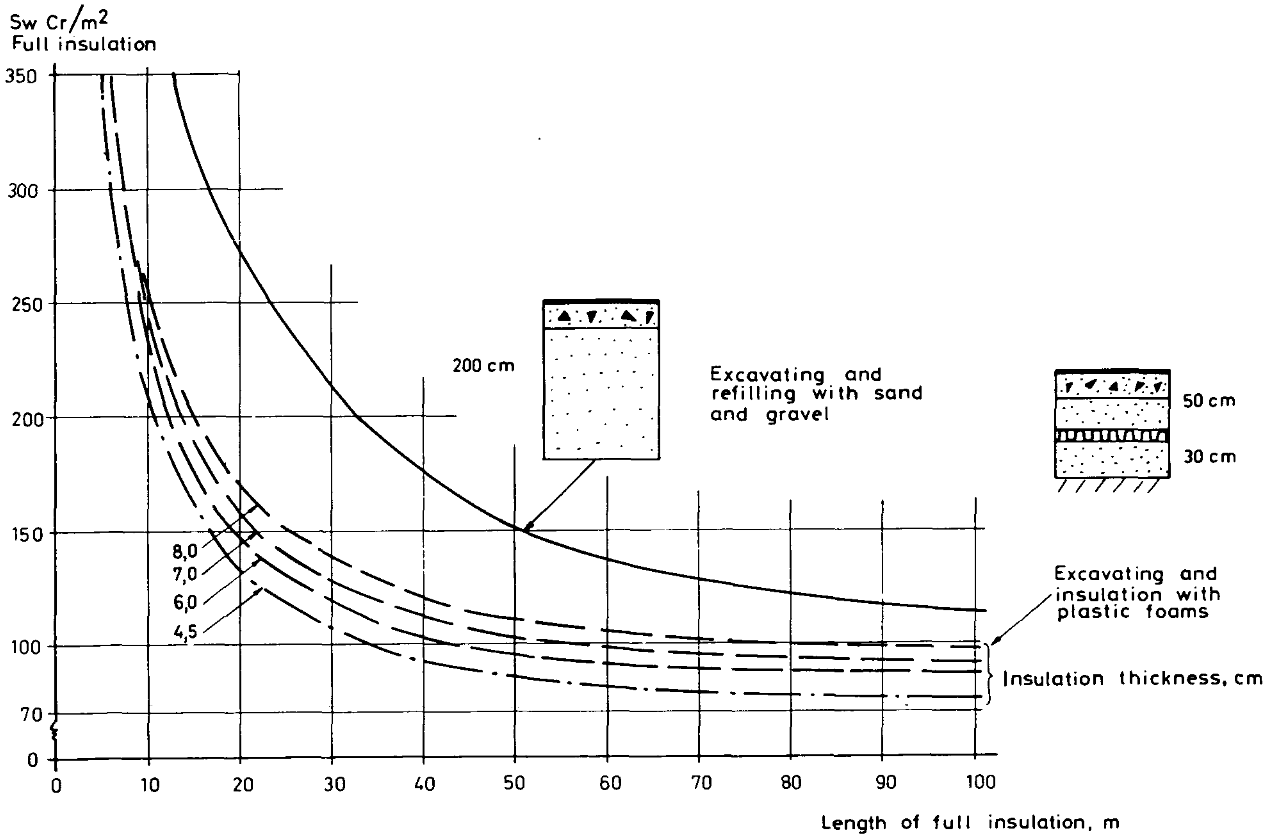

FIGURE 9. Calculated construction costs for repairing roads in the north of Sweden when excavating the poor material *in situ* and refilling it by pure sand-gravel material and polystyrene foam.

and sand-gravel material is delivered to the site at a fixed price. The transportation distance for the sand-gravel material is 5 km. It is also assumed that the road is to be repaired by excavating the poor material *in situ* and refilling it with new sand-gravel material and polystyrene foam.

For all lengths of repair it is cheaper to frost protect with polystyrene foam. For instance, the construction cost for 100 m of insulation with polystyrene foam is 75 SW. Cr/m^2 and for the sand-gravel alternative is 125 SW. Cr/m^2.

If the thickness of the sand-gravel base is reduced to 120 cm the cost for this base will be 72 SW. Cr/m^2, but this reduction would give a frost heaving of 6 cm, when the freezing index reaches 1000 degree-days (*see* Figure 4).

References

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SKAVEN-HAUG, SV. 1971. The design of frost foundations, frost-heat and soil heat. Norwegian Geotech. Inst. Publ. Nr. 90 Oslo, pp. 1-18.