Control of Frost Penetration in Road Shoulders with Insulation Boards

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The replacement method for the control of frost penetration of soils is commonly used for pavements on roads with light traffic in Japan. However, because of recent concern for the protection of the natural environment and shortages of natural resources, special frost control techniques such as the insulation method now need to be developed. This method prevents frost damage from frost penetration by the use of insulation boards placed between the subgrade and subbase in road shoulder areas only. It is intended for pavement construction where narrow existing gravel roads with a sand and gravel subbase are widened. A frost control design method that combines the insulation method used for road shoulders with the replacement method used in the travel lanes is described. Estimations from calculations are compared with observed measurements of frost heave and frost penetration obtained from the test road in winter. From the results of observations on the experimental sites, this new method is found to be promising for the control of frost penetration in both the widening and the paving of existing gravel roads.

Control of frost penetration for road pavement construction is essential in severely cold regions. The replacement method, digging out frost-susceptible soils and replacing them with granular non-frost-susceptible materials such as pit-run gravel and sand, is commonly used in Japan. Because of its economy and ease of application, this method has been extensively used for low-cost road pavements and road shoulders *(1)*. However, because of recent concerns for protection of the natural environment and shortages of natural resources as well as difficulties of finding places to dump the frost-susceptible materials, special control techniques such as the insulation method, the soil-stabilization method, and the water-cut-off method must now be developed *(2, 3)*.

A design method for frost penetration control is discussed that combines the insulation method, using extruded polystyrene foam (insulation board) in the road shoulders, with the replacement method using pit-run sand and gravel subbase in roadways. The method is intended for paving and widening of narrow existing gravel roads. Estimations are also compared with observed measurements of frost heave and frost penetration obtained at the test road in winter. The test road is a part of a newly extended 75-km-long road constructed with the combined method.

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APPLICATIONS OF INSULATION METHOD AND OBSERVED RESULTS

The insulation method prevents frost damage from frost penetration by the placement of insulation boards between subgrade and subbase. Generally, the engineering problems with this method are *(a)* poor bending strength under heavy wheel loads, *(b)* the possibility of decreasing insulating efficiency due to water absorption, and *(c)* the increased frequency of surface frost or ice. However, experiments on the test road over 18 years have shown no decrease of insulating efficiency and less frequency of differential icing in paved roads in Japan. Also, the problem of poor bending strength can be overcome by installing the insulation boards in the road shoulder areas, which have a very low frequency of wheel loads. The remaining problem is to determine the thickness of the sand layer above the insulation boards in order to ensure that rolling with compacting equipment will not break or crush the boards during construction.

When the depth of cover over the insulation boards is determined, the final placement depth is determined from a balance of two conflicting requirements: insulation efficiency, which requires the board to be placed near the surface, and bending strength, for which the boards should be deep in the pavement structure. In the case where insulation boards are placed only in the road shoulder, the thickness of the subbase over the insula-

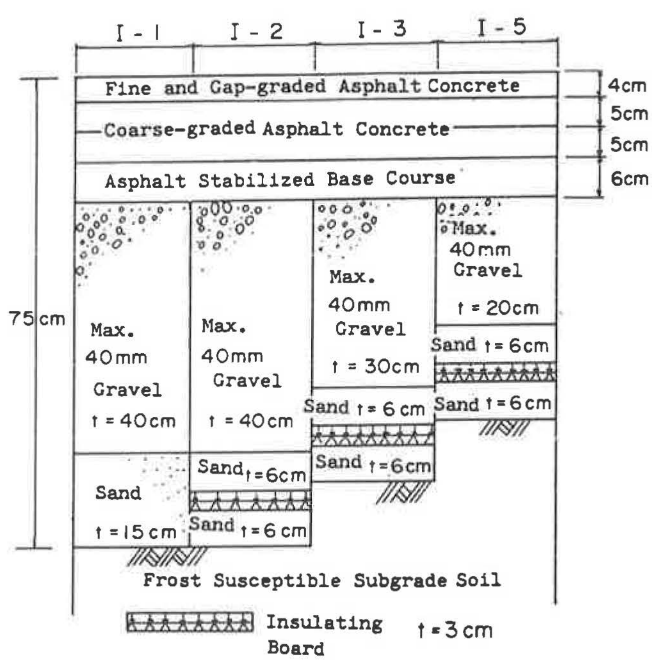

FIGURE 1 Schematic cross section of Bibi Test Road.

tion boards can be determined by considering only the bending strength necessary to avoid damage from construction equipment working on the surface, binder, and base courses.

To determine the optimum buried depth for the insulation boards in the insulation method, a test road (Figure 1) was constructed in 1973 on National Road Route 36, Tomakomai, Hokkaido. The depth of frost penetration, amount of frost heave, and bearing capacity of subbase and subgrade were measured. In Figure 1, cross section *I-1* shows the standardized pavement structure of national roads in this area. For each cross section of the test road, the amount of frost heave and depth of frost penetration were observed with the level and frost depth indicators in winter for the 6 years between 1973 and 1978.

Figure 2 shows the maximum frost heave on the road surface and the maximum frost penetration depth in the subgrade and compares them with the maximum freezing index for each year. The maximum amount of frost heave increases in proportion to the maximum freezing index in winter, and there is a high correlation between them. The amount of frost heave becomes slightly smaller when the buried depth of the insulation boards is shallow, but in general the differences in buried depth of insulation boards do not greatly affect the amount of frost heave. The amounts of frost heave observed in the cross section for the insulation method are clearly smaller than the amount in the standard section *(I-1)*. The depth of frost penetration in the subgrade becomes less with increasing buried depth of the insulation boards. This is the combined effect of the insulation board and additional depth of non-frost-susceptible materials. The depth of frost penetration observed in the cross sections with insulation is much less than the depth in the standard section for the replacement method. Considering insulation efficiency only, it may be concluded that the control of frost penetration with insulation boards is rational and reasonable in the antifrost roads.

ESTIMATES AND ACTUAL MEASUREMENTS WITH INSULATION METHOD

To estimate depth of frost penetration in road pavements in winter, the modified Berggren formula is commonly used *(4)*:

$$Z = \lambda/[172800F/(L/k)_{\mathrm{eff}}]^{1/2} \tag{1}$$

$$\begin{aligned}(L/k)_{\mathrm{eff}} = {} & (2/X^2)\{L_1d_1(d_1/2k_1) + L_2d_2[(d_1/k_1)(d_2/2k_2)] \\ & + L_3d_3[(d_1/k_1) + (d_2/k_2) + (d_3/2k_1)] \\ & + \ldots + L_nd_n[(d_1/k_1) + (d_2/k_2) \\ & + \ldots + (d_n2k_n)]\}\end{aligned}$$

where

- x = $d_1 + d_2 + d_3 + \ldots + d_n$ = estimated depth of frost penetration (cm),
- d_n = thickness of each layer down to the estimated depth of frost penetration (cm),
- d = thickness of the surface layer (cm),
- k_n = thermal conductivity of each layer (cal/cm•sec•°C),
- Ln = volumetric latent heat of fusion of each layer (cal/cm^3),

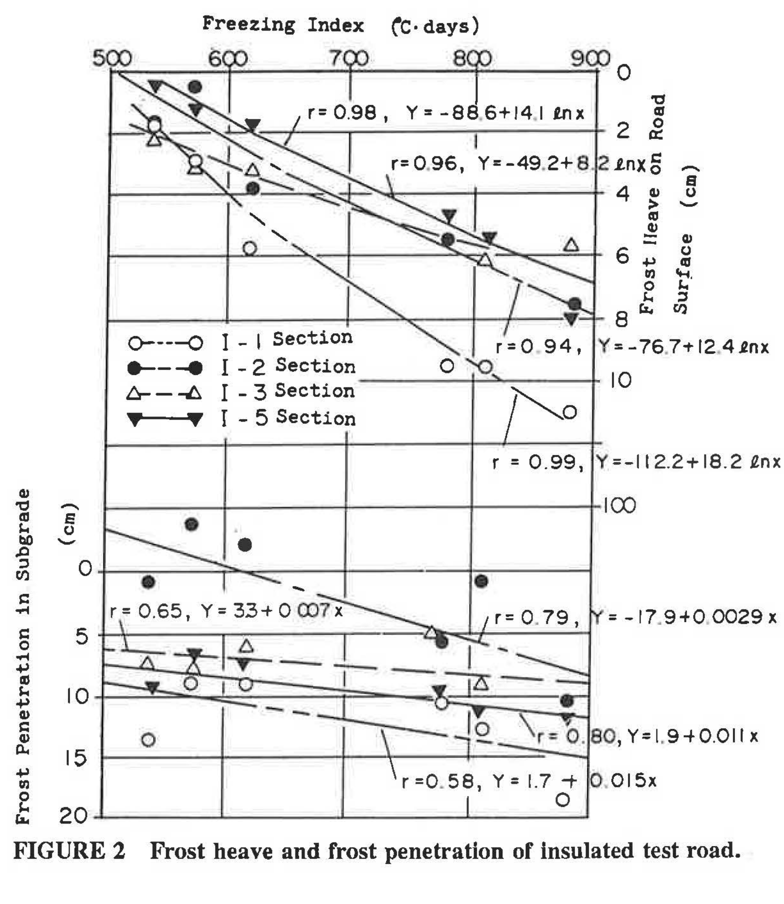

FIGURE 2 Frost heave and frost penetration of insulated test road.

F_n = freezing index (°C•days),
Z_n = depth of frost penetration (cm), and
λ = dimensionless coefficient.

The thermal conductivities of the crushed gravels, sands, and soils in the test roads shown in Figure 1 were calculated with the Kersten formula *(5)* based on the average dry density and moisture content obtained from actual measurements of national highways in Hokkaido. The values suggested by Ifukube *(6)* for the thermal coefficients of asphaltic concrete composed of surface, binder, and base courses and the insulation boards were used in the estimations. Table 1 shows the thermal coefficients used for calculating frost penetration depths in the test roads.

TABLE 1 THERMAL PROPERTIES OF MATERIALS USED IN BIBI TEST ROAD

Material	Thermal Conductivity k (cal/cm•sec•°C)	Volumetric Heat Q (cal/cm^3•°C)	Latent Heat of Fusion L (cal/cm^3)
Asphalt concrete	0.00346	0.448	0
Insulating board	0.00008	0.011	0
Gravel[a]	0.00779	0.483	5.28
Sand[b]	0.00376	0.389	9.80
Subgrade soil[c]	0.00279	0.626	50.40

[a] γ_d = 2.1 g/cm^3, w = 8 percent.
[b] γ_d = 1.75 g/cm^3, w = 7 percent.
[c] γ_d = 0.9 g/cm^3, w = 70 percent.

Figure 3 shows the relationship between estimated and observed frost penetration in the test road sections constructed with the insulation method and the replacement method, and it shows the relationship between freezing index and the estimates calculated with Equation 1. From Figure 3 it is clear that the estimated depth of frost penetration calculated with the modified Berggren formula is very close to the actual measurements, and it is possible to estimate the depth of frost penetration for the insulation method as accurately as for the replacement method.

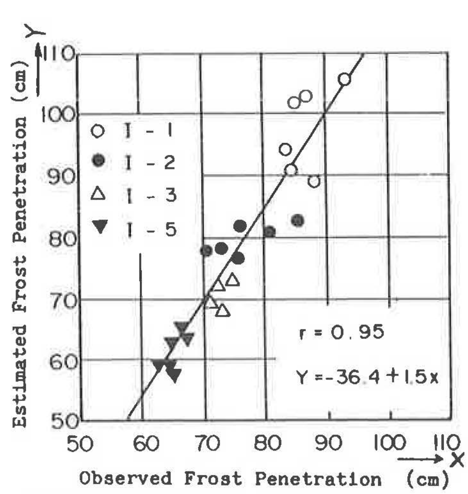

FIGURE 3 Relationship between estimated and observed frost penetration.

EXPERIMENTS

When a low-traffic road 75 km long was constructed in the Nemuro area of eastern Hokkaido, it was necessary to broaden the roadway with frost penetration control from 5.5 to 6.0 m. Winters are severe in this area and there is practically no snow until around March. Further, the soil in the road shoulder areas and subgrade has a high moisture content and is extremely frost susceptible. In this area, there are no good quality replacement materials such as crushed gravel or sand.

Under these restrictions, a new frost penetration control method combining the insulation method in the road shoulder (Figure 4) and the replacement method in the roadway (Figure 5) was introduced. With this method, it is necessary to determine the thickness and the placement depth of insulation boards used in the insulated areas. From a comparison of the cost of replaced materials for the standard pavement structures *(7)*, 25-mm-thick insulation boards were chosen for this experiment. The depth of placement of the insulation boards was determined from the difference between the frost penetration of the subgrade soil in the road shoulders and in the traveled roadway. The concept is to keep the frost penetration and heave in the shoulder and roadway the same to eliminate or minimize differential heaving. Figure 6 shows the relationship between freezing index and the depth of frost penetration calculated with the modified Berggren formula based on measured moisture content. From this figure, the replacement ratios of thickness of the replaced materials in the subgrade to the depth of frost penetration in the road shoulders and roadway, respectively, were calculated and are listed in Table 2.

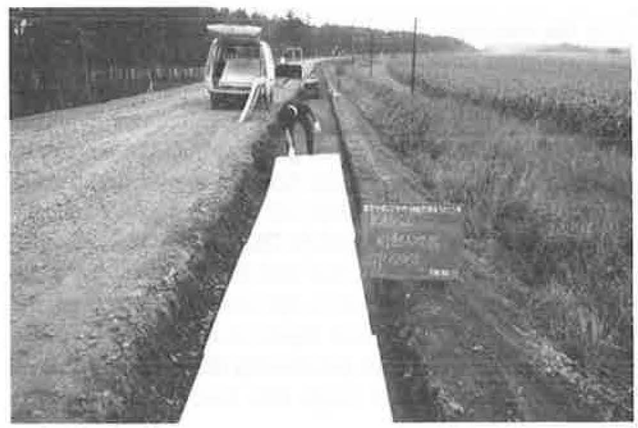

FIGURE 4 Placement of insulation boards in road shoulder.

From Table 2 the thickness of the sand layer on the insulation board in the road shoulder equivalent to the replacement depth in the roadway is 20 cm, and Figure 5 shows the required road pavement structure. This sand layer also satisfies the minimum thickness required for bearing the weight of the rolling equipment on the insulation boards. The insulation board was placed at a gradient of 2 percent away from the road center for drainage of water. On the test section constructed with this method, observations of frost penetration depth and frost heaving during winter were conducted for 2 years starting in 1981.

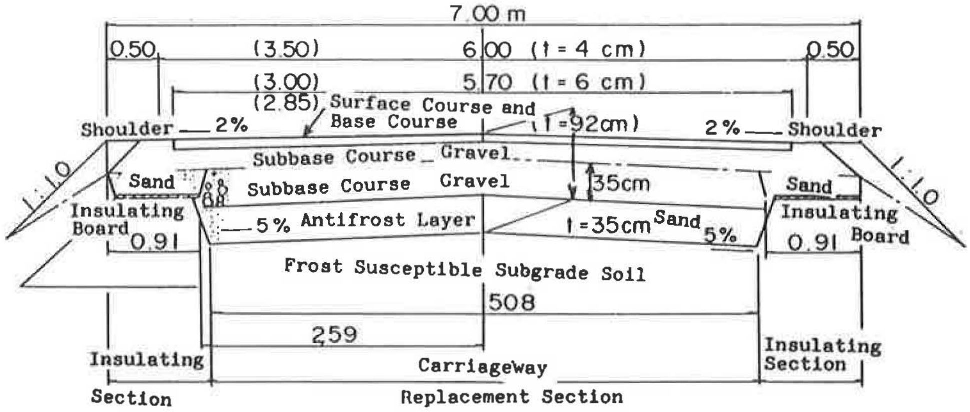

FIGURE 5 Antifrost measures with insulation and replacement methods.

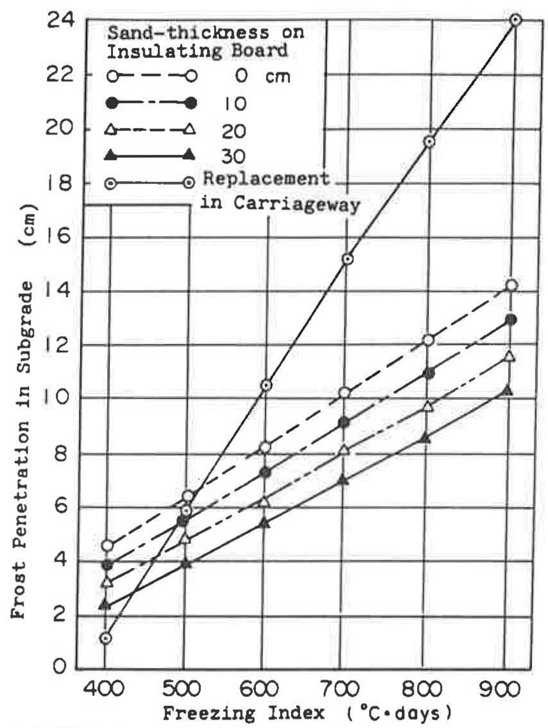

FIGURE 6 Relationship between freezing index and frost penetration in subgrade.

TABLE 2 REPLACEMENT RATIOS OF THICKNESS OF NON-FROST-SUSCEPTIBLE MATERIALS TO FROST PENETRATION IN PAVEMENT STRUCTURES

Sand Thickness in Shoulder (cm)	Replacement in Carriageway (%) by Freezing Index (°C•days) 600	700	800	900
0	90	86	82	79
10	85	82	79	76
20	89	86	84	81
30	92	90	88	86

DISCUSSION OF RESULTS

Figure 7 shows the depth of frost penetration and the amount of frost heave during winter in both road shoulder areas constructed with the insulation method and roadways constructed with the replacement method. From Figure 7 it was found that the maximum frost heave on the road surface in the middle of March was almost the same in both road shoulder and roadway. This suggests that the determination of the buried depth of the insulation boards was appropriate by equating the replacement rates in road shoulder and roadway.

Figure 8*a* shows changes of the frost heave transversely

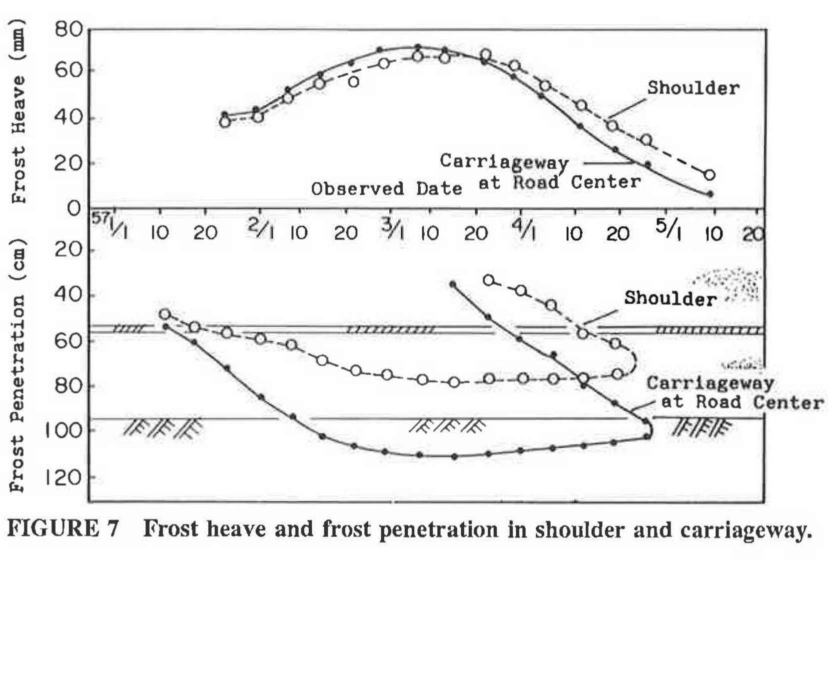

FIGURE 7 Frost heave and frost penetration in shoulder and carriageway.

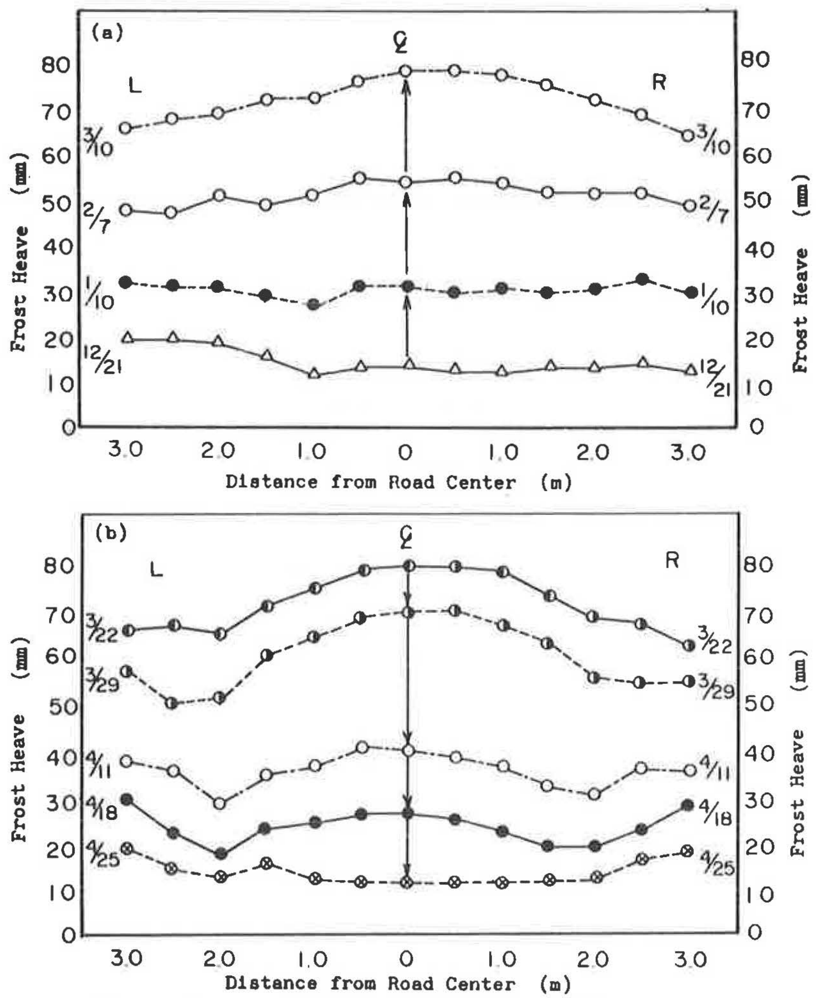

FIGURE 8 *(a)* **Increase of frost heave in winter and** *(b)* **decrease of frost heave in spring.**

across the road from December 21 to March 10 until the frost heave reaches the maximum. It shows that the amount of frost heave increases almost uniformly across the section until around February 7. However, in spring, as shown in Figure 8*b*, from the end of March to the end of April, the amount of frost heave does not decrease evenly across the section, but there is a sharp decrease at the 2-m point from the center of the roadway. This gap appears at the boundary between the road shoulder constructed with the insulation method and the roadway with the replacement method.

CONCLUSIONS

Research on a frost penetration control method that combines the insulation method in road shoulder areas and the replacement method in the roadway was conducted on roads with relatively light traffic. The results of the observation may be summarized as follows:

1. From the observations on the test road, it can be concluded that the insulation method may be practical to use for control of frost penetration in paved roads.
2. It is possible to accurately calculate the depth of frost penetration in a road constructed with the insulation method as well as that by the replacement method by using data on moisture content, dry density, and freezing index obtained with actual measurements and the modified Berggren formula.
3. Considering economy, construction, and the narrow width of the required roadway, the new method, which combines the insulation method applied in road shoulder areas and the roadway replacement method, is promising for control of frost penetration when existing gravel roads are both widened and paved. However, it is essential to consider the differences in the thawing of the frost heave that takes place in spring at the boundary between the insulation method and the replacement method.

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