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INSULATED ROAD STUDY

by E. Penner

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SOMMAIRE

Les résultats d'une étude de trois ans sur un chemin calorifugé montrent que la pénétration du gel vers l'intérieur depuis le bord d'une zone calorifugée équivaut à peu près à la pénétration vers le bas dans une section contrôlée. L'humidité c'est accumulée dans l'infrastructure gélive lorsque le front de gel a pénétré l'isolant. En cas de refroidissement rapide, la baisse de température à la surface de la chaussée peut entraîner le givrage de la surface lorsque les conditions d'humidité atmosphérique s'y prêtent. Une couche d'isolant qui se termine brusquement sans encastrement provoque des changements abrupts du niveau de la chaussée par suite du gonflement.

Insulated Road Study

E. Penner, Division of Building Research, National Research Council of Canada

The results of a 3-year insulated road study showed that frost penetration inward from the edge of an insulated area is about the same as the downward penetration on a control section. Moisture accumulated in the frost-susceptible subgrade after the frost line penetrated the insulation. During periods of rapid cooling, the temperature of the surface above an insulated pavement may be lowered sufficiently to permit surface icing if atmospheric moisture conditions are suitable. Terminating the insulation without feathering induces abrupt changes in elevation in the roadway as a result of heaving.

Thermally insulated roads attenuate frost penetration in winter by reducing ground heat loss to the air. The pavement thickness of such roads can be reduced in areas where frost penetration and its subsequent damage are critical factors. Since base course material is becoming scarce in some areas, the use of insulation may reduce the cost of road construction.

Insulated road sections have been constructed in Canada and the northern regions of the United States (1, 2, 3, 4, 5). In Ontario insulation is now used as a standard method for repairing frost-damaged highway sections, although it has not yet been used in new highway construction. The information in the literature is still sparse on some aspects of the field performance of insulated roads despite the general acceptance of the technique for the fast and efficient repair of busy highways. Among the less understood aspects are (a) the extent of ice lensing when the frost line penetrates and remains below the insulation layer in frost-susceptible soil for a considerable period and (b) the thermal pattern in the soil at the transition zone between the insulated and uninsulated sections.

The first is particularly significant if an insulated section has been underdesigned, either in error because of a lack of air temperature information or intentionally to keep construction costs as low as possible or to decrease the likelihood of surface icing. Information about the thermal regime at the transition zone is important for extending the insulation a sufficient distance beyond the protected area to prevent abrupt changes in elevation at the ends.

SOIL CONDITIONS

The experimental work was conducted on the grounds of the National Research Council of Canada in Ottawa. The soil is a postglacial clay of marine origin that is commonly referred to as Leda clay (6). It consists of about 70 percent clay-size and 30 percent silt-size particles. Frost heaving is approximately 9 to 12 cm (0.3 to 0.4 ft) during most winters in snow-cleared areas.

DESIGN OF INSTALLATION

Figure 1, a plan of the 30.5-m (100-ft) test road, shows the location of the instrumentation, which consists of thermocouple strings, survey plates, and access holes for neutron moisture measurements. The pavement design for the 15-m (50-ft) insulated section is shown in Figure 2. The procedure for preparing the subgrade for placement of the insulation boards was to fine grade it, then hand rake the surface. The 0.6 by 1.2-m (2 by 4-ft) insulation boards were staggered and held in place with 15-cm (6-in) wooden dowels. The crushed rock base was end-dumped from trucks and spread by hand.

MEASUREMENT TECHNIQUES

Temperatures were measured by 0.8-mm (20-gauge) copper-constantan thermocouples attached to 4-cm (1.5-in) diameter wooden dowels. A 0.3-m (1-ft) length of thermocouple lead was wrapped around the dowel in a groove at each measurement position to minimize conduction errors. At each location in the control section at which temperatures were measured, thermocouples were placed 0.076, 0.3, 0.6, and 1.2 m (3, 12, 24, and 48 in) from the surface; in the insulated section thermocouples were placed 0.076, 0.2, 0.3, 0.6, and 1.2 m (3, 10, 12, 24, and 48 in) from the surface.

Subgrade moisture contents were determined with a neutron moisture meter near the center of each section (7, 8). The access holes of the neutron meter probe were

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cased with 4-cm (1.5-in) diameter aluminum tubes sealed with rubber stoppers; desiccant was kept inside the tubes to prevent moisture condensation on the inner walls. Elevation surveys for heave measurements were carried out with a precise level on metal plates embedded in the surface of the asphaltic concrete at the locations shown in Figure 1 and referenced to a stable benchmark.

RESULTS AND DISCUSSION

The thermal pattern for the time of maximum frost pene-

Figure 1. Plan of test road.

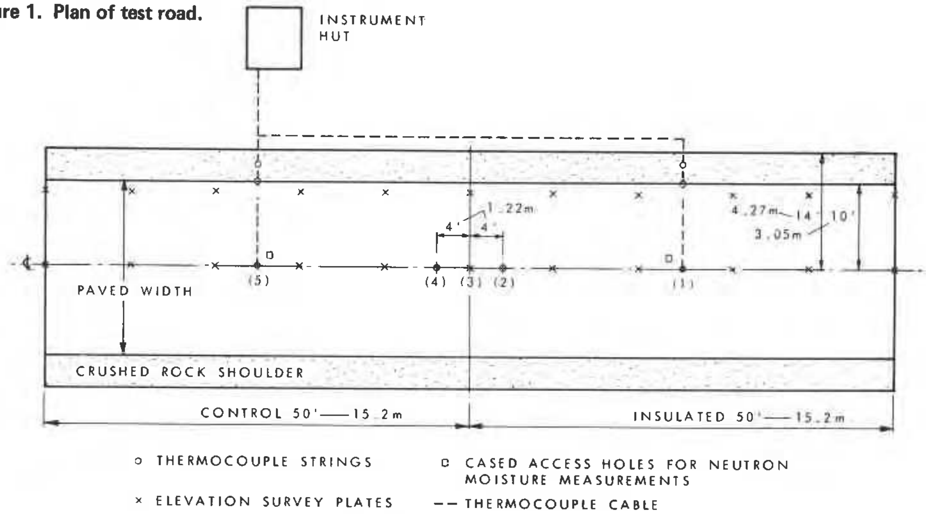


Figure 2. Cross section of insulated road section.

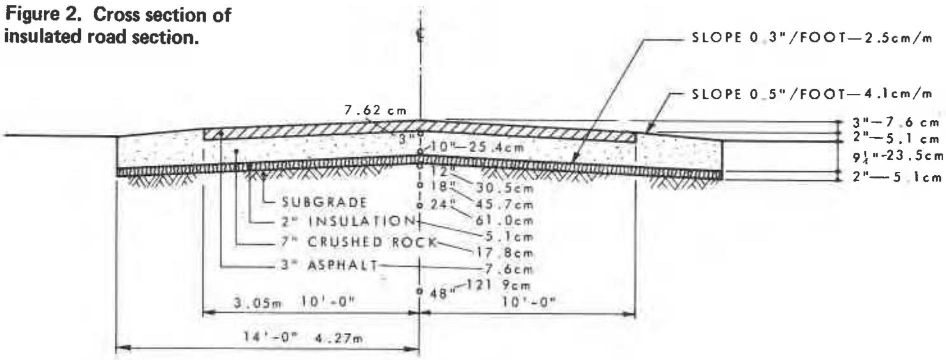


Figure 3. Isotherms near time of maximum frost penetration at end of insulated section on centerline of snow-cleared road.

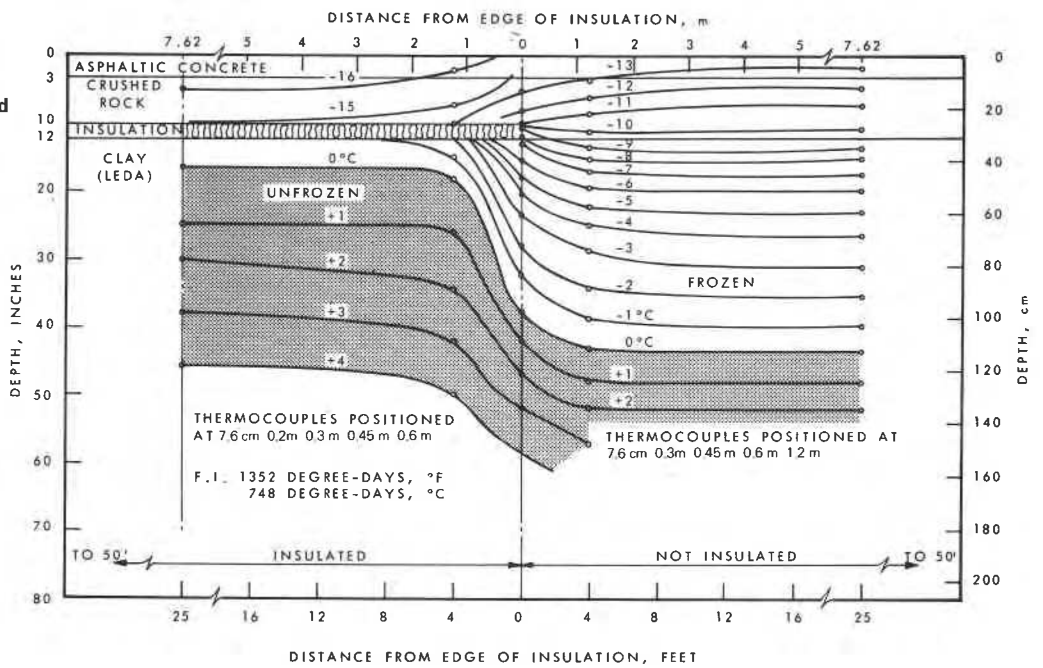


Figure 4. Depth of frost line at various locations as given in Figure 1 for winter 1965-66.

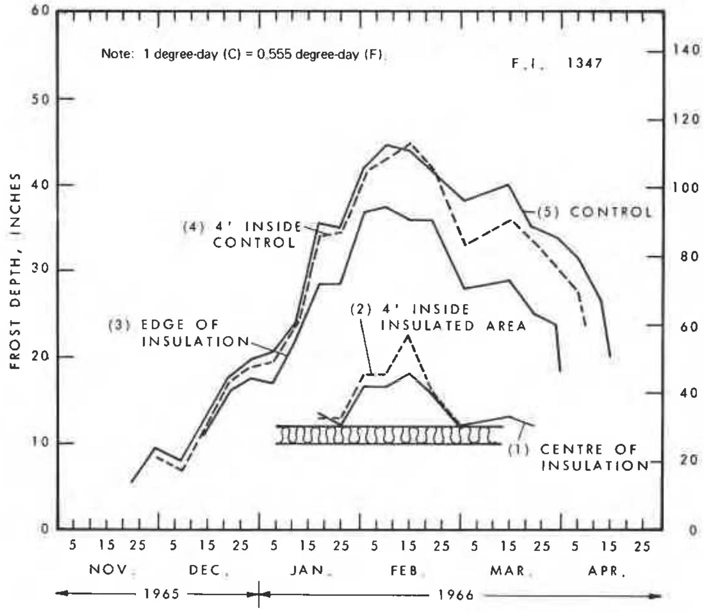


Figure 5. Frost heave on road centerline of insulated section and adjacent control.

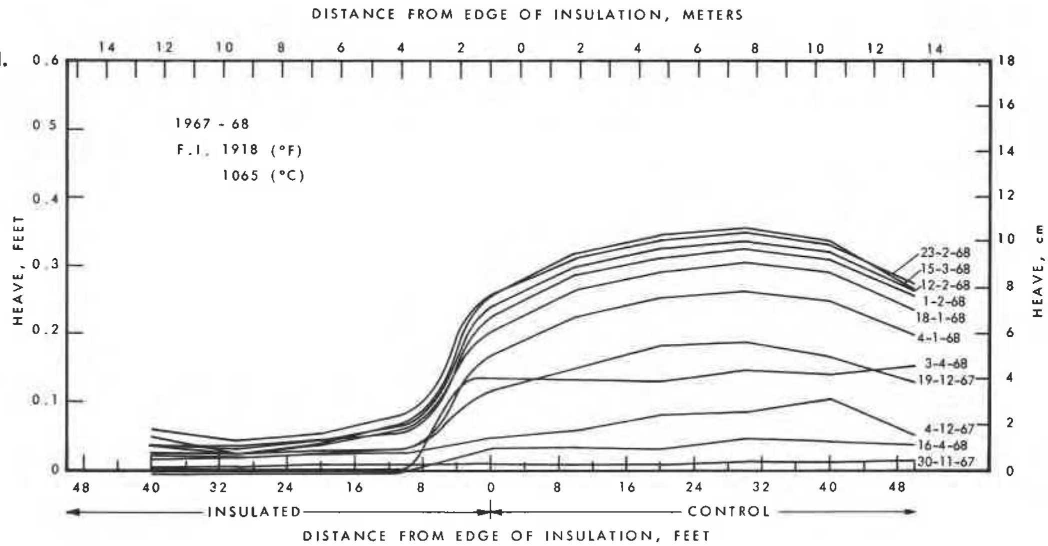
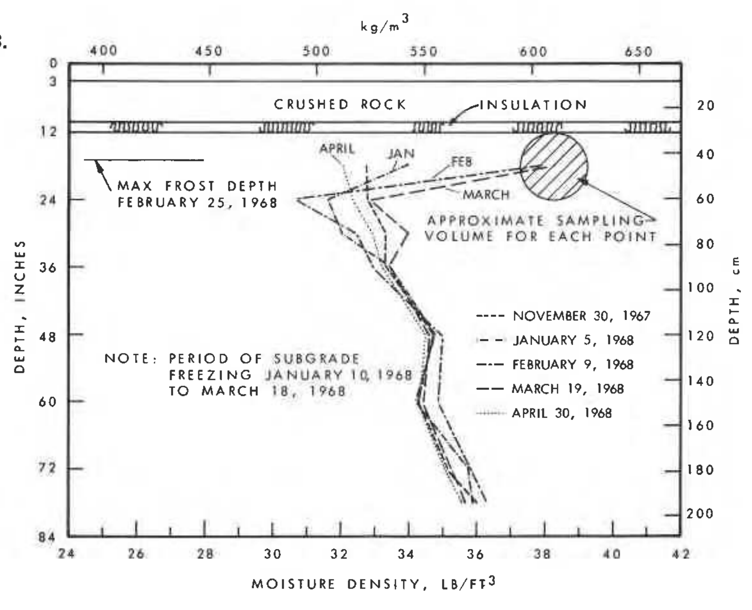


Figure 6. Moisture density profile in subgrade, 1967-68.



tration, at the transition zone between the insulated and control sections on the road centerline, was similar for the 3 consecutive years, 1965-66, 1966-67, and 1967-68. Figure 3 gives such a pattern for 1 year. The base course above the insulation was colder than the surface of the control section, but differences in the temperatures of the surfaces would depend on the air temperature prior to the measurements. The thermal response of the base course above the insulation to changes in the air temperature gave warmer temperatures for the insulated sections in the summer and colder temperatures in the winter.

Figure 4 shows the frost penetration at the edge of the insulation 1.2 m (4 ft) inside the insulated area, 1.2 m (4 ft) inside the control area, and at the center of each section. In all cases, the frost penetration at the center of the control area and that at a point 1.2 m (4 ft) from the edge of the insulation were similar. During the 3-year period when the measurements were made, the frost penetration in the control area ranged from about 1.1 to 1.5 m (45 to 55 in). Thus, at a distance inside the insulated area equal to the depth of frost penetration almost all end effects due to insulation have disappeared.

The heave pattern for the three winters shows the severity of frost heave in Leda clay. Figure 5 gives the results for 1967-68. Heaving was observed in the insulated area as well as in the control section since 5 cm (2 in) of insulation does not provide complete frost protection for the subgrade. The water table at the site characteristically rises to the ground surface in the fall; as the surface of the pavement is level with the surrounding terrain, this results in a fully saturated base course. The small heave above the insulation measured during the period of freezing is attributed solely to expansion of water. Normal ice lens growth is thought to be responsible for the measured heave that takes place after the frost line has passed through the insulation into the subgrade. The measure of moisture increase below the insulation is given in terms of moisture density in Figure 6, which also shows the position of the frost line at a maximum penetration in relation to the depth at which the moisture was measured.

Two final items are of particular interest. The thermal equivalents of soil versus insulation for the Ottawa trials and for those at another test site in Sudbury, Ontario, are shown in the table below, which also lists the cumulative degree-days for each year at each site.

Location and Year	Penetration Into Subgrade Below Insulation (cm)	Penetration Into Subgrade in Control (cm)	Insulation Equivalents (cm)	Degree-Days
Ottawa				
1965-66	15	84	14	748
1966-67	20	104	17	988
1967-68	13	105	19	1065
Sudbury				
1964-65	30	119	18	1443
1965-66	13	94	16	1127
1966-67	33	107	15	1212
1967-68	46	117	14	1476

The values range from 14 to 19 cm of soil per centimeter of insulation. The average thermal conductivity of the insulation (measured in the laboratory) was 0.39 W/m·K (0.27 Btu·in/h·ft^2·°F) after 10 years burial at the Ottawa test site. After 6 weeks drying at 41°C (105°F) this value was reduced to 0.35 W/m·K (0.24 Btu·in/h·ft^2·°F). The moisture absorbed and retained was 6.8 percent by volume, which appears entirely acceptable after 10 years of exposure in the ground.

CONCLUSIONS

Although the heat extraction rate is slow when the frost line is in wet frost-susceptible soil below insulation, moisture flow is induced and heaving occurs. Under the soil and climatic conditions of this study, frost penetration inward from the edge of the insulation was about the same as that downward in an uninsulated area. Abrupt heaving at the edge of the insulation was well demonstrated and can be avoided by feathering the insulation at the ends of the insulated sections.

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