Performance of City Pavement Structures Containing Foamed Plastic Insulation

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This paper presents one winter's results of two 100-ft city pavement sections insulated with a 2-in. thickness of extruded polystyrene plastic foam in Sudbury, Ontario, Canada. The experimental results consisted of temperature measurements, frost-depth measurements with methylene blue gages, elevation measurements for frost heave and Benkelman beam deflections following the thawing period.

The insulation reduced frost penetration by 35 in. during a 2600 degree-day winter. Thermoconductivity measurements showed that no deterioration occurred in the insulating properties of the insulation. Frost penetration in the control area was approximately 65 in., which compares favorably with the depth predicted by the U. S. Army Corps of Engineers from measurements in granular base course beneath snow-cleared airport runways.

THE CONCEPT of thermally insulating frost-susceptible subgrades has been used widely on Norwegian railroads since the turn of the century (1). The practice has been to replace frost-susceptible soil in the freezing zone with a layer of peat blocks or other highly fibrous materials. Such materials usually contain more water than soil. When wet peat freezes a proportionately larger quantity of latent heat is released and hence the freezing plane moves downward more slowly. The frostline may also be attenuated with a dry insulating layer of high thermal resistance placed in the pavement structure. This is the basis of a technique that has received attention recently.

The first full-scale field trials with a dry insulation using extruded polystyrene plastic foam with surface skins were described by Oosterbaan and Leonards (2) and Young (3). An earlier study, which compared predicted and measured frost penetration depths beneath small concrete slabs, also included a small amount of data on an insulating layer of cellular glass (4).

The desirability of decreasing frostline penetration in highways and streets in areas of seasonal frost arises because the design pavement thickness, based strictly on load-carrying capacity, is usually less than the thickness required to prevent frost penetration into the subgrade. Consequently, detrimental frost action ensues if the subgrade is frost-susceptible.

If an insulating material is embodied in the pavement structure it should retain its thermal resistance over the lifetime of the road in spite of a varying moisture regime in the surrounding material. Further, the insulating layer should not interfere significantly with the stability of the pavement structure, either because of the flexible nature of the insulation or by creating an unfavorable water condition in the other components of the road.

The amount of insulation required will depend on the type of pavement structure, the thermal constants of the various layers, and the climate. As there are some difficulties

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associated with the prediction of reliable thermal patterns in pavement structures, field trials have been initiated.

In the present paper the results of one winter's observations are given for two street sections in the City of Sudbury insulated with extruded polystyrene plastic foam with surface skins. The project was a joint undertaking by Dow Chemical of Canada Ltd., the City of Sudbury, and the Division of Building Research of the National Research Council of Canada.

CONSTRUCTION AND INSTRUMENTATION

Insulated sections were constructed at two locations in Sudbury, on Antwerp and Byng Streets, which were unpaved streets slated for reconstruction and surfacing. Figure 1 shows a plan view of both the insulated and control sections on Antwerp Street. The 100-ft insulated section was 35 ft wide and extended beneath the east sidewalk over most of its length and to the edge of the sidewalk on the west side. Letters A to G give the seven thermocouple locations; the circled numbers are the locations of the frost-depth gages.

A similar plan view shows the Byng Street location (Fig. 2). This site was instrumented with frost-depth gages only. The insulated area was 108 ft long and 35 ft wide. Again, the insulation extended underneath the proposed sidewalk area on the east side but the sidewalk was not constructed before the first winter's observations.

Figures 3 and 4 show cross-sections of the pavement structure and thermocouple depths for both the insulated and control areas on Antwerp Street. The pavement design on the east half of Antwerp Street consisted of $3\frac{1}{2}$ in. of asphaltic concrete, 3 in. of "A" base material, 9 in. of "B" subbase and 2 in. of insulation. On the west half, an additional 7 in. of "B" subbase was placed below the insulation. The control area

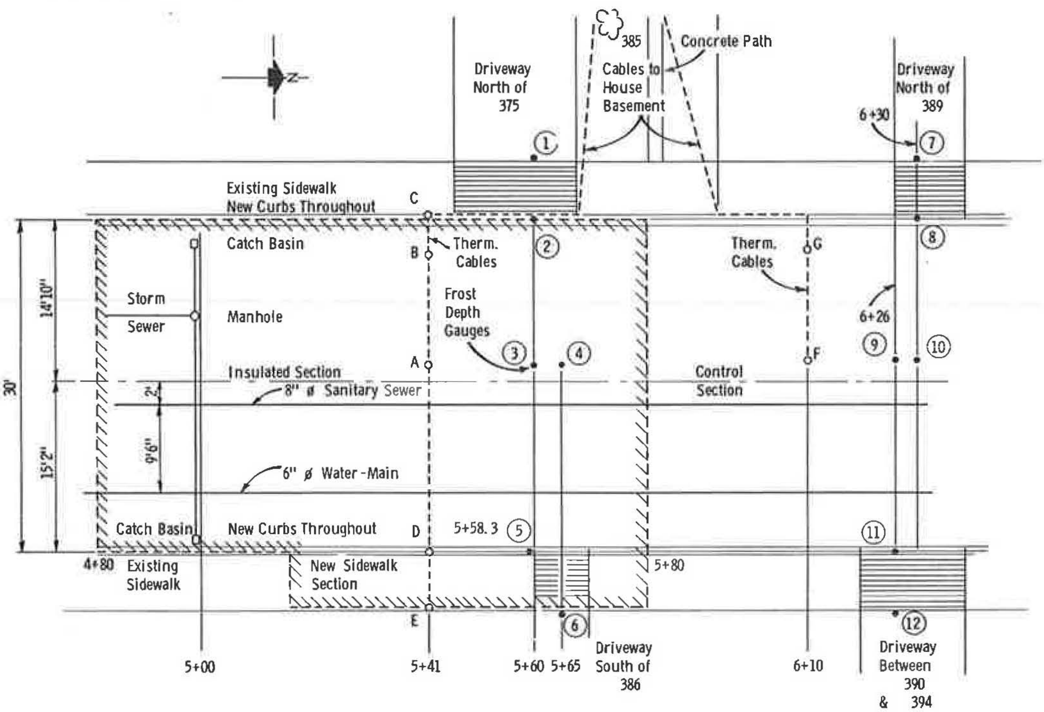

Figure 1. Plan of insulated and control section on Antwerp Street with locations of thermocouples and frost-depth gages.

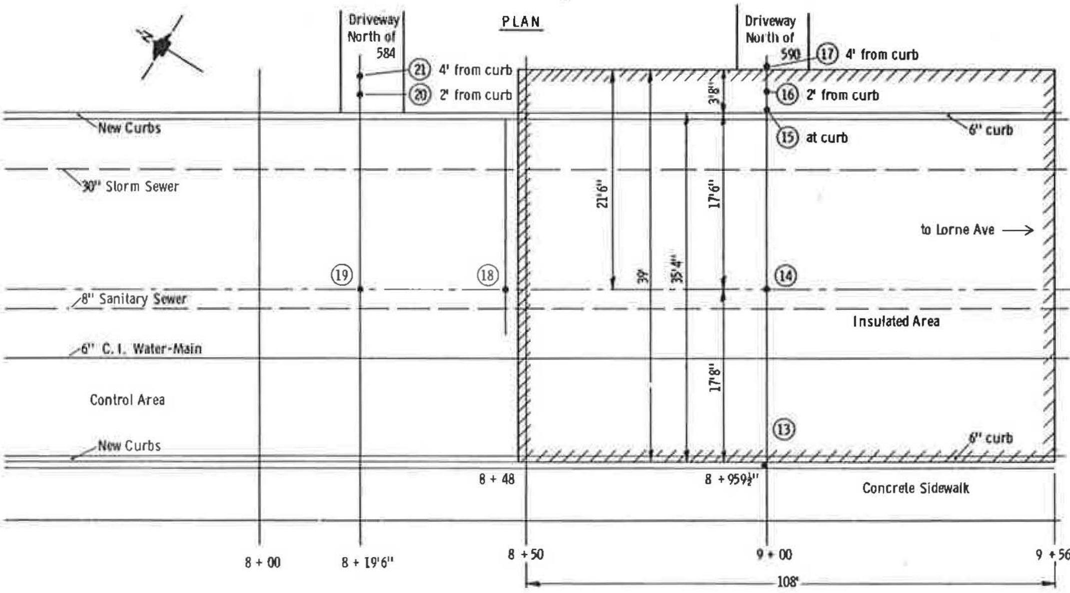

Figure 2. Plan view of insulated and control areas on Byng Street showing location of frost depth.

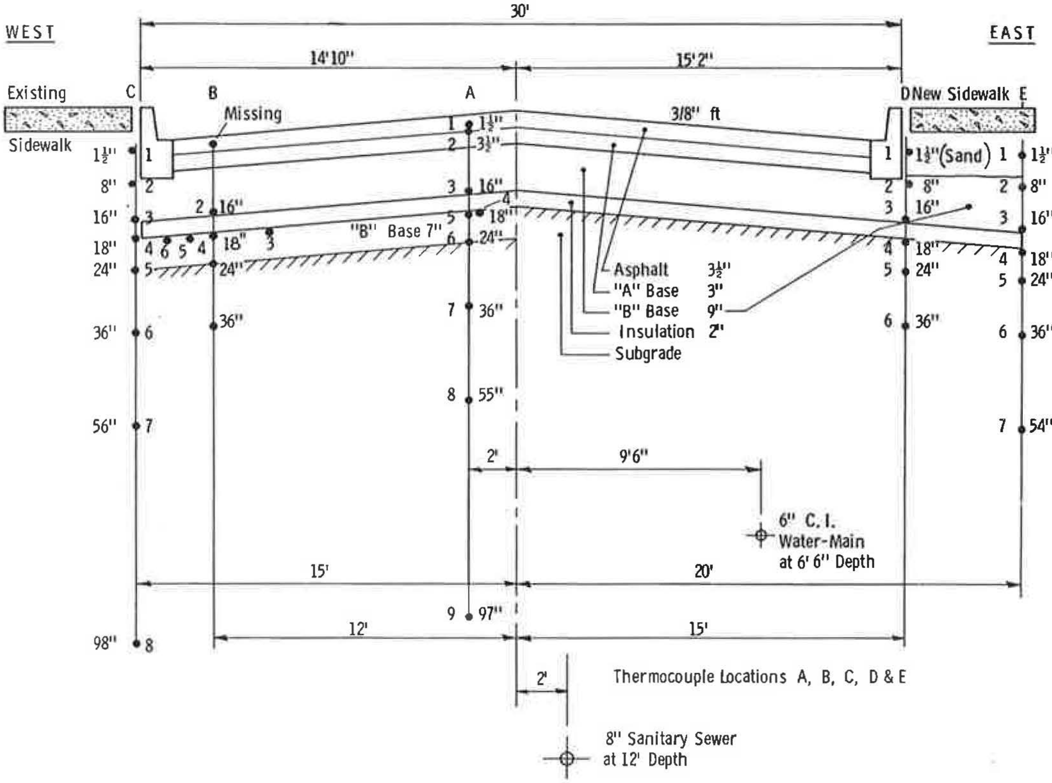

Figure 3. Pavement design and thermocouple locations of insulated section at Station 5+41, Antwerp Street.

was uniform on both sides consisting of 3½ in. of asphaltic concrete, 3 in. of "A" base course, and 18 in. of "B" subbase.

Cross-sections of the pavement structure on Byng Street are shown in Figures 5a and 5b. The pavement design of 3½ in. of asphaltic concrete, 3 in. of "A" base course

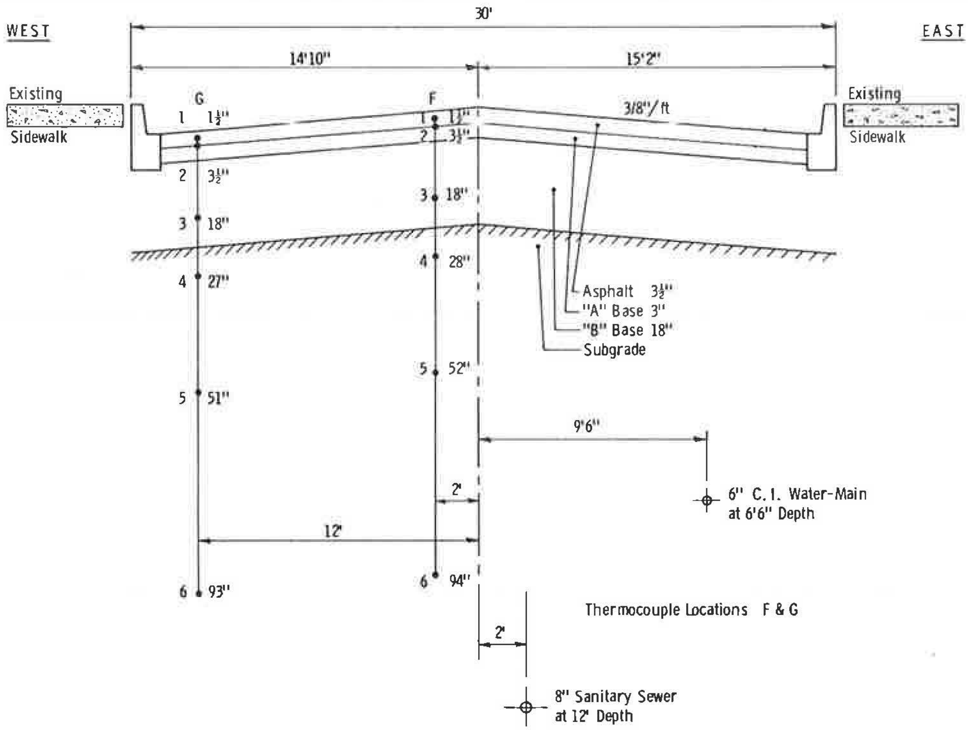

Figure 4. Pavement design and thermocouple locations of control section at Station 6+10, Antwerp Street.

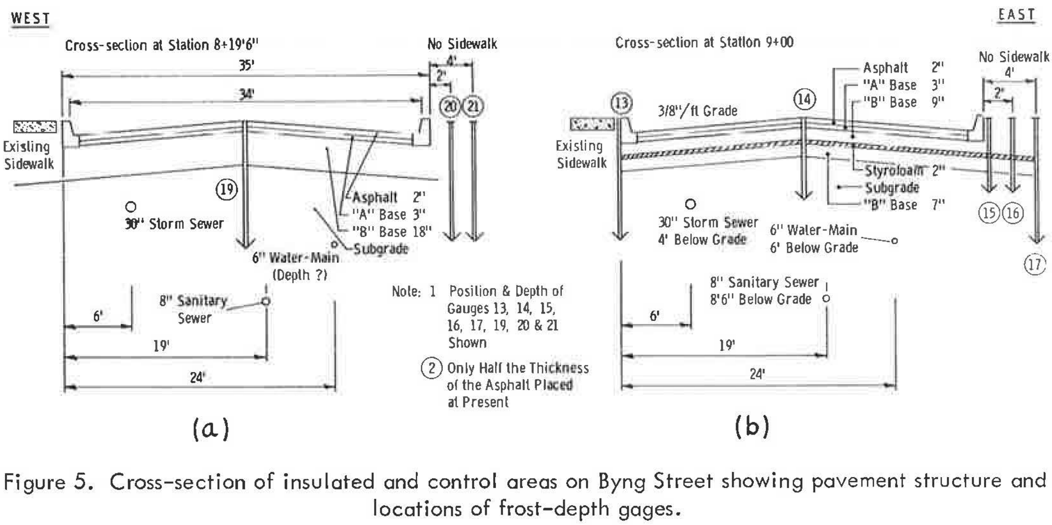

Figure 5. Cross-section of insulated and control areas on Byng Street showing pavement structure and locations of frost-depth gages.

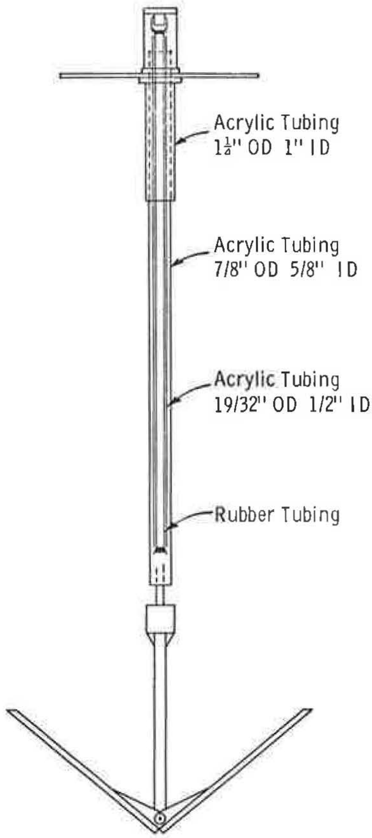

Figure 6. Frost-depth gage.

and 18 in. of "B" subbase was based on the standard practice of the City of Sudbury for the subgrade soils at both locations. Only 2 in. of asphaltic concrete was placed at Byng Street prior to freeze-up. The remaining 1½ in. was scheduled for placement in the summer of 1965.

Frost-Depth Gages

The frost-depth gages (Fig. 6) were of Swedish design, the details of which have been published (5). Briefly, the gage consists of two telescoping lucite tubes. The inner plastic tube contains a soft rubber tube and the annulus between the rubber tube and plastic outer tube is filled with an aqueous solution of methylene blue. The thin annulus of solution can expand easily on freezing by compressing the inner rubber tube. The outer tube, anchored at the surface, can move vertically in case of heave or settlement without damaging the gage. The gages were read weekly to follow the progress of the freezing plane by this method.

Thermocouple Installation

Fifty 20-gage copper-constantan thermocouples were installed on Antwerp Street (Figs. 3 and 4) and connected to a panel located in the basement of a house adjacent to the experimental area. Twenty thermocouples were connected to a suitably preamplified millivolt recorder for continuous measurements and the remaining thirty were read either daily or weekly depending on the depth of installation. In most cases the thermocouples located in the upper strata of the pavement and above the insulation were connected to the recorder; the lower ones were read with a standard manually operated potentiometer. An automatic thermoelectric ice bath was used as a reference temperature.

A Stevenson screen containing a thermograph was installed on the Antwerp Street site for air temperature measurements.

Frost Heave Measurements

Elevations at the tops of the frost-depth gages were determined weekly to measure frost heave. Every three weeks, elevations were determined on the surface of the road on a 20-ft grid system.

Site Preparation

Site preparation for the placing of the extruded polystyrene insulation boards (2 ft by 4 ft by 2 in.) was to fine grade and hand rake the surface. The panels, placed in a staggered fashion, were held in place with 6-in. wooden dowels. No attempt was made to seal the cracks between adjacent boards. The subbase was end-dumped from trucks and then bladed over the insulation by track vehicles riding on an 8-in. cushion of the subbase material.

The Byng Street experimental site had a gentle upward slope of 1.5 percent from south to north. On Antwerp Street, the slope was about 4 percent in the same direction.

TABLE 1

GRADING REQUIREMENTS

Tyler Screen Size Square Openings	Percent Passing	
	"A" Base Course	Modified Granular "B" Subbase
4 in.		100
2½ in.		85-100
1 in.		60-100
⅞ in.	100	57-100
⅝ in.	75-100	48-100
No. 4	35-60	25-92
No. 8		15-85
No. 14	15-35	10-75
No. 28		
No. 48	5-20	5-38
No. 100	4-15	4-22
No. 200	3-8	3-8

The east side of the pavement was about 6 in. lower than the west side at both locations. This had some bearing on the drainage and deflection pattern of both test sections.

BASE-COURSE MATERIALS AND SOILS

The particle-size grading requirements for both the "A" base course and "B" subbase materials are given in Table 1. These were compacted in accordance with the usual practice followed by the City of Sudbury.

As both installations were built on previously unpaved streets, the first few feet of material below the surface varied considerably. Although it was hoped that the insulation on the east half of Antwerp Street could be placed directly on natural

TABLE 2

SOIL TEST DATA ON ANTWERP STREET PRIOR TO PRESENT CONSTRUCTION
September 14, 1964
Hole 1, Station 5+45, 6 ft west of centerline
Hole 2, Station 4+96, 2 ft west of centerline

Hole	Depth (ft)	W_n	W_L	W_p	γ	Description
1	0-2	—	—	—	—	Sandy gravel fill with slag and ashes; dry.
	2-4	22.3	—	—	—	As above to 2.5 ft, then brown silty fill to 3.9 ft, then 1 in. peat, then dense brown silt.
	4-5.7	22.0	22.7	22.1	125	Brown cohesive sand silt with numerous oxidized stains. Hit obstruction at 5.7 ft. Move rig 2 ft.
	6-8	22.6	—	—	—	Brown moist silt.
	8-10	18.6	25.3	19.3	—	Brownish grey, stratified, fissured cohesive silt. Could not jack sample. Silt partings at frequent intervals.
2	0-2	—	—	—	—	Dry sandy gravel fill with slag and ashes to 20 in., then brown clayey silt.
	2-4	23.2	35.1	22.1	121	
	4-6	20.1	—	—	—	Grey and brown coarse silt, very moist 4.5 to 4.7 ft.
	6-8	15.4	17.9	17.5	132	
	8-10	21.8	—	—	—	Dense brown silt, thin clay seams, moist only.

Note: W_n = natural moisture, W_L = liquid limit, W_p = plastic limit, γ = natural unit weight.

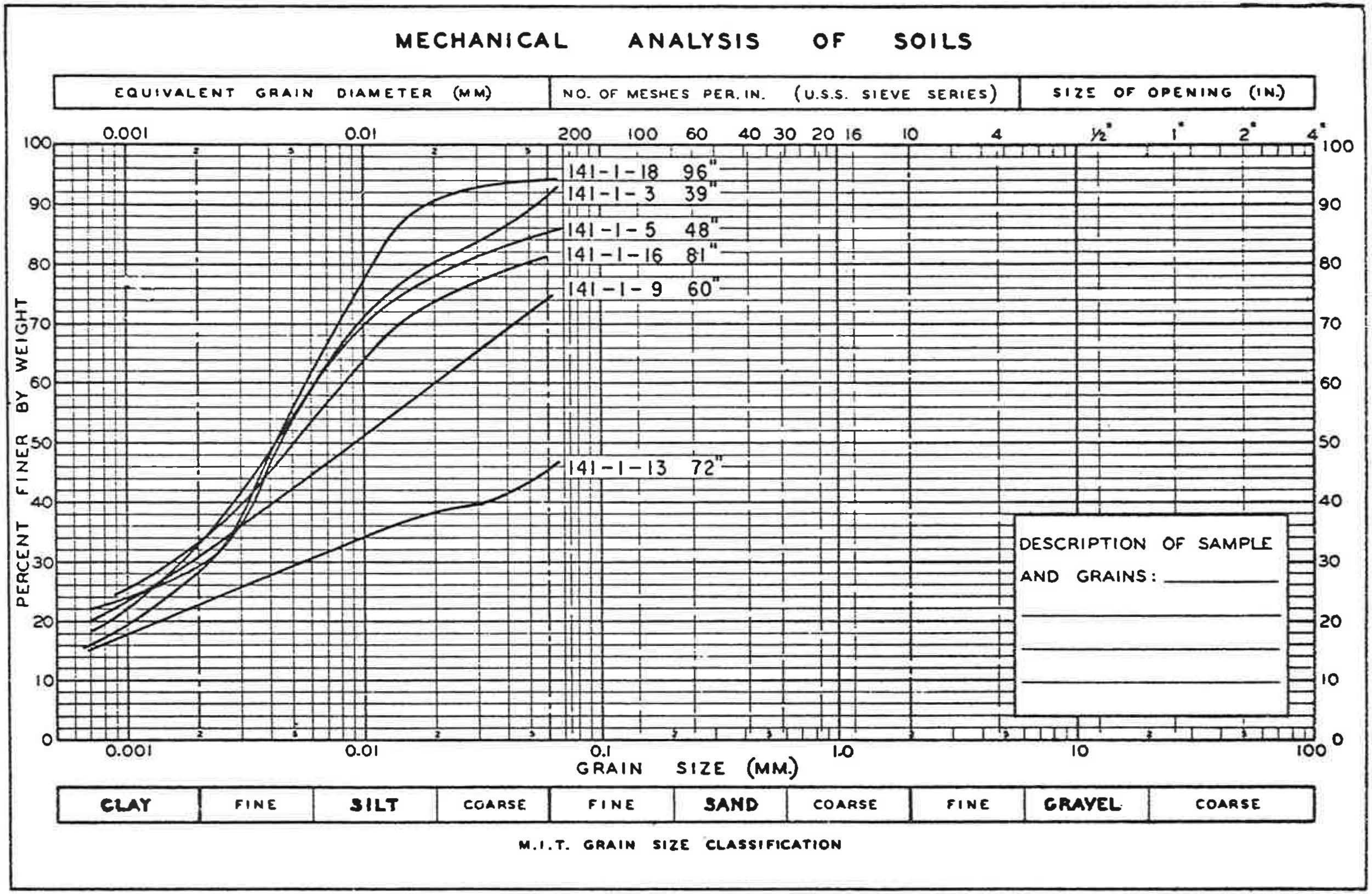

Figure 7. Hydrometer analyses of soil samples at Station 5+41, 2 ft west of centerline.

subgrade soils, this was in fact not the case. At the Antwerp site, the upper few feet consisted of fill material of slag and ashes mixed with silt. Grain-size curves for samples of the subgrade below 39 in. are given in Figure 7. These show 18 to 26 percent in the clay sizes, most of the remaining percentage in the silt size, and a small amount of fine sand. The moisture contents ranged from 17 to 22 percent by weight just before construction. Test results and a description of the soils on Antwerp Street are given in Table 2.

The Byng Street installation was constructed on a previously filled low-lying swampy area. Again, the upper materials consisted of a slag-ash fill intermixed with silts. Below 3 ft the organic residues and silts were too soft to sample with a hand auger.

RESULTS

Air Temperature and Freezing Index

The air freezing index based on degree-days F, calculated from thermograph measurements on the site, was 2600 (Fig. 8). The average for 1954-1960 at the Sudbury airport 12.5 miles NE of the city was 2387.

The design freezing index for the area is 3200 degree-days (6). The freezing index was 1770 degree-days at a depth of $1\frac{1}{2}$ in. in the asphaltic concrete over the insulated area and 1500 at the same depth in the control area. This gives an "n-factor" of 0.68 for the insulated area and 0.58 for the control area.

Subsurface Temperatures

The average daily air temperatures are shown in Figure 9a for the winter of 1964-65. Figures 9b and 9c show the temperatures at various depths (2 ft off centerline) of the control area and insulated area respectively. The shaded area gives the temperature difference across the 2 in. of insulation.

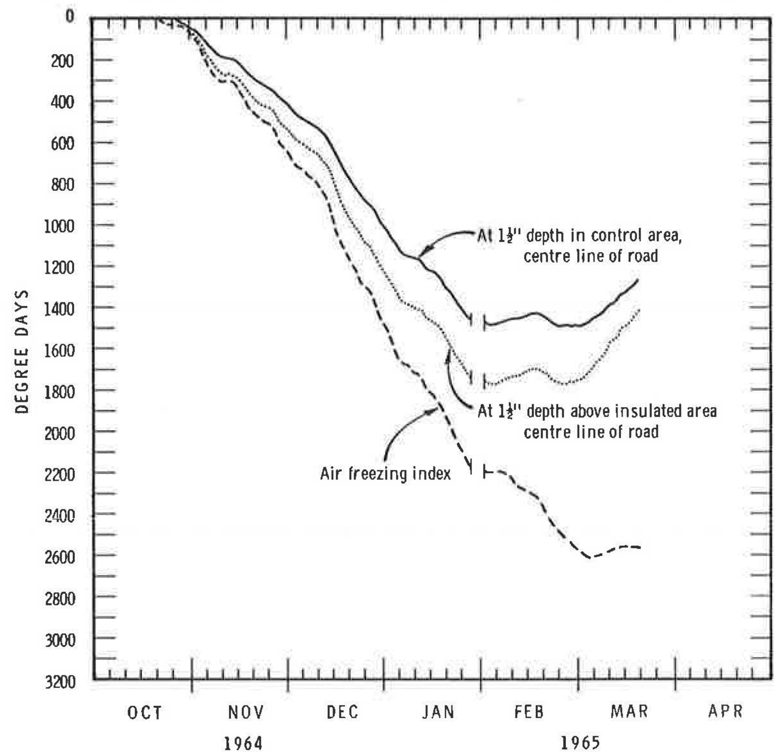

Figure 8. 1964-65 freezing index, Antwerp Street.

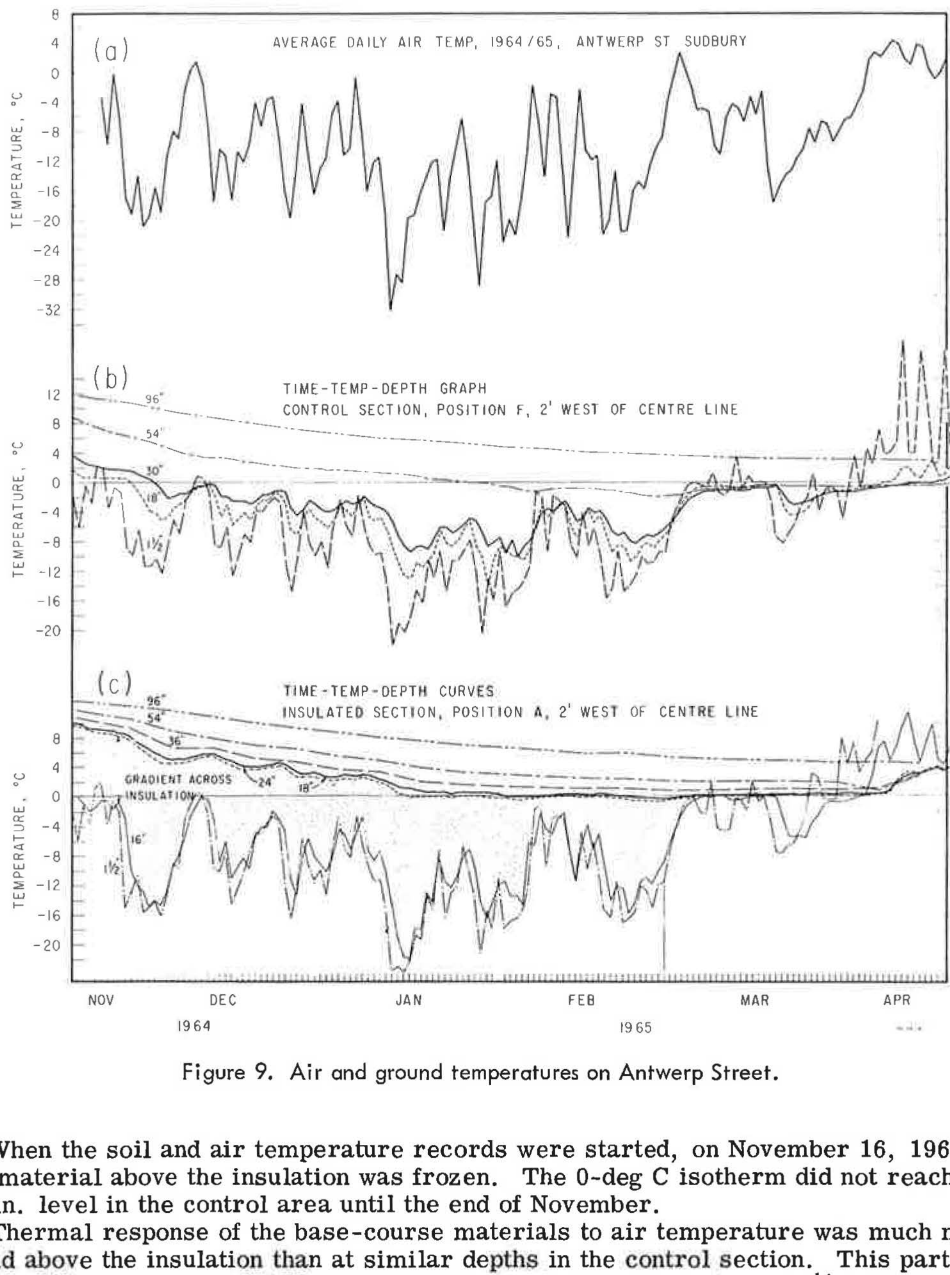

Figure 9. Air and ground temperatures on Antwerp Street.

When the soil and air temperature records were started, on November 16, 1964, all the material above the insulation was frozen. The 0-deg C isotherm did not reach the 18-in. level in the control area until the end of November.

Thermal response of the base-course materials to air temperature was much more rapid above the insulation than at similar depths in the control section. This particular feature is shown by the small differences between the temperature at 1½ in. and 16 in. The differences were usually much greater in the control area (Fig. 9b).

The frostline, based on the depth of the 0-deg C isotherm, was below the insulation for 80 days at position A, 2 ft west of centerline. The maximum penetration—12 in. below the insulation—was on March 2, 1965 (Fig. 10a). The minimum temperature just beneath the insulation at this position was -0.9 C on February 28, 1965. The average temperatures were +0.8 C during January, -0.45 C during February, and -0.15 C during March. At the top of the natural subgrade soil the minimum temperature was -0.4 C.

At position B, 12 ft west of centerline (3 ft from the west edge of the insulation), the period of frost penetration was 65 days (Fig. 10b). The maximum penetration was 9 in. at this position on March 2, 1965. The minimum temperature just beneath the insulation at this point was -0.3 C on March 2, 1965. The average temperature at this point during February and March was about 0 C.

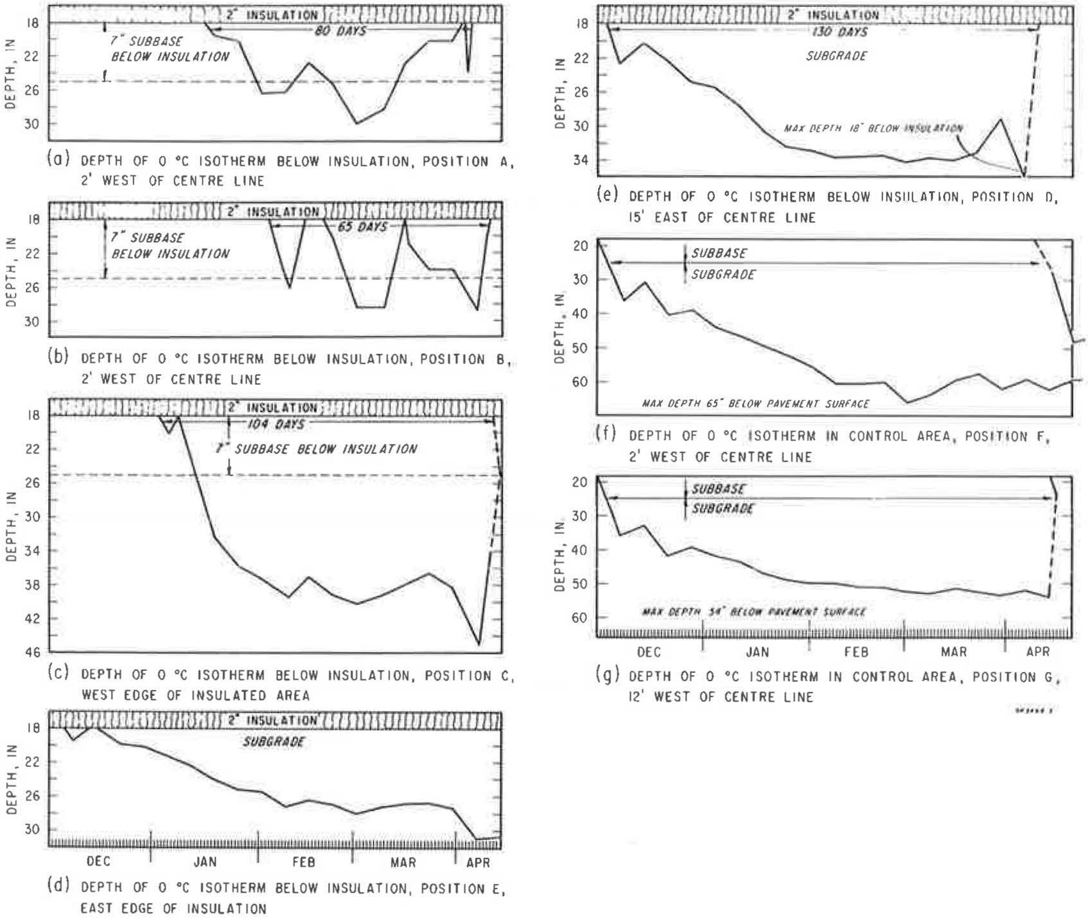

Figure 10. Frost penetration on Antwerp Street.

Directly below the west edge of the insulation (position C), the period of freezing below the insulation was 104 days and the maximum frost penetration was 27 in. (Fig. 10c).

For the east half of the street the insulation was placed directly on the subgrade; the thermocouple positions in this area were D and E. At position D (which is at the curbline on the east side, 5 ft in from the east edge of the insulation) the period of frost penetration below the insulation was over a longer period and to a greater depth than at a comparable position on the west side (Figs. 10b and 10e). This aspect is discussed in detail later in this paper.

The depths of the 0-deg C isotherm for the two positions in the control section are given in Figures 10f and 10g. The minimum temperature at the 18-in. depth was -14 C on January 30, 1965. The minimum temperature at the 30-in. depth was -10 C on February 4, 1965. The maximum frost penetration at this point was 65 in.

Comparison of Frost-Depth Gages with Zero Isotherms

Figure 11a gives the comparison of frostline depth as a function of time between gage measurements and those estimated from temperature gradients. The comparison is favorable in the control area as long as the frostline was actively penetrating downwards. In the insulated areas the gages indicated a greater penetration (average of 5.5 in.) than did temperature measurements when the frostline was in the vicinity of the insulation. This is perhaps not unexpected since the thermal conductivity of the plastic gage is much greater than that of the insulation.

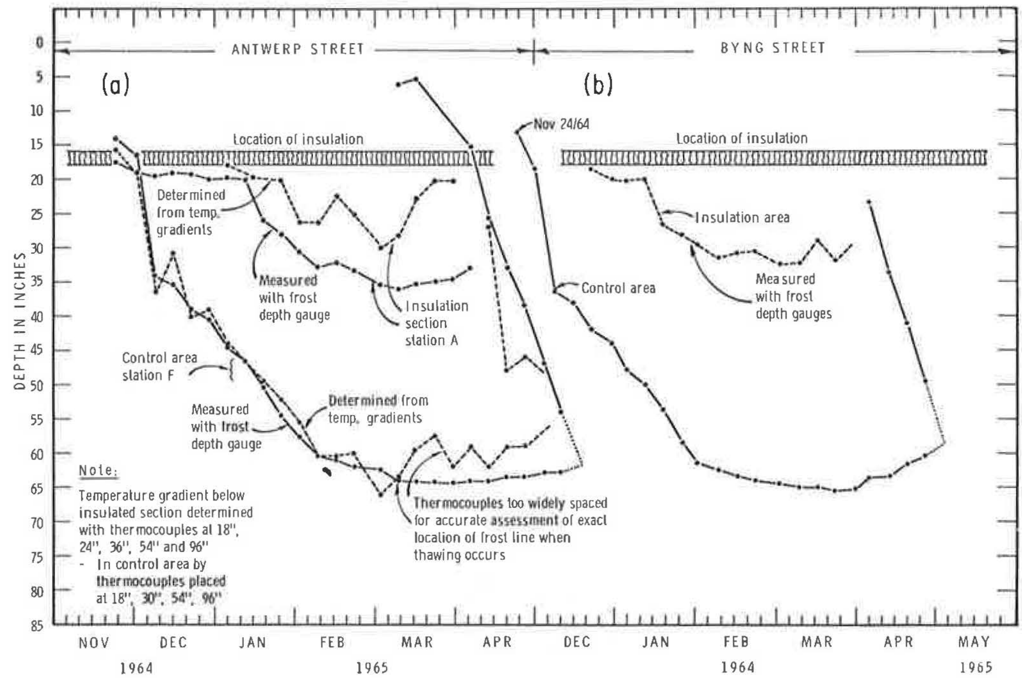

Figure 11. Frost depth determinations with frost-depth gages and temperature measurements.

There was also poor agreement toward the end of the freezing period when the frostline was receding in the control area. A part of the disagreement results from estimating the freezing plane from widely spaced thermocouples, particularly when thawing was occurring both from the top and the bottom of the frozen layer. During the active thawing period the frozen layer was too close to zero degrees to estimate accurately the location of the freezing plane from temperature gradients.

Frost penetration as measured by frost-depth gages on Byng Street is shown in Fig. 11b. The depth of freezing was about the same (65 in.) as on Antwerp Street in the control area. The frost penetration curve beneath the insulation shows a trend similar to that at the Antwerp Street location. No temperature measurements were carried out at this site, but consideration of the difference between the gage and thermocouple frost depths indicates that the actual frost penetration was about 27 in. (9 in. below the insulation).

Frost Heave Measurements

Figure 12 gives the results of surface elevation measurements on Antwerp Street. The first measurements (January 21) showed some settlement in the insulated area. By this date the control area had heaved a maximum of 0.3 ft in one spot, but in general the heave was less than 0.2 ft. By February 20, 7 in. of frost penetration had occurred beneath the insulation at the centerline. The west side (with the additional 7 in. of subbase beneath the insulation) showed no heaving; the east side (without the additional subbase) had heaved 0.1 ft, and at a position 2 ft off centerline it was slightly less. As shown, additional heaving occurred in March but by April 12 the pavement in the insulated area was back to its original position.

At the Antwerp Street location, heaving was greatest on the east side, where drainage conditions were known to be poor, and least on the west side. The average heave in the insulated area was one-third to one-half of the heave in the areas to the north and south.

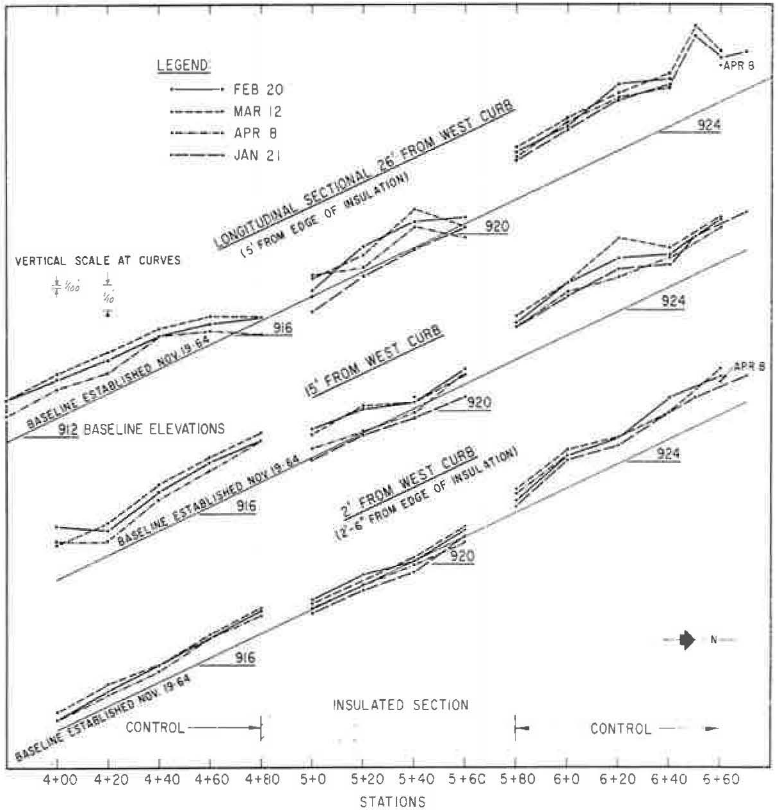

Figure 12. Frost heave measurements on Antwerp Street.

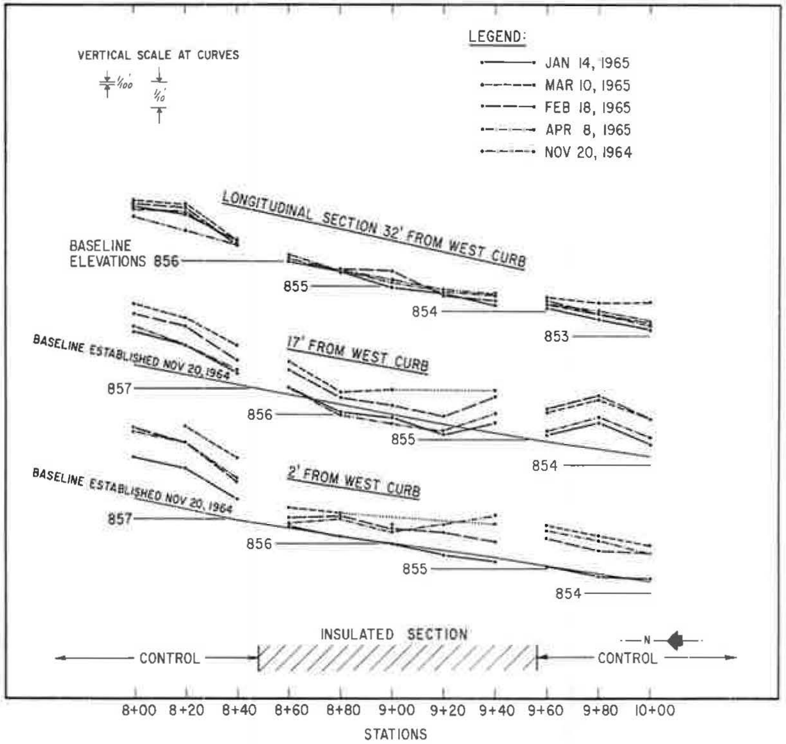

Figure 13. Frost heave measurements on Byng Street.

The heaving pattern was the same on Byng Street (Fig. 13). Heaving was greatest in the central areas beyond the ends of the insulated section and the onset of heaving in the insulated area was consistent with the time of frost penetration of the insulation and the underlying subbase. More heaving occurred on the east side, where drainage conditions were poor, than on the west side. Again, the average heave in the insulated section was about one-half of the heave in the control areas.

Prediction of Frost Penetration Depth

The variable material in the subgrade at both locations reduced the possibility of obtaining meaningful theoretical frost-depth predictions—even for the center of the road where one-dimensional heat flow might be anticipated. It is of interest, however, to compare the frost depth measured in the control section with the design curve for frost penetration obtained by the U. S. Army Corps of Engineers (7) from measurements

TABLE 3

ASSUMED PROPERTIES FOR FROST PENETRATION PREDICTION, ANTWERP STREET

Freezing Index, 1500 and 2600 degree-days F; Freeze Time, 126 days; Mean Annual Temperature, 37 F

Layer	Thickness, d (ft)	Water Content, w (%)	Density, γ_d (lb/cu ft)	Thermal Conductivity, k (BTU/ft-hr-deg F)	Volumetric Heat Capacity, c (BTU/cu ft-deg F)	Latent Heat of Fusion, L (BTU/cu ft)
Asphalt	0.29	0	143	0.84	30.4	0
"A" base	0.25	6.0	135	1.76	29.3	1160
"B" base	1.50	8.0	130	1.90	29.9	1490
Subgrade	—	22.7	102	1.05	34.7	3330

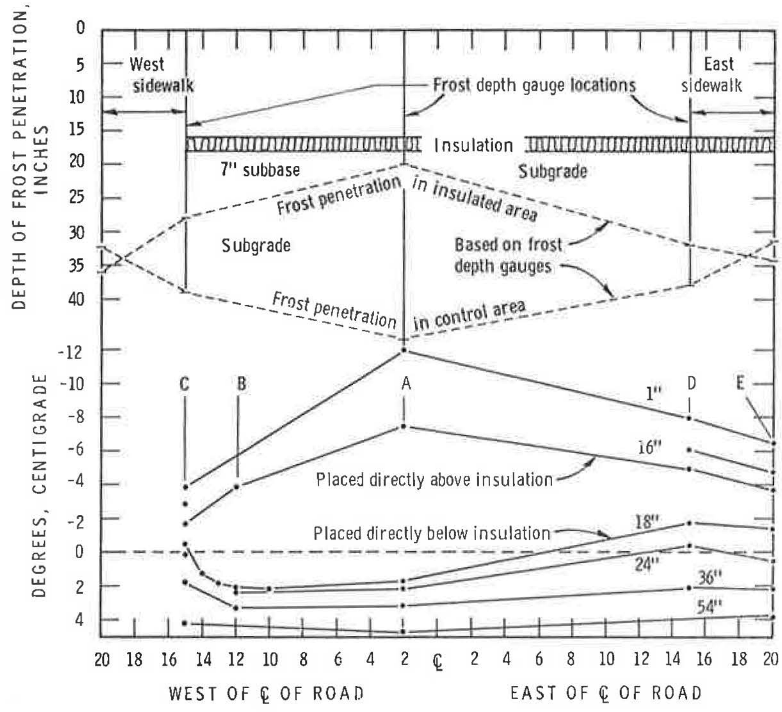

Figure 14. Cross-section of temperature pattern in insulated road section (5+41) and depth of frost penetration in insulated and control section, Antwerp Street, January 12, 1965.

in granular base courses beneath cleared airport runways and by the prediction based on the Modified Berggren Method.

For a 2600 degree-day freezing index (based on air temperature measurements on the Antwerp site) the design curve predicts 65 to 70 in. of frost penetration; the Modified Berggren Method predicts 81 in. (8). This compares favorably with the experimental value of 65 in. in the control area (2 ft west of centerline). For a 1500 degree-day freezing index the Modified Berggren Method predicts a frost penetration of some 63 in. The soil properties used in this calculation are given in Table 3.

Maximum frost penetration 2 ft west of centerline in the insulated area was 30 in. For this type of pavement, depth to insulation, and climatic conditions, 2 in. of this insulation attenuated frost penetration by some 35 in.

Soil Temperature Pattern and Edge Effects

A weekly temperature pattern was plotted for the control section (at Station 6+10) and the insulated section (Station 5+41) on Antwerp Street to follow the thermal changes in the ground. Figure 14 shows such a graph for January 12, 1965. The thermal pattern is not only influenced by the insulation but obviously also by snow-clearing practices. The east side of the roadway was also more shaded than the west side. These factors, in addition to the variability of the subgrade, ruled out the possibility of making meaningful comparisons between the thermal edge effects observed with theoretically computed values.

One anomaly was the earlier and deeper frost penetration of the insulation 15 ft east of center (location D) than at location B, 12 ft west of centerline. Figure 14 shows the temperature at 18 in. (directly below the insulation) to be above freezing at A (2 ft west of centerline) and at B (3 ft from the west edge of the insulation), but -1.8 C at D, which was 5 ft from the east edge of the insulation. Temperature distributions of this type persisted during the entire winter but were most marked during the period when the frostline was actively progressing downward. At the time of maximum frost penetration the frostline was 4 in. deeper at D than at A. This was not a temperature measurement error because the methylene blue frost-depth gages also showed a similar trend as can be observed from Figure 14. Based on temperature measurements, the period when freezing occurred beneath the insulation was about 130 days at D and only about 65 days at B.

During construction it was noted that the drainage was poor on the east side and, following a heavy rain during construction, the desired compaction was difficult to obtain. The poor compaction resulted in greater pavement deflections as will be shown later. The subbase and subgrade materials were sampled for moisture content immediately after thawing at locations A and D. The subbase at the center of the road had an average moisture content of 6 percent. At D the subbase was completely saturated, as water was seen to rise in boreholes above the depth of the insulation.

Because the thermal conductivity of soils increases with moisture content, the differences noted in the cooling rate between the center of the road and the east side might be attributed in part to the influence that moisture content has on heat conduction. It was deemed desirable, however, to inspect the insulation and to measure its moisture content and thermal conductivity. A 2-ft-wide trench was excavated from the centerline to the east edge of the insulation in early June and samples of the insulation were removed from the center and east side of the installation near the position of the thermocouples at Station 5+41. In the area where poor compaction was obtained beneath the insulation some of the panels had hairline cracks which were attributed to poor subgrade support.

Evaluation of Antwerp Street Insulation After Nine Months' Service

Two samples, approximately 14 in. square, were taken from two insulation panels near the center of the road (location A), and two more were taken between locations D and E which were in the "wet" zone. The samples were sealed in polyethylene bags for transportation and for the thermal tests.

Thermal conductivities were determined on a guarded hot plate apparatus 12 in. square at a mean temperature of 75 F and at a temperature difference of 40 deg.

The measured average K value of panels 1 and 2 near the center of the road was 0.23 (BTU-in.)/(sq ft/hr/deg F). The samples were then reversed with respect to hot and cold sides and the conductivity values were redetermined. The measured K was 0.23. Since stone indentations made a somewhat unsatisfactory thermal contact with the plate, the outside portions of the insulation were shaved off to leave a 1-in. thickness of insulation. This was oven-dried to constant weight and its K value in the dry state was determined to be 0.24. The moisture content of panel 1 was 22.8 percent by weight or 0.77 percent by volume. Its measured dry density was 2.1 lb/cu ft. The moisture content of panel 2 was 11.6 percent by weight, 0.43 percent by volume and its density was 2.28 lb/cu ft.

Panels 3 and 4 from the wet area (east side) had an average thermal conductivity of 0.25 before drying. The average moisture content of panel 3 was 4.7 percent by weight and 0.16 percent by volume when tested in the wet state. The center 1½-in. layer had a moisture content of 2.63 percent by weight (0.092 percent by volume). It is concluded that the unusual heat flow pattern observed on the east side of Antwerp Street was not due to any change in the thermal conductivity of the insulation.

Benkelman Beam Rebound Measurements

Deflection measurements by the Ontario Department of Highways were made 6 to 8 ft in from the curb at intervals on both the control and insulated sections under 9000-lb dual loads. The deflection for the particular section given in Table 4 is an average of five. This information is also shown in Figure 15.

The deflections were greater for the insulated sections at both locations. At Antwerp Street the greater deflections on the east side for both control and insulated areas are considered to be the result of poor subgrade support and inadequate drainage. On the west side the deflections of the insulated section were 0.005 to 0.010 in. greater than the deflections of the control section. The mean fall deflection of 0.035 in. is considered quite tolerable for this street. There was also an additional 6 in. of subbase on the west side.

At the Byng Street location the increased deflection of the insulated section is considered to be the result of two factors.

One, the pavement surface is 2 in. of asphaltic concrete. This relatively thin surface may not be adequate to distribute the loads to an acceptable amount at the depth of the insulation.

TABLE 4

AVERAGE BENKELMAN BEAM DEFLECTIONS, INCHES

Date	Antwerp Street				Byng Street			
	Insulated		Control		Insulated		Control	
	East	West	East	West	East	West	East	West
April 22, 1965	0.079	0.043	0.052	0.042	0.095	0.072	0.039	0.040
May 19, 1965	0.055	0.041	0.051	0.036	0.078	0.052	0.025	0.034
June 3, 1965	0.046	0.032	0.051	0.036	—	—	—	—
June 17, 1965	0.050	0.036	0.042	0.028	0.064	0.047	0.022	0.024
June 30, 1965	0.048	0.040	0.041	0.028	0.062	0.047	0.021	0.023
July 14, 1965	0.047	0.035	0.043	0.028	0.064	0.066	0.020	0.044
July 27, 1965	0.049	0.038	0.037	0.029	0.066	0.042	0.021	0.024
August 12, 1965	0.043	0.031	0.028	0.022	0.055	0.050	0.019	0.020
August 24, 1965	0.043	0.033	0.034	0.022	0.058	0.050	0.019	0.020

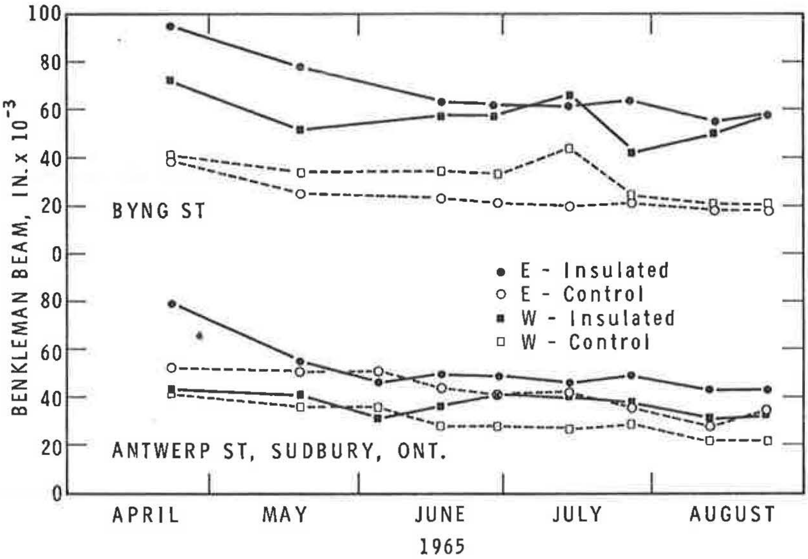

Figure 15. Benkelman beam deflections on Antwerp and Byng Streets.

Two, the frost penetration into the upper 9 in. of the subgrade soil has been slow enough to create a large amount of ice lensing (0.10-ft surface heave for 9 in. frost penetration, compared with 0.24-ft surface heave for 40 in. frost penetration into the subgrade in the control section, based on frost-depth gage measurements).

These ice layers subsequently released a large amount of moisture into the subgrade soil at the end of freezing which would lower the bearing capacity of the normally weak subgrade. Furthermore, the smaller slope on this street attenuated drainage of this excess moisture. This factor is considered to be the most significant and is most probably the cause of the large deflections of the insulated section on Byng Street.

Minimum rebound values in the fall of the year were estimated at 20 to 30 for the control sections at both streets. For the insulated sections, 40 and 50 are estimated for Antwerp and Byng Streets, respectively.

CONCLUSIONS

For the conditions at Sudbury, Ontario, 2 in. of the particular insulation used attenuated 35 in. of frost penetration during a winter when the air freezing index approached the design value. This insulating layer also reduced the amount of heave by one-half to two-thirds of that measured in an uninsulated pavement.

Poor drainage conditions at the east side of the installations caused greater frost penetration, large pavement deflections in the Benkelman beam test, and eliminated the possibility of obtaining meaningful results on thermal effects at the edge of the insulation.

The methylene-blue frost-depth gages are accurate in uninsulated sections. In insulated sections the gage predicts frost penetrations that are too large.

The thermal properties of the insulation were unaffected by 9 months' exposure to severe moisture conditions.

Benkelman beam deflection tests showed that the insulated sections had somewhat larger deflections. Where the asphaltic concrete surface was 3½ in. the deflections in the insulated section were 0.005 to 0.010 in. more than deflections of the control section. The estimated mean fall rebound values in the insulated area (0.040 to 0.050 in.) are considered tolerable. On Byng Street the large rebound values in the insulated section are considered a result of the relatively large amount of ice lens formation in the top of the subgrade and the thin (2 in.) asphaltic concrete surface.

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