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Experimental Pavement Structures Insulated with a Polyurethane and Extruded Polystyrene Foam

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Abstract

The purpose of insulating roads in areas of seasonal frost is to attenuate frost penetration and thus permit the design pavement thickness to be reduced. For satisfactory operation the requirements are that the insulating material must retain a high thermal resistance during the lifetime of the installation despite a varying moisture regime in the surrounding material. Also, it should not interfere significantly with the stability of the pavement structure either because of the flexible nature of the insulation or by creating an unfavourable water condition in the other components of the road bed. Early indications from actual use are that polystyrene insulation will meet these requirements.

Two 100-ft (32.8-m) sections of street were constructed in Sudbury, Ontario, Canada, in September 1964 using 2-by 4-ft by 2-in. (0.610-by 1.220-m by 5.08-cm) sheets of extruded polystyrene insulation in the pavement structure at a depth of 16 in. (0.406 m). During the first winter of operation (1964–1965) the air freezing index was 2 600 deg·day below 32°F (1 444 deg·day below 0°C). The maximum frost penetration was 65 in. (1.65 m) in the centre of the road in the control area, and 30 in. (0.76 m) in the insulated area, that is, the insulation attenuated frost penetration by 17.5 in. per inch (17.5 cm/cm) of insulation. Benkelman beam deflections were somewhat higher in the insulated areas but the amount of heaving was considerably retarded. In the summer of 1965 two additional insulated road sections were constructed in Ottawa, Ontario, Canada. Two types of insulation and methods were used. Extruded polystyrene boards were placed by hand (the same as at Sudbury) at the desired elevation. Polyurethane was foamed in place by spraying the chemicals on the road bed with a specially constructed self-propelled spraying machine.

This paper discusses the relative merits of the different methods of insulating roads and, in a broader context, the protection against freezing of underground utilities, such as water mains and sewers.

I. Introduction

The performance of pavement structures in regions of seasonal frost is dependent to a large extent on the ability of these structures to resist the detrimental effects of freezing and thawing. An undesirable feature resulting from frost action is the differential distortion of the road surface during the freezing period caused by ice lensing which reduces the riding quality of the road. Equally serious is the loss of subgrade support during and immediately after the thawing period.

It is also well known that surface deflection in flexible pavements due to traffic loads is at a maximum after thawing occurs and is at a minimum in the period preceding the next winter. This characteristic deflection rhythm is repeated each year although it is not well understood when no frost heaving occurs. When deflection is excessive, characteristic pavement cracking and surface deterioration result which emphasizes the destructive phenomena associated with seasonal freezing and thawing.

There is a trend toward thicker pavements in present highway design to accommodate heavier loads on a year-round basis. Complete snow removal and thicker granular bases cause deeper frost penetration. It would seem, therefore, that the reduction of frost penetration with a thermal barrier in the pavement structure is an approach worthy of study in road research. In some areas of Canada and the U.S.A. shortages of good granular material are developing and this has further stimulated the interest of designers in considering alternative methods of constructing roads in areas where cold winters are experienced.

Frost-susceptible subgrades in Norway have been protected from freezing and heaving by a high water-content organic layer above the subgrade. This has been used extensively in railway construction (Skaven-Haug, 1959) and to a lesser degree on roads. The use of mineral wool for preventing frost penetration in roads has been described (Rengmark, 1965). A small thermal study using cellular glass was reported by Quin and Lobacz (1962). Several full-scale road installations using factory-produced boards of extruded polystyrene foam have been reported (Oosterbaan and Leonards, 1965; Young, 1965; Penner *et al.*, 1966).

The use of insulation in a permanent road structure requires that the insulating material has a predictable thermal and structural performance for the lifetime expectancy of the road. Loss of thermal performance, which may occur either by moisture absorption, physical crushing, or other deterioration, cannot be tolerated. Such insulating layers are partial moisture barriers and may cause unfavourable moisture accumulations which can result in excessive deflections in the road. Further, the flexibility of the insulation itself should not induce undesirable pavement deflections due to traffic loads. Experiments using extruded polystyrene foam as a thermal barrier are showing promising results although most installations have only had a few years of service.

There are several aspects of both street and highway design where the use of an insulating layer appears practicable. In the first place, the desirability of decreasing frost penetration with a thermal barrier arises where the design pavement thickness based strictly on the load-carrying capacity is less than the thickness required to prevent frost penetration into the subgrade and subsequent frost heaving. Secondly, an insulating layer may provide thermal protection to structures such as culverts in rural areas, and water and sewer mains in urban areas. Thirdly, insulation may prove to be useful in remedial construction of sections of roads which have heaved excessively owing to unsatisfactory subgrade conditions.

It is now standard practice in some areas of Canada to install an insulating layer under structures such as curling rinks, skating rinks, and cold storage buildings in order to prevent destructive heaving. Where poor subgrade conditions exist in the freezing zone it is usually more economical to use insulation than to use deep excavations and non-frost-susceptible backfill.

Alternatives to the use of factory-produced insulation boards are now also being studied in order to arrive at the most economical method of installation. One alternative technique involves spraying the basic constituents on the prepared subgrade and allowing the material to foam and cure in place. Polyurethane rigid insulation has been produced in this way. Although the placement method has obvious advantages, the first installation has not been completely successful.

II. Installation at Sudbury, Ontario

The Division of Building Research, National Research Council installed a 100-ft section of insulated pavements on two suburban streets in Sudbury, Ontario during the summer of 1964 in co-operation with Dow Chemical of Canada Ltd. and the City of Sudbury. The insulation used was extruded polystyrene foam boards 2 by 4 ft by 2 in. (0.61 by 1.22 m by 5.08 cm) produced by Dow Chemical of Canada Ltd. The insulation was hand placed on specially prepared subgrades during reconstruction of the streets. The pavement design used in the insulated section on the Antwerp Street site is shown in Fig. 1. The design of the adjacent control area, which is standard for the City of Sudbury, consisted of 3−1/2 in. (8.9 cm) asphaltic concrete, 3 in. (7.62 cm) of selected base course and 18 in. (0.46 m) of subbase. Figure 2 shows a view during construction of the insulated section on Antwerp Street.

The performance of the street in Sudbury containing a thermal barrier was assessed on the basis of the thermal changes below the insulating layer, amount of frost heave, and pavement deflection characteristics as measured with the Benkelman beam. All

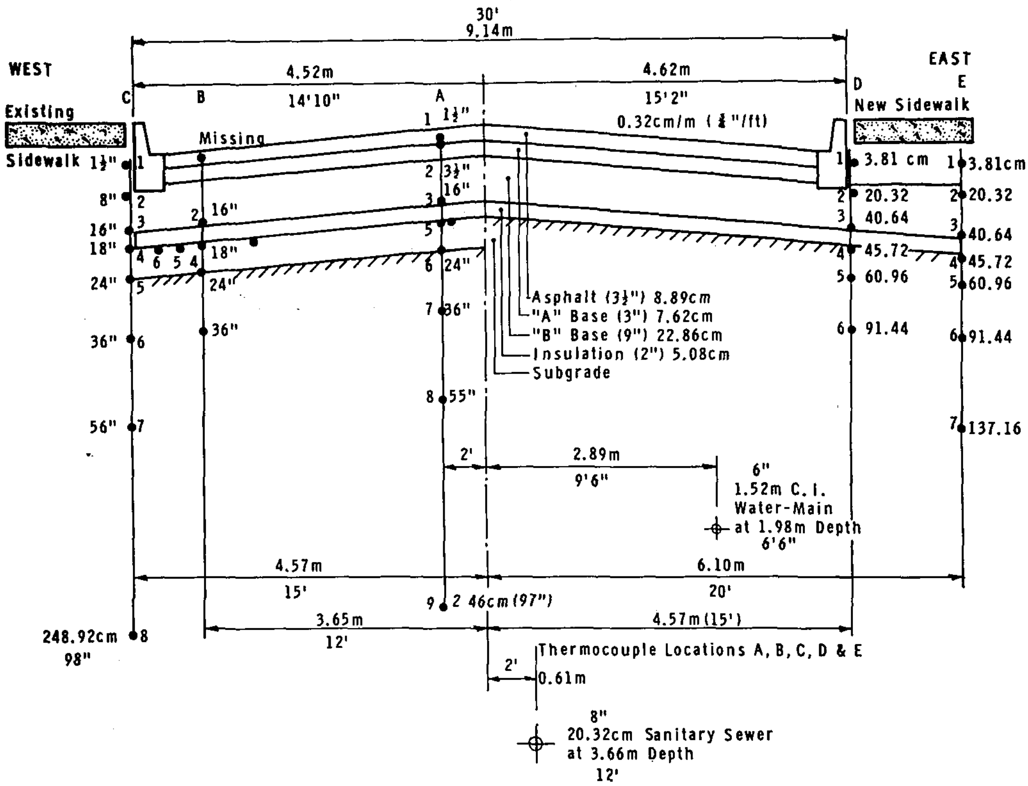

Fig. 1. Pavement design and thermocouple locations of insulated section at Station 5+41, Antwerp St., Sudbury, Ontario, Canada

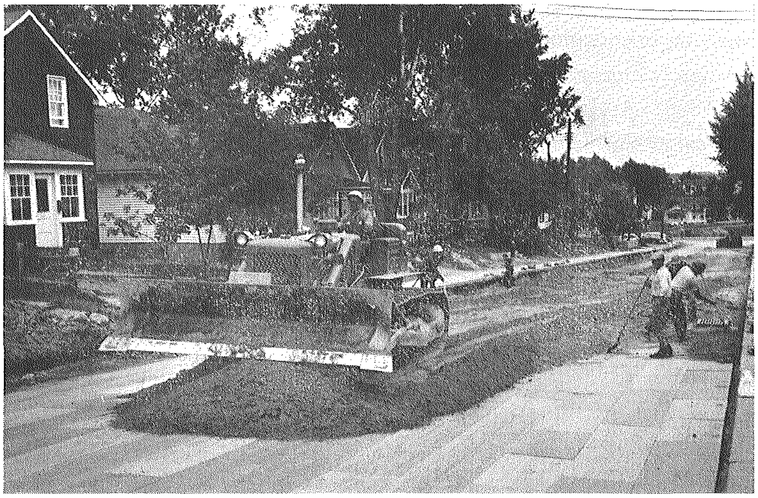

Fig. 2. Placing subbase on extruded polystyrene foam insulation, Sudbury

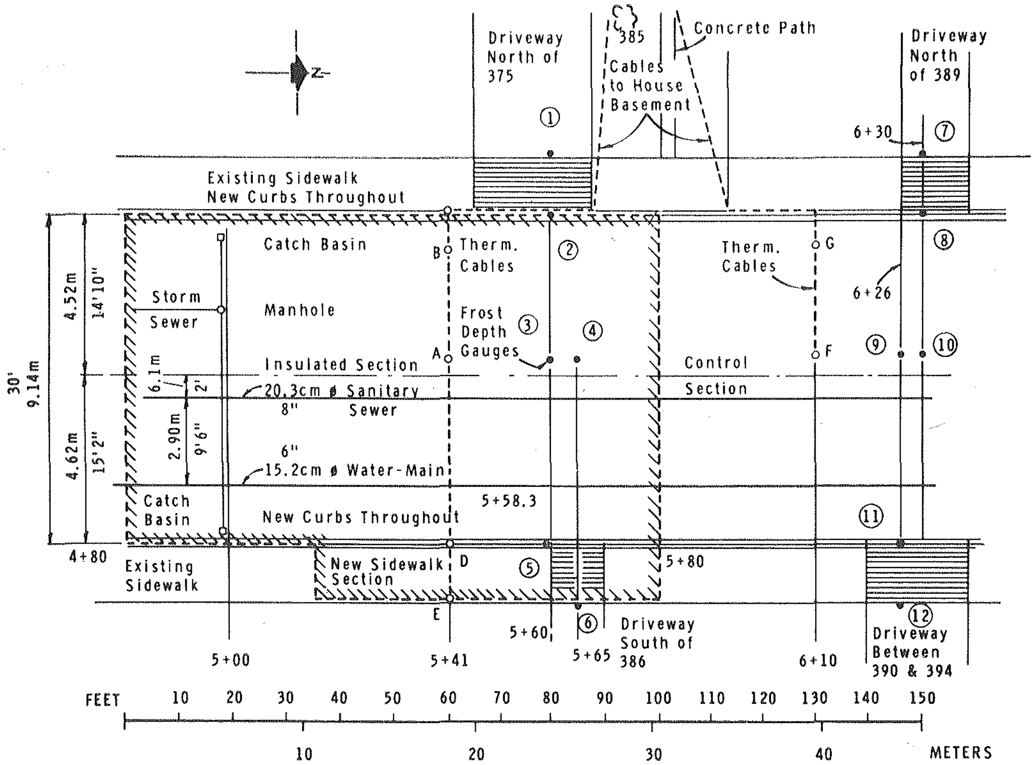

Fig. 3. Plan of insulated and control sections on Antwerp St. with locations of thermocouples and frost depth guages

were compared with the adjacent control sections. The Antwerp Street site was instrumented with thermocuples and methylene-blue frost depth gauges as shown in the plan view in Fig. 3. Soil exploration studies revealed a variety of subgrade materials but all were highly frost-susceptible.

Figure 4 shows a comparison between the frost line attenuation in the centre of the insulated section based on the 32°F (0°C) isotherm and that of a similar position in the uninsulated area. During the winter of 1964/65 the freezing index* was 2 600 deg·day below 32°F (1 444 deg·day below 0°C) and under these conditions the reduction in frost penetration was 35 in. (0.89 m) for this particular subgrade. The amount of heave that occurred as the winter progressed is shown in Fig. 5 for various locations on the Antwerp Street experimental site. Only a small amount of heaving occurred in the insulated area, but, as expected, considerable heaving took place at both edges of insulation. The extreme heave at the east side resulted from poor drainage conditions which were known to exist.

Benkelman beam rebound measurements under 18 000-lb (8 172-kg) single-axle loads were made by the Ontario Department of Highways during the spring and summer of 1965. Each value plotted in Fig. 6 for a given date is the average of five measurements along the insulated or control areas. The rebound values are also shown for the other site in Sudbury (Byng Street) where apparently excessive rebound occurred over the insulated area. The values measured on Antwerp Street are considered to be acceptable. The differences between the east and west side are consistent with the frost heave results. Neither insulated street section has shown any sign of distress and the minimum fall rebound values, shown in Fig. 6, are not considered excessive.

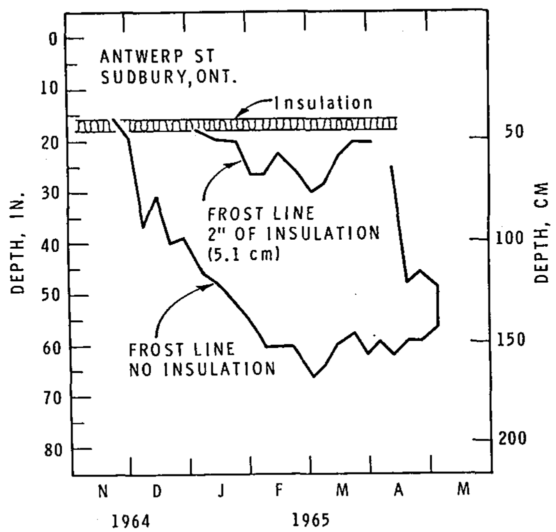

Fig. 4. Reduction in frost penetration with 2 in. of extruded polystyrene insulation

* *Freezing index* as used in North America is the summation of the difference between 32°F (1 deg·day below 32°F is equivalent to 5/9 deg·day below 0°C) and the average daily temperature for the winter period.

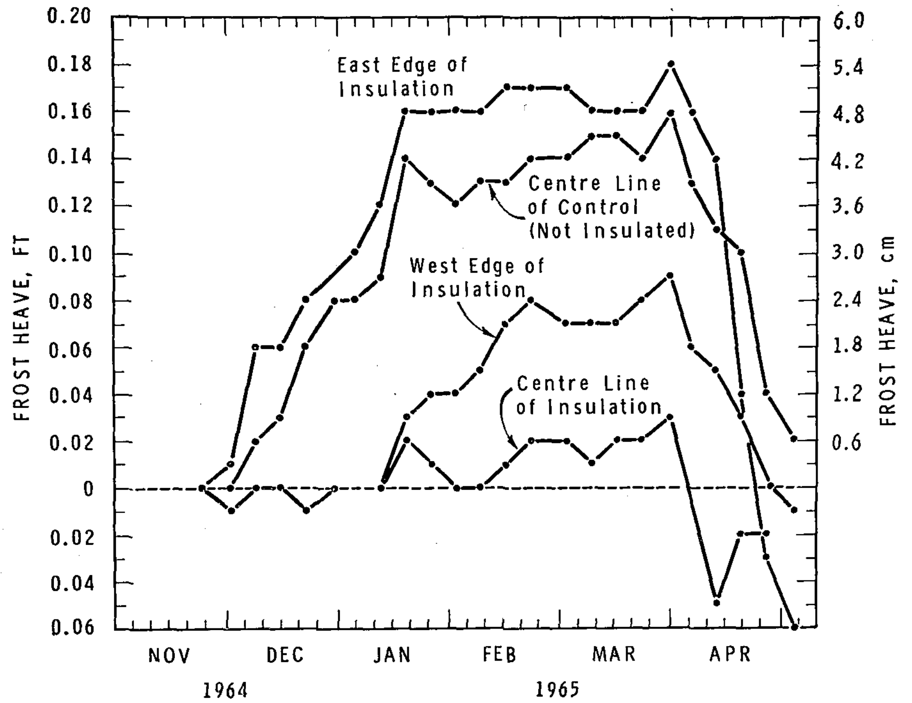

Fig. 5. Heave-time relationships at selected locations on Antwerp St. experimental site

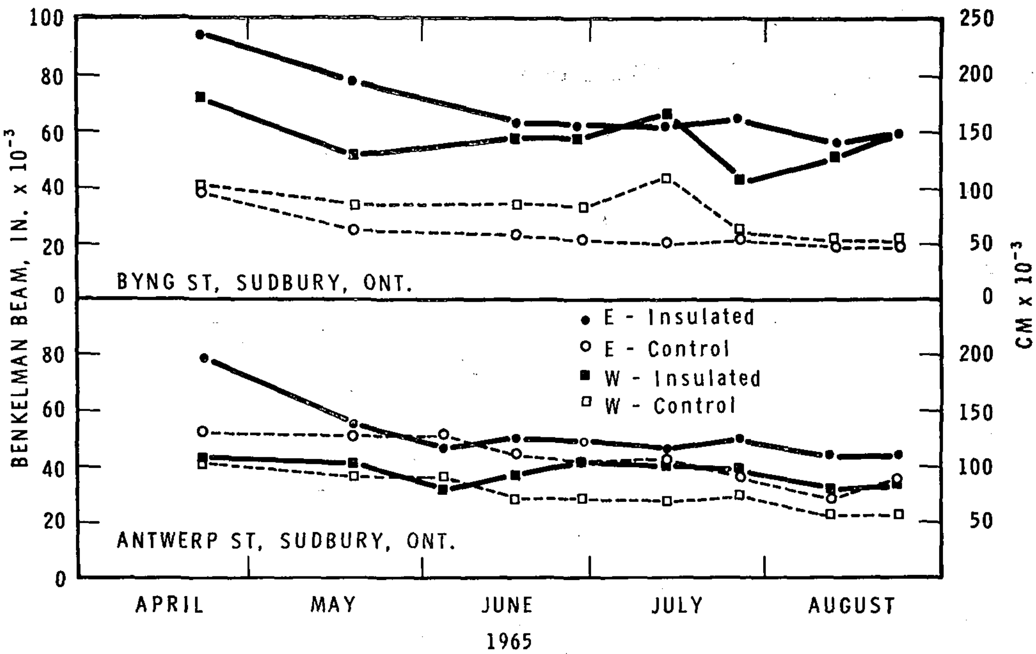

Fig. 6. Benkelman beam deflections on Antwerp and Byng Streets

III. Installation at Ottawa, Ontario

Two experimental road sections on the property of the National Research Council, Montreal Road, Ottawa were insulated with two kinds of insulation during the summer of 1965. Only one experimental section is described in this paper. The pavement design used on the insulated areas, for which performance results are given, is shown in Fig. 7. The control section consisted of 3 in. (7.62 cm) of asphaltic concrete and 9 in. (22.86 cm) of good quality base course on a silty clay subgrade. The insulated sections were each 50 ft (15.25 m) long with a 50-ft (15.25-m) control section in between.

On one section, extruded polystyrene foam boards 2 ft by 4 ft by 2 in. (0.61 m by 1.22 m by 5.08 cm) were placed by hand on the fine-graded subgrade. On the other section, polyurethane was placed by foaming the insulation on the subgrade with a self-

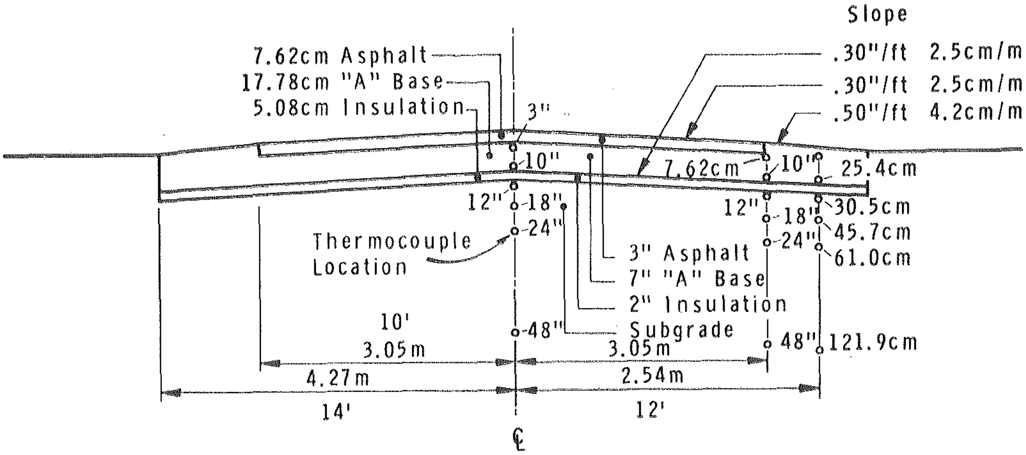

Fig. 7. Pavement design and thermocouple locations for insulated sections at the Ottawa site

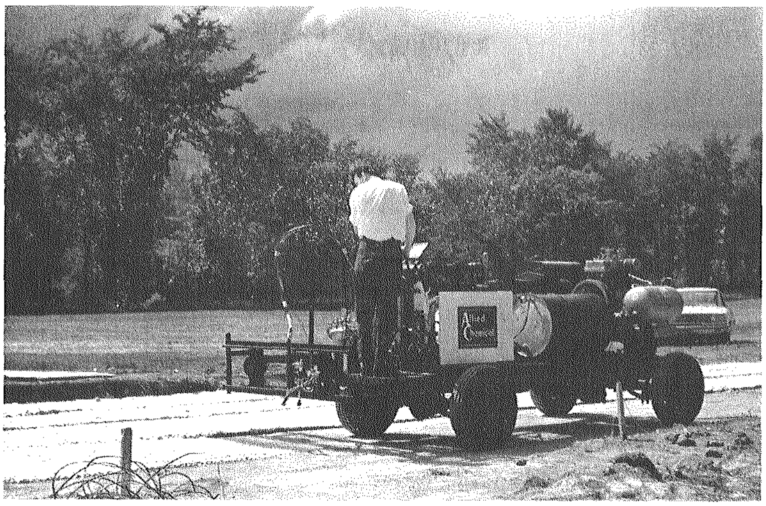

Fig. 8. Self-propelled foaming machine in operation

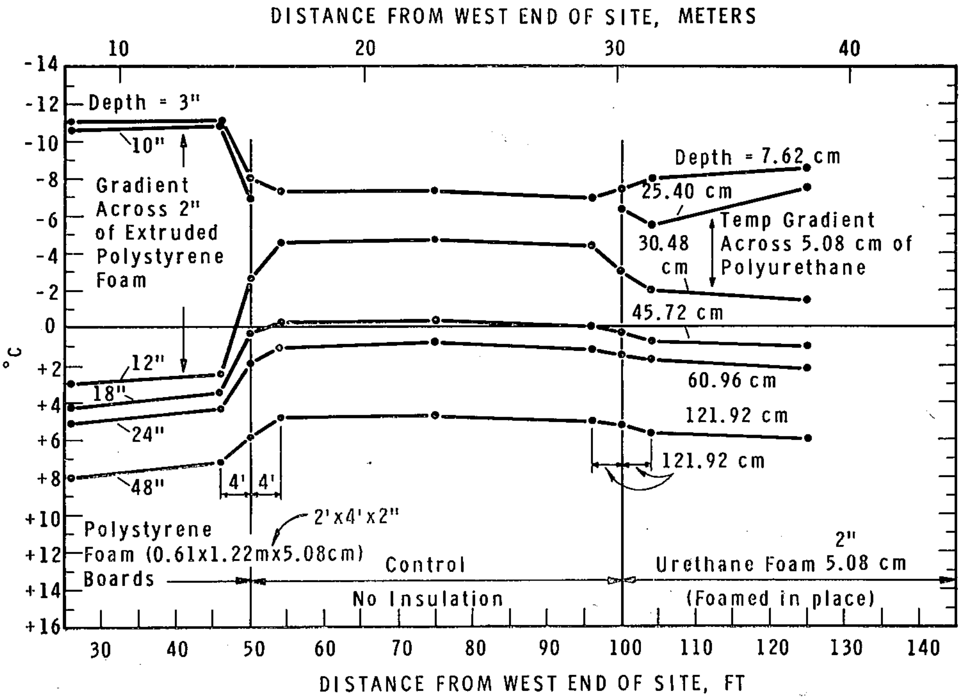

Fig. 9. Temperature profiles in longitudinal section on centre line of snow-cleared experimental road, Ottawa, 28 December, 1966

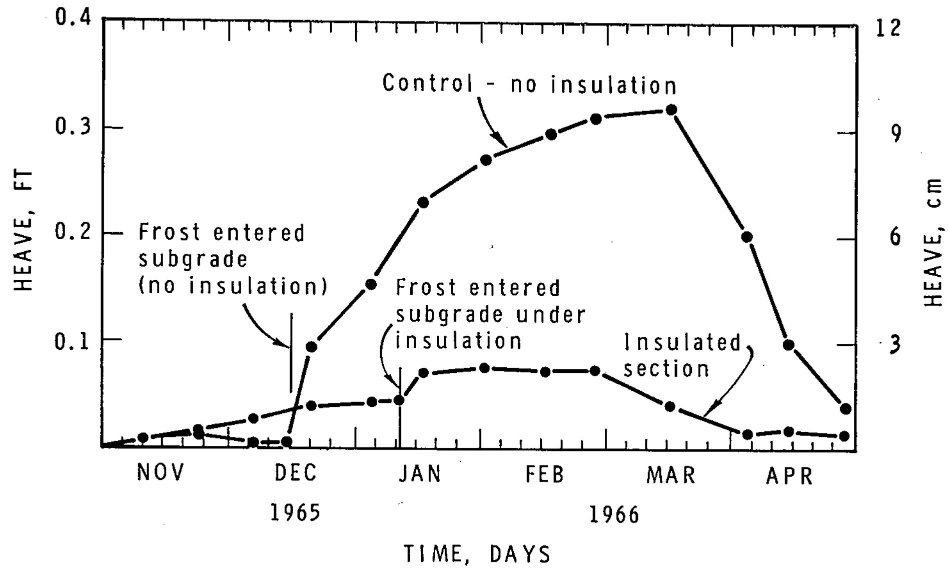

Fig. 10. Frost heave vs. time on centre line of snow-cleared test area, Ottawa

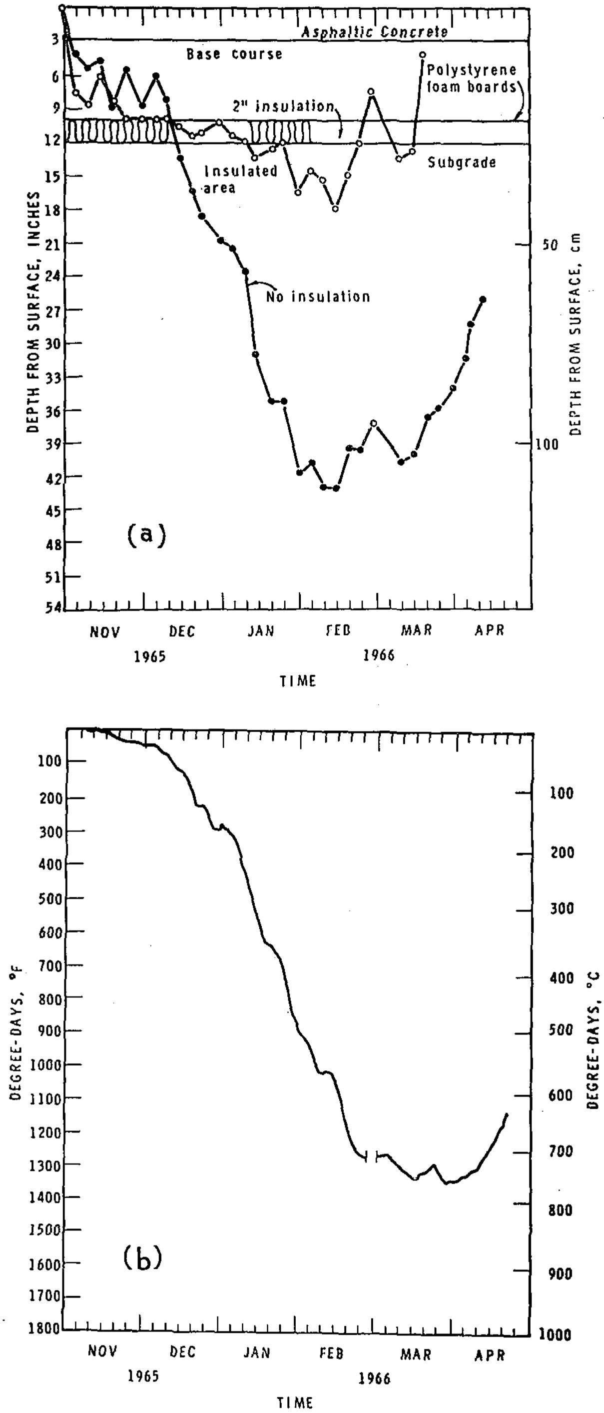

Fig. 11. (a) Frost penetration on centre line of snow-cleared road, 1965, Ottawa

(b) Deg-day curve, 1965–66, Ottawa (basis °F) propelled machine constructed and operated by Allied Chemical Canada Ltd., for the particular experiment described. Barrels containing the chemicals were mounted directly on the machine. One barrel contained a premix of the resin, the catalysts, the emulsifier and blowing agent; the other barrel contained the diisocyanate. The chemicals were metered in a predetermined ratio to a mixing nozzle and then sprayed as a liquid on the subgrade by a 4-ft (1.22-m) traversing jig. Foam rise (average 2 in. (5.08 cm)) was complete in seconds and in a few minutes the foam was sufficiently rigid to carry the weight of a man. A view of the machine in operation is shown in Fig. 8. The machine travelled at 3 to 5 ft (0.91 to 1.52 m) a minute and operated satisfactorily during the experimental installations for which it was intended.

As will be shown later the required foam quality was not achieved because soil particles were incorporated during the blowing process. A further installation is planned for 1966 where this difficulty will be overcome. The method, however, is sufficiently unique and promising to warrant brief description in this paper.

If good quality urethane can be shown to perform satisfactorily thermally and structurally, this method of placement has obvious advantages of versatility for various kinds of installations, such as over water and sewer mains, around buried structures such as culverts, manholes and catch basins. A further advantage of foaming the insulation on the site involves the lower costs in shipping the basic chemicals to the site as compared with the cost of shipping manufactured insulation.

Temperature profiles for a particular day (28 December, 1965) are shown in Fig. 9 at the centre line of the road for both types of insulation and the uninsulated control area. The superiority of the *in situ* quality of the polystyrene foam boards (left side) is clearly demonstrated.

Figure 10 shows the small amount of frost heave at the centre line of the polystyrene foam section as compared with the control section which heaved about 3.5 in. (8.9 cm). All areas, as in Sudbury, were kept free of snow. The snow around the perimeter, however, modified the thermal picture to some extent at the edges.

Frost line penetration is shown in Fig. 11 together with the degree-day curve. Frost penetration of the subgrade was retarded by a month by using insulation (see also Fig. 4). The maximum frost penetration by 15 February, 1966 was 43–1/2 in. (1.1 m) in the control area as opposed to 18 in. (45.7 m) in the insulated area which gives a frostline attenuation of about 13 in. per inch (13 cm per cm) of insulation.

IV. Discussion

During the spring of 1965 several sections of the insulation installed the previous September at Sudbury were removed by excavation, in order to undertake thermal conductivity (K) and moisture absorption measurements. The K values of these samples, which had been buried for some 9 months, ranged from 0.23 (Btu in.)/(ft^2/hr/deg F) to 0.25 (0.29 to 0.31 cal/hr·cm·deg C) which was the same as for the original material. Moisture contents by volume were 0.77, 0.43 and 0.16%. In one test, the 2-in. (5.08-cm) board had a moisture content of 0.16% but when the outside 1/4 in. (0.635 cm) of material was removed from each face, the centre $1^1/_2$-in. (3.81 cm) thickness had only 0.092%

Fig. 12. Snow remains on insulated surface as evidence that after a cold period, surface temperatures on insulated area are colder than on non-insulated area

moisture which shows greater moisture concentrations in the surface layers. It was concluded that the 9 months of exposure to the high moisture regime of the road had not affected the insulating properties of extruded polystyrene foam boards. Visual examination showed no physical deterioration of the boards under traffic loads but some small stone indentations were observed.

Insulation in the pavement structure causes rapid cooling in the layers above the insulation at the onset of the winter period. This is caused by the reduced heat flow from the underlying soil. A photograph was taken of the experimental sections after a light snowfall at the Ottawa site (Fig. 12). The road section in the foreground, covered with snow, is underlain with extruded polystyrene foam at a depth of 10 in. (25.4 cm), the area adjacent with no snow is not insulated and the area next to the parking lot with patches of snow was underlain by polyurethane. The possibility of surface icing similar to that experienced on exposed bridge decks should not be overlooked.

Aspects of economy and design

It is recognized that the long-term behaviour (structurally and thermally) of polystyrene insulation in the pavement structure has still not been established, but these short-term experiments suggest the method shows promise. Assuming satisfactory behaviour, its general use in road building will depend on savings in subgrade excavation and granular subbase as compared with the cost of the installed insulation. Obviously this will depend on the design of the pavement structure, the nature of the subgrade, and availability of materials in any particular area. Numerous short sections have been built already or are planned as a remedial measure on an experimental basis but as yet no fullscale road construction using insulation has been proposed.

Structural stability of the insulation after many years of flexing is not known and its influence on the breakdown of the closed cell system needs to be established. A further question is the proper design depth in relation to the climate at which the insulation should be placed and the thickness required. There is also the suggestion that some frost penetration of the subgrade may be permissible without losing stability in the asphaltic concrete surfacing. The experiments described herein and in the literature indicate that some penetration may not be harmful.

In these studies the insulation thickness was determined by reference to the expected freezing index for the area. It is hoped that design values can be predicted after the present installations have been in service for a longer period.

Acknowledgments

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References

1) OOSTERBAAN, M. D. and LEONARDS, G. A. 1965 Use of insulating layer to attenuate frost action in highway pavements. *Highway Research Record*, No. **101**, 11–27.
2) PENNER, E., OOSTERBAAN, M. D. and RODMAN, R. W. 1966 Performance of city pavement structures containing foamed plastic insulation. *Highway Research Record*, No. **128**, 1–17.
3) QUIN, W. F. and LOBACZ, E. F. 1962 Frost penetration beneath concrete slabs maintained free of snow and ice, with and without insulation. *Highway Research Board Bull.*, Nat. Acad. Sci. N.R.C., Washington, D. C., **331**, 98–115.
4) RENGMARK, F. 1965 Use of mineral wool for preventing frost penetration in roads. Proc. Sixth International Conf. on Soil Mechanics and Foundation Engineering, **2**, 179–183.
5) SKAVEN-HAUG, SV. 1959 Protection against frost heaving on the Norwegian railroads. *Géotechnique*, **IX**, No. 3, 87–106.
6) YOUNG, F. D. 1965 Experimental foamed plastic base course. *Highway Research Record*, No. **101**, 1–10.