INDIANA'S THERMALLY INSULATED TEST ROAD

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Data presented show that small thicknesses of foam plastic insulation prevented frost penetration into a highway subgrade in an area where the freezing index is less than 1,000 deg days. The data were obtained from a test road (flexible pavement) that was built in northern Indiana and consisted of a control (normal) section with no insulation, a normal section with 1 in. of insulation, and a normal section with the 6-in. subbase eliminated and $1\frac{1}{2}$ in. of insulation added. In the analysis of the 5-variable subsurface temperature problem, 3 of the 4 independent variables—3-dimensional subspace and time—were held constant while the effect on temperature of the fourth was examined. In addition, limited data on differential surface icing of adjacent insulated and uninsulated sections indicate that insulated pavements are colder during a seasonal cooling and uninsulated pavements are colder during a seasonal warming. The overall performance of the insulated sections is satisfactory after 3 winters of service.

•FOAM PLASTIC has become an effective means of preventing frost penetration into a highway subgrade. A number of installations (1) have been built in various northern states of the United Stated and in Canada where winters are very severe. In 1969, the effects of subgrade insulation in a more moderate climate were studied in an insulated test road that was built in north-central Indiana, where the freezing index is generally less than 1,000 deg days. The road was instrumented, and 2 years of data have been collected. This paper summarizes the performance of the road.

LOCATION AND DESIGN

The test installation is on Ind-26, approximately 13 miles east of Lafayette and just west of the Rossville town limits.

A finite difference solution of the 2-dimensional heat flow model developed at Purdue (3) was used in the design of the test installation. That method of design allowed possible design combinations to be easily checked by subjecting them to actual design-year conditions. The design year was the 1962-63 winter, the coldest of the preceding 10 winters, having a freezing index of 1,274 deg days.

Plan and profile views of the test sections are shown in Figure 1 and Figure 2 respectively. Section C is the normal (control) design section. Section A is the same as section C except for a 1-in. thick, 34-ft wide layer of insulation placed on the subgrade surface. The subbase was eliminated in section B, and a 1.5-in. thick, 46-ft wide layer of insulation was placed directly beneath the base course. The temperature sensors, thermistors, were located at the center of each 2,000-ft long section. The thermistors were installed only in the north half of the highway. Figures 3, 4, and 5 show the thermistor positions in sections A, B, and C respectively.

SITE CONDITIONS

Soil borings were located on the northern half of the highway at stations where the thermistors were placed. Also, soil samples were obtained at the time of thermistor

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Figure 1. Plan of test road.

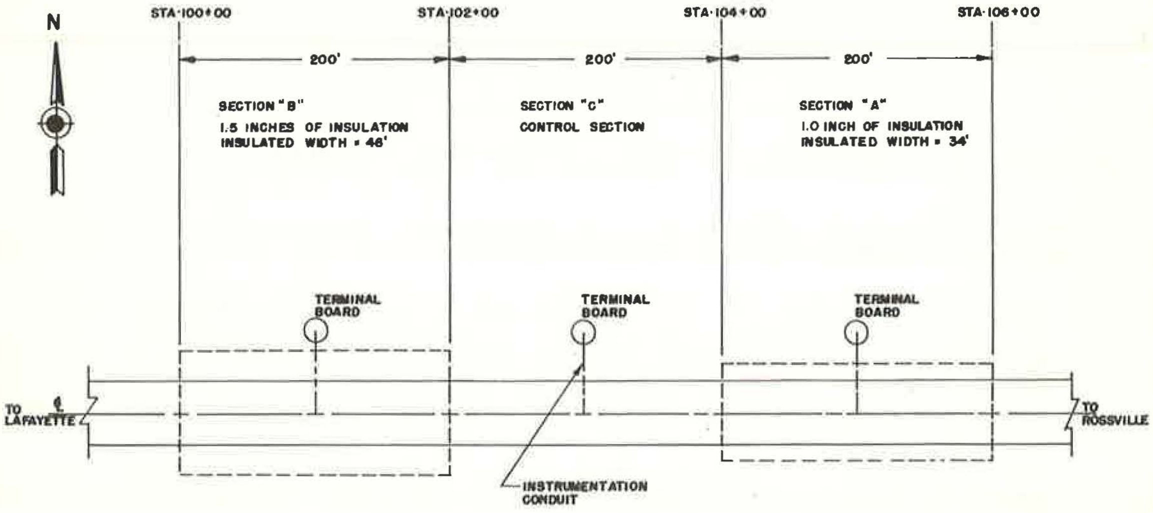


Figure 2. Profile of test road.

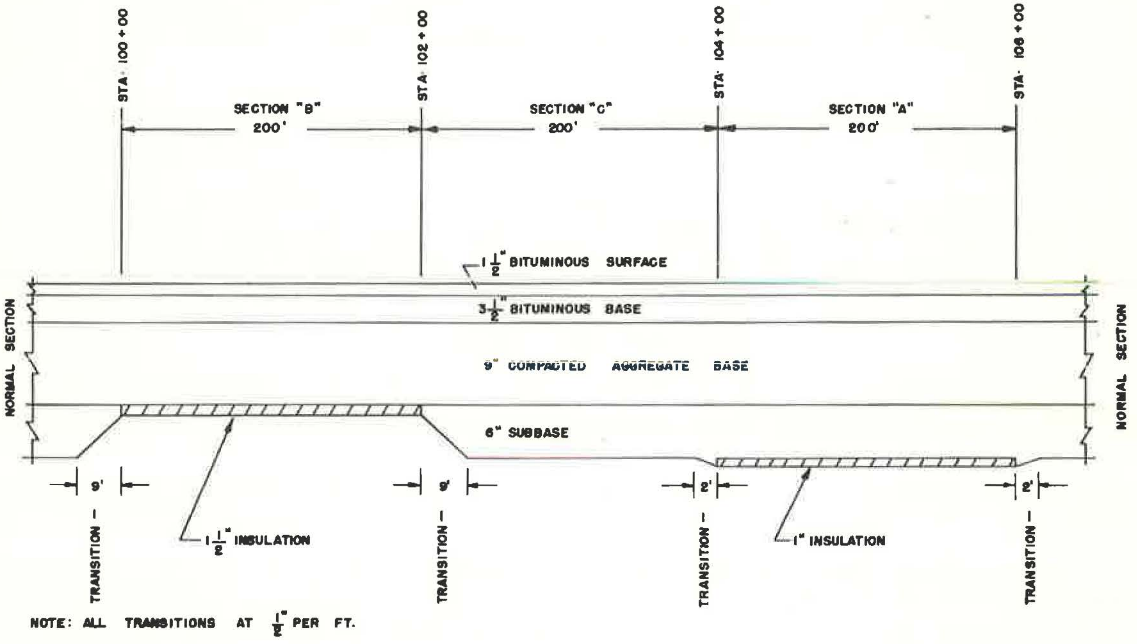


Figure 3. Section A instrumentation.

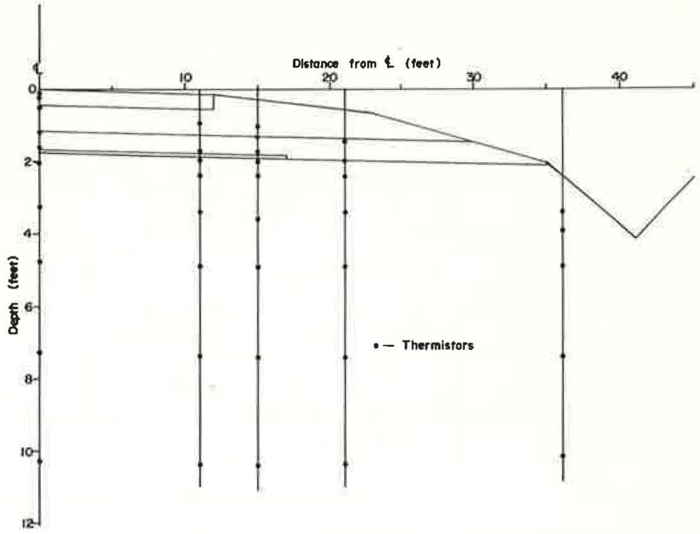


Figure 4. Section B instrumentation.

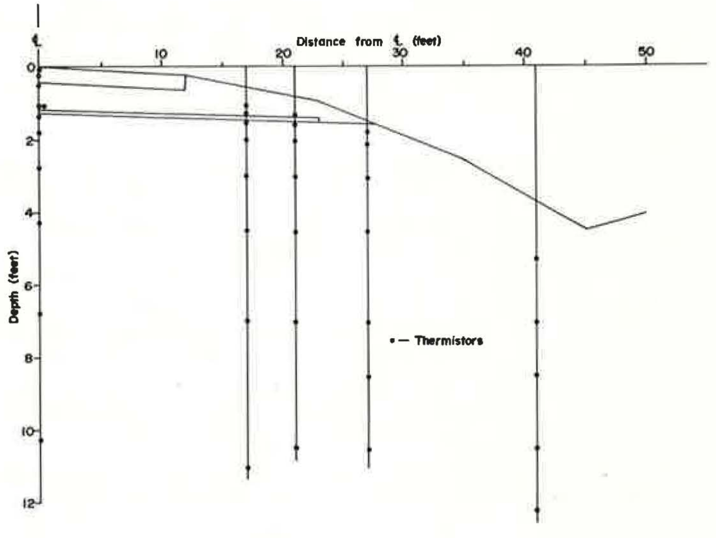
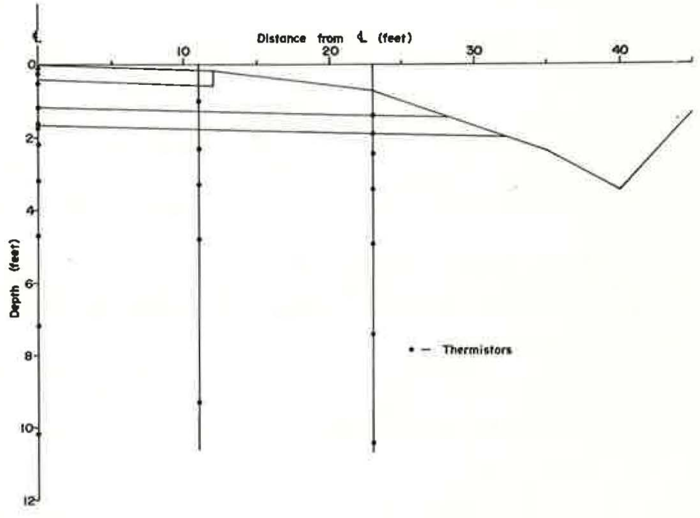


Figure 5. Section C instrumentation.



installation from the sides of the 4-ft deep installation trench. From those investigations, the soil profile and moisture conditions were determined.

The subgrade soils of section A are 4 ft of AASHO classification A-2-4 soil over more than 8 ft of A-1-b soil. The water contents of the soils were about 5 to 6 percent. The water table in section A was about 14 ft below the pavement surface. The borings in section A were the only borings in which the water table was encountered. The borings in each section were 11 to 15 ft deep. Section b soils consist of 1 ft of A-2-4 soil over 3.5 ft of A-4 soil over A-6 soil. The water contents were 5, 13, and 17 percent respectively. Section C soils generally consist of 1.5 ft of A-2-4 soil over A-1-b soil. An additional layer of A-1-a soil about 6 in. thick is located 2 ft below the top of the subgrade. Section C water contents were from 5 to 7 percent.

The site was in an area of generally silty soils and was placed in a cut rather than a fill to increase the wetness. Unfortunately, neither soil nor water conditions were such to produce hoped-for high-frost-damage potential. In spite of that, nearly all of the objectives of the study were realized.

PERFORMANCE EVALUATION

Personnel of the Indiana State Highway Commission Research and Training Center collected data at the test installation during the 1969-70 and 1971-72 winters. First-year data were collected every working day. When we found that lesser amounts of data could adequately define the trends, we collected 1971-72 data twice a week except when sudden or extreme periods of cold dictated that additional data were required. The freezing indexes of the 1969-70 and 1971-72 winters were low: 673 deg days during a freezing season of 65 days and 355 deg days during a freezing season of 52 days respectively.

The analysis of subsurface thermal patterns is a 5-variable problem. Temperature is the dependent variable with time and with the 3-dimensional subsurface space. The analysis was conducted by holding 3 of the independent variables constant and studying the effect on temperature of the fourth.

Figures 6 and 7 show a comparison of temperatures at points below the insulation in sections A and B with temperatures at points at approximately the same depth in section C. The effect of the insulation is clearly shown in Figure 6. Section B, having the thicker insulation, remains the warmest of the 3 sections throughout the freezing season. However, care must be exercised when the sections shown in Figure 7 are compared. The combined effect of different thicknesses of insulation and different depths of points makes direct comparison difficult. Comparison of different depths was dictated by the loss of some instrumentation during the 3 years of service. If it is assumed that there is a vertical thermal gradient, i. e., no temperature change, from the depth of the point observed in section B to the same depth as observed in section C, then section B subgrade is warmer. The effect of the insulation is also shown in Figure 8, where the temperature above and below the insulation in section A is compared. The 1-in. insulation was enough to allow the subgrade to remain unfrozen while the temperature directly above the insulation was as low as 17 F.

Figures 9, 10, and 11 show isotherms for each of the 3 sections for January 20, 1970, approximately the time of maximum frost penetration in the control section during the 1969-70 winter. For the uninsulated section, the isotherms are approximately parallel to the ground surface, which is intuitively expected when there is slight lateral variation of soil properties and no snow cover. In sections A and B, the insulation modified both the shape and the magnitude of the isotherm at a given depth. The effect is greater for section B.

Temperature gradients (temperature versus depth curves) are shown in Figure 12 for January 22, 1970. Section B, besides having the warmest subgrade temperatures, has the coldest pavement temperatures. This effect will be discussed in more detail later in the paper.

The depth of penetration of the 32-deg isotherm in section C for the 1969-70 freezing season is shown in Figure 13. Although the penetration was to a depth of 4 ft in section C, the 32-deg isotherm did not penetrate the insulation in either section A or section B.

Figure 6. Temperatures below insulation from Nov. 1969 to March 1970.

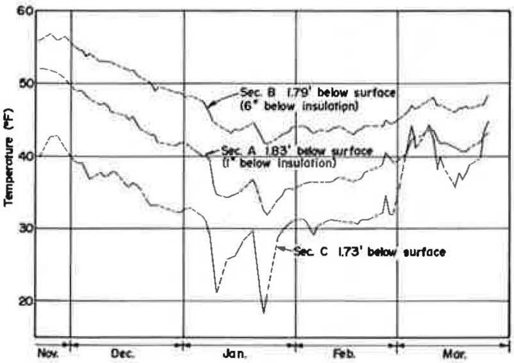


Figure 7. Temperatures below insulation from Nov. 1971 to March 1972.

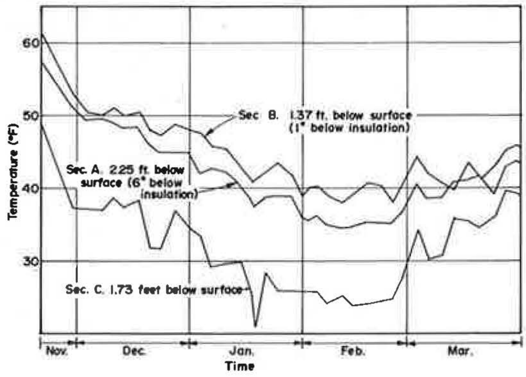


Figure 8. Temperatures above and below insulation from Nov. 1971 to March 1972.

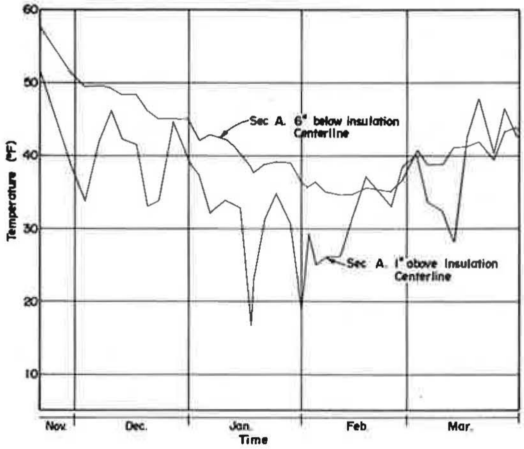
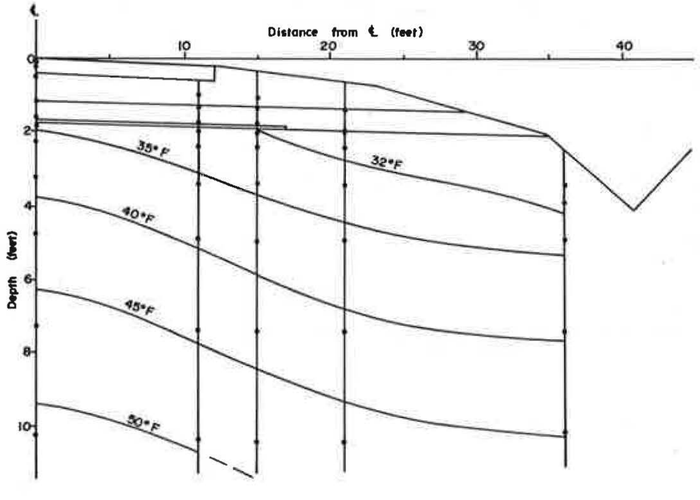


Figure 9. Section A isotherms for Jan. 20, 1970.



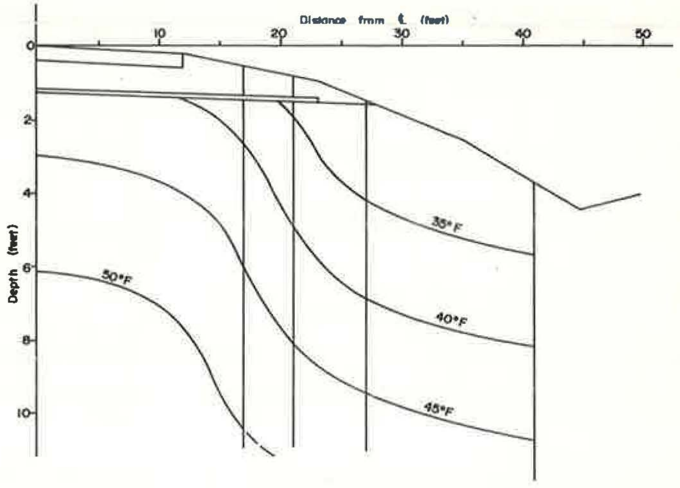


Figure 10. Section B isotherms for Jan. 20, 1970.

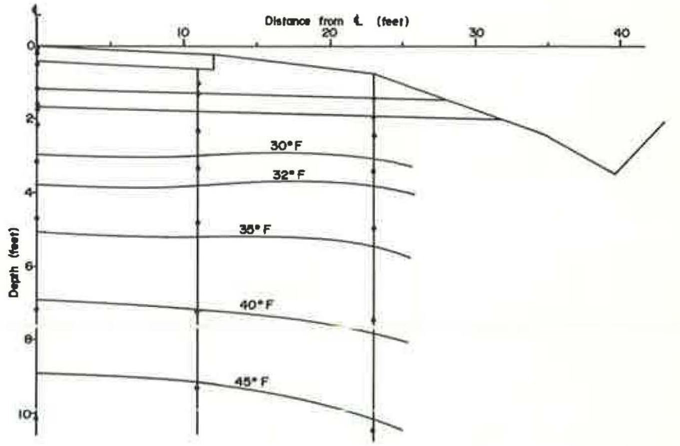


Figure 11. Section C isotherms for Jan. 20, 1970.

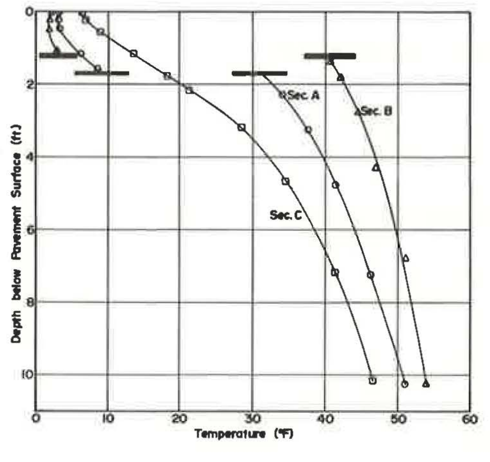


Figure 12. Centerline temperature gradients for Jan. 22, 1970.

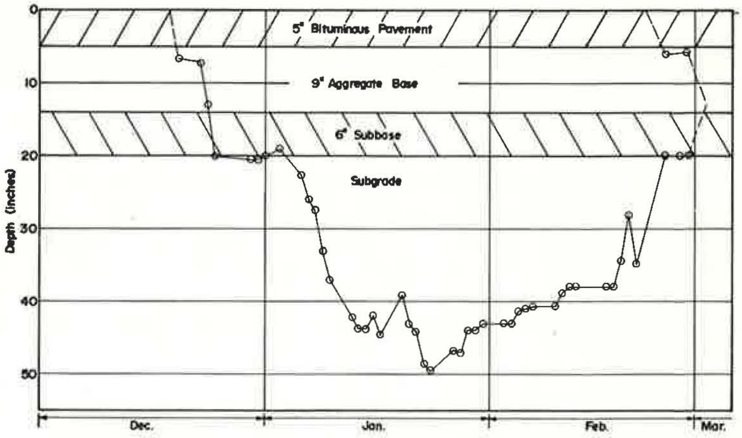


Figure 13. Penetration of 32-deg isotherm into uninsulated section during 1969-70 winter.

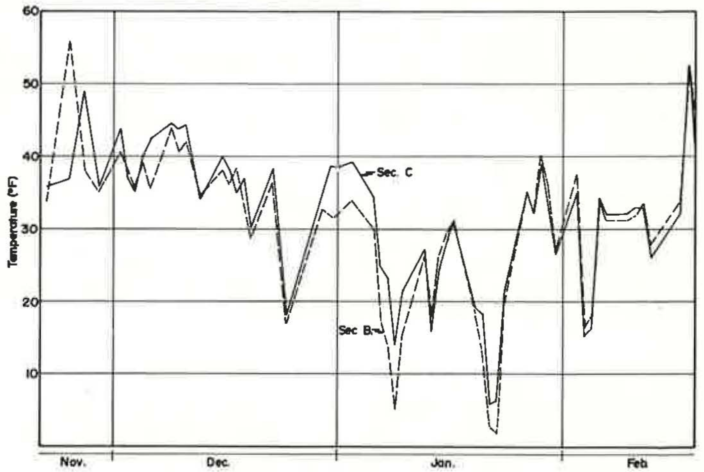


Figure 14. Temperature 1 in. below pavement surface from Nov. 1969 to Feb. 1970.

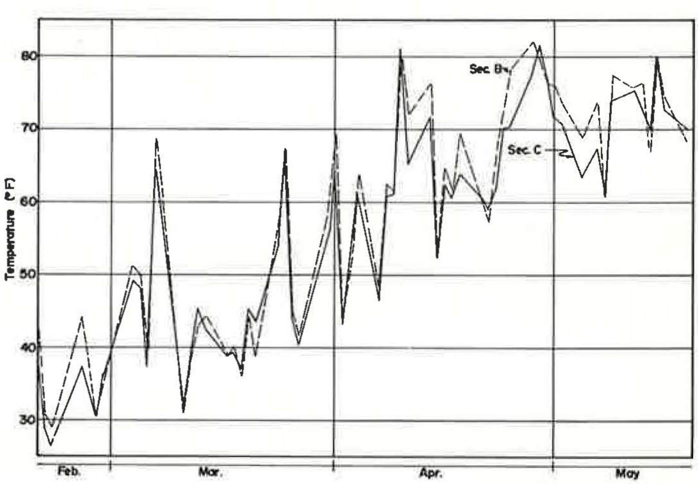


Figure 15. Temperature 1 in. below pavement surface from Feb. to May 1970.

Some transverse and longitudinal cracking of the bituminous surface has developed on the test sections, but the cracking is consistent with cracking that has occurred outside the limits of the test site. Thus, it does not seem likely that the insulation has lead to any poor structural performance.

ICING POTENTIAL STUDY

The presence of an insulation layer will alter the normal heat flow through a pavement. Subgrade insulation used in sections of limited length can produce different temperatures in adjacent insulated and uninsulated pavement surfaces and cause preferential icing of those surfaces. Figures 14 and 15 show the temperatures of points 1 in. below the pavement surfaces in sections B and C for 1969-70. The general trend is that pavement above the insulation may be either cooler or warmer than the adjacent pavement without insulation, depending on whether the air temperature is in a general cooling trend or a general warming trend.

An attempt was made to observe whether any degree of differential icing occurred on the test road during the 1971-72 winter. The distance of the test installation from Purdue University limited that study to a random daily observation of the pavement condition. No differential icing was observed during the survey, but some difference in behavior was observed. On a number of occasions, the insulated sections were darker in color because of the presence of moisture in the minute surface cracks of the asphaltic surface. The reverse situation was also seen when, during a light snowfall, the insulated sections remained dry because the snow was blown off the colder surface but melted on the warmer uninsulated section and caused the pavement surface to be slick.

The findings of this study with respect to differential pavement icing are inconclusive for several obvious reasons. However, generally the tendency for an insulated section to ice with respect to an uninsulated one (or vice versa) depends on the general trend of air temperatures (Figs. 14 and 15). The insulated sections are more likely to have surface ice during a general cooling trend, and the uninsulated sections are more likely to have ice during a general warming trend.

CONCLUSIONS

Data show that samll thicknesses of insulation—1 and 1.5 in.—were sufficient to prevent subgrade frost penetration in areas of low freezing indexes.

Although no surface icing was encountered during the study, the conclusion that icing is not a problem is inadvisable because of the limited number of pavement observations. In general, the insulated sections are more likely to ice during seasonal cooling, but the uninsulated ones are more likely to ice during seasonal warming.

The 2-dimensional heat flow model is an effective thermal design tool in that combinations of thickness of insulation and depth of placement may be compared with relative ease and for each the appropriate combination can be selected for the specific design situation.

ACKNOWLEDGMENTS

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REFERENCES

1. Performance Study Report on Insulation Board (Polystyrene). AASHO-ARBA Subcommittee on the Development, Evaluation and Recommendation of Hew Highway Materials, 1970.
2. Bowers, M. M. Thermally Insulated Test Road: State Road 26—Performance and Temperature Prediction Studies. Purdue Univ., Lafayette, Ind., Joint Highw. Res. Proj. Rept. 2, March 1972.

3. Ho, D. M. Prediction of Frost Penetration Into a Soil-Water System. Purdue Univ., Lafayette, Ind., PhD thesis, Aug. 1969.
4. Horton, J. A. Thermally Insulated Test Road: State Road 26—Final Performance and Temperature Prediction Studies. Purdue Univ., Lafayette, Ind., Joint Highw. Res. Proj. Rept. 39, Nov. 1972.
5. Stulgis, R. P. Insulated Test Road: State Road 26. Purdue Univ., Lafayette, Ind., Joint Highw. Res. Proj. Rept. 12, July 1968.
6. Toenniessen, J. D. Thermally Insulated Test Road: State Road 26—Phase II, Performance Studies. Purdue Univ., Lafayette, Ind., Joint Highw. Res. Proj. Rept. 10, May 1970.