PLANNING FOR A THERMALLY
INSULATED TEST ROAD

OCTOBER 1968

NO. 28

Joint
Highway
Research
Project

by

C. W. LOVELL, Jr
and
R. P. STULGIS

PURDUE UNIVERSITY
LAFAYETTE INDIANA

PLANNING FOR A THERMALLY INSULATED TEST ROAD

To: J. F. McLaughlin, Director
Joint Highway Research Project

From: H. L. Michael, Associate Director
Joint Highway Research Project

October 30, 1968

Project No: C-36-16F

File No: 6-10-6

The attached Technical Paper has been submitted by authors C. W. Lovell, Jr. and R. P. Stulgis for approval of publication by the Highway Research Board. The paper, "Planning for a Thermally Insulated Test Road" has been offered for presentation at the 1969 Annual HRB Meeting.

The paper summarizes a report on the same subject previously presented to the Board. The plans contained herein are the basis for the experimental thermally insulated section being constructed on SR 26 near Rossville.

The paper is submitted to the Board for approval.

Respectfully submitted,

Harold L. Michael
Associate Director

HLM:mz

Copy: F. L. Ashbaucher	R. H. Harrell	C. F. Scholer
W. L. Dolch	J. A. Havers	M. B. Scott
W. H. Goetz	V. E. Harvey	W. T. Spencer
W. L. Grecco	G. A. Leonards	H. R. J. Walsh
G. K. Hallock	F. B. Mendenhall	K. B. Woods
M. E. Harr	R. D. Miles	E. J. Yoder
	J. C. Oppenlander	

PLANNING FOR A THERMALLY INSULATED TEST ROAD

October 30, 1958

Project No. 7-35-102

File No. 6-10-6

To: L. V. McLaughlin, Director
Joint Highway Research Project

From: H. L. Michael, Associate Director
Joint Highway Research Project

The attached Technical Paper has been submitted by Messrs. C. W. Lovell, Jr. and H. P. Briggs for approval of publication by the Highway Research Board. The paper, "Planning for a Thermally Insulated Test Road" has been offered for presentation at the 1959 Annual Meeting.

The paper contains a report on the work subject previously presented to the Board. The plans contained therein are the basis for the experimental thermally insulated test road constructed on US 50 near Knoxville.

The paper is submitted to the Board for approval.

Respectfully submitted,

H. L. Michael

Digitized by the Internet Archive
in 2011 with funding from

LYRASIS members and Sloan Foundation; Indiana Department of Transportation

C. W. Lovell, Jr.
H. P. Briggs
W. E. Harvey
H. L. Michael
K. E. Woods
J. C. Yoder

H. L. Michael
J. A. Harvey
V. E. Harvey
G. A. Jackson
W. B. McDaniel
E. U. Wilson
J. C. Yoder

Copy:
V. L. Anderson
W. E. Boice
W. H. Boice
W. L. Crook
G. K. Eiland
M. E. Eide

Technical Paper

**PLANNING FOR A THERMALLY
INSULATED TEST ROAD**

by

C. W. Lovell, Jr.
Associate Professor in Civil Engineering,
Purdue University

and

R. P. Stulgis
Civil Engineering Section,
ESSO Research and Engineering Company
(Formerly Graduate Assistant in Research,
Purdue University)

Joint Highway Research Project

Project: C-36-16F

File: 6-10-6

Purdue University

Lafayette, Indiana

October 30, 1968

ABSTRACT

The planning for construction of an Indiana test road incorporating sections insulated to attenuate frost penetration is described. The flexible pavement installation is comprised of three 200-foot long sections, two of which have a foamed plastic insulating layer. All sections are intensively instrumented with temperature sensors, and a comprehensive evaluation of both thermal and structural performance is planned.

The facility was designed using empirical data derived from previous installations in other states and Canadian provinces, as well as output from a versatile analytical model of one-dimensional heat flow developed at Purdue University. The installation, which will probably be built early in 1969, has two objectives: (a) the acquisition of first-hand experience with the construction and performance of insulated pavements, and (b) the validation, refinement, and extension of extant solutions for thermal pavement design.

Both instrumentation and special construction features are described.

INTRODUCTION

The use of thermal barriers beneath transportation routes, for the purpose of minimizing frost damage, has received recent impetus with the availability of relatively inexpensive foamed plastics which are excellent insulators.

Research and development effort over the past decade (1, 2, 7, 8, 9)¹ has demonstrated both the technologic and the economic feasibility of such insulating layers in highway pavements. As these applications increase in volume, improvements in the materials, as well as in the technology of their placement, can be expected to provide even greater motivation for their use.

A sizeable number of highway agencies are currently testing the insulating layer concept under the service conditions peculiar to their geographies (3, 6, 10, 13). This paper reports on the planning of Indiana's first thermally insulated installation, which has two principal objectives. In addition to the obvious one of obtaining first-hand experience with construction and performance of the insulated design, a rather complete temperature instrumentation of the project should aid both validation and extension of extant analytical models for thermal pavement design (2, 4).

1. Numerals refer to entries in the Bibliography, page 15.

DESCRIPTION OF THE TEST INSTALLATION

The proposed test road will be constructed, probably in 1969, on State Road 26, some fifteen miles east of Lafayette, Indiana. The soils at the site are silty clays and clays of glacial origin. The location was selected to provide a relatively severe testing of the insulated design; specifically, the soils are highly frost susceptible, the water table is high (slight cut section), and the existing roadway seems to show considerable frost damage.

The length of experimental sections totals 600 feet, being comprised of equal lengths of two insulated and one non-insulated designs. Figure 1 shows the thicknesses of the component layers of the flexible pavements, where Section C is the normal design, less any subgrade treatment in the form of undercutting and granular replacement as might be judged necessary. Thermal analysis (12) indicates substantial frost penetration below Section C, and Section B effects a simple addition of 1 inch of insulation. In Section A there is an effective replacement of 6 inches of subbase by 1 1/2 inch of insulation.

The roadway includes a 24-foot width of travel lanes and a 22-foot width of shoulders...totaling 46 feet. The insulation is extended outside the travel lanes to control lateral heat losses. The width of insulation in Section B is 46 feet, while in Section A, it is 34 feet. Each of the three sections is to be intensively instrumented for temperature measurement.

NOTE: ALL TRANSITIONS AT 1/2" PER FT.

FIGURE 1 TEST SECTION PROFILE

DESIGN LOGIC FOR THE TEST SECTIONS

Design decisions were based upon a mélange of theoretical and empirical considerations, as well as certain practical constraints. The general location was dictated in part by the construction scheduling of the State, and the specific location by the desire to have multiple contiguous sections in a single cut. The 200-foot section length was judged to be generous with respect to control of thermal end effects and adequate for evaluation of structural performance.

The normal flexible pavement design for the 3.1-mile reconstruction project will be either that of the Control Section (C), or this section plus a subgrade treatment of undercutting and granular replacement. The choice depends upon a judgement of the potential frost problems along the route. Insulated Section A thus provides a comparison between the subgrade treatment and a 1-inch layer of insulation. Insulated Section B was designed to provide about the maximum replacement of granular courses by foam insulation.

For both thermal and structural reasons, the insulation should be placed as deep in the pavement section as practicable, viz., on the subgrade. All material placed above the foam is assumed to be essentially non-frost-susceptible. It is desired to hold the vertical stress on the foam to about 15 psi, and it is estimated that a minimal section of three inches of bituminous materials and twelve inches of gravel will accomplish this objective (11). Section B meets this structural constraint, in essence.

To check the thermal adequacy of any proposed design, use was made of a computerized finite difference solution (2). Under the constraint of one-dimensional heat flow by conduction, this program allows the

prediction of the distribution of temperature with time throughout a layered medium. There are essentially no solution limitations on the functional form of initial and boundary conditions, or on the variation of physical (including thermal) properties of the layered system.

Naturally, the predictive capability of the solution is tempered by the quality of the input, which includes: the thicknesses and certain physical properties of the layered cross section, an air temperature-time relationship, an air-surface transfer factor, a temperature magnitude or gradient versus time at a relatively large depth, and an initial ground temperature distribution. However, if reasonable estimates of these quantities can be generated, the predictions of time-temperature-depth have shown good agreement with field measurements (4).

A thermally acceptable section is one which prevents significant freezing penetration into frost-susceptible materials. Therefore, particular attention is paid to the position of the 32°F isotherm¹ with time. It would be customary to check the thermal regime for the conventional or non-insulated design, followed by checks for assumed insulated sections, involving logical choices of depths and thicknesses of the insulation. As mentioned earlier, there are structural restraints, as well as considerations of economics, in the selection of insulated designs to be tested. Optimization procedures, which systematically examine the thermal, structural, and economic factors, have not been formally developed to date (1968).

1. This is recognized as a simplification (5). The analytical model accommodates the freezing of soil water in increments below 32°F.

For the Indiana installation most of the input for thermal analysis was estimated, using either data from other test installations or knowledge of local conditions. Sensitivity analysis to assess the magnitude of errors that could be introduced by inaccuracies in the various physical property and temperature factors was not undertaken. However, it was felt that the inputs for unit weight, water content, volumetric heat, thermal conductivity, air-surface transfer factor, and initial ground temperature gradient were suitably conservative.

The upper and lower boundary conditions of temperature versus time would be expected to exert a significant and sustained influence on the thermal prediction. Selecting values for the lower boundary is particularly troublesome, and the test sections will contain deep temperature sensors to help reduce uncertainties in future work. In the interim, the ground temperature eight feet below the pavement surface was assumed to maintain a constant value of 50°F.

A march of mean daily air temperatures, as recorded at the nearest regular weather station, was used for the upper bound. The station records were examined in terms of the freezing index¹ for a number of past winters. Prediction was based upon approximately the coldest winter in ten. That is, the mean daily temperatures for the winter with the largest freezing index in 10 years were used for the upper boundary condition.

The fruition of the calculations described is represented in part by Figures 2 through 4, viz., Figure 2 shows the freezing index for the design winter, while Figures 3 and 4 have selected time-temperature plots for the Control Section and insulated Section B, respectively.

1. Freezing index calculations were computerized (12).

FIGURE 2. CUMULATIVE DEGREE - DAYS ABOVE AND BELOW 32°F AT W. LAFAYETTE (PURDUE)

FIGURE 3. PREDICTED TIME VS. TEMPERATURE - CONTROL SECTION

FIGURE 4. PREDICTED TIME VS. TEMPERATURE - SECTION "B"

Since the selection of design data is believed to be basically conservative, the minor penetration of the 32°F isotherm through the insulation of Section B is considered acceptable. On the other hand, there could be almost two feet of such penetration below Section C.

The insulated widths are selected at two arbitrary levels...probably both conservative. The test sections contain a considerable amount of temperature instrumentation intended to monitor lateral gradients in the thermal regimen. This can help sharpen empirical judgements with respect to requisite insulated widths, as well as providing experimental checks for a two-dimensional heat conduction model currently under development at Purdue University.

EVALUATION OF THE TEST SECTIONS

At the time of this writing, the detailed plan for monitoring and interpreting both the thermal and structural aspects of performance was not yet finalized. A layout of temperature sensors (thermistors) has been recommended, and involves 105 gages in the three sections, viz., 42 in Section A, 39 in Section B, and 24 in Section C. It is also likely that an adjacent section of roadway incorporating the subgrade treatment will be instrumented.

Figure 5 shows the plan for thermistor placement in Section A. Sensors are located at the center station of each test section; and the vertical strings are placed on a single side of the centerline, since the thermal regime is presumed to be symmetrical. The most important points of measurement are at 1-inch above and below the insulation, where thermistors are paired at the centerline to provide insurance against malfunction. As mentioned previously, the instrumentation patterns are intended to provide data favorable for the checking of both one and two dimensional heat flow models.

FIGURE 5. INSTRUMENTATION OF SECTION "A" CROSS SECTION AT STA. 105+00

The thermistors will be placed in either trenches or holes cut into the completed component layers of the sections, taking all practicable precautions to minimize the artifacts of disturbance. Sensor leads will be collected and conducted in a convenient manner to a terminal location on the adjacent side slope.

A thermograph and rain gage installation, as well as a ground water well are planned for the site. Structural performance evaluations may take several forms, but will probably include Benkelman beam measurements (10).

CONSTRUCTION OF THE TEST SECTIONS

The normal construction specifications and standards will be supplemented by special features designed to protect the insulation and the temperature instrumentation. The former will be placed by the contractor and the latter by the State.

The technology of insulation placement has been developed through the experiences of earlier installations, and will be treated here with brevity. The insulation boards will be laid with butt joints and affixed to the subgrade by wooden skewers. Board placement should proceed from one end of the section to the other, and from the centerline outward. Alternate board rows are displaced by one-half board length... Figure 6. Previous experience indicates that the board can be placed at the rate of about 800 bd. ft. per man-hour (11).

The placement and compaction of the first granular lift over the foamed plastic requires special protective features. The lift material should be dumped adjacent to the boards and levelled over them by a relatively light vehicle...Figure 7. Placement and spreading will proceed from one end of the section to the other. Compactor pressures should be limited to about 80 psi (11).

FIG. 6 INSULATED SECTION - OWATONNA, MINNESOTA

(Courtesy of The Dow Chemical Co.)

FIG. 7 SPREADING BASE - SUDBURY, ONTARIO

(Courtesy of The Dow Chemical Co.)

Once a lift of at least 6-inch thickness has been compacted, the remaining layers may be constructed in essentially the conventional manner, with appropriate precautions to avoid damage to the temperature instrumentation.

ACKNOWLEDGEMENTS

Financial assistance which made this study possible was provided by the Joint Highway Research Project between the Indiana State Highway Commission (ISHC) and Purdue University. The following persons were generous in rendering assistance in various phases of the work: Dr. M. E. Harr, Professor of Soil Mechanics, Purdue University; Mr. Da-Min Ho, Graduate Assistant in Soil Mechanics, Purdue University; Mr. W. T. Spencer, Head of the Division of Materials and Tests, ISHC; Mr. H. R. J. Walsh, Director of the Research and Training Center, ISHC; and Mr. Wayne G. Williams, The Dow Chemical Co., Midland, Michigan.

BIBLIOGRAPHY

1. Bloom, M. J. "An Analysis of the Highway Frost Problem in the North Central United States". MSCE Thesis, Purdue University. 1965. 171 pp.
2. Ho, D. M. and Harr, M. E. "Computer Program for One-Dimensional Analysis of Temperature Distribution in Layered System". Purdue University, Unpublished Report. 1967. 77 pp.
3. Iowa State Highway Commission. "Subgrade Insulation to Prevent Soil Freezing". Iowa Highway Research Board Project HR-87. 1965.
4. Leonards, G. A., Harr, M. E. and Ho, D. M. "Prediction of Transient Temperature Distributions in Insulated Pavements". Paper presented at the Conference on Frost Protection of Highways Using Insulating Layers, Wurzburg, Germany. May 1968.
5. Lovell, C. W., Jr. "Temperature Effects on Phase Composition and Strength of Partially Frozen Soil". HRB Bulletin 168. 1957. pp. 74-95.
6. Maine State Highway Commission. "Insulation of Subgrade; Evaluation of First Year Data". Soil Mechanics Series Technical Paper 66-1. 1966.
7. McCammon, N. R. "Experimental Investigation of the Rate of Frost Penetration in Clay". MSCE Thesis, Purdue University. 1962. 104 pp.

BIBLIOGRAPHY (CONT'D)

8. Oosterbaan, M. D. "Investigation of Foamed Plastic as an Insulating Layer in Highway Pavements". MSCE Thesis, Purdue University. 1963. 247 pp.
9. Oosterbaan, M. D. and Leonards, G. A. "Use of Insulating Layers to Attenuate Frost Action in Highway Pavements". Highway Research Record 101. 1965. pp. 11-27.
10. Penner, E., Oosterbaan, M. D. and Rodman, R. W. "Performance of City Pavement Structures Containing Foamed Plastic Insulation". Highway Research Record 128. 1966. pp. 1-17.
11. Personal Communications with Mr. Wayne G. Williams, The Dow Chemical Company, Midland, Mich.
12. Stulgis, R. P. "Insulated Test Road...State Road 26". Joint Highway Research Project Report No. 12, July 1968. Purdue University. 100 pp.
13. Young, F. D. "Experimental Foamed Plastic Base Course". Highway Research Record 101. 1965. pp. 1-10.