

EVALUATION OF STYROFOAM AS INSULATION AGAINST  
FROST ACTION IN A FLEXIBLE PAVEMENT FOUNDATION

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MICHIGAN DEPARTMENT OF STATE HIGHWAYS

EVALUATION OF STYROFOAM AS INSULATION AGAINST  
FROST ACTION IN A FLEXIBLE PAVEMENT FOUNDATION

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## EVALUATION OF STYROFOAM AS INSULATION AGAINST FROST ACTION IN A FLEXIBLE PAVEMENT FOUNDATION

In 1963, as part of the reconstruction of M 47, an experimental test section was constructed to evaluate the suitability of styrofoam as an insulation against frost penetration into the subgrade of a flexible pavement. The primary objectives of this project were:

1. To determine if a layer of styrofoam insulation, incorporated as part of a highway pavement structure, could serve as an effective barrier against frost penetration into the subgrade.
2. To determine if the presence of styrofoam in the pavement structure would have detrimental effects on pavement performance.
3. To evaluate the insulation method as a possible economical substitute for the present method of treating frost-susceptible subgrades.

Construction and instrumentation details of this project were presented in Research Report No. R-527R (1).

Current Departmental methods for correcting frost-susceptible subgrade conditions require the excavation of frost active materials to the depth of normal frost penetration and backfilling with granular, non-frost active material. The development of an economical method, whereby excavation and backfilling could be reduced or eliminated would give the Department an alternate procedure for handling frost problems in subgrades. In areas where granular materials are scarce, the use of an insulating material could result in conservation of aggregate supplies and reduced construction costs. Furthermore, even in those areas where granular materials are not scarce, the availability of an alternate, competitive method of construction might lead to reduced materials cost.

This report describes the performance and condition of the test project during the first five years of service and discusses the technical and economic potential of styrofoam as a highway construction material. The general layout of the test areas and the instrumentation system are shown in Figures 1 and 2. It should be noted that the subbase thickness in the styrofoam area is 12 in., whereas the uninsulated control sections were undercut and backfilled to give a total subbase depth of 25 in. The styrofoam was of special construction grade, (designated HI brand), 1-1/2 in. thick, and

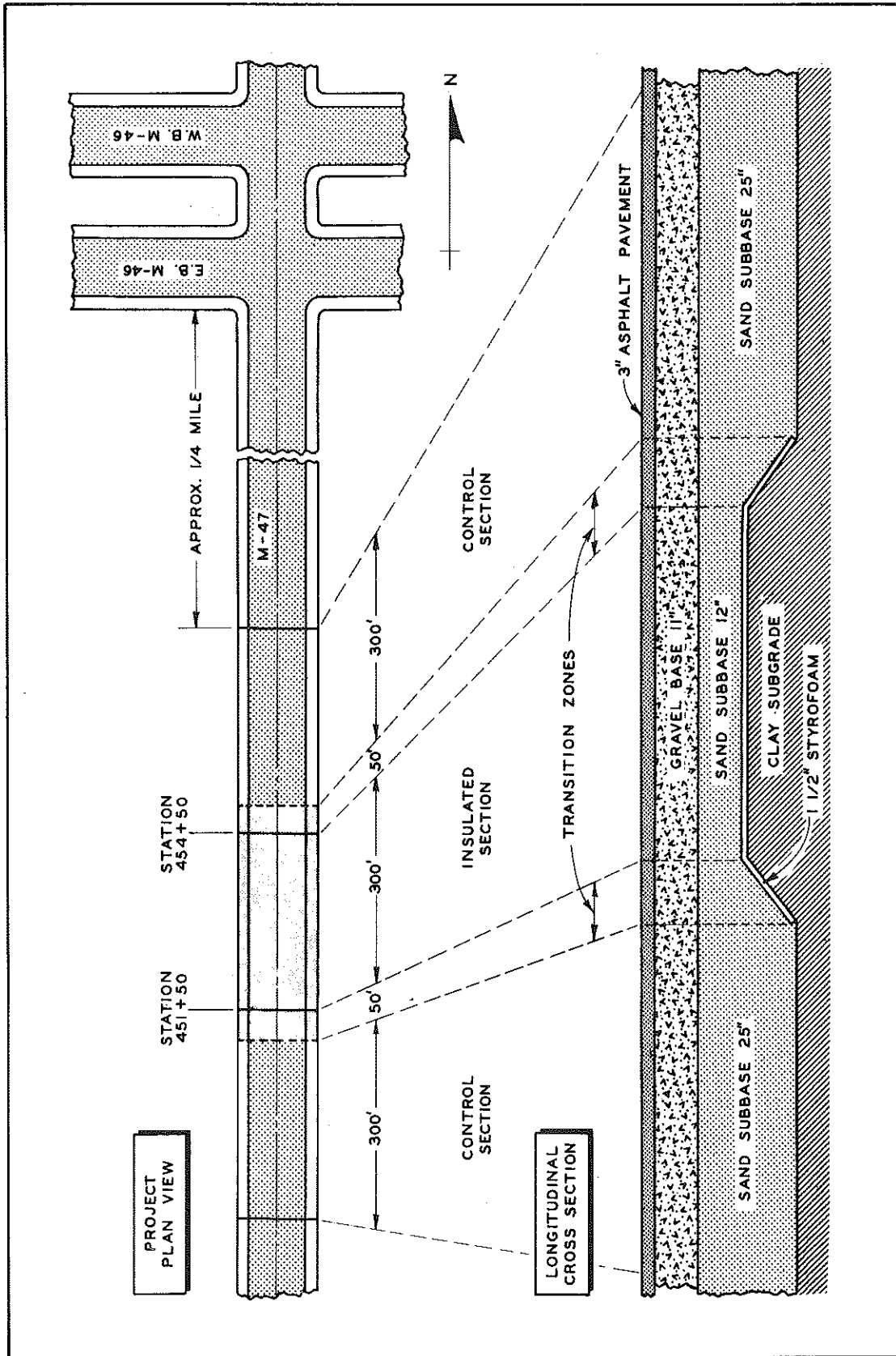


Figure 1. Project location and longitudinal cross section.

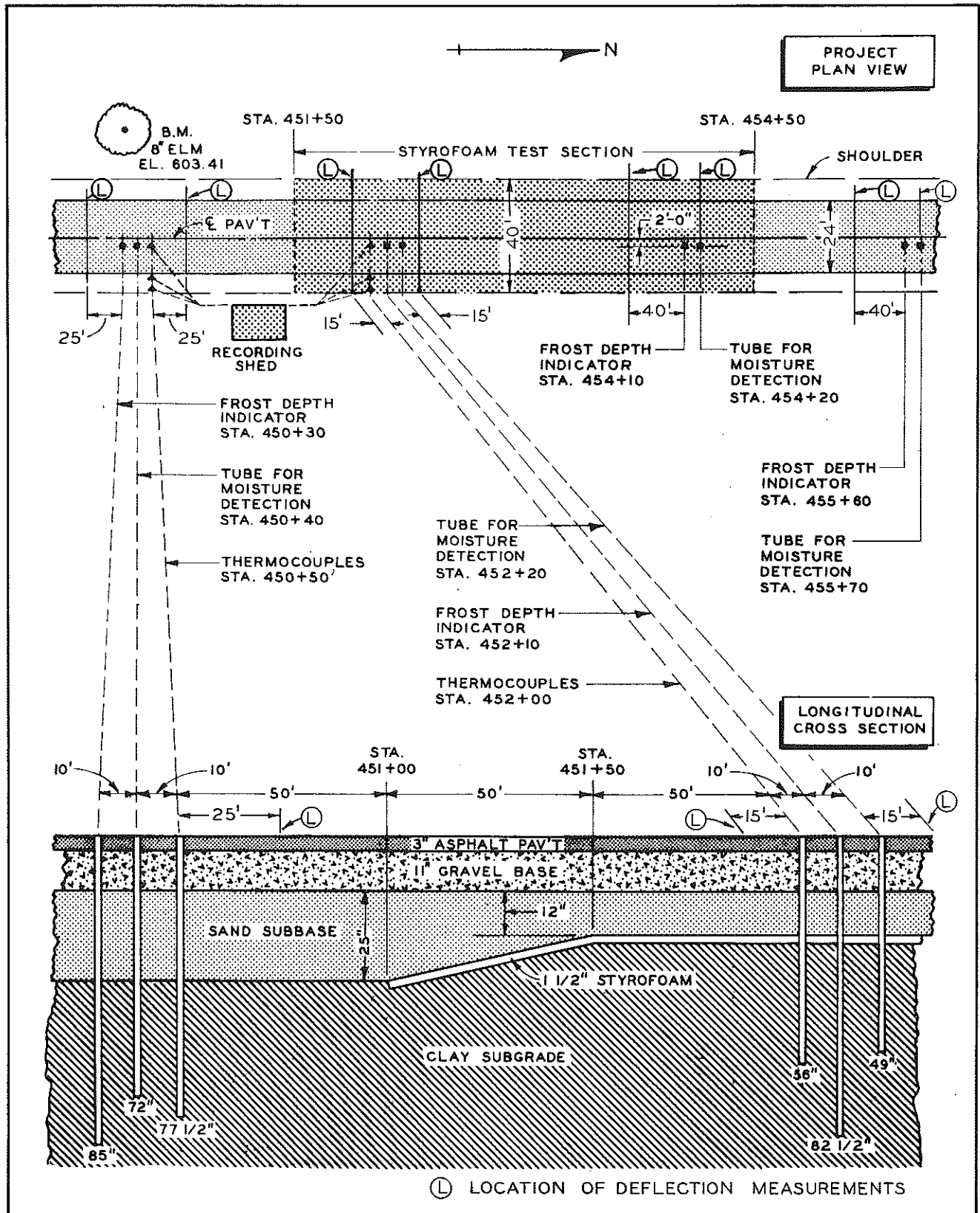


Figure 2. Instrumentation plan and longitudinal cross section.

extended the full width of the pavement and shoulders. Subsequent findings have indicated that this might not have been the most economical design for this area.

The styrofoam used was furnished by the Dow Chemical Company whose engineers have cooperated closely with the Department in technical aspects of this study and provided some of the data presented in this report.

## EFFECTIVENESS OF STYROFOAM AS A FROST BARRIER

During the past five years the temperatures throughout the styrofoam and the control test areas have been obtained and studied through instrumentation and direct reading measurements. During the first two years, continuous records of temperature throughout the pavement were made for the entire year. Since then, only winter temperatures have been recorded. In addition, special frost depth indicators have been used to measure the actual depth of frost penetration throughout the winter seasons (1).

### Vertical Frost Penetration

The primary purpose of using styrofoam is to prevent frost penetration into the subgrade during severe freezing conditions. For the purpose of this report such conditions are considered to be the "design freezing season," the coldest season occurring during the past ten years as expressed in degree days. In the area of this project the coldest 10-year season has been the winter of 1962-63 (the winter prior to constructing the styrofoam test area) in which the freezing index (cumulative degree days above and below freezing) reached 1,336 degree days.

During the duration of this project, all data indicate that there has been no frost penetration through the styrofoam layer (Table 1 and Fig. 3). It will be noted, however, from Figure 4 that all winters included in this observation period have been much milder than the 1962-63 design freezing season. For this reason the data are insufficient to prove that styrofoam will prevent subgrade freezing under more severe winter conditions.

TABLE 1  
MAXIMUM DEPTH OF FROST PENETRATION

Year	Control Sections (Depth of Subgrade = 39")		Styrofoam Section (Depth to Subgrade = 26")	
	North	South	North	South
1964-65	48"	43"	26"	26"
1965-66	42"	36"	26"	26"
1966-67	33"	28"	26"	26"
1967-68	39"	44"	26"	26"
1968-69	39"	35"	26"	26"

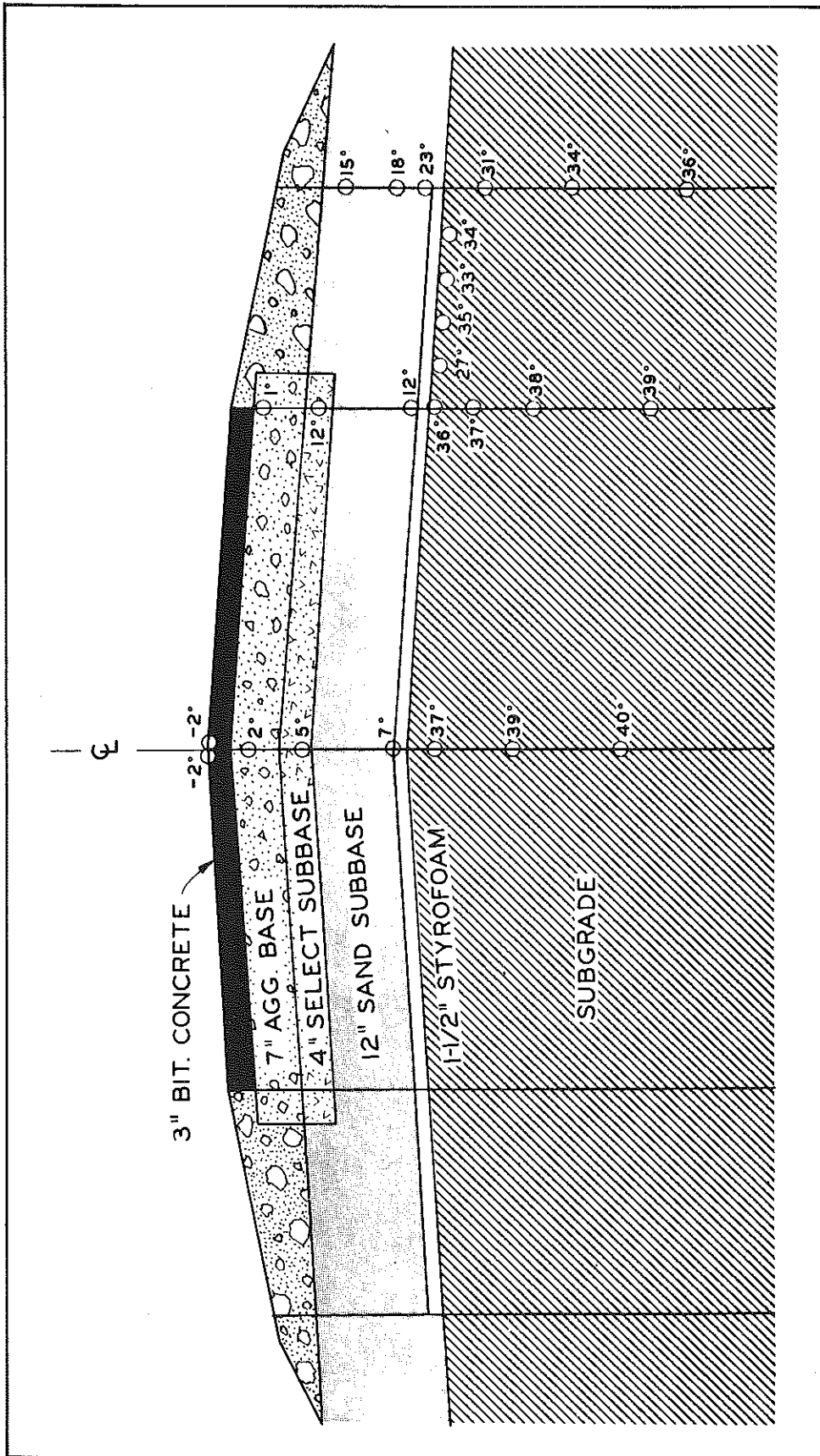


Figure 3. Lowest temperatures in the styrofoam test section recorded between January 1964 and April 1968 (deg F).



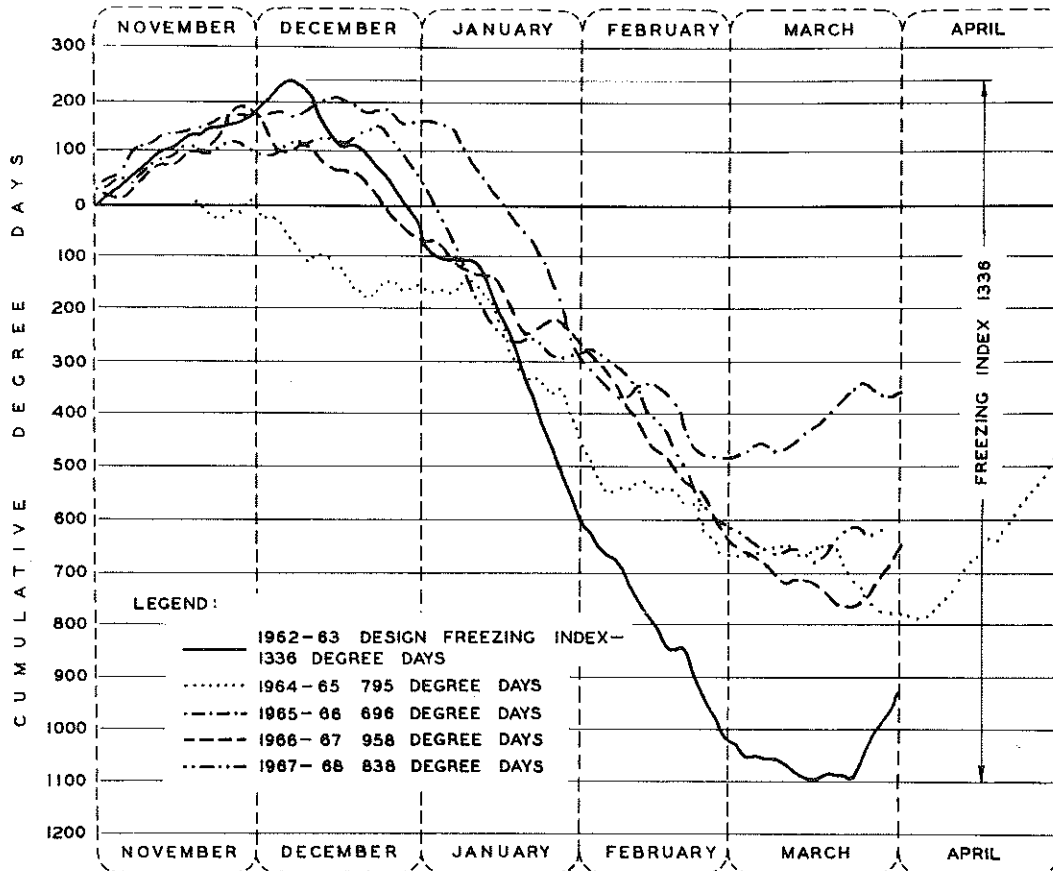


Figure 4. Cumulative degree days above and below 32 F at the test site.

To avoid waiting for design winter conditions in order to complete the evaluation of styrofoam, a method developed by G. A. Leonards of Purdue University was utilized, whereby the subgrade temperatures beneath a styrofoam layer can be estimated for any range of ambient temperature conditions. This method was developed through contract with the Dow Chemical Company and details of the procedures have not yet been released. All estimated temperatures used in this report were furnished by Dow engineers.

In order to establish the accuracy of this method in the area of our test project, a comparison was made between actual subgrade temperatures, measured during the winters of 1965-66 and 1967-68, and corresponding subgrade temperatures as computed by the method of Dr. Leonards. Results of this comparison indicate that the coldest temperature obtained by calculation agreed within 0.5 F of the actual measured temperature (Fig. 5).

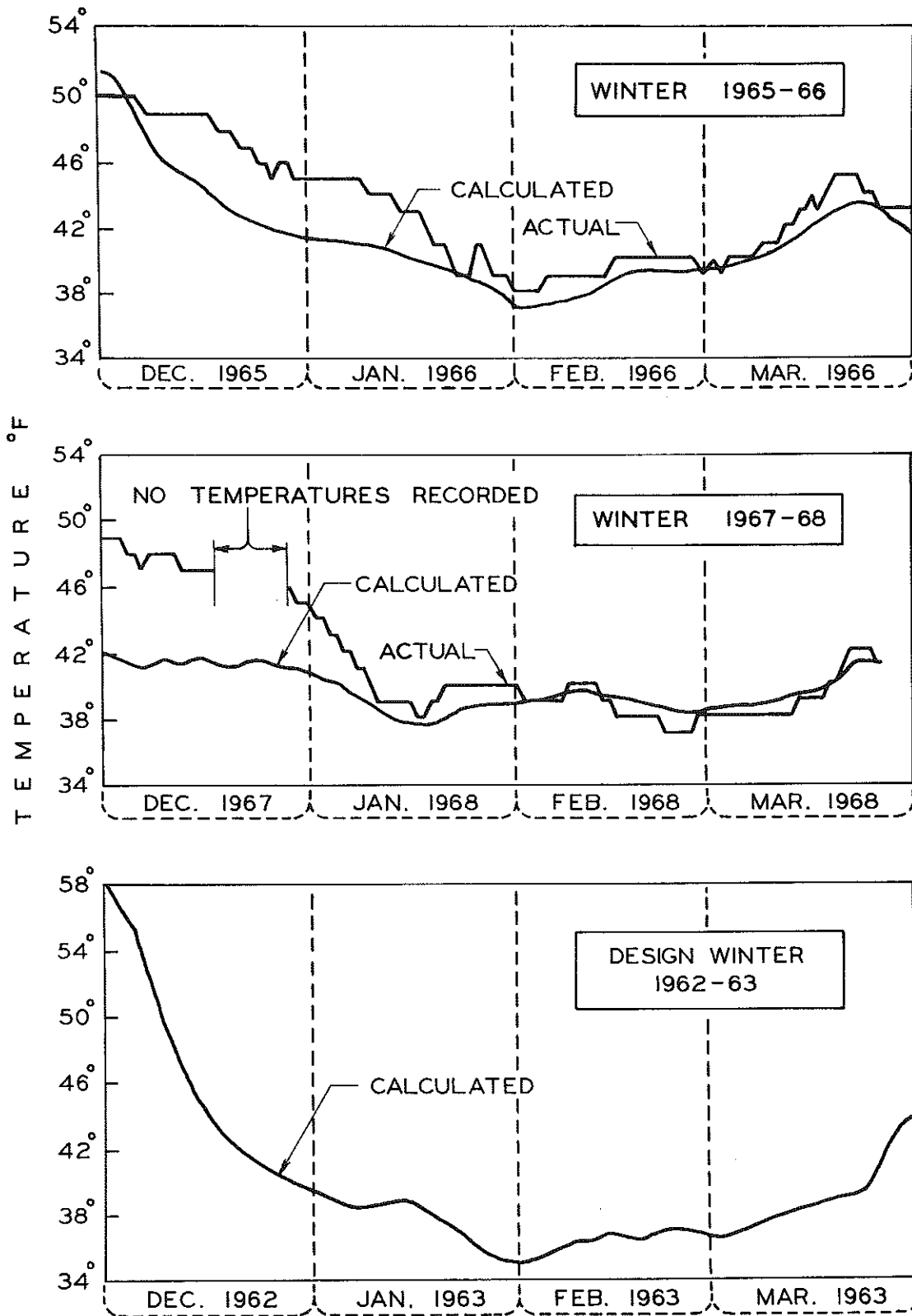


Figure 5. Calculated and measured subgrade temperatures under styrofoam.

From these data it was concluded that the method developed by Dr. Leonards is sufficiently accurate to permit a useful prediction of the subgrade temperatures reached during the design freezing season. Using this method, the low temperatures of the subgrade beneath the styrofoam during the 1962-63 design winter was calculated to be 34.5 F (Fig. 5), a value high enough to indicate the insulation layer to be of adequate design and able to prevent subgrade freezing under severe low temperature conditions.

Although all of the winters during this project have been relatively mild, there has been frost penetration into the subgrade of the control (un-insulated) sections.

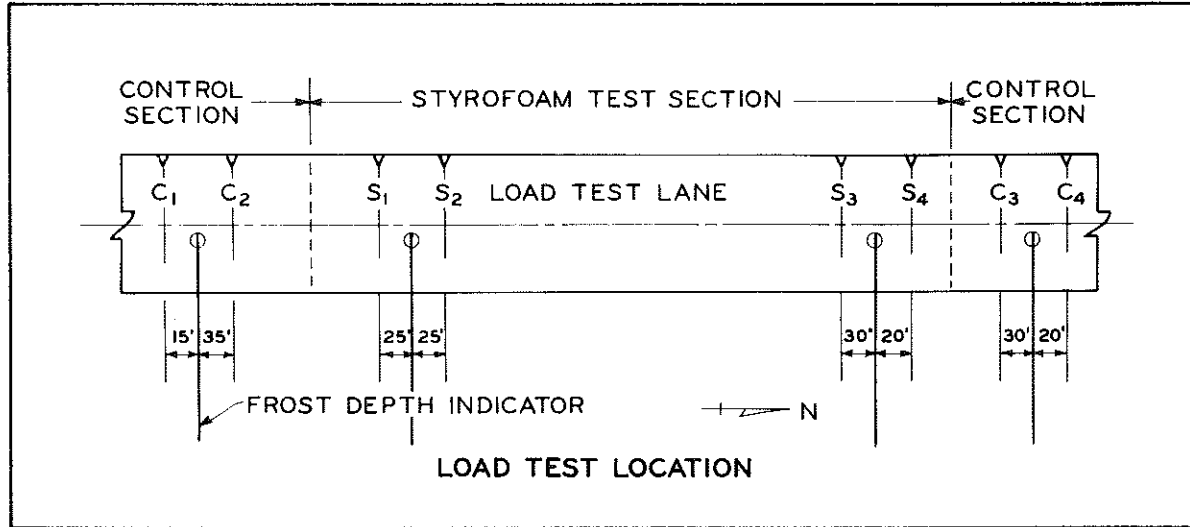
#### Lateral Frost Penetration

When this project was initiated there was concern as to possible lateral penetration of frost inward from the outside edges of the insulation. Various methods had been used by other investigators to limit lateral frost movement, should it occur, but no positive procedures have been developed (2, 3). When the M 47 project was constructed, Dow engineers felt that extending the styrofoam to the outside shoulder edges would be the most positive way to prevent lateral penetration of frost under the pavement edge.

In order to measure the amount of lateral penetration, thermocouples were placed below the styrofoam on one-foot centers, extending inward from the shoulder edge to the pavement edge (Fig. 3). The temperatures shown by the thermocouples indicated no significant lateral frost penetration during the period of observation, in which the most severe winter had a freezing index of 800 degree days. Other researchers have reported a limited amount of lateral frost penetration in areas where winter conditions are more severe than they have been so far at the M 47 site (2, 3). Based on these results and general observations of the M47 project, it is believed that limited lateral frost penetration could occur in Michigan should the severity of a winter exceed 800 degree days and that this should be taken into consideration in future design of insulated sections.

The thermocouples located at two and four feet from the shoulder edge are directly below longitudinal joints in the styrofoam boards (Fig. 3). The lower temperatures recorded at these points, as compared with the temperatures of adjacent thermocouples, indicates some heat loss below the joints and that this heat loss caused local subgrade freezing. Special effort should be made in any future work to insure that all joints are butted tightly.

Work of other investigators in this field substantiates, generally, the findings of the M 47 project (4, 5, 6, 7, 8).



REBOUND VALUES IN INCHES FOR 18K AXLE LOAD

Test Location	Nov. 1, 1965 Wheel Path		April 26, 1966 Wheel Path		April 26, 1967 Wheel Path		May 13, 1969 Wheel Path	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
C <sub>1</sub>	0.0095	0.0150	0.016	0.016	0.024	0.018	0.015	0.018
C <sub>2</sub>	0.0165	0.0195	0.012	0.015	0.026	0.022	0.025	0.020
Ave.	0.0130	0.0172	0.014	0.0155	0.025	0.020	0.020	0.019
S <sub>1</sub>	0.0180	0.0220	0.0180	0.0230	0.030	0.029	0.025	0.025
S <sub>2</sub>	0.0200	0.0230	0.0220	0.0225	0.032	0.032	0.035	0.035
Ave	0.0190	0.0225	0.0200	0.0230	0.031	0.030	0.030	0.030
C <sub>3</sub>	0.0185	0.0190	0.0160	0.0130	0.024	0.019	0.025	0.020
C <sub>4</sub>	0.0160	0.0160	0.0180	0.0120	0.020	0.016	0.025	0.020
Ave.	0.0172	0.0175	0.0170	0.0125	0.022	0.018	0.025	0.020
S <sub>3</sub>	0.0185	0.0215	0.0205	0.0195	0.031	0.024	0.030	0.025
S <sub>4</sub>	0.0200	0.0215	0.0205	0.0200	0.030	0.023	0.025	0.020
Ave.	0.0192	0.0215	0.0205	0.0200	0.030	0.024	0.027	0.022

Figure 6. Benkelman beam rebound values, 1965, 1966, 1967, and 1969.

## OTHER CHARACTERISTICS OF THE INSULATED PAVEMENT

In addition to the primary study to determine the insulating properties of styrofoam, investigations were made to determine the effects that an insulation layer might have on other characteristics of the pavement structure. These are discussed separately.

### Structural Strength

An investigation was made to determine the deflection of both the insulated and control sections under a 9-kip dual wheel load, applied by the Research Laboratory Load Truck having an 18-kip single-axle load. Departmental Research Report No. R-527R indicates the subgrade of the test and control sections to be an A-7-6(14) soil which is normally considered to have a low bearing capacity when wet (1). The objective of the deflection study was to determine if the insulated test section is sufficiently thick to perform satisfactorily over such a weak subgrade and to determine the strength difference between the subgrade insulation method, which prevents loss of subgrade bearing capacity due to frost action, and the undercut back-fill method, which adds structural strength to the pavement by adding thickness to the subbase.

Pavement deflection values have been determined annually at the same locations each spring (Figs. 2 and 6). Benkelman beams equipped with LVDT's (Lineal Variable Differential Transformers) are used to measure deflection by placing the beam pointer between the dual wheels and measuring the total rebound of the pavement as the load truck moves at creep speed.

The test results, summarized in Figure 6, indicate that deflections are greater for the insulated section than for the control sections. The significance of these results were determined using Benkelman's guidelines (9) for the use of deflection data for pavement rehabilitation work, in which the following deflection values are listed as tolerable: 1) for light traffic - 0.060 in., 2) for moderate traffic - 0.045 in., and 3) for heavy traffic - 0.030 in. Traffic count over the test section has averaged about 3,400 passenger cars and 600 commercial vehicles per day for the past several years. This traffic volume is considered to be moderate so that the maximum allowable deflection for satisfactory service should be less than 0.045 inches. From Figure 6 it can be seen that deflection values for the insulated test section have averaged 0.030 inches or less, which is considerably below toleration limits. The control sections deflected no more

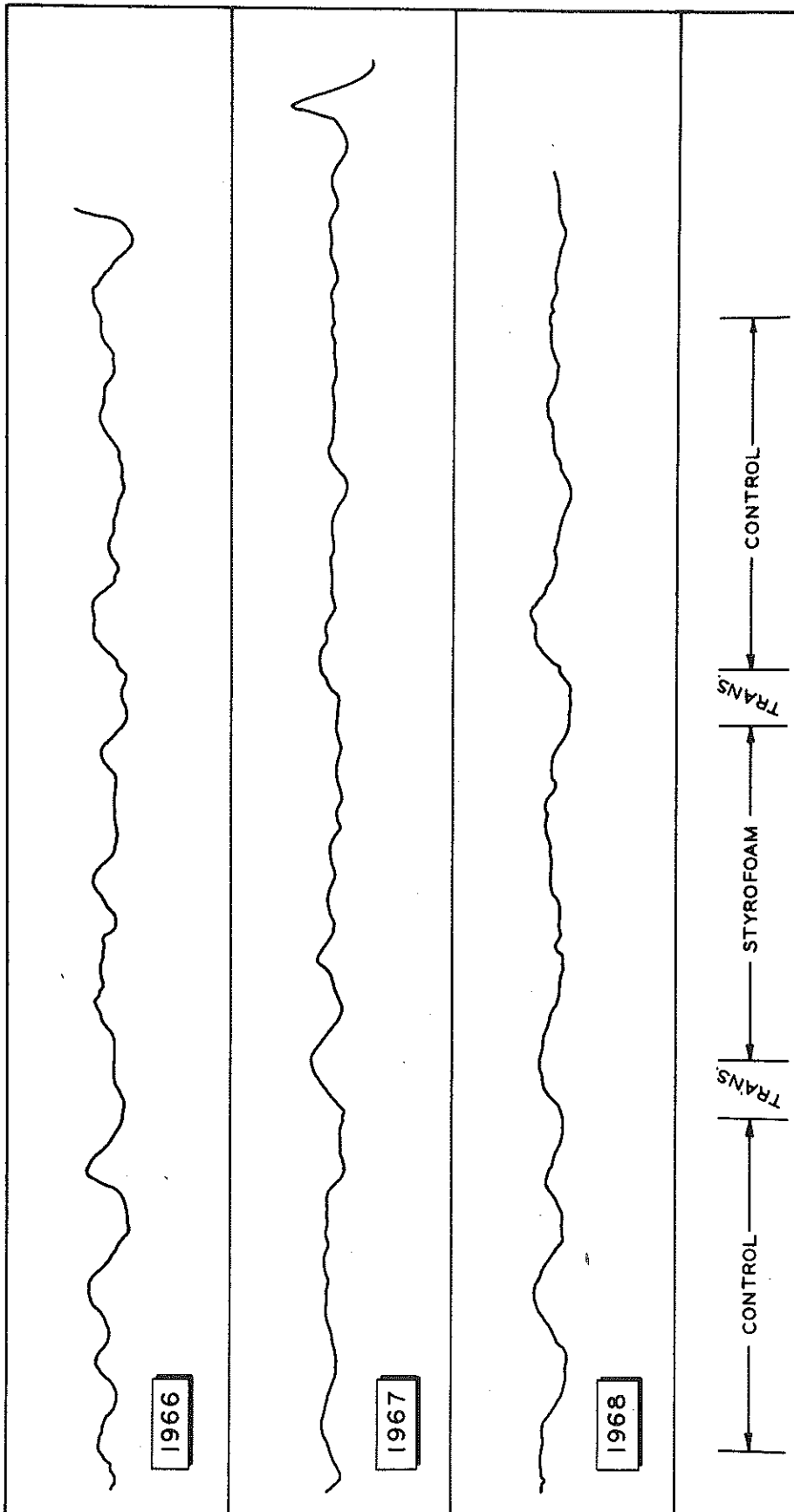


Figure 7. Profilometer measurements of insulated and control section (1966-68).

than 0.023 in., indicating sufficient strength to carry a much larger volume of traffic. On the basis of these data it is concluded that the insulated test section is strong enough to perform satisfactorily although the undercut control sections are stronger than the insulated test section.

### Riding Quality

Michigan's Rapid Travel Profilometer was used in an attempt to determine the relative riding qualities of the insulated and control sections. Roughness measurements were not made because the test sections are too short to obtain meaningful results. The pavement surface profiles, obtained with the profilometer during 1966-1968, are shown in Figure 7. Results indicate that the profile of the insulated test section has remained at least as smooth as that of the control sections. It is concluded that the riding quality of the insulated section is as good or better than that of the control sections.

### Subgrade Moisture Study

An attempt was made to determine whether the styrofoam layer would cause the underlying subgrade to become more saturated than the uninsulated subgrades. Aluminum access tubes which would accept a nuclear moisture probe were installed in the insulated and control sections. No meaningful results were obtained for the following reasons: 1) the bottom of the access tubes were filled with surface water, 2) condensation was present on the walls of the access tube, 3) the styrofoam layer contains a high concentration of hydrogen which interfered with nuclear gage moisture readings. This phase of the study was discontinued.

### Freeze-Thaw Cycles in the Pavement Surface

Both bituminous and portland cement concrete pavement surfaces can be damaged by freeze-thaw action. Experiments with an insulated concrete pavement in Iowa show that there were a greater number of freeze-thaw cycles in the concrete surface of the insulated section than there were in the surface of an uninsulated control section (4). The Iowa report gave no conclusions as to the detrimental effect that the increased freeze-thaw cycles might have on the pavement's performance.

Temperatures recorded on the M47 project show that there were a few less freeze-thaw cycles in the bituminous concrete surface of the insulated section than for the surface of the control sections (Table 2). These results are opposite from those obtained in Iowa and are believed to be due to

differences in the cross sections of the two areas (Figs. 2 and 8). Results obtained from the Michigan and Iowa experiments indicate that the number of freeze-thaw cycles of the pavement surface is an inverse function of the depth of the styrofoam layer. There should be no significant change in the number of freeze-thaw cycles of a pavement surface when styrofoam is used to insulate the subgrade of standard Michigan pavement sections.

TABLE 2  
 NUMBER OF FREEZE-THAW CYCLES  
 IN BITUMINOUS CONCRETE SURFACE

Year	Control Section	Insulated Section
1964-65	52	50
1965-66	68	71
1966-67	72	61
1967-68	58	53

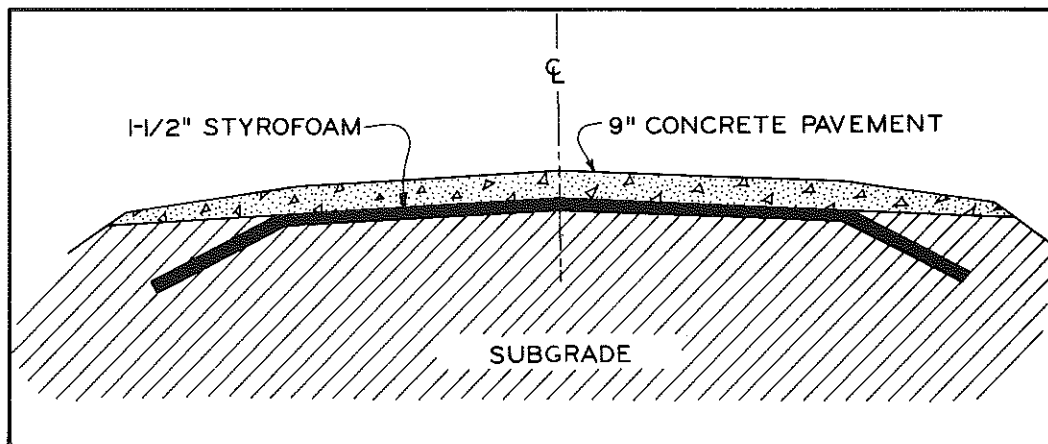


Figure 8. Cross section of the Iowa styrofoam test section.

#### Pavement Surface Temperature

The possibility of damage to a bituminous concrete surface increases directly with increases in the range of temperature extremes to which it is subjected. For the styrofoam test section, bituminous concrete surfaces are colder in the winter and warmer in the summer than the surfaces of



the adjacent control sections. Daily high and low temperatures of bituminous concrete at the M 47 test site are summarized in Table 3. These data show that when the hottest and coldest days are considered, the range of temperature extremes is 123.5 F for the styrofoam section and 115.5 F for the adjacent control section.

When the hottest and coldest two-month periods, July - August and January - February, are considered, the range of these average temperature extremes is 88 F for the styrofoam section compared to 85 F for the adjacent control section (Table 4). The temperature differences noted are thought to be too small to significantly effect the performance of the bituminous concrete surface, but this point warrants further investigation.

TABLE 3  
HIGHEST AND LOWEST BITUMINOUS CONCRETE  
SURFACE TEMPERATURES

Year	Control Section		Insulated Section	
	Low	High	Low	High
1964-65	11 <sup>o</sup> F	122 <sup>o</sup> F	9 <sup>o</sup> F	125 <sup>o</sup> F
1965-66	5 <sup>o</sup> F	125 <sup>o</sup> F	-2 <sup>o</sup> F	129 <sup>o</sup> F
Average	8 <sup>o</sup> F	123.5 <sup>o</sup> F	3.5 <sup>o</sup> F	127 <sup>o</sup> F
Average Difference	115.5 <sup>o</sup> F		123.5 <sup>o</sup> F	

TABLE 4  
HIGH AND LOW BITUMINOUS CONCRETE SURFACE  
TEMPERATURES AVERAGED OVER TWO-MONTH PERIODS

Year	Control Section		Insulated Section	
	Jan-Feb	July-Aug	Jan-Feb	July-Aug
1964-65	21 <sup>o</sup> F	106 <sup>o</sup> F	19 <sup>o</sup> F	106 <sup>o</sup> F
1965-66	22 <sup>o</sup> F	107 <sup>o</sup> F	19 <sup>o</sup> F	108 <sup>o</sup> F
Average	21.5 <sup>o</sup> F	106.5 <sup>o</sup> F	19 <sup>o</sup> F	107 <sup>o</sup> F
Average Difference	85 <sup>o</sup> F		88 <sup>o</sup> F	

## RECOMMENDED DESIGN PROCEDURES FOR INSULATED SECTIONS

Although field testing of the M47 test site project indicates the acceptability of styrofoam as a subgrade insulating material, the data obtained are not sufficient to enable the Department to design insulating layers. To do this it is necessary to determine the thickness and width of the insulating layer and the form and length of transition zones to be used at the ends of the insulated sections for the various thicknesses of base and subbase required.

### Thickness of Insulation

The thickness of styrofoam insulation required to prevent pavement subgrade freezing depends, in general, on climatic conditions and thickness of the pavement layers. The Dow Chemical Company has collected a large amount of data from Canadian and U. S. styrofoam test sections by means of which they have developed an empirical method for determining insulation thickness. From their analysis they found that the thickness of styrofoam required is dependent upon two primary factors: thickness of the overlaying pavement layers, and the design freezing index for the area. Using the Department's three basic pavement thicknesses (10) and U. S. Army Corps of Engineers "Design Freezing Index for Michigan," Dow engineers prepared Figures 9, 10, and 11 for use in determining normal styrofoam thickness to be used in Michigan, for different base plus subbase thicknesses. If for some reason a limited subgrade frost action could be tolerated (under severe winter conditions only) design thicknesses could be modified as shown in Figures 12, 13, and 14.

### Width of Insulation

As indicated in this report, there may be lateral penetration of frost beneath the styrofoam during severe winters. For this reason the insulated layer should be wide enough to extend beyond the point where no frost action can be tolerated. Straub and Williams (3) concluded that an 8-ft extension beyond such point is more than adequate while Korfhage (2) suggested a 2-ft extension for styrofoam 2 in. or less in thickness and 3 ft when the styrofoam thickness exceeds 2 in. On the basis of these reports, and on experience gained with the M47 test section, it is recommended that Korfhage's suggestions be used to determine the width of insulating layers in Michigan.

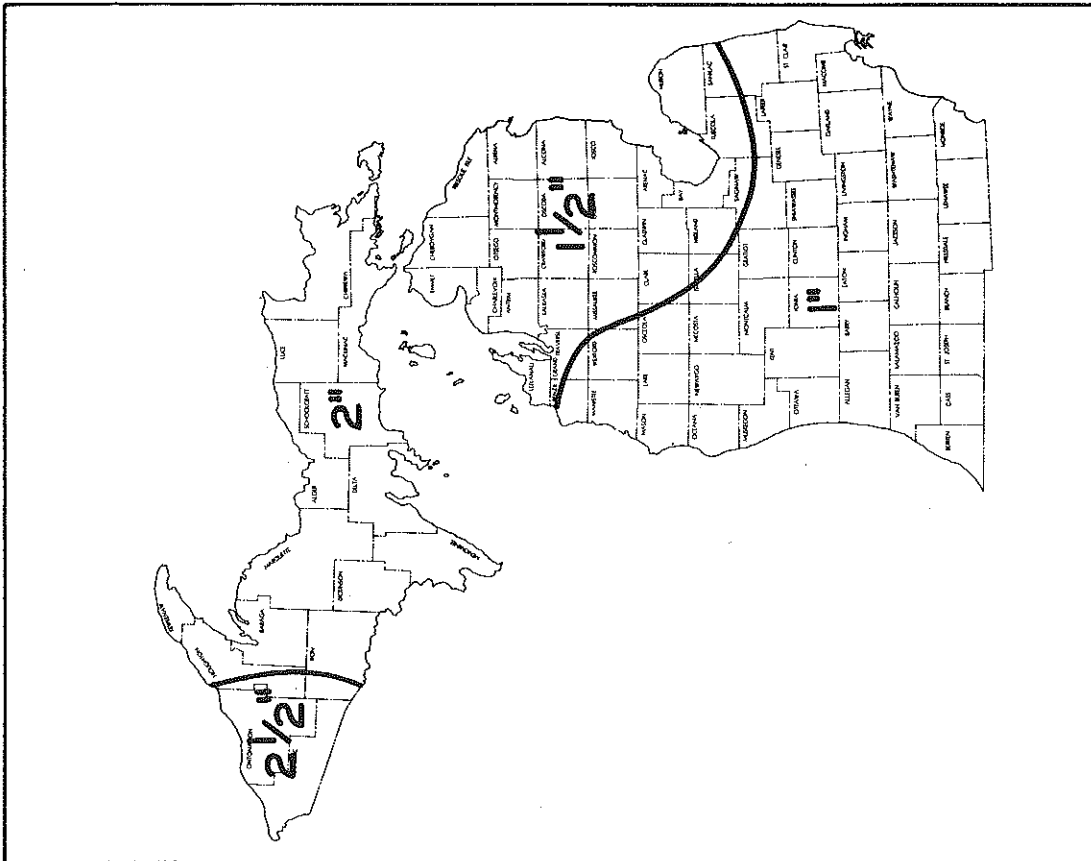


Figure 9. Styrofoam thickness required in different areas of the state (base and subbase thickness - 14 ± 2 in.).

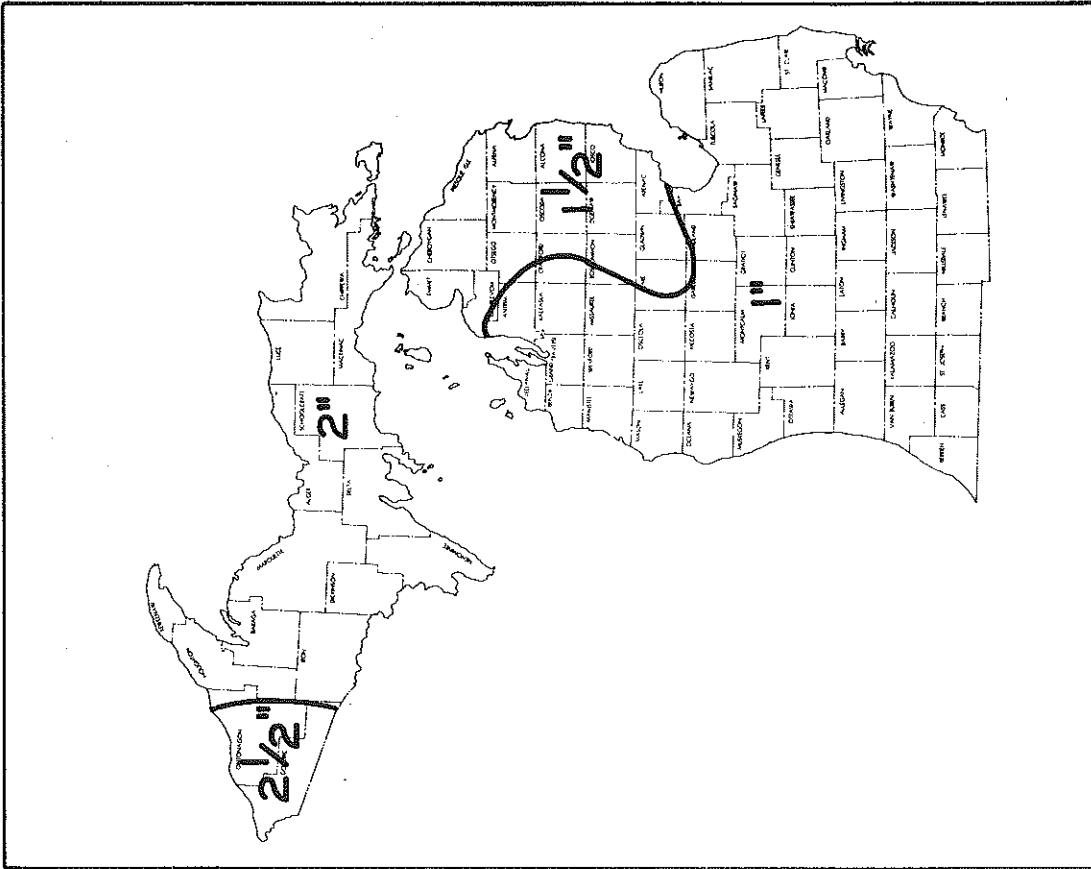


Figure 10. Styrofoam thickness required in different areas of the state (base and subbase thickness - 24 ± 2 in.).

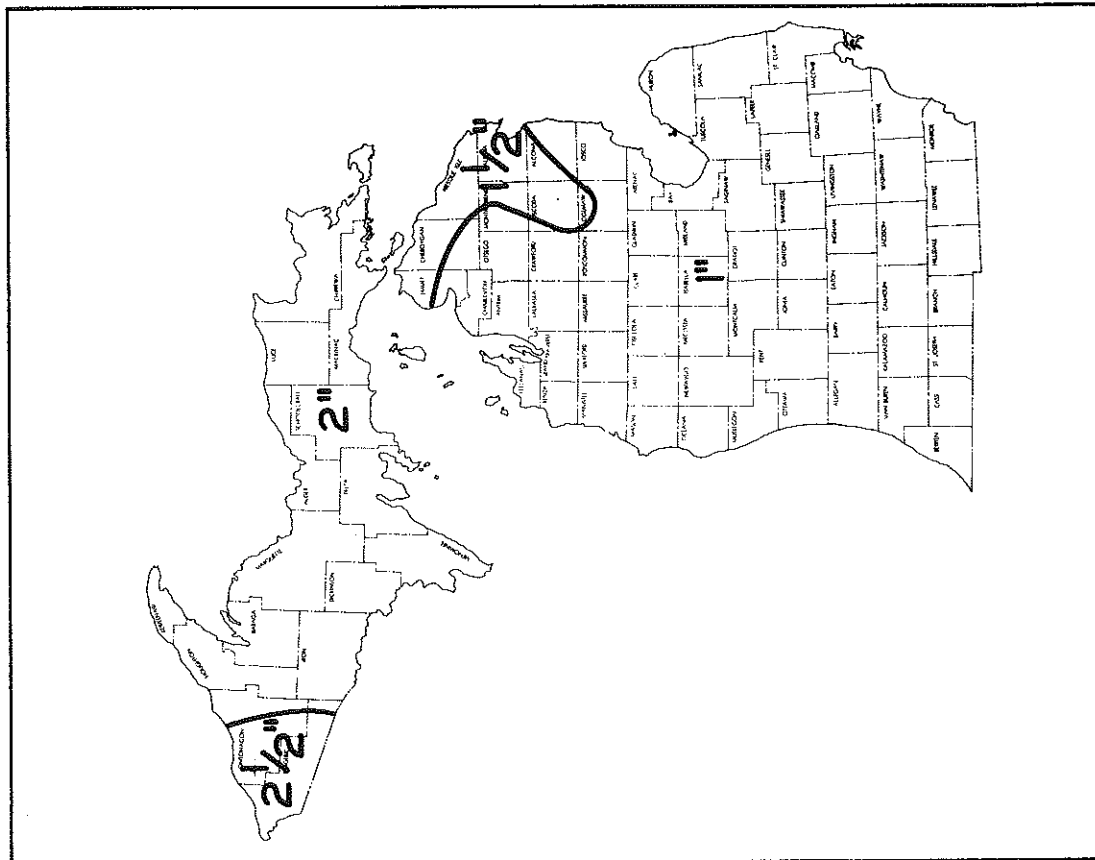


Figure 11. Styrofoam thickness required in different areas of the state (base and subbase thickness - 36 + 2 in.).

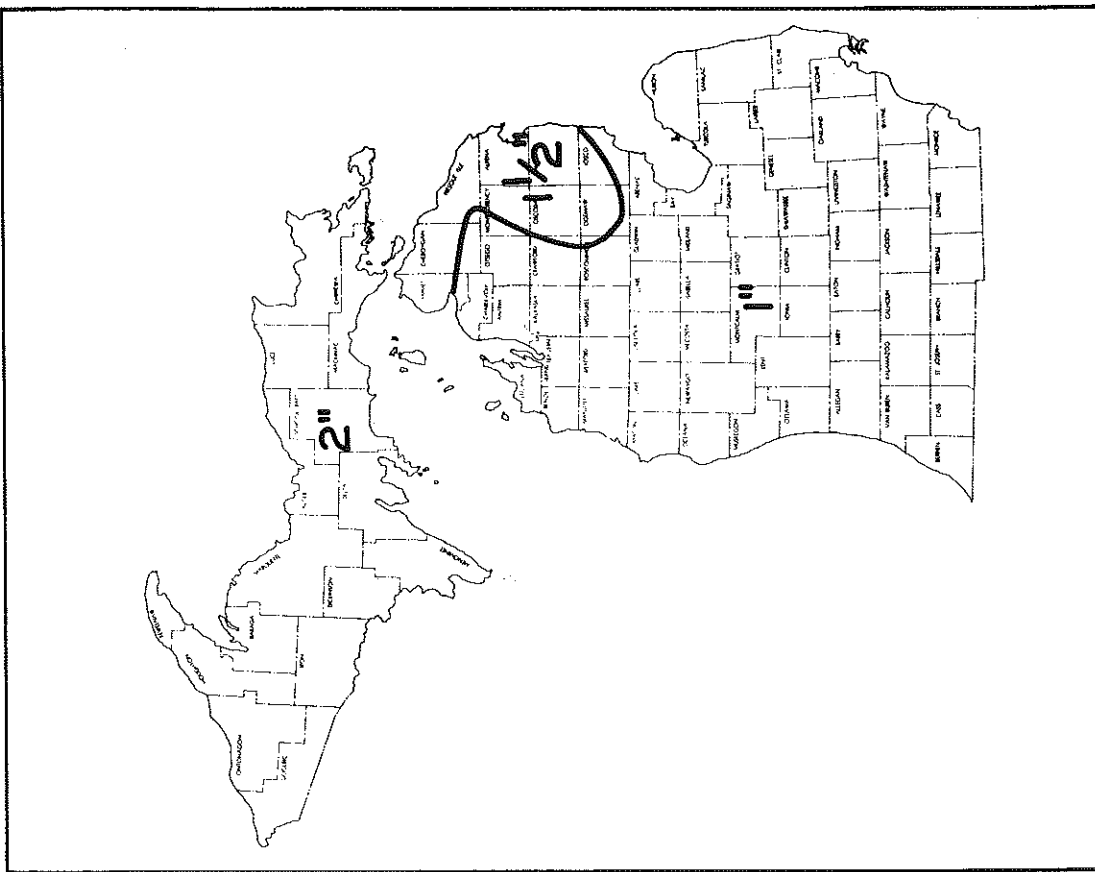


Figure 12. Styrofoam thickness required to provide only limited frost penetration into the subgrade (base and subbase thickness - 14 ± 2 in.).

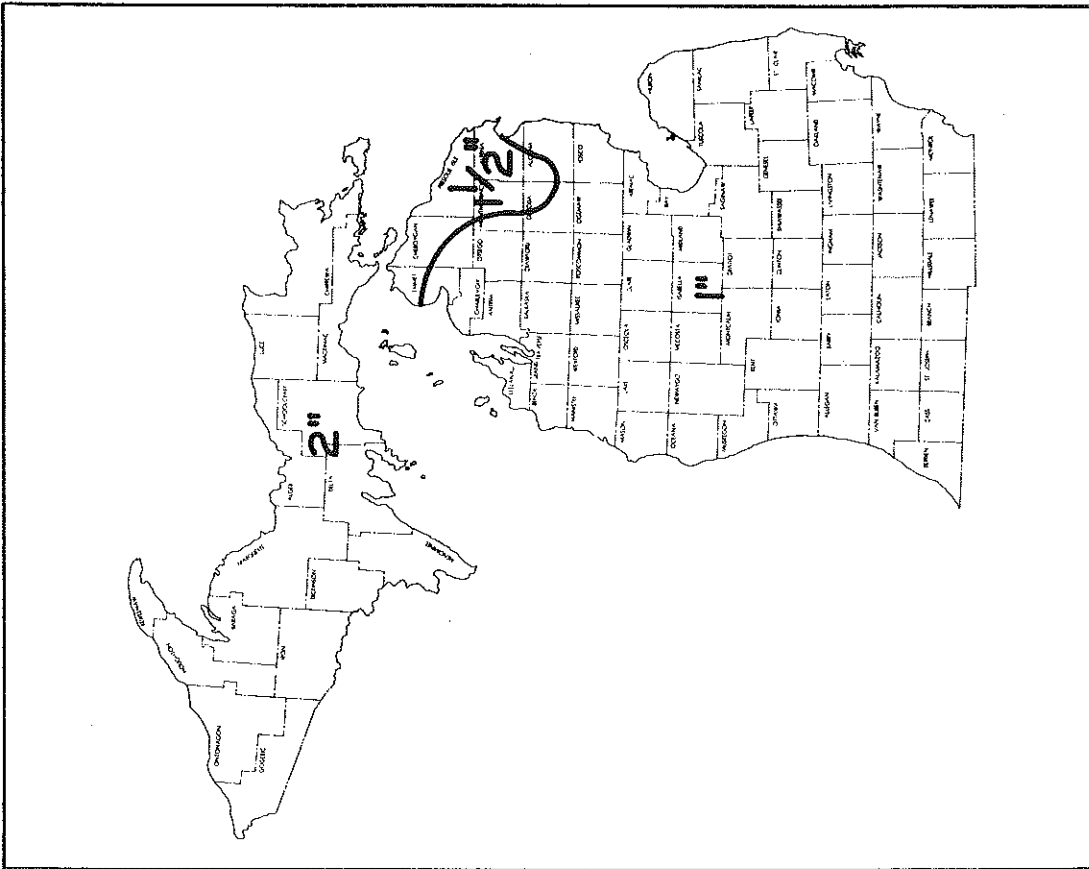


Figure 14. Styrofoam thickness required to provide only limited frost penetration into the subgrade (base and subbase thickness -  $36 \pm 2$  in.).

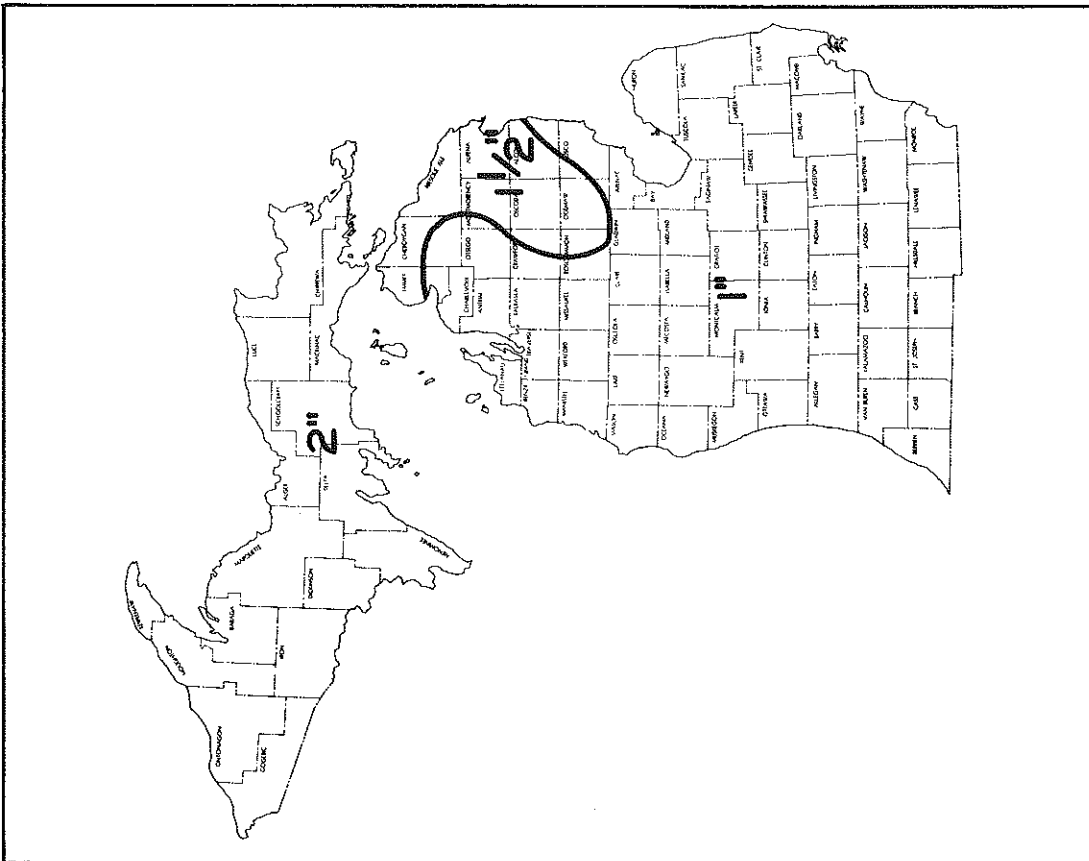


Figure 13. Styrofoam thickness required to provide only limited frost penetration into the subgrade (base and subbase thickness -  $24 \pm 2$  in.).

## Length of Transition Zones

At each end of the M 47 test section the transition zones are undercut and overlaid with styrofoam as shown in Figure 2. Under typical construction conditions the adjacent frost susceptible and non-frost susceptible subgrades would be on the same level. When the transition zones are level, it was found in Minnesota that--unless corrective measures are taken--severe bumps might form at the ends of insulated sections (2). To alleviate this problem in Minnesota, Korfhage (2) recommends that "thermal transition zones" be constructed by reducing the thickness of the insulation, in one or more increments, and arranging the ends of the insulation to form a saw-tooth pattern, both as shown in Figure 15. These design procedures are recommended for use in Michigan until such time as experience may indicate a need for modification.

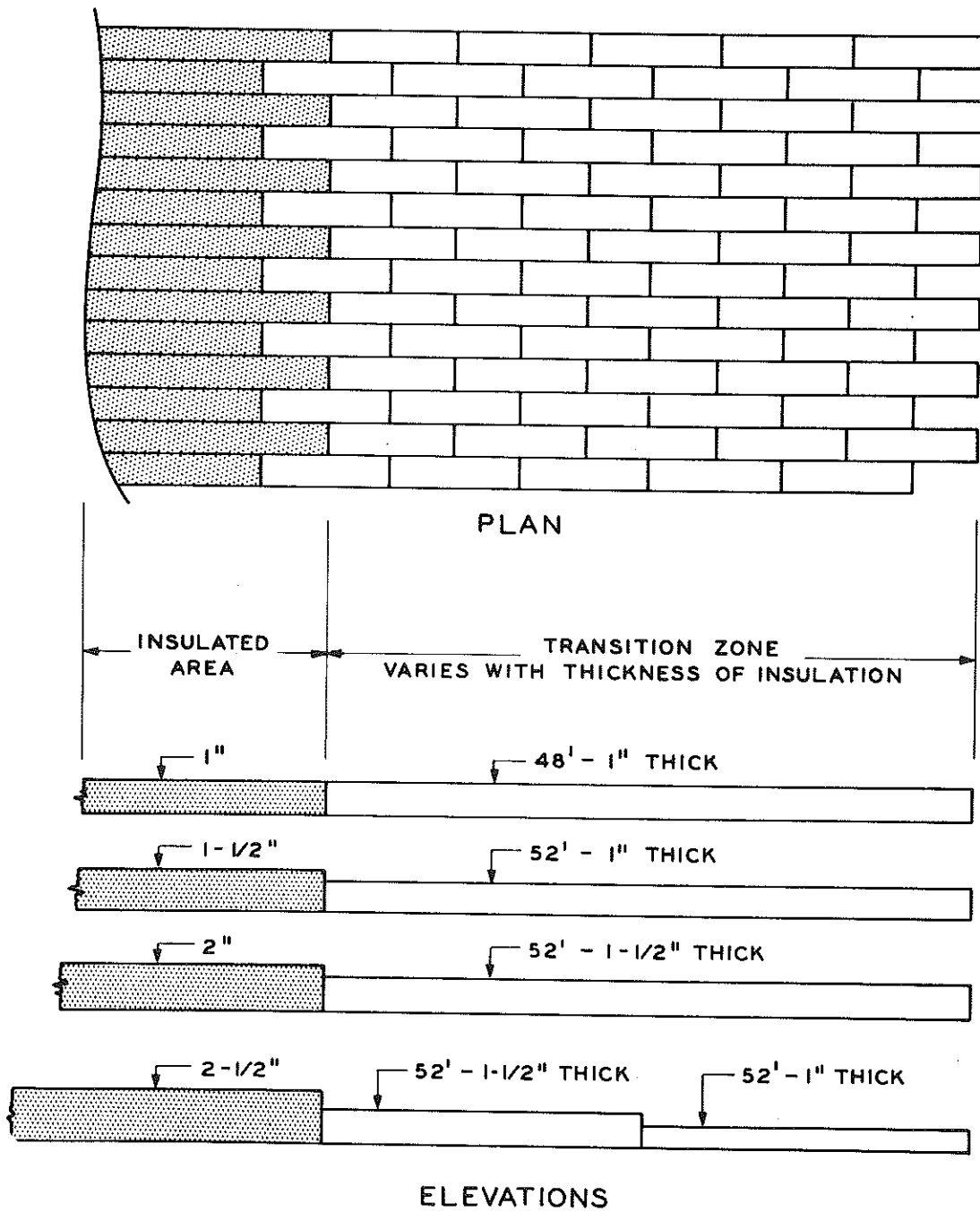


Figure 15. Design of insulated transition zones (not to scale).

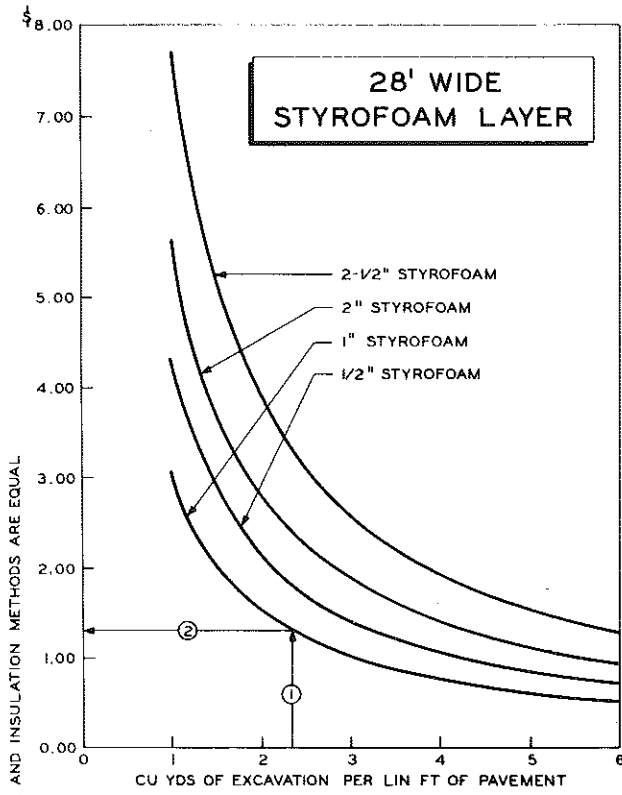


Figure 16. Cost analysis curves for 28-ft wide styrofoam layer.

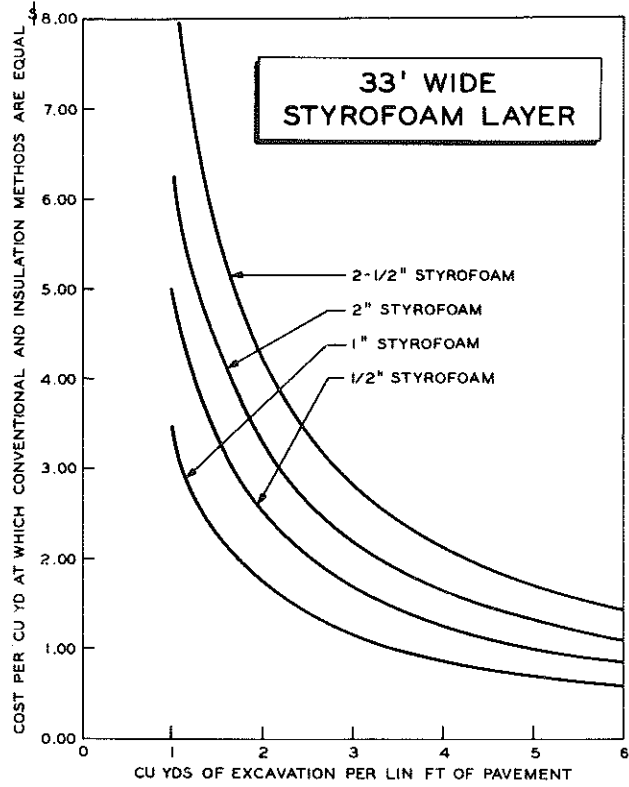


Figure 17. Cost analysis curves for 33-ft wide styrofoam layer.

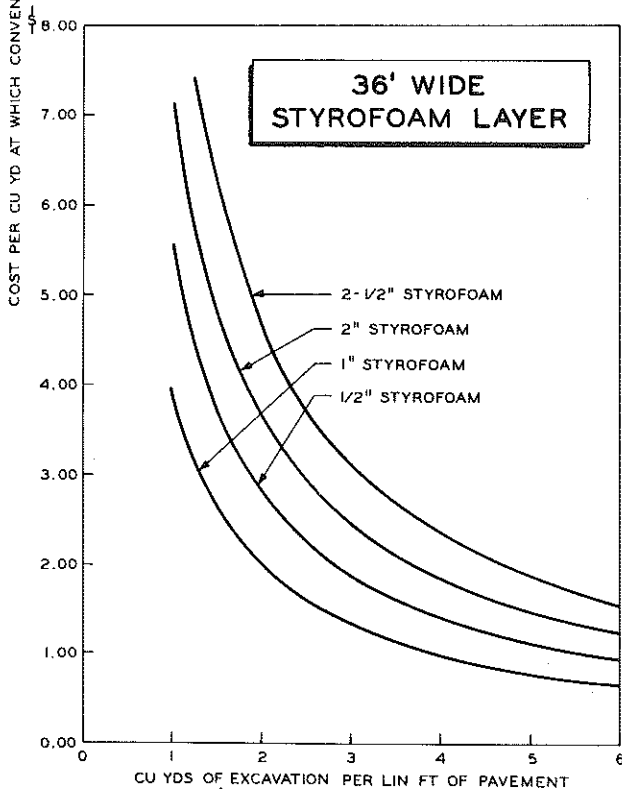


Figure 18. Cost analysis curves for 36-ft wide styrofoam layer.



COMPARATIVE COST OF  
CONVENTIONAL AND INSULATED CONSTRUCTION

Whether the conventional excavation and backfill method or the insulation method is the most economical for protecting a subgrade from frost action depends upon several factors which, in the final analysis, must be determined for each specific job. To arrive at a comparative cost it is necessary to know the cost of buying and installing the styrofoam and the quantity and cost of the excavation and backfill that can be replaced by the insulation.

Based on experience gained from several styrofoam insulation projects, the Dow Chemical Company has compiled average unit cost data for different areas of the country which include costs of material, freight and installation. Values applicable to the Michigan area are:

Styrofoam Thickness	Unit Cost per Square Foot
1 in.	\$0.1100
1-1/2 in.	0.1545
2 in.	0.2010
2-1/2 in.	0.2575

The unit costs of excavation and backfill, required for the conventional undercut method, vary with haul distances, subgrade condition, and cost of backfill materials. Although the volume of material involved can be computed, the unit cost must await the bid price. For this reason Figures 16 through 18 have been developed to allow a direct comparison of costs as soon as the unit cost of excavation and backfill are known. These figures show the cost at which conventional and insulation methods are equal. Higher or lower cost would determine the most economical selection. For example, in order for the two methods to be equal in cost the following relationship must exist:

$$QU = SA$$

or:

$$U = \frac{SA}{Q}$$

where: A = sq yd of styrofoam needed  
 S = unit cost of styrofoam - \$/sq yd  
 Q = cu yd excavation and back fill  
 U = unit cost of excavation and backfill - \$/cu yd

Thus, when the unit costs of excavation and backfill (U) are known, this value can be used as shown in Figure 16 to show whether this cost is above or below that of the corresponding required styrofoam insulation.

Using the M 47 project as an example, the following cost comparison could be made by the above method:

(a) From Figure 10, the required thickness of styrofoam should be 1-in. for the project test site (actually 1-1/2-in. thickness was used).

(b) Allowing 2-ft extensions in width on each side of the styrofoam, the total width should be  $24 + 2 + 2$ , or 28 feet.

(c) The volume of excavation required was 2.33 cubic yards per linear foot of pavement.

(d) From Figure 16 (for 28-ft wide styrofoam) it can be found by following Steps 1 and 2, that the cost for insulating this area would equal the cost of the conventional method if the unit cost of excavating and backfilling were \$1.30 per cubic yard.

(e) The actual bid price for excavating and backfilling was only \$1.18 thus, for this job, the conventional procedures would have been more economical.

Although it is necessary to know the bid price of excavation and backfilling before a positive comparison between costs of the two methods can be made, it often would be possible to estimate this cost close enough to decide whether the use of insulation would be economically feasible for consideration.

Should edge drains be required for the conventional undercut method, their estimated cost per lineal foot of pavement should be considered when comparing costs.

## SUMMARY AND CONCLUSIONS

Based on an evaluation of the Michigan styrofoam test project and on reports by other investigators concerning the performance of similar test installations, the following conclusions appear warranted:

1. Penetration of frost into the subgrade can be prevented by incorporating an adequately thick layer of styrofoam as part of the pavement structure.

2. The pavement surface of an insulated test section has had fewer freeze-thaw cycles each winter season than does the uninsulated control section. This reduction, however, is thought to be too small to have significant beneficial effect on pavement performance.

3. The range over which pavement surface temperatures vary, both daily and seasonally, is greatest for the insulated pavement section. However, this increase is quite small and probably will have no effect on pavement performance. This factor will be given close attention, however, in future observations of the project.

4. For the pavement section used in the M 47 project no lateral frost penetration occurred under the outer edges of styrofoam. For the coldest winter observed, however, the freezing index did not exceed 800 degree days. Other researchers have observed lateral frost penetration under more severe winter conditions. As a result, it is concluded that lateral frost penetration could occur in the Michigan test section should the freezing index exceed 800 degree days.

5. The styrofoam insulated test section, with a total pavement thickness of 26 inches, is sufficiently stiff, according to one deflection criterion, to perform satisfactorily over its A-7-6(14) clay subgrade. According to the same criterion, the control sections having a total pavement thickness of 39 inches, are stronger than the styrofoam test sections and much stronger than required to carry existing traffic.

6. Profilometer tests, show the riding quality of the styrofoam insulated section to be at least as good as that of the control sections.

7. Styrofoam insulation has been found to be an effective frost barrier by all other known reported investigations.

8. Insulating with styrofoam is a satisfactory alternative to the undercut-backfill method of treating frost-susceptible subgrades, and its cost under some conditions should be competitive.

9. The conservation of granular materials for future use is an important advantage gained by insulating frost-susceptible subgrade with styrofoam. Because the price of granular materials is based on availability and demand, any reduction in demand should result, to some degree, in lower material cost.

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