Use of Insulating Layer to Attenuate Frost Action In Highway Pavements

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Conventional methods of treating the detrimental effects of frost action are aimed at replacing or altering the frost-susceptible soils and/or controlling the water supply. The use of a Styrofoam insulating layer to attenuate frost action to reduce the effect of the freezing temperatures has been under study for the past 5 yr. Styrofoam insulating layers have shown promising results under test in a new flexible pavement at Midland, Mich., in a new rigid pavement near West Union, Iowa, and in a maintenance treatment of severe frost heave in flexible pavement near Minneapolis, Minn. A relatively smooth subgrade surface is required on which to place the Styrofoam boards, and an 8-in. thick lift of granular material placed over the Styrofoam will support construction traffic.

•FROST ACTION occurs in the presence of frost-susceptible soils, freezing temperatures, and a supply of water. Therefore, all solutions to the problem of frost action must be aimed at reducing or removing entirely the effect of one or more of these factors (1).

The most common approach to minimizing the effects of frost action is to replace the frost-susceptible soils with nonfrost-susceptible soils and provide adequate drainage for the pavement structure. Other methods utilize a layer of high heat capacity (2), a layer that cuts off moisture movements (3), or chemicals that retard freezing of the soil water (1).

From the standpoint of initial cost, effectiveness, and permanence, none of these methods is generally applicable to solving the wide range of problems with frost action encountered in highway construction.

The use of an insulating layer for attenuating frost action in highway and airfield pavements has been under study by Purdue University and the Dow Chemical Co. for 5 yr. A small-scale field test using a different insulating material was reported by the U. S. Army Corps of Engineers in 1962 (7). The work done at Purdue makes use of polystyrene plastic foam (Styrofoam) as the insulating layer.

Full-scale field test installations have been made in the northern United States and in Canada: three in Michigan, and one each in Iowa, Minnesota, Maine, Ontario, and Manitoba. One installation in Michigan and one in Manitoba are presently in their third winter. The installations in Iowa and Minnesota and the second one in Michigan are now in the second winter of service. The Maine and Ontario installations and the last one in Michigan were constructed during the summer of 1964.

This paper covers the results of the original installation in Michigan (5) and briefly reviews the Iowa and Minnesota installations.

DEFINITIONS

The following terms are used in this paper (6):

Mean annual temperature. The average of the average annual temperatures for several years.

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Degree-days. The number of degree-days for any day is the difference between the average daily air temperature and 32 F.

Freezing index. The number of degree-days between the highest and lowest points on a curve of cumulative degree-days vs time for one freezing season. The index determined for air temperatures at 4.5 ft above the ground is commonly designated as the air freezing index, and that determined for temperatures immediately below a surface is known as the surface-freezing index. The surface-air freezing index is used here to define the freezing index determined for air temperatures $2\frac{1}{2}$ in. above the pavement surface.

Design freezing index. The average air freezing index of the three coldest winters in the latest 30 yr of record. If 30 yr of record are not available, the air freezing index for the coldest winter in the latest 10-yr period may be used.

Mean freezing index. The freezing index determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 yr, and preferably 30, and should be the latest available.

n-factor. The ratio of surface freezing index to air freezing index.

k-factor. Thermal conductivity in units of Btu-in./sq ft-hr-°F.

Styrofoam. A type of polystyrene extruded and expanded 40 times; manufactured by the Dow Chemical Co., Midland, Mich.

Tautochrone. Vertical temperature variation in a test section at one point in time.

FIELD INSTALLATION

The original full-scale field test of the applicability of a foamed plastic insulating layer to attenuate frost action was built as part of an access road to the Dow Chemical Company plant at Midland, Mich., in 1962. This installation is presented to show use of the insulating layer in the construction of new flexible pavement. All freight trucks entering and leaving the plant used this road. As shown in Figure 1, traffic could be shifted at will to pass over the test sections.

The soil in the area is part of the lacustrine lake bed clays that cover parts of Michigan. The Michigan State Highway Department places this soil in the Selkirk series. In the Unified Classification System the subgrade soil would be a CH material. It is a brown plastic clay with gray mottlings. The index properties of this soil are given in Table 1.

Design of Test Installation

The load limits in Michigan are 18 kips per single axle and 32 kips per tandem axle. For traffic volumes less than 2,000 veh/day, the Michigan State Highway Department (8) recommends that a pavement section totaling $28\frac{1}{2}$ in. be used where subgrade soils have a CBR of 5 and frost action is not considered a serious problem. The section

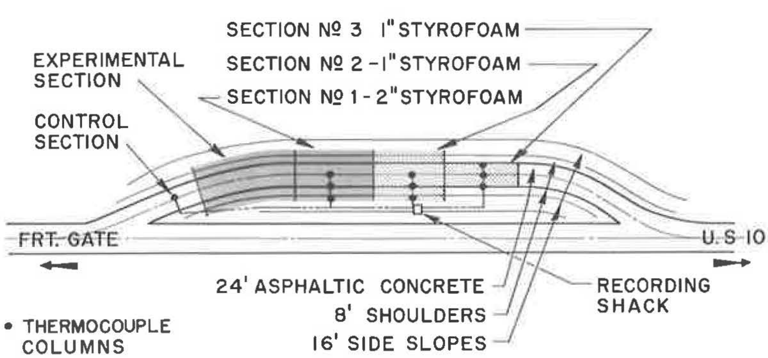

Figure 1. Plan of test installation, Midland, Mich.

TABLE 1

PROPERTIES OF SUBGRADE SOIL, MIDLAND, MICH.

Property	Value
Natural water content (%)	23-26
Liquid limit	55-60
Plastic limit	22-25
Plasticity index	30-38
% < No. 200 U.S. standard sieve	97
Clay fraction (% <0.002 mm, approx.)	70
In situ wet density (pcf)	122
Optimum density (standard proctor, pcf)	101
Optimum moisture content (%)	23
Soaked CBR	5-10

consists of a $2\frac{1}{2}$-in. surface of asphaltic concrete, an 8-in. base of crushed gravel; and an 18-in. subbase of porous material Grade A. Where frost action is a problem, it is recommended that the subbase be increased 12 to 18 in. or more. A section with a 26-in. subbase was used as the control section. For the insulated test sections it was felt that frost action would not be a problem, hence the subbase thickness was reduced to 14 in.

McCammon (9) conducted a controlled model study which indicated that 1 in. of foamed plastic insulation could attenuate freezing temperatures at Midland if one-dimensional heat flow could be assured. Accordingly, two thicknesses of the insulating layer were used in the test sections—1 and 2 in.—and their widths were varied to define the limits within which one-dimensional heat flow might occur in the road. Section 1, with a 50-ft width and 2-in. thickness of the insulating layer, is shown in Figure 2; section 2, with a 50-ft width and 1-in. thickness, is shown in Figure 3; section 3, a 26-ft width and 1-in thickness, is shown in Figure 4.

Instrumentation to measure thermal performance during the winter months consisted of thermocouples. These were placed to give temperatures with depth at the centerline, at the edge of pavement, and at the edge of the insulating layer of the three test sections. The thermocouples were connected to Minneapolis-Honeywell strip-chart recorders. Temperatures were recorded at intervals of 2 to 5 days, usually between 8 and 10 a.m.

Temperature Observations and Results

Temperature observations were made at the test installation during the 1962-1963 and 1963-1964 winters. The results of the 1962-1963 winter are presented here since they give performance during a winter that was more severe than the usual design condition for the Midland, Mich., area. The results of the mild 1963-1964 winter were

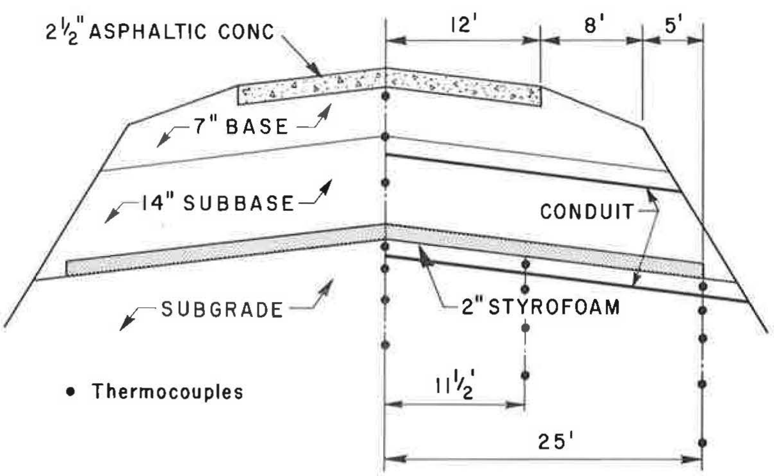

Figure 2. Instrumentation and cross-section of section 1, Midland, Mich.

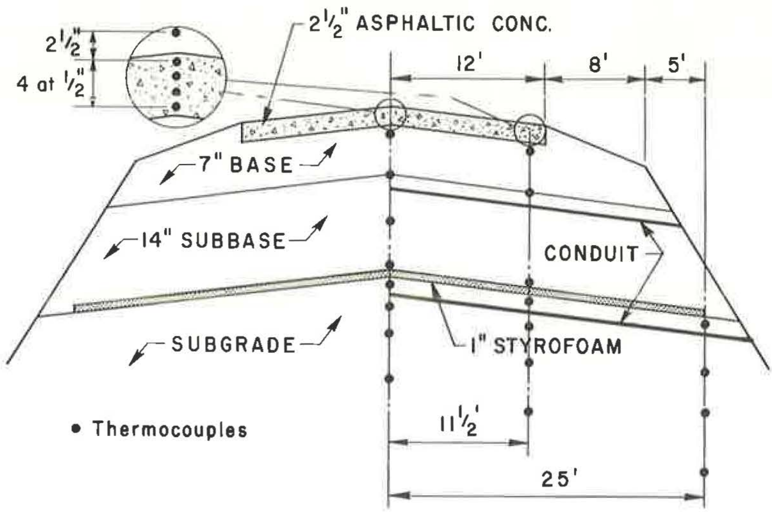

Figure 3. Instrumentation and cross-section of section 2, Midland, Mich.

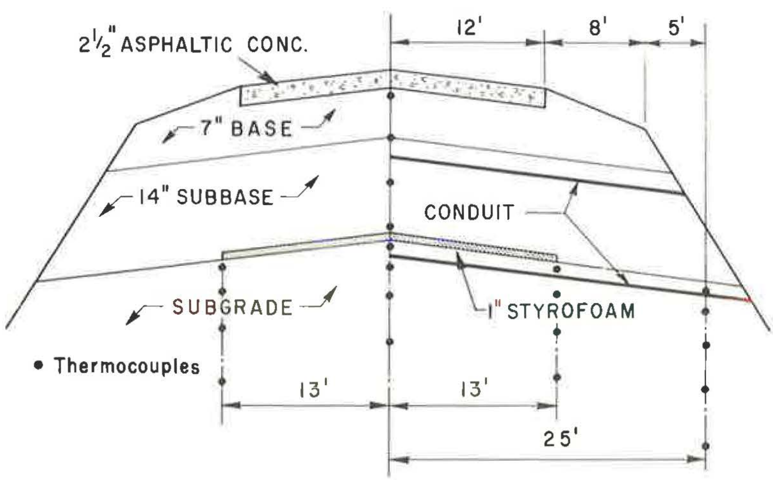

Figure 4. Instrumentation and cross-section of section 3, Midland, Mich.

similar but did not show frost penetrations as deep or temperatures as severe as recorded the previous winter. However, they are summarized later for comparison purposes.

The mean freezing index for the Midland area is 850 degree-days. The design freezing index for the area is 1,300 degree-days and usually spans 110 days. The mean annual temperature is 44 F at this location (10).

The 1962-1963 winter was the coldest in 26 yr at the Midland weather station. A freezing index of 1,263 degree-days was recorded over a 99-day period as shown in Figure 5. At the Tri-City Airport, some 10 mi southeast of Midland, a freezing index of 1,622 degree-days was recorded over 107 days. The Midland weather station is located some 15 ft from the Tittabawasee River which undoubtedly moderates the temperature and accounts for the 360-degree-day difference in the freezing index.

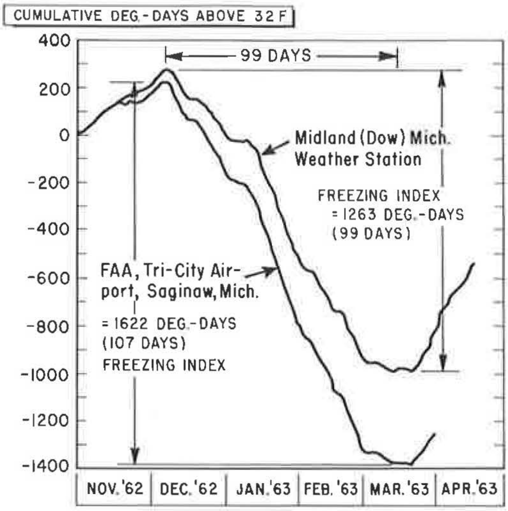

Figure 5. Cumulative degree-days above and below 32 F at Midland and Tri-City Airport weather stations.

The test installation is ½ mi from the Midland weather station and about 100 yd from the river. The surface-air freezing index determined from temperatures recorded at the test installation was 1,302 degree-days. The surface freezing index was found to be 1,261 degree-days.

n-Factors

Kersten's study of n-factors in Minnesota showed a range from 0.6 to 0.8 (12). Sanger, in discussion of Kersten's paper, states that an n-factor of 0.9 ± 0.05 was found from a statistical analysis of U. S. Army Corps of Engineers' data. Quinn and Lobacz found n-factors of 0.98 for an insulated portland cement concrete slab and 0.66 and 0.71 for uninsulated portland cement concrete slabs (7).

Using the air freezing index of the Midland weather station, an n-factor of approximately 1.00 is obtained; using the air freezing index of the Tri-City Airport, an n-factor of 0.78 is obtained; and using the surface-air freezing index at the test site, an n-factor of 0.97 is obtained. These values indicate that local environmental conditions at a weather station can materially affect the computed n-factor.

Temperatures in Test Sections

1962-1963 Winter.—In the interest of brevity, only those measurements defining progressive temperature changes at critical points in each test section will be presented. The times for which tautochrones are shown correspond to:

1. End of construction;
2. After start of freezing season;

3, 4, 5. Times when lowest temperatures were recorded above and below the insulating layer;

6. End of freezing season; and
7. Approximate time of spring breakup.

In section 1 (2-in. Styrofoam), the temperature above the insulating layer reached a minimum of 8 F on Jan. 15, as shown in Figure 6. At the same time, the temperature below the insulation was 42.5 F, or a differential of 17 F/in. of insulation. The minimum temperature below the insulation, 38 F, was recorded March 1.

It is of interest to note that at the start of the freezing season, Dec. 6, the temperature at the top of the subgrade was 50 F. This is 6 F above the mean annual temperature for this area.

At the centerline of section 2 (1-in. Styrofoam), the temperatures shown in Figure 7 were recorded. On Jan. 28, the minimum temperature above the insulation was 14 F and below the insulating layer was 31.7 F. Again, the differential was 17 F/in. of insulation.

If 32 F is considered the freezing point, although undercooling and freezing point depressions are known to exist, the temperature gradients indicate a "frost penetration" of about 2 in. (noted by the arrow on Figure 7.) The existence of frost was verified nearly a month later, on Feb. 20, when a core of the subgrade revealed randomly oriented ice lenses about 2 mm thick to a depth of ½ in. below the insulation. The temperature recorded just below the insulation at this time was 32.8 F. This discrepancy is not incompatible with the accuracy of the measurements, which is believed to be on the order of 1 F.

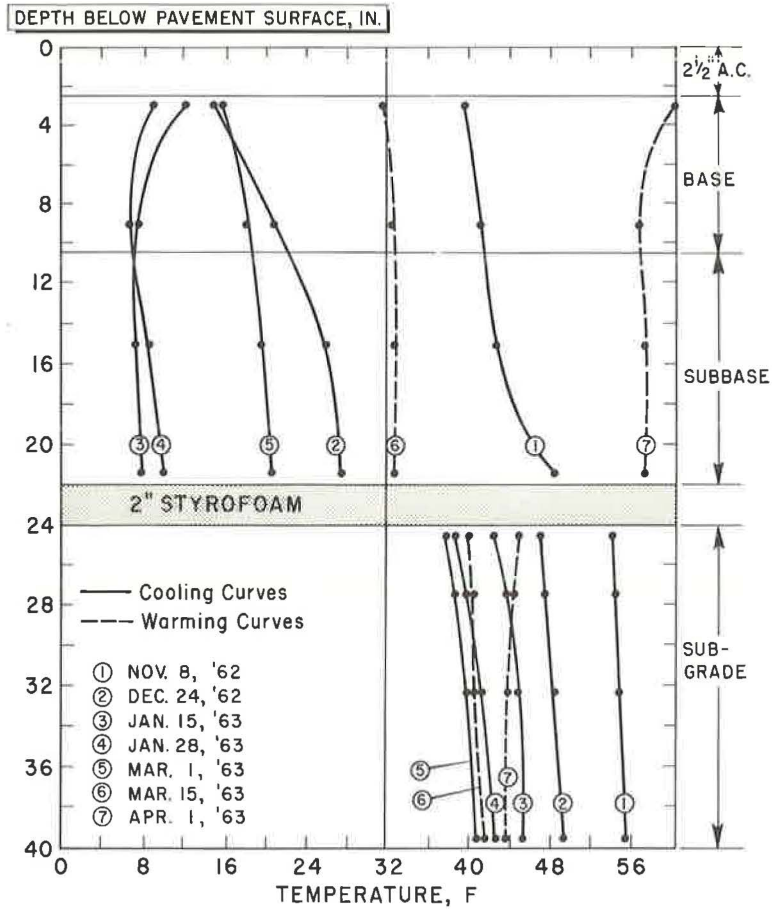

Figure 6. Temperatures at selected times, section 1 centerline (2-in. Styrofoam insulation), Midland, Mich.

The temperatures recorded at the centerline of section 3 were similar to those recorded at the centerline of section 2.

The depth of the 32 F isotherm was interpreted from the recorded data and is plotted in Figures 8, 9, and 10.

The shaded areas in Figure 8 show the zones within which the temperature dropped below 32 F at the centerline, edge of pavement, and edge of insulation in section 1. No frost penetration was found beneath the 2-in. insulating layer at the centerline or pavement edge where one-dimensional heat flow was occurring. At the edge of the insulation (5 ft out from the shoulder), two-dimensional heat flow occurred and the 32 F isotherm penetrated to 20 in. below the edge of the insulation by March 15.

Data similar to that of Figure 8, but for section 2, are shown in Figure 9. "Frost" penetrated to a maximum of 6 in. below the insulating layer at the edge of pavement about March 1. About Feb. 1, temperatures below 32 F were also noted at this same point to a depth of 3 in. These "frost" penetrations lasted for 5 to 10 days (until the surface conditions became warmer and the heat flow from the earth was sufficient to raise the temperature above freezing). At the edge of the insulating layer, frost penetrated to a depth of 20 in. in a situation similar to that found in section 1.

In section 3, where the 1-in. insulating layer extended only 1 ft beyond the pavement edge, the frost penetration at the centerline was found to be similar to that of section 2

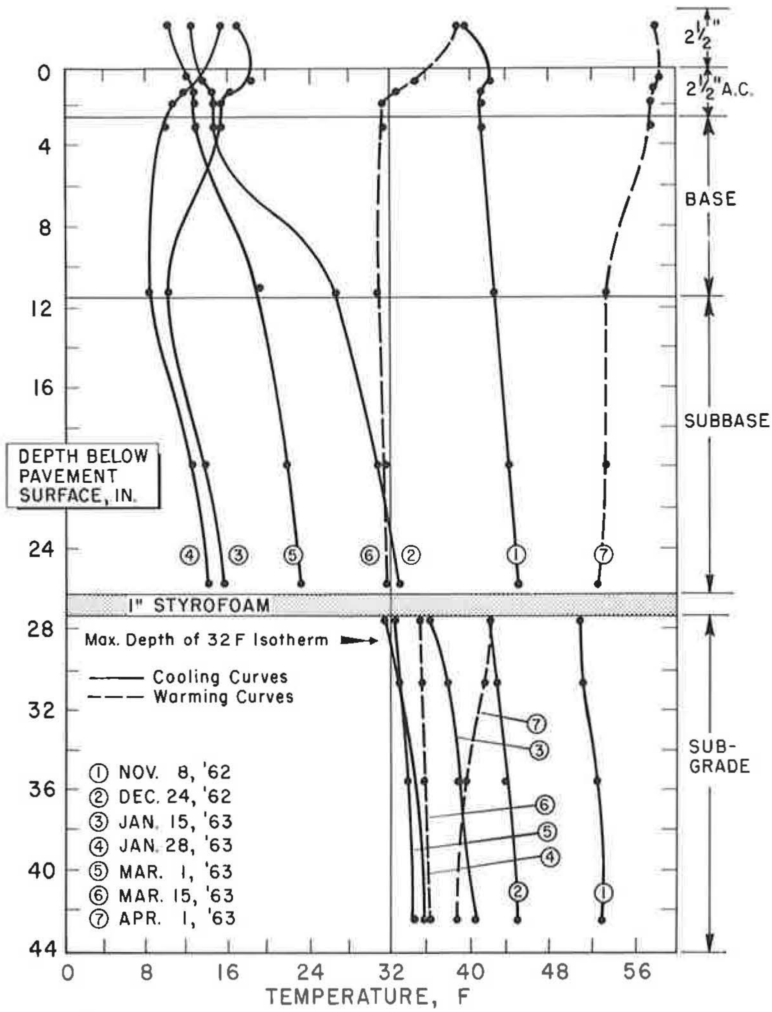

Figure 7. Temperatures at selected times, section 2 centerline (1-in. Styrofoam insulation), Midland, Mich.

(Fig. 10). At the edge of the insulating layer (or the edge of pavement) "frost" penetrated 15 in. on the left and 19 in. on the right into the subgrade—a situation again very similar to that found at the edge of the insulation in sections 1 and 2.

Frost penetration at the edge of the pavement was 15 to 19 in. below the insulating layer throughout February. This was verified by a soil core taken Feb. 20 at the right edge of the pavement. The core showed ice lenses in the subgrade to a depth of 18 in. These were $^1/_{16}$ to $^1/_8$ in. thick and occurred at intervals of about $^1/_2$ in., totaling approximately $^1/_2$ in. of ice. The moisture contents in this zone had increased some 20 percent from the moisture contents at the time of construction.

Heaves of about 0.40 in. were found at the pavement edge in section 3, but no movement was found at the centerline where frost penetration was negligible. This is compatible with the ice formation found in the soil cores.

Some selected temperatures recorded in the control section are shown in Figure 11. The minimum temperature recorded at the top of the subgrade was 27 F on Feb. 27.

To estimate the full depth of frost penetration in the control section, an extrapolation was made based on a temperature gradient of 3 F/ft. This placed the frost penetration at $4^1/_2$ to 5 ft. From tautochrones 7 and 8 (Fig. 11) it is estimated that frost did not leave this section until April 2.

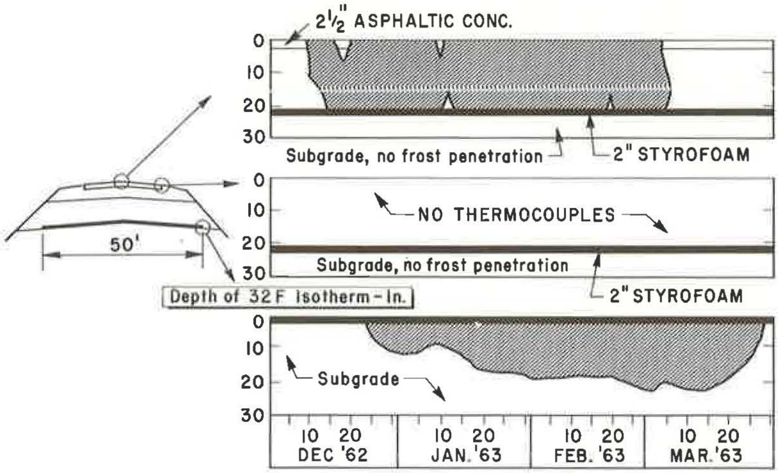

Figure 8. Depth of 32 F isotherm with time, section 1, Midland, Mich.

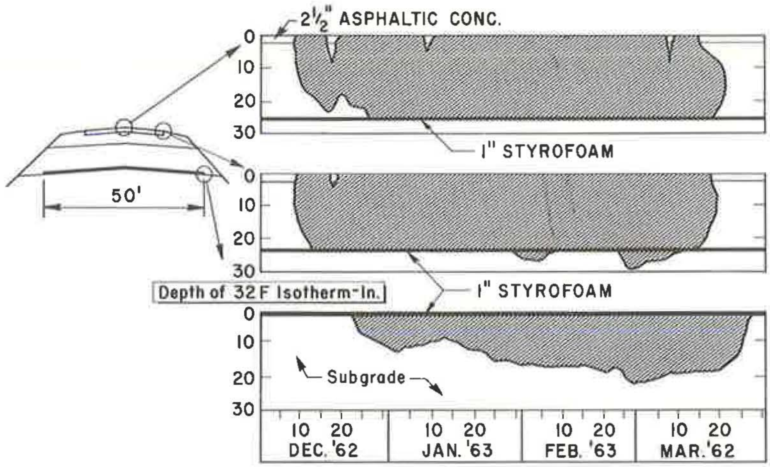

Figure 9. Depth of 32 F isotherm with time, section 2, Midland, Mich.

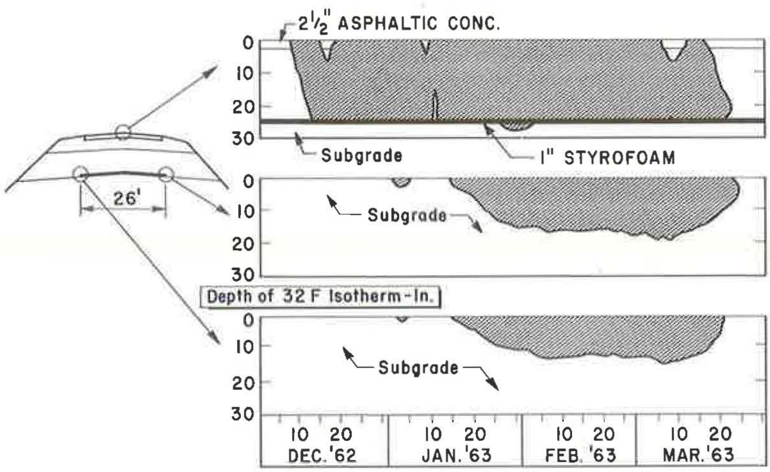

Figure 10. Depth of 32 F isotherm with time, section 3, Midland, Mich.

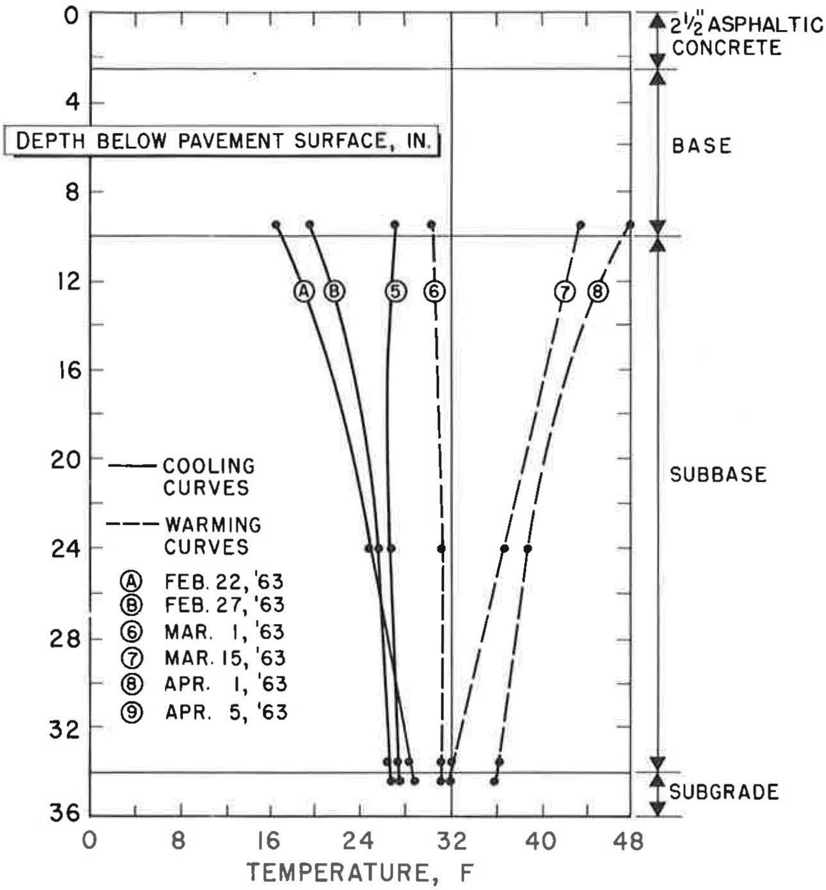

Figure 11. Temperatures at selected times, control section centerline, Midland, Mich.

1963-1964 Winter.—This winter was considerably milder than the previous one. A freezing index of 700 degree-days was recorded at the Midland weather station and 689 degree-days at the Tri-City Airport weather station over a 91-day freezing season. This is some 100 degree-days less than the mean freezing index for the area and 560 to 980 less than those recorded the previous winter.

The temperatures recorded below the insulating layer in the insulated test sections were 2 to 5 F above those recorded the previous winter. The frost penetration into the subgrade at the edge of the insulating layer (edge of pavement) in section 3 was 5 to 10 in. In the control section the depth of frost penetration into the subgrade was estimated to be 6 to 10 in., or one-third of that found the previous winter.

Moisture Conditions in Insulated Sections

The effect of the insulating layer on the moisture regime in the pavement structure was an intriguing question at the start of this investigation. Colman soil moisture cells (Model 351, Beckman Instruments, Inc.) were installed in sections 2 and 3 in an attempt to give a picture of the changes that might take place. It soon became apparent that prior calibration curves were invalid. Hence, soil cores were taken at various times to give the desired data.

Figure 12 shows the moisture contents obtained from soil cores in section 2. Above the insulating layer, the moisture content of the subbase increased substantially during the winter months. The water contents (frozen) of 14 to 17 percent recorded Feb. 20, 1963, are nearly equivalent to 100 percent saturation for this soil. When the ice in the

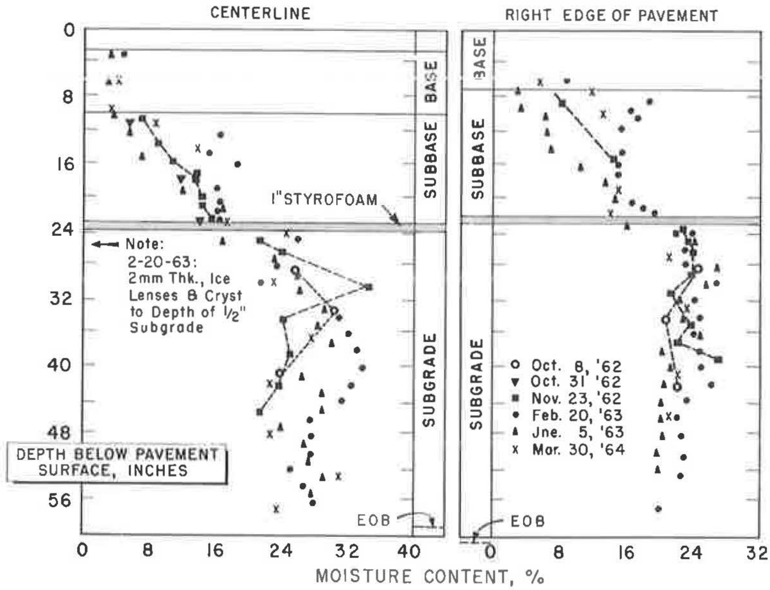

Figure 12. Change of moisture content with time, section 2, Midland, Mich.

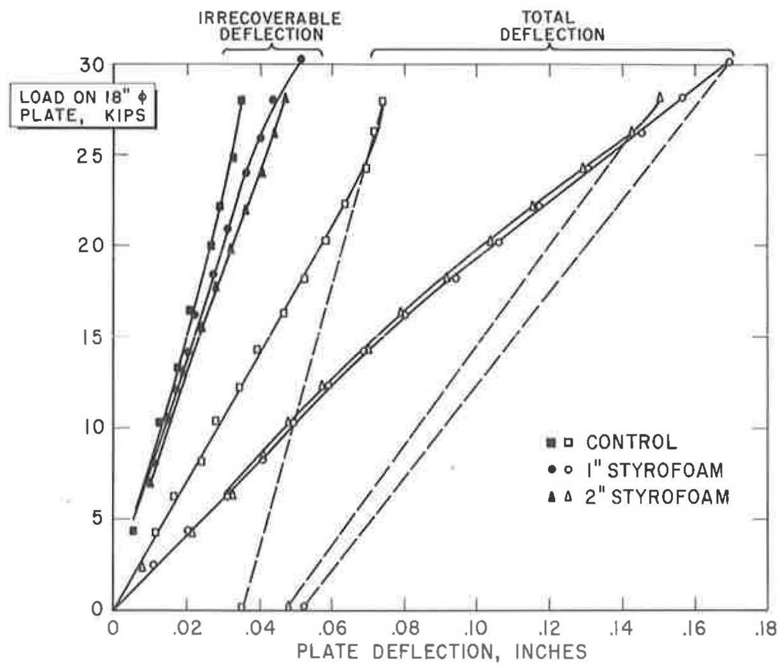

Figure 13. Results of plate loading tests on test sections, spring 1964 (after 2 winters of service), Midland, Mich.

subbase melted at the end of the freezing season, it undoubtedly contributed to some loss of supporting strength in the pavement structure. As ice melted from the shoulders, the subbase drained and the capacity of the pavement was restored substantially to its initial condition, as indicated by load test data.

TABLE 2

k-FACTORS AND WATER PICKUP OF STYROFOAM INSULATING LAYER, MIDLAND TEST INSTALLATION[a]

Layer Thickness (in.)	Water Pickup (% by vol)	k-Factor $\left(\frac{\text{Btu-in.}}{\text{sq ft-hr-}^\circ\text{F}}\right)$		
		Wet	Dry	Δk
1	0.65	0.27	0.25	0.02
2.1	0.34	0.25	0.24	0.01

[a]After two winters ($1\frac{1}{2}$ yr) of service.

Just below the insulating layer, moisture contents at the centerline increased about 8 percent during the freezing season, but by June 5 they had essentially returned to the initial condition.

Load-Carrying Capacity

To assess the comparative load-carrying capacity of the insulated and uninsulated test sections, load tests were performed immediately after construction (November 1962), in the spring of 1963, and again in the spring of 1964. A typical set of results is shown in Figure 13.

From the load vs total deflection curves, it is evident that the insulating layer increases the temporary deflection of the pavement materially; however, for wheel loads under 10 kips the deflection is less than 0.05 in., which is considered tolerable in the case of flexible pavements (13).

The irrecoverable deformation vs load curves show that the support provided by the insulated and uninsulated sections are comparable, even though the control section has an added subbase thickness of 12 in. This suggests that the Styrofoam provides a cushioning effect which distributes subgrade stresses more evenly, thereby adding a useful structural function to its insulating qualities. Further studies of the structural advantages which may accrue through the use of a Styrofoam insulating layer are currently in progress.

Insulating Layer Properties

Samples of the insulating layer were removed on April 4, 1964, to determine the physical properties of the insulating layer after two winters of service. The effectiveness of an insulating layer is dependent on the permanence of its thermal properties. The k-factors for wet and dry specimens are given in Table 2.

The wet k-factors were determined for the samples as they were taken from the test installation. After drying to remove the water in the specimen, the k-factor test was rerun to determine the effect of moisture pickup.

The type of insulating layer used in this test—Styrofoam SM brand insulation—is especially resistant to moisture pickup and, hence, should not change appreciably in thermal conductivity. The water pickup (percent by volume) by these specimens was small and the changes in k-factor that resulted from this minor amount of moisture pickup were not detected by the k-factor test. The limit of accuracy of the test is 0.01 Btu-in./sq ft-hr-°F.

Further testing along this line is being conducted by the Dow Chemical Co. using accelerated freeze-thaw tests to determine the freeze-thaw durability of various insulating materials that might be used to attenuate frost action beneath pavements.

Summary and Conclusions

The first full-scale field test installation using a foamed plastic insulating layer in a flexible pavement showed that:

1. A 1-in. thickness of Styrofoam insulation effectively prevented frost action in the subgrade of a flexible pavement in an area where the freezing index reached 1,600 degree-days.
2. A width of insulation some distance beyond the pavement edge is required to prevent frost formation beneath the pavement. Studies are presently under way to determine the lateral extent of the frozen zone at the edge of the insulating layer.
3. Frost penetrations beneath a foamed plastic insulating layer to a depth of 6 in. for a short period of time did not appear to be detrimental. Heat flow from the earth dissipated the ice formed as soon as a temporary cold cycle passes.
4. The excess moisture that collects in the subbase during the freezing season is responsible for some of the loss in bearing capacity during spring breakup.
5. The presence of an insulating layer that is essentially impermeable to moisture did not cause moisture concentrations in the subgrade over a period of 2 yr.
6. The insulating layer showed negligible moisture pickup and, hence, no significant change in thermal conductivity after two winters of effective performance.
7. The foamed plastic insulating layer reduced the thickness of the flexible pavement structure normally required for satisfactory performance in frost areas. Studies are currently under way to establish its economic applicability.

IOWA TEST INSTALLATION

The Iowa test installation was constructed in 1963 2 mi west of West Union, Iowa, on US 18. The original concrete pavement was badly cracked, and in certain areas had experienced perennial frost heaves. In these areas the conventional subgrade treatment was to remove the subgrade soil for a depth of 3 ft and replace it with a nonfrost-susceptible material. In one of these treatment areas a Styrofoam insulating layer 1½ in. thick was used in lieu of the 3 ft of nonfrost-susceptible material for 250 ft of the 450-ft treatment.

Figure 14 shows the cross-sections and the instrumentation placed in the two treatments. The conventional treatment served as the control section in this installation. Another section similar to the insulated section, but having two layers of the insulating material, each ¾ in. thick, was also instrumented.

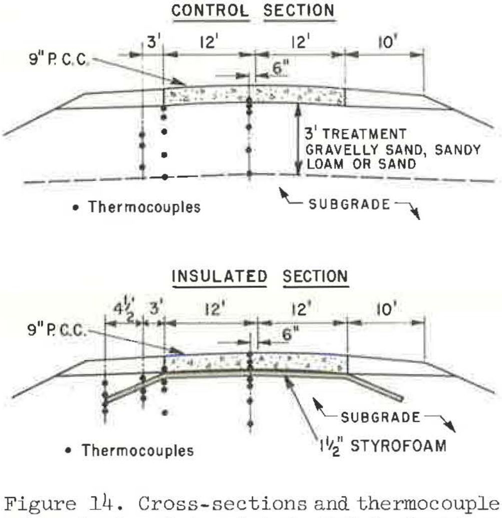

Figure 14. Cross-sections and thermocouples of control and insulated P.C.C. Sections, West Union, Iowa.

The freezing index for the 1963-1964 winter at Waterloo, Iowa, some 40 mi southeast of the test installation, was 1,217 degree-days over 130 days. An air thermocouple at the site furnished data for computing a 1,461 degree-day freezing index, also over a period of 130 days. The mean freezing index for this area is 1,100 degree-days over a 105-day period and the design freezing index was 1,700 degree-days (10).

Temperatures at this installation were recorded from 24 thermocouples at 2-hr intervals by a strip-chart recorder. At weekly intervals, data were taken for 1 day from 24 additional thermocouples.

The temperatures recorded above and below the 1½-in. Styrofoam insulating layer during the 1963-1964 winter are shown in Figure 15. The 8:00 a.m. tem-

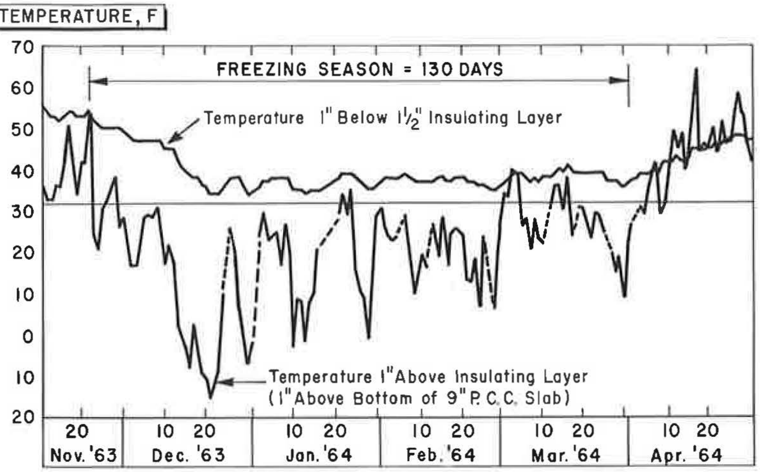

Figure 15. Temperatures above and below insulating layer throughout 1963-1964 freezing season at 8:00 a.m., West Union, Iowa.

peratures were chosen as being representative of the performance of the insulating layer. During the freezing season the temperature above the 1½-in. insulating layer dropped as low as -15 F. The temperature below the insulating layer never dropped below 34 F.

Intermittently, heat flow from the earth and relatively warmer surface temperatures caused the temperature below the insulating layer to rise 3 to 5 F.

Freezing indices were computed from the data of several thermocouples in the insulated and control sections using a computer program developed by Straub and Wegmann (11). The freezing indices computed from these thermocouples are shown in Figure 16.

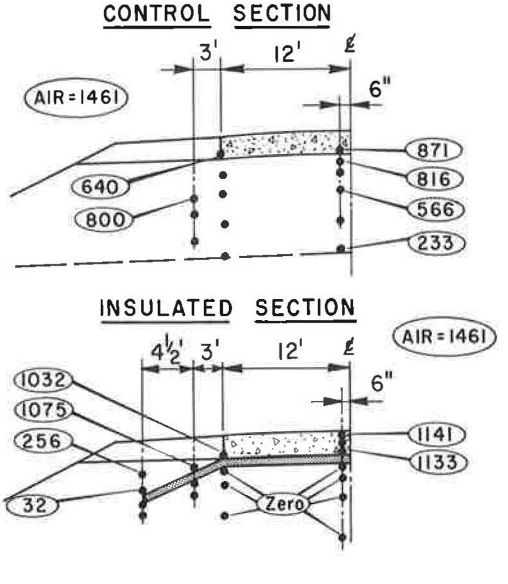

Figure 16. Computed freezing indices at various points in control and insulated sections, West Union, Iowa.

In the control section, the freezing index at the bottom of the treatment (-46 in.) was 233 degree-days. Extrapolation of the tautochrone below this point at Jan. 15 places the frost line at -5 ft.

The n-factor for the insulated section was 0.77. Based on an increase of 16 degree-days per inch of concrete (7), the surface freezing index of the control section would have been 983 degree-days. This would give an n-factor of 0.67. A smaller gradient, as the 10 degree-days presently recommended by the Corps of Engineers (7), would give an n-factor of 0.65. These values are similar to those reported by Kersten from his Minnesota study (12). In the absence of an air thermocouple near the pavement surface, a surface air freezing index (and its corresponding n-factor) could not be computed.

During the first year of service, the insulated section (with the concrete directly on the insulating layer) showed no visual evidence of structural deterioration. In the early summer of 1964, 3 in. of asphaltic concrete were placed on US 18 throughout the area under study so that the pavement section now totals 12 in.

Moisture samples taken from the control and insulated sections in April 1964 showed that the moisture content of the silty clay subgrade ranged from 15 to 17 percent. Original specifications required compaction at 18 percent moisture.

Centerline elevations taken during February 1964 showed that since December the section of conventional treatment had heaved 0.03 ft, the Styrofoam treatment heaved 0.02 ft, and an adjacent untreated area had heaved 0.08 ft. In May the elevations were about equal to those recorded in December. It is considered that the apparent anomaly of frost heave occurring in the Styrofoam area, where no freezing temperatures were recorded in the subgrade, is the result of leveling error.

Summary and Conclusions

1. A 1½-in. Styrofoam insulating layer placed directly on a frost susceptible subgrade prevented frost penetration beneath a rigid pavement during a normal winter in northeastern Iowa.
2. Based on the temperatures recorded in the subgrade of both frost action treatments and on observations of comparative performance, the 1½-in. insulating layer effectively replaced more than 3 ft of granular material.

MINNESOTA INSTALLATION

The installation in Minnesota was made during 1963 as a maintenance operation by the Minnesota Highway Department on Trunk Highway 25 about 25 mi southwest of Minneapolis. This highway had experienced frost heaves of 0.2 to 0.4 ft, developed chuckholes, and required perennial spring repairs. The original pavement section was, in general, 6 in. of bituminous concrete, 10 in. of loamy sand, and a sandy, silty, clay loam subgrade.

In the two heave areas treated (48 and 68 ft long), the pavement was removed to a depth of 23½-in. Then a 2-in. thickness of Styrofoam, 30 ft wide, was placed on the subgrade. This was then covered by 17 in. of sand and gravel and 3 in. of bituminous concrete. An additional 1½ in. of bituminous concrete was then placed as resurfacing for the entire area.

Thermocouples were installed to give an indication of performance. These were read infrequently and gave only enough data to determine that freezing did not occur below the insulating layer during the 1963-1964 winter, which had a freezing index of 1,500 degree-days over 124 days.

During the winter, levels run through the treated areas showed no change in elevation. However, at the end of the insulating layer treatment, heaves up to 0.35 ft were recorded.

In general, this installation performed well and has given assurance that the insulating layer can be especially helpful in severe problem areas.

SUMMARY OF CURRENT CONSTRUCTION TECHNIQUES

Subgrade

The use of Styrofoam brand insulation boards requires that the subgrade be fine-graded so that deviations from a 10-ft straightedge are in the range of ± ½ in. This is intended to prevent puncture damage from clods of soil and cracking damage if an uneven support condition exists when granular materials are placed on the Styrofoam. Figure 17 shows Styrofoam being placed over an acceptable subgrade at a Michigan installation.

For a rigid pavement, the usual grading requirements for placing concrete are sufficient and the Styrofoam insulation can be placed without additional work. Figure 18 shows Styrofoam being placed at the Iowa installation.

Alignment

The long dimension of the 2- by 8-ft Styrofoam boards is kept parallel to the centerline by means of a stringline. The boards are secured in place by driving three or four

Figure 17. Styrofoam insulating layer being placed on graded subgrade for flexible pavement in Michigan.

Figure 18. Placement of Styrofoam insulating layer for concrete pavement in Iowa.

pointed wooden dowels ($\frac{1}{4}$ by 6 in.) through the foam into the subgrade as shown in Figure 17. This not only keeps the boards in place during placement operations, but also enables the use of uncaulked butt joints between boards.

In the original installation at Midland, the thermal efficiency of various joints was investigated. It was found that butt joints, with a gap less than $\frac{1}{4}$ in. between boards, allowed the temperature at the bottom of the joint to fall only several degrees below the temperature recorded below a perfectly sealed, insulating joint. It is felt that the cost involved in sealing and insulating a joint does not justify the small increase of thermal efficiency that would be realized.

Good alignment and tight joints are maintained by working outward from the string line in a step pattern and driving the wooden skewers at an angle to keep the board being placed from drifting away from those placed previously. Staggering the joints also helps to maintain alignment and tight joints. Figure 17 also shows these details.

Labor used on these installations have been primarily contracter's personnel. However, in one case the laborers were obtained from the local unemployment office. Even with these inexperienced people, there was no problem in obtaining the desired quality of workmanship. The installation techniques were explained and demonstrated in a few minutes.

Figure 19. Placement of concrete on Styrofoam insulating layer in Iowa.

Figure 20. Spreading subbase to 8-in. depth on Styrofoam insulating layer in Michigan.

Pavement Structure Above Styrofoam

For a rigid pavement the insulation is placed inside conventional concrete paving forms and the concrete is placed directly on the Styrofoam as shown in Figure 19. After the forms have been removed the shoulder area is graded and the Styrofoam boards to insulate the shoulder area are butted against those at the bottom of the slab.

For a flexible pavement the granular material in the layer immediately above the Styrofoam is either end dumped at the edge of the treated section or spread alongside the insulation. A bulldozer or grader is then used to spread the granular material over the Styrofoam in a layer at least 8 in. thick as shown in Figure 20. This thickness is required to prevent excessive stress on the Styrofoam by construction equipment. This lift can then be compacted or used as a roadway for the trucks or earthmoving equipment hauling granular material. Vibratory compaction by a plate-type compactor is recommended because of its efficiency and relatively light weight, although other methods have been used to obtain the required density.

At this point normal construction equipment and techniques required for placement of the remainder of the pavement structure can be used without danger of damaging the Styrofoam insulating layer.

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