FIELD EVALUATION OF STYROFOAM AS INSULATION AGAINST FROST EFFECTS IN FLEXIBLE PAVEMENT FOUNDATION COMPONENTS

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SYNOPSIS

This report describes the construction of a highway test section in which an insulating layer of foamed plastic (Styrofoam) was placed over the subgrade in an effort to eliminate or reduce frost action.

The test area is 300-ft long and extends the full width of the pavement and shoulders. Two adjoining 300-ft long control sections permit comparison between the insulated section and normal construction. The sections are instrumented with thermocouples, placed within and below the pavement structure. By this means, detailed information concerning temperature variations can be obtained at any time. Supplemental instrumentation was provided for measuring depth of frozen areas and their moisture contents.

The project is now undergoing periodic performance observations. Preliminary results indicate that the Styrofoam has prevented penetration of frost into the subgrade during periods when frost had penetrated through uninsulated areas. However, more observations and study will be required before full effects of the insulation can be properly evaluated.

For several years, the Dow Chemical Co. has been testing the value of foamed plastics (Styrofoam) under both concrete and asphaltic surfaces, for insulating pavement subgrade against the effects of freezing temperatures. The highway departments of Iowa, Maine, Minnesota, and Manitoba, Canada, have placed test installations using Styrofoam as an insulating medium, and the Dow Chemical Co. has an installation of this type at their Midland, Michigan plant. Construction and preliminary findings of these tests have been reported. [1,2,3,4]

On May 29, 1963, a cooperative project with the Dow Chemical Co. was approved by the Department's Pavement Selection Committee, in which the value of Styrofoam was to be determined for preventing frost action in the subgrade of an asphalt pavement. At this time a section of the M 47 relocation project was approved as suitable for the test, and the experimental installation was included as part of Control Sections SS 73031A, C9 and Mb 73031A, C8 (Federal No. 5164(4)), awarded to the Sargent Construction Co. of Saginaw.

For this project, Dow agreed to provide the Styrofoam and house the data recording apparatus without cost to the Department and to assist in supervising the Styrofoam's installation. Responsibility for evaluating and reporting the findings was assigned to the Research Laboratory Division.

Representing the Department on this project were William Travis, Project Engineer; Paul Baumgartner, Soils Engineer; and E. C. Novak of the Research Laboratory, who was in charge of the test installation. Dow was represented by Marvin Oosterbaan.

The project was constructed during the Fall of 1963, and opened to traffic in late October without the final wearing course, which was placed in June 1965. Periodic instrumentation readings began on a continuing basis in January 1965.

Project Description

The test project forms part of the M 47 relocation construction just south of M 46 near Saginaw. A general plan of the area and section views of the different components of the test section and adjoining pavement are shown in Fig. 1. The test section is 300-ft long with 50-ft transitional areas at each end, in which the Styrofoam slopes to the full 25-in. depth of the adjoining sand subbase. These transition zones are not considered parts of the test area.

Two 300-ft long control sections of conventional bituminous pavement are located adjacent to the two transition zones. These are being used for performance comparisons with the Styrofoam-modified area. As shown in Fig. 1, the control and the test sections are the same, except that in the test section 1-1/2-in. of Styrofoam has replaced 13-in. of sand subbase.

The grain size analysis and other properties of the clay subgrade soil are listed in Table 1. This soil is of the Selkirk series and is considered to be susceptible to frost action. It is normally excavated to a depth of 25 in. below grade and replaced by a porous sand fill.

The Styrofoam used is a rigid polystyrene foamed plastic, manufactured by Dow. It was supplied in 2 ft by 8 ft by 1-1/2 in. sheets. Styrofoam is extremely light in weight, has a relatively high compressive strength, will not absorb moisture, is chemically inert, and is an excellent insulating material.

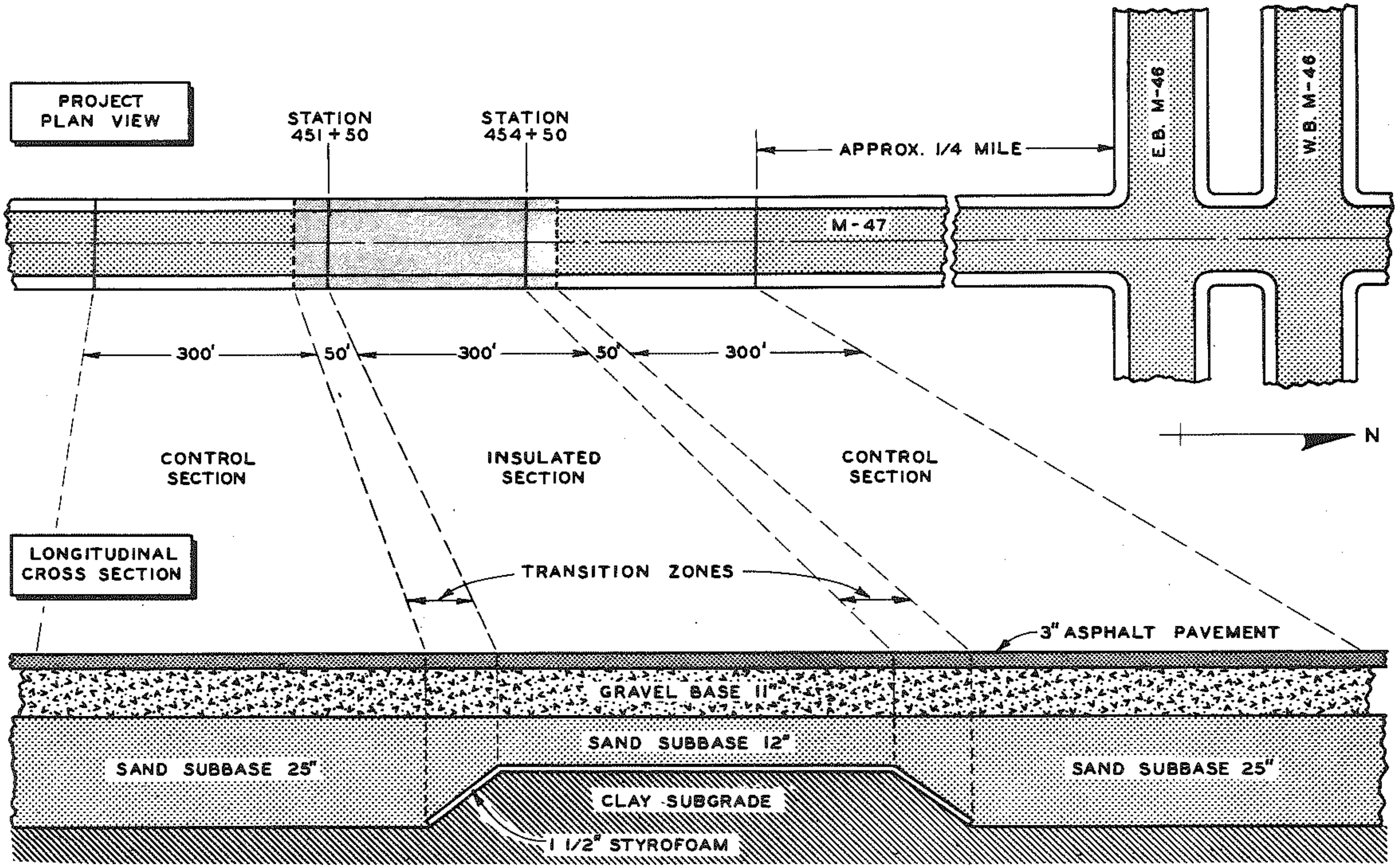


Figure 1. Project location and longitudinal cross section.

Construction Operations

The clay subgrade was brought to proper elevation and shaped as smooth as possible. Average dry density of this material was 121.1 pcf, as determined by 10 Rainhart tests taken at random locations within the test area. Rainhart values ranged from 111.9 to 133.5 pcf, and were considerably higher than maximum densities determined by the T-99 compaction test (Table 1). Fig. 2 shows this subgrade just before placing the Styrofoam, with a stringline used down the roadway centerline as a reference in aligning the first row of plastic sheets.

TABLE 1
SUBGRADE SOIL PROPERTIES
AASHO Classification A-7-6 (14)

Mechanical Analysis (Average of 19 tests)			
Sieve Analysis		Hydrometer Analysis	
Sieve Size	Percent Passing	Fraction	Percent
No. 4	100.0	Coarse Sand	5.1
No. 10	98.7	Fine Sand	17.4
No. 40	94.9	Silt	19.9
No. 200	77.5	Clay	57.6

Atterberg Limits, percent*		Moisture - Density	
Liquid Limit	42.3	Maximum Density (T-99)	113.8 pcf**
Plastic Limit	18.8	Optimum Moisture	15.0%*
Plasticity Index	23.5	Field Dry Density (Rainhart)	121.1%*
		Field Moisture	18.6%*

* Average of 10 tests
** Average of 9 tests

Consecutive steps in construction of the test section are shown in Figs. 3 and 4. After unloading from vans, the Styrofoam sheets were stored temporarily along the side of the construction site. They were placed directly on the subgrade, and fixed in place by 5-1/2 in. long wooden pegs. The 2 by 8 ft sheets were staggered half their length in alternating rows, each being held in place by at least four pegs. They were butt-jointed as tightly as possible, without use of sealer at the joints. After thorough inspection, the sheets were covered by the sand subbase. This material was pushed ahead of the grader so that it rode on sand, thereby protecting the Styrofoam layer.

Figure 2. Appearance of prepared subgrade immediately before Styrofoam placement; note stringline used for alignment of Styrofoam sheets.

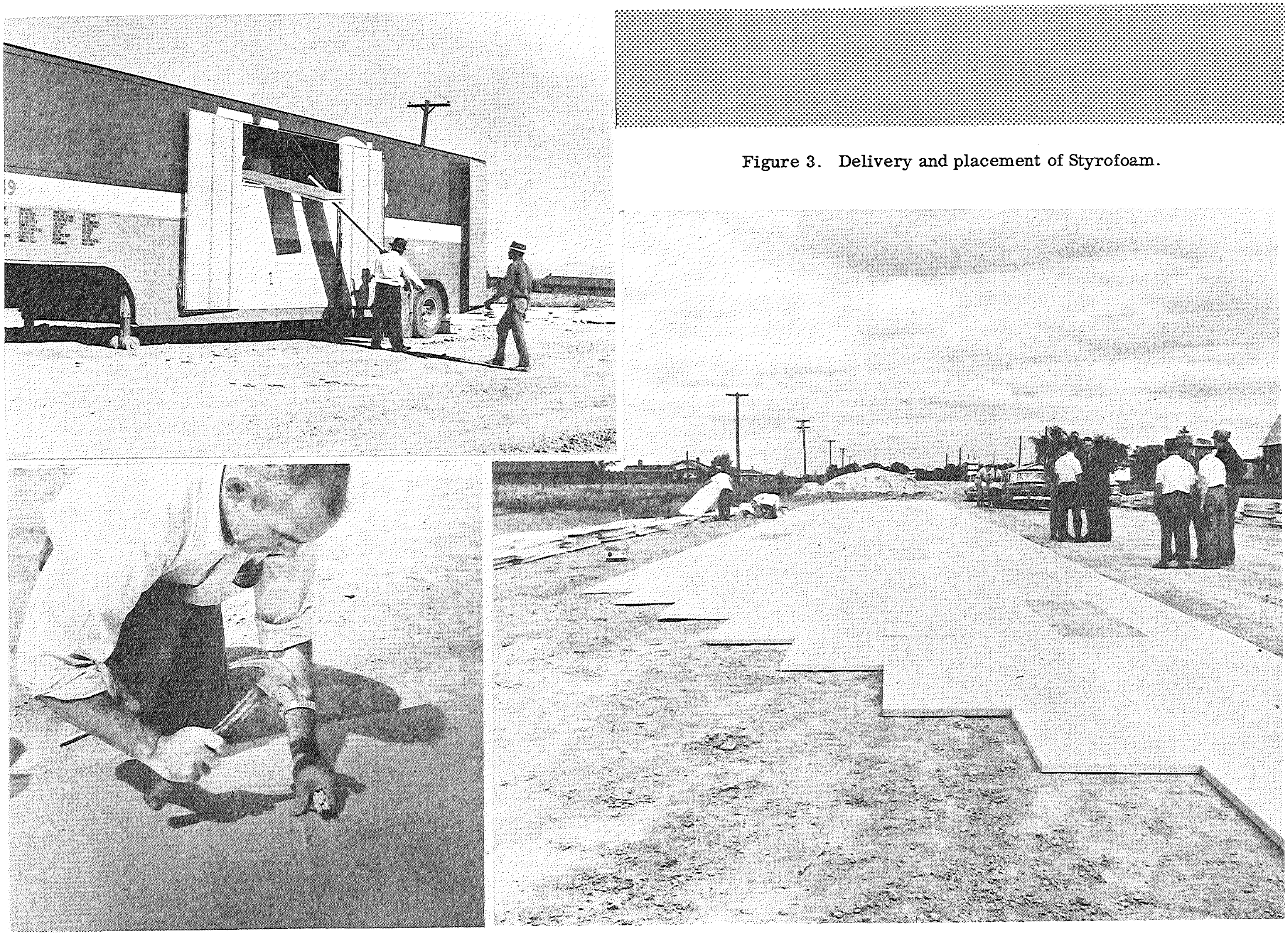


Figure 3. Delivery and placement of Styrofoam.

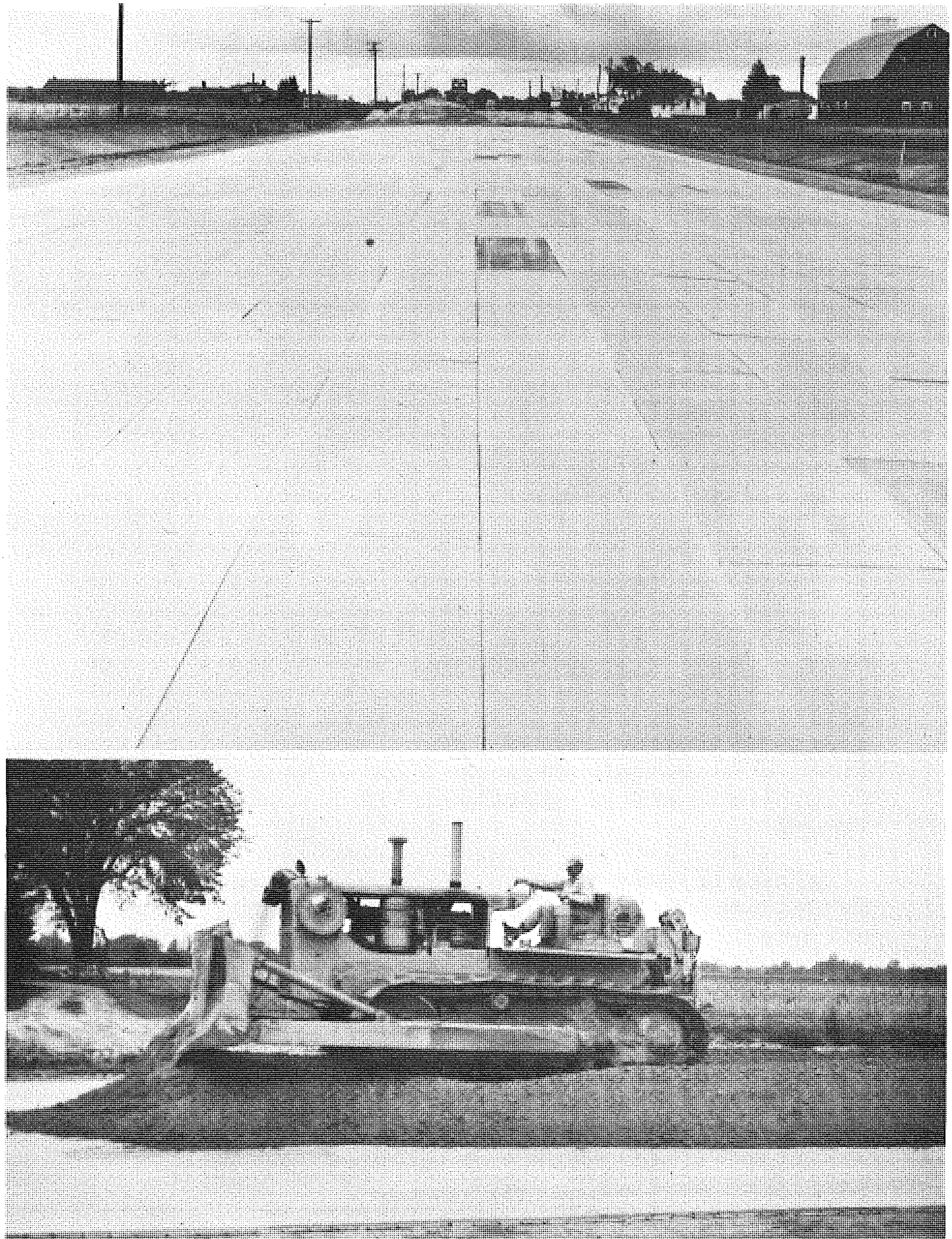


Figure 4. Appearance of Styrofoam in place on subgrade (above), and spreading sand subbase over Styrofoam (below).

The adjoining control sections were conventionally constructed with slight modifications as required in the transitional zones, and the whole area finished above the subbase by standard construction procedures to the thickness shown in Fig. 1. The asphaltic concrete wearing course was applied eight months later.

Instrumentation

Several forms of instrumentation were installed in both the test section and the control sections for obtaining periodic data throughout project test life. These include 1) a system of thermocouples for measuring temperatures in the various components of the pavement, 2) special frost depth indicators by means of which the frozen zone in the pavement structure can be measured directly, and 3) access tubes through the pavement structure into which nuclear sources can be inserted to obtain moisture and density readings at various depths. A plan view of the location of these instruments and a general profile view are given in Fig. 5.

Thermocouple Installations

The thermocouples used in this project are the heavy-duty type consisting of No. 16 copper-constantan wires fused together at the ends. Each wire is enclosed in a polyvinyl cover for permanent moisture resistance, and over this a nylon cover furnishes additional toughness and strength. By using these heavy-duty wires it was possible to place them directly in the pavement without use of an additional conduit, which simplified the installation. Approximately 8000 ft of thermocouple wire was used.

In order to protect the thermocouple ends and maintain them at fixed locations in the pavement, they were carefully positioned and sealed with 1-1/2-in. square polyethylene rods or blocks. Polyethylene has been used with success by others for housing thermocouples under similar conditions.[5] It is rugged enough for field use, has an extremely low thermal coefficient, and does not influence the functioning of the thermocouples.

Details of thermocouple installation are shown in Fig. 6. Each polyethylene rod contains four thermocouples, with the four lead cables taped together before insertion into a 1-1/2-in. hole augered in the subgrade. Due to their low coefficient of friction, the polyethylene rods were easily inserted by light tapping into both the subgrade and base

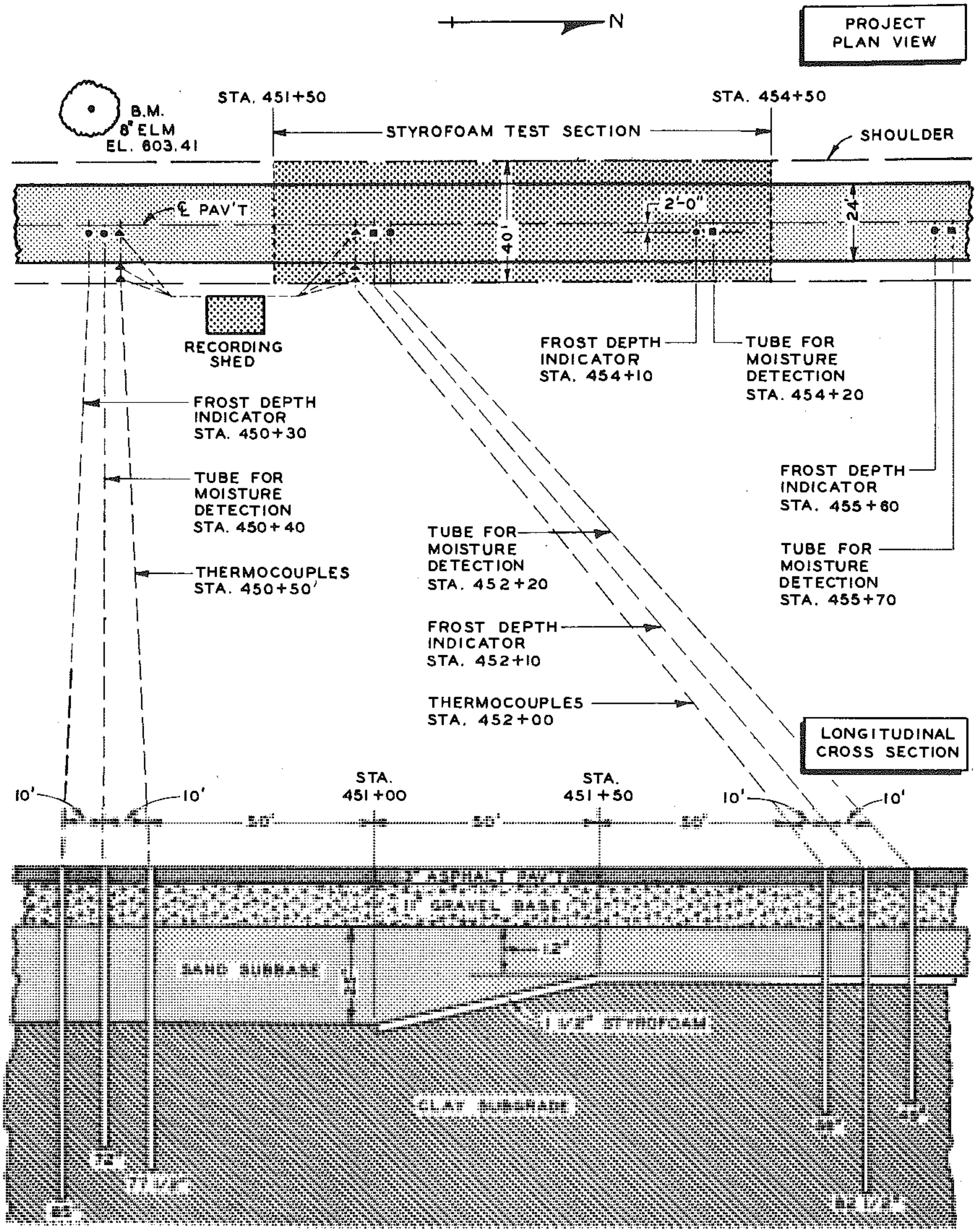
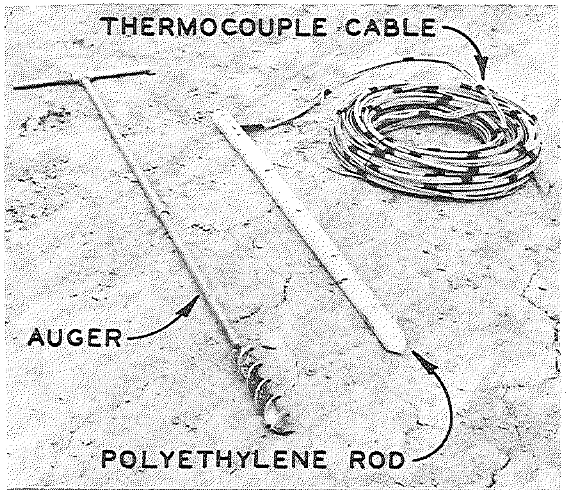


Figure 5. Instrumentation plan and longitudinal cross section.



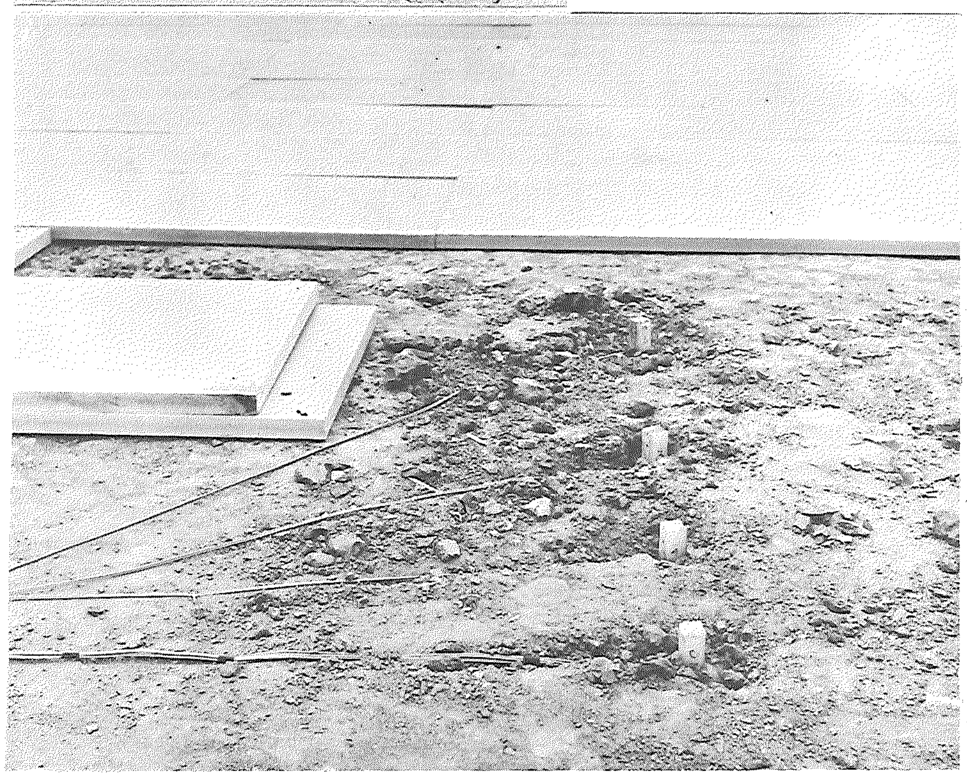


Figure 6. Equipment used in placing thermocouples (upper left), insertion of rod in subgrade (upper right), appearance of installation before covering (lower left), and placement of cables directly on subgrade using U-clips (lower right).

course materials. Thermocouple distances from the top of the rod are fixed so that tamping the top to proper elevation placed the thermocouples in the desired position. Groups of cables were fixed in place on the subgrade by means of U-clips, the cables taken to the edge of the pavement, taped into groups, and led to the recorder shed.

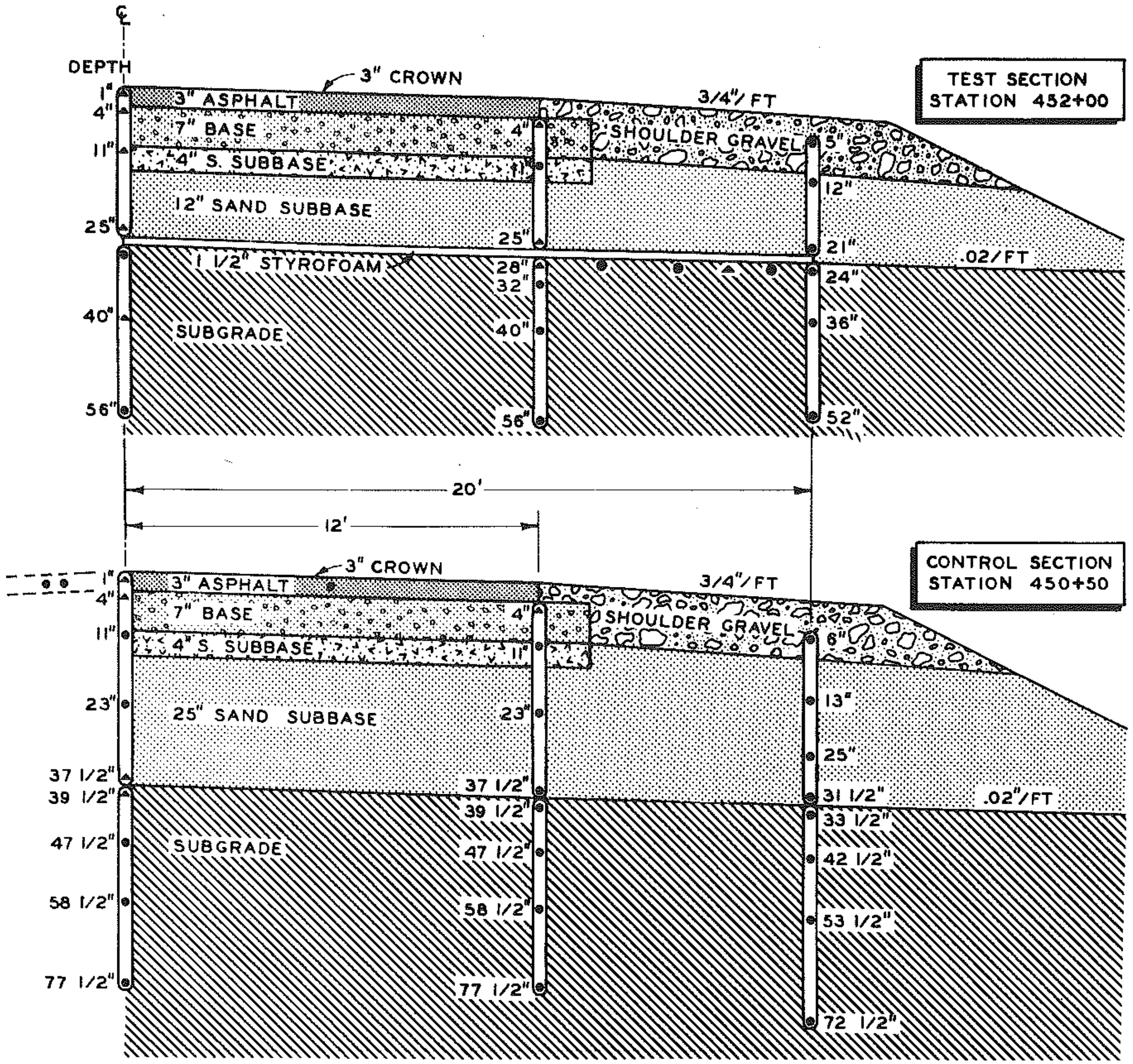
Respective thermocouple locations within the pavement components are illustrated in Fig. 7. These locations were selected to give information at critical points in the test and control areas, to a significant depth into the subgrade, so as to measure any penetration of the freezing zone inward from the edges of the Styrofoam. As the figure indicates, two additional thermocouples are located in the asphalt surface, left of centerline near the middle of the other lane. One more is near the recorder shed for measurement of air temperature.

A total of 56 thermocouples are being used on this project, of which 16 (including that for air temperature) are arranged to record automatically every 2 hr, with the remainder to be read once a week. Fig. 8 shows the Leeds and Northrup 16-point recorder and its heated shed housing.

Direct-Measuring Frost Indicators

As a supplement to the thermocouple readings, and to locate the frozen zone more accurately within and below the pavement structure, a recently developed frost depth indicator was installed in both the test and control sections of this project. This type of instrument has been used in Sweden since 1956, and more recently in Canada, during which time it has proved to be a valuable tool in locating and measuring frozen areas in and beneath roadway structures. (6)

Fig. 9 shows the principal parts and an assembled view of the indicator, modelled after the Swedish device but made in the Department's Research Laboratory. Basically, the instrument consists of a head, an indicator tube calibrated in inches and containing a dye solution which changes color when frozen, and a plastic liner tube into which the indicator tube can be inserted. The instrument is approximately 6 ft long and 3/4-in. in diameter below the head assembly. The plastic liner tube is about 1-in. ID, which allows free insertion and removal of the indicator tube. It is provided with an anchoring device at the bottom. The indicator dye is a 0.05-percent solution of methylene blue, which at temperatures above freezing is of dark blue color. At lower temperatures, however, the solution freezes into colorless ice and remains in this condition until the temperature rises above 32 F, at which point it reverts to a blue solution.

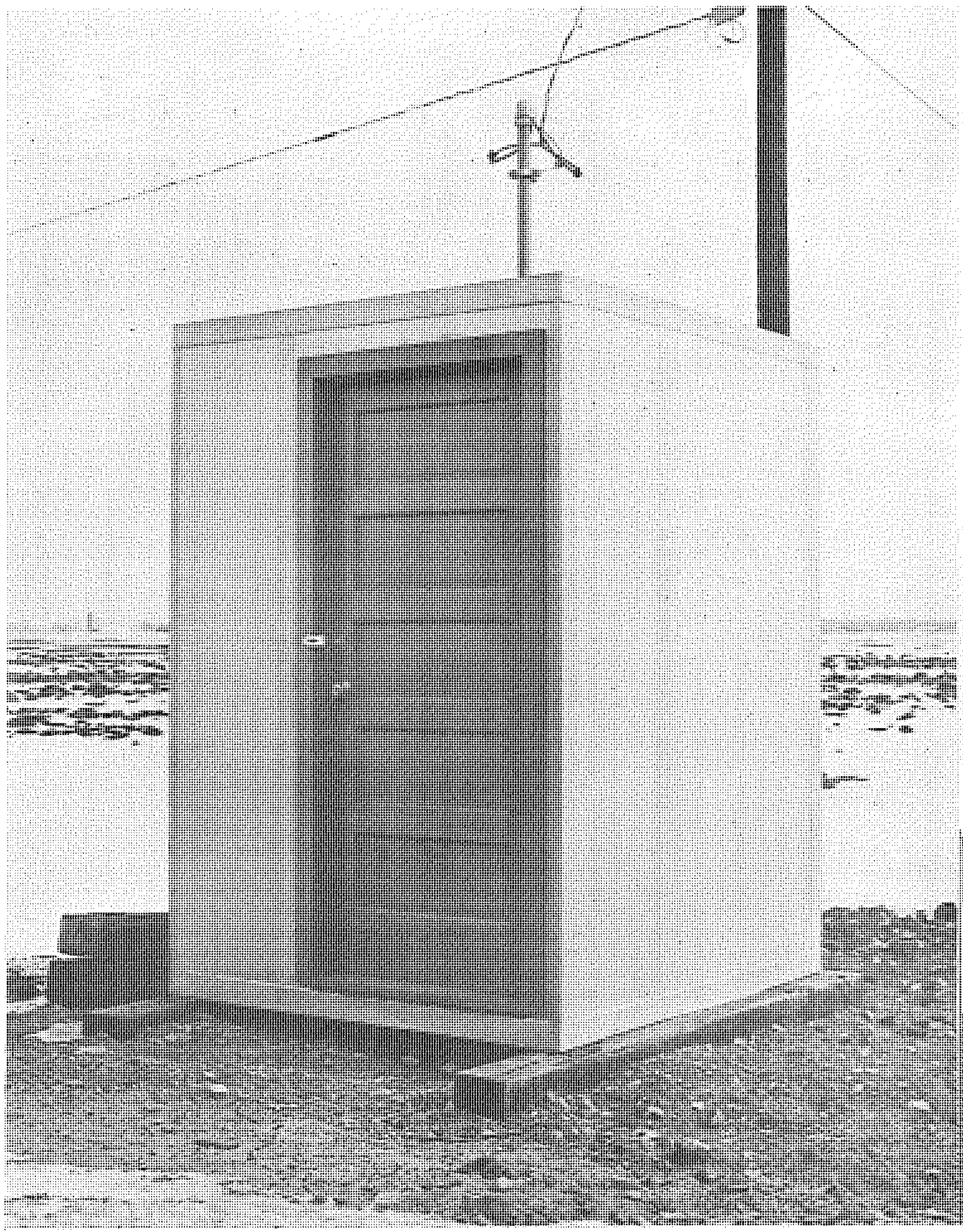


LEGEND

▲ - TEMPERATURE RECORDED EVERY 2 HOURS

● - TEMPERATURE RECORDED WEEKLY (TWO ADDITIONAL THERMOCOUPLES LOCATED IN ASPHALT SURFACE LEFT OF CENTERLINE - ALSO READ WEEKLY

Figure 7. Detail drawing of thermocouple locations in test and control sections; depths measured from pavement or shoulder surface.



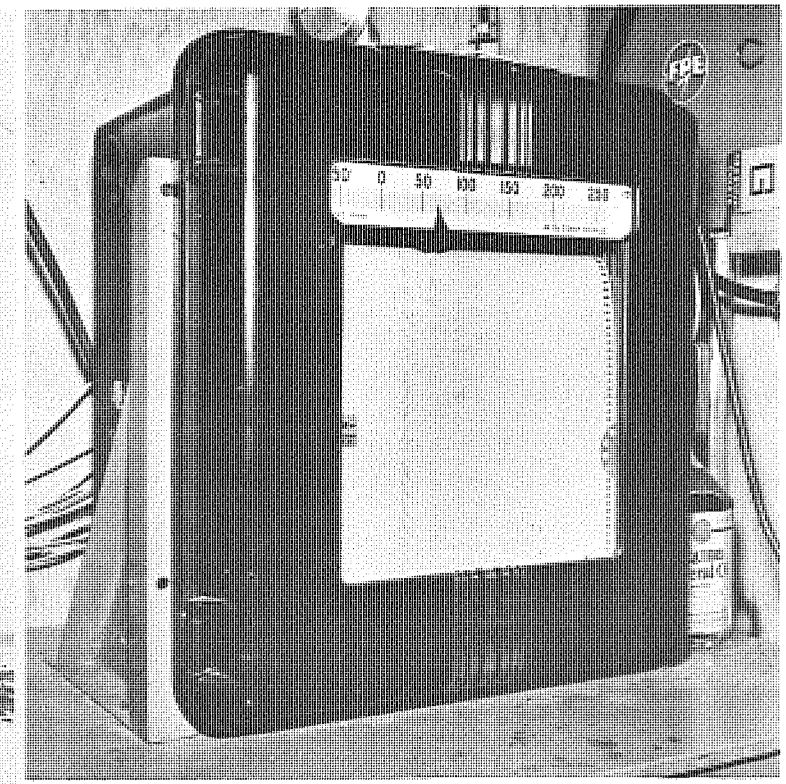


Figure 8. 16-point recorder for thermocouple data and heated shed housing the recorder.

Two of these frost indicators were placed in the insulated test section and one in each of the control sections at the locations shown in Fig. 5. The top of one of these installations, buried flush with the pavement and sealed in place with cold patching, is shown in Fig. 9. To remove the indicator it is merely necessary to turn the top with the device shown, and lift the head assembly for reading.

One reading in Fig. 9 was taken in the insulated section and shows that the frozen zone (shown by the light portion of the indicator) extends from the surface to the top of the Styrofoam, or about 24 in. A corresponding reading, taken in the uninsulated control section, shows the frozen zone extending to about 44 in. but thawed to a depth of 10 in. from the surface. These tests show how well the Swedish-type indicator can follow the frozen zone in the soil and base course. The device is calibrated in inches of depth below the surface.

Nuclear Measurement of Moisture Content

For periodic measurements of moisture content in various portions of the pavement structure, four access tubes were placed to depths of about 6 ft, into which nuclear moisture indicating sources may be inserted for readings at desired elevations. Locations of these tubes are indicated in Fig. 5, and surface appearance of a finished installation is shown in Fig. 10.

Of particular interest in this study is the possibility that moisture accumulation beneath the Styrofoam insulation might seriously weaken the subgrade. Using the nuclear source, seasonal changes in moisture content can be measured conveniently without disturbing the drainage or other structural characteristics of soil in the vicinity of the reading area.

Cost Considerations

In this particular test installation, the Styrofoam was furnished at no charge by the Dow Chemical Co. However, according to Dow's representative, the normal cost of the Styrofoam type used for such construction is 8 cents per board foot. Based on this figure and on construction costs furnished by William Travis, Project Engineer, costs of the Styrofoam installation and of the normal construction that was replaced by the Styrofoam are computed as follows:

Styrofoam Construction

Cost of Material (12,000 sq ft)		$1440.00
Cost of Placing		318.75
Truck Demurrage (3-day storage)		60.00
	Total	$1818.75

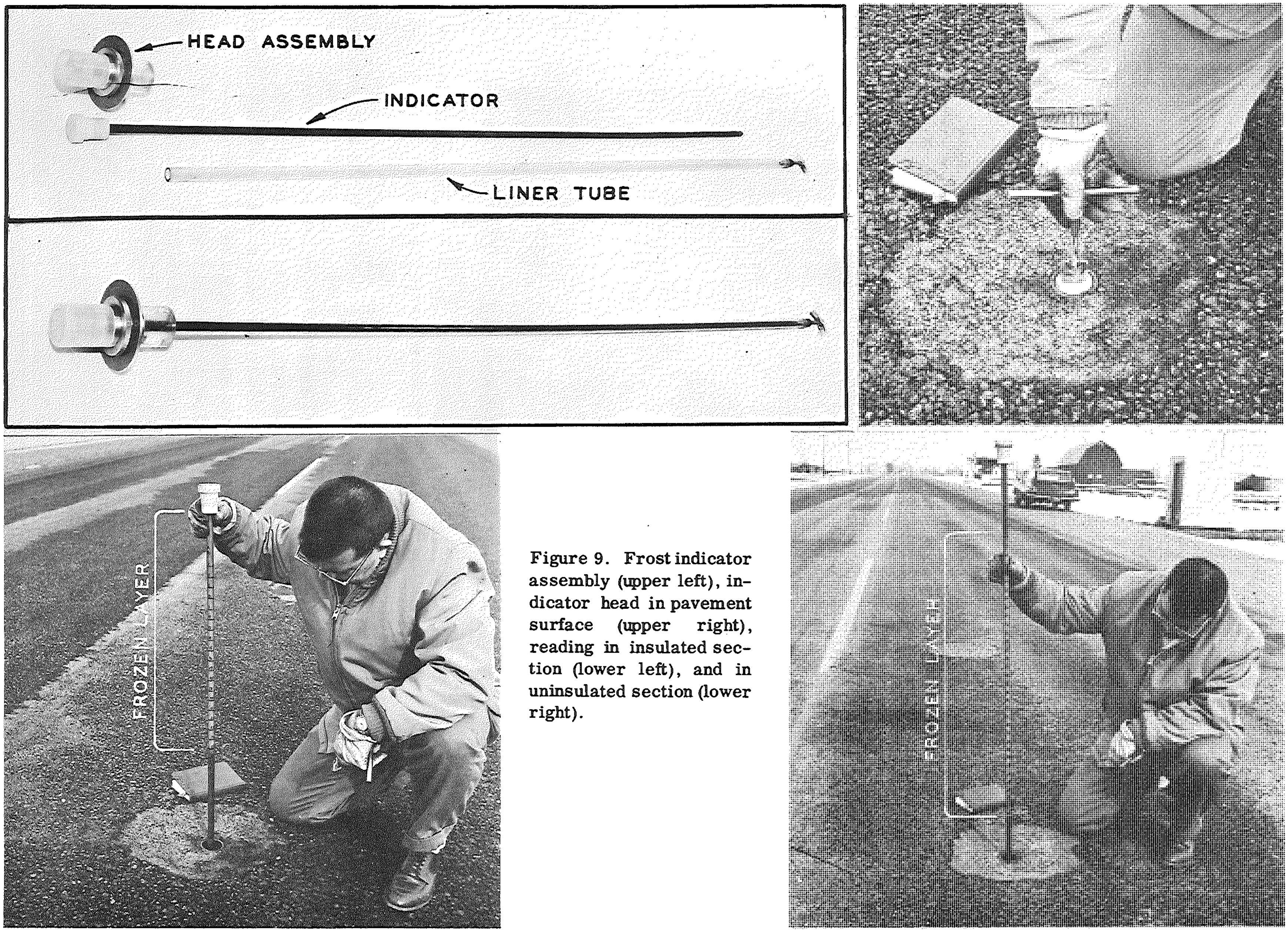


Figure 9. Frost indicator assembly (upper left), indicator head in pavement surface (upper right), reading in insulated section (lower left), and in uninsulated section (lower right).

Normal Construction Replaced by Styrofoam

Earth Excavation - 701 yd @ 40¢ per yd		\$280.40
Sand Backfill (including 20 percent shrinkage factor) @ 78¢ per yd		707.93
	Total	\$988.33

For the 300-ft test area, the Styrofoam construction cost \$830.42 more than would comparable normal construction, an increase in cost of about 85 percent. The transition zones were not included in this comparison because they probably would not be used with normal Styrofoam installation.

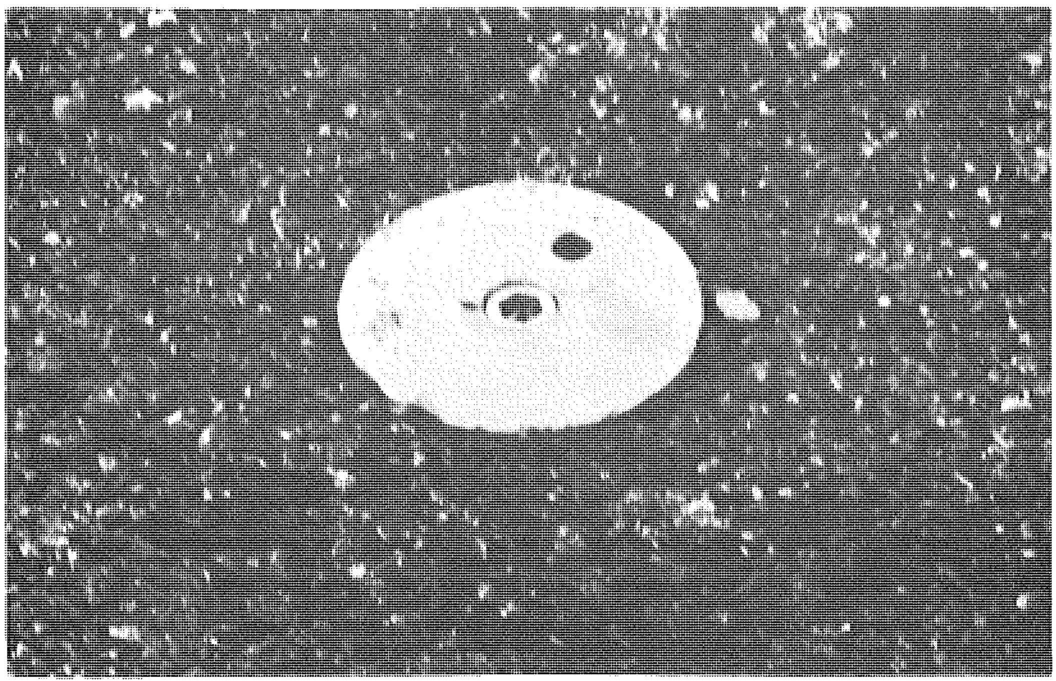


Figure 10. Top of access tube for nuclear moisture-measuring sources.

Conclusions

The Styrofoam test section and control sections have been completed and all instrumentation installed. The wearing course was placed, but does not affect the instrumentation since allowance was made for the increase in asphalt thickness. Roughometer and profilometer measurements will be made on the finished surface and periodically throughout the life of the project. Thermocouple and moisture readings will be made throughout the year, and the general condition of the sections will be evaluated.

During the installation of the Styrofoam and from preliminary measurements the following conclusions are made:

1. No significant construction problems were encountered during styrofoam placement.

2. Styrofoam was not damaged during construction nor after it was covered.

3. The thermocouple installation and the Swedish-type frost indicators appear to be operating in a satisfactory manner.

4. During the first winter, the freezing zone did not penetrate below the Styrofoam. Frost penetrated about 24 in. deeper than that level in the uninsulated control sections.

5. Under conditions of rising temperature after a freeze, material above the Styrofoam appeared to remain colder longer than did corresponding material in the uninsulated areas. This is apparently due to the Styrofoam insulation's blocking warmth from the ground and keeping the material above cold enough to resist immediate thawing.

6. A full evaluation of the effects of Styrofoam must await more detailed study of the project over a significant period of time.

7. For this project, the cost of the Styrofoam test section was about 85-percent higher than that of equivalent normal construction.

References

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