SUBGRADE INSULATION FOR FROST HEAVE CONTROL

CONSTRUCTION, INSTRUMENTATION,

AND

FIRST YEAR SUMMARY

State of Alaska, Department of Highways
Materials Division

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INTRODUCTION

Differential frost heaving of roadways can occur to the extent that severe safety hazards are created during the winter months. Deterioration of the pavement often follows during the spring thawing season, due to the excess moisture released by melting of segregated ice. Control of frost heaves can be effected by removing either the water supply or the frost susceptible soil, or by protecting the heaving soils from freezing temperatures. Of these alternates, control of the groundwater sources, primarily by use of subdrains, has frequently proven ineffective in Alaska in controlling potential heave areas, due to the strong capillary forces acting to draw water to the freezing plane in heave-susceptible soils. Removal of the frost susceptible soils to be effective, must be carried to the maximum depth that frost will penetrate in the material used as backfill. In the Anchorage area, it is necessary to replace the upper ten to twelve feet to insure against heaving. The third alternative, that of protecting the subgrade soils from freezing temperatures, is the objective of this study.

Two frost heave areas were selected as experimental insulation test sites. The sites are located 12 miles south of Anchorage, Alaska. Climatological records in this area show an average annual freezing index of about 2200 degree days.

Two rigid expanded foam insulation materials were chosen for the insulation test sections. The first of these was a foamed-in-place Urethane insulation as produced by the CPR Division of the UpJohn Company. The second was an extruded polystyrene foam insulation, developed and produced by Dow Chemical Company under the trademark "Styrofoam HI," specifically for use as a roadway subgrade insulation. No record was found of any prior installation of foamed-in-place urethane as a roadway insulation in the United States, although one unsuccessful installation was reported from Canada.[7] Urethane insulation appears to be attractive for this use because the insulation components are shipped in concentrated liquid form, and foaming of the insulation occurs when the components are mixed and sprayed on the ground surface. The resultant polyurethane foam also presents a lower thermal conductivity than that of the polystyrene foams.

Because of the better insulation value anticipated, a thickness of two inches of urethane foam was specified for the first test section, designated as Section 1A. The second section, Test Section 1B, received three inches of "Styrofoam HI" insulation, in the form of factory extruded 2 ft. x 8 ft. boards in 1 in. and 2 in. thicknesses. Thermocouples were installed to measure ground temperatures directly above and beneath the insulation layers, at various elevations in the soils underlying the insulation, and in two adjacent uninsulated areas used as control sections.

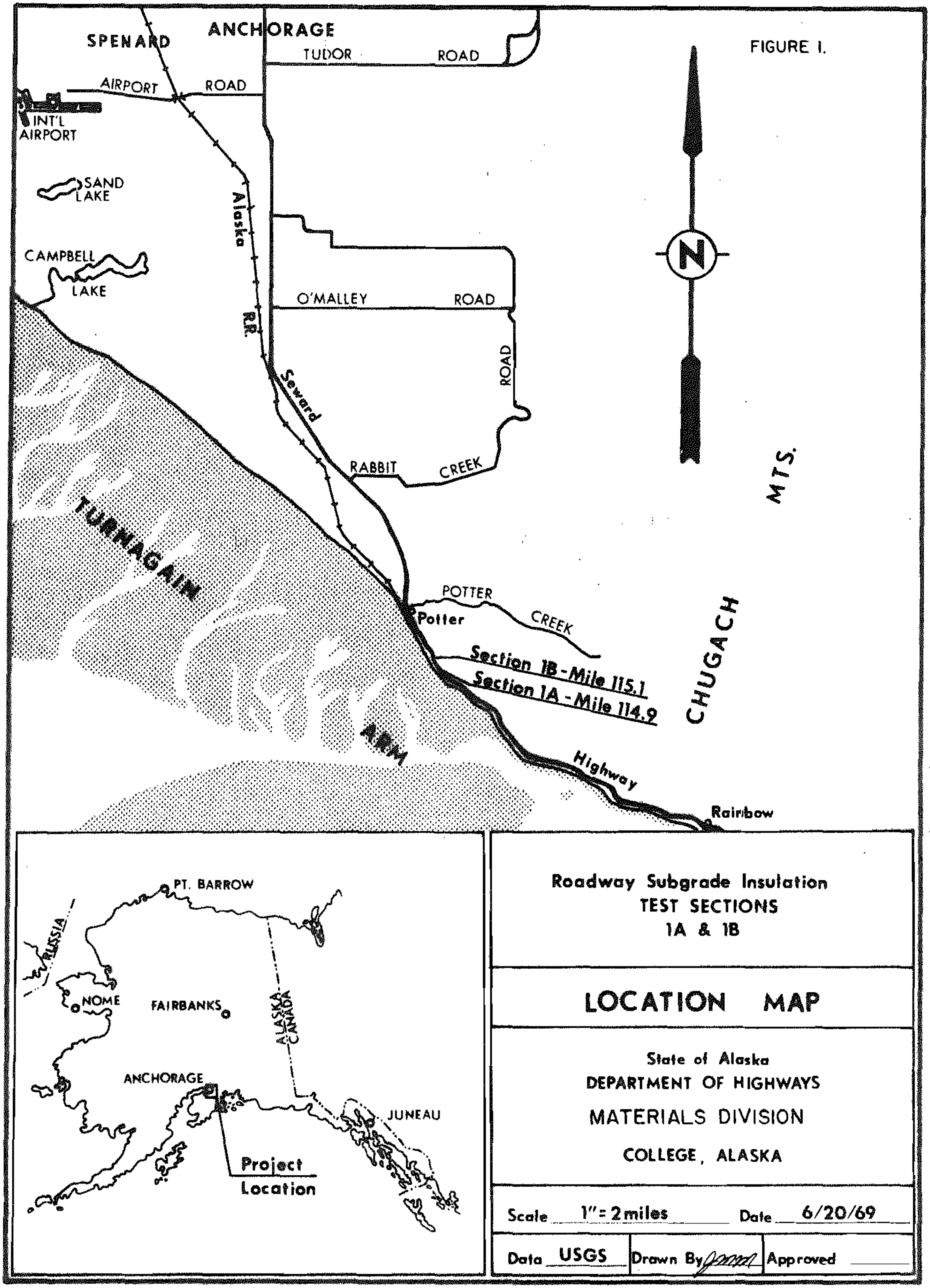


FIGURE I.
SPENARD
ANCHORAGE
TUDOR ROAD
AIRPORT ROAD
INT'L AIRPORT
SAND LAKE
CAMPBELL LAKE
Alaska R.R.
O'MALLEY ROAD
ROAD
Seward Highway
RABBIT CREEK
TURNAGAIN ARM
POTTER CREEK
Potter
Section 1B - Mile 115.1
Section 1A - Mile 114.9
CHUGACH MTS.
Rainbow
PT. BARROW
RUSSIA
NOME
FAIRBANKS
ALASKA CANADA
ANCHORAGE
JUNEAU
Project Location
Roadway Subgrade Insulation
TEST SECTIONS
1A & 1B
LOCATION MAP
State of Alaska
DEPARTMENT OF HIGHWAYS
MATERIALS DIVISION
COLLEGE, ALASKA
Scale 1" = 2 miles
Date 6/20/69
Data USGS
Drawn By
Approved

Roadway surface elevations were recorded at monthly intervals during the 1967-68 winter, to show the heave behavior prior to insulation. To evaluate the performance of the test sections, surface elevations were again recorded during the winter of 1968-69, and thermocouples were read weekly or bi-monthly, depending on air temperatures.

ACKNOWLEDGEMENTS

The Alaska Department of highways gratefully acknowledges the cooperation of Dow Chemical Company and of the UpJohn Company, CPR Division, in supplying, free of charge, the polystyrene and urethane foam insulations; and of Northern Ventures, Inc. of Anchorage, for performing the foam-in-place installation of the urethane.

Construction of the test sections was done by the Anchorage Maintenance Division of the Alaska Department of Highways, under the supervision of Mr. Frank Lee. Coordination and promotion leading to the installations is to the credit of Mr. D.W. Herman, Anchorage District Materials Engineer. Thermocouple assemblies were fabricated and installed by Mr. Lance Trent of the Department of Highways, Road Materials Laboratory.

The assistance of Mr. Wayne Williams of Dow Chemical Company in supervising the field installation of the Styrofoam insulation boards was especially appreciated.

PROJECT LOCATION AND DESCRIPTION

The two sites selected for installation of the insulation materials are located at Mile II4.9 and II5.I on the Seward Highway, about 12 miles south of the City of Anchorage, Alaska, as shown by the site plan. (Figure 1) The roadway in this area lies along the shore of Turnagain Arm, a tidal arm of Cook Inlet. The Chugach Mountains rise steeply from the shore of the inlet. Soils generally consist of a mantle of glacial till overlying bedrock.

The test sites were selected after studying the vertical movements of six frost heave areas on the Seward and Sterling highways during the winter of 1967-1968. Pavement elevation profiles were run monthly and the data was used to determine the severity and extent of the heaving in each of the six areas.

PROJECT DESIGN DATA

The two heave sections selected for the insulation test sections showed maximum heave differentials of from zero to 0.32 and 0.60 ft., within distances of 20 feet, as shown by Figures 2(a) and 2(b). These sections were located 900 feet apart, which presented the chance to compare the performance of two separate installations presenting very similar conditions as to climatological environment and terrain. Both sections were provided with decreased insulation thicknesses at the ends, to provide thermal transitions from uninsulated to fully insulated areas. Selection of the starting and ending points was done on the basis of the heave profiles. Insulation widths were designed to provide coverage for a distance of four feet beyond the edge of the pavement, for a total width of 32 feet. A minimum total overlay of base plus pavement of 18 inches was provided above the insulation.

The manufacturers' listed maximum thermal conductivities at 75 degrees F. are 0.14 BTU/hr. ft.^{2} ^{o}F/in. for the CPR Urethane and 0.23 for the Styrofoam HI insulations. Based on these values, a thickness of two inches of urethane was selected for installation on test section 1A, as equivalent in insulation value to the three inches of "Styrofoam HI" planned for section 1B. Plan and typical section views of the insulation test sections 1A and 1B are shown by Figures 3 and 4.

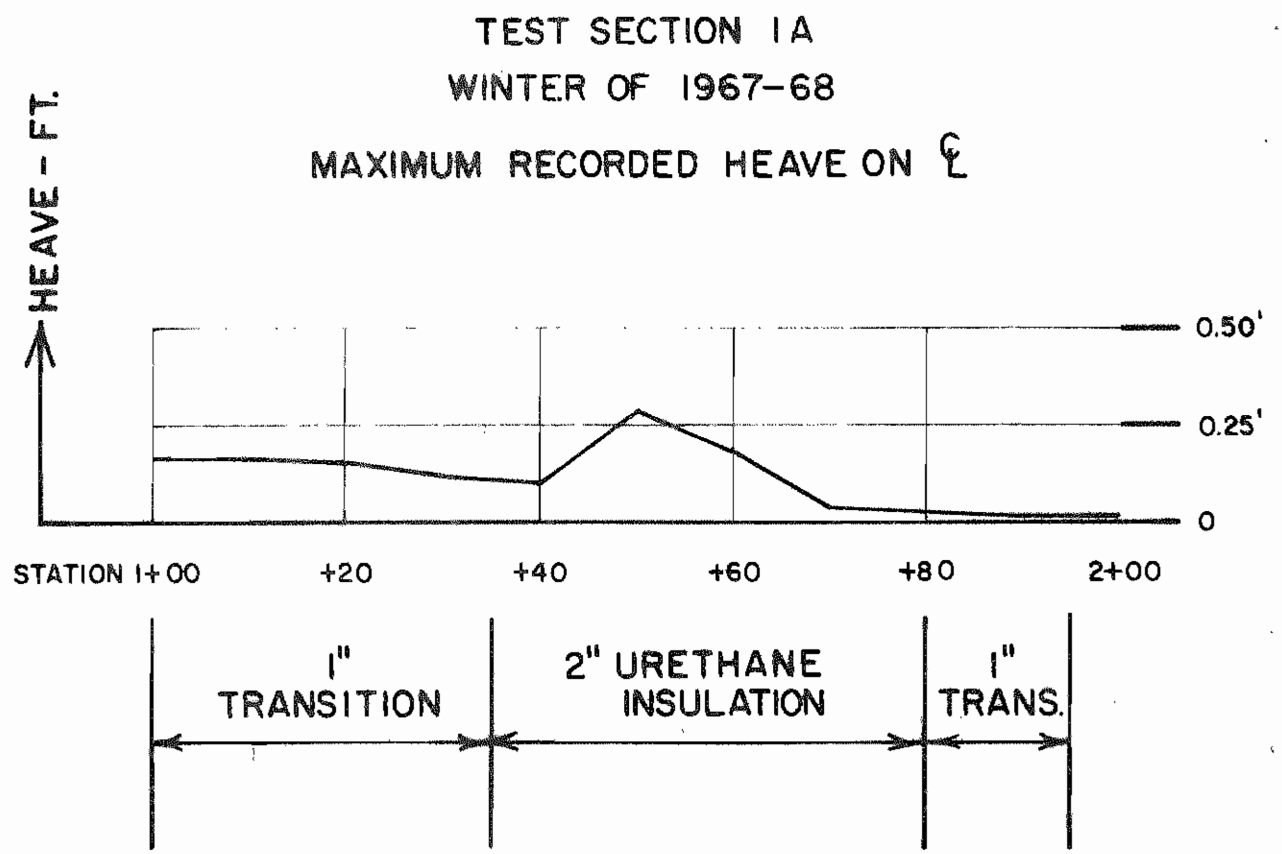


FIGURE 2(a)

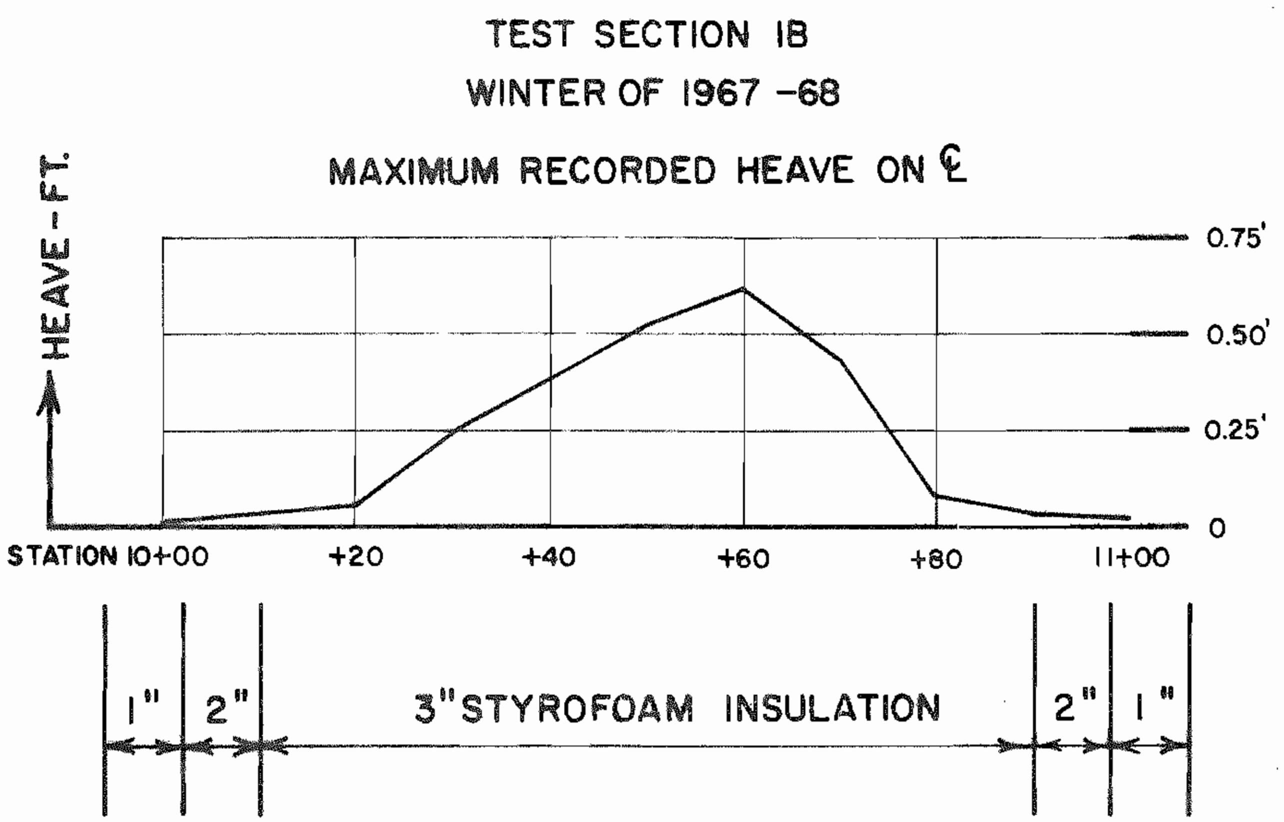
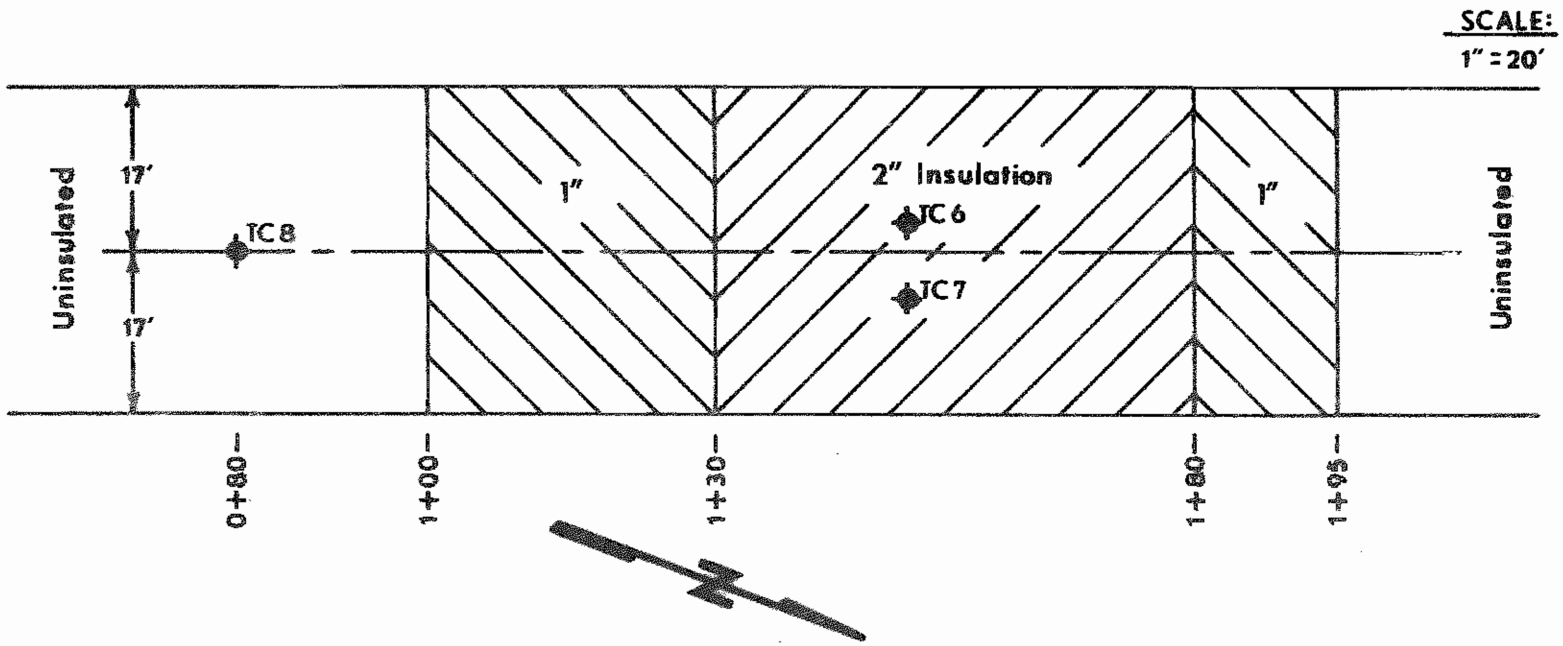


FIGURE 2(b)

TEST SECTION 1A MILE 114.2 SEWARD HIGHWAY

"CPR" FOAM-IN-PLACE URETHANE INSULATION



TYPICAL "AS-BUILT" SECTION
Station 1+30 To 1+80

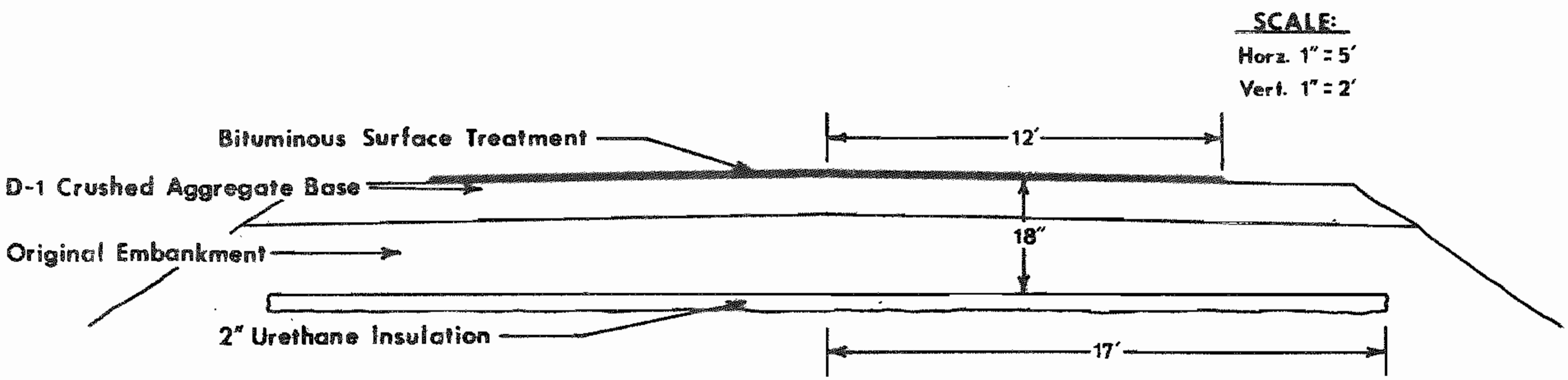
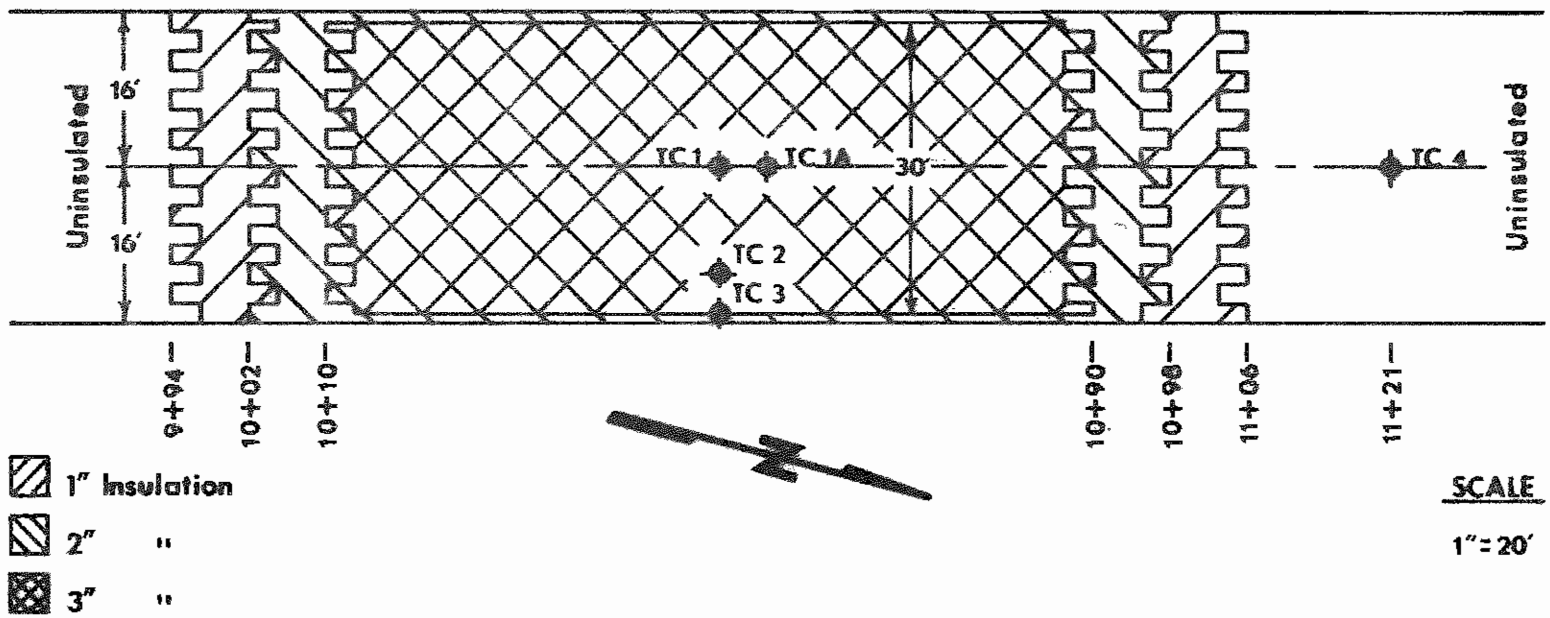


FIGURE 3.

TEST SECTION 1B MILE 1151 SEWARD HIGHWAY

"STYROFOAM HI" INSULATION BOARD



TYPICAL "AS-BUILT" SECTION

Station 10+14 To 10+86

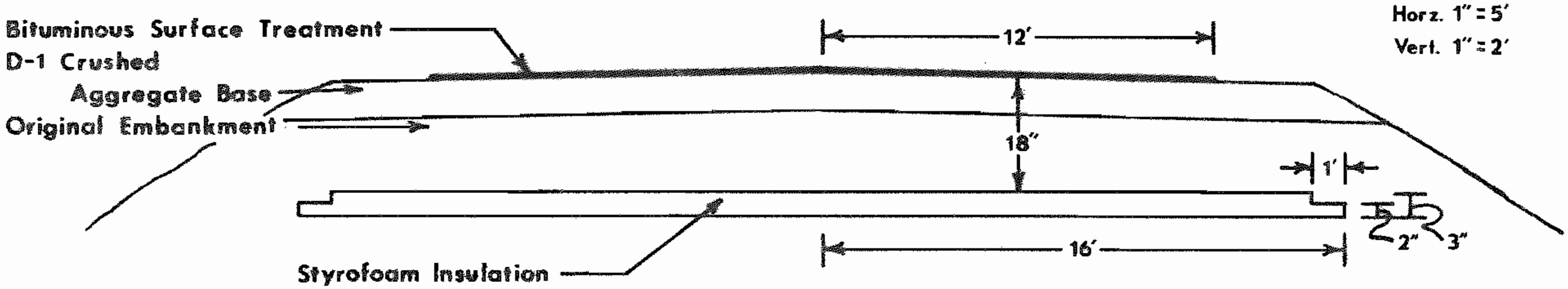


FIGURE 4.

Research on prior use of foam-in-place urethane as a roadway insulation showed a record of one test section of this type having been constructed in North America.[7] In this installation, located in Ottawa, Canada, the urethane absorbed detrimental amounts of moisture. The failure of the insulation was attributed to poor quality foam production from foaming on moist soil.

To protect the urethane foam from detrimental moisture absorption, particularly during the critical foaming and curing period, a coating of AC 200-300 penetration grade asphalt was applied both above and beneath the insulation layer.

CONSTRUCTION

Test Section 1A: Foam-In-Place Urethane Insulation

Excavation of the roadway pavement and base layers to a depth of 21 inches was done on August 28, 1968, by means of a front end loader. After leveling, the surface was rolled with a vibratory steel wheel roller, which resulted in a satisfactory surface for insulation placement. Borings were made for placement of two thermocouple strings beneath the insulated area and one thermocouple string located beneath the adjacent uninsulated roadway at Station 0+80.

The thermocouple borings showed a layer of two to three feet of silty gravel of frost classification F-1, below the insulation depth. Underlying the silty gravel was a deposit of wet grey gravelly silt of AASHO classification A-4 and frost classification F-4, with the water table at a depth of 4½ feet. Logs of all borings made for thermocouple placement, and test data on soil samples, are contained in Appendix A.

Application of the urethane insulation started on August 29. Because a rain shower during the night had saturated the previously prepared surface, it was necessary to delay operations and permit the roadway to dry prior to application of the preliminary asphalt coating. The asphalt, a 200-300 penetration grade, was heated to 350 degrees F. and applied at an average rate of about 0.2 gallon per square yard. Due to minor equipment problems, foam application was not completed until 2:00 P.M. on August 30. The urethane foam results from mixing two pre-heated components and spraying the resultant fluid. Average production rate for the single gun-type foaming apparatus used was 500 board feet per hour. Width of the insulation averaged 34 feet. Transition sections received one inch of foam, while two inches were placed on the center section. The foam surface is naturally somewhat irregular and the actual thickness of the foam is dependent upon the skill of the operator. Repeated checks on the foam thickness, made by penetrating it with a knife blade, showed the thickness to average quite close to the two and one inch thicknesses specified. After foaming, the insulation could support the weight of a man in about one minute. The strength increases for a number of hours after foaming, according to the manufacturer. Next, a second asphalt coating was applied at the same rate and temperature as the initial coat. The hot asphalt had no detrimental effect on the foam as far as could be determined.

Backfilling started immediately after completion of the foaming operation. The initial 9 in. thick layer was spread with the loader, leveled with a motor grader, and compacted with several passes of a steel-wheel vibratory roller. The backfill material was a sandy gravel with some cobbles. In two areas the first lift was accidentally spread too thin, resulting in less than 4 inches of gravel beneath the wheels of the loader. In both instances, excavation showed negligible damage or crushing of the foam. A second lift of gravel was placed and compacted. Following this, the section was brought to grade with a crushed aggregate base material, and opened to traffic on the evening of August 30.

Test Section 1B—"Styrofoam HI" Insulation

Excavation, instrumentation, insulation placement, and backfilling operations to 6 in. below grade, were

Photo 1A-1

Excavation of pavement and base with loader.

Photo 1A-2

Excavation and leveling completed. Vibratory roller used to compact and smooth surface prior to foam placement.

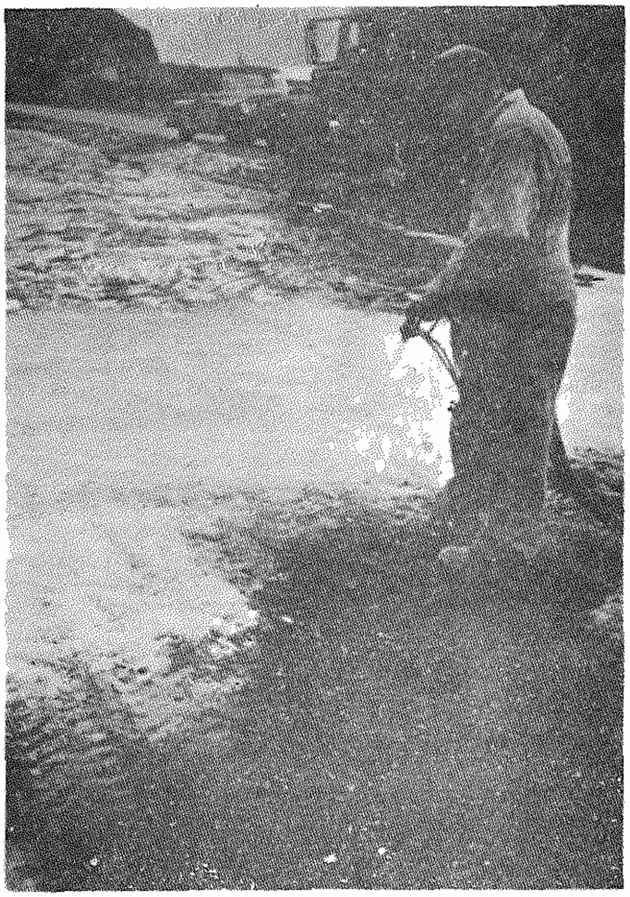


Photo 1A-3

Polyurethane foam placement in operation. Two components are heated, mixed at the nozzle, and sprayed on the roadway subgrade. The surface beneath the insulation has been given a preparatory coating of asphalt to prevent the foam from absorbing moisture. The asphalt coating applied to the top of the foam is visible in the background.

Photo 1A-4

Foaming operation completed. Spraying of final coating of hot asphalt over polyurethane foam is in progress.

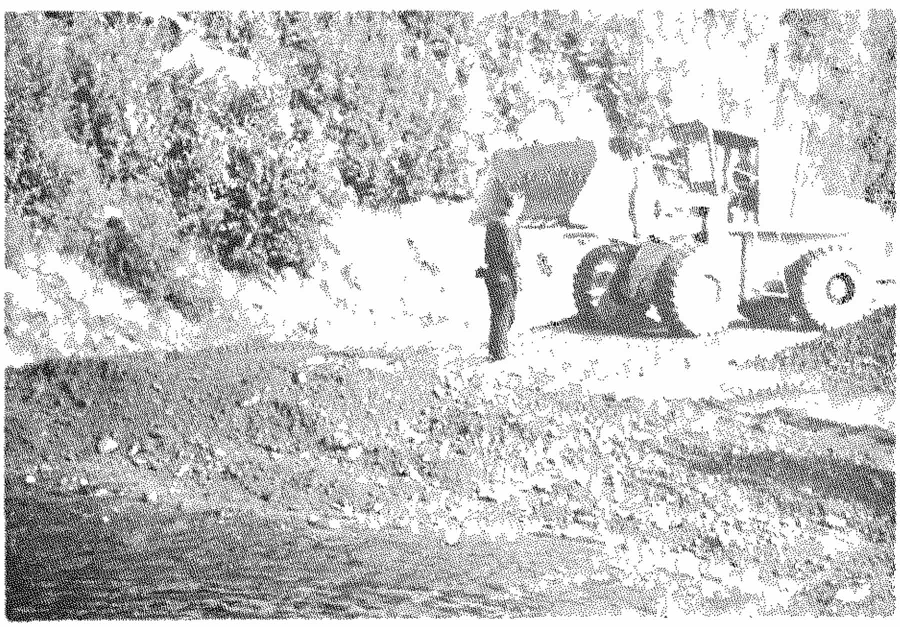


Photo 1A-5

Placement of initial lift of backfill over the urethane foam. Note cobbles up to 6 inch size in the sandy gravel backfill.

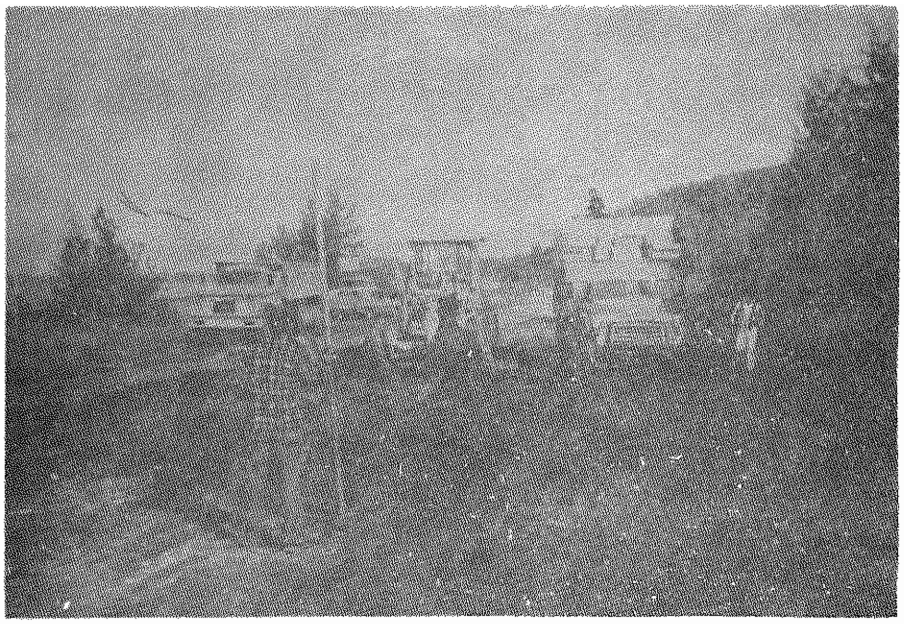


Photo 1B-1

Leveling of subgrade prior to insulation placement.

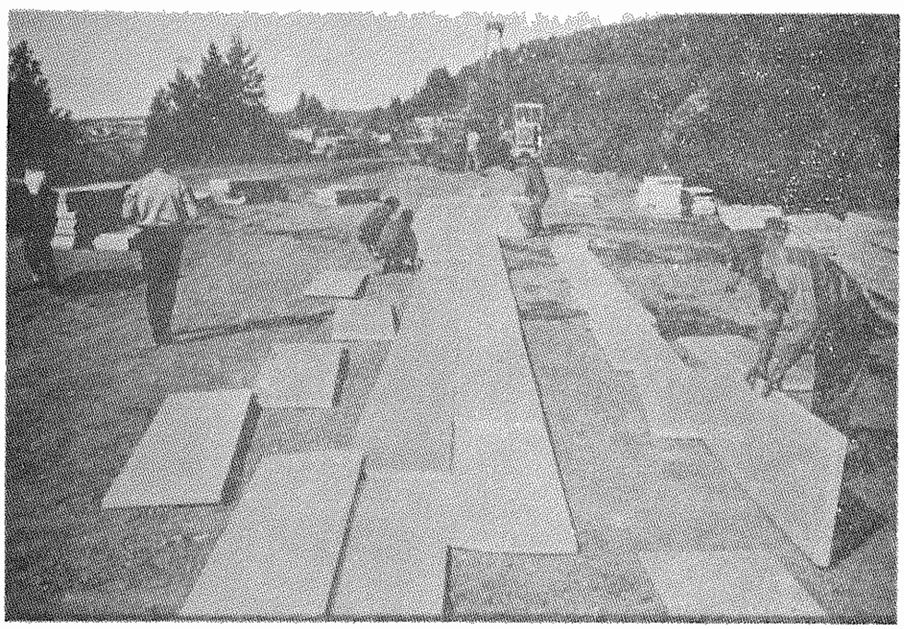


Photo 1B-2

Start of Styrofoam insulation placement. Two boards for the 1 inch transition section have been placed in foreground. Drill in background is working for placement of uninsulated control section thermocouple string.

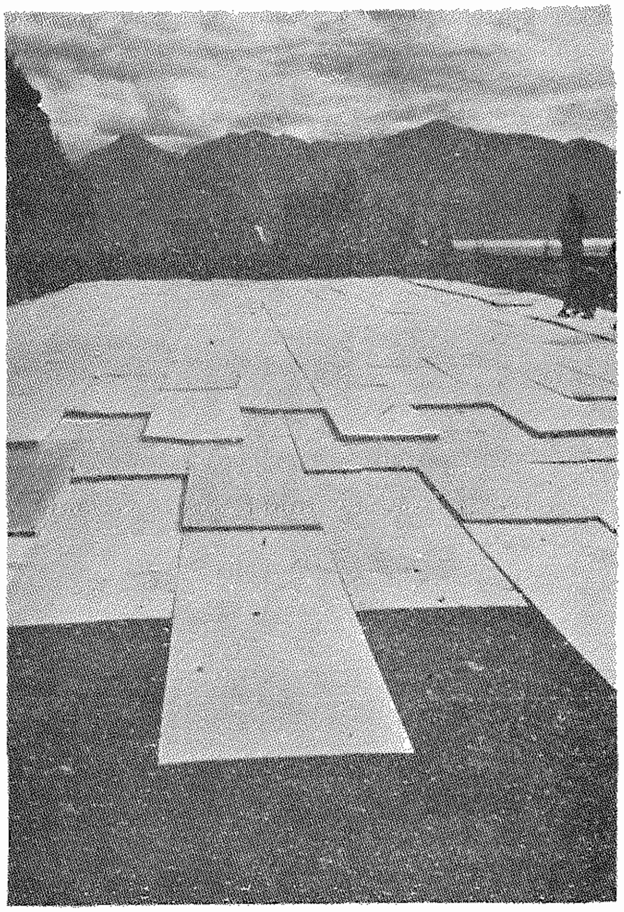


Photo 1B-3

Insulation placement nearing completion. The thickness transitions from 3 inch to 2 inch to 1 inch are shown. Boards are staggered to provide lapped joints where possible.

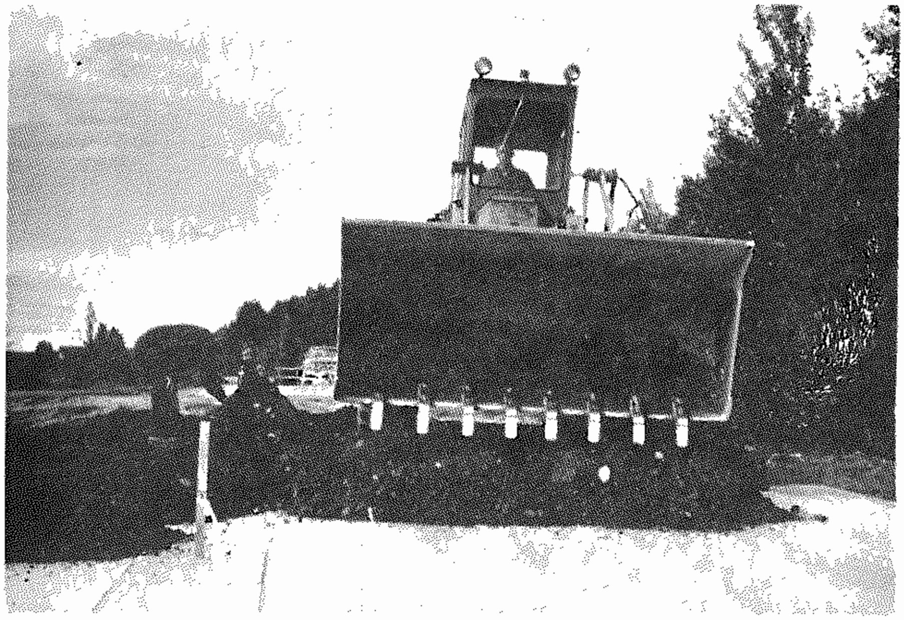


Photo 1B-4

Start of backfilling operations. Stakes were placed on centerline to control lift thickness.

Photo 1B-5

Compaction of backfill above insulation.

to installation of the insulation, using a 6 in. diameter flight auger driven by a Mobile 8-38 drill. The thermocouple strings were assembled, taped to wood lath to maintain the desired spacing, and inserted into the borings. To retain the original conditions as far as possible, the borings were backfilled by replacing the excavated soils. Thermocouple leads were carried to junction panels located on the backslope east of the roadway. The thermocouple temperatures are read by using a Leeds and Northrup Model No. 8692 temperature potentiometer. Maximum error of this instrument, under repeated laboratory checking, has proven to be less than plus or minus 1 degree F. This potentiometer uses an internal standard reference cell which eliminates the need for a reference thermocouple and ice bath.

Air temperatures and other climatological data are recorded continuously at the Anchorage International Airport weather station, located 11 miles northwest of the test sites. Air temperatures are also being recorded at a temporary weather station established at "Isle" by the Department of Highways. This station is on the shore of Turnagain Arm approximately 3 miles south of the test sites. Air temperatures were recorded at the test sites whenever readings were made on the thermocouples.

After paving was completed, elevation reference points were set along centerline and along lines located both five and ten feet right and left of centerline. Points were spaced at 10 foot intervals along these lines, which extended well beyond the limits of the insulated areas.

First Year Summary:

Air Temperatures:

The winter of 1968-1969 was more severe than normal for the Anchorage area. The air freezing index for the winter, as computed from average daily temperatures at Anchorage International Airport, was 2508 degree days. December and January had average temperatures of 7.2 degrees F. and 7.5 degrees F. below the normal monthly averages. The length of the freezing season, determined from the maximum and minimum points on a plot of cumulative degree days below 32 degrees, Figure 5, was 162 days. Temperatures at Isle were higher than at the airport station because of the proximity to the unfrozen tidewater of Turnagain Arm. The freezing index for Isle was 1890 degree days. Air temperatures at Isle Weather Station were plotted by a recording thermograph.

Comparison of air temperatures at the test sections with those recorded at the same time at the Isle station showed slightly colder temperatures at the test sites during October and November, and slightly warmer temperatures during January and February. Due to lack of data at the test sites, the best estimate of the air freezing index for the test sections during the 1968-1969 winter is approximately 2000 degree days. During the coming winter, a thermograph will be placed at the test site to determine the actual difference between the site and the Isle and Anchorage Airport freezing indices. This should permit a better estimate to be made of the site freezing index for the past winter, as well as providing better future data.

Ground Temperatures--Section 1A

Two thermocouple strings were used to monitor temperatures beneath the urethane insulation on Section 1A. These installations, designated as locations TC No. 6 and TC No. 7, were located, for cross-checking purposes, at 3 feet right and left of centerline near the middle of the fully insulated area. Temperatures were observed directly above and beneath, and at depths of 6, 12, 18, and 24 inches beneath the insulation.

During this first winter, freezing temperatures were first noted beneath the insulation on January 6, 1969. By January 16, frost penetration beneath the foam of six and fifteen inches was indicated at

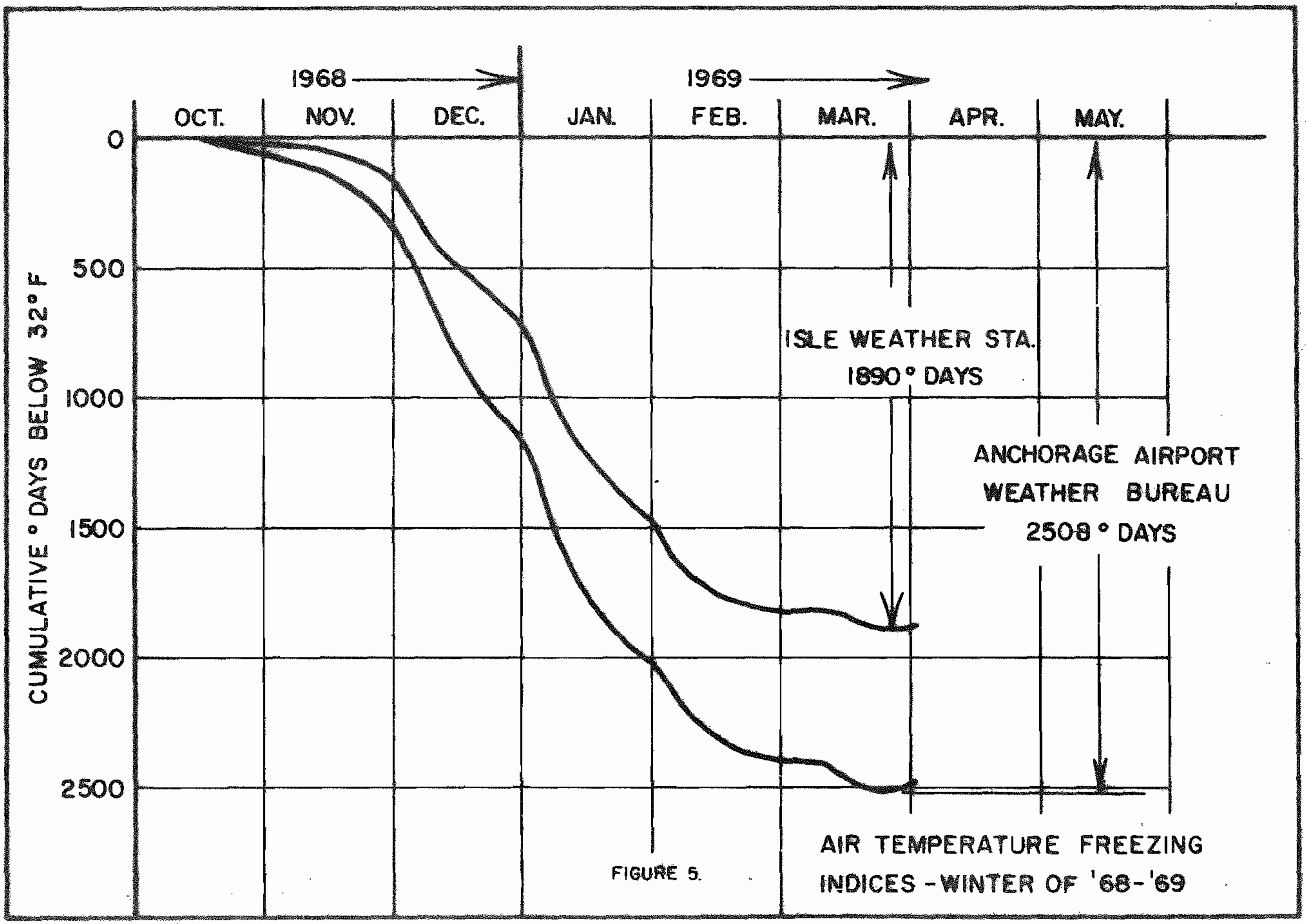


FIGURE 5.

AIR TEMPERATURE FREEZING INDICES - WINTER OF '68-'69 locations TC-6 and 7, respectively. The frost penetration fluctuated from zero to 18 inches beneath the foam for the next 50 days, with the penetration noted above again being recorded on February 26, 1969. Temperatures moderated considerably in March and the freezing season effectively ended on March 26, 1969. By April 17, the date on which all thermocouples were again read, all of the soils throughout the test sections had thawed.

The control thermocouple string for this section, located on centerline 20 feet away from the end of the insulation, showed increasing frost penetration up until mid-January. At that time the total penetration was nearly six feet. For the reminder of the winter, frost penetration did not increase significantly.

Figures 6 and 7 show the depth of the 32 degree F. isotherm plotted versus time at the thermocouple locations related to Section 1A. It should be noted that no thermocouples were located above the upper surface of the insulation and that the advances of the freezing and thawing planes through the materials above the insulation were not defined.

Heave Measurements--Section 1A

The heave profiles for Section 1A showed that minor heaving of the fully insulated area had occurred by January 14, 1969. By mid-February, the heave was at its maximum for the winter in most areas. Heave elevation checks showed only one point, out of the thirty within the fully insulated area, at which the heave exceeded 0.10 feet. The heave magnitude increased through the southern transition section to 0.20 to 0.30 feet at the uninsulated end of the transition. Beyond the control thermocouple location, Station 0+80, the heave increased to a maximum of 0.4 to 0.5 feet, creating a rather severe bump. The bump was some 30 feet beyond the insulated section and does not appear to have been created by the test section. This heave was not noticeable during the winter of 1967-1968, and elevation checks run in the preliminary study of frost heave magnitudes did not extend far enough to cover the area. The maximum heave magnitudes recorded during the 1968-69 winter on centerline and on lines located 10 ft. right and left of centerline are plotted on Figure 8. This should be compared with Figure 2(a) showing heaving prior to insulation placement.

Heave profiles for the previous winter showed a uniform heave of about 0.15 feet at the point where the southern insulation transition section was ended. Because of limited funds, lack of an adequate detour route, and lack of information of the southern end of the heave area, the test section was provided with a long transition section, rather than extended further to the south.

Comparison of freezing indices shows that the winter of 1968-1969 was considerably more severe than the preceeding winter. The records of the Anchorage Airport Weather Bureau gave a freezing index of 2060 degree days for 1967-68, versus the 2508 degree days recorded for 1968-1969.

Ground Temperatures--Section 1B

The four thermocouple strings placed beneath Section 1B were designed to indicate frost penetration on centerline and near the edge of the insulation. Thermocouple strings were located at distances of 1 ft. and 5 ft. in from the outer insulation edge, and at two locations on centerline. One of the two centerline probes, at location TC-1A, was installed as a check on probe TC-1, and contained only three thermocouples. Penetrations of the 32 degree F. Freezing plane for all thermocouple strings in Section 1B are plotted versus time on Figures 9, 10, and 11.

Frost penetration beneath the insulation was noted on all thermocouple strings by January 10, 1969 and confirmed by all readings on January 16.

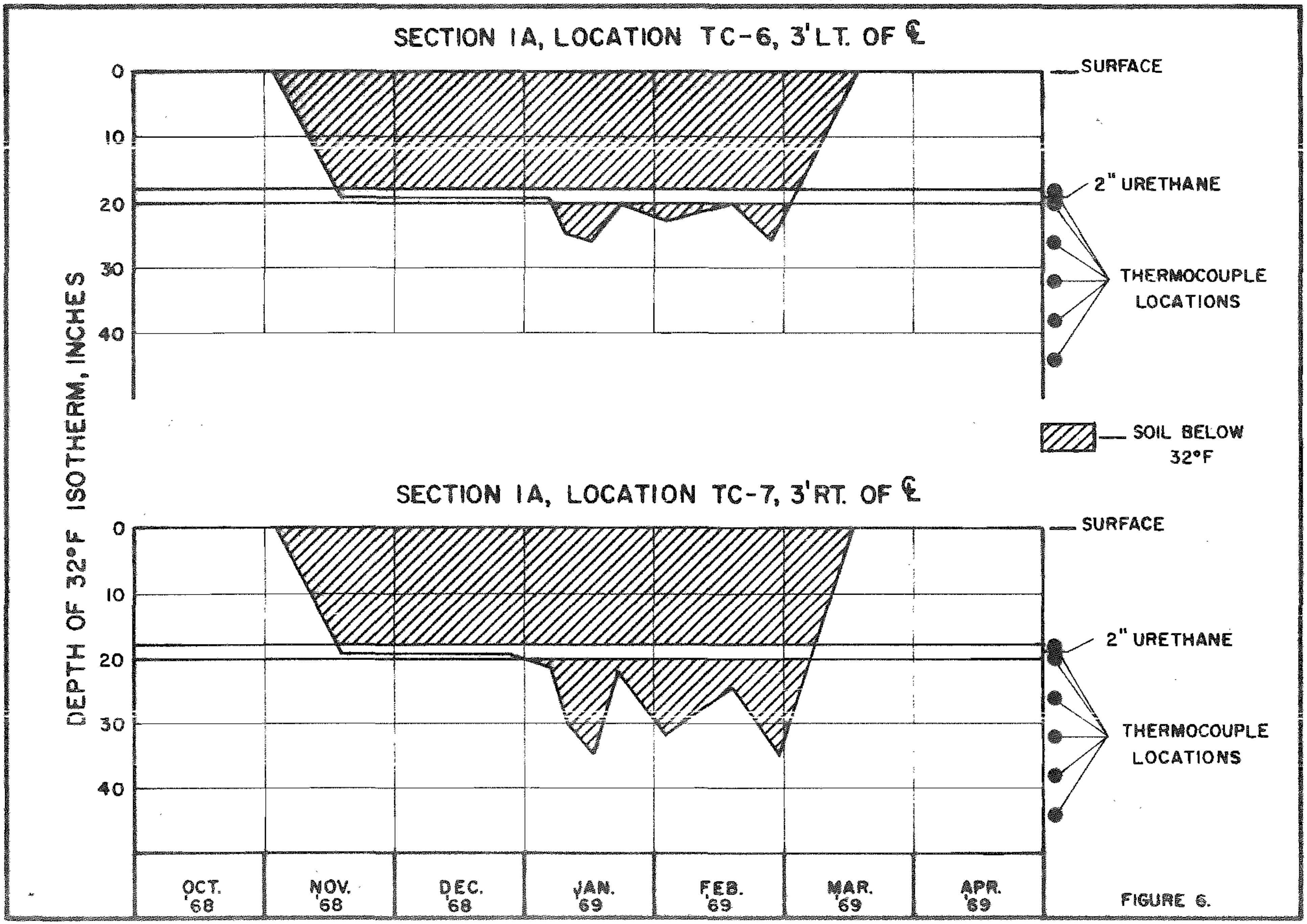
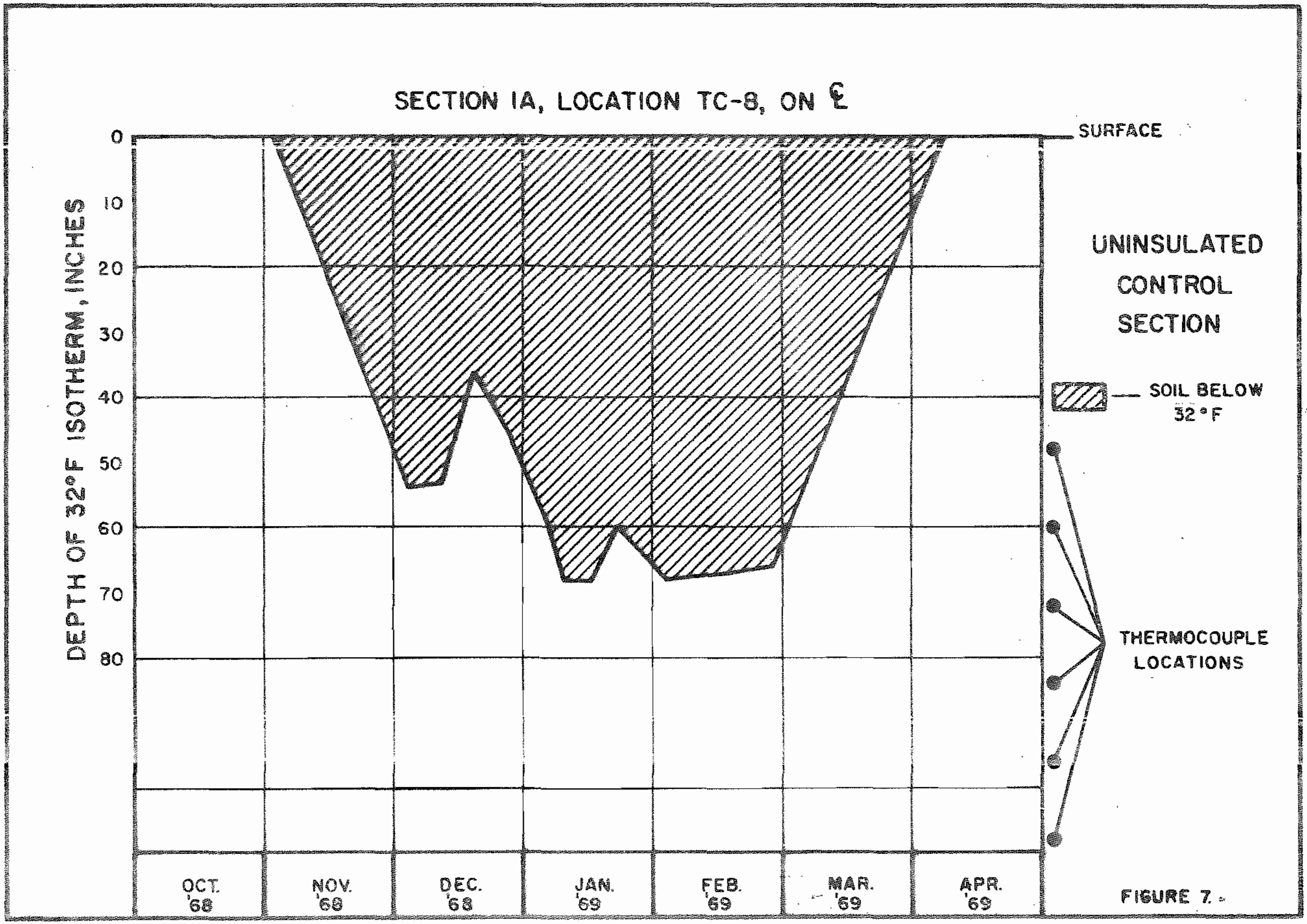

SECTION 1A, LOCATION TC-6, 3'LT. OF ℄
SECTION 1A, LOCATION TC-7, 3'RT. OF ℄
DEPTH OF 32°F ISOTHERM, INCHES
0
10
20
30
40
SURFACE
2" URETHANE
THERMOCOUPLE LOCATIONS
SOIL BELOW 32°F
OCT. '68
NOV. '68
DEC. '68
JAN. '69
FEB. '69
MAR. '69
APR. '69

FIGURE 6.


SECTION IA, LOCATION TC-8, ON ℄
SURFACE
DEPTH OF 32°F ISOTHERM, INCHES
0
10
20
30
40
50
60
70
80
UNINSULATED CONTROL SECTION
SOIL BELOW 32°F
THERMOCOUPLE LOCATIONS
OCT. '68
NOV. '68
DEC. '68
JAN. '69
FEB. '69
MAR. '69
APR. '69
FIGURE 7.

MAXIMUM ROADWAY HEAVE PROFILE
TEST SECTION IA, 1968–69 WINTER

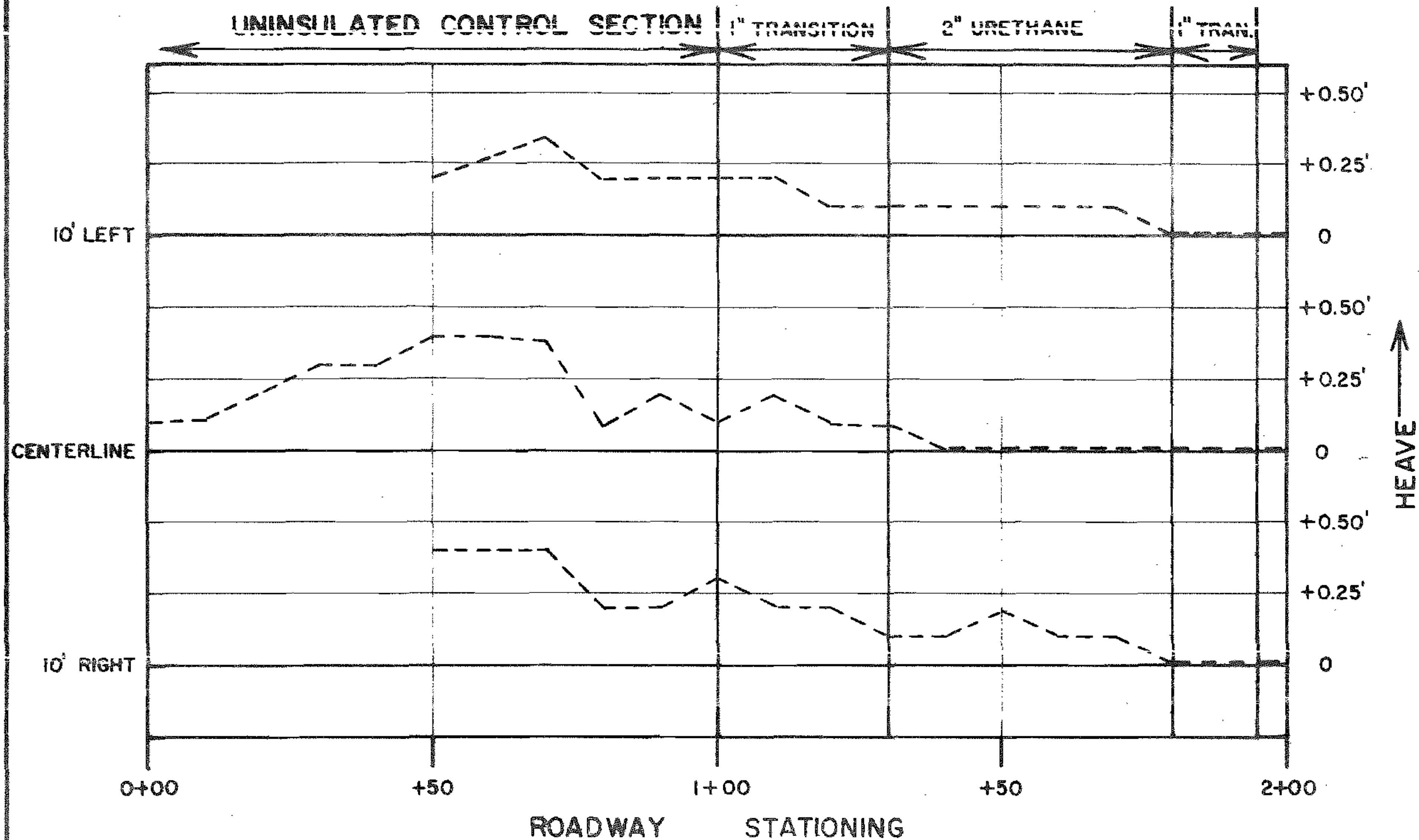


FIGURE 8.

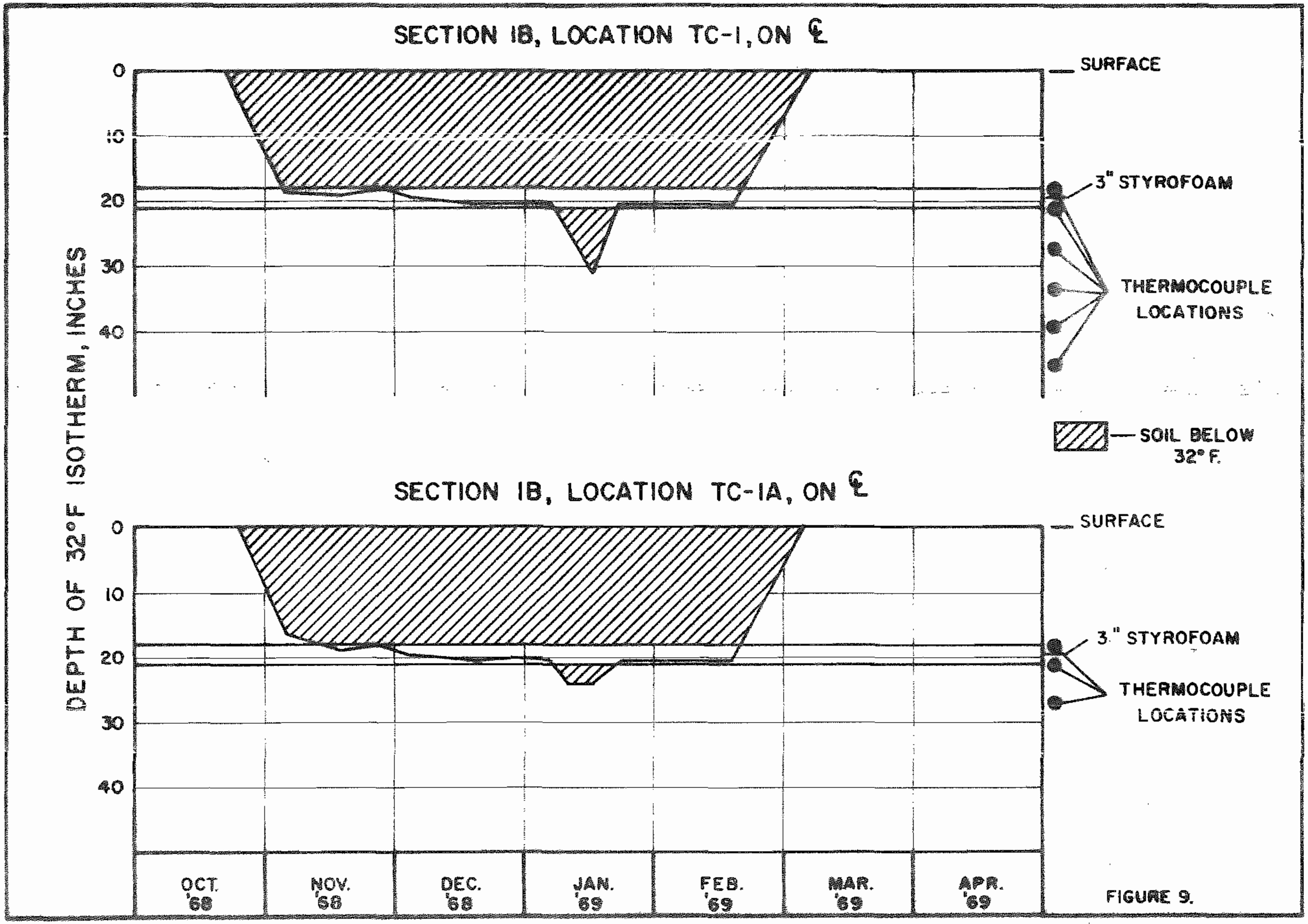

SECTION IB, LOCATION TC-1, ON ℄
SURFACE
3" STYROFOAM
THERMOCOUPLE LOCATIONS
SOIL BELOW 32° F.
SECTION IB, LOCATION TC-1A, ON ℄
SURFACE
3" STYROFOAM
THERMOCOUPLE LOCATIONS
DEPTH OF 32°F ISOTHERM, INCHES
0
10
20
30
40
OCT. '68
NOV. '68
DEC. '68
JAN. '69
FEB. '69
MAR. '69
APR. '69

FIGURE 9.

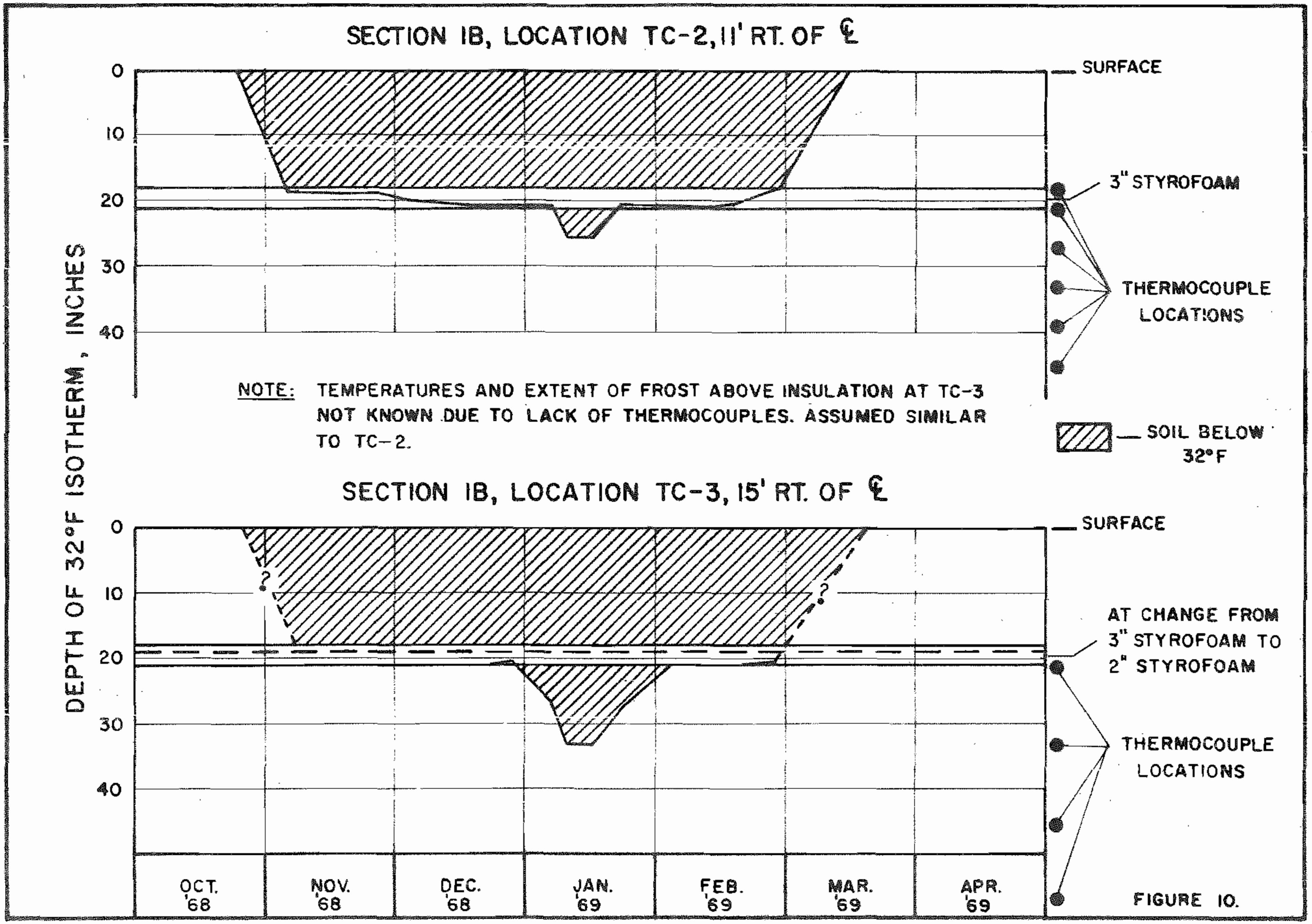

SECTION IB, LOCATION TC-2, 11' RT. OF ℄
SURFACE
3" STYROFOAM
THERMOCOUPLE LOCATIONS
DEPTH OF 32°F ISOTHERM, INCHES
0
10
20
30
40
NOTE: TEMPERATURES AND EXTENT OF FROST ABOVE INSULATION AT TC-3 NOT KNOWN DUE TO LACK OF THERMOCOUPLES. ASSUMED SIMILAR TO TC-2.
SOIL BELOW 32°F
SECTION IB, LOCATION TC-3, 15' RT. OF ℄
SURFACE
AT CHANGE FROM 3" STYROFOAM TO 2" STYROFOAM
THERMOCOUPLE LOCATIONS
?
?
OCT. '68
NOV. '68
DEC. '68
JAN. '69
FEB. '69
MAR. '69
APR. '69

FIGURE 10.

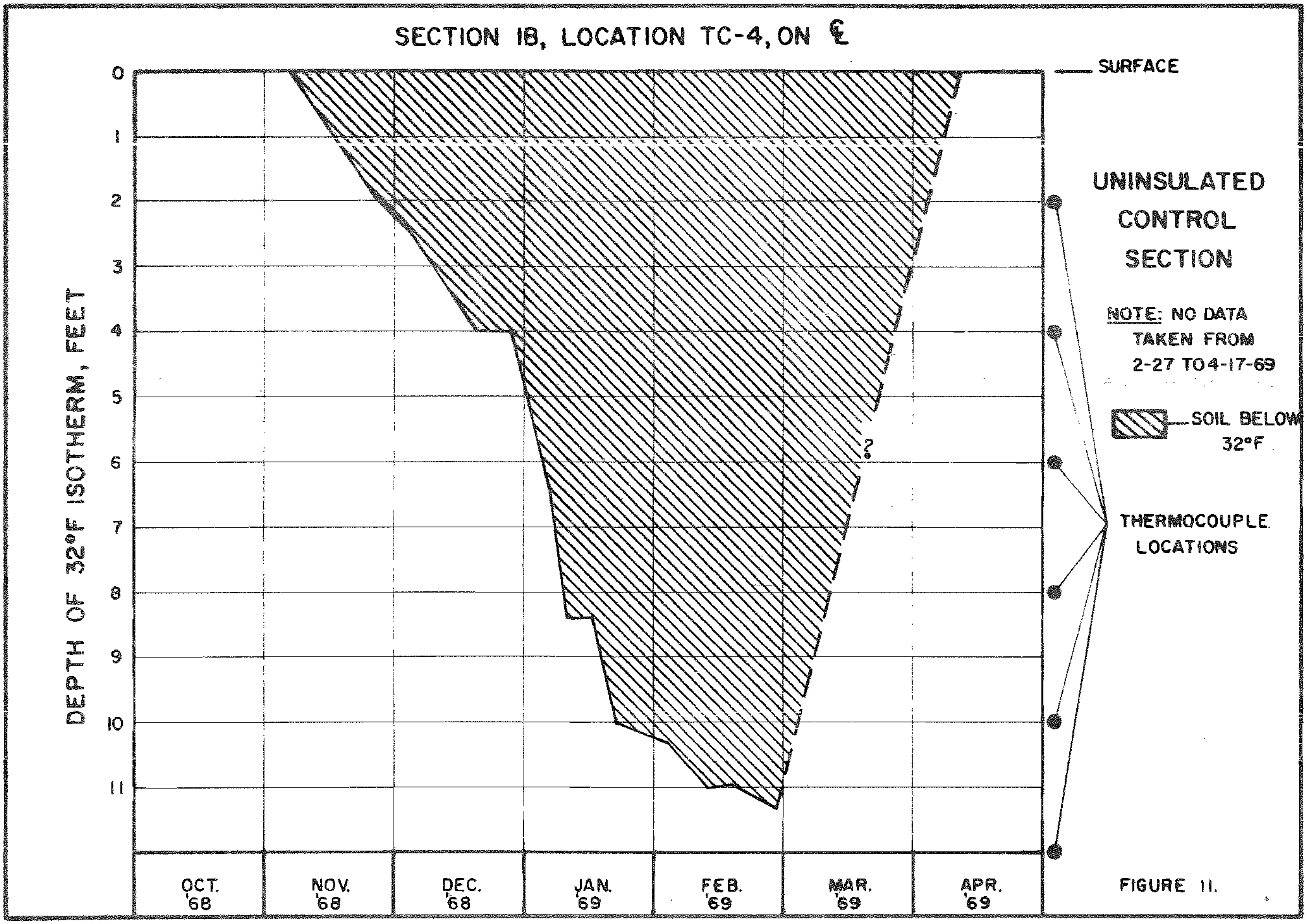

SECTION 1B, LOCATION TC-4, ON ℄
SURFACE
DEPTH OF 32°F ISOTHERM, FEET
0
1
2
3
4
5
6
7
8
9
10
11
?
OCT. '68
NOV. '68
DEC. '68
JAN. '69
FEB. '69
MAR. '69
APR. '69
UNINSULATED CONTROL SECTION
NOTE: NO DATA TAKEN FROM 2-27 TO 4-17-69
SOIL BELOW 32°F
THERMOCOUPLE LOCATIONS

FIGURE 11.

The maximum penetration indicated at locations 1, 1A, and 2 was about 8 inches. No significant difference could be detected between temperatures at centerline and at 5 feet in from the outer edge of the insulation. At a distance of one foot in from the outer edge, frost penetration occurred earlier, lasted longer, and reached a depth of 12 inches below the insulation. It was anticipated that the "edge effect" of frost penetrating around the edge of the insulation would be more noticeable than indicated. However, the lateral berms of snow left on the shoulders as a result of snow plowing appear to have considerable insulating value. On roads maintained by the Alaska Department of Highways, the snow is plowed out onto the shoulders of the roadway, but no attempt is made to remove snow and ice to the bare pavement by use of salt or other means.

Thermocouple readings taken on February 3, 1969 indicated that all soils beneath the insulation had thawed. Frost penetration in the control area, at thermocouple location TC-4, continued to increase through February, 1969, reaching a maximum depth of 11½ feet.

Heave Measurements—Section 1B

The maximum heave profiles for Section 1B are shown by Figure 12. In general, a heave of 0.10 to 0.20 feet occurred throughout the insulated area. Areas at either end of the insulation showed practically no movement. It should be noted that these areas also showed negligible heave during the winter of 1967-68. In an area near the right shoulder around Station 10+25, a heave of up to 0.30 feet was indicated. This same area was very soft during construction and a mud boil developed while backfilling over the insulation. This resulted in the insulation layer being seriously deformed by rutting. It was necessary to excavate and replace a small portion of the insulation directly above the boil. It appears that damage was extensive enough to reduce the overall insulation value significantly and permit increased frost penetration and heaving.

Maximum heave recorded during the 67-68 winter, before the insulation was installed, was 0.62 feet. The insulation resulted in a general reduction in heave, as compared to the previous season, of about 0.4 feet, which completely eliminated the safety hazard and discomfort involved in traversing the test section.

Elevation profiles for 1968-69 indicate that heaving continued to increase through the month of February in some areas. At the thermocouple locations, however, heaving had reached its maximum by mid-February. Since thermocouple temperatures indicated that soils beneath the insulation had thawed early in February, it is not certain why some additional heaving occurred. It is possible that, in the areas which heaved after February 1, frost penetrated slightly deeper and lasted longer than at the thermocouple locations.

By mid-March, elevation profiles still showed the heave to be at the maximum for the winter. Again, since the thermocouples indicated that the soil above and below the insulation was at 32 degrees or above by late February, the reason why the heave was still at a maximum in March is not known. Assuming that the thermocouple readings are correct, the delay in heave reduction appears to represent a decrease in density of the underlying soils caused by expansion due to frost action. It is possible that a considerable period of time is required for the action of traffic to recompact the heaving soil.

One point to be considered in evaluating the frost penetration and minor heaving which occurred in test section 1B, is the possibility that considerable damage to the insulation resulted from cracking of the insulation layer as a result of the very soft condition of the subgrade during and after insulation placement. Determination of the extent of this damage would require excavation of the overlying gravel layers and inspection of a relatively large area of the test section. At present no plans have been made to attempt this.

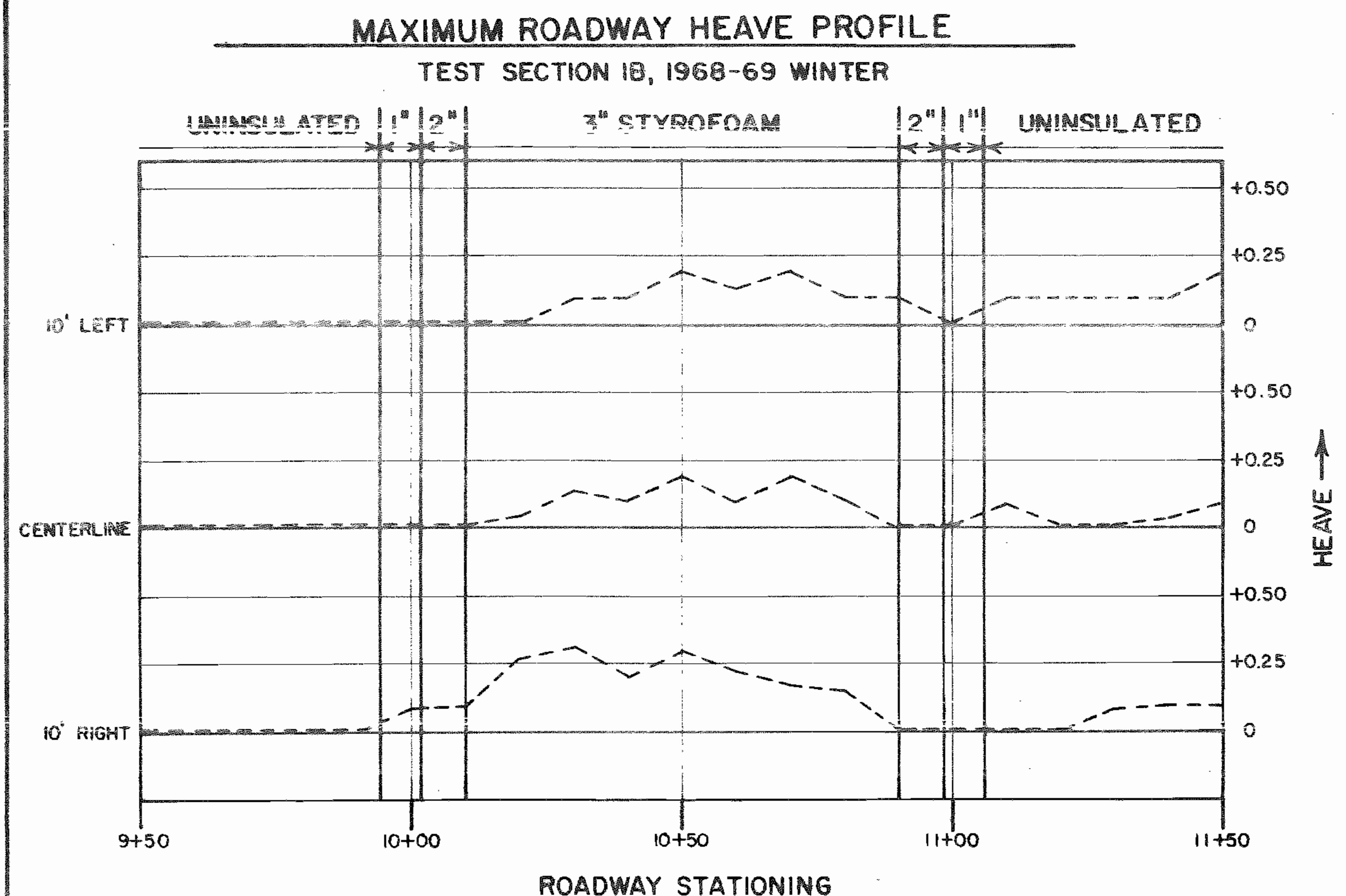

MAXIMUM ROADWAY HEAVE PROFILE
TEST SECTION IB, 1968-69 WINTER
UNINSULATED
1"
2"
3" STYROFOAM
2"
1"
UNINSULATED
10' LEFT
CENTERLINE
10' RIGHT
+0.50
+0.25
0
HEAVE
9+50
10+00
10+50
11+00
11+50
ROADWAY STATIONING

FIGURE 12.

Insulation Inspection—May 1969

On May 15, 1969, one excavation was made in each test section to examine the insulation layer and the soils above and below the insulation. Samples of the insulation were removed for laboratory examination and replaced with patches of similar material.

Test Section 1A

A trench was hand excavated from the shoulder of the roadway at Station 1+60 and a 2 ft. x 2 ft. sample of the insulation was taken at six feet right of centerline. The sample was examined, measured, and tested for moisture content and compressive strength. Both upper and lower surfaces of the foam were wet when removed. Bond between the subgrade and the insulation was very good. The soil layers above and beneath the insulation were relatively firm and showed no excessive moisture. In some areas the urethane foam appeared to hold considerable water. Wet zones in the foam were generally confined to the upper and lower surfaces and to the surfaces where new foam was sprayed over that placed during the previous pass. Apparently, after a layer has been foamed and has hardened for more than about one minute, new foam placed on top does not bond to the base layer. The resultant joint is then capable of conducting water. Water can then penetrate into the interior of the foam mass from the outer surfaces and also from the joint areas. Wetted foam areas appeared to be confined mostly to the 1/8 inch of insulation adjacent to surfaces or joints. The asphalt moisture barrier used above and beneath the insulation was apparently ineffective in keeping moisture from reaching the insulation.

Moisture contents were run on three pieces cut from the sample. The outer 1/8 inch, plus or minus, of the foam was cut away to remove the bonded asphalt and soil particles and obtain a moisture representative only of the foam. Moisture contents by volume were 1.9, 2.6, and 3.7% for the three pieces. Because the surface skins had to be trimmed off, some of the wettest areas were necessarily removed. However, the results do indicate some tendency to absorb moisture. The piece showing the 3.7% moisture content contained one of the joints made between foaming passes, and was the wettest for this reason. To determine whether water absorption will progressively reduce the insulating effectiveness of the foam-in-place urethane, continuing observations of the temperatures above and below the insulation, and future sampling and testing for moisture pickup, will be necessary.

Measurements showed the average thickness of the foam sample to be 1.46 inches. Since this was considerably less than the 2 in. nominal thickness specified for Section 1A, it appeared that the foam may have compressed under load. Density of the excavated sample, based on four determinations, was 2.11 lbs. per cubic foot. The average density of an insulation sample taken during construction at a point 10 feet away was 2.17 pcf. This indicates that the foam had not compressed significantly and that thickness at this location was deficient after placement.

Compressive strengths were compared between the recovered sample and the samples taken during placement and stored in the laboratory. Six tests on the stored samples showed compressive strengths ranging from 28.8 to 32.7 psi at 5% strain, with an average value of 31.5 psi. Four pieces cut from the recovered sample showed a range in strength from 21.3 to 31.1 psi, with an average of 24.9 psi. Samples for strength tresting were trimmed to approximately 2 in. x 2 in. x 1 in. high, and loaded in the vertical direction at 4% strain per minute. Apparently the insulation beneath the roadway has lost some of its original strength due to the repeated traffic loadings, weathering, or both. The strengths obtained on the recovered samples still appear to be adequate for service with the overlay thickness used above the insulation.

Section 1B

Samples of the "Styrofoam HI" insulation board were taken from Station 10+50 at 9 ft. left of centerline. Samples were also taken of the soils above and below the insulation. When removed, the surfaces of the insulation board were wet, with some water present between the upper (1 in.) and lower (2 in.) boards. The soils above and below had moisture contents ranging from 4.0 to 6.6%, and appeared to be well compacted. The soil surface beneath the insulation showed areas where the fines of the soil had been washed away leaving an appearance similar to "exposed aggregate" concrete. This indicates that the water table had reached a level at least as high as the bottom of the insulation at some time since August, 1968.

One crack, apparently due to flexure caused by the initially soft subgrade, was noted in the 2 ft. x 2 ft. sample taken of the insulation. Gravel indentation of up to ¼ inch was found on both upper and lower insulation surfaces. Due to gravel damage, the average effective thickness of the insulation appears to be about 2.8. inches. Thin layers of fine sand placed above and below the insulation would be of some benefit in reducing the extent of this damage, but the increased placement costs may outweigh the benefits derived.

Compressive strength, density and moisture content tests were run on the Styrofoam samples. Comparisons with results from samples taken during construction showed no significant change in strength or density after one winter of service. Strength of the original material ranged from 42 to 60 psi at 5% deflection, based on six tests, for an average of 51.6 psi. Two tests on the recovered Styrofoam sample gave strengths of 44 psi and 47 psi. All strengths were well above the manufacturer's suggested minimum of 35 psi at 5% strain. Stress-strain curves for the Styrofoam HI showed the compressive resistance reaching ultimate above 10% strain, as shown by the typical stress-strain curves, Figure 13. Density of the Styrofoam averaged 2.16 pounds per cubic foot on samples taken during placement and 2.15 pcf on samples removed after the first winter of service. The samples removed were within the stated manufacturing tolerances for thickness of plus or minus 1/16 inch.

Samples for moisture absorption tests were taken from the 1 in. thick Styrofoam layer, since this material would be expected to show higher moisture contents by volume than the 2 in. layer, due to the greater surface area to volume ratio. Two samples were prepared by trimming off the outer 1/8 in., plus or minus, in a manner similar to the urethane sample preparation, to remove any adhering moist soil particles. The highest moisture content of the two samples was .099% by volume. Three samples prepared by brushing away the adhering soil particles, showed moisture pickup of 0.50 to 0.69% by volume.

Summary First Year of Observations

Data accumulated from the first winter of observations, and from tests on recovered samples, leads to the following conclusions:

1. A very great reduction was achieved in the frost penetration due to the installation of the insulation layers. Frost penetration in the area insulated with two inches of foamed-in-place urethane reached a maximum depth of 35 inches, compared with 68 inches beneath the adjacent uninsulated roadway. Frost penetrated to a depth of 31 inches in the section insulated with 3 inches of "Styrofoam HI" insulation boards. Adjacent to this insulated section, the frost penetration reached a depth of 136 inches on centerline.

2. Some heaving of the insulated test sections still occurred, apparently due to the freezing of the subgrade soils to a depth of 6 inches to 18 inches beneath the insulation. Heaving of both insulated sections was considerably reduced during the 1968-69 winter from that measured during the previous winter, prior to the insulation installation. The discomfort in traversing the test sections was eliminated.

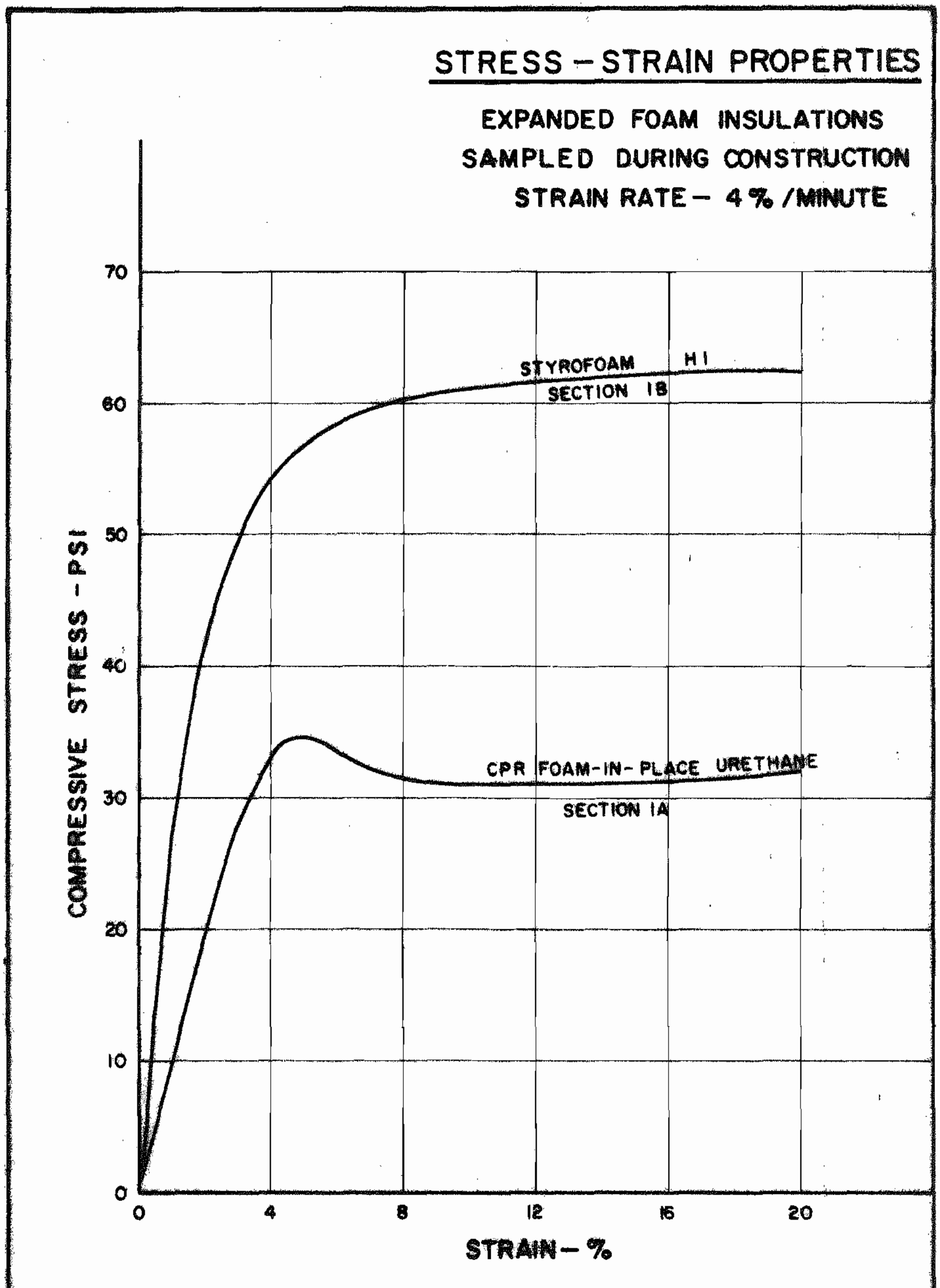

STRESS – STRAIN PROPERTIES
EXPANDED FOAM INSULATIONS
SAMPLED DURING CONSTRUCTION
STRAIN RATE – 4% /MINUTE
STYROFOAM HI
SECTION IB
CPR FOAM-IN-PLACE URETHANE
SECTION IA
COMPRESSIVE STRESS - PSI
0
10
20
30
40
50
60
70
0
4
8
12
16
20
STRAIN – %

FIGURE 13.

3. The frost penetration beneath the 2 inch urethane insulation section was slightly greater than beneath the 3 inch Styrofoam section. Comparison of thermal conductivities of the two insulations at 32 degrees indicates that this should be expected, since the insulating effectiveness of "R" value of two inches of urethane would be slightly less than that of three inches of Styrofoam.

4. Samples of the insulation removed after one winter of service, indicated some tendency toward moisture pickup and possible strength loss in the foamed-in-place urethane insulation. Additional observations over a period of years are needed to determine whether these trends will progress to the point of danger to performance. Strength losses and moisture pickup in the "Styrofoam" insulation boards were small or insignificant. No proof of compression under load was found in either material.

Observations of the insulated Test Sections 1A and 1B will continue for at least two additional winters, and occasional checks will be made each subsequent winter for as long as necessary to verify the continuing performance of the insulations.

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7. E. Penner. *Experimental Pavement Structures Insulated with a Polyurethane and Extruded Polystyrene Foam.* Proceedings—International Conference on Low Temperature Science, Hokkaido University, Sapporo, Japan, 1967.

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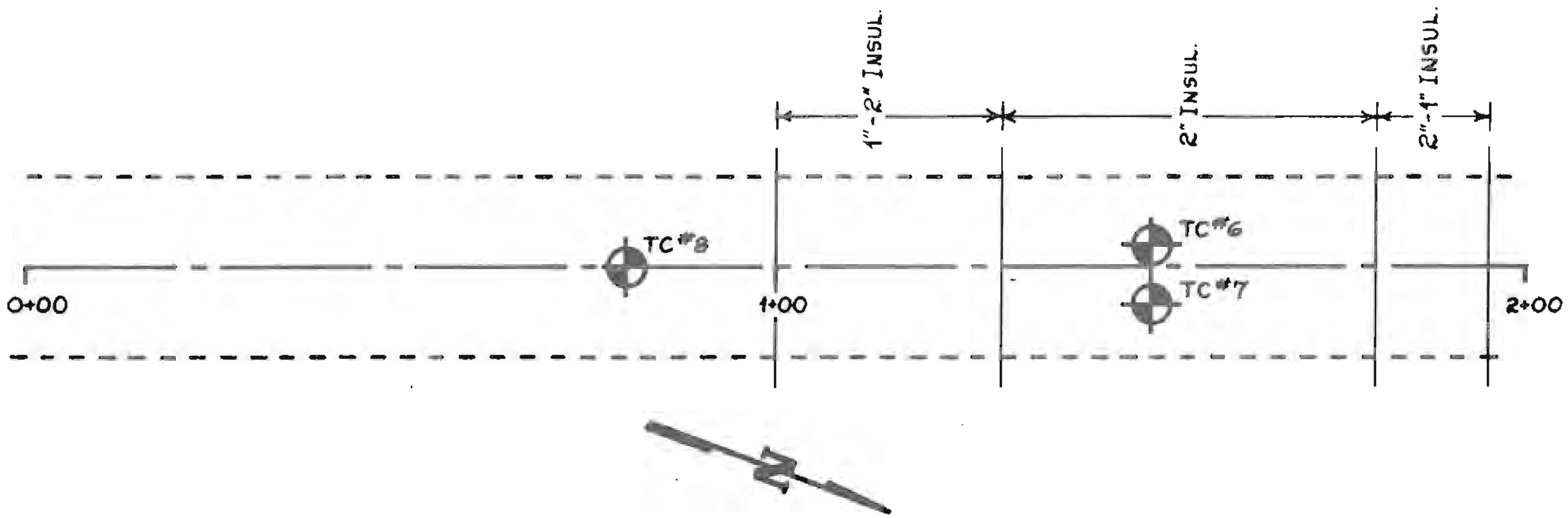
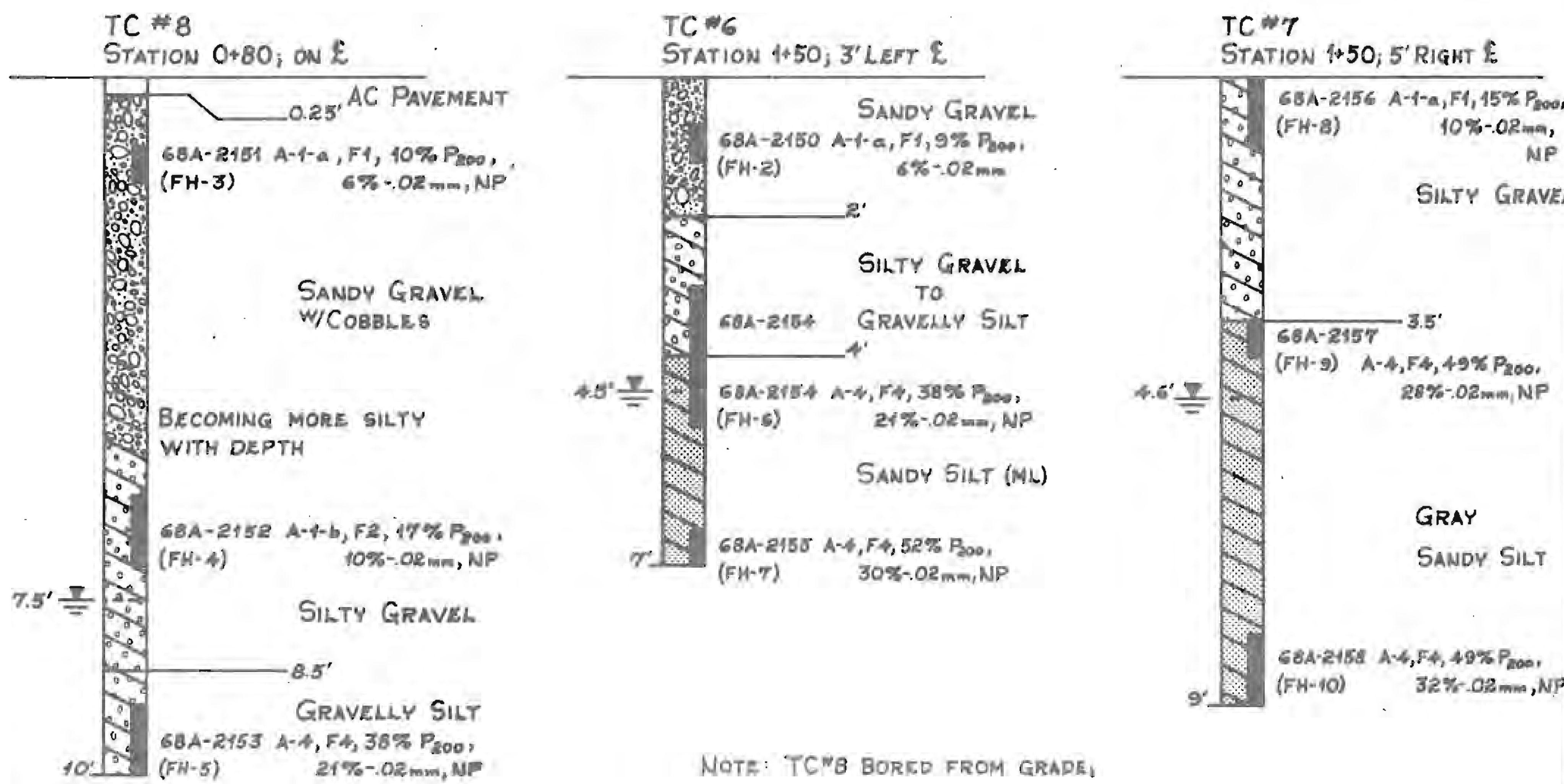
11. L.M. Hatch. *Use of Insulation to Attenuate Frost Heaving.* Idaho Department of Highways, Research Report Number 38, 1969.

APPENDIX A

SUBGRADE SOIL PROPERTIES

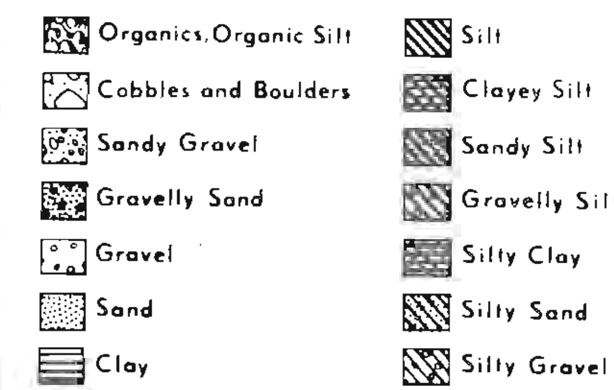
STATE	PROJECT NO.	SHEET No	TOTAL SHEETS
ALASKA		1	2

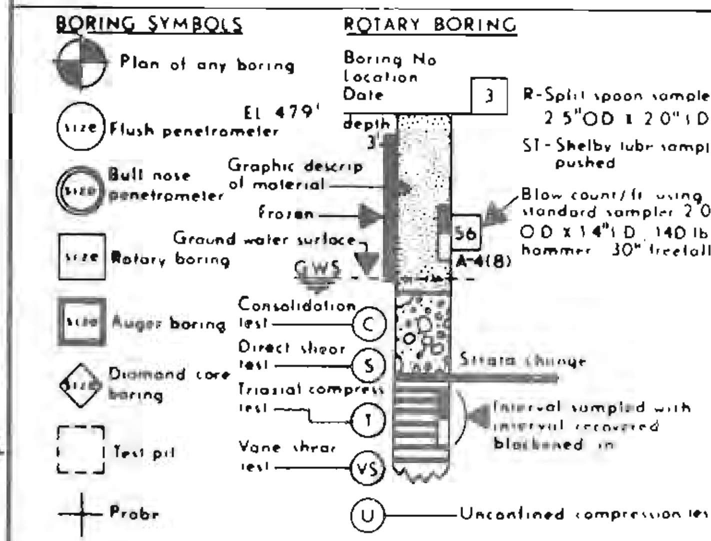




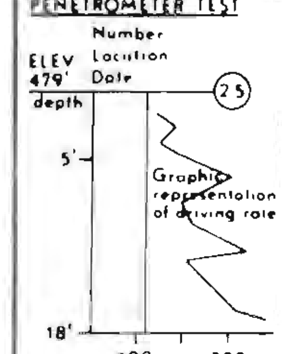
NOTE: TC#8 BORED FROM GRADE; ALL OTHERS BORED FROM 1.75' BELOW GRADE

MATERIAL SYMBOLS





PENETROMETER TEST



Blows/foot ___ penetrometer with ___ # hammer, 30" drop

RELATIVE DENSITY AND CONSISTENCY CLASSIFICATION

According to standard penetration test

GRANULAR		COHESIVE	
Blows/ft	Rel Density	Blows/ft	Consistency
0-4	very loose	0-1	very soft
5-10	loose	2-4	soft
11-20	firm	5-8	firm
21-30	very firm	9-15	stiff
31-50	dense	15-30	very stiff
Over 50	very dense	Over 30	hard

LOG OF TEST BORINGS

Roadway Subgrade Insulation

TEST SECTION

1A

Bridge No. ______

State of Alaska

DEPARTMENT OF HIGHWAYS

Juneau, Alaska

Date 6/20/69

Approved ______

Drawing No. ______

ALASKA DEPARTMENT OF HIGHWAYS

INSULATION TEST SECTION 1A

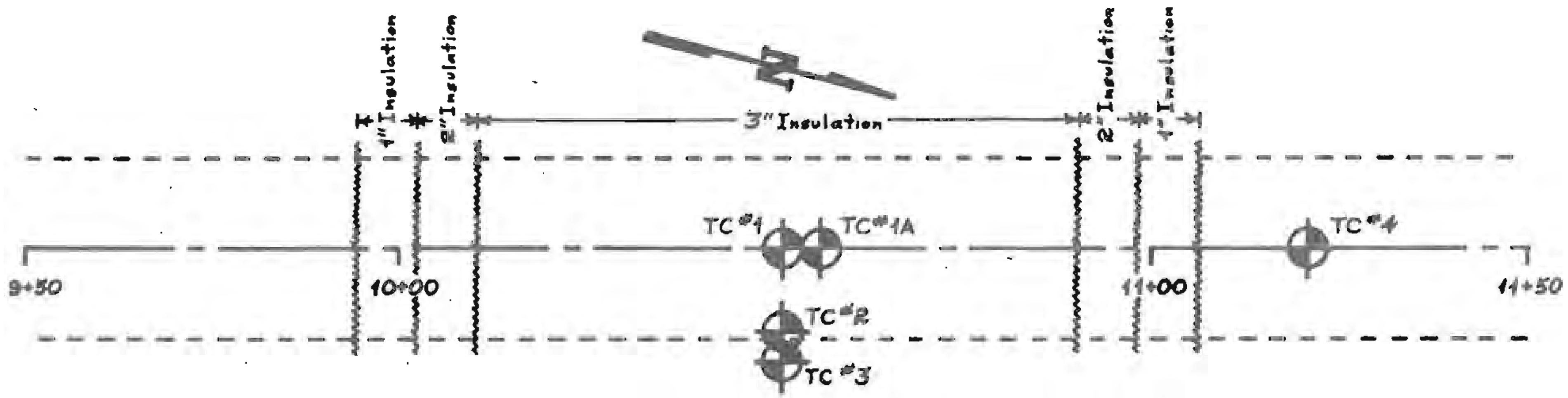
SUMMARY OF TEST DATA — FOUNDATION SOILS

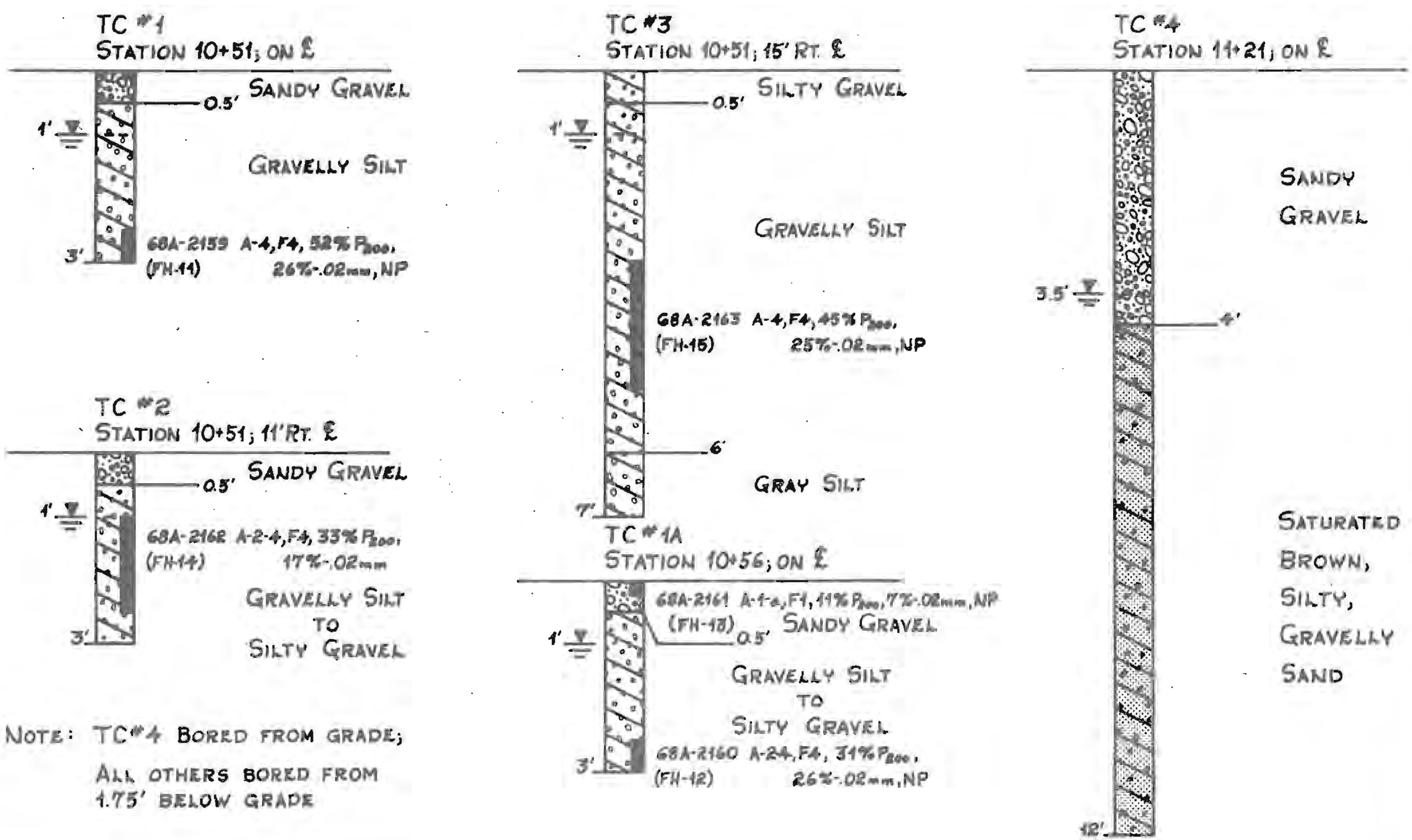
Project No. Project Name sheet of sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .005	Atterberg Limits: Liquid Limit	Atterberg Limits: Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.
FH-2	1-1.5	68A-2150	86	60	45	31	16	9	6	4	NV	NP		3.4	2.70	F-1	A-1-a
FH-3	1-1.5	68A-2151	91	63	46	31	17	10	6	4	NV	NP			2.71	F-1	A-1-a
FH-4	6-7	68A-2152	100	92	75	48	29	17	10	6	NV	NP		3.5	2.70	F-2	A-1-b
FH-5	9-10	68A-2153	99	91	82	73	69	38	21	10	NV	NP		7.4	2.68	F-4	A-4
FH-6	2-7	68A-2154	98	83	75	68	57	38	21	9	NV	NP		9.5	2.70	F-4	A-4
FH-7	6.5-7	68A-2155		100	97	89	77	52	30	-	NV	NP		11.1	2.69	F-4	A-4
FH-8	0-1	68A-2156	94	71	55	41	28	15	10	5	NV	NP			2.69	F-1	A-1-a
FH-9	3.5-4	68A-2157	100	94	89	83	72	49	28	12	NV	NP		10.7	2.68	F-4	A-4
FH-10	8.9	68A-2158		100	98	90	77	55	32	-	NV	NP		11.5	2.68	F-4	A-4

Remarks:

STATE	PROJECT NO.	SHEET No.	TOTAL SHEETS
ALASKA		2	2

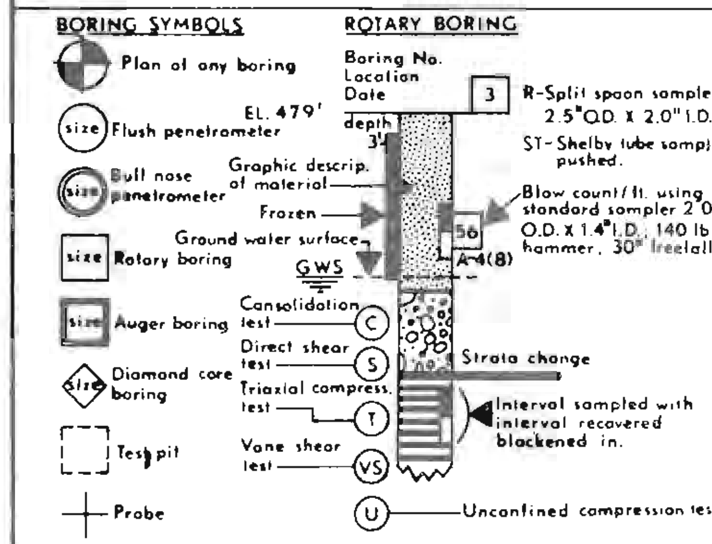


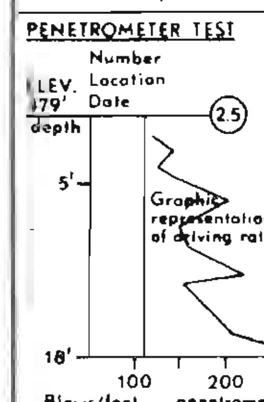


NOTE: TC#4 BORED FROM GRADE;
ALL OTHERS BORED FROM
1.75' BELOW GRADE

MATERIAL SYMBOLS

Organics, Organic Silt	Silt
Cobbles and Boulders	Clayey Silt
Sandy Gravel	Sandy Silt
Gravelly Sand	Gravelly Silt
Gravel	Silty Clay
Sand	Silty Sand
Clay	Silty Gravel





RELATIVE DENSITY AND CONSISTENCY CLASSIFICATION

According to standard penetration test

GRANULAR		COHESIVE	
Blows/ft.	Rel. Density	Blows/ft.	Consistency
0-4	very loose	0-1	very soft
5-10	loose	2-4	soft
11-20	firm	5-8	firm
21-30	very firm	9-15	stiff
31-50	dense	15-30	very stiff
Over 50	very dense	Over 30	hard

LOG OF TEST BORINGS
Roadway Subgrade Insulation
TEST SECTION
1B

Bridge No. ______

State of Alaska
DEPARTMENT OF HIGHWAYS
Juneau, Alaska

Date 6/20/69
Approved ______
Drawing No. ______

ALASKA DEPARTMENT OF HIGHWAYS

INSULATION TEST SECTION 1B

SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. ______ Project Name ______ sheet ___ of ___ sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .005	Atterberg Limits: Liquid Limit	Atterberg Limits: Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist. %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.
FH-11	2.5-3	68A-2159	100	97	95	85	75	52	26	-	NV	NP		13.0	2.67	F-4	A-4
FH-12	2.5-3	68A-2160	100	80	74	60	49	31	18		NV	NP		11.0	2.68	F-4	A-2-4
FH-13	0-0.5	68A-2161	81	61	47	35	21	11	7	4	NV	NP			2.67	F-1	A-1-a
FH-14	1-3	68A-2162	96	88	76	66	53	33	17	7	NV	NP		8.9	2.68	F-4	A-2-4
FH-15	3-5	68A-2163	100	93	86	77	64	45	25	12	NV	NP		9.8	2.70	F-4	A-4

Remarks:

ALASKA DEPARTMENT OF HIGHWAYS

SELECT MATERIAL FOR BACKFILL OVER INSULATION

SUMMARY OF TEST DATA —

Project No. ______ Project Name ______ sheet ___ of ___ sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing: Gravel 1"	Gravel 3/8"	Gravel #4	Sand #10	Sand #40	Silt #200	Silt .02	Clay .005	Atterberg Limits: Liquid Limit	Atterberg Limits: Plastic Index	Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	Loc.	Station	Test Section
FH-21	1-1.5	68A-2169	90	62	45	30	17	3			NV	NP					A-1-a	3'Rt.	1+50	1A
FH-16	1-1.5	68A-2164	92	70	55	40	21	11			NV	NP					A-1-a	8'Rt.	10+20	1B
FH-17	0.5-1	68A-2165	95	71	54	37	18	9			NV	NP					A-1-a	℄	10+55	1B
FH-18	0.5-1	68A-2166	89	65	51	34	16	9			NV	NP					A-1-a	6'Lt.	10+85	1B
PR-1	0.5-1	68A-2170	96	73	58	42	22	11			NV	NP			2.71		A-1-a			1B
A	1-1.5	69A-260	86	67	51	36	20	11	7		NV	NP			2.66	F-1	A-1-a	10'Lt	10+50	1B

Remarks: Maximum Dry Density for Sample FH-21 was 144 pcf at 5.6% moisture.
Maximum Dry Density for sample PR-1 was 144 pcf at 4.8% moisture.
Maximum Compacted Densities determined by AASHO Test Method T-180-D.

APPENDIX B

INSULATION COST DATA

Items of additional work which are considered necessary for preparation and installation of a layer of foamed plastic subgrade insulation include the following:

A. Linear grading of the surface prior to insulation placement.

B. Surface compaction with a steel-wheel vibratory roller.

C. Insulation laydown.

D. Placement of initial lift of backfill by end-dumping and spreading with a light dozer or loader.

Of the various costs incurred in insulating a section of roadway, those of the insulation and of the laydown operation appear to be the only items which may lead to difficulties in preparing a reasonably accurate cost estimate. Anticipated current (1969) costs for these items are as follows:

Foamed-in-Place Urethane Insulation

Since the full laydown operation of the foam-in-place urethane is usually handled by factory authorized distributors, information on the breakdown of costs is not available at present. Verbal communications indicate that the installed cost would range between $.25 to $.30 per board foot in the Anchorage area. Since the components are shipped in liquid form, this type of installation would not be nearly so sensitive to shipping rates as is the board-type insulation. Allowance of an additional $.04 to $.06 is suggested to cover the cost of the asphalt coating as was applied above and beneath the insulation on Section 1A.

"Styrofoam HI" Insulation Board

Cost estimates of insulation and placement have been made by Dow Chemical Company for use by contractors in bidding on two Alaskan projects calling for polystyrene foam insulation to be installed as a subgrade insulation layer. The two projects provide for installation of 1.4 million board feet beneath an airfield runway at Kotzebue, Alaska, for the Division of Aviation, and 110,000 board feet beneath various sections of the roadway on the Willow to Talkeetna project for the Alaska Department of Highways. Based on this information, the breakdown of estimated costs of placement in the Fairbanks and Anchorage areas is as follows:

ITEM	COST ($/BD. FT.)	COMMENT
1. Material - Styrofoam HI Brand Plastic Insulation F.O.B. Torrence, Calif. Plant	$.091	Price applies to quantities over 40,000 bd. ft.
2. Shipping Rail Freight (Estimated) Torrence to Fairbanks	$.065	Based on box car quantities $2430/car
or shipping Rail Freight (Estimated) Torrence to Anchorage	$.038	
3. Placement		
a) Transport Insulation from rail yard to job site.	$.010	Estimated allowance only variable depending on distance and trucking rates.
b) Handling and Installation Based on 618 $ft.^2$/man hr. Ratio of $ft.^2$ to bd. ft. = 0.5 Assuming all boards 2 in. thickness. (Slight adjustment needed for other thicknesses.)	$.009	Assumed labor @ $10.00/hr. (Linear adjustment needed for other labor rates)
c) Wooden Skewers, ¼ in. dia. x 6 in./long	$.007	Based on 2 per board @ $8/1000
d) Extra Insulation	$.004	Allows 4% extra for damage, etc.
Fairbanks Area Cost Total	$.186	
Anchorage Area Cost Total	$.159	

For purposes of bid estimating, an allowance for overhead and profit must be added to the above figures. Total costs for installation at sites other than those mentioned will be contingent on available modes of transportation and shipping rates.