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THE INFLUENCE OF INSULATION UPON FROST
PENETRATION BENEATH PAVEMENTS

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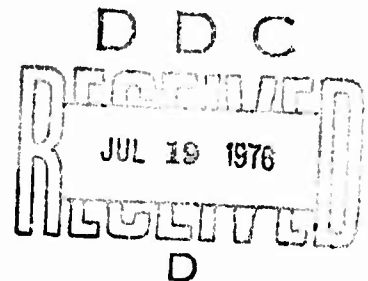
Special Report 76-6

THE INFLUENCE OF INSULATION UPON FROST PENETRATION BENEATH PAVEMENTS

Robert A. Eaton and Daniel E. Dukeshire

May 1976

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from differential (uneven) heaving can be costly depending on the amount of granular material required and its availability. A method of reducing the amount of granular material is the use of a thermal insulating layer beneath all or part of the base course which prevents freezing temperatures from reaching the non-uniform subgrade. A test road which includes Styrofoam board insulated test sections was constructed at CRREL in 1973. A transition section was built between a control section and an insulated section to minimize the drastic difference in frost penetration and resultant differential frost heave. Despite a mild winter (average freezing index), large temperature differences were measured between the insulated and conventional sections, frost penetrations were one-third as deep beneath the insulated section, differences in frost heave were negligible, and pavement deflections were approximately the same on the two sections. Surface differential icing did occur between the control and insulated sections.

Unclassified

PREFACE

This report was prepared by Robert A. Eaton, Research Civil Engineer, Northern Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory, and Daniel E. Dukeshire, Cooperative Education Student at Northeastern University, Boston, Massachusetts.

The work was done under DA Project 4K078012AAM1, Engineering
Criteria for Design and Construction; Work Unit 030, Field Performance
of Pavement Test Sections in Seasonal Frost.

Technical reviewers of the report were Dr. R.L. Berg and Gary Phetteplace of USACRREL.

Assistance with data collection, reduction, and tabulation was given by Gordon W. Dow, Cooperative Education Student at Northeastern University, and Judith Zimicki, student at Dartmouth College, Hanover, New Hampshire.

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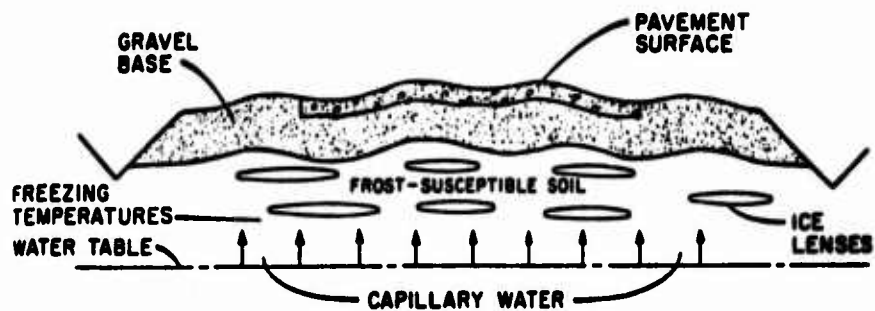
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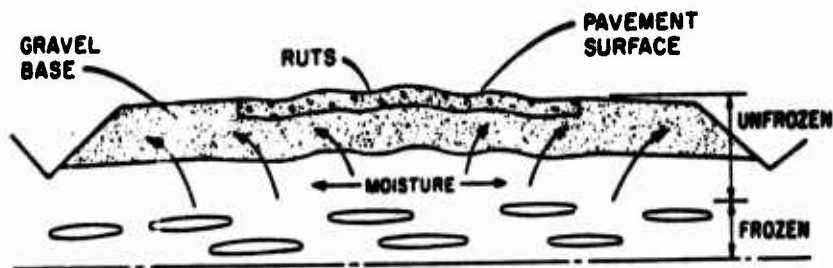
INTRODUCTION

Frost action in soils causes pavement structures to heave because of ice lense growth during the freezing season (Fig. 1a). The loss of structural support in the spring caused by the melting of the ice lenses can precipitate pavement failure (Fig. 1b). Three factors necessary for deleterious frost action to occur are freezing temperatures, frost susceptible soil, and a source of water, all existing at the same time. In order to minimize differential frost heaving, granular material is placed on top of the frost-susceptible subgrade, with the thickness depending on the depth of frost penetration and desired protection. This method of protection can be costly depending on the amount of granular material required and its availability. A method of reducing the amount of granular material and heat loss from the subgrade is the use of a thermal insulating layer beneath all or part of the base course, thereby preventing freezing temperatures from reaching the frost susceptible subgrade (Fig. 2).

The concept of using an insulating layer in pavements is not new. In Europe, different materials have been used to prevent frost action in pavements for the last 40 years (Withers 1974). The U. S. Army Corps of Engineers built several insulated test sections in Alaska in 1946 (Berg, 1973). Cellular glass insulation was found to be the best insulator but its cost was very high and a great amount of labor was required for installation (Berg 1973).

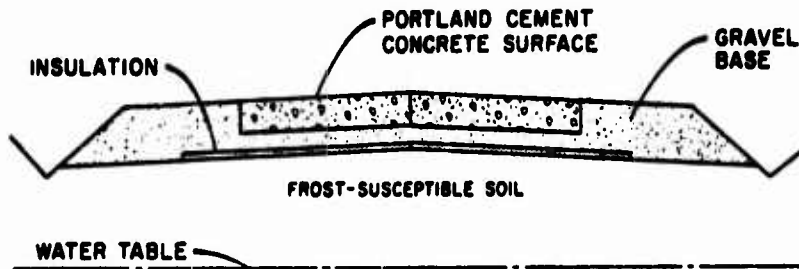


a. Frost heave

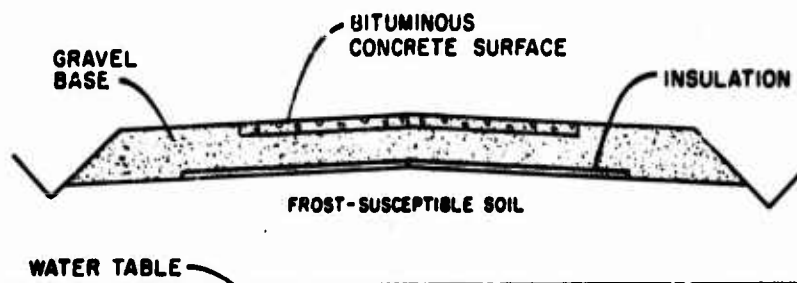


b. Spring break up

Figure 1: Frost action damage to highways.



a. Portland Cement Concrete Surface



b. Bituminous Concrete Surface

Figure 2: Insulated pavement concept

In 1962, Dow Chemical Company began marketing an extruded, expanded polystyrene insulation, designated "HI", for highway insulation. Since 1962, 19 states and Canadian provinces have used the extruded polystyrene board insulation in highway construction. Eleven of the 19 agencies have observed differential icing conditions between the insulated and uninsulated pavement sections (similar to bridge deck icings). Seven of the 11 indicated that the differential icing conditions are, to some extent, an obstacle to more wide spread use of insulating layers (Johnson et. al. 1975).

BACKGROUND

An experimental access road was constructed on USACRREL property in the fall of 1973 to study and compare the performance of various highway pavement test sections under freeze-thaw conditions (see Fig. 3). The road is 970 ft long x 16 ft wide, with two 4-ft shoulders on each side. The nine test sections (Fig. 4) consist of (a) a control section of a "conventional" design (thin pavement over a granular base course), (b) two types of insulation in "conventionally" designed insulated sections, (c) a transition section between the control and insulated sections, (d) two strengths of polyurethane insulation in a "top" insulated section, (e) additives and their effect within Membrane Encapsulated Soil Layer (MESL) sections using a highly frost susceptible silt, (f) a lime fly-ash silt mixture base course, and (g) various asphaltic concrete mixes with regard to thermally-induced cracking (Berg

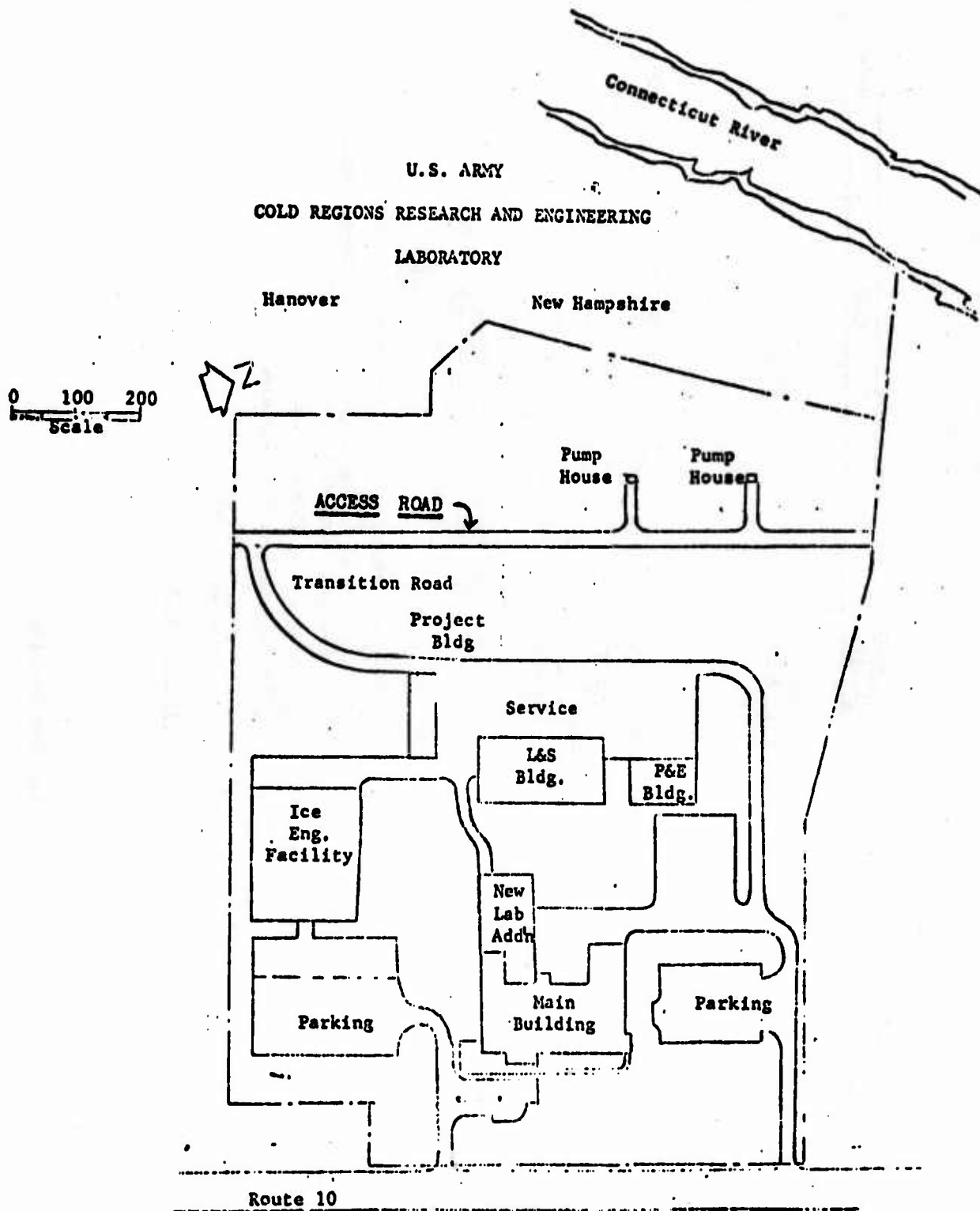


Figure 3: Site Plan

and Eaton 1974). This report will be concerned with the performance of the transition between the control section (Section A) and the "conventionally" insulated section (Section D) (see Fig. 5).

DESIGN AND CONSTRUCTION OF THE TRANSITION SECTION

To minimize the drastic difference in frost penetration and resultant frost heave between conventionally insulated and uninsulated pavements, a transition section was constructed. Appendix A contains photographs of this construction.

The transition section separates a control section (section A) consisting of 9 in. of concrete sand, 6 in. of 3/4-in. maximum size crushed stone, and 2 in. of asphalt concrete pavement; and an insulated section (section D) consisting of a 1/2-in. bedding and leveling course of concrete sand, a 2-in. layer of Styrofoam boards (35 psi compressive strength) measuring 2 ft. x 8 ft., 8 in. of 1-1/2-in. maximum size aggregate crushed bank-run gravel, and 2 in. of asphalt concrete pavement (see Fig. 5).

To transition into the insulated section from the uninsulated section, the following design was proposed and constructed.

The transition section consists of 16 ft of perforated 1-in.-thick, 2-ft x 8-ft Styrofoam boards with 4-in. diam holes drilled on an 8-in. center-to-center grid, from station 1+50 to 1+66 (section B) and 16 ft. of solid 1-in.-thick, 2-ft x 8-ft Styrofoam boards from station 1+66 to 1+82 (section C).

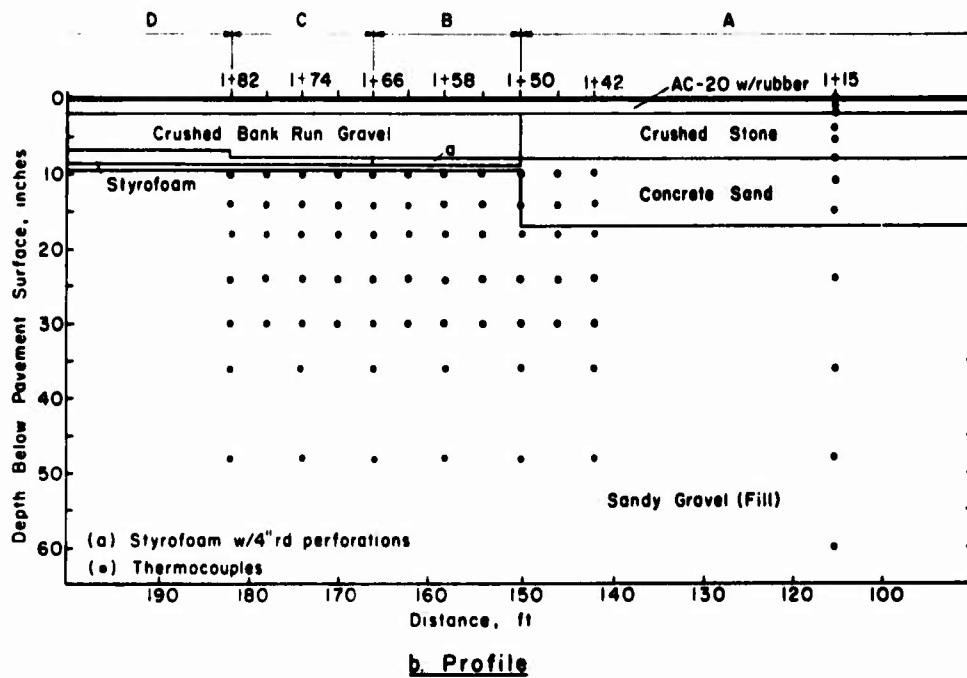
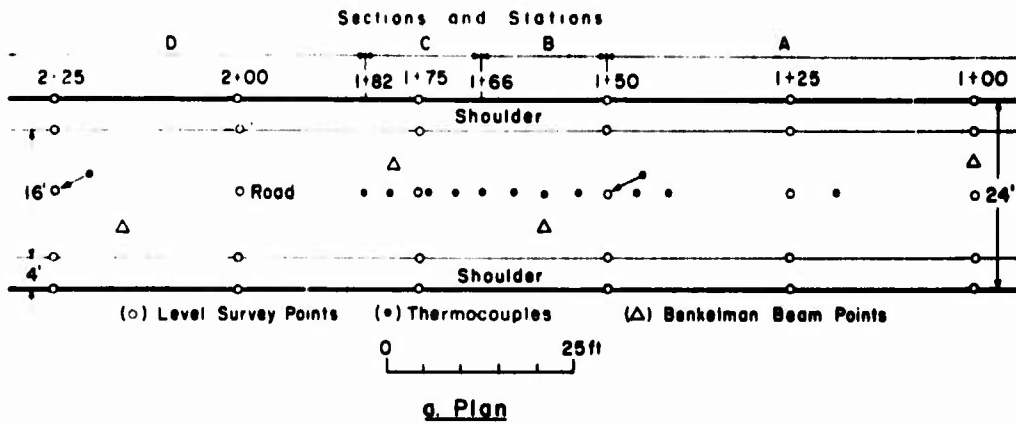


Figure 5: Plan and Profile of Insulated Transition

The purpose of the perforated 1-in.-thick insulation was to create another step of lesser insulating thickness to provide an approximately 0 in., 1/2-in., 1-in., 2-in. step from the control, to a fully insulated section as recommended by Dow Chemical Company (Williams, 1968). An approximately 1/2-in. bedding and leveling layer of concrete sand was placed beneath the insulation and 9 in. of 1-1/2-in. maximum-size aggregate crushed bankrun gravel and 2 in. of pavement were placed on top of the insulation. Each board was anchored by driving a 1/2-in.-diam x 12-in. wooden dowel on a skew through each end of the board until it was flush with the top. The board placement was staggered to prevent transverse joint alignment (Fig. 6).

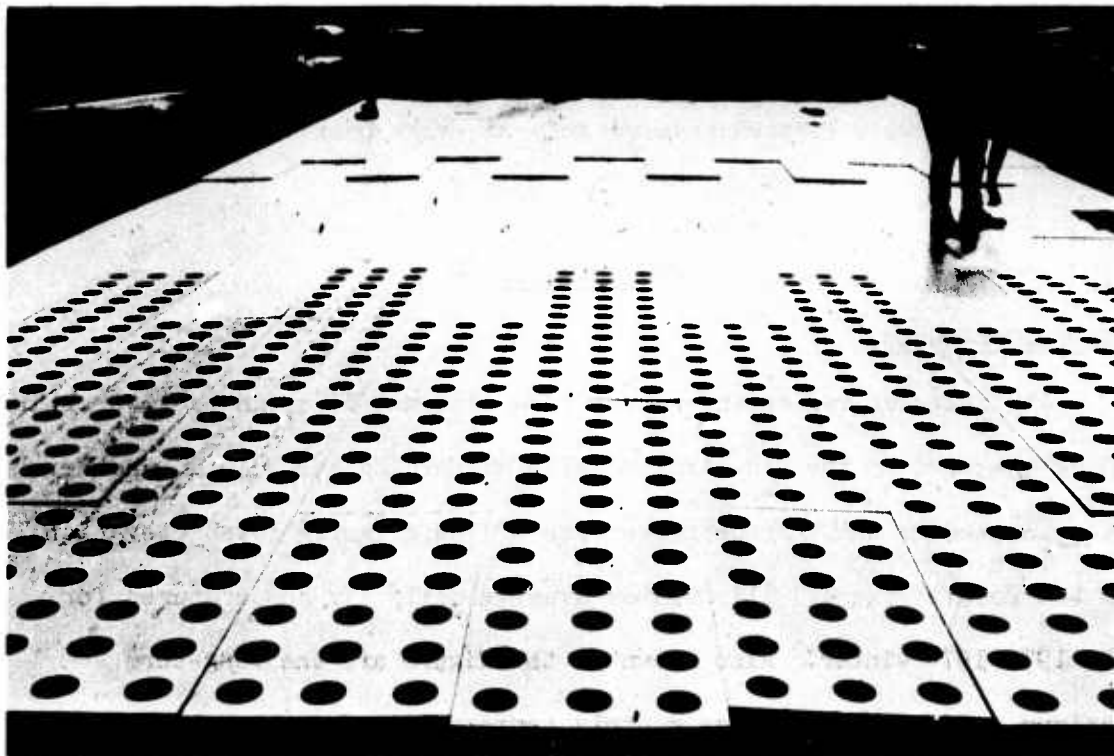


Figure 6. Transition insulation board placement.

INSTRUMENTATION AND TESTS

To monitor the performance and effectiveness of the transition section, the following instrumentation was installed and tests were conducted. Copper-constantan thermocouples were installed through the transition at 4-ft intervals along the centerline to a depth of 4 ft to monitor subsurface temperatures (see Fig. 5). The thermocouples were read by a data logger with a 4-hour scan interval which punched the data on paper tape. The data system is located in a shelter at station 4+80 on the east side of the road.

The Benkelman beam test was used to measure the structural strength of the pavement. Test points were located at stations 1+00, 1+58, 1+78, and 2+15 (see Fig. 5a).

Level surveys were also conducted to measure frost heave. Five survey points were located transversely at every 25-ft station (see Fig. 5a).

DATA RESULTS

Air Temperatures

Air temperatures at the access road site may be slightly lower than those measured by the U.S. Army Maynard Meteorological Team at another site located on CRREL property because of the slightly lower elevation of the road. Figure 7 illustrates average daily air temperatures for the 1973-1974 winter. Also shown on the figure are the long-term maximum, minimum and average monthly temperatures for the National Oceanic and Atmospheric Administration meteorological station in Hanover,

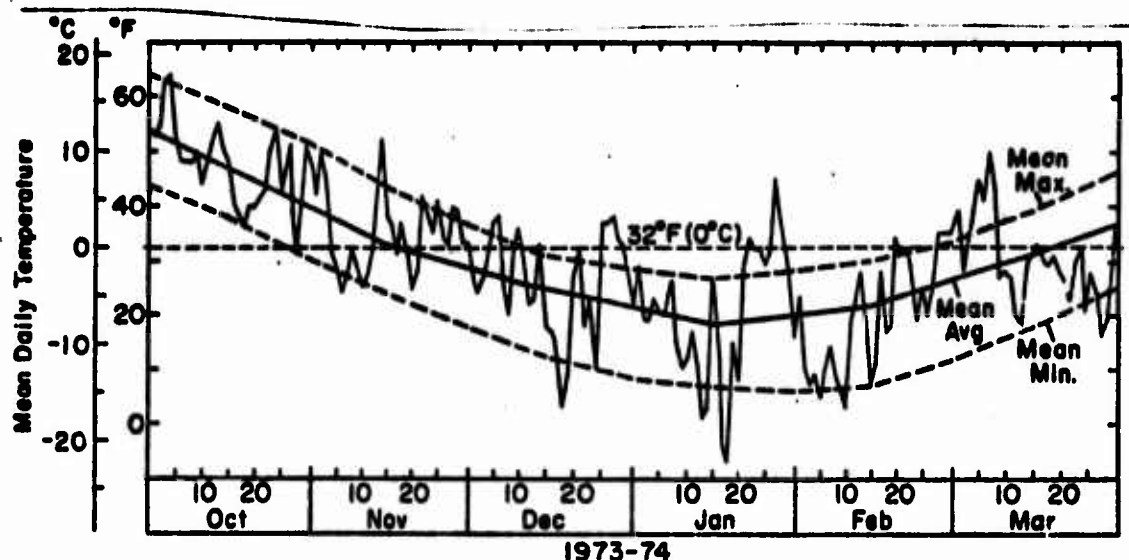


Figure 7. Average daily air temperatures.

New Hampshire. This station is at Dartmouth College and is approximately 1 mile south of the CRREL facility.

The air freezing index measured at CRREL during the 1973-1974 winter is presented in Figure 8 and was 1021°F days. The mean freezing index for the Hanover meteorological station is 1060°F days and the design freezing index is 1820°F days, based on the average of the three coldest years in thirty (Gilman 1964). Thus, the 1973-1974 winter was slightly lower than the mean for this area.

Table I lists the monthly total precipitation and snowfall for the 1973-1974 winter and long-term mean monthly values for the Hanover meteorological station. Monthly and total snowfall for the 1973-1974 winter was considerably below the average. Total precipitation for the winter and for the months of December through March was greater than normal. The total precipitation for December 1973 was nearly three

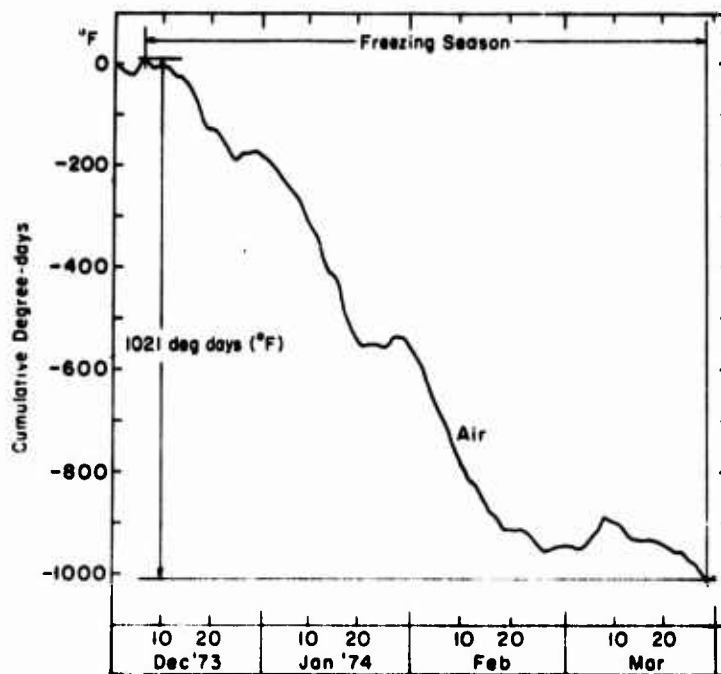


Figure 8. 1973-1974 Freezing index at USACRREL.

Table I. Precipitation at Hanover, New Hampshire

Month	SNOWFALL		WATER EQUIVALENT	
	Mean*	1973-74 Winter	Mean*	1973-74 Winter
November	6	0	2.9	2.9
December	13	10	2.6	7.7
January	17	12	2.6	3.3
February	19	9	2.3	2.4
March	12	9	2.6	3.3
April	<u>5</u>	<u>8</u>	<u>3.2</u>	<u>2.5</u>
TOTAL	72	48	16.2	22.1

*From Bilello (1966)

times the mean value. Since snowfall for the month was below normal, much more rain occurred than in most years. Above-normal rainfall occurred during January, February and March also, but variations from mean values were substantially less than for December.

Frost Penetration

Ground temperature data have been available since late January 1974, when the monitoring system was installed. Temperature sensors in all of the sections have been monitored once every four hours.

Figure 9 illustrates penetration of the 32°F isotherm in sections A, B, C, and D based on the daily 1200-hour readings. Sections C and D (the two solid insulated sections) had the shallowest frost penetrations. Section D, with the 2-in.-thick solid insulation, prevented frost from

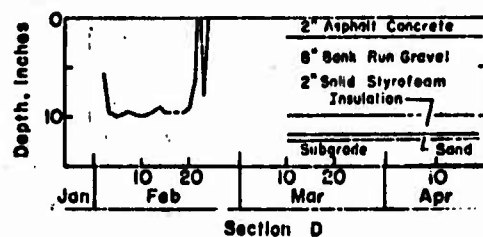
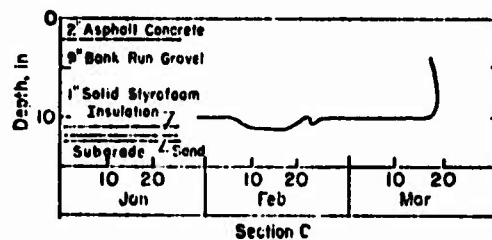
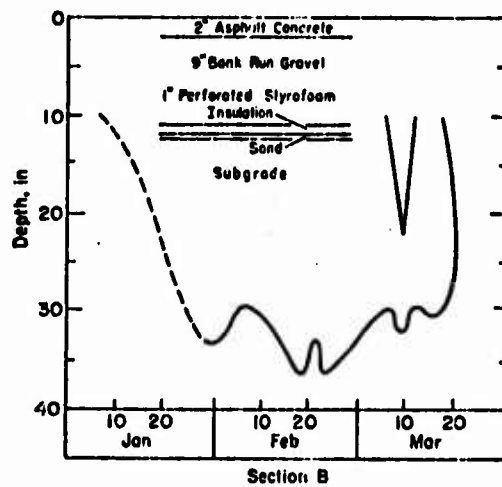
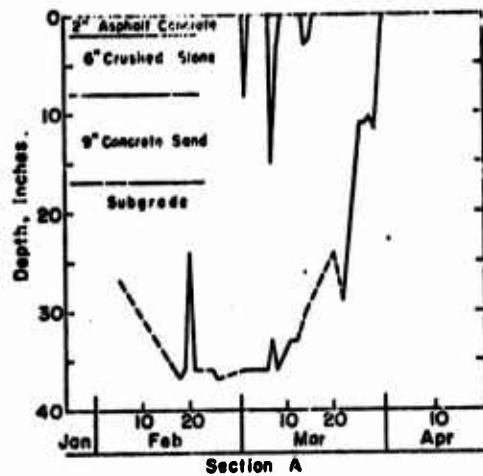


Figure 9. Penetration of 32°F Isotherm.

reaching the frost-susceptible subgrade. Section C, with 1-in.-thick solid insulation, permitted only 1 in. of frost penetration into the subgrade beneath the insulation. Section B, with 1-in.-thick insulation, with 4-in.-diam holes on 8-in. centers, permitted frost penetration to 36 in. Section A, the control or uninsulated section, permitted frost to penetrate to a 37-in. depth. From these data it is apparent that the 1-in.-thick perforated insulation in section B served no useful purpose and did not hinder or slow frost penetration.

When using air freezing index values to calculate frost penetration depths, a surface transfer coefficient n-factor is used to provide a surface freezing index. The n-factor for winter conditions recommended by the Department of the Army (1966) is 0.90 for paved surfaces. Surface temperatures at the access road were not measured for the entire winter; therefore, it was not possible to determine n-factors for these test sections.

Frost Heave

Table II gives the surface elevation changes between the normal period (29 November 1973) and the date of maximum change or greatest frost depth (15 March 1974). Sixty percent, or 15 of 25 points, had a 0.02-ft or less change in elevation, which was within the error of precision of the survey. The other 10 points changed a maximum of 0.04 ft, or less than 1/2 in.

Figure 10 illustrates these differences on a greatly expanded scale. The largest frost heave is at station 2+00 on the left side of centerline.

Table II. Surface Elevation Changes 1973-74 Winter

<u>Station</u>	<u>ELEVATIONS</u>		
	<u>29 Nov 1973</u>	<u>15 Mar 1974</u>	<u>Difference (ft)</u>
1+00 L	466.97	467.01	.04
	466.02	467.03	.01
*	467.12	467.15	.03
	467.04	467.05	.01
R	466.95	466.96	.01
1+25 L	466.87	466.90	.03
	466.90	466.93	.03
*	467.04	467.06	.02
	466.97	466.98	.01
R	466.80	466.82	.02
1+50 L	466.94	466.95	.01
	466.94	466.97	.03
*	467.06	467.08	.02
	467.04	467.07	.03
R	466.88	466.89	.01
1+75 L	466.93	466.95	.02
	466.99	467.02	.03
*	467.06	467.08	.02
	466.98	466.98	.00
R	466.77	466.78	.01
2+00 L	466.92	466.93	.01
	466.95	466.99	.04
*	467.01	467.05	.04
	466.92	466.93	.01
R	466.78	466.81	.03

NOTE: * is centerline

A possible explanation for this could be contamination of the gravel above the insulation during construction. This could have been caused by traffic using a ramp, located on the left side of the road at station 2+00, and bringing mud or dirt from the side of the road onto the gravel. This contamination in turn would cause the gravel to become frost susceptible (by adding fines) and result in minor heave.

Figure 11 shows the centerline frost heaves, also on a greatly expanded scale. As shown on Table II, the station 2+00 centerline elevation

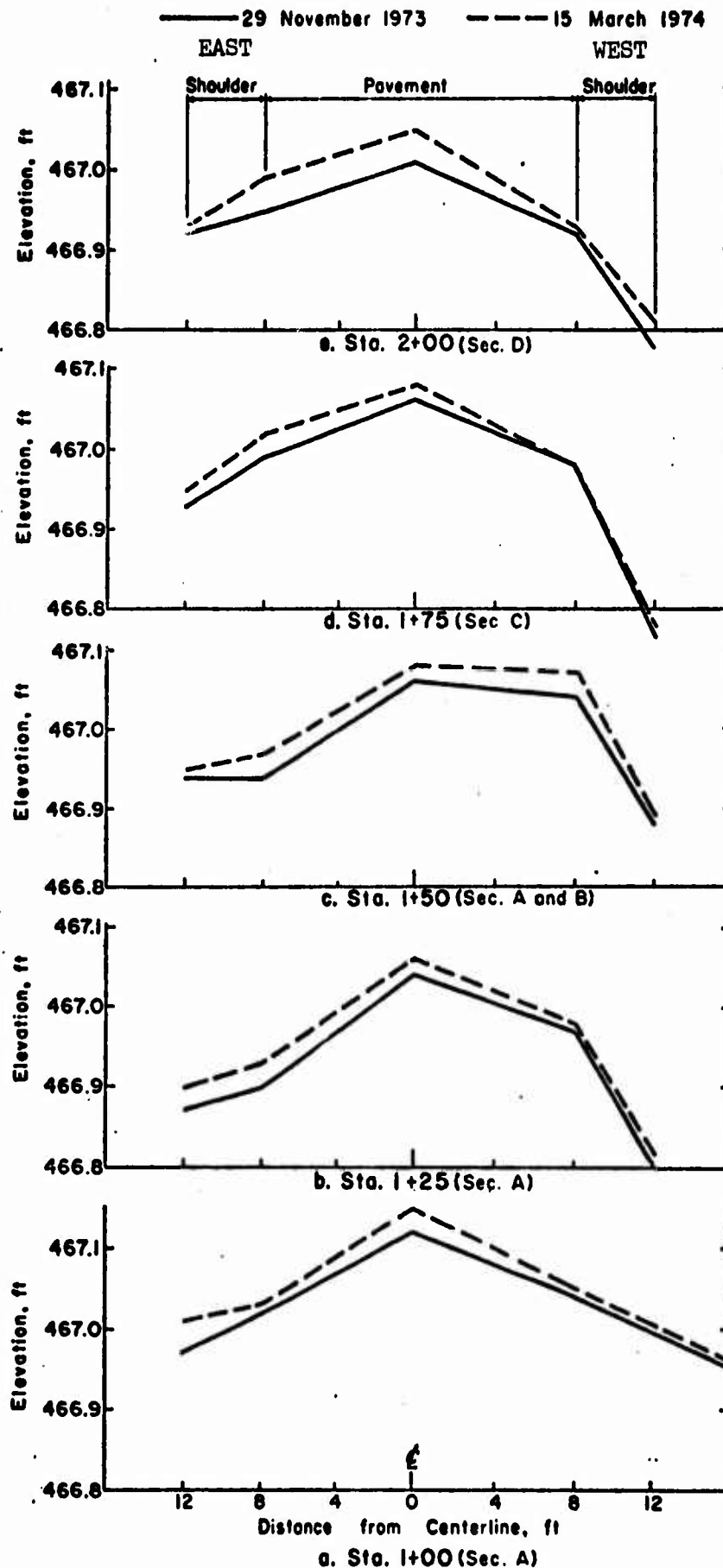


Figure 10. Transverse Frost Heave

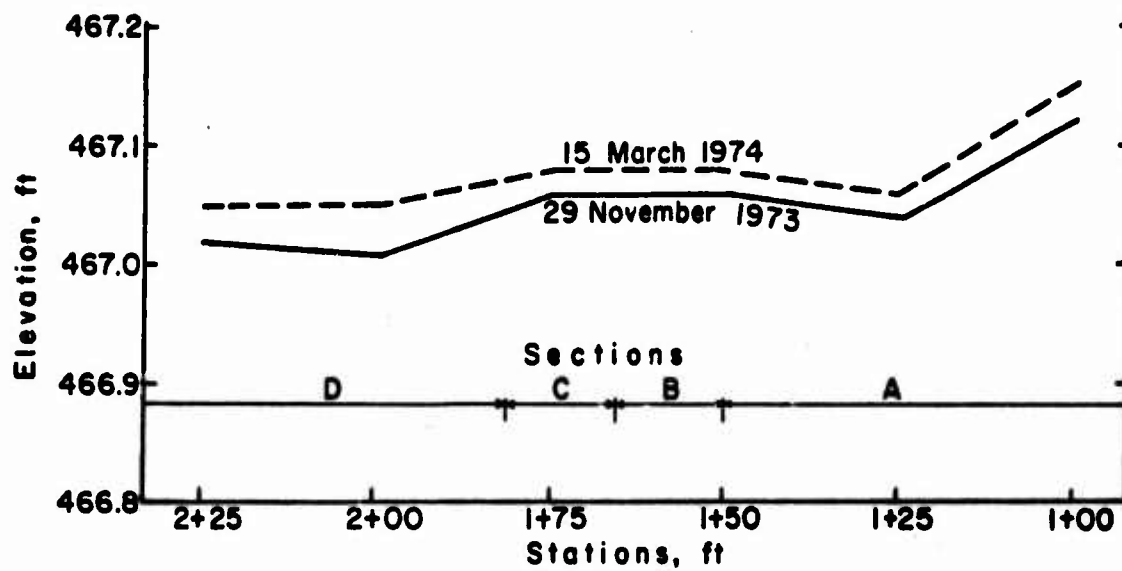


Figure 11. Frost heave along centerline.

difference is .04 ft or 1/4 in. greater than the other stations centerline elevations. The possible reasons for this have been previously described. The relatively uniform frost heave can be attributed to the fact that the frost was contained within the sandy gravel fill between the section and highly frost-susceptible in situ subgrade.

Temperature Changes

Copper-constantan thermocouples were installed along the centerline from Station 1+42 to 1+82, at each 4-ft station, to monitor subsurface temperatures through the transition area. They were connected to a Joseph Kaye Model 8000 data logger which took automatic readings every four hours on punch paper tape. Data collection began on 28 January 1974 and, for this analysis, the daily noon readings will be used.

Isotherms of the transition area were drawn periodically to observe the changing levels of temperature beneath the insulation and to observe the effect of the insulation upon them (Fig. 12a-12n).

As shown in the first profile, 29 January 1974, the 32°F isotherm was approximately the same depth below the pavement in sections A and B. The solid 1-in. insulation in section C, and the 2-in. solid insulation in section D both resisted frost penetration.

The 9 February profile occurs during the coldest period of the winter. Sections A and B had frost penetration to the same depth. The 1-in. insulation in section C had been penetrated by frost, but only by about 1 in. Section D showed no sign of frost penetration from the surface, although the colder temperatures of sections B and C affected

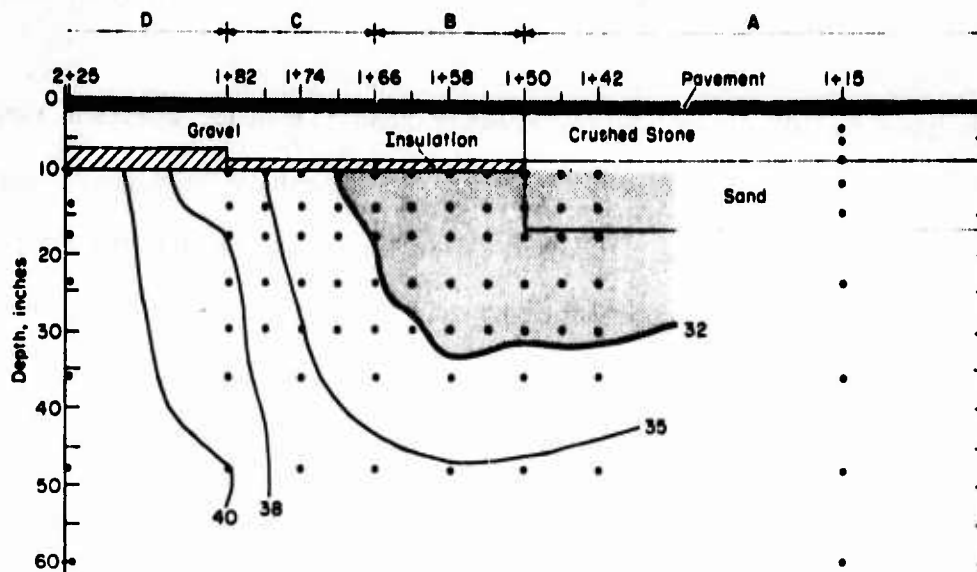


Figure 12a. 29 January 1974 isothermal profiles.

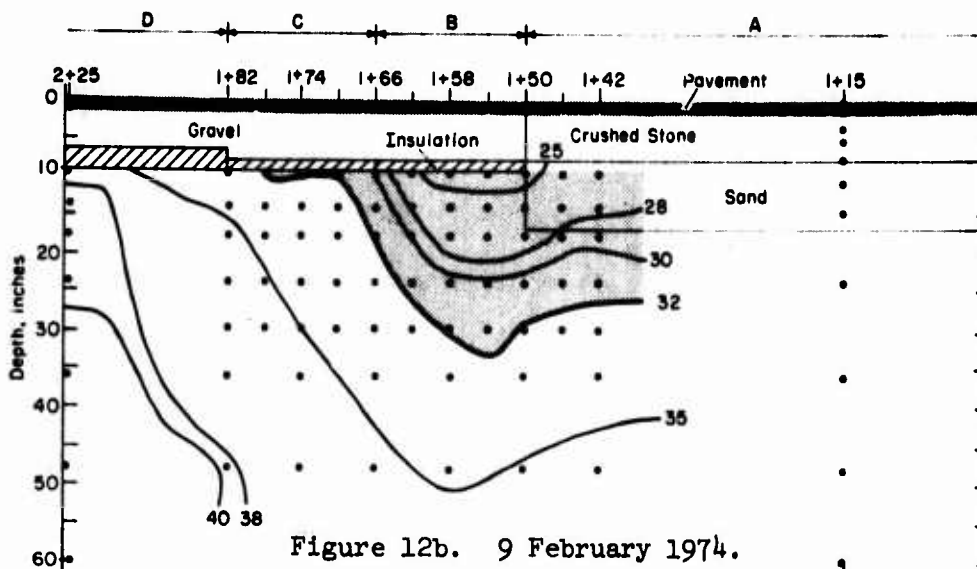


Figure 12b. 9 February 1974.

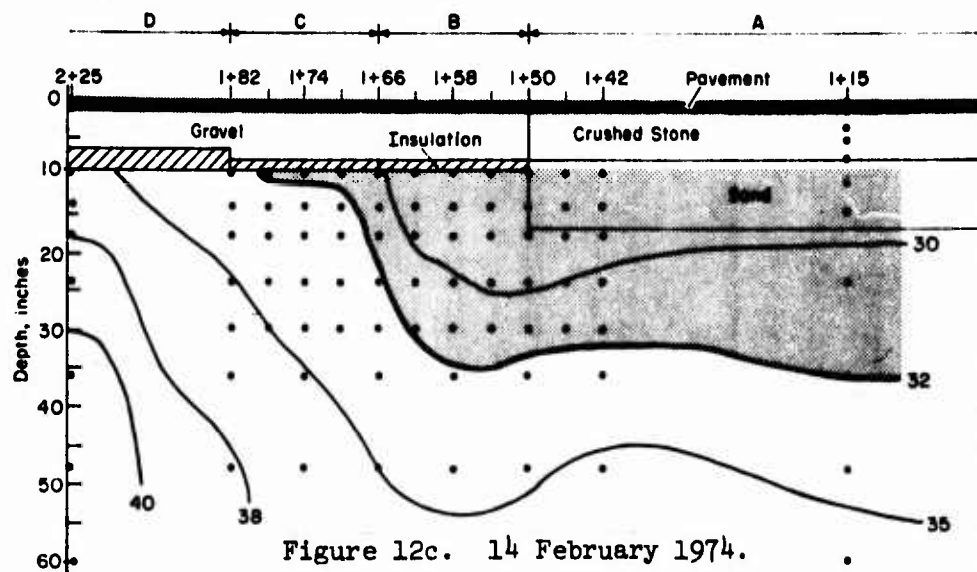
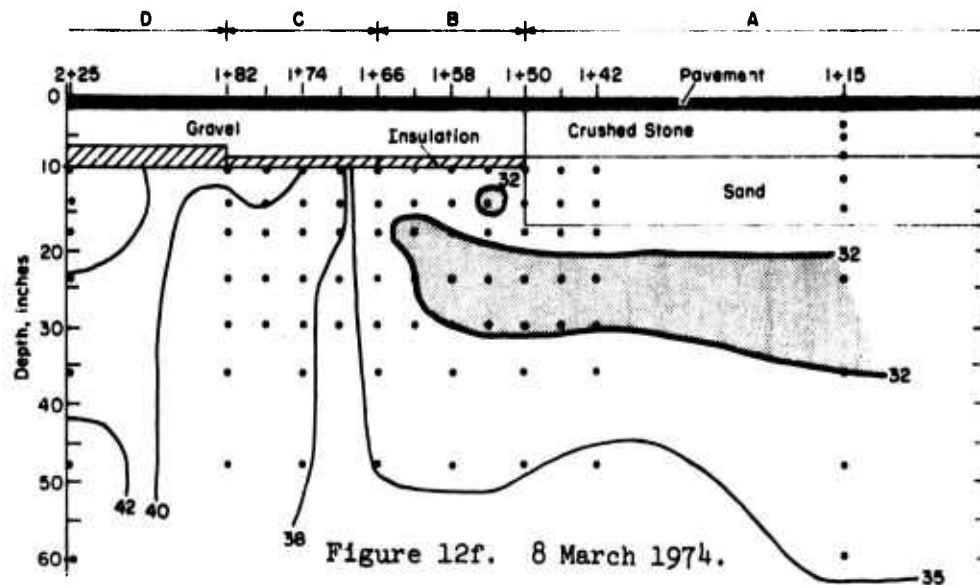
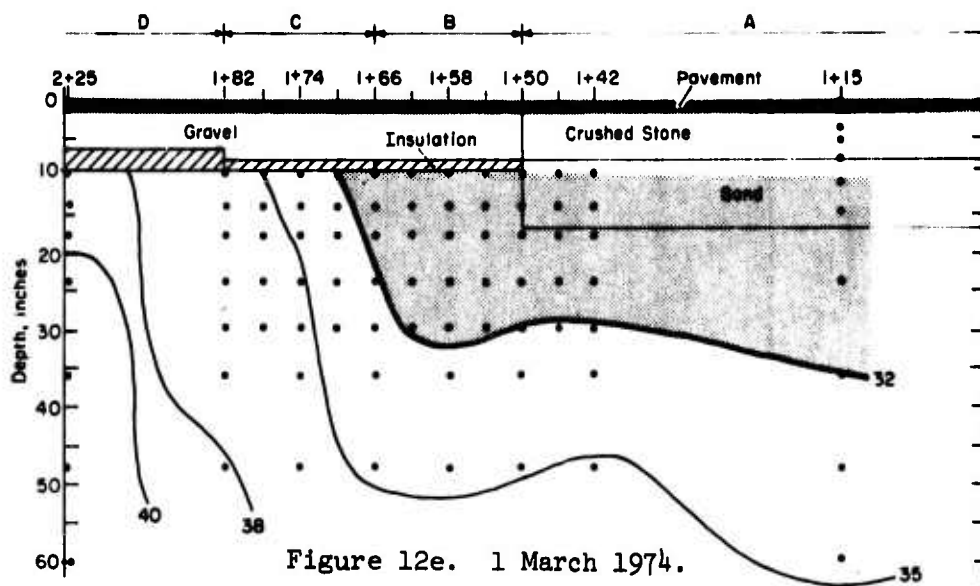
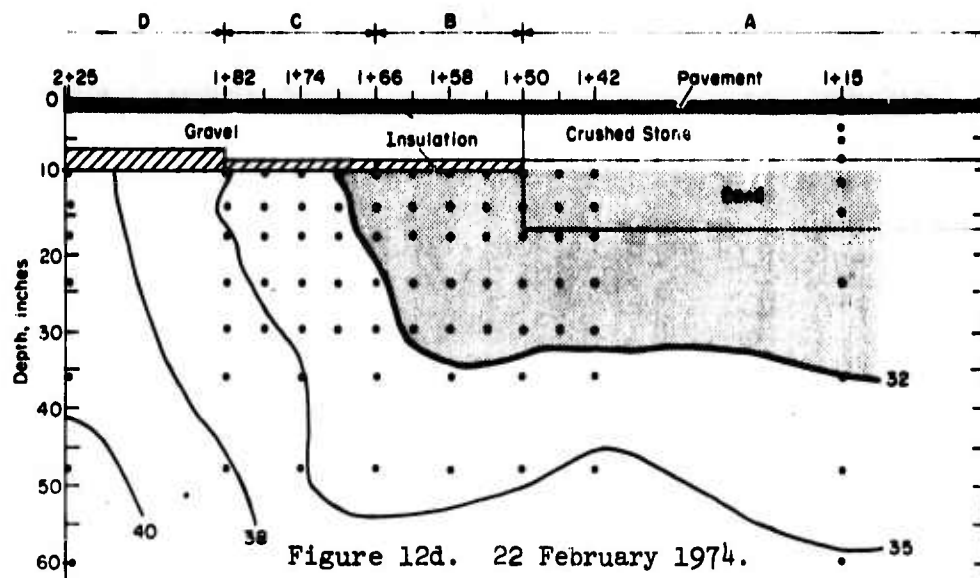


Figure 12c. 14 February 1974.



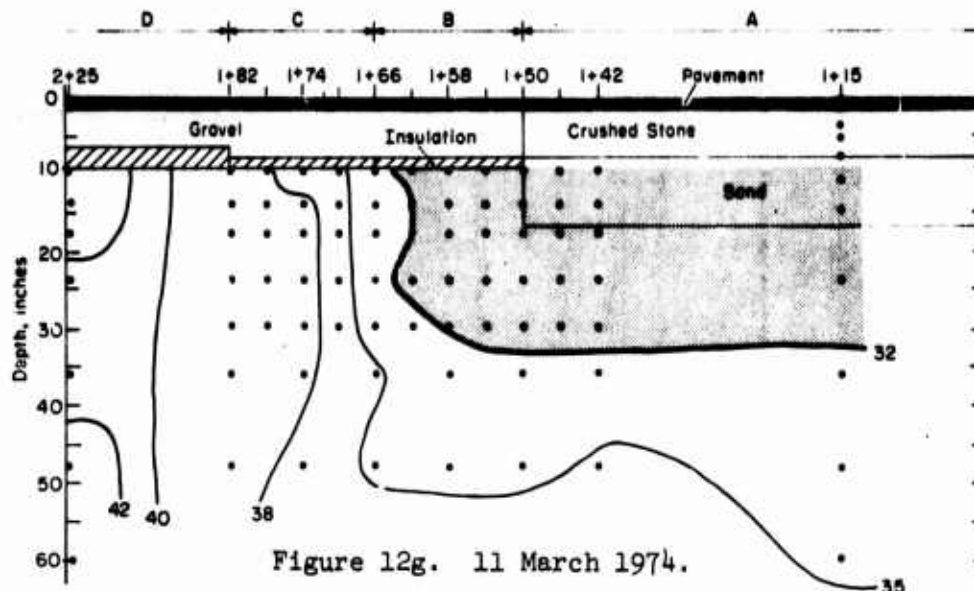


Figure 12g. 11 March 1974.

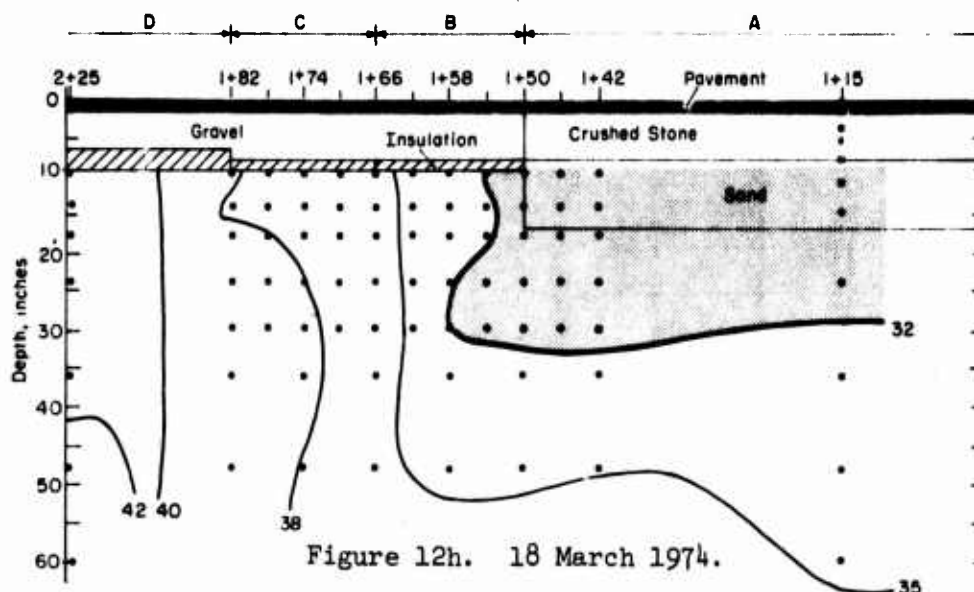


Figure 12h. 18 March 1974.

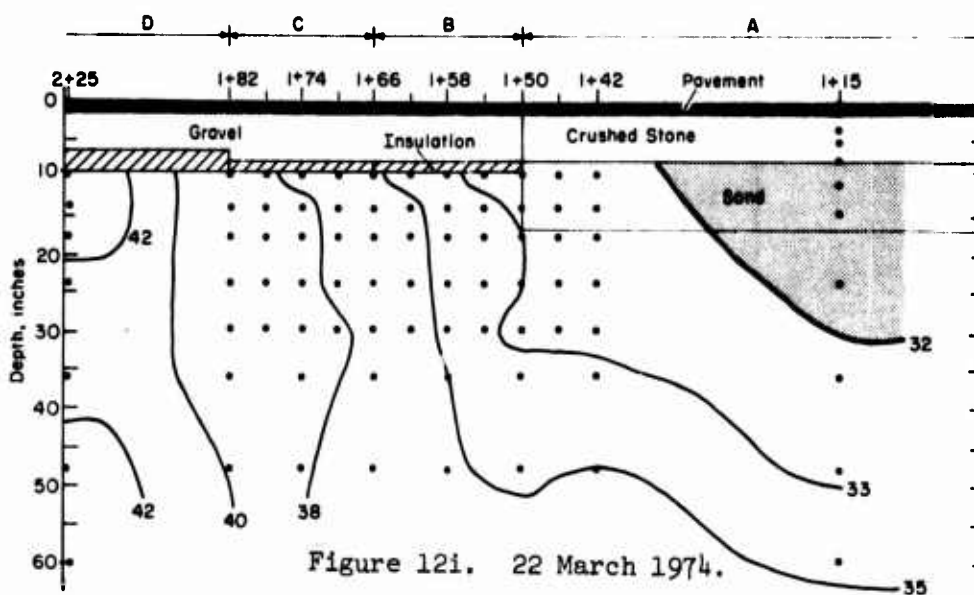
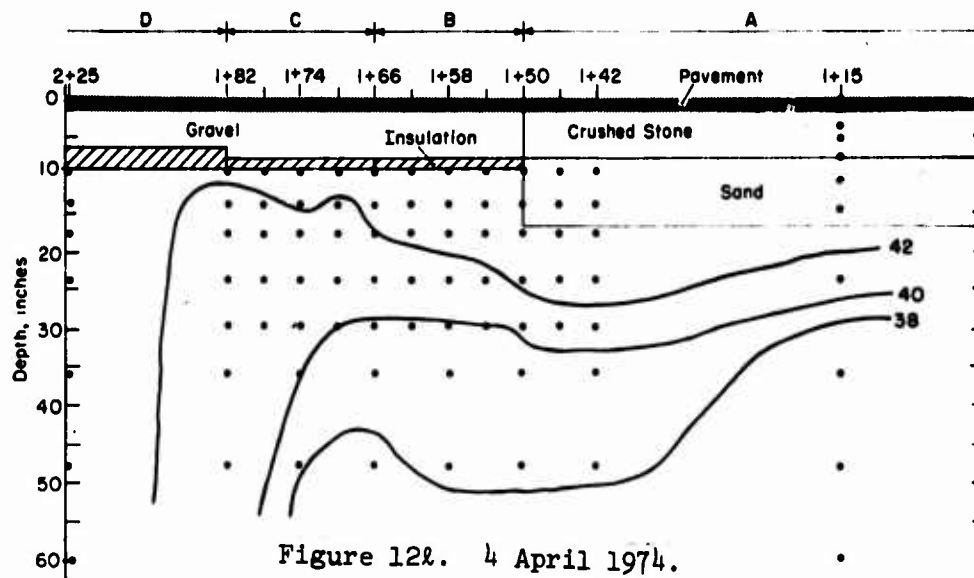
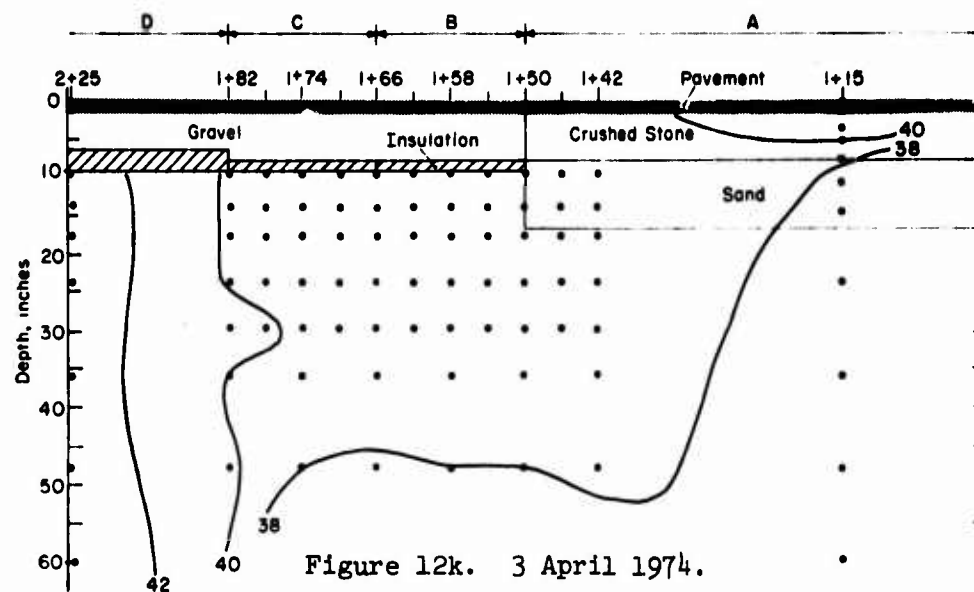
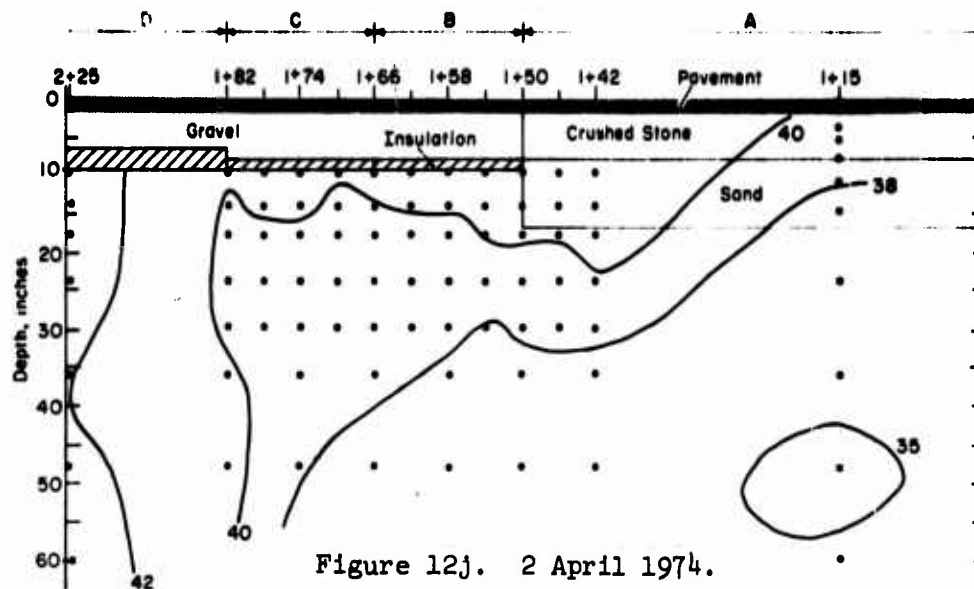


Figure 12i. 22 March 1974.



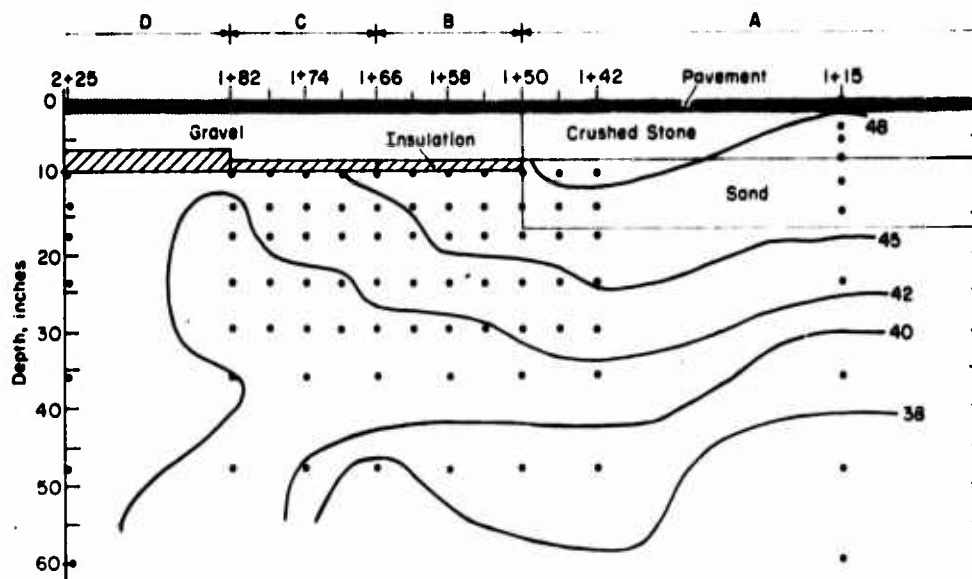


Figure 12m. 5 April 1975.

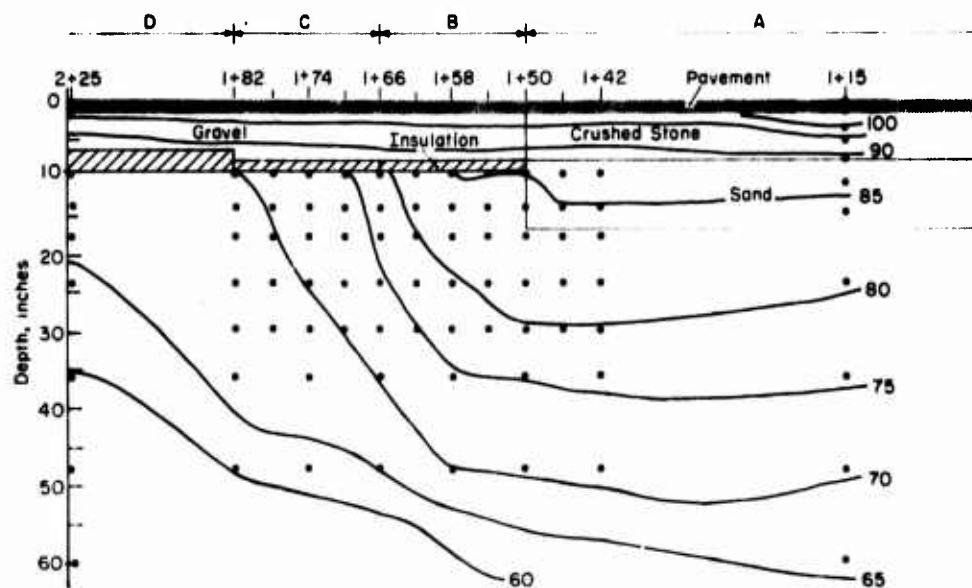


Figure 12n. 10 July 1974.

section D, as shown by the 35°F and 38°F isotherms. The heat was flowing in a generally horizontal path from section D towards sections A, B, and C.

Temperatures in the subgrade immediately below the 1-in. perforated insulation in section B increased slightly by 14 February. However, the depth of the 32°F isotherm remained constant. The heat flow had increased from section D; this is indicated by movement of the 35°F isotherm to the left. The 2-in. solid insulation in section D resisted the colder temperatures from the surface.

Subgrade temperatures held steady throughout the remainder of February, as shown in the profile of 22 February.

The subgrade began the first thaw in the early days of March. The profile of 8 March shows that section B held the frost longer than section A, as shown by the 32°F isotherm running higher in section B than in section A. The insulation was then impeding the warmer temperatures moving downward from the surface, causing the subgrade to resist thawing. In sections C and D the heat flow was toward sections A and B because the 1- and 2-in. solid insulation resisted penetration of warmer temperatures from either the surface or the subgrade.

The 11 March profile shows that the subgrade in sections A and B had gone into another freezing cycle. The penetration of the 32°F isotherm was the same in sections A and B, and it is seen that the perforated insulation in section B had no effect on frost penetration. The temperatures in sections C and D had not changed, and the 1-in. insulation in section C had not been penetrated in this freezing cycle.

Average daily air temperatures in this cycle were below 32° on the four days prior to 11 March, but these temperatures were much higher than the temperatures of the first freezing cycle, in which section C was penetrated by frost.

The subgrade began the final thaw on 18 March. The profile for 22 March shows that section A was the only section that was still frozen. The heat flow from section D into sections A, B, and C was thawing the subgrade horizontally, as seen by the vertical isotherms. The insulation was resisting any penetration of heat, and heat flow was from section D into sections A, B, and C.

During the first five days of April, the surface temperatures increased rapidly. Profiles from the second through the fifth of April display the rapid increase of subgrade temperatures in this period. Note the flow of heat from section D through section C and B to A. A minor amount of heat escaped through the perforated 1-in. insulation in section B, but the major portion flowed into section A. The 1-in. solid insulation in section C and the 2-in. solid insulation in section D were resisting the passage of any heat, either from the subgrade or into the subgrade.

The 10 July 1974 profile shows conditions on the warmest day of the year. Note the isotherms above the insulation. Temperatures in this region were quite uniform throughout all sections. Temperatures beneath the insulation varied drastically in all sections. Section B, with the perforated 1-in. insulation, was similar to section A. The heat had penetrated through this section of insulation. Sections C and D had

much lower temperatures because of the repulsion of the surface temperatures by the solid insulation. The higher temperatures in sections A and B affected sections C and D, as shown by the 65°F and 70°F isotherms.

Benkelman Beam Deflections

The Benkelman beam test consists of driving a loaded dump truck with an 18,000-lb rear axle load over the test point. The amount of deflection is measured using the Benkelman beam. Tests were run throughout the year on marked points: two on sections A and D, and one each on sections B and C.

The results are shown in Table III. Figure 13 shows a plot of deflection versus time for each section. The two points in sections A and D (stations 0+50 and 1+00, and 2+15 and 2+60, respectively) were averaged to give one value for each day the test was run.

Figure 13 and Table III show that on the first test date, 29 January 1974, the amount of deflection, 0.0275 in. in section A, the control section, was less than one-third that of any other section. Sections B, C, and D had approximately the same initial value of 0.086 in. The crushed stone and sand base in section A was a stronger material than the gravel base and insulation in sections B, C, and D.

During the middle of February, when the subgrade had maximum frost penetration, all sections displayed minimum deflections. Sections A and B, which had frost penetration to a depth of 36 in., exhibited practically no deflection at all. Section C, which had frost penetration

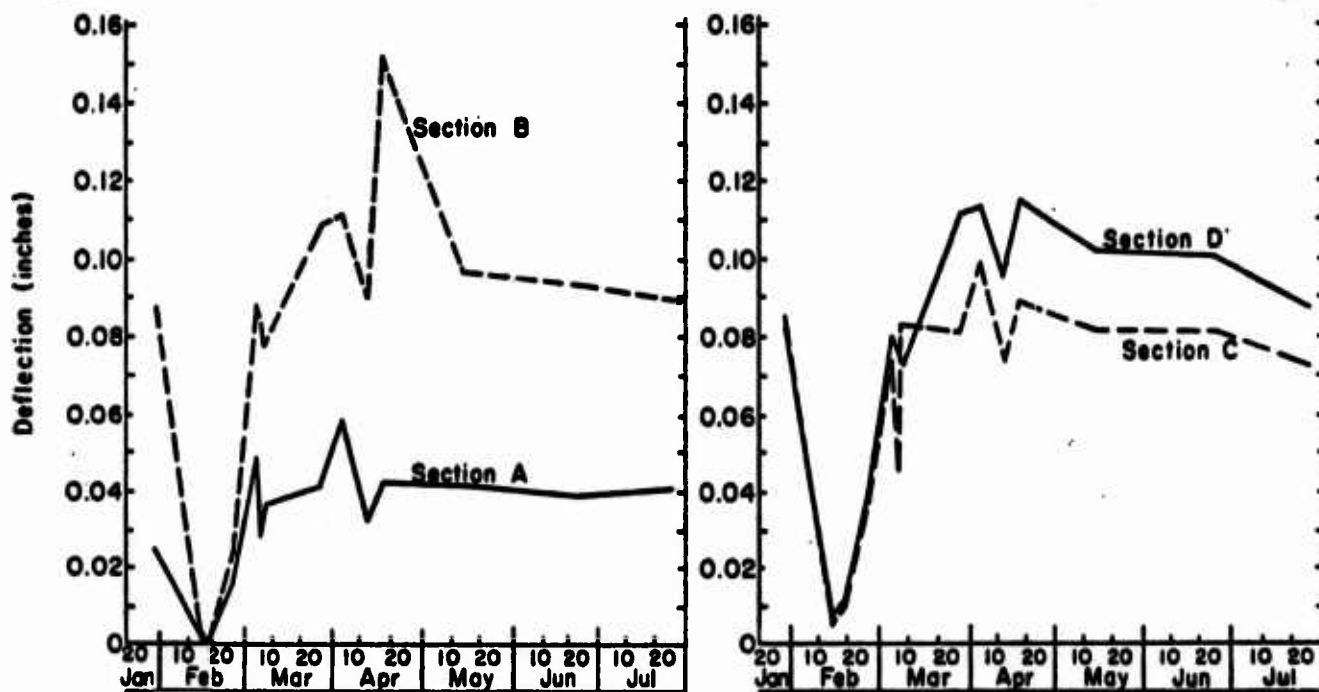


Figure 13. Benkelman beam deflections, 1974.

Table 3. Benkelman beam deflections (inches)

TEST PT.	SECTION	STA.	LOCATION	29Jan74 DEFLAC.	15Feb74 DEFLAC.	19Feb74 DEFLAC.	27Feb74 DEFLAC.	4Mar74 DEFLAC.	6Mar74 DEFLAC.	7Mar74 DEFLAC.	27Mar74 DEFLAC.	3Apr74 DEFLAC.
1	A	0+50	4' Left ϕ	.0275	.0010	.0000	.0080	.0010	.0245	.0725	.0675	.0575
2	A	1+00	4' Right ϕ	.0250	.0005	.0005	.0175	.0485	.0290	.0360	.0415	.0580
3	B	1+58	4' Left ϕ	.0870	.0025	.0010	.0245	.0870	.0840	.0770	.1080	.1110
4	C	1+78	4' Right ϕ	.0835	.0050	.0095	.0360	.0730	.0440	.0825	.0805	.0990
5	D ₁	2+15	4' Left ϕ	.0800	.0075	.0110	.0395	.0800	.0770	.0720	.1110	.1130
6	D ₁	2+60	4' Right ϕ	.0880	.0050	.0100	.0455	.0790	.0430	.0810	.0935	.1120

TEST PT.	SECTION	STA.	LOCATION	12Apr74 DEFLAC.	17Apr74 DEFLAC.	19May74 DEFLAC.	25Jun74 DEFLAC.	26Jul74 DEFLAC.	1Aug74 DEFLAC.	19Aug74 DEFLAC.	8Nov74 DEFLAC.	8Jan75 DEFLAC.
1	A	0+50	4' Left ϕ	.0460	.0640	.0555	.0480	.0530	.0395	.0350	.0320	.0165
2	A	1+00	4' Right ϕ	.0320	.0420	.0410	.0385	.0400	.0330	.0390	.0255	.0095
3	B	1+58	4' Left ϕ	.0905	.1515	.0965	.0930	.0890	.0800	.0820	.0640	.0190
4	C	1+78	4' Right ϕ	.0730	.0880	.0810	.0810	.0720	.0590	.0640	.0505	.0290
5	D ₁	2+15	4' Left ϕ	.0930	.1140	.1010	.1000	.0870	.0800	.0800	.0670	.0210
6	D ₁	2+60	4' Right ϕ	.0750	.1070	.1020	.0830	.0920	.0750	.0830	.0675	.0195

NOTE: ϕ is centerline

1 in. below the 1-in. solid insulation, and section D, which had no frost penetration through the 2-in. solid insulation, had approximately the same values of 0.005 in. deflection.

As air temperatures increased during late February and the first week of March, subgrade temperatures increased. All sections showed an increase in deflections due to the weakening of the subgrade by the thaw. Sections B, C, and D had higher values of deflection than section A, which has the crushed stone and sand base. The insulation and gravel in sections B, C, and D did not exhibit the strength of the subgrade in section A.

During late March and the month of April, air temperatures continued to increase, and the subgrade in all sections thawed completely. As the ground temperatures rose, the amount of deflection in each section increased, and all sections experienced maximum deflections during the middle of April during "thaw weakening." Section A had the lowest value of maximum deflection of 0.060, and the strongest subgrade. Sections C and D had deflections of approximately twice that of section A, but the 1-in. solid insulation in section C had lower deflections than the 2-in. solid insulation in section D. This was caused by the "cushioning" effect of the insulation. Section B, with the perforated insulation, exhibited the greatest deflection, on 17 April, of .1515, but the deflection reduced quickly to remain consistent with sections C and D.

All test sections leveled off during May, June, and July. Sections B, C, and D had approximately the same values of deflection of 0.07 to

0.11, but section D, with the 2-in. solid insulation, had the highest deflections due to the "cushioning" effect. Section A had the lowest value of deflection, about one-half the deflections of sections B, C, and D. The crushed stone and sand base in section A was a stronger base than the more compressible insulated sections.

CONCLUSIONS

The 1973-1974 air freezing index was 1,021°F-days, just below the mean freezing index of 1,060°F-days. Thus the 1973-1974 winter was close to the mean for this area.

Frost penetrations beneath the pavement surfaces were 37 in. for section A, 36 in. in section B, 13 in. in section C, and 10 in. in section D. Section B, with the 1-in.-thick perforated insulation, was intended to provide another step in insulation between the 1-in. solid and uninsulated section. It was ineffective as shown by its having approximately the same frost penetration as the uninsulated section A. The 1-in.-thick solid insulation, however, allowed the frost to penetrate only 1 in. below the insulation to a total depth of 13 in., or approximately one third the depth of sections A and B. Section D, on the other hand, with 2 in. of solid insulation, prevented any frost penetration through it.

Frost heave was relatively uniform with no noticeable differential heaving within each section, or between sections. This was due to the non-frost susceptible fill above the native subgrade which contained the freezing temperatures beneath the sections; and the mild winter.

Benkelman beam deflections for the noninsulated section A, which had the least deflection, ranged from 0.005 in. to a maximum of 0.058 in. Section B, which had the 1-in.-thick perforated insulation with 4-in. holes on 8-in. centers, showed the greatest amount of deflection, ranging from 0.001 to 0.152 in. Section C, with 1-in.-thick solid insulation, deflected from 0.005 up to a maximum of 0.099 in. The 2-in.-thick insulated section D deflected from 0.008 to 0.113 in.

In order of deflection from the least to maximum, section A, the noninsulated section was lowest, then section C with the 1-in.-thick solid insulation, section D with the 2-in.-thick solid insulation, and section B with the 1-in.-thick perforated insulation. When insulation is introduced into the pavement structure, the deflections increase in proportion to the thickness and strength of the insulation.

The temperature measurements throughout the transition area show that: 1) the 1-in.-thick perforated insulation with 4-in. holes on 8-in. centers was virtually ineffective in that the isotherms were nearly identical to those of the control (noninsulated) section A; 2) the frost penetrated 1 in. below the 1-in.-thick insulated section C, but did not penetrate the 2-in.-thick insulated section D; 3) during the spring thaw, the insulation impeded the warmer temperatures moving downward, causing horizontal heat flow from beneath section D longitudinally towards section A; and 4) on the hottest 1974 summer day, subgrade temperatures beneath the solid 1-in. and 2-in. insulations were 15°F cooler at the same depth than the noninsulated section A.

Insulation prevented frost penetration into frost susceptible subgrades, thereby minimizing frost heave and reducing base course thickness requirements, but structural deflections were greater when the insulation was at least within 12 in. of the pavement surface.

Surface differential icing did occur between the noninsulated control section and the 2-in. insulated section.

More research is needed to define depths of insulation installation, with respect to deflection under loads, and lengths of transitions required between insulated and noninsulated sections.

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APPENDIX A

PHOTOGRAPHS

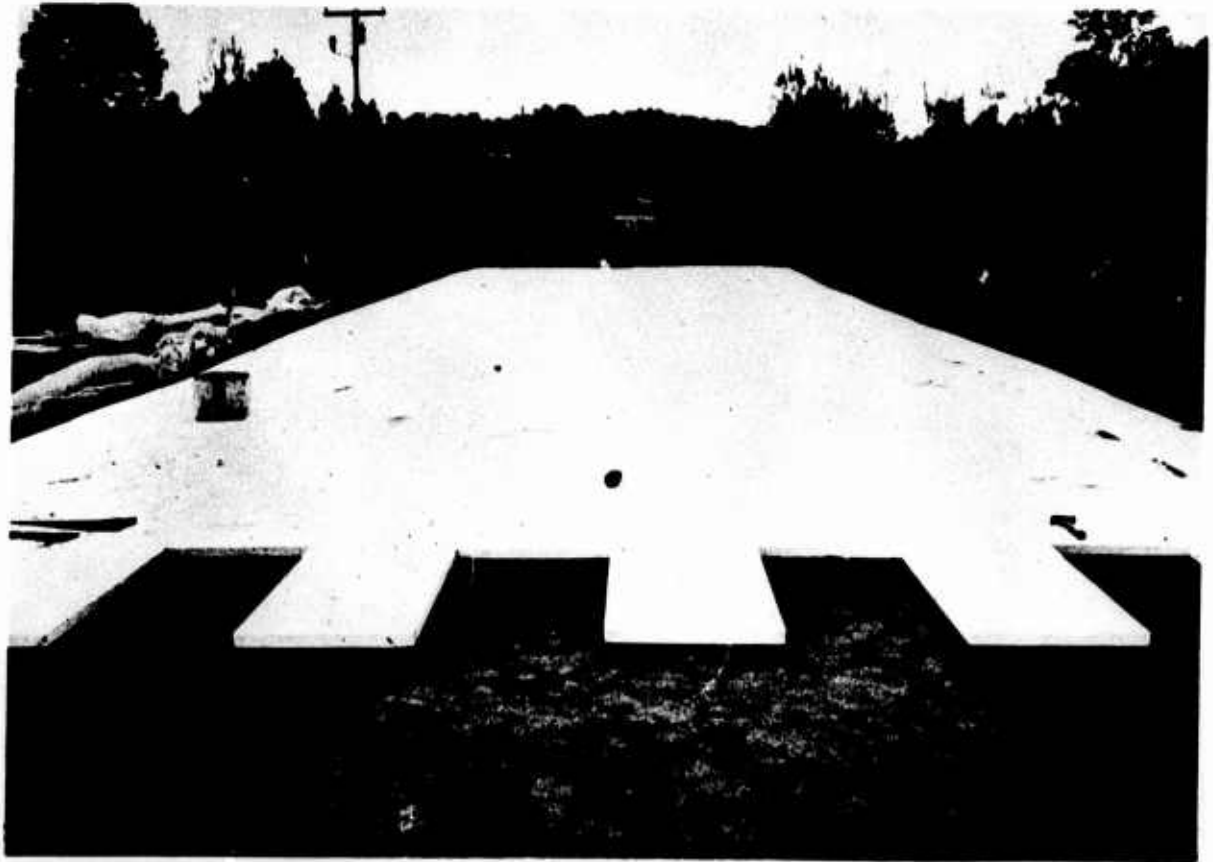


Figure A1. Two-in. thick insulation in section D.

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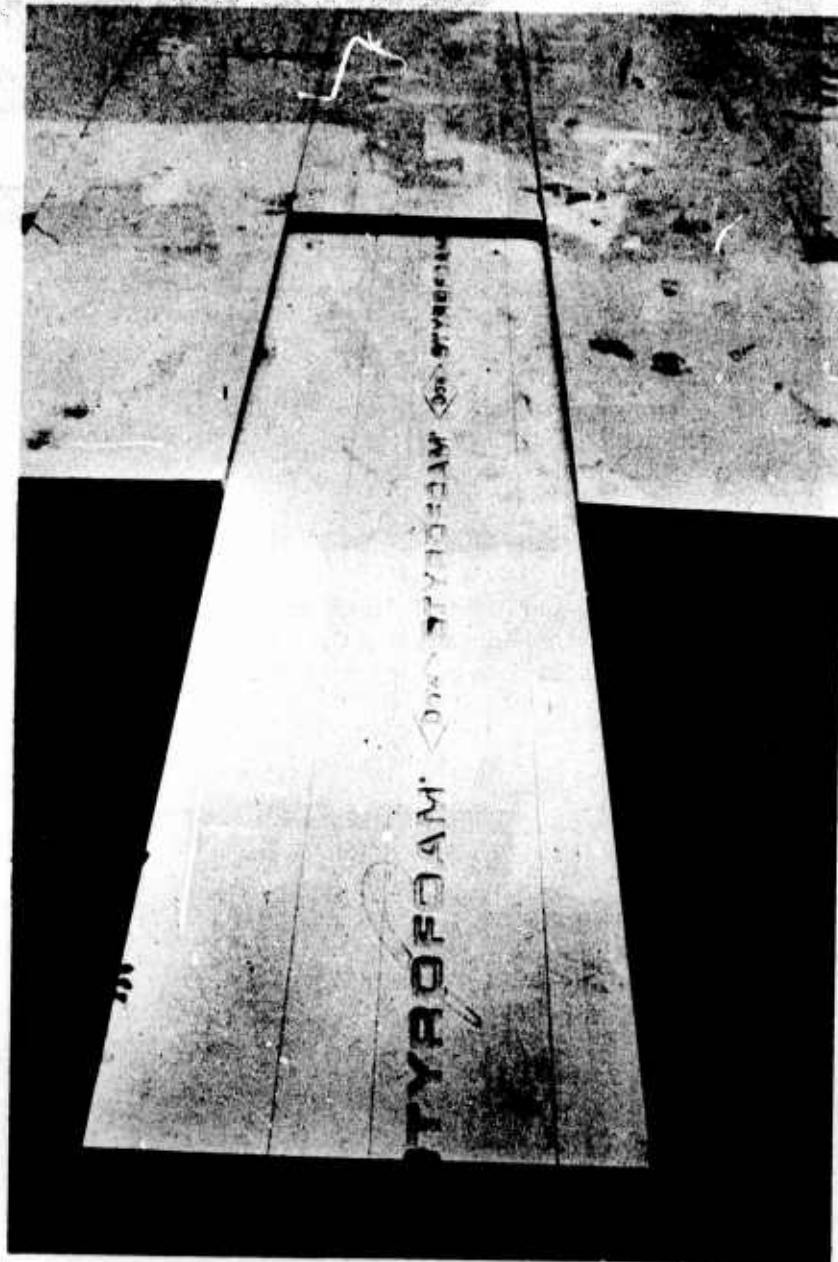


Figure A2. One-in. thick solid insulation in section C in foreground.

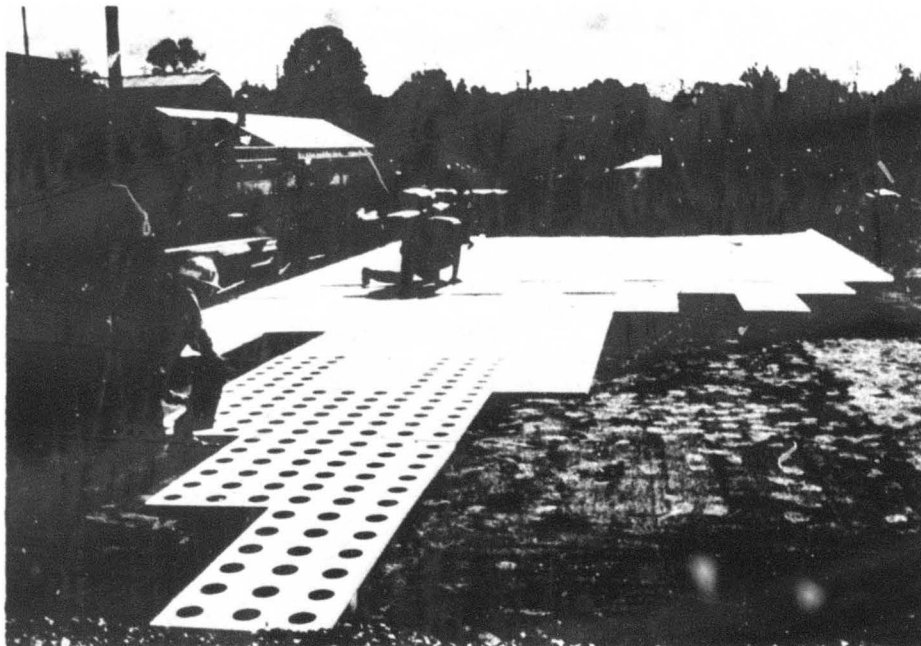


Figure A3. One-in. perforated insulation in section B; 1-in. solid insulation in section C; and 2-in. solid insulation in section D.



Figure A4. End dumping 8 in. of crushed bank-run gravel on 2-in. insulation.

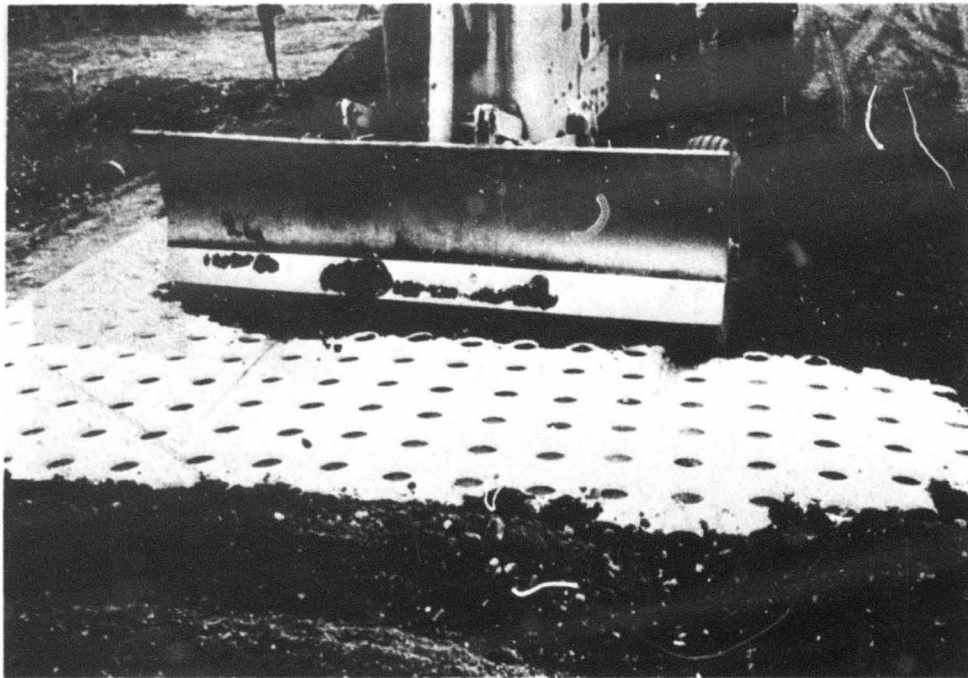


Figure A5. Leveling gravel on insulation.



Figure A6. Gravel lift over insulation meets crushed stone in section A in foreground.

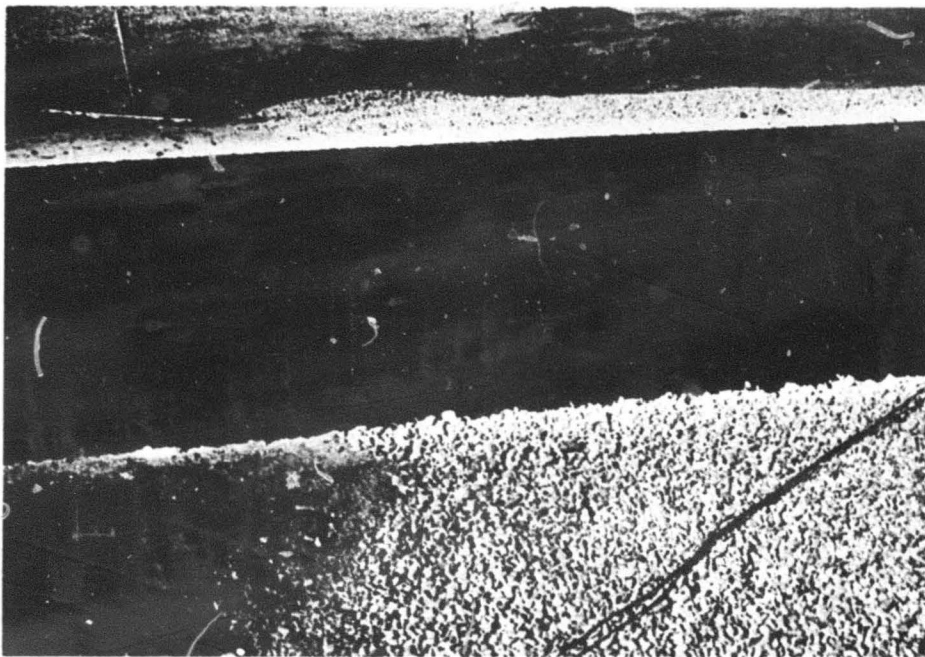


Figure A7. 2-in. asphalt concrete over section A crushed rock on right and section B bank-run gravel on left.



Figure A8. Bare section A in foreground with ice-covered transition and section D in background.

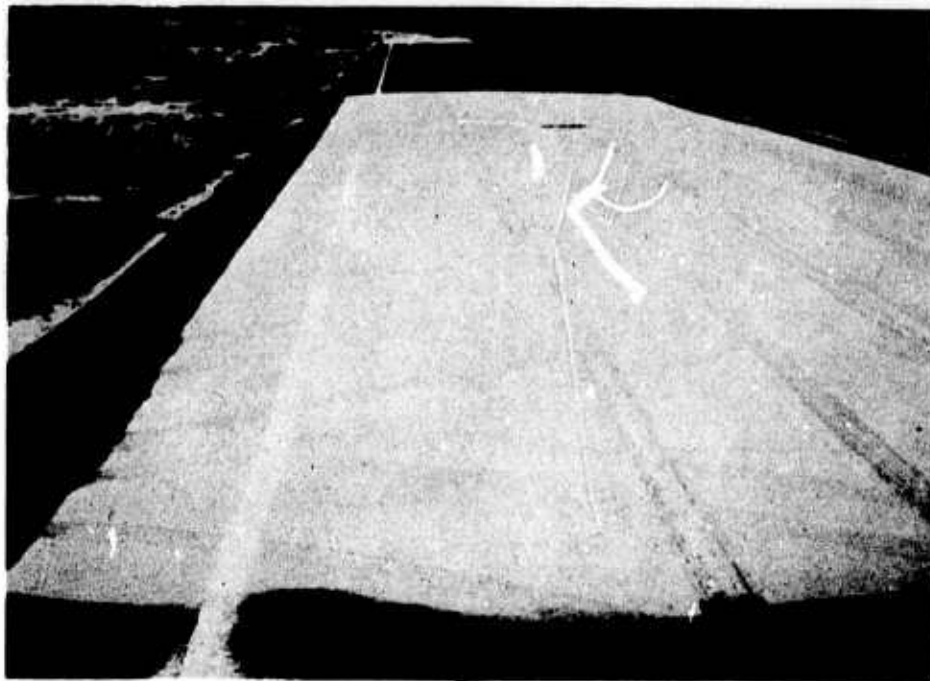


Figure A9. Closeup showing differential ice between insulated section in foreground and noninsulated section in background.



Figure A10. Partially thawed section C in foreground and solid ice on section D in background.