Frost Penetration and Moisture Changes Related to Highway Pavement Shoulder Color

ARTHUR L. STRAUB, Clarkson College of Technology;
PAUL F. DUDDEN, U. S. Department of the Air Force; and
FRANK T. MOORHEAD, New York State Department of Transportation

This paper reports the observations of temperature and moisture under an insulated and noninsulated portland cement concrete pavement slab resulting from shoulders purposely made white and black for comparison. The sealed shoulders on each side were made identical in all respects except for surface color.

The study period extended from late fall through the spring of one season for a test road exposed to a northern New York climate. Detailed temperature data for the cross sections were collected from 53 thermistor probes. Detailed moisture data at 6-in. intervals were collected from 23 access tubes using a nuclear depth moisture gage. Patterns of temperature and moisture for the pavement cross sections are presented in a series of isoline plots for selected dates to show key information.

Substantial differences were observed throughout the test road, especially laterally, indicating that studies of pavements exposed to actual climates should include instrumentation giving much more detail than is commonly available. The temperature patterns showed black shoulders to be substantially warmer than white shoulders (due to absorption of solar energy), and especially were affected by midwinter thaws. Temperatures under white shoulders were cooler, caused earlier freezing, later thawing, and were generally associated with lower moisture content. The large moisture increase observed under the black shoulder and pavement edge during a brief midwinter thaw was shown caused by gravitational melt water from adjacent snow banks flowing through the shoulder. This did not occur under the white shoulder because it remained solidly frozen during this same brief period.

Further study is needed to understand how to prevent rapid increases of moisture under pavements and shoulders during thaw periods, perhaps by the use of surface color to control the underlying temperature regime.

•IN recent years the attention of pavement designers has been directed toward the use of paved or stabilized sealed shoulders as important elements in the overall pavement cross section. Attention has also been given to constructing shoulders with contrasting surface color for purposes of increasing roadway delineation for safety. However, very little information has been published on the variations in temperature and moisture conditions in the overall pavement cross section which occur as the result of the use of shoulders which have different color.

Paper sponsored by Committee on Frost Action and presented at the 48th Annual Meeting.

Obviously, dark colored surfaces will absorb more solar energy and become warmer than light colored surfaces. The resulting effects, however, are not well documented. This paper attempts to shed some light on the subject of shoulder color by reporting observations on a portland cement concrete test pavement exposed to a northern New York climate. The pavement's shoulders were purposely made white and black for comparison. The study period extended from late fall 1967 through spring 1968, and therefore emphasizes the period of one year subject to frost penetration and subsequent thaw.

This study is one of a series of projects being conducted at Clarkson College of Technology at Potsdam, N. Y., to relate climate factors to temperature and moisture conditions in and under paved surfaces. Previous work on frost attenuation and on bituminous pavement temperatures have been reported (6, 7). The present paper is based on work recently completed (1, 2, 3, 5).

TEST ROAD SECTION AND INSTRUMENTATION

The main implement of study was a full-scale test road section (Fig. 1) which is analogous to a 24-ft wide portland cement (slab thickness 9-in.) concrete pavement on a 4-ft high fill. The base material is crushed road gravel and the subgrade fill material is classified as an A-2-7 soil. The design cross section included 8-ft wide shoulders constructed of bituminous-stabilized gravel with a sealed surface. The test road was constructed in accordance with specifications of the New York State Department of Transportation (4) wherever possible.

As reported previously (7) the ends and the division between the two 10-ft long test sections make use of vertical sheets of 1-in. thick insulation in a manner which nearly duplicates the two-dimensional thermal characteristics of a highway of infinite length. The slab of one section is underlain by a 1-in. thick layer of insulation while the slab of the noninsulated (control) section rests directly on the crushed gravel base, thus facilitating a study of frost penetration.

The site as modified for the present study now includes a total of 53 Fenwal matched thermistor temperature probes distributed throughout the insulated and the noninsulated sections. The normal data collection schedule called for daily readings of all probes using a remotely located Fenwal temperature sensing indicator. Calibration checks showed accuracy to within ± 1 F.

The site also now incorporates a total of 23 vertical aluminum access tubes (Fig. 2) extending to an average depth of 4.5 ft. These tubes are for use in measuring moisture with a Nuclear-Chicago Model P-19 depth moisture gage connected to a Model 5910 ratemeter. The ratemeter is an integrating device yielding neutron counts per minute as a dial reading. The system was calibrated to measure moisture content in percent

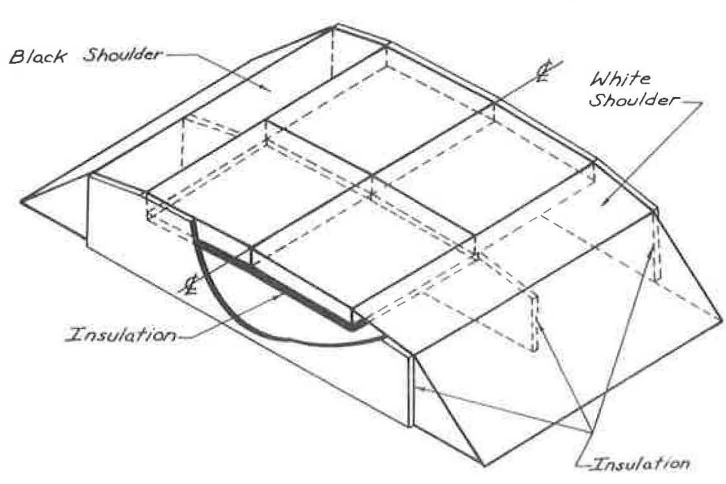

Figure 1. Oblique view of test road.

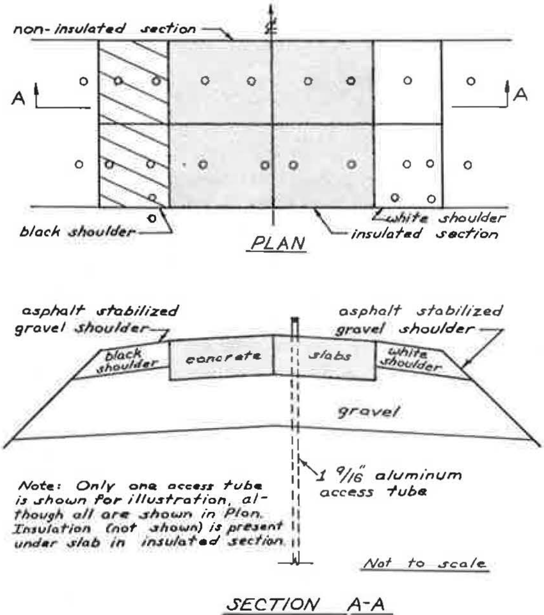

Figure 2. Location of aluminum access tubes.

by volume. The system is capable of measuring water existing in any physical state, whether liquid, solid or vapor. The normal data collection schedule called for complete cross section readings about every two weeks, but readings were taken as frequently as every two or three days during the thaw period when more rapid moisture changes occurred. Each set of data included readings at 6-in. depth intervals throughout the site. A statistical analysis of moisture data collected established a 95 percent confidence limit of about ± 0.8 percent moisture by volume over the range of moistures encountered. This corresponds to about ± 0.5 percent moisture by dry weight of solids, and readings of this order of accuracy were deemed to be adequate for the purposes of this study.

The temperature and moisture data for both cross sections were taken in sufficient quantity to give much more detailed information than was previously available, and form the bases of this report.

To isolate the variable of shoulder color, the shoulders on both sides were first made to be identical in all respects, i. e., 4-in. of compacted bituminous-stabilized gravel on a gravel base with the surface carefully sealed with cutback asphalt. Then one side only was painted with white traffic marking paint on December 5, 1967. The resulting test site consisted of an insulated slab and a noninsulated slab, each with one white and one black shoulder.

During the winter, any accumulation of snow was promptly removed from the pavement and shoulders and was piled in banks on the side slope to correspond to common maintenance practice.

The late fall, winter, and spring climate to which the test road was exposed is summarized in Figure 3 showing accumulated degree days for the air temperature (air freezing index of 1762.5). The 30-yr average air freezing index for this location is 1430 (8). Figure 3 also shows precipitation compared to 30-yr norms (9). Permanent snowbank accumulation began December 27, over the winter averaged about 3 ft deep, and was completely dissipated by March 29. Solar energy received by the site was recorded by using silicon solar cells and a dc ampere-hour meter, reported elsewhere (10, 11). In general the season

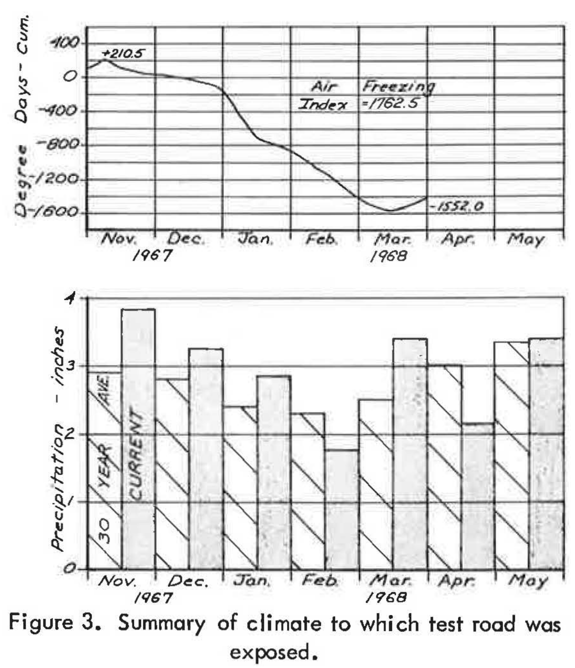

Figure 3. Summary of climate to which test road was exposed.

observed can be described as having been a little colder than average for this location.

OBSERVATIONS AND CONCLUSIONS

Cross Section Effect

From reviewing data taken over three years, it is noted that both temperature and moisture are well shown by plots of isolines in the cross section for specific dates. For purposes of showing temperature patterns, temperatures less than 32 F are assumed to be in frozen soil. Moisture is shown as percent by volume as measured by the nuclear probe. At any given depth, the temperature and moisture content are quite likely to vary considerably (Figs. 4 through 8). Sometimes a lateral distance of only a few feet can mean a considerable difference in temperature or moisture content.

This observation suggests that pavement research projects involving sites exposed to actual climates should be much more thoroughly instrumented than has been commonly practiced.

The plots shown represent a small part of the total data, but were selected to illustrate key information summarized in the following paragraphs.

Shoulder Color's Effect on Temperature and Moisture Conditions

Temperature and moisture characteristics differed greatly (at times) between the area influenced by the black shoulder, and the area influenced by the white shoulder. Figures 4 through 8 illustrate these differences.

Temperature Conditions—The temperature characteristics were significantly influenced by the introduction of shoulder color on December 5, 1967. Figures 4A and 4B show the temperature pattern for November 27, 1967, for the insulated and noninsulated sections respectively. Both shoulders on this date were black. Temperature conditions were about the same on each side of centerline for each section. Figures 5A and 5B show both sections on January 21, 1968. The area under the white shoulder became only a few degrees colder than the area under the black shoulder (only a relatively small amount of solar radiation was received during midwinter). Figures 6A and 6B for March 17, 1968, show much more of a significant difference. The spring thaw had been in effect for the several days preceding March 17. Again, the area influenced by the white shoulder (in both sections) was colder than the area influenced by the black shoulder. The temperature differences became especially significant, since they ranged distinctly above and below 32 F. In each case, the black shoulder partially thawed out, but the white shoulder remained completely frozen. This condition had great influence on changes in the moisture cross section, as will presently be shown. Figures 7A and 7B show the temperature cross sections on April 7, 1968. There was still a zone of frozen material under the white shoulder of each section. The area under the black shoulder had, however, reached temperatures up to 60 F.

By systematic examination of these plots of temperature patterns within the cross section, it was seen that white shoulder color tended to maintain a colder temperature in the underlying material. This phenomenon tended to hold frost in the ground much longer under the white shoulder than under the black shoulder.

Moisture Conditions—Moisture conditions were affected by the temperature conditions which were just described. The moisture content pattern for November 27, 1967, are shown in Figures 4C and 4D. This represents the conditions before the shoulder color difference was introduced. The moisture content pattern was approximately symmetrical about the centerline. January 21, 1968 (Figs. 5C and 5D), represents the midwinter condition before any significant thaws had occurred. There were still no great differences in moisture content between sides of the sections.

Figure 8 shows the effect on the insulated section of a midwinter thaw of short duration. The frost line had moved out to the outside edge of the black shoulder, but the white shoulder remained frozen. The moisture contents on the black side at approximately the edge of pavement increased greatly. The moisture contents on the white

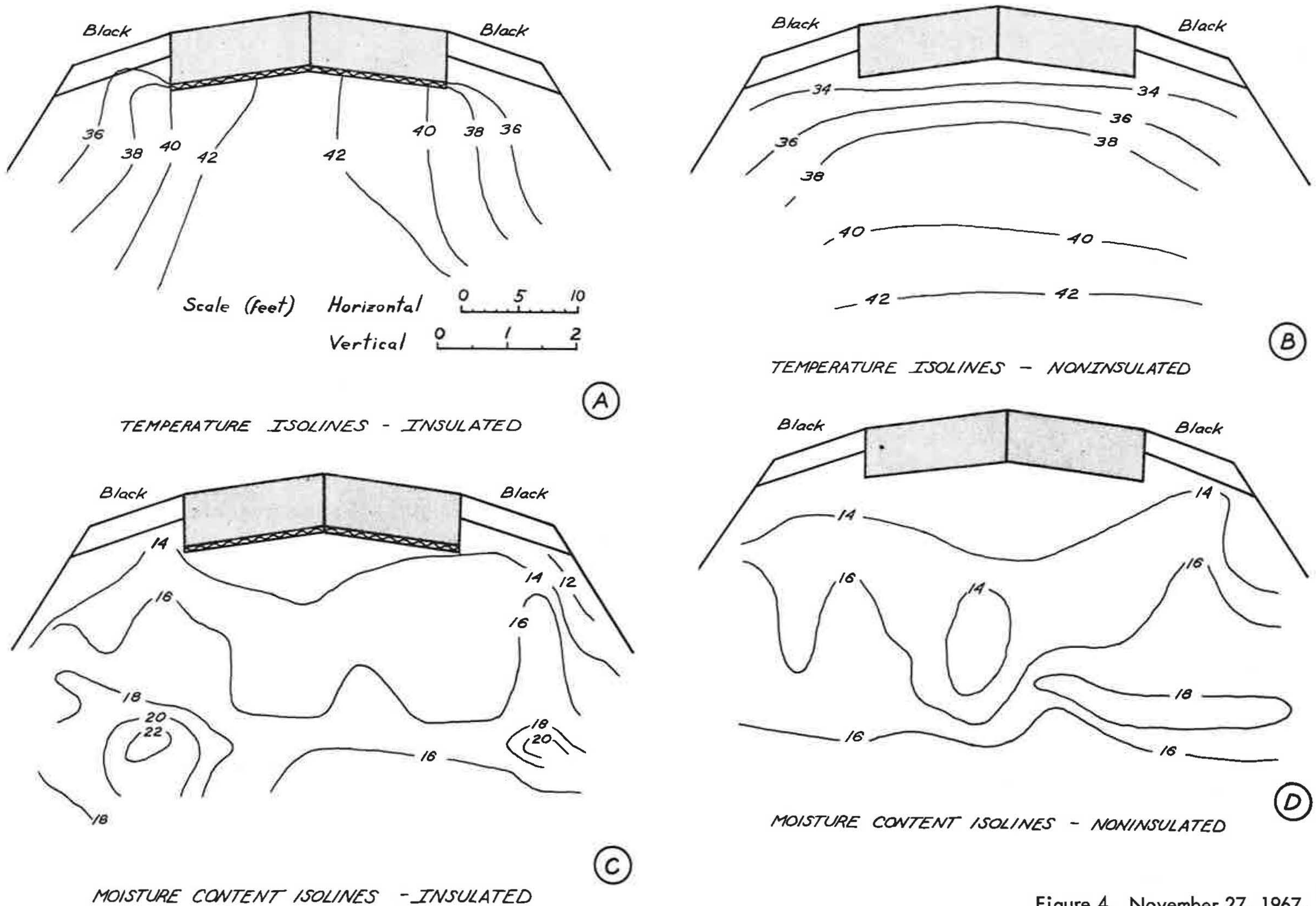

Figure 4. November 27, 1967.

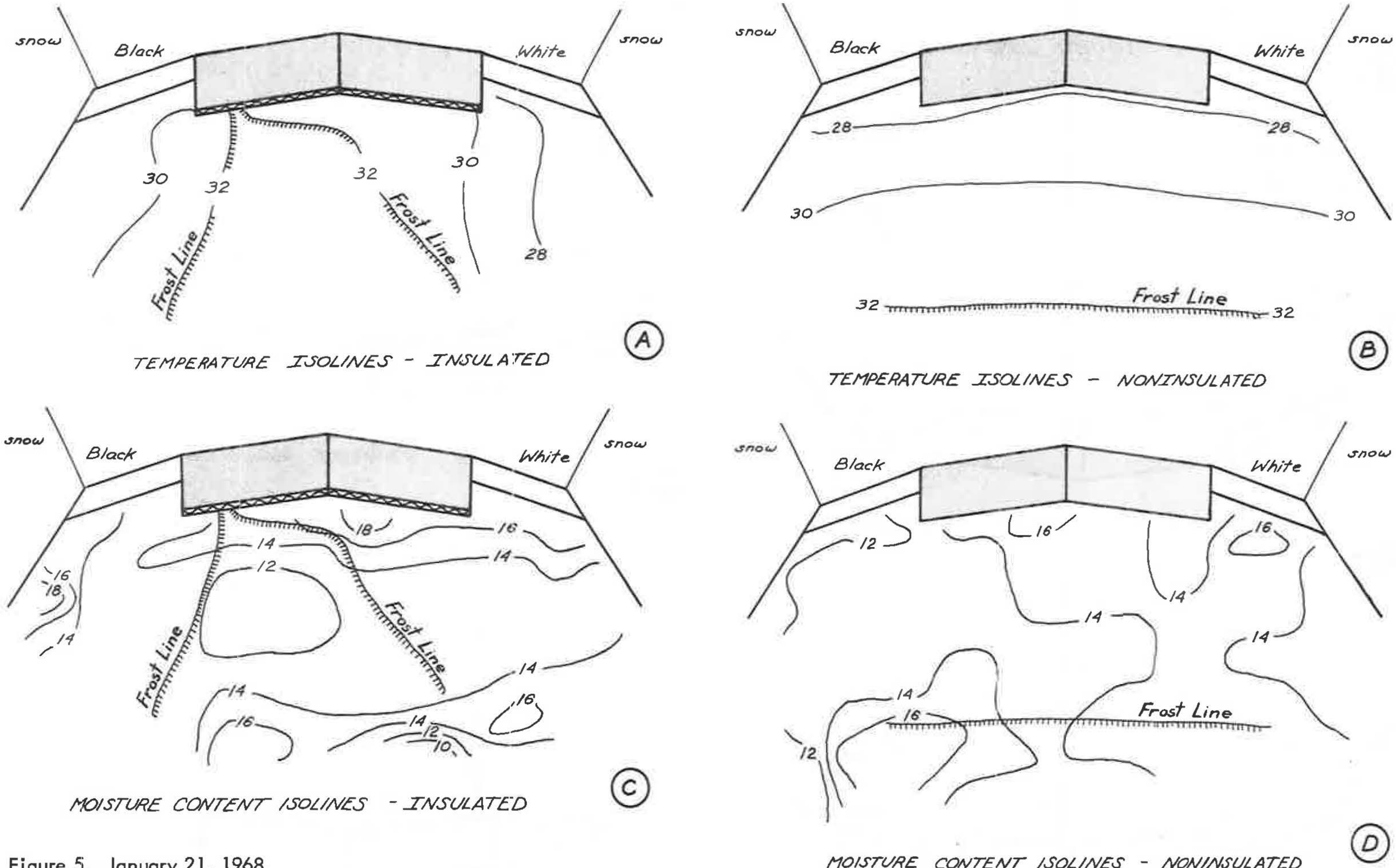

Figure 5. January 21, 1968.

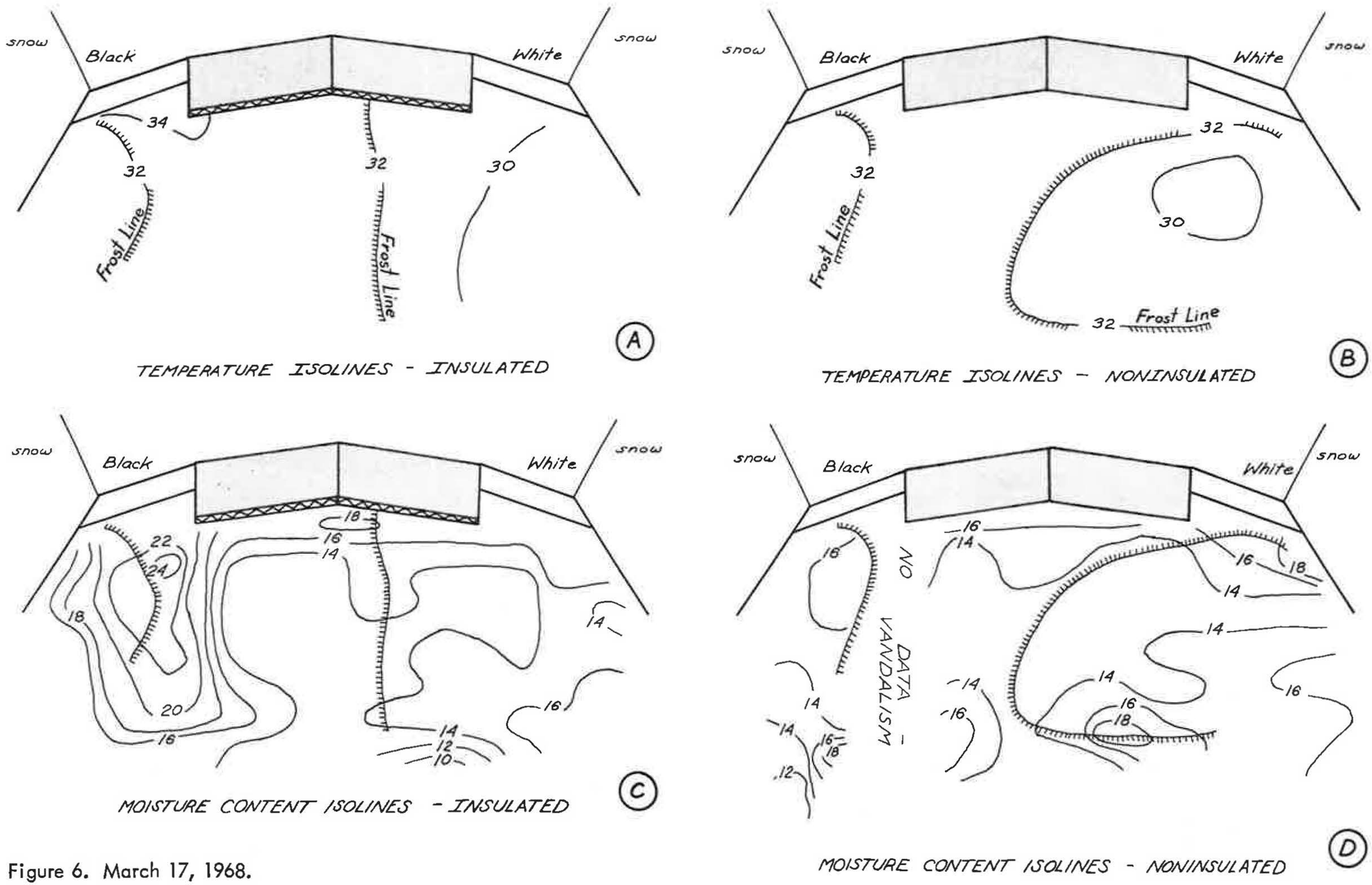

Figure 6. March 17, 1968.

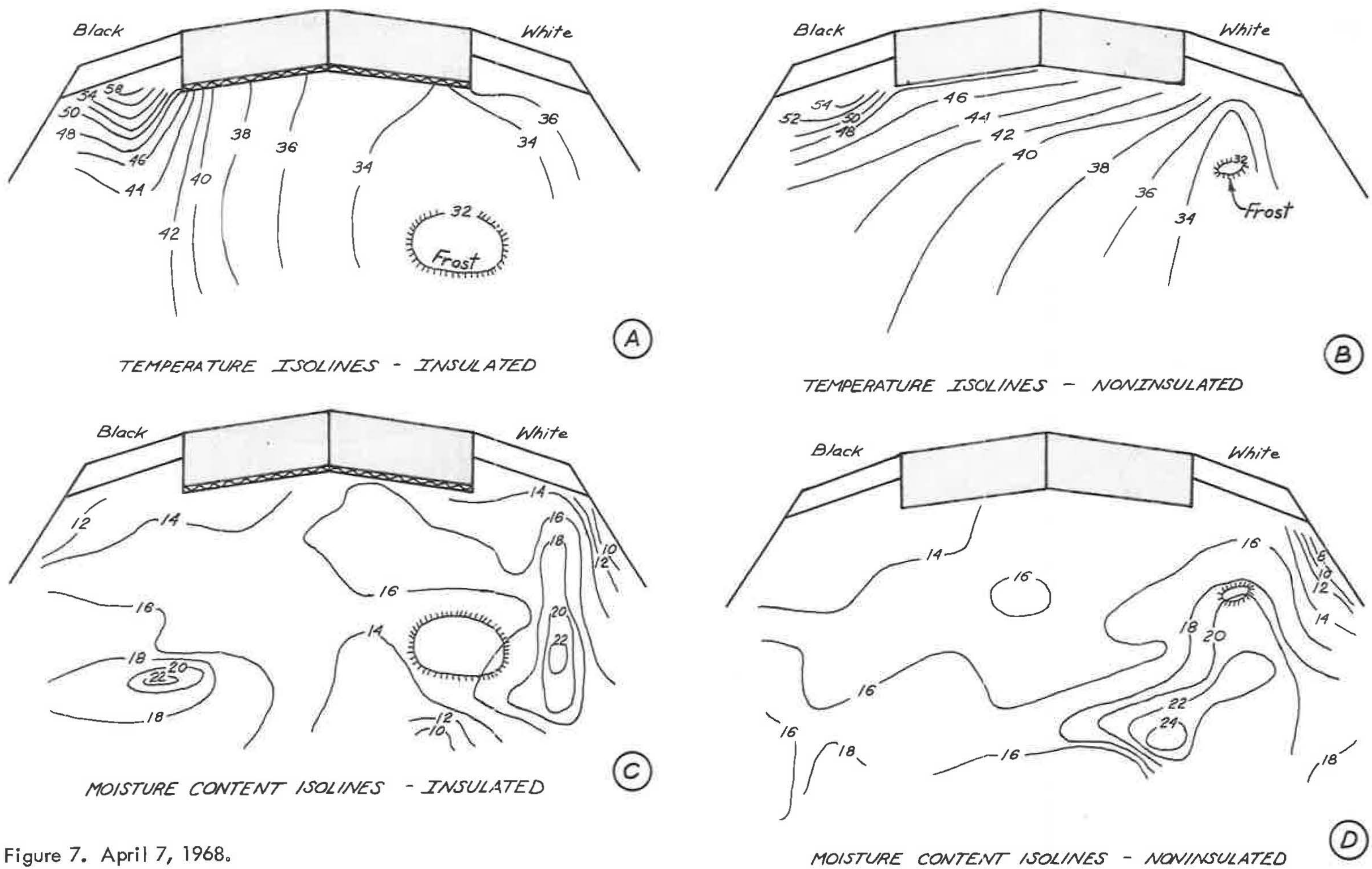

Figure 7. April 7, 1968.

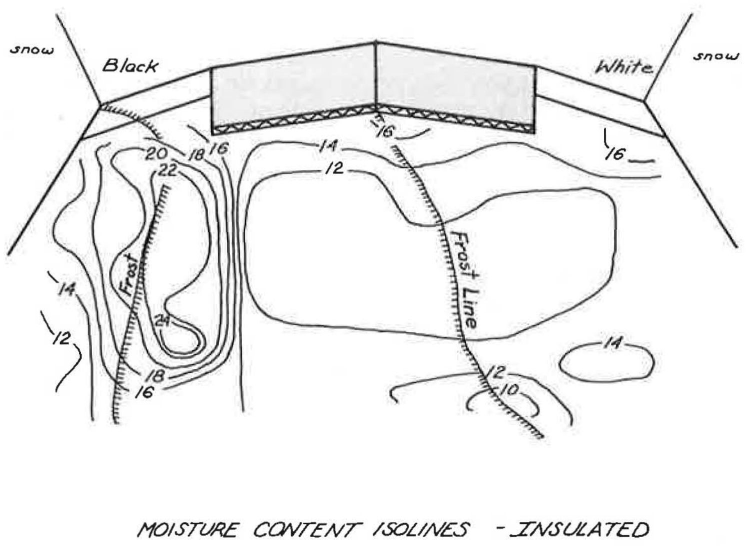

Figure 8. Moisture conditions in insulated section on February 8, 1968.

side were still at midwinter levels. Figures 6C and 6D (March 17, 1968) show the same effect (of thawed black shoulder and frozen white shoulder) on the moisture characteristics in the cross sections. An act of vandalism, which plugged one access tube, left a gap in data for the edge of pavement on the black side of the noninsulated section for the period of Feburary 8 to April 2, 1968. This hampers our knowledge of what happened during the spring thaw season this year. Figures 7C and 7D (April 7, 1968) show the moisture characteristics for a time nearly at the termination of spring thaw. The high moisture contents under the black side had dissipated, but the white side had then risen to higher moisture contents.

Figure 9 shows the average volumetric moisture content of the shoulders of the insulated pavement for the period of study. Clearly indicated in the figure is that the black shoulder sustained a substantially higher average moisture content than the white shoulder, especially during the period from late January to early April.

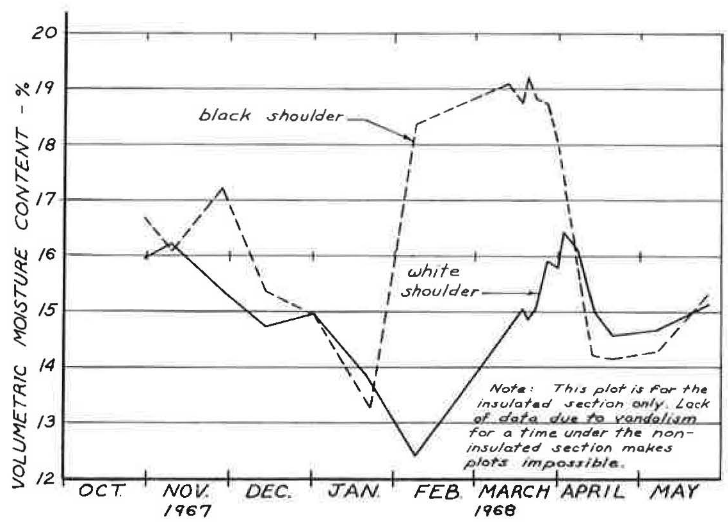

Figure 9. Average volumetric moisture content of shoulders or insulated pavement for period of study.

Source of High Moisture During Thaw—It appears, from the study of observations, that the high moisture contents which occurred under shoulder and pavement during the course of the season were caused by gravitational flow of snowbank melt-water. This conclusion can be validated by examining the insulated section for January 21, 1968, and February 8, 1968 (Figures 5C and 8). The common explanation of high moisture contents, often emphasized in explaining seasonal frost phenomena, is that ice lenses (which have built up over the course of the winter) have melted. If this had been the case, the moisture contents on January 21 and February 8 should have been the same. The frost line was low enough on January 21 so that any ice lensing in the upper regions of the site should have occurred by that time. The only explanation for the high moisture contents on the black side on February 8 is that moisture from outside must have entered the cross section (by some means other than melting ice lenses) between January 21 and February 8, 1968, during a midwinter thaw of a few days duration. The shape of the frost line in Figure 8 (February 8, 1968) and the fact that the snowbank were decreasing in size provide clues leading to identification of the source. Gravitational flow of snowbank melt-water along the frost line is the obvious explanation.

SIGNIFICANCE OF RESEARCH

It has been shown that shoulder color influences greatly the temperature characteristics under road shoulders. It is suggested that the effect of a white shoulder remaining frozen longer than a black shoulder might be used to reduce the flow of melt-water from snowbanks to a position under the pavement. The observed accumulation of water at edge of pavement (during a thaw period) is consistent with the often-observed phenomenon of pavement failure and weakening of material under the pavement edge.

Further research is justified to understand more fully the general application of findings. It is likely that differences in patterns observed in this study for part of one year might be even greater if observed over a full year (especially with carry-over effects to the winter from the previous summer and fall). The effects of in between colors (light gray or dark gray) have not been studied.

The effect of black and white shoulder color in combination with a bituminous pavement should be investigated, since this combination is likely to produce results different from those reported here.

In the past, a great deal of emphasis has been placed on the evaluation and use of nonfrost-susceptible materials in the pavement structure. Findings in this study suggest that increased attention should be placed on preventing the entrance into the pavement structure of water from melting snow, perhaps by the use of color (natural or artificial aggregate selected for color and/or colored seal material). The research discussed in this paper points to white shoulder color as a promising starting point for any new research aimed at the problem.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Division of Research and the Department of Civil Engineering of Clarkson College of Technology, together with many individuals who willingly gave assistance at the times and in the ways needed.

Special acknowledgment is made to former students whose work on instrumentation and test site design and construction made this particular study possible, including Wayne G. Williams, William Carman, Peter Rojeski, Frank E. Przybycien, L. Raymond Powers, and David L. Cornish.

REFERENCES

1. Cornish, David L. A Study of Predicting Depth of Frost Penetration Under a Highway Pavement Using the Modified Berggren Equation. Unpublished, MSCE thesis, Clarkson College of Technology, 1968.
2. Dudden, Paul F. Shoulder Color's Influence on Moisture Conditions Under a Test Pavement. Unpublished, MSCE thesis, Clarkson College of Technology, 1968.

3. Moorhead, Frank T. A Study of the Effect of Colored Shoulders on the Depth of Frost Penetration Under a Highway Pavement. Unpublished, MSCE thesis, Clarkson College of Technology, 1968.
4. New York State Department of Public Works, Public Works Specifications, 1962.
5. Powers, L. Raymond. Moisture Conditions Under Highway Pavement. Unpublished, MSCE thesis, Clarkson College of Technology, 1967.
6. Straub, Arthur L., Schenck, H. N., Jr., and Przybycien, Frank E. Bituminous Pavement Temperatures Related to Climate. Highway Research Record 256, p. 53-77, 1968.
7. Straub, Arthur L., and Williams, Wayne G. Use of Insulation to Uniformly Retard Frost Penetration Under a Highway Pavement. Highway Research Record 181, p. 77-93, 1967.
8. Straub, Arthur L., and Wegmann, Frederick J. Determination of Freezing Index Values. Highway Research Record 68, p. 17-30, 1965.
9. U. S. Weather Bureau, Annual Summary, New York State, Climatological Data, 1965.
10. Whillier, Austin. Integrating Instrument for Measuring Solar Radiation. Solar Energy Quarterly, Vol. VIII, No. 4, Oct.-Dec., 1964.
11. Whillier, A., and Tout, D. New Integrating Instrument for Measuring Daily Values of Total Solar Radiation. Solar Energy Quarterly, Vol. IX, No. 4, Oct.-Dec., 1965.