

WHITE PAINT FOR HIGHWAY THAW SETTLEMENT CONTROL

FINAL REPORT

By

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March 1985

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in cooperation with

U.S. Department of Transportation
Federal Highway Administration

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1. Report No. FHWA-AK-RD-85-16		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle White Paint for Highway Thaw Settlement Control				5. Report Date March 1985	
				6. Performing Organization Code FHWA-AK-RD-85-16	
7. Author(s) Matthew K. Reckard				8. Performing Organization Report No.	
9. Performing Organization Name and Address Alaska Dept. of Transportation & Public Facilities Research Section 2301 Peger Road Fairbanks, AK 99701				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. F24572	
12. Sponsoring Agency Name and Address Alaska Dept. of Transportation & Public Facilities Pouch Z Juneau, AK 99811				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.					
16. Abstract <p>The report discusses the effects of painting roadways over thaw sensitive ground. An experimental program including four test sections on Interior Alaskan roads is described along with the results of two years of settlement and subsurface temperature measurements.</p> <p>The report concludes that the higher albedo of the painted sections resulted in less thaw settlement and lower subsurface temperatures.</p> <p>It is recommended, however, that the technique <u>not</u> be used as a regular road maintenance procedure due to several factors. These include the high cost of painting, the difficulty of pinpointing areas with subsoils favorable to the procedure, and the inability of the paint to reduce heat input through the embankment slopes (an "edge effect").</p> <p>Road slipperiness was also found to be a major drawback to the technique. The painted sections provided less skid resistance than unpainted pavements; they also experienced localized icing such as occurs on bridge decks.</p>					
17. Key Words thaw settlement, permafrost, skid resistance, frost heave, ground thermal regime				18. Distribution Statement Unrestricted	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price N/A

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Introduction

Highways built in areas of permafrost often suffer from severe differential settlements due to thawing of underlying soils with high ice content. This is a common problem in much of Alaska which results in high road maintenance costs in the affected areas. The roughness of these roads adversely affects the safety and comfort of highway users and increases wear on their vehicles.

The warming of the ground beneath highways is attributable to several causes. These include the following:

- Removal of surface vegetation. The organic mat over undisturbed frozen ground, such as a moss layer, acts as thermal insulation for the underlying soil.
- Reduction in evaporation. The evaporation of moisture from a natural ground surface has a cooling effect which is largely eliminated by the relatively waterproof surface of a paved road.
- Loss of shading. The clearing for a road exposes the surface to more sunlight, thus warming the ground. This is compounded by the following factor.
- Lower albedo. The dark surface of an asphalt pavement absorbs more (and reflects less) incoming radiation than does a natural ground cover. Black pavement, in other words, is a better "solar collector", resulting in the warming of the ground.

A number of techniques have been tried or proposed to counteract these effects. The surface organic mat, for example, is often intentionally left in place when new roads are built in Alaska. Despite being compressed by the embankment on top of it, this layer retains some insulating value.

Attempts have also been made to increase the insulating value of the embankment itself. This can be done by increasing the depth of fill, or by incorporating layers of natural (e.g., peat) or man-made (e.g., polystyrene) insulation in the embankment.

The loss of evaporative cooling can be avoided, or at least reduced, by not paving the road. The author knows of no case where this principle has actually affected design decisions, however.

Another approach to reducing thaw settlement of highways is to paint the road surface a lighter color. Such a higher albedo surface will reflect more incoming radiation and stay cooler as a result. It is this approach that was investigated and is reported herein.

Prior to this study there had been a limited amount of field experience with white-painted pavements (discussed later in this report). A literature search, however, revealed no experience with the application of primary interest to this study, which is on roadways in subarctic climates. The only known previous test in a subarctic climate was made on a 50 foot experimental embankment (not trafficked roadway).

That test and other previous work provide some useful information. This study, however, was intended to be of larger scope, i.e., more and larger test sections subjected to traffic and tire wear. The objectives were to empirically compare settlement in white-painted road sections to that of unpainted control sections, and to develop information by which the cost effectiveness of the procedure as a maintenance tool could be judged. The effect of the paint on traffic (such as the potential slipperiness of the pavement) was also evaluated.

Five test sections were painted for this study. They and adjoining unpainted control sections were repeatedly surveyed to measure thaw settlement. One of these sections proved to be in an unsuitable location and produced no useful results. Another section was abandoned after about a year of monitoring as will be discussed. Three sections have been monitored for about two years, and it is planned to continue observations at these locations.

Summary and Conclusions

This study examined the effects of painting roadways over thaw sensitive ground. Data was gathered and analyzed from four painted test sections, located on two-lane paved highways in the subarctic Tanana River drainage of Interior Alaska. A fifth test site was painted, but was abandoned as unsuitable due to nonuniform subsoils. The following conclusions can be made based on the information to date:

1. The higher albedo of the white paint led to significantly less thaw settlement in all test sections compared to the unpainted controls. At the one test section where subsurface temperature data were gathered, significant cooling was noted at depth following paint application.
2. The costs of painting roadways are likely to be greater than the savings achieved through reduced road maintenance except in localized areas where thaw settlement problems are extreme.
3. Repainting will be required more in areas of heavy traffic due to abrasion of the paint and in areas with greater settlement problems due to patches requiring paint. The greater the need, in other words, the greater the cost for this procedure.
4. White paint is less effective near the road shoulders than at centerline due to heat input from the unpainted embankment slopes. This "edge effect" probably extends 10 feet or more in from the shoulder. This indicates the technique is less effective on narrow road embankments than on wider paved areas such as runways.
5. Traffic paint provides less skid resistance than does unpainted pavement. Painting roads would thus create safety hazards, particularly if it were done on steep grades or curves. Additionally, localized icing can occur on painted pavement under certain circumstances, precisely because the paint succeeds in reducing surface temperatures.

6. Where ice-rich soils are limited to a shallow surface layer, painting of roads will not reduce the ultimate amount of settlement, but merely slow it down. To reduce maintenance costs in such areas, it would be better to subexcavate the ice rich material, to pre-thaw it, or merely to leave the road unpaved for a few years.
7. An extensive soils investigation (drilling program) prior to road construction would be needed to determine where painting would be most advantageous. Due to the costs of such an investigation, white paint would be more favorable if used only for existing problem areas. Before applying paint to these areas, they should be investigated to determine if further thawing of ice-rich material can be expected.

Implementation

The knowledge gathered to date indicates that the use of white paint to control highway thaw settlement would not be cost effective in most situations. The procedure might reduce road maintenance costs in limited areas with severe problems which are expected to continue. Because of the difficulty of identifying such areas, and because of safety problems such as slipperiness and localized icing in painted areas, it is recommended that the DOT&PF not initiate the use of this procedure at this time.

The test sections used in this study have provided useful information regarding ground thermal regimes and heat transfer at the ground surface. This information complements other work being performed by the DOT&PF Research Section. Further gathering of data from the existing test sites can be done at little cost. It is therefore recommended that the Research Section maintain the test sites at the Shaw Creek and Canyon Creek locations.

Previous Work

The concept of reducing thaw depths by increasing the surface albedo (reflectivity) is not new. A significant amount of theoretical information on ground temperatures exists in the literature. There has also been a limited amount of prior field experimentation with white-painted pavements, the most notable of which took place at the Thule, Greenland Air Force Base and at an experimental embankment at the U.S. Army cold Regions Research and Engineering Laboratory (CRREL) field station at Fairbanks, Alaska.

The first major field trial was in the arctic environment at Thule. Thirteen hundred feet of runway which was experiencing thaw settlement problems was painted in 1959, and an additional forty seven hundred feet was painted the following summer. Measurements there indicated that the paint, when new, absorbed about 16% of the incoming solar radiation. The adsorptivity rose to about 42% after one year due to weathering and traffic. The paint reduced maximum thaw depths from 6 or 7 feet to 4 or 5 feet, an average difference of about 2 feet or 30% (1, 2).

Part of the runway at the Barrow, Alaska airport was painted white during the summer of 1984. Barrow, like Thule, is located in a dry, arctic environment. The performance at Barrow is being monitored, but there has not been enough time to assess performance at that location. There have been complaints from pilots that the painted surface is slippery, despite the fact that masonry sand was broadcast over the wet paint in an attempt to achieve a gritty texture (3).

Another field trial was started in the subarctic climate of Fairbanks, Alaska in 1965. Here a 2½ foot thick embankment was built with several types of paved and unpaved surfaces. Total embankment width was 36 feet; the top surface width (shoulder to shoulder) was 24 feet. Each test section was 56 feet long; one of these had a white-painted asphalt pavement surface.

Maximum thaw depths, which had been about 3 feet at the undisturbed site, increased to about 11.3 feet beneath a conventional asphalt surface. Thaw depths beneath the painted pavement were 7¼ to 8¼ feet, or about 3½ feet less than those beneath the unpainted pavement (2, 4). This reduction in thaw depth is about 30%, which is similar to the percentage reduction that occurred at Thule.

Berg and Quinn (2) present theoretical work in addition to discussing the Thule and Fairbanks field tests. Using the modified Berggren equation, they concluded that white paint should reduce thaw depths into gravel by about 4 feet for climates with thawing indices between 500 and 3500°F-days. This theoretical reduction compares well with the field results in Fairbanks, but is about twice what was reported in Thule.

Miller (5) presented a ground surface heat balance modeling program along with some results of its use. The model was originally verified by comparing its output with the field results of the Fairbanks tests, so it is not surprising that its results agree well with the Fairbanks field results. The model also predicted a thaw depth reduction of about 2 feet in an arctic climate. This agrees well with the results from the field tests in Thule.

Test Sites

Five test sites have been used on the project, all located between 64° and 65° N. latitude in the Tanana River drainage between Fairbanks and Delta Junction. Two are located on a newly-reconstructed secondary route (Johnson Road) where it traverses a new alignment over ice-rich soils. Two are located on a primary route (Richardson Highway) which was reconstructed, without change in alignment, in an area with historical thaw settlement problems. A fifth site, established five months after the others, is also on the Richardson Highway. This site was used previously as a test site for the experimental use of a peat layer to insulate beneath the roadway (6).

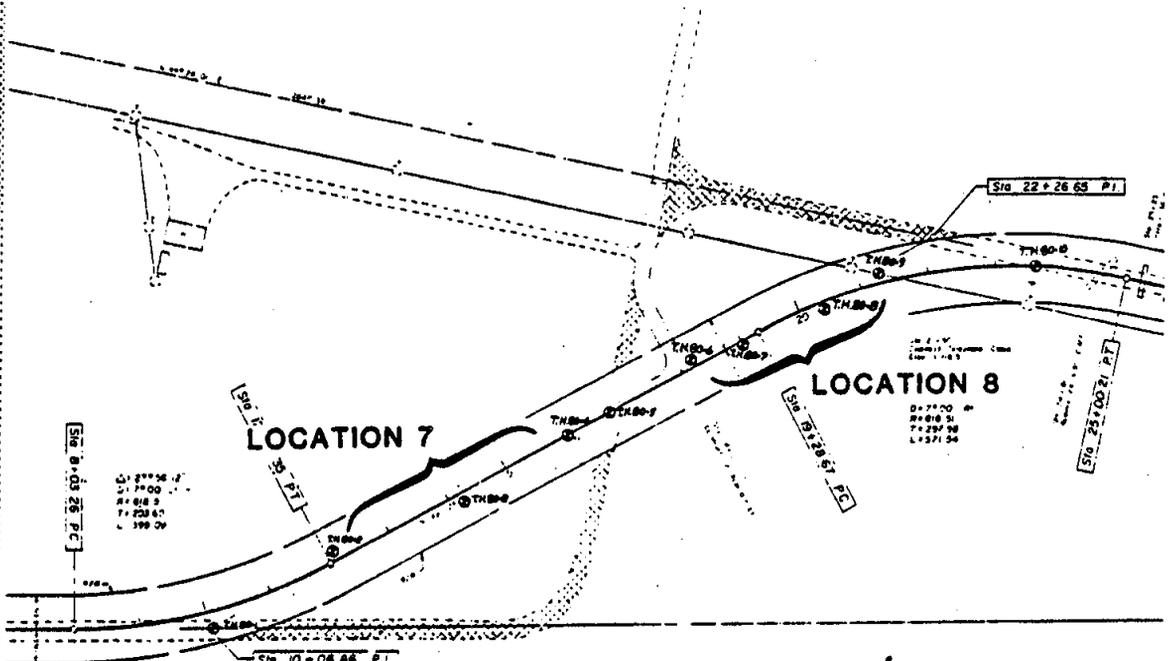
Johnson Road Sites:

Borings made in November, 1980, (see Figure 1) indicated that thaw settlement could be expected at the Johnson Road sites, known as locations 7 and 8. At location 7 a fairly uniform layer of sandy silt extended from the surface organic mat to about 8 feet, with sandy gravel below that level. The permafrost table was high (about 3' below the surface), and the frozen silt contained considerable ice.

Soil conditions were highly variable at location 8, which was therefore a much less desirable test site. The beginning of the painted test section was similar to the soils at location 7 except that the sandy silt had a very high ice content (approximately 50% segregated ice between 3.5 and 6.0 feet). The test section then crossed an old drainage channel where 4 feet of wet peat overlaid 3 feet of sandy silt. No permafrost was encountered above the underlying gravel.

Beyond the old drainage channel permafrost was encountered again, but the silt layer extended only to about 5 feet, with gravel below. It was in this area that the painted test section changed to the unpainted control. The far end of the control section lay in an old telephone line clearing. This exposure had "pre-thawed" the area, none of the silt here was frozen.

1980 SOIL BORINGS, JOHNSON ROAD



Boring ID	Soil Description	Depth (ft)	Notes
TH80-1	00-25 Slightly Silty Sandy Gravel	00-25	Sample 80-250 A-4, NFS
TH80-1	25-70 Silty Silt w/ trace cobbles	25-70	Sample 80-255 A-4(2), F-3 Mo SF, 280
TH80-1	70-85 Silty Gravel w/ med. cobbles	70-85	Sample 80-276 A-4, NFS
TH80-2	00-03 Organic Mat	00-03	
TH80-2	03-70 Silty Silt	03-70	Sample 80-257 A-4(1), F-4 Moist: 57.6
TH80-2	70-100 Silty Gravel w/ med. cobbles	70-100	
TH80-3	00-03 Organic Mat	00-03	
TH80-3	03-20 Silty Silt	03-20	Sample 80-258 Organic top Moist: 49
TH80-3	20-100 Silty Gravel w/ med. cobbles	20-100	
TH80-4	00-30 Silty Sand	00-30	
TH80-4	30-105 Silty Silt	30-105	Sample 80-260 Organic top Moist: 28.8
TH80-4	15-115 Silty Sand	15-115	Sample 80-262 A-4, F-3
TH80-4	115-200 Silty Gravel w/ med. cobbles	115-200	
TH80-5	00-03 Organic Mat	00-03	
TH80-5	03-30 Silty Silt	03-30	Sample 80-263 A-4(2), F-4 Moist: 52.6
TH80-5	30-70 Silty Sand	30-70	
TH80-5	70-110 Silty Sandy Gravel w/ med. cobbles	70-110	Sample 80-260 Moist: 28.8
TH80-6	00-03 Organic Mat	00-03	
TH80-6	03-20 Silty Silt	03-20	Sample 80-264 A-4(2), F-3
TH80-6	20-25 Silty Gravel w/ med. cobbles	20-25	
TH80-6	00-10 Organic Mat	00-10	
TH80-6	10-60 Silty Silt	10-60	
TH80-6	60-100 Silty Gravel w/ med. cobbles	60-100	
TH80-7	00-10 Organic Mat	00-10	
TH80-7	10-60 Silty Silt	10-60	
TH80-7	60-100 Silty Gravel w/ med. cobbles	60-100	
TH80-8	00-10 Organic Mat	00-10	
TH80-8	10-60 Silty Silt	10-60	
TH80-8	60-100 Silty Gravel w/ med. cobbles	60-100	
TH80-9	00-03 Organic Mat	00-03	
TH80-9	03-20 Silty Silt	03-20	
TH80-9	20-25 Silty Gravel w/ med. cobbles	20-25	
TH80-9	00-25 Organic Mat	00-25	
TH80-9	25-80 Silty Silt	25-80	
TH80-9	80-90 Back Fill	80-90	
TH80-9	90-130 Silty Silt	90-130	
TH80-9	130-160 Silty Gravel w/ cobbles	130-160	

Source: Reference 7

Figure 1

Locations 7 and 8 were each 300 feet long. This included 150 feet which was painted with white traffic paint and an adjoining 150 foot unpainted control section. Nails were placed in the asphalt pavement for use as surveying reference points every 10 feet throughout the 300 foot section along five lines. One line was the road centerline; the others were 7 feet and 12 feet on both sides of the centerline.

Locations 7 and 8 were located about 0.25 and 0.40 miles, respectively, from Johnson Road's intersection with the Richardson Highway. The new roadway embankment was about 3 feet thick with a 26 foot paved surface. The road was completed in late summer of 1982. Painting and initial surveys were completed by the first week in November.

Shaw Creek Sites:

The first two test sites on the Richardson Highway, known as locations 2 and 3, are located in flat terrain near the Shaw Creek Bridge. Borings were made in the area in November 1972 prior to construction of the road along the present alignment (see Figure 2). These revealed a surface layer of vegetation and/or peat underlain by layers of organic silt, then sand, and finally sandy gravel. The layers are not sharply defined. In some places the silt contains sand and in some the sand is silty. Permafrost was encountered throughout the area at depths of 2 to 5 feet and extending into the gravel layer.

Thaw settlement had caused severe road maintenance problems throughout the Shaw Creek flats ever since the road was built. Prior to reconstruction of the road in 1982, five potential test locations were selected. An attempt was made to choose areas which showed consistently severe pavement distress for at least 300 feet. Tests were eventually made at the second and third sites.

At location 2 the peat layer was 2 feet thick, the silt layer 1 to 3 feet thick, and the sand 1 to 4 feet thick. At location 3 the peat was $1\frac{1}{2}$ to $4\frac{1}{2}$ feet thick, the silt $3\frac{1}{2}$ to $7\frac{1}{2}$ feet thick. There was no significant sand layer, although some of the silt and all of the underlying gravel was sandy.

1972 SOIL BORINGS, SHAW CREEK

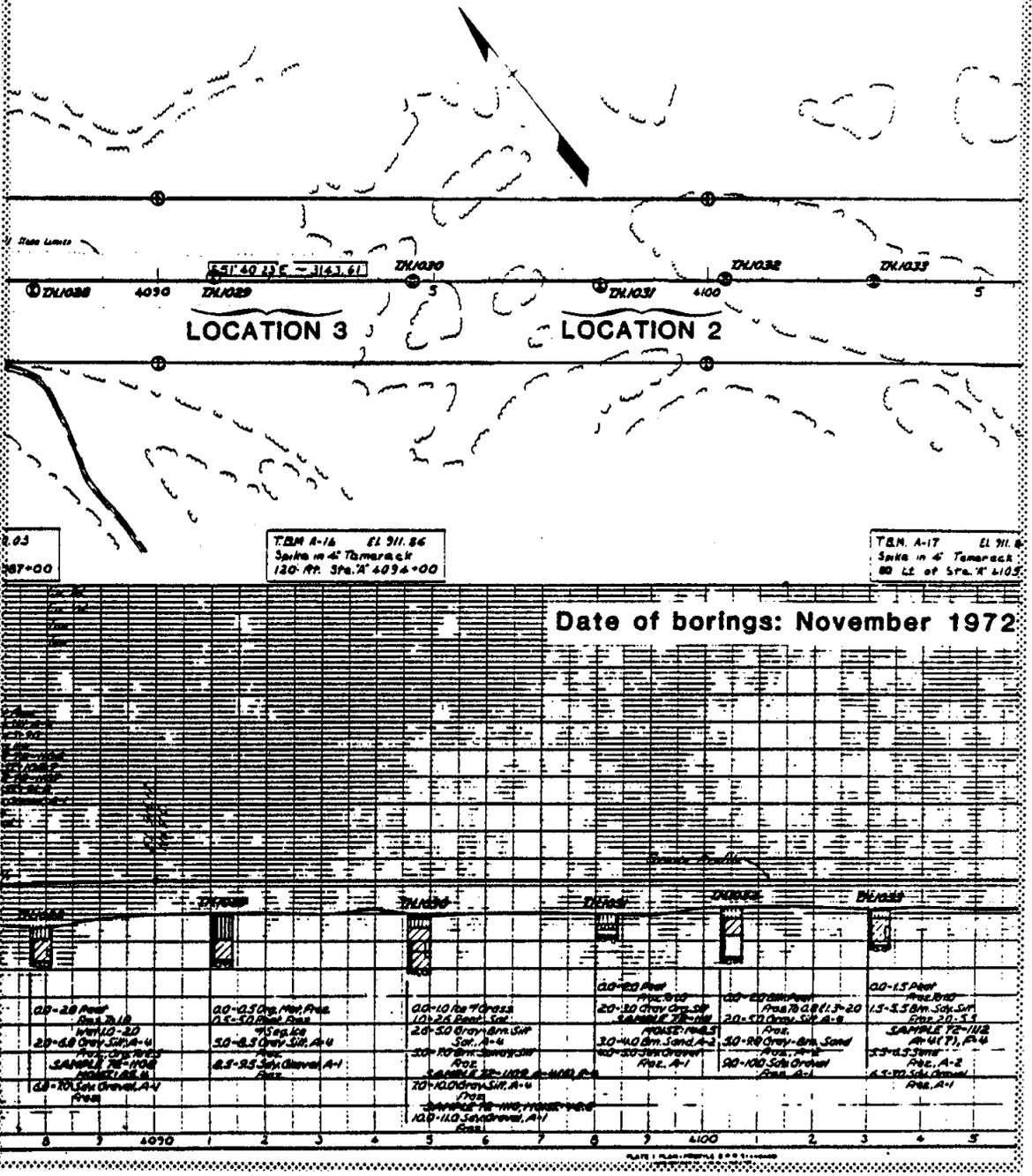


Figure 2

The length of test and control sections and the layout of survey points (nails) at the Shaw Creek sites was the same as at the Johnson Road sites. Location 3 is 0.7 miles south of the Shaw Creek Bridge, near milepost 286 of the Richardson Highway; location 2 is an eighth of a mile south of that. The asphalt pavement surface at these sites is 40 feet wide. Leveling and repaving work on the road was completed in August 1982. The test sections were painted that fall and the initial surveys were performed the first week in November.

Six test holes were drilled and logged in November, 1984 at Shaw Creek sites revealing that thawing of permafrost had not reached the stable underlying gravels (see Figure 3). The embankment was about 7 feet thick over the original ground layer. Wet thawed soils were encountered for 2½ to 4 feet below this level. Between one and five feet of the organic silt layer remained frozen in all holes.

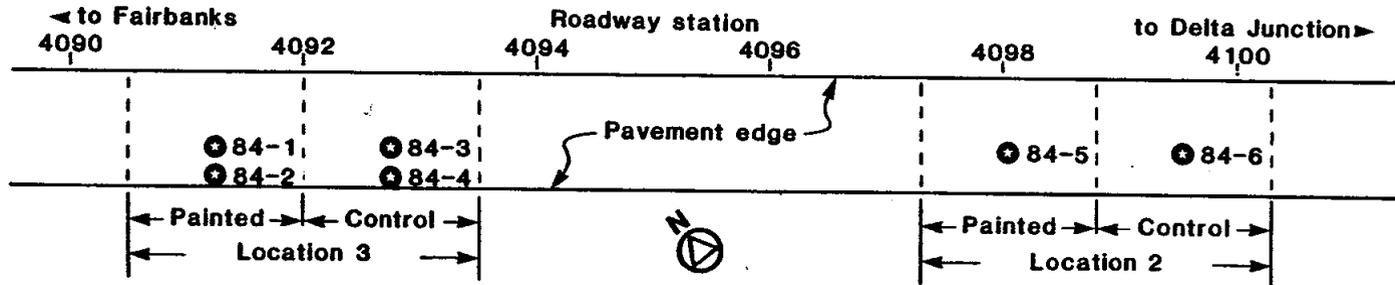
Canyon Creek Site:

The Canyon Creek test site is located in an experimental peat underlay section which had been placed during original construction in 1973. Settlement plates and thermocouple strings were already in place at the site and had been monitored since initial construction (6, 8).

The previous work indicated that the ground beneath the roadway was approaching thermal equilibrium by the time painting and surveying for the current project was begun in April 1983. Large amounts of settlements therefore were not anticipated. It was expected, however, that the extensive instrumentation at the site would enable accurate observations to be made of any subsurface cooling in the white-painted test sections.

The test section at Canyon Creek is 200 feet long, with 100 foot unpainted control sections located adjacent to each end of the test section. The subsoils beneath all of these consists of a thick layer of frozen organic silt with moisture content well above the liquid limit overlying schist bedrock. The upper portion of the road structure consists of a 1½ inch asphalt pavement over 4½ inches of crushed base course over a 6 inch subbase.

NOVEMBER 1984 SOIL BORINGS, SHAW CREEK



TH84-1



0.0-0.5 A.C. Pavement & crushed base
 0.5-7.0 Brown sandy gravel, A-1 (fill)
 7.0-7.1 Old organic mat
 7.1-8.0 Chocolate brown wet organic silt, A-4
 8.0-14.0 Gray organic silt, A-4, wet to 8.5, frozen below
 14.0-14.5 Brown sandy gravel, A-1, frozen

TH84-2



0.0-0.5 A.C. Pavement & crushed base
 0.5-7.0 Brown sandy gravel, A-1 (fill)
 7.0-7.1 Old organic mat
 7.1-8.0 Chocolate brown wet organic silt, A-4
 8.0-12.5 Gray organic silt, A-4, wet to 10.5, frozen below 10.5
 12.5-13.0 Brown sandy gravel, A-1, frozen

TH84-3



0.0-0.5 A.C. Pavement & crushed base
 0.5-7.0 Brown sandy gravel, A-1 (fill)
 7.0-7.1 Old organic mat
 7.1-9.0 Brown silt, A-4, saturated
 9.0-15.0 Gray organic silt, A-4, saturated to 10.0, frozen below 10.0
 15.0-15.5 Brown sandy gravel, A-1, frozen

TH84-4



0.0-0.5 A.C. Pavement & crushed base
 0.5-7.0 Brown sandy gravel, A-1 (fill)
 7.0-7.1 Old organic mat
 7.1-8.5 Brown silt, A-4, saturated
 8.5-14.0 Gray organic silt, A-4, saturated to 11.0, frozen below 11.0
 14.0-14.5 Brown sandy gravel, A-1, frozen

TH84-5



0.0-0.5 A.C. Pavement & crushed base
 0.5-6.0 Brown sandy gravel, A-1 (fill), frozen to 2.5
 6.0-6.1 Old organic mat
 6.1-7.5 Brown silt, A-4, wet
 7.5-10.0 Gray organic silt, saturated to 9.0, frozen below 9.0
 10.0-11.0 Brown sandy gravel, A-1, frozen

TH84-6



0.0-0.5 A.C. Pavement & crushed base
 0.5-7.0 Brown sandy gravel, A-1 (fill), frozen to 2.5
 7.0-7.1 Old organic mat
 7.1-9.0 Chocolate brown organic silt, A-4, saturated
 9.0-14.0 Gray organic silt, A-4, saturated to 10.0, frozen below 10.0
 14.0-15.0 Brown sandy gravel, A-1, frozen

Figure 3

The material between the subsoil and the subbase varies at different sections at the site (see Figure 4). One control section was also a control for the peat underlay study. Here there is about 8 feet of organic gravel fill. Beneath the painted test section there is about 3.6 feet of gravel fill on top of a layer of peat which was 4 feet thick when it was placed there in a frozen state. Beneath the second control section the gravel fill is about 3.3 feet thick and the peat layer below that was 5 feet thick when placed.

The Canyon Creek site is near milepost 300 of the Richardson Highway, about 66 miles southeast of Fairbanks and 14 miles northwest of the Shaw Creek sites. Survey points (nails) were laid out in a pattern similar to those at the other sites.

CANYON CREEK SITE PROFILE

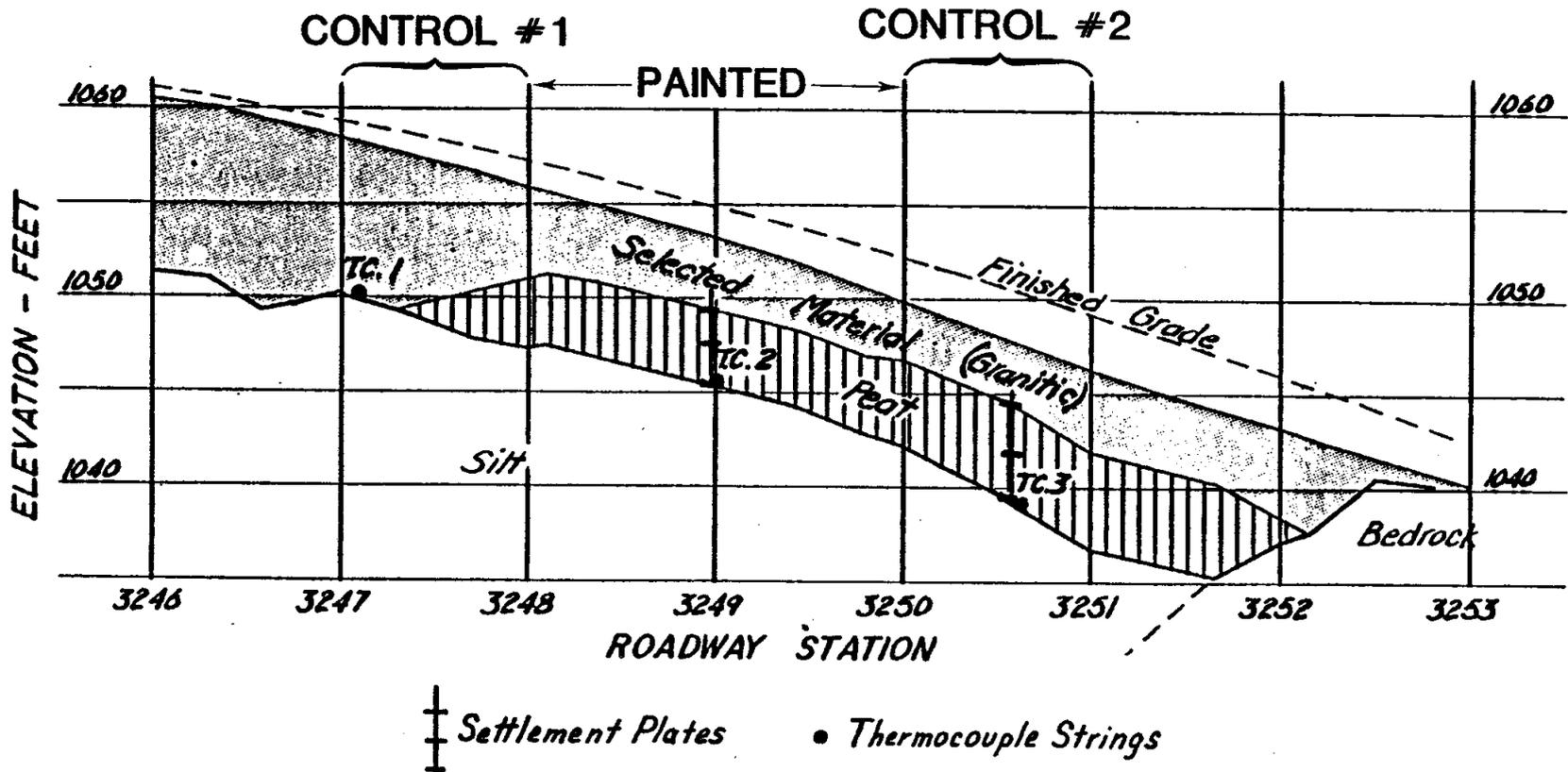


Figure 4

Field Test Results

Johnson Road (locations 7 & 8):

The Johnson Road sites were initially painted and surveyed in early November, 1982. Additional surveys were made the following April, June and August. Severe settlement in the areas of new alignment had begun before construction was completed in October, 1982. By the following June differential settlement had progressed far enough that maintenance crews had leveled parts of the road by filling depressions with gravel. This gravel cover included much of location 8. By August, more gravel had been spread, and it covered most of location 8 and part of the painted section of location 7.

The gravel cover at location 8, along with the non-uniform soils beneath it, made this useless as a test site, and survey data from that location is not presented in this report. Because of the gravel cover, surveys at location 7 were discontinued after August 1983. The results up to that date are presented below.

Pavement leveling and patching was done by the contractor before construction on Johnson Road was completed. The initial surveys of locations 7 and 8, made shortly after the construction was finished, revealed distortions from the designed road profile of as much as 0.2 feet (vertical) in 10 feet (horizontal) and 0.7 feet in 70 feet.

Ground elevations at location 7 were higher the following April due to frost heaving (see Figure 5). The heaving was seemingly greater in the painted section than in the control. The author suspects, however, that frost heaving was relatively uniform. The apparent difference was probably due to greater settlement in the control area before the ground froze at depth the previous winter.

The results of the next survey (June 19) are consistent with this hypothesis. Settlement between the April and June surveys was quite uniform, as would be expected from thawing of uniformly heaved soil. By June all points were at or below their elevations at the time of the original survey.

By the time of the August survey the control section at location 7 had settled an average of 0.131 feet and a minimum of 0.07 feet. Average settlement in the painted section was 0.078 feet with a minimum of 0.03 feet.

Figures 6 and 7 summarize the August settlement measurements. Figure 6 shows the least, greatest, and average settlements of the five transverse points at each of the 10 foot longitudinal stations. The irregularity of the settlement is apparent from the figure, as is the generally better performance of the painted test section.

Figure 7 shows similar information along each of the five longitudinal lines of survey points, for both the painted and control sections. More settlement, in general, occurred to the right of centerline than to the left. The road at location 7 bears N 49° 25' 32" E, so the right slope of the embankment faces southeast while the left faces northwest. The greater exposure to solar heat gain on the right presumably led to the greater settlement there.

Shaw Creek (locations 2 & 3):

The Shaw Creek sites were initially painted and surveyed at the same time as those at Johnson Road (early November, 1982). The next year the sites were surveyed in April, June and September. Unlike the Johnson Road sites, settlement was not severe at Shaw Creek, and testing continued through 1984. That summer the paint was touched up, and surveys were performed in May and September.

An abutment of the Shaw Creek Bridge was felt to be the nearest point free from frost heaving. This was therefore used as a benchmark for the surveys. Unfortunately, this required a traverse of more than a mile, with a resulting loss of survey accuracy. Errors of closure were as great as 0.05 feet for the traverses; the (adjusted) elevations for each survey may thus be in error by one or two hundredths of a foot. Settlements computed by comparing two surveys may thus be in error by as much as three or four hundredths of a foot. This potential error is large compared to the settlements and heaves computed for the Shaw Creek sites, shown in Figures 8 through 13.

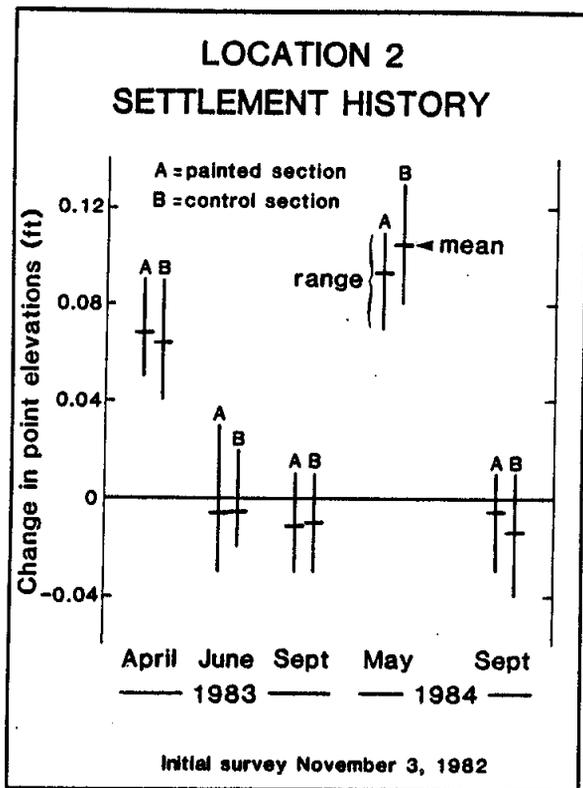


Figure 8

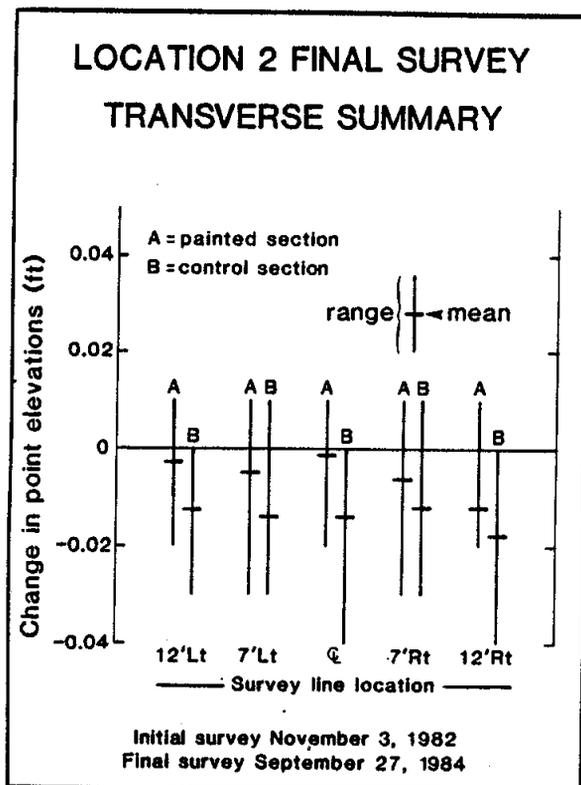


Figure 10

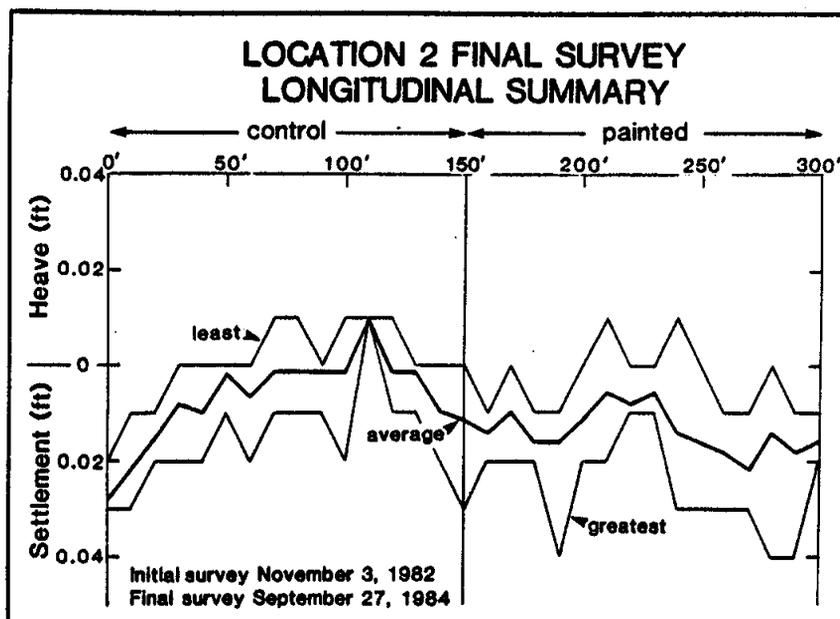


Figure 9

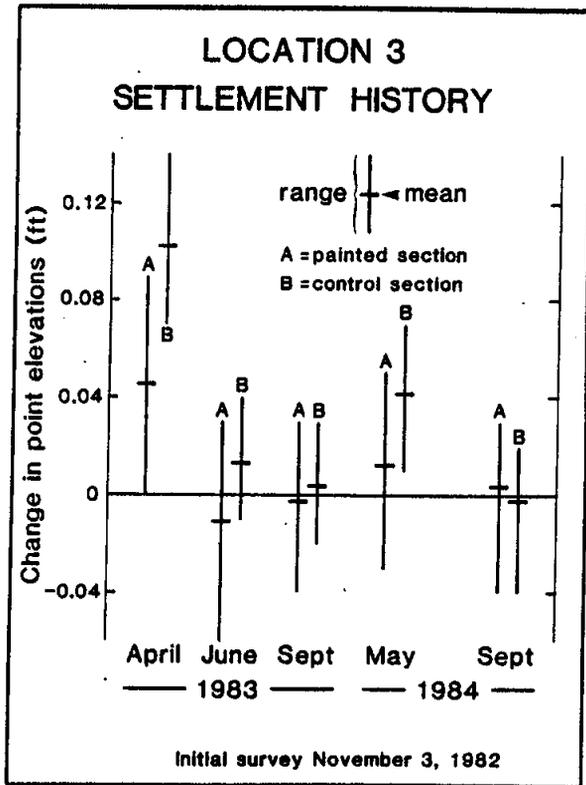


Figure 11

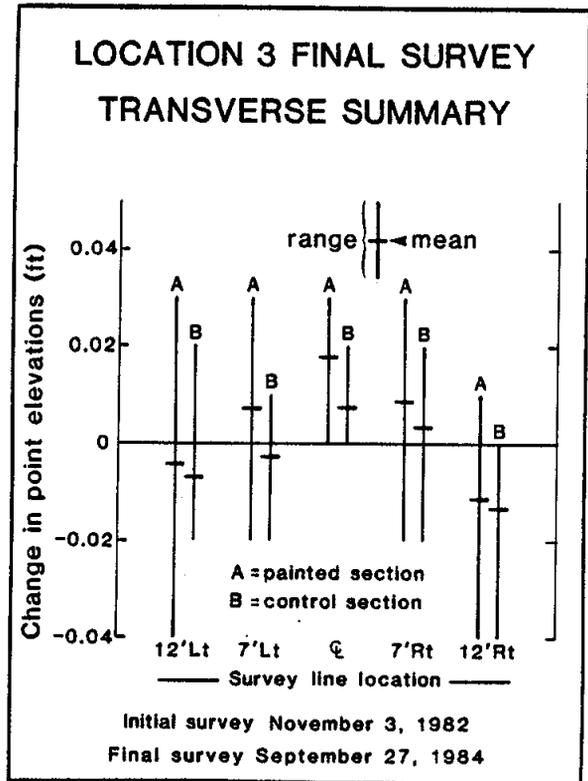


Figure 13

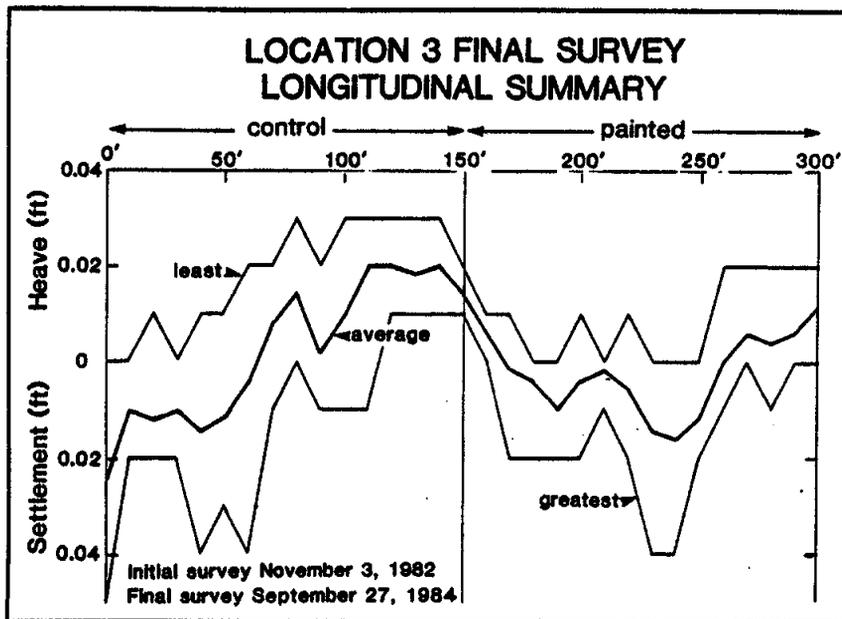


Figure 12

The settlement histories for sites 2 and 3 (Figures 8 & 11) show more frost heaving and less settlement than occurred at the Johnson Road site. The road at the Shaw Creek site has followed the current alignment for about 10 years. After this length of time, the soils there should be approaching a new thermal equilibrium, and a slower rate of thaw penetration and thus thaw settlement can be expected. The active layer at Shaw Creek is currently thicker than at Johnson Road. This may explain the greater frost heaving there. The total heaving would be greater with more soil to freeze, even if the percentage of heaving was the same.

The final summaries (Figures 9, 10, 12 and 13) show that while all movements have been small, the painted sections have settled less (or heaved more) by all means of comparison. Somewhat greater settlement has occurred to the right of centerline than to the left regardless of surface color. As was the case at Johnson Road, this may be due to greater solar exposure since the right shoulder at the Shaw Creek sites faces southwest while the left faces northeast. These small differences are difficult to see in the figures, despite the fact that the scale is larger than that on the figures for Johnson Road. The data have thus been summarized in Table 1.

TABLE 1

Settlement Summary, Shaw Creek Sites

	Settlement (hundredth of feet)		
	Left of Centerline	Right of Centerline	All Points
Location 2, Painted	0.393	0.929	0.557
Location 2, Control	1.333	1.500	1.373
Location 3, Painted	(0.286)	0.286	(0.357)
Location 3, Control	0.467	0.500	0.240

Note: Figures in parentheses indicate heave

There may be significant errors in the absolute elevations of the surveyed points, as previously stated. Within any single survey, however, the elevations of the points relative to each other should be quite accurate. This is because all of the points in a test section were surveyed without moving the surveying instrument. The result of this is that, while the amounts of settlement noted in the table may be in error, the difference in settlement between the painted and control sections at a given location should be quite accurate. At location 2, for example, the average settlement measured in the control section was about 0.008' more than in the painted section (0.0137' - 0.0056'). This difference is probably quite accurate despite the fact that the absolute settlement figures themselves may not be.

Canyon Creek Site:

The initial survey at the Canyon Creek site was made on the same date as the second surveys at the other sites, in April 1983. Further surveys were made on the same dates as at the Shaw Creek sites.

A comparison of the first and last surveys in Figures 15 & 16 shows only small elevation changes, as was the case at the Shaw Creek Sites.

In the first control section (the one with no peat underlay) these changes range from 0.06 feet of settlement to 0.03 feet of heave. The average of these changes was essentially zero (less than 0.001 foot of heave). The principal trend apparent is a small amount of heaving along centerline and slight settlement near the shoulders of the road.

In the second control section (with 5 feet of peat underlay), the range was from 0.08 feet of settlement to 0.02 feet of heave; the average was 0.023 feet of settlement. Again, settlement was greatest near the road shoulders and very slight heaving was noted along the road centerline. There is also a noticeable trend towards increasing settlement as the distance from the white test section becomes greater.

Elevation changes in the painted test section itself ranged between 0.02 feet of settlement and 0.05 feet of heave, with an average of 0.022 feet of heave. The longitudinal summary in Figure 15 shows that the average heave at each of the 10 foot stations within the painted section was

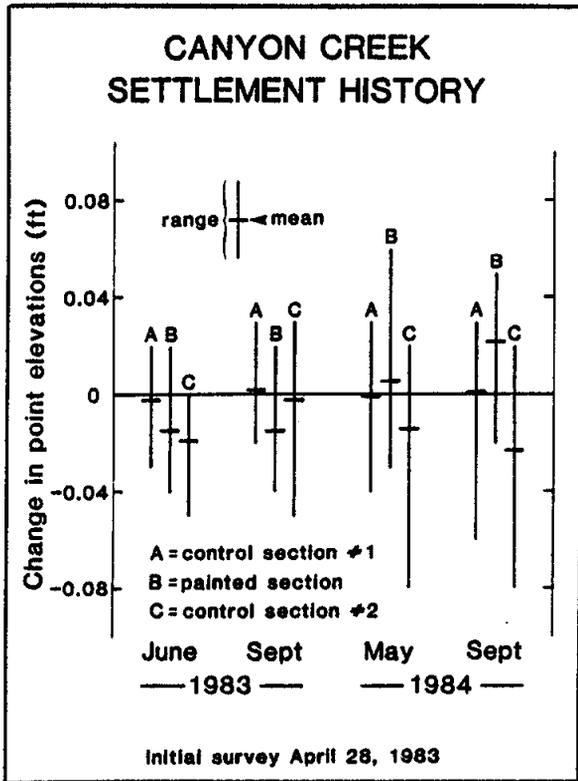


Figure 14

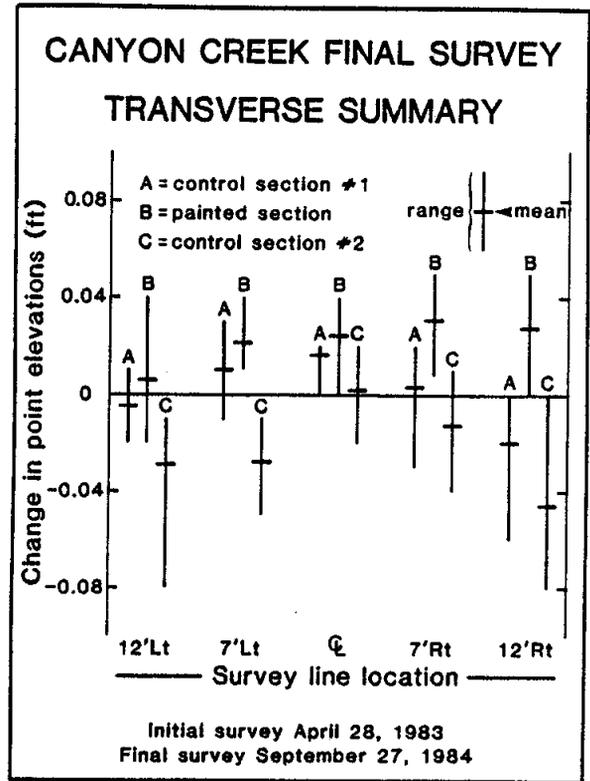


Figure 16

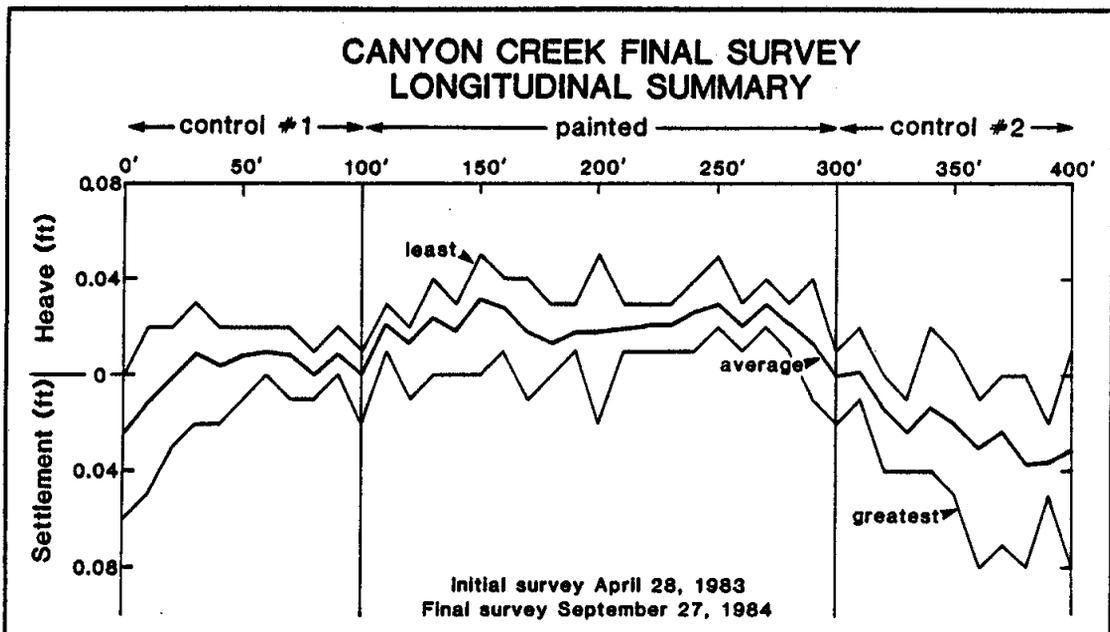


Figure 15

greater than the average at any of the stations in either control section. Similarly, the transverse summary (Figure 16) shows that the average heave along each of the five longitudinal lines was greater for the painted section than for the corresponding lines in either control section. The trend towards greater settlement at greater distance from centerline, noted above for both control sections, is true for the painted section only to the left of centerline. The surveys show a slight heave relative to centerline for points to the right of centerline within the painted section.

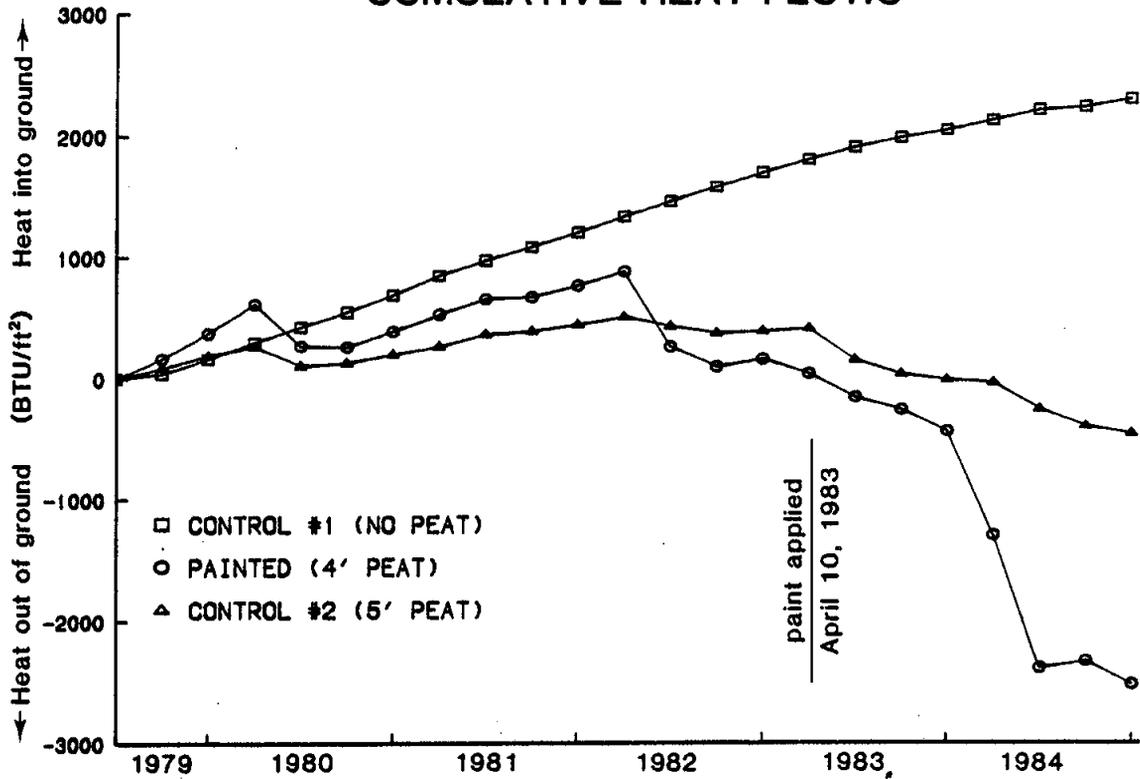
An established benchmark to one side of the Canyon Creek Site was used for the surveys there. Since no long traverses were required to perform the surveys, the accuracy of the settlement data for Canyon Creek is probably greater than at the Shaw Creek Sites.

Ground temperature data have been gathered from a number of thermocouple strings at the Canyon Creek Site since 1973. Three vertical thermocouple strings, located on the road centerline, are particularly useful for this study. One of these strings is located near the middle of each of the control sections and the painted section at the site. Vertical heat flows into and out of the underlying permafrost can be compared for the different sections by means of the temperature data. This had been done previously for the peat underlay study. The procedure is as follows:

Cumulative heat flows were estimated based on vertically spaced thermocouple pairs located within the permafrost, just below the depth of maximum thaw. Since the soil between thermocouples remained frozen, a constant conductivity of $2.1 \text{ W/m } ^\circ\text{K}$ ($1.21 \text{ Btu/hr-ft-}^\circ\text{F}$), estimated from known soil moisture and density conditions (Kersten 1949), was assumed for the analysis. Positive values indicate a net accumulation of heat going into the ground (net warming), while negative values indicate a net heat loss or net cooling (Ref. 8).

The resulting heat flows shown in Figure 17 are cumulative from July of 1979, almost four years before the paint was applied. The figure shows that control section #1 has been gaining heat at a very constant rate. The active layer has been getting deeper there, slowly but steadily, as a result. Control section #2 has been in approximate thermal equilibrium

CANYON CREEK TEST SITE CUMULATIVE HEAT FLOWS



Note: This graph was prepared from temperature data measured at depths of approximately 12 to 14 feet below the road surface.

Figure 17

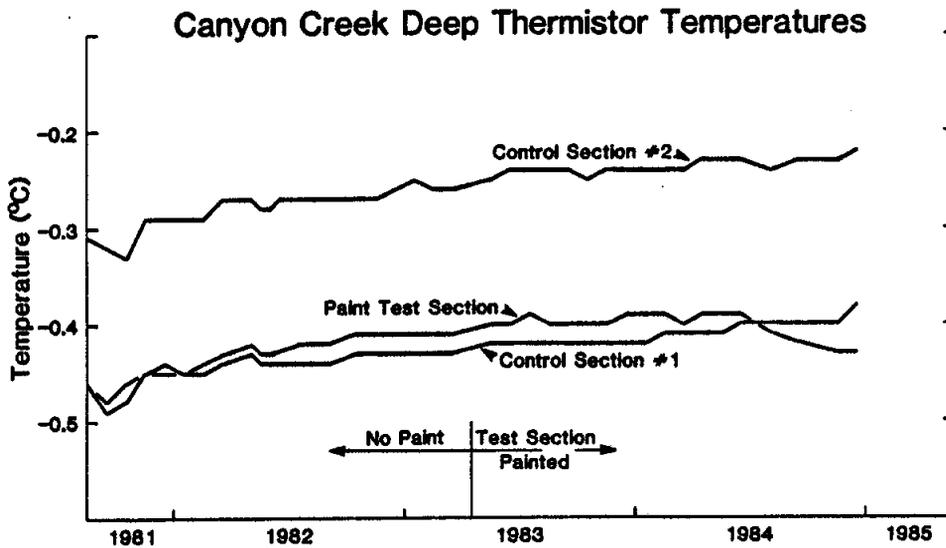


Figure 18

(cumulative heat flow fluctuates around zero). The painted section was also near equilibrium before the paint was applied. The figure clearly shows a dramatic loss of heat, however, after the paint was applied. The time lag between the date of painting and when its effects could be noticed at depth is clear in the figure.

The flow of heat in a situation like this - changing a moist soil from a temperature just above freezing to one just below - acts almost entirely to change the moisture from a liquid to a solid (latent heat change); very little is seen as a change in the sensible heat of the soil and moisture. The cumulative cooling beneath the test section since the paint was applied is sufficient to have frozen about 17 pounds of water per square foot. If soil moisture were 20%, this implies that the top of permafrost would have risen about a foot (40% moisture similarly implies a rise of about half a foot). Thermocouple data indicates that maximum annual thaw depths have experienced a reduction of about this magnitude. Since the thermocouples are spaced one foot apart at these depths, however, a precise determination of thaw depth reduction is not possible.

Figure 18 illustrates temperature data from thermistors located at the bottom of the thermocouple strings, almost 30 feet below the road surface. This too shows the cooling influence of the white paint. Prior to paint application, the temperatures in all three sections showed a slow warming trend. This has continued in the two control sections. This trend has apparently been reversed, however, in the painted section after a time lag of somewhere between 8 and 14 months. Longer term data would be useful to see if temperatures beneath the white-painted section continue to fall.

Discussion of Results:

To analyze whether differences in average settlement between painted and control sections at each test site could have been a result of pure chance, statistical analyses of variance (ANOVA tests) were made on the data. At each of the four test sites the ANOVA test results indicate there is more than a 99% confidence level that chance was not responsible for the settlement differences. Similar tests were run for the data along incidental longitudinal lines (centerline points, 7 foot right points,

etc.). For each of these lines the confidence level that chance was not responsible for settlement differences was at least 90% (for most of them it was more than 99%).

The painted section at location 7 (on Johnson Road) settled an average of 40% less than the control section during the 10 month test period. Major leveling and patching was needed, despite the paint, less than a year after road construction was completed. The embankment and the silt layer are both relatively thin at location 7. The ground there is likely to thaw to the level of thaw-stable gravels whether or not the pavement is painted. Thaw settlement should stop when that happens. The white paint in this case would not reduce the total amount of settlement, but merely slow it down. By doing so, the use of paint might increase long-term maintenance costs, even if one ignores the cost of painting itself.

In situations like this, where ice-rich soils are limited to a shallow surface layer, a better strategy for reducing thaw-settlement maintenance costs would be to "pre-thaw" the site, to withhold paving for a few years after construction, or both. Another, more expensive option is to subexcavate the ice-rich material.

Pre-thawing may be accomplished by means as simple as clearing the site of vegetation well in advance of construction. As previously discussed, part of location 8, a few hundred feet from location 7, crossed an old telephone line clearing. The ground there was thawed down to stable gravels. While this ruined location 8 as a test site for this study, it is a good demonstration of the results of clearing land. The concept of pre-thawing, along with results of tests, are more fully discussed in reference 9.

If ice-rich soils are deep enough, the thawing induced by road construction will not penetrate to stable soils. Instead, a thaw bulb will grow, with accompanying ground settlement, until a thermal equilibrium is reached. Since this stable thaw bulb will be smaller beneath a painted road than an unpainted one, painting may lessen the ultimate amount of settlement in such cases.

This may be what is occurring at the Shaw Creek Test Sites, locations 2 and 3. Data to date indicates an average settlement in the painted sections of 0.001 feet since the paint was first applied, compared with

0.008 feet for the control sections. The thaw bulbs beneath the painted sections may therefore, be relatively stable now, while they continue to grow beneath the control sections. Given the accuracy of the surveys and the magnitude of the measured settlement, this hypothesis cannot be considered proven, however. Continued painting, surveying, and perhaps additional drilling at the sites in future years will be necessary to verify this.

The availability of temperature data at Canyon Creek allows conclusions to be drawn with greater confidence for that site. The heat flow computations summarized in Figure 17 show a dramatic loss of heat from the ground below the white paint since it was first applied. The thaw bulb at this location is apparently shrinking; this rise in the permafrost table may account for the average heave in the section revealed in the surveys. Had the paint been applied a few years earlier, the ground which is now refreezing might never have thawed, and both the present heaving and some previous settling might never have occurred.

As the previous discussion shows, painting roads will prevent some thaw settlement in areas where ice-rich soils are deeper, than the stable thaw bulb beneath a white surface. The depth of such a thaw bulb depends on many factors, but a principal one is climate. The experience at Thule, Greenland, shows maximum thaw depths of only 4 or 5 feet beneath a white pavement in that arctic climate (ref. 1, 2). This project's data indicate deeper thaws in interior Alaska's subarctic climate, as could be expected. At Canyon Creek, it appears that maximum thaw depth beneath a painted pavement will stabilize at 6 to 8 feet of which the first 4 to 5 are gravel and the remainder peat. At Shaw Creek, if one assumes the thaw bulb has stabilized beneath the painted sections, it appears that the maximum thaw will penetrate about 7 feet of gravel plus 3 or 4 feet of wet silt and organics. Longer-term data, as previously stated, is needed to confirm this.

Skid Resistance

Painted pavements provide less skid resistance than unpainted pavements. This is a safety problem which may dictate against using painted pavement as a maintenance tool. It is, of course, most serious where traction is needed the most, e.g., on curves, steep grades, and areas with heavy traffic.

Anderson and Henry (ref. 10) made laboratory and field measurements of wet pavement friction on various marking materials. Their field data indicate that friction is about 30%-40% greater for unpainted pavement than for pavement marked with alkyd traffic paint (which is used by DOT&PF). As stopping distances are inversely proportional to friction coefficients, this indicates that stopping distances on paint are about 30%-40% greater on painted than on unpainted pavements during wet weather.

DOT&PF Research Section performed similar friction testing during dry summer weather on painted and unpainted pavements. These tests indicated stopping distances were about 20% greater on the painted pavement during dry weather. These figures indicate a serious problem, but there is yet another skid resistance problem with white paint. Frost will form on white pavements and snowfall will stick on them sooner than on unpainted pavements. This is a direct result of the cooler surface temperatures on the lighter colored pavement. This effect has been observed several times on this study's test sections. The result was patches of very slippery road on the painted test sections in what was otherwise a wet, but not very slick, road. This is potentially a serious safety problem, similar to the localized icing on some bridge decks.

Costs

White traffic paint was applied on the test sections in accordance with state specifications, with the exception that reflective glass beads were not required. Paint was applied during the study by two private contractors and by DOT&PF crews. The cost of the work from the private contractors was about \$3.00 per square yard, not counting travel time and mobilization. The same work cost about \$2.50 per square yard when state crews were used.

Prices would be less if the paint were applied on a large scale. Assuming that an oil distributor truck or similar equipment could apply the paint, costs might be only half what they were for the study, i.e., \$1.25 to \$1.50 per square yard. Costs could not go much lower than this, however, as the materials cost alone (paint, thinner, and incidentals) cost over \$1.00 per square yard for the study.

At \$1.25 per square yard it would cost over \$26,000 to paint a mile of 36-foot-wide road. If painting was needed every third year, the annual cost would be nearly \$9,000 per mile. If this painting reduced maintenance costs due to thaw settlement by 60% - an optimistic estimate - it would thus appear to be economically justified only in areas where thaw settlement repairs cost at least \$15,000 per mile annually.

Road maintenance costs are compiled by the DOT&PF in several categories. One of these is "surface maintenance" costs, which for a paved road is basically leveling and patching costs. A recent study of these costs (ref. 11) showed that surface maintenance costs, averaged over several years, did not exceed \$15,000 for any mile of any major two-laned alaskan highway except in urban areas.

It thus seems clear even from this simple analysis that painting roads to control thaw settlement will not be economically attractive on a large scale in Alaska. At best, this technique might prove worthwhile on isolated trouble spots.

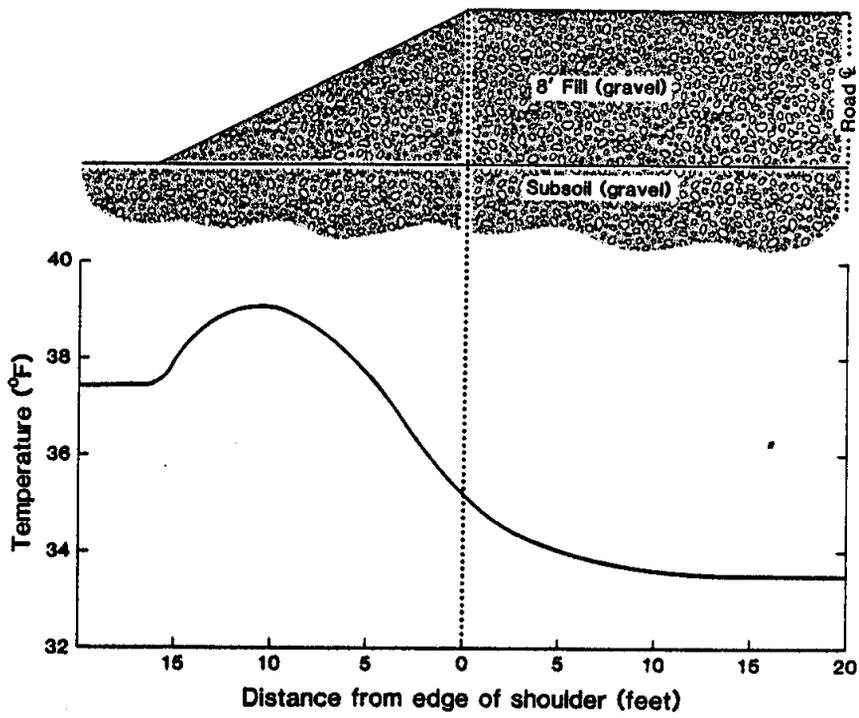
Edge Effects

Much of the heat which thaws permafrost beneath roadways enters the ground not through the pavement but through the unpaved side slopes of the embankment. This heat, as it diffuses into the ground, will affect the temperature of the ground for some distance in from the edge of the pavement. As a result, thawing and settlement may occur near the shoulders of the road even if the white paint is effective enough to prevent it along the road centerline.

The data from all of the test sites illustrate this point. The transverse summaries (Figures 7, 10, 13 and 16) generally show greater average settlement along both outside survey lines than along centerline. There are two exceptions to this: one of the four painted sections (Canyon Creek) and one of the five control section (location 7). In both of these cases the centerline has settled slightly more than one of the outside survey lines, but less than the other.

An analysis of this edge effect was made using the "Finite Element Heat Conduction Program" of Dow Chemical (ref 12). Air temperature input to this computer model was a sinusoidal approximation of annual temperatures in Fairbanks. A two-foot snow cover was modeled on the road shoulders between October 15 and April 15 (the road surface was modeled as bare year-round). After cycling the model through several years, temperatures at the bottom of the 8-foot gravel fill were computed for late October; the results are shown in Figure 19.

Subsurface Temperature: Computer Model Results

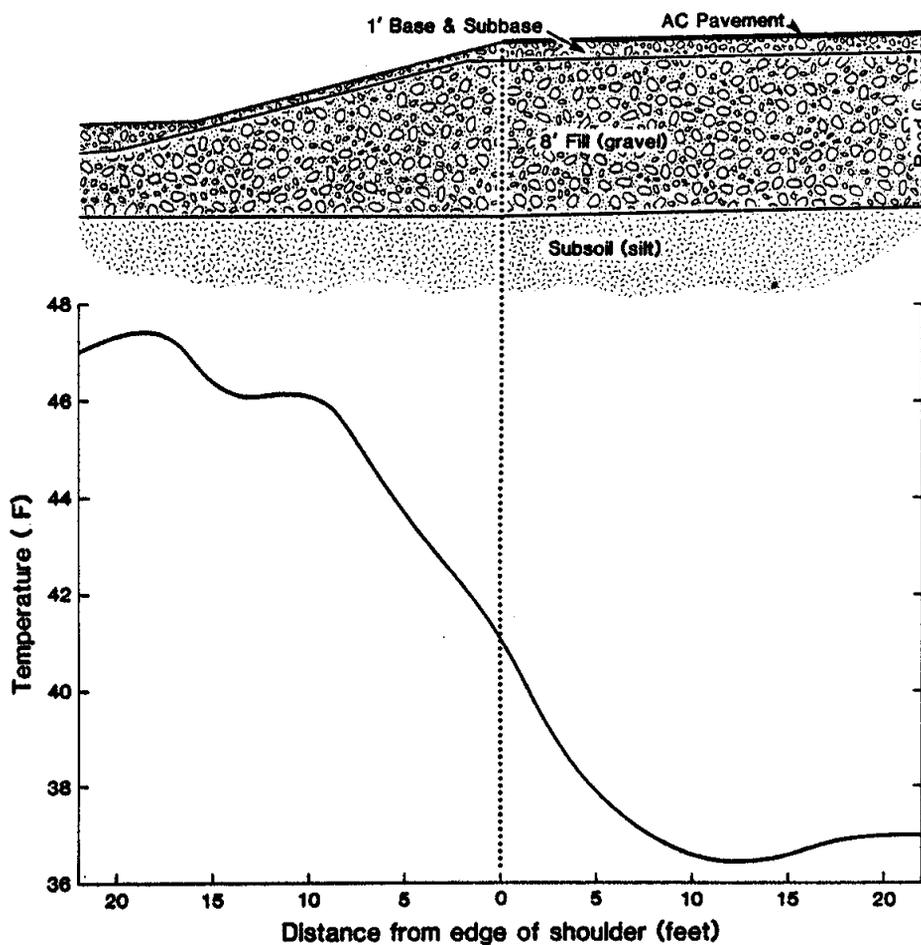


Notes: Temperatures were calculated for top of subsoil in late October.
Air temperatures approximated Fairbanks, Alaska weather.
Ground temperature at depth assumed to be 34°F.

Figure 19

Somewhat similar temperature data are available from field measurements at Canyon Creek. The horizontal thermocouple string beneath the painted test section has unfortunately been inoperative for several years. Data were available, however, for the horizontal strings beneath the control sections. Annual maximum temperatures recorded at the bottom of the gravel fill at control section #1 were averaged for the past five years; the results are shown in Figure 20.

Subsurface Temperature: Field Measurements at Canyon Creek Control Section #1



Notes: Temperatures were measured at top of subsoil.
Data are averages of annual maximums 1980-1984.

Figure 20

Both the field and the computer-generated data show temperature "edge effects" extending about 10 or 12 feet inside of the shoulder at about an 8 foot depth below the pavement.

The effect of white paint does not figure in either set of results. Temperatures beneath the road centerline would be lower if paint had been used, as this reduces heat input to the road surface. Heat input from the side slopes and surrounding ground, however, would remain the same. Thus one would expect the edge effects to be more pronounced, and to extend further, beneath a painted surface than beneath an unpainted one.

These results would be of less significance if the edge effects extended only beneath the shoulder of a road. Shoulders on Alaska's rural highways rarely exceed 8 feet, however, and are often less. Edge effects, then, are likely to detract from the effectiveness of white paint within the driving lanes.

This contrasts with the conditions at a painted runway, because of the difference in widths. The pavement at the airport in Barrow, for example, is 150 feet wide (part of the length of that runway was painted during the summer of 1984). If edge effects there to extend 15 feet into the painted area, only 20% of the pavement would be affected. The same edge effects on a 40 foot wide road, however, would affect 75% of the surface.

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