# REPORT DOCUMENTATION PAGE

*OMB No. 0704-0188*

**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
September 1989

**3. REPORT TYPE AND DATES COVERED**
Final Report

**4. TITLE AND SUBTITLE**
Cost-Effectiveness of Geotextiles
Review of Performance in Alaskan Roads

**5. FUNDING NUMBERS**
PR-HPR 86-7

**6. AUTHOR(S)**
Matthew K. Reckard, P.E.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Alaska Department of Transportation
and Public Facilities
Statewide Research Section
2301 Peger Road Fairbanks, AK 99709-6394

**8. PERFORMING ORGANIZATION REPORT NUMBER**
FHWA-AK-RD-90-04

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Same as above

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
FHWA-AK-RD-90-04

**11. SUPPLEMENTARY NOTES**
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

The Alaska Department of Transportation and Public Facilities installed over four million square yards of geotextiles in road embankments between 1978 and 1989. The report describes the results of a project to study the effectiveness of these installations at improving road performance. Northern Region design staff initiated the project because they were concerned with the adequacy of design theory and saw a need for field verification under Alaskan conditions.

Work included research of project records, field installation location and inspection, mapping of pavement cracks and patches, determination of thermal crack spacing, survey and excavations of installations, and interviews with construction and maintenance personnel. The report concludes that while designers correctly identified problem areas of roadways for treatment, the geotextile installations have generally been ineffective in reducing long-term roadway distress. Most installations have incorporated one or two layers of relatively low-strength fabric; site-specific designs using more and stronger materials are likely to be of more benefit.

A lack of adequate control sections and the short life to date of most installations made the evaluation difficult. Continued observation of some sites, especially some more recent ones built with more scientific controls and design methods, is recommended.

**14. SUBJECT TERMS**
Geotextiles, slope stabilization, thaw settlement, thermal cracking, pavement fatigue, rutting

**15. NUMBER OF PAGES**
55

**16. PRICE CODE**

**17. SECURITY CLASSIFICATION OF REPORT**
UNCLASSIFIED

**18. SECURITY CLASSIFICATION OF THIS PAGE**
UNCLASSIFIED

**19. SECURITY CLASSIFICATION OF ABSTRACT**
UNCLASSIFIED

**20. LIMITATION OF ABSTRACT**
SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

# COST-EFFECTIVENESS OF GEOTEXTILES

## Review of Performance in Alaskan Roads

Final Report

Matthew Reckard, P.E.
Senior Research Engineer
State of Alaska
Department of Transportation and Public Facilities
Statewide Research

September 1989
Revised February 1991

Prepared for

State of Alaska
Department of Transportation and Public Facilities
Statewide Research M/S 2554
2301 Peger Road
Fairbanks, Alaska 99701

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

Production Cost: $6.00

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PHOTOS

## INTRODUCTION

The Northern Region of the Alaska Department of Transportation and Public Facilities (DOT&PF) began using geotextiles in road construction in 1978. 9332 square yards of "Subgrade Stabilization Fabric" were installed that year beneath a 6" thick gravel base course on sections of the Phillips Field Road prior to the placement of a 1 1/2" hot asphalt pavement. The road sections treated with geotextile had exhibited softness in the pre-existing gravel surface during spring thaws.

Contracts awarded in the Northern Region included about 23,000 square yards of geotextiles in 1980. About 90% of this was used on the New Point Hope Road, a remote unpaved road.

In the following years the use of "filter cloth," "separation geotextile," and "reinforcement geotextile" in roadways grew extremely rapidly, and by 1983 contract amounts exceeded a million square yards. Geotextile use remained high for several years; over 500,000 square yards were specified for a single project in 1986. DOT&PF's Northern Region had invested almost five million dollars in roadway geotextiles by the end of 1989. This geotextile use is summarized in Table 1 and detailed in Table 2.

1983 seems to have been a peak year for geotextile use. A declining trend generally appears thereafter. Excluding the Delong Mountain Road (discussed below) geotextile use totalled just over 250,000 square yards in 1987. 1988 contracts included under 70,000 square yards on two roadway projects.

The quantity of geotextiles used in roadways increased again in 1989, although they were used on only two projects as of late August. The material used on both projects was much heavier than was typical in previous years. Almost 300,000 square yards were used on a single project on the Tok Cutoff. It has yet to be seen if this increased use in heavy geotextiles is a new trend.

The Delong Mountain Road project, begun in 1987, included almost 1.4 million square yards of geotextiles. This road leads from the Red Dog Mine in northwest Alaska to the Bering Sea coast. Although the road was state financed and the construction was supervised by the DOT&PF, it was not designed by the department and is not considered part of the state highway system. The Delong Mountain Road project is not included in Tables 1 and 2.

## TABLE 1.

## GEOTEXTILE HIGHWAY USE SUMMARY ALASKA DOT&PF NORTHERN REGION

| YEAR | NUMBER OF PROJECTS | QUANTITY ($YD^2$) | TOTAL COST ($) | AVERAGE PRICE ($\$/yd^2$) |
|---|---|---|---|---|
| 1977 | 1 | 9,332 | 13,065 | 1.40 |
| 1978 | 2 | 13,700 | 28,250 | 2.06 |
| 1979 | 0 | 0 | - | - |
| 1980 | 3 | 23,137 | 45,631 | 1.97 |
| 1981 | 6 | 55,422 | 69,221 | 1.25 |
| 1982 | 16 | 275,137 | 309,892 | 1.13 |
| 1983 | 10 | 1,167,261 | 1,423,190 | 1.22 |
| 1984 | 12 | 425,271 | 455,233 | 1.07 |
| 1985 | 10 | 514,163 | 567,270 | 1.10 |
| 1986 | 7 | 941,834 | 755,419 | 0.80 |
| 1987[1] | 8 | 256,371 | 239,607 | 0.93 |
| 1988 | 2 | 69,696 | 60,249 | 0.86 |
| 1989[2] | 2 | 348,112 | 928,703 | 2.69 |
| TOTALS: | 79 | 4,099,436 | 4,895,730 | 1.19 |

[1] Geotextiles for the Delong Mountain Road are not included (see text)

[2] As of late August; impermeable membranes for Tok Cutoff M. 0 to 30 are not included in the figures

## TABLE 2: GEOTEXTILE QUANTITIES AND COSTS BY YEAR AND PROJECT FOR USE IN ROAD EMBANKMENTS, ALASKA DOT&PF NORTHERN REGION

| YEAR | BID ITEM | PROJECT TITLE | | QUANTITY SQ YDS | BID PRICE $/YD$^2$ | COST $ |
|---|---|---|---|---|---|---|
| 1977 | 638(1) | Phillips Field Road | | 9,332 | @ 1.40 | 13,065 |
| 1978 | 638(1) | Chena Hot Springs Road | | 7,700 | @ 2.50 | 19,250 |
| | 638(1) | Chena Pump Bike Path | | 6,000 | @ 1.50 | 9,000 |
| | | | TOTALS | 13,700 | @ 2.06/avg | 28,250 |
| 1979 | | NONE | | | | |
| 1980 | 638(1) | Central Road | | 367 | @ 2.00 | 734 |
| | 638(1) | Peger-Van Horn-South Cushman | | 1,285 | @ 1.50 | 1,927 |
| | 638(1) | New Point Hope Road | | 21,485 | @ 2.00 | 42,970 |
| | | | TOTALS | 23,137 | @ 1.97/avg | 45,631 |
| 1981 | 638(1) | Dawson, Easy, & Newby Roads | | 9,176 | @ 1.50 | 13,764 |
| | 638(1) | Sth Peger, Cartwright, & Alston | | 26,400 | @ 0.80 | 21,120 |
| | 638(1) | Tanana to RCA Site | | 15,660 | @ 1.75 | 27,405 |
| | 207(3) | A Street, Nenana | | 366 | @ 2.00 | 732 |
| | 207(3) | Mountain View - Skylane Drive | | 940 | @ 2.00 | 1,880 |
| | 207(3) | McGrath Road | | 2,880 | @ 1.30 | 4,320 |
| | | | TOTALS | 55,422 | @ 1.25/avg | 69,221 |
| 1982 | 207(3) | Gambell - Savoonga Road | | 6,940 | @ 1.50 | 10,410 |
| | 207(3) | Johnson Road | | 31,754 | @ 1.00 | 31,754 |
| | 207(3) | Ski Boot Hill Road | | 1,011 | @ 1.15 | 1,163 |
| | 207(3) | City Lights Blvd. & Peters Road | | 2,318 | @ 2.25 | 5,216 |
| | 207(3) | Gilmore Trail | | 2,227 | @ 1.60 | 3,563 |
| | 207(3) | Nome Creek Road | | 667 | @ 2.00 | 1,334 |
| | 638(2) | Delta - Nistler Road | | 10,631 | @ 1.00 | 9,500 |
| | 207(3) | Bradway Road | | 15,050 | @ 1.40 | 21,070 |
| | 638(1) | Northway Road | | 14,000 | @ 1.40 | 17,500 |
| | 207(3) | Persinger Road | | 27,750 | @ 1.25 | 36,688 |
| | 638(1) | Steese Hwy-Central to Circle | | 83,650 | @ 1.00 | 83,650 |
| | 638(1) | Richardson-Sourdough to 7M North | | 8,000 | @ 2.00 | 16,000 |
| | 207(3) | Skyridge Drive | | 905 | @ 2.00 | 1,810 |
| | 207(3) | Sheep Creek-Goldstream Road | | 29,234 | @ 1.00 | 29,234 |
| | 638(1) | College Road Recycle | | 22,000 | @ 1.00 | 22,000 |
| | 207(3) | Harding Lake Road Overlay | | 19,000 | @ 1.00 | 19,000 |
| | | | TOTALS | 275,137 | @ 1.13/avg | 309,892 |

## TABLE 2 CONT.: GEOTEXTILE QUANTITIES AND COSTS BY YEAR AND PROJECT FOR USE IN ROAD EMBANKMENTS, ALASKA DOT&PF NORTHERN REGION

| YEAR | BID ITEM | PROJECT TITLE | | QUANTITY SQ YDS | BID PRICE $/YD$^2$ | COST $ |
|---|---|---|---|---|---|---|
| 1983 | 207(3) | Alaska Hwy - Border to 1235 | | 271,880 | @ 1.12 | $ 304,505 |
| | 207(3) | Wiseman to Nolan | | 13,545 | @ 1.75 | 23,704 |
| | 638(2) | Tok Cutoff 30-38 & 52-91 | | 160,200 | @ 2.00 | 320,400 |
| | 207(3) | Pilgrim Hot Springs Access | | 28,200 | @ 1.50 | 42,300 |
| | 207(3) | Pedro Dome & Skiland Road | | 3,000 | @ 1.25 | 3,750 |
| | 207(3) | Persinger Drive & Keeling Road | | 4,000 | @ 1.07 | 4,280 |
| | 638(1) | Parks Hwy - Rex to McKinley | | 282,400 | @ 0.94 | 265,456 |
| | 207(3) | Nome City Streets | | 3,636 | @ 1.25 | 4,545 |
| | 638(1) | Central to Circle-spot repairs | | 185,000 | @ 1.00 | 185,000 |
| | 638(1) | Richardson Resurfacing 125-207 | | 215,400 | @ 1.25 | 269,250 |
| | | | TOTALS | 1,167,261 | @ 1.22/avg | 1,423,190 |
| 1984 | 207(3) | Richardson Hwy Overlay | | 19,198 | @ 1.00 | 19,198 |
| | 207(3) | Ravenwood Road | | 3,583 | @ 1.48 | 5,303 |
| | 207(3) | Tok Cutoff 38 to 52.1 | | 20,000 | @ 1.00 | 20,000 |
| | 207(3) | Glenn Hwy Rehab 138-189 | | 20,400 | @ 1.00 | 20,400 |
| | 207(3) | Alaska Hwy, Tanana-Tok | | 97,812 | @ 1.07 | 104,659 |
| | 207(3) | Richardson-Boondox-Canyon Creek | | 118,320 | @ 1.00 | 118,320 |
| | 207(4) | Parks Hwy-Airport to Peger | | 25,000 | @ 1,00 | 25,000 |
| | 638(1) | Dexter to Banner Creek-Grading | | 7,650 | @ 2.00 | 15,300 |
| | 638(1) | Gilmore Trail | | 16,103 | @ 1.50 | 24,155 |
| | 638(1) | Central Dust Control-Phase III | | 14,200 | @ 1.25 | 17,750 |
| | 638(1) | Nome-Council MP 3-14 | | 15,620 | @ 2.00 | 31,240 |
| | 638(1) | Steese Hwy, Central/Circle III | | 67,385 | @ 0.80 | 53,908 |
| | | | TOTALS | 425,271 | @ 1.07/avg | 455,233 |
| 1985 | 207(3) | Ballaine Rd-Bike Trail | | 8,815 | @ 1.30 | 11,460 |
| | 638(1) | Fairbanks Dist Repair & Maint | | 4,088 | @ 2.00 | 8,176 |
| | 628(1A)[1] | Nenana South | | 4,670 | @ 2.00 | 9,340 |
| | 638(1)[2] | Nenana South | | 10,300 | @ 3.00 | 30,900 |
| | 638(1) | Elliot Hwy, Fox to Mile 7 | | 34,800 | @ 1.00 | 34,800 |
| | 638(2) | Parks-Little Coal Crk/M.Fork | | 39,700 | @ 2.00 | 79,400 |
| | 638(1) | AK Hwy-Dot Lake-Robertson River | | 56,290 | @ 1.10 | 61,919 |
| | 638(2) | Nenana South | | 257,850 | @ 1.00 | 257,850 |
| | 638(1) | Hurst Road Extension | | 150 | @ 2.00 | 300 |
| | 638(1) | Parks Hwy Rehab/Climbing Lane | | 97,500 | @ 0.75 | 73,125 |
| | | | TOTALS | 514,163 | @ 1.10/avg | 567,270 |

[1] Specified as "Heavy Duty Geotextile"

[2] Specified as "Geogrid"

## TABLE 2 CONT.: GEOTEXTILE QUANTITIES AND COSTS BY YEAR AND PROJECT FOR USE IN ROAD EMBANKMENTS IN ALASKA DOT&PF NORTHERN REGION

| YEAR | BID ITEM | PROJECT TITLE | | QUANTITY SQ YDS | BID PRICE $\$/YD^2$ | COST $ |
|---|---|---|---|---|---|---|
| 1986 | 638(1) | Richardson Mile 25 to 35 | | 7,389 | @ 1.30 | 9,606 |
| | 638(1) | Nome-Taylor Hwy 13 to 21 | | 11,334 | @ 1.50 | 17,001 |
| | 638(1A)[1] | Parks - Mile 325 to Ester | | 38,225 | @ 2.00 | 76,450 |
| | 638(1) | Parks-McKinley V. to Dragonfly | | 47,000 | @ 0.70 | 32,900 |
| | 638(1) | Edgerton Hwy Rehab | | 231,422 | @ 0.50 | 115,711 |
| | 638(2) | Richardson Hwy. Mile 129-148 | | 513,564 | @ 0.80 | 410,851 |
| | 638(2) | Parks-Mile 325 to Ester | | 92,900 | @ 1.00 | 92,900 |
| | | | TOTALS | 941,834 | @ 0.80/avg | 755,419 |
| 1987[2] | 207(3) | Richardson Hwy. Mile 100-106 | | 90,899 | @ 1.00 | 90,899 |
| | | Taylor Highway Mile 43 to 66 | | 9,500 | @ 0.90 | 8,550 |
| | | Denali Highway Mile 0 to 21 | | 30,840 | @ 0.70 | 21,588 |
| | 638(1) | Cushman/Van Horn Intersection | | 6,324 | @ 1.00 | 6,324 |
| | 638(1) | Parks Hwy, Peger To Rich Hwy | | 40,473 | @ 1.00 | 40,473 |
| | 638(2) | Northway Village Roads | | 1,900 | @ 3.10 | 5,890 |
| | 638(2) | Richardson Hwy Upgrade, Phase II | | 35,172 | @ 0.70 | 24,620 |
| | 638(2) | Peger Rd to College Connector | | 41,263 | @ 1.00 | 41,263 |
| | | | TOTALS | 256,371 | @ 0.93/avg | 239,607 |
| 1988 | 638(1) | 23rd Avenue Extension | | 24,770 | @ 0.80 | 19,816 |
| | 638(1) | Tok Cutoff Mile 65 to 75 | | 44,926 | @ 0.90 | 40,433 |
| | | | TOTALS | 69,696 | @ 0.86/avg | 60,249 |
| 1989[3] | 638(2) | Tok Cutoff Mile 0 to 30* | | 292,112 | @ 2.70 | 788,703 |
| | | Alaska Hwy. Johnson R to Dot Lake* | | 56,000 | @ 2.50 | 140,000 |
| | | | TOTALS | 348,112 | @ 2.69/avg | 928,703 |

[1] Specified as "Heavy Duty Reinforcement Geotextile" or "Heavy Duty Geosynthetic"

[2] Geotextiles for the Delong Mountain Road are not included for 1987 in this table (see text).

[3] As of late August; does not include 10,000 SY of impermeable membrane used on Tok Cutoff under bid item 638(2).

Soil conditions which are unusual in other states - notably permafrost - cause chronic and expensive road maintenance problems in Alaska. A comparison of the Tok Cutoff Highway and the southern part of the Parks Highway illustrates this. Both are two-lane, largely rural Alaskan roads; the Parks carries several times as much traffic as the Tok Cutoff. Much of the Tok Cutoff lies on thaw sensitive permafrost, however, while the southern Parks does not. Patching, leveling and related surface maintenance costs have been more than four times as great for the former as for the latter (Reckard, 1983).

Much of DOT&PF's geotextile use in the mid-1980's was intended to improve road performance in areas with bad foundation conditions. Geotextiles were specified for new roads and road reconstruction areas where problem soils were present or suspected. They were placed as separators between soils containing fines and cleaner fill materials. They were also used where pavement structures were known to be inadequate, or where problems such as frost heaving or surface settlement from permafrost thawing were contributing to road roughness.

Established design procedures did not always adequately address the desired geotextile applications, especially those for unique Alaskan conditions. Separators, for example, were often desired due to the frequent occurrence of silty and/or organic subgrades kept saturated by the impermeability of underlying permafrost. Such soils are subject to liquefaction under dynamic loads, and are "pumped" upwards where they contaminate granular fill material. The FHWA's Geotextile Engineering Manual, however, points out that "the actual magnitude of the applied load necessary to initiate liquefaction is not well defined" and that "it is difficult to characterize soils susceptible to liquefaction" (Christopher and Holtz, 1985).

The designs thus often relied substantially on engineering judgement. This was often influenced by the relatively low cost of geotextiles and the impression that they "had to help" reduce roadway problems. If one layer did not appear to be adequate, two or three layers were specified.

In 1985 a team of Design Managers wrote that "the use of geotextiles ... has expanded ... perhaps faster than our knowledge of the physical and cost effectiveness of their use." They proposed a study of the benefits of geotextiles through the examination of road sections where they had already been installed. This report covers the results of that study.

It was clear from the outset that there would be difficulties performing a field study in this way. The absence of good design theory for Alaskan conditions and firm criteria for determining when and how to include geotextiles in a roadway made it hard to judge what performance had been expected of the geotextiles. Furthermore, geotextiles had been installed without untreated control areas. Nearly all sections in the

Northern Region, moreover, were less than five years old, making it difficult to assess long-term benefits.

Various embankment failure modes were considered and the possible roles of reinforcement geotextiles in reducing or eliminating these failures were discussed with designers and others. A series of possible field evaluation methods were considered before the final field observation procedures were selected by Research and Design staff. Field research studies began in 1986 and were completed early in 1988. Field work concentrated on older installations so that the longest term effects could be observed.

This study has resolved some questions, left others unresolved, and raised some new questions as discussed herein.

## EMBANKMENT DISTRESS MODES

Discussions with designers indicated that the specification of geotextiles during resurfacing, rehabilitation, and restoration (3R) projects was primarily aimed at reducing distress caused by the following:

1. Permafrost Foundation Thaw, Settlement & Ride Roughness
2. Lateral Spreading and Cracking of Embankments on Permafrost
3. Pavement Fatigue or "Alligator" Cracking
4. Pavement Rutting from Subgrade Deformation Under Wheel Loads

The first two of these are unique to cold climates. An explanation of these failure modes is offered below for those not familiar with Alaskan conditions:

### Permafrost Foundation Thaw & Settlement

Permafrost (soil which has remained frozen for more than two years) underlies much of the paved road system in Interior Alaska. In many permafrost areas the frozen ground contains discreet masses of nearly pure ice, which exist in the form of vertical wedges, horizontal lenses, and irregular masses (Photo 1). In other areas the permafrost may not have massive ice deposits but still contain much more moisture than the soil can retain after thawing. Upon thawing, ice masses simply disappear, leaving voids and irregular surface settlements known as "thermokarst" features. Soils with excess frozen moisture will also consolidate upon thawing, but settlements will generally be more uniform than when massive ice is present.

The construction of a roadway embankment over previously vegetated permafrost terrain increases the depths of annual freezing and thawing, as well as creating a slightly warmer mean annual surface temperature. The annual thaw depth beneath a new embankment surface in most of Interior Alaska typically ranges between 5 and 15 feet, compared to thaw depths between 1 and 4 feet for naturally vegetated permafrost areas. The increased thaw frequently reaches beneath the new embankment and progressively thaws and consolidates some of the permafrost foundation soils and subsurface ice deposits.

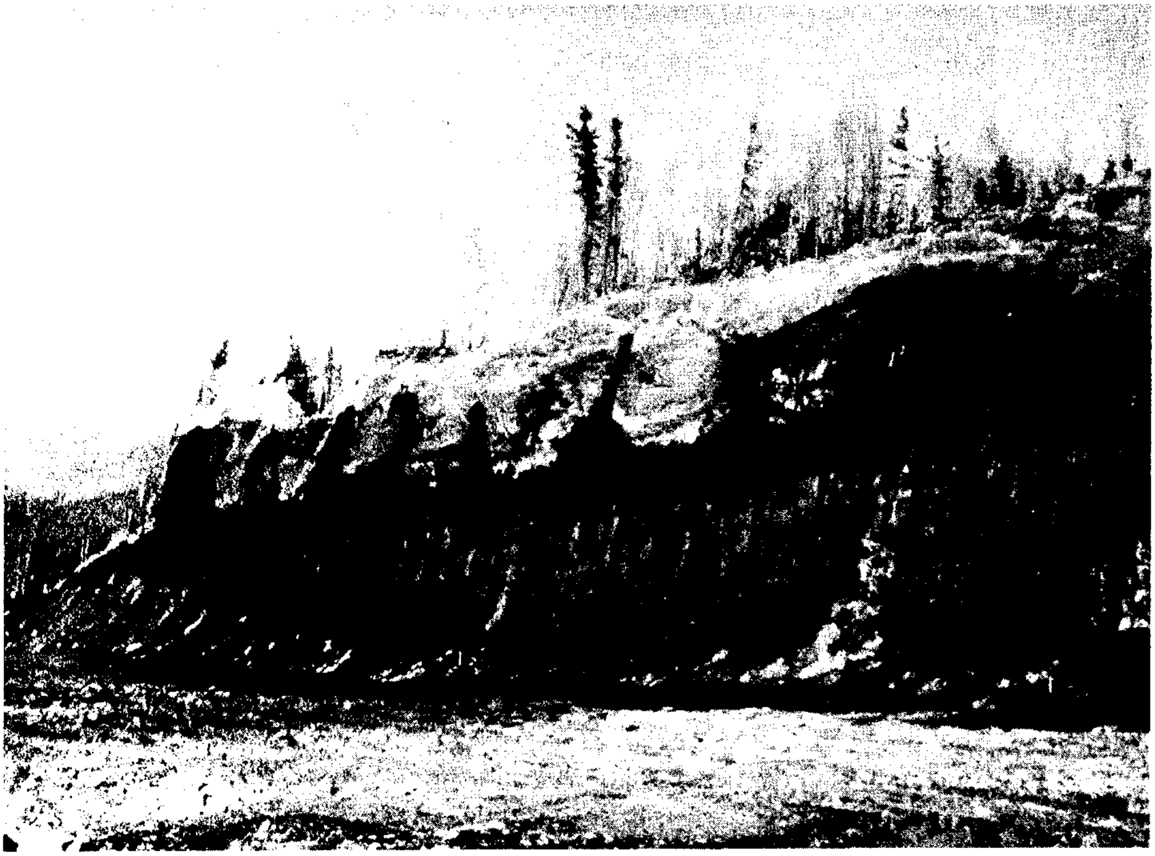


Photo 1. Massive ground ice in permafrost

The road surface roughness which develops (Photo 2) results in the need for frequent and costly road maintenance work to level the dips and to re-create a level surface. Under the worst permafrost conditions, maintenance may be required several times a

Photo 2. Road roughness resulting from thaw settlement

year and total repaving of the route every 5 to 8 years. Cost savings would obviously be large if differential settlements could be reduced or prevented by reinforcement with geotextiles.

## Lateral Spreading and Cracking

Embankment side slopes present a second type of thaw related stability problem. These slopes have been found to have much higher average annual surface temperatures than paved roadway or airfield surfaces. This is both because the slopes are typically insulated from wintertime cooling by snow cover and because they are exposed to and frequently inclined toward the summer sun.

Recorded temperature measurements of several roadway side slopes have indicated slope surface temperatures range from 3° to 9°F warmer than road surface temperatures on an average annual basis (Esch, 1988). This warming, coupled with the fact that the embankment thickness tapers to zero at the toes of the slopes, results in deeper thaw zones beneath the slopes than beneath the road surface. If permafrost moistures are excessive, the thawing results in greater consolidation beneath the slopes of the embankment than beneath its center. The result can be either slope failures (Figure 1) or lateral spreading and longitudinal cracking of the embankment (Figure 6b).

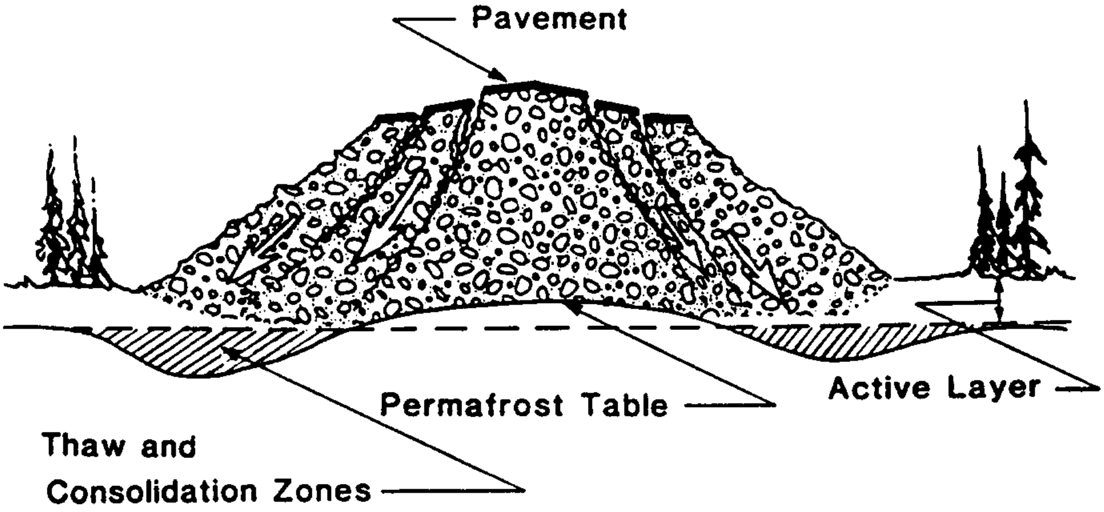


Figure 1. Roadway slope failures caused by thawing permafrost

Measurements of spreading at one roadway site near Fairbanks indicated total lateral extension of about 1.4 feet over an eight year period, for an average lateral strain rate of 0.62% annually. When the lateral strain reached 3% (5 years), the roadway surface began to crack excessively, and had to be reconditioned annually after that time to fill the developing cracks and ruts.

The potential for reducing maintenance costs from lateral spreading using a single very strong geotextile layer is under examination by the University of Alaska. Field trials, funded by the Alaska DOT&PF, are now under evaluation.

## GEOTEXTILES AS A CONSTRUCTION AID

In addition to the potential roles of geotextiles in reducing the distress of completed embankments, these materials can serve an important role during construction by providing reinforcement when starting embankment placement across soft muskegs or swamps. It is a curious feature of construction practice that equipment too large and heavy to be allowed on a completed roadway is used to place roadway foundation layers across soft and often unstable terrain. A single layer of geotextile reinforcement, properly chosen and installed, can almost double the wheel load bearing capacity of the initial lifts of fill when placed over very soft soils. The use of geotextiles in such situations can often reduce the requirements for expensive subexcavations.

As layers of fill are added and compacted, however, and as the foundation soils consolidate and gain strength, the wheel load bearing capacity becomes of less concern. Flexible pavement structures are designed on the basis of tolerable elastic deflections and accumulated strains. Factors of safety against single load bearing capacity failures are always very high after the embankment is completed and paved.

A reinforcement layer which allows fill placement and compaction may therefore be found to have no further purpose after the embankment has been completed and placed in service. This further complicates the post-construction evaluation of the benefits of geotextile use. It also suggests that the geotextile function must be evaluated separately for new construction and for reconstruction involving excavation and replacement within existing embankments.

## WORK ACCOMPLISHED DURING THE STUDY

Work for this study was performed in the following areas:

- The study's proposers were consulted about their design objectives, the performance characteristics that should be investigated, and the study methodology.

- Records research and compilation. Plans, specifications, geology report recommendations, and other information about geotextile use on Northern Region construction projects were gathered and reviewed. The study greatly benefited in this area from the efforts of Maury Bellville, who had already compiled much of this information for earlier projects.

- Field location and marking of geotextile locations. These locations are generally marked with paint on the pavement during the construction process. This marking was not done, however, on some projects. On others the original markings had been lost when the pavement was patched. Where markings were missing, the sections were located (often by making excavations into the road shoulder) and new paint markings were placed.

- Inspections of installations. Virtually all geotextile installations on paved roads in the Northern Region were inspected visually at least once during the course of the study. The general appearance and performance of the sections were noted and their suitability for more detailed investigation was considered.

- Cracks and patches both with and adjacent to geotextile sections were mapped. The sections were built without scientific controls. Mapping was therefore generally confined to a length of 200 feet to either side of the end of each geotextile section. It was hoped that within this distance soil and other conditions would be sufficiently similar to allow some valid performance comparisons to be made.

- Thermal crack spacing was determined both within and outside of geotextile sections. This crack counting was performed on a few projects over much greater areas than the mapping efforts mentioned above. This work was done in order to determine if the geotextiles affected the frequency of thermal cracking in the pavement.

- Settlement and spreading surveys were performed at a few sites. The sites selected were those where the conditions in untreated areas appeared similar enough to those in the geotextile sections to serve as adequate controls. Nails placed in the pavement were repeatedly surveyed to detect settling of the roadway; the distances between nails placed in a line across the road were repeatedly measured to detect spreading of the road surface.

- Excavations were made at selected sites to uncover the geotextiles and assess their performance. These excavations were in addition to those made to determine geotextile locations. They were generally made at crack sites to determine if the geotextiles remained intact.

- In situ permeability measurements were attempted on one project to try to determine if geotextiles "clogged" with fine material impeded the drainage of moisture. Excavations were made to expose the geotextile and modified percolation tests were performed both with the geotextile in place and with it removed.

- Interviews were conducted with many of the inspectors and engineers who had worked on projects where geotextiles were installed. These people were a source of a good deal of valuable, if usually subjective, information. The information regarding the geotextiles' usefulness during the construction process itself was particularly valuable.

The field work performed for the study is summarized by project in Table 3.

## OBSERVATIONS ON THE EFFECTS OF GEOTEXTILES

### Thermal Cracks

During early inspection trips for this study, it appeared that thermal cracks were spaced much further apart in some geotextile areas than in the adjacent roadway without geotextiles. This, indeed, was the only obvious difference in performance, although it had not been a primary design objective. Due to these early observations, thermal cracking was investigated in more detail.

Results of thermal crack spacing surveys are presented in Table 4. The first project surveyed (Parks Highway, Rex-McKinley) revealed that thermal cracks were spaced more than twice as far apart in geotextile sections as outside of them two years after construction. On the Parks Highway, Little Coal Creek-Middle Fork of Chulitna River project, almost no thermal cracks were found in geotextile areas one year after construction.

On both projects, however, the geotextile was not the only construction difference in the geotextile sections. On the Rex-McKinley project, there was a 2.5' grade raise in the geotextile areas but not elsewhere; on the other project the geotextile was placed in a 1.5' to 2' subcut, later backfilled.

The Dawson-Easy-Newby project in the North Pole area was therefore inspected next, as the geotextile itself was the only construction difference on that project. Five years after construction there was little difference in thermal crack spacing between the geotextile and untreated areas, as is seen in Table 4.

This seemed to indicate that grade raises and subcuts, rather than the geotextile, had affected the frequency of thermal cracks. It was hypothesized that cracks in an existing embankment might reflect quickly through a new surface, but that this process might be slowed by the grade raises or subcuts. This would explain why crack spacing on the Little Coal Creek-Middle Fork project (one year old) was much greater than that on Rex-McKinley (two years old). A follow-up survey on Rex-McKinley in 1987 supported this; more thermal cracks had appeared in the geotextile/grade raise areas in the intervening year, but not in the untreated areas. The spacing was still larger in the geotextile/grade raise areas than in untreated ones. It would be of

# TABLE 3

## GEOTEXTILE TESTING & INSPECTIONS: SUMMARY BY PROJECT

### PARKS HIGHWAY

1. Nenana - South FIR-1-OA4-4(2) - built in 1986
   Inspected July 29, 1987 (also 1986 after construction)
   2 Tensar sections are being surveyed/spread measurements as Experimental Feature AK 85-01

2. Rex-McKinley A-81061 - built in 1984
   Thermal crack counts October 13, 1987 and June 25, 1986
   Crack mapping, July 29, 1987 and June 25, 1986 (all 7 sites)

3. McKinley Village - Dragonfly Creek IR-OA4-3(4)/63369 - built 1987
   Full width patch noted in one area October 13, 1987

4. Nenana - North I-R-OA4-5(1) - built 1986
   Inspected Fall 1987

5. Little Coal Creek - Middle Fork Chulitna River I-R-OA4-3(2) - built 1985
   Inspected, Thermal crack counting June 25, 1986 and July 30, 1987

### RICHARDSON HIGHWAY, DELTA SOUTH

6. Sourdough - 7 Mile A81661 - built 1982
   Difficulty getting stationing on 4 layer section but resurvey done to compare w/as-builts

7. Glenallen North Mile 115-125 F-RF-071-2(18) - built 1982
   Inspected and crack mapped one site August 21, 1986

### TOK CUTOFF

8. Tok Cutoff Mile 52-91 A-84151 Phase II - built 1984
   Inspected, crack mapping (13 sections), spread measurements (2 sections), July 9, 1986 and September 23, 1987

9. Tok Cutoff Mile 38-52 F-IR-OA1-3(1) - built 1985
   Inspected, spread measurements (1 site), July 8, 1986 and September 23, 1987

## TABLE 3 (CONT.)

## GEOTEXTILE TESTING & INSPECTIONS: SUMMARY BY PROJECT

### FAIRBANKS AREA LOCAL ROADS

19. Sheep Creek/Goldstream A81231 - built 1982
    Inspections 1986, inspections, excavations, etc. 1987

20. Gilmore Trail A80241 - built 1982 (lower part), Gilmore Trail A84371 - built 1984-85, McGrath Road X20184 - built 1981-82, Mt.View-Skyline Drive A80381 - built 1981
    Inspected in 1986 by Herring, but little documented information from him

21. South Peger, Cartwright, Alston X20166 - built 1981
    Inspected and crack maps (on S. Peger) 1986, permeability tests (on Cartwright) 1986, excavations/gradations for separator evaluation

22. College Road Recycle A81051 - built 1982
    Dip by Beaver Sports surveyed by Ludington, notes lost

23. Phillips Field Road X20087 - built 1978
    Inspected, crack maps June 10, 1986

24. Ravenwood Road A84231 - built 1984
    Inspected, crack maps June 9, 1986

25. Chena Hot Springs Road RS-TQS-0650(17) - built 1979-80
    Inspected Aug 1986, large excavation of 5 layer section by Two Rivers Lodge June 1987

### OUTLYING AREA ROADS

26. Harding Lake Roads A-81261 - built 1982
    Inspected, crack mapping July 18, 1986

27. "A" Street, Nenena SOS-2(010) - built 1982
    Inspected 1986

28. Johnson Road A-80231 - built 1982
    Inspected, crack mapping July 1986

## TABLE 4. THERMAL CRACK SPACING

| Project | Treatment | Length inspected (ft) | No. of thermal cracks | Average spacing of cracks (ft) |
|---|---|---|---|---|
| Parks Highway, Rex-McKinley (2 years after construction) | 3 layer geotextile and grade raise | 21,090 | 117 | 180 |
| | No geotextile or grade raise | 11,570 | 157 | 74 |
| Parks Highway, Rex-McKinley (3 years after construction) | 3 layer geotextile and grade raise | 20,000 | 148 | 135 |
| | No geotextile or grade raise | 7,000 | 94 | 74 |
| Dawson-Easy-Newby (5 years after construction) | 1 layer geotextile (both lanes) | 2,230 | 20 | 112' |
| | 1 layer geotextile (one lane only) | 980 | 7 | 140' |
| | No geotextile | 8,490 | 72 | 118' |
| Parks Highway, Little Coal Creek - Middle Fork of Chulitna River (1 year after construction) | 1 layer geotextile in 1 - 2' subcut | 8,550 | 5 | 1,710 |
| | No geotextile, no subcut | 10,150 | 62 | 164 |
| Tok Cutoff, MP 52-91 (2 years after construction) | 3 layer geotextile in 2' subcut | 2,989 | 9 | 332 |
| | no geotextile or subcut | 5,189 | 35 | 148 |

## TABLE 4. THERMAL CRACK SPACING (CONT.)

| Project | Treatment | Length inspected (ft) | No. of thermal cracks | Average spacing of cracks (ft) |
|---|---|---|---|---|
| Johnson Road | One layer geotextile one foot or more extra fill placed in geotextile areas | 2,000 | 8 | 250 |
| (4 years after construction) | No geotextile | 2,000 | 16 | 125 |
| Phillips Field Road | One layer geotextile | 600 | 7 | 86 |
| (8 years after construction) | No geotextile | 400 | 5 | 80 |

interest to repeat these crack counts in the future to determine if and when thermal crack frequency in the treated areas reaches that in the untreated areas.

The hypothesis that grade raises and subcuts slow the reappearance of thermal cracks in a roadway, but that relatively weak geotextiles do not, was supported by crack counts made on the other projects shown in the table.

Excavations at thermal crack sites also tended to support this hypothesis. Early in the project several holes were dug in road shoulders at thermal crack locations to expose the edge of the geotextile. The geotextile was usually not torn at these locations. Later examinations within travelled lanes (away from the edge of the geotextile), however, revealed torn geotextile at thermal cracks in every case. Photo 3 shows such a tear in a fabric (Mirafi 500X) buried 15" below the surface on Persinger Drive near North Pole.

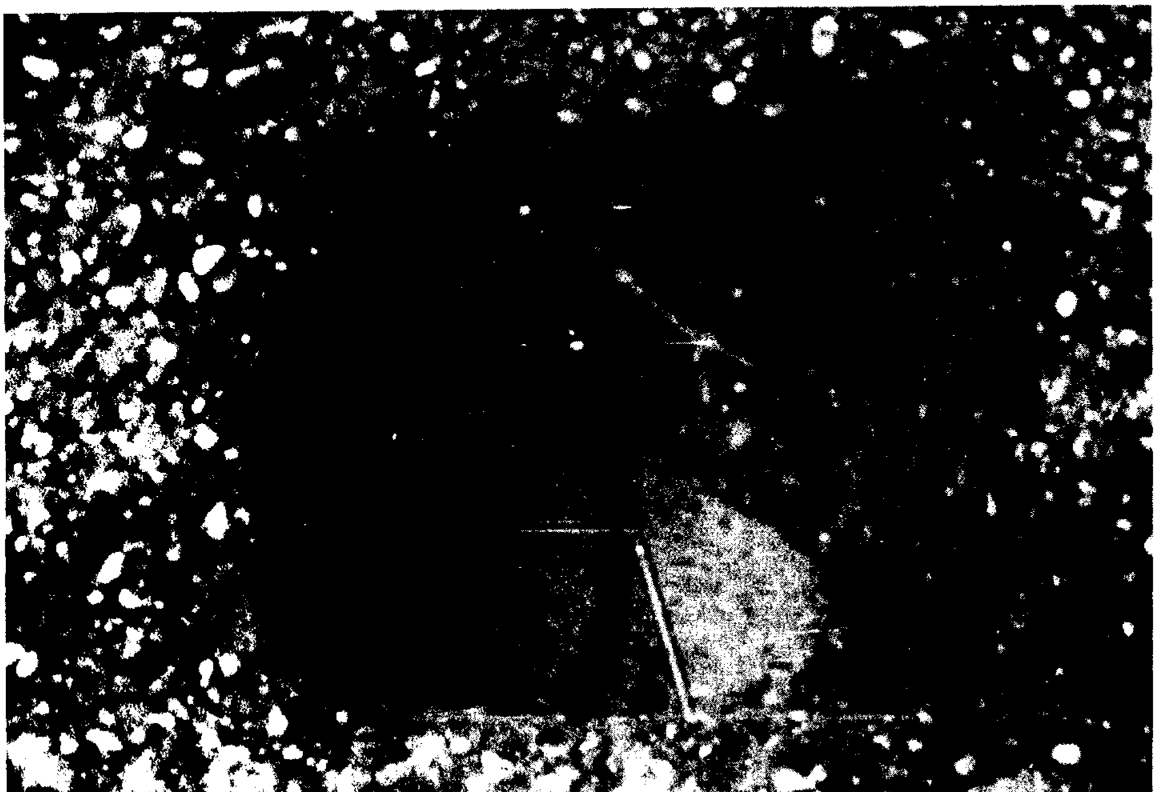


Photo 3. Geotextile torn at thermal crack, Persinger Drive

Thermal cracks widen in winter when the geotextile is frozen firmly into the embankment material, so the strain produced by the opening crack is probably concentrated in a very small portion of the geotextile. It might be expected that the material would tear in such circumstances, even if it has a low modulus of elasticity. (The manufacturer reports that Mirafi 500X reaches 10% strain at a load of 110 lb./inch. Grab tensile strength is 200 lb. at 35% strain.)

This implies a reduction of the long-term effectiveness of geotextiles as separators in cold climates. Deflections of a pavement are probably largest at crack locations and thus the greatest likelihood of pumping of fines into the embankment is also at these locations. The evidence of this study, then, is that the geotextiles failed at precisely those locations where they would be most useful as separators. This has no effect on their usefulness as separators during construction, however.

### Longitudinal Cracks

Large longitudinal cracks are common on roads in the Northern Region. The observations made for this study indicate that existing geotextile installations have not, in general, had much effect on this longitudinal cracking.

In certain cases the lack of benefit was quite clear. An example is the geotextile installation on the Richardson Highway near the Salcha Baptist Church. This is the second northernmost section placed on the Boondox to Canyon Creek project, and is composed of two layers of a woven polypropylene material (Propex 2002). In 1986, the year after paving, a longitudinal crack had appeared at the northern end of this section. The crack extended across the northern boundary of the section with no apparent difference between the treated and untreated areas. By 1987 this crack was more severe and extended the entire length of the geotextile section. The crack ended at the southern boundary of the geotextile section, and did not extend into the untreated area south of the section.

A similar example was seen on the second southernmost geotextile section placed on the Parks Highway, Little Coal Creek to Middle Fork project. Here a single layer of geotextile (again Propex 2002) was placed in 1985. By the next year a longitudinal crack extended through the southern boundary of the section with no difference apparent between the treated and untreated areas. The area is shown in Photo 4, taken one year after paving. Two years after paving the crack reached over 100 feet into the geotextile section (and 80 feet outside of it).

A number of examples were also found on Goldstream Road near Fairbanks, where a layer of woven polypropylene fabric (Mirafi 500X) was placed in a number of sections in 1982. A lot of severe longitudinal cracking has occurred on this road, requiring extensive leveling and patching. The presence of geotextile did not appear to have affected these problems in any case.

Photo 4. Longitudinal crack one year after paving. The paint at the edge of pavement and on centerline marks the end of a geotextile section. The photo was taken on the Parks Highway near Little Coal Creek.

A major crack near milepost 88 of the Tok Cutoff had appeared by 1986 in a three layer geotextile section placed in 1984 (see Photo 5). This was not a longitudinal crack; instead it extended diagonally across the road embankment. While not a longitudinal crack, it appeared to result from a similar cause, a loss of support in the foundation soils. In this case the loss of support appeared to occur on the fill side of a cut/fill transition.

In 1987, this failure zone was excavated to inspect the geotextile. By this time the settlement was so severe that a gravel patch had been placed over the area. The upper geotextile layer was torn across its entire width at the crack. The other two layers were partially torn and were severely strained elsewhere. Damage to the geotextile was greater near the center of the roadway than near the edges. The geotextile installation was clearly not strong enough to prevent the failure at this location. There was no evidence that the installation had even slowed the progress of the failure by any substantial amount.

Photo 5. Crack in a 3 layer geotextile section two years after construction. The photo was taken in 1986 near milepost 88 of the Tok Cutoff Highway.

While the evidence is that the geotextile installations examined generally have not reduced major cracking from embankment failures, this does not mean that such reduction is not possible. Design methods for geotextile reinforcement to prevent slope failures exist and have been used successfully. These, however, generally are not meant to address failures due to permafrost thaw settlement, which is the cause of many of the failures seen during this study. Geotextiles will not prevent such subgrade settlement but may prove useful in altering the manner in which the failure affects the roadway surface.

This seems to have been what occurred at a five layer section on Chena Hot Springs Road, the principal example found during this study where it appeared geotextiles did stop a major longitudinal crack. That site was excavated in 1987 and is discussed in a separate section of this report.

## Settlement

Differential settlement of roadways due to the thawing of permafrost foundation soils causes severe problems in many parts of Alaska. Such settlement can continue for many years, creating a continuous and expensive maintenance problem. The roller coaster ride produced on the affected roads is at best an inconvenience to motorists and can be dangerous. Indeed, personnel doing field work for this study assisted at the scene of an accident where a speeding motorist lost control on a severe dip and rolled his car.

Differential settlement of muskeg and other soft soils can also be a problem in Alaska. Thawed soils, however, consolidate over a relatively short period. The settlement problems resulting from these conditions, then, tend to be shorter lived.

Photo 6. A five layer section on Chena Hot Springs Road starts even with the wheel lying against the right guardrail. Longitudinal cracking and patching end at about this point, but settlement dips continue (note the sharp dip in the right guardrail).

It would be nice if a relatively inexpensive geotextile installation could eliminate the dips and wows produced by differential settlement or at least significantly reduce their severity. This was one of the desired benefits on many earlier geotextile installations in the Northern Region.

Unfortunately, there is no evidence that geotextiles have had this effect in any of the installations examined for this study. Photograph 6, for example, shows a section of the Chena Hot Springs Road where five layers of a relatively low strength geotextile (Typar 3401), spaced about nine inches apart, were installed in 1980. Severe dipping in the road can be seen in both the road surface and in the guardrail. The geotextile does not appear to have had any beneficial influence on the differential settlement at this site. It does appear, however, that the installation has arrested a severe longitudinal crack in the roadway at the site. This effect is discussed elsewhere in this report.

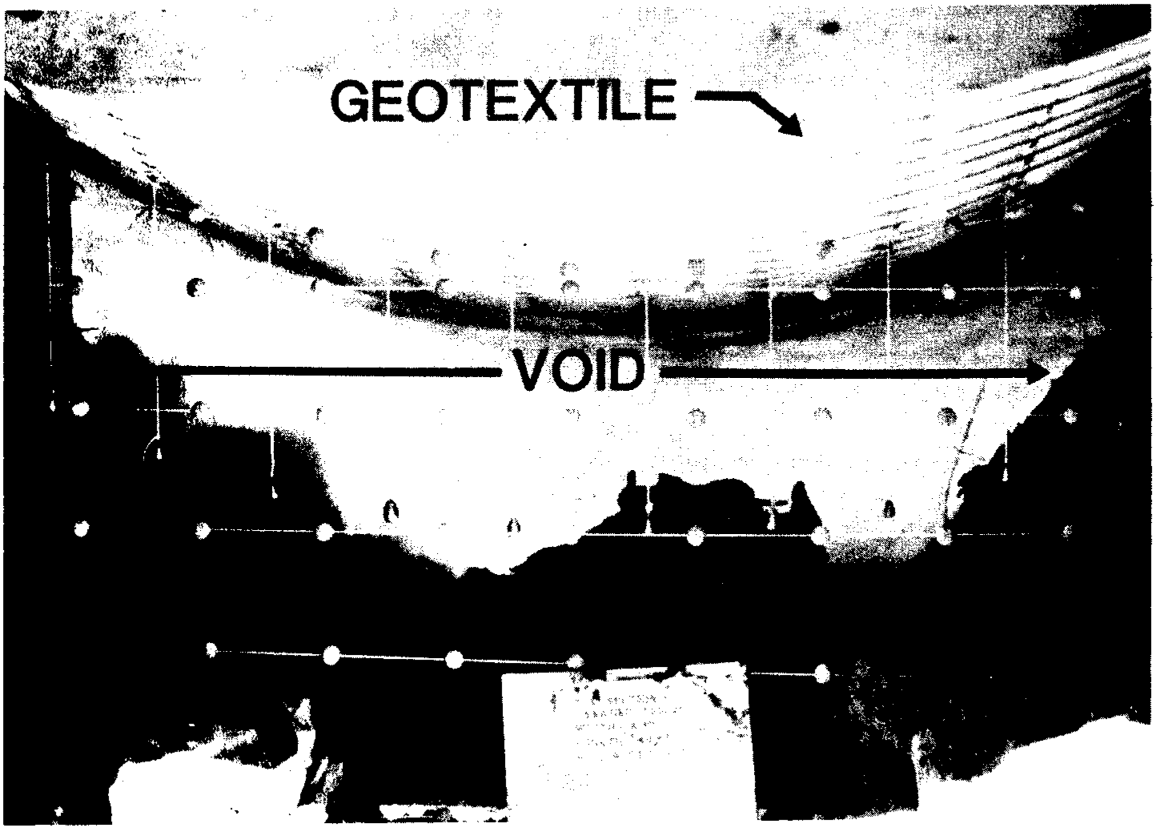


Photo 7. High strength geogrid supporting 3 feet of fill across a six foot void. The photo is of one of a series of experiments by Dr. Tom Kinney of the University of Alaska Fairbanks.

This lack of beneficial effect on differential settlement problems is relatively easy to understand. Most geotextiles have a low modulus of elasticity, and must therefore be stretched a great deal in order to develop their strength. The elongation resulting from a dip in a road, however, is relatively small even if the dip is severe. A depression two feet deep in a 25 foot length of road, for example, would seem like a crater to a motorist, yet would strain a geotextile by less than 1 1/2%. This would develop only about 10% of the strength of the type of geotextile usually used in the installations examined for this project. Moreover, there may even be this much slack left in the geotextile when it is placed in an embankment.

Research studies (Kinney, 1985, 1986) have shown that very stiff and strong geotextiles and geogrids can span sharp voids such as longitudinal cracks; this is discussed elsewhere in this report. Even these materials sag a great deal, however, before they support the load of the embankment above them. Photograph 7 shows the sag in a geogrid supporting three feet of fill across a six foot wide trench. The sag in this test installation was just under two feet; even the strongest material tested sagged more than 16 inches in a six foot span (Kinney, 1986).

Differential settlement from permafrost thawing or consolidation of soft thawed soils would rarely produce a surface as sharply deformed as that in Kinney's test installation. Consequently Kinney concluded that "geotextiles and related products should not be expected to significantly effect (sic) road surface settlement due to thawing of large ice masses or ice rich permafrost" (Kinney, 1985, p. 90).

### Separation

One of the principal uses of geotextiles has been as a separator between poor subgrade soils and embankment material. The intent of the geotextiles in this application is to prevent contamination of clean fill with fines throughout the embankment and also to prevent localized "mud boils" from pumping through the embankment as it is built.

The general feeling among construction personnel who have used geotextiles for this purpose is that it has worked well in new alignments and in reconstruction of roads with thin embankments.

The author, for example, worked on one of the earlier projects on which geotextiles were used. Three local roads in the North Pole area (Dawson, Easy and Newby) were rebuilt under this project in 1981. The existing embankments were spread in preparation for new fill. This left a very thin, weak embankment in which several soft areas developed under the heavy traffic loads of the construction equipment. A relatively low strength geotextile (Typar 3401) placed over these areas under an Extra Work Order enabled construction without subexcavation of the poor soils or pumping of the fines. The cost was much lower than subexcavation would have been.

There have been similar experiences on several other recent projects in the Northern Region. As a result of these experiences, several construction engineers have expressed a desire to have separation geotextiles available as a contingency item on all projects where soft subgrade areas can be expected. The exact locations of the geotextile installations under this scheme would be selected in the field as conditions warranted. It has been suggested that sewn seams be required when geotextiles are placed on very soft or uneven ground, as muck can work its way between pieces of geotextile even if a large overlap is used. This was the case, for example, on the Mt. View-Skyline Drive and McGrath Road resurfacing projects built in 1981.

Subexcavation of existing roadway in order to place a separation geotextile has been done on several projects. This procedure has not always worked well, in the opinion of the construction personnel. The problem is that the subexcavation leaves a thin embankment prone to pumping. By the time the geotextile and backfill are placed, these areas can turn into a quagmire under heavy construction traffic, leaving them worse than they would have been without the geotextile. This was felt to be the case, for example, in some areas on the Nenana-South and Little Coal Creek to Middle Fork projects built on the Parks Highway in 1986.

Construction personnel cited clear benefits from the use of separator. geotextiles during construction. It is not as clear that they provide long-term benefits. The Dawson-Easy-Newby project cited above, for example, has held up quite well in the seven years since construction. During this period, however, the roads have never been subjected to traffic as severe as that during construction, nor has the traffic driven on such a thin embankment. It can only be speculated whether the roads would or would not have held up well without the geotextile.

Separation geotextiles were found torn along thermal cracks in the roadway, at least where the geotextiles were near the surface. Prevention of pumping is probably most important at crack locations. In this light the tearing of geotextiles is a drawback to their long-term benefits as separators. Tearing was observed frequently during excavations made for this study (e.g. on Goldstream Road, Persinger Drive and Dawson-Easy-Newby). In the road shoulder the edges of the geotextile were usually not torn. Excavations near the center of roadways, however, revealed torn geotextile at thermal cracks in every case examined. Presumably geotextiles would not tear if placed deep enough in the embankment (where crack movements are smaller). It is not clear, however, that there would be enough "pumping action" at such depths to warrant a geotextile anyhow.

Some DOT&PF personnel feel, however, that intrusion of fines can occur - and separators be warranted - at substantial depths in an embankment. Most design guidelines suggest separators are needed only on thin embankments (2' or less) over very weak soils (CBR < 3), based on wheel load stresses imparted to the subgrade. It is possible that intrusion occurs at greater depths for other reasons (e.g. moisture migration and freeze/thaw cycling under the weight of the embankment itself).

Deep excavations to examine this were not within the scope of the project (although some were made to examine reinforcement effectiveness). Moreover if intrusion were found at depth it would be difficult to determine whether it had occurred during construction or later.

Shallow excavations were made to examine separator effectiveness, however, on Cartwright Road in Fairbanks. This is a two-lane gravel surfaced road which crosses wet ground. In 1981 the thin embankment was spread and covered with Typar 3401, a variable amount of borrow, and 4 inches of crushed gravel.

Gradation tests were run on samples taken in 2" layers from the surface to 12" (4" below the geotextile). The samples were obtained about 5' from the end of the geotextile section; similar samples were taken at identical depths from 5' beyond the section.

Results were inconclusive as they showed intrusion was not a problem even without geotextile. The old material just below the geotextile depth (i.e. 8"-10") had a minus #200 sieve (fines) content of only 6-7%. Just above the geotextile there were only 1.3% fines. At the same depth where there was no geotextile there were 3% fines.

Geotextile clogging has been observed on at least one construction project. On the Alaska Highway Border to Mile 1235 project, built in 1983, the upper of two layers of Typar 3601 was placed just below the base course. The base course stayed wet and soft following rains, causing problems in the paving operations. In the opinion of the project personnel, this was due to clogged geotextile which prevented vertical drainage. This would also create a long-term problem if the geotextile inhibited drainage of water entering the embankment through cracks and potholes in the pavement.

## CRACK AND PATCH MAPPING RESULTS

Cracks and patches in the pavement were mapped in the vicinity of the ends of many geotextile sections in the Northern Region. In many cases this was done in both 1986 and 1987 so that the progress of cracking could be judged. In general, crack maps were made for 400' at both ends of a section, 200' of which were inside the geotextile section and 200' outside. Where the total length of a geotextile section was less than 400', the length of the mapped untreated areas were reduced proportionately.

Many geotextile sections inspected for this study were unsuitable for mapping. This included most of the sections showing the worst performance, where much or all of the original pavement had been patched. Among these sections were those on the Sheep Creek Road/Goldstream Road project and on the Tok Cutoff Milepost 38-52 project, both of which are discussed later in this report. The sections with the best performance were also not mapped, as they had at most one or two thermal cracks, both within and outside of the geotextile section.

Of the sections which were mapped, the results from 64 sections on 13 projects are summarized in Table 5. These were considered the sections where the best comparisons could be made, and represent a total of over 9 miles of roadway. For sections which were mapped more than once, only the most recent results were used in compiling the table.

Overall, the amount of cracking in the pavement was approximately the same both within and without the geotextile sections. Sections with large differences either way were rare; for all 64 sections the combined length of cracks within the treated areas was 7% less than in the untreated areas (see the last page of the table). This difference is mostly because more cracks had been covered with patches in the treated areas; patched areas were almost 2 1/2 times as great inside the geotextile areas as without. The treated areas had only 2% less cracks per unit area of unpatched pavement.

In three quarters of the sections summarized in the table, the geotextile was not the only difference between treated and untreated areas. The additional difference usually was either a subcut or grade raise made in order to place the geotextile but not made in untreated areas.

In the sections where geotextiles were the only difference, the amount of cracking within the treated areas was an average of 3% greater than in the untreated areas (see the last page of Table 5). The difference, as before, is small and not considered significant. Patched areas were greater in the treated sections where geotextiles were the only difference, but less so than in the case of all projects investigated (an average of 47% more rather than 141%).

This would seem to indicate that the subcuts and grade raises were detrimental to performance. Grade raises could have increased consolidation of underlying soils, making differential settlement greater. Subcuts could have exposed subgrades to heavy construction traffic, resulting in pumping and softening of these soils.

Grade raises and subcuts were generally used in areas with a history of problems. Cracking and patching in the untreated areas adjacent to sections with grade raises or subcuts were more heavily cracked and patched (by 113% and 65%, respectively) than those adjacent to sections where the geotextile was the only difference.

This suggests that designers had, in fact, targeted more severe problem areas for more extensive measures. The subsequent performance in these areas, however, indicates that these more extensive measures were inadequate to rectify the problems.

The cracking and patching information, sorted by the type of geotextile, the number of layers used, and the age of the installation, is summarized in Table 6 and shown in Figures 2, 3, and 4.

## TABLE 5. CRACK AND PATCH MAPPING SUMMARY

| Project | Parks Highway Rex to McKinley | Richardson Hwy. Glennallen - North (MP 115-125) | Tok Cutoff MP 52 - 91 |
|---|---|---|---|
| Number of geotextile sections mapped | 7 | 1 | 13 |
| Age of sections at time of mapping (years) | 3 | 4 | 2 |
| Brand of geotextile | Trevira 1120 | Mirafi 500X | Propex 2002 |
| Number of layers | 3 | 1 | 3 |
| Differences other than geotextile between treated and untreated sections | 2.5' grade raise in geotextile areas | Geotextile in new alignment | 2.5' subcut, pavement differs |
| Cracks (ft) | | | |
| geotextile sections | 1290 | 170 | N/A |
| untreated sections | 1530 | 235 | N/A |
| Patches (ft$^2$) | | | |
| geotextile sections | 2,000 | 6,600 | 8,305 |
| untreated sections | 35 | 0 | 1,855 |

## TABLE 5. CRACK AND PATCH MAPPING SUMMARY (CONT.)

| Project | Alaska Highway, Tanana River to Tok Jct. | Alaska Highway Border to MP 1235 | Dawson, Easy and Newby (North Pole Area) |
|---|---|---|---|
| No. of geotextile sections mapped | 3 | 8 | 5 |
| Age of sections at time of mapping (years) | 3 | 3 | 5 |
| Brand of geotextile | Typar 3601 | Typar 3601 | Typar 3401 |
| No. of layers | 2 | 2 | 1 |
| Differences other than geotextile between treated and untreated sections | 1.5' subcut in geotextile areas | 1.5' subcut in geotextile areas | None |
| Cracks (ft) | | | |
| geotextile sections | 2565 | 7575 | 885 |
| untreated sections | 4330 | 6585 | 790 |
| Patches ($ft^2$) | | | |
| geotextile sections | 1380 | 3370 | 360 |
| untreated sections | 2024 | 1400 | 50 |

## TABLE 5. CRACK AND PATCH MAPPING SUMMARY (CONT.)

| Project | Freeman Road (North Pole Area) | Bradway Road (North Pole) | South Peger, Cartwright and Alston |
|---|---|---|---|
| No. of geotextile sections mapped | 5 | 9 | 3 |
| Age of sections at time of mapping (years) | 5 | 3 | 5 |
| Brand of geotextile | Typar 3401 | Trevira 1115 | Typar 3401 |
| No. of layers | 1 | 2 | 1 |
| Differences other than geotextile between treated and untreated sections | 2" additional base course in geotextile areas | 8" subcut in geotextile areas | None |
| Cracks (ft) | | | |
| geotextile sections | 275 | 885 | 675 |
| untreated sections | 385 | 845 | 675 |
| Patches ($ft^2$) | | | |
| geotextile sections | 10,130 | 4,370 | 3,735 |
| untreated sections | 6,055 | 2,530 | 2,570 |

## TABLE 5. CRACK AND PATCH MAPPING SUMMARY (CONT.)

| Project | Ravenwood Road | Phillips Field Road | Harding Lake Road |
|---|---|---|---|
| Number of geotextile sections mapped | 1 | 2 | 2 |
| Age of sections at time of mapping (years) | 2 | 8 | 4 |
| Brand of geotextile | Mirafi 500X | Typar 3401 | Mirafi 500X |
| Number of layers | 1 | 1 | 1 |
| Differences other than geotextile between treated and untreated sections | 1.0' grade raise in geotextile areas | None | None |
| Cracks (ft) | | | |
| geotextile sections | 135 | 125 | 145 |
| untreated sections | 75 | 150 | 200 |
| Patches ($ft^2$) | | | |
| geotextile sections | 0 | 10 | 0 |
| untreated sections | 0 | 10 | 0 |

## TABLE 5. CRACK AND PATCH MAPPING SUMMARY (CONT.)

| Project | Johnson Road | All 13 Projects | 5 Projects Where Geotextile is the Only Difference |
|---|---|---|---|
| Number of geotextile sections mapped | 5 | 64 | 16 |
| Age of sections at time of mapping (years) | 4 | 2 to 8 | 2 to 8 |
| Brand of geotextile | Mirafi 500X | Varies | Varies |
| Number of layers | 1 | Varies | 1 |
| Differences other than geotextile between treated and untreated sections | None | Varies | None |
| Cracks (ft) | | | |
| geotextile sections | 460 | 15,185<br>(7% less) | 2,280<br>(3% more) |
| untreated sections | 515 | 16,315 | 2,205 |
| Patches (ft$^2$) | | | |
| geotextile sections | 10 | 40,270<br>(141% more) | 4,115<br>(47% more) |
| untreated sections | 175 | 16,704 | 2,805 |

## TABLE 6. CRACK AND PATCH RESULTS SORTED BY VARIOUS PARAMETERS

| | Cracks | | | | Patches | | | |
|---|---|---|---|---|---|---|---|---|
| | No. of Projects | No. of Sections | ft/section (avg.) Geotextile | Untreated | No. of Projects | No. of Sections | $ft^2$/section (avg.) Geotextile | Untreated |
| **Fabric Type*** | | | | | | | | |
| Woven, higher modulus | 4 | 9 | 101 | 114 | 5 | 22 | 678 | 92 |
| Nonwoven, low modulus | 8 | 42 | 340 | 364 | 8 | 42 | 604 | 349 |
| **Number of Layers** | | | | | | | | |
| 1 | 8 | 24 | 120 | 126 | 8 | 24 | 869 | 369 |
| 2 | 3 | 20 | 551 | 588 | 3 | 20 | 456 | 298 |
| 3 | 1 | 7 | 184 | 219 | 2 | 20 | 515 | 95 |
| **Age of Installation** | | | | | | | | |
| 2 years | 2 | 6 | 68 | 77 | 3 | 19 | 970 | 416 |
| 3 years | 4 | 27 | 648 | 699 | 4 | 27 | 585 | 315 |
| 4 years | 3 | 8 | 97 | 119 | 3 | 8 | 826 | 22 |
| 5 years | 2 | 8 | 195 | 186 | 2 | 8 | 512 | 328 |
| 8 years | 1 | 2 | 63 | 75 | 1 | 2 | 5 | 5 |

* Woven materials were AMOCO Propex 2002 and Mirafi 500X;
Unwovens were Typar 3401, Typar 3601, Trevira 1115, and Trevira 1120

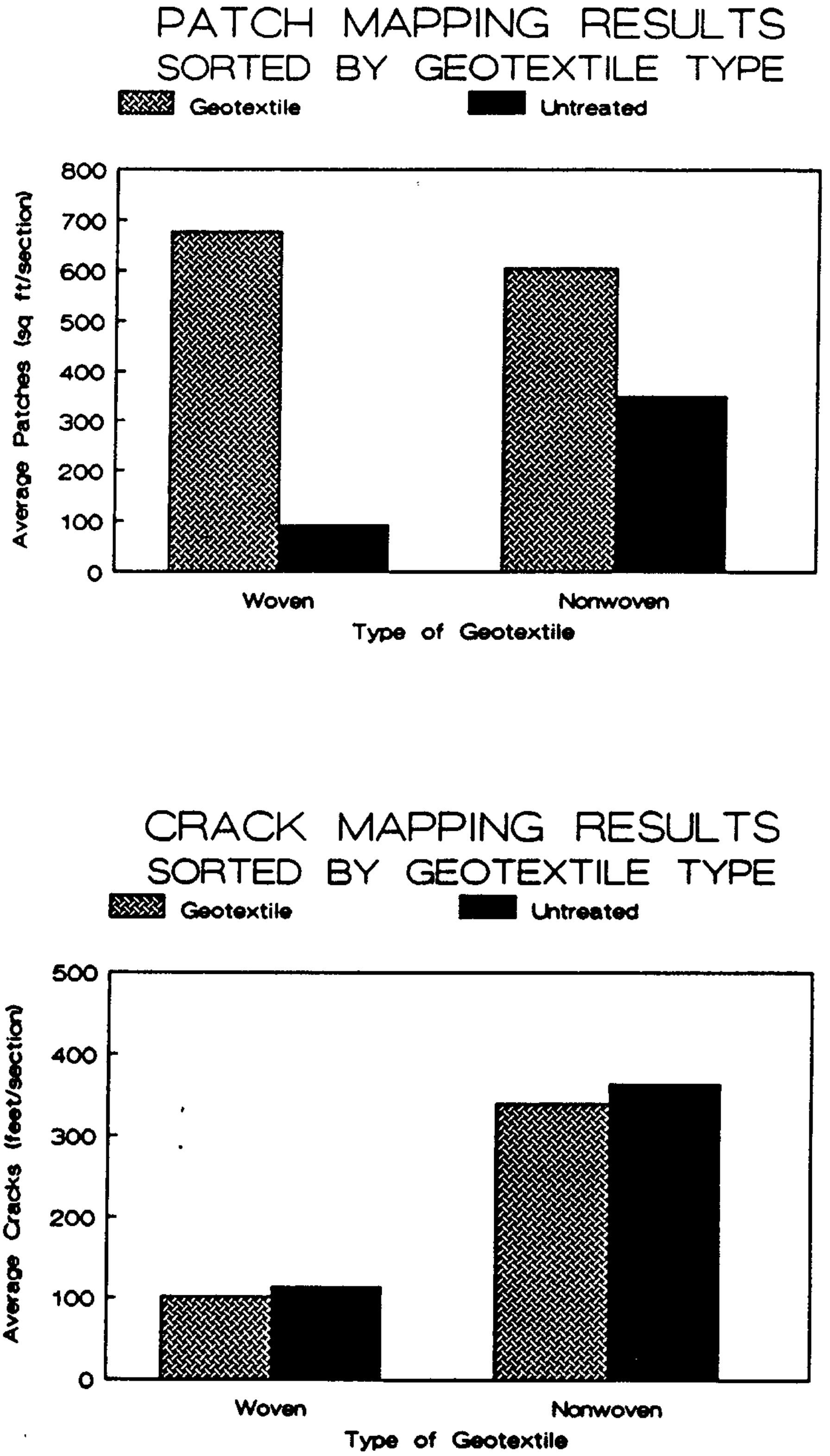
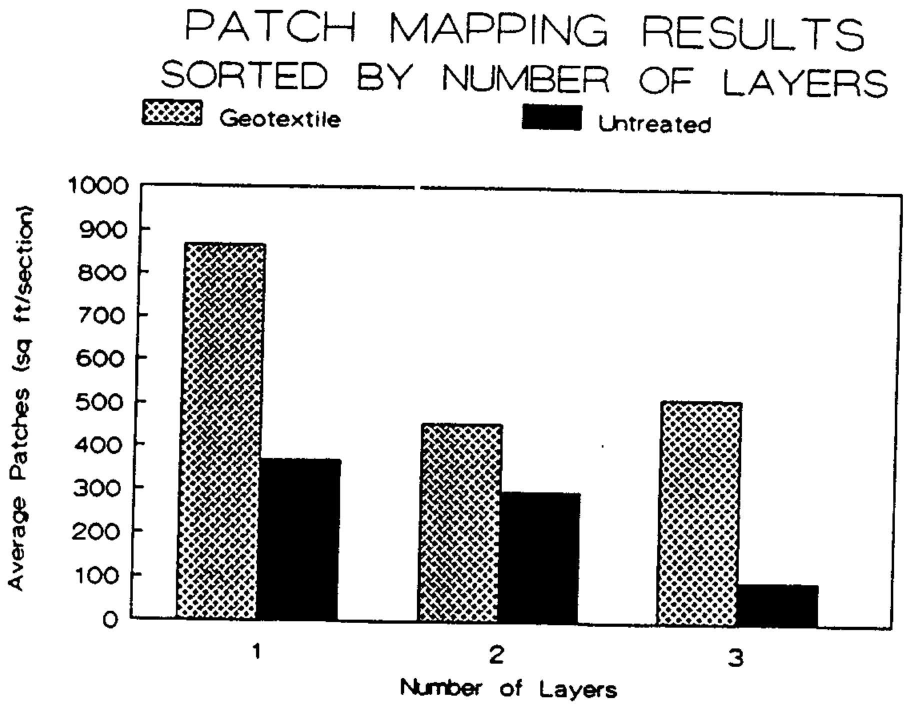


Figure 2. Crack and Patch Mapping Results Sorted by Geotextile Type



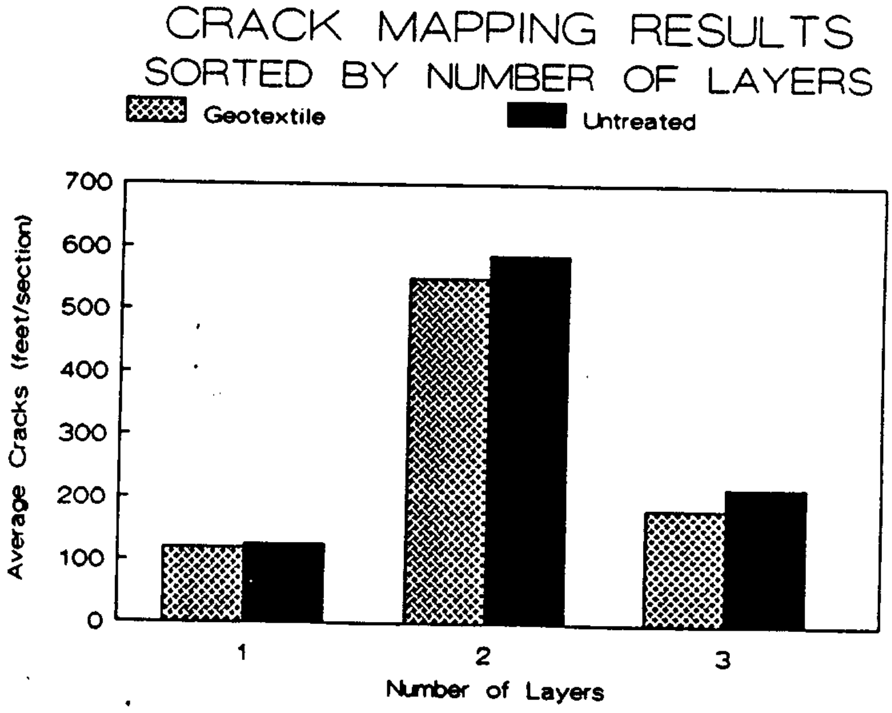


Figure 3. Crack and Patch Mapping Results Sorted by Number of Layers

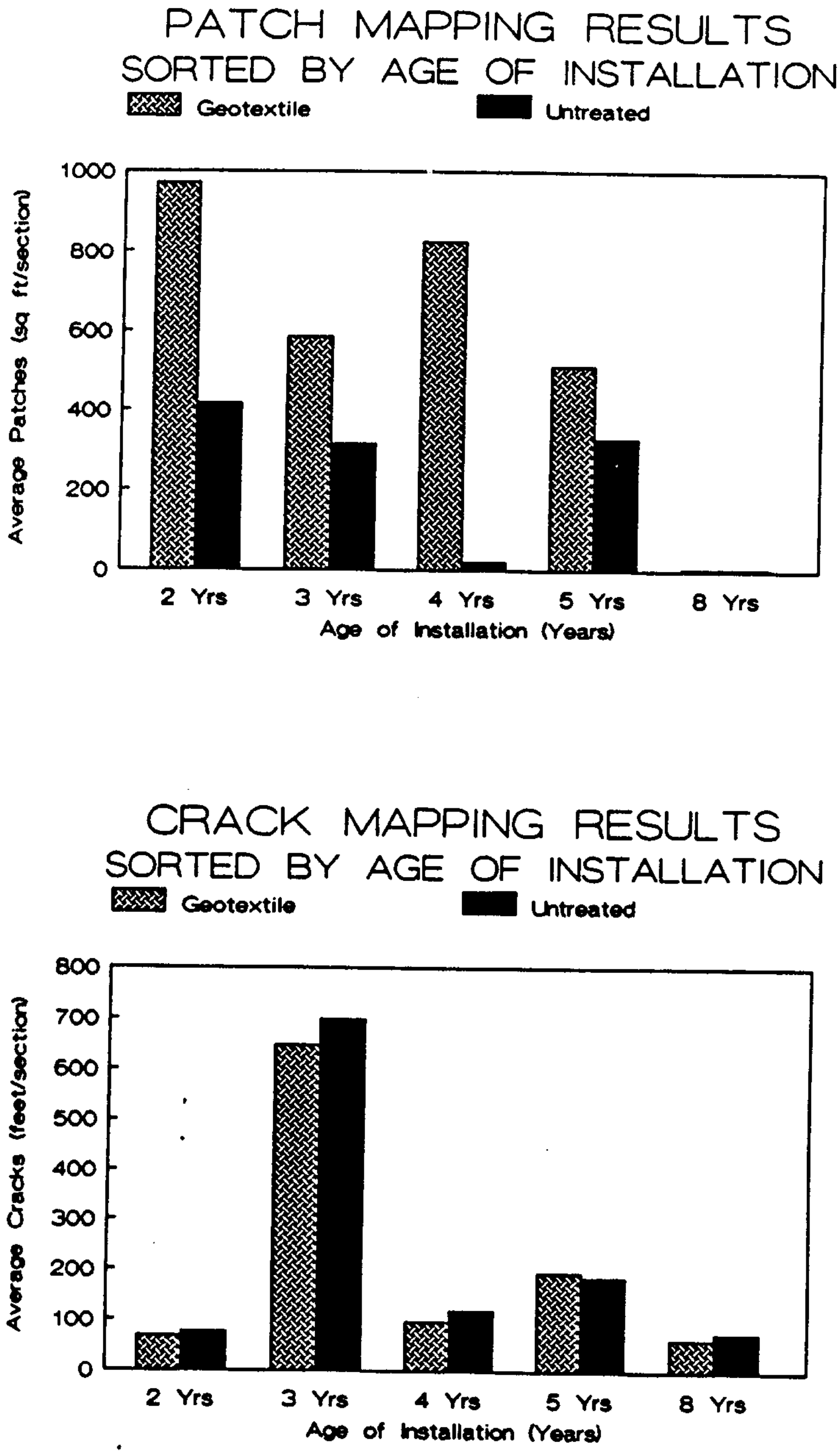


Figure 4. Crack and Patch Mapping Results Sorted by Age of Installation

### Fabric Type

All of the geotextiles used in the listed projects have similar reported grab tensile strengths (between 150 and 200 pounds) with the exception of the Trevira 1115 used on one project, which is somewhat weaker. Some projects, however, used woven materials (Propex 2002 and Mirafi 500X) which have a higher modulus of elasticity as computed from their strain at failure in the grab tensile strength test. Both woven materials, however, are made of polypropylene (as are some of the nonwovens), which is known to creep at modest loads. The strain of the woven materials under prolonged loading thus might not be less than that for the nonwovens.

The type of fabric used had no discernible effect on cracking; in both cases the treated sections had slightly less cracking than adjacent untreated areas. Nonwoven sections were patched 73% more than their adjacent untreated areas, while this difference was more than 700% in the sections with woven geotextiles (see Figure 2). This seems to indicate better performance by the nonwoven materials, although it is not clear why this would be so. The data are perhaps an illustration of the inadequacy of the untreated areas as controls for comparative purposes. Alternatively, it may reflect the specification of woven fabrics for areas having a history of more severe settlement.

### Number of Layers

The average amount of cracking in two layer sections is about four times as great as in one layer sections, but the same is true of the untreated areas adjacent to the sections (see Figure 3). In both cases, cracking is slightly less inside sections than in adjacent untreated areas. This is largely due to the greater patching in the treated areas, which covered up some of the cracks.

Patching is more frequent in treated than untreated areas, whatever the number of geotextile layers. A comparison of two layer sections with one layer sections, however, seems to indicate that the second layer was beneficial, as patching amounts are smaller both in absolute terms and in comparison to adjacent untreated areas. The trend is not continued when the figures for three layer sections are examined, however. Compared to two layer sections, patching is increased, even though patching in adjacent untreated areas is less than in the two layer cases.

### Age of Installation

The age of the geotextile sections has no major discernible effect on the cracking and patching amounts (see Figure 4). The amount of cracks inside and outside of the sections was found to be roughly the same whatever their age. The amount of patching inside the sections seems to <u>decrease</u>, if anything, with age. This could indicate that as geotextiles were used more often in the Northern Region they also were used less effectively (i.e. installations with higher present value were constructed first). This, however, may also be merely coincidence.

## RESULTS FOR SPECIFIC ROADS

### Chena Hot Springs Road

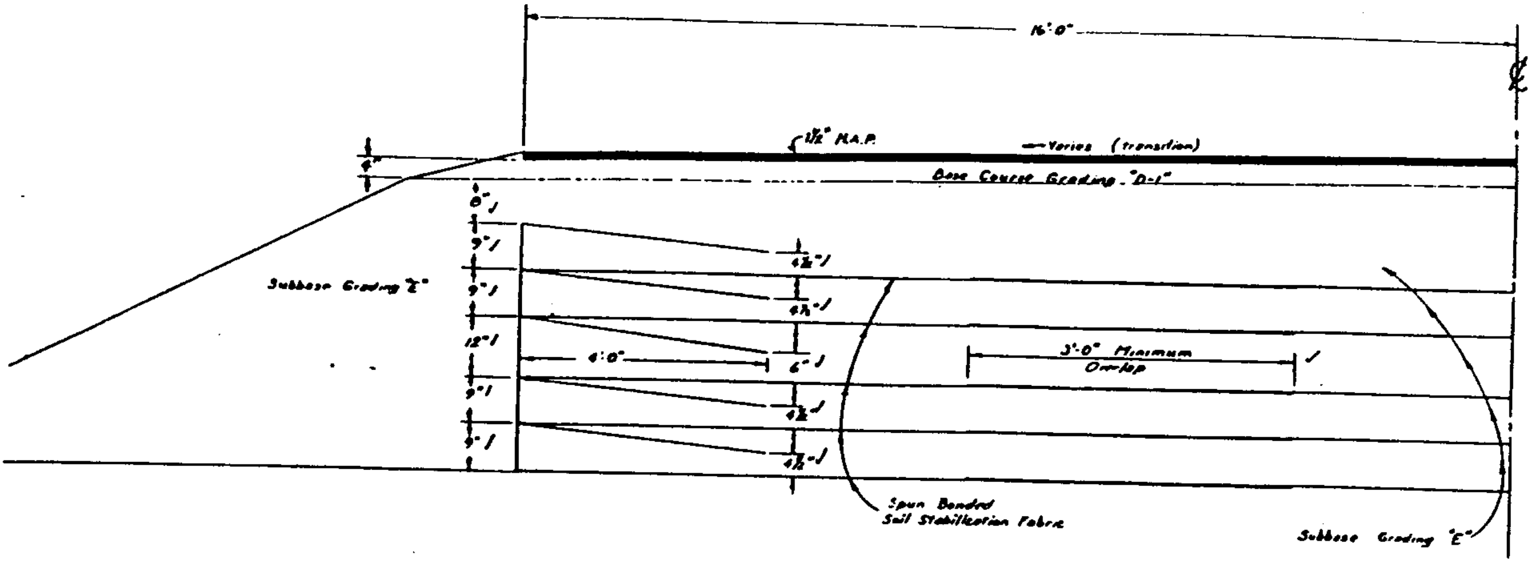
Of all the geotextile sites examined for this study, the only one where it appeared the installation had halted major longitudinal cracking and rutting in the roadway was near Milepost 16 of Chena Hot Springs Road, just beyond the second approach to the Two Rivers Restaurant. The 350 foot long section consists of five layers of Typar 3401 placed between about 2 and 5 feet below finish grade (see Figure 5). It was built in 1979 and is the oldest multi-layer section in Interior Alaska.

The reinforced area lies in a slight sag vertical curve. The road, with earth stabilizing berms on both sides, runs between two ponds. At the first inspection in August 1986 it was noted that beyond the end of the section the road suffered from considerable longitudinal rutting and cracking and the full width of the roadway had been patched more than once. Both the cracking and the patching, however, stopped in the vicinity of the end of the geotextile section (see Photo 6).

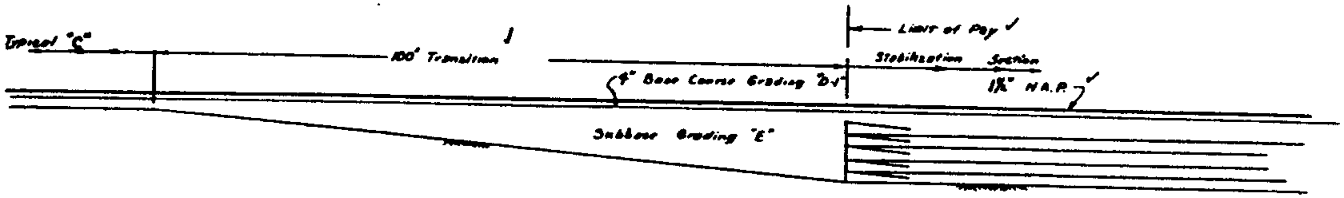
Although cracking and patching ended in the geotextile section, there was a considerable amount of dipping and sagging of the road surface, indicative of differential settlement. An acute sag in the guardrail, associated with a severe dip in the pavement, can be seen on the right in the photo. There was thus no clear evidence that the geotextile had reduced differential settlement as it had apparently reduced longitudinal rutting and cracking.

In June 1987, an excavation was made with a small backhoe in the center of the road to expose this end of the geotextile installation (see Photos 8 and 9). Although the as-built plans indicate a vertical geotextile wall at the end of the section (which would have required temporary form work to build), what was found was a stepped or terraced configuration of layers. The planned wrapping or folding over of the ends of the geotextile was missing on two of the layers. The thicknesses of the gravel between geotextile layers also did not conform to the as-built plans, although this may be a result of construction difficulties at the ends. Farther into the section the layers may be spaced as indicated in the plans.

The exposed geotextile was in good condition. It was not torn or noticeably deformed. The geotextile was punctured in some places by stones in the fill, however. The fill material was clean, rounded alluvial sand and gravel, with few or no sharp edges or fractured faces. There were no visible cracks in the fill. The geotextile, then, did not appear to be "bridging" over voids in the fill.



SPECIAL SOIL STABILIZATION SECTION



TRANSITION DETAIL
(Half Section - Apply to Both Ends)

Note:
This treatment shall extend from approximate station 842+80 to 846+30 as directed by the engineer. Ends of fabric shall be lapped over in the same manner as shown for edges.

Figure 5: Plans of 5 layer geotextile section on Chena Hot Springs Road

Photo 8. Excavation of 5 layer section on Chena Hot Springs Road, June, 1987.

The fact that the severe rutting and cracking end very close to the geotextile section boundary, coupled with the fact that the geotextile structure has remained intact, seems to indicate that the geotextile has accomplished its intended purpose. It is possible, of course, that it is merely by chance that the pavement distress starts where the geotextile ends, but this seems unlikely.

Although the installation seems successful, the reason for this success is not clear. Longitudinal cracks of the sort seen at this site occur when settlement of subgrades is greater in the road shoulder areas than beneath the road centerline. This is typical of permafrost thaw settlement. An idealized view of this situation is shown in Figure 6b.

It is not realistic to expect geotextiles to prevent a road from settling along with the subgrade in such a situation. To do so would require cantilevering the sides of the embankment out over the settled shoulder areas. Geotextiles, however, may be used to modify the effects of such settlement on the road surface.

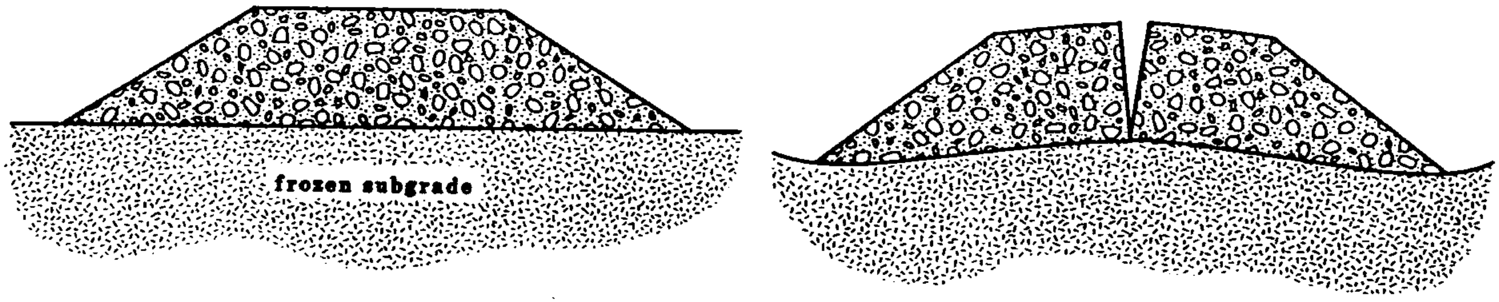


**Figure 6a: Embankment as built**

**Figure 6b: Unreinforced embankment after thaw settlement**

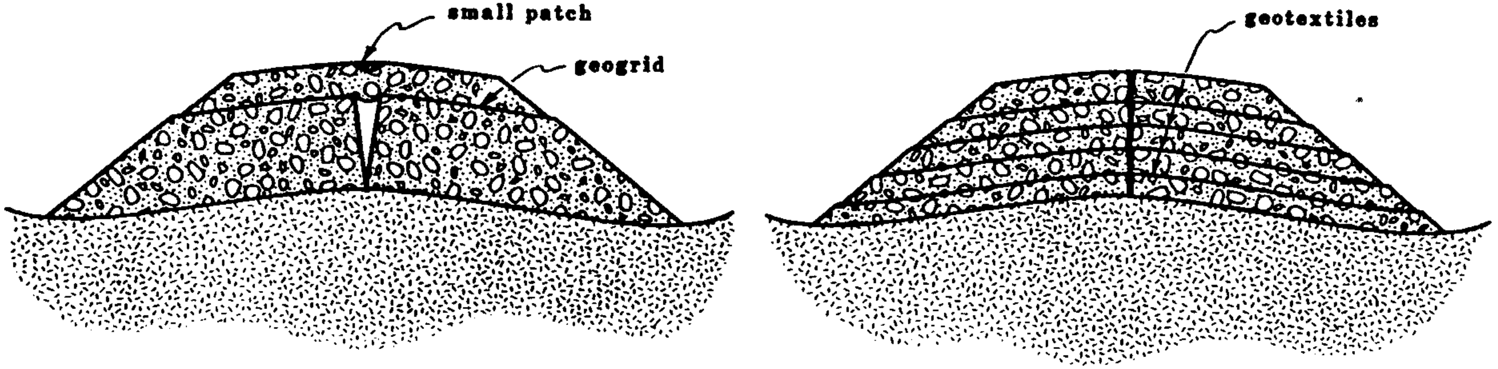


**Figure 6c: Geogrid bridging longitudinal crack**

**Figure 6d: Geotextile-induced shear failures minimizing crack width**

Figure 6: Conceptual Views of Longitudinal Crack Formation and Amelioration

Photo 9. Ends of fabric layers exposed. Only 3 of the 5 layers can be seen in this photo. Note the stepped or terraced configurations of the layers.

One such means is illustrated in idealized form in Figure 6c. In this situation, the tensile strength of the reinforcing layer holds the upper portion of the embankment together while the lower part of the embankment slides out beneath the reinforcement. The reinforcement must then be capable of bridging the resulting longitudinal crack.

Considerable research on this technique has been done in Fairbanks in the last few years. The results of much of this work are published in Kinney, 1985 and Kinney, 1986.

The research has demonstrated that this method holds promise. In order to bridge a large void, however, the reinforcement must be extremely strong. Furthermore, if the reinforcement does not have a high modulus of elasticity it will sag severely, leaving a large rut in the surface. Because of this, geogrids rather than geotextiles have been used in successful tests. A short section of Farmers Loop Road in Fairbanks was rebuilt using geogrid in this manner in July 1988. Nearly 300,000 square yards of extremely high strength geotextile were installed on the Tok Cutoff during the summer of 1989 based on Dr. Kinney's design methodology.

The Typar 3401 used on Chena Hot Springs Road cannot have acted in this manner, as it has a low tensile strength and modulus of elasticity. Moreover it was not observed to be spanning any voids, as noted above.

The mechanism by which the geotextile on Chena Hot Springs Road may have reduced longitudinal cracking is shown in idealized form in Figure 6d. In this case, the embankment is induced to fail in shear along the planes of the geotextile layers. The shear strength of a geotextile-soil interface has been shown to be significantly less than that of the soil itself in cases where the geotextile's pore openings are smaller than the soil particle sizes and the geotextile surface is smooth (Kinney, 1985). This was the case at the Chena Hot Springs Road site. The clean, rounded sand and gravel used for borrow there, moreover, would be weak in shear to begin with. For this mechanism, then, the tensile strength added by geotextile layers may ironically be less important than the shear weakness introduced.

Rough calculations using a number of simplifying assumptions indicate that this may be a viable design, and that a low modulus of elasticity may actually be desirable. Complete structural analysis of this mechanism is made difficult by the complexity of the arrangement and by the large deformations involved, however, and is beyond the scope of the current project.

### Tok Cutoff MP 38-52

This part of the Tok Cutoff was reconstructed in 1985. The work included realigning the road in some areas. A single layer of relatively lightweight woven geotextile was placed over the original ground in some of these new alignment areas (in both cuts and fills) where the soils were poor. The geotextile (Exxon GTF-200) is described both as "subgrade stabilization fabric" and as "filter cloth" in the as-built plans.

The project was first inspected for this study on July 8, 1986, about a year after the original BST pavement (double chip seal) was placed. Five of the six geotextile sections had already suffered severe damage by this time. Nearly half of the total length of the geotextile sections (3095' of 6700') were covered with temporary gravel patches. Most of the remainder had received full-width BST patches. A crew from the Tazlina Maintenance Station was beginning to place new BST surfacing over the gravel-patched areas. The foreman stated that some of the gravel-patched areas had already been resurfaced once. These areas, in other words, were about to receive their third BST surface in less than a year. Only one 700' section in a fill area (Sta. 1-038 to Sta. 1045) appeared to be in good shape.

By September 23, 1987, 200' of that section had also been patched and the remainder was in poor shape with considerable cracking and settling evident. By this time 84% of the length of the geotextile sections (5630' of 6700') on the project had received full-width patching; further rutting, cracking, and dipping was observed in some of the areas.

The single geotextile layer has clearly done little to improve long-term performance of the roadway in these areas. Such a result would have been a valuable secondary benefit. The purpose of these installations, however, was to make new alignment areas constructable without subcuts. This goal was, indeed, achieved.

Ron Hollingsworth, the grade inspector on the project, has stated that long-term performance improvements would have been too much to expect under the circumstances. The thawing permafrost in the geotextile areas, according to him, became so sloppy that "you needed hip boots to walk around," and mud waves were created in front of the fill. Hollingsworth feels that (in the absence of subcuts) the embankment construction would have been difficult or impossible without the use of geotextiles.

### Sheep Creek Road - Goldstream Road

These roads were reconstructed in 1982. Parts of them received only a leveling course and overlay of hot asphalt. Other areas were reconditioned and then repaved. In eight areas the road was subcut 16", a woven geotextile (Mirafi 500X) was placed, and the road was rebuilt and paved. In three simple overlay areas a geotextile (Mirafi 900N) was placed directly beneath the asphalt overlay for the purpose of reducing reflective cracking.

The subcut installations were inspected thoroughly for this report. The installations are some of the oldest examples of a type of reconstruction which was later used extensively in the Northern Region for "subgrade stabilization" purposes (although the plans for this project call the geotextile a "filter cloth").

These roads cross permafrost over much of their length, and have had a history of severe differential settlement, longitudinal cracking, and alligator cracking. Ted Niemiec, DOT&PF's project engineer, noted in the project history that what was needed was not separation of fine materials from gravels, but embankment reinforcement: "During construction ... it was found that the problems were not due to inadequate or contaminated materials in the embankment structure, but instead due to foundation failure caused by ... permafrost."

These roads were suffering major damage by 1987, five years after construction. Mapping of pavement cracks near the geotextile section boundaries, which was done on many inspections for this study, was useless since the original paving had been replaced by full road width patches of unknown age in almost every case.

Areas with full width patching on Sheep Creek and Goldstream Roads were inventoried as part of the inspections. The results for Goldstream Road are summarized in Table 7.

All of the subcut areas which were not patched as of June 30, 1987 were in very poor shape and merited immediate full width patching. The same was true of many other areas on the road, including significant amounts of previously patched areas both in and out of subcut sections. Maintenance forces performed major patching along Goldstream Road later in 1987.

The fact that geotextile treated areas required patching much more frequently than untreated areas does not mean that the installation of geotextiles detracted from performance, of course. A more likely explanation is that the designers correctly identified many of the "problem areas" in the road, but that the geotextile treatment did not remedy them.

It could be asserted that performance in the treated sections would have been even worse without the geotextile. This is hard to disprove since there are no adequate control areas for comparison. Given the evidence, however, it seems the burden of proof is on those who would assert that the geotextiles provided significant benefits on these roads rather than on those who assert that they did not.

Inspections of three transverse thermal cracks in subcut areas revealed that the geotextile was torn at each of the crack locations. At this location, where thermal cracks were wide, the torn fabric could be seen by using a fiber optic borescope without digging the road up (Photo 10). This tearing of geotextiles at thermal cracks was subsequently found on other projects, although excavation was usually required to expose the fabric. Tearing at thermal cracks appears to occur nearly universally in the Interior, at least where low to moderate strength geotextiles are placed within two feet or so of the surface.

## TABLE 7. FULL WIDTH PATCHES - GOLDSTREAM ROAD

### Between Murphy Dome Road and Goldstream Creek Bridge as of June 30, 1987

| Roadway Section Subcut areas with geotextile | Total length (feet) | Length patched (feet) | % of section patched |
|---|---|---|---|
| Sta. 45+50 - 52+50 | 700 | 700 | 100 |
| Sta. 262 - 263 | 100 | 100 | 100 |
| Sta. 336+79 - 337+79 | 100 | 100 | 100 |
| Sta. 479+50 - 490 | 1,050 | 0 | 0 |
| Sta. 495+50 - 505+50 | 1,000 | 900 | 90 |
| Sta. 515+50 - 521 | 550 | 550 | 100 |
| Sta. 530 - 538 | 800 | 800 | 100 |
| All subcut areas | 4,300 | 3,150 | 73 |
| All other areas | 40,840 | 13,575 | 33 |
| All areas | 45,140 | 16,725 | 37 |

Note: 5,100 feet of roadway not rebuilt in 1982 are not included in the listed figures.

Photo 10. An inspector looks into a thermal crack using a fiber-optic borescope. The geotextile at this location was torn, as was usually the case at thermal cracks.

## CONCLUSIONS

1. Geotextiles placed in road embankments in the Northern Region have had no noticeable effect on the amount of cracking in the overlying pavement. This is based on mapping of 64 geotextile treated sections and adjacent untreated areas, totalling over 9 miles of roadway.

2. Within the mapped sections, pavement patching was almost 2 1/2 times as frequent in geotextile treated areas than outside of them. It seems likely that designers correctly identified road sections with the most severe problems when selecting geotextile placement areas. The geotextile treatments, however, have been generally insufficient to cure or substantially lessen the problems.

3. Most geotextile installations in the Northern Region have been made with relatively low strength materials at shallow depths in the roadway embankments. These materials have torn consistently at thermal crack locations. This reduces the long-term usefulness of such installations as separators.

4. Thermal cracks in embankments have "reflected" through new surfacing within a year or two in the Northern Region. The geotextiles generally used to date have not retarded this reflective cracking. Subexcavations and grade raises, however, were observed to slow the reappearance of thermal cracks.

5. Existing installations have generally had little effect on major longitudinal cracking in the Northern Region. Site specific designs using high strength materials seem promising, however, based on test and early field trial results.

6. Multiple layers of weaker material may also be successful at preventing or reducing longitudinal cracks if used in embankments made of granular material with low shear strength (i.e. rounded particles and/or uniform grading). Further investigations of this concept would be useful.

7. The geotextile installations observed have had little or no effect on differential settlement in roadways caused by thawing of permafrost. Very little of the tensile strength of the geotextiles is mobilized by the small strains induced by ground settlement of this type, as Kinney's work has shown. Little beneficial effect could be expected in such situations even if stronger, higher modulus geotextiles were to be used.

8. The geotextile benefit most commonly cited by construction personnel was its use as a construction aid for building embankments on soft, unstable ground. This benefit could not be adequately assessed in this study, in which inspections were made after construction was complete.

9. The widespread use of geotextiles without specific design objectives and methods is unlikely to be cost effective. It appears from this study, however, that site specific geotextile designs may be cost effective in many situations in the Northern Region, especially in addressing slope instability and longitudinal cracking problems.

10. Most of the geotextile installations in the Northern Region were less than five years old, which limited the study in some ways. Greater knowledge may be obtained by longer-term observations. Specific installations which may yield valuable information include the 8 layer section at the Bonanza Creek embankment near Parks Highway milepost 330. This was built in 1986 to treat slope instability due to thawing permafrost subgrades.

Other examples are the sections placed on the Tok Cutoff Highway between mileposts 0 and 30. These were to be built in 1989 to treat longitudinal cracking.

11. The untreated areas examined for this study were poor "control" sections, as is evident from inconsistent trends in some of the data.

## IMPLEMENTATION

DOT&PF design engineers should specify geotextiles only at those sites where analysis shows them to be effective in obtaining specific objectives. Such objectives may include facilitating embankment construction over soft subgrades, prevention of longitudinal cracking in the pavement, and embankment strengthening against slope failures. The latter two situations generally require very strong geotextiles and/or multiple layers.

Designers should not use geotextiles in attempts to eliminate or "even out" large dips in road surfaces resulting from differential thaw settlement or frost heaving. Both experience and analysis show this to be ineffective. Lightweight geotextiles have also been shown ineffective at reducing thermal cracking in roadways, and should not be used for this purpose.

These design recommendations have already been largely implemented within the Northern Region as a result of the early dissemination of the results of this study and the observations of the designers themselves.

If geotextiles are used in applications where design theory is not well established and/or there is little field experience, measures should be taken to ensure follow-up evaluation of the installation.

It may be possible to do this by including sections in the FHWA's Experimental Features in Highway Construction program, as was done for the Bonanza Creek embankment on the Parks Highway. Early dissemination of the results of the Bonanza Creek evaluation should be made to design engineers.

Performance evaluations should be made of the extensive installations on the Tok Cutoff Highway between mileposts 0 and 30. These installations can be used as a large scale field verification of a method of controlling longitudinal cracking. The Research Section should investigate the possibility of including the installations formally or informally in the Experimental Features program.

# REFERENCES

Christopher, Barry R. and Holtz, Robert D., 1985. *Geotextile Engineering Manual*, STS Consultants Ltd. for Federal Highway Administration, National Highway Institute, Washington, D.C.

Esch, David C., 1988. "Embankment Case Histories on Permafrost," in *Embankment Design and Construction in Cold Regions*, E.G. Johnson, Editor, American Society of Civil Engineers, New York (ISBN O-87262-650-4).

Kinney, Thomas C., 1985. *Field and Laboratory Study of the Use of Geotextiles to Bridge Thermokarsts*, Alaska DOT&PF Research Report No. FHWA-AK-RD-85-31, Fairbanks, Alaska.

Kinney, Thomas C., 1986. *Tensile Reinforcement of Road Embankments on Polygonal Ground by Geotextiles or Related Material*, Alaska DOT&PF Research Report No. FHWA-AK-RD-86-29, Fairbanks, Alaska.

Reckard, Matthew, 1983. *Multi-Year Maintenance Costs of Selected Alaskan Highways*, Alaska DOT&PF Research Report No. AK-RD-83-34, Fairbanks, Alaska.