

# Subarctic Alaska DESIGN IMPROVEMENTS FOR MINE ACCESS ROADS

by Nils I. Johansen and Nicasio Lozano

**A**NY KIND OF DEVELOPMENT must include some sort of transportation system. Historical examples are the land and water trails to the Klondike gold fields, and the riverboat traffic on the Yukon and Tanana rivers to support mining ventures and the growing towns in interior Alaska. Construction of access roads in permafrost regions of the Arctic and subarctic is necessary for the development and extraction of mineral resources and for reaching remote population centers. Reliable access to a mining property is very important for a successful operation.

Permafrost was both a help and hindrance to the early placer miners: the presence of frozen ground made drift mining of frozen placer deposits possible, but surface disturbances would turn the foundations for access roads or railroads into seemingly bottomless bogs in some areas. The annual spring breakup compounded the problems.

Low-cost unsurfaced development roads, common in the Arctic and subarctic,<sup>1</sup> are subject to the same thaw degradation that causes some of the worst highway maintenance problems in Alaska. In sections of the Alaska Highway that overlie ice-rich silt, differential settlements of as much as 5 feet have occurred where embankments have been placed over warm permafrost (30°F).<sup>2</sup> In fact, when the Alcan Highway was constructed during World War II, the ice-rich soil that turned to jelly when it thawed was called "bull's liver silt."

Permafrost engineering has progressed since the Alcan was built. Many studies have shown there are ways to maintain the underlying permafrost by incorporating insulation in the roadfill and to mini-

mize the embankment thickness by adjusting the depth of gravel and insulation to that appropriate to the local climate and anticipated axle loads. In Alaska, researchers are also studying culvert design, so that roads crossing drainage areas for streams and seasonal runoff can handle the heavy traffic associated with mining and other resource development.

## DRAIN DESIGN

Cross drainage in Alaska is designed according to specifications in the Hydraulics Manual of the Alaska Department of Transportation and Public Facilities (DOTPF). A concentrated flow of water during spring breakup and summer rains can wash out roads with poorly designed drainage systems. Because of the lack of field data during the construction of the North Slope haul road (Dalton Highway), two methods were used to determine flood discharges; the method showing the largest discharge was then used for selecting the size of the culvert to be used. The first method, the area constant drainage method, assumed a flood peak south of the Brooks Range of 0.33 m<sup>3</sup> per second per km<sup>2</sup> of tributary drainage area, and a flood peak north of the Brooks Range of 0.22 m<sup>3</sup> per second per km<sup>2</sup> of tributary drainage area. The second method was based on a Bureau of Land Management method which estimated a 10-year and 25-year recurrence interval flood.

Roadway flooding and icing are major problems in Alaska, especially during spring breakup. In the fall, drainage channels can become progressively covered with surface icings. Ice develops from natural factors and human activities. The natural factors are (1) an abundance of

ground water in the supra-permafrost layer or annual frost zone of the soil, generally resulting from rainy weather prior to freeze-up; (2) low air temperatures and little snow during the first half of the winter; (3) proximity of the permafrost table to the ground surface; and (4) substantial snow depth accumulation during the latter part of the winter. Human activities that affect icing come from the construction of highways, railroads, air fields, structures, and other works that alter the natural surface hydrology.<sup>3</sup>

The Alaska Department of Transportation presently uses several methods of thawing culverts where icing and flooding are problems: hot water boilers, steam generators, oil-fired barrel stoves, electrical heat tape, solar-assisted thawing devices (experimental), and, in the Kuparuk field, polyethylene is used to cover the inlet and outlet of culverts and is removed before spring breakup.<sup>4</sup>

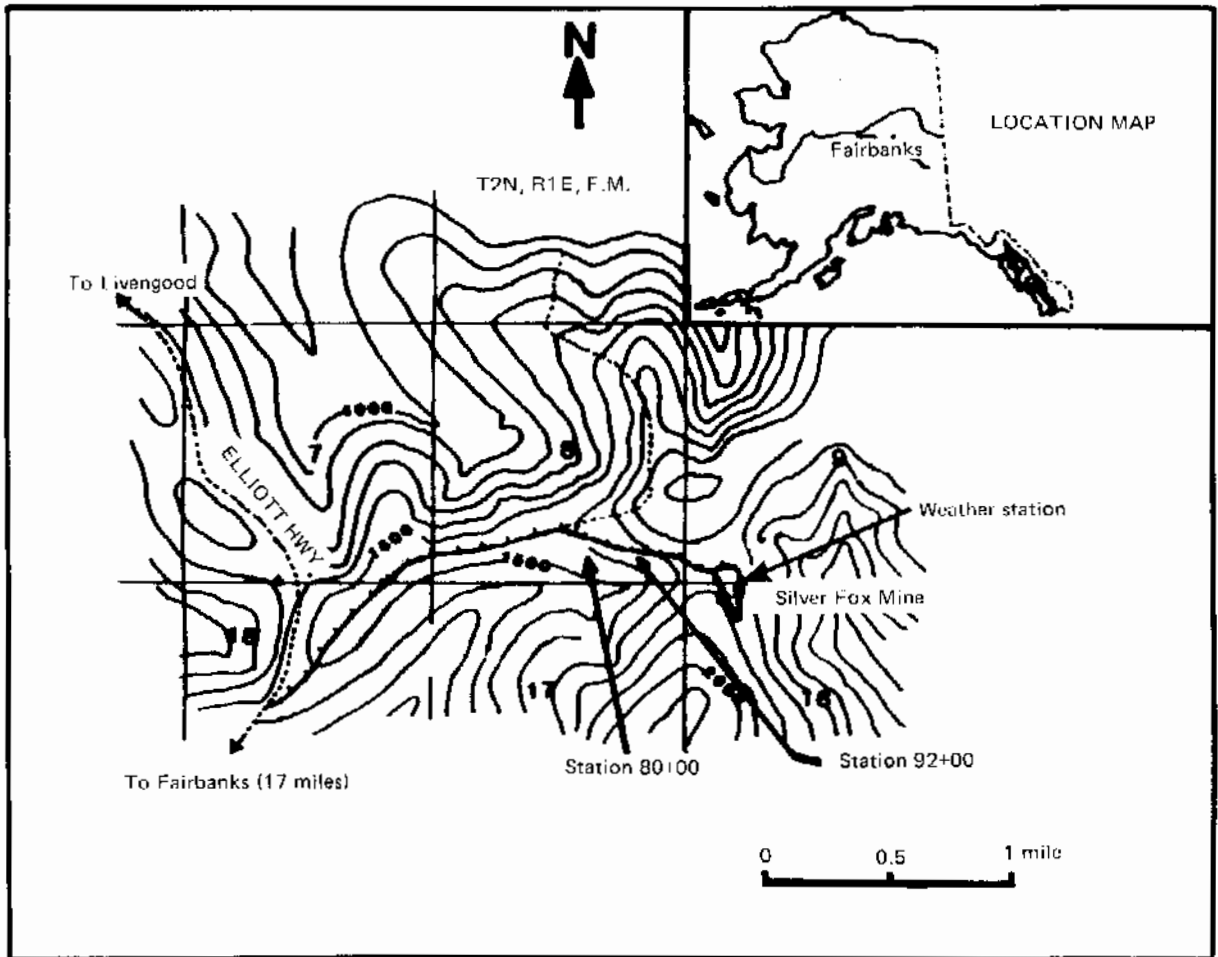
## FILTRATION DIKES

Studies made during the construction of access roads at Thule Air Base in Greenland described the use of coarse rock fill, consisting of cobbles and boulders, under the culverts. It was reported that water flowed through the fill the greater part of the time. In July, the flow measured approximately 100 cfs, with no water running through the culvert.<sup>5</sup> Also, a deep fill of highly permeable material provided a satisfactory crossing under the road for an old stream bed or shallow valley having no surface flow.

Carey<sup>3</sup> reports that filtration dikes are being used in the Soviet Union but not in North America. Russian investigators have suggested that filtration dikes could

---

Nils I. Johansen, a registered professional engineer in Alaska and Indiana, is currently an associate professor of geological engineering at the University of Alaska-Fairbanks. His area of research is geotechnical and permafrost engineering, especially relating to resource development in the north. Much of the work in this paper is from Nicasio Lozano's (UAF) master's thesis, "Use of a French drain as an alternative cross-drainage structure." Mr. Lozano is currently pursuing a Ph.D. degree at the University of Mississippi.



be used in many cases where small bridges or culverts are now specified. Also, Russian experience indicates that these dikes neither create nor aggravate icing, as might be supposed, because they do not disrupt natural conditions as bridges and culverts do.<sup>3</sup> Filtration dikes do not alter the cross section available for near surface ground water flow and they serve as insulators, reducing the penetration of seasonal frost. It is reported that pore spaces within a filtration dike remain ice-free through the winter. Any water approaching the dike freezes at or near its face, which is cold, while its interior remains above freezing. Thus, during the spring, ice melts more rapidly on the face of a dike than within a culvert; hence, water flow across the right of way can begin earlier. Filtration dikes are claimed to be suitable for use across normally dry roads or across permanent streams where discharge is generally small.

At Thule Air Base, it has been found that roadway and airfield embankments constructed of very coarse rocks permitted water passage for only a few years. As

thermal equilibrium was established in the embankment, ice filled the coarse fill pores and did not thaw during the brief summer season. Thus, the fills became dams to percolating water.<sup>3,6</sup> This may limit use of the dikes to warmer subarctic regions unless the fill is redesigned for a colder environment.

The other problem facing this type of design is that the rapid and turbulent flow through very coarse material could lead to erosion of fine-grained materials in the original ground. This problem could be avoided if geofabric materials were used as part of the fill.

#### THE STUDY

The purpose of this study is to find a method to mitigate the problems of icing, upstream ponding, and downstream concentrated flow. Research was carried out at an experimental mine, the Silver Fox Mine, owned by the School of Mineral Engineering, University of Alaska-Fairbanks. Located about 20 miles north of Fairbanks, the mine is reached via a 2.2-mile access road from the Elliott Highway.

Originally, the Silver Fox Road was a trail following a ridgeline to the mine. Gradually the trail was improved to become a road. Before the university purchased the property, the road was maintained intermittently. It was not plowed during winter months and the mine was not accessible until the road dried out in the spring. In early summer the road was repaired and the mine became accessible for a few months until winter snow again prohibited access.

The surficial deposit of the mine area consists of fine-grained (silt to fine sand), light brown soil, 1 to 3 feet thick. The soil is of uniform texture and is generally covered by a layer of moss. Below this fine-grained soil is a layer of coarser textured soil, 3 to 5 inches thick. This lower formation decomposes into sandy soil. The bedrock is composed of metamorphic and volcanic intrusive rocks.

#### Initial Conditions

The first phase of this research focused on a thorough investigation of the existing road conditions and on gathering climatic

data in the mine area. Since the closest reporting station, Fairbanks International Airport, is 20 miles south and 1200 feet lower in elevation, it was necessary to obtain site-specific temperature and precipitation data.

**Present Conditions**

Along with the present research project, an appropriations bill passed by the Alaska State Legislature set aside funds for DOTPF to undertake a major upgrade of the Silver Fox Road, constructing a road loop around the mine portal for improved access and upgrading the existing road from the Elliott Highway to the mine.

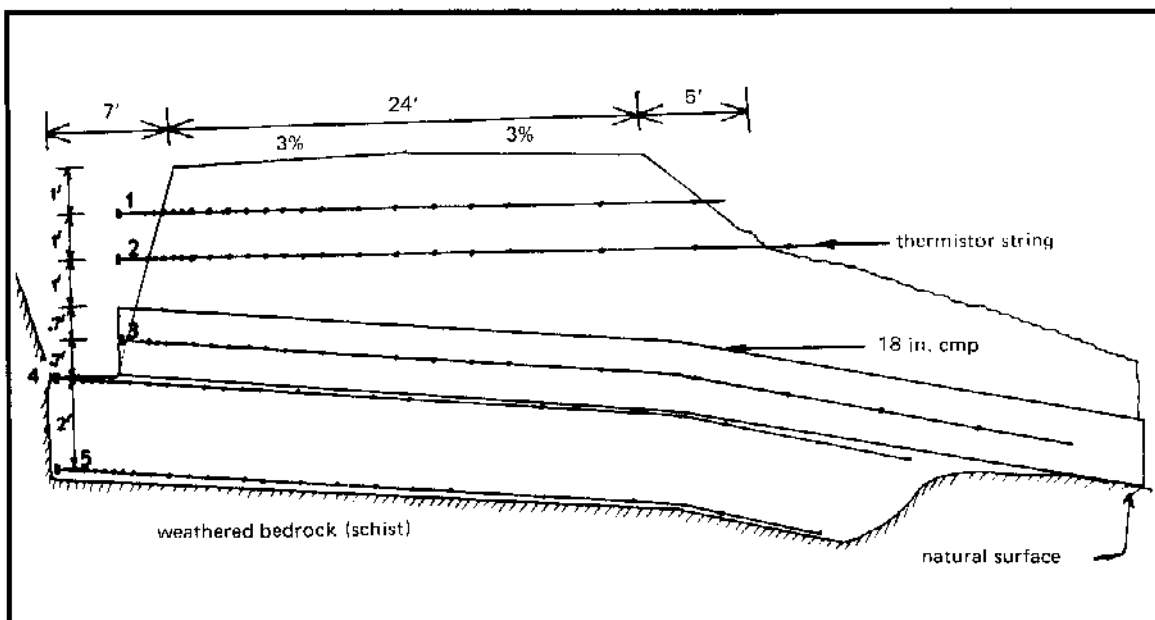
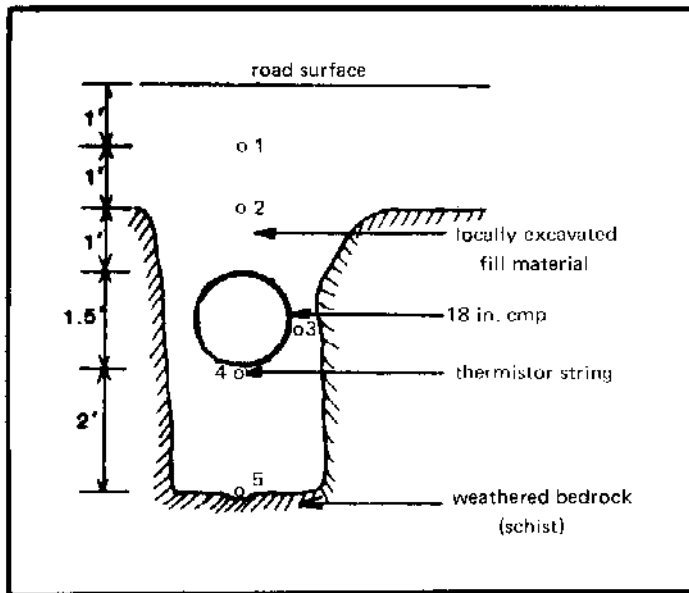
Work by DOTPF was coordinated with this project; actual improvement of the road commenced on 21 May 1985 and was essentially completed in late July 1985. Upgrading included clearing trees and shrubs on both sides of the road for a 50-foot right of way. The road was surfaced with gravel excavated from the area.

The access road presents a totally different picture. A wide (18-foot), elevated, and gravel-surfaced road now exists. Drainage ditches as deep as 6 feet in places were dug along the sides of the roadbed to assure adequate drainage. Culverts were installed at selected locations to facilitate cross drainage.

After a field study was made of the road improvements, two culverts were installed and instrumented with thermistors in early August 1985 so ground temperatures could be monitored throughout the year. The test site consists of a control culvert at station 80+00 and an experimental cross-drainage design at station 92+00. The control culvert is a corrugated metal pipe (cmp) 54 feet long and 18 inches in diameter. The road surface is 25 feet wide and the total embankment width is 30 feet. The culvert was buried 3 feet below the road surface and, where it extended beyond the embankment, it was covered by loose dirt. This culvert was expected to remain dry, except during spring breakup and summer rains.

The experimental culvert at station 92+00 is a cmp 24 inches in diameter and 34 feet long. The base of the embankment is 34 feet wide. The culvert was buried 3 feet below the road surface, over highly weathered bedrock, and serves as a cross-drainage passage for a small spring.

A French drain was constructed directly above the culvert. The drain was 2 by 3 by 32 feet and consisted of "sewer rock" enveloped by geofabric (Tyrar 3401). In the Fairbanks area, sewer rock is used in septic tank installation and its size varies from 2 to 8 inches in diameter. The geofabric was used mainly to minimize piping and erosion of fine materials from the sides of the French drain when turbulent flow occurs. It also serves as a capillary break near the surface of the road.<sup>7</sup> At the control culvert at station 80+00, the sandy gravel used for road fill was placed above the culvert. At both stations the



Two views of the control culvert at station 80+00: cross section (top) and longitudinal section (bottom).

top part of the embankment (2 feet thick) along the road consisted of sandy gravel (A-1) excavated nearby especially for road surfacing.

Both culverts were monitored with 5 strings of thermistors. Each string consisted of 23 thermistors spaced at 6-, 12-, 24-, and 60-inch intervals. These thermistors were assembled and calibrated to read to a tenth of a degree Celsius. These were read periodically using an 8060A true RMS multimeter.

Two hourly temperature recorders were placed at the site, one on a northeast-facing slope and the other one on a southwest-facing slope. Two thermometers, used to measure the maximum and minimum temperatures between the periodic readings, were placed on each side of the embankment near the culverts. These thermometers monitored the temperature differences between the shaded and non-shaded sides of the road. The snow depth was monitored with snow poles throughout the winter. The field study included monitoring the change in temperature of the embankment with respect to time. Measurements were taken periodically from weekly to daily readings during spring breakup in May at 1, 2, 3.7, 4.5, and 6.5 feet deep at the culvert at station 80+00, and at 1, 2, 4, 5, and 7 feet at the culvert at station 92+00.

**RESULTS**

The freezing and thawing indexes at the study site from July 1985 to June 1986

were recorded and are summarized below:

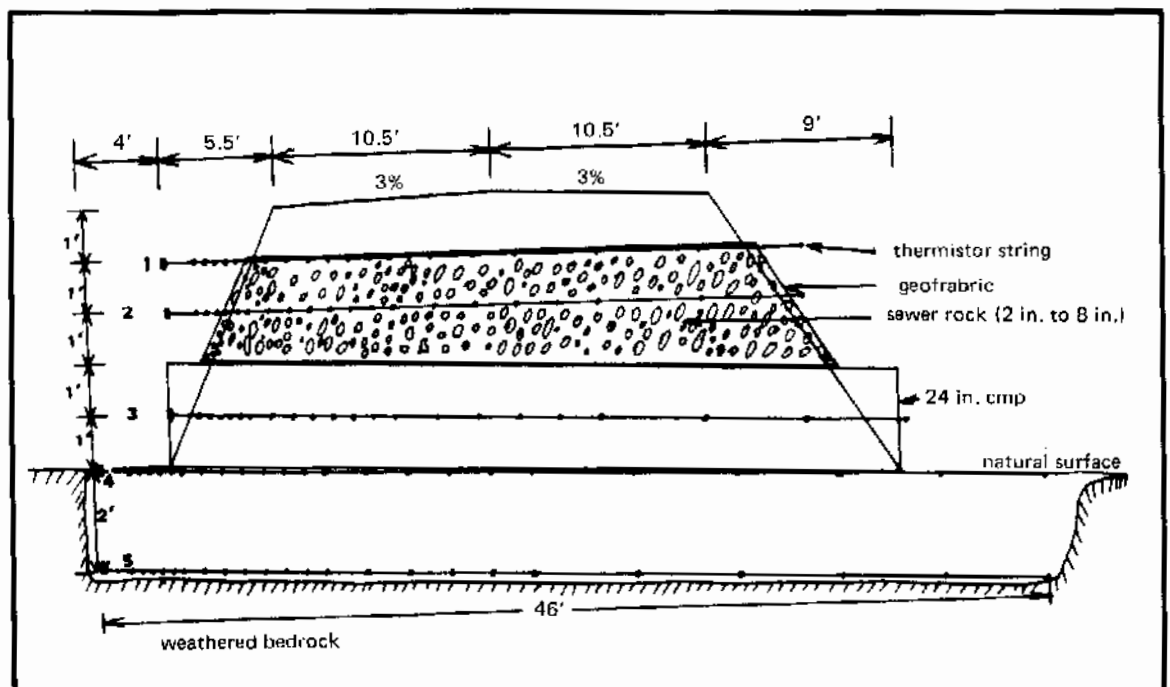
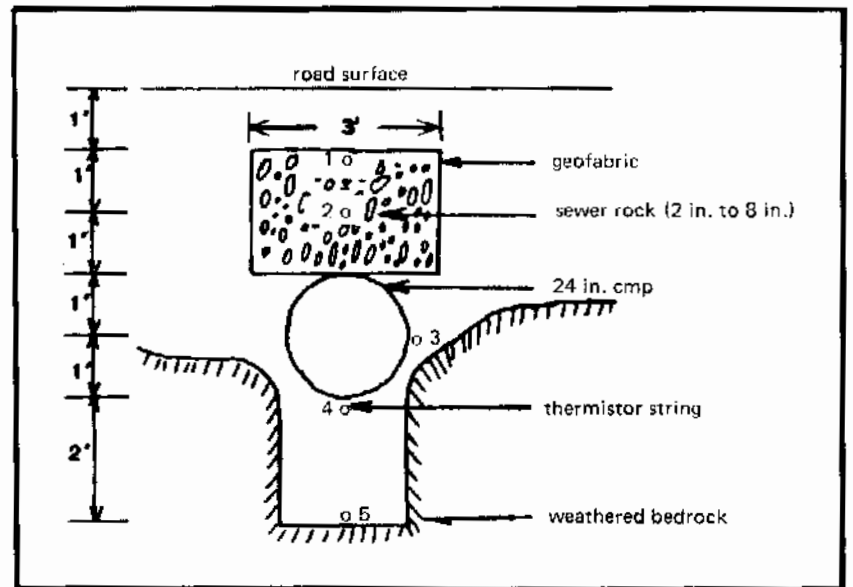
- Freezing index 2570°C (4627°F) degree days
- Thawing index 1247°C (2245°F) degree days

The mean freezing index for Fairbanks is 5500°F degree days and the design freezing index is 6500°F degree days. The mean thawing index for the same area is 3000°F degree days and the design thawing index is 3500°F degree days.<sup>9</sup>

The thermistor strings located at both stations were monitored from 19 October 1985 to 1 July 1986. Culvert icing devel-

oped first at station 92+00. This contributed to the migration of the channel flow away from and higher than the original channel. The culvert at station 80+00 remained free of ice and open until mid-December, when ice started to build up from the outlet toward the inlet.

Icing continued building up at the inlet of both culverts. At station 92+00 where water continued to flow from a spring, the icing grew faster, reaching a maximum height of 7.2 feet on 10 April. The thickness of ice over the road surface at that time varied from 1 to 2 feet, with the greatest thickness being at the inlet side. In the previous year (1985), the icing that



Two views of the experimental French drain at station 92+00: cross section (top) and longitudinal section (bottom).

began in early April was caused by snow melt; the natural spring froze that winter and hence the maximum ice thickness was only 10 inches in the ditch.

In contrast, the 1986 icing continued to build until 10 April and at station 80+00 reached a maximum thickness of 4.2 feet. On 16 April it was noted that the spring was flowing under the snow and along the edge of the ice mass at station 92+00. The flow continued through the cut slope into the drainage ditch. The flow of water developed a channel through the snow all along the drainage ditch, reached the culvert at station 80+00, and continued flowing along the drainage ditch. The runoff from melting snow began about 20 April and lasted for a few hours during the day. The flow usually started after 2 pm when the air temperature rose above freezing.

The snow melted faster on the cut slopes and slower beyond the cut slopes. Snow outside the right of way had melted completely by 6 May, but the ice on the inlet of the culverts and ditches persisted longer. After the snow was gone, seepage from melting ground ice appeared in the cuts and contributed to the runoff. By 17 May, the flow of water at station 80+00 had formed a large pond at the culvert inlet.

On 23 May, the water from the spring flowed across the French drain above the test culvert at station 92+00. This flow of water contributed to the accelerated melting of the ice within the culvert. Five days later, water was noted flowing through the culvert, while the culvert at station 80+00 was still completely filled with ice.

On 1 June a washout of the berm was noted at the inlet of the culvert at station 80+00, due to heavy precipitation on the previous day. The same runoff flowed through the culvert at station 92+00, but the culvert at station 80+00 was still full of ice, even though the inlet portion was no longer blocked by ice. The culvert at station 80+00 was ice free by 22 June and another heavy precipitation flow went through this culvert in late June.

### ISOTHERMAL DISTRIBUTION IN THE ROAD EMBANKMENT

The isothermal distribution in the embankments at the test culvert and at the control culvert varied significantly from time to time. The freezing front at station 80+00 advanced downward faster than at the test culvert at station 92+00. This might have been due to the energy given off by the flowing water from the spring.

At both culverts, the coldest part of the embankment was at the centerline. This developed a trough-like isotherm, colder at the center and warmer at the shoulders of the road due to the insulating effect of snow and ice.

During breakup, the coldest isotherms were found at the center of the embankment. It appears that the thawing front approached from every direction, including from the bottom. The isotherm distribution for 1 May shows that the coldest temperature at station 92+00 is greater than  $-2^{\circ}\text{C}$  while at station 80+00 it is greater than  $-4^{\circ}\text{C}$ . By the end of June, the thawing front at both culverts had reached down to 7 feet.

### COMPARISON OF CENTERLINE THERMISTORS

The comparison of the temperature of thermistor string no. 1 at a depth of 1 foot indicates that the temperature at station 92+00 remained colder from October to mid-December than at station 80+00. From mid-December to the first week of January, the temperatures were similar. After that period, the ground temperature at station 92+00 remained warmer than at the control culvert. This appears to be the result of energy released from ice formation. The road surface above the culvert at station 92+00 was covered by 1 to 2 feet of ice, and the thawing front reached 1 foot deep a few days earlier than at station 80+00. The differences in centerline temperature at the two stations at a depth of 2 feet followed the same pattern as in string no. 1. Prior to spring breakup, the difference in temperature between the stations became greater. The temperature at station 92+00 at a depth of 2 feet rose above  $0^{\circ}\text{C}$  about a week earlier than at station 80+00.

The ice in the test culvert thawed much faster than the ice in the control culvert at station 80+00. This was attributed to flow through the French drain. The temperature at the centerline and at the culvert-soil contact at station 92+00 reached  $0^{\circ}\text{C}$  two weeks earlier than at station 80+00. The string of thermistors at station 92+00 was 0.25 feet deeper than at station 80+00. Also, the culvert at station 80+00 was filled by ice prior to spring breakup.

### CONCLUSION

It appears that the coarse material in the test culvert installation remained ice free except at the inlet shoulder. The center did not remain above freezing as

reported by Carey,<sup>3</sup> but it adjusted to the surroundings as the air temperature changed. In general, this layer of coarse rocks remained warmer than at 80+00 at the same depth, where local material was used.

The culvert at station 80+00 was plugged by ice until mid June. Water began flowing across the French drain at station 92+00 on 23 May, as soon as the ice barrier on the left shoulder was gone. This further contributed to faster melting of the ice inside the culvert. The design used here appears to accelerate thawing of the embankment, contributing to earlier flow of water across an embankment. This design could decrease the length of time a stream is impounded along roadways. With the elevated embankment and deep drainage ditches, the gravel-surfaced road remained accessible all year round. During the thawing period, the deepest rut was observed to be less than 0.5 inches at places where meltwater reached the road surface.

### REFERENCES

- <sup>1</sup>Hennion, F.B., and E.F. Lobacz. 1973. Corps of Engineers technology related to design of pavement in areas of permafrost. *In* North American Contribution to the Second International Conference on Permafrost. National Academy of Sciences, Washington, DC, pp. 658-664.
- <sup>2</sup>Reckard, M.D. 1983. Economic aspects of high speed gravel roads. *In* DOTPF Final Report, prepared for the State of Alaska.
- <sup>3</sup>Carey, K.L. 1973. Icings Developed from Surface Water and Groundwater. Monograph III-D3, U.S. Army CRREL Cold Regions Science and Engineering, Hanover, NH.
- <sup>4</sup>Brown, J., B.E. Brackett, and K.E. Howe. 1984. Interaction of gravel fills surface drainage and culverts with permafrost terrain. *In* DOTPF Report No. AK-RD-84-11, prepared for the State of Alaska, p. 35.
- <sup>5</sup>U.S. Army Corps of Engineers. 1959. Approach roads, Greenland 1955 Program. *In* Technical Report No. 3-505, U.S. Army CRREL Cold Regions Science and Engineering, Hanover, NH.
- <sup>6</sup>Linell, K.A., and G.H. Johnston. 1973. Engineering Design and Construction in Permafrost Regions: A Review. MP 772, U.S. Army CRREL Cold Regions Science and Engineering, Hanover, NH.
- <sup>7</sup>Bell, J.R., T. Allen, and T.S. Vinson. 1983. Properties of geotextiles in cold regions applications. *In* Proceedings of the Fourth International Conference on Permafrost. National Academy of Sciences, Washington, DC, pp. 51-56.
- <sup>8</sup>Hartman, C.W., and P.R. Johnson. 1984. Environmental Atlas of Alaska. Institute of Water Resources, Engineering Experiment Station, University of Alaska-Fairbanks. ♦