

## 20 YEAR PERFORMANCE HISTORY OF FIRST INSULATED ROADWAY ON PERMAFROST IN ALASKA

David C. ESCH, P.E.

*State of Alaska, Department of Transportation and Public Facilities  
Statewide Research, 2301 Peger Road  
Fairbanks, Alaska 99709-6394 U.S.A.*

### Abstract

In 1969, extruded polystyrene foam insulation layers were experimentally installed beneath a new section of the Edgerton highway constructed over warm (-1 °C) permafrost soils near Chitina, Alaska. This was the first such installation in North America for preventing or controlling thawing of permafrost foundation soils beneath a roadway. Periodic monitoring of temperatures, thaw depths, and settlements has continued since construction. In 1989 this installation reached its theoretical 20-year "design life", and the performance history has been reviewed and summarized as reported in this paper.

The polystyrene insulation placed in 1969 beneath the new road embankment was very effective in reducing road surface settlements, particularly for the first years after construction. Over time, the annual settlement rates in the insulated areas have accelerated, but insulated area road surface settlement rates have never reached the rates observed on the adjacent uninsulated road sections. Because of the warming influence of the roadway and particularly the side-slopes, progressively deeper annual warming and thawing is now acting to undermine the entire embankment, in spite of the fact that the insulation was extended out to the lateral limits of the embankment. Talik zones below the slopes grow in depth and lateral extent each year, and after 20 years have progressed to where they are affecting even the center of this relatively narrow (8 m wide) roadway section. The insulation layers have effectively reduced the thawing rates by 30 to 50% and the insulation layers have retained their thermal properties very well over time. However, periodic road maintenance levelling and resurfacing has been necessary in order to provide adequate safety and ride quality on this roadway.

### Résumé

En 1969, des couches de mousse d'isolant polystyrène, ont été installées à titre d'expérience, sous une nouvelle section de la route Edgerton construite sur du pergélisol tiède (-1 °C) proche de Chitina en Alaska. C'était la première installation du genre en Amérique du Nord pour la prévention et le contrôle du dégel du pergélisol sous une route. Le suivi périodique des températures des profondeurs de dégel et de l'affaissement du terrain a été assuré depuis la construction. En 1989, cette installation est parvenu au terme de sa vie théorique de 20 ans. L'histoire de son comportement a été compilée et est présenté dans cet article.

L'isolant polystyrène mis en 1969 sous le remblai de la nouvelle route, a été très efficace pour réduire les affaissements de la chaussée, particulièrement durant les premières années après la construction. Avec le temps, les taux annuels d'affaissement dans le tronçon isolé ont accéléré, mais les taux d'affaissements de la route isolée n'ont jamais atteint les taux observés sur les sections routières voisines non isolées. A cause de l'influence thermique de la chaussée et particulièrement des bas-cotés, la pénétration annuelle de plus en plus profonde de la chaleur et du dégel sont maintenant en train de miner entièrement les remblais, même si l'isolant avait été étendu jusqu'aux limites latérales du remblai. Les taliks en dessous des pentes croissent en profondeur et s'étendent latéralement chaque année, et après 20 ans ont progressé au point où ils affectent maintenant le centre de cette route de 8 m de largeur. Les couches d'isolant ont effectivement réduit les taux de dégels de 30 à 50% et elles ont très bien conservé leurs propriétés thermiques. Cependant, des renouvellement routier périodiques et des remises en état de la route ont été nécessaires afin de garantir des conditions sécuritaires et un roulement agréable.

### Introduction

In 1969, extruded polystyrene foam insulation layers were installed beneath a section of the Edgerton Highway near Chitina, Alaska. The product used was Styrofoam HI-35 as produced by the Dow Chemical Co. This is believed to be the first foam plastic insulation application in

North America for preventing or controlling thawing of permafrost foundation soils beneath a roadway. The design, construction, and 3-year performance history were described in a publication by Esch (1973). In 1989 this installation reached the theoretical 20-year "design life", and it is appropriate that the performance history be reviewed and summarized.

## Chitina - site history

This project involved the insulation of two relatively short (25 m) adjacent roadway sections, using insulation thicknesses of 51 and 102 mm. The roadway was newly constructed in August of 1969, and crossed a muskeg area underlain by warm (-1 °C) permafrost soils consisting of frozen silty peat underlain by ice-rich silts. The location is 10 km north of the town of Chitina and was built as a part of the "Chitina-North" construction project.

Prior to insulation placement, the trees and brush were hand-cleared and placed on the moss-covered surface; except for the segment to be insulated, which received a levelling layer of gravelly sand roughly 0.3 m in thickness instead of the brush layer. The insulation was placed in August of 1969 after first levelling and compacting the gravelly sand fill to provide a stable base for the 51 mm x 0.61 m x 2.44 m insulation boards. Near the south end of the test site, a short "cut section" was required, where the surface vegetation had to be stripped away. This section allowed for further comparisons between "cut" and "fill" sections. Temperature instrumentation was installed in the two insulated sections, in the adjacent normal or "control" embankment sections, and in the cut area, for a total of five cross-sections under study.

The original 1969 road construction project provided only for a gravel-surface on this secondary highway. However, the costs of installing insulation beneath an embankment are primarily justified when the surface is paved. For this reason, and to provide for accurate surface elevation surveys and settlement observations, the road was paved with a road-mixed asphalt surfacing in July of 1971. This surfacing extended only for 165 meters to cover the insulated sections and the adjacent uninsulated control and cut sections. This temporary pavement provided a basis for surface elevation surveys from 1971 through 1974.

During the first five years after construction the settlements of the road surface were very rapid in the sections which were not insulated. The control area settlements were as great as 280 mm over the 39 month period ending in October of 1974, while the maximum insulated area settlement was only 30 mm. Patching and levelling had to be done with gravel, and the paved surface was finally removed early in 1975 to allow for periodic regrading and levelling of this roadway segment.

From June, 1975 through July, 1987 the road remained gravel-surfaced. Elevation surveys were based on 14 steel settlement plates installed in September of 1977 at 3.6 m left

and right of the road centerline. The plates were placed 0.3 m below the surface and re-excavated for annual surveys. During this period, the surface settlement rates rose in the insulated areas and decreased in the control areas, for reasons not yet known. It is possible that thawing beneath the insulation by this time had simply progressed through the low thaw-strain soils of the old active layer and into the more ice-rich permafrost foundation soils. However it appears more likely that progressive thawing beneath the side-slopes has allowed lateral spreading to occur, and this spreading has resulted in some settlements of the entire road surface. In the years following construction; lateral spreading cracks were first observed in the side-slopes, then in the shoulders, and finally in the outer and inner wheel-paths. No spreading measurements were made at this site, but observations at a site near Fairbanks (Esch, 1988) indicated that the top of such a roadway may widen by 0.5 to 1.0 % per year.

In August of 1987 this highway was finally "paved" with an asphalt surface treatment consisting of 2 layers of rock "chips" bonded with an asphalt emulsion of grade CMS-2. Since the final surface of the road is covered by a layer of rock chips bonded on their underside with asphalt in this method, the surface has an initially higher reflectivity or "albedo" than a hot-mixed asphalt pavement. However, the sealed surface does have the effect of eliminating the evaporative cooling effects noted with gravel surfaces, and thereby raising the average summer surface temperature. During the 1988 and 1989 thawing seasons, the settlement rates increased from 58 to 75 % over the averages for the previous 10 year period (Table I). Again during this period, the uninsulated area settlement rates were higher than where insulation was used. However, the differences were not nearly as dramatic as during the first five years. By the summer of 1989, some levelling and patching was again required over the north (control) end of the study site, demonstrating that this roadway had not "stabilized" after 20 years of service.

Table I.  
Average Annual Settlement Rates (mm/yr) from Elevation Surveys of Shoulder Area Reference Points.

Embankment Type	Surface Conditions and Years of Data		
	Paved '71 - '74	Gravel '77 - '86	Paved '87 - '89b
Normal Fill & Cut	67 mm/yr	40 mm/yr	67 mm/yr
Insulated (102 mm)	9 mm/yr	24 mm/yr	43 mm/yr
Insulated (51 mm)	12 mm/yr	36 mm/yr	58 mm/yr

Table II.  
Average Settlements (mm) at Road Shoulders over Various Time Periods.

Surface Condition	Gravel 1969-70	Paved 1971-74	Gravel 1975-76	Gravel 1977-87	Paved 1988-89	20 Year Totals
Thawing Season						
Normal Fill	104	180	100	405	131	920
102 mm Insulation	12	21	30	244	85	393
51 mm Insulation	15	27	46	365	116	569
Cut Section	98	158	91	372	137	856

The primary purpose for insulating a roadway on permafrost is to reduce the thaw depths and thereby reduce or eliminate the long-term settlements and settlement-related cracking of the road surface. The ultimate goal is to minimize both ride roughness and long-term maintenance costs. Observed settlement rate averages and observation periods based on measurements on the road shoulders at 3.5 m left and right of the centerline, are shown by Table 1.

Total shoulder area settlement estimates, based on periods of actual settlement observations which covered 67% of the last 20 years, and on interpolations between those times, are shown by Table II. These estimates indicate that the outer edges of the roadway driving surface have settled nearly a meter since construction, while the insulated areas have settled roughly half that much.

Comparisons between settlements at centerline and at the outer edges of the driving lanes could be made only at the times when the road was asphalt surfaced. In the 1971-74 period, centerline settlements were similar to the shoulder settlements. Most recently (1988-89), the normal fill settlements were 15% greater at the lane edges than at centerline, while in the insulated areas, settlements averaged 29% greater at the lane edges. Lateral spreading of the embankment also occurred with the settlements of the shoulders. Exact measurements of spreading were not made, but from cross-section surveys, the embankment widths apparently increased by about 1.5 m over 20 years.

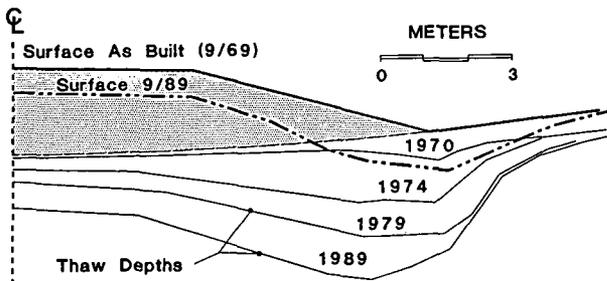


Figure 1. Cross-Section view of normal Embankment, constructed over surface vegetation and cut brush layers. Maximum thaw depths after 1, 5, 10, and 20 years., and settlements after 20 years.

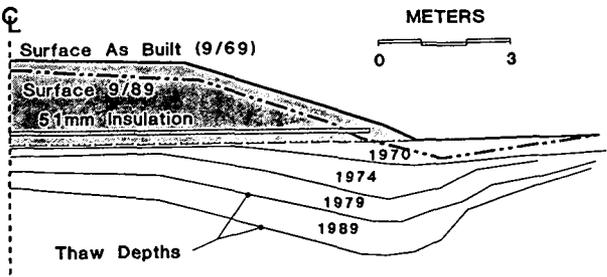


Figure 3. Embankment constructed over surface vegetation, with 51 mm insulation layer. Maximum thaw depths and 20 year settlements.

Table III. Thaw Depth Increases and Maximum (m) Depths Beneath the Road at Centerline

Embankment Type	Observation Period		Maximum Thaw Depth After 20 Years
	1969 - 1979	1979 - 1989	
Normal Fill	0.67 m	0.52 m	3.26 m
102 mm Insulated	0.51 m	0.21 m	2.56 m
51 mm	0.55 m	0.36 m	2.92 m
Cut Section	2.01 m	0.45 m	3.78 m

THAW DEPTHS

Roadways constructed on warm permafrost almost always cause some net surface warming and progressively deeper annual thawing of the permafrost foundation soils. Two methods have been used to measure the maximum annual thaw depths. A total of 12 vertical strings of thermocouples were installed beneath the roadway in 1969. The September and October temperature measurements are used to determine the depths of the thaw/freeze interface (permafrost surface) beneath the road surface at the end of each thawing season.

Thaw depth changes at the road centerline over the first and second ten year periods after construction are shown by Table III. The final 20 year depths of thaw beneath the original road surface are also shown, and indicate that the 102 mm insulation layer reduced the long-term thaw depths by 22 to 32% as compared to uninsulated fill and cut areas. Hand or machine probing of frost depths in the lower side-slope areas provided additional thaw depth data where it was

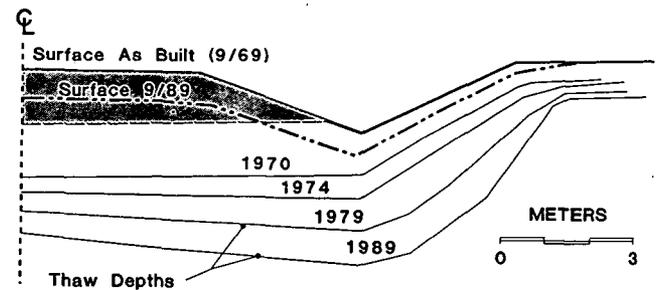


Figure 2. Embankment constructed in "cut" section where all surface vegetation is first removed. Maximum thaw depths and 20 year settlements.

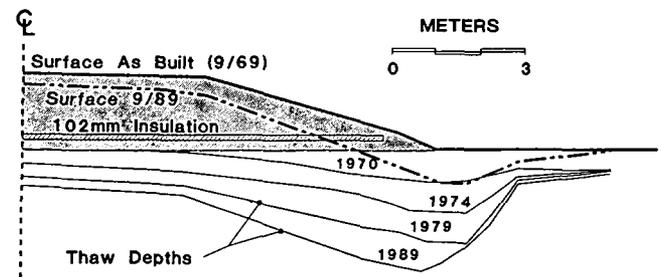


Figure 4. Embankment constructed over surface vegetation, with 102 mm insulation thickness placed in two layers. Maximum thaw depths and 20 year settlements.

possible to penetrate the embankment with these procedures. Surface elevation surveys along with the probing have provided the data for plotting the typical embankment cross-section changes and thaw depth changes over time, as shown by Figs. 1 - 4. As can be seen from these plots, thaw depths beneath the road centerline have advanced into the underlying permafrost by a small amount over the last 20 years, in comparison to the major changes which have occurred beneath the side-slopes and shoulders of the embankment. Thawing near the "embankment toe", where the fill intersects the undisturbed ground, has progressed to depths of 2.9 to 3.1 m over 20 years in non-insulated areas, and to 2.5 to 2.6 m with insulation. Thaw depths beneath the side-slopes at a distance of 1.8 m inside the embankment toe are plotted versus time in Figure 5. These deep thaw zones demonstrate what is perhaps the primary problem with road embankments on warm permafrost: the net warming and progressive thawing caused by the embankment slopes which are exposed to solar heating in summer and insulated by snow in winter. Thaw rates beneath the slopes were reduced by 30 to 50% by the insulation. Data from other instrumented road sections in Interior Alaska have shown that side-slope surface temperatures typically average from 4 to 8°C warmer than the annual average air temperatures (Esch, 1988). These high average slope surface temperatures indicate a persistent heat source from solar warming, which acts to degrade any underlying permafrost.

At the Chitina site, heat from the warm slopes has progressively thawed the underlying permafrost to the extent that the entire roadway structure is now affected. Even the center of the insulated embankment is effectively being undermined by thaw and consolidation of soils beneath the slopes. This situation demonstrates that the most successful applications of insulation in embankments may be where a very wide top surface is provided and is maintained free of snow. The periodic removal of snow from the side-slopes would also be of benefit in slowing the progressive thawing process by allowing greater wintertime cooling.

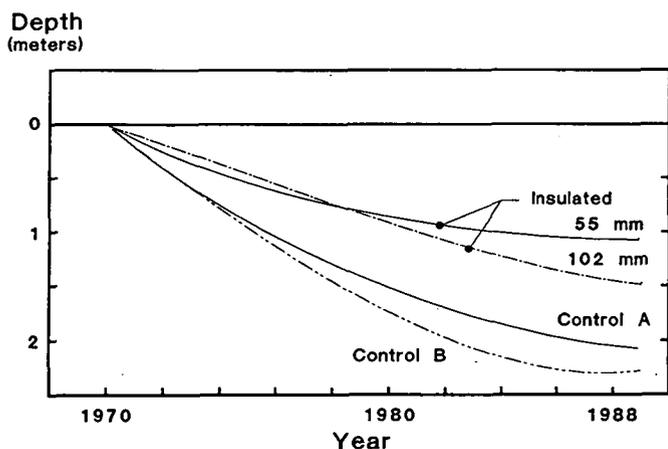


Figure 5. Thaw depth changes beneath roadway embankment side-slopes over 20 years. Based on probing to permafrost surface at a distance of 1.8 m inside of embankment toe. Control sections A and B are located before and after the insulated areas.

#### TEMPERATURE OBSERVATIONS AND TRENDS

For the first five years, on-site air temperature records were kept through the use of a 30-day chart recorder. Equipment problems have since required a reliance on records from the Gulkana airport, located 86 km northwest of the Chitina site. Based on the years when direct temperature comparisons were possible, the Chitina site averaged 84.7% of the freezing indices and 97.3% of the thawing indices measured at Gulkana. On this basis extended over the data period of 1950-1980, the Chitina site had estimated mean freezing and thawing indices of -2200 and +1575°C days, and a long-term mean annual temperature of -1.7°C.

There is some evidence that this site, along with many other parts of Alaska, is being affected by an air temperature warming trend since about 1975, of roughly 1-2°C. The lack of recent site-specific air temperature data makes this warming impossible to document for the project site. However, at the Gulkana airport, located 65 km northwest of this site, the mean annual temperature from 1976 through 1988 was -1.83°C, compared to a long-term average of -3.05°C,

#### SUBSURFACE TEMPERATURE TRENDS

Subsurface temperature trends are observed by periodic voltage measurements of 125 thermocouples installed in 1969 in 11 different boreholes covering the five study sections, and in one borehole in the undisturbed forest. The dependability of this system has been remarkable, with only four of the thermocouples not functioning after 20 years, and an estimated accuracy level of + 0.3°C or better, based on point to point and month to month comparisons.

At the undisturbed forest site, located 17 m south of the roadway clearing area, permafrost temperatures at the 9.1 m depth have risen progressively from -1.1°C in 1970 to -0.5°C by 1984. Since that time temperatures have remained stable at about -0.5°C, which approaches the thawing point of the peat (-0.10 to -0.3°C). Undisturbed forest area deep

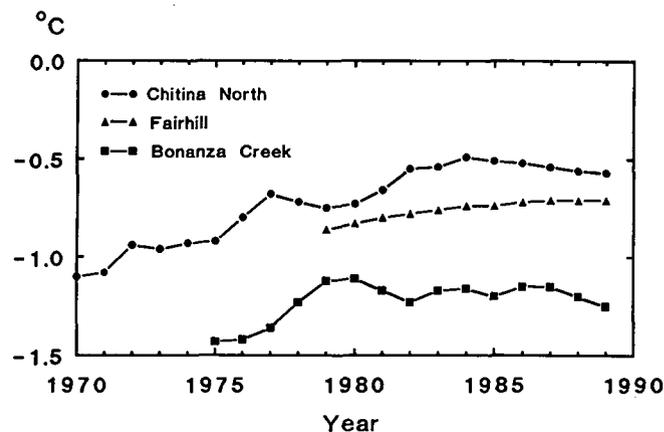


Figure 6. Mean annual permafrost temperatures below undisturbed forest areas in central Alaska. Depths are 6 m at Chitina and 9 m at Bonanza and Fairhill Sites near Fairbanks.

Table IV.  
Permafrost temperatures in early October. Temperature at a Depth of 6.1 m.

Condition	Location	Temperatures (°C)			
		10/14/69	10/09/72	10/03/79	10/10/89
Uninsulated	Centerline (A)	-1.3	-0.8	-0.5	-0.4
Fill Sections	Centerline (B)	-1.2	-1.1	-0.6	-0.4
102 - mm	Centerline	-1.1	-0.5	-0.4	-0.3
Insulation	8.2 m right	-1.1	-0.4	-0.4	-0.3
	9.8 m right (toe)	-1.1	-0.5	-0.4	-0.2
51mm Insulation	Centerline	-1.1	-0.6	-0.5	-0.5
	8.2 m right	-1.1	-0.4	-0.4	-0.4
	9.8 m right (toe)	-1.0	-0.6	-0.5	-0.3
Cut Section	Centerline	-1.2	-1.2	-0.6	-0.4
	Ditch Bottom	-1.1	-0.8	-0.5	-0.3
Undisturbed	27 m right	-1.0	-0.8	-0.7	-0.6

temperature data for the China site and also for two similar undisturbed sites near Fairbanks, Alaska are shown by Figure 6. All three sites demonstrate a recent permafrost warming trend. However, measurements of the undisturbed area seasonal thaw depths by probing at these locations have shown no trend toward increased active layer thicknesses in undisturbed forest areas.

Temperatures at various depths beneath the center of the roadway at the end of the thawing season, which typically occurs at the end of September, are indicative of both the maximum depth of thaw and the maximum permafrost temperatures at shallow depths. Late September temperatures after 2, 10, and 20 years are shown by Table IV for the different roadway sections. The maximum depths of refreezing are typically indicated by March and April temperature readings. The data from the 1988-89 winter, which was colder than average, indicate that total refreezing of the active layer was not occurring in any of the twelve instrumented boreholes. This is based on the fact that temperatures at some depth along each thermocouple string always remained warmer than -0.35°C. Beneath the road centerline, this residual thaw layer or "talik" was very thin, while it was approximately 2 m in thickness beneath the side-slopes. Instrumentation was not extensive enough to more clearly define the talik zones than the above approximations. However, it is very apparent from the data that the taliks are enlarging in roughly equal annual increments and that the underlying permafrost is warming progressively.

#### INSULATION PERFORMANCE

Insulation sampling and testing to measure moisture absorption and compression under field conditions was performed three times during this study. Two test pits were hand-excavated through the right side-slope in 1972, 1984, and 1989. At these locations there was approximately 0.5 m of gravel cover over the insulation. Laboratory test results were as shown by Table V.

In all cases, the highest moisture absorption values were on samples from the single-layer (50 mm) insulation section. Moisture contents from the two layer insulation section averaged only 50 to 60% as high as in the single layer. It is possible that the typically higher temperature gradient across the 51 mm insulation layer, and the correspondingly higher water vapor pressure gradient, were the reasons for greater moisture absorption in the single layer. At the times of the last two sampling efforts (1984 and 1989), the insulation samples were removed from below the groundwater level. Insulation thickness measurements averaged 53.2 mm in 1972, and 50.5 mm in 1989, indicating about a 5% decrease in thickness. Adjusting for the differences in static load on the insulation between the sampling locations and the center-roadway areas indicates that the maximum 20 year compression might be on the order of 15%. When the thickness changes are coupled with the 5% rise in wet thermal conductivity values indicated between 1972 and 1989, the data suggest that the thermal resistance of the insulation layers may have decreased by 10 to 20% over the first 20 years of service. This is considered to be excellent performance in view of the long-term immersion of the insulation boards.

Table V.  
Moisture Absorption and Thermal Conductivity of Field Samples Taken in Late September after 3, 15, and 20 years in Service.

Property	Layer	Year Sampled & Tested		
		1972	1984	1989
Moisture % Volume	Single	--	1.54	2.20
	Top	0.42	0.71	1.10
	Bottom	0.15	0.88	1.70
Thermal Conductivity mW/m <sup>2</sup> K	Single	--	34.2	30.7
	Top	29.4	31.1	31.0
	Bottom	29.6	32.4	31.3

## Performance Summary

At the Chitina Site, the polystyrene insulation placed in 1969 beneath the new road embankment was very effective in reducing road surface settlements for the first 5 to 8 years after construction. Over time, the annual settlement rates in the insulated areas have accelerated, but insulated area road surface settlement rates have never reached the rates observed on the adjacent uninsulated road sections. The beneficial effects of the insulation have been less apparent beneath the side-slopes, where progressively deeper annual warming and thawing is now acting to undermine the entire embankment in spite of the fact that the insulation was extended out almost to the lateral limits of the embankment. Talik zones below the slopes grow in depth and lateral extent each year, and after 20 years have progressed to where they are affecting even the center of this relatively narrow (8 m wide) roadway section. The insulation layers have retained their thermal properties very well over time, and continue to perform their function as intended.

## Research Needs

This review of the 20 year performance of the Chitina Insulation site has demonstrated some of the benefits and problems of insulated and uninsulated road embankments constructed over warm permafrost. As documented above, the net warming effects of the gravel surfaced side slopes

have contributed greatly to the long-term settlements of the entire embankment. This problem has also been found to predominate in cut sections (Reckard, 1988), and in fill sections at other warm permafrost sites (Esch, 1988). The potential for passively cooling embankment slopes with elevated coverings was evaluated by Zarling and Braley (1987). Their studies of snow shed/solar screen structures demonstrated that mean slope surface temperatures could be lowered by as much as 6°C by this means.

Suggested research areas in need of further work are as follows:

- Non-contact or surficial methods of sensing and mapping thaw-unstable permafrost conditions, for determination of the starting and ending points in insulation applications, and also for selection of the most favorable routes.
- Slope surface to air temperature relationships for different soil and vegetation types, different slope angles, heights, and orientations, and different latitudes, and precipitation levels.
- Slope surface modifications for altering the heat balance, such as slope coverings, air cooling ducts, and thermosyphons.
- Economical pre-thawing techniques for use in advance of construction.
- Forecasting methods for future climatic factors, as global warming forecasts indicate that the past climate is no longer a guide to the future.

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