PERMAFROST DEGRADATION AND ADAPTATIONS OF AIRFIELDS AND ACCESS ROADS NUNAVIK, QUEBEC, CANADA

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ABSTRACT

In Nunavik, permafrost degradation is now inevitable and it will eventually become problematic for the integrity of some transportation infrastructures owned by Ministère des Transports du Québec (MTQ). This study was initiated by the MTQ in order to adapt its transportation infrastructures to the new climatic reality. The purpose of this study is to identify the consequence of global warming on infrastructures, to review all mitigation techniques that can be used to counter permafrost degradation under transportation infrastructures and to carry out a performance assessment of the Nunavik runways and access roads since their construction in order to determine the appropriate adaptation techniques to reduce permafrost degradation. The assessment made it possible to identify six unstable runways and two unstable access roads. However, three airports in Nunavik need to be monitor very closely : Kangirsuk, Salluit and Tasiujaq. Three mitigation methods are proposed to reduce permafrost degradation at Nunavik transportation infrastructures : heat drain, air convective embankment and reflective surface.

INTRODUCTION

The territory of Nunavik is located in Quebec's Arctic region. It is situated north of the 55^{th} parallel and covers approximately 20 % of the surface of the province of Quebec. Its territory extends over seven degrees of latitude passing through the sporadic, the discontinuous and the continuous permafrost zones (Figure 1). The climate of Nunavik is characterized by a subarctic and arctic climate. The mean annual air temperature in Kuujjuaq is approximately -4.5°C while in Salluit, it is approximately -9°C. The population of Nunavik, mainly Inuit, is distributed in the fourteen communities located along the coast of Hudson Bay, Hudson Strait and Ungava Bay.

In 1975, the signature of the James Bay and Northern Quebec Agreement generated the construction of twelve airports for the Inuit communities. The construction of the airports started in 1984 and finished in 1992 at the cost of 100 million dollars. Each airport was designed with a gravel landing strip, an access road to the airport, a terminal and a garage.

In the next sections, the paper will identify and describe problems related to thawing permafrost under transportation infrastructures, include a review of technical and operational mitigation techniques and present a performance assessment of the Nunavik runways and access roads since their construction in order to determine the appropriate adaptation techniques to reduce permafrost degradation.

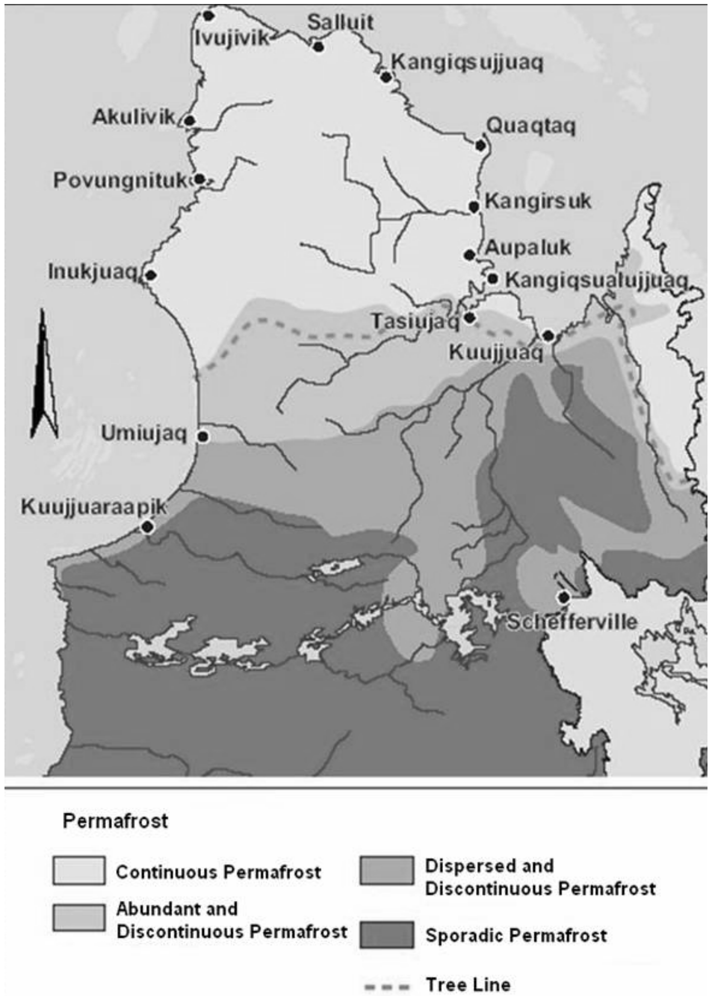

Figure 1 : Nunavik and permafrost distribution map (Allard et Séguin, Consortium Ouranos, [1])

GLOBAL WARMING

Pavements, which had long been stable, are now beginning to show signs of instability due to the climate warming prevailing in Nunavik. Since 1992, the entire Nunavik territory has experienced a clear climatic change trend (Figure 2) (MTQ, [2]). An important warming now prevails. This warming is beginning to have significant impacts on many infrastructures built on permafrost. By the end of the century, the temperatures in Nunavik are likely to increase by as much as 5°C to 10°C. The northern region of Quebec is the region which will undergo the most important changes in the next decades by a modification of its climate and environment and the degradation of the continuous permafrost zone (Consortium Ouranos, [1]).

Since the territory of Nunavik is not accessible by land, either by road or railway, air transportation is essential to ensure the communications between the fourteen communities and the southern part of Quebec. The runways constitute communication links that are essential for the socio-economic development of the Inuit population allowing displacement of people and transport of goods. Permafrost degradation could result in an important loss of the structural and functional capacities of the runways and access roads, which could compromise the safety and the comfort of the users. This situation could become an important engineering problem for the transportation infrastructures in these cold regions.

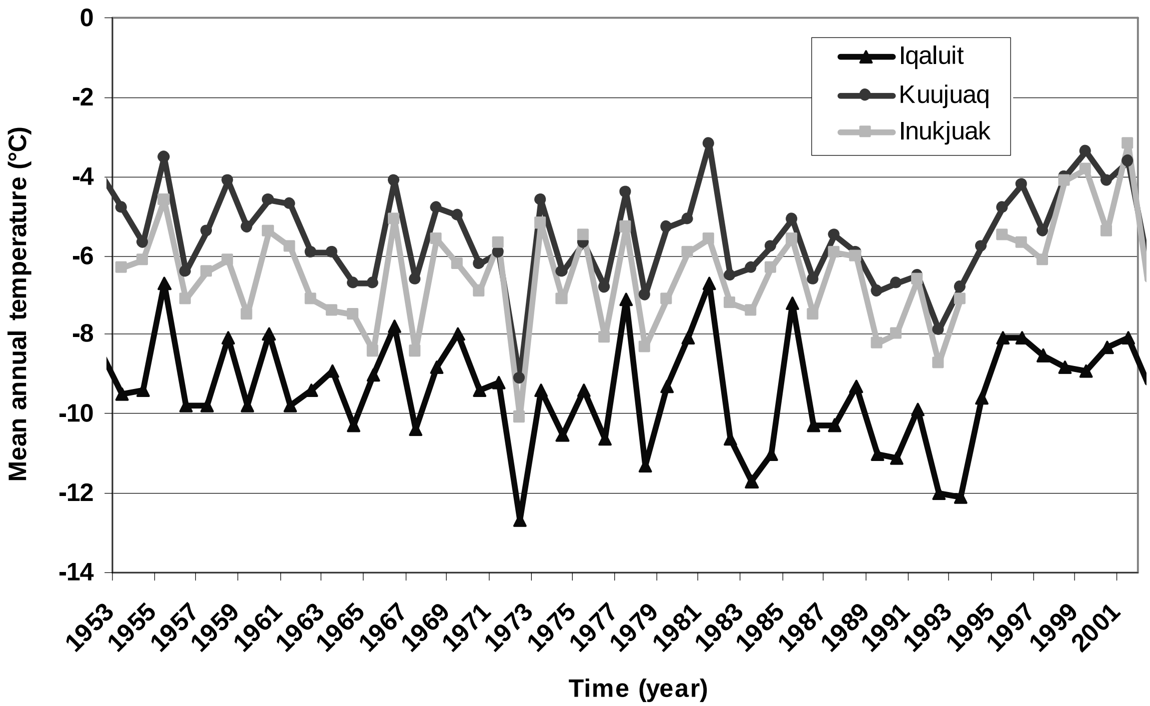

Figure 2 : Mean annual air temperature in Nunavik since 1950 (Allard, MTQ, [2])

CONSEQUENCES OF GLOBAL WARMING ON TRANSPORTATION INFRASTRUCTURES (Permafrost Degradation Mechanisms)

The main consequences of permafrost degradation are mainly thaw settlement and drainage related problems. The most frequent problems observed in Nunavik are depressions along airstrip edges and roadsides and water ponding in drainage ditches. These problems are mainly caused by the embankment geometry. In winter, snow accumulates on the side-slopes and tends to insulate the embankment limiting ground cooling during winter. As a result, the ground temperature under the side-slopes will increase causing permafrost degradation and loss of support if the permafrost is ice-rich. At the pavement surface, the settlements will generate longitudinal cracking or shoulder rotation (Figure 3). Figure 4A and 4B presents examples in Alaska of longitudinal cracking and shoulder rotation.

In permafrost zones, the construction of an embankment results in a readjustment of the permafrost table depth. Consequently, the active layer will become deeper. To counter these problems, the thickness of the embankment must be designed to contain the freezing and thawing depth in the granular materials, which are not frost or thaw susceptible. One of the main consequences of permafrost degradation is thaw settlement. Settlement can be caused by the degradation of uniform ice-rich soil or by the variability of ice content and the composition of soil. For example, settlements can be observed by the displacement of the drainage infrastructures (e.g. culvert) or by the creation of unequal undulations on pavement surface (Figures 4C and 4D).

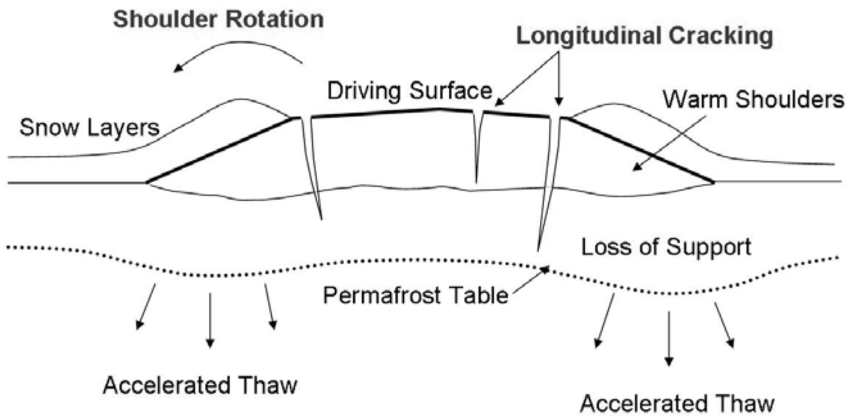

Figure 3 : Transportation infrastructure degradation mechanisms related to the embankment geometry (Goering, [3])

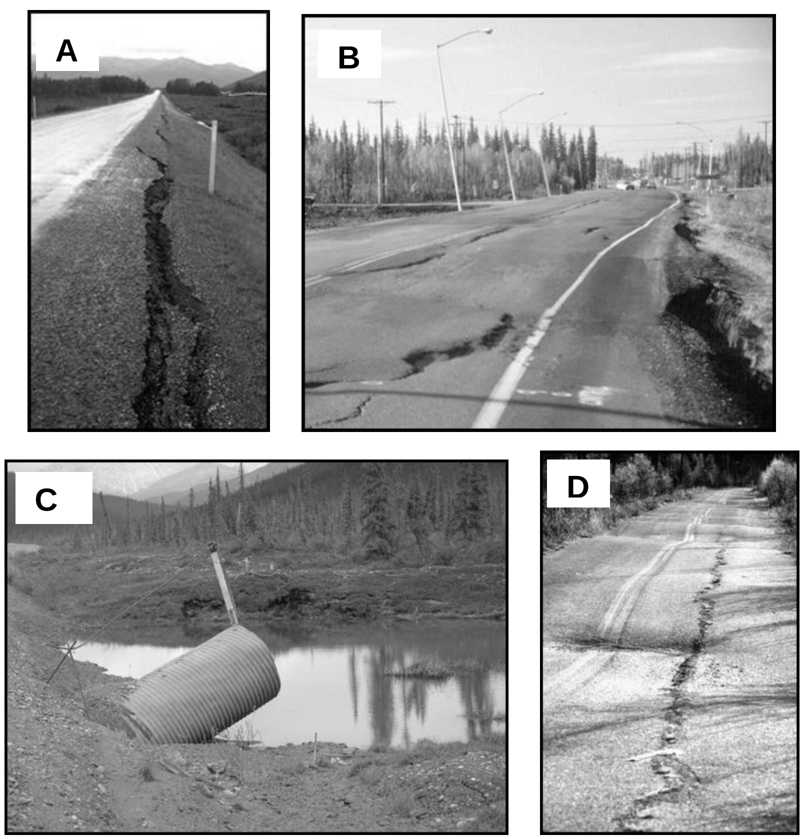

Figure 4 : Longitudinal cracking (A), shoulder rotation (B), drainage infrastructure displacement (C) and differential settlement (D) (Elliott Highway (A, C), Farmer's Loop Road (B) and Richardson Highway (D))

Settlements can also be localized and are induced by the degradation of massive ice and ice-wedges. They are often associated to thermokarst. In Figure 5A, it is possible to observe massive ice located in the Permafrost Tunnel in Alaska. A thermokarst and tears generated by the collapse of ground can be seen in Figure 5B.

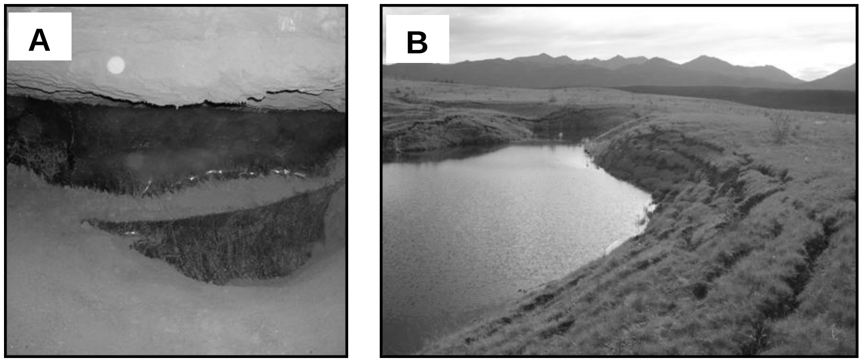

Figure 5 : Massive ice (A) and thermokarst (B)
(Permafrost Tunnel, Alaska (A) and Alaska Highway, Yukon (B))

Moreover, the degradation of ice wedges present under transportation infrastructures could generate localized settlement problems and damage on the pavement surface. It is possible to observe in Figure 6A an ice-wedge in the Permafrost Tunnel in Alaska. Figure 6B shows an ice-wedge going under a road in Yukon. At this time, this ice-wedge seems to be stable.

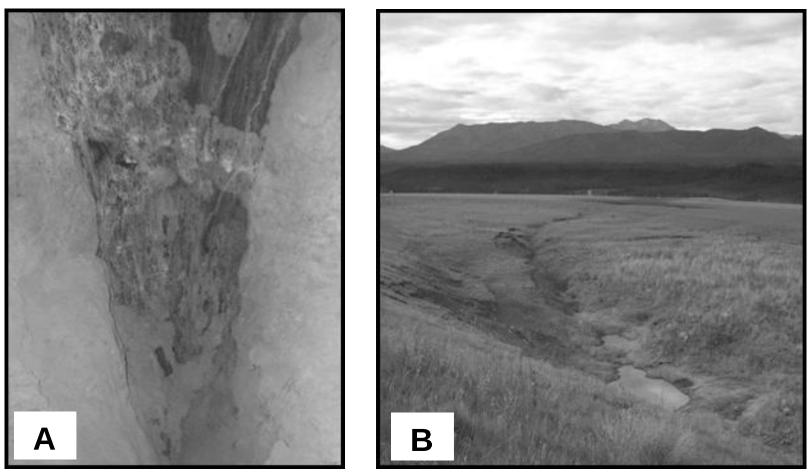

Figure 6 : Ice wedges (Permafrost Tunnel, Alaska (A) and Alaska Highway, Yukon (B))

In permafrost, ice can be distributed in soil in different ways. In sand and gravel, ice fills generally the voids while in silt and clays, ice appears in ice lenses and fills vertical cracks to create a network of veins filled with ice. When the thaw front penetrates the permafrost, the moisture content of the thawing soil will be greater than the soil thawed void volume exceeding the moisture content needed in normal consolidation. As a result, the thawed soil will begin to settle under its own weight tending to the normal consolidation even if any outside load is applied (Ladanyi, [5]). In permeable granular soils, the rate of settlement follows closely the rate of penetration of the thaw front. In other words, settlement at every moment is proportional to the thickness of the thawed layer under the foundation. Settlement will increase with time and will follow a square root function of time. Settlement will stop when the thawed front reaches a non-compressible layer. For impermeable fine-grained soils like silt and clays, water pore pressure cannot be dissipated during penetration of the thawed front. As a result, final settlement and final consolidation will be reached only a long time after the thaw front had stopped (Ladanyi, [5]). Under undrained conditions, thawed soil will return under its original volume. On the other hand, under drained conditions, thawed soil will be subjected to extra volume changes that depend on the degree of consolidation and the structural change that occurred during the previous cycle (National Research Council of Canada, [6]. Hence, more settlements are occurring when drainage is permitted.

WATER PORE PRESSURE AND DRAINAGE

The presence of ice lenses in ice rich permafrost increases considerably the average porosity of the thawing soil. The thawing soil is initially characterized by a loose saturated structure with a high void ratio. At that point, pore pressure is high and the effective stress of the soil is minimum. Water is gradually forced out of soil and settlements occur increasing the internal soil stress. The shear strength increases as the pore water pressures decrease. The decrease of pore water pressure with time follows the theory of consolidation. If pore pressures remain high during the thaw process, severe problems can occur in the thawing soil (National Research Council of Canada, [6]). Among other problems, slope stability and loss of bearing capacity of thawing soils are of major interest for engineering structures built over permafrost.

When a load is suddenly applied to a saturated fine-grained soil, an increase in water pressure equal to the applied load is generated. When an ice-rich permafrost thaws, excess water is generated at the freeze-thaw interface (Ladanyi, [5]). In the beginning, there is no change in void ratio and in shear strength (National Research Council of Canada, [6]). With the action of time, water is forced out of soil and settlements occur as the applied stress in soil particles increases. The shear strength increases as the pore water pressures decrease. If the thawing rate is fast enough, water will be discharged at a rate superior to the one it can flow from the soil. So, pore pressure in excess will be generated. If maintained, these excess pore pressures will cause severe problems (National Research Council of Canada, [6]). If the soil permeability is sufficiently low, the pore water cannot flow away from the interface during thawing, the overburden pressure is supported partly by the pore water and excess pore pressure developed (Johnson and Kinney, [4]). Where ground ice contents are high, the permafrost degradation will lead to possible instability (slope failure) and potential thaw settlement. The thawing of ice-rich permafrost can also produce subsidence of the ground surface as the ice volume turns into slurry (Cole, Colonell, Esch, [7]).

IDENTIFICATION, DESCRIPTION AND CLASSIFICATION OF APPLICABLE MITIGATION METHODS

Since the 1960’s, many methods have been proposed and tested to counter the permafrost thawing effects. Some of them have been developed and tested by Alaska Department of Transportation and Public Facilities (ADOTPF). Several have been rejected for different reasons and others are still used in construction. The methods can be classified in three categories :

- Methods based on limiting heat intake underneath the embankment,
- Methods based on heat extraction from the embankment,
- Methods based on the reinforcement of the embankment in order to resist permafrost degradation problems.

Examples of each kind of method will be described and discussed. The applicability of each method will be discussed based on different factors such as the permafrost context, cost, material and equipment availability as well as safety issues. The main objective of this section is to review possible technical and operational solutions in order to identify realistic adaptation scenarios to be further analysed and developed for application in instable permafrost conditions.

<u>Methods based on preventing heat intake underneath the embankment</u>

The main source of heat causing permafrost degradation is solar radiation acting on the embankment surface. The following methods are essentially impeding heat from flowing toward the underlying permafrost thus reducing the risk of degradation.

Embankment insulation

The use of insulation in embankments is aimed to reduce the heat flow into the permafrost and prevent frost heave (Figure 7). Permafrost temperatures during summer remain low instead of increasing even if no insulation has been installed. During winter, insulation does not allow permafrost to cool and permafrost temperatures increase because insulation does not permit evacuation of ground heat. Depending of the thermal balance over the year and the mean annual surface temperature (MAST), the increase of permafrost temperature during winter can be in most cases ignored if the MAST remains below 0°C. On the other hand, if the MAST is positive, insulation alone is not efficient and some other methods would have to be integrated in the design. Often, insulation is used with a granular pad that is thick enough to avoid the effects of a positive MAST.

Figure 7 : Insulation installation (Courtesy of John Zarling)

Over the years, the use of polystyrene has been well established in roads and runways and has shown long-term moisture and creep compression resistance. Insulation will be mostly effective if placed as close as possible to the surface, but the depth of cover above has to be thick enough to prevent crushing of the insulation from cyclic wheel loadings (Esch, [8]). Moreover, the insulation should not be placed too close to the surface in order to prevent the formation of differential icing at the pavement surface. If the insulation thickness placed in the embankment is well designed, thaw settlement can be negligible and fill material be reduced (Johnston, [9]).

Reflective surface

The warming of the soil beneath paved roads is attributable to several causes such as removal of vegetation, reduction in evaporation due to the presence of pavement, loss of shading and reduction of albedo caused by darker surfaces (ADOTPF, [10]). The effect of these factors is often integrated in n-factor. Several years ago, a mitigation method consisting of painting the pavement surface in white (Figure 8A) to reduce the penetration of solar radiation was developed in Alaska by the Cold Regions Research and Engineering Laboratory (CRREL). In Figure 8B, it can be possible to observe that the painted section is relatively in good condition after 30 years compared to the unpainted which subsided and is now covered with vegetation and water.

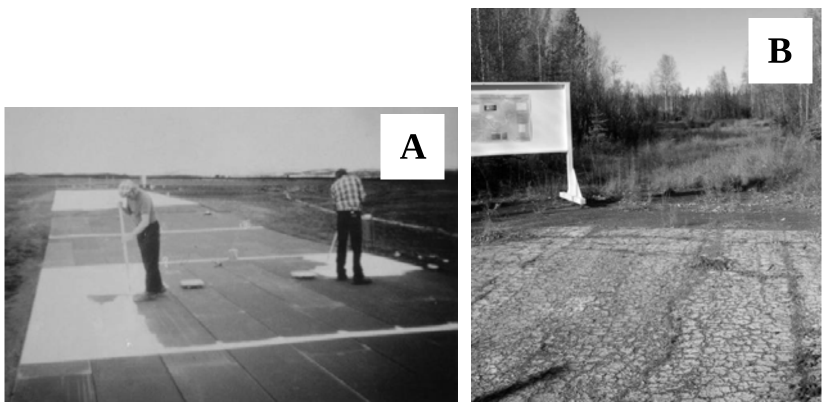

Figure 8 : Paint application in an experimental section in Alaska (A) and pavement condition after 30 years (B)

ADOTPF has applied white paint on different roads to reduce thaw settlement problems. For example, on Peger Road in Fairbanks, Alaska, a white-painted section had a MAST of -0,5°C compared to a normal pavement temperature of 1,1°C for a mean annual air temperature (MAAT) of -3,3°C (Esch, [11]). In other words, paint applications have reduced average pavement temperatures by 1°C and settlement (Esch, [8]).

Many problems with white-painted surfaces were observed. These include :

- High costs are associated with the application of paint.
- Localized icing formation causing the roads and runways to be slippery.
- Slippery surface especially after rain in curves, intersections and braking zones.
- Dazzling surface causing hazardous driving or landing conditions.
- Rapid wearing of the surface requiring annual repainting (Esch, [11]).

In spite of these limitations, this mitigation method is regarded as effective. This adaptation solution showed good results to reduce the penetration of the thaw front and the degradation of permafrost (Esch, [11]).

Sunsheds or snowsheds

Sunsheds or snowsheds let the cold air circulates during winter to protect embankment slopes from snow insulation. In summer, they can eliminate direct solar radiation on the embankment slopes. At Bonanza Creek, Alaska, an experimental embankment was built with snowsheds along the slopes. The mean annual slope surface temperatures were reduced from a normal slope value of 3,9°C to a value of -2,3°C beneath the sheds (Esch, [11]). Figure 9 illustrates sunsheds used in Alaska and China. In spite of good performance, the use of sheds was not considered practical in Alaska for safety reasons. Guardrails are required along the embankment to prevent hazards for vehicles accidentally leaving the road (Esch, [8]). In addition, sheds required a high-maintenance cost and lacked durability, but are a low cost deployable system compared to other methods.

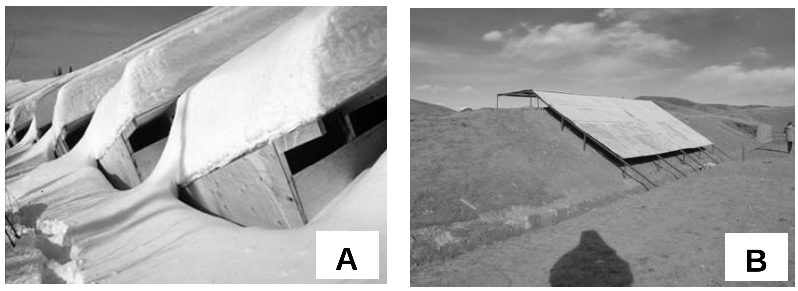

Figure 9 : Snowsheds in Bonanza Creek, Alaska (A) and Sunsheds, Qinghai-Tibet Roadway (B) (Courtesy of John Zarling (A) and of Professor Ma, Lanzhou, China (B))

<u>Methods based on heat extraction from the embankment</u>

The following methods are based on active removal of heat from underneath the embankment in order to preserve stable permafrost conditions.

Air ducts

The air duct cooling is a system that allows heat extraction beneath the embankment by natural convection. As a result, air ducts can cool the embankment or the side slope areas during winter. This system has to be disabled during summer and protection has to be installed at the pipe outlets to prevent warm air intrusion (Esch, [8]). Ducts can be placed parallel to the road under the embankment slope or perpendicular to the road. Water ponding and ice formation within the ducts can be real problems and can compromise the ducts performance. They will impede air flow and reduce the heat extraction. To have the best chance of long-term performance without water ponding or snow plugging risks, culverts must be placed high in the embankment and slightly sloped. Ventilation ducts are currently being studied in Qinghai-Tibet railway embankment (Niu et al., [12]). In Qinghai-Tibet roadway, the ventilated embankment has already been used (Figure 10).

Figure 10 : Ventilated embankment with culverts, Qinghai-Tibet Roadway Road, Alaska (Courtesy of Professor Ma, Lanzhou, China)

Thermosyphons

A thermosyphon is composed of a corrugated pipe which includes a refrigeration gas, such as ammonia, carbon-dioxide or propane in a liquid and gas phases. When the air is colder than the ground, heat from the ground causes the liquid to vaporize. The vapor flows upwards from the evaporator section (below ground) to the condenser section (above ground) where the vapor condensates back to a liquid because of cooling by ambient air. The condensate flows downwards by gravity on the internal wall surface of the thermosyphons where it absorbs heat from the ground and is re-evaporated to continue the process (Sorensen et al., [13]). When air temperature is warmer than the saturation temperature of the liquid, the thermosyphon is not working. The main problem with thermosyphons is their high cost. They typically cost $1500/piece. For this reason, thermosyphons are only used in severe permafrost degradation areas. The other problem is the presence of condensers along roads and runways. The condensers are exposed to vandalism and impacts by vehicles. They also constitute a risk for automobile or aircraft. A solution to avoid problems is to bury the condensers underneath the surface of the pavement using hairpin thermosyphons.

Air Convection Embankments (ACE)

ACE technique is based on the formation of convective cells in embankment using large poorly-graded porous rocks with a low fine content. Difference in temperature creates convective cells if the voids in a rock embankment are large and interconnected. In winter, the air present in voids is cooled at the top of rock layer. Dense cool air moves downward pushing warm air upward. The induction of convective cells, such as illustrated in Figure 11, speeds the cooling and the refreezing of the permafrost underneath (Esch, [8]).

In summer, with warm air at the top and cold air at the bottom, convection heat transfer does not occur. The rock layer provides greater heat exchange in winter than in summer. It seems that convection can transfer heat upwards out of the embankment at a rate that may be more than an order of magnitude larger than conduction, resulting in an effective winter cooling (Goering, [14]). As a result, ACE will increase wintertime cooling rates and will decrease summertime warming rates (Esch, [8]). The main problem with ACE is to find good competent coarse rocks that are big enough to allow the creation of convective cells. ACE is an alternative that can become costly because of the crushing and sieving operations required.

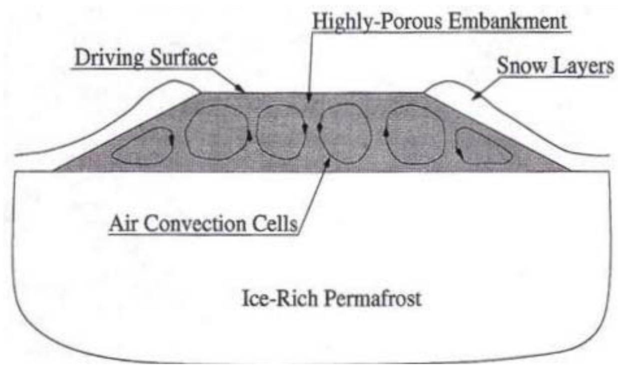

Figure 11 : Air Convective Embankment (Goering, 1998)

Methods based on embankment reinforcement

In some conditions where preventing permafrost degradation is not practical, embankment reinforcement to resist faulting, spreading and localized subsidence might be a good alternative.

Geosynthetics

Installation of geotextile in embankment over thawing permafrost areas can only reduce lateral spreading, cracking and dips on thaw-weakened foundations (Esch, [11]). Embankments can be reinforced with a single layer of geosynthetic to help solve toe and side slopes thaw settlement and formation of grabens.

Berms

Berms are used to protect the lower embankment slopes from excessive thawing. Two approaches can be used. The first approach is based on the use of available material such as silty soils or peat. This approach proved to have very minor impacts on slowing thawing along the slopes and hence, increase settlements (Esch, [11]). The best approach consists of using porous material such as ACE.

Other methods

Pre-thawing

This method is usually used to achieve thawing and consolidation prior construction for unstable permafrost layers. Performing pre-thawing prior construction during one or two thawing seasons can reduce significantly thaw settlements. Pre-thawing can be performed in shallow ice-rich permafrost layers, but has to be avoided when deeper ice is present (Esch, [11]). Different methods can be used to accelerate pre-thawing (Esch, [8]). For example, vegetation can be stripped to expose the soil to the sun in summer or a dark material (gravel of plastic) can be used to absorb solar radiations. Pre-thawing does not involve high costs but requires flexibility and time. It is also difficult to accurately anticipate the final result.

Excavation and replacement

Excavation and replacement can be used to replace shallow ice-rich foundation soils by non frost susceptible soils when time is not available to proceed to pre-thawing. This method can be really expensive, but it is one of the best methods to reduce thaw settlements.

Build and maintain

The most frequently used method is to build a structurally adequate but thermally inadequate embankment (Esch, [11]). Designers simply accept that excessive embankment movements are going to occur and hence, accept to perform the required maintenance and rehabilitation when problems occur (Connor, personal communication, 2003).

Gravel roads

Another way to reduce problems with permafrost is to leave roads with gravel surfaces. Gravel roads reduce absorption of sun radiation compared to roads paved in asphalt. Unpaved runways and roadways can easily be graded to correct surface irregularities. However, they require more maintenance and do not offer a good level of service to users.

Applicability

Many methods described above only slow permafrost degradation and are not long-term solutions. Settlement, cracking and lateral spreading still occur over the years. For many reasons such as effectiveness, cost, safety, high maintenance, few of these methods are widely used. In order to prevent permafrost degradation and settlement problems in these areas, several alternatives were reviewed. Methods were documented based on their effectiveness, cost, safety and required maintenance. Pre-thawing, ACE and air ducts seem to be the best methods according to the previous enumerated factors. Their performance can be increased in combination with thermal insulation and geotextile. Reflective surface could become feasible if more further developed.

AIRFIELDS AND ACCESS ROADS PERFORMANCE ASSESSMENT

The performance assessment of the Nunavik runways and access roads was done using airport plans and specifications, geotechnical studies, maintenance reports, base material thickness to make longitudinal profiles, air photographs, field observations and technical reports. At this time, the condition of Nunavik airfields and access roads is generally acceptable. Problems such as depressions, water accumulations and cracks, were observed on some airstrips and access roads. Some problems could become critical if they are not taken care of. The transportation infrastructures that should be monitored very closely in Nunavik are : Kangirsuk, Salluit (runway and access road) and Tasiujaq. Other infrastructures that should be monitored are : Akulivik, Inukjuak, Puvirnituq, Umiujaq (access road) or any project where asphalt paving is planned. Table 1 shows a summary of the conditions of all airports and relevant recommendations.

PROPOSED MITIGATION METHODS FOR NUNAVIK

Three protection techniques, that have the potential for large-scale application in the Nunavik, have been chosen to mitigate permafrost degradation under transportation infrastructures in Nunavik (Beaulac et al., [15]). Air convective embankment, heat drain and reflective surfaces have been selected for their operational and economical feasibility. These techniques will be mostly used on recently paved access roads. These techniques will be used only at places affected by important permafrost degradation. The use of protection technique will increase the service life of the Nunavik transportation infrastructures. These three solutions will be tested on the Salluit airport access road in summer 2006 in order to determine their operational and economical feasibility and to identify those having the best potential for large-scale application.

Two of the proposed techniques, the heat drain and reflective surface, were tested in laboratory and in the field before testing them in Salluit. A new mitigation method, the heat drain, was developed to counter permafrost degradation problem on the side-slopes of the embankment. The heat drain was developed by the Groupe de recherche en ingénierie des chaussées de l'Université Laval. This technique allows heat extraction from the embankment during winter. The heat drain consists in a highly permeable geocomposite placed in the shoulder and its thickness is 30 mm. The geocomposite is marketed by Solmax-Texel and is called Soldrain (Figure 12A). In the industry, this product is especially designed to evacuate infiltration water and to filter fine particles. In this project, the heat drain was used to evacuate another fluid : air.

Table 1. Summary of airports conditions and recommendations

Airport	Runway Condition	Recommendations
Akulivik	Acceptable (important depression)	Field observations Install level references *
Aupaluk	Stable	Monitor ice wedges condition Monitor drainage ditches at the end of the runway
Inukjuak	Acceptable (depressions)	Field observations Install level references * and thermistors
Ivujivik	Stable (bedrock)	-
Kangiqsualujjuaq	Stable	Monitor the general condition of the runway
Kangiqsujuaq	Stable (bedrock)	Field observations
Kangirsuk	Vulnerable (excavation zone)	Make deep drilling and take undisturbed samples Install reference levels *
Kuujjuarapik	Absence of permafrost	-
Puvirnituq	Acceptable (Clayey valley)	Determine thermal regime Install a thermistor in the clayey valley Make snow depth evaluation in the clayey valley Install reference levels * Make deep drilling and take undisturbed samples
Quaqtaq	Stable	Monitor drainage ditches and the excavation zone
Salluit	Vulnerable (runway and access road)	Determine the thermal regime Make deep drilling and take undisturbed samples Install reference levels * Test adaptation solutions on the access road **
Tasiujaq	Vulnerable	Determine the thermal regime Make deep drilling and take undisturbed samples Make snow depth evaluation near runways Install reference levels * Test adaptation solutions on the runway **
Umiujaq	Acceptable (runway and access road)	Install reference levels on the access road * and in the depression in the runway

(* performed in summer 2005, ** performed in summer 2006)

This new permafrost protection technique was tested in a large cold room where the ambient air temperature was kept at -10°C for the first test and at -20°C for the second test. To verify its effectiveness, a small-scale embankment (SSE), representing the side-slope of a road or a landing strip embankment, was built in an insulated wood box (Figure 12B and C). At the base of the SSE, temperature was maintained at 0°C with a heating system (Figure 12B). The heat drain was placed on a compacted gravel sand layer, then was covered with soil until the total height of the SSE (Figure 12D). The SSE includes two sections (Figure 12E). The right section was built with a heat drain while the left section was built without a heat drain to be used as the reference section. The heat drain effectiveness was evaluated by comparing the thermal regime of the two sections. The SSE was insulated all around the wooden box with polystyrene. A layer of polystyrene was placed between the two sections to avoid heat losses. Glass wool was placed on the top of SSE to recreate the snow insulating effect on the ground (Figure 12F). The SSE has a total length of 1,84 m, a total width of 1,22 m and a total height of 1,09 m. Each section has a total length of 0,82 m (Figure 12C).

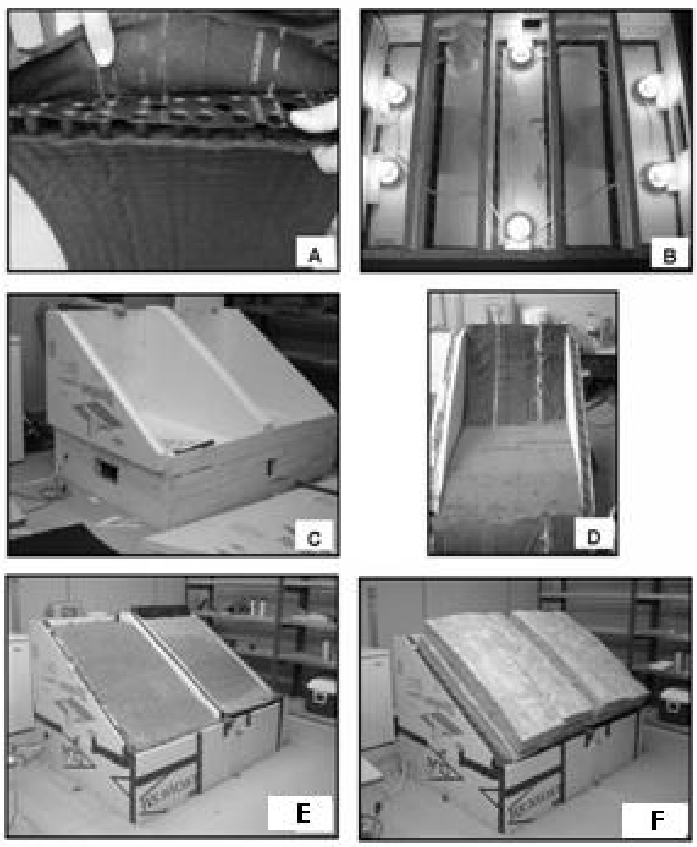

Figure 12 : Small-scale embankment construction in laboratory

A) Heat drain membrane, B) Heating system (light bulbs and fans) to control temperature at the bottom of the embankment, C) Construction and insulation, D) Heat drain and soil installation, E) Final small-scale embankment, F) Glass wool installation

The two sections were instrumented to monitor continuously the thermal regime. Six thermistors were installed vertically at the center of each section. Data were recorded by an automatic data acquisition system. Thermistors position in the SSE for both sections is presented in Figure 13.

For a large-scale installation, an air intake will be placed in the middle of the embankment side-slope in order to allow upward circulation of air in the membrane during winter (Figure 14A). Figure 14B shows the air convective embankment and the air intakes configuration will also be used in the heat drain to allow the air circulation. The movement of air is generated by the relatively low density of warm air. It is expected that the drain should allow efficient heat extraction from the embankment by convection. Initially, heat flows by conduction to the drain and is then evacuated by convection out of the embankment. The main purpose of this method is to extract heat from the embankment in order to raise the permafrost table in the ground.

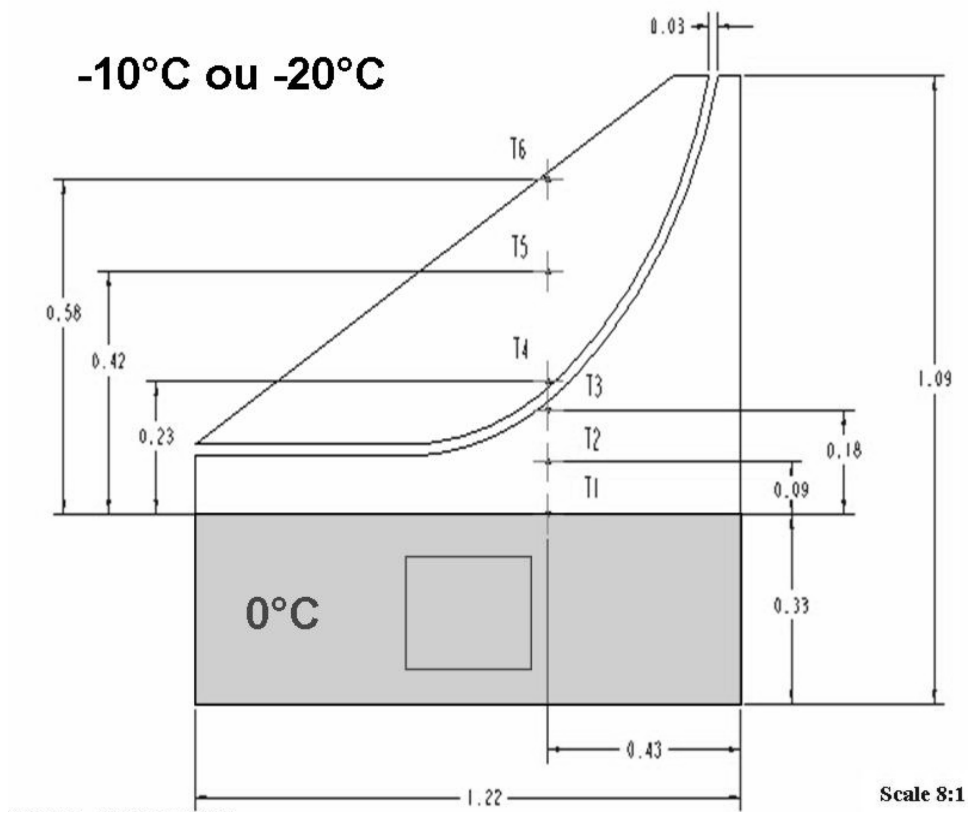

Figure 13 : Thermistors position in the SSE for both sections

Figure 15 presents a thermal profile for the test between 0°C and -20°C when the final steady state was reached. On the chart, the heat drain effect was observed between thermistors T3 and T4. The temperature difference between these two thermistors was 3,41°C for the test between 0°C and -20°C. In addition, it was observed that the heat drain had really evacuated the heat inside the SSE because the heat drain section temperatures were colder than the reference section temperatures. Temperature variation of 5,14°C for thermistor T4 was observed between the reference and the heat drain sections for the first and second test. As a result, the heat drain tested in laboratory had a significant effect to reduce the ground temperature.

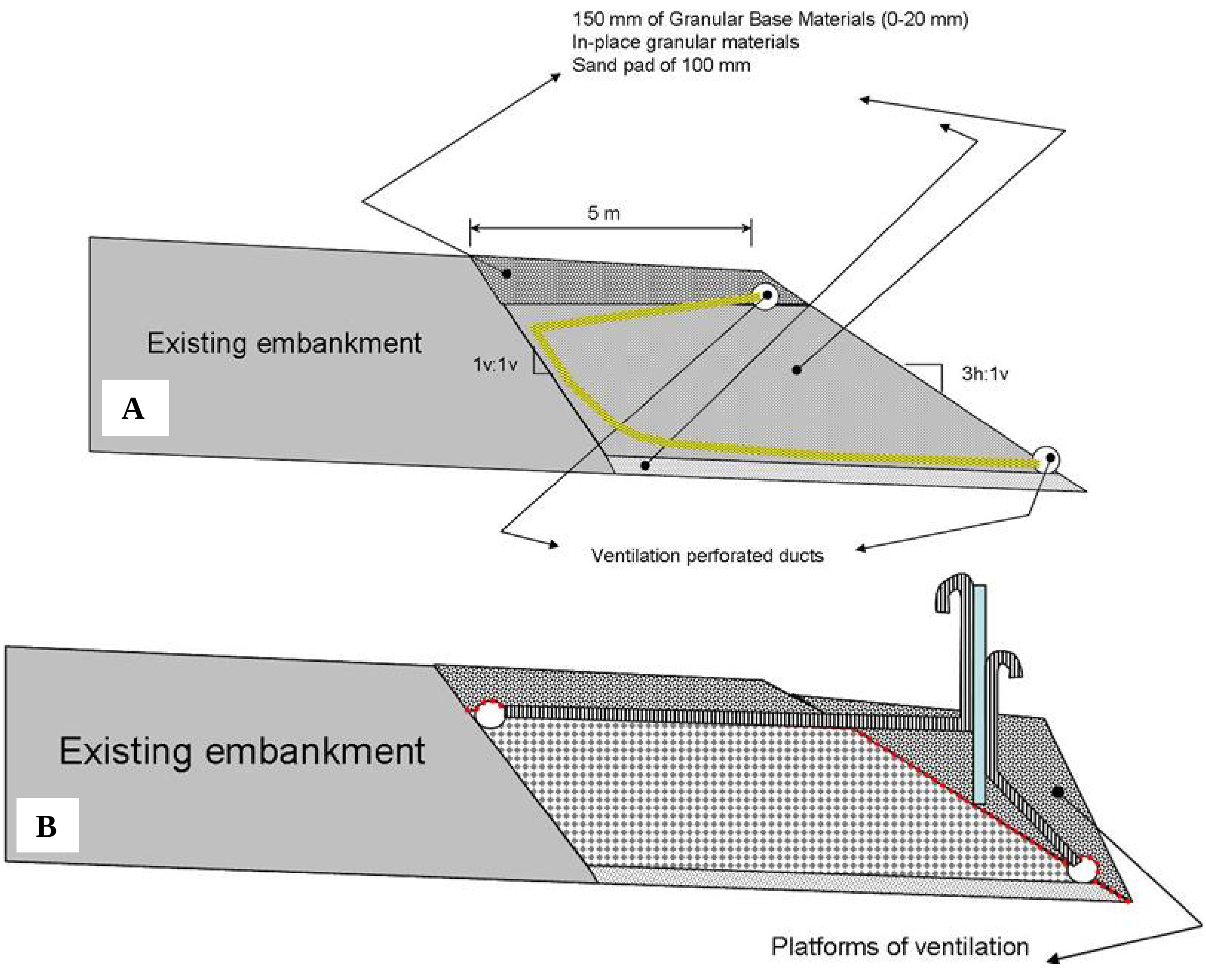

Figure 14 : Heat drain

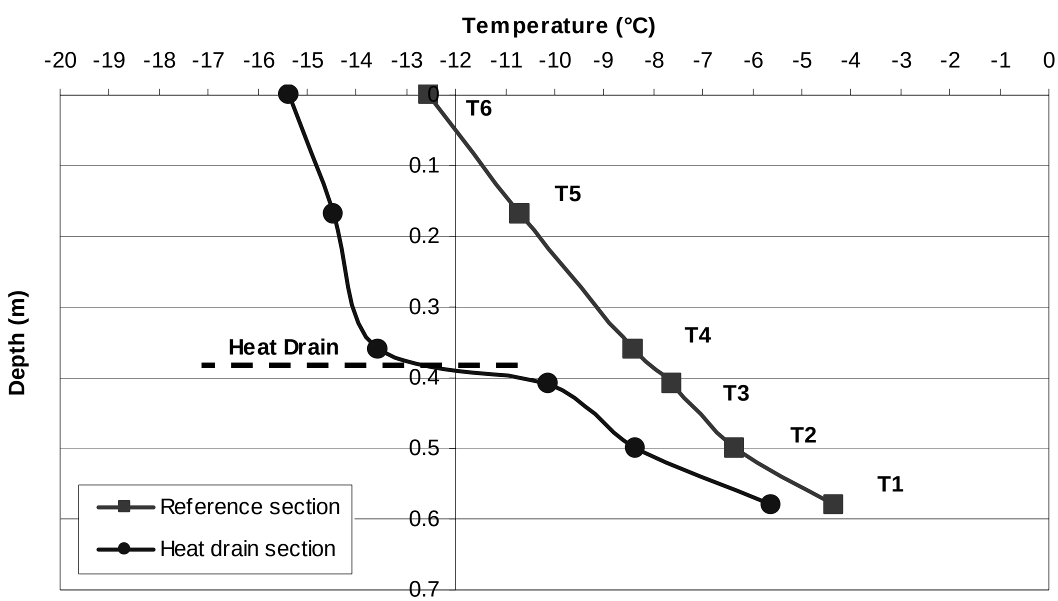

Figure 15 : Thermal profiles plotted when the final steady state was reached for the test between 0°C and -20°C

In conclusion, it was possible to prove the effectiveness of the heat drain by laboratory tests. The results showed that it is possible to lower significantly ground temperature if a heat drain is installed in the embankment.

Reflective surface were also chosen to be installed in Salluit in 2006. Because application of paint on asphalt pavement can significantly reduce surface friction, the technique was modified to reduce this problem. New products will be used to color the surface. These products include cement grouts, latex polymers and epoxy compounds. In the industry, these products are used for road marking, for ceramic installation and for cracks sealing. Prior to construction in Salluit, many products were tested at SERUL, an experimental road test site located in Parc des Laurentides, Québec and owned by Université Laval. Six testing sections were built with different products and instrumented with thermistors to determine which section had the lowest surface temperature. A normal asphaltic pavement surface was used as a reference section. In addition, skid resistance was also measured with the skid resistance tester to evaluate which product applied on pavement will be the safest for the users. Figure 15 presents the temperature of two white products (Tech-Mix and Mapelastic) applied on the pavement surface compared to a normal asphalt pavement surface. As it can be observed on this figure, the temperature difference between the surface with Tech-Mix and the asphalt pavement surface is not really significant compared to the difference between Mapelastic surface and the asphalt pavement. A temperature difference up to 9°C can be observed between the Mapelastic and asphaltic surfaces. Mapelastic surfaces should be used to reduce the solar radiation absorption into the embankment and thus, to reduce permafrost degradation.

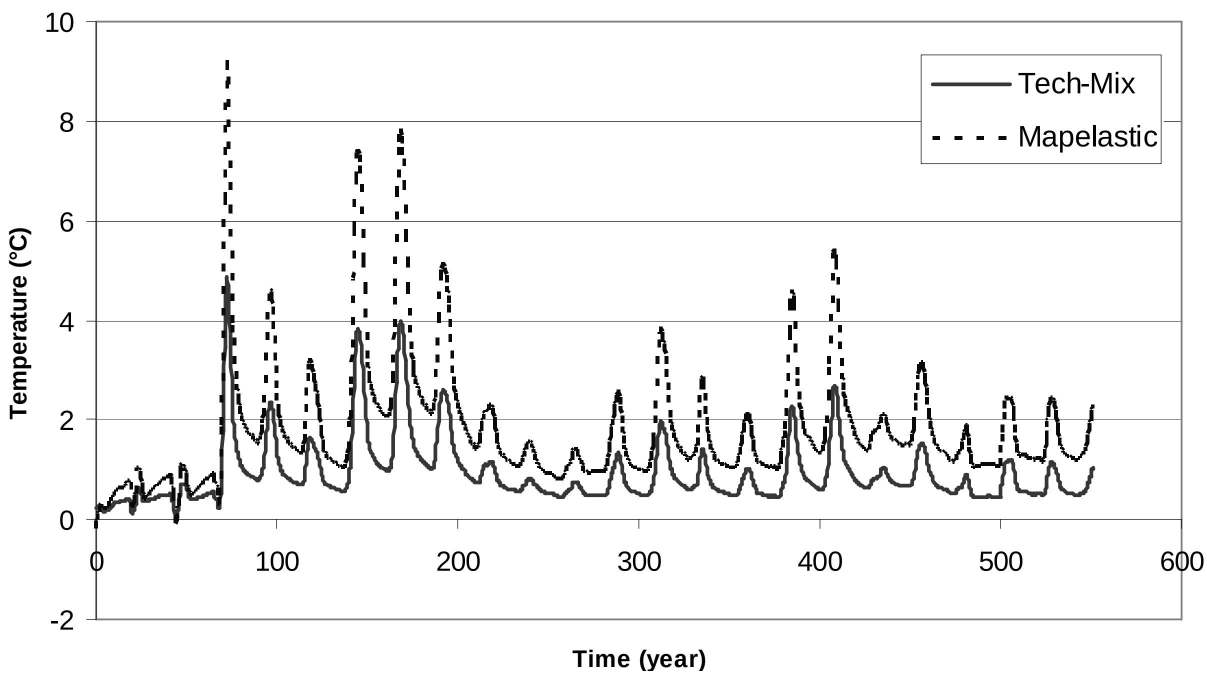

Figure 15 : Temperature difference between the reference section (asphaltic section) and the instrumented sections

The preliminary results demonstrated that these products are effective to lower the pavement temperature and to decrease the heat absorption in the roadway. These products also showed a better adherence than white painting. More tests should be done in a longer period of time to study the resistance of the products to traffic.

CONCLUSION

Three protection techniques, that have the potential for large-scale application in the Nunavik, have been chosen to mitigate permafrost degradation under transportation infrastructures in Nunavik. Air convective embankment, heat drain and reflective surface will be tested in summer 2006 in Salluit access road. At this time, the condition of Nunavik airfields and access roads is generally acceptable. The transportation infrastructures that should be monitored very closely in Nunavik are : Kangirsuk, Salluit (runway and access road) and Tasiujaq. Recommendations for the problematic airports, such as permafrost characterization through deep drilling and implementation of mitigation methods, were given at the end of the study.

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