Cost and Constructability of Permafrost Test Sections Along the Alaska Highway, Yukon

Donna Reimchen, Government of Yukon
Guy Doré, Université Laval
Daniel Fortier, University of Montreal
Bill Stanley, Government of Yukon
Robin Walsh, Government of Yukon

Paper prepared for presentation

at the **Soil Stabilization for Changing Environments** Session

2009 Annual Conference
Transportation Association of Canada
Vancouver, British Columbia

Abstract

A significant amount of Yukon's highway infrastructure is constructed on warm, ice-rich permafrost interlaced with ice wedges. Reconstruction of the North Alaska Highway 10-15 years ago induced thawing of the permafrost. As a result, the highway is continually subjected to severe settlements and longitudinal cracking. Currently, increased attention is being given to the problem of permafrost thawing underneath infrastructure due to the global focus on climate change.

Yukon Highways and Public Works has undertaken an extensive research project aimed at finding cost-effective construction techniques to reduce permafrost thawing underneath the highway embankment.

Several test sections along a 600m length of highway were constructed in April-June 2008. Mitigation techniques being tested include: air convection embankments (ACE), heat drains, longitudinal air ducts, light-coloured aggregate surfacing, side slope snow clearing, and snow sheds. The test sections are instrumented with thermistors, surface temperature loggers, and weather monitoring equipment.

The primary goals of the research are to find methods suitable for rehabilitation of existing embankments, thereby reducing the ongoing maintenance costs over the life cycle of the highway and improving the ride and safety of the highway. The examination of the cost and constructability of the test sections, covered in this paper, is the first step in evaluating the potential of the mitigation techniques. The analysis includes descriptions of the procedures used for construction, specific construction challenges, and recommendations for future work. As well, the costs of implementing the various techniques have been compiled and compared.

1 Introduction

Warm, ice-rich permafrost underlies much of the North Alaska Highway in Yukon. As seen in Figure 1, the most-affected area is from Destruction Bay to the Canada-United States border. This highway was reconstructed, and in some areas, realigned, 10-15 years ago. The reconstruction induced thawing of the permafrost underneath the road embankment. Since this permafrost degradation is continuing to occur, the highway is subject in many areas to severe settlements and longitudinal cracking. The problem of permafrost degradation and infrastructure is currently receiving increased international attention due to the present focus on climate change.

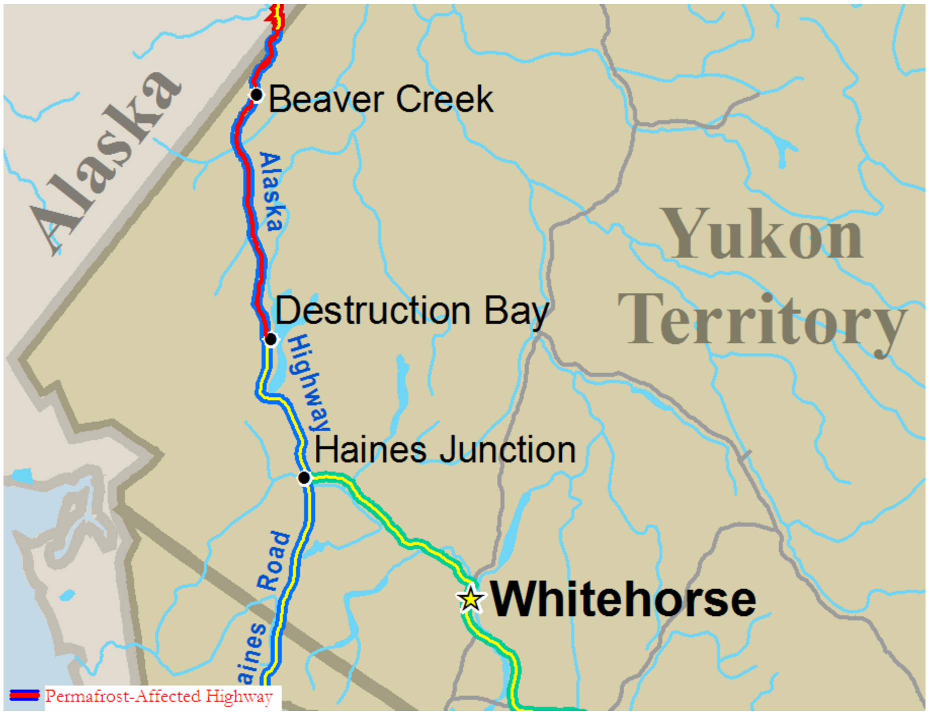

Figure 1: Map showing permafrost-affected area on North Alaska Highway.

Yukon Highways and Public Works is taking a proactive approach to the issues of thawing permafrost and melting ground ice by carrying out a highway research project. The goal of the project is to investigate several construction techniques for modifying highway embankments that could preserve the underlying permafrost and thus improve the performance of the roadway. Research support and funding for the project has been provided by the U.S. Federal Highways Administration (through the Shakwak project), Transport Canada, AUTC, Université Laval, University of Montreal, and Public Works and Government Services Canada.

The highway test sections were constructed in April-June 2008 about 8 kilometres south of the community of Beaver Creek. Beaver Creek is approximately 30 km south of the Canada-United States border, located at 62° 22' 59" N, 140° 52' 29" W. The mitigation techniques being tested include: air convection embankments (ACE) built with 150-300mm rock, heat drains, which involve ventilation pipes and geocomposite, longitudinal air ducts, light-coloured aggregate surfacing, grass-covered side slopes, and side slope snow clearing. Construction of snow sheds is expected to occur in early summer 2009. Each section is 50 m long, so the total length of highway involved in the project is 600 m. The test site is heavily instrumented, with 22 thermistor strings, 150 surface temperature loggers, and weather monitoring equipment (air temperature, snow depth, wind speed and direction).

The objectives of this paper are to present the test section construction operations realized in 2008 and to compare the cost of the various test sections to those related to road maintenance due to permafrost degradation. Descriptions of the procedures used for construction, specific construction challenges, and recommendations for future work have been included. For example, the issues encountered during construction include: acquiring and using the geocomposite material, scheduling, and ground and surface water.

Costs related to each mitigation technique were carefully compiled during the course of construction and are presented here. Techniques such as grass-covered embankments and snow clearing are the least expensive over their respective lifetimes, while all of the sections using a variation on heat drains proved to be the most costly to construct. The uncovered ACE slopes section has been the most effective at cooling the road embankment over the first winter after construction, and is relatively inexpensive compared to the snow sheds, heat drains, and full ACE embankment.

Maintenance costs for work relating to highway damage caused by permafrost are also analyzed. The costs were extracted from expenditure data from the previous three years. However, in spite of the large amounts of money spent, the Beaver Creek-area highway does not provide the same level of service as Yukon highways not affected by thawing permafrost.

By collecting large amounts of temperature data over the next several years and performing thermal modelling analysis, the research project will provide a solid scientific basis on the performance of the mitigation techniques. Based on all of the available information, decisions may be made to use certain techniques in a range of efforts, from modifying severely affected or critical sections of highway to rehabilitating sections that are several kilometres long.

2 Constructability

1 Air Convection Embankments

Concept

The concept of air convection embankments (ACE) involves building all or a portion of a road embankment with coarsely-graded rock fill. For the test sections, the rock used was a light-coloured granite and met a 150 mm to 300 mm specification. Constructing the side slopes or entire embankment out of this rock allows cold, dense air to sink into the embankment during the winter. Three test sections, the schematics of which are in Figures 2 through 4, were built based on the ACE concept: one involved reconstructing the entire embankment out of ACE rock and placing organics on top of the ACE on the slopes and two required the excavation and reconstruction of the side slopes. One of the side slope sections consisted of covering the rock with a 15 cm layer of organics and installing ventilation pipes in the near surface embankment material, while the other section was left uncovered and without ventilation pipes. The reason for using an organic cover is to provide some insulation value and to prevent warm wind incursions into the rock cover during the summer. Ventilation pipes were used to increase the flow of cold air underneath the organic cover and into the ACE rock.

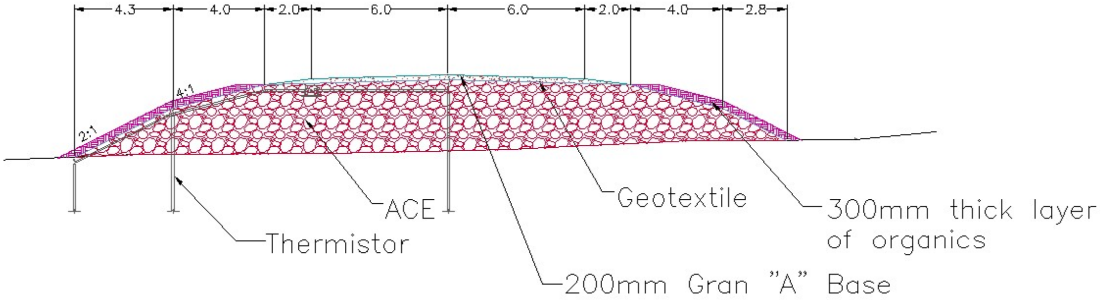

Figure 2: Schematic of full embankment with ACE material.

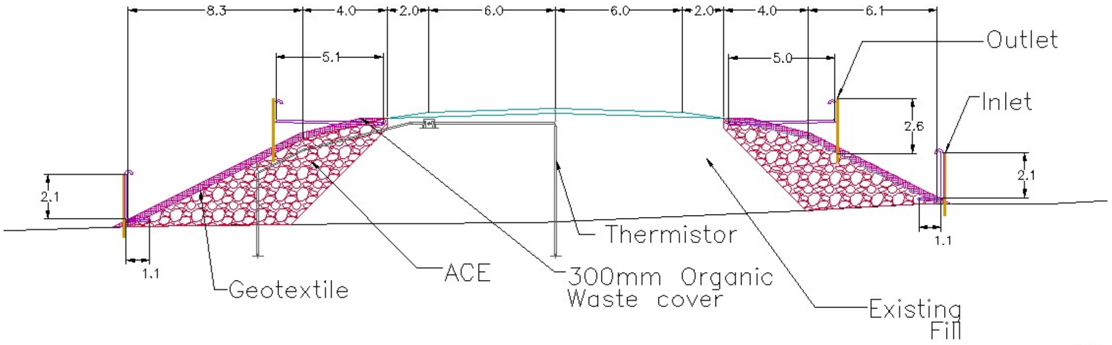

Figure 3: Schematic of ACE side slopes with organic cover and ventilation pipes.

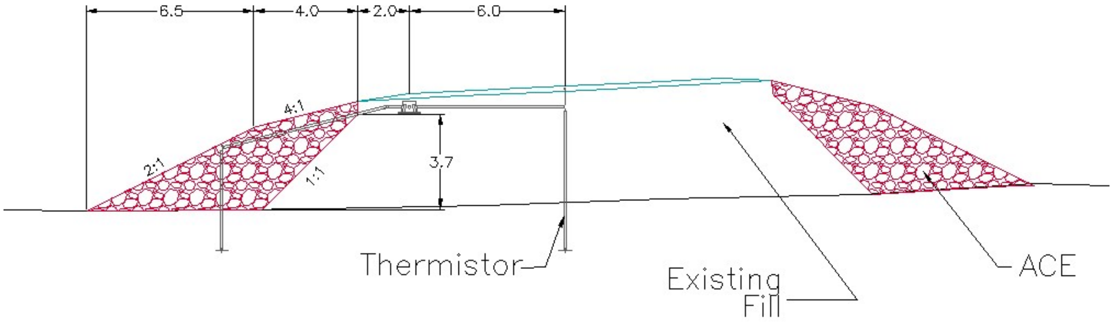

Figure 4: Schematic of uncovered ACE side slopes.

Procedure

Each ACE area was excavated to within 70 cm of the ground water level. As soon as possible after the excavations were complete, they were backfilled with ACE rock. Due to the long haul involved in moving the rock to the construction site and the need to effectively use the equipment on site, some of the excavations were brought to 1 m above grade and left that way for several days, until enough rock was on site to begin a substantial portion of the backfill. In Figure 5, the full ACE embankment and uncovered ACE slopes sections have the entire rock fill in place.

The ventilation pipes were installed along the shoulders and toes of the embankments on one of the slope sections. Stand pipes were placed at 10 m intervals along the longitudinal ventilation pipes to serve as inlets and outlets for airflow. Before the organic layer was placed on this section and the full embankment sections, geotextile was laid out in order to prevent contamination of the ACE rock by the fine organic material.

a) b)

Figure 5: a) Full ACE embankment built; placing geotextile prior to base course. b) Finished uncovered ACE slopes section.

Challenges

Constructing the three ACE sections was an exercise in logistics. Production of the ACE rock was concurrent with the test sections construction; however, this component of the work did not negatively impact the schedule. Hauling the ACE rock to the test site proved to be the largest timing issue, as the quarry was about 130 km away and it was a challenge for the contractor to keep a large number of trucks hauling material. In total, it took 27 days to haul all of the material. Ideally, as soon as an excavation of the side slope for a section was complete, there would be enough ACE rock on site to fill the excavation. In reality, the excavations often took several days to be backfilled. Since space for storing material at the construction site was very limited, the ACE haul only began a few days before the first excavation was complete. As soon as the excavation was finished, the ACE rock was placed.

In order to use the equipment efficiently, subsequent side slope excavations had to be started before sufficient ACE rock was on site. In order to avoid exposing the permafrost for unreasonable lengths of time, a 1 m cover of existing fill was left in the excavation until there was enough ACE rock on site to begin backfilling.

The full ACE section was backfilled with ACE rock as material was available. The side slope sections were given priority over the full section. As a result, the full section was left open for a significant amount of time, particularly the east side of the road, as backfilling began on the west side and proceeded towards the east side. As the site is monitored over the next several years, it will be observed whether there is a difference in road surface integrity between the two sides.

Construction of the ACE sections was achieved with minimal contamination by fine material. Minor contamination did occur when material had to be stockpiled at the construction site prior to placement. Over time, the performance of the uncovered ACE section may be compromised if large amounts of dust and sand fall amongst the rock fill.

Several waste areas along the highway were investigated in the search for accessible, suitable organic material. However, the only available organic material was found in a gravel pit about 80 km away from the test site. Due to the difficulty in finding good quality organic material and the long haul distance, the organic cover over two of the sections is of minimal thickness (~15 cm). The material used is a mixture of organics and volcanic ash.

Recommendations

Based on the first winter's data, the uncovered ACE on the side slopes is performing better than the other two sections. However, benefits of the organic cover will only become clear after the site is monitored through a summer season.

The permafrost underlying the full ACE section was affected by the extensive excavation required to complete the section, more so than sections only requiring side slope work. As a result, the first year of temperature data is going to contain construction-related perturbations. As such, it will be at least two or three years before the performance of the full ACE section can begin to be evaluated.

2 Heat Drains

Concept

Heat drains are an experimental method of passing cold air into an embankment. A layer of geocomposite, a synthetic egg carton-like material covered on both sides with geotextile, is placed underneath the whole embankment or in the side slopes. Pipes are attached to the geocomposite parallel to the road embankment, and connected at regular intervals to stand pipes that serve as the inlets and outlets for the cold air penetration into and the release of warm air from the embankment. Figures 6 through 8 show schematics of the various heat drains test sections.

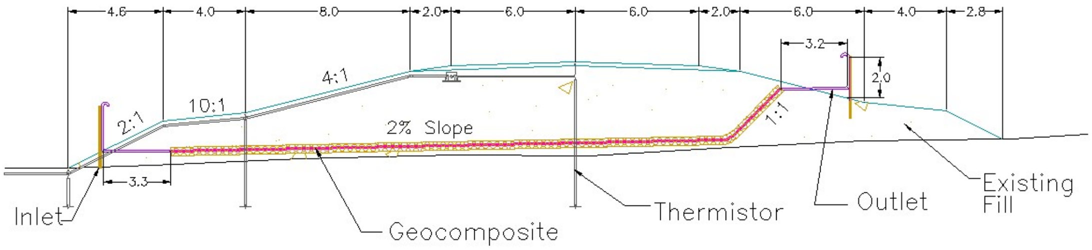

Figure 6: Schematic of full heat drains.

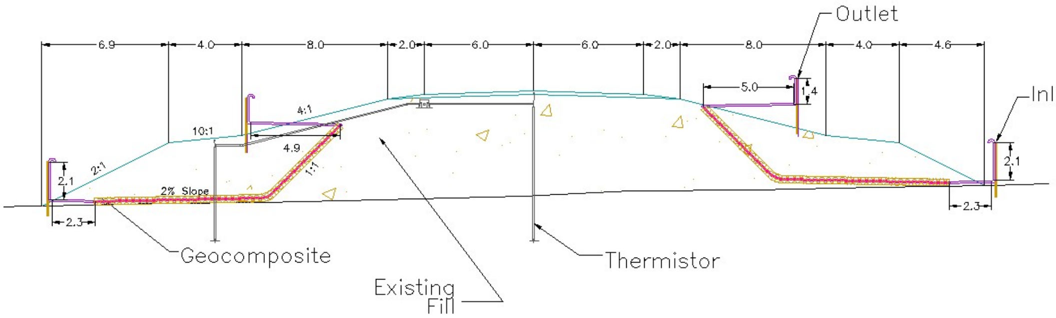

Figure 7: Schematic of heat drains on the side slopes.

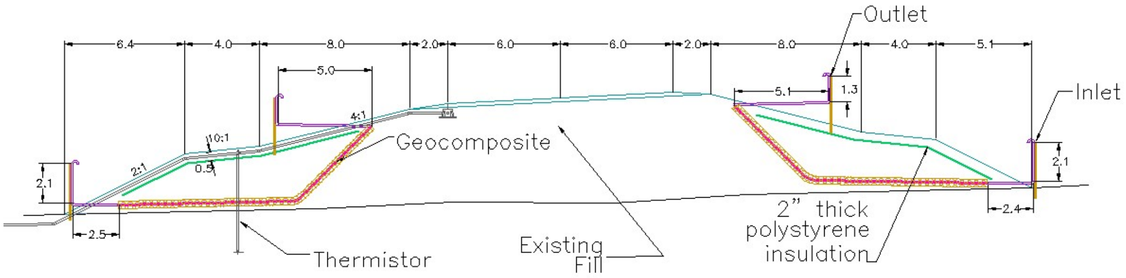

Figure 8: Schematic of heat drains on the side slopes with insulation.

Procedure

Three different heat drains sections were constructed: one in the full embankment, one in the side slopes, and one in the side slopes also incorporating polystyrene insulation. The following is a list of the steps used to construct the heat drains test sections: excavate and stockpile existing embankment fill material, place a 20-30 cm lift of 20 mm aggregate, place geocomposite material, attach end fittings to geocomposite and build ventilation pipe system, backfill over geocomposite with 40 cm lift of 20 mm aggregate, continue backfilling with existing embankment material until grades achieved, and finish the ventilation pipe system by mounting the pipes to wooden posts. Figure 9 shows the backfill in progress followed by the finished section. The section that incorporated insulation had 120 cm x 240 cm x 5 cm insulation slabs placed on top of the 20 mm aggregate cover over the geocomposite. To limit breakage, the insulation was also covered with a lift of 20 mm aggregate.

a) b)

Figure 9: a) Backfilling over geocomposite on slope heat drain section. b) View of finished heat drains with insulation section.

Challenges

The heat drain sections were extremely labour-intensive, requiring handwork for the geocomposite placement as well as assembling the ventilation pipes. Initially, the work went rather slowly; however, as the labour crew gained familiarity with the materials and procedures, the pace of work markedly increased.

The materials used for the heat drains would be a challenge to work with in long-term, larger scale installations. The maximum width available for the geocomposite rolls is 90 cm. In order to limit gaps between the rolls, they were attached to each other using cable ties. This method of installation, while effective, is not practical for larger-scale work. The ventilation pipe system utilized 4" and 6" flexible drainage pipe. It was found that the fittings available for this pipe are not easy to secure. Cable ties were used to secure the pipes to the wooden posts. While this technique appears to be sufficient for most of the inlet and outlet pipes, it has been observed after one winter that some of the pipes are twisted around the posts due to the impact of blowing snow from maintenance operations.

In all of the test sections involving excavations, efforts were made to limit the amount of time each excavation was left open in order to minimize adverse effects on the underlying permafrost. The heat drains sections posed an additional challenge, as the exposed black geocomposite was a potent heat absorber. Because of careful scheduling, the excavations of the heat drains sections were finished by end of shift one day, with initial backfilling, geocomposite placement, and ventilation pipe assembly done the next day. The geocomposite was left exposed for one night, with backfilling commencing the following day. While it may have been possible to compress this schedule and limit exposure even further, the schedule used was considered to be practical for a larger-scale project.

The largest difficulty concerning the heat drain installation related to the compression strength of the geocomposite. The specified compression strength of the material should have been sufficient to withstand loading by machinery. However, in some places, the material was crushed during backfill operations. Backfill procedures were consistent from one section to the next: granular material would be piled at the edge of the geocomposite by end dump trucks, which were kept off the geocomposite material. The initial backfill was done by a 28 tonne excavator working from the adjacent area. As a 40 cm lift of material was placed, the excavator and a small 16.6 tonne dozer traveled on the backfill material in order to keep spreading additional material. Compaction was done using a static roller. The roller only began compacting after an additional 60-80 cm lift of pit run embankment material was placed.

The state of the geocomposite was monitored throughout backfill operations. In some cases, the geocomposite withstood the various loading without any difficulties. In other areas, it experienced 50-90% crushing. Despite reviewing the manufacturer's specifications and discussions with academic researchers, no explanation was found for the wide variance in the performance of the material. As the test sections are monitored, it will be found whether the performance of areas with crushed geocomposite is affected relative to areas where the geocomposite is intact.

Another concern with the geocomposite is the thickness of the material. The maximum commercially available thickness is 2.5 cm. While this thickness provided sufficient airflow in laboratory tests, it is uncertain whether it will be sufficient for embankments 4-5 m thick.

In the course of construction it was necessary to build supports for the upper ventilation pipes near the road shoulder. In doing so, roadside hazards were created inside the clear zone. In the future, designs of these supports and perhaps the entire ventilation pipe system would have to be changed.

The use of insulation did not pose any significant installation issues. The material generally resisted crumbling. The biggest challenge was keeping the insulation slabs in a uniform layer, as the backfill layer upon which they were placed was not always smooth and even.

Recommendations

If heat drains are found to have potential for road embankment use, the materials used should be customized for the project. For example, it would be beneficial to have a custom-made geocomposite that is in wider rolls. As well, the compression strength should be verified and possibly increased, in conjunction with carefully creating an improved backfill procedure. Further laboratory tests should be done to confirm the required thickness of the geocomposite to be effective for various embankment thicknesses. A more robust system of creating the ventilation pipe system should also be developed.

As with the full ACE embankment section, the first year of temperature data from the full heat drains section is likely showing perturbations from construction and cannot be relied on to evaluate the performance of the technique.

3 Longitudinal Culverts

Concept

Longitudinal culverts were installed in the side slopes of the embankment. Each culvert system has an inlet, outlet, and 18 m of straight 700 mm diameter pipe running parallel to the road embankment. As seen in Figure 10, the inlets are horizontal and face away from the embankment. The outlets are vertical, extending 2-3 m above the slope surface. They are capped with a 90° elbow at the top, so the opening is perpendicular to the ground. Two culvert systems are in each side of the 50 m long test section. The system is designed to allow cold winter air to circulate through the side slope and promote heat extraction trough the chimney system.

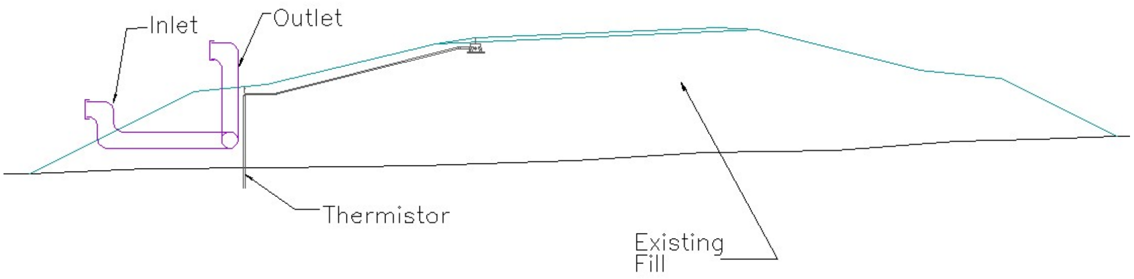

Figure 10: Schematic of longitudinal culverts.

Procedure

Trenches were excavated for the culverts. They were installed in a similar manner to regular culverts. A similar culvert technique has been tried in Alaska; however, ground water penetration of the culverts limited any benefits. Hence, care was taken to ensure the longitudinal culverts were not installed too deeply. However, placing the culverts deeper increases their effectiveness at cooling the embankment, so a balance had to be reached. Taking these factors into account, the culverts were installed approximately 0.7 m above ground water level. Figure 11 shows the longitudinal portions of the culverts as well as the inlets and outlets.

a) b)

Figure 11: a) Longitudinal culverts placed in trench with some heat shrinking complete (blue joints) and prior to heat shrinking and backfill. b) Finished longitudinal culverts showing inlets (horizontal pipes) and outlets (upright pipes).

Challenges

High-density polyethylene (HDPE) pipe was used for the culverts. The main advantage of using HDPE pipe was the ability to seal the joints. Every joint was gasketed and shrink-wrapped using the manufacturer's recommended product. Installation was fairly straightforward, with no notable difficulties. The skill of the crew in installing regular culverts was directly translatable to the longitudinal HDPE culverts.

The main issue encountered was after the initial installation. Because the culverts were the first test section to be built, they were observed throughout most of the construction period. Several days after they were installed, water was noticed in one of the inlets. Despite efforts to ensure the culverts were above the ground water level and to waterproof the joints, something was still a problem. After vacuuming out the water, the culvert was explored to see if a cause could be determined. It was found that there might have been pinhole leaks at the 90° seam of the elbow used to connect the straight pipe to the inlet, in which case the problem was a manufacturer's defect rather than an installation problem. Water infiltration recurred in the first problem inlet, as well as one other inlet several days later. The water was again removed from the pipes. French drains were constructed parallel to these inlets, in an effort to drain water from the road embankment into the muskeg. Additional 45° elbows were used on the inlets to elevate them further above the embankment slope. The finished inlets are about 1 m above the ground. The pipes were monitored during the remainder of the construction period, and were dry when the project was finished.

Recommendations

Great care needs to be taken with regards to placement of the culverts. For future work, it would be helpful to do more investigating with regards to ground water in order to optimize the depth of the culverts. As well, efforts could be made to seal the seams of the HDPE pipe to further reduce the likelihood of water infiltration into the culverts. The actual installation and assembly of the pipe was straightforward and easily accomplished.

4 Snow Clearing

Concept/Procedure

In the snow clearing test section, the embankment was not modified. Rather, special maintenance techniques of clearing the snow from the entire side slopes are used throughout the winter to minimize the insulating effect of snow. Figure 12 shows the section where the snow had recently been cleared.

Figure 12: Test section a few days after snow clearing was performed.

Challenges

During the first winter, snow clearing was done by the local maintenance crew. Due to their main commitment to keeping the highway in a safe condition, the test section snow clearing was probably not done often enough to achieve optimal cooling.

Recommendations

In order to achieve the desired snow clearing frequency, it may be advisable in future years to hire a private contractor to do the work despite the extra costs that would be encountered or designate specific funds in the maintenance budget for the work.

5 Grass-Covered Side Slopes

Concept/Procedure

Vegetation removal during road construction has a detrimental effect on underlying permafrost. Planting grass on the side slopes is an attempt to restore some of the natural insulation effect created by natural vegetation. For the test section, organic material was spread onto the side slopes of the embankment and a native grass seed mixture was planted. Figure 13 shows the grass beginning to grow on the side slopes.

Figure 13: Grass-covered embankment side slopes.

Challenges

The same issue was encountered with sourcing useable organic material for this section as for the ACE sections with an organic cover. For the grass-covered side slopes, a material was used that was a mixture of organics and granular material. Due to the sub-optimal soil, the grass may not grow well enough to have a noticeable effect on the embankment temperature.

Recommendations

Grass-covered side slopes may not be a practical option for preserving cold road embankments due to the lack of suitable organic material in permafrost areas along the North Alaska Highway. In other locations or if it is feasible to import soil, it may be possible to grow a dense grass carpet that would have an ability to insulate the embankment. It remains to be seen if the mediocre soil used in the test section is able to sufficiently support a grass cover to create positive results.

6 Light-Coloured Bituminous Surface Treatment

Concept

Increasing the albedo of a surface increases the amount of incident sunlight that is reflected. By surfacing the road with a special bituminous surface treatment (BST) using light-coloured aggregate, more sunlight should be reflected from the surface and thus less heat absorbed into the embankment.

Procedure

As seen in Figure 14, the process and equipment used for applying the BST was the same as that used for normal road BST surfacing. The only difference was the use of a light-coloured aggregate instead of the typical darker-coloured aggregate.


Figure 14: Placing the light-coloured BST.

Challenges

The light-coloured aggregate had to be sourced from a particular quarry 80 kilometres away from the site. However, the quantity required was small, so hauling the material was not a large obstacle to the work. For any future work, the need to use a certain source would involve incurring extra costs for crusher mobilization and hauling the material as compared to sourcing regular aggregate from the nearest gravel pit.

L.A. abrasion test results indicate that the light-coloured aggregate should withstand traffic loading as well as regular aggregate, so the quality of the material is not anticipated to be a problem.

Recommendations

The light-coloured BST has potential to reduce heat absorption into the embankment. Like the other test methods, the effectiveness of the technique remains to be seen. If it is effective, it would be a practical technique to use on a larger scale, as it uses conventional application techniques. It may also be possible to use a light-coloured bitumen.

7 Construction Season

Determining when to schedule construction of the test sections was one of the major decisions made during the project planning process. The most significant reason for considering winter construction was the advantage of minimizing disturbance to the permafrost, as road embankment excavations tend to initiate permafrost thawing. However, winter construction also poses significant problems. Firstly, while the permafrost would be generally preserved, the embankment would be frozen, making excavation difficult. As well, cold temperatures make it difficult to keep machinery functioning. Worker productivity suffers because of the cold and the short daylight hours. The research project involved using synthetic geocomposite and various plastic pipes that could also be more difficult to work with in extreme temperatures. These issues cast serious doubt on the quality of work that could be expected by constructing the test sections during winter months.

Utilizing the summer construction season would have alleviated many of the concerns associated with winter. Unfortunately, excavating the road embankment in warm temperatures and long daylight hours would be extremely detrimental to the temperature regime of the underlying permafrost. Since the overarching purpose of the project is to seek ways to preserve the permafrost, summer construction was not considered a viable option.

After considering the pros and cons of different construction seasons, the decision was made to compromise and schedule the work to begin in early spring. The guideline used for choosing a start date was the time when daily highs and lows were neutral, meaning the absolute values of daytime highs and nighttime lows were the same. The rationale for this timing was because anything that thawed during the day would refreeze at night.

Based on climate data from preceding years, construction was scheduled to begin around April 15. At the beginning of construction, temperatures were neutral. However, during May, daytime highs during construction averaged about 11˚C, with lows about 0˚C. These warmer temperatures may have resulted in notable warming of the permafrost underneath some of the sections where deep excavation was required. This might have induced the formation of taliks (pockets of soils that remain unfrozen during winter) in some areas of the project. It is expected that perturbations of the thermal regime induced by construction operations will disappear after one or two seasons.

Test section construction began on April 18, 2008, with completion of the work around May 25, 2008. All of the near-surface embankment material was frozen during the duration of the project. Removing the material required ripping the embankment with a large bulldozer, followed by excavation with excavators. Temperatures were warm enough for the synthetic geocomposite and pipe systems to be flexible and the granular material for backfill to be thawed. Working during a period of increasing daylight hours was useful for increasing worker morale and productivity. Snow melt on the site occurred during the construction timeline, resulting in substantial amounts of runoff water on the site.

8 Further Information

Construction of snow sheds is intended to occur in summer 2009. They will comprise an additional test section. The snow sheds will be wood frame structures, covered with a white sheet metal roofing material, and be about 0.5 m high.

The snow shed and longitudinal culvert sections are adjacent to one another. While there is a culvert on the other side of the snow shed section, water was flowing through the road embankment in the area of these two test sections in spring 2008. This water seepage is likely having a detrimental effect on the permafrost integrity in these two sections, a consideration to be noted once temperature data begins to be analyzed and compared amongst all test sections. This water may also have contributed to the difficulties with water infiltration into the longitudinal culverts during construction.

3 Cost Analysis

1 Test Section Costs

One of the main goals of the test sections project is to compare the costs of the various mitigation techniques to the costs currently incurred maintaining the highway. Consideration of the cost differences, in conjunction with any improvements in highway performance at the test sections, will form the basis for any further implementation of the mitigation techniques.

Engineering, construction, materials, and other costs were carefully tracked during the course of the project. Table 1 shows a summary of the costs related to the test sections. Each test section is 50 m long. The construction cost of the snow sheds is based on a design estimate, as the contract to build them has not yet been tendered and awarded.

Table 1: Costs related to test section design and construction.

Test Section Description	Design Eng.	Prelim. Geotech	ACE Production	Construction Contract	Construction Materials	On Site Eng.	Total
ACE – full embankment	$ 10,000	$ 3,000	$ 96,000	$ 458,000	$ 4,000	$ 35,000	$ 605,000
ACE – slopes, covered	$ 18,000	$ 3,000	$ 51,000	$ 303,000	$ 10,000	$ 26,000	$ 411,000
ACE – slopes, uncovered	$ 7,000	$ 3,000	$ 45,000	$ 223,000	$ 1,000	$ 19,000	$ 297,000
Heat Drains – full embankment	$ 18,000	$ 3,000	$ -	$ 226,000	$ 43,000	$ 15,000	$ 305,000
Heat Drains – slopes	$ 10,000	$ 3,000	$ -	$ 83,000	$ 46,000	$ 7,000	$ 148,000
Heat drains – (slopes) with insulation	$ 12,000	$ 3,000	$ -	$ 138,000	$ 66,000	$ 12,000	$ 230,000
Longitudinal culverts	$ 24,000	$ 3,000	$ -	$ 150,000	$ 59,000	$ 13,000	$ 248,000
Snow Clearing	$ 2,000	$ 3,000	$ -	$ 8,000	$ 1,000	$ -	$ 14,000
Grass-covered embankment	$ 3,000	$ 3,000	$ -	$ 29,000	$ 1,000	$ 2,000	$ 37,000
Light-Coloured BST	$ 7,000	$ 3,000	$ -	$ 23,000	$ 1,000	$ 2,000	$ 34,000
Control	$ 4,000	$ 3,000	$ -	$ 24,000	$ 1,000	$ 2,000	$ 34,000
Snow sheds	$ 11,000	$ 3,000	$ -	$ 181,000	$ 1,000	$ 1,000	$ 196,000

The design engineering costs include Government of Yukon staff hours as well as time contributed by Université Laval and AUTC. Geotechnical investigation work was done the year prior to construction, and is reflected in the prelim. geotech. column. The ACE production costs reflect the differing amounts of material required for each of the three ACE sections, and include blasting, crushing, and stockpiling.

The construction contract costs reflect the monies spent actually building the test sections. They include hauling all ACE rock, 20 mm aggregate, and light-coloured aggregate to the site for the respective sections. A detour was constructed around the two full embankment sections to facilitate traffic movement. The detour construction and removal costs are incorporated into the costs for these two sections. The construction costs also include the money spent to resurface the road after construction was complete with a BST surface, matching the standard of the adjacent road sections.

Construction materials include all synthetic materials used in the project such as HDPE culverts, ventilation pipes, geocomposite, and geotextile. On site engineering covers the expense of the Government of Yukon staff who monitored construction.

The test section costs were extrapolated into a cost per kilometre over a given lifespan. The results of the analysis are in Table 2. The design costs were considered to remain constant, whether there is 50 m of highway being modified or several kilometres. The cost of snow clearing is given over fifty years, with the amount being converted to 2008 dollars. Lifespans were estimated based on predicted longevity of materials. While minor maintenance is expected over the lifespan, the systems should remain essentially intact for the duration.

As with the large scale savings estimates, the lifespan projections used in the analysis are just one possible scenario. An accurate evaluation of the longevity of each section will not be available until the test sections have been in place and observed for several years.

The cost estimates have been compiled on the basis of highway rehabilitation as opposed to new construction. Therefore, costs such as building detours around the full embankment test sections have been included, since they are not necessary if the alternative of doing no rehabilitation is chosen.

If construction is done over several kilometres, it is anticipated that there will be some cost savings due to the increased quantities. These savings are presumed to be different, with larger savings available in blasting and crushing ACE rock and lesser savings for techniques involving large quantities of synthetic materials, as the expense of procuring and shipping these materials is not expected to markedly decrease regardless of quantity.

Table 2: Cost estimates for mitigation techniques for long-term lifespans.

Test Section Description	Design/ Geotech Cost (50m)	Construction Cost (50m)	Operational Cost over Lifespan (per km, 5% infl/yr)	Lifespan (yrs)	Large Scale Project Savings	Cost per year per km
ACE – full embankment	$ 13,000	$ 592,000		50	20%	$ 190,000
ACE – slopes, covered	$ 21,000	$ 390,000		50	20%	$ 125,000
ACE – slopes, uncovered	$ 9,000	$ 288,000		50	20%	$ 92,000
Heat Drains – full embankment	$ 21,000	$ 284,000		10	10%	$ 513,000
Heat Drains – slopes	$ 13,000	$ 136,000		10	10%	$ 245,000
Heat drains – (slopes) with insulation	$ 15,000	$ 215,000		10	10%	$ 389,000
Longitudinal culverts	$ 26,000	$ 222,000		35	5%	$ 121,000
Snow Clearing	$ 4,000	$ 6,000	$2,073,000	50	15%	$ 44,000
Grass-covered embankment	$ 5,000	$ 28,000		50	5%	$ 11,000
Light-Coloured BST	$ 9,000	$ 25,000		10	0%	$ 51,000
Control	$ 7,000	$ 27,000		50	97%	$ 500
Snow sheds	$ 14,000	$ 182,000		20	15%	$ 156,000

2 Maintenance Costs

The cost of maintaining highway sections adversely affected by permafrost is much higher than that for non-affected areas. In order to estimate the extra money required for permafrost areas, expenditure data for two different sections of the Alaska Highway was used. Since the last major reconstruction was complete in 2005, the data set includes the three fiscal years between 2005 and 2008. All figures have been converted to 2008 dollars based on inflation rates used by engineering planning staff.

One area looked at was the section of the Alaska Highway, which is about 130 km long, in the Haines Junction maintenance area. Haines Junction is approximately 300 km south of Beaver Creek. The other area considered was the Alaska Highway in the Beaver Creek maintenance area. This section is also about 130 km long; of this length, approximately 100 km is affected by thawing permafrost.

Table 3 shows the maintenance activities that were considered for the comparison. In general, winter maintenance activities, such as snow removal and sanding, were not considered as they are not related to the presence or lack of permafrost. The average expenditures over the three years considered are also shown.

Table 3: Average maintenance costs for Beaver Creek and Haines Junction.

Activity	**Beaver Creek Average 2005-2008**	**Haines Junction Average 2005-2008**
Surface Blading	$ 1,800	$ -
Surface Repairs	$ 45,700	$ 1,900
Dust Control/Calcium Chloride	$ 8,200	$ -
Patching with Premix	$ 328,800	$ 81,700
Clean & Reshape Ditches	$ 2,100	$ 2,800
Guard Rail/Post Maintenance	$ 1,200	$ 2,400
Sign and Post Maintenance	$ 30,800	$ 25,400
Gravel Crushing - Summer	$ 171,600	$ 137,800
BST Regular	$ 858,500	$ -
BST Patching	$ 507,700	$ 64,500
Gravel Crushing - Winter	$ 234,900	$ -
BST Sweeping	$ 47,500	$ -
Rip & Reshape/Reclaiming	$ 158,500	$ 2,800
Ditching	$ 80,000	$ 6,600
Grade Raises	$ 44,900	$ -
Berm Work	$ 4,000	$ -
Total:	**$ 2,526,200**	**$ 325,900**

The difference between the two sections is approximately $2.2 million. Based on the activities considered, this amount is the extra cost of maintaining thawing permafrost-affected highway sections. However, the Beaver Creek section is not maintained to a standard equivalent to that found in the Haines Junction section. Taking into account that the Beaver Creek area has 100 km that are disturbed by thawing permafrost, the current average cost per year per kilometre to compensate for thawing permafrost is about $22,000.

The money spent per kilometre for 2003 for the Beaver Creek section was about $36,000, a year in which about 20 km of the highway north of Beaver Creek was rehabilitated and resurfaced. Considering that the projected lifetime of BST surfaces on permafrost-affected highway is 3 years, it can be seen that the money currently allocated to maintenance work is far from sufficient to sustain the level of service that is the standard for most of Yukon's highway network. As a result, the above analysis was undertaken with the understanding that the monies allocated to maintenance are budget-dependent, not necessarily needs-dependent. If climate change predictions are correct, the highway will be subject to increased subsidence and damage from more rapidly thawing permafrost, requiring more money to be spent on maintenance.

3 Comparison of Mitigation Techniques and Maintenance Activities

As seen in the above analysis, the amount spent per highway kilometre on permafrost-related maintenance is $22,000. In comparison, the least-expensive mitigation technique being tested is the grass-covered embankment, which costs about $11,000 per year per kilometre over its lifetime. The uncovered ACE slopes, which have been the most effective at cooling the embankment during the first winter (2008-2009), would cost about $92,000 per year per kilometre.

The ranking of the cost per year per kilometre of the various techniques, from lowest to highest and not including the control section, is as follows:

1. Grass-covered Embankment	$ 11,000
2. Snow Clearing	$ 44,000
3. Light-Coloured BST	$ 51,000
4. ACE – slopes, uncovered	$ 92,000
5. Longitudinal Culverts	$121,000
6. ACE – slopes, covered	$125,000
7. Snow Sheds	$156,000
8. ACE – full embankment	$190,000
9. Heat Drains – slopes	$245,000
10. Heat Drains (slopes) with insulation	$389,000
11. Heat Drains – full embankment	$513,000

1. Current Maintenance Practices	$ 22,000-$36,000 and up

Based on this information, grass-covered embankments are the only technique less expensive than current maintenance practices. The lifetime projections used in the analysis are estimates only; as such the heat drains may in fact prove to be viable once several years have passed and a more accurate assessment of their longevity is available. The same logic should be applied to the other sections.

A further option for highway rehabilitation, which is outside the scope of this analysis, would be to develop a more specialized maintenance program with increased funding for permafrost-affected highway, improving the current practice of attempting to maintain a well-performing road without addressing the underlying issues.

Cost differences between the mitigation techniques is only one factor in the determining whether to implement any of the mitigation techniques on a wider scale. It may become clear over the next several years, through thermal modelling and site observations, that a technique significantly improves the performance of the road, which will serve as a support for further use of the technique in spite of the increased cost. Thermal modelling is also expected to show whether or not there are benefits in combining the mitigation techniques; for example, using ACE on the side slopes in conjunction with a light-coloured BST surface.

Cost estimates, budget availability, and performance will be the main factors in determining whether any of the mitigation techniques are implemented on a wider scale. Further implementation could range from modifying a large portion of the permafrost-affected North Alaska Highway, to focusing on critical areas such as bridge approaches and short sections of highway that are the most distressed.

4 Conclusions

The construction of several of the mitigation techniques was fairly straightforward. The longitudinal culverts and light-coloured BST used conventional installation and construction methods. Completing the grass-covered embankment was also simple, once a source of organic material was found. The various ACE sections were time and equipment-intensive; however, the work was not especially difficult. The snow clearing was done using a loader with a blade during the first winter of operation. The heat drains sections were the most difficult to construct, as the material sizes and quality were not well suited to highway construction. Issues with the geocomposite quality and the difficulty in creating a robust ventilation pipe system may make it difficult to realize thermal benefits from the heat drain technique.

In general, ground water proved to be one of the main challenges faced during the construction of the test site. For optimal performance of most techniques, excavation of existing embankment fill should have been as deep as possible; however, the excavation limits were set at 0.7 m above the detected level of ground water in an attempt to compromise between ground water infiltration into the materials used and maximum thermal benefit. Despite these precautions, there were problems with water seeping into some of the longitudinal culverts. While French drains were added along the pipes, the water was pumped out, and the culverts were dry at the end of the construction period, it remains to be seen whether water infiltration will again be a problem in spring 2009.

Using the given estimates for lifespans and large-scale project savings, the cost per year per kilometre to implement the various techniques ranges from $11,000 for the grass-covered embankment to $513,000 for the full embankment heat drains. Currently, $22,000 per kilometre is spent on maintenance directly related to damage caused by degrading permafrost. However, this figure could be much higher if increased funding was available. Some of the sections that were relatively easy to construct, such as the light-coloured BST and the uncovered ACE slopes, are estimated to cost $51,000 and $92,000 per kilometre per year respectively.

Due to the high costs of most of the mitigation techniques, further implementation will be contingent on proof from temperature data and thermal modelling that they can considerably increase the performance of the highway and decrease the costs of permafrost-related maintenance. Once an adequate amount of thermal data is accumulated, the cost and constructability issues will be considered in conjunction with performance improvements to determine if any mitigation techniques will be used to rehabilitate the highway, whether it be short, severely affected sections, critical bridge approaches, or long stretches of highway. In the event that increased maintenance is required due to progressive permafrost thawing resulting from climate change, implementation of mitigation measures might become an interesting and cost effective alternative.