Alyeska's 40-plus Years of Experience with Heat Pipes on the Trans Alaska Pipeline

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Heat pipes (thermosyphons) were installed in the vertical support members (VSMs) of the Trans Alaska Pipeline where the pipeline is elevated in areas with warm non-thaw-stable permafrost. More than 124,000 heat pipes were installed during pipeline construction in the mid-1970s to thermally stabilize the permafrost surrounding the VSMs. Shortly after pipeline construction non-condensable-gas(NCG) began to occur in some of the heat pipes affecting their performance. Alyeska conducted an extensive research effort to identify the root cause for the occurrence of NCG and performed a test program on the degradation in heat pipe performance with the build-up of NCG. Two procedures have been used to repair underperforming heat pipes due to NCG issues: (1) Using "getter devices" and (2) recharging the heat pipes with carbon dioxide. Using getter devices was not a permanent solution to the NCG problem and experience has shown recharging to be a successful repair option. This paper describes several heat pipe options Alyeska considered prior to construction and the choice and development of the heat pipes that were used on the pipeline along with the operational experience during the last 40-plus years. This paper presents findings from the test program on the degradation in heat pipe performance with build-up of NCG, and the use of heat pipes as a thermometer to monitor end of thaw season ground temperatures at the base of VSMs.

Initial Performance of Sloped Thermosyphons for Stabilization of Massive Ground Ice Beneath the Alaska Highway, Yukon Territory

Christopher Stevens SRK Consulting (U.S.) Inc.

The Dry Creek Highway Section is located along the Alaska Highway in the Yukon Territory of Canada. The site was identified as a key highway section that required stabilization due to warm (>-0.5°C), degrading ice-rich permafrost and massive ground ice in excess of 9 m thick. The thermal design for permafrost stabilization was based on a 30-year design life and incorporated sloped thermosyphons installed beneath the existing highway embankment to passively cool the permafrost foundation. The design specified 58 thermosyphon installed every 7 m on center beneath the existing highway embankment, with evaporator pipes 34 m in length that were installed in a cased borehole at an ~11° incline beneath the embankment. A vertical riser pipe with a 19.5 m2 surface radiator was installed for each unit. The inclined boreholes were drilled from the embankment toe to limit the need for excavation and to maintain integrity of the existing embankment, allowing for unimpeded use of the vital cross-border transportation route between Alaska and the Yukon Territory. Numerical thermal modeling was used to verify performance of the design and optimize thermosyphon radiator size and evaporator pipe distance in the ground to reduce project cost and ensure long-term performance with consideration of climate change. This presentation will cover the thermal design and initial performance over the first two years since construction. Temperature measured at two monitoring sections have confirmed initial cooling of the foundation by several degrees Celsius in response to seasonal heat extraction by the thermosyphons. The most notable change in ground temperature from the baseline period has occurred beneath the centerline where the embankment thickness is the greatest. At some sideslope positions, the permafrost table has begun to aggrade upward into thaw-stable material. The Dry Creek Permafrost Stabilization project contributes to evaluation of sloped thermosyphons for the adaptation of surface infrastructure to climate change in permafrost environments.

Effects of Foundation Performance on TAPS from Changing Thermal Conditions

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The Trans-Alaska Pipeline (TAPS) has been impacted adversely by the changing climate over the last 40 years of operation. This paper will discuss the performance issues due to thermal changes of underlying permafrost soil at a location along TAPS, near Pipeline Line Milepost (PLMP) 680. This site has been closely monitored and design for the repair options is underway. The site is located near the southern end of the pipeline in an area of discontinuous permafrost. The change in climate has caused permafrost degradation impacting the foundations of the Vertical Support Members (VSM) supporting the pipeline. PLMP 680 has a history of continued vertical and lateral movement, which has accelerated in the last 20 years. Despite the passive cooling installed in the VSM's during construction, permafrost degradation has continued at these sites leaving only a frozen bulb around the VSMs. The thermal changes at PLMP 680 have caused significant vertical and tilt movement of the VSMs. Starting in the 1990's, the VSM's had heave up to three feet causing lateral tilting of the VSM's. The heave appears to have been caused the by formation of a vertical ice lens along the VSM. The heat pipes were covered at one of the supports to minimize the heat extraction and reduce the heave rate. Since then, movement at the VSM's have continued with tilting up to 10 percent since construction. Current movement at the site now appears to be primarily due to permafrost degradation and expansion of the wetlands. Recent lateral movement at the site is believed to be caused by consolidation of the newly thawed fine-grained soils around and below the VSMs.

Centrifuge Modelling of Steel Piles in Frozen and Thawing Ground

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Northern climates create an increased complexity in soil-foundation interactions compared to temperate regions. The continuous and discontinuous permafrost that varies throughout the arctic has a crucial role in pile foundation design. The uncertain quality of frozen soil, and its interaction with an ad-freeze steel pile provides a strong motive to further understand the strengths and bearing capacities of foundations in frozen soil. Centrifuge modelling was used to simulate in-situ forces acting on steel ad-freeze piles in frozen soils. A centrifuge allows for the experimentation of small-scale models in a laboratory to be interpreted with real world parameters. By increasing the magnitude of gravity, a miniature pile foundation in a frozen soil can be modelled at full size for its entire design life in a fraction of time and space of the full-scale equivalent. The model pile was designed to recreate the soil-structure interface of ad-freeze piles used in permafrost region foundations. The piles and surrounding soil were instrumented and frozen prior to testing. Thermistors placed at specific locations in the test apparatus provided the changing thermal profiles of the soil before, during, and after testing. A load cell measured the axial load applied. Inclinometers detected the small factored displacements that occurred within the frozen soil. The steel piles had allocated small expected displacements due to initial loading. Initial load-displacement responses were recorded, as were secondary settlements that occurred during the re loading. The purpose of these centrifuge experiments was to provide further insight through experimental validation on the strength, bearing capacity, and initial stiffness of soils in frozen and increasingly thawed conditions. This was documented by measuring the load-displacement response of varying thermal soil-pile interfaces. Results quantify the ability of piles to sustain intended loads in frozen and thawing permafrost.

Using Airborne LIDAR to Assess Elevation Trends on the Alaska North Slope

Karl Kyzer Hilcorp Alaska, LLC

Measuring elevation changes of Arctic infrastructure is labor-intensive by means of conventional survey methods. This talk describes techniques using airborne LIDAR surveys to improve efficiency.

Topics include:

1) Real-world application for subsidence mitigation.

2) Collection parameters for airborne lidar surveys.

3) Deliverables.

4) Accuracy and precision expectations.

5) Quality control.

6) Analysis methods and tools.

7) Advantages and disadvantages vs. conventional survey methods.

Overall, the use of airborne LIDAR has been a successful tool used to efficiently assess trends in elevation changes enabling timelier mitigative measures to be put in place on the Alaska North Slope.

Slope Stabilization Along a Buried Crude-Oil Pipeline in Ice-Rich Permafrost

Peppi Croft
Oliver Hoopes   Shannon & Wilson, Inc.
Frank Wuttig
Chuck Shulz
Wendy Mathieson

The Trans Alaska Pipeline System (TAPS) transports warm oil through a 48-inch diameter pipeline (mainline) 800 miles from Prudhoe Bay to Valdez, in Alaska. The system traverses continuous and discontinuous permafrost and is supported aboveground or belowground, depending on permafrost and ground conditions. The study site is in the discontinuous warm permafrost of the Copper River Basin in the southern interior of Alaska. Subsurface conditions in the Copper River Basin consist of locally ice-rich glaciolacustrine and glacial deposits. The mainline at the site is buried in thaw-unstable permafrost and actively refrigerated to allow for animal crossings. Thermistor strings were installed in 2001 to monitor subsurface temperatures. In 2012, Alyeska Pipeline Service Company (APSC) observed evidence of ground movement at the study site threatening to uncover the mainline. Instrumentation showed movement related to a combination of permafrost thawing, groundwater seepage, and creep near the top of permafrost. We used coupled 2-dimensional (2D) and axisymmetric finite element thermal simulations to evaluate and develop mitigation. Mitigation consisted of an array of thermosyphons and woodchip surface insulation designed to freeze and buttress movement. APSC installed mitigation and additional instrumentation in fall 2017. Slope inclinometer and thermistor string data indicate freezeback and significant cooling of frozen soils in the treatment area arresting slope movement adjacent to the mainline. The paper demonstrates how geotechnical hazards are being managed along TAPS and how the Alyeska Pipeline Service Company is adapting to changing environment and permafrost conditions. We evaluate our thermal modeling approach and mitigation design by comparing predicted and observed subsurface conditions at the study site. We base our evaluation on thermal modeling results and slope inclinometer and thermistor string data between 2017 and 2020.

Climate Change Adaptation - Saving our Critical Infrastructure

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The Problem

Soils with high moisture content and massive ice can exist in permafrost and can be relatively warm. When permafrost melts, the soils subside and the structures founded on the permafrost can experience significant settlement. Heat transmitted into the ground from warm structures must be removed to prevent the ground from thawing. This is often done through passive thermosiphons. Warmer winter air temperatures are preventing passive cooling systems from working as designed and may render many facilities unusable if not properly addressed in time.

The Solution

ANTHC-DEHE is developing an easy to install, relatively inexpensive refrigeration collar. It adds active cooling to the existing passive thermosiphon, keeping the foundation stable. The system can be installed as a retrofit to existing thermosiphons or new construction. The refrigeration collar is expected to be less expensive than a new thermosiphon installation and can avert costly damage. Potential applications exist in remote communities and industrial centers across the Arctic.

Thermal Refrigeration Collar

The refrigeration collar is a clamp-on cooling system. It is ruggedized for Alaska's climate. Installation requires mounting on a thermosiphon, plugging in a power source, and turning it on. Each unit can deliver over 500 W of cooling, which has been demonstrated with lab work. Each unit can be powered with solar panels and a 24V battery bank.

The unit consists of two parts: an insulated evaporator enclosure that mounts at the base of the thermosiphon, and a compressor and condenser assembly that mounts on the evaporator enclosure. The unit uses quick connects to allow connection of the compressor and evaporator in the field without losing refrigerant.

Testing is underway for the second prototype and field evaluation on the North Slope of Alaska is planned for 2022.

Cruz Construction 2021 Regional Permafrost Conference Abstract

Jeff Miller Cruz Construction, Inc.

To Whom It May Concern: Cruz Construction is willing to be a part of a discussion focused on the means and methods of construction in permafrost. Specifically, as it applies to construction for the oil & gas, and mining industries. Our primary focus as a company is to construct heavy civil projects in remote Alaska. We face the challenges of permafrost all year long as we construct jobs both in the summer and winter. We have used many types of methods to deal with the effects of destabilized permafrost and/or eroding conditions. This includes insulation, shot rock, thermosiphons, and various other methods. Due to project specific constraints and funding limitations there is no "one size fits all" answer. We would appreciate the opportunity to share and learn in a discussion format environment on this subject matter. The following are brief summaries of recent projects that had various elements of this topic associated with them. If there was interest we will be willing to drill down in more detail the specifics of these projects and discuss any questions associated with them. Brief Project Summaries: Project Name: Newtok Airport Relocation - 2021-2022 Location: Newtok, Alaska Client: Alaska DOT/PF Project Description: The village of Newtok has been on national news due to its emergency need to be relocated. The village has been rapidly eroding into the Bering Sea. Cruz has been contracted to construct a new runway at the new village site. The project site and mine site have many challenges due to poor aggregate quality and soils conditions. This project is a summer time build in a challenging environment. The project quantities include; 63 acres of clearing; 110,000 CY of excavation; 350,000 SY of geotextile; 15,000 ton of porous backfill & ditch lining; 1.15 million tons of borrow; 75,000 ton of subbase; and 60,000 ton of surface course. Project Staffing: Cruz Construction - Jeff Miller (Contract Manager); Greg Miller (Project Manager); Kyle Motsko (Superintendent). Project Cost: $25-$30,000,000.00

Concrete Construction in Cold Regions – Quantifying the Impact of Daily Temperature Variations on Required Frost-Protection Measures

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Concrete Construction in Cold Regions – Quantifying the Impact of Daily Temperature Variations on Required Frost-Protection Measures

Benjamin E. Watts, PhD, Danielle E. Kennedy

Abstract

In cold temperatures, fresh concrete can be irreversibly damaged by internal formation of ice before adequate strength has developed. Industry-standard protection measures, prescribed in ACI 306, are frequently laborious, expensive, and time-consuming. The USACE ERDC Cold Regions Research and Engineering Laboratory (CRREL) has developed ARCTEC (Additive Regulated Concrete for Thermally Extreme Conditions) to enable the use of standard concrete additives as alternative freeze protection in cold conditions.

A core component of ARCTEC is guidance to recommend additive dosage required for a successful concrete placements. This recommendation depends upon multiple aspects of a concrete placement, including geometry, mixture proportions, ambient temperature, and placement time. The number of unique cases implied by these parameters precludes physical testing of every possibility, so a transient finite-element thermal model was created to simulate and quantify the degree of frost protection required for concrete placed over a wide range of environmental and spatial configurations. Inputs for this model were obtained through laboratory characterization of the thermal and mechanical behavior of concrete at multiple curing temperatures and additive dosages.

Daily ambient temperature profiles were synthesized based on regional average minimum and maximum air temperatures, as well as day of year and latitude. Temperature profiles were used to simulate the impact of concrete placement hour on the degree of freeze protection measures required for flatwork of varying thickness. Results indicate that even in winter months, selection of the proper time of day for concrete placement can result in substantial savings in the cost of freeze protection measures. The results define a pathway to development of guidance for successful implementation of additive-based freeze protection measures regardless of time of placement or ambient conditions.

Permafrost Test Sites: A Summary of Alaskan Pipeline Industry Efforts in Addressing Frozen Ground and Related Technical Issues

James Rooney

This paper is an attempt to identify and provide a brief summary of some industry efforts that occurred during the late 1960's on through the mid-1980's, that I was involved with or aware of. All of the test sites were focused on evaluating terrain conditions and assessing potential pipeline impacts that would be involved while dealing with frozen ground conditions. The efforts included various organizations and participation by government agencies that occurred during both the Alyeska Pipeline Service Company (APSC), Artic Gas Pipeline and Alaska Northwest Natural Gas Transmission System early project activities. There were at least 11 test sites having locations in various parts of Alaska. These included Barrow, Prudhoe Bay, Prospect Creek, Hess Creek, the Fairbanks area and Glennallen. They addressed concerns relating to thermal modeling of a hot oil 48 inch pipe buried in frozen ground, thaw settlement/ frost heave effects, trench excavation methods, and testing vertical support solutions for the designated above ground pipeline segments. Access to published information on these test sites is varied and the concern is that some of this past history on early pipeline studies, related design input and the possible influence on eventual construction (at least for APSC) be recorded.

Construction and Structural Analysis of an Arched, Cellulose-Reinforced Ice Bridge for Gap Crossing by (Military) Vehicles

Emily Asenath-Smith	US Army ERDC-CRREL
Kiera Thompson Towell	US Army ERDC-CRREL
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Devin O'Connor	US Army ERDC-CRREL

As the potential for conflict in the Arctic rises, the US military has a renewed interest in using ice as an indigenous material. While ice covers have been leveraged to traverse water bodies during cold months, ice has seen little use as a standalone bridging material for vehicle mobility. To address this knowledge gap, an arched bridge made from ice reinforced with 0.3 wt% cellulose was constructed using a spray deposition method. The bridge was built over a dry gap (3 x 3 m) in a temperature-controlled facility and was able to support the static and dynamic loading of military-grade vehicles (up to 3,000 kg) with no visible damage to the bridge. Flexural and compression testing of ice specimens extracted from the bridge post traverse indicated that the cellulose reinforced ice is almost 2x greater in strength compared to pure ice. Microstructural analysis showed a layered structure with smaller ice grains in layers with more cellulose. A computational model that incorporated the measured material properties was used to probe the effect of ice thickness, gap width and arch curvature on the strength of ice bridges. The model results predicted that the bridge as built could support up to 16,800 kg of static loading, which is safely in the range of military tactical vehicles (e.g., M1083, 13,480 kg). Increasing the curvature of the bridge effectively increases the load capacity of the bridge by approximately 50%, while larger gaps and widths are still able to support military-grade vehicles up to 3,000 kg if the ice is thickened by 50%. The versatility of this new approach is of high impact to both civilian and military mobility in cold regions, adding a critical new tool to the cold regions engineering toolbox.

Design and Construction of an At-Grade LNG Storage Tank on Warm Permafrost in Fairbanks, Alaska

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Andrew Daggett Golder Associates, Member of WSP
David Prusak Stantec

To improve air quality in interior Alaska Fairbanks Natural Gas (FNG) has invested in the development of a new liquefied natural gas (LNG) storage facility. The site is in an area of warm, discontinuous permafrost in Fairbanks, Alaska where there is concern over the continued permafrost degradation. An innovative shallow foundation system was selected because of the cost of deep foundations, due to the high seismic conditions and need for long-term foundation cooling. Long-term performance and constructability were two major issues for this foundation system.

The LNG is stored at a temperature of -160°C and the permafrost soils only extend approximately 40m deep and the site is adjacent to the Tanana River. The aggradation of permafrost was considered unacceptable over a 75-year design life. The delicate balance of maintaining warm permafrost was evaluated, modeled, and designed to allow for the construction of an at-grade foundation system. The shallow foundation system is designed balance the cold from the LNG within the storage tank to maintain the permafrost, but not significantly lower the temperature of the permafrost.

In addition to design, construction issues arose due to the tight timeline for construction, weather, and the need to compact structural fill soils during the winter. Historically, compaction has shown time and again to be challenging during wintertime placement, often with poor results. The LNG storage tank construction timeline provided very few options for excavation and backfill activities to occur during warmer months. Careful consideration was given to key parameters required for compaction during the winter in Fairbanks, where the average winter temperature is -15°C. Air temperature, wind, soil temperature, and moisture conditioning constraints were defined prior to the start of winter compaction efforts. Careful execution of the plan and attention to the weather and soil behavior allowed for a successful structural backfill compaction effort.

Keywords: warm permafrost, LNG storage tank, permafrost foundations.

Linking climate change and human systems: a case study of Arctic pipelines

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This case study estimates the potential economic risk from permafrost thaw on oil and gas pipelines in the Russian Arctic as part of a larger effort to better understand complex interactions between human and earth systems in the Arctic. Pan-Arctic simulations of permafrost thaw-depth from the Community Land Model version 4.5 and ground ice characteristics were used to generate thaw-induced ground subsidence projections over the period 2020 to 2040 with a quantification of uncertainty. Engineering analysis and expert input were used to estimate the magnitude of ground subsidence likely to cause significant pipeline damage. Russian oil and gas transmission pipeline networks were then overlaid on the ground subsidence projections in ArcGIS to identify pipelines vulnerable to damage from permafrost thaw. Recent pipeline construction costs were used to estimate the total replacement costs for at-risk pipelines under several thaw scenarios. The results indicate that permafrost thaw poses a major threat to pipeline infrastructure, especially gas pipelines, in the Russian Arctic. Over the twenty-year study period, total replacement costs for oil and gas pipelines were estimated at $110 billion in 2020 USD. The study also includes an uncertainty analysis on the range of possible replacement cost estimates due to combined uncertainty from permafrost projections, pipelines’ subsidence tolerance, and Arctic construction costs. Reduced economic viability of pipelines under climate change could trigger major shifts in the Russian oil and gas industry, which would have impacts on global markets, emissions, and geopolitics.

Improving Construction and Performance of a Runway in Nuiqsut, Alaska

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Jeremy Dvorak
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Airports provide the only means of reliable access to many arctic communities in Alaska and are essential for goods, transportation, and medical care. Despite being surfaced with gravel, the runways must provide reliable access year round. Many of the runways in the North Slope region were constructed in the 1980's when conventional engineering design indicated 1.3-meter to 2-meter embankments were adequate to protect the runways from thermal degradation of the underlying permafrost and subsequent settlement. Global climate change has resulted in thaw instability of many runways. Short, wet, cold construction seasons make construction of arctic runways challenging. In addition, gravel surfacing is difficult to produce locally and generally of poor quality. This paper presents the solutions developed to address the challenges for resurfacing the gravel runway in Nuiqsut, Alaska. Insulation was installed in the runway embankment to limit the potential for future global warming to thaw the underlying permafrost. Wicking fabrics accelerated drainage during reconstruction of the embankment fill over the insulation. Dust control additives were blended into the gravel surfacing to increase strength and performance. This paper also presents lessons learned through design and construction. Recommendations are provided for design of future runways and the value of the insulation, wicking fabric, and dust control blending is discussed.

Embankment Fill Slope Movement on Thaw Sensitive Permafrost: Movement Mechanisms and Thermal Conditions at Lost Creek along the Trans Alaska Pipeline System (Lost Creek – Part 1)

Peppi Croft

Oliver Hoopes Shannon & Wilson, Inc.

Frank Wuttig

Wendy Mathieson

The Trans Alaska Pipeline System transports warm oil through a 48-inch diameter pipeline (mainline) 800 miles from Prudhoe Bay to Valdez, Alaska. The system traverses continuous and discontinuous permafrost and is supported aboveground or belowground, depending on permafrost and ground conditions. The Lost Creek site is about 60 miles northwest of Fairbanks in discontinuous permafrost on a northwest-facing cut and fill slope. The permafrost is warm with temperatures between 30 and 31.5°F. The embankment fill is up to 45 feet thick and was placed over frozen colluvium along the hillslope and ice-rich peat and silt near the base of the slope. The mainline is supported aboveground by thermal vertical support members (VSMs) which were installed in 1976 and consist of drilled pipe piles fitted with thermosyphons. In 1990, Alyeska Pipeline Service Company first noted ground cracking at the site. Starting in early 2000, shoe displacement indicated VSM downhill movement and maintenance activities increased. APSC advanced exploratory borings in 2006, 2009, and 2010 and instrumented the site with three thermistor strings and three inclinometer casings to study movement mechanisms. In 2017, University of Alaska Fairbanks researchers advanced four shallow borings using a handheld Snow, Ice and Permafrost Establishment (SIPRE) drill in peat deposits adjacent to the embankment to obtain samples for laboratory creep and thermal testing. This study presents our interpretation of geotechnical site conditions based on geotechnical instrumentation monitoring, soil and permafrost observations, and laboratory creep testing results. Movement and deformation mechanisms at the site consist of 1) longitudinal creep movement within a shear zone concentrated in ice-rich organic (peaty) permafrost and 2) transverse shoulder rotation due to thaw settlement. We integrated creep, thermal, and slope stability analyses and developed mitigation options to control ground movement and present our approach in a separate paper within these proceedings (Lost Creek – Part 2).

Embankment Fill Slope Movement on Thaw Sensitive Permafrost: Combining Creep Testing and Thermal Simulations to Develop Mitigation Options at Lost Creek along the Trans Alaska Pipeline System (Lost Creek – Part 2)

Oliver Hoopes Shannon & Wilson, Inc.

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Frank Wuttig

Chuck Shulz

Wendy Mathieson

The Trans Alaska Pipeline System transports warm oil through a 48-inch diameter pipeline (mainline) 800 miles from Prudhoe Bay to Valdez, Alaska. The system traverses continuous and discontinuous permafrost and is supported aboveground or belowground, depending on permafrost and ground conditions. The Lost Creek site is about 60 miles northwest of Fairbanks in discontinuous permafrost on a northwest-facing cut and fill slope. The embankment fill is up to 45 feet thick and was placed over frozen colluvium along the hillslope and ice-rich peat and silt near the base of the slope. The mainline is supported aboveground by thermal vertical support members (VSMs) which were installed in 1976 and consist of drilled pipe piles fitted with thermosyphons. APSC observed fill slope movement beginning in 1990. Movement mechanisms at the site consist of longitudinal creep movement along a shear zone in ice-rich permafrost and transverse shoulder rotation due to thaw settlement. The movement causes lateral pile loading, VSM tilt, VSM downhill displacement, and extensive embankment cracking and displacement. Frequent maintenance activities include adjusting crossbeams, shoe positions, and pipeline position, and regrading the drivelane and embankment slopes. APSC plans to replace VSMs and mitigate slope movement at the site to maintain pipeline integrity. We combined creep testing laboratory results, thermal modelingdesign simulations, and slope stability design analyses to establish relationships between temperature, shear load, and creep rate based on Glen's Flow Law and developed mitigation options. Based on our analyses, APSC selected a thermal improvement strategy consisting of passive ground cooling and woodchip insulation to mitigate permafrost degradation and to slow creep movement. We present our interpretation of site conditions based on instrumentation readings, site observations, existing condition thermal modeling, and creep testing laboratory results in a separate paper (Lost Creek – Part 1).