Analysis of road salt use and its impact on groundwater within the context of changing winter weather conditions

Dikshya Parajuli University of Maine
Shaleen Jain University of Maine
Jonathan Rubin University of Maine

The study focuses on the contamination risk of groundwater wells due to winter road salt, sodium chloride, with particular attention to changes in long-term weather conditions. Despite great advantages for traffic safety, road salt infiltrates soil, and eventually joins surface and ground-water leading to their salinization. We use data on contamination concentrations in the wells tested by the Maine Department of Transportation to estimate well contamination risk in Maine.

Since there exist no practical technologies for removing salt from contaminated water sources, reducing salt application, where appropriate, is the only solution. Winter severity Indices (WSI) are tools used to assess and compare the severity of winters and road salt use. In this study we also relate a wide range of WSIs with statewide road salt usage and compare their ability to explain the trend in road salt in Maine. We compute WSIs at 12 locations and apply Principal Component Analysis to achieve dimensionality reduction and address multicollinearity. Our linear regression-based results show that various combinations of WSI indices show statistically significant relationships with salt usage. At the same time, the spatial patterns associated with the principal components highlight the regional differences in winter severity across Maine's climate zones. Ongoing work seeks to relate salt use to climatic variability and changes in usage patterns; at the same time, new suite of indices to include non-snow or precipitation situations are being developed, so as to understand the salt applications in frost-induced icing situations, and their changing prevalence over the past two decades.

On the use of Electrical Resistivity Tomography measurements and Induced Polarization-surveying in arctic landfill assessments

Regula Frauenfelder Norwegian Geotechnical Institute, Oslo, Norway

Asgeir Olav

Kydland Lysdahl Norwegian Geotechnical Institute, Oslo, Norway

Andreas Olaus HarstadSkanska AS, Oslo, Norway

Sara Bazin Institut Universitaire Européen de la Mer, Plouzané, France

Variations in ground temperature affect the physical properties of permafrost, such as the amount of unfrozen water and the ice content. In the context of arctic landfills, it is important to understand to which extent permafrost acts as a geological barrier, and how this barrier characteristics will be impacted by climate change. This applies to both existing landfills for waste from local communities and mining activities, as well as for the planning of future landfills.

Here, we present three examples where combined Electrical Resistivity Tomography (ERT) measurements and Induced Polarization-surveying (IP) were used to detect the interface between sediments and bedrock within permafrost ground, and to investigate potential environmental hazards related to run-off paths from existing and planned landfills. Study sites were an active landfill near the town of Longyearbyen, and two potentially new landfills near Longyearbyen and Barentsburg (the latter one for surplus masses resulting from coal mining). As permafrost traditionally had been considered as a natural flow barrier for such landfills, understanding its degradation owing to climate change is key in the planning of future sites.

Eight profiles were carried out in September 2018, when expected active layer thicknesses were at their maxima. Two-dimensional inversion was performed with the commercial software RES2DINV for the resistivity data and Ahrusinv for the chargeability data. The results of our case studies show the benefit of simultaneous ERT- and IP-measurements, to both map active layer depths and determine sediment depths in permafrost areas. They also gave valuable insights in understanding potential environmental hazards related to run-off from the landfills, as a consequence of water entering the landfill in the summer period.

ERT/IP surveys are flexible and relatively easy to deploy. The technique is non-destructive and is, therefore, also suitable for planning and maintenance activities in vulnerable arctic tundra environments.

Teamwork in the Trenches: an interdisciplinary effort to address utility-related tundra rehabilitation

Lorene Lynn	Red Mountain Consulting LLC
Anna Liljedahl	Woodwell Climate
Christopher Stevens	SRK Consulting (U.S.) Inc.
Sue Bishop	ABR
Tim Cater	ABR

In Arctic Alaska, fiber optic cables were installed in 2015 to 2017 along a 240-mile stretch of the Dalton Highway. The cables were installed mostly in winter with some installation having been completed in summer using various trenching techniques. The region is characterized by continuous permafrost and ecosystems with widely varying ground ice volume from boreal forest to the coastal plain. Shortly after installation, mechanical and thermal erosion was observed to have caused ground subsidence within and adjacent to the trenches. A team of science and engineering expertise that includes geocryology, permafrost hydrology, tundra revegetation, restoration ecology, water resources engineering, and remote sensing was assembled to address the permafrost degradation using multiple rehabilitation techniques of the tundra surface. Individual rehabilitation plans for each problem site were informed by thermal balance equations, evaluations of watershed hydrology, experience in rehabilitating and revegetating tundra, and repeat photogrammetry by unmanned aerial vehicle (UAV). The sites were evaluated using historic and current aerial photography and visiting sites during high-water spring freshet and during mid-summer. Rehabilitation techniques include backfilling subsided areas and placing transplanted tundra sod over the backfill, placing water bars in strategic locations, live-staking willows, and placing transplanted tundra sod by hand in highly sensitive areas. The rehabilitation work began in 2020, continues in 2021, and will likely continue for several more years.

Arctic Expeditionary Infrastructure Research

Kevin Bjella U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Lab

Rosa Affleck

Lynette Barna

Justine Yu

Daniel Vandevort

Andrew Margules

The warming of high latitude regions is spurring development across the Arctic. The need for tested and developed Arctic infrastructure, particularly the more expedient type, is required. Operating requirements for high latitude conditions are vastly divergent compared to temperate locations, with parameters to sustain human habitation at -60oF (-80°F survivable), withstand 100 mph wind speed and support 25 lb/ft2 snow load. Although great advances have been made in providing efficient and comfortable Arctic infrastructure since the onset of the Cold War, significant work remains to further increase efficiencies, and adapt to changing climate parameters. To address infrastructure technology gaps, we recently launched an Arctic Infrastructure Research Group (AIRG). Current members of AIRG include ERDC researchers and other US Federal agency stakeholders. The purpose of the AIRG is to provide a forum and platform to coalesce and pursue needs, ideas, and technical projects. Current ERDC efforts on additive construction provide innovative solutions for Arctic infrastructure capabilities. Leveraging prior joint service Small Business Innovative Research efforts in rigid-wall insulation kits, ERDC will build an Arctic version of Mobile Insulation System for Energy Reduction (MISER), with Permafrost protection. Also, a parallel effort is initiated to fully characterize the effects of extreme environments on certain expeditionary structures at the Farmers Loop Permafrost Experiment Station (FLPES). Our goal is to create a research centric facility at FLPES to test new technologies and innovative materials while testing the requirements of Arctic hardened infrastructure for the benefit of all Arctic stakeholders.

A brief review of frigid-winter and ice effects on earth embankments: three case studies

Robert Ettema Colorado State University

This paper briefly reviews the present state-of-knowledge regarding winter and ice effects on embankments in cold regions. It draws on the writer's experience in cold-regions hydraulics and presents three case-study examples of ice effects, discusses the physical processes associated with ice effects, indicates the likely consequences for riprap and other means of embankment protection, and describes early, hydraulics laboratory experiments conducted to improve understanding of ice effects on levees.

Frigid winter and ice effects may pose problems for diverse earthen embankments: e.g., dams, levees, roads, and port causeways. Thermal effects may weaken earthfill used to form embankments. Water currents (especially during ice-cover break-up) may drive ice floes and rubble against and on to embankments. Also, wind drag may impart large momentum to floating ice sheets, causing them to severely impact embankments. Moreover, continuous ice impact can lead to ice override of embankments, imperiling near-by facilities. Current- or wind-driven ice places unforeseen loads on embankments and the various erosion-protection methods intended to shield embankments from erosion. For example, riprap rock protecting a dam's or levee's upstream face may be dislodged. Ice impact and override weakens embankments, exposing them to subsequent erosion and possible failure by water flow. There is scant information on ice-sheet override and ice loads, and little guidance on how to protect embankments or on how to maintain soil strength year-round.

Early evidence shows that ice impact accumulation may lead to erosion of the embankment's downslope, while ice accumulation against an embankment's upstream slope may impose additional forces whose type and magnitude vary greatly. The three case studies illustrate several mechanisms of winter and ice interaction with earth embankments.

Synopsis: Permafrost Engineering in a Warming Climate – Current State and Future Strategy

Kevin Bjella U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Lab

Heather Brooks

Zhaohui (Joey) Yang

Edward Yarmak

Post-World War II and Cold War activities initiated North American studies on permanently and seasonally frozen soils. The 1970's was a pinnacle period where the knowledge and technology advances culminated in the successful design of a warm oil pipeline constructed to traverse the disturbance sensitive permafrost terrains of Alaska. Since that time, a few technological advances have been made, mostly in the area of maintaining permafrost in the frozen state. Now the profession is confronted with the next stage of evolution in frozen ground engineering as the last few decades have seen a steady rise in permafrost temperature, with some areas experiencing significant foundation weakening and active thermokarst terrain. Overall, the changing environment is generating uncertainty with regards to safe engineering and planning, resulting in overly conservative designs which greatly increase development costs while affecting government, private sector, and industry planning. Therefore a high priority is the next generation of technology and methodology for design, construction, and maintaining of frozen ground infrastructure in a warming climate. The ASCE Cold Regions Engineering Department (CRED); Frozen Ground, Structures and Foundations, and the Transportation and Infrastructure committees, agreed that a review of the current state of the profession and an outline of a future strategy was needed to facilitate advances for the common good of everyone in cold regions. The International Permafrost Association (IPA) sanctioned an Action Group to perform a current look at the permafrost engineering discipline, determine knowledge gaps, and suggest a path forward. This paper will present a synopsis of the more important findings of this Action Group and provide a forum for further discussion. Some of the more important findings are the need for programmatic work in developing 'living' permafrost temperature forecast tools, and technical advances in methods to design for increasing thaw sensitivity, designing and planning with threats from altered hydrology (thermo-erosion) and slope instabilities, and techniques to mitigate thaw-affected vertical and horizontal infrastructure, to name a few. Most importantly, the engineering profession, with the help of universities, must promote the backfill of the retiring frozen ground engineering workforce.

New Economical Ice Coring Method for Accreted Ice on Vertical Piles

Scott Hamel University of Alaska Anchorage

Jasmine Langmann University of Alaska Anchorage

Ice coring auger machines can cost thousands of dollars and are generally made for vertical extraction from sea ice or glaciers. This research required compression testing of ice accreted on vertical piles at the Port of Alaska in Anchorage, Alaska, USA. This meant extraction was horizontal and needed to be completed during the short low tide window. This presentation will cover the development of a method to economically harvest and process ice into cylindrical cores.

The best method to obtain ice from the field location was found to be to cut roughly 24-inch cubes with a chain saw and extract them with a crane. The cubes were then transported and cored in a laboratory walk-in freezer. Cores were drilled with a hand drill using a core-bit that was custom fabricated from a 3-inch diameter, 8-inch long steel tube welded to two concentric holesaws. It was found that the hole saw blades cut quickly and produced smooth ice surfaces if a mechanism was provided to evacuate the cut ice chips. To facilitate this, two adjoining ¾-inch diameter evacuation holes were drilled prior to coring. These evacuation holes had to be located and directed precisely so that they connected with the outside diameter of the forthcoming core cut over its entire length, but did not infringe on and damage the ice core. To do this, a metal cutting template was laid flat on the ice surface and used to locate the three holes. The template also included a steel rod welded perpendicular to the plate which guided the hand drill so that all three holes were aligned and parallel through the block. With this new method, an ice block can be converted into up to a dozen test-ready compression cylinders within a few hours.

Employing Polyols for Increasing Ice Melting Capacity and Decreasing Freezing Point of Salt Brine Deicer

Hizb Ullah Sajid North Dakota State University

Ravi Kiran North Dakota State University

Salt brine deicers are commonly employed in North America for snow removal operations during the winter season. While NaCl-based brines (23.3% wt. NaCl) are effective in mild winter, their effectiveness reduces significantly when temperatures drop below -21°C regardless of any increase in the NaCl concentration. Moreover, NaCl-based brine has been observed to become ineffective in ice melting when temperatures drop below -10°C. This study aims to improve the effectiveness of NaCl-based salt brine deicer by employing three types of polyols namely sorbitol, mannitol, and maltitol. To this end, each of these polyols is separately added to 23.3% NaCl salt brine in concentrations ranging from 7.14% to 27.77%, and their influence on ice melting capacity and freezing point depression is investigated using extensive experimentation. Moreover, their effect on the skid resistance of pavements and dissolved oxygen levels is also studied. The results obtained from freezing point depression tests and ice melting capacity tests revealed the addition of 7.14% to 27.77% polyols in the salt brine deicing solutions significantly improve the ice melting capacity of salt brine and considerably depressed the freezing point of NaCl brine. The highest ice melting capacity is observed in the case of mannitol whereas the freezing point of salt brine is observed to reach -38.1°C after the addition of 27.77% polyol in the salt brine. The results obtained from the skid resistance tests showed that polyol-based deicers result in slightly lower skid resistance in the PCC pavement when compared to NaCl salt brine. Moreover, the dissolved oxygen levels did not increase considerably after the addition of polyols in the NaCl salt brine deicers. Overall, the polyol-based deicing solutions are observed to significantly improve the ice melting capacity and reduce the freezing point of salt brine with minimal impact on the skid resistance of PCC pavement and dissolved oxygen level in river water when compared to salt brine deicers. The results obtained from this study will lead to improving the effectiveness of salt brine deicers in snow removal operations, particularly at very low temperatures.

Application of empirical correlations for predicting thaw settlement: A case study of Nunavik, Canada

Seyedeh Zakieh Mohammadi — Department of Civil Engineering, University of Calgary
Jocelyn L. Hayley — University of Calgary

Permafrost is widespread in the Arctic and sub-arctic regions. Covering 40% of Canada, permafrost provides support for infrastructure built in these regions. Climate warming has altered the ground thermal regime in permafrost regions, initiating permafrost thaw and degradation, and thus threatening the safety and stability of the built environment and impacting future development in these regions. Quantifying the ground settlement induced by permafrost loss is essential for designing infrastructure to avoid compromised serviceability and safety conditions. Current practice uses empirical correlations relating permafrost and sediment index properties to estimate thaw strain and settlement. This study reviews the available thaw settlement correlations and illustrates their applicability using data from Nunavik. The applicability of the most widely used correlations is assessed by comparing the values obtained from these methods with thaw consolidation test results conducted by the Centre d'Études Nordiques (CEN) on approximately 100 permafrost samples from Nunavik, Quebec. Despite the extensive data available, some of the proposed empirical methods required inputs that were not recorded, thus this restricted application of some correlations. Comparison of thaw strain estimated from the correlations with measured values from the dataset, shows a large dispersion between the results. This can be partially attributed to the proposed correlations being established based on a wide scatter of data points, covering all sediment and permafrost types. Deviation of measured values from the estimations is particularly large for ice-rich permafrost samples, with the applied correlations underestimating the thaw stain for the majority of samples, particularly in ice-rich samples. Since the thaw settlement properties of soil are highly dominated by the compositions and fabric of the soil, developing a unique relation between index properties and thaw settlement properties for different soil types and ice conditions would improve the correlation coefficient and our confidence in permafrost thaw settlement predictions.

Deformation Caused by Frost Heave on a Rock Slope of Mudstone

Otgonjargal D. Writer Environmental and Energy Engineering, Kitami Institute of Technology
Dai N. Author
Takayuki K. Author
Shunzo K. Author

Hokkaido, the northernmost island in Japan, suffers from frequent frost damage due to its cold climate. It has also been reported that civil engineering structures such as tunnels, roads, and slope protection works can be deformed by the frost heaving of rock. Therefore, it is important to understand the frost susceptibility of bedrock in Hokkaido, Japan. Especially, the occurrence of freezing phenomenon on a rock slope may lead to a major disaster such as a bedrock collapse, and therefore, it has been attracting a lot of attention. With this background, we have been investigating the deformation of rock slopes. In this study, we measured the freezing depth, the amount of frost heaving, and the weathering depth of the mudstone slope where the damage occurred. In addition, frost heaving test and slaking test were conducted on rocks collected in the field. The results of the laboratory tests, it was found that the rocks collected in the field were easy to slake and had high frost susceptibility. From the field measurements, it was found that the rock slope frost heave significantly in winter and that the surface layer of the slope thaws in spring and becomes extremely weak. Furthermore, the weathering depth of the rock slope was found to be in good agreement with the freezing depth. On the other hand, the weathering depth of the rock slope did not change during the summer, and no slaking was observed due to repeated dry and wet. In summary, it is clear that the weakening of rock slopes in cold regions is largely influenced by freezing and thawing cycles.

A Second Foundation Review of AHTNA Corporation Glennallen Facility, ALASKA, USA

James Rooney Retired

Charles Riddle

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.

Laboratory testing of thermosyphon fin designs

Alexander Stott Cold Regions Research and Engineering Laboratory
Anna Wagner Cold Regions Research Engineering Laboratory
Edward Yarmak

Air temperatures in the Arctic and sub-Arctic are increasing at an alarming rate which can lead to failure in existing infrastructure where permafrost is present. Designing future and existing infrastructure to be resilient to a changing climate is critical to avoid collapsing infrastructure due to thawing permafrost. Thermosyphons, passive ground freezing heat transfer devices, can be used to freeze and stabilize the ground when constructing infrastructure (both vertical and linear). Thermosyphon freezing rates depend on a variety of factors (e.g., air temperature, wind velocity, fin area, and thermosyphon material). The condensation of the pressurized fluid that transfer heat from the bottom to the top of the thermosyphon takes place at the fins (the condenser). In the past, there has been limited testing on different fin designs. To address this shortfall, we tested and evaluated four different fin designs (twisted fins, stainless steel twisted fins, helical fins, and no fins) within a controlled environment at the Frost Effects Research Facility (FERF) at the Cold Regions Research and Engineering Laboratory (CRREL). The twisted fins are currently used by the manufacturer and therefore are referred to as the control. Freezing rates of the four thermosyphons are comparable. The helical fin design had a slightly lower rate of cooling close to the thermosyphon. At a distance of 25 cm away from the helical fin thermosyphon, freezing occurred 12 days later than the control and 21 days later at 50 cm away from the thermosyphon. The freezing front for the no fin thermosyphon reached 25 cm 1 day earlier than the control and reached 50 cm only 2 days later compared to the control thermosyphon. The freezing front for the stainless steel thermosyphon reached 25 cm 4 days later than the control but was 2 days earlier at the 50 cm distance. Varying soil moisture and sensor placement could have impacted these rates, but these results suggest that a simplified design of the thermosyphon with no fins could be used in place of a more expensive design where expedient freezing rates are not crucial for construction.

Rethinking water and sanitation in challenging environments: lessons learned from installing portable, adaptable, mid-tech household systems

Kaitlin Mattos Alaska Native Tribal Health Consortium
John Warren
Mia Heavener
Karl Linden

Traditional permanent water and sanitation infrastructure faces major technical and economic challenges in cold regions communities because of the threats of freeze-thaw cycles, permafrost instability, and a changing climate. As a result, thousands of households suffer health and wellbeing consequences because they live without basic access to clean water, safely managed sanitation, and appropriate hygiene. In response, the Alaska Native Tribal Health Consortium has spent five years developing, piloting and deploying portable, adaptable, mid-tech household water and sanitation systems in unpiped communities in rural Alaska. These Portable Alternative Sanitation Systems (PASS) work with natural freeze-thaw cycles to manage wastewater, can be adapted to various modes of operation based on end-user preferences, require little training and technical expertise to operate and maintain, and can be easily moved to new locations if households have to relocate. End users have demonstrated that PASS units can be successful at providing incremental improvements in water and sanitation services to households, if they are appropriately designed, installed, and supported. We discuss lessons learned from deploying these innovative mid-tech systems in houses, such as the need to develop basic technical standards and socially appropriate trainings to ensure success of the technology. These lessons can be used to support the development of new types of adaptive and resilient infrastructure with low environmental impacts for cold climate communities to ensure the wellbeing and livelihoods of the people who live there.