CANADIAN PERMAFROST ASSOCIATION
ASSOCIATION CANADIENNE DU PERGÉLISOL

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Recent Publications on Transportation Infrastructure

Canadian Permafrost Association – Association Canadienne du Pergélisol

Introduction

The Deportment of Infrastructure of the Government of the Northwest Territories (INF-GNWT) requested from the Canadian Permafrost Association (CPA) a synopsis of most recent scientific literature on research relating to transportation infrastructure in permafrost environments (Contribution Agreement No. 20181016151452488, dated October 12, 2018). This synopsis focuses on scientific publications, such as peer reviewed journal or conference publications, as well as Masters or PhD theses, that were published in 2018 and the beginning of 2019. However, some publications that were published earlier are also included, as well as some extended conference abstracts if considered relevant.

Synopsis

In total, 60 documents were reviewed, of which 52% were published in 2018 and 7% in 2019. Another 10%, 17% and 12% are from 2015, 2016 and 2017, respectively. Most of the publications selected focus on research related to North American transportation infrastructure. However, nine publications were included that present research carried out on the Tibet Plateau of China, where major transportation infrastructure was designed and constructed in recent years. Two publications are included that discuss risk assessments of pipelines in Russia. These publications were selected because they provide input that may be useful for Canadian transportation infrastructure.

General

In 2010, the Transportation Association of Canada published guidelines for the development and management of transportation infrastructure in permafrost regions (McGregor *et al.*, 2010). This guideline is a valuable resource for any road project in the NWT, but it has since been augmented by other publications, such as the AMEC (2016) report on improving maintenance procedures for highways in permafrost regions, the series of standards developed through the Northern Infrastructure Standardization Initiative (NISI)[1] or design tools for mitigation techniques proposed by Kong *et al.* (2016; 2019). The approach proposed by Kong *et al.* (2016; 2019) is novel as it focuses on heat fluxes as a design value rather than temperature.

Challenges and economic impacts of degrading permafrost and climate change on infrastructure in permafrost environments are discussed in Melvin *et al.* (2017) and Hjort *et al.* (2018). A recent paper by Lewkowicz & Way (2019) further highlights the impact of extreme summer climate conditions triggering thousands of thermokarst landslides in a High Arctic

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[1] http://www.scc.ca/en/nisi

environment thereby forming a potential major hazard to transportation infrastructure. In this context, the new ground ice map presented by O'Neill *et al.* (2018) as well as the discussion of an integrated Earth system approach for the design of infrastructure proposed by Vincent *et al.* (2017) are of interest for planning new transportation infrastructure in the NWT. Finally, Doré *et al.* (2016) provide a valuable overview of adaptation methods used for road embankments in permafrost environments.

For highway infrastructure planning as well as performance monitoring purposes, the mapping of permafrost dynamics with the help of unmanned aerial vehicles (UAVs) (van der Sluijs *et al.*, 2018) or active satellite signals, such as InSAR (Rudy *et al.*, 2018) may be advantageous. Both show promise for reliable and cost-effective monitoring of linear infrastructure. The availability of such data along transportation corridors is essential for the development of system-wide risk assessments (Brooks, 2019) and for evaluating the impact of permafrost thaw on highways (Calmels *et al.*, 2018).

Case Studies

Several Canadian research sites exist where highway embankment behaviour is being investigated and mitigation techniques tested. The Alaska Highway test section near Beaver Creek, YT, is a site where several mitigation techniques, including air convection embankment (ACE), ventilated shoulders, snow sheds, high albedo surfaces and heat drains have been tested for many years. In addition, the effect of snow as well as water circulation through the embankment on the structure's thermal regime were studied in detail. Recent publications with results from this test site were published by Lanouette *et al.* (2015), Malenfant-Lepage (2015), Richard *et al.* (2015), Richard (2017), and Kong & Calmels (2018). Long-term changes in the permafrost conditions within the Alaska Highway corridor were presented by Lewkowicz *et al.* (2018).

Some of the mitigation techniques that were researched at the Beaver Creek site, such as heat drains, were subsequently tested on a 1 km long road section at Salluit in Northern Quebec (Boucher *et al.*, 2012; Lamontagne *et al.*, 2015; Périer *et al.*, 2016; Brooks, 2019). At this site, innovative distributed temperature monitoring using fibre optics was also successfully tested (Roger *et al.*, 2015).

The Inuvik to Tuktoyaktuk Highway (ITH), which was opened in November 2017, initiated several research projects. An overview of the whole project was presented by Grozic (2018). Results from the University of Manitoba research site at km 82+375 of the ITH include the effect of geotextiles on the deformation behaviour of high fill embankments built during winter (De Guzman, 2015; De Guzman *et al.*, 2016; 2017), the thermal behaviour of a high embankment (Piamsalee, 2019) and of a culvert through the highway embankment (Kaluzny *et al.*, 2018).

In northern Manitoba, research on a highway embankment has been carried out on Provincial Road (PR) 391 near Thompson. This site is in discontinuous and degrading permafrost, and the only frozen soil remnants present are located in the foundation beneath the centreline. This permafrost controls the embankment's thermal and deformation behaviour (Flynn *et al.*, 2016; Kurz *et al.*, 2018).

Additional research on transportation infrastructure in permafrost environments was carried out at the Iqaluit International Airport, NU, where recent research focused on the effects of the permafrost hydrology on infrastructure (Shojae Ghias *et al.*, 2018) and the development of a risk assessment framework (Brooks, 2019). The impact of snow on permafrost was evaluated at the Tasiujaq airport in northern Quebec by Lanouette *et al.* (2015).

Outside of Canada, recent concerns about the potential impact of creeping frozen debris lobes on the Dalton Highway and the Trans Alaska Pipeline led to detailed investigations of their creep behaviour and hazard potential (Darrow *et al.*, 2016; 2017). In China, various highway and railway construction activities on the Tibet Plateau have resulted in considerable research. Recent publications include field studies and numerical analysis of air convection embankment and the impact of crushed rocks on the ground thermal regime (Chen *et al.*, 2018; Zhang *et al.*, 2018d), or the use of sun-shades (Luo *et al.*, 2018). Other research focused on the deformation and stability of road embankments (Ming *et al.*, 2018; Wu *et al.*, 2018), the impact of water and poor drainage on railway embankments (Mu *et al.*, 2018), and the thermal interaction with thermokarst along transportation infrastructure (Yinfei *et al.*, 2016; Wen *et al.*, 2018; Wenbing *et al.*, 2018; Zhang *et al.*, 2018c). Ran *et al.* (2017) discuss potential impacts of climate change on infrastructure while Zhang *et al.* (2018b) present the use of frozen soil engineering in design. Transportation corridor mapping with InSAR is described by Zhang *et al.* (2018a). Finally, Guo *et al.* (2018) discuss the thermal behaviour of transmission towers that follow the same linear infrastructure corridor. Wang *et al.* (2018) present a case study on the effect of permafrost thaw on a pipeline in Northeast China. Pipeline integrity is also a major concern in Russia as outlined by Sergeev (2018) in a study on permafrost related geohazards in Russia.

Geotechnical Properties and Soil Behaviour

In addition to field investigations, the geomechanical and geothermal behaviour of frozen, freezing and thawing soils have been examined in laboratory tests. Pavon (2018) published a study on the thermal properties of soil found along the ITH, and Brookes *et al.* (2018) present a summary of the effect of the geotechnical index property variation on thermal conductivity. The mechanical behaviour of frozen and thawed soils was tested by De Gusman *et al.* (2018) and Stafford *et al.* (2018) using material from the Manitoba test Section along the ITH. Dumais *et al.* (2015), on the other hand, presented a new approach to estimate thaw consolidation.

For bridge abutments, the paper by Hoeve & Trimble (2018) on adfreeeze piles as well as a study by Aldaeef & Rayhani (2018) on pile-frozen soil interaction are worth highlighting.

Finally, a new ground temperature measurement probe was developed by Egorov & Krys (2018) to achieve more accurate measurements. The new instrument was successfully tested alongside Highway 3 near Yellowknife, NT.

Summary

The construction of the ITH has provided a unique opportunity to investigate the behaviour of transportation infrastructure in permafrost and test new mitigation options. It sparked a wealth of innovation and furthered the understanding of highway embankments in the Arctic. However, in order to understand the processes several years of monitoring are needed. The results from the Beaver Creek test site in the Yukon that have recently become available, demonstrate that long-term monitoring is essential for a full understanding of the complex system created through the interaction of the built environment and permafrost. To date it is undisputed that the construction and presence of a transportation infrastructure affects the ground thermal regime and the hydrology, and significantly alters the degradation of permafrost in the foundation of the embankment and the right-of-way. The observations at PR39 in northern Manitoba show that the road construction resulted in increased permafrost thaw along the highway but protected some of the ground ice from thawing under the centreline.

Given the challenges that Canada's northern infrastructure faces as the climate warms, case studies, such as those summarized in this document, are vital, constituting the fundamental basis for predicting future behaviour of existing infrastructure and for designing new infrastructure. Long-term monitoring and observations are critical as they are the only way the projected impact of different climatic conditions on infrastructure behaviour can be validated.

In addition to a better understanding of the thermal and mechanical processes related to transportation infrastructure, novel approaches are under development that will improve assessment of risk to the highway system and will provide tools that improve its operations.

Closure

The Canadian Permafrost Association (CPA) prepared this document for the use of the Government of the Northwest Territories. The material in it reflects the judgment of the CPA in light of the information available to the CPA at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions based on it is the responsibility of such third parties. The CPA accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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Yours sincerely,

Canadian Permafrost Association.
per:

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