Performance of Bridges in Cold Regions with Sliding Seismic Isolation Bearings

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Effects of extreme temperature on highway bridges in cold regions seismically isolated with sliding type bearings is investigated. The critical factor in consideration is the change in the performance of isolation bearings with significant variation in temperature between seasons. The sliding bearing behavior is characterized by the friction coefficient of the sliding surfaces. The friction coefficient during a seismic motion varies with the sliding velocity and temperature at the sliding surface. Tests associated with past applications have indicated a marked increase in the value of friction coefficient resulting in higher stiffness of bearings at very cold temperatures. The effects of change in bearing stiffness on seismic performance of the bridge in general and the substructure in particular are demonstrated here. This study aims to capture the change in bearing response and subsequently the overall structural response considering a temperature variation between -400C and +400C. Response parameters considered for this study are the base shear in the piers, the acceleration of the bridge deck, maximum and residual displacement of the isolation bearings as well as the energy dissipation capacity. It is observed that the higher bearing stiffness at extreme cold temperature lead to additional forces on the substructure which reduces the margin of safety and hence should be considered carefully in design.

Developing Pavement Performance Prediction Models Using Rutting Criteria for a Cold Region Environment

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Maintenance and rehabilitation of roadway pavements in Alaska's south central and south coast regions are triggered by rutting based on the FHWA threshold of 0.5 in. (12.7 mm) used by Alaska DOT&PF. This leads to short pavement life due to a relatively high rut rate caused by studded tire use during wintertime. Research into the overall rut in these regions shows insignificant rutting from truck traffic. Average pavement resurfacing life in these regions, when considering the effects of rutting, is seven to nine years for freeways and higher for other road classes. This represents about half of the expected design life for principle arterials. Establishing a prediction models that considers the overall rutting will allow agencies to incorporate these models in their Pavement Management System (PMS). Using rutting and age as the dependent and independent variables, respectively, two models were developed, one for interstate pavements and another for other principal arterial pavements.

Modelling consequences of permafrost degradation for Arctic infrastructure – a case study of the Dalton highway

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The fate of infrastructure in the Arctic and in high altitude regions is heavily depending on the stability of frozen ground which it is built on. Climate change and consequent degradation of permafrost will negatively affect various infrastructure types and can cause ultimate failure. Comprehensive pan-Arctic assessments are urgently needed to better quantify environmental, economic and societal risks and to help adaptation planning. The use of physical models can be a powerful tool for risk evaluation, but modelling challenges remain with respect to resolving construction details at infrastructure scales together with decadal-scale climate change impacts. Here we used the dynamic permafrost land-surface model CryoGrid3 (including a soil subsidence module) to capture both - the effects from the interaction of small-scale infrastructure with permafrost and large-scale climate change effects evolving in the 21st century under an extensive climate warming scenario. We discuss how infrastructure can affect ground temperatures, and how climate change increases the risk of future infrastructure failure. As an exemplary case of permafrost-affected infrastructure failure, we modelled a gravel road on continuous permafrost at Prudhoe Bay (Alaska). We investigate the timing of infrastructure failure from soil subsidence in dependence of assumed embankment thickness and depth of excess ice in the ground.

Numerical modeling of a new covered arch bridge and its future impact on the surrounding ground thermal regime in continuous permafrost

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Gunghi Creek site, located at 131.2 kilometers at the north end of Inuvik-Tuktoyaktuk Highway (ITH) in the Northwest Territories, Canada, recently had corrugated steel pipe (CSP) culvert replaced by concrete arch bridge with adfreeze piles. There are anticipated challenges with the ground thermal regime that could be affected by both the structure, the creek, and future climate change. In this study, a detailed 1D and 2D thermal analyses were conducted to simulate the thermal regime prior to and post construction of the arch bridge.

The numerical modeling simulations (using Temp/W from GeoStudio) were initially calibrated and developed with historical air temperatures, input values from the literature and site-specific data from earlier geotechnical investigation. Future climate projection models were used to obtain projected ground temperatures, under a number of variations, including the cross-section, creek depth and climate projections. The results showed that when all thermosyphons are operating as intended, the subsurface temperatures around the piles increase at an average rate of 0.03 °C/year, thus ensuring that the arch bridge remains fully serviceable for it’s intended design life. In contrast, when no thermosyphons are functioning the subsurface temperatures surrounding the thermosyphons increases at a rate of 0.12 °C/year for 4 decades, before gradually slowing due to latent heat. The results of this study highlight the critical importance the thermosyphons will have on the stability and resilience of this foundation design, and the importance in ensuring their long-term functionality.

Permafrost degradation effect on seismic response of bridge pile foundation along Qinghai-Tibet Railway

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With climate warming, widespread permafrost degradation is found worldwide in recent years. For permafrost regions located in earthquake belts, i.e. the Qinghai-Tibet Plateau permafrost region in China, permafrost degradation effect on seismic performance of the bridge pile foundation is worthy of research in the recent following decades. In this study, a pile-soil interaction model considering thermal-mechanical effect is presented and applied to a case study of the bridge pile foundation along Qinghai-Tibet Railway. Seismic responses of the bridge pile foundation are analyzed with consideration of the permafrost degradation. Numerical results show that permafrost degradation can influence the lateral displacement, shear force, and bending moment of the bridge pile foundation under seismic actions. The freeze-thaw state of the active layer should be considered when analyzing the permafrost degradation effect on seismic responses of bridge piles. It can be found that the seismic security of the bridge pier with pile foundation in permafrost region should be paid more attention under cold condition (frozen active layer) than warm condition (thawed active layer). The seismic security of the existing bridge pile foundations along Qinghai-Tibet Railway is evaluated. It is recommended that seismic design of bridge with pile foundation in permafrost region should consider the thermal-mechanical effect of pile-soil system and the permafrost degradation effect.

Simulating the thermal regime of railway embankment structure on the Tibetan Plateau under climate change

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The Qinghai-Tibet Railway (QTR), which is located in the largest high-altitude permafrost area, is a vital infrastructure linking the rest region of China and the Tibetan Plateau (TP). With global warming and its amplifying effect in the TP, the permafrost on the TP has been significantly degraded, manifested by thermokarst subsidence, the decrease of permafrost thickness, and the increase of active layer depth, causing irreversible damage to the infrastructure above it (if built on ice-rich ground). For better understanding and assessing the stability of the QTR in the future, there is a need for physically-based model analyses of the thermal regime of the railway embankment and for the evaluation of the risk of railway failure under future climate change scenarios.

In this study, we used a laterally coupled version of the one-dimensional CryoGrid3 land surface model, which adopted a tiling approach to represent different units of the embankment, to simulate the thermal regimes of railway subgrade under present and future conditions, and to provide the threshold of subgrade stability under the projected scenarios. Our model results reveal a satisfactory performance with respect to the comparison between measured and modeled thermal regimes. Under the present climate conditions, the crushed-rock embankment structure provides good protection for QTR operations as our results show less heat penetration into the ground under the railway units as compared to the natural tundra. The thawing depths under the sunny slopes are the largest and reach almost the embankment base under the present climate. This means thaw settlement damage is expected to first occur at the sunny slope with warming air temperature. Furthermore, our results suggest that railway failure depends on the magnitude of warming air temperature. Under conditions typical for our investigated case site at Beiluhe, our simulations suggest that the railway might maintain safe operation until the end of the century under the RCP2.6 scenario. In contrast, inevitably settlement of the subgrade will occur under the strong future warming (RCP8.5) and the permafrost under it will permanently disappear. We hope this paper can mark a step forward in studying the stability of infrastructure located in permafrost areas, especially infrastructure located in the TP.

Quantification of Rut Detection and Height Mapping in Winter Terrains for Off-Road Mobility

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Off-road autonomous vehicle navigation in winter environments requires reliable identification and quantification of potential obstacles, such as deep vehicle rutting or buried objects. The advent of consumer-grade LiDAR and Unmanned Aerial System (UAS) based photogrammetry present new avenues for the implementation of change detection algorithms for the purpose of obstacle identification. Few studies have provided a quantifiable statistical method for determining the input parameters of these change detection algorithms based upon user-defined confidence metrics. Previous detection methods also fail to derive the degree of assurance associated with the identification of a perceived obstacle. Here we present an automated method for identification of snow-covered obstacles and vehicle ruts within LiDAR-derived digital elevation models based upon false-alarm probabilities. Probability of detection and accurate height maps are generated for objects by the algorithm to demonstrate the reliability of this method to assist with obstacle avoidance in snowy off-road conditions. The algorithm described here is a reliable and fast method for the identification and measurement of snow-covered obstacles. While this study is concerned with snow-covered terrain, the methods described here may be leveraged to monitor deformation features as a result of vehicle traffic across a variety of terrain types.

Monitoring ground temperatures on portage sites along the Tibbitt-Contwoyto winter road to assess road resiliency

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The Tibbitt to Contwoyto winter road (TCWR) provides critical ground transportation from Yellowknife to several mines in the Northwest Territories. The 400+ kilometer road is predominantly an ice road over water bodies with approximately 60 kilometers of the road on land portages which consist of snowpack and ice with various subgrades. The TCWR road is typically open for only 8 weeks a year thereby the resilience of the road during that operational window is critical. In this study, the performance of varying depths of subgrade at several locations along the winter road were evaluated using numerical modelling techniques to examine their influence on the thermal regime and resulting road resilience. Ground temperatures were measured at 3 portage locations for the duration of the 2020 winter road season. Preliminary results from the thermistor strings at 3 portage locations were used to calibrate the numerical models. These thermistor strings had 15 thermistor beads each and were installed in the road to a maximum depth of 1.8 meters. A sensitivity study was used to evaluate subgrade thickness, ice thickness, susceptibility to solar load and slope face direction on the resulting thermal profile. The findings from this study found that the south facing slopes and areas with extended exposure to sunlight along the road are the most at risk to thermal vulnerability, almost irrespective of the thickness of subgrade material. For locations with no significant slope, this study found that there were diminishing returns on the thermal performance of the portage when the gravel thickness was increased beyond 0.2 metres. Overall, the results of this study can be used to better manage the construction and maintenance of the portage site, prioritizing the high-risk locations for additional subgrade material and thicker ice cover to maintain roadway integrity.

Recent Experiences with Existing Passively Cooled At-Grade Foundations

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Passively cooled at-grade foundations on permafrost rely on cold winter air to remove heat to maintain permafrost and structural stability. As the climate warms in northern latitudes, this natural heat sink is reduced, thus reducing the heat removal capacity of passive systems and jeopardizing the stability of the structures being protected. Three at-grade water treatment plant structures originally constructed between 1995 and 1999 in western Alaska at Eek, Quinhagak, and Nunam Iqua using thermosyphons for subgrade cooling are currently being modified or in the queue to be modified to increase their useful life. Modifications are due to the rapid climatic warming that has occurred and is predicted to continue. At all three sites, the structures are constructed on gravel fills over permafrost soils and use passive thermosyphons to maintain permafrost beneath the insulation within the fill material. The original thermosyphon systems have operated at full efficiency over the existing life of the structures without any deficiencies. Warming from the areas outside of the fills has caused deterioration of the perimeter of the gravel pads and has impacted the stability of the structures. To maintain structural stability, each of the insulated gravel pads are being expanded in areal extent and additional cooling is being added on the perimeter of the foundations to compensate for the encroaching warming. Additionally, the capacities of the existing thermosyphon systems are being increased, and even converted to hybrid so that they may be actively cooled, to maintain structural stability into the future. These three retrofits are but a few that will likely be required in the future to maintain service from similar facilities founded at-grade on passively refrigerated gravel pads as the climate warms.

Prediction of Climate Change Impact on a Highway in Warm Permafrost

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A warming climate and its effects on warm permafrost have become increasingly significant. They cause persistent problems to the transportation infrastructure such as roads, airports, and pipelines and threaten their safe operation. Such problems are particularly severe in areas where ice-rich and thaw-unstable permafrost exists extensively. This paper presents the preliminary results of a case study of the Bethel Airport, located in deep, warm permafrost in western Alaska and assesses the climate change influence on the thermal state of warm permafrost and its potential impact on the airport runways and roads. It first analyzes the characteristics of the two-meter-above-ground temperature predictions for Bethel, Alaska, from 31 models in the Coupled Model Intercomparison Project Phase 5 (CMIP5) for the next century. The air freezing and thawing indices are evaluated from the climate modeling results and compared with historical data. Then a thermal model of an ice-rich site is used to assess the ground temperature variation and permafrost degradation during the next century. Subsequently, the thaw settlement due to thaw and consolidation of the permafrost is predicted, and their potential impact on the built transportation infrastructure is discussed.

Nondestructive Evaluation of a New Concrete Bridge Deck Subject to Excessive Rainfall during Construction: Implications for Durability in a Cold Region

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Nondestructive evaluation (NDE) techniques were applied to investigate the effects of excessive rainfall during construction of a new concrete bridge deck in northern Utah. Because excess water can reduce the strength and/or durability of the concrete, testing was necessary to determine whether the portion of the deck affected by rainfall would be expected to still provide satisfactory performance. Given that chloride-induced corrosion of the top mat of reinforcing steel is the leading cause of deck damage in northern Utah as a result of routine deicing salt applications during winter maintenance, evaluating the ability of water and chloride ions to penetrate the concrete and quantifying the overall protection of the reinforcing steel were important objectives. Because the deck was new, the owner specifically requested consideration of NDE techniques that would minimize damage to the deck during the testing process. To that end, resistivity and vertical electrical impedance (VEI) were measured at 10 test locations within each of three deck sections (A, B, and C) defined by the contractor based on their exposure to rainfall. To account for potential interactions, concrete cover depth, deck surface temperature, and Schmidt rebound number were also measured at each of the same test locations. Statistical analyses were performed to investigate differences among the three sections. Every significant difference involved section C, which had received the greatest rainfall. Section C had the highest average cover depth, the lowest deck surface temperature, and the lowest average Schmidt rebound number. Although the lowest average resistivity measurement also occurred in section C, the comparatively small differences between section C and either section A or B were not statistically significant. The lowest average VEI value occurred in section A, but the comparatively small differences between section A and either section B or C were also not statistically significant. Although variations in deck temperature and/or cover depth can potentially affect resistivity and VEI, explicitly accounting for differences in these properties among the sections did not change the outcome of the analyses.

Drivers of permafrost degradation along the Inuvik to Tuktoyaktuk Highway

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Infrastructure construction on permafrost is challenging. Not only are northern regions undergoing a faster and more intense global warming than the rest of the world, inducing thawing of the permafrost at a global scale. In addition, linear infrastructures such as gravel highways built on embankments to protect the underlying permafrost favor snow accumulation and produces dust, which can enhance permafrost degradation. The objective of this study was to use satellite (Landsat) and repeat airborne laser scanner observations to explore the physical parameters that drive permafrost degradation in the regions adjacent to the Inuvik to Tuktoyaktuk Highway (ITH) in Northwest Territories, Canada. To test if snow accumulates next to the road, we used digital elevation models produced from airborne laser scanner data collected on one snow free day in August 2018 and one as the landscape was snow covered in April 2019 over a 3 km road segment located close to Trail Valley Creek (TVC). The zone of enhanced snow accumulation was within 47 m from the road, with maximum snow depths of 1.2 m occurring directly next to the road. The area beyond 47 m was undisturbed with average snow depths of 0.4 m. Despite this finding, our analysis of Landsat images using the normalized difference snow index to discriminate between snow-covered and snow-free areas show that the areas next to the road became snow-free earlier in spring than the areas further away. The road construction affected the region in close proximity the most, and the impact decreased with distance from the road to about 400 m. Increased snow cover will increase the thermal insulation as well as produce higher melt water and likely promote permafrost degradation at present and in the future of the newly constructed highway. Moreover, earlier melting may trigger other ecological feedbacks such as early greening of the tundra on the long term, highlighting the importance for more observations and additional measurements along the highway.

Spontaneous Corrugation on Snowy and Icy Road Surface Produced by Moving Vehicles in Cold Regions

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In cold regions, as widely observed, the corrugation on snowy and icy road surfaces spontaneously emerges due to the repeated moving traffic loads. This phenomenon is also known as “washboard road” and it not only deteriorates traffic comfort, produces traffic congestion, but also threatens the safety of running vehicles due to the loss of friction between tires and road surface. The formation of washboard roads in cold regions is a complicated process including the climate factors and the traffic influences accompanied with the repeated phase change among water-snow-ice. To disclose the mechanism of washboard roads, in this study, first, we proposed the prerequisite conditions (accumulation of snow, suitable air temperature, and sufficient amount of traffic) for the formation of corrugation on a snowy and icy road in Hokkaido based on the field survey, which is a critical finding for washboard road in cold regions. Accumulated snow and suitable air temperature are climate factors that are out of our control. Therefore, we turn to investigate the role played by the moving vehicles during the formation process of corrugation. We designed a series of indoor tests and numerical simulations to clarify the forming and dynamic evolution of corrugation on the snowy and icy road. Then the influences of natural frequency and the touching pressures of the moving vehicles on the corrugation have been clarified. This new finding can help us to understand how the vehicles promote the formation of washboard roads. On the other hand, this finding shows the potential measures by adjusting the traffic factors to avoid the formation of washboard roads for the traffic administrative authorities.

Upper Silvis Lake Spillway and Powerhouse Failure

James Rooney Retired

In the late 1960's a small hydroelectric project was designed by an out of state private consulting engineering firm. The project was completed and operating by 1969. During a heavy rainstorm period, the spillway became engaged with first time heavy runoff and failed because of erosion of underlying unstable material lying below in the spillway channel. Debris from the failure moved downslope and destroyed the below lying powerhouse! The site is located east and south of Ketchikan on George Inlet. Issues involved included limitations in project financial funds and constraints imposed on the project development effort.

This paper is an attempt to identify and document some of the project history and subsequent legal ramifications involved. The project was redesigned and put back into operation and continues to function well!

Use of a Portable Friction Tester on Snow and Ice Pavement

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The purpose of this work was to determine the effect of cold temperatures on the operation and accuracy of commercially available pavement friction measuring tools. We evaluated the consistency of test results for each device and identified any trends in the results. Our tests entailed a series of experiments conducted in a controlled environment at the Cold Regions Research and Engineering Laboratory (ERDC-CRREL). Two portable fixed slip continuous measurement devices were evaluated: the Micro GripTester (mGT) from Findlay Irvine and the T2Go from SARSYS-ASFT. In addition, one deceleration spot measurement device was evaluated: the Dynamic Friction Tester (DFT) from Nippo Sangyo. This series of controlled tests determined that the devices could be operated in conditions as cold as -25 °C. However, care must be taken in interpreting the results of tests conducted at cold temperatures. The ambient temperature and the duration of exposure to these conditions will affect the accuracy of testing. Pronounced changes in the T2Go test results occurred after 30 minutes of exposure to -20 °C and below; for the mGT this occurred after one hour of exposure to -25 °C. The DFT was most sensitive to temperature change with significant changes in friction readings after 90 minutes of exposure to 0 °C or any exposure to temperatures below 0 °C. These devices should not be stored in freezing temperatures prior to testing, and temperature and length of exposure should be monitored and recorded during field testing. Based on the cold room testing, we evaluated the Micro GripTester (mGT) during field tests on packed snow and ice surfaces at the Keweenaw Research Center in Feb 2020. Several of these tests were run side by side with the SAAB Friction tester, which has been used on cold runway surfaces for many years. The testing showed excellent agreement between the SAAB and the mGT and therefore validating the use of the mGT portable friction tester for snow and ice surface testing.