# Initial Monitoring of Instrumented Test Sections along the Inuvik-Tuktoyaktuk Highway

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
There are uncertainties related to the mechanical behaviour of embankments that were initially compacted with frozen fill and then experienced natural thawing and settlements during the summer following construction. Side-slope sloughing and fill cracking may occur because of localized thaw settlements under the shoulders and side slopes of the embankment. Two instrumented test sections were constructed side by side along the new Inuvik-Tuktoyaktuk Highway and are being continuously monitored after its construction to study these uncertainties. This paper presents the initial monitoring recorded from the completion of the test sections. Test Section A, the control section, is an unreinforced slope section conforming to the original design of the road embankment. Test Section B is a reinforced slope section with geotextile layers at the slope acting as its reinforcement. Section A and Section B are both instrumented with thermistors for temperature readings, ShapeAccelArrays for the vertical and horizontal deformation monitoring, vibrating wire piezometers for pore water pressures, and thermal conductivity sensors for matric suctions. Strain gauges were also installed in the geotextile reinforcements for Section B to measure the deformations in the geotextile layers.

RÉSUMÉ
Il y a des incertitudes liées au comportement mécanique des remblais qui ont été initialement compactés avec du matériau de remblayage gelé et ont ensuite connu un dégel naturel, ainsi que du tassement après la construction d'été. L'évasement de la pente de talus et la fissuration du remblai peuvent se produire en raison du dégel localisé du tassement le long des accotements et des pentes de talus des remblais. Deux sections d'essais ont été construites côte à côte le long de la nouvelle route Inuvik-Tuktoyaktuk et sont régulées continuellement pour étudier ces incertitudes. Ce papier démontre les résultats préliminaires lors de l'achèvement de la construction des sections d'essais. La section d'essais A est la section de contrôle, soit une section de pente non armée qui est conforme à la conception initiale du remblai routier. La section d'essais B est une section de pente renforcée avec des couches géotextiles qui agissent comme renforcement à la pente. Les sections A et B sont toutes les deux instrumentées avec des thermistances pour indiquer la température, *ShapeAccelArrays* pour la surveillance des déformations verticale et horizontale, des piézomètres à fil vibrant pour la pression d'eau interstitielle et des mesures de conductivité thermique pour la pression interstitielle. Des extensomètres ont été installés dans les renforcements géotextiles de la section B pour mesurer les déformations des couches géotextiles.

## 1 INTRODUCTION

The completion of the Inuvik to Tuktoyaktuk Highway (ITH) has been a long standing goal of the Town of Inuvik, the Hamlet of Tuktoyaktuk, and the residents of the Inuvialuit Settlement Region (EIRB 2011). The construction of the ITH will help address the goals of Northern economic development, enabling future natural resource exploration, development, and production (such as the natural gas and oil reserves in the Mackenzie Delta and Basin), and reinforcing Canadian sovereignty objectives (EIRB 2011, Infrastructure Canada 2015).

Detailed road alignment, environmental data gathering, and engineering design were conducted in the 1960's and 70's and has been continuously revised to address the concerns of local communities and other stakeholders during an extensive environmental review process, leading to the development of the route alignment alternatives in 2009. The highway has been identified as a priority development by the Government of Canada and Government of the Northwest Territories (GNWT). The ITH, which extends the Dempster Highway past the community of Inuvik to the Arctic Coast, will be an all-weather transportation link and will complete Canada's road network from coast to coast to coast. Figure 1 shows the designed alignment of the highway.

The warming trend in air temperatures due to climate change in the NWT (IPCC 2014) has and will continue to pose challenges for the transportation system (TAC 2010). Climate change has impacted fall freeze-up and spring thawing, causing delays and reduced operations. Construction is done only during the winter season for ease in moving fill materials and to minimize environmental impact. Typical 'cut and fill' techniques employed in the southern areas of the Northwest Territories are not used in this project in order to protect the permafrost terrain along the highway alignment (EIRB, 2011). There are uncertainties related to the mechanical behaviour of embankments that were initially compacted with frozen fill and then experienced natural thawing and settlements during the summer following construction. The fill material of the ITH embankment will be dominated by fine till that includes ground ice. Fills are very difficult to compact at sub-zero temperatures when ice is present, but are relatively strong while they remain frozen. However, they become soft and compressible after thawing.

In order to comply with vertical road geometry constraints, the embankment fill height can easily exceed five metres. Higher fills cause problems of side-slope sloughing and spreading, resulting in longitudinal embankment cracking due to the thawing of the frozen fill material. Side-slope sloughing and fill cracking can also be related to localized thaw-settlements under the shoulders and side slopes of the embankment created by the rising of the permafrost table into the embankment fill in combination with depression of the permafrost table at the toe of the embankment.

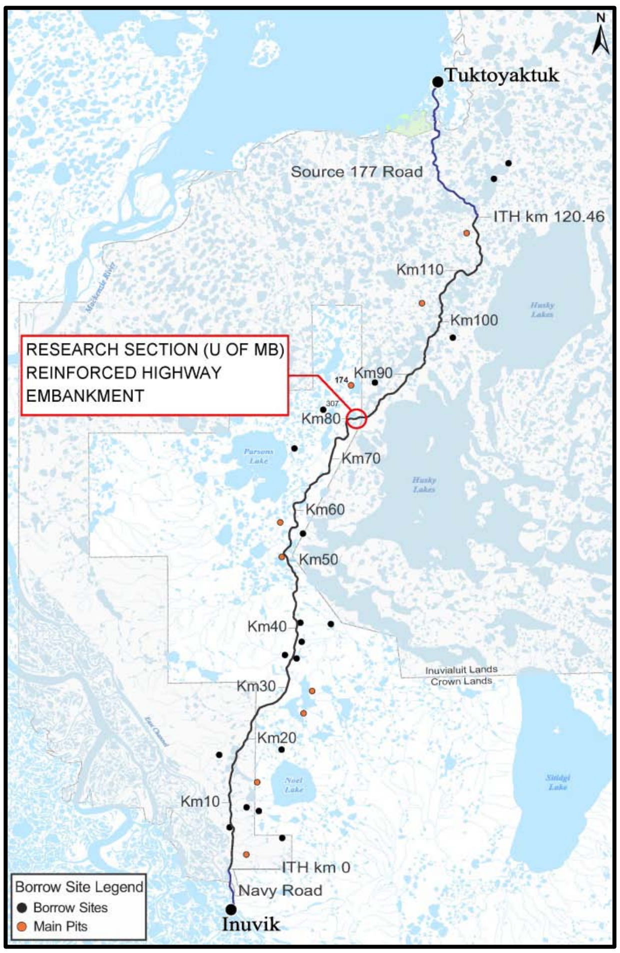


Figure 1. Alignment of the Inuvik-Tuktoyaktuk Highway and the University of Manitoba's research section.

Knowledge gaps exist on the behaviour of high fills compacted under Arctic winter construction conditions. Therefore, research is needed to (1) investigate the operating mechanisms causing instabilities and deformations of the embankment; and (2) to develop efficient mitigation strategies. A partnership was developed between the University of Manitoba and the Department of Transportation of the Government of Northwest Territories to construct two 20 m-long test sections side-by-side along the ITH to address these research needs. The location of the research section of the University of Manitoba along the ITH, which was completed in April 2015, is shown in Figure 1. Construction and installation of instrumentations in the embankments will be discussed in this paper and preliminary readings following the construction are presented.

## 2 EMBANKMENT CONSTRUCTION

Two 20 m-long test sections were constructed along the Inuvik-Tuktoyaktuk Highway. The first 20 m (STA 82+380 to STA 82+400), referenced hereto as Section A, was constructed using the typical embankment design, but instrumented to serve as the control section for the research program. The second 20 m (STA 82+400 to STA 420), referenced hereto as Section B, was an instrumented embankment similar to Section A, but its side slopes are reinforced with woven geotextiles. The instrumentations installed in both test sections are discussed in Section 4.

Prior to construction on April 14, 2015, an initial lift of 600 mm fill material had already been placed over the test sections. This initial fill height allowed the contractor to proceed with the remaining stretch of road scheduled for this year's construction (Figure 2). Non-woven geotextiles 6 m in length were placed at the toe of the embankment towards the centreline as a separator between the natural ground and the fill material.

Figure 2. Site condition before construction of test sections, April 14, 2015.

The woven geotextiles installed at the side slopes of Section B have drainage capabilities in addition to their reinforcement function. It is assumed they provide drainage paths for the water during spring and summer seasons when the embankment undergoes thawing. The woven geotextile is a Mirafi® $H_2$Ri wicking geotextile supplied by TenCate. Selected properties of the geotextile in cross direction (CD) are summarized in Table 1. This type of geotextile has been successfully used to prevent the occurrence of frost boils in the Dalton Highway Beaver Slide Area in Alaska (Zhang et al. 2014).

Table 1. Some properties of Mirafi® $H_2$Ri

| Mechanical Properties | Units | Minimum Average Roll Value |
|---|---|---|
| Tensile Strength (at ultimate) | kN/m | 78.7 |
| Tensile Strength (at 2% strain) | kN/m | 13.1 |
| Tensile Strength (at 5% strain) | kN/m | 56.9 |
| CBR Puncture Strength | N | 10235 |
| Permittivity | $sec^{-1}$ | 0.24 |
| Apparent Opening Size | mm | 0.43 |
| Wet Front Movement (vertical) | inches | 6.0 |
| Wet Front Movement (horizontal) | inches | 73.3 |

Figure 3 shows the placement of the woven geotextile at both sides of the embankment. The geotextile has an overhang of 0.5 m (Figure 4) to allow water flow out of the embankment faster and to dissipate the potential build-up of pore water pressure during thawing.


Figure 3. Placement of geotextiles in the field.

Figure 4. Geotextiles exposed on the side slopes of the embankment with 0.5 m overhang.

## 3 GRAB SAMPLES

Grab samples were collected at the embankment and the nearest borrow source (Pit 174) during the initial site visit on March 31, 2015. Additional grab samples were collected during the actual embankment construction from April 14 to 20, 2015. Grab samples were transported to the University of Manitoba and were tested for moisture contents. Some samples, before oven drying, are shown in Figures 5a to 5d.

Table 2 shows the moisture contents of the samples obtained. Based on these results, it can be concluded that the variability on the consistency of the frozen fill material used for the embankment construction is high. High moisture contents recorded are attributed to the sample being of organic composition (EGS-8, AC-5, AC-6, AC-7, and AC-8). Grab samples AC-5 and AC-6 were obtained at the foundation centreline and the toe of Section A, respectively. Similarly, AC-7 and AC-8 were obtained at the foundation centreline and toe of Section B.

Table 2. Moisture contents of different grab samples

| Embankment Grab Samples Mar. 31, 2015 | | Pit 174 Grab Samples Mar. 31, 2015 | | Embankment Grab Samples Apr. 14-20, 2015 | |
|---|---|---|---|---|---|
| Label | MC (%) | Label | MC (%) | Label | MC (%) |
| EGS-1 | 15.8 | P174-1 | 11.5 | AC-1 | 13.8 |
| EGS-2 | 8.3 | P174-2 | 19.0 | AC-2 | 20.9 |
| EGS-3 | 10.3 | P174-3 | 9.7 | AC-3 | 21.9 |
| EGS-4 | 7.3 | P174-4 | 9.8 | AC-4 | 3.5 |
| EGS-5 | 20.2 | P174-5 | 8.6 | AC-5[2] | 1891.9 |
| EGS-6 | 6.1 | P174-6 | 18.2 | AC-6[2] | 664.7 |
| EGS-7 | 20.5 | P174-7 | 18.1 | AC-7[3] | 105.2 |
| EGS-8[1] | 555.7 | P174-8 | 17.8 | AC-8[3] | 410.1 |
| | | | | AC-9 | 14.4 |
| | | | | AC-10 | 16.5 |
| | | | | AC-11 | 17.9 |

[1]Frozen peat sample; [2]Foundation samples of Section A; [3]Foundation samples of Section B

(a) (b)

(c) (d)

Figure 5. Typical soil samples collected before oven drying: (a) EGS-6, (b) P174-6, (c) AC-1, (d) AC-8.

## 4 INSTALLATION OF INSTRUMENTATIONS AND PRELIMINARY RESULTS

Installation of instrumentations commenced on April 14, 2015 and was completed on April 20, 2015. The instruments installed in both test sections and the preliminary results obtained are discussed in this section. Section A and Section B are both instrumented with thermistors for temperature readings, ShapeAccelArrays (SAAs) for the vertical and horizontal deformations, vibrating wire piezometers for pore water pressures, and thermal conductivity sensors for matric suctions. Strain gauges were also installed in the geotextile reinforcements for Section B.

Data collection is scheduled every three (3) days from May to October, and fourteen (14) days from November to April. A number of readings are expected to be collected from the onset of the thawing season until the beginning of the winter season. There is currently limited access to the site as the embankment is still thawing (as such no vehicle access is permitted), but the data acquisition system will continue to record and save data.

### 4.1 Thermistor Strings

Thermistor strings with an accuracy of +/- 0.1 ºC were installed at different locations within the embankment and the foundation. Two thermistor strings were laid out horizontally at the top (TS-C1, TS-R1) and the base (TS-C2, TS-R2) of the embankment, and another two vertically installed through the foundation at the centreline (TS-C3, TS-R3) and at the toe (TS-C4, TS-R4). Figure 6 shows a schematic diagram where the thermistor strings were installed on the west side of both test sections. Figure 7 shows the mean, maximum, and minimum air temperatures at a climate station in Tuktoyaktuk, Northwest Territories (Latitude: 69$^{o}$26’00 N, Longitude: 133$^{o}$01’00 W) at the time of test section construction.

Preliminary results are presented in Figures 8 to 11 for the top, base, centreline, and toe of the embankment, respectively. It can be seen that there has been an increase in temperature at the thermistor nodes nearest to the ground surface since the completion of the test sections in April 20. The thermistor readings responded to changes in ambient temperatures as presented in Figure 7. It is expected that these temperatures will increase as the thawing season continues.

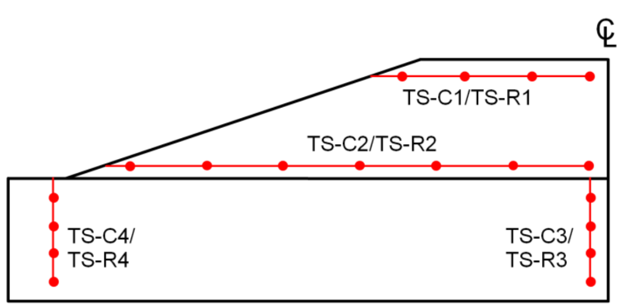


Figure 6. Schematic diagram: Placement of thermistor strings in Section A and Section B.

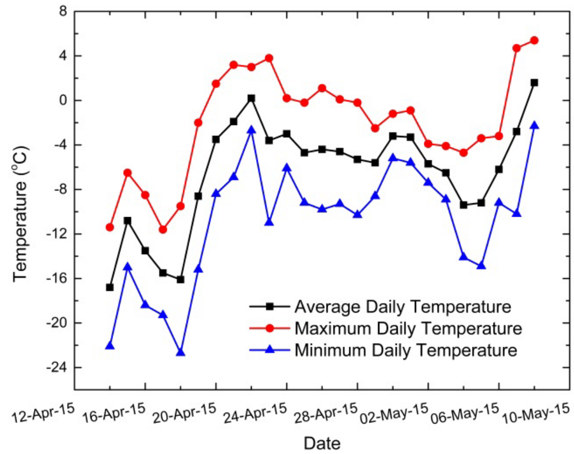


Figure 7. Daily temperatures recorded at a climate station in Tuktoyaktuk, Northwest Territories.

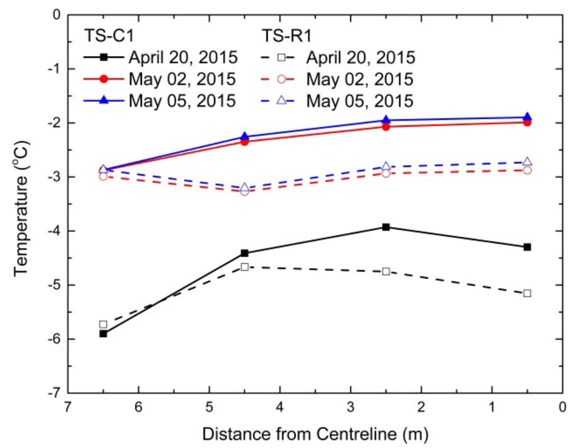


Figure 8. Thermistor readings at the top of the embankment.

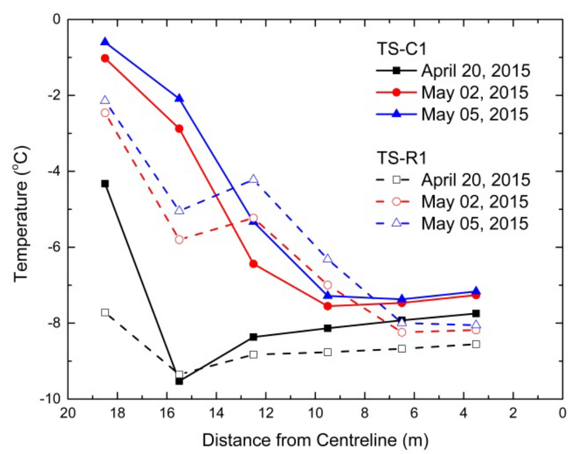


Figure 9. Thermistor readings at the base of the embankment.

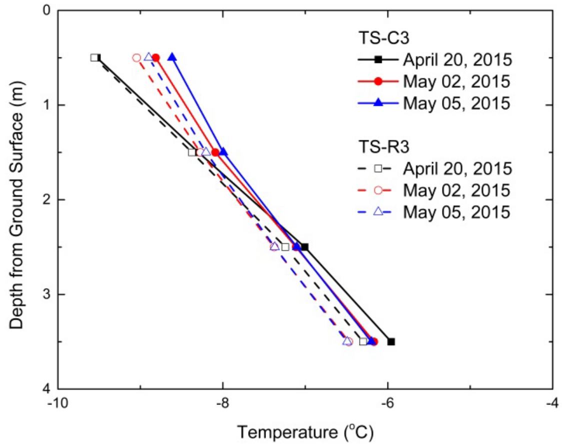


Figure 10. Thermistor readings at the centreline of the embankment below ground surface.

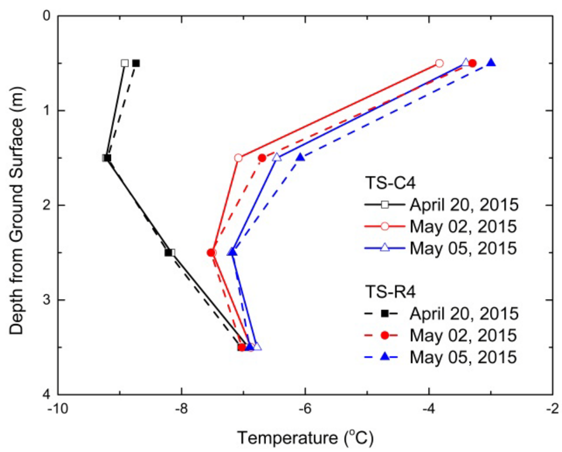


Figure 11. Thermistor readings at the toe of the embankment below ground surface.

4.2 ShapeAccelArrays (SAAs)

SAAs were installed horizontally and vertically to measure vertical and horizontal deformations, respectively. Figure 12 shows a schematic diagram with the locations of the SAAs installed on the west side of both test sections.

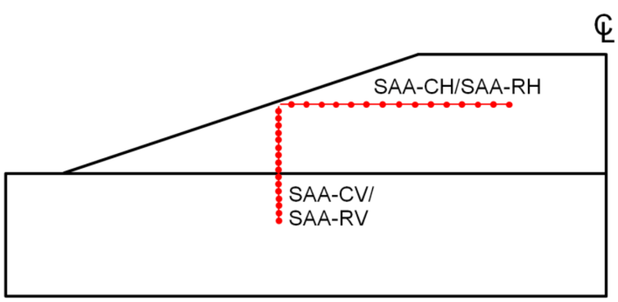


Figure 12. Schematic diagram: Placement of SAAs in Section A and Section B.

Figures 13 and 15 show the initial results of the horizontal SAAs for Section A and Section B, respectively. The test sections have settled by approximately 4 mm near the centreline. Figures 14 and 16 show the results of the vertical SAAs for Section A and Section B, respectively. The test sections have laterally deformed approximately by 2 mm. It is expected that these displacements will increase as the thawing season continues.

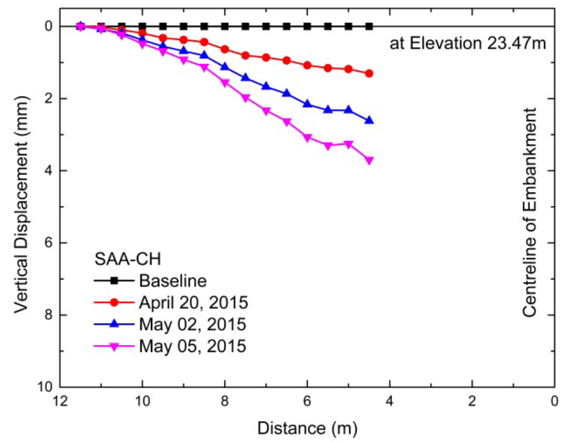


Figure 13. Vertical deformations at Elevation 23.47 in Section A.

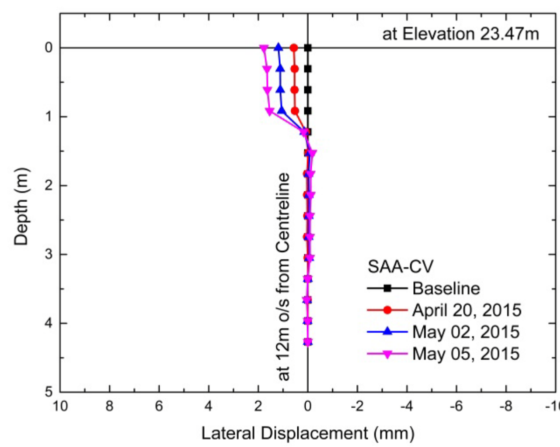


Figure 14. Horizontal deformations at 12m o/s from centreline in Section A.

4.3 Vibrating Wire Piezometers

Vibrating wire piezometers were installed at a 6.0 m offset from the centreline of the embankment. For both test sections, one piezometer (PZ-C1, PZ-R1) is installed within the embankment, and the other (PZ-C2, PZ-R2) is installed in the foundation. Figure 17 shows a schematic diagram where the piezometers were installed on the west side of both test sections.

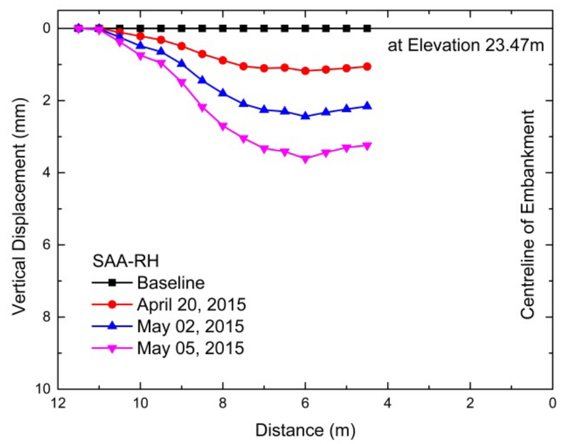


Figure 15. Vertical deformations at Elevation 23.47 in Section B.

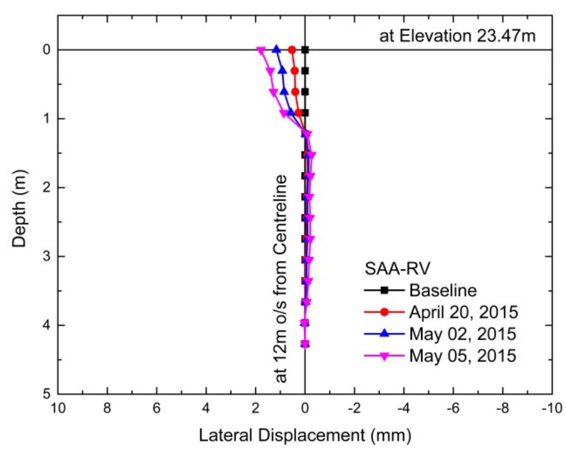


Figure 16. Horizontal deformations at 12m o/s from centreline in Section B.

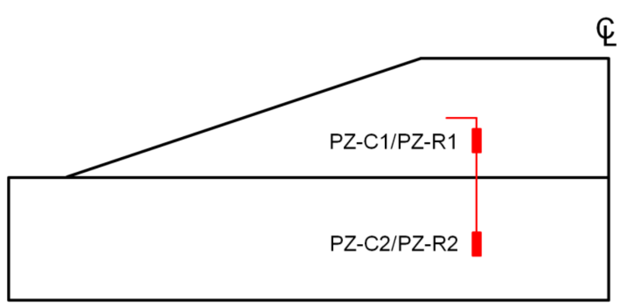


Figure 17. Schematic diagram: Placement of piezometers in Section A and Section B.

The VW piezometers were installed to measure possible development of excess pore water pressures when the embankment begins to thaw; that is, the excess pore water pressure develops as the embankment consolidates. No pore water pressures are recorded, probably because the fill material and the embankment foundation are still frozen.

## 4.4 Thermal Conductivity Sensors (TCS)

TCS were installed at different locations within the embankment to measure the development of suction (negative pore water pressure) with time. Figure 18 shows a schematic diagram where the TCS were installed on the west side of both test sections.

According to Rahardjo and Leong (2006), suction is affected more by the climatic conditions rather than the loading conditions as in the case with pore water pressures in saturated soils. Leong et al. (2012) discussed the performance and applicability of TCS to measure in-situ matric suctions. They concluded that the effect of hysteresis (wetting and drying) on matric suction measurements is significant and needs to be considered when interpreting results. Shuai et al. (2002) found that soil suction readings drop to zero when the soil is frozen. It is expected the TCS will record matric suctions when the soils begins to thaw. At the time of this paper preparation no matric suction is recorded because the fill material is still frozen.

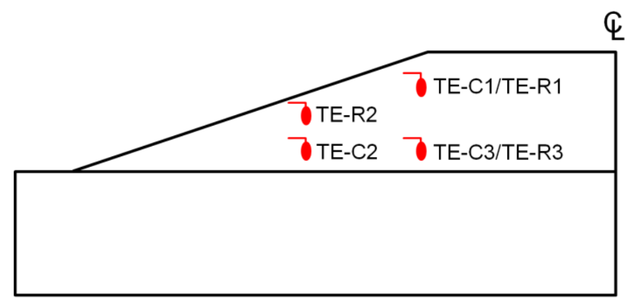


Figure 18. Schematic diagram: Placement of TCS in Section A and Section B.

## 4.5 Strain Gauges

Strain gauges were installed on the woven geotextile to measure the development of strains as the embankment deforms. This will determine the effectiveness of the geotextiles as reinforcement and how it can reduce the lateral displacement of the slope. The strain gauges were attached to the geotextiles following the recommendations by Warren et al. (2010). Han and Jiang (2013) presented a review on the application of geotextiles in cold regions and provided a summary of their expected behaviour.

Three geotextile layers were instrumented with strain gauges. Figure 19 shows a schematic diagram where the geotextiles were installed on the west side of Section B. A total of nine (9) strain gauges were installed per geotextile layer: seven (7) at the top and (2) at the bottom. Figure 20 shows the strain gauge attached to geotextile. An additional RTV rubber was used to protect the strain gauge from water upon installation. As expected, the strain gauge readings indicate little or no change up to now because the tension in the geotextiles is yet to be mobilized.

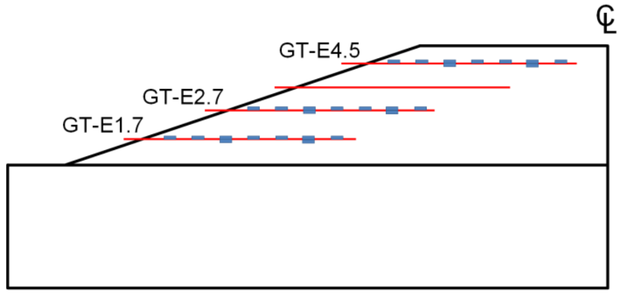


Figure 19. Schematic diagram: Placement of strain gauges in Section B.

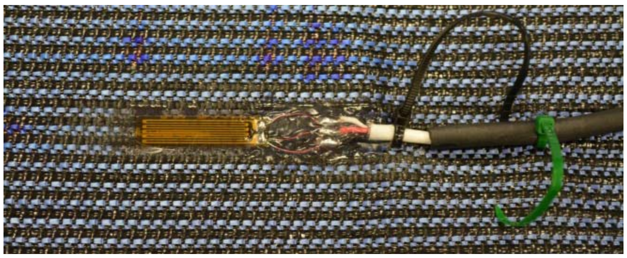

Figure 20. Attachment of strain gauge to the geotextile.

## 5 CONCLUSIONS

Installation of instrumentations to monitor the performance of two test sections along the ITH has been successfully completed. According to the authors' understanding, these are the first test sections constructed to study the effect of winter construction on the embankment performance in Arctic Regions. With construction of the embankment and installation of the monitoring instruments being completed on April 20, 2015 only initial results are available that do not yet allow for any detailed conclusion to be drawn. However, these preliminary readings indicated the thermistor closest to the ground surface are responding quickly to the warming ambient temperatures. The vertical SAAs are recording deformations closest to the ground surface, while the horizontal SAAs are showing maximum settlements near the centreline of the embankment. Readings for the piezometers, TCS, and strain gauges showed little or no change during this reporting period.

The test sections will be continuously monitored to evaluate their performance. Laboratory testing will be carried out on the soil samples obtained from the site to determine its mechanical, hydraulic, and thermal properties. Pullout and tensile capacity of the geotextile will also be tested at different temperatures and environmental conditions. These properties will ultimately be used in numerical modelling to assess the behaviour of embankments constructed in Arctic Regions in winter and develop mitigation strategies.

## 6 ACKNOWLEDGEMENTS


The work presented in this paper was supported by the Department of Transportation (DOT) of the Government of the Northwest Territories and Transport Canada. E. Gruben's Transport Ltd. was the contractor for the north-side construction of the highway. TenCate donated the woven geotextiles used in this research project. The assistance of Kerry Lynch in the installation of instrumentations is greatly appreciated. DOT personnel provided logistical support at the construction site and formed a critical part to the successful construction of the two test sections.


## 7 REFERENCES


Environmental Impact Review Board. 2011. EIS for Construction of the Inuvik to Tuktoyaktuk Highway, NWT. EIRB File No.: 02/10-05. Retrieved from http://www.dot.gov.nt.ca/_live/documents/content/EIS%20Inuvik%20to%20Tuk%20Highway%20low%20res.pdf.

Han, J. and Jiang, Y. 2013. Use of geosynthetics for performance enhancement of earth structures in cold regions, Sciences in Cold and Arid Regions, **5**(5): 517-529.

Infrastructure Canada. 2015. Inuvik to Tuktoyaktuk Highway. Retrieved from www.actionplan.gc.ca/en/initiative/inuvik-tuktoyaktuk-highway.

IPCC, 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 688.

Leong, E.C., Zhang, X.H., and Rahardjo, H. 2012. Calibration of a thermal conductivity sensor for field measurement of matric suction, Geotechnique, **62**(1): 81-85.

Rahardjo, H. and Leong, E. C. 2006. Suction measurements. *In* Fourth International Conference on Unsaturated Soils, Carefree, Arizona, United States, pp. 81-104.

Shuai, F., Clements, C., Ryland, L., and Fredlund, D.G. 2002. Some factors that influence soil suction measurements using a thermal conductivity sensor. *In* Proceedings of the Third International Conference on Unsaturated Soils, Recife, Brazil, pp. 325-329.

Transportation Association of Canada. 2010. Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions. Ottawa, Canada.

Warren, K. A., Christopher, B., and Howard, I. L. 2010. Geosynthetic strain gage installation procedures and alternative strain measurement methods for roadway applications, Geosynthetics International, **17**(6): 403-430.

Zhang, X., Presler, W., Li, L., Jones, D., and Odgers, B. 2014. Use of Wicking Fabric to Help Prevent Frost Boils in Alaskan Pavements. Journal of Materials in Civil Engineering, American Society of Civil Engineers, **26**(4):728-740.