Development of design tools for convective mitigation techniques to preserve permafrost under northern transportation infrastructure

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Introduction -> Permafrost and Embankment Degradation

Source: Fabrice Calmels, Yukon Research Centre
Introduction -> Permafrost and Embankment Degradation

Differential Settlement
Introduction -> Permafrost and Embankment Degradation

Embankment Spreading
It is essential to keep permafrost frozen under transportation infrastructure.

To protect permafrost:
- Prevent heat intake
- Extract heat from the ground
Introduction -> Heat Transfer

- Principle of preventing heat intake
Introduction -> Heat Transfer

- Principle of preventing heat intake

[Diagram showing insulation layer in winter and summer]
Introduction -> Heat Transfer

- Heat extraction – Heat Drain technique
Introduction -> Mitigation Techniques

Heat extraction

- Thermosyphons
- Air Duct System
- Heat Drain
- Air Convection Embankment
- Snow / Sun shed
- Insulation & High Albedo Surface

Prevent heat intake

Source: Modified from Ferell, 2010
Research Project -> Improve Knowledge on Mitigation Techniques

- Main factors
  - Climate warming
  - Snow accumulation
  - Water flow

- Permafrost degradation
- Engineering problems
- $$$ (ex: $12 M to maintain in Alaska)

- Mitigation techniques
  - Improve knowledge
    - Cost / benefit consideration
    - Define field applications
    - Design procedures
    - Heat drain
    - ACE
Research Project -> Develop Engineering Tools

**Project Goal**

Develop optimized engineering tools to design air convective protection systems

- Create a decision tool from existing techniques for the selection of an appropriate mitigation method that considers the local context and need
- Develop design procedures for convective mitigation techniques: heat drain and air convection embankment
Model Development

SVHeat & SVAir Flow

Model for conventional embankment

Tasiujaq

Beaver Creek

Model with mitigation techniques

Salluit

- One model examines permafrost degradation, the other examines the effectiveness of the mitigation methods
- 3 field sites available to validate models
Heat balance method will be used to:
- validate models (field data)
- test heat extraction ability of mitigation techniques

Difference between temperature of permafrost and temperature at ‘embankment / natural ground’ interface

\[ \text{colder than } 0 \, ^\circ \text{C but still unstable} \]
Research Project -> Methodology

Model Development

SVHeat & SVAir Flow

Model for conventional embankment
Tasiujaq

Model with mitigation techniques
Beaver Creek
Salluit
Preliminary Outcomes -> Model development

Beaver Creek test site, Yukon

- A 2D thermal model was developed based on the control section at Beaver Creek, Yukon
- The thermal model was well calibrated by the field data along the centerline
A 2D thermal model was developed based on the control section at Beaver Creek, Yukon. The thermal model was well calibrated by the field data along the centerline.
The chart of heat balance was obtained by sensitivity analysis and validated with data from Tasiujaq site (embankment thickness: 2.4 m). The 2nd chart allows engineers to estimate the thermal stability of the infrastructure.
Model Development

- SVHeat & SVAir Flow
  - Model for conventional embankment
    - Tasiujaq
  - Model with mitigation techniques
    - Beaver Creek
    - Salluit
Preliminary Outcomes -> Air convection embankment (ACE)

Beaver Creek test site, Yukon
Preliminary Outcomes -> Air convection embankment (ACE)

Beaver Creek test site, Yukon

During construction

50 m
The thermal model was well calibrated
Preliminary Outcomes -> Air convection embankment (ACE)
Preliminary Outcomes -> Air convection embankment (ACE)

Conventional embankment

ACE

Heat extraction ability = f (controlling parameters)

Heat balance

pos. heat balance => Unstable

neg. thermal gradient => Stable

Practical Design Considerations
Conclusion

Important to:

- Define field of application of mitigation techniques
- Develop a method to select the appropriate mitigation techniques
- Propose design procedures for Heat Drain and Air Convection Embankment

Project schedule

- Modeling – on going
- Analysis of field data – on going
- Development of design criteria – starting soon
THANK YOU TO OUR PARTNERS AND COLLABORATORS