


Rethinking our Approach to Permafrost and Infrastructure for the Next 40 Years

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The Future of Geotechnics
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Outline

- Permafrost and unique properties
- Climate-driven changes to permafrost
- Impacts to Infrastructure
- Adaptation & new approaches
- The Next 40 Years

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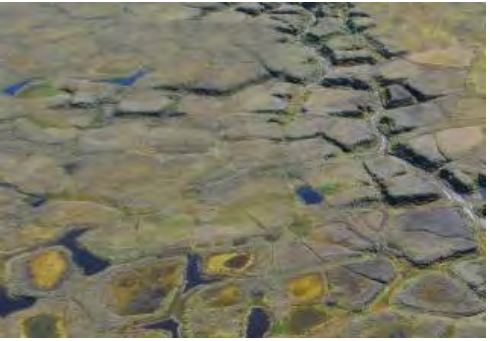
Permafrost

- Ground (soil, rock, ice, and organic material) that remains at or below 0°C (32°F) for at least two consecutive years, including the intervening thawing season
  - Thermally defined condition of earth materials
  - Not all permafrost (soil or rock) is frozen



Permafrost Distribution

Northern Hemisphere, Polar View

- Distribution is defined by area of land underlain by permafrost
- Permafrost
  - Lowland permafrost
  - Mountain permafrost
  - Subsea permafrost

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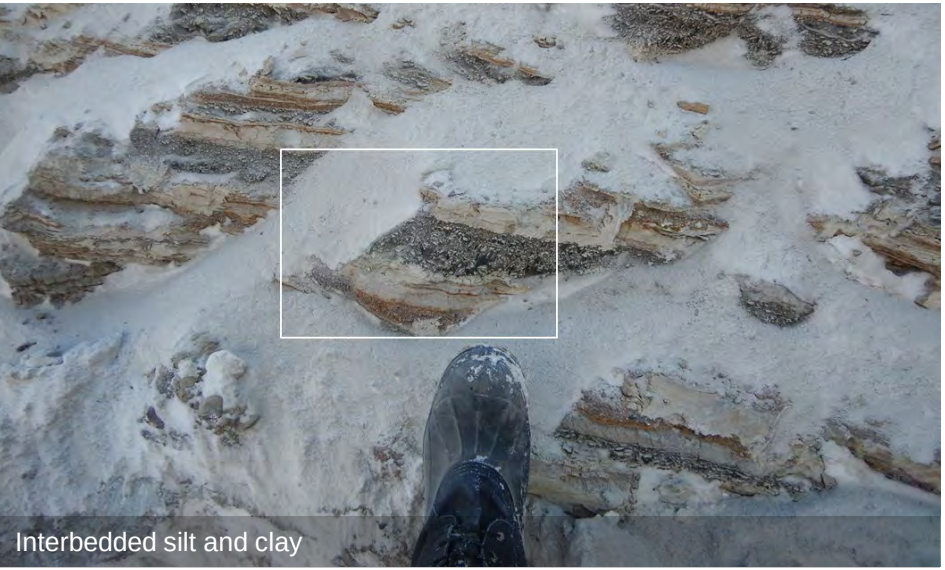
Ground Ice



Interbedded silt and clay

Segregated ice lenses

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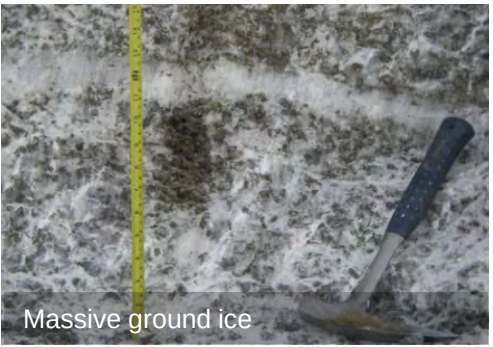
Ground Ice


Massive ground ice


Organic rich soil (peat)


Massive ground ice exposed in head scarp of retrogressive thaw slump


Ice wedge


Reticulate ground ice

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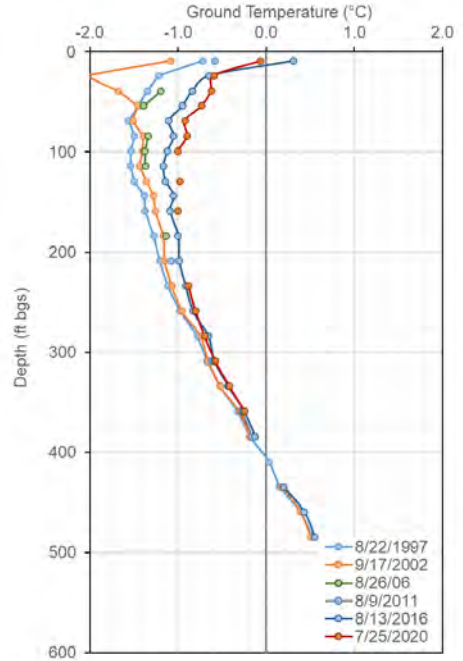
Climate-driven Changes to Permafrost

- Climate-driven changes to permafrost are taking place
- Modification of the geotechnical properties of soil and rock
- Feedback processes are accelerating thaw
- Non-linear response of permafrost across the landscape being observed
- Permafrost degradation is contributing to environmental change


Retrogressive thaw slump


Thawed soil runout into river



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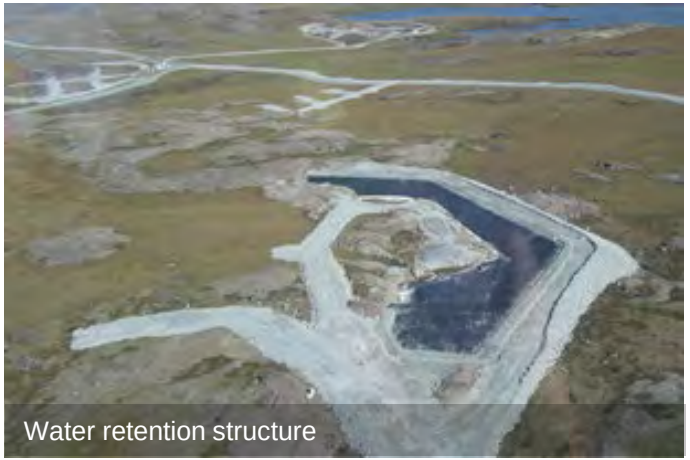
Critical Infrastructure

- Any infrastructure that is essential for the daily operation, safety, and protection of the environment
- Infrastructure remote, costly, and little to no redundancy
- Resiliency of infrastructure to climate change will continue to be a concern

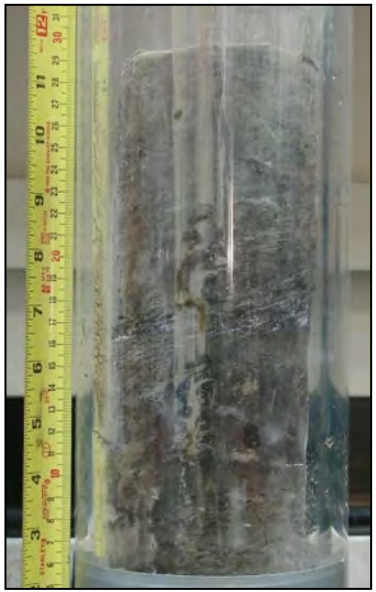

Transportation infrastructure


Water retention structure

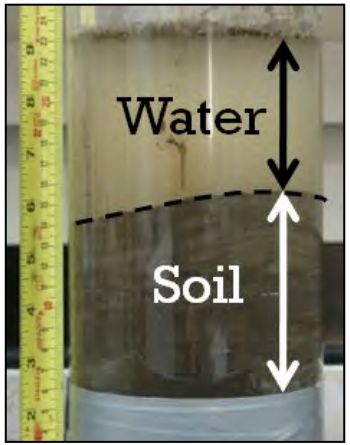

Freeze containment of waste

Frozen vs Thawed Soil

Frozen core



Thawed core



Change in geotechnical properties is temperature dependent and occurs prior to reaching the materials unfrozen state

Impacts to Infrastructure

Highway embankment failure from perpetual thaw of ice-rich permafrost foundation

Differential settlement of adfreeze piles supporting pipeline rack

Impacts to Infrastructure

Thaw-settlement impacts on culvert

Dam failure

Rapid void development from thermal erosion

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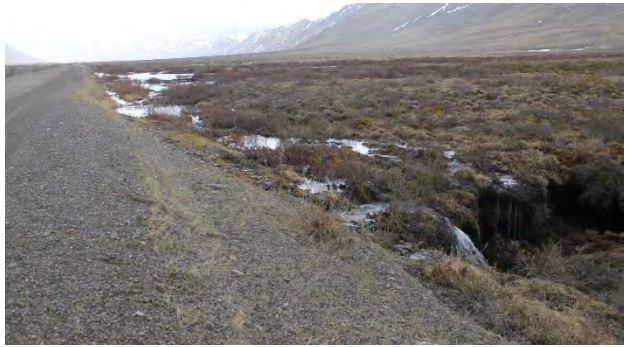
Thermal Erosion

Combined thermal and mechanical erosion of permafrost

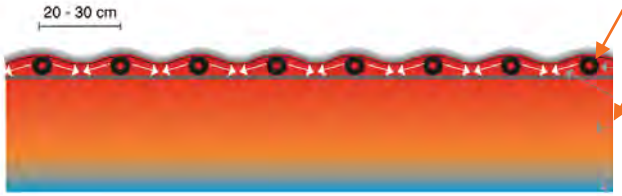


Frozen Soil Creep

Time-dependent deformation due to applied stress on frozen soil with ground ice or pore ice

Rethinking Our Approach –
Prethaw of permafrost foundations

- Commonly used design approach is to maintain a frozen foundation
- Traditional approaches may be impractical in the future
- Pre-thaw of permafrost to target depth prior to construction
- Passive and active thaw techniques
- Foundation improvement through removal of ground ice

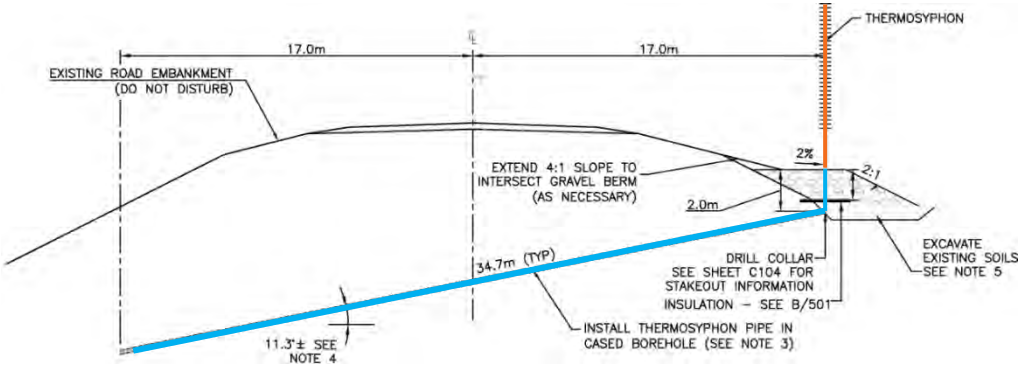


Flexible hose
(cross sectional view with heated fluid)

Heat induced into the ground to
allow for controlled thaw

Adaptation of Existing Infrastructure –
Sloped Thermosyphon Test Section


Massive ground ice recovered from drill core




Thermosyphon radiators

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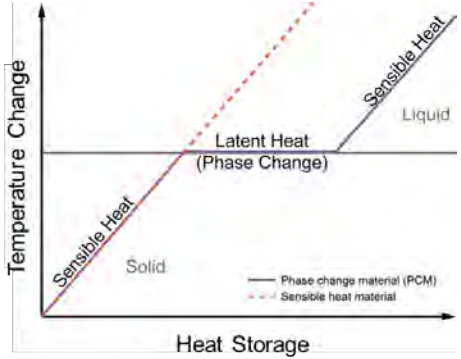
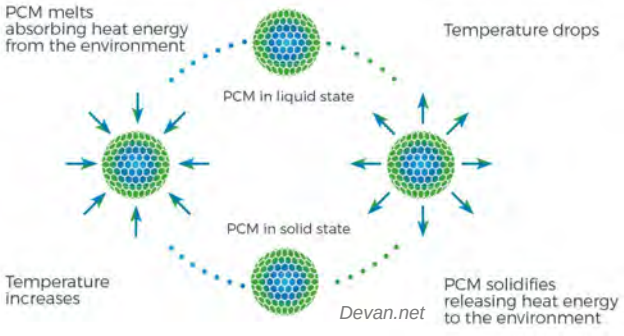
Innovation Construction Materials – Phase Change Materials



Latent heat to break hydrogen bonds (melting phase 334,000 J kg^{-1})



Macroencapsulated

The Next 40 Years

- Climate-driven changes will continue into the near future
- Impacts to infrastructure are expected to increase
- Increase O&M cost and potential risk to users, if not adequately addressed
- Progress is being made but more is needed now

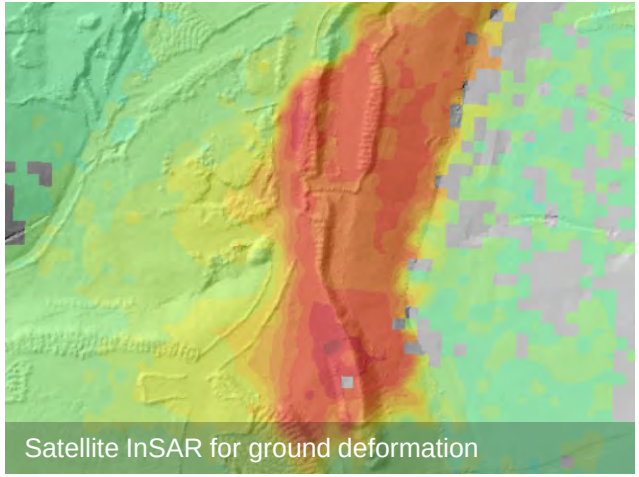
The Next 40 Years –
Proactive vs Reactive Approach

- Key to addressing the challenges is adopting proactive approach
  - Proactive involves short term goals and actions to achieve long-term strategy
  - Lower cost mitigation of upcoming issues prior to large scope challenges
  - *Doing the right things…at the right time*
- Reactive approach often leads high cost and risk to infrastructure

The Next 40 Years –
Leverage Technology

- Geotechnical characterization of permafrost (lab and field settings)
- Permafrost and ground ice mapping
- Improvement in infrastructure performance monitoring for decision-making
- Surveillance and early warning


Advancement in instrumentation


Satellite InSAR for ground deformation


Developments in materials for infrastructure design

The Next 40 Years –
Rethinking permafrost and infrastructure

- Development of alternative thermal designs
  - Prethaw of permafrost foundations
  - Integration of new materials into designs
  - Adaptation measures to address climate change
- Consideration of infrastructure impacts that may be prior to reaching a thawed state
  - Impact of soil creep on stability
  - Recognizing the role of convection
- Integration of climate change predictions
  - Geotechnical response of the material (time and space)
  - Development of climate change design parameters
- Realization that multiple solutions & approaches will be needed for the next 40 years
  - Challenge conventional thought!

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