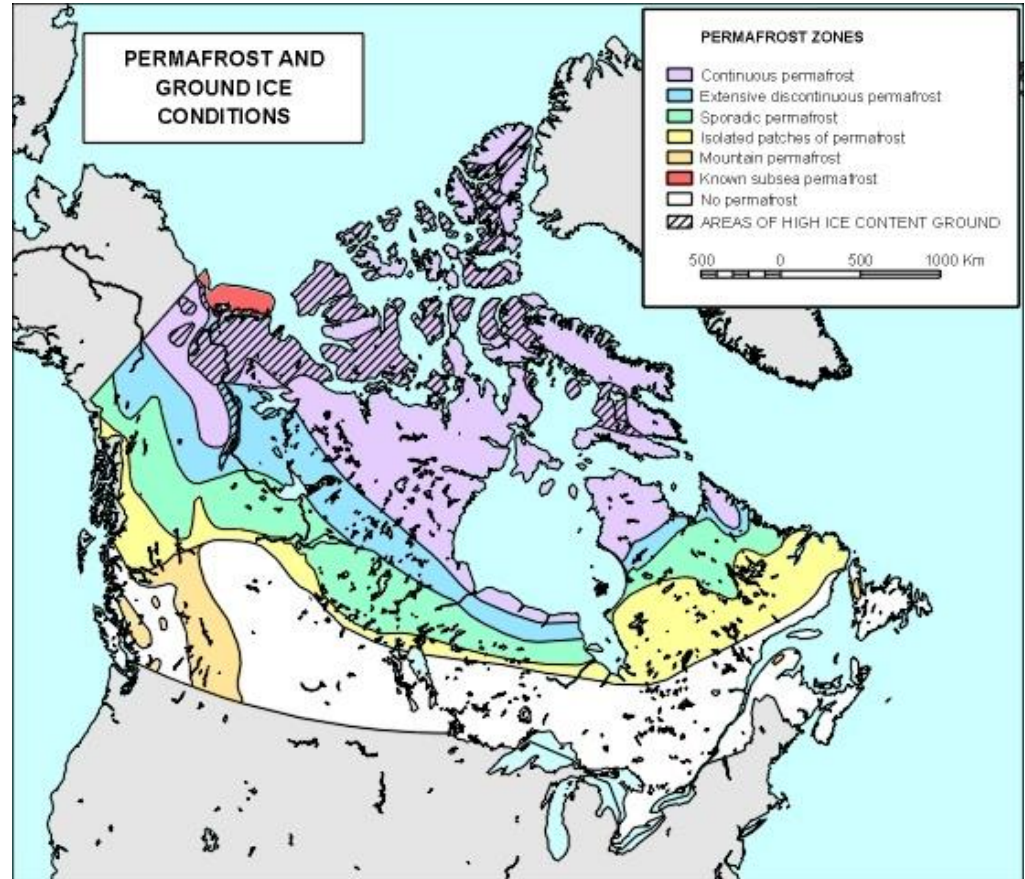




Warming of Foundations in Cold Regions

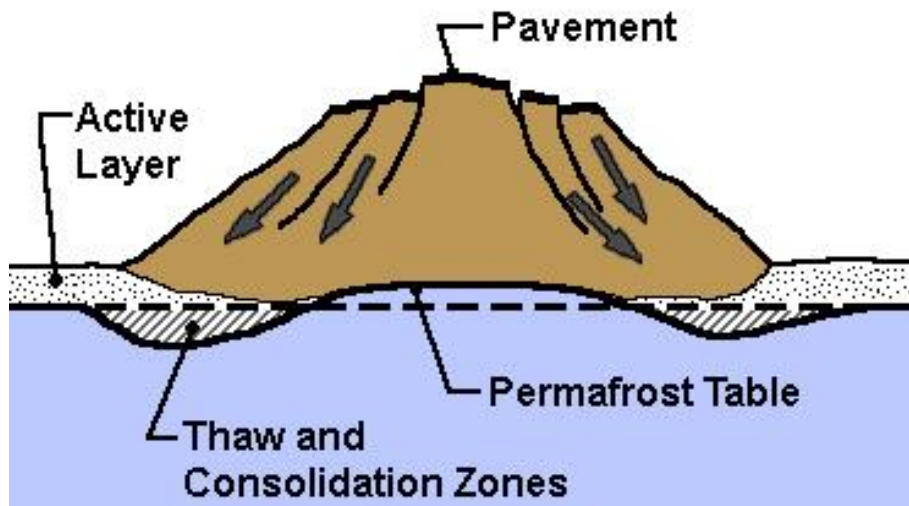
- Permafrost
 - Continuous
 - Discontinuous
- Climate Warming
- Human Activities
- Thawing of Permafrost & Engineering Implications





Warming of Foundations in Cold Regions

- Lateral Spreading
- Shoulder Rotation
- Excessive Settlements





Geotechnical Vulnerability

Permafrost degradation
(Temperature related impact)



Excessive deformations





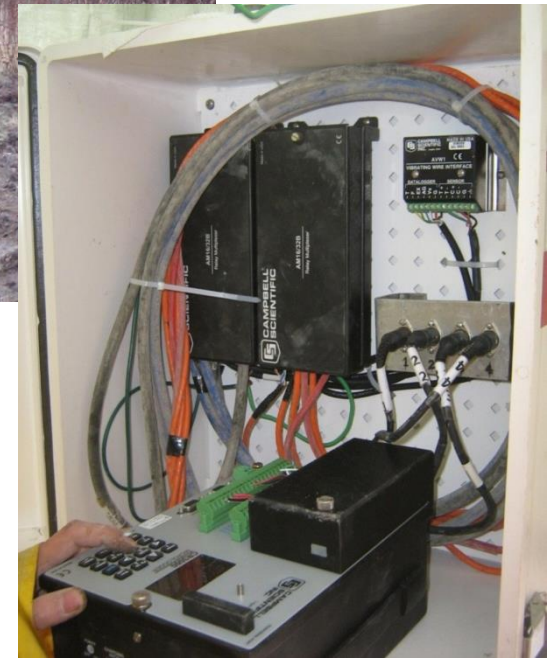
Methodology

- Detailed geotechnical site investigation to determine conditions
 - soil stratigraphy, groundwater conditions and depth of bedrock
- Materials (and availabilities), Laboratory testing
- Instrumentation and Constituent Analysis
- Modelling (predictions)



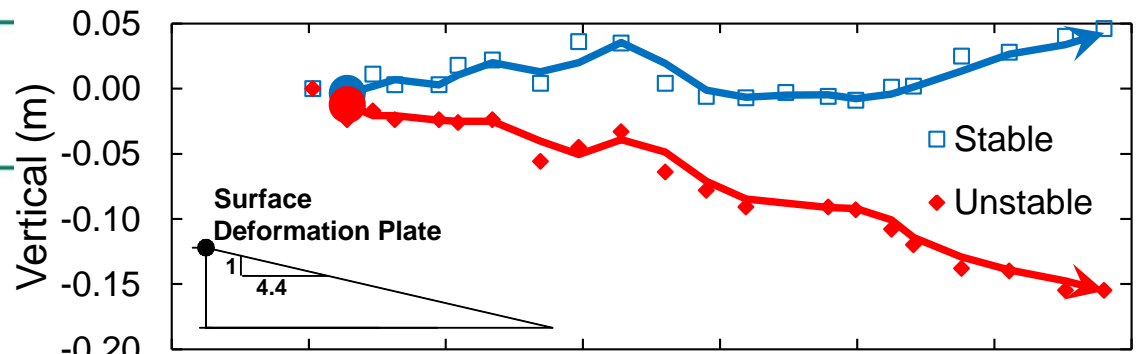
Data collection

- Temperatures
- Deformations
- Pore water pressures
 - Water flow in the ground

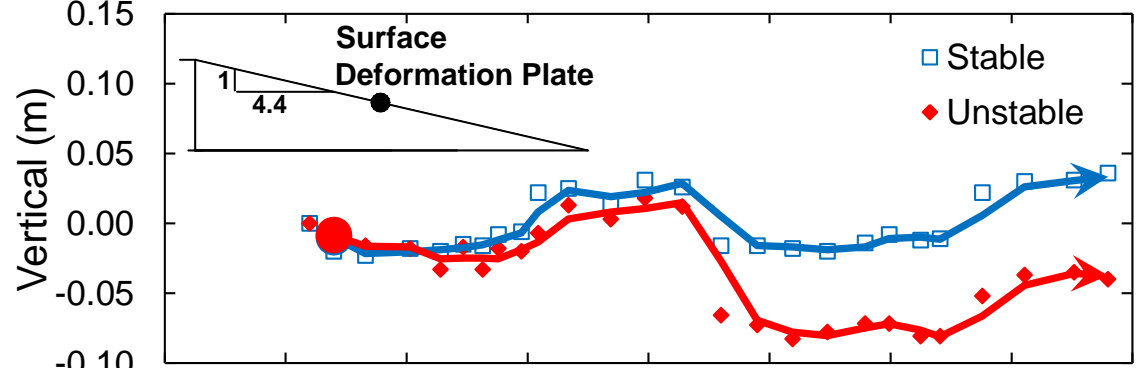




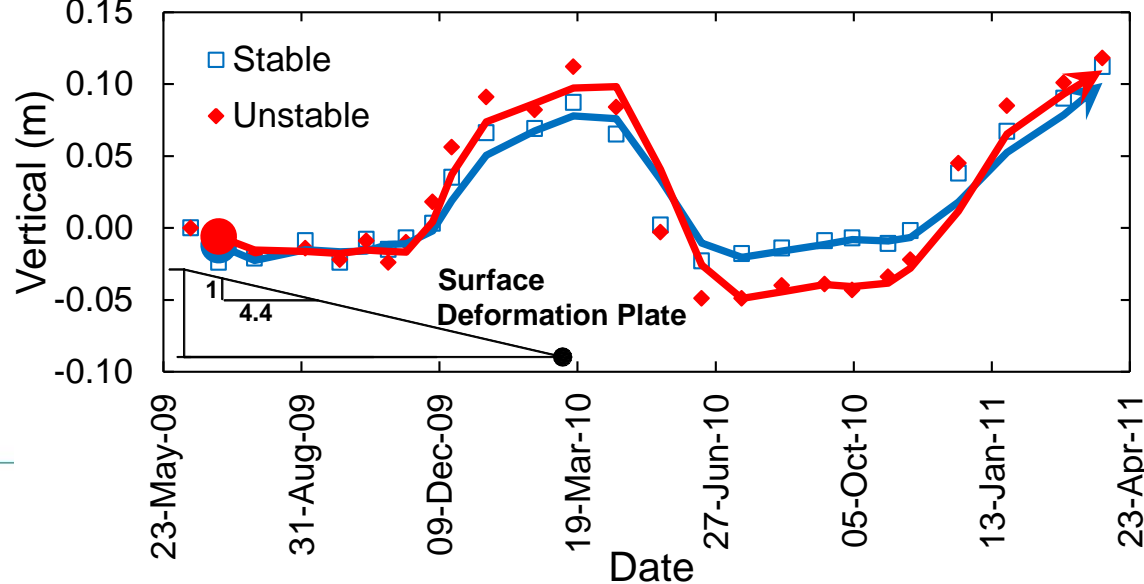
Shoulder



Displacement at Mid slope



Toe

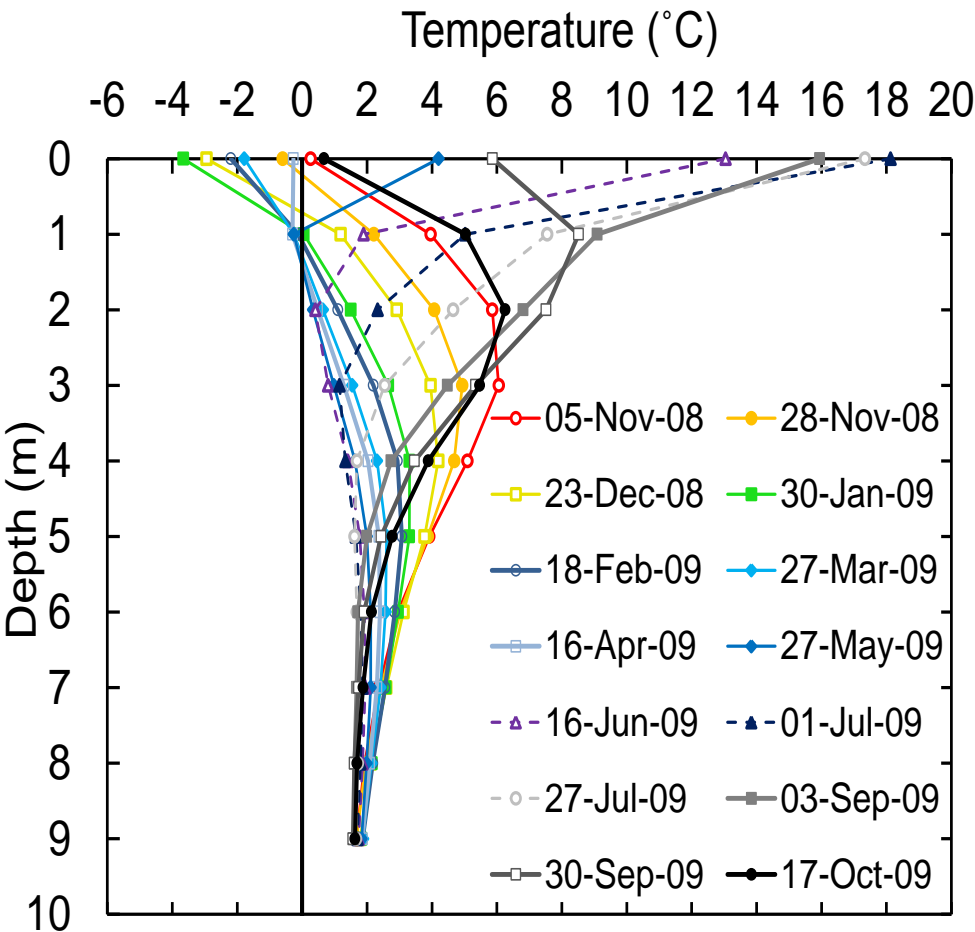




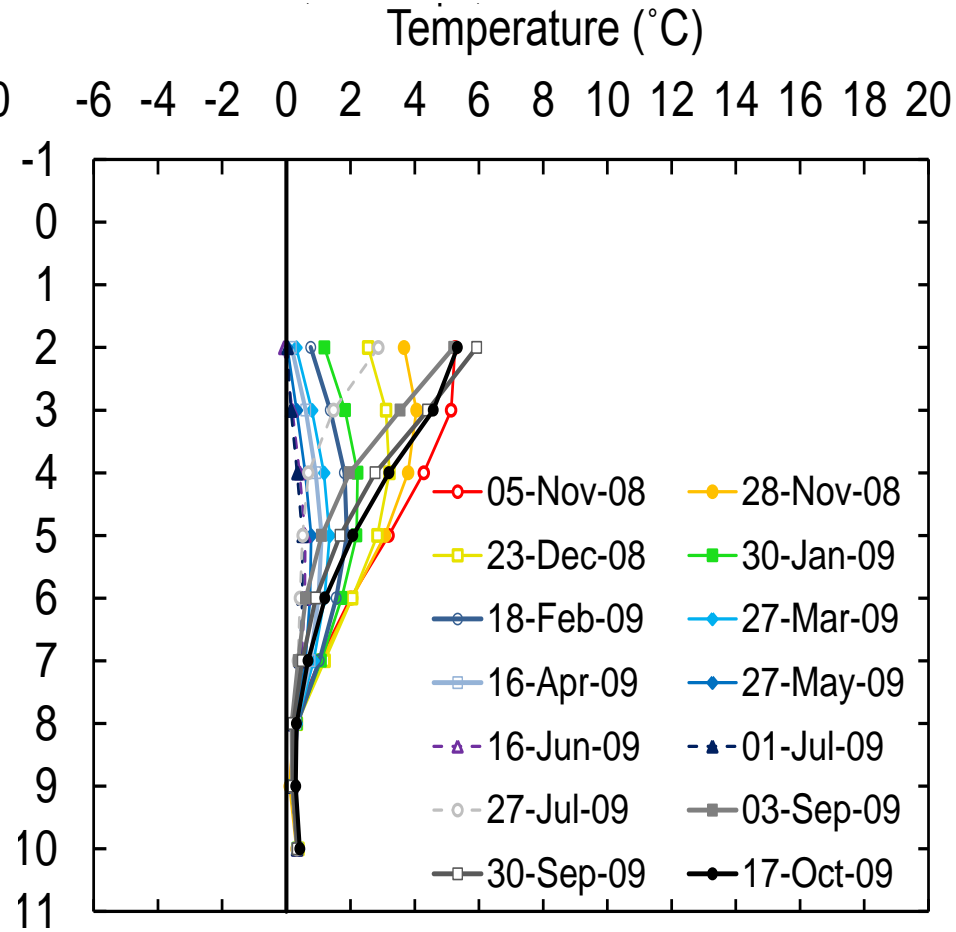
Field Results

Monthly temperature profiles

Toe



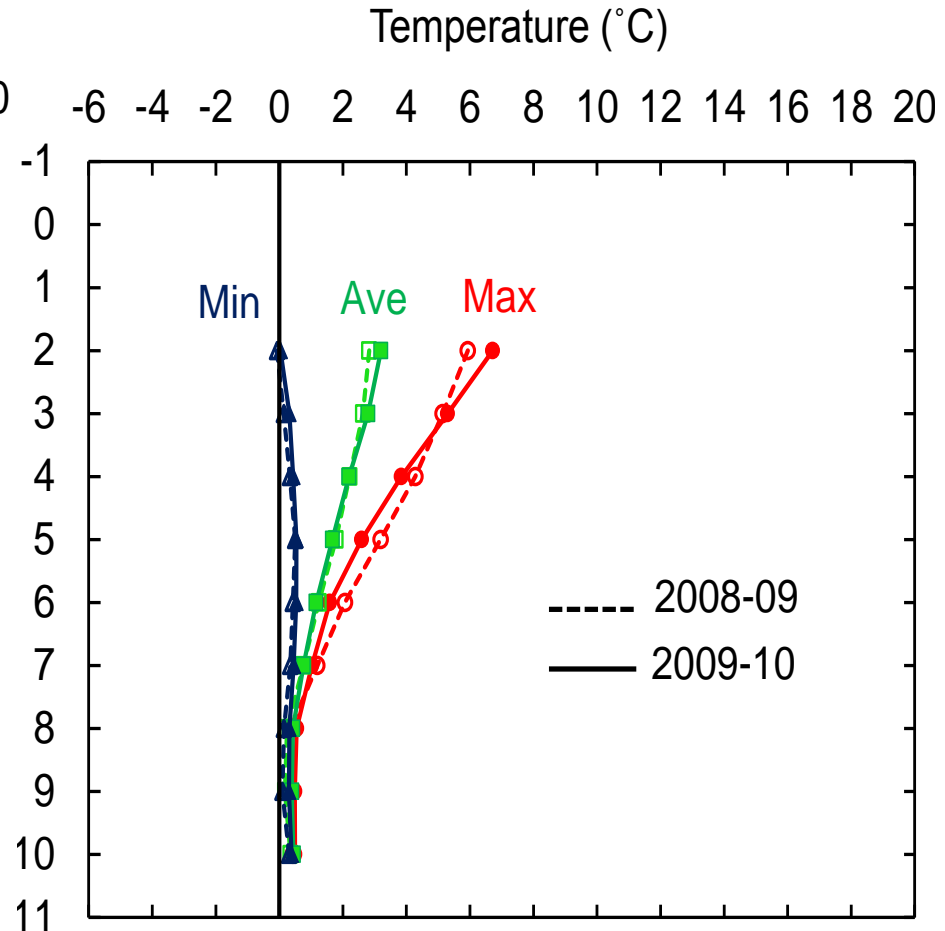
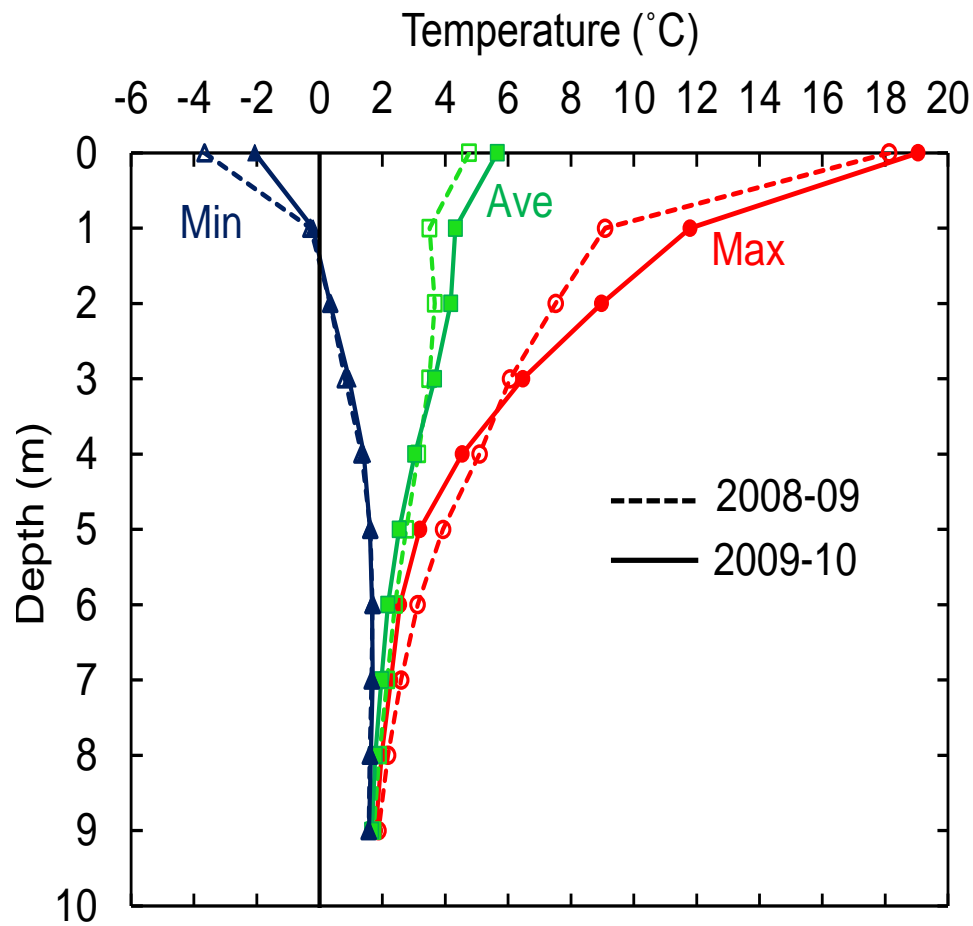
Mid slope





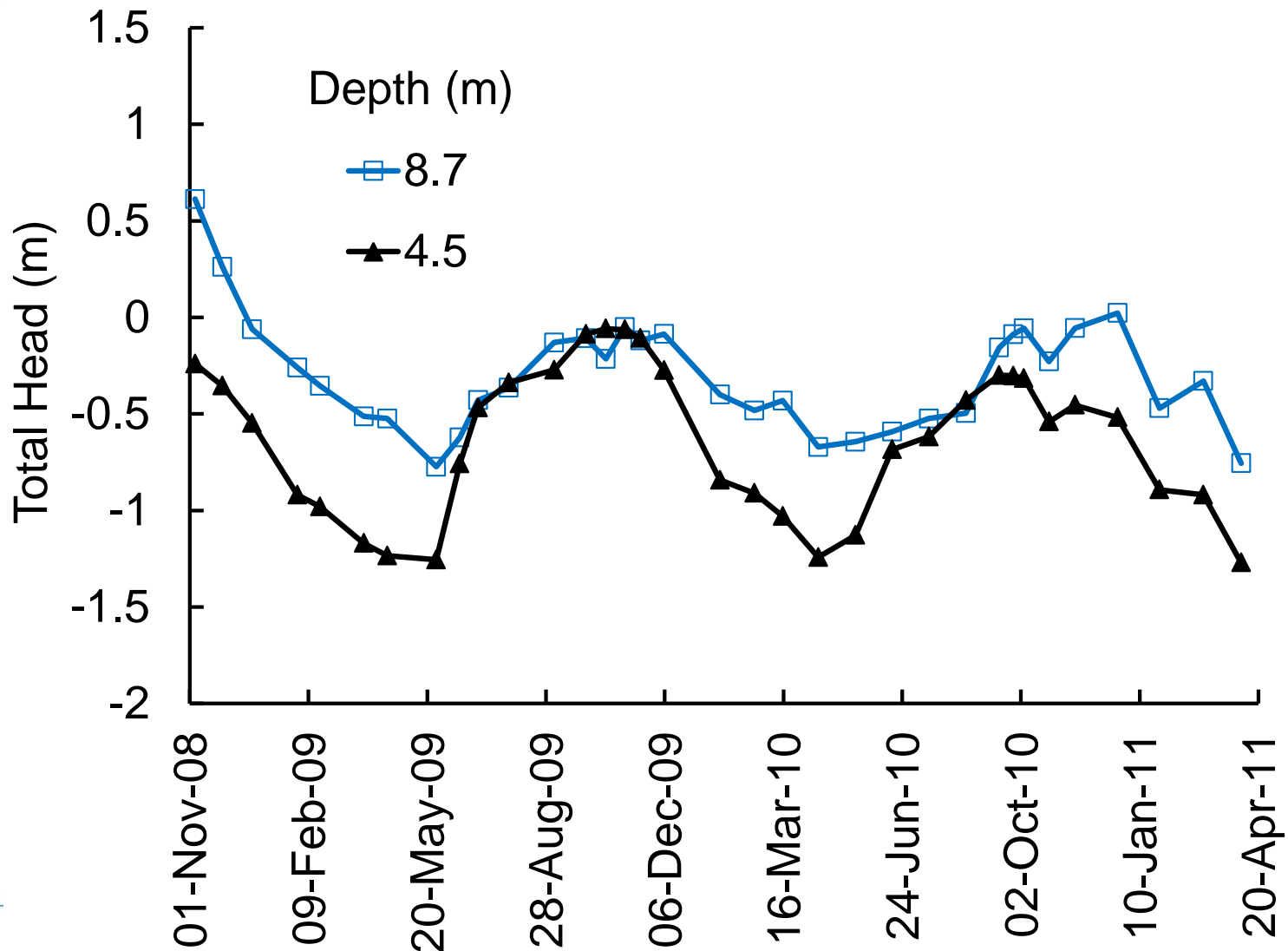
Field Results

Annual temperature envelopes





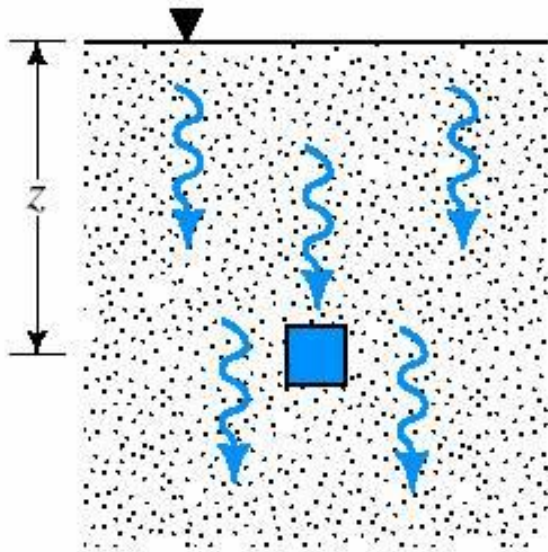
Field Results



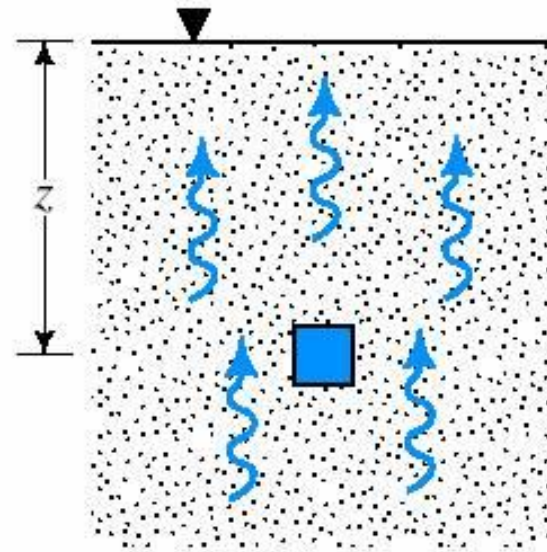
Total head vs. time at different depths



Effect of upward flow on effective stress



(a) Downward seepage



(b) Upward seepage

$$\sigma'_z = \gamma'z + iz\gamma_w = \gamma'z + j_s z$$

$$\sigma'_z = \gamma'z - iz\gamma_w = \gamma'z - j_s z$$

- Upward flow decreases effective stress



Red Dog Mine Back Dam (Kotzebue, Alaska)



The cut-off wall is being constructed with a trench cutter to excavate through fractured bedrock in permafrost and achieve the design depths required for seepage reduction.

Slide courtesy of Mr. Mark Musial, Golder in Anchorage, Alaska



Degrading Permafrost Foundation Stabilization - Thermosyphon Design-Build

- Permafrost loss due to ground disturbance
 - Several feet off settlement
 - Loss of adfreeze support
- Stabilized Foundation
 - Helicopter Access Only



Slide courtesy of Mr. Mark Musial, Golder in Anchorage, Alaska



Rural Energy Relief – Wind Power



April 22, 2014

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Slide courtesy of Mr. Mark Musial, Golder in Anchorage, Alaska





Wind Tower Foundations on Permafrost

ThermoPile Foundations Stabilize Thaw Susceptible Permafrost



Setting tower in Kwinhagak, Alaska





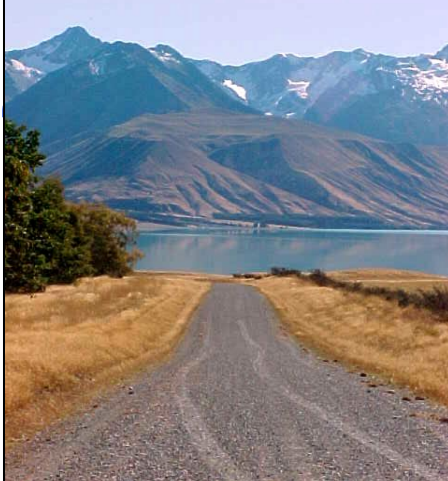
Low-Volume Roads and Heavy Haul Roads

Typical / average axle load

heavy



light

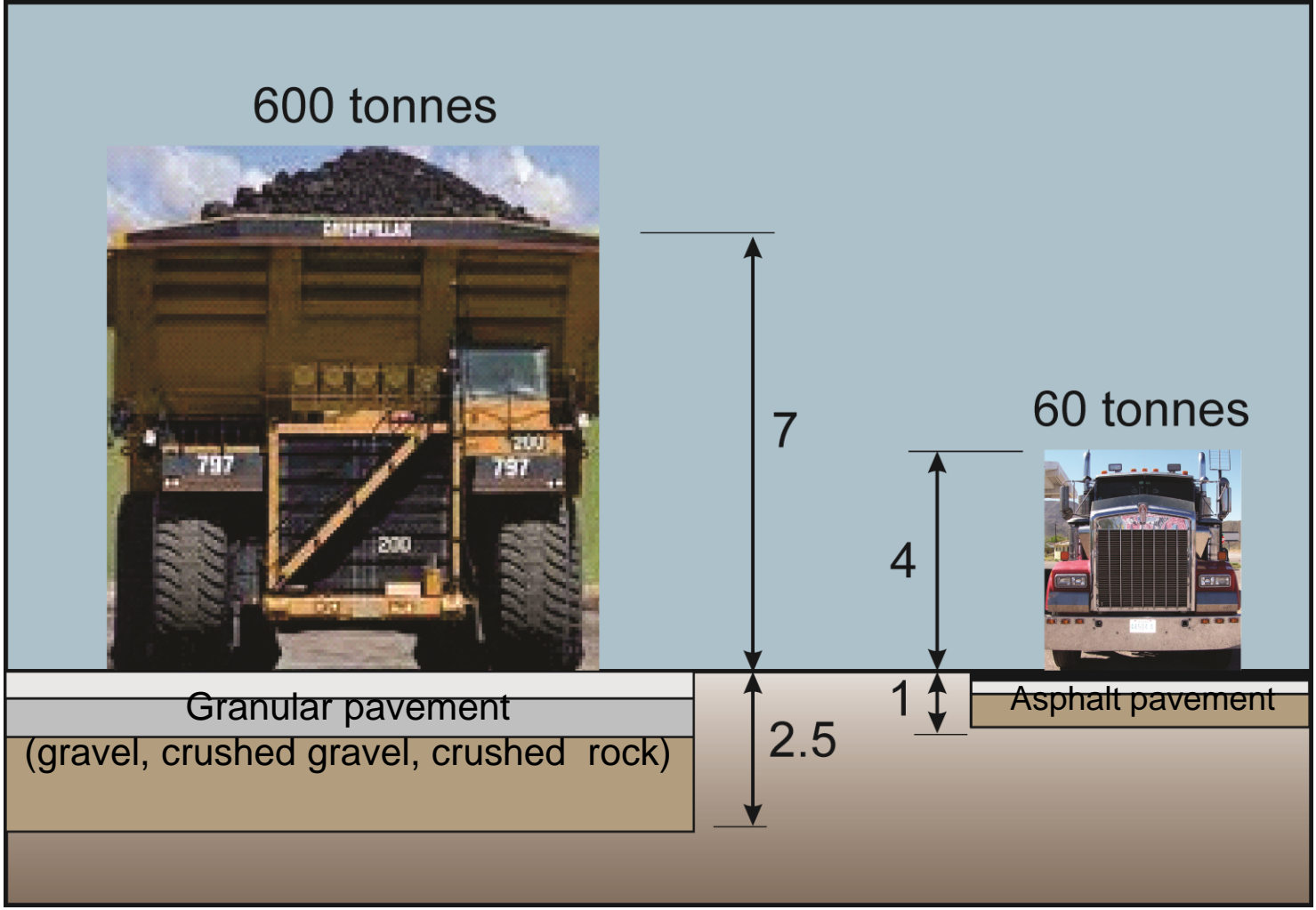


low

high

Traffic volume (veh/day)

Slide courtesy of Dr. Robert Douglas, Golder in Mississauga





Cold Regions - Thermal Analysis

- Development and persistence of frozen layers within tailings deposits;
- Impact of temperature on consolidation behaviour on tailings deposits;
- Impact of temperature on drainage and discharge rates in a frozen layered system;
- Frost penetration and/or thaw depth in various applications;
- Impact of changing climate (warming/cooling trends) and forward prediction;

Thanks!

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April 22, 2014

