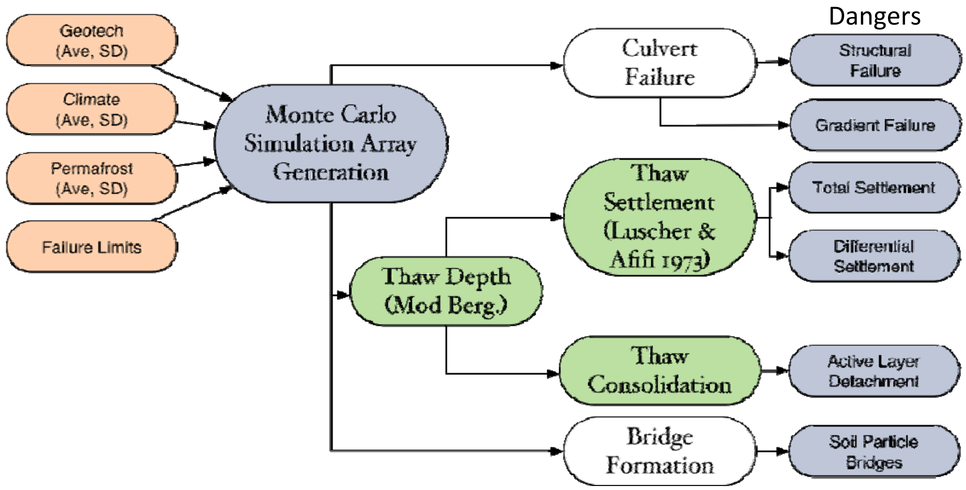
Quantitative Risk Analysis for Linear Infrastructure Supported by Permafrost: Methodology and Computer Program

Heather Brooks, Guy Doré (Director), Ariane Locat (Codirector)
Theme 3 - Ph.D. Project

Objective

Create a quantitative risk analysis methodology and tool for embankment-supported infrastructure on permafrost utilizing:

- Site conditions (geotechnical, permafrost, climate)
- Physical and/or empirical engineering calculations
- Direct cost and casualty and societal indirect consequence factors
- Fragility assessment to determine changes in hazard and risk due to warming mean annual air temperatures

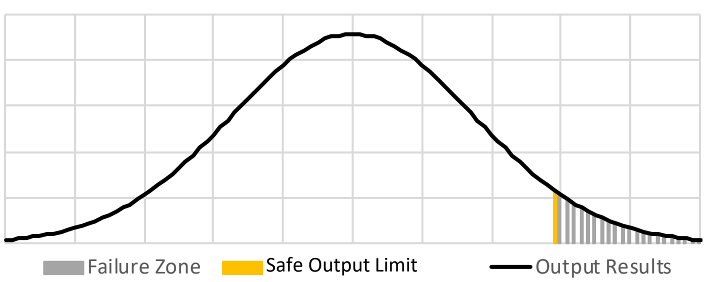


Hazard Calculation Process: Inputs (orange) of stochastic variables for average (Ave) and standard deviation (SD), calculations (green) and hazard calculations from the limit state functions (blue).

Hazard Calculation

The calculation of hazard (probability of failure) is determined using reliability analysis principles and Monte Carlo simulation techniques, in which, all of the random variables considered in the analysis are randomly selected from defined probability density functions. Calculating the limit state function result with the randomly varied input properties many times (simulations) results in the statistical variation of the limit state function. The hazard is calculated from the following equation, where the number of simulations exceeding the safe limit (figure to the left) is divided by the total number of simulations.

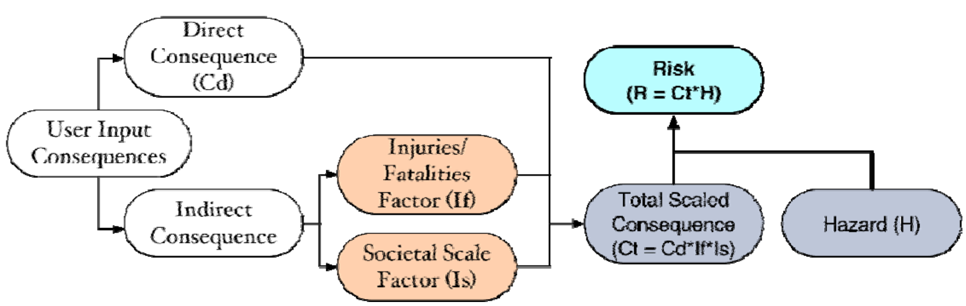
$$H = \frac{\#S_{fail}}{\#S_{Total}}$$



Since the soil condition change with the geology, the hazards, consequences and risks need to be recalculated

Consequence Calculation

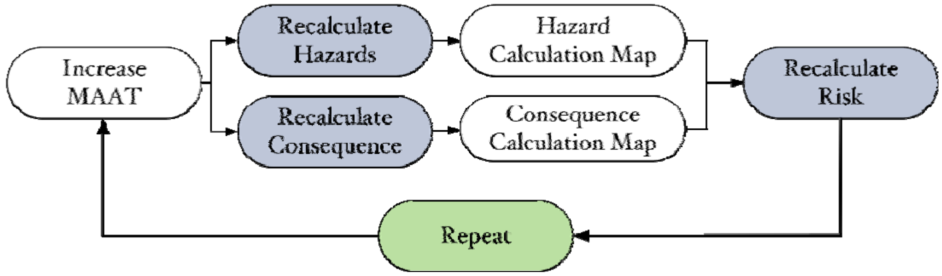
The direct consequence (Cd) for repairing each danger's damage includes labor, equipment and materials. The indirect health and societal consequence factors reflect the injuries and fatalities at the time of the danger's occurrence and community economic and health impact to communities during repairs.



Consequence and Risk Calculation Process for Each Danger: Inputs for direct cost and indirect consequence factors (orange), risk calculation inputs (blue) and calculated risk (turquoise).

Fragility Assessment

Given warming climate conditions in permafrost regions, an infrastructure's hazards and risks will change with mean annual air temperature (MAAT). The figure outlines the process of determine climate warming fragility.

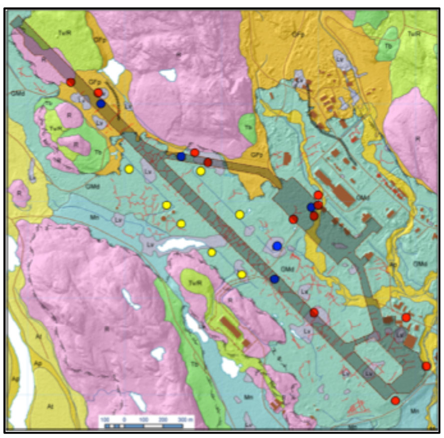


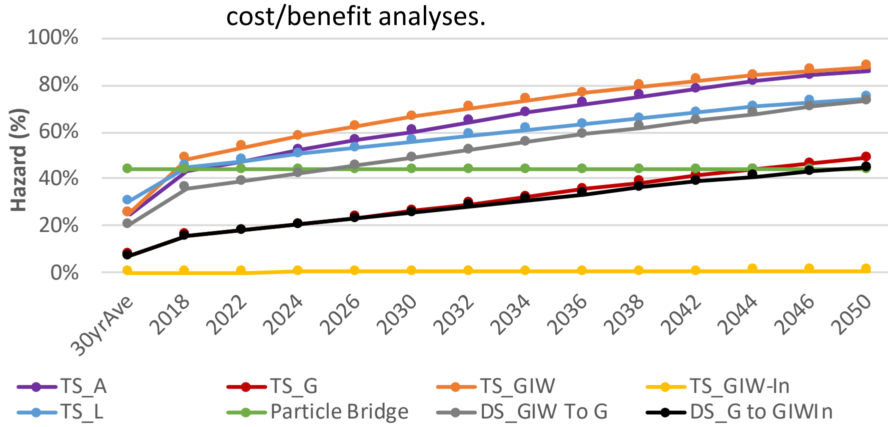
Example: Iqaluit Airport

The Iqaluit Airport was constructed on an alluvial (A, yellow), glaciomarine (G, blue) and lacustrine (L, purple) geologic settings, as shown in the surficial geology map below. Recently, the airport was reconstructed and insulation placed in the embankment section over regions with ice wedges where fissures and significant settlement where observed in the past.

This example study determined the reductions in hazard associated with changing air temperatures through time for the different geologic (A,L, G) and site conditions (G with ice wedges, GIW and insulated ice wedges, GIWIn). Three dangers were analyzed: total (TS) and differential (DS) thaw settlement, and particle bridging.

The changes in hazard due to 2.5°C warming from 2010 to 2050 are presented in the figure below. The addition of insulation to the embankment section greatly reduces the hazard of total thaw settlement (yellow line) but only reduces the differential thaw settlement (black line) by approximately 20% through time. These results can be used to determine repair and construction schedules for cost/benefit analyses.





Project Outcomes and Benefits

- Hazard and risk calculation with an Excel-based program for a: - single site : Arquluk-RISK[SS]
  - linear infrastructure : Arquluk-RISK[LI]
- Probabilistic hazard, thaw depth and thaw settlement analyses, Modified Berggren equation, Luscher and Afifi (1973) empirical equations and danger limit state functions; which can be used to design infrastructure based on confidence intervals.
- Consequence analysis includes local direct costs (equipment, labor and material) and indirect cost factors which allow the inclusion of casualty and societal effects from a danger's occurrence.
- Risk analysis of six dangers: total and differential thaw settlement, culvert structural collapse and gradient failure, active layer detachment landslides and particle bridge formation.
- Fragility assessments to determine changes in hazard and risk due to mean annual air temperature changes.
- These analyses can be used in cost/benefit analyses to compare mitigation strategies for embankment infrastructures.

KRYOTEK WSP TETRA TECH NIPPO COLAS OURANOS Transport Canada
Transports, Mobilité durable et Électrification des transports Québec GHD KATIVIK Yukon Research Centre Cold Climate Innovation Yukon Highways and Public Works Université de Montréal