Geotechnical Implications of Climate Impacts in Permafrost

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How Do Changes in Permafrost Affect Geotechnical Engineering?
What are the Tools We Use?
What are the Tools We Use?
What are the Tools We Use?
What are the Tools We Use?
What are the Tools We Use?
Are There Other Tools?

- Climate Data
  - Air Temperatures, AFI, ATI

**FIGURE 3-5** Assumed sinusoidal annual variation in surface temperature.  
*Source: Reproduced from Aldrich and Paynter 1966.*
Air Temperatures

Note: Data is generally from low-lying coastal and river valley areas. It is probably not valid for higher elevations.
Air Freezing Index
SNAP – Scenarios Network for Alaska & Arctic Planning

- A database created by UAF of free climate data for Alaska, including high resolution monthly climate data for ~1901-2100.
- 5 world recognized Global Climate Models used to simulate historical and future climate conditions
- 3 Emission Scenarios to model various climate trends
SNAP – Scenarios Network for Alaska & Arctic Planning

• Final product is ‘downscaled’ climate data on 2 km by 2 km grid for entire state which accounts for land features such as slope, elevation and coastline, as well as knowledge of local climate experts.

• SNAP purpose is to help people plan in a changing climate.
SNAP – Emission Scenarios

Average Monthly Temperature for Bethel, Alaska
Historical PRISM and 5-Model Projected Average, Low-Range Emissions (B1)

Average Monthly Temperature for Bethel, Alaska
Historical PRISM and 5-Model Projected Average, High-Range Emissions (A2)
SNAP – Scenarios Network for Alaska & Arctic Planning

Average Annual Air Temp vs Time - Barrow, AK

- Measured Average Annual Air Temp
- Projected Average Annual Air Temp
SNAP – Scenarios Network for Alaska & Arctic Planning

Average Annual Air Temp vs Time - Bethel, AK

- Measured Average Annual Air Temp
- Projected Average Annual Air Temp
### Table X: Engineering Climate Indices for Bethel, Alaska

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Average Air Temperature</td>
<td>29.4 °F</td>
<td>31.8 °F</td>
<td>33.0 °F</td>
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<tr>
<td>Average Freezing Index</td>
<td>3650 °F-days</td>
<td>3010 °F-days</td>
<td>2620 °F-days</td>
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<tr>
<td>Average Thawing Index</td>
<td>2700 °F-days</td>
<td>2920 °F-days</td>
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<tr>
<td>Design Freezing Index</td>
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<td>4210 °F-days</td>
<td>3380 °F-days</td>
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<tr>
<td>Design Thawing Index</td>
<td>3160 °F-days</td>
<td>3440 °F-days</td>
<td>3380 °F-days</td>
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</tbody>
</table>

Notes: 1) Projected by UAF SNAP, Composite of 5 Global Climate Models, Emission Scenario A1B
2) Air temperatures are estimates prepared by UAF SNAP
Climate Impacts

- Thicker active layer
- Warmer permafrost
- Shorter winter season
- Degrading permafrost where initially warm
- Increased coastal erosion
- Changes in river flooding patterns
- Increased risk of slope instability
Change in Conditions = Change in Permafrost
Increased Coastal Erosion
Riverbank Erosion
Failing Infrastructure
Failing Infrastructure
Failing Infrastructure
Increased Risk of Slope Instability
Increased Risk of Slope Instability
Permafrost Foundation Design Principles

Basic Principles

I - Preserve the frozen condition
II - Design for thaw if the settlements can be kept within allowable limits

Variations

Preconstruction thawing
Preconstruction freezing of degraded permafrost
Permafrost Pile Design

Initial Ground Temperatures

32°
Pile Capacity is Very Sensitive to Warming

- If a pile design is based on 30°F
- At 31°F, only 50% remains
- At 31.5°F, only 25%
- So, why not design for the unfrozen case?
What happens if the permafrost degrades
Pile Performance in Degrading and Thaw-unstable Permafrost
Foundation Design Options

- Post and pad footings
- Driven pile (steel pipe or H)
- Drilled and slurried timber or steel pile
- Drilled and slurried thermopile
- Torqued steel screw piles
- Steel space frame (Triodetic®)
- At-grade with insulation and subgrade cooling
Post and Pad Foundations

- Bearing on permafrost below the depth of future thaw
- Connection with pad must resist frost heave forces on post
- Can be insulated and cooled if fill material is available
Driven Piles

- Keep frozen or design for settlement and downdrag loads
- Must be deep enough to resist frost heave
- Installation is sensitive to soil type and ground temperature and requires heavy equipment
Drilled and Slurried Piles

- Allows for verification of permafrost condition
- Easy to measure temperatures
- Must be deep enough to resist frost heave
- Requires drill and slurry
- Pipe piles or secondary pipes allow for future cooling systems
Drilled/Slurried ThermoPiles

- Provides long term cooling of the soil and highest adfreeze strength
- Removes frost heave
- Requires drill and slurry
- Can cause frost heave below the tip
ThermoPile Cooling

Measured Temperatures

Air Temperatures

4-Oct 8-Oct 12-Oct 16-Oct 20-Oct
At-Grade Systems

- Provides positive support if perimeter thaw is controlled
- Used for concrete and timber floors, fuel tanks and water tanks
- Requires a sand or gravel fill or super-thick EPS
- Snow drifting is aggravated
- Frost heave is a risk if unfrozen zones are present
- Design for the warmer winters
A Risk Based Evaluation

• How sensitive is the project to climate impacts and what are the consequences of potential failures

• The relationship between sensitivity and consequences defines the risk that climate impacts pose to the project

• The degree of sensitivity and the severity of the consequences are used to establish the level of climate analysis
Sensitivity to Climate

- Initial permafrost temperatures
- Soil’s sensitivity to temperature changes
- Changes in surface conditions
- Lifetime of the project
- Level of over-design or safety margin
Level of Analysis

• Level A - Quantitative, numerical w/ peer review and field monitoring
• Level B - Limited quantitative w/ field monitoring
• Level C - Qualitative w/ professional judgment
• Level D - Analysis of climate impacts is not needed
Our goal as Alaskan designers should be to reduce Alaska’s vulnerability to climate impacts.

- Our factors of safety should reflect our level of ignorance and the importance of the project.
What Can You Take Home From This Presentation?

• Climate will impact your foundation
• It is more cost effective to address the potential effects of thawing permafrost during design rather than 5 to 10 years down the road
• The engineering design teams that you select should anticipate climate impacts for the life of the structure
• You should engage your design team and discuss their climate assumptions
• There are current tools to aid in developing appropriate climate assumptions
Acknowledgements

• Duane Miller, Rick Mitchells, and others from Golder
• David Lockard of AIDEA
• Arctic Foundations, Inc.
• The Internet

QUESTIONS?