Cold Regions Engineering

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Cold Regions Engineering

- Issues of cold regions geotechnical engineering that are of interest to structural engineers.
- Definitions and language relating to arctic and cold regions, climate, seasonally frozen ground, and permafrost.
- Permafrost terrain features and thermal regime, and how they affect the design of foundations and structures.
- Foundation settlement due to creep of ground ice and the effects of warming permafrost on the bearing capacity of the foundations.
- Design challenges on seasonal frost areas, such as frost heave, differential frost heave, and frost jacking with mitigation measures.

Instructor

- Hannele Zubeck, Ph.D., P.E.
  - MS in Civil Engineering, Tampere University, Finland.
  - Ph.D. in Civil Engineering, Oregon State University.
  - Registered Professional Engineer in the State of Alaska.
  - UAA College of Engineering faculty since 1995 – 2019
  - Co-author of Cold Regions Pavement Design
Outcomes

- After completing the session, participants will grasp the design challenges resulting from the effects of ground freezing, and
- how these challenges may change some of the requirements of the design of the overlaying superstructures.

Schedule

- 3 presentations with Q&A after each:
  - Arctic Perspectives
  - Frozen Ground
  - Foundations in Frozen Ground
- Two 7-min breaks between the presentations

Arctic Perspectives

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Outcomes

- At the completion of this presentation participants are able to
  - grasp the design challenges resulting from the effects of ground freezing and
  - how these challenges will change some of the requirements of the design of the overlaying superstructures.

Introduction

- Definitions
- Climate
- Perspectives

Definitions

- Perennial Frost
- Seasonal Frost
- Cold Region
- Arctic Region
- Sub Arctic Region
- Freezing and Thawing Indices
Definitions - Frost

- Perennial Frost or Permafrost: Soil or rock having temperatures < 0°C at least two consecutive winters and the intervening summer.
- Not related to water or ice, i.e., dry and loose gravel below 0°C would be permafrost if frozen > 2 winters + 1 summer.
- Seasonal Frost: Soil or rock having temperatures below 0°C in winters.
- Active Layer: top layer in which temperature fluctuates above and below 0°C during the year.

Trumpet and Whiplash Curves

- a) Seasonal frost
- b) Permafrost

Continuous or Discontinuous PF?

- Active Layer
  - 0.5m Barrow
  - 1-2m 1/2 Barrow-Fairbanks
  - 2-3m Anchorage
  - -230m -12°C
  - -60m -8...-4°C
  - 60m -0.3...-0.7°C
  - Farbanks 15-76m
  - Continuous
  - Discontinuous
  - Sporadic
Definitions – Cold Regions

- Defined in terms of:
  - Air temperature (mean temp. of coldest month < 0°C)
  - Depth of ground freezing: Depth of seasonal frost penetration of 300 mm (~12 in.) once in 10 years = southern boundary of cold regions
  - Arctic Region:
    - Region above Arctic Circle
    - Permafrost region
  - Sub Arctic ~ Area in cold regions minus permafrost areas

https://m2.crrel.usace.army.mil/aedis/frames_pc.html
Freezing and Thawing Indices

- Air Freezing Index (Fla) is the yearly sum of the differences between 0°C and the daily mean air temperature for the days with means below 0°C.
- Air Thawing Index (Tla) is the yearly sum of the differences between 0°C and the daily mean temperature for the days with means above 0°C.

Used in the estimation of frost depth at the seasonal frost areas and the depth of thaw in permafrost areas.

Other uses:
- Fl ≥ 3900°C for continuous permafrost to exist (Doré and Zubeck, 2009)

Example
- Determine the Fla and Tla for the daily mean temperatures given below.

<table>
<thead>
<tr>
<th>Day</th>
<th>Temp. °C</th>
<th>Fla</th>
<th>Tla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td>-1</td>
<td>-1</td>
<td>2</td>
</tr>
<tr>
<td>Tue</td>
<td>-3</td>
<td>-4</td>
<td>5</td>
</tr>
<tr>
<td>Wed</td>
<td>-2</td>
<td>-6</td>
<td>6</td>
</tr>
<tr>
<td>Thu</td>
<td>-5</td>
<td>-11</td>
<td>6</td>
</tr>
</tbody>
</table>

- Cumulative Fla = 11°C-days
- Cumulative Tla = 6°C-days
- Typically calculated for entire year.
Surface freezing and thawing indices

- Most engineering applications need surface freezing and thawing indices
- Convert air indices to surface indices with "n-factors"
  - $n_f = \frac{F_I_s}{F_I_a}$
  - $n_t = \frac{T_I_s}{T_I_a}$
- The indices for freezing and thawing conditions have been measured at certain location, n-values solved from above equations, and n-values published.

<table>
<thead>
<tr>
<th>Material</th>
<th>n-freezing</th>
<th>n-thawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>0.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Turf</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Asphalt Pavement</td>
<td>0.3-1.0+</td>
<td>1.2-2.3</td>
</tr>
<tr>
<td>Spruce trees over peat</td>
<td>0.29 (under snow)</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Summarized from several sources (Andersland and Ladanyi, 2004)
Example

- Use values in Slide 20 to evaluate surface freezing and thawing indices for a site with gravel surface.
- $F_{f_{\text{z}}} = n \times F_{f_{\text{z}}} = 0.9 \times 11^\circ\text{C-days}$
  $= 9.9^\circ\text{C-days}$
- $T_{t_{\text{z}}} = n \times T_{t_{\text{z}}} = 2.0 \times 6^\circ\text{C-days}$
  $= 12^\circ\text{C-days}$

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<th>$n_{\text{thawing}}$</th>
</tr>
</thead>
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<td>1.0</td>
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Climate

- Definitions:
  - MAT – mean annual temperature
  - MAAT – mean annual air temperature
  - MAST – mean annual surface temperature
  - Depth of Snow (snow pack) - total snow and ice on the ground (new, old snow and ice)
  - Snow water equivalent depth – converts density to that of liquid water and is given in the unit of length (in or mm)
  - Snow Fall - depth of unmelted snow received over a period of time
Observed Mean annual temperature (°C) in Alaska for 2000-2009 [http://scenarios.globalchange.gov/node/1091]
Consequences

- Melting glaciers
  - Sea level rising: Increased coastal erosion threatens coastal communities
- Degrading permafrost
  - Structures and infrastructure founded in permafrost are in danger or failing
- Increased storms
  - Rain water drainage systems do not meet the capacity requirements – floods and related problems
- Challenges: obtain and apply new data, retrofit existing assets for new conditions, prevent erosion

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Changing climate

- Warming permafrost causes
  - Decrease in the soil bearing capacity
  - Stability of the overlying structures decreases
  - Settlement results and the entire structure may become useless
- Engineers need to obtain and apply new data to retrofit existing assets for the new conditions as well as adjust the design criteria for new structures.
Perspectives

Sustainable development
- Consider the environment, society, and economics equally.
- WCED (1987): "Development which meets the needs of present without compromising the ability of future generations to meet their own needs.
- Engineers as well as decision makers are to incorporate the concept of sustainable infrastructure to Arctic designs.

Sustainable development
- Essential: include all stakeholders to decision making, planning and design
- In Alaska, various factors have caused engineered utilities to fail (Schubert et al. 2009)
  - due to judgment errors during early planning, engineering design, defective materials, poor construction practices, and improper operational procedures.
  - avoid failures by using appropriate approaches, such as researching using indigenous methodology, educating Westerners about native perspectives, partnering with local communities, and using capacity building strategies.

References
- University of Alaska Anchorage on-line courses in Arctic Engineering and Frozen Ground Engineering
  - Short courses
  - Semester long courses