# Cold Regions Engineering

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1

## 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


2

2

## 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.

3

3

## 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.

4

4

## Schedule

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

5

5

## Arctic Perspectives

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6

## 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.

7

7

## Introduction

- Definitions
- Climate
- Perspectives

8

8

## Definitions

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

9

9

## 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.

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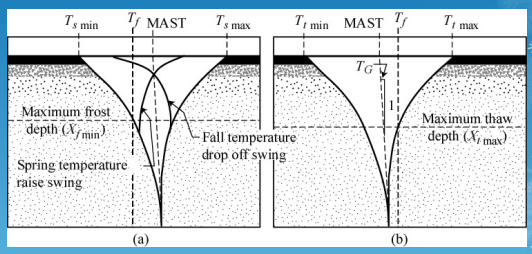
10

## Trumpet and Whiplash Curves



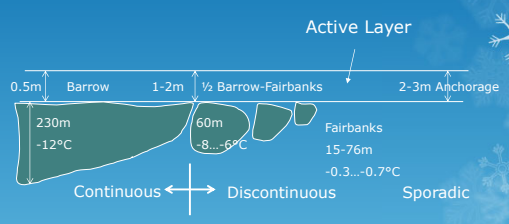

a) Seasonal frost b) permafrost

11

Doré and Zubeck, 2009

11

## Continuous or Discontinuous PF?

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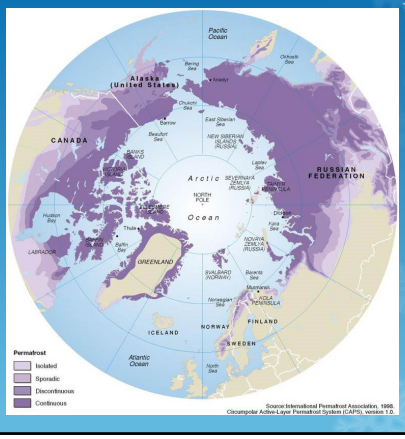
12

## 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

13

13

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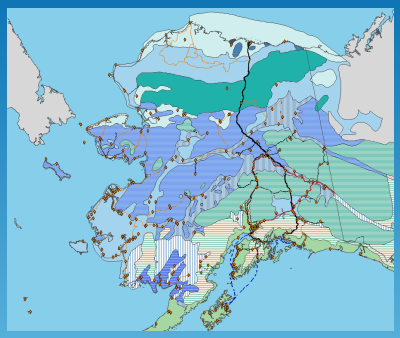


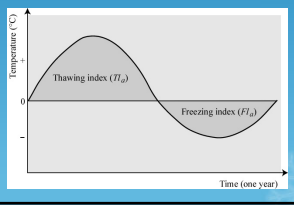

https://m2.crrel.usace.army.mil/aedis/frames_pc.html

15

15

## Freezing and Thawing Indices

- Air Freezing Index ($FI_a$) is the yearly sum of the differences between 0ºC and the daily mean air temperature for the days with means below 0ºC .
- Air Thawing Index ($TI_a$) is the yearly sum of the differences between 0ºC and the daily mean temperature for the days with means above 0ºC .

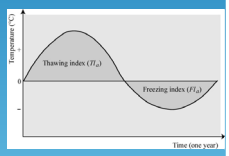


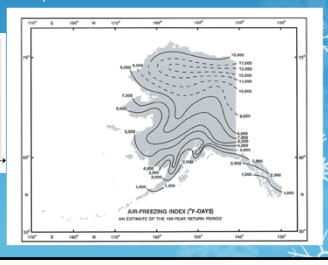

16

16

## Freezing and Thawing Indices

- Used in the estimation of frost depth at the seasonal frost areas and the depth of thaw in permafrost areas.
- Other uses:
  - Fi ≥ 3900°C for continuous permafrost to exist




Doré and Zubeck, 2009

17

17

## Example

- Determine the $FI_a$ and $TI_a$ for the daily mean temperatures given below.

| | Mon | Tue | Wed | Thu | Fri | Sat | Sun |
|---|---|---|---|---|---|---|---|
| Mean Temp. °C | 2 | 3 | | | 1 | | |
| | | | -1 | -3 | | -2 | -5 |
| FI | | | -1 | -4 | | -6 | ***-11*** |
| TI | 2 | 5 | | | ***6*** | | |

- Cumulative $FI_a$ = 11C°-days
- Cumulative $TI_a$ = 6°C-days
- Typically calculated for entire year.

18

18

## Surface freezing and thawing indices

- Most engineering applications need surface freezing and thawing indices
  - ≠ air freezing indices
- Convert air indices to surface indices with "n-factors"
  - $n_f = FI_s/FI_a$
  - $n_t = TI_s/TI_a$
- The indices for freezing and thawing conditions have been measured at certain location, n-values solved from above equations, and n-values published.

19

19

## Surface freezing and thawing indices

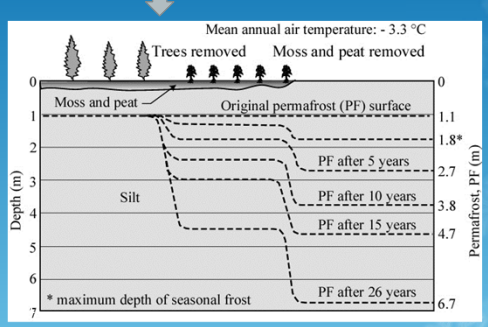
| Material | n-freezing | n-thawing |
|---|---|---|
| Snow | 1.0 | - |
| Sand and gravel | 0.9 | 2.0 |
| Turf | 0.5 | 1.0 |
| Asphalt Pavement | 0.3-1.0+ | 1.2-2.3 |
| Spruce trees over peat | 0.29 (under snow) | 0.37 |

Summarized from several sources (Andersland and Ladanyi, 2004)

20

20

Changes in n-factor




21

Doré and Zubeck, 2009

22

22

## Example

- Use values in Slide 20 to evaluate surface freezing and thawing indices for a site with gravel surface.
- $FI_s = n*FI_a = 0.9*11°C\text{-days} = 9.9\ °C\text{-days}$
- $TI_s = n*TI_a = 2.0*6°C\text{-days} = 12°C\text{-days}$

| Mat. | n-freezing | n-thawing |
|---|---|---|
| Snow | 1.0 | - |
| Sand and gravel | 0.9 | 2.0 |
| Turf | 0.5 | 1.0 |
| Asphalt Pavement | 0.3-1.0+ | 1.2-2.3 |
| Spruce trees over peat | 0.29 (under snow) | 0.37 |

Summarized from several sources (Andersland and Ladanyi, 2004)

23

23

## 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

24

24

## NOME WSO AIRPORT, ALASKA (506496)

**Period of Record Monthly Climate Summary**

**Period of Record : 9/ 1/1949 to 12/31/2005**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 13.6 | 13.6 | 17.5 | 26.8 | 42.4 | 53.6 | 57.3 | 55.7 | 48.5 | 34.2 | 23.1 | 14.1 | 33.4 |
| Average Min. Temperature (F) | -1.9 | -2.5 | 0.2 | 11.7 | 29.8 | 39.6 | 45.2 | 44.2 | 36.3 | 22.6 | 10.5 | -0.8 | 19.6 |
| Average Total Precipitation (in.) | 0.87 | 0.73 | 0.61 | 0.70 | 0.73 | 1.06 | 2.16 | 3.33 | 2.48 | 1.47 | 1.10 | 0.88 | 16.11 |
| Average Total SnowFall (in.) | 9.4 | 8.5 | 7.4 | 6.6 | 2.1 | 0.1 | 0.0 | 0.0 | 0.4 | 4.5 | 11.1 | 10.2 | 60.4 |
| Average Snow Depth (in.) | 14 | 15 | 16 | 13 | 2 | 0 | 0 | 0 | 0 | 1 | 4 | 8 | 6 |

Percent of possible observations for period of record.
Max. Temp.: 99.8% Min. Temp.: 99.8% Precipitation: 99.8% Snowfall: 99.8% Snow Depth: 99.8%
Check Station Metadata or Metadata graphics for more detail about data completeness.

*Western Regional Climate Center, wrcc@dri.edu*

25

## BARROW WSO AIRPORT, ALASKA (500546)

**Period of Record Monthly Climate Summary**

**Period of Record : 9/ 2/1949 to 12/31/2005**

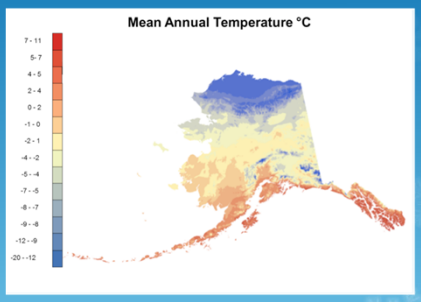
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | -7.4 | -11.3 | -7.9 | 6.6 | 24.6 | 38.7 | 45.6 | 42.9 | 34.4 | 20.0 | 5.3 | -5.1 | 15.5 |
| Average Min. Temperature (F) | -19.7 | -23.2 | -20.5 | -7.3 | 15.0 | 29.9 | 33.8 | 33.6 | 27.6 | 10.7 | -6.1 | -16.8 | 4.8 |
| Average Total Precipitation (in.) | 0.18 | 0.15 | 0.13 | 0.17 | 0.16 | 0.35 | 0.91 | 1.04 | 0.68 | 0.48 | 0.24 | 0.16 | 4.63 |
| Average Total SnowFall (in.) | 2.2 | 2.2 | 1.9 | 2.4 | 2.0 | 0.6 | 0.3 | 0.7 | 4.1 | 7.0 | 3.6 | 2.5 | 29.5 |
| Average Snow Depth (in.) | 9 | 10 | 11 | 11 | 6 | 1 | 0 | 0 | 1 | 4 | 7 | 8 | 6 |

Percent of possible observations for period of record.
Max. Temp.: 99.9% Min. Temp.: 99.8% Precipitation: 99.9% Snowfall: 99.7% Snow Depth: 99.7%
Check Station Metadata or Metadata graphics for more detail about data completeness.

*Western Regional Climate Center, wrcc@dri.edu*

26

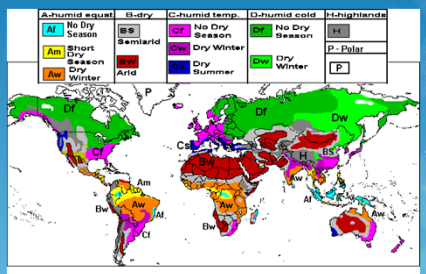
Observed Mean annual temperature (˚C) in Alaska for 2000-2009
[http://scenarios.globalchange.gov/node/1091]




27

27

## Climate in Cold Regions




http://www.harpercollege.edu/mhealy/g101ilec/intro/phy/phcli/phclifr.htm

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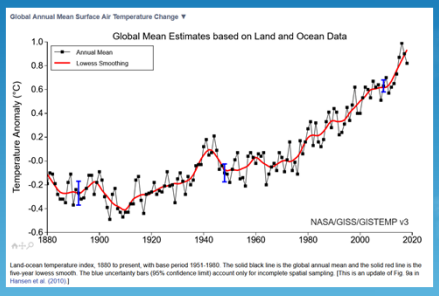
28

## Changing climate

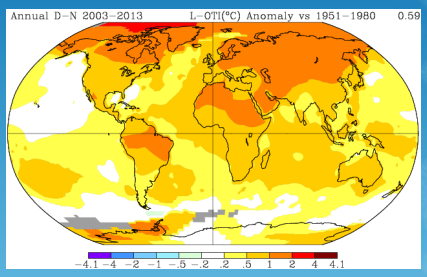



http://data.giss.nasa.gov/gistemp/graphs_v3/

29

29

## Extreme warming in far north

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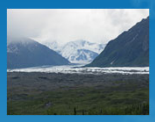
30

## 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

31

31

Doré and Zubeck, 2009

32

Photo courtesy of Anastasia Tseeva

32

## Changing climate

- Warming permafrost causes
  - decrease in the soil bearing capacity
    - stability of the overlaying 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.

33

## Perspectives

- Sustainable development
  - Considers the environment, society and economics; ideally valued equally.
  - WCED (1987): "development which meets the needs of the 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


34

## 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.

35

## References


- Doré, G. and Zubeck, H., 2009, *Cold Regions Pavement Engineering*, Mc-GrawHill, ASCE Press, Reston, VA.
- Andersland, O., Ladanyi, B., 2004, Frozen Ground Engineering, ASCE Press, Reston, VA.

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

36

36