Roads and Airfields Constructed on Permafrost

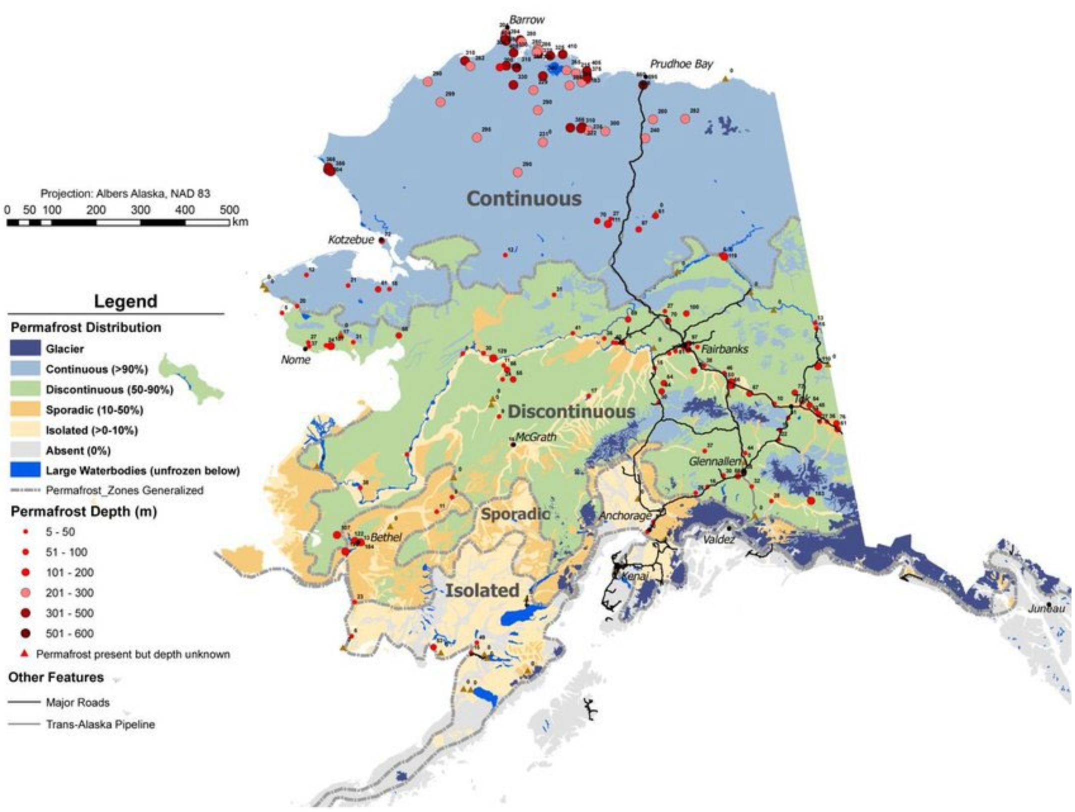
Technical Brief 1/18/2022

Based on Roads and Airfields Constructed on Permafrost-A Synthesis dated 12/22/2020.
This Synthesis was performed by University of Alaska Fairbanks at the request of Alaska DOT&PF to compile the many learned engineering principles regarding transportation infrastructure in Alaska. This Technical Brief summarizes the final report.

Permafrost

Permafrost is more complicated than the commonly used definition of ground that remains at or below 0° C (32° F) for two or more years. We must consider how much ice or moisture is contained in the frozen soil and how the permafrost was formed. In addition, the distribution of permafrost varies across the geography: it can be isolated, sporadic, discontinuous or continuous, and the temperature of the permafrost varies. Permafrost can be *ice-rich thaw unstable*, or *ice-poor thaw stable*.

A generally warm permafrost found in areas of sporadic and discontinuous permafrost will result in thawing with even small increases in temperature. When permafrost is both warm and ice-rich the probability of severe damage, due to thaw, to a constructed embankment increases, which may result in cracking, settling, slope collapse or other severe surface distortions.



Permafrost map of Alaska (Jorgenson et al., 2008b).

Engineering Design

Engineering designs are difficult across Alaska due to the complex nature of permafrost, the environment and the climate. A pavement is designed for a 15-year life, while the alignment and embankment beneath the pavement can last for 50 years, thus both engineering and economics must be considered.

It is important, therefore, to know what data is required and how to apply it. For example, there is a big difference in the data required to answer the question of how thick the active permafrost layer is, and how deep will it thaw or remain over the next 20 years.

Sources of data vary in cost and method and include geotechnical investigations and thermal modeling.

Geotechnical Data Sources can include:

- Aerial or satellite photos and LIDAR (increasingly readily available)
- Geological and permafrost maps (field studies and localized drilling)
- Ground penetrating radar (GPR) and resistivity (ERT) methods (provide detailed data, more expensive)
- Drilling, logging and sampling (easy to employ, expensive and local borehole specific)

Thermal Modeling Studies include:

- Analytical Modeling
- Numerical Modeling
    - 1D finite element analysis (simplified to vertical analysis only)
    - 2D finite element analysis (usually required) considers temperature variation between the embankment centerline and shoulders, such as for a paved highway that is plowed in the winter with snow accumulating on the side slope, resulting in relatively cold asphalt and warmer shoulders due to insulating effect of the snow.
    - 3D finite element analysis may be required, for example if there is ground water flow and temperature variation along the road centerline.
- Thermal Modeling: Thermal Convection / Heat transfer (roadway structure is subject to moving fluids - melt water or air through the embankment)
- Difficulties may include time requirement for analysis over several seasons to capture varying air temperatures, soil properties and moisture conditions.
- Thermal modeling methods may not accurately match complex real-world situations.

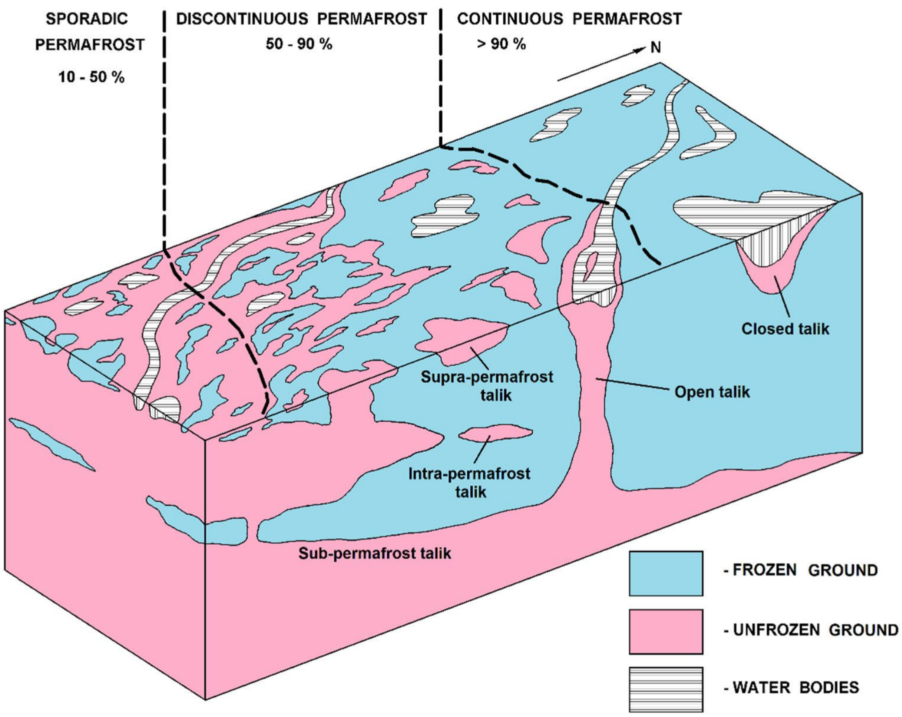
Possible design alternatives to best preserve the permafrost can include:

- Avoid the permafrost.
- Remove and replace a thin permafrost layer.
- Accept the consequences of thaw beneath the structure and minimize disturbances.
- Thaw the area and allow the subsequent consolidation of the soil.
- Preserve the Permafrost/ Keep the ground frozen by various methods:
    - Insulation
    - Air Convection Embankments (ACE)
    - Shading with Snow Sheds
    - Thermosyphons
    - Winter Construction

Environment

There is a correlation between permafrost and its surrounding environment: mean annual air temperature (MAAT); snow cover, vegetation, type of soil and moisture content (MAGST mean annual ground surface temperature), and thermal conductivity of soil in frozen and unfrozen states (TTOP temperature at the permafrost top).

Continuous Permafrost that depends substantially on climate may be minimally affected by local disturbances. Discontinuous and Sporadic Permafrost are affected by both climate and local factors such as topography, soil properties and types (peat, clay, silt, sand, and gravel), snow depth and vegetation.



Typical permafrost distribution in continuous, discontinuous, and sporadic permafrost zones (modified from Shur et al., 2011).

Construction

Federal and state laws dictate construction activities including storm water discharge, erosion and sediment control, and maintained water quality. These laws include the Clean Water Act and the State of Alaska Water Quality Standards (18 AAC 70), Anadromous Fish Act, and Fish Passage Act (AS 16.05.841 & 871).

Projects are designed based on the readily available information and information gathered using the above-mentioned geotechnical investigations. The distribution of ice in the soil may be difficult to know with certainty prior to the exposure made during a construction cut into the material. Each specific location creates a unique challenge and relies on recent data for geotechnical assumptions in permafrost areas. Although there has been some success using designs from previous projects, previous design may be unreliable. Design is also based on the benefit-risk analysis for the scale of the project and available funding for that location.

Construction activities that affect permafrost include clearing vegetation, excavation of ditches, and side and through cuts. The duration of time excavations are exposed is an important factor, especially if excavation must occur during warm conditions. Construction during summer and fall increases the potential to permafrost thaw. Diverting and concentrating melt ice flow accelerates erosion, and silts and fine sands are more susceptible. When thawing, ice-rich permafrost experiences substantial reduction in strength due to high water content, lack of drainage, and consolidation, and can cause slope failure. Construction during winter is considerably more expensive.

Three material types exposed in permafrost cut slope, prior to any thaw.
(Dalton Highway example of surprises encountered when constructing a cut slope in icy materials)

<u>Recommended Practices</u>

Recommended management practices as of 2020 include:

- Select route alignments, use design features, and implement practices that minimize or eliminate thawing of ice-rich permafrost or massive ground ice.
- The design should be amenable to simple modifications during construction and post construction.
- Anticipate that unknowns may become evident as construction progresses.
- Develop drainage and erosion controls to account for thermal impacts from both air and water.

<u>Communication and Education</u>

Communicate with everyone on the project in design and construction, including equipment operators, inspectors, etc. regarding the importance of adhering to specifications, permits and best practices. It is helpful for staff to understand why the specifications are written the way they are. Once the thermal regime has been disturbed, it cannot be undone. We want to avoid unintended consequences in permafrost terrain. For example, removing trees for sight-line can cause thaw consolidation and ponding water, parking equipment on tundra outside the construction zone can trigger thawing and result in a Talik which in turn may result in maintenance problems for many years. Repair to construction damage to the permafrost is rarely effective.

It is also important to educate maintenance personnel on the impact of activities on permafrost. Activities such as damage to roadside vegetation, alteration of drainage patterns, active layer measurements by drilling, ditch cleaning, and damaged culverts will leave lasting effects.