# Taku Gardens Frost Jacking Study
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## Introduction

The purpose of this study was to estimate the depth of frost penetration and consider the potential for frost heave at the Taku Gardens Resite, Fort Wainwright, Alaska. Frost penetration depths were estimated using the Modified Berggren solution, a one-dimensional heat flow model, suitable for multi-layered soils in horizontal construction projects such as roadways, airfields, and building foundations, located in arctic and subarctic regions. The calculation procedure was incorporated into BERG2, a simple computer program with a user-friendly graphical interface. Model inputs include an air freezing index, determined from air temperature readings, and soil parameter data.

## Computer simulation

To estimate the depth of frost penetration, a one-dimensional heat flow model was used. BERG2 was developed for the Alaska Department of Transportation (Braley and Connor 1989) and is based on the Modified Berggren solution, Equation 1 (Army and Air Force 1988).

$$X = \lambda\sqrt{\left(\frac{48knF}{L}\right)} \quad \text{(Equation 1)}$$

Where:
X = depth of frost penetration
λ = correction coefficient
***k*** = soil thermal conductivity
***n*** = factor to convert air temperatures to surface temperatures
***F*** = air freezing index
***L*** = latent heat of the soil

It should be noted that the model considers only heat flow, and not the movement of moisture within the soil matrix during freezing. The Modified Berggren equation employs the following assumptions:

- Each layer of material is homogeneous and isotropic;
- The average thermal properties of frozen and unfrozen soil may be applied;
- That all water in the soil matrix freezes at 32 °F.

## Computer Simulation Inputs

*Soil Parameters*

Soil boring logs collected during the geotechnical site investigation in March 2004 provided background on the soil types and layers present at the Taku Gardens Resite. Since that time, the site has been altered from construction activity to build junior enlisted family housing units. Recent soil borings drilled in 2007 for monitoring wells are shown in Figure 1, along with the locations of the 2004 borings. Using both sets of boring logs, the area was grouped into four main sections to develop representative soil profiles for the computer simulation (Figure 1).

Seven soil profiles were created based on the soil boring logs from the monitoring wells installed during the September-October 2007 timeframe (Figure 2 and Table 1). Profiles 1 through 5 represent soil profiles encompassing the soil types and layers encountered within the munitions and explosives of concern (MEC) area. Profiles 6 and 7 both represent 'worst case' soil profiles. Profile 8 estimates the effects of placing a 4 in. layer of insulation below the silt layer (2 feet) in Profile 2, to reduce the frost depth.

The soil properties were estimated from the initial March 2004 site borings and the laboratory analysis conducted on selected soil samples collected during the drilling (US Army Corps of Engineers 2004). Construction activities have altered the upper soil layers at the site. Therefore, soil moisture content values were estimated from the laboratory analysis conducted in 2004. The soil moisture values ranged from 6 to 15%, therefore, an average value of 10% was selected as an input value for Berg2. Values for soil dry density were estimated based on a recommendation made by Mr. Marcus Palmer (communication 5 November 2007). These values were also compared with the recorded blow count from the boring log (USACE 2004). Soil type, particle size, moisture, and density play a major role in a soil's thermal properties. An initial run of three cross sections varying the moisture content resulted in similar depths of frost. The following estimated soil properties were used as input values in the Berg2 computer program (Table 2).

*Climatic Input*

In addition to the soil properties, a freezing index value was calculated from the average daily air temperature readings from the Fairbanks International Airport (Station ID 502968) between 1 January 1984 through 30 July 2007 (Figure 3). Three freezing index values were identified over the time period: the coldest (5,906 °F-days), the average (5,264 °F-days), and a less cold value (3,793 °F-days). The freezing index values are converted to a surface freezing index through an n-factor; 0.7 was used for bare soil (US Army and Air Force 1988).

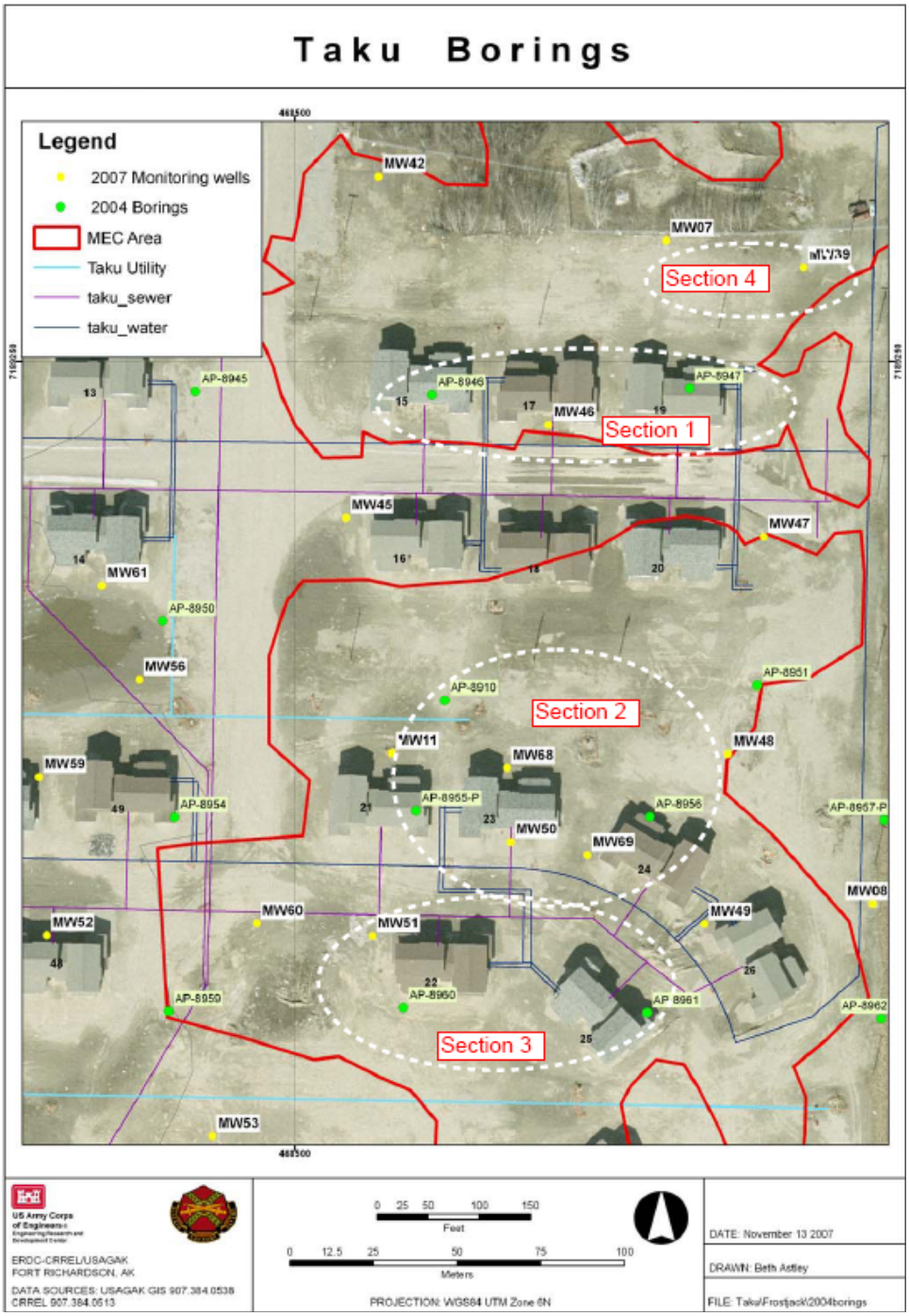


**Figure 1. Boring locations at Taku Gardens site.**

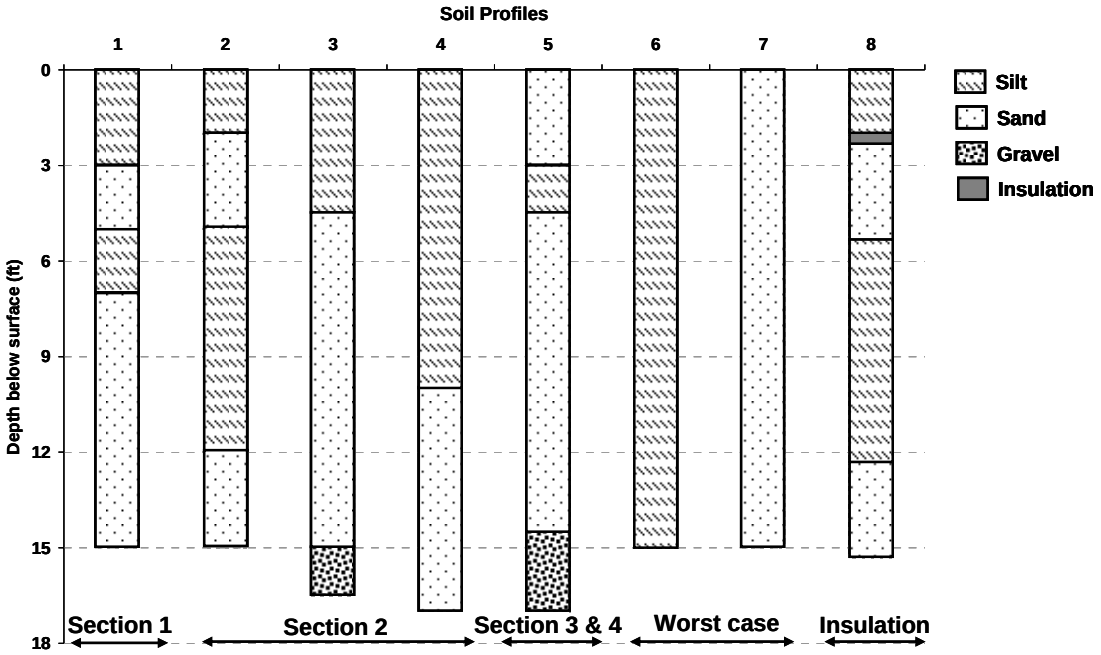


**Figure 2. Representative soil profiles used in computer simulation.**

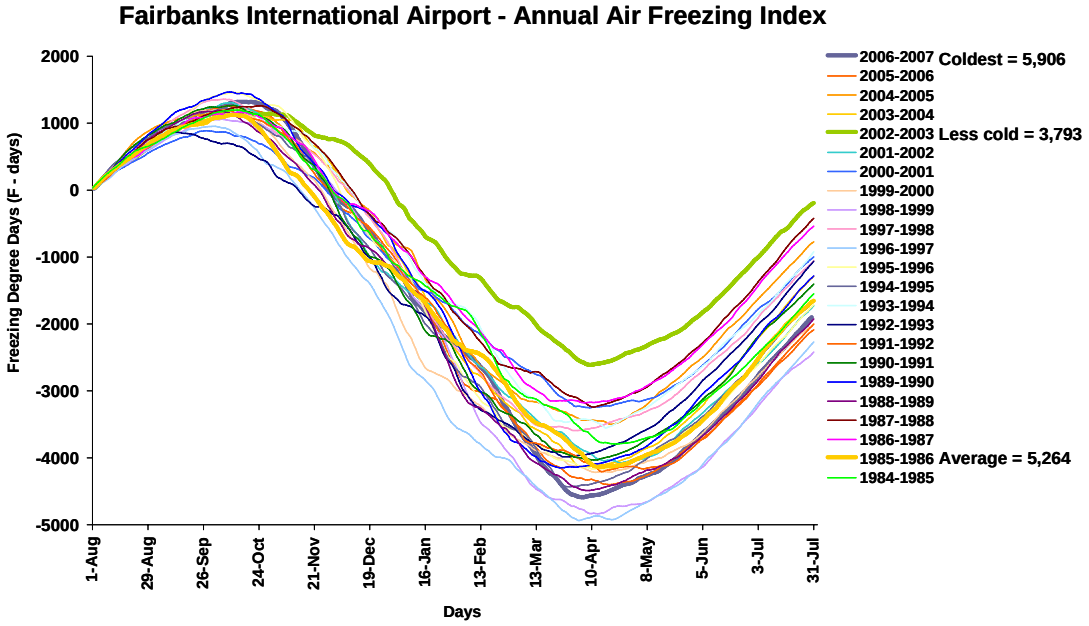


**Figure 3. Calculated annual air freezing index curves for Fairbanks International Airport from 1984 to 2007.**

**Table 1. Computer simulation soil types and layers of representative soil profiles and estimated frost depth.**

| | Profile 1 | | Profile 2 | | Profile 3 | | Profile 4 | | Profile 5 | | Profile 6 | | Profile 7 | | Profile 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alternating silt over sand - thick bottom sand layer | | Alternating silt over sand - thick bottom silt layer | | Shallow fine silt over coarse materials | | Thick fine silt layer over coarse material | | Shallow sand layer over silt and coarse materials | | Full depth fine layer | | Full depth coarse layer | | Silt over insulation layer over | |
| Layer | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) | Layer Material | Layer Thickness (feet) |
| 1 | Silt | 3 | Silt | 2 | Silt | 4.5 | Silt | 10 | Sand | 3 | Silt | 15 | Sand | 15 | Silt | 2 |
| 2 | Sand | 2 | Sand | 3 | Sand | 10.5 | Sand | 7 | Silt | 1.5 | | | | | Insulation | 0.3 |
| 3 | Silt | 2 | Silt | 7 | Gravel | 1.5 | | | Sand | 10 | | | | | Sand | 3 |
| 4 | Sand | 8 | Sand | 3 | | | | | Gravel | 2.5 | | | | | Silt | 7 |
| 5 | | | | | | | | | | | | | | | Sand | 3 |
| Total depth | | 15 | | 15 | | 16.5 | | 17 | | 17 | | 15 | | 15 | | 15.3 |
| | Estimated Depth of Frost | | | | | | | | | | | | | | | |
| Freezing Index (degree F-days) | (feet) | | (feet) | | (feet) | | (feet) | | (feet) | | (feet) | | (feet) | | (feet) | |
| 5,906 | 6.30 | | 6.70 | | 6.10 | | 6.37 | | 8.09 | | 6.96 | | 8.29 | | 3.75 | |
| 5,264 | 6.10 | | 6.61 | | 6.04 | | 6.29 | | | | | | 8.23 | | | |
| 3,793 | 4.77 | | 6.42 | | 5.89 | | 6.09 | | | | | | 8.09 | | | |

**Table 2. Estimated soil moisture content and dry density values used in Berg2.**

| Soil type | Moisture content | Dry density |
|---|---|---|
| | (%) | (lbs/ft$^3$) |
| silt | 10 | 80 (upper layer) |
| | 10 | 95 (lower layer) |
| sand | 10 | 95 (upper layer) |
| | 12 | 95 (lower layer) |
| gravel | 4 | 105 |

**Estimated Frost Depth**

The estimated depths of frost penetration for each freezing index value are included in Table 1. For soil profiles 1 through 5, the depth of frost penetration ranges from approximately 4.75 to 8 ft. For the full-depth silt and sand profiles, representing 'worst-case' conditions, the frost depths were approximately 7 and 8.3 ft, respectively.

The frost depth for profile 8 was calculated using a soil profile identical to profile 2 but with the addition of a 4 in. thick insulation layer placed 2 ft below the surface. Using the coldest freezing index (5,906 °F-days) with profile 8, the frost depth was reduced to 3.75 ft (from 6.7 ft without insulation).

To determine the effect of snow cover on frost depth (snow is an insulator), Profile 2 was modified to include a 1-ft layer of snow on the surface. The frost depth was reduced to 1.3 feet. This calculation considers only the flow of heat in the soil and assumes that the layer of snow would be on the ground at the start of the freezing season.

**Frost Heave Potential**

To promote significant frost heave, three necessary conditions are needed: frost-susceptible soil, a source of water, and freezing temperatures (US Army and Air Force 1985). One way to estimate the frost-susceptibility of a soil is based on the grain size distribution. The grain size distribution of a soil with 3% or more material finer than 0.02 mm in diameter is considered frost-susceptible (US Army and Air Force 1985).

The Taku Gardens site has freezing temperatures and an adequate freezing season to support frost heave. The water source may come from a water table or from the infiltration of water from the surface. The Corps of Engineers report (USACE 2004) states that the hydrology in the area tends to "flow in a west-northwestward direction," and the groundwater table ranges from approximately 9 to 19 feet below the surface. In the MEC area, the water table is listed as 12 to 18 feet below the surface, therefore minimizing the availability of a water source to support significant frost heaving. However, available water from surface drainage may contribute to potential frost heave.

The third component, frost-susceptible soils, are present at the MEC site. Based on extensive laboratory testing, the chart in Figure 4 (US Army and Air Force 1985) shows the estimated average rate of heave based on the frost-susceptibility classification of the different USCS soil types. For the silty soils present at the MEC, the percentage of fines passing the recommended sieve opening ranges from 6 to as high as 79%. This soil classifies as F4 and the potential for frost heave ranges from low to very high. In locations were all three conditions are present, the potential for significant frost heave is high. This may be the case in more localized areas and not necessarily pertain to the entire site.

While the conditions at the Taku Gardens site are favorable for frost heave potential, heaving beneath the building foundations is not likely due to the transfer of heat from the building.

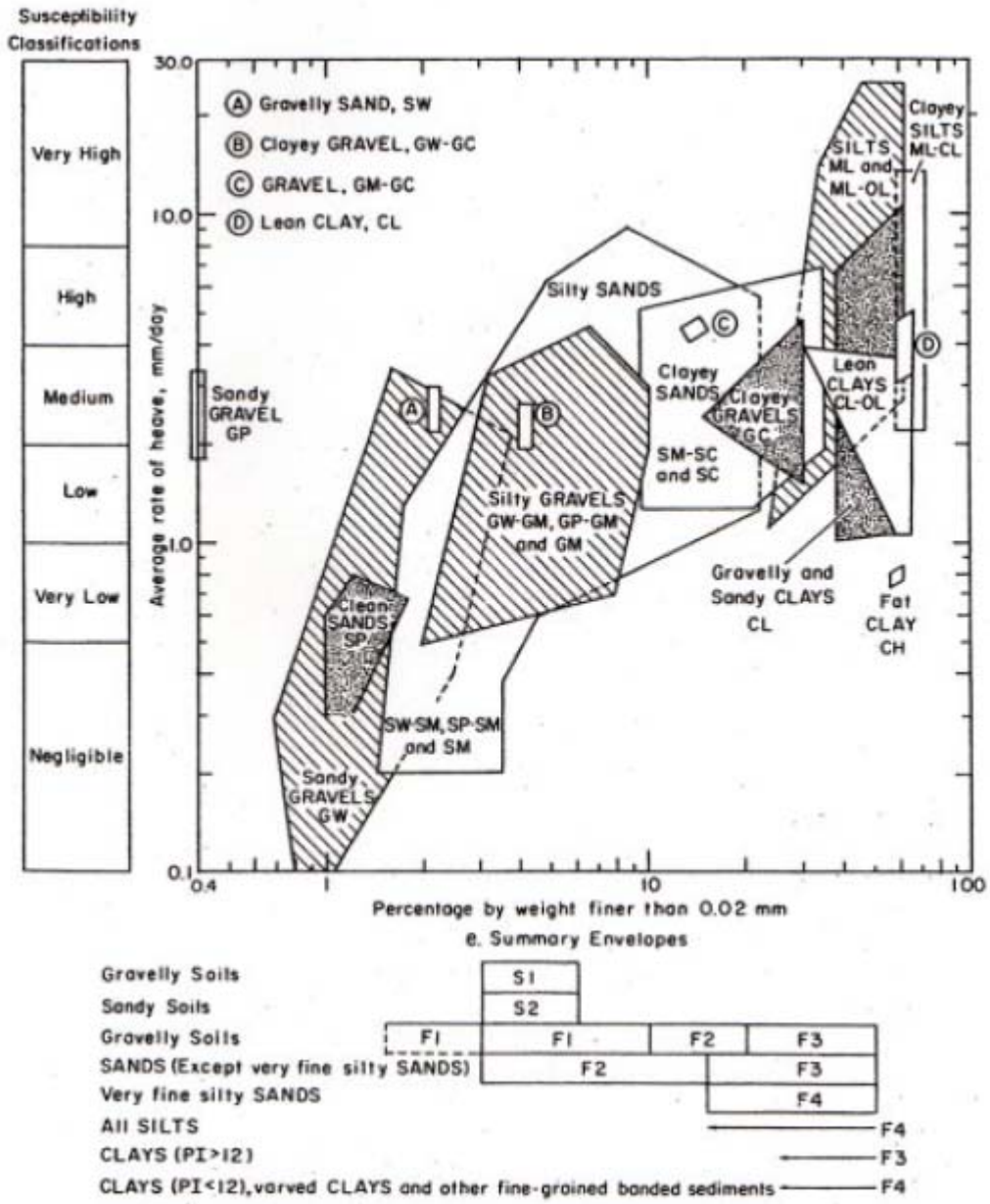


**Figure 4. Average rate of frost heave based on soil frost susceptibility and USCS soil type from laboratory testing (US Army and Air Force 1985).**

## Summary and Recommendations

Using the data collected from the soil boring logs, laboratory analysis, and boring logs drilled to install monitoring wells, the soil moisture and dry density values were estimated for use in a one-dimensional heat flow computer model to estimate the depth of frost penetration.

- The depth of frost penetration ranges from approximately 4.75 to 8 feet below the ground surface;
- With the addition of buried insulation, frost depth was reduced to 3.75 ft;

- Snow provides natural insulation that reduces frost penetration; it is most effective when a thick snowpack is present throughout the freezing season;
- The three conditions that promote frost heave are present at the MEC site;
- Based on the presence of the three conditions for frost heave, the potential exists for frost heave to occur in the soil matrix;
- The significance of moisture movement in the subsurface layers is important to fully examine the extent of potential frost heave;
- Since the current computer simulation is not robust enough to quantify the extent of frost heave potential at the MEC site;
- A physical study would verify the appropriate input values, such as moisture content and soil density, to be used in a computer simulation;
- In the absence of a physical study, laboratory frost heave testing of the soils located at the MEC site would provide an indication of frost heave potential.
- A follow-on computer simulation using a model that considers both heat and moisture flow would be beneficial for estimating frost heave.

**References**

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