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Cold Regions Research and Engineering Laboratory

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Geophysical Investigation at Eielson Air Force Base, Alaska

Subsurface Features Influencing Building 6385

Garrett Speeter, Kevin Bjella, Stephanie Saari, and Jon Maakestad

June 2019

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Final Report

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Under Interagency Agreement number 1996-010, “Building 6385, EIE431, F-35 ADAL Conventional Munitions Facility”

Abstract

The U.S. Army Cold Regions Research and Engineering Laboratory conducted geophysical research of subgrade conditions to aid foundation design and to address differential settlement of Building 6385 on Eielson Airforce Base, Alaska. The study used electrical resistivity tomography and data from subsurface borings to characterize subsurface geologic units. Bedrock present beneath the building at a depth of approximately 80–105 ft has an approximate east–west strike and shallow dip to the northwest. Geophysical data indicates that frozen conditions beneath the site are a patchwork of thawed and thawing permafrost that is generally ice-poor with sporadic perched water on top of localized degrading ice-rich permafrost. Frozen soil beneath Building 6385 is thawing at a rate of at least 0.81 ft/year and has reached depths up to 80 ft. Advanced permafrost degradation is present beneath Quarry Road at the toe of the embankment slope for Building 6385. Permafrost beneath the north and northwest sides is more degraded and has more localized ice-rich soil. Fill on the west side of the building is thicker, suggesting more settlement has taken place. Permafrost degradation may have destabilized the tow of the embankment slope and contributed to settlement at the north edge of building.

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Preface

This work was performed for the U.S. Army Corps of Engineers, Alaska District, under Interagency Agreement number 1996-010, "Building 6385, EIE431, F-35 ADAL Conventional Munitions Facility."

The work was performed by the Force Projection and Sustainment Branch (CEERD-RRH) and the Engineering Resources Branch (CEERD-RRE) of the Research and Engineering Division (CEERD-RR), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Mr. Justin Putnam was Acting Chief, CEERD-RRH; Dr. Caitlin Callaghan was Acting Chief, CEERD-RRE; and Mr. Jared Oren was Acting Chief, CEERD-RR. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

COL Ivan P. Beckman was Commander of ERDC, and Dr. David W. Pittman was the Director.

Acronyms and Abbreviations

CRREL	Cold Regions Research and Engineering Laboratory
ERDC	Engineer Research and Development Center
ERT	Electrical Resistivity Tomography
ICE	Massive Ice
Ice	Ice with Soil Inclusions
Nbe	Nonvisible with Excess Ice
Nbn	Nonvisible with No Excess Ice
Nf	Nonvisible Poorly Bonded Friable Ice
P.G.	Professional Geologist
SPT	Standard Penetration Test
USACE	U.S. Army Corps of Engineers
Vx	Visible Individual Ice Inclusions

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters

Executive Summary

In support of the U.S. Army Corps of Engineers, Alaska District, the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL) conducted a geophysical study to provide information to aid in foundation design for improving or replacing Conventional Munitions Facility EIE387/EIE431 Building 6385, which is experiencing differential settlement.

The primary objective for this study was to answer the following questions:

1. Is bedrock present below the building? If so, at what depth and orientation?
2. Is frozen soil beneath the building more ice-rich on the west or east side?
3. Where should further drilling be conducted to better understand foundation conditions in subgrade?

Ground truth data is available in the form of borings conducted in separate drilling campaigns completed in 1995 (USACE 1995), 1997 (Ambler 1997), 2016 (Design Alaska 2016), 2017 (R&M Consultants 2017), and 2018 (R&M Consultants 2018). Drilling illustrates that frozen conditions beneath Building 6385 are a patchwork of thawed and thawing permafrost that is generally ice-poor but has a sporadic perched water table on top of localized degrading ice-rich permafrost. Several borings (boring numbers 16-01, 16-03, AP-6096, AP-6124, and AP-6100) suggest that more frozen soil is present on the north and northwest side of the building than on the east side of the building. Drilling results over time, as discussed in this report, suggest that frozen soil logged in several 1995 borings (boring numbers AP-5088, AP-5087, and AP-5088) are likely thawed at this time, as shown in nearby borings drilled in 2016, 2017, and 2018.

CRREL researchers recorded key relationships in resistivity with bore logs by using the following testable and reproducible relationships:

- Construction fill is well compacted and relatively dry. It is mostly alluvial gravel that is compositionally and texturally mature, meaning it is well traveled and composed of strong lithologies, including chert and quartz, which are siliceous and highly resistive. Therefore, construction fill typically shows as downward-trending high resistivity signals in pseudosections.

- Frozen soil, where intercepted, has degraded to various depths that range from 24 to 81 ft below the native ground surface and typically is overlain by a perched water table. In the pseudosections, this presents as resistive material with thin, low resistivity directly above it.

- Bedrock is highly resistive except where saturated. The presence of bedrock was detected in the well log for the 1997 Building 6385 well and in AP-6098 and possibly AP-6097, where it shows in the pseudosection as highly resistive signals with a sudden resistivity drop-off in the water table or in saturated fractured zones.

As evidenced by drilling relationships summarized in section 3.3 of this report, it is well established that frozen soil beneath Building 6385 is thawing at a significant rate of at least 0.81 ft/year based on contrast in frozen conditions reported by AP-5895, AP-5087, AP-5086, AP-5088, 16-02, and 16-04. This is also evidenced by the resistivity data in pseudosections and boring data. CRREL Researchers collected resistivity data in three transects mapped on Figure 1.

Beneath Building 6385, resistivity data and drilling data suggest permafrost is in a state of advanced degradation to depths of approximately 82 ft (25 m on pseudosection) below the ground surface. Patchwork resistivity signals in this interval suggest that the subgrade soils likely have generally low moisture contents and are locally wet and thawed or ice-rich and frozen. Based on a comparison between the pseudosections of Transects 2 and 3, Transect 3 on the west side of the building shows that the remaining frozen soil is more resistive, and therefor likely more ice-rich. Permafrost degradation also appears to be more severe on the west side as evidenced by more pronounced conductivity in Transect 3 when compared to Transect 2.

Pseudosections for Transects 2 and 3 show advanced permafrost degradation and low resistivity beneath Quarry Road at the toe of the embankment slope for Building 6385. It is likely that this is a result of accelerated permafrost degradation related to surface drainage downslope, disruption of the organic mat prior to construction, and excessive heat transfer related to albedo of the road surface. It is likely that thawing of frozen soil beneath Quarry Road could have contributed to settlement in the apron on the north side of Building 6385 by destabilizing the toe of the embankment slope.

Bedrock is present beneath the building at a depth of approximately 80–118 ft below the finished grade of Building 6385, depending on location. This is inferred based on high resistivity signals propagating from depth (from the bottom of the pseudosection) in all three pseudosections and confirmed by drilling results. Pseudosections from Transect 2 and 3 both show bedrock to have an apparent shallow north dip. The pseudosection for Transect 1 is perpendicular to Transect 2 and 3 and suggests bedrock has a shallow west dip. These relationships suggest that the bedrock surface (not actual foliation attitude) is approximately 85–105 ft below finished grade and has an approximate east–west strike and shallow dip to the northwest. It is important to note, due in part to depth smearing of lower resistivity in the water table, that there is significant uncertainty in pseudosections at depth. Interpreted bedrock orientations are supported by drilling results although bedrock information is limited to the 1997 well log, AP-6124, AP-6097, and possibly AP-6098.

A series of borings were proposed in the initial draft of this report. R&M Consultants (2018) completed the proposed borings, which are included within the discussion of this revised report and are shown in Figure 8. Comprehensive drilling has now been completed. However some additional drilling may be warranted, especially on Quarry Road and on the embankment slope north of Building 6385 to access slope mobility. Table E-1 summarizes the proposed borings. Further explanation of boring location are presented in the conclusions section.

Suggestions for additional borings are presented below with locations presented in detail in Figure 12 of the report.

The combination of resistivity data and boring data supports the interpretation that subgrade soil conditions beneath Building 6385 are generally composed of homogeneous loess with low moisture contents. Localized ice-rich soil and massive ice are present within the more homogenized subgrade and documented well in terms of depth and areal extent in resistivity data and ground truthed with boring logs. The localized ice-rich soil and massive ice beneath Building 6385 is captured in pseudosections presented in Figures 9–11.

Table E-1. Drilling recommendations.

Boring Type	Quantity	Method	Justification
Borings in conductive zones to evaluate silt with low bearing capacity	2	Hollow-stem auger with SPT[a] every 5–30 ft	• Quantify density in fill • Identify soil lithology
Deep fill and shallow subgrade characterization (30 ft depth)	2	Hollow-stem auger with SPT every 5–30 ft and Shelby Tubes at 10, 20, and 30 ft	• Quantify density in fill • Identify soil lithology • Identify frozen condition and ice type/content • Quantify subgrade density
Shallow slope inclinometer tube installation (30 ft depth)	1	Hollow-stem auger with SPT every 5–20 ft and install slope inclinometer tube to monitor embankment slope for movement over time if needed	• Monitor embankment slope movement • Quantify density in fill • Identify soil lithology • Identify frozen condition and ice type/content

[a] Standard penetration test

Lack of positive drainage throughout the project area has led to further permafrost degradation, especially beneath Quarry Road and the northern Building 6385 fore slope, which shows in Figures 10–11 as conductivity beneath the ditch on the south side of Quarry Road adjacent Building 6385. The combination of completed recommended drilling and resistivity provides a generalized description of bedrock orientation beneath the project area as shown in Figures 9–11. Completing the recommended drilling in Table E-1 will help ascertain if the north embankment slope has destabilized due to drainage-related permafrost degradation and hydraulic mobilization of loess at the toe of the slope in the ditch adjacent to Quarry Road.

1 Introduction

1.1 Background

Eielson Air Force Base is located approximately 25 miles southeast of Fairbanks, Alaska. Building 6385 of the Conventional Munitions Facility EIE387/EIE431 is located approximately 3 miles east of the Eielson Air Force Base main campus on Quarry Road.

Settlement in Building 6385 has prompted an investigation into rehabilitating or replacing that structure. The U.S. Army Corps of Engineers (USACE), R&M Consultants Inc., Design Alaska, and Shannon and Wilson Inc. (in support of Design Alaska) have previously conducted separate geotechnical investigations of the site to determine the cause of the settlement of Building 6385. Investigations conducted by USACE and R&M Consultants attribute settlement to both the long-term consolidation and lateral movement of thick classified fill placed on a cut in silt on the hillside (R&M Consultants 2017). Design Alaska utilized data collected by Shannon and Wilson and attributed settlement to postconstruction thawing and subsequent settlement of permafrost soils (Design Alaska 2016).

To better understand site subgrade conditions, the USACE Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), performed a geophysical investigation consisting of three electrical resistivity tomography (ERT) transects. For each transect, CRREL provided a pseudosection that displays the resistivity of in-place construction fill, geological stratigraphy in subgrade, and geological stratigraphy in undeveloped ground in the immediate vicinity of Building 6385.

ERT surveys were completed between 9 July 2018 and 12 July 2018. Fieldwork was completed by Stephanie Saari, Jon Maakestad, Ariel Ellison, and Garrett Speeter, P.G.[*] Pseudosection data can be used in conjunction with ground truth data (drill data and site observations) to interpret depth of fill materials, subsurface permafrost and seasonal frost conditions, composition of subgrade soils, groundwater conditions, and bedrock depths.

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[*] Professional Geologist

1.2 Objectives

The primary objective for this study was to answer the following questions:

1. Is bedrock present below the building? If so, at what depth and orientation?
2. Is frozen soil beneath the building more ice-rich on the west or east side?
3. Where should further drilling be conducted to better understand foundation conditions in the subgrade?

1.3 Approach

This investigation both reviewed historical borings and acquired geophysical data to provide answers to the three questions presented above.

We analyzed historical boring data for trends in thawing permafrost, bedrock data, soil classifications, and groundwater relationships. The boring data was also used to correlate resistivity data to geologic properties of materials in the subgrade.

CRREL performed geophysical surveys using nonintrusive methods over three transects distributed across the study area (Figure 1). Transect locations were identified in consultation with the USACE Alaska District, and consist of two northwest–southeast-trending transects and one east–west-trending transect. ERT data was collected along each transect as stationary surveys by installing steel electrodes into the ground.

The electrical resistivity of subsurface materials is calculated by injecting electric current into the ground and measuring the resultant voltage changes in the standard unit of measurement (ohm-meter). Resistivity is related to many physical properties, including mineral composition, water saturation, phase state (frozen vs. thawed), grain size, density, and thermal state (Bjella et al. 2015; Hoekstra et al. 1975; Wightman et al. 2003). Resistivity has been an effective tool for delineating frozen vs. thawed and ice-rich vs. ice-poor conditions (Bjella et al. 2015; Hoekstra et al. 1975). Electrical resistivity also assists in identifying the distribution of subsurface geologic layers through mineral composition and grain size.

When correlated with ground truth data from borings and considered in the context of cryological, hydrological, and geomorphological processes, the processed data provide an illustrative cross section (pseudosection) of the subsurface.

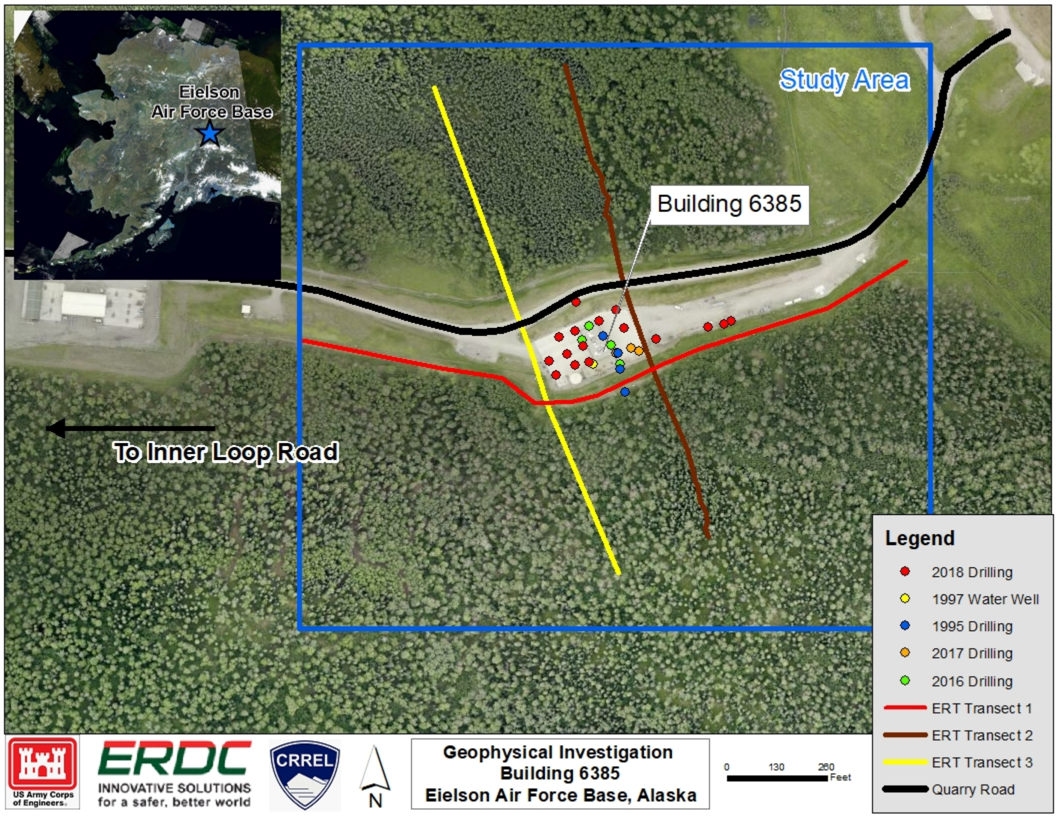
For this study, resistivity methods were used in conjunction with boring data to help determine areas of ground ice (permafrost) and groundwater and the distributions of silts, sands, gravels, and bedrock. This data was used to provide answers to the questions posed above.

2 Geologic Context

2.1 Study area

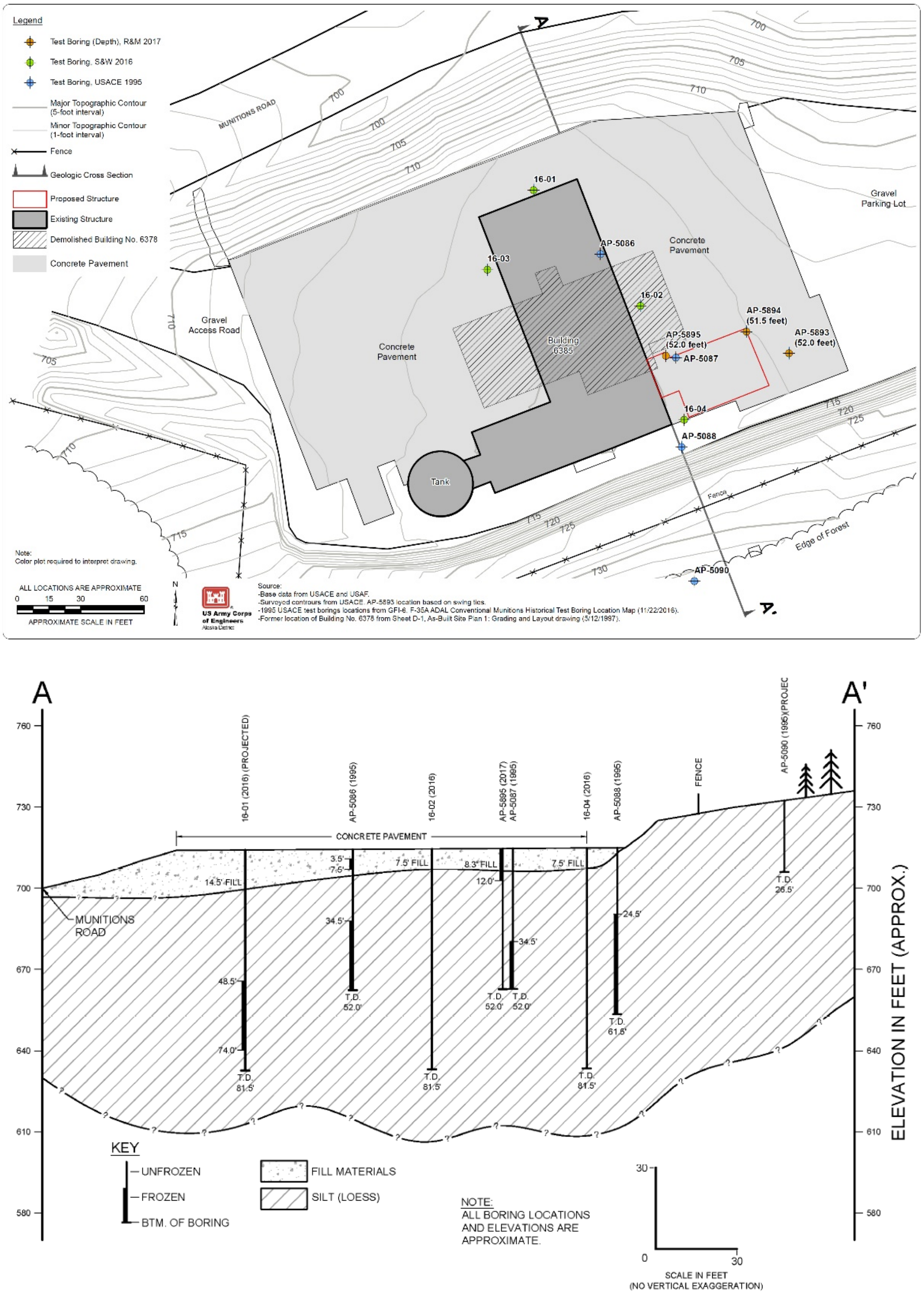
The study area is accessible via Quarry Road and a guarded, locked gate that provides security for the Conventional Munitions Facility EIE387/EIE431. The study area (Figure 1) is a north-facing, heavily wooded slope dominantly composed of loess deposits.

Figure 1. Location of the Conventional Munitions Facility EIE387/431 Building 6385.



This study centers on Building 6385 (Figure 2) (6385 is a building within the facility EIE431), which is experiencing differential settlement. This geophysical investigation was conducted to provide data to aid foundation design for the replacement and redesign of Building 6385.

Figure 2. Key features of Building 6385 and the associated fence diagram (R&M Consultants 2017).



Source:
-Base data from USACE and USAF.
-Surveyed contours from USACE. AP-5893 location based on swing ties.
-1995 USACE test borings locations from GFI-6. F-35A ADAL Conventional Munitions Historical Test Boring Location Map (11/22/2016).
-Former location of Building No. 6378 from Sheet D-1, As-Built Site Plan 1: Grading and Layout drawing (5/12/1997).

2.2 Geological overview

The following are terrain units mapped by Péwé et al. (1966) and Weber (1971) within a mile of the study area contain (from youngest to oldest):

- Alluvium—gravels, sands, and silts that are all unconsolidated and well stratified
- Alluvium and colluvium—boulders, gravel, sand, silt, and angular rock fragments
- Loess—eolian silt, unconsolidated, massive, and poorly stratified
- Bedrock—quartzite, meta-argillite, phyllite, slate, and marble.

The project area is located within the zone of discontinuous permafrost in Alaska. Building 6385 is constructed on a pad of texturally and compositionally mature alluvial fill installed on a cut slope in eolian loess. The loess that mantles hills and ridges in the interior often contains warm (~31°F) permafrost, which is highly sensitive to changes in thermal regime.

Construction in the area has modified the surficial geology, organic mat, and thermal regime, resulting in permafrost degradation. Thermokarst degradation features are clearly visible in the study area north of Quarry Road (Figure 3).

Figure 3. Thermokarst features in the study area north of Quarry Road.

ERT Transects 1 and 2 travel through frost boils, small thermokarst ponds, and filled pits and gullies. Evidence of forest fires within the last 10 years is present in the north part of the study area, which suggests that damage to the thermal insulating organic mat has occurred, further disrupting the thermal regime on-site. The dominant factors driving permafrost degradation on-site appear to be damage to the insulating organic mat in cut areas; pooling of groundwater against embankments and structures; lack of positive drainage; and clearing of trees, resulting in excess warming of the surface during summer months.

Borings logged by Garrett Speeter at a separate investigation for the nearby (approximately 0.40 miles to the east) Buried Munitions Facility EIE 381 recorded the following pertinent descriptions of geologic units in subgrade at EIE 381:

- Organic silt and reworked loess (windblown silt modified by colluvial processes)—This unit has organic contents that range from slightly organic to organic. Ice in these soils typically were field classified as visible individual ice inclusions (Vx), nonvisible well bonded ice with excess ice (Nbe), or nonvisible well bonded ice with no excess ice (Nbn). Organic ice-matrix ice structures and lenticular ice structures were observed. Ice contents in organic silt were observed to be as high as 25% visible ice.

- Massive ice cryostructure—This unit is typically underlain by a thin layer of frozen organic silt that is underlain by a thick sequence of windblown loess as described below. This unit was field classified as 100% massive ice (ICE) and sometimes ice with soil inclusions (Ice).

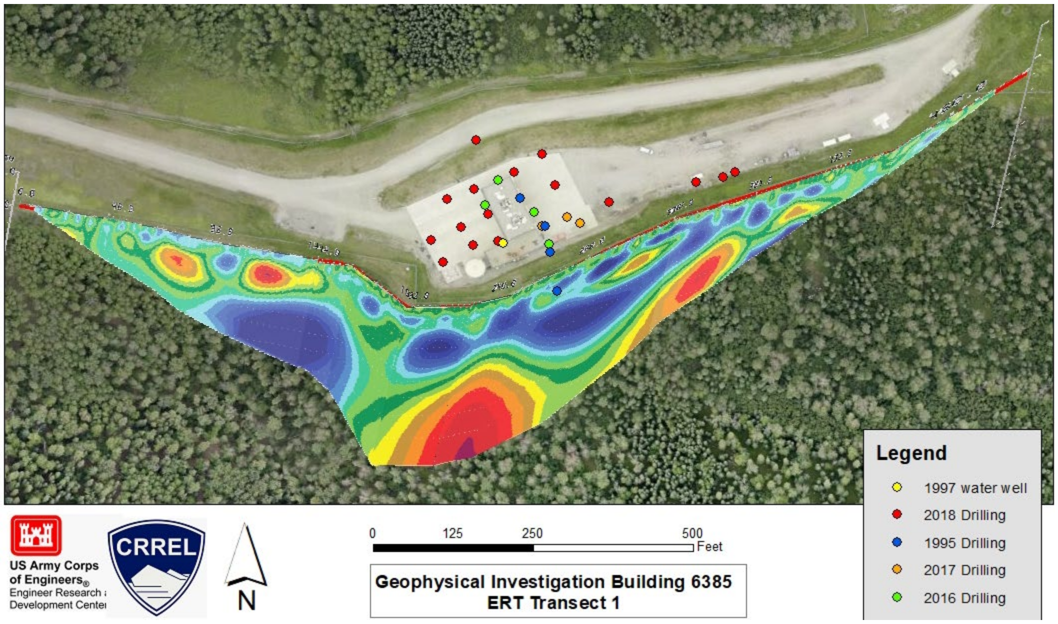
- Windblown loess—Phase states in this unit are difficult to distinguish. This unit is typically dry to moist, poorly graded and porous, and therefore has a high thermal conductivity. It is more massive and homogenous in character due to its windblown depositional environment. It was often above 32°F when measured in the field, though hand thermometers in the field in cold temperatures are not always reliable. Samples in the field (pulled from intact soil cores) had the consistency of flour and would only take 4–10 geo-probe hammer blows to complete a 5 ft deep run, even directly below thick intervals of solid massive ice. Loess soils were often iron stained and oxidized, which suggest chemical mobility and at least temporary unfrozen moisture. Iron staining was observed directly below organics at the base of massive ice. Samples frozen in the CRREL laboratory (to verify phase state) were observed to have higher strength than witnessed in the field. Loess samples frozen in the laboratory at in situ moisture contents thawed very quickly and had similar mechanical properties to soil logged in the field once re-thawed. This unit had several isolated sections of higher moisture where it was field classified as moist to wet and it liquefied when agitated. Occasionally windblown loess that was obviously frozen and contained Nbe, Nbn, or pore ice structures (Vx) were encountered in drilling. These occasional ice-rich frozen intervals are analogous to high resistivity signals in loess that are presented later in this report. Overall this unit was dry to moist, and if frozen was classified as poorly bonded friable ice (Nf).

3 Geophysical Investigation

CRREL performed geophysical surveys by using nonintrusive methods over three transects distributed across the study area (Figure 1). Transect locations were identified in consultation with the USACE Alaska District, and consist of two northwest–southeast-trending transects and one east–west-trending transect. ERT data was collected along each transect as stationary surveys by installing steel electrodes into the ground at 16.4 ft (5 m) spacing. The unit for resistivity is the ohm-meter; therefore, some mixing of units occurs in this report as the metric units for resistivity contradict USACE protocol to use Imperial units.

ERT Transect 1 (Figure 4) is the longest of the three transects and traverses the fence line on the south side of Building 6385, trending roughly east–west. It is oriented perpendicular to Transects 2 and 3 so that it can provide a cross reference of data, provide a tie to subsurface features in three dimensions, and assess the depth of thaw at the cut for the building foundation.

Figure 4. ERT Transect 1.



ERT Transect 2 (Figure 5) trends northwest–southeast and runs along the concrete parking lot of Building 6385 on its east side, which is a crucial orientation as it parallels the fence diagrams featuring drilling data presented by R&M Consultants. ERT Transect 3 (Figure 6) trends northwest–

southeast and runs along the concrete parking area of Building 6385 on its west side. Both Transects 2 and 3 traverse through original, undisturbed ground south of Building 6385, then through the developed pad beneath the building, down the north facing embankment slope and over Quarry Road, then into original ground with thermokarst degradation on the north side of the developed area. These orientations are essential for collecting data on permafrost degradation associated with construction and poor drainage because they provide subsurface resistivity contrast between disturbed ground with development, undisturbed ground, and undisturbed ground with modified drainage.

Figure 5. ERT Transect 2.

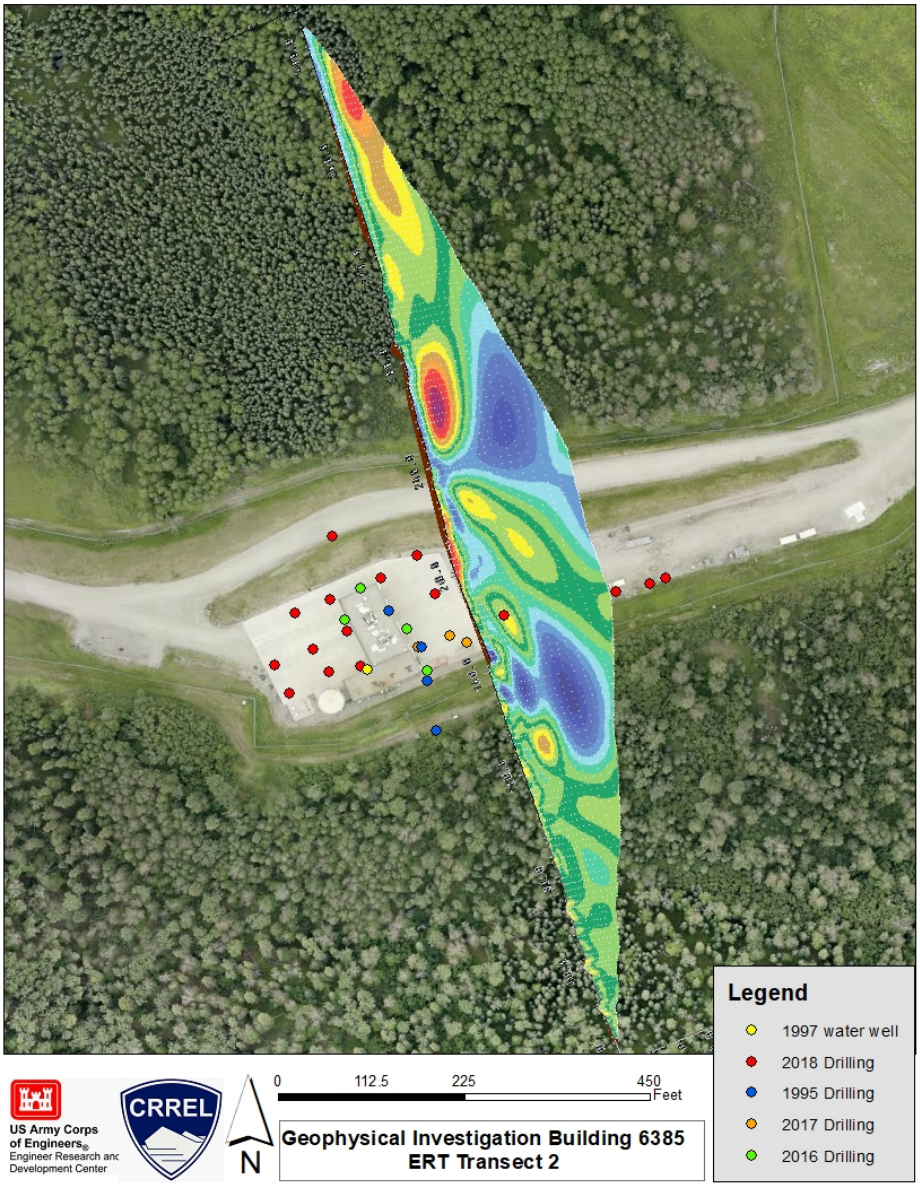
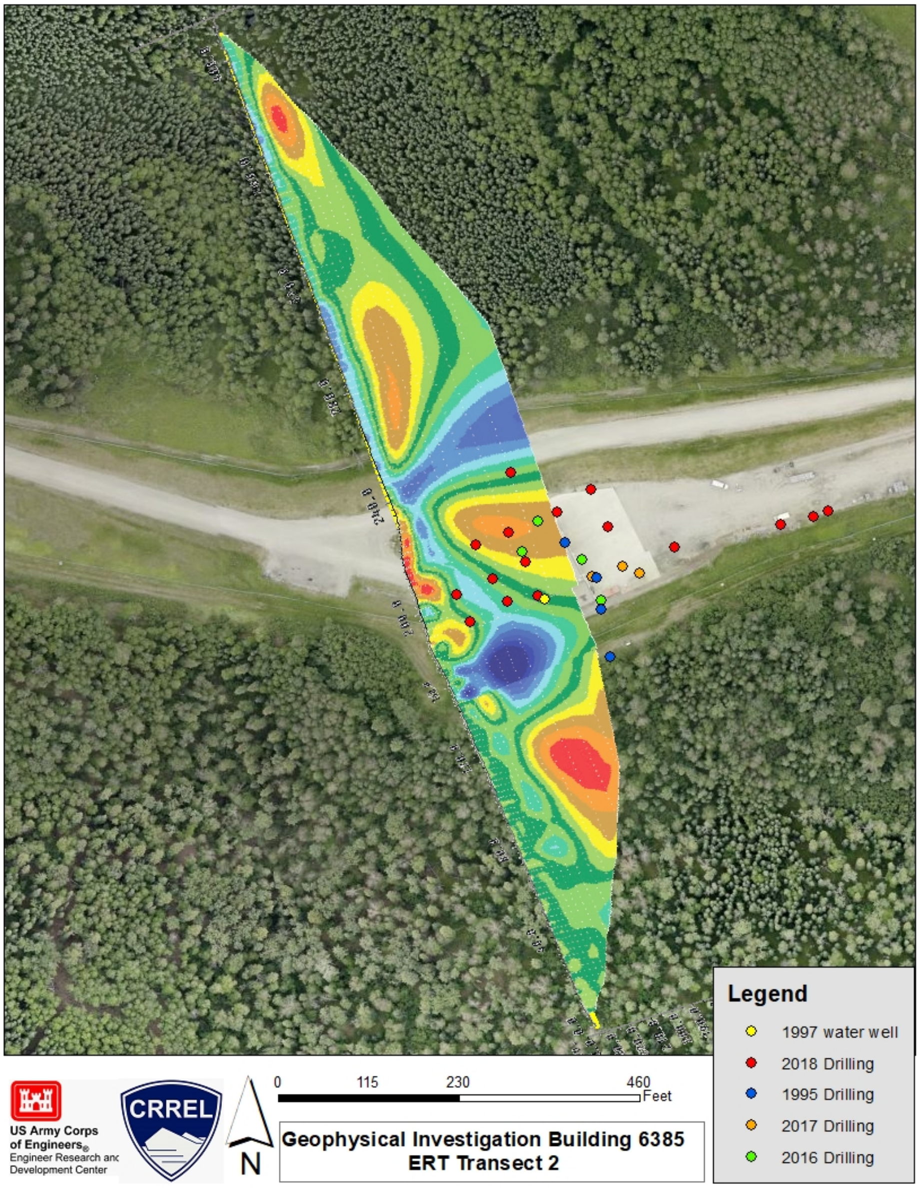


Figure 6. ERT Transect 3.

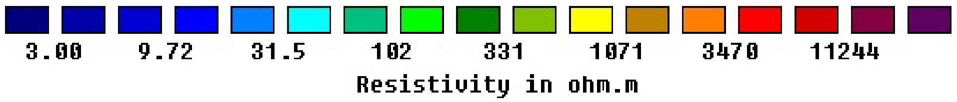


3.1 Electrical resistivity

The electrical resistivity of subsurface materials is calculated by injecting electric current into the ground and measuring the resultant voltage changes in the standard unit of measurement (ohm-meter). Resistivity is related to many physical properties, including mineral composition, water saturation, phase state (frozen vs. thawed), grain size, density, and thermal state (Bjella et al. 2015; Hoekstra et al. 1975; Wightman et al. 2003). In this instance, phase state is the most influential as frozen water is highly resistive to the flow of electric current in comparison to the conductive nature of water; therefore, resistivity increases with increasing ground ice content. Resistivity has been an effective tool for delineating frozen vs. thawed and ice-rich vs. ice-poor conditions (Bjella et al. 2015; Hoekstra et al. 1975). Electrical resistivity also assists in identifying the distribution of subsurface geologic layers through mineral composition (e.g., siliceous [more resistive] vs. mafic [more conductive]) and grain size (Wightman et al. 2003). Considered in context of cryological, hydrological, and geomorphological processes, the processed data provide an illustrative cross section (pseudosection) of the subsurface to a measured depth where resistivity values may be interpreted as depicting changes in ice content and, to a much lesser extent, mineralogical composition. For this study, resistivity methods help determine areas of ground ice (permafrost) and the distributions of silts, sands, and gravels.

We used RES2DInv 3.55 software manufactured by Geotomo Inc. to process the resistivity data and to develop subsurface pseudosections along each transect. Resistivity inversion is an iterative process to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of each block in a model grid (Loke et al. 2003). Figure 7 shows the normalized scale used for all resistivity surveys is shown. Low resistivity (high conductivity) is in the blue portion of the spectrum, and increasing resistivity moves to the red potion of the spectrum. In general, experience has shown that 0 to 100 ohm-m (blue to green) could indicate thawed and potentially wet materials; 100 to 1000 ohm-m (green to yellow) could indicate ice-poor, frozen coarse-grained material such as sands and gravels; and 1000 to 100,000 ohm-m (orange to red) (Figure 7) could indicate ice-moderate to very ice-rich materials (Hoekstra et al. 1975). Anomalies of high resistivity (very ice-rich or massive ice) or low resistivity (wet-saturated) locations generally are of interest for calibration with borehole investigations. Surface elevation data is entered into the processed resistivity images, where often resistivity values are coincident. For example, low-lying areas may report less resistive conditions due to water, while transitions from valley to hill slope may report abrupt changes in high resistive conditions, such as the transition from frozen valley floor to thawed south-facing slope.

Figure 7. Normalized ohm-meter index used for all ERT surveys. *Blue* values are very low resistivity while *red* to *purple* indicate very high values.



3.2 Electrical resistivity tomography (ERT)

ERT measures resistivity by directly injecting a current into the subsurface via two current electrodes and reading the resultant voltage via two potential electrodes. By measuring the current, voltage, and the geometry of the electrodes, the resistivity of the subsurface can be calculated. This system is time-consuming as the electrodes must be hammered into the subsurface, and each survey is limited to the length of the cables at maximum electrode spacing. The advantage is that deeper depths are attainable than with other resistivity methods. The system used for this study was the Advanced Geosciences Inc. Super Sting R-8 with 84 electrodes. For Transect 1, we used 19.7 ft (6 m) electrode spacing and cables installed over a 1634 ft (498 m) span. For Transects 2 and 3, we used 16.4 ft (5 m) electrode spacing and cables installed over an 11361.5 ft (498 m) span. The command file and RES2DINV format conversion used the Advanced Geosciences Administrator software. A dipole-dipole extended data array command file was used for all ERT data collection; and RES2DINV software was used for inversions, editing, and image creation.

3.3 Drilling data review and correlation

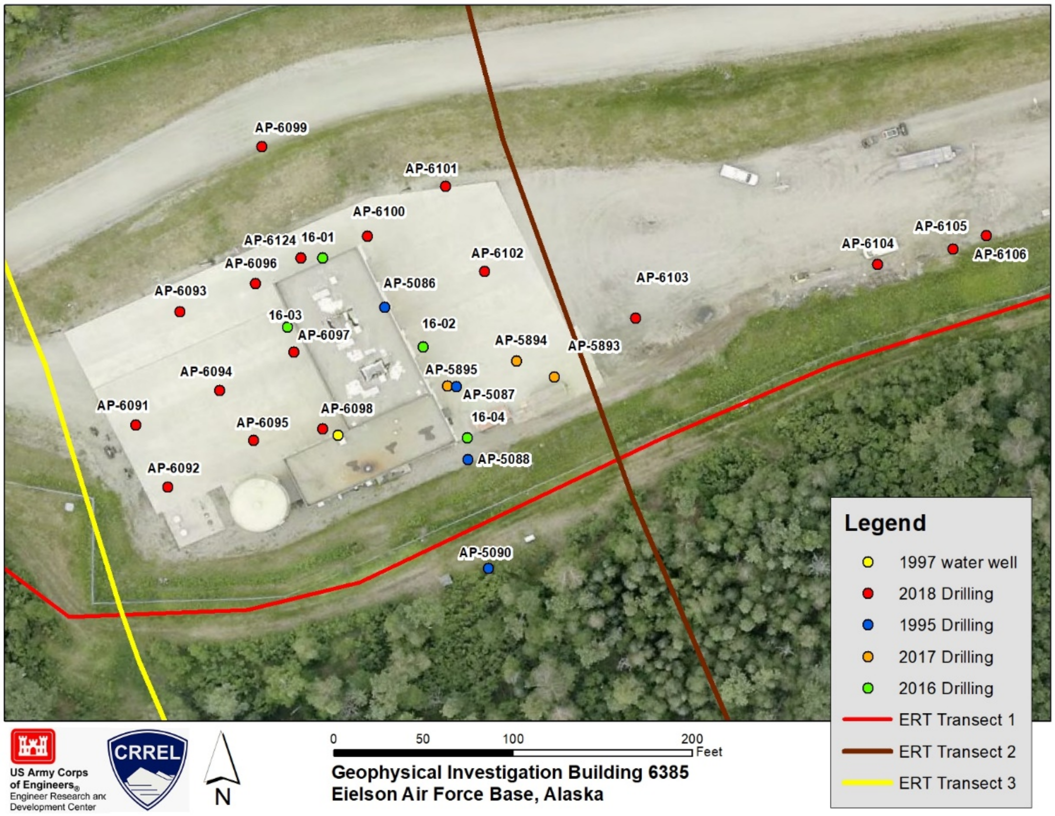
Figure 8 shows the drilling conducted by Ambler Exploration Inc., Shannon and Wilson (in support of Design Alaska), USACE, and R&M Consultants.

Drilling data collected by Ambler Exploration (1997) intercepted bedrock (Birch Creek Schist) at a depth of 80 ft below the ground surface. This was confirmed by several borings R&M Consultants completed in 2018. The drilling data presents the following key relationships:

- AP-5895 (52 ft drilled in 2017) and AP-5087 (52 ft, 1995) were drilled approximately 5 ft apart. AP-5087 (1995) encountered frozen soil from a depth of 34.5 ft to the bottom of the test hole, while AP-5895 (2017) encountered thawed soil to a depth of 52 ft. This contrast illustrates the extent to which thaw has propagated into the subgrade over the 23 year span.

- 16-02 (81.5 ft, 2016) encountered thawed soil from the ground surface to a depth of 81.5 ft, and 16-04 (81.5 ft, 2016) encountered thawed soil to a depth of 81.5 ft.

Figure 8. Drilling data overview.



- AP-5086 (52 ft, 1995) and AP-5088 (61.5 ft, 1995) both intercepted frozen soil at depths of 34.5 and 24.5 ft, respectively. These test holes are both located relatively close to more recent borings (16-02 and 16-04) that encountered thawed soil to depths greater than 80 ft. This relationship suggests frozen soil documented by AP-5086 and AP-5088 is now thawed.

- AP-5893 (52 ft, 2017) was drilled in March and encountered 12 ft of seasonal frost and frozen soil beneath a perched water table from depths of 32 ft to the bottom of the test hole. AP-5894 (51.5 ft, 2017) was drilled in March 2017 and encountered 9 ft of seasonal frost and frozen soil from a depth of 30 ft below the ground surface to the bottom of the test hole. AP-6103 (22 ft, 2018) was drilled 22 ft away from AP-5893 and intercepted thawed soil to the bottom of the test hole.

- 16-01 (81.5 ft, 2016) encountered frozen soil from depths of 48.5 ft below the ground surface to 74 ft below the ground surface at the north end of Building 6385. AP-6100 (101.5 ft, 2018) was drilled at the northeast corner of Building 6385 and intercepted frozen soil from 48 to

82 ft below the ground surface and perched water at a depth of 34 ft. AP-6096 (101.5 ft, 2018) encountered frozen soil at a depth of 49 ft that persisted to a depth of 78 ft below the ground. 16-03 (81.5 ft, 2016) encountered frozen soil from depths of 18.5 to 57 ft. AP-6124 (150 ft, 2018) encountered frozen soil from depths of 50 to 81 ft. This cluster of borings shows relatively consistent frozen soil beneath the north-northwest edge of the building.

- AP-6097 (101.5 ft, 2018) was drilled 16 ft to the south of 16-03 on the west side of Building 6385 and encountered thawed soil from the surface to a 101.5 ft depth. AP-6098 (101.2 ft, 2018) was drilled on the southwest edge of Building 6385 and encountered thawed soil and bedrock at a depth of 100.5 ft, which correlates with bedrock reported when a water well was drilled in 1997.

- AP-6091 (21.5 ft, 2018), AP-6092 (21.5 ft, 2018), AP-6093 (21.5 ft, 2018), AP-6094 (21.5 ft, 2018), and AP-6095 (51.5 ft, 2018) were drilled in the apron on the west side of Building 6385 and encountered average fill thickness of 8.1 ft compared to average fill thickness of 6.35 ft on the east side of the building. In general, test holes drilled on the west side of the building encountered thawed soil, with the exception of AP-6091, which encountered frozen soil at a depth of 20.5 ft.

- AP-6104 (51.5 ft, 2018), AP-6105 (51.5 ft, 2018), and AP-6106 (101.5 ft, 2018) were drilled approximately 290 ft east of Building 6385. These test holes all encountered perched groundwater underlain by frozen soil. Depths to perched water in these holes was 10 ft, depth to frozen soil averaged 23 ft below the ground surface, and frozen soil persisted to depths up to 79 ft.

Drilling illustrates that frozen conditions beneath Building 6385 are a patchwork of thawed and thawing permafrost that often has a perched water table on degrading frozen soil. The borings 16-01, 16-03, AP-6100, and AP-6096 suggest that more frozen soil is present on the north and northwest side of the building, which matches resistivity data.

Drilling results over time, as discussed above, suggest that frozen soil logged in 1995 borings AP-5088, AP-58087, and AP-5088 is likely thawed at this time as shown in nearby borings drilled in 2016, 2017, and 2018.

Excess fill thickness on the west side of the building and the degraded permafrost as described in borings drilled in the west apron suggest permafrost degradation and settlement. This shows clearly in the pseudosection for ERT Transect 3, which shows considerably thicker fill than ERT Transect 2. Subgrade in this area is generally composed of loose, thawed, dry silt with scattered localized wet areas that are likely compressible.

Frozen soil and perched groundwater encountered by AP-6104, AP-6105, and AP-6106 correlate well with high resistivity overlain by conductivity presented in the pseudosection for Transect 1, which includes laterally continuous data that provides needed geological context (Figure 9).

4 Discussion

4.1 Overview

For spatial reference, Figures 4–6 illustrate the orientation of each ERT transect.

Subsurface structures imaged in the pseudosections are generally composed of differing earth materials, and the features and properties related to these materials may be enhanced by other associated components, such as increased water and organic content and, in the case of permafrost, increased or decreased ice content. These changes are readily identifiable in resistivity pseudosections.

Ground truth data is available in the form of borings conducted in separate drilling campaigns completed in 1995 (USACE 1995), 1997, 2016, 2017, and 2018. However, drilling programs were conducted in various seasons. Key relationships recorded in resistivity were correlated with boring logs by using the following testable and reproducible relationships:

- Construction fill is well compacted and relatively dry. It is mostly alluvial gravel that is compositionally and texturally mature, meaning it is well traveled and composed of strong lithologies, including chert and quartz, which are siliceous and highly resistive. Therefore, construction fill typically shows as downward-trending high resistivity signals in pseudosections.

- Frozen soil, where intercepted, has degraded to various depths that range from 24 to 81 ft below the native ground surface and typically is overlain by a perched water table. In the pseudosections, this presents as resistive material with thin, low resistivity directly above it.

- Bedrock is highly resistive except where saturated. The presence of bedrock was detected in the 1997 well log for Building 6385, AP-6098, AP-6124, and possibly AP-6067 where it shows in the pseudosection as highly resistive signals with a sudden resistivity drop-off in the water table. Drill data suggests bedrock is highly fractured and saturated at the contact with the loess and therefore shows high conductivity zones at the bedrock surface. High resistivity signals in bedrock depicted in pseudosections for Transects 1–3 are somewhat atypical when compared to resistivity signals in bedrock from other areas as Transects 1–3 are less continuous and appear to be broken up by low resistivity signals, which correlate with depth and position of the water table and the saturated fractured bedrock zones reported in the well logs.

- Conductivity signals in areas associated with excess water tend to show smearing with depth in pseudosections. We interpret this to be due to the ability of wet soil to conduct large amounts of electricity. We believe depth smearing seen in pseudosections both overstates the conductivity of stratigraphy at depth and masks the continuous nature of geologic formations at depth.

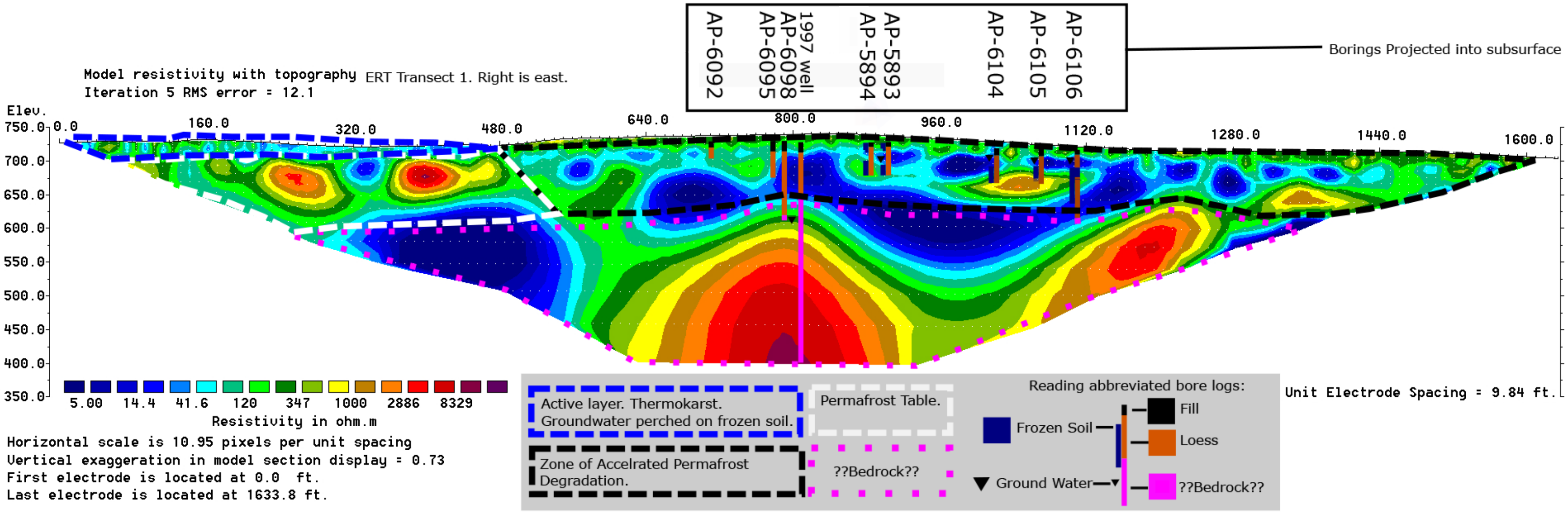
- It is very common to have degraded permafrost and wet soils in areas where water collects at the base of embankment slopes in ditches. ERT Transects 2 and 3 clearly show conductivity in the installed French drains and ditches at the toe of Quarry Road embankment slopes and toe of Building 6385. These areas are introducing water into the subsurface and accelerating permafrost thaw.

- Surface water introduced into the subsurface at the base of embankment slopes, culverts, French drains, and cut intervals locally increases moisture content of loess in the subgrade. Boring logs show the loess to be generally loose (based on blow counts) and relatively dry. It is likely that these soils become mobile and compressible when wet.

4.2 ERT transect interpretation

ERT Transect 1 runs approximately east–west along the south side of Building 6385 (Figure 1). Abbreviated borings are shown with color-coded lithologies (see Figure 9 abbreviated bore log data).

Figure 9. Interpreted ERT Transect 1.



This transect was run within the cleared and disturbed area that parallels the perimeter fence around Building 6385. As a result, frozen ground in the pseudosection is mostly thermally degraded. The following summarizes the four distinct geomechanical units, their engineering properties, and how they present in the pseudosection:

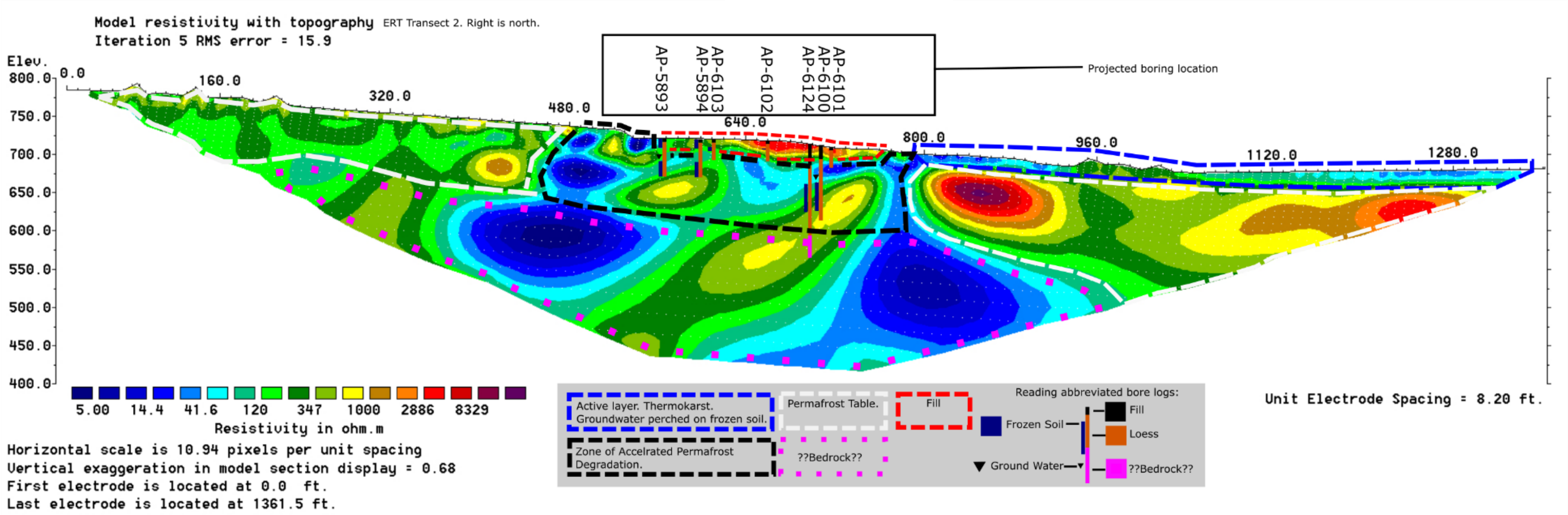
- **Active layer, thermokarst, and groundwater perched on frozen soil—**This unit is delineated by blue dashed lines in Figure 9. The surface expression in this unit is wet and moist soil that is easily compressed and poorly drained. Evidence for thermokarst development and damage to the insulating organic mat (caused by old forest fires) was documented in the field within this unit. Building on this unit would likely result in highly differential settlement. This unit presents in the pseudosection as relatively low resistivity signals (thawed wet soils) depicted in shallow downward-trending signals that are perched on higher resistivity signals (permafrost).

- **Zone of accelerated permafrost degradation—**This unit is delineated by black dashed lines in Figure 9. The most recent borings drilled on the project are projected into the pseudosection in Figure 9, and all borings are shown in Figure 8. As previously discussed, borings drilled in 1995 show frozen soil that is now thawed in borings drilled in 2016, 2017, and 2018. This is typical of areas in interior Alaska where structures have been built on permafrost, especially where the organic mat has been stripped and cuts have been excavated. In this zone, isolated remnants of frozen soil exist within a patchwork of thawed and frozen soil with variable moisture contents. Frozen soil in this interval will often have water perched on top of it, which accelerates phase degradation of frozen soil beneath. Because of thermal instability, building on soils depicted in this zone will likely result in differential settlement. This zone presents in the pseudosection as large “blob-like” resistive signals (areas where frozen soil remains) surrounded by conductive signals (thawed soil with varying moisture contents).

- **Permafrost table—**This unit is delineated in Figure 9 with dashed white lines. Material within this unit is frozen year-round and will remain stable as long as it remains in a frozen state. Boring data suggests that frozen soil in the area is relatively ice-poor and, therefore, thaw stable. Resistivity data suggests that frozen soil in the subgrade is a patchwork of ice-rich and ice-poor soil, with more ice on the west and northwest side of Building 6385. This suggests that the subgrade is generally thaw stable with localized thaw-unstable soils, particularly in the west. This unit is illustrated in the pseudosection as high resistivity signals within a zone of moderate resistivity.

- **Bedrock—**This unit is delineated in Figure 9 with dashed pink lines and question marks to illustrate uncertainty. Bedrock in the area was encountered by the well drilled in 1997, AP-6098, and possibly AP-6097 (Figure 8). In the pseudosection, bedrock is shown as broad, generally high resistive areas with signals trending up from depth. There is localized low resistivity within this interval that is likely related to the groundwater in the fractured upper interval of the bedrock. Conductivity in this unit correlates with saturated fractures intercepted by the well log at a depth that is consistent with the change from low to high resistivity in the pseudosection. Based on this pseudosection, it appears that the bedrock has a shallow west apparent dip. AP-6098, AP-6097, and the 1997 well log have bedrock encounter depths that support the interpretation that the top of bedrock, as it is shown in Transect 1, has an apparent shallow west dip.

Figure 10. Interpreted ERT Transect 2.



ERT Transect 2 runs approximately northwest–southeast along the east side of Building 6385 (Figure 1). Abbreviated borings are shown with color-coded lithologies (see Figure 10, abbreviated bore log data).

This transect runs through undisturbed ground on the south side with natural drainage (that is not modified by construction), through the developed lot parallel to the concrete apron on the east side, over Quarry Road, and back into undisturbed ground (with surface drainage patterns that are heavily modified by construction) on the north side. The following summarizes the five distinct geomechanical units, their engineering properties, and how they present in the pseudosection:

- **Construction fill—**This unit is delineated by orange dashed lines in Figure 10. The surface expression in this unit is well-graded and poorly graded alluvial fill material that is texturally and compositionally mature and dry. CRREL researchers had to soak electrodes with electrolyte water in this unit to achieve signal lock because it was dry. The silicic and dry nature of this material results in its being very resistive; and therefore, it shows as very high resistivity in signals that trend downward from the surface.

- **Active layer, thermokarst, and groundwater perched on frozen soil—**This unit is delineated by blue dashed lines in Figure 10. The surface expression in this unit is wet and moist soil that is easily compressed and poorly drained. Thermokarst features are common within this interval (Figure 3). Building on this unit would likely result in high differential settlement. This unit presents in the pseudosection as relatively low resistivity signals (thawed wet soils) depicted in shallow downward-trending signals that are perched on higher resistivity signals (permafrost).

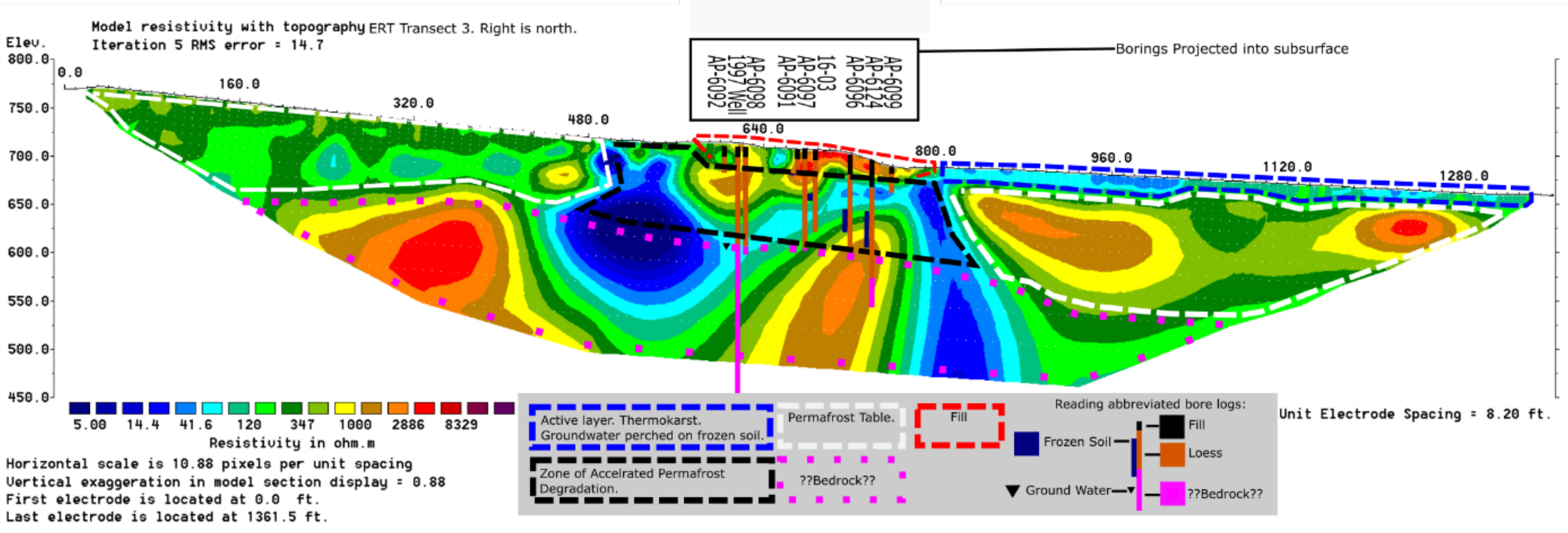
- **Zone of accelerated permafrost degradation—**This unit is delineated by black dashed lines in Figure 10. The most recent borings drilled on the project are projected into the pseudosection in Figure 10, and all borings are shown in Figure 8. As previously discussed, borings drilled in 1995 show frozen soil that is now thawed in borings drilled in 2016, 2017, and 2018. This is typical of areas in interior Alaska where structures have been built on permafrost, especially where the organic mat has been stripped and cuts have been excavated. In this zone, isolated remnants of frozen soil exist within a patchwork of thawed and frozen soil with variable moisture contents. Frozen soil in this interval will often have water perched on top of it, which accelerates phase degradation of frozen soil beneath. Due to thermal instability, building on soils depicted in this zone will likely result in differential settlement. This zone presents in the pseudosection as large “blob-like” resistive signals (areas where frozen soil remains) surrounded by conductive signals (thawed soil with varying moisture contents).

- **Permafrost Table—**This unit is delineated in Figure 10 with dashed white lines. Material within this unit is frozen year-round and remains stable as long as it remains in a frozen state. Boring data suggests that frozen soil in the area is relatively ice-poor and therefore thaw stable. Resistivity data suggests that frozen soil in the subgrade is a patchwork of ice-rich and ice-poor soil, with more ice on the west and north side of the project area. This suggests that the subgrade is generally thaw stable with localized thaw-unstable soils, particularly in the west and northwest. This unit is illustrated in the pseudosection as high resistivity signals within a zone of moderate resistivity.

- **Bedrock—**This unit is delineated in Figure 10 with dashed pink lines and question marks to illustrate uncertainty. Bedrock in the area was encountered by the well log drilled in 1997 and 2018 borings AP-6098 and AP-6097, and AP-6124 (Figure 8 and Figure 11). In the pseudosection, bedrock shows as broad, generally high resistive areas with signals trending up from depth. There is localized low resistivity within this interval that is likely related to the groundwater in bedrock that was intercepted by the well log at a depth that is consistent with the change from low to high resistivity. Based on this pseudosection, it appears that the bedrock surface has a shallow north apparent dip. This interpretation is supported by the 1997 well log data and by boring data from AP-6098, AP-6124, and AP-6097.

- **Vegetation correlation—**The pseudosection for Transect 2 (Figure 10, Figure 3, and Figure 1) shows well defined changes in resistivity that correlate with vegetation type. The north part of this transect (north of Quarry Road) is mostly vegetated by black spruce and other evergreen tree species. North of Quarry Road, there is also thermokarst topography (Figure 3). The pseudosection for Transect 2 shows higher resistivity (more ice-rich soil) beneath the “evergreen” vegetation and thermokarst in the north end and slightly lower resistivity (less ice in soil) on the south end of the transect (south of the fence) where there is primarily deciduous trees and no thermokarst topography.

Figure 11. Interpreted ERT Transect 3.



ERT Transect 3 runs approximately northwest–southeast along the west side of Building 6385 (Figure 1 and Figure 6). Abbreviated borings are shown with color-coded lithologies (see Figure 11, abbreviated bore log data). This transect runs through undisturbed ground on the south side with natural drainage (that is not modified by construction), through the developed lot parallel to the concrete apron on the west side, over Quarry Road, and back into undisturbed ground (with drainage patterns that are heavily modified by construction) on the north side. The following summarizes the five distinct geomechanical units, their engineering properties, and how they present in the pseudosection:

- **Construction fill—**This unit is delineated by orange dashed lines in Figure 11. The surface expression in this unit is well-graded and poorly graded alluvial gravel fill material that is texturally and compositionally mature and dry. CRREL researchers had to soak electrodes with electrolyte water in this unit because it was too dry to achieve signal lock in its in situ condition. The silicic and dry nature of this material results in its being very resistive; and therefore, it shows as very high resistivity in signals that trend downward from the surface.

- **Active layer, thermokarst, and groundwater perched on frozen soil—**This unit is delineated by blue dashed lines in Figure 11. The surface expression in this unit is wet and moist soil that is easily compressed and poorly drained. Thermokarst features are common within this interval (Figure 3). Evidence for damage to the organic mat from forest fires is present in this unit. Building on this unit would likely result in high differential settlement. This unit presents in the pseudosection as relatively low resistivity signals (thawed wet soils) depicted in shallow downward-trending signals that are perched on higher resistivity signals (permafrost).

- **Zone of accelerated permafrost degradation—**This unit is delineated by black dashed lines in Figure 11. The most recent borings drilled on the project are projected onto the pseudosection in Figure 11, and all borings are shown in Figure 8. As previously discussed, borings drilled in 1995 show frozen soil that is now thawed in borings drilled in 2016, 2017, and 2018. This is typical of areas in interior Alaska where structures have been built on permafrost, especially where the organic mat has been stripped and cuts have been excavated. In this zone, isolated remnants of frozen soil exist within a patchwork of thawed and frozen soil with variable moisture contents. Frozen soil in this interval will often have water perched on top of it, which accelerates phase degradation in the frozen soil beneath. Because of thermal instability, building on soils depicted in this zone will likely result in differential settlement. This zone presents in the pseudosection as large “blob-like” resistive signals (areas where frozen soil remains) surrounded by conductive signals (thawed soil with varying moisture contents).

- **Permafrost Table—**This unit is delineated in Figure 11 with dashed white lines. Material within this unit is frozen year-round and remains stable as long as it remains in a frozen state. Boring data suggests that frozen soil in the area is relatively ice-poor and therefore thaw stable. Resistivity data suggests that frozen soil in the subgrade is a patchwork of ice-rich and ice-poor soil, with more ice on the west and north side of the project area. This suggests the subgrade is generally thaw stable with localized thaw-unstable soils, particularly in the west and northwest. This unit is illustrated in the pseudosection as high resistivity signals within a zone of moderate resistivity.

- **Bedrock—**This unit is delineated in Figure 11 with dashed pink lines and question marks to illustrate uncertainty. Bedrock in the area was encountered by the well log drilled in 1997, AP-6098, and possibly AP-6097 (Figure 8 and Figure 11). In the pseudosection, bedrock shows as broad, generally high resistive areas with signals trending up from depth. There is localized low resistivity within this interval, which is likely related to the groundwater in fractured bedrock that was intercepted by borings at a depth that is consistent with the change from low to high resistivity. Based on this pseudosection, it appears that the bedrock has a shallow north apparent dip. This interpretation for bedrock orientation is supported by 1997 well log data and AP-6098, AP-6124, and AP-6097.

- **Vegetation correlation—**The pseudosection for Transect 3 (Figure 11, Figure 1, and Figure 6) shows well-defined changes in resistivity that correlate with vegetation type. The north part of this transect (north of Quarry Road) is mostly vegetated by black spruce and other evergreen tree species. North of Quarry Road there is also thermokarst topography (Figure 3). The pseudosection for Transect 3 shows higher resistivity (more ice-rich soil) beneath the “evergreen” vegetation and thermokarst in the north end and slightly lower resistivity (less ice in soil) on the south end of the transect (south of the fence) where there are primarily deciduous trees and no thermokarst topography.

5 Conclusion

CRREL conducted this study in support of the USACE Alaska District to provide information to aid in foundation design for improvement or replacement of Building 6385 of the Conventional Munitions Facility EIE387/EIE431. The primary objective for this study was to answer the following questions:

1. Is bedrock present below the building? If so, at what depth and orientation?
2. Is frozen soil beneath the building more ice-rich on one side or the other?
3. Where should further drilling be conducted to better understand foundation conditions in the subgrade?

Drilling relationships summarized in section 3.3 and resistivity data summarized in section 4.2 strongly suggest that frozen soil beneath Building 6385 is thawing at a significant rate.

In general, moisture contents in subgrade loess deposits are low (below saturation). Permafrost in a state of advanced degradation is present beneath Building 6385 to depths of approximately 80 ft (25 m) below the ground surface. Patchwork resistive signals in this interval suggest that the subgrade soils likely have localized variable moisture contents and are locally thawed or frozen. Based on pseudosections (comparison between Transects 2 and 3), the remaining frozen soil is more resistive, and therefore potentially more ice-rich, beneath the north and northwest sides of the building in Transect 3 where permafrost degradation is more severe and remaining frozen soil appears to be more ice-rich.

Pseudosections for Transects 2 and 3 show advanced permafrost degradation and low resistivity beneath Quarry Road and at the toe of the embankment slope for Building 6385. It is likely that this is a result of accelerated permafrost degradation related to surface drainage downslope, disruption of the organic mat prior to construction, and excessive heat transfer related to the albedo of the road surface. We believe that thawing of frozen soil beneath Quarry Road could have contributed to settlement in the apron on the north side of Building 6385 by destabilizing the tow of the embankment slope.

The resistivity signature for the north side vs. south side of Building 6385 correlates well with the change in vegetation type (most especially in Transects 2 and 3). In areas with black spruce and Thermokarst Topography (North of Quarry Road) (Figures 1, 3, 7, and 8), there is higher resistivity and higher ice content in the subsurface than in the south side (south of Building 6385) transects where no thermokarst topography is present and the vegetation is primarily deciduous trees.

Based on 1997 well log data, bedrock is present beneath Building 6385 at a depth of approximately 80–85 ft below the finished grade of the apron. AP-6098 is slightly northwest of the 1997 well log, and bedrock was encountered at a depth of 100.5 ft. AP-6097 is north of AP6098 and the well log and was terminated in colluvial material, suggesting the possibility of weathered bedrock at least 101.5 ft deep at that location. AP-6124 is the northernmost boring drilled deep enough to encounter bedrock, which it did, at a depth of 118 ft. Pseudosections from Transects 2 and 3 both show bedrock to have an apparent shallow north dip. The pseudosection for Transect 1 is perpendicular to Transects 2 and 3 and suggests that bedrock has a shallow west dip. These relationships suggest that the bedrock surface (not actual foliation attitude) is approximately 85 to greater than 118 ft below the finished grade of Building 6385 and has an approximate east–west strike and shallow dip to the northwest. It is believed depth smearing is observed in the very low resistivity inferred as saturated fractured bedrock with water table. This possible smearing complicates determination of bedrock orientation, but orientations derived from pseudosections are supported by referenced boring data.

The preliminary draft of this report included suggestions for additional borings, which have now been completed by R&M Consultants (2018). In general, sufficient boring data has now been collected. However, additional borings on the embankment slope north Building 6385 and in Quarry Road could help evaluate the potential for movement on the north embankment slope as a cause for settlement of Building 6385. Installing a slope inclinometer tube in the upper 30 ft of the slope on the north side of Building 6385 could be beneficial because it would allow designers to track lateral and vertical displacement and movement if present. It may also be beneficial to drill areas of low resistivity in structurally critical locations to ascertain depth and thickness of saturated thawed silt with low bearing capacity. Figure 12 and Table 1 present suggested borings and locations.

Figure 12. Proposed drilling footprint.

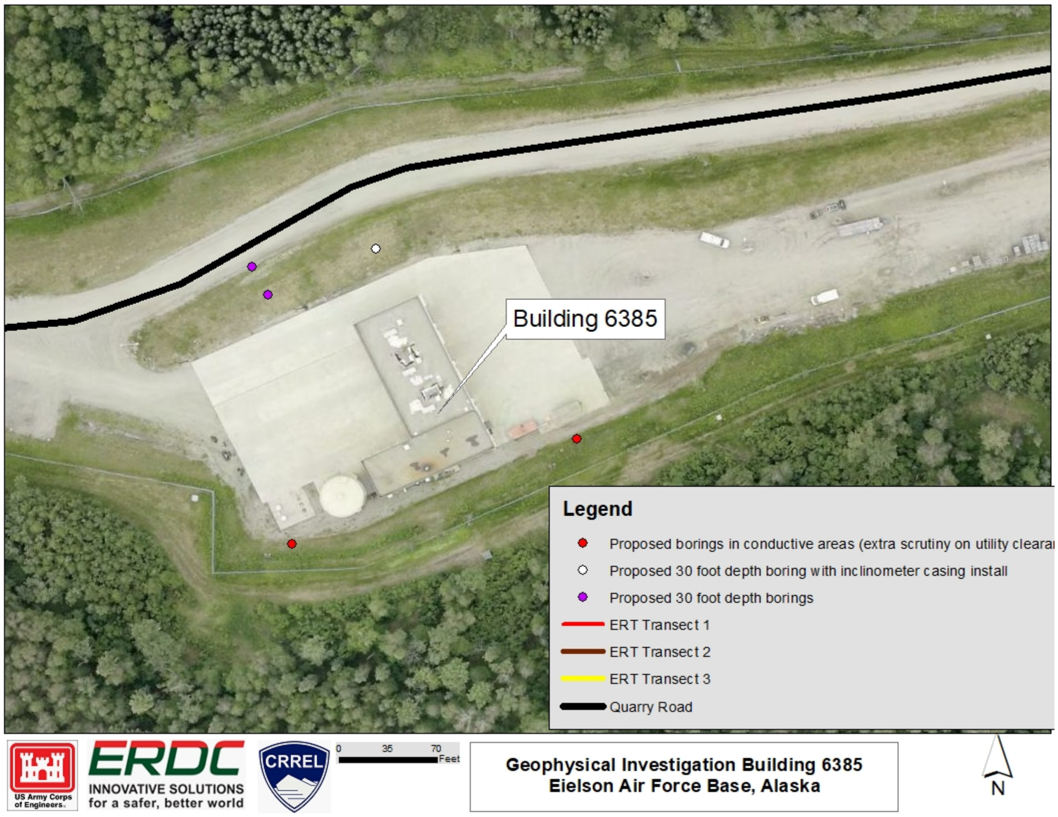


Table 1. Boring recommendation summary.

Boring Type	Quantity	Method	Justification
Borings in conductive zones to evaluate silt with low bearing capacity	2	Hollow-stem auger with SPT[a] every 5–30 ft	• Quantify density in fill • Identify soil lithology
Deep fill and shallow subgrade characterization (30 ft depth)	2	Hollow-stem auger with SPT every 5–30 ft and Shelby Tubes at 10, 20, and 30 ft	• Quantify density in fill • Identify soil lithology • Identify frozen condition and ice type/content • Quantify subgrade density
Shallow slope inclinometer tube installation (30 ft depth)	1	Hollow-stem auger with SPT every 5–20 ft and install slope inclinometer tube to monitor embankment slope for movement over time if needed	• Monitor embankment slope movement • Quantify density in fill • Identify soil lithology • Identify frozen condition and ice type/content

[a] Standard penetration test

The combination of resistivity data and boring data supports the interpretation that subgrade soil conditions beneath Building 6385 are generally composed of homogeneous loess with low moisture contents. Localized ice-rich soil and massive ice are present within the more homogenized subgrade and documented well in terms of depth and areal extent in resistivity data and ground truthed with boring logs. The localized ice-rich soil and massive ice beneath Building 6385 is captured in pseudosections presented in Figures 9–11.

Lack of positive drainage throughout the project area has led to further permafrost degradation, especially beneath Quarry Road and the northern Building 6385 fore slope, which shows in Figures 10–11 as conductivity beneath the ditch on the south side of Quarry Road adjacent Building 6385. The combination of completed recommended drilling and resistivity provides a generalized description of bedrock orientation beneath the project area as shown in Figures 9–11. Completing the recommended drilling in Table 1 will help ascertain if the north embankment slope has destabilized due to drainage-related permafrost degradation and hydraulic mobilization of loess at the toe of the slope in the ditch adjacent to Quarry Road.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Army Cold Regions Research and Engineering Laboratory conducted geophysical research of subgrade conditions to aid foundation design and to address differential settlement of Building 6385 on Eielson Airforce Base, Alaska. The study used electrical resistivity tomography and data from subsurface borings to characterize subsurface geologic units. Bedrock present beneath the building at a depth of approximately 80–105 ft has an approximate east–west strike and shallow dip to the northwest. Geophysical data indicates that frozen conditions beneath the site are a patchwork of thawed and thawing permafrost that is generally ice-poor with sporadic perched water on top of localized degrading ice-rich permafrost. Frozen soil beneath Building 6385 is thawing at a rate of at least 0.81 ft/year and has reached depths up to 80 ft. Advanced permafrost degradation is present beneath Quarry Road at the toe of the embankment slope for Building 6385. Permafrost beneath the north and northwest sides is more degraded and has more localized ice-rich soil. Fill on the west side of the building is thicker, suggesting more settlement has taken place. Permafrost degradation may have destabilized the tow of the embankment slope and contributed to settlement at the north edge of building.

15. SUBJECT TERMS
Eielson Air Force Base (Alaska), Electrical resistivity tomography, Foundation, Frozen ground, Geophysical surveys, Geophysics, Geotechnical engineering, Permafrost, Thermokarst

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