ERDC/CRREL TR-23-6

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

Preliminary Testing of Expedient Ground Anchor Solutions for Guyed Towers in Remote Cold Regions

Considerations for Cold Remote Regions with Limited Tools

Kevin Bjella, Daniel Vandevort, and Sarah Kopczynski

July 2023

The US Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdc.usace.army.mil.

To search for other technical reports published by ERDC, visit the ERDC online library at https://erdclibrary.on.worldcat.org/discovery.

ERDC/CRREL TR-23-6
July 2023

Testing Expedient Ground Anchor Solutions for Guyed Towers in Remote Cold Regions

Considerations for Cold Remote Regions with Limited Tools

Kevin Bjella, Daniel Vandevort, and Sarah Kopczynski

Cold Regions Research and Engineering Laboratory
US Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755

Final Report

Distribution Statement A. Approved for public release; distribution is unlimited.

Prepared for US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Under FLEX-4

Abstract

Ground anchors connected to guy wires for tower structures in cold climates suffer from frost heaving, which causes loss of wire tension and subsequent structural instability. It is necessary to understand what ground anchors are available to resist this tendency yet are still capable of expedient installation in remote areas. To that end, three metal, traditional ground-anchor types (arrowhead, bullet, and penetrating auger) and one novel polyvinyl chloride (PVC) T-post anchor were evaluated in frozen gravels and frozen silts at a research facility in Fairbanks, Alaska. Criteria included installation capability, failure loading, and removal ability. Additionally, expedient installation techniques for use in field conditions were also demonstrated. All three traditional ground anchors failed to penetrate frozen gravels. The penetrating auger also failed to penetrate frozen silts, but the arrowhead and bullet anchors did penetrate frozen silts with difficulty. The PVC anchor is capable of being installed only in a predrilled pilot hole. Under flexural load, the arrowhead anchor cable failed at 3686.72 lb, and the bullet anchor cable failed at 1753.44 lb. The PVC slid out of its hole at a direct-pull force of 1978.24 lb and failed under flexural stress at 202.32 lb.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for the US Army Engineer Research and Development Center, under FLEX-4. Dr. Orian Welling was the technical monitor.

The work was performed by the Force Projection and Sustainment Branch of the Research and Engineering Division, US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication of this report, Dr. Orian Welling was branch chief, and Dr. Caitlin A. Callaghan was division chief. The acting deputy director of ERDC-CRREL was Dr. Ivan P. Beckman, and the director was Dr. Joseph L. Corriveau.

The authors appreciate Dr. Wendy Wieder and Dr. Rosa Affleck at ERDC-CRREL for technical review of this report.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

Interest in expanding and furthering development in the Arctic is accelerating. These developments are tightly coupled with expansion and improvements in communication networks of many types and frequency ranges. High-elevation towers are often associated with communications development, and in these high-latitude regions, these towers are often built on ice-rich frozen ground, or permafrost.

Cable guy wires are a critical supporting component for communication poles, antennas, and towers to resist lateral forces (i.e., wind) and overturning moments. Securing these guy wires requires installation of ground anchors into the permafrost. The function of the ground anchor is to hold the cable in the ground, resisting the tension load exerted by the guy wire. For ground anchors installed in permafrost, maintaining the function and effectiveness of these anchors can be a challenge.

Due to its ice content, permafrost is considered an unstable material to construct on or in unless completely protected so that it remains in the frozen state. Ground anchors installed in permafrost tend to fail under visco-elastic stress or by creep. The deformation is highly temperature dependent and even more susceptible in warmer permafrost.

Common industrial practices already provide myriad solutions for large, deep, stable ground-anchor systems using large earth-moving or drilling equipment for installation and various protection measures to retain frozen conditions within the permafrost. However, there remains an unresolved need for *expedient solutions*, those that will allow installation of ground anchors in remote parts of the Arctic where large equipment is not accessible, thereby limiting methods to human-portable hand tools and equipment.

This report details work conducted to identify or develop expedient ground anchors, and the methods for installing them, for communication tower or antenna guy lines in permafrost at remote locations. The report will identify the benefits or drawbacks of each anchor investigated regarding providing the required loading and maintaining permafrost stability.

1.2 Objective

The objective of this study is to investigate expedient solutions for installation of ground anchors in permafrost, quantify the resulting load capacity of each tested solution, and determine extraction methodologies. The intent is to conclude with actionable recommendations to practitioners regarding permafrost stability and functional ground anchors.

1.3 Approach

An in-depth review of frozen-ground applications of ground anchors in cold regions was beyond the scope of this study. Rather, the focus of this study is to briefly introduce ground anchors, provide a short review of common frozen ground solutions, and focus primarily on testing of four possible anchor types which can easily be deployed to remote areas with minimal logistical limitations. Tests conducted were intended to measure efficacy of each anchor in frozen ground with the intent to recommend the most ideal solutions as anchors for guy lines on tall structures deployed in the Arctic.

This report will test several of the smaller anchor solutions described above which are capable of securing guy lines for antennas installed in frozen ground of remote cold regions areas using hand tools. This report will focus on the following expedient solutions: penetrating auger, bullet, arrowhead, and polyvinyl chloride (PVC) T-post anchors. The PVC T-post was selected to reduce the thermal energy transmitted underground. The others were selected because of their common use in the industry, light weight, and ease of installation with hand tools.

The testing methodology consisted of installing three traditional ground anchors (penetrating auger, bullet, and arrowhead anchors) typically used for unfrozen soils, and one type of PVC T-post (typically used in agricultural applications) approximately 40 in.* into both in situ frozen

* For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–7, respectively. https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

gravel and frozen silt located within the Cold Regions Research and Engineering Laboratory (CRREL) Permafrost Tunnel. A slurry consisting of local silt and water was added to the boring to allow bonding during refreezing. The anchors were left for 3 days to allow sufficient refreezing. After 3 days, the anchors were pulled out using a compact track loader mounted with a dynamometer to allow for the measurement of force required to release each anchor (i.e., asses the strength of each anchor). Qualitative observations were also made regarding damage to each anchor. A second test was performed on the PVC T-post to evaluate its shear strength against a load applied perpendicular to its long axis.

2 Ground Anchors

2.1 General Definition

A ground anchor is a structural component designed to transmit an applied tensile force into a reliable consolidated or unconsolidated matrix (e.g., ground, rock) wherein the tensile stress is resisted by shear strength of the matrix or by cementing or fixing a portion of the anchor into solid material such as bedrock. Anchors are designed to resist an uplift force or reinforce the ground foundation with a sufficient weight to offset the required force. Ground anchors vary with the engineering application and embedment matrix (material into which the anchor is installed).

2.2 Engineering Applications of Ground Anchors

References to unfrozen-ground-anchor applications abound in civil engineering literature and case studies (Adam and Klym 1972; Briaud et al. 1998; Majid and Zakaria 2012; Kongkitkul et al. 2013; Lin et al. 2013; Ozhan and Guler 2017; Sabatini 1999; Turner 2015; Wymer et al. 2003). Ground anchors have been in use for decades for earth retention, slope stability, and as tie-down solutions for structures spanning the fields of transportation, power, communications, construction, and utility applications where they are commonly installed to

- support tension loads such as those exerted by transmission towers and masts, suspension bridges, pipelines, and tension roof structures;
- provide restraint to structures such as retaining walls, gravity walls, hybrid walls, soil and rock slopes, landslides, cliffs, etc.; and
- support structures subject to hydrostatic uplift or flotation such as any type of guyed structure, dock structures or stormwater tanks, and even airplanes on airport aprons.

The application of ground anchors to support tension loads is of interest in this report.

2.3 Common Ground Anchor Types

The type of anchor selected for a project is dependent on the required load resistance and condition of the embedment matrix. Many anchor types exist. The following discussion does not attempt to be exhaustive; rather, examples are selected from broad classes for general context with the focus being on those suitable for our application.

2.3.1 Mechanical Anchors

Examples of lighter-load, mechanical anchors include the screw anchor; expanding or spreading anchor; anchors with plates, disks, cones, crosses; arrowhead anchor; penetrating auger anchor; bullet anchor; PVC T-posts; etc. These anchors interact mechanically with the soil matrix to resist pull out. Often these lighter anchors have maximum recommended load limits of up to 20,000 to 40,000 lb and are used to secure guy wires under the loads such as would be required by power companies for poles or small towers (Kovacs 1975).

These mechanical anchors lend well to expedient solutions in remote regions where only small power tools are available for installations, though multiple anchors may be needed per structure to satisfy the load requirement (Kovacs et al. 1975). The length, or depth of embedment, of these anchors varies according to loading requirements. Recommended design loads are usually specified by the manufacturer according to anchor type, size, and some measure of the soil type and condition.

2.3.2 Grouted Anchors

Some anchors are installed with grouting such as those installed in a solid matrix like rock. These involve metal rods or stakes inserted into predrilled holes, which are then injected with a suitable grout or soil slurry mixture. Anchors installed in an unconsolidated matrix are generally not grouted. In this case, the soil will yield rendering a grouted anchor ineffective, especially when the anchor is in tension, and the entire grouted plug around the anchor may pull out of the soil. Conversely, in solid matrix applications such as bedrock, the grout cements the anchor to the rock, effectively transmitting the stress to the competent material, providing greater pull-out resistance. The same concept applies to anchors installed in permafrost or ice where slurry materials are used to cement the anchor to the proximal matrix via adfreezing. In lieu of a traditional grout used for rock anchors, in frozen ground scenarios a wet soil slurry (water or soil or both, ratios vary) can be poured into the drilled hole once the anchor is installed allowing the soil to quickly refreeze around the anchor.

The Malone anchor, consisting of a rod extending into a larger grout blub, is applied in conditions where cohesive matrix materials are available and there does not exist a risk of cavity collapse. Grouted anchor styles vary widely in form and installation approach but are generally used in cohesive materials where grouting is appropriate.

2.3.3 Gravity and Foundation Anchors

The following much-larger anchors discussed below require significant equipment footprints for installation thereby excluding them as typical expedient candidates. They are included for completeness of the topic.

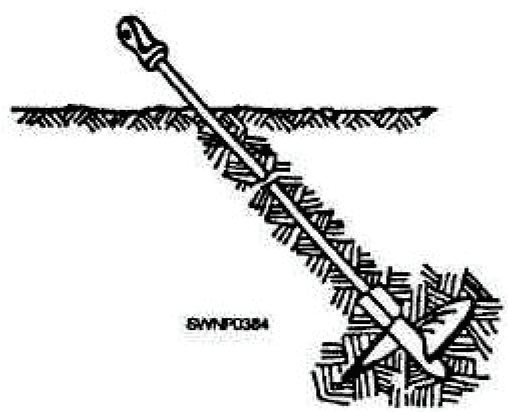
Concrete structural anchors, or blocks, are widely used as gravity-anchor solutions in various forms and applications. Block anchors typically consist of a reinforced concrete block connected via rods or cables to the supported structure. Blocks can be as large as 30 ft^3 in volume or larger. These may sit on the ground surface or may be buried. Typically, a long, buried horizontal component perpendicular to the tension force of the guy line is considered a *dead man*, where the length provides surface area to *anchor* in the soil and the weight of the soil over the top prevents pull out. A buried block anchor serves this function as well, providing resistance both due to its mass and the mass of the overburden soil (Kovacs et al. 1975). Foundation anchors (e.g., steel grillage foundation, concrete) can also serve both as structural foundations and anchors (Kovacs et al. 1975). For example, foundation piles for large power-transmission towers will support the tower weight over the underlying soil while also anchoring the tower during high winds.

Pile generally refers to a column extending to the subsurface, either end bearing on very firm soil or bedrock or of sufficient diameter and length that the skin friction provides resistance. The pile is generally designed for vertical downward loads. When a pile is angled to resist the resultant of a force, it is often called *battered*. In the case of securing towers, piles would generally exist only to support the downward force of the tower base. Piles are not by themselves used for lateral support as they generally are much weaker in tension or flexural strength than in compression along the axis. Gathered in pile groups and connected with pile caps, and battered, they then can be used to resist lateral force. Piles are also employed in combination with foundation anchorages to increase support (Kovacs et al. 1975).

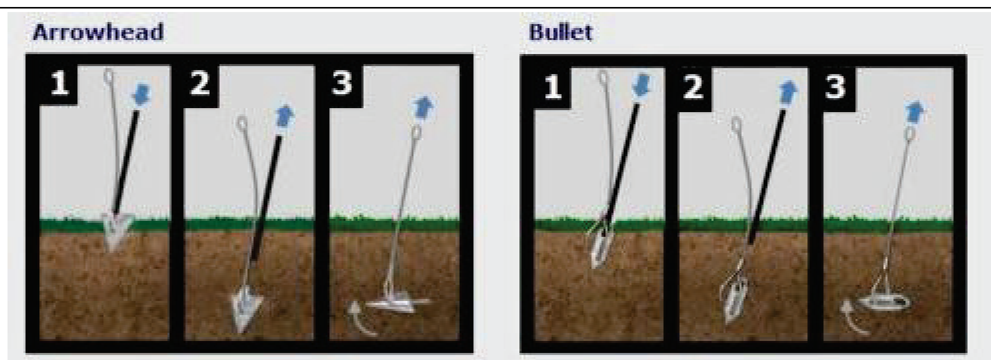
2.3.4 Ground Anchors for Guy-Wire Applications

Smaller, more portable anchors that may lend themselves well to securing guy wires are illustrated in Figure 2-1. They include mechanical anchors such as the screw-type anchor, small, bullet-type or arrowhead anchors with a cable attachment, which are driven into the soil, and drilled or driven embedded bars or rods with machined connections for cable attachment. Rod anchors are typically steel and may be nongrouted or grouted depending on the soil matrix conditions.

Figure 2-1. Examples of anchors used to secure guy wires.

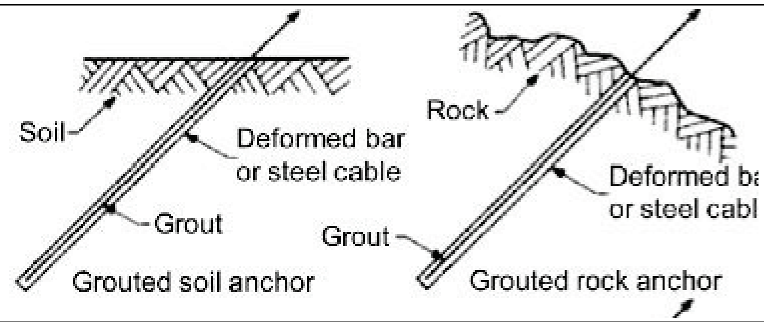


(A) Mechanical screw anchors.



(B) Arrowhead and bullet anchors with cable.

Figure 2-1. (cont.). Examples of anchors used to secure guy wires.



(C) Grouted anchors.

2.4 Typical Installation Techniques

Hironaka (1974) outlines a lengthy list of common installation approaches for anchors in unfrozen materials (soil and rock) including driving; screwing; augering, placing, and backfilling; excavating, placing, and backfilling; augering, placing, and grouting; excavating, placing, and grouting; drilling, placing, and backfilling; drilling, placing, and grouting. Common drilling methods for ground anchors include rotary, percussion, rotary-percussive, or auger drilling, which are described in Bruce (1989). The installation approach will be dictated by conditions identified during the site assessment to include the geology as well as the need to reduce risk to other structures proximal to the ground anchor. As well, Sabatini et al. (1999) warn that drilling methods must minimize “excessive ground loss into the drill hole and ground surface heave,” which can result in damage to anchor placement and the structures being supported by the anchors.

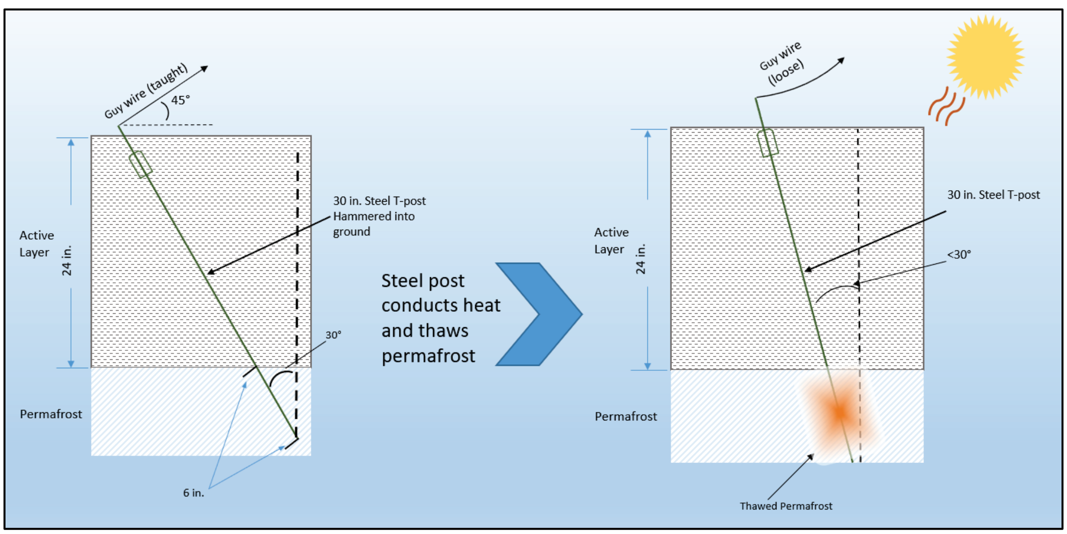
2.5 Frozen Ground Challenges in Cold Regions

While unfrozen-ground-anchor solutions have been discussed extensively in the literature for decades, application of reliable frozen-ground anchors in cold and Arctic regions continue to pose some unique challenges. Reliable solutions do exist, though application requires careful considerations of both anchor type and installation environment. The type of embedment matrix (silts, gravels, bedrock, etc.) and the character of the matrix (frozen vs. unfrozen ground, ice content, warm vs. cold permafrost, etc.) require different geotechnical considerations. An understanding of the “uniaxial compressive strengths of silts, sands, and gravels are important to consider. The uniaxial compressive strength of a given frozen soil varies with soil type, percent ice content, unit weight of frozen soil, viscoelastic properties of soil, and rate of loading” (Hironaka 1974).

2.5.1 Depth of Embedment

Installation of any object (especially metal) in frozen ground often alters the ground thermal regime leading to warming and thaw of the matrix and eventual failure of the installed structure. Larger and more complex anchor solutions and installation techniques have been developed to provide more reliable long-term anchoring that resists creep and frost heaving (examples discussed below). For smaller applications, generally, anchors are not embedded in the active layer where freezing and thawing are common above the permafrost. Hironaka (1974) reports that testing experience in Alaska indicates that a 10 ft (3 m) embedment length in permafrost is safe in critical places of warm permafrost and air temperature extremes. However, over time, smaller expedient metal anchor systems installed even to these specifications can succumb to creep and heave failure. This is demonstrated in Figure 2-2. showing an example of thermal transmission of heat along a steel post causing slow failure of the anchor resulting in slack of the guy line.

Figure 2-2. Ground anchor failure in permafrost.



2.5.2 Creep

Geotechnical attributes of the frozen ground are critical design considerations when predicting creep of frozen-ground anchors. In general, anchors under constant loading embedded in permafrost, especially ice-rich permafrost, are prone to creep displacement or failure (Lin et al. 2013; Johnston and Ladanyi 1972; Sayles and Haines 1974; Biggar and Kong 2001). Disturbance of the soil thermal regime after anchor embedment contributes to displacement. Johnston and Ladanyi (1972) conducted pullout test on piles installed in permafrost near Manitoba; results showed that creep behavior of ice-rich soil was similar to the steady-state creep of ice. Anchors installed in warmer permafrost (temperatures near 0°C) will experience higher rates of creep than colder permafrost (temperatures below −5°C). Recent laboratory pull-out tests of anchors embedded in remolded ice-rich silt confirmed that failure rates increase with increasing ground temperature and water content (Lin 2013). Note that discontinuous permafrost zones tend to be warmer than continuous.

2.5.3 Frost Heaving

Frost heaving occurs in materials (usually silt and clay rich mediums) that are most susceptible to formation and growth of ice lenses. Ice lenses grow in the soil matrix, which displaces proximal materials, forcing the anchor upward toward the ground surface, which reduces the anchor burial depth thereby reducing the anchor capacity (Hironaka 1974; Ono 2015). The probability of frost heaving and the magnitude of frost heave potential varies with sediment grain size, sediment temperature, sediment water content or water availability or both, heat flow, and pressure within the sediment column.

2.5.4 Installation

With regard to anchor installation in cold regions, Hironaka (1974) notes that many unfrozen-ground techniques are also directly applicable to installation methods successfully applied for anchors in snow, ice, and permafrost; however, there exist considerable other challenges that must be assessed for applications in cold regions. In frozen ground, an open hole is possible once into the permafrost (e.g., the hole collapse is unlikely), but getting through the active layer in the summer is not unlike thawed soil elsewhere. Therefore, pounding the stake is most suitable for expedient installation to avoid hole collapse.

2.6 Review of Select Frozen Ground Anchor Solutions

Engineering literature provides myriad examples of portable, temporary, and permanent ground anchors successfully applied in snow, ice, frozen ground, and permafrost, most commonly to secure towers, poles, bridges, and pipelines (Bjella 2015; Crory et al. 1969; DeFrees 1955; Drage and Brooks 2012; Hironaka 1974; Johnston and Ladanyi 1972; Lin et al. 2013; Zubeck and Liu 2003). The practitioner is advised to read case studies relevant to the cold-regions environment into which the anchors are applied as lessons-learned are critical to successful adaption to projects.

2.6.1 Frozen Ground Anchors

As illustrated in Table 2-1, there exist a variety of frozen-ground anchor methods. This list is not intended to be exhaustive; rather, it is intended to illustrate some common examples used in frozen ground when site access does not restrict anchor choice.

Table 2-1. Examples of frozen ground anchors (modified after Hironaka 1974).

Method	Reference Source
Dead Man Anchor, Block Anchor	Hironaka (1974); Kovacs et al. (1975)
Pile Anchor	Hironaka (1974)
Grouted Rod Anchor	Johnston and Ladanyi (1972)
Hook Anchor	Kovacs (1973)
Thermopile	Hironaka (1974); Drage and Brooks (2012); Wagner (2014)
Arrowhead Ground Anchors*	Crory et al. (1969)
Arctic Adapter, Drive Pickets	DeFrees (1955)
Guy Stake, GP-112/G	Bernardin (1961)
Helical Anchors	Zubeck (2003)
Penetrating Auger*	Hironaka (1974)
Bullet Anchor*	Hironaka (1974)
PVC Anchor Posts*	None found to date

*Tested and discussed in this study for efficacy as expedient solutions.

2.6.1.1 Predrilled, Grouted Rod Anchor

Several very simple and commonly used frozen-anchor solutions exist for securing guy wires. A predrilled, grouted rod anchor includes a steel reinforcing bar embedded in the soil with grout included in the drilled hole. A hook anchor represents a family of anchors that include a bar with a formed *V* shape on the end that typically includes an eye. Arrowhead ground anchors are typically smaller single-piece metal castings shaped as an arrowhead driven into the ground attached to a short shank via a driving rod and cables. The anchor is placed, the rod extracted, and the cable pulled to set the arrowhead into the surrounding soil. Bullet anchors are similar, with a different head shape. Guy-stake anchors and GP-112/G anchors are constructed of a long cylindrical shaft with a sharp tip on one side and a shackle on the other (Hironaka 1974).

2.6.1.2 Helical Anchor

Helical anchors are also commonly used in cold environments, though they assume several forms and names (helix anchor, screw anchor, or helical pile). In general, this anchor is constructed of a central shaft (square or round, solid, or hollow) that is connected to a series of spiral plates designed to maximize soil resistance (Zubeck 2003).

2.6.1.3 Concrete Anchor

As discussed in the prior section, concrete anchor—often precast—solutions are commonly applied in unfrozen conditions. Concrete anchor solutions are also applied in frozen ground. The dead-man anchor consists of a concrete block and is used to mitigate anchoring problems in frost-heave susceptible materials; this has proven to be a simple and cost-effective solution in regions where large concrete blocks can be transported. Large blocks (large loads) can be effectively applied as anchors, able to resist frost heave if the bearing capacity of the supporting medium is not exceeded. In other cases, nonfrost-susceptible granular backfill is applied to increase the dead load on footings. Dead weights have also been applied to mitigate against guy wire-anchor failures resulting from frost heaving (Hironaka 1974).

2.6.2 Site Preparation

Site preparation techniques (excavation and insulation) can enable successful guy-anchor foundations in challenging frozen-ground scenarios. A recent case study in Thule, Greenland, used a rod anchor assembly with the foundation in conjunction with excavation and site preparation to solve a complex anchoring problem to secure a tall transmitter antenna in ice-rich permafrost soils subject to high winds (Bjella 2015). In general, given the remote site location and limited availability of on-site concreting capabilities, foundations require precasting the anchor and anchor rod assemblies and shipping via ocean transport vessel to Greenland. Site engineers sought to avoid shipping large precast concrete blocks and instead applied an alternative plan involving site preparation and a foundation design with anchor rods. Ice-rich permafrost materials were excavated from the foundation site. Removing these ice features reduced the potential for long-term creep settlements due to sustained foundation loading and, in case of unexpected thawing, mitigated against excessive settlement beneath guy-anchor foundations. Geotextile and extruded polystyrene board-type insulation were installed in the excavation to maintain and improve the foundation subsurface thermal regime. The modified foundation including anchor rods, insulation, and nonfrost-susceptible structural replacement was backfilled into the excavation. The resulting anchor solution successfully secured the harsh winds acting against the tower (Bjella 2015).

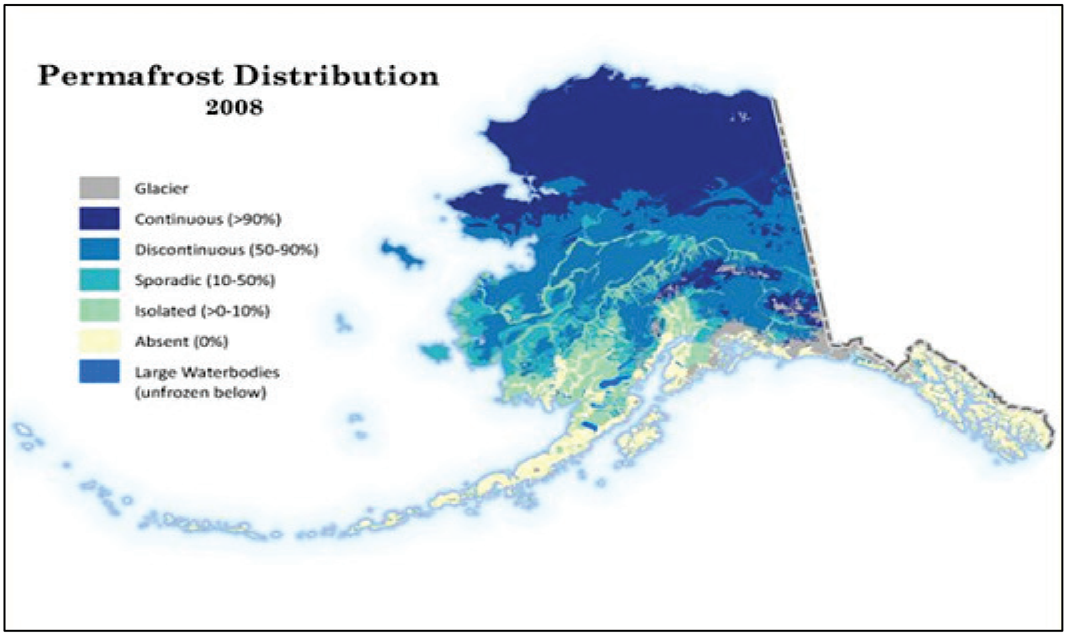
3 Environmental Background

The focus of this study is the testing of expedient anchor solutions that can be applied in remote areas of Alaska, primarily in the frozen grounds of the central and northern regions. In these locations, remotely located towers for antennas and other infrastructure require numerous guy lines to secure high towers against harsh northern winds and other forces. The anchor tests conducted for this study were conducted at the CRREL Permafrost Tunnel Research Facility, which was selected as a proxy for ground conditions in these more remote northern Alaska areas. For this reason, we provide a brief review of the geology of northern Alaska and of the Permafrost Tunnel area. Geological conditions support using the Permafrost Tunnel geology as a broad geological proxy for northern Alaska.

3.1 Regional Geology and Climate of Central and Northern Alaska

Central Alaska is generally known as the *Interior* because of its position between the Northern and Southern Cordilleras and is an intermontane plateau comprised of four ecoregions (Begét et al. 2006). The two bounding cordilleras limit the external influences from the polar north and the Pacific, and the Interior's high latitude means low solar influence for a significant portion of the year (Begét et al. 2006). Subsequently, topography has a much stronger influence on climate, and the four, large Tanana, Yukon, Kuskokwim, and Koyukuk Rivers that meander through the region provide another decisive influence. The Interior falls into the *Dfc* Subarctic Köppen classification (Figure 3-2) and experiences extreme temperature variability. In this classification, *D* indicates a continental climate, *f* indicates there is no dry season, and *c* indicates regular subarctic temperature such that only 1–3 months are above 50°F (Köppen 1884). The lowest and highest temperature records for the state were recorded in the interior: 100°F in Fort Yukon and −80°F in Prospect Creek (Western Regional Climate Center, n.d.). Much of the interior is covered in wind-blown silt deposits known as *loess*. Deposit thickness varies across the region but can be as thick as 300 ft or more in some places while only a few feet or less in others. The loess deposits carry much of the permafrost (any ground that is frozen for 2 or more years) throughout the region making it subject to notable change should the permafrost regime be disturbed (Péwé 2018). Additionally, "permafrost is abundant in the discontinuous zone of central Alaska under present climatic conditions and is strongly influenced by topography and local ecosystem characteristics. In Alaska, south of 67°N, permafrost is generally discontinuous to sporadic and relatively warm (0°C–2°C) in most areas" (Panda et al. 2010) (Figure 3-1). Where rivers and streams cut through the unfrozen loess or permafrost deposits, fluvial gravels and glacier-fed silts can build terraces amid the loess.

Figure 3-1. Permafrost across Alaska (reproduced with permission from Jorgenson et al. 2008).



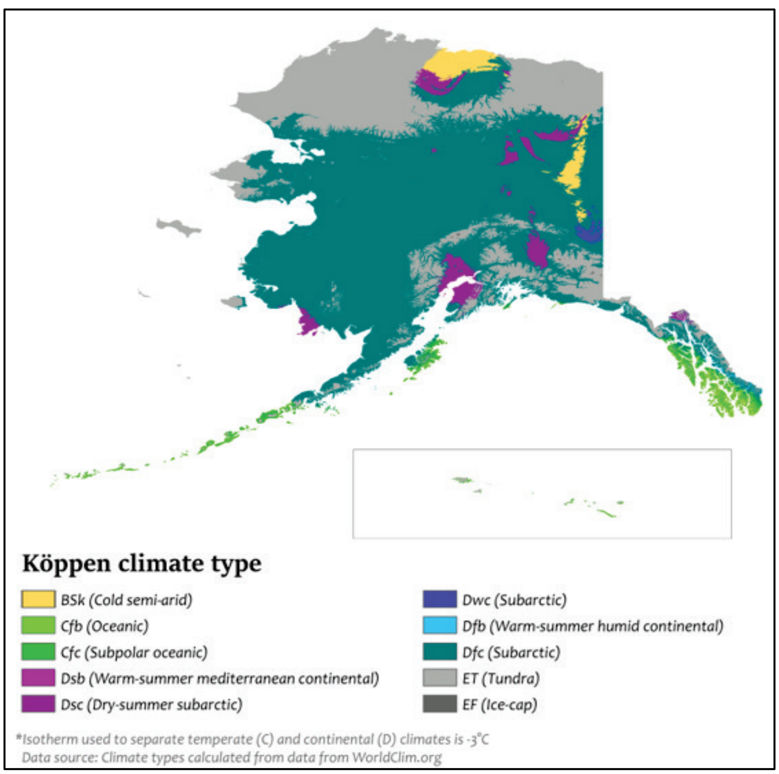
North of the Brooks Range lies the Arctic Coastal Plain, Köppen classification ET (Tundra) (Figure 3-2). According to the US Geological Survey, "The Arctic Coastal Plain (ACP) is a large region of low-lying, lake-rich land on the North Slope of Alaska. This region is underlain by thick ground ice, which is susceptible to erosion and thaw" (USGS 2019). Furthermore,

> Soils are composed of silts to fine sands, which are ubiquitous across the lowlands of the ACP and thaw during the summer to a depth of less than 1 m. Soils are saturated each spring by snowmelt and generally stay nearly saturated throughout the summer, albeit with some loss of moisture during the mid-summer dry period. Organic layers on top of the mineral soils are only centimeters thick in most locations but plugs of organic material may also exist at depth under the troughs. (Koch 2016, 3,919)

Climate in the northern regions of Alaska is harsh and diverse, barely influenced by human population. According to researchers from the University of Alaska Fairbanks,

> The climate of northern Alaska can be divided into three different zones: Arctic Coastal, Arctic Inland, and Arctic Foothills. The Arctic Coastal zone is characterized by cool summers and relatively warm winters, due to the impact of the ocean. Precipitation is the lowest in the region, and more than 50% falls as snow. The Arctic Inland zone has the warmest summers and coldest winters in the region although its mean annual air temperature is very close to the values of the Arctic Coastal zone to the north. Precipitation is higher than in the Arctic Coastal zone and about 40 to 45% occurs as snow. The Arctic Foothills zone has the warmest winters in the region, due to the influence of the weaker atmospheric temperature inversion compared with the coast, but its summer temperature is slightly colder than that of the Arctic Inland zone. Precipitation is the highest in the region and snowfall accounts for about 40% of it. (Zhang et al. 2018, 509)

Figure 3-2. Köppen climate types of Alaska.



3.2 Geology and Climate of the Permafrost Tunnel Research Facility

The CRREL Permafrost Tunnel is located approximately ten miles north of Fairbanks, Alaska. The silts and gravels found at the facility have been described as

> . . . massive, homogeneous unconsolidated, well-sorted silt of Aeolian origin containing less than 10% clay, locally rich in organic silt and larger organic fragments. Inorganic components are angular grains of quartz, feldspar, and mica, locally cemented by iron oxides. It is buff to brown or gray, locally mottled. Organic silt is brown to grayish black. (Péwé et al. 1966, 2)

The layers of silt were deposited by aeolian methods, and the gravels were deposited from the local Fox Creek meandering through the valley. Ice content of the weathered schist averages 11.7%, and frozen silt containing cryostructures may have moisture contents up to 140% (Lin et al. 2013). Climate at the facility is typical of the greater Fairbanks area. The long winters from late September through mid-April experience temperatures as low as −50°F, and snow accumulations average 60–65 in. (Alaska Climate Research Center 2023).

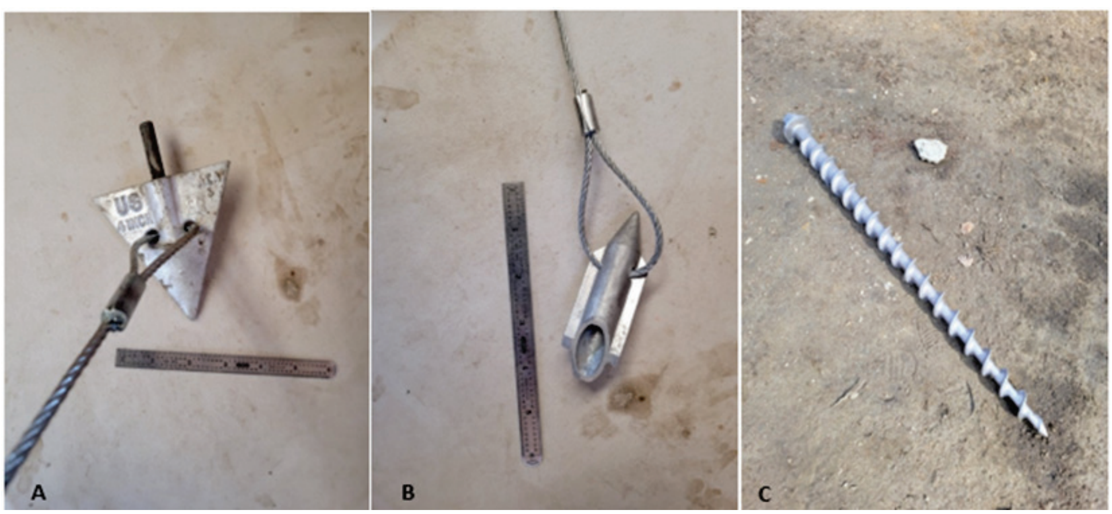
4 Test Method

4.1 Characteristics of Anchors Tested

4.1.1 Traditional

Three types of traditional ground anchors were tested in frozen gravel and frozen silts: penetrating auger, bullet, and arrowhead anchors. These are metal anchors and are typically used for unfrozen ground. The arrowhead anchor is available in varying sizes with the 4 in. base model being tested here (Figure 4-1*A*). The bullet style anchor has a hollow, ½ in. diameter core with winglets on either side (Figure 4-1*B*). It is available only in one size. The penetrating auger is available in various lengths with the 46 in. long model being used here (Figure 4-1*C*). The arrowhead and bullet anchors are each equipped with ⅛ in. steel cable standard; the penetrating auger has holes in the hex head through which a similar cable could be inserted after the anchor is set.

Figure 4-1. Traditional anchors: (*A*) arrowhead—scale in inches; (*B*) bullet—scale in inches; and (*C*) penetrating auger—length approximately 4 ft.

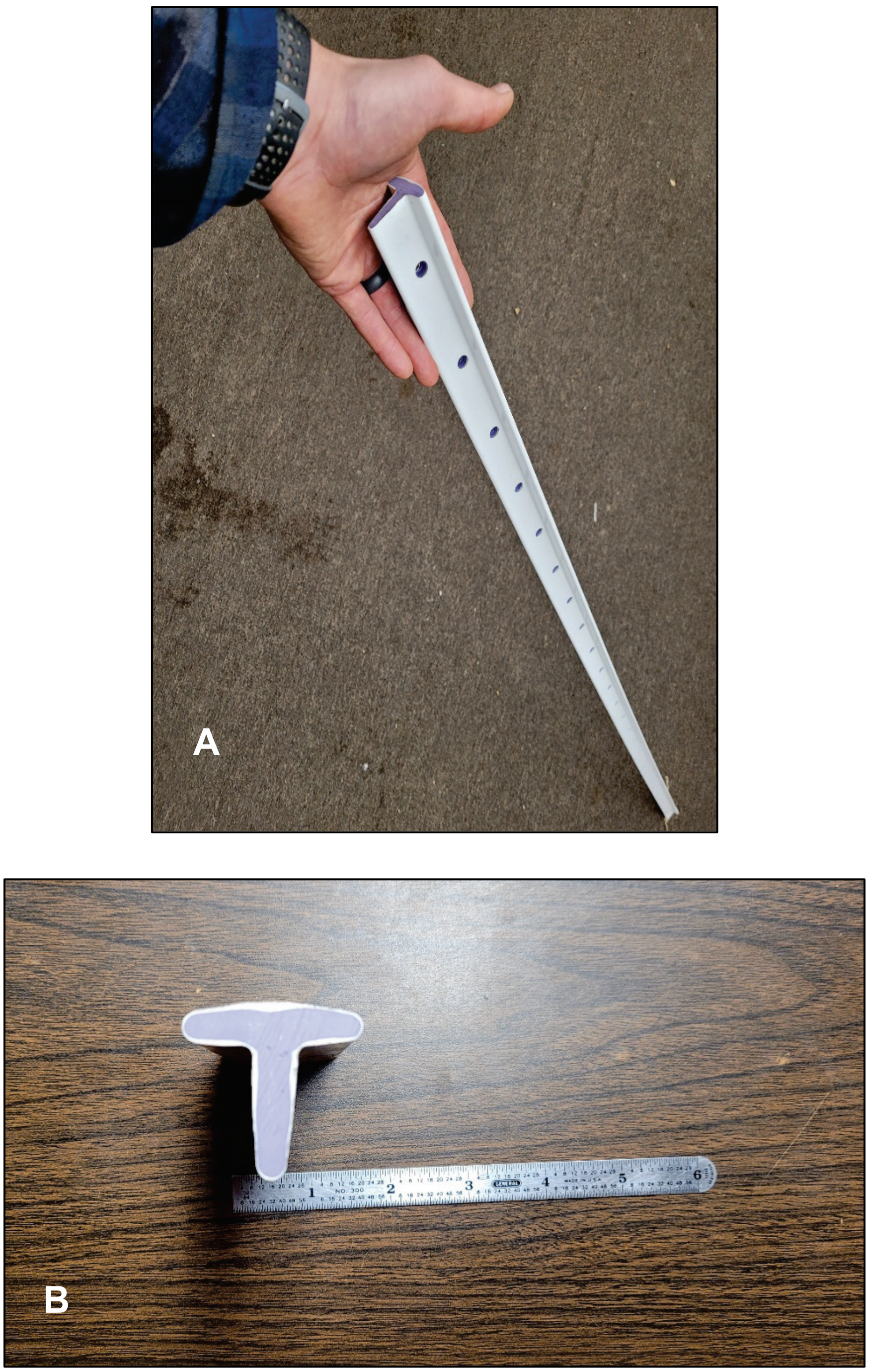


4.1.2 PVC T-post

The PVC T-post (Figure 4-2) is traditionally used for fence posts but is tested here to evaluate if it will function as a comparable anchor to the traditional options described above. The material properties for PVC will not conduct significant heat into the ground thereby thawing the permafrost, and this may make it a candidate for cold-climate ground anchoring solutions. The PVC T-posts used here were 4 ft long with $1^{1}/_{2}$ in.

widths along their *T* cross sections (Figure 4-2*A* and *B*). Additionally, the PVC T-post had small holes spaced every 2 in. through which the ⅛ in. steel cable was fed. In general, the PVC T-post does not have any special tip for ground penetration, but the penetrating end is slightly angled so it is not the full *T* cross section.

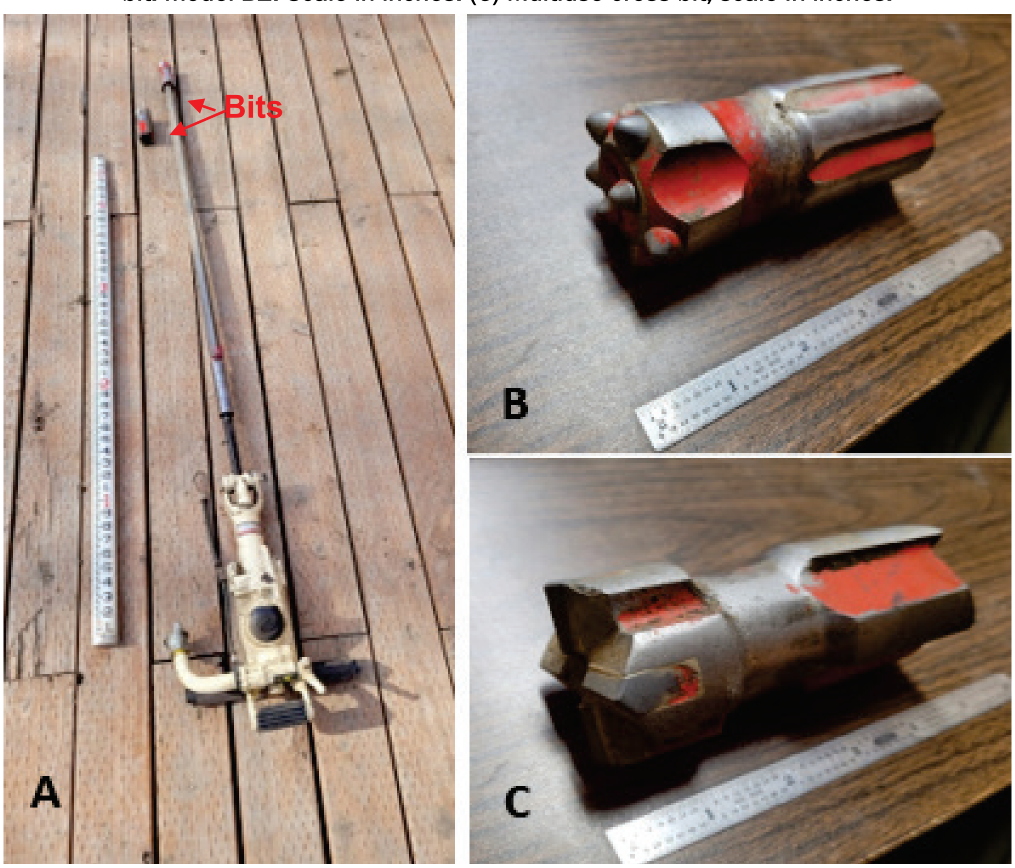
Figure 4-2. PVC T-post (*A*) and cross section (*B*), scale in inches.



4.2 Drilling in Frozen Gravels and in Frozen Silts

The same drilling system was used for both the frozen gravel and frozen silts soils to predrill holes for two of the four anchor types: the arrowhead anchor and the PVC T-post. It was selected as a proxy for expedient installation solutions that could be used in the field. The drilling system was comprised of an air compressor, hoses, air rock drill, steel rod extension for the drill, and two drill bits. The air compressor used was a trailer-mounted, diesel engine compressor producing 185 ft^3/min of airflow. The Ingersoll Rand air rock drill with T-grip had a shank size of $^7/_8 \times 4–^1/_4$ in., required pressure of 90 lb/in^2., three-speed throttle with reversible pawls and was connected to the compressor with a $^3/_4$ in. air hose protected at each connection with whip retainers. The $^7/_8$ in. hex steel rod was 4 ft long with R25 rope thread. Two rock drill bits were used: a Rockmore flat-face, B2 top-hammer button bit with full-ballistic carbide tips and a Rockmore multiuse cross bit both with front-flushing air holes and retract skirts (Figure 4-3*A*, *B*, and *C*).

Figure 4-3. (*A*) Drilling assembly less air components; scale in feet. (*B*) Top-hammer button bit: model B2. Scale in inches. (*C*) Multiuse cross bit; scale in inches.



During the drilling process, air-lubrication oil was introduced to the system to maintain equipment. When drilling in both the frozen gravels and silts, the operator placed the air rock drill vertically to begin the hole and then adjusted to the desired angle after 1 or 2 in. of penetration had been achieved (Figure 4-4). Ideal angles are typically in the range of 45° to 60°. The operator retracted the bit to expel cuttings approximately once every minute to prevent cuttings buildup as the bit penetrated deeper. In the event cuttings were not expelled soon enough, the retract skirts were able to cut back through the buildup if the operator applied consistent back pressure, but this increased total drill time.

Figure 4-4. Drilling in frozen gravels.

4.3 Anchor Installation

4.3.1 Traditional Anchors

Attempts were made to install all the anchor types according to their standard installation methods in frozen gravels and frozen silt. The standard installation methods for each anchor are as follows:

- Penetrating auger anchor: portable rotary-hammer drill equipped with 2 in. hex socket
- Bullet anchor: the hammer setting on a rotary-hammer drill against its steel drive rod inserted in the back of the bullet anchor (Figure 4-5*A* and *B*)

- Arrowhead anchor: one operator to hold the driving rod against the back of the anchor and another operator to drive in the anchor with repeated blows of a sledgehammer (Figure 4-6*A* and *B*)

All the traditional anchor types failed to penetrate frozen gravels with standard installation methods, and the penetrating auger anchor also failed to penetrate frozen silts with and without a pilot hole. In each case, the standard installation method did not provide enough driving force to enable the anchors to penetrate the hard and stiff frozen gravels. Additionally, in the case of the penetrating auger, it proved too wide at the tip of the screw to embed into the silt. When a pilot hole was drilled ahead of the penetrating auger, the auger tip was still unable to bite into the silt and simply spun freely on the surface. Subsequently, one 4 in. arrowhead and one bullet anchor were installed in frozen silts with their standard driving installation methods to depths of 6 and 12 in., respectively. It took approximately 10 min to install both anchors to their depths. For its part, the bullet anchor had an easier time penetrating the silt whereas the arrowhead anchor tended to fracture clods of silt and ice as it was driven. That is, the arrowhead did proceed to depth, but it took more time to proceed below the surface because the effective surface was lowered as the clods were fractured. No grout or slurry was needed for these anchors because their standard installation methods were successful.

Figure 4-5. Bullet style anchor installation.

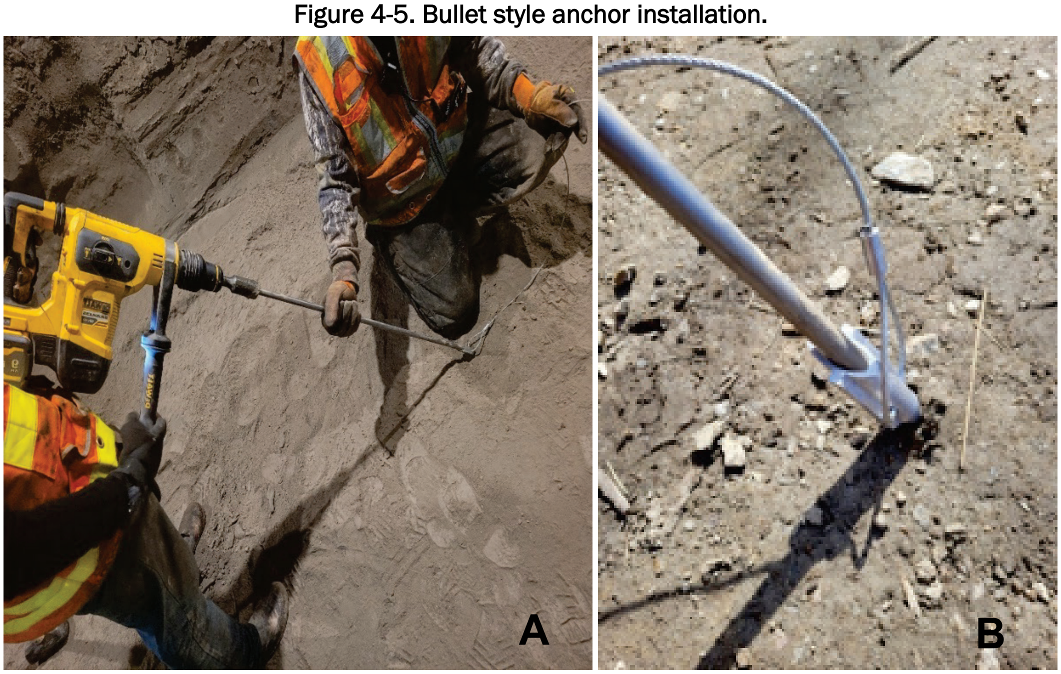
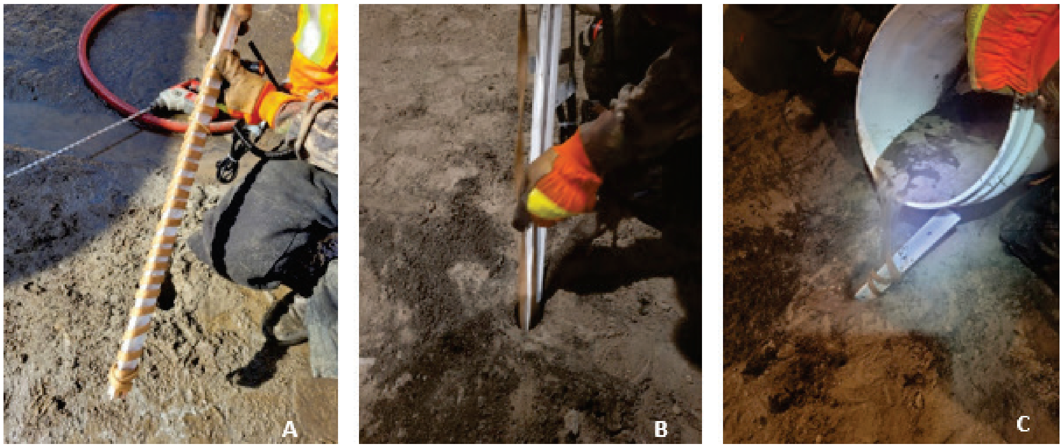


Figure 4-6. Arrowhead anchor installation. (*A*) Drive rod nested against arrowhead. (*B*) Two operators needed to install.

4.3.2 PVC T-post

To install the PVC T-posts, a $^{1}/_{2}$ in. diameter hole for each post was drilled with the same methods described in Section 4.3. The PVC T-post was installed in frozen gravels and another in frozen silts to depths of approximately 40 in., leaving approximately 8 in. of post above the surface to which the cable was attached. The post installed in gravels was wrapped with heat-trace tape (Figure 4-7*A*), and the post in frozen silts had heat-trace tape fed down the hole after insertion (Figure 4-7*B*). In actual-use situations, the PVC T-post must be removed after project completion for environmental conservation. In cold-climate areas, the PVC T-post may be frozen in place even during summer months; therefore, heat-trace tape will allow for post removal by thawing the ground around it. Here, heat-trace tape was included to replicate actual use. After each post and heat-trace tape were installed, each hole was backfilled with a water/soil mixture (Figure 4-7*C*) and allowed to freeze over 3 days.

Figure 4-7. (*A*) heat trace wrapped; (*B*) heat trace fed; (*C*) backfill slurry.

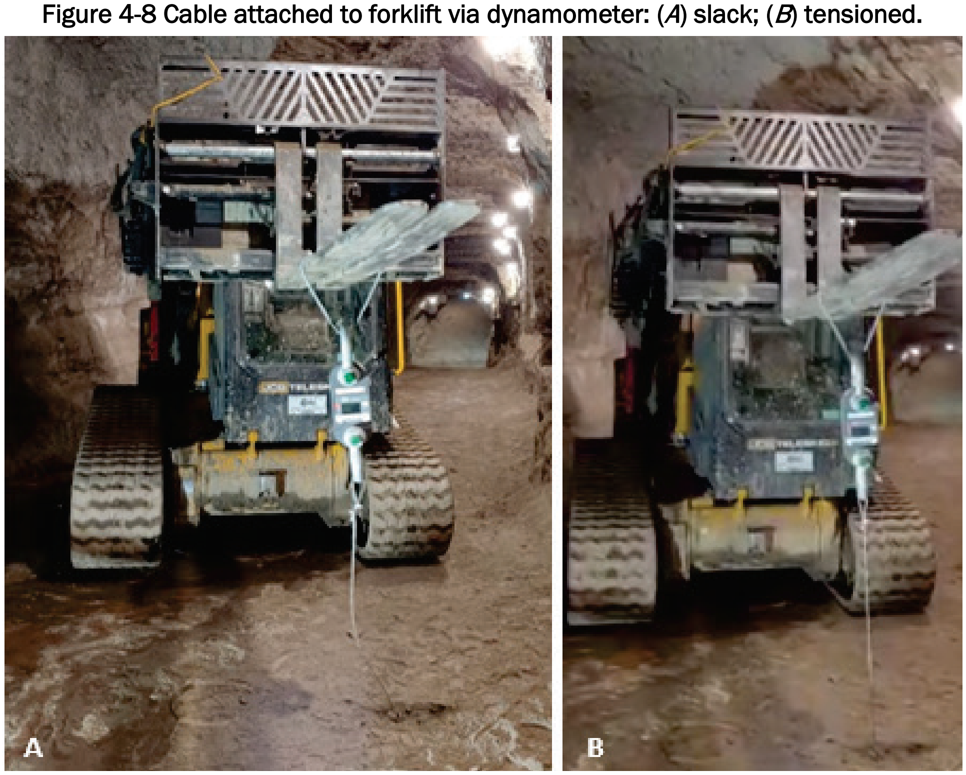


4.4 Anchor Failure Testing

4.4.1 Arrowhead and Bullet Anchors

For the failure test, each anchor's cable was attached to a dynamometer rated to 25,000 lb capacity. The dynamometer was then attached the forklift attachment on compact track loader, which was used to apply vertical force against the anchors (Figure 4-8*A* and *B*). For both tests, the ambient air temperature was 23°F, and in-ground temperature was 29°F.

Figure 4-8 Cable attached to forklift via dynamometer: (*A*) slack; (*B*) tensioned.



4.4.2 PVC Anchor Post

In the same manner as the traditional anchors, each PVC anchor post was attached with a steel cable to a dynamometer that was then attached to the forklift attachment of the compact track loader. The open-ended cable was closed via two, tightened cable clamps sized for that cable. Using the loader, force was applied along the long axis of the post until failure. A second test was performed on the PVC anchor post to evaluate its flexural strength against a load applied perpendicular its long axis. The post was originally installed at approximately 45° to the horizontal and then cabled to the dynamometer that was then attached to the forklift attachment on the compact track loader. Force was applied perpendicular to the long axis of the post until failure (Figure 4-9*A*, *B*, *C*, *D*). For both tests, the ambient air temperature was 23°F, and in-ground temperature was 29°F.

Figure 4-9. PVC in-ground flexural stress test: (*A*) Slack; (*B*) Moderate tension; (*C*) Heavy tension; (*D*) Failure.

5 Test Results

5.1 Drilling Observations for Both Ground Types

For both material types (frozen silts and frozen gravels), it was found that the multiuse cross bit tended to bind once the bit was below ground surface, necessitating the operator to retract the bit much more than with the top-hammer button bit. Conversely, the top-hammer button bit did not bind and proved more effective for penetration in both materials. The top-hammer button bit penetrated frozen gravels at a rate of approximately 0.1 ft/min and frozen silts at a rate of 0.5 ft/min. That is, it took approximately 4.25 min to drill 1 ft depth in frozen gravels but only 1.75 min to drill 1 ft depth in frozen silts. These times do also include bit retraction for hole cleaning, which was done approximately every minute.

All three traditional anchor types failed to penetrate frozen gravels with standard installation methods. In each case, the standard installation method (see Section 4.3.1) did not provide enough driving force to enable the anchors to penetrate the hard and stiff frozen gravels. Additionally, in the case of the penetrating auger, it proved too wide at the tip of the screw to embed into the silt. When a 1 in. diameter pilot hole was drilled ahead of the penetrating auger, the auger tip was still unable to bite into the silt and simply spun freely on the surface.

5.2 Anchor Test Results

The following table shows the results of all anchor types in frozen gravels and in frozen silts (Table 5-1). Only the arrowhead and bullet anchors penetrated the frozen silt. For both the arrowhead and bullet anchors, the cable failed rather than the anchor coming out of the ground (Figure 5-1*A* and *B*). The cables tore near the linkage point fraying the cables into individual strands. This suggests cable-joining techniques may be inherently weaker than the anchor itself. The direct-pull test for the PVC T-post yielded an unexpected result in that the PVC T-post simply slide out of the hole in the direction of pull. It was anticipated that the PVC would crack or fracture else the cable would tear in a similar manner to the arrowhead and bullet anchors. Yet, the PVC T-post slid easily out of the hole with no damage to the post itself or the cable. This suggests that the grout (in this case silt and water mixture) is the limiting factor determining the PVC T-post's resistance to pull out. That is, the frictional force between the grout and the in situ material must be greater than the applied force for the PVC T-post to remain in place. Additionally, force was applied perpendicular to the long axis of the PVC T-post to evaluate its flexural integrity. In this case, the PVC itself fractured rather than the cable failing, and the force at which failure occurred is notably less than the force at which the cables failed (Figure 4-9*D* in Section 4.3.2). The failure loads for each anchor type are also tabulated in Table 5-1.

Table 5-1. Results.

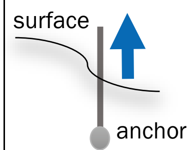
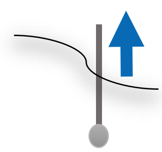
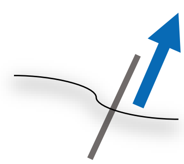
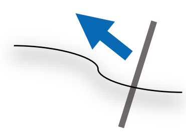
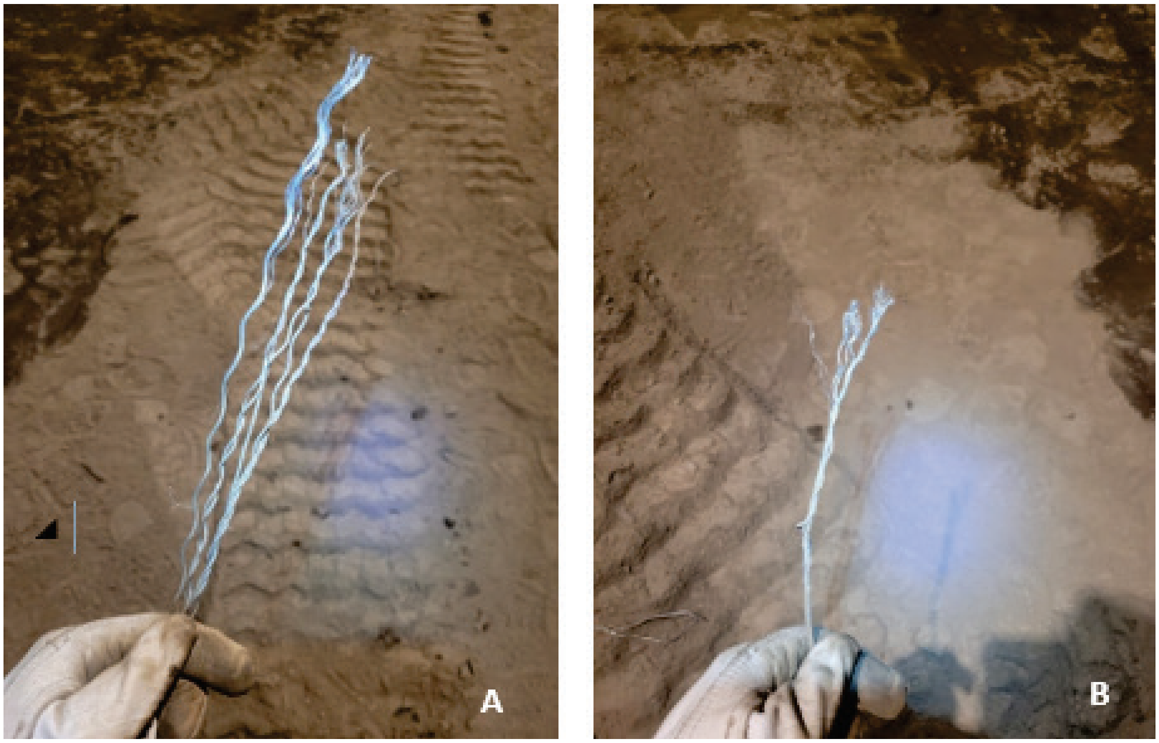
Anchor	Test Type	Failure Load (lb)	Force Type	Force Direction	Notes
Arrowhead (6 in. depth)	Direct Pull	3686.72	Tensile		Cable failure. Figure 5-1*A*
Bullet (12 in. depth)	Direct Pull	1753.44	Tensile		Cable failure. Figure 5-1*B*
PVC T-post	Direct Pull	1978.24	Frictional		Slide out. No damage
	Flexural Stress	202.32	Flexural		Clean break. Figure 4-8*D*

Figure 5-1. (*A*) arrowhead cable failure, (*B*) bullet cable failure.



6 Analysis

Installation of traditional or PVC T-post in either frozen silts or frozen gravels will likely be most efficient with an air-powered drill affixed with a top-hammer button bit as was demonstrated here. Drill bit sizes would depend on the installer's preferences. The system is deployable in the field provided there is a way to transport the air compressor to the site. Typically, airlifting has been used to transport equipment such as this to remote sites.

Regarding in situ conditions, frozen silts are easier for drilling than frozen gravels that, here, took almost four times as long to penetrate. Different volumetric combinations of silt and gravel will, of course, present different penetration times; therefore, the times discovered here are not indicative of all drill times. One key variable is the number of times the drill bit is retracted to remove cuttings. Since cuttings in either frozen gravels or frozen silts tend to refreeze as the drill bit proceeds deeper, efficiency is maximized when the bit is periodically retracted to remove cuttings. Retraction rate depends entirely on field conditions such as ambient air temperature, soil or gravel temperature or both, water content of the material, desired depth of the hole and others. The methodology presented here is intended to demonstrate an expedient, handheld drilling system that is capable of penetrating frozen material, and the times and quality of penetration function as estimates for field conditions.

Unexpectedly, the result of the direct-pull test on the PVC T-post was it smoothly sliding out of the hole. This may be because the smooth surface of the PVC provides little to no grip on the natural surface. Attempting to replicate field conditions, in situ material was used to create the fill mixture (or grout) that was poured into the hole with the PVC T-post. Here, the mixture was silt and water, but other mixtures may exist that provide a better frictional surface against pull-out forces. However, over a given period and regardless of grout type, the PVC T-post may be able to work its way out of hole under periodic pull-out forces of lesser value. These forces could manifest in varying wind loads, for example. Another key result is that the direct pull-out failure force was almost 10 times more than the flexural failure force for one continuous pull. This result suggests angling the PVC post such that the load is directed along the long axis is more effective than directing the load perpendicular to the long axis.

7 Conclusions and Recommendations

7.1 Conclusions

The traditional arrowhead and bullet anchors struggled to penetrate both soil types even with a pilot hole drilled first. Furthermore, if traditional anchors are desired and a pilot hole is drilled, the bullet and arrowhead anchors may prove less effective. This is because they each depend on cable tensioning to rotate and drive their wedges into the soil; therefore, a pilot hole may decrease the resistance area available to the wedge. Finally, since the traditional anchors are metal wedges with steel cables, they conduct significantly more heat than the PVC T-post. Therefore, using traditional anchors may induce ground thawing at a rapid rate in warm seasons.

7.2 Recommendations

From preliminary tests, the following is recommended:

- Further study be conducted specifically evaluating the rate at which metal anchors thaw permafrost ground and compare to the rate for PVC T-posts.
- Additional study be conducted regarding the cabling used to attach the PVC T-post to the force applier. Determine at what point the post will fail given varying sizes of cable.
- Additional evaluation of different grout mixes be conducted during direct-pull test on PVC T-posts.
- Further study be conducted where the PVC T-posts are monitored long term to evaluate the effect of irregular forces over multiple seasons.

References

Adams, J. I., and T. W. Klym. 1972. "A Study of Anchorages for Transmission Tower Foundations." *Canadian Geotechnical Journal* 9 (1): 89–104.

Alaska Climate Research Center. 2023. "Fairbanks AP." Alaska Climate Research Center: The Alaska State Climate Center. https://akclimate.org/climate/.

Begét, J. E., D. Stone, and D. L. Verbyla. 2006. "Regional Overview of Interior Alaska." In *Alaska's Changing Boreal Forest*, edited by F. S. Chapin III, M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. L. Verbyla, 12–20. New York, New York: Oxford University Press, Inc.

Bernardin, R. M. 1961. *Aircraft Mooring Equipment*. Fort Eustis, VA: Army Transportation Research Command.

Biggar, K. W., and V. Kong. 2001. "An Analysis of Long-Term Pile Load Tests in Permafrost from the Short-Range Radar Site Foundations." *Canadian Geotechnical Journal* 38 (3): 441–460.

Bjella, K. 2015. *Geotechnical Study and Foundation Structural Design, Next Generation Ionosonde (NEXION) Installation, Thule Air Base, Greenland*. ERDC/CRREL TR-15-13. Hanover, NH: US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.

Briaud, J., R. B. Griffin, A. T. Yeung, A. Soto, A. Suroor, and H. Park. 1998. *Long-Term Behavior of Ground Anchors and Tieback Walls*. Report No. 1391-1. Austin, TX: Department of Transportation, Research and Technology Transfer Office.

Bruce, D. A. 1989. "Methods of Overburden Drilling in Geotechnical Construction—A Generic Classification." *Ground Engineering* 22 (7): 25–32.

Crory, F., R. Reed, W. Tizzard, and C. Font-Jimenez. 1969. *Installation and testing of Arrowhead Universal Ground Anchors in Frozen and Thawed Ground*. Technical Report. Hanover, NH: US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory.

DeFrees, L. J. 1955. *Arctic Adapters, Drive-Type Pickets*. Project 1763 Arctic, AD 72108. Fort Monroe, VA: Continental Army Command, Arctic Test Branch Big Delta Alaska.

Drage, J., and H. Brooks. 2012. "Performance of a Thermopile (Long Thermopile) Foundation- 50 Years Later." In *Cold Regions Engineering 2012*: *Sustainable Infrastructure Development in a Changing Cold Environment,* 358–368. https://doi.org/10.1061/9780784412473.036.

Hironaka, M. C., 1974. *Anchoring in Snow, Ice, and Permafrost*. Technical Note N-1344. Washington, DC: Naval Facilities Engineering Command, Civil Engineering Laboratory, Naval Construction Battalion Center.

Johnston, G. H., and B. Ladanyi. 1972 "Field Tests of Grouted Rod Anchors in Permafrost." *Canadian Geotechnical Journal* 9 (2): 176–194.

Jorgenson, T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, and B. Jones. 2008. *Permafrost Characteristics of Alaska*. Fairbanks, AK: University of Alaska, Fairbanks. https://permafrost.gi.alaska.edu/sites/default/files/AlaskaPermafrostMap_Front_Dec2008_Jorgenson_etal_2008.pdf.

Koch, J. C. 2016. "Lateral and Subsurface Flows Impact Arctic Coastal Plain Lake Water Budgets." *Hydrological Processes* 30:3918–3931. doi:10.1002/hyp.10917.

Kongkitkul, W., S. Srisakorn, T. Chantachot, S. Youwai, P. Jongpradist, and C. Bunjongruksa. 2013. "Evaluation of Guy Anchorage Strength in Clay for Transmission Tower." *Journal of Testing and Evaluation* 41 (4): 564–570.

Köppen, W. 1884. "The Thermal Zones of the Earth According to the Duration of Hot, Moderate, and Cold Periods and of the Impact of Heat on the Organic World." *Meteorologische Zeitschrift* 1:215–22. http://koeppen-geiger.vu-wien.ac.at/koeppen.htm.

Kovacs, A. 1973. *Hook Anchor Tests in Frozen and Unfrozen Ground*. SR 229. Hanover, NH: US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory.

Kovacs, A., B. McKelvy, and H. Colligan. 1975. *On the Theory of Ground Anchors*. TR 258. Hanover, NH: Cold Regions Research and Engineering Laboratory.

Lin, C., L. Chen, X. Zhang, and R. Mchattie. 2013. *Creep Behavior of Shallow Anchors in Ice-Rich Silt*. Fairbanks: University of Alaska, Fairbanks.

Majid, M. R. A., and Z. Ideris. 2012. "Pullout Behavior of Vertical Ground Anchor in Dry Homogenous Sand at Different Relative Densities." *ESTEEM Academic Journal* 8 (1): 28–38.

Ono, T. 2015. "A Method for Estimating Frost Heave Forces Acting on Ground Anchors. Cold Regions Engineering." In *American Society of Civil Engineers. 16th International Conference on Cold Regions Engineering,* July 19–22, 2015, 394–403. Salt Lake City, UT.

Ozhan, H., and E. Guler. 2017. "Critical Tendon Bond Length for Prestressed Ground Anchors in Pullout Performance Tests Conducted in Sand." *International Journal of Civil Engineering* 16 (11): 1–12.

Panda, S. K., A. Prakash, D. N. Solie, V. E. Romanovsky, and M. T. Jorgenson. 2010. "Remote Sensing and Field-Based Mapping of Permafrost Distribution along the Alaska Highway Corridor, Interior Alaska." *Permafrost and Periglacial Processes* 21:271–281. https://doi-org.erdclibrary.idm.oclc.org/10.1002/ppp.686.

Péwé, T. L. 2018. "Permafrost." *Encyclopædia Britannica*. https://www.britannica.com/science/permafrost.

Péwé, T. L., C. Wahrhaftig, and F. Weber. 1966. *Geologic Map of the Fairbanks Quadrangle, Alaska*. Series No. 455. Reston, VA: US Geological Survey. https://www.usgs.gov/maps/geologic-map-fairbanks-quadrangle-alaska.

Sabatini, P. J., D. G. Pass, and R. C. Bachus. 1999. *Geotechnical Engineering Circular No. 4: Ground Anchors and Anchored Systems*. FHWA-IF-99-015. Federal Highway Administration Technical Manual. Washington, DC: Office of Bridge Technology.

Sayles, F. H., and D. Haines. 1974. *Creep of Frozen Silt and Clay*. Technical Report 252. Hanover, NH: US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory.

Turner, M. 2015. "Chapter 66 Geotechnical Design of Ground Anchors." In *ICE Manual of Geotechnical Engineering: Volume II*. Thomas Telford, Ltd: London, England. https://www.icevirtuallibrary.com/doi/full/10.1680/moge.57098.1011.

USGS (US Geological Survey). 2019. "Arctic Coastal Plain Studies." https://www.usgs.gov/centers/asc/science/arctic-coastal-plain-studies?qt-science_center_objects=0#qt-science_center_objects.

Wagner, A. 2014. *Review of Thermosyphon Applications*. ERDC/CRREL TR-14-1. Hanover, NH: US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.

Western Regional Climate Center. n.d. "State Extremes." Accessed 4 May 2021. https://wrcc.dri.edu/htmlfiles/state.extremes.html.

Wymer, P. A., R. A. Robinson, and D. T. Sharp. 2003. "Ground Anchor Practice in New Zealand: A Review of Applications, Design and Execution." In *Proceedings of Technical Groups—Institution of Professional Engineers New Zealand* 30 (1GM), 417–427.

Zhang, T., T. E. Osterkamp, and K. Stamnes. 2018. "Some Characteristics of the Climate in Northern Alaska, USA." *Arctic and Alpine Research* 28 (4): 509–518. doi:10.1080/00040851.1996.12003204.

Zubeck, H. K., and H. Liu. 2003. "Design of Helical Pier Foundations in Frozen Ground." *International Conference on Permafrost Proceedings* 8 (2): 1307–1312.

REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	3. DATES COVERED END DATE
July 2023	Final Report	FY 21	FY 22

4. TITLE AND SUBTITLE

Preliminary Testing of Expedient Ground Anchor Solutions for Guyed Towers in Remote Cold Regions: Considerations for Cold Remote Regions with Limited Tools

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

6. AUTHOR(S)

Kevin Bjella, Daniel Vandevort, and Sarah Kopczynski

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army Engineer Research and Development Center Cold Regions Research and Engineering Laboratory 72 Lyme Road Hanover, NH 03755	ERDC/CRREL TR-23-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
US Army Engineer Research and Development Center (ERDC) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	ERDC	

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

FLEX-4

14. ABSTRACT

Ground anchors connected to guy wires for tower structures in cold climates suffer from frost heaving, which causes loss of wire tension and subsequent structural instability. It is necessary to understand what ground anchors are available to resist this tendency yet are still capable of expedient installation in remote areas. To that end, three metal, traditional ground-anchor types (arrowhead, bullet, and penetrating auger) and one novel polyvinyl chloride (PVC) T-post anchor were evaluated in frozen gravels and frozen silts at a research facility in Fairbanks, Alaska. Criteria included installation capability, failure loading, and removal ability. Additionally, expedient installation techniques for use in field conditions were also demonstrated. All three traditional ground anchors failed to penetrate frozen gravels. The penetrating auger also failed to penetrate frozen silts, but the arrowhead and bullet anchors did penetrate frozen silts with difficulty. The PVC anchor is capable of being installed only in a predrilled pilot hole. Under flexural load, the arrowhead anchor cable failed at 3686.72 lb, and the bullet anchor cable failed at 1753.44 lb. The PVC slid out of its hole at a direct-pull force of 1978.24 lb and failed under flexural stress at 202.32 lb.

15. SUBJECT TERMS

Anchorage (Structural engineering); Frost heaving; Frozen ground; Geotechnical engineering; Guy anchors; Permafrost

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
Unclassified	Unclassified	Unclassified	SAR	42

19a. NAME OF RESPONSIBLE PERSON	19b. TELEPHONE NUMBER (include area code)
Daniel Vandevort	907-361-6276