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THE ASSISTANT SECRETARY OF DEFENSE
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The Honorable James M. Inhofe
Chairman
Committee on Armed Services
United States Senate
Washington, DC 20510

Dear Mr. Chairman:

Senate Report 115-262, page 398-399, accompanying S. 2987, the John S. McCain National Defense Authorization Act for Fiscal Year 2019, requests the Assistant Secretary of Defense for Energy, Installations, and Environment submit a report with an assessment of military structures in permafrost areas. The report is enclosed.

Thank you for your continued support of Defense installations. An identical letter has been sent to the other congressional defense committees.

Sincerely,

Robert H. McMahon

Enclosure:
As stated

cc:
The Honorable Jack Reed
Ranking Member

Department of Defense

REPORT TO CONGRESS
ON
MILITARY STRUCTURES IN PERMAFROST AREAS

The Office of the Under Secretary of Defense
(Acquisition and Sustainment)

May 2019

The estimated cost of this report for the Department of Defense is approximately $10,000 for the 2019 Fiscal Year.
This includes $1,000 in expenses and $9,230 in DoD labor.
Generated on 2019May22 RefID: 4-9587060

REPORT TO CONGRESS
MILITARY STRUCTURES IN PERMAFROST AREAS

Senate Report 115-262, page 398-399, accompanying S. 2987, the John S. McCain National Defense Authorization Act for Fiscal Year 2019, requests the Assistant Secretary of Defense for Energy, Installations, and Environment submit a report with an assessment of military structures in permafrost areas no later than 180 days after the enactment of the Act:

> Assessment of Military Structures in Permafrost Areas
>
> The committee remains concerned that climate-related events are already being observed at Department of Defense (DOD) installations and that the effects of which will continue to have an impact on both the security environment in which military forces operate and on DOD infrastructure worldwide. For instance, the committee notes that melting permafrost in Alaska had led to costly and unexpected repairs of facilities. Additionally, the committee is concerned that a failure to address identified deficiencies can over time put DOD military readiness, mission capability, military construction, and valuable taxpayer resources at risk. Accordingly, the committee directs the Assistant Secretary of Defense for Energy, Installations, and Environment to submit to the congressional defense committees a report with an assessment of military structures in permafrost area no later than 180 days after the enactment of this Act. The assessment shall include: (1) An inventory of all military structures currently built in permafrost areas, including Alaska, Greenland, and northern European countries to include all planned new military construction in permafrost areas for the next 4 fiscal years; (2) An inventory of which structures at Eielson Air Force Base, if any, are experiencing stresses and impacts associated with melting permafrost foundation degradation to include proposed repairs or new construction; (3) An explanation of how the DOD determines what constitutes a permafrost area; (4) A description of the process by which the DOD determines whether a deep foundation is necessary in a permafrost area, including cost factors; (5) An assessment of how design and construction standards account for foundation integrity in the event of permafrost degradation; (6) A description of the cost difference between building on standard foundations and deep foundations associated with permafrost degradation to include repairs over the life of the project for both; and (7) Any other information or recommendations the Assistant Secretary of Defense determines appropriate.

Background

The Arctic and sub-Arctic regions are vast, encompassing a variety of unique environments and extreme climatic conditions. Special equipment, materials, and techniques have been developed over the years to meet DoD needs in this, largely, austere and remote region of the world. Prior to World War II (WWII) the U.S. Department of Defense (DoD) had limited large scale operational experience in the high latitude regions of the world. Major build-up of several military installations in Alaska began in the early 1940's, necessitated by the Japanese occupation in the Aleutian Islands and the threat of further invasion, and facilitated by the construction of the Alaska/Canada Highway. With the onset of the Cold War, Arctic military reconnaissance operations, surveillance missions, and military strategy planning became paramount, resulting in the construction of additional installations scattered across Alaska, Canada, and Greenland. The 1990's saw the ending of the Cold War and, as a result, the DoD attention turned away from the Arctic and sub-Arctic region.[1]

However, rising air temperature in the Arctic domain is creating change, which is drawing attention back to the region. Increases in economic opportunities as well as geo-political concerns are often cited as outcomes of this increase in temperature and, under current projections, the perceived opening of the Arctic could result in the DoD being called upon to operate at a volume and tempo beyond the current capacity. In order to provide a secure and stable region where U.S. national interests are safeguarded and U.S. homeland is defended, DoD infrastructure will need to be logistically efficient, robust to the rigors of the region, and remain as maintenance free and useful for as long as required.[2]

The DoD strategy (Arctic Strategy 2013) uses a definition of Arctic, codified at 15 U.S.C. § 4111, defined as all U.S. and foreign territory north of the Arctic Circle and all U.S. territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian islands chain. The climate of the Arctic is formidable. Winter temperatures can drop to as low as -51°C (-60°F) in Alaska and Canada and -62°C (-80°F) in Yukutia, Russia. Winters are long—eight to nine months in duration—with limited to no direct sunlight from November to February. During the winter months, lakes, rivers and seas remain frozen and winter storms often bring hurricane force winds. Arctic infrastructure must provide reliable and robust shelter capable of high thermal efficiency, wind and snow drift resistance, humidity control for modern electronic instrumentation, limited thermal expansion and contraction, and resistance to freezing/thawing cycles. The persistent cold has also produced a unique landscape attribute of perennially frozen ground, also known as permafrost. Permafrost exists nearly everywhere in the Arctic, is vulnerable to increasing atmospheric temperatures and presents unique stability challenges to both new and existing infrastructure. Some of the more critical factors for consideration when developing logistically efficient, robust and maintenance free Arctic infrastructure include: resiliency to permafrost thaw, thermal efficiency, lightweight and high strength materials, ease of reconfiguration, and adaptability to building utility and data technology advances. The following sections describe existing DoD facility assets and associated construction techniques and requirements needed to respond to a changing Arctic environment, a strategy to, at least partially, meet those requirements and a synopsis of the current state of art in cold region construction techniques and materials.[3]

Responses to specific requests are provided in the following section.

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[1] U.S. Army Corps of Engineers white paper, "Assessment of Military Structures in Permafrost Areas" (Kevin Bjella, P.E. author), May 2019

[2] Ibid.

[3] Ibid.

REPORT TO CONGRESS
MILITARY STRUCTURES IN PERMAFROST AREAS

(1) An inventory of all military structures currently built in permafrost areas, including Alaska, Greenland, and northern European countries to include all planned new military construction in permafrost areas for the next four fiscal years

U.S. military installations and their degree of underlying permafrost are summarized in Table 1 below. These installations are:

1. Clear Air Force Station, 100km (60mi) southwest of Fairbanks, constructed on what was once pre-historically frozen ground that is now considered to be mostly in the thawed state and not problematic.

2. Eielson Air Force Base (EAFB) and Fort Wainwright (FTW) near Fairbanks, Alaska, where the majority of infrastructure was constructed on ice-poor to ice-moderate permafrost. Records indicate buildings 1001, 4070, and Old Bassett Army Hospital were built on frozen gravels. However recent construction in the last 10 years has provided spotty evidence of near surface permafrost. Because the land was cleared of dense boreal forest which insulates and protects the permafrost from thawing, permafrost has probably thawed to a depth of 12m to 15m (40ft to 50ft) and still exists across most of both installations but at depth not encountered by project geotechnical drilling. At EAFB, some structures are currently on frozen ground and do have some minor problems.

3. Fort Greely, 160km (100mi) southeast of Fairbanks on the foothills of the north slope of the Alaska Range, largely constructed on thawed gravels of Jarvis Creek. This includes all the infrastructure of the Missile Defense Agency Ground-based Midcourse Defense system (GMD) with no known permafrost issues.

4. The North Warning System (NWS) of surveillance and tracking radars (AF 611th) stretching across the northwest and northern coast of Alaska and through Canada to the Atlantic. This is a remnant of the Defense Early Warning (DEW) Line. All the structures are constructed on permafrost and are constructed to maintain the ground in the frozen state. There are no notable problems due to permafrost, but coastal erosion is affecting two of the sites due to longer ice-free seas in the autumn season which allow the coastlines to be vulnerable to aggressive autumn storms.

5. Thule Air Base in the northwestern portion of Greenland, the northernmost U.S. military installation. Every structure is located on ice-rich permafrost and each is constructed to maintain the ground in the frozen state. A small percentage of the structures have moderate to severe problems due to thawing ground ice. The problems are mainly constrained to structures that had been improperly engineered during retrofit or enlargement, and the problems are actively being managed and do not affect the mission.

Table 1. DoD installations located in known permafrost areas[4]

Installation	Location	Type of permafrost	Structures on permafrost	Structures with known permafrost problems	Projects planned FY20-23
Clear AFS	Anderson, AK	Discontinuous	None	None	2
Eielson AFB	North Pole, AK	Discontinuous	Numerous	2	1
Ft. Greely	Delta Jct, AK	Discontinuous	None	None	1
Ft. Wainwright	Fairbanks, AK	Discontinuous	Numerous	None	1
North Warning System	Across Alaska and Canada	Continuous	All	None	None
Thule AB	NW Greenland	Continuous	All	9	None

Table 2. Planned new construction

FY	Project description	Location	Organization/ Command	Construction agent	Est. cost ($000)
2020	F-35 Alternate Mission Equipment Storage Facility	Eielson AFB	PACAF	USACE	$8,600
2021	Consolidated Civil Engineers and Security Forces Complex	Clear AFS	AFSPC	USACE	$66,800
2021	84-person Dormitory	Clear AFS	AFSPC	USACE	$59,100
2021	Communication Facility, Ground-based Midcourse Defense System	Ft. Greely	MDA	USACE	$48,000
2023	Automated Multipurpose Machine Gun Range	Ft. Wainwright	USARPAC	USACE	$15,000

Facilities inventories for installations listed in Table 1 are provided in an electronic spreadsheet as a separate FOUO enclosure. This spreadsheet provides information on 7,042 asset records pulled from the DoD Real Property Asset Database for End-of-Year FY 2018.

(2) An inventory of which structures at Eielson Air Force Base, if any, are experiencing stresses and impacts associated with melting permafrost foundation degradation to include proposed repairs or new construction

Eielson AFB was constructed in the later part of World War II as an alternate landing site for what was then Ladd Air Force Base, now Fort Wainwright. Most of the development as is seen today occurred at that time. EAFB is a mixture of permafrost types, with moderate ice-rich alluvial gravels largely underlying the main cantonment, and very ice-rich soils in the hills to the east and northeast.

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[4] Ibid. Although located in Alaska, both Joint Base Elmendorf-Richardson (near Anchorage) and Eareckson Air Force Station (located on Shemya Island in the Aleutian chain) are in regions of isolated or no permafrost due to mean average air temperatures being too warm. The Navy no longer has facilities on permafrost terrain since relinquishing ownership of the former Navy Arctic Research Laboratory (NARL) in Utqiagvik, Alaska (Barrow).

The Air Force identified six military construction projects at Eielson Air Force Base since 2016 (out of 19 total MilCon projects completed or still in progress) that have encountered permafrost. The following table lists these projects, ranging in estimated cost from $12.8 million to $44.9 million, along with the required mitigation and associated cost for each project.

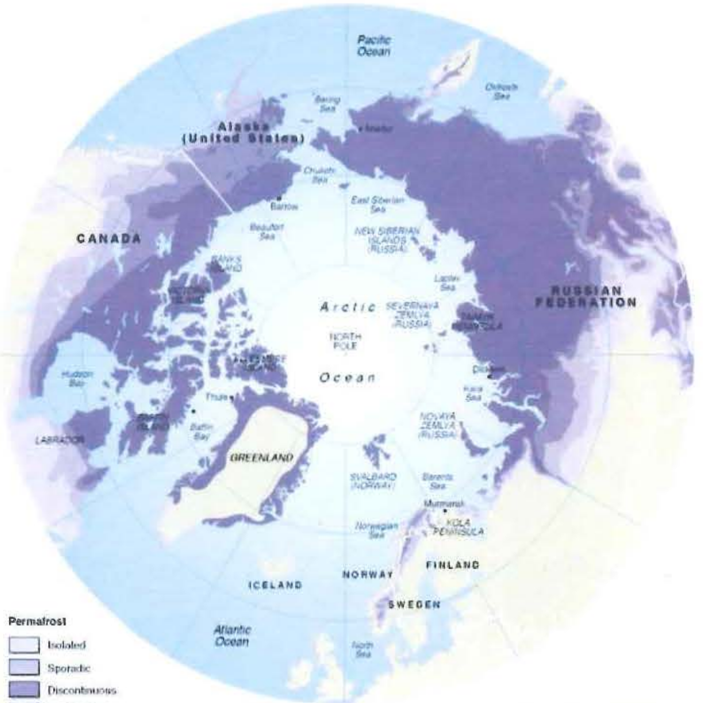
FY	Project No.	Project Title	PA ($000)	Permafrost mitigation measure	Mitigation cost	
					($000)	(% of PA)
2016	FTQW163011	F-35A Flight Sim / ADAL Squadron Ops/ AMU	$37,000	Permafrost was removed and replaced with non-frost susceptible fill.	$360	1.0%
2017	FTQW170106	F-35A Hangar/ Propulsion Maint/ Dispatch	$44,900	Ground thawing 30 feet below level of excavation, Deep Dynamic Compaction (DDC), classified material backfill	$1,600	3.6%
2017	FTQW170113	F-35A Earth Covered Magazines	$11,300	Passive Cooling - Site is constrained by explosive site safety arc and cannot be relocated outside of the approved area. Passive cooling has been selected as the method of mitigation due to the extent of permafrost underlying the area.	$830	7.3%
2017	FTQW170114	F-35A Hangar/ Squadron Ops/ AMU Squadron #2	$42,700	Ground thawing 30 feet below level of excavation, Deep Dynamic Compaction (DDC), classified material backfill	$1,100	2.6%
2017	FTQW170107	F-35A Missile Maintenance Facility	$12,800	Permafrost was observed in 27 of the 32 boreholes (16 feet or 50 feet) at the site. In some cases where permafrost was observed, it was encountered just below the active layer nd extended to the bottom of the borehole. However, in many boreholes, especially near the center and southern portions of the site, permafrost was observed near the surface, but did not extend to the bottom of the borehole. As the permafrost at the site degrades, there is a potential for liquefaction in previously frozen layers which may lead to greater than predicted liquefaction induced settlement. Perform all initial excavation to approximately elevation 547 feet or as required to remove all organics and frost susceptible soils. During Geotechnical Investigations, groundwater was encountered from 547 to 549 feet. Backfill with classified material to 3 feet above water table and proof roll Deep Dynamic Compaction surface prior to DDC.	$680	5.3%

FY	Project No.	Project Title	PA ($000)	Permafrost mitigation measure	Mitigation cost	
					($000)	(% of PA)
2019	FTQW1054329	F-35 Conventional Communications Maintenance Facility	$15,500	Permafrost was encountered in six of the sixteen test borings below depths greater than about 20 feet from ground surface, and was generally absent in the test borings nearest the existing Bldg 6385. The potential geologic hazards considered most likely to affect design and construction include permafrost and earthquakes (i.e. strong ground shaking and liquefaction). The permafrost soils once thawed as expected to be susceptible to earthquake induced liquefaction. Existing subgrades under the building, fire water tank, and paved areas will be over excavated. If frozen soils are present, excavate additional 2 feet minimum or allow to thaw.	$500	3.2%

(3) An explanation of how the DOD determines what constitutes a permafrost area

DoD Unified Facilities Criteria (UFC) 3-130-01, General Provisions - Arctic and Sub-Arctic Construction, defines permafrost as perennially frozen ground. It may be defined more specifically as a thermal condition in soil or rock in which temperatures below 0°C (32°F) persist over at least two consecutive winters and the intervening summer. Permafrost consists of soil, rock, and ground ice, and generally provides rigid base material suitable for the foundation of Arctic infrastructure.

Key characteristics of a permafrost area are thickness and degree of continuity. Figure 1 depicts permafrost continuity in the northern hemisphere based on data from the International Permafrost Association. Permafrost is extensive across the glacial margins of Greenland, and across northern Canada to include all the North Warning System installations. Over 60 percent of Russia is composed of permafrost terrain, particularly large portions of Siberia and the Far East. Nearly 25 percent of the northern hemisphere land surface, and 85 percent of Alaska, is composed of permafrost. At extreme northern latitudes such as Utqiagvik, (Barrow) Alaska and Thule AB, Greenland, the permafrost is very cold (-11°C or 12°F), very thick (greater than 300m or 1000ft), and extends laterally without discontinuities. Moving southward, the thickness and continuity of the permafrost decreases with the increasing mean annual air temperature. Interior Alaska permafrost is very warm at -2.0°C to -0.8°C (29°F to 31°F), seldom greater in thickness than 60m (200ft), and predictably absent at certain locations such as on the south side of slopes. Further south in Anchorage, the permafrost is located only in scattered isolated pockets.



Source: International Permafrost Association, 1998
Circumpolar Active-Layer Permafrost System (CAPS), version 1.0

Figure 1. Permafrost continuity in the Northern Hemisphere

For engineering purposes, a designer must account for more than the ground temperature to understand the nature of a permafrost area and its suitability for construction. Ice content is the most critical aspect for engineering. For example, if a very dry gravel (negligible moisture content) is below freezing temperatures, and there is no ice to bind the soil particles together, the gravel behaves as if at an above freezing temperature. Borehole drilling is the best method to absolutely identify the existence and boundaries of permafrost, where the drilling resistance alone often identifies exactly the depth where thawed soils of any type, are now frozen. Borehole drilling allows for the taking of soil/rock samples and moisture content and soil type testing is conducted to better classify the materials. Borehole drilling is costly and time consuming, and the samples are taken at a small point in often very ground-ice heterogenous terrain. DoD has been leading the way in using surface-based geophysical methods to 'connect-the-dots' between the boreholes and draw a more complete and realistic map of the subsurface variable ground-ice condition. Surface features also help the engineer in identifying permafrost terrain. Specific vegetation species thrive in colder and poorly drained soils, thermokarst features (areas that have experienced thaw settlement) are ready indicators of ice-rich terrain. Roadways and other structures nearby might also be affected by thawing permafrost and this is readily visible to a trained professional.

(4) A description of the process by which the DOD determines whether a deep foundation is necessary in a permafrost area, including cost factors

Engineers use various methods to construct on frozen ground. The appropriate solution is dependent on both the nature of the permafrost (the amount of ground ice within the proposed infrastructure thaw zone, and the type and layering of the soil or rock), and the nature of the proposed structure to be built upon it (its function, intended life span, and the consequence of foundation failure). When the soil is an alluvial gravel—very common in valley bottoms in Arctic regions—the ground ice consists primarily of matrix ice and little to no massive ice. In this soil type, the resulting thaw settlement will be low and 'thaw-stable'. Elsewhere where alluvial gravel cannot accumulate (such as on hill slopes and ridge lines), finer-grained sediments are often found which can contain extreme levels of ground ice. This soil type produces very large thaw settlements and is termed 'thaw-unstable'.

Due to these disparate soil type thaw characteristics, foundation alternatives range from rather simple to extremely complex. Shallow ice-rich layers can be excavated and removed, whereas deeper lying ground ice may require the structure to be elevated on piles or columns/pads to allow for winter air to flow under the structure. Alternatively, mechanical freezing may be prescribed with either passive methods (thermosyphons/heat-pipes) or mechanical cooling with buried refrigeration loops.

Generally speaking, colder permafrost temperature is easier to engineer as thermal equilibrium is more difficult to disrupt to the point of thawing the ground ice. Areas of warmer temperature and discontinuous permafrost as found at Fort Wainwright and Eielson Air Force Base are much more sensitive to permafrost thaw and less suitable to simple design solutions. In such areas with discontinuous permafrost, thorough site characterization surveys are essential to understand the best engineering alternatives. Proper characterization utilizes a combination of borehole drilling and soil sample testing.

DoD Unified Facilities Criteria (UFC) 3-130-04, Foundations for Structures - Arctic and Sub-Arctic Construction, provides the methodology to determine what bearing capacity is possible for a particular type of foundation (footings, rafts, piers) for a particular type of soil/rock. Assuming the soil conditions are based on subsurface testing and ground ice mapping, foundation geometry can be adjusted to potentially attain the required bearing capacity. The engineer will calculate bearing capacity of the soil/rock after the ground ice has thawed. This, combined with the anticipated deflection (thaw-settlement) based on thawed ground ice will determine how to proceed for the determined foundation type. If it is not possible within realistic physical constraints to attain bearing capacity after thaw with a shallow footer foundation, and thaw-settlements will be too great for the structure to resist, other solutions must be considered to attain the required bearing capacity.

If geologically possible, the next feasible option is to establish firm founding in a long-term stable earth material such as bedrock via steel piles. Driving piles is costly, but favorable when compared to the long term maintenance and rehabilitation costs associated with the failing shallow footer foundation. Pile foundations placed firmly in competent bedrock material, or driven solidly into deeper frozen ground that has been calculated to remain frozen during the life of the structure, are the often the preferred alternative when compared to the more-costly alternative of actively freezing and maintaining the ground conditions in the frozen state.

Pile driving is generally cost-effective to depth between 30m to 45m (100 ft to 150ft). Driving of piles into deeper lying permafrost requires calculation of long term visco-elastic deformation due to ground ice creep. Ice creep deformations are generally only a fraction of the size of settlement from permafrost thawing.

Although a structure foundation may be designed to withstand continued thawing of permafrost underneath it, potential will still exist for settlement of parking aprons and roadways and other ancillary infrastructure not specifically designed to withstand thaw settlement. Such horizontal construction is generally not suitable for a deep foundation due to its extensive footprint on the ground and the associated prohibitive cost.

(5) An assessment of how design and construction standards account for foundation integrity in the event of permafrost degradation

DoD Unified Facilities Criteria (UFC) UFC 3-130-04, Foundations for Structures - Arctic and Sub-Arctic Construction, provides the methodology to understand the consequences of the introduction of heat to the permafrost ground ice condition. The engineer will review the geotechnical data obtained, and calculate thaw-settlement potential for an anticipated ultimate life thaw depth. Once the anticipated ultimate settlement is calculated for a thermally unprotected foundation option, the engineer then weighs all the impending factors to cost effectively offset the settlement via alternate foundation methods (deep foundation, over-excavation, ambient air or mechanical freezing). This is an extremely site-specific cost analysis due in large part to local costs for manpower and availability of materials.

For example, for a project at Thule Air Base in Greenland, a shallow ground ice layer (7m or 23ft) was over-excavated and backfilled with processed river gravel not susceptible to ice formation from a source only 1km (0.6mi) away. This alternative provided a 'climate neutral' and cost-effective solution in perpetuity.

In light of continued climate warming, the engineer must take into account rising permafrost temperatures during the life of the structure. In discontinuous permafrost zones, the relatively "warm" permafrost is very sensitive to even slight changes in the thermal regime, causing it to thaw and become deeper—a factor significant to the design analysis of deep foundation alternatives. Unfortunately, there are no vetted design standards to provide engineers a method for calculating thaw depth or ice strength in the very long term. Many engineers (both government and industry) are using the projected increase in air temperature from modeled climate scenarios provided by the International Panel on Climate Change (IPCC). Others are extrapolating the air temperature rise which has occurred over the last three decades to provide a linear approximation, or adding a value based on other estimating methods. Developing an industry standard practice to estimate this projected temperature increase is of high importance to resilient Arctic and sub-arctic construction.

(6) A description of the cost difference between building on standard foundations and deep foundations associated with permafrost degradation to include repairs over the life of the project for both

As described in item (4) above, the initial cost of a deep pile foundation is significantly higher than the cost of a standard foundation. Army cost guidance for the additional cost of a deep foundation resting on 50-foot-long steel "H" piles is $50 per square foot of foundation area, unadjusted for location. This cost compares with a published unit cost (dollars per square foot) for a dining facility of $500 per square foot and $133 per square foot for an unheated storage building (both unadjusted for location, with a standard foundation).[5] Thus, the approximate premium for such a deep pile foundation would be 10 percent for a typical dining facility, and 37 percent for an unheated storage building. When adjusted for location to Ft. Wainwright, Alaska, using the current DoD Area Cost Factor of 2.35[6], all of the above costs would increase accordingly (by a factor of 2.35), with the relative comparisons remaining the same.

The generic costs above for deep pile foundations do not include added costs that could be necessary in permafrost areas to either drive piling in stiff permafrost soils, or to pre-bore and place piles with ad-freeze slurry. These costs would increase the relative cost of the foundation to the overall structure.

In general, the cost to repair a structure built upon a properly-designed deep foundation due to permafrost thaw would be negligible. On the other hand, the cost to repair a structure

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[5] Army Facilities Pricing Guide / PAX Newsletter 3.2.2, 30 May 2018 (USACE)

[6] UFC 3-701-01, DoD Facilities Pricing Guide with Change 1, 23 May 2018

built upon a standard foundation due to permafrost thaw is not possible to state generally, as it would be dependent upon several key variables:

1. The nature and amount of permafrost underlying the foundation
2. The degree of permafrost thaw over time
3. The structure's ability to resist or accommodate differential settlement (construction type, materials, strength, and elasticity)
4. The structure's purpose and tolerance for structural deterioration
5. The structure's replacement cost
6. The structure's expected service life

The engineer would need to consider these variables and their associated costs for each project in comparison to the cost for a deep pile foundation. In many cases, the cost of a deep foundation is highly economical compared with the cost (as well as potential risk to the mission) of a failed or failing structure upon a standard foundation.

(7) Any other information or recommendations the Assistant Secretary of Defense determines appropriate

Permafrost soils/rock can have greatly changing ground-ice contents, often within very short distances (tens of feet). Because of this, the methods to construct in permafrost areas are also wide ranging: from simply adjusting the location of a structure by a hundred feet to avoid a permafrost ice lens, to over-excavating ice-rich soils near the surface and replacing with compacted gravel fill, to constructing deep pile foundations and/or elaborate refrigerated foundations to insure soil rigidity and long term safety. Not surprisingly, the cost premiums associated with these approaches range from nearly nothing, to up to 50 percent of the total project. The need for adequate project planning and subsurface geotechnical surveys to establish appropriate project budgets cannot be overstated.

Engineers in DoD and industry have the general tools required to build in a warming Arctic and sub-arctic. The Department would further benefit from a vetted methodology for estimating long-term permafrost temperatures.