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Geotechnical Study and Foundation Structural Design, Next Generation Ionosonde (NEXION) Installation, Thule Air Base, Greenland

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Final Report

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Abstract

This report presents the results of our geotechnical and structural design for the transmitter antenna of the Next Generation Ionosonde (NEXION) at Thule Air Base, Greenland, for the Space and Missile Systems Center, Remote Sensing Space Environmental Branch, and Air Force Weather. NEXION is a commercial-off-the-shelf ionospheric sounder used to measure the electron density of ionospheric plasma. The design required special considerations for installation, construction, and shipment due to the ice-rich permafrost soil conditions at Thule Air Base's remote and logistically difficult location. In particular, anchored tension ground connections could not withstand viscoelastic creep of ground ice under extreme wind-loading events. In addition, predicted future climate change required additional considerations to protect the thermal regime of the thaw-unstable sediments.

Recommendations include excavation into permafrost soils, non-frost-susceptible structural replacement fill, and extruded polystyrene board-type insulation to facilitate maintaining and improving the subsurface thermal regime and to provide favorable foundation performance for the NEXION tower system. Furthermore, given the remote site location and limited availability of on-site concreting capabilities, foundations require pre-casting and shipping via ocean transport vessel to Greenland. As such, we designed an alternative foundation detail, including anchor rods, to mitigate the potential for irreparable damage that may occur during shipping and transporting.

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Preface

This study was conducted for the Space and Missile Systems Center Remote Sensing Space Environmental Branch (SMC/RSSE) under MIPR# F3LGWD5009G003. The technical monitor was Richard Biagioni, SMC/RSSE.

The work was performed by Kevin Bjella (Force Projection and Sustainment Branch, Dr. Loren Wehmeyer, Acting Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Loren Wehmeyer was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

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COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Official
AB	Air Base
AFDD	Air Freezing Degree Days
AOS	Apparent Opening Size
ATDD	Air Thawing Degree Days
CRREL	Cold Regions Research and Engineering Laboratory
ERDC	U.S. Army Engineer Research and Development Center
MAAT	Mean Annual Air Temperature
NEXION	Next Generation Ionosonde
NFS	Non-Frost-Susceptible
RSSE	Remote Sensing Space Environmental
Rx	Receive
SMC	Space and Missile Systems Center
TCI	Technology for Communications International, Inc.
Tx	Transmit

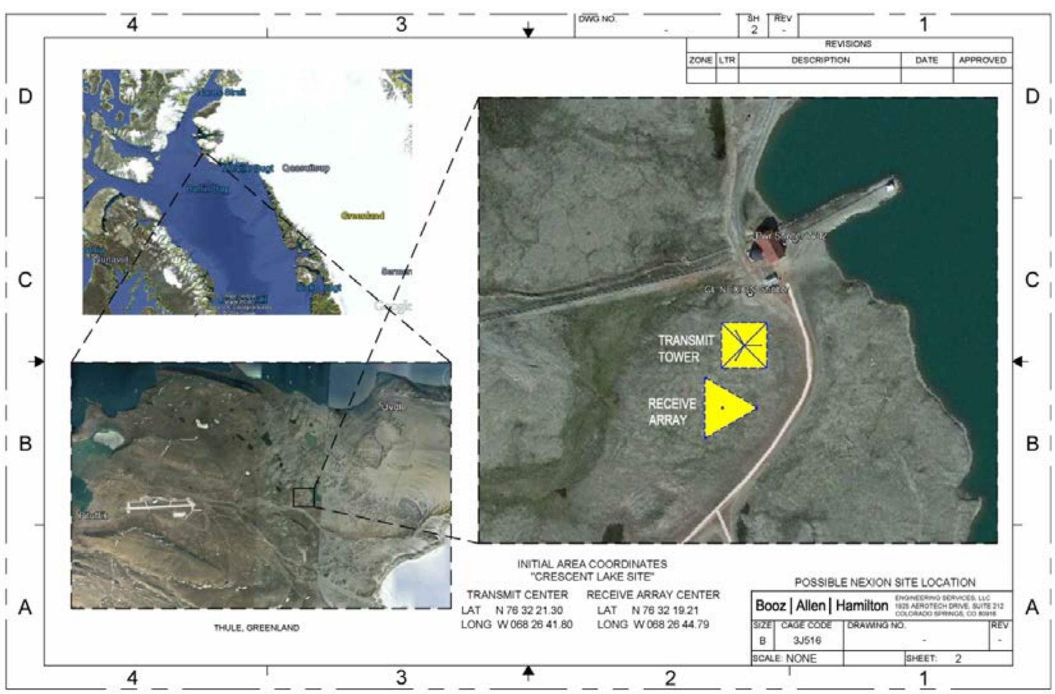
Unit Conversion Factors

Multiply	By	To Obtain
British thermal units (International Table)	1,055.056	joules
British thermal unit per hour per foot per degrees Fahrenheit	1.77296	Watts per meter per Kelvin
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
pounds (force) per square foot	47.88026	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters

1 Introduction

This report presents the results of our geotechnical studies for the proposed Next Generation Ionosonde (NEXION) at Thule Air Base (AB), Greenland, for the Space and Missile Systems Center (SMC) Remote Sensing Space Environmental (RSSE) Branch. The NEXION is a commercial-off-the-shelf ionospheric sounder used to measure the electron density of ionospheric plasma. The NEXION consists of a transmit (Tx) antenna and supporting 98.5 ft (30 m) guyed tower, a receive (Rx) antenna array, and associated foundations. The purpose of our studies was to develop site-preparation and foundation recommendations for the Tx antenna and supporting guyed tower considering the ice-rich, perennially frozen, glacial till of the Thule AB region. Based on communication with the project team, the system will be installed at the Crescent Lake site identified in the Site Survey Report prepared by ARINC Aerospace dated 3 December 2014. Figure 1 shows a vicinity map for the Crescent Lake site.

Figure 1. A map of the Crescent Lake site vicinity.



The tower is a pre-engineered 98.5 ft (30 m) guyed tower (typically Rohn 55G or Nello 55N) manufactured and supplied by Technology for Communications International, Inc. (TCI), from Fremont, CA. TCI typically provides standard drawings, specifications, and installation manuals for tower systems (TCI 2011). However, given permafrost conditions and the logistically remote Thule area, the project team deemed the standard site preparation and foundation design for these systems unsuitable. Therefore, this project required project-specific site preparation and foundation design recommendations. Additionally, the design had to be logistically robust for vessel shipment and construction placement in the field.

Our geotechnical recommendations include excavation into permafrost soils, non-frost-susceptible structural replacement fill, and extruded polystyrene board-type insulation to facilitate maintaining and improving the subsurface thermal regime and to provide favorable foundation performance for the NEXION tower system. Furthermore, given the remote site location and limited availability of on-site concreting capabilities, foundations require pre-casting and shipping via ocean transport vessel to Greenland. As such, we designed an alternative foundation detail, including anchor rods, to mitigate the potential for irreparable damage that may occur during shipping and transporting.

2 Test-Pit Exploration

Booz Allen Hamilton ES, the consultant selected by SMC/RSSE to perform the required integration and installation of the NEXION system, coordinated and contracted with Greenland Contractors to have two test pits excavated to evaluate subsurface conditions at the Crescent Lake site. Excavation depths were not reported to us but appeared to be on the order of 6 to 10 ft (2 to 3 m). The excavations were within approximate footprints of planned foundation elements and were not backfilled.

On 22 September 2014, Greenland Contractors excavated test pits, exposed soil conditions and ground-ice features, and took photographs for evaluation. SMC/RSSE provided the project team with photographs of the test pits for us to review; Cold Regions Research and Engineering Laboratory (CRREL) representatives were not on-site to log conditions or to document excavations. The test pits were reportedly not backfilled; and to our knowledge, no laboratory testing was conducted on soils excavated from the test pits.

3 Site Conditions

Thule AB is situated in the northwest-trending valley of Pituffik Kugsua (North River). This 7.5-mile-long (12 km) valley is glacier free, and drains the Greenland Ice Cap on the east towards the North Star Bugt on the west. North Mountain bounds the lower reach of this valley on the north, with hilly terrain northward to Wolstenholme Fjord. South Mountain bounds the lower reach of the valley on the south, with a relatively flat plateau southward to Parker Snow Bugt. The region is void of vertical vegetation and is restricted to low herbs, grasses, dwarf shrubs, mosses, and lichens. The valley rises in elevation toward the inland ice cap where vegetation gives way to a rocky, boulder-strewn landscape.

The Crescent Lake site is approximately 6 miles (9.5 km) from North Star Bugt and due east of the AB. The frontal edge of the Greenland Ice Cap is approximately 3.2 miles (5.1 km) east-southeast of the site. The site is generally higher in elevation than the lower valley, and the surface consists of a rocky, boulder-strewn landscape with little vegetation.

3.1 Climate

The climate of Pituffik Kugsua valley is high-arctic marine modified by the proximity to the inland ice cap. High temperatures can exceed 50°F (10°C), with low temperatures approaching −40°F (−40°C). The mean annual air temperature (MAAT) is 12.2°F (−11°C) with occasional hurricane-force winds. The average air thawing degree-days (ATDD) from 1953 to 2015 is 769 °F-days (427°C-days), and the air freezing degree days (AFDD) for the same period is 7915°F-days (4397°C-days). The average length of the thawing season is 125 days from mid-May to mid-September.

3.2 Geology and glaciology

The glacially sculpted geology of the region is dominated by an alternating sequence of sedimentary rocks, termed the Thule Supergroup. More specifically, the Upper Thule Supergroup is composed of sediments of the Narssarssuk Group and the Dundas group (Dawes 2006). These siliciclastic red beds and pale carbonaceous sediments are visible in the glacially eroded slopes of the North and South Mountain, Dundas Fjeld, and Saunders Ø. These lithified sediments are essentially underformed; however, half-grabben structures are numerous, displaying vertical displacement of tens to hundreds of meters. A regional swarm of basic dykes and sills are noted in this group, with a prominent exposure of Diorite having been cut for the Thule AB runway. This strata generally dips to the south-southwest at shallow angles, with the strike trending west-northwest, consistent with the trend of the North River Valley.

The regional glacial history described by Funder (1990) suggests that during the late Pleistocene Epoch, multiple glacial advances covered the Pituffik Kugsua valley. The greatest extent of glaciation and the earliest recorded in the existing sediment resulted for the Agpat Glaciation and extended westward beyond Saunders Ø. The extent of the following interglacial is undetermined, but the ice is hypothesized to have retreated to Wolstenholme Fjord (Dawes 2006; Funder 1990). The following Narssarssuk Glaciation filled Pituffik Kugsua valley and extended southwestward, terminating on the plateau south of the valley, with the following interglacial hypothesized to have retreated to Wolstenholme Fjord. The next and last glacial advance, in the early Holocene Epoch, failed to progress from Wolstenholme Fjord; and no further advances in the valley are noted. Because of multiple glacial events, a large amount of till and outwash sediments overlie the sedimentary bedrock in the Pituffik Kugsua valley. The glacial sediment thickness varies from 20 ft (6 m) to 60 ft (18 m), with progressively thicker deposits towards the existing ice cap margin and thinner deposits towards the beaches of North Star Bugt. Glacial tills of larger cobble and bolder are evident in the valley. The Crescent Lake site is situated on relatively thicker glacial sediments closer to the ice cap margin.

3.3 Permafrost, ground ice features, and active layer

A periglacial environment currently exists in the Pituffik Kugsua valley and has existed in the high Arctic through the Pleistocene and Holocene Epochs. During glacial retreat, the sediments and rock are exposed to low temperatures, allowing the establishment of permanently frozen ground (permafrost) and associated ground-ice features, including matrix and segregated ice, wedge ice, and relict ice. Permafrost is generally continuous in lateral extent and could be more than 950 ft (300 m) thick. Currently, permafrost temperatures at the depth of zero annual amplitude are approximately 14°F (−10°C). Permafrost near the project site was formed epigenetically—the rock and sediments were deposited in full thickness and subsequently permanently frozen.

3.3.1 Matrix and segregated ice

The freezing process during creation of the permafrost can create excess ice in the soil if the proper conditions exist. From a conservative standpoint, it is generally assumed that soils are saturated when they become permanently frozen. Therefore, the 10% volume expansion that occurs to fresh water upon freezing will cause individual soil particles to move apart within the matrix ice. Fine-grain soils contain more water (ice) at saturation than do coarser-grain soils. Also, if fine grain soils exist along with an additional supply of water, the matrix ice can evolve into segregated ice because of the wicking action of the fine grain soils, creating near-horizontal layers or lenses of ice fractions of inches to inches in thickness, and inches to feet in length. During sediment deposition in the Pituffik Kugsua valley, the amount of water available was variable. Therefore it is common to find very high ice content soils directly above, below, or adjacent to soils with lower ice content.

3.3.2 Wedge ice

Cold temperatures in the winter contract the surface soils and allow cracks to develop that are several feet deep, tens of feet long, and fractions of inches wide. Surface water in the spring and summer migrates into the cracks and freezes, creating a thin vein of ice. This location of ice intrusion is a zone of weakness, and the process will repeat at the same location for hundreds and thousands of years with the resultant ice vein becoming an ice wedge. These wedges can be several feet deep, 3 to 6 ft (1 to 2 m) wide, and several feet to tens of feet long. Most often, the wedges will interconnect into polygon shapes that are several feet in diameter, and these shapes can be seen at the surface because of the mechanical distortion that occurs along with the ice intrusion. The Pituffik Kugsua Valley has a high occurrence of wedge ice, and the probability is very high for its existence at the project site.

3.3.3 Relict ice

During glacial retreat, the margin of the ice sheet is a very dynamic with glacial till being exposed and deposited, large volumes of water flowing off the ice sheet and carrying outwash, and ice fracturing and depositing on top and in loose piles of sediment. This fractured ice can be deposited and buried with sufficient expediency to prevent the ice from melting prior to permafrost creation. Therefore, chunks of ice, termed relict ice (Corte

1962), can exist in the permafrost and in a very random manner. The North River channel, however, moves such large volumes of water and sediment that the probability of relict ice surviving in the benches that are now exposed near the river is relatively low.

3.3.4 Active layer

The active layer is the near-surface soils that undergo an annual process of thawing in the summer and complete refreezing during the winter. In Arctic regions, the active layer commonly freezes to the permafrost table where the bottom of the active layer is the top of permafrost. The depth of annual thaw is dependent on vegetative cover, soil type, soil moisture, and solar aspect. For Pituffik Kugsua Valley, the active layer ranges from a 1 ft (30 cm) depth in vegetative areas under thick organic cover to 5 to 6.5 ft (1.5 to 2 m) in non-vegetated areas. It is common to find a thick sequence of segregated ice at the base of the active layer due to permafrost acting as an aquitard, pooling water that subsequently freezes.

3.4 Subsurface soil conditions

Subsurface soils in the valley are predominately glaciofluvial in origin, including glacial till, deposited or overridden during glacial occupation and retreat. Our review of project photographs suggests that similar conditions exist. Soil particle size distribution ranges from silt to cobble and boulder sizes but are predominantly gravel size. The depth dimension, lateral dimension, particle size distribution, and ice content can be very localized due to this depositional process. A particular depositional interval may not be traceable to within meters. Based on our review of test-pit excavation photographs and our experience in the area, we consider soils within the active layer to be potentially frost susceptible, which could result in undesirable frost-heaving-related differential movement on freezing.

It does not appear that either excavation encountered groundwater. In their Site Survey Report, ARINC Aerospace (2014) reported active-layer depths of about 9.8 ft (3 m) at the time of test-pit exploration. Our experience in the area and review of test-pit photographs suggest the active layer could be approximately 5 to 6.5 ft (1.5 to 2 m). Our review of test-pit photographs also confirms that permafrost conditions exist below the active layer, including matrix, segregated, wedge, and relict ground-ice features. The photographs also illustrate glaciofluvial and glacial till materials, including cobble- and boulder-sized particles. Figure 2 and Figure 3 illustrate glaciofluvial and glacial till gravel, cobble, and boulder materials, relative active-layer thickness, and ground-ice features we observed in test-pit excavation photographs; Figure 3 is a close-up view of ground-ice features illustrated in Figure 2.

Figure 2. A Crescent Lake test-pit excavation. The photo suggests glaciofluvial and glacial till gravel, cobble, and boulder-sized materials. It also depicts approximate active-layer thickness and ground-ice features below the active layer.

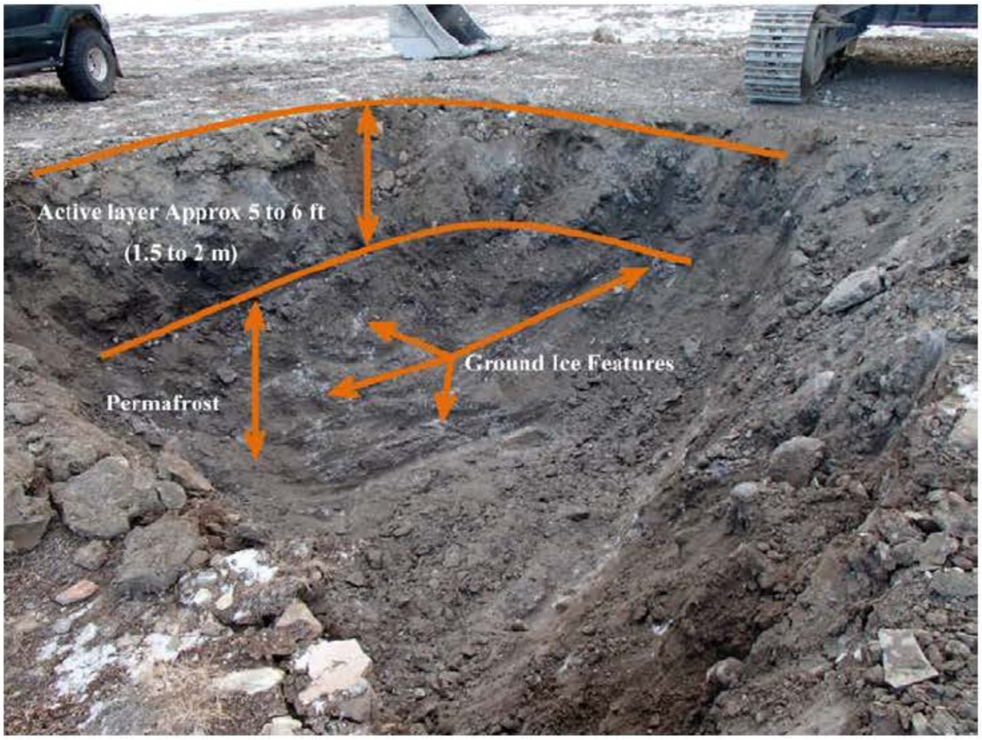


Figure 3. A detailed photograph of relict ground-ice feature illustrated in Fig. 2. Thawing of ground-ice features below foundation elements will result in significant distress and differential movement.

Given the proximity to the ice cap margin and our understanding of glaciofluvial sediment thicknesses in the area, we do not anticipate bedrock within the upper 50 ft (15 m) of the subsurface profile. However, permafrost conditions along with cobble- and boulder-sized materials will be encountered during foundation site preparation, which could make excavation difficult, especially in frozen ground.

In our opinion, after reviewing the test-pit photographs, the subsurface conditions, including permafrost and ground-ice features described above, are consistent with our understanding of conditions in the Thule AB area.

4 Geotechnical Discussion and Recommendations

Test-pit excavations at the Crescent Lake site and our experience in the area indicate that ice-rich, thaw-unstable soils are present within the proposed NEXION footprint. We also consider active-layer soils to be potentially frost susceptible and relatively loose due to seasonal freezing and thawing action. If ice-rich permafrost soils are allowed to thaw, the potential for the loss of bearing capacity or damaging differential settlement is relatively high. If foundation-bearing soils are frost susceptible and allowed to seasonally freeze and thaw, the potential for differential frost-heaving-related movements is also relatively high.

In our opinion, the Tx antenna and supporting guyed tower can be founded on conventional spread footing systems. To mitigate frost-heaving-related movements, we recommend excavating all active-layer soils extending into permafrost soils and replacing them with a thick section of compacted structural fill. The structural fill we recommend may exhibit greater thermal conductivity than in-situ materials excavated, potentially increasing active-layer thickness and inducing thawing of ice-rich permafrost below the excavation. To mitigate permafrost thaw, we recommend strategically placing insulation around the foundation elements, extending out beyond the foundation perimeters to control excessive heat loss from permafrost soils during thawing seasons, to assist permafrost regeneration after construction, and to maintain or improve the ground thermal regime around foundation elements. The following sections provide specific recommendations.

4.1 Site preparation

The base of excavations should extend out beyond foundation footprints a minimum 2 ft (0.6 m) and be free of massive ice (wedge ice and relict ice) and organic material. Our experience in the area indicates locally deeper ground-ice features may require deeper excavations to remove these materials. Also, horizontal excavation limits shall be wide enough to accommodate polystyrene board-type insulation placed nominally 2 ft (0.6 m) below the finished site grade and extending out a minimum of 8 ft (2.4 m) beyond the edge of foundation element perimeters.

The vertical extents of the excavation should extend through active-layer soils and nominally 1 ft (0.3 m) into permafrost. Additionally, the vertical extents of the excavation beneath footings should be deep enough to accommodate a minimum 2 ft (0.6 m) thick section of structural fill. We anticipate that the maximum extent of the active-layer thawing near the end of the freezing season. Depending on the timing of construction, active-layer soils could be seasonally frozen during site preparation. Therefore, we recommend a minimum excavation depth of at least 7 ft (2.1 m) below the original site grade prior to construction if excavation is completed prior to mid-August. The depth to the top of the permafrost could be taken as the thickness of thawed active-layer soils for excavations completed after mid-August but before seasonal frost penetration reaches the top of permafrost during the freezing season.

As stated above, we understand test pits were excavated but not backfilled. If test pits were excavated within foundation footprints, the base of the test pit should be considered as the original ground surface prior to construction.

A qualified geotechnical engineer should observe the base of the excavation prior to placing and compacting structural fill material. Additional excavation may be necessary to remove massive ice (wedge ice and relict ice) deposits exposed in the base. Removing these ice features will mitigate potentially damaging long-term creep settlements related to sustained foundation loading and, in case of unexpected thawing, mitigate excessive settlement beneath guy anchor foundations. A qualified geotechnical engineer shall determine the limits of additional excavation, if needed. On-site observation during construction is preferred but may be logistically challenging and costly. Alternatively, geotechnical observation and approvals could be conducted by reviewing detailed construction photographs taken during and after excavation and prior to backfilling. The qualified geotechnical engineer shall dictate the type and number of photographs for each excavation.

After geotechnical observation and approval, we recommend placing a geotextile separator fabric in the base of the excavation. The purpose of the fabric is to separate in-situ silty permafrost soils from relatively clean structural fill. Although our design intends to maintain frozen conditions beneath the base, if soils below the base begin to thaw after beginning structural fill placement, the fabric will mitigate fine-grained soil migration (pumping) into the structural fill due to repeated loading from compaction equipment during construction. After fabric placement, structural fill should be placed up to the bottom of the polystyrene board-type insulation according to our recommendations in this report. After placement of the insulation, the excavation should be backfilled with structural fill up to the planned finished site grade.

Excavation and backfill should proceed in a timely manner. If the base of excavation thaws prior to backfilling, thawed soils below the base shall be removed down to frozen soils and replaced with additional structural fill. Although likely unrealistic, timing construction near the end of the thawing season could be advantageous and potentially limit extents of thawing and additional excavation to remove thawed soils.

All excavations should be sufficiently sloped or shored to provide a stable bank. We recommend the stability of the excavated slopes be made the responsibility of the contractor as they will be most familiar with the conditions encountered in the excavations and have direct control of working conditions at the site. For planning purposes, we recommend assuming unsupported excavation slopes will be no steeper than 1 vertical to 1 horizontal. It is also important to note that temporary excavation slopes may initially stand steep but slough and cave as they thaw and dry, particularly when equipment is operated nearby. Similarly, steep cuts made in seasonally or perennially frozen ground can become unstable on thawing.

4.2 Foundation recommendations

We recommend conventional spread-footing foundations bearing on a uniform layer of compacted, granular, non-frost-susceptible (NFS) structural fill a minimum 2 ft (0.6 m) thick. The minimum recommended width for spread footings is 2 ft (0.6 m) to mitigate a punching-type bearing-capacity failure. We recommend a minimum depth of burial of 3 ft (0.9 m) below the finished site grade.

Long-term strength generally governs the design of conventional spread-footing foundations on ice-rich soils. The long-term strength of ice-rich soils is a function of time and temperature. Johnston (1981) gives a conservative empirical estimation of long-term. This estimate is based on a compilation of data from ice-rich soils and from investigators, both North American and Russian. Using this estimate and Terzaghi's shallow-foundation bearing-capacity theory, we developed our allowable soil-bearing-capacity recommendations.

Spread footings can be designed for a maximum allowable bearing pressure of 3000 lb/ft^2 (140 kPa) at footing level. Allowable bearing-capacity values assume a minimum safety factor of 3 and a maximum permafrost temperature at the structural fill and in-situ soil interface of 31°F (−0.5°C).

Site preparation and foundation recommendations for the FY12 Dormitory Project at Thule AB are similar to our recommendations for this NEXION project (Bjella 2012). Although the dormitory is a heated structure, it is elevated above grade, exposing the ground surface to outdoor temperatures, similar to ground-surface conditions for this NEXION project. Site preparation for the FY12 Dormitory also included replacing the active layer with controlled structural fill and installing extruded polystyrene board-type insulation nominally 2 ft (0.6 m) below grade, similar to recommendations for this NEXION project. Thermal modeling performed for the FY12 Dormitory project calculated a maximum temperature at the permafrost and structural fill interface of 28.4°F (−2.2°C), corresponding to an allowable bearing capacity of 3450 lb/ft^2 (165 kPa) and a safety factor of 3 (Bjella 2012).

The modeling performed for the FY12 Dormitory project suggests that our design maximum temperature at the structural fill and in-situ soil interface is relatively conservative (i.e., relatively warm).

These recommendations do not specifically determine the amount of settlement that will occur. However, given our site preparation recommendations including structural replacement fill and insulation, we believe long-term creep settlement will be relatively small and within normal tolerances for foundations such as this.

The Structural General Foundation Plan Drawing G-102 in Appendix A presents our foundation and site preparation recommendations and structural details. In our opinion, the details presented on this drawing sheet meet the intent of our geotechnical design.

4.3 Uplift resistance, lateral earth pressures, and frictional resistance

The dead weight of the structure, including the footing and the weight of soil above the footing within a zone described by a vertical surface extending upward from the horizontal limits of the footing, could be used to provide uplift resistance. For compacted structural fill, we recommend using an in-place unit weight of 130 lb/ft^2 (6.2 kPa). This value does not include a safety factor.

Passive-earth pressures against buried portions of structures and friction along the base of buried portions of the structure can be used to resist lateral forces and movement. To estimate passive-earth pressures, we assumed a sand and gravel structural fill placed with an internal friction angle near 34° with an in-place, compacted unit weight of 130 lb/ft^2 (6.2 kPa). We recommend using an equivalent fluid weight of 460 lb/ft^3 (7370 kg/m^3) to estimate passive-earth pressures for structural fill. These values do not include a safety factor.

Frictional resistance against sliding along the base of foundations may be computed using a coefficient of friction of 0.4 between pre-cast concrete and structural fill. These values do not include a safety factor.

Active-earth pressures could develop on foundation pilasters, depending on construction sequencing, fill placement, and methods of compaction. To mitigate these pressures, fill should be brought up evenly around perimeters of foundation pilasters.

4.4 Materials

4.4.1 Structural fill

Structural fill should consist of unfrozen, gravelly sand or sandy gravel meeting the Table 1 gradation limits after compaction.

Table 1. Structural fill gradation limits.

Size	Percentage Passing
4 in.	100
No. 4 sieve	30–60
No. 200 sieve	Less than 5 (based on the ¾-inch minus fraction)
0.02 mm	Less than 3 (based on the ¾-inch minus fraction)

In general, structural fill should be placed in layers not exceeding 12 in. (30.5 cm) in loose height; and the material in each layer should be compacted to achieve a density of at least 95% of the maximum dry density based on the Modified Proctor moisture–density relationship (ASTM 2012a). ASTM (2015) should be used to determine in-place densities at a rate equal to one test per lift per foundation element. Water content of the fill should be altered by wetting or drying as necessary to achieve the desired compaction.

The fill should consist of unfrozen materials and be placed at above-freezing air temperatures. If previously placed fill freezes, for instance overnight, the frozen material should be excavated and wasted or allowed to thaw and re-compacted prior to placement of additional fill.

4.4.2 Geotextile separator

We recommend the geotextile separator conform to the requirements of American Association of State Highway and Transportation Officials (AASHTO) M 288 for a Class 2 geotextile with an elongation of greater than or equal to 50% (Fannin 2004). The Class 2 geotextile should conform to the requirements of Table 3, Separation Geotextile Property Requirements, in AASHTO M 288, except the minimum permittivity of the fabric should be 0.05 per second. The geotextile separator should also have an apparent opening size equal to or between the No. 70 and No. 100 U.S. Standard Sieve as determined by ASTM (2012b). Class 2 geotextiles may be joined either by sewing or overlapping.

4.4.3 Insulation

The insulation used in construction should have a minimum thermal conductivity of 0.02 Btu/hr-ft-°F (0.034 W/m-K) and exhibit no greater conductivity with time. The insulation should be suitable for direct burial with a minimum compressive strength of 40 lb/ft^2 (1.9 kPa) and suitable long-term creep characteristics for loads imposed by fill and construction. The insulation should extend a minimum of 8 ft (2.4 m) beyond the limits of the foundation elements on all sides. The insulation should be bedded on a carefully prepared, relatively planar surface. Insulation should be placed with staggered joints to avoid continuous joints through the insulation layer.

4.5 Surface drainage

The area around the facilities should be sloped to direct surface water and runoff away from the structures. Fills should be placed to prevent ponding of water near the proposed structures or infiltration of large quantities of water into soils near foundation systems.

5 Structural Foundation Design

Coupled with our geotechnical study, we teamed with the U.S. Army Corps of Engineers Alaska District to provide foundation structural design drawings incorporating our geotechnical recommendations. We understand this drawing will be used for estimating and constructing foundation components. The structural loading conditions used for our design are based on loadings provided on TCI's standard drawings (TCI 2011), including wind loading, as directed by the project team. Appendix A presents the drawing package we developed, Structural General Foundation Plan Drawing G-102. In our opinion, the details presented on this drawing sheet meet the intent of our geotechnical design.

Given the remote site location and limited availability of on-site concreting capabilities, foundations require pre-casting the anchor and anchor rod assemblies and shipping via ocean transport vessel to Greenland. The project team and the Alaska District designed an alternative anchor rod connection detail primarily for the potential for irreparable damage occurring during shipping and transporting. The design significantly reduces the unprotected anchor rod lengths from approximately 10 ft (3 m) to under 1 ft (0.3 m), resulting in a significant reduction in damage potential during transport and shipment.

6 Conclusions

We designed foundations to mitigate effects of viscoelastic creep of ground ice under extreme wind-loading events. We included additional considerations to protect the thermal regime of the thaw-unstable sediments by using site preparation techniques and ground insulation to provide favorable foundation performance for the NEXION tower system. Furthermore, given the remote site location and limited availability of on-site concreting capabilities, foundations require pre-casting and shipping via ocean transport vessel to Greenland. As such, we designed an alternative foundation detail, including anchor rods, to mitigate the potential for irreparable damage that may occur during shipping and transporting. Combined, these designs and techniques could meet the performance requirements of the project by mitigating the challenges posed when building on ice-rich permafrost soils and when developing infrastructure in a logistically remote locale.

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Appendix A: Structural General Foundation Plan and Design Analyses

US Army Corps
of Engineers
Alaska District

NEXT GENERATION IONOSONDE (NEXION) INSTALLATION

THULE AIR BASE, GREENLAND

FINAL, 10 JUNE 2015

CRE001

Drawing X:\UNIFIED\EN-TE\Jobs\CRE001\10_DWGS\FTG127-G-001.dwg last saved on 6/11/2015 11:23 AM was plotted by Adams, Eric M POA on 6/11/2015 11:42 AM

Drawing # ---- Sheet 1 of 2

FOUNDATION NOTES:

I. DESIGN LOADS & LOAD COMBINATIONS :

1. DESIGN LOADS ARE BASED ON LOADINGS PROVIDED IN TCI DRAWINGS

II. STRUCTURAL FILL:

GRADATION:

SIZE	% PASSING
4-INCH	100
NO. 4 SIEVE	30-60
NO. 200 SIEVE	0-5
0.02 MM	0-3

LOOSE THICKNESS: LESS THAN 12 INCHES (300 mm)

COMPACTION: 95% OF MAXIMUM DENSITY BASED ON MODIFIED PROCTOR MOISTURE-DENSITY RELATIONSHIP (ASTM D1557). ASTM D6938 SHALL BE USED TO DETERMINE IN-PLACE DENSITIES AT A RATE OF AT LEAST ONE TEST FOR EACH LIFT FOR EACH FOUNDATION ELEMENT.

CONDITION: FILL SHALL CONSIST OF UNFROZEN MATERIALS AND PLACED AT ABOVE FREEZING TEMPERATURES. IF PREVIOUSLY PLACED FILL FREEZES DURING BACKFILLING, FOR INSTANCE, OVERNIGHT, IT SHALL BE REMOVED OR ALLOWED TO THAW AND RECOMPACTED BEFORE PLACING ADDITIONAL FILL .

III. EXCAVATION:

1. EXTEND BASE OF EXCAVATION NOMINALLY 1 FOOT (300mm) BELOW TOP OF PERMAFROST AT TIME OF CONSTRUCTION.

2. BASE OF EXCAVATION IS TO BE OBSERVED BY A QUALIFIED GEOTECHNICAL ENGINEER TO DETERMINE IF ADDITIONAL EXCAVATION WILL BE REQUIRED TO REMOVE UNSUITABLE MATERIALS ORGANICS AND EXCESS ICE. GEOTECHNICAL OBSERVATIONS MAY BE PERFORMED BY REVIEW OF DETAILED CONSTRUCTION PHOTOGRAPHS DURING EXCAVATION AND PRIOR TO BACKFILLING. THE TYPE AND NUMBER OF PHOTOGRAPHS REQUIRED FOR EACH EXCAVATION SHALL BE AS PRESCRIBED BY THE GEOTECHNICAL ENGINEER.

3. EXCAVATION AND BACKFILL SHOULD PROCEED IN A TIMELY MANNER. IF BASE OF EXCAVATION THAWS PRIOR TO BACKFILLING, THAWED SOILS BELOW THE BASE SHALL BE REMOVED AND REPLACED WITH ADDITIONAL STRUCTURAL FILL.

4. BASE OF EXCAVATION LIMITS SHALL EXTEND OUT A MINIMUM OF TWO FEET (600mm) FROM FOUNDATION PERIMETER LATERALLY IN ALL DIRECTIONS.

IV. GEOTEXTILE SEPARATOR:

1. CONFORM TO THE REQUIREMENTS OF ASHTO M288, CLASS 2 WITH ELONGATION EQUAL TO OR GREATER THAN 50%; TABLE 3 EXCEPT MINIMUM PERMITTIVETY SHOULD BE 0.05 PER SECOND. APPARENT OPENING SIZE BETWEEN NO. 10 AND NO. 100 U.S SIEVE SIZE.

2. CLASS 2 GEOTEXTILES MAY BE JOINED BY EITHER SEWING OR OVERLAP.

V. CONCRETE NOTES

1. ALL CONCRETE SHALL BE PROVIDED AS PRECAST CONCRETE UNITS.

2. ALL CONCRETE CONSTRUCTION SHALL BE IN ACCORDANCE WITH ACI 318 LATEST EDITION.

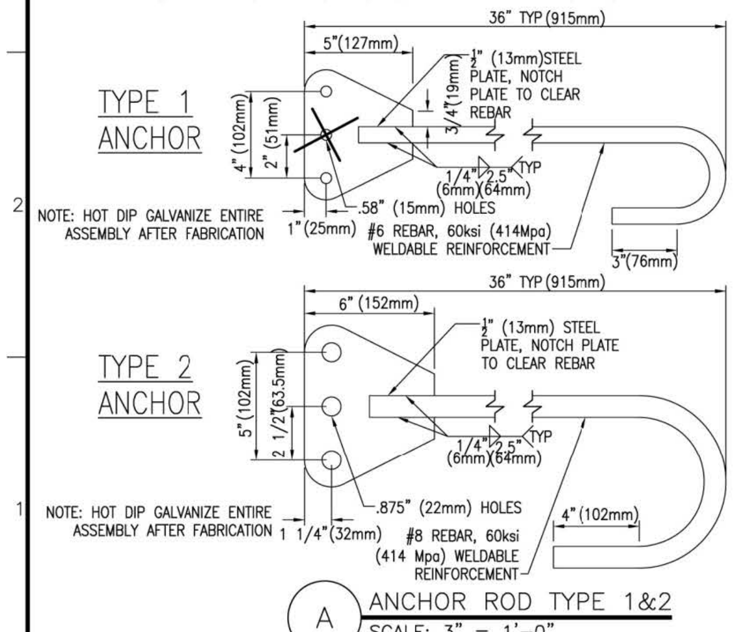
3. ALL CONCRETE SHALL HAVE MINIMUM 28 DAY COMPRESSIVE STRENGTH, F'C = 4,000 PSI. (28 Kpa)

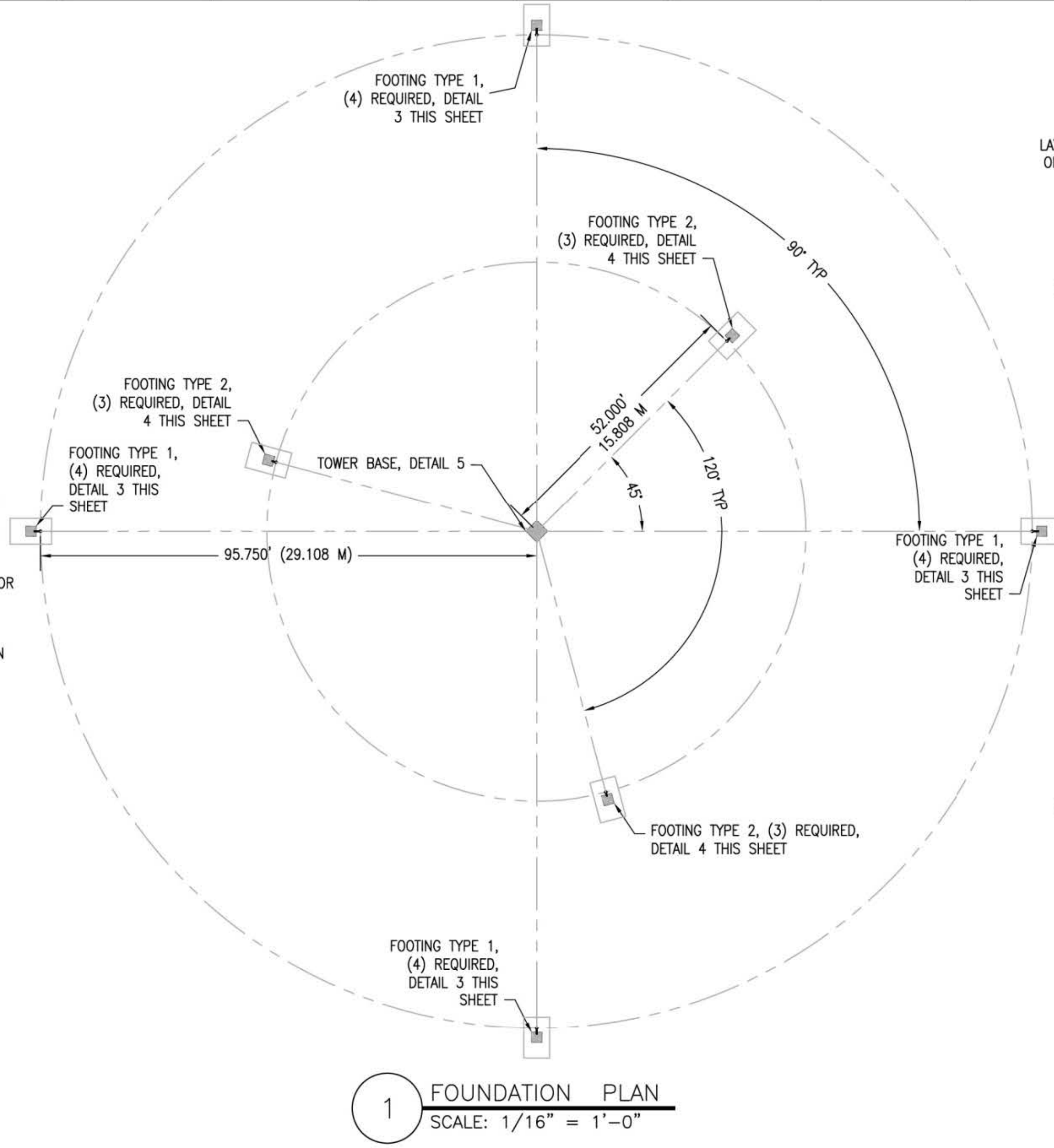
4. ALL REINFORCING BAR SHALL CONFORM TO ASTM A 706, GRADE 60 (413 Mpa).

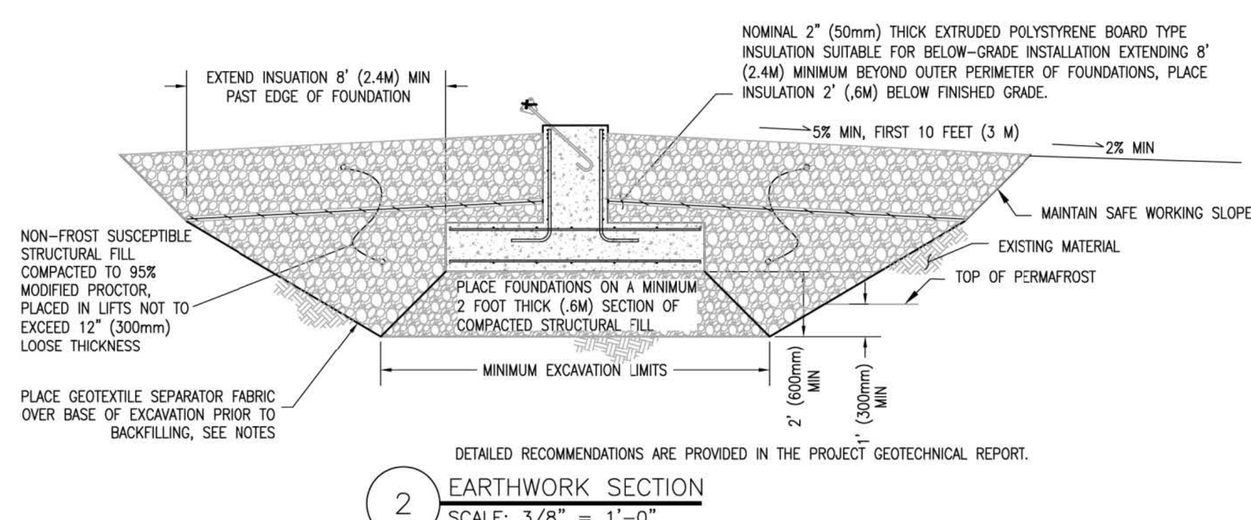
5. U.N.O. MINIMUM REINFORCING BAR LAP SPLICES SHALL BE 57 BAR DIAMETERS FOR #6 AND SMALLER AND 71 BAR DIAMETERS FOR #7 & LARGER OR 12-IN (300mm) WHICHEVER IS GREATER.

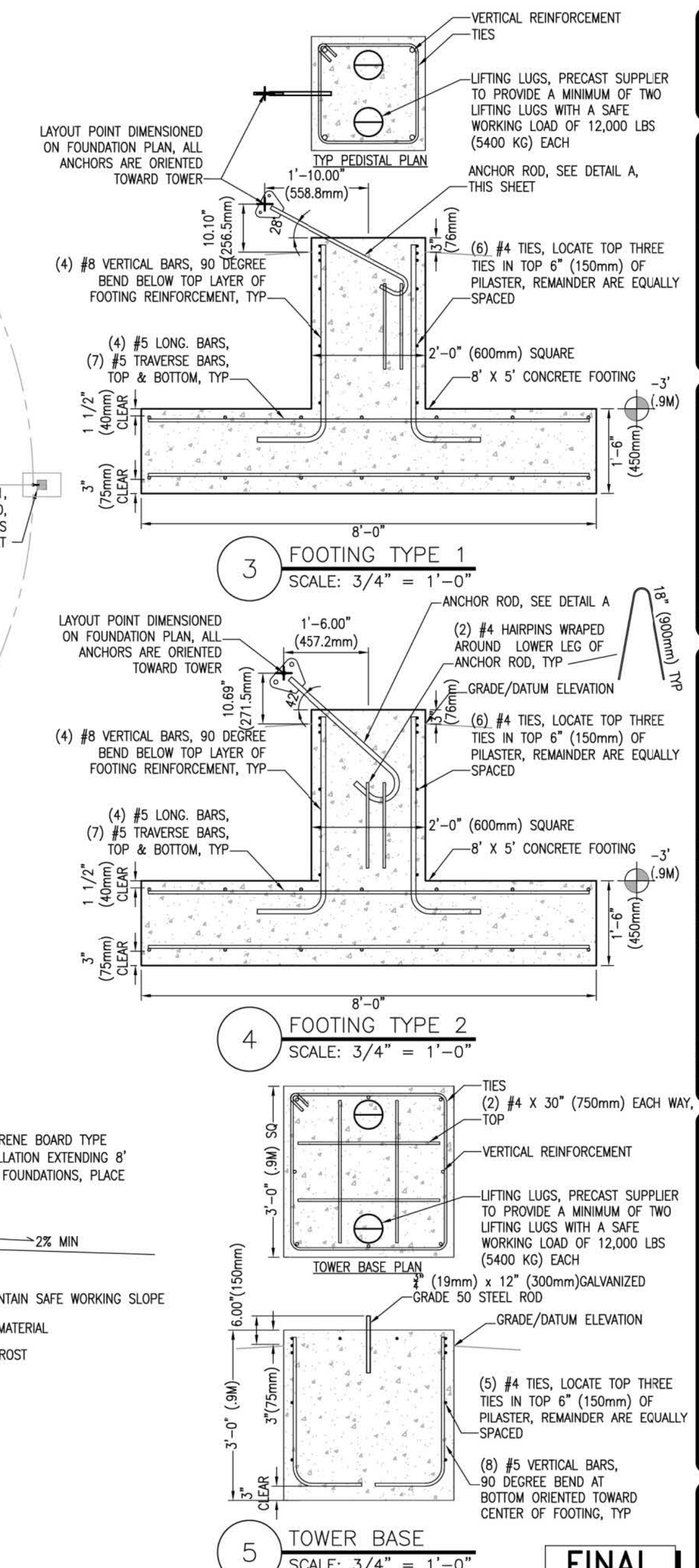
6. FORMED SURFACES; EXTERIOR EXPOSED SURFACES SHALL HAVE CLASS C FINISH.

7. CONCRETE COVER: THE FOLLOWING MINIMUM CONCRETE COVER SHALL BE PROVIDED FOR REINFORCEMENT: #6 THROUGH #8 - 2" (50mm), #5 & SMALLER - 1 ½" (40mm)









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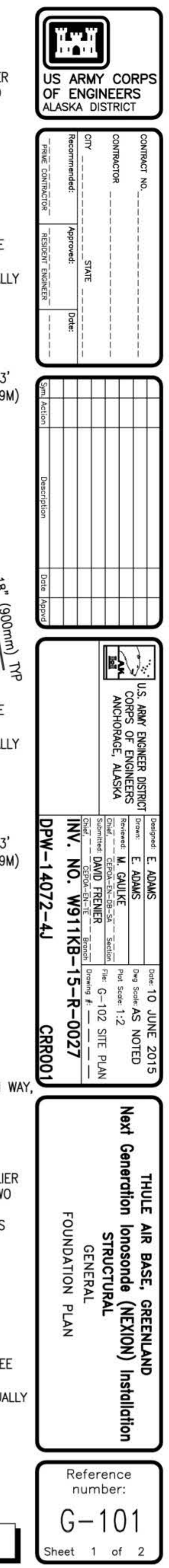


DESIGN ANALYSIS

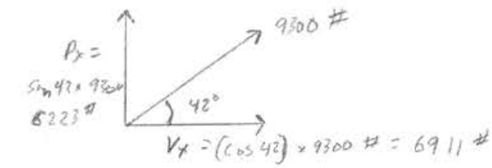
Next Generation Ionosonde (NEXION)
FOUNDATION
Thule Air Base
Greenland

HAND CALCS

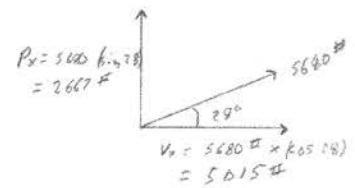
CRR001

E. Adams
1 April 2011

Resultant Loads on Footings



Det 3_TCI



DET 2_TCI

Size Anchor RoD:

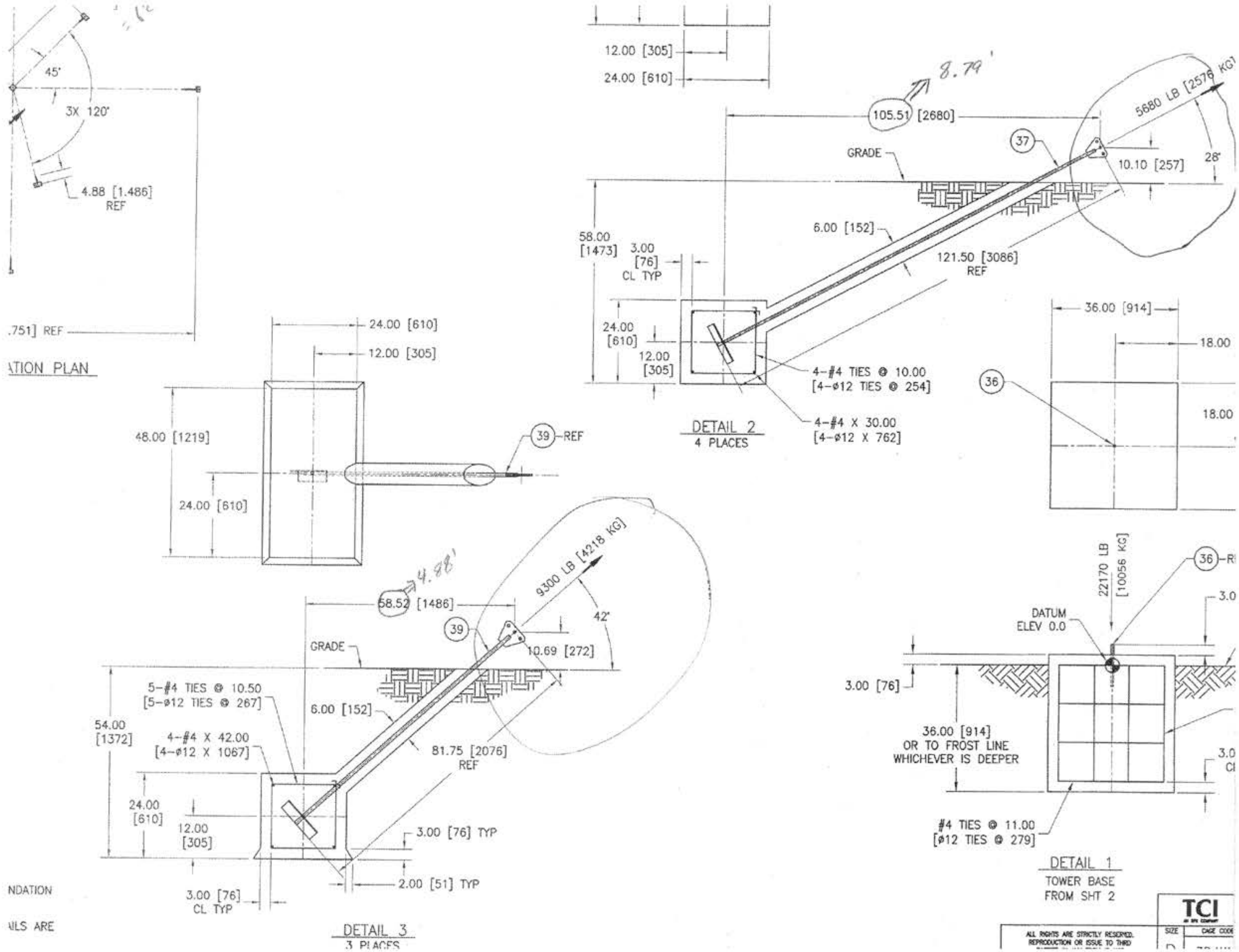
Load = 9300 #
Assume Live Load
Factored Load = 14880 #

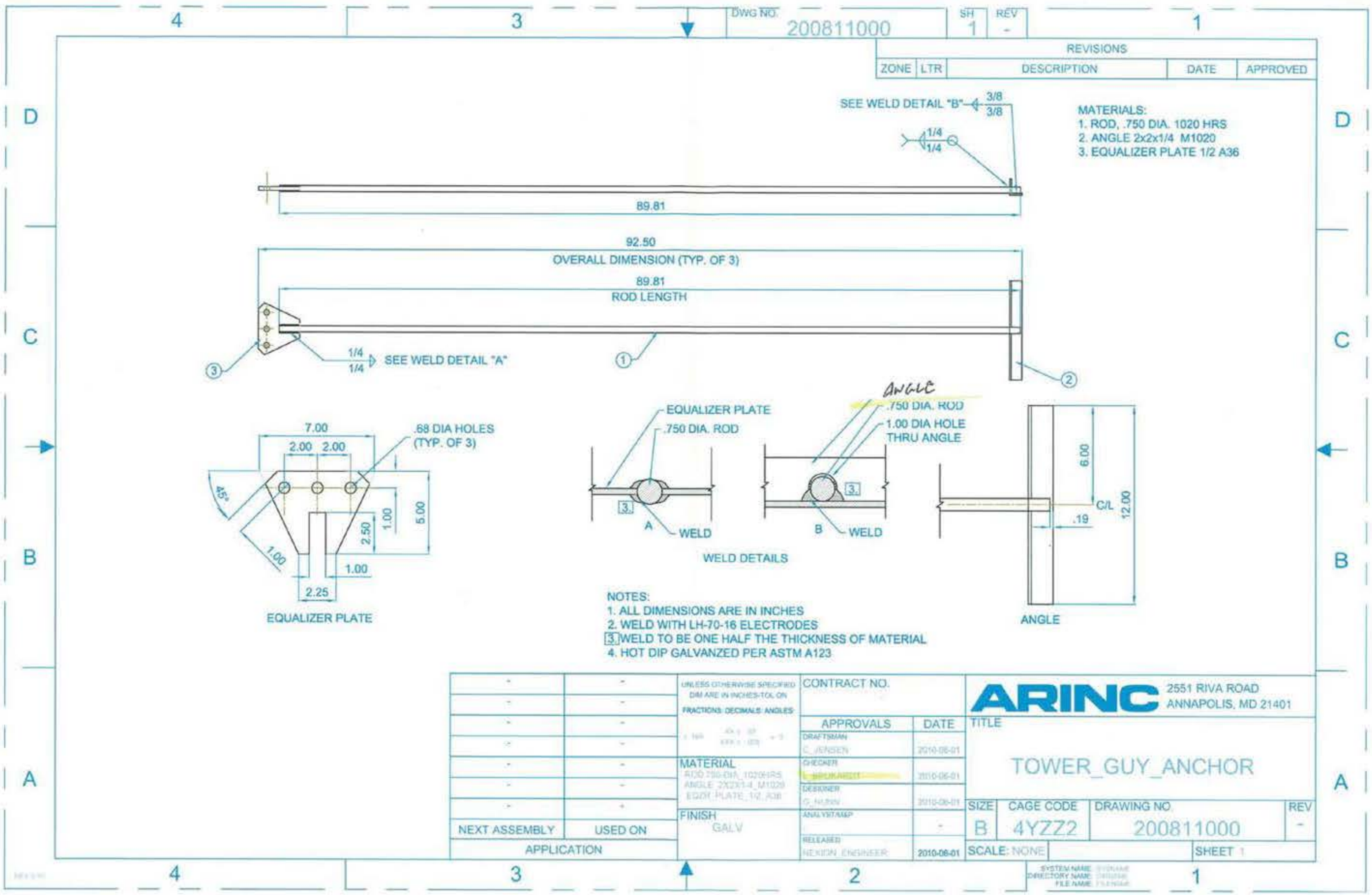
Tension Limit State ⇒ $.9 F_y A_g$
F_y = 40,000 psi

A_s req = .4133 in^2 Use #6 Bar

$L_{development}$ (ACI 318 12 2) $\frac{f_y}{25\sqrt{f'c}} \times d_b$

Ld = 24" for f_y = 40K & f'c = 4K


45°
3X 120°
4.88 [1.486]
REF
.751] REF
ATION PLAN
24.00 [610]
12.00 [305]
48.00 [1219]
24.00 [610]
39 -REF
12.00 [305]
24.00 [610]
8.79'
105.51 [2680]
5680 LB [2576 KG]
37
GRADE
10.10 [257]
28°
58.00
[1473]
3.00
[76]
CL TYP
6.00 [152]
121.50 [3086]
REF
24.00
[610]
12.00
[305]
4-#4 TIES @ 10.00
[4-ø12 TIES @ 254]
4-#4 X 30.00
[4-ø12 X 762]
DETAIL 2
4 PLACES
36.00 [914]
18.00
36
18.00
9300 LB [4218 KG]
4.88'
58.52 [1486]
42°
39
GRADE
10.69 [272]
5-#4 TIES @ 10.50
[5-ø12 TIES @ 267]
6.00 [152]
54.00
[1372]
4-#4 X 42.00
[4-ø12 X 1067]
81.75 [2076]
REF
24.00
[610]
12.00
[305]
3.00 [76] TYP
2.00 [51] TYP
3.00 [76]
CL TYP
NDATION
ILS ARE
DETAIL 3
3 PLACES
22170 LB
[10056 KG]
36 -R
DATUM
ELEV 0.0
3.0
3.00 [76]
36.00 [914]
OR TO FROST LINE
WHICHEVER IS DEEPER
3.0
C
#4 TIES @ 11.00
[ø12 TIES @ 279]
DETAIL 1
TOWER BASE
FROM SHT 2
TCI
ALL RIGHTS ARE STRICTLY RESERVED.
REPRODUCTION OR ISSUE TO THIRD
SIZE
CAGE CODE

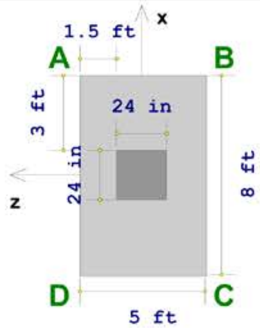

DWG NO.
200811000
SH 1
REV -
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
MATERIALS:
1. ROD, .750 DIA. 1020 HRS
2. ANGLE 2x2x1/4 M1020
3. EQUALIZER PLATE 1/2 A36
SEE WELD DETAIL "B"
3/8
3/8
1/4
1/4
89.81
92.50
OVERALL DIMENSION (TYP. OF 3)
89.81
ROD LENGTH
1/4
1/4
SEE WELD DETAIL "A"
7.00
2.00 2.00
.68 DIA HOLES
(TYP. OF 3)
45°
1.00
2.50
1.00
5.00
1.00
2.25
EQUALIZER PLATE
EQUALIZER PLATE
.750 DIA. ROD
A
WELD
ANGLE
.750 DIA. ROD
1.00 DIA HOLE
THRU ANGLE
B
WELD
WELD DETAILS
6.00
C/L
.19
12.00
ANGLE
NOTES:
1. ALL DIMENSIONS ARE IN INCHES
2. WELD WITH LH-70-16 ELECTRODES
3. WELD TO BE ONE HALF THE THICKNESS OF MATERIAL
4. HOT DIP GALVANZED PER ASTM A123
CONTRACT NO.
ARINC
2551 RIVA ROAD
ANNAPOLIS, MD 21401
APPROVALS
DATE
TITLE
TOWER_GUY_ANCHOR
MATERIAL
FINISH
GALV
NEXT ASSEMBLY
USED ON
APPLICATION
SIZE
B
CAGE CODE
4YZZ2
DRAWING NO.
200811000
REV
-
SCALE: NONE
SHEET 1

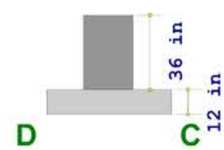
RISA FOOT OUTPUT

Company :
Designer :
Job Number : **Nexion Tower**

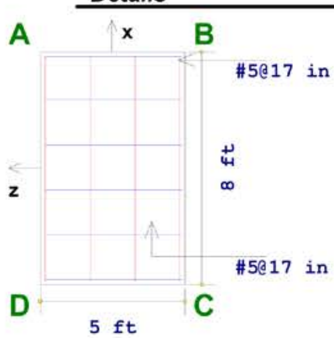
April 3, 2015
Checked By:_____

Sketch

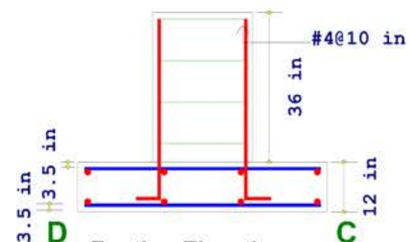




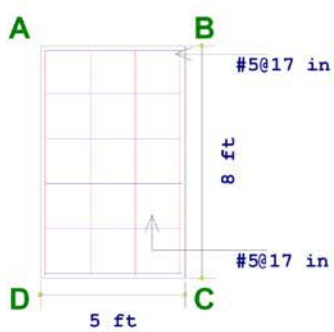
Details



Bottom Rebar Plan

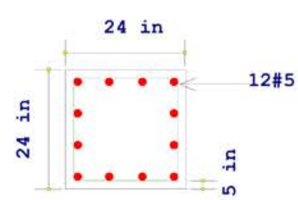


Footing Elevation



x Dir. Steel: 1.23 in^2 (4 #5)
z Dir. Steel: 1.84 in^2 (6 #5)

Top Rebar Plan



Pedestal Rebar Plan

Company :
Designer :
Job Number : **Nexion Tower**

April 3, 2015
Checked By:_____

Geometry, Materials and Criteria

Length	:**5 ft**	eX	:**0 in**	Gross Allow. Bearing	:**5000 psf (gross)**	Steel fy	:**60 ksi**
Width	:**8 ft**	eZ	:**0 in**	Concrete Weight	:**145 pcf**	Minimum Steel	:**.002**
Thickness	:**12 in**	pX	:**24 in**	Concrete f'c	:**3 ksi**	Maximum Steel	:**.0075**
Height	:**36 in**	pZ	:**24 in**	Design Code	:**ACI 318-11**		

Footing Top Bar Cover	:**3.5 in**	Overturning / Sliding SF	:**1.5**	Phi for Flexure	:**0.9**
Footing Bottom Bar Cover	:**3.5 in**	Coefficient of Friction	:**0.3**	Phi for Shear	:**0.75**
Pedestal Longitudinal Bar Cover	:**1.5 in**	Passive Resistance of Soil	:**0 k**	Phi for Bearing	:**0.65**

Loads

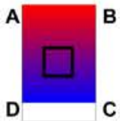
	P (k)	Vx (k)	Vz (k)	Mx (k-ft)	Mz (k-ft)	Overburden (psf)
DL	**-6.223**	**6.911**				**400**
	+P	+Vx A D	+Vz D C	+Mx D C	+Mz A D	+Over

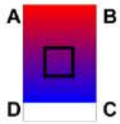
Soil Bearing

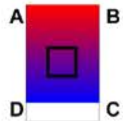
Description	Categories and Factors	Gross Allow.(psf)	Max Bearing (psf)	Max/Allowable Ratio
ASCE 2.4.1-1	**1DL**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-2	**1DL+1LL+.75LLS**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-3a	**1DL+1RLL+1SL+1SLN+1RL**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-4	**1DL+.75LL+.75LLS+.75..**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-5a	**1DL+1WL**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-5b	**1DL+.7EL**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-6a	**1DL+.75WL+.75LL+.75L..**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-6b	**1DL+.525EL+.75LL+.75..**	**5000**	**935.06 (A)**	**.187**
ASCE 2.4.1-7	**.6DL+1WL**	**5000**	**561.036 (B)**	**.112**
ASCE 2.4.1-8	**.6DL+.7EL**	**5000**	**561.036 (B)**	**.112**

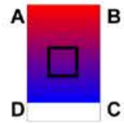
Company :
Designer :
Job Number : **Nexion Tower**

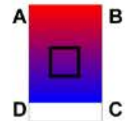
April 3, 2015
Checked By:_____



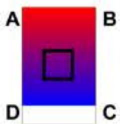


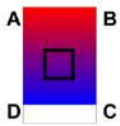


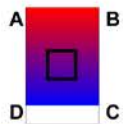


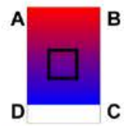


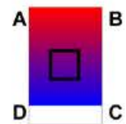
1DL	1DL+1LL+.75LLS	1DL+1RLL+1SL+1SLN+1RL	1DL+.75LL+.75LLS+.75	1DL+1WL
QA: 935.06 psf	QA: 935.06 psf	QA: 935.06 psf	QA: 935.06 psf	QA: 935.06 psf
QB: 935.06 psf	QB: 935.06 psf	QB: 935.06 psf	QB: 935.06 psf	QB: 935.06 psf
QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf
QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf
NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in
NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in











1DL+.7EL	1DL+.75WL+.75LL+.75L	1DL+.525EL+.75LL+.75	.6DL+1WL	.6DL+.7EL
QA: 935.06 psf	QA: 935.06 psf	QA: 935.06 psf	QA: 561.036 psf	QA: 561.036 psf
QB: 935.06 psf	QB: 935.06 psf	QB: 935.06 psf	QB: 561.036 psf	QB: 561.036 psf
QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf
QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf
NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in
NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in	NAX: 80.681 in

Footing Flexure Design (Bottom Bars)

As-min x-dir (Top Flexure): **1.575 in^2**
As-min z-dir (Top Flexure): **2.52 in^2**
As-min x-dir (Bot Flexure): **1.575 in^2**
As-min z-dir (Bot Flexure): **2.52 in^2**

As-min x-dir (T & S): **1.296 in^2**
As-min z-dir (T & S): **2.074 in^2**

Description	Categories and Factors	Mu-xx UC Max	Mu-xx (k-ft)	z-Dir As Required (in^2)	z-Dir As Provided (in^2)	Mu-zz UC Max	Mu-zz (k-ft)	x-Dir As Required (in^2)	x-Dir As Provided (in^2)
ACI-2005 9-1	1.4DL	0	0	0	1.841	.18753	7.91	.224	1.227
ACI-2008 9-2	1.2DL+1.6LL+1.6LL..	0	0	0	1.841	.16074	6.78	.192	1.227
ACI-2008 9-3a	1.5DL+1LL+1LLS+1...	0	0	0	1.841	.20092	8.47	.24	1.227
ACI-2008 9-3b	1.2DL+.8WL+1.6RL..	0	0	0	1.841	.16074	6.78	.192	1.227
ACI-2008 9-4	1.2DL+1.6WL+1LL+1..	0	0	0	1.841	.16074	6.78	.192	1.227
ACI-2008 9-5	1.2DL+1EL+1LL+1LL..	0	0	0	1.841	.16074	6.78	.192	1.227
ACI-2008 9-6	.9DL+1.6WL	0	0	0	1.841	.12055	5.08	.144	1.227
ACI-2008 9-7	.9DL+1EL	0	0	0	1.841	.12055	5.08	.144	1.227

Footing Flexure Design (Top Bars)

Description	Categories and Factors	Mu-xx (k-ft)	z Dir As (in^2)	Mu-zz (k-ft)	x Dir As (in^2)
SW+OB	1SW+1OB-(ACI-2008 9-..,ACI-2008 9-..)	1.722	0	11.729	0

Moment Capacity of Plain Concrete Section Along xx and zz= **20.083k-ft,12.552k-ft** Per Chapter 22 of ACI 318.

Company :
Designer :
Job Number : **Nexion Tower**

April 3, 2015
Checked By:_____

Footing Shear Check

Two Way (Punching) Vc: **219.979 k** One Way (x Dir. Cut) Vc **82.816 k** One Way (z Dir. Cut) Vc: **51.76 k**

		Punching		x Dir. Cut		z Dir. Cut	
Description	Categories and Factors	Vu(k)	Vu/⌀Vc	Vu(k)	Vu/⌀Vc	Vu(k)	Vu/⌀Vc
ACI-2005 9-1	1.4DL	NA	NA	1.437	.023	8.387	.216
ACI-2008 9-2	1.2DL+1.6LL+1.6LLS+.5R..	NA	NA	1.232	.02	7.189	.185
ACI-2008 9-3a	1.5DL+1LL+1LLS+1.6RLL+1..	NA	NA	1.54	.025	8.986	.231
ACI-2008 9-3b	1.2DL+.8WL+1.6RLL+1.6S..	NA	NA	1.232	.02	7.189	.185
ACI-2008 9-4	1.2DL+1.6WL+1LL+1LLS+...	NA	NA	1.232	.02	7.189	.185
ACI-2008 9-5	1.2DL+1EL+1LL+1LLS+.2S..	NA	NA	1.232	.02	7.189	.185
ACI-2008 9-6	.9DL+1.6WL	NA	NA	.924	.015	5.392	.139
ACI-2008 9-7	.9DL+1EL	NA	NA	.924	.015	5.392	.139

Pedestal Design

Shear Check Results (Envelope):

	Vc	Vs	Vu	Vu/phi*Vn	phi
Shear Along x Direction:	0	51.1	10.366	.27	.75
Shear Along z Direction:	0	51.1	0	0	.75

Pedestal Ties : **#4 @ 10 in**

Bending Check Results (Envelope): PCA Load Contour Method (for biaxial)

Unity Check	: .18	Phi	: .9	Parme Beta	: .65
Pu	: 0 k	Mux	: 0 k-ft	Muz	: 31.099 k-ft
Pn	: -220.893 k	Mnx	: NC	Mnz	: 191.936 k-ft
Governing LC	: 13	Mnox	: NC	Mnoz	: NC
Pedestal Bars	: 12 #5	% Steel	: .6392		

Concrete Bearing Check (Vertical Loads Only)

Bearing Bc : **2937.6 k**

Description	Categories and Factors	Bearing Bu (k)	Bearing Bu/⌀Bc
ACI-2005 9-1	1.4DL	0	0
ACI-2008 9-2	1.2DL+1.6LL+1.6LLS+.5R..	0	0
ACI-2008 9-3a	1.5DL+1LL+1LLS+1.6RLL+1..	0	0
ACI-2008 9-3b	1.2DL+.8WL+1.6RLL+1.6S..	0	0
ACI-2008 9-4	1.2DL+1.6WL+1LL+1LLS+...	0	0
ACI-2008 9-5	1.2DL+1EL+1LL+1LLS+.2S..	0	0
ACI-2008 9-6	.9DL+1.6WL	0	0
ACI-2008 9-7	.9DL+1EL	0	0

Company :
Designer :
Job Number : **Nexion Tower**

April 3, 2015
Checked By:_____

Overturning Check (Service)

Description	Categories and Factors	Mo-xx (k-ft)	Ms-xx (k-ft)	Mo-zz (k-ft)	Ms-zz (k-ft)	OSF-xx	OSF-zz
ASCE 2.4.1-1	1DL	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-2	1DL+1LL+.75LLS	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-3a	1DL+1RLL+1SL+1SLN..	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-4	1DL+.75LL+.75LL..	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-5a	1DL+1WL	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-5b	1DL+.7EL	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-6a	1DL+.75WL+.75LL..	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-6b	1DL+.525EL+.75L..	15.557	54.85	52.536	87.76	3.526	1.67
ASCE 2.4.1-7	.6DL+1WL	9.334	32.91	31.522	52.656	3.526	1.67
ASCE 2.4.1-8	.6DL+.7EL	9.334	32.91	31.522	52.656	3.526	1.67

Mo-xx: Governing Overturning Moment about AD or BC
Ms-xx: Governing Stablizing Moment about AD or BC
OSF-xx: Ratio of Ms-xx to Mo-xx

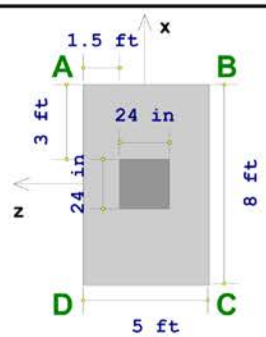
Sliding Check (Service)

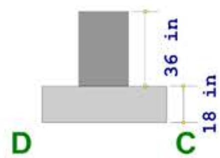
Description	Categories and Factors	Va-xx (k)	Vr-xx (k)	Va-zz (k)	Vr-zz (k)	SR-xx	SR-zz
ASCE 2.4.1-1	1DL	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-2	1DL+1LL+.75LLS	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-3a	1DL+1RLL+1SL+1SLN..	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-4	1DL+.75LL+.75LL..	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-5a	1DL+1WL	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-5b	1DL+.7EL	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-6a	1DL+.75WL+.75LL..	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-6b	1DL+.525EL+.75L..	6.911	4.715	0	4.715	.682	NA
ASCE 2.4.1-7	.6DL+1WL	4.147	2.829	0	2.829	.682	NA
ASCE 2.4.1-8	.6DL+.7EL	4.147	2.829	0	2.829	.682	NA

Va-xx: Applied Lateral Force to Cause Sliding Along xx Axis
Vr-xx: Resisting Lateral Force Against Sliding Along xx Axis
SR-xx: Ratio of Vr-xx to Va-xx

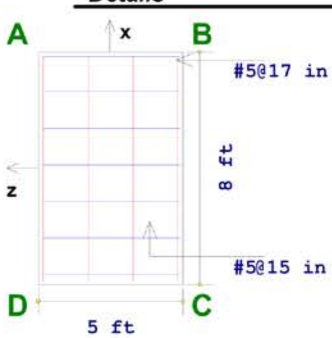
Company : **USACE** April 3, 2015
Designer : **E ADAMS**
Job Number : **CRR001** **Nexion Tower** Checked By:_____

Sketch

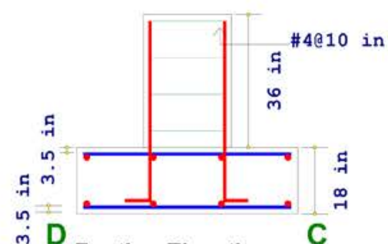




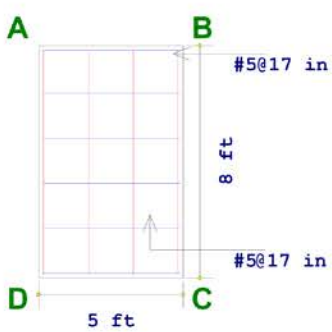
Details



Bottom Rebar Plan

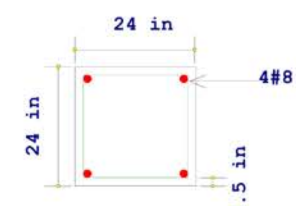


Footing Elevation



x Dir. Steel: 1.23 in^2 **(4 #5)**
z Dir. Steel: 1.84 in^2 **(6 #5)**

Top Rebar Plan



Pedestal Rebar Plan

Company : **USACE**		April 3, 2015
Designer : **E ADAMS**		
Job Number : **CRR001**	**Nexion Tower**	Checked By:_____

Geometry, Materials and Criteria

Length	:**5 ft**	eX	:**0 in**	Gross Allow. Bearing	:**8000 psf (gross)**	Steel fy	:**60 ksi**
Width	:**8 ft**	eZ	:**0 in**	Concrete Weight	:**145 pcf**	Minimum Steel	:**.002**
Thickness	:**18 in**	pX	:**24 in**	Concrete f'c	:**3 ksi**	Maximum Steel	:**.0075**
Height	:**36 in**	pZ	:**24 in**	Design Code	:**ACI 318-11**		

Footing Top Bar Cover	:**3.5 in**	Overturning / Sliding SF	:**1.5**	Phi for Flexure	:**0.9**
Footing Bottom Bar Cover	:**3.5 in**	Coefficient of Friction	:**0.3**	Phi for Shear	:**0.75**
Pedestal Longitudinal Bar Cover	:**1.5 in**	Passive Resistance of Soil	:**0 k**	Phi for Bearing	:**0.65**

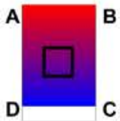
Loads

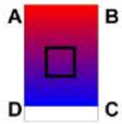
	P (k)	Vx (k)	Vz (k)	Mx (k-ft)	Mz (k-ft)	Overburden (psf)
DL	**-6.223**	**6.911**				**400**

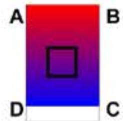
Soil Bearing

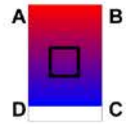
Description	Categories and Factors	Gross Allow.(psf)	Max Bearing (psf)	Max/Allowable Ratio
ASCE 2.4.1-1	**1DL**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-2	**1DL+1LL+.75LLS**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-3a	**1DL+1RLL+1SL+1SLN+1RL**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-4	**1DL+.75LL+.75LLS+.75..**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-5a	**1DL+1WL**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-5b	**1DL+.7EL**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-6a	**1DL+.75WL+.75LL+.75L..**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-6b	**1DL+.525EL+.75LL+.75..**	**8000**	**1065.57 (A)**	**.133**
ASCE 2.4.1-7	**.6DL+1WL**	**8000**	**639.345 (A)**	**.08**
ASCE 2.4.1-8	**.6DL+.7EL**	**8000**	**639.345 (A)**	**.08**

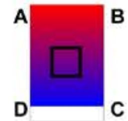
Company : **USACE**		April 3, 2015
Designer : **E ADAMS**		
Job Number : **CRR001**	**Nexion Tower**	Checked By:_____



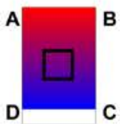


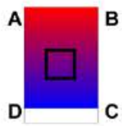


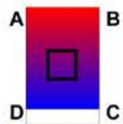


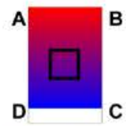


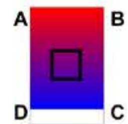
1DL	1DL+1LL+.75LLS	1DL+1RLL+1SL+1SLN+1RL	1DL+.75LL+.75LLS+.75	1DL+1WL
QA: 1065.57 psf	QA: 1065.57 psf	QA: 1065.57 psf	QA: 1065.57 psf	QA: 1065.57 psf
QB: 1065.57 psf	QB: 1065.57 psf	QB: 1065.57 psf	QB: 1065.57 psf	QB: 1065.57 psf
QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf
QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf
NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in
NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in











1DL+.7EL	1DL+.75WL+.75LL+.75	1DL+.525EL+.75LL+.75	.6DL+1WL	.6DL+.7EL
QA: 1065.57 psf	QA: 1065.57 psf	QA: 1065.57 psf	QA: 639.345 psf	QA: 639.345 psf
QB: 1065.57 psf	QB: 1065.57 psf	QB: 1065.57 psf	QB: 639.345 psf	QB: 639.345 psf
QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf	QC: 0 psf
QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf	QD: 0 psf
NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in	NAZ: -1 in
NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in	NAX: 83.862 in

Footing Flexure Design (Bottom Bars)

As-min x-dir (Top Flexure): **2.775 in^2**
As-min z-dir (Top Flexure): **4.44 in^2**
As-min x-dir (Bot Flexure): **2.775 in^2**
As-min z-dir (Bot Flexure): **4.44 in^2**

As-min x-dir (T & S): **1.944 in^2**
As-min z-dir (T & S): **3.11 in^2**

Description	Categories and Factors	Mu-xx UC Max	Mu-xx (k-ft)	z-Dir As Required (in^2)	z-Dir As Provided (in^2)	Mu-zz UC Max	Mu-zz (k-ft)	x-Dir As Required (in^2)	x-Dir As Provided (in^2)
ACI-2005 9-1	1.4DL	0	0	0	2.148	.12367	9.31	.149	1.227
ACI-2008 9-2	1.2DL+1.6LL+1.6LL..	0	0	0	2.148	.106	7.98	.128	1.227
ACI-2008 9-3a	1.5DL+1LL+1LLS+1...	0	0	0	2.148	.1325	9.98	.16	1.227
ACI-2008 9-3b	1.2DL+.8WL+1.6RL..	0	0	0	2.148	.106	7.98	.128	1.227
ACI-2008 9-4	1.2DL+1.6WL+1LL+1..	0	0	0	2.148	.106	7.98	.128	1.227
ACI-2008 9-5	1.2DL+1EL+1LL+1LL..	0	0	0	2.148	.106	7.98	.128	1.227
ACI-2008 9-6	.9DL+1.6WL	0	0	0	2.148	.0795	5.99	.096	1.227
ACI-2008 9-7	.9DL+1EL	0	0	0	2.148	.0795	5.99	.096	1.227

Footing Flexure Design (Top Bars)

Description	Categories and Factors	Mu-xx (k-ft)	z Dir As (in^2)	Mu-zz (k-ft)	x Dir As (in^2)
SW+OB	1SW+1OB-(ACI-2008 9-..,ACI-2008 9-..)	1.788	0	12.995	0

Moment Capacity of Plain Concrete Section Along xx and zz= **51.413k-ft,32.133k-ft** Per Chapter 22 of ACI 318.

Company : **USACE**
Designer : **E ADAMS**
Job Number : **CRR001** **Nexion Tower**

April 3, 2015
Checked By:_____

Footing Shear Check

Two Way (Punching) Vc: **460.539 k** One Way (x Dir. Cut) Vc **145.913 k** One Way (z Dir. Cut) Vc: **91.196 k**

		Punching		x Dir. Cut		z Dir. Cut	
Description	Categories and Factors	Vu(k)	Vu/⌀Vc	Vu(k)	Vu/⌀Vc	Vu(k)	Vu/⌀Vc
ACI-2005 9-1	1.4DL	NA	NA	.585	.005	7.6	.111
ACI-2008 9-2	1.2DL+1.6LL+1.6LLS+.5R..	NA	NA	.502	.005	6.514	.095
ACI-2008 9-3a	1.5DL+1LL+1LLS+1.6RLL+1..	NA	NA	.627	.006	8.143	.119
ACI-2008 9-3b	1.2DL+.8WL+1.6RLL+1.6S..	NA	NA	.502	.005	6.514	.095
ACI-2008 9-4	1.2DL+1.6WL+1LL+1LLS+...	NA	NA	.502	.005	6.514	.095
ACI-2008 9-5	1.2DL+1EL+1LL+1LLS+.2S..	NA	NA	.502	.005	6.514	.095
ACI-2008 9-6	.9DL+1.6WL	NA	NA	.376	.003	4.886	.071
ACI-2008 9-7	.9DL+1EL	NA	NA	.376	.003	4.886	.071

Pedestal Design

Shear Check Results (Envelope):

	Vc	Vs	Vu	Vu/phi*Vn	phi
Shear Along x Direction:	0	50.658	10.366	.273	.75
Shear Along z Direction:	0	50.658	0	0	.75

Pedestal Ties : **#4 @ 10 in**

Bending Check Results (Envelope): PCA Load Contour Method (for biaxial)

Unity Check	: .211	Phi	: .9	Parme Beta	: .65
Pu	: 0 k	Mux	: 0 k-ft	Muz	: 31.099 k-ft
Pn	: -188.496 k	Mnx	: NC	Mnz	: 164.116 k-ft
Governing LC	: 13	Mnox	: NC	Mnoz	: NC
Pedestal Bars	: 4 #8	% Steel	: .5454		

Concrete Bearing Check (Vertical Loads Only)

Bearing Bc : **2937.6 k**

Description	Categories and Factors	Bearing Bu (k)	Bearing Bu/⌀Bc
ACI-2005 9-1	1.4DL	0	0
ACI-2008 9-2	1.2DL+1.6LL+1.6LLS+.5R..	0	0
ACI-2008 9-3a	1.5DL+1LL+1LLS+1.6RLL+1..	0	0
ACI-2008 9-3b	1.2DL+.8WL+1.6RLL+1.6S..	0	0
ACI-2008 9-4	1.2DL+1.6WL+1LL+1LLS+...	0	0
ACI-2008 9-5	1.2DL+1EL+1LL+1LLS+.2S..	0	0
ACI-2008 9-6	.9DL+1.6WL	0	0
ACI-2008 9-7	.9DL+1EL	0	0

Company : USACE			April 3, 2015
Designer : E ADAMS			
Job Number : CRR001		Nexion Tower	Checked By:_____

Overturning Check (Service)

Description	Categories and Factors	Mo-xx (k-ft)	Ms-xx (k-ft)	Mo-zz (k-ft)	Ms-zz (k-ft)	OSF-xx	OSF-zz
ASCE 2.4.1-1	1DL	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-2	1DL+1LL+.75LLS	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-3a	1DL+1RLL+1SL+1SLN..	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-4	1DL+.75LL+.75LL..	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-5a	1DL+1WL	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-5b	1DL+.7EL	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-6a	1DL+.75WL+.75LL..	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-6b	1DL+.525EL+.75L..	15.557	62.1	55.991	99.36	3.992	1.775
ASCE 2.4.1-7	.6DL+1WL	9.334	37.26	33.595	59.616	3.992	1.775
ASCE 2.4.1-8	.6DL+.7EL	9.334	37.26	33.595	59.616	3.992	1.775

Mo-xx: Governing Overturning Moment about AD or BC
Ms-xx: Governing Stablizing Moment about AD or BC
OSF-xx: Ratio of Ms-xx to Mo-xx

Sliding Check (Service)

Description	Categories and Factors	Va-xx (k)	Vr-xx (k)	Va-zz (k)	Vr-zz (k)	SR-xx	SR-zz
ASCE 2.4.1-1	1DL	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-2	1DL+1LL+.75LLS	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-3a	1DL+1RLL+1SL+1SLN..	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-4	1DL+.75LL+.75LL..	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-5a	1DL+1WL	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-5b	1DL+.7EL	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-6a	1DL+.75WL+.75LL..	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-6b	1DL+.525EL+.75L..	6.911	5.585	0	5.585	.808	NA
ASCE 2.4.1-7	.6DL+1WL	4.147	3.351	0	3.351	.808	NA
ASCE 2.4.1-8	.6DL+.7EL	4.147	3.351	0	3.351	.808	NA

Va-xx: Applied Lateral Force to Cause Sliding Along xx Axis
Vr-xx: Resisting Lateral Force Against Sliding Along xx Axis
SR-xx: Ratio of Vr-xx to Va-xx

Appendix B: Crescent Lake Site Test-Pit Excavation Photographs

Figure B1.

Figure B2.

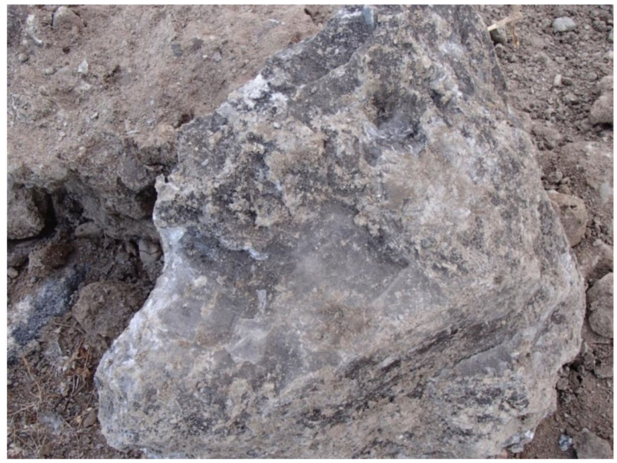


Figure B3.

Figure B4.

Figure B5.

Figure B6.

Figure B7.

Figure B8.

Figure B9.

Figure B10.

Figure B11.

Figure B12.

Figure B13.

Figure B14.

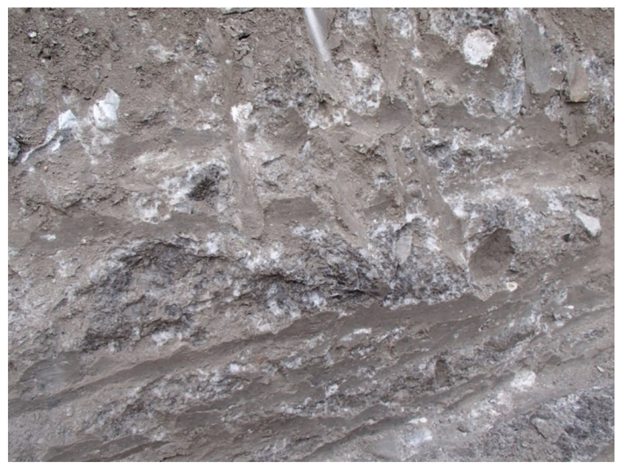


Figure B15.

Figure B16.

Figure B17.

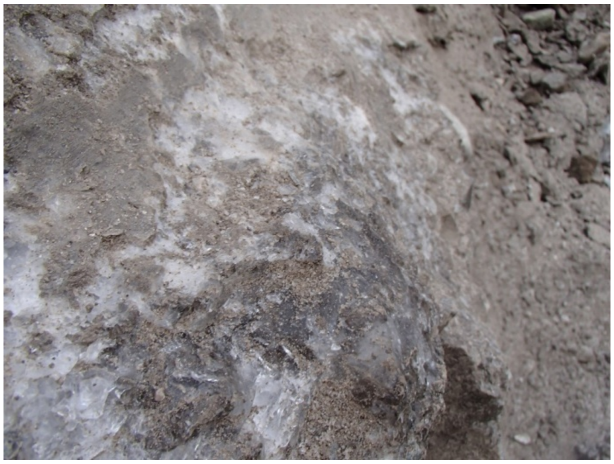


Figure B18.

Figure B19.

Figure B20.

Figure B21.

Figure B22.

Figure B23.

Figure B24.

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Figure B26.

Figure B27.

Figure B28.

Figure B29.

Figure B30.

Figure B31.

Figure B32.

Figure B33.

Figure B34.

Figure B35.

Figure B36.

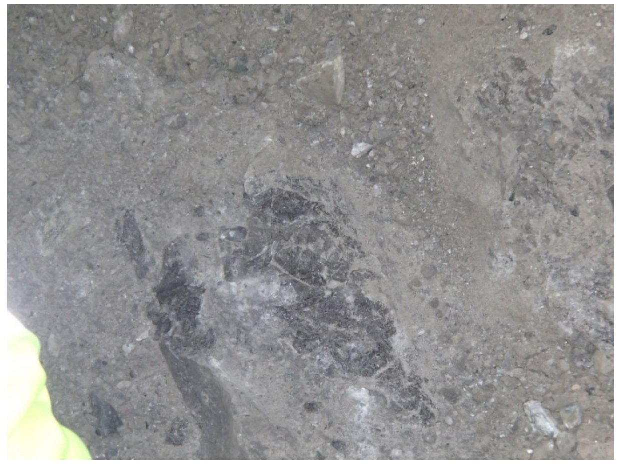

Figure B37.

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14. ABSTRACT
This report presents the results of our geotechnical and structural design for the transmitter antenna of the Next Generation Ionosonde (NEXION) at Thule Air Base, Greenland, for the Space and Missile Systems Center, Remote Sensing Space Environmental Branch, and Air Force Weather. NEXION is a commercial-off-the-shelf ionospheric sounder used to measure the electron density of ionospheric plasma. The design required special considerations for installation, construction, and shipment due to the ice-rich permafrost soil conditions at Thule Air Base's remote and logistically difficult location. In particular, anchored tension ground connections could not withstand viscoelastic creep of ground ice under extreme wind-loading events. In addition, predicted future climate change required additional considerations to protect the thermal regime of the thaw-unstable sediments.

Recommendations include excavation into permafrost soils, non-frost-susceptible structural replacement fill, and extruded polystyrene board-type insulation to facilitate maintaining and improving the subsurface thermal regime and to provide favorable foundation performance for the NEXION tower system. Furthermore, given the remote site location and limited availability of on-site concreting capabilities, foundations require pre-casting and shipping via ocean transport vessel to Greenland. As such, we designed an alternative foundation detail, including anchor rods, to mitigate the potential for irreparable damage that may occur during shipping and transporting.

15. SUBJECT TERMS

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