Attachment 8.8

Milne Port Geotechnical Recommendations

(13 Pages)

Baffinland Iron Mines Corporation
Mary River Expansion Study - Stage II

Preliminary Geotechnical Recommendation for Infrastructures at Milne Inlet

2017-01-10	1	Approved for Use	M. Buykx	J. Cleland	J. Cleland	M. Weaver
2016-09-01	0	Approved for Use	G. Liang	K.S. Ho	J. Cleland	M. Weaver
Date	**Rev.**	**Status**	**Prepared By**	**Checked By**	**Approved By**	**Approved By**
HATCH						**Client**

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1. Introduction

Baffinland Iron Mines Corporation (BIM) currently operates the Mary River iron ore mine in Nunavut, Canada. BIM plans to increase the production rate of the mine from current 4.2 million tonnes per annum (Mtpa) to 12Mtpa, shipping the output through Milne Port. This will be achieved by upgrading the mine fleet, constructing a 105 km long rail line from the mine site to the port, building a new crushing and screening facility at the port, construction of larger ore stockpiles and building a second ore dock and ship loader.

This report summarizes preliminary geotechnical recommendations for different types of foundation of infrastructures at Milne Inlet (the Site) based on the existing geotechnical investigation data, as part of the Mary River Expansion Study – Stage II. It should be noted that the site layout is not finalized; the structural loadings and the site specific geotechnical investigation data are not available at this time. The recommendations for foundation design provided in this report are preliminary. Detailed geotechnical engineering assessment (i.e. geotechnical investigation, temperature measurements, thermal analysis, bearing capacity and settlement analyses of foundations) will be required to confirm their performance and optimize the preliminary design in the next design stages. Detailed geotechnical recommendations and construction considerations are not discussed in this report. 1

2. Scope of Work

The geotechnical assessment summarized in this report was developed to support the pre feasibility study for the foundation design of infrastructures at Milne Inlet and for the Railway Bridges. Figure 2-1 shows the preliminary layout of the proposed infrastructures at this design stage. Table 2–1 summarizes the preliminary infrastructure list.

Table 2–1: Summary of Preliminary Infrastructures List at Milne Inlet and Railroad Bridges [1]

No.	Proposed Infrastructures
1	Rail car rotary tipper building
2	Ship loaders
3	Elevated conveyors
4	Bridges foundations for railroad
5	Conveyor transfer towers and drive houses
6	Ground level yard conveyor and stacker/reclaimer
7	Crushing and screening buildings
8	Rail workshop

Note ([1]) - the infrastructure lists are preliminary, which will be updated based on the final layout design.

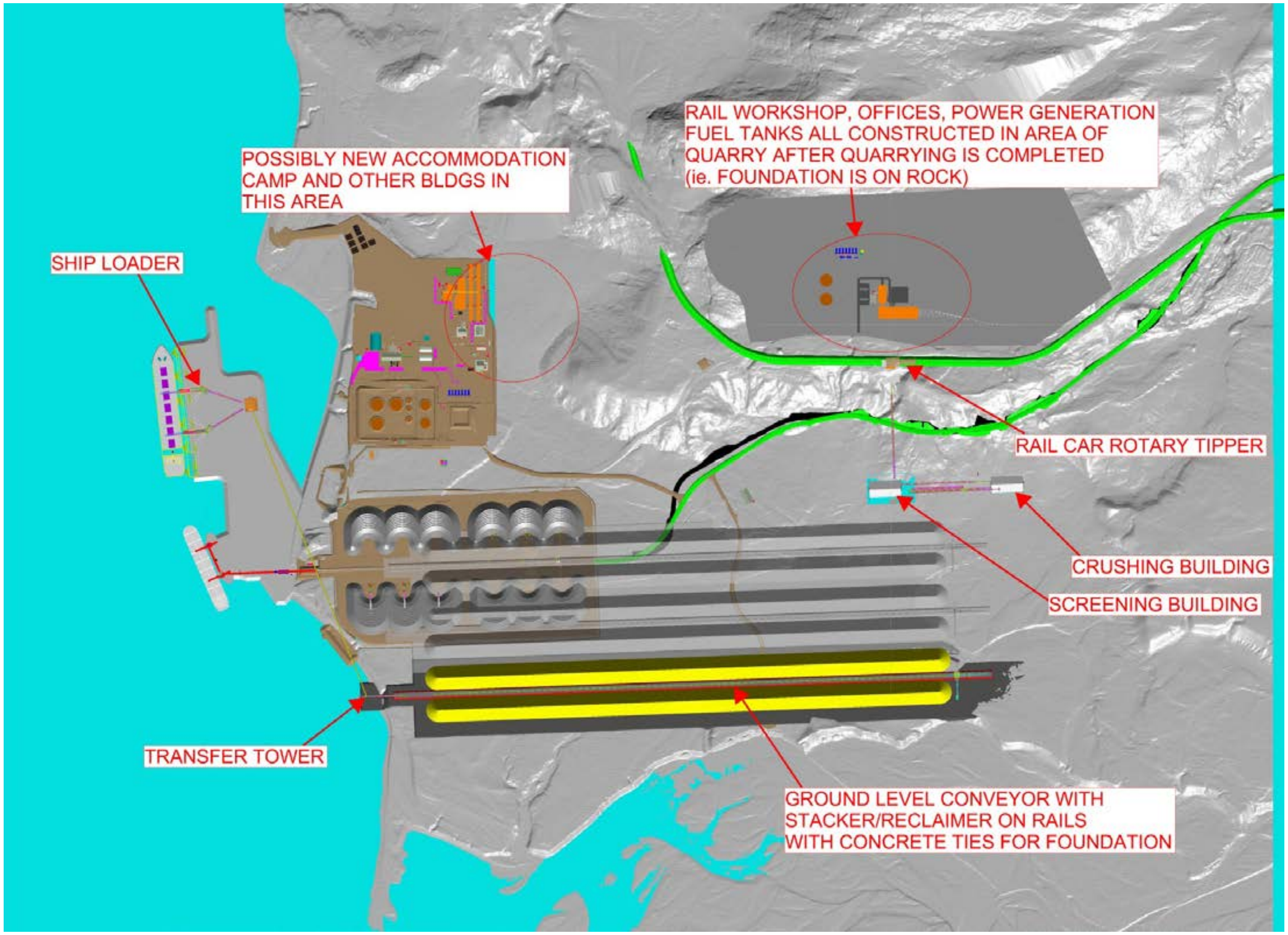


Figure 2-1: Preliminary Layout of Infrastructures at Milne Inlet (For Reference Only)

3. Reference Document

The preliminary geotechnical recommendation for the infrastructure foundation design at Milne Inlet provided in this report are based on the following information and investigation:

- AMEC Earth & Environmental, 2010. Geotechnical, Geochemical and Quarry Sourcing Investigation (Draft). Project No. TC101510. Dec. 2010.
- Knight Piesold Consulting Ltd. (KP) report “Mine Site Infrastructure, Pit Overburden and Waste Dumps – 2006 Site Investigation Summary Report”, (Ref. No. NB102-00181/3-2), February 28, 2007.
- Knight Piesold Consulting Ltd. (KP) report “Mine Site Infrastructure, Pit Overburden and Waste Dumps – 2007 Site Investigations and Foundations Recommendations Summary Report”, (Ref. No. NB102-00181/8-2), December 14, 2007.
- Knight Piesold Consulting Ltd. (KP) boreholes (PMT-001, PMBC-002, PMPL-002, PMTF-001, PMSD-001 and BS-001) advanced at Milne Inlet in May 2007.
- Knight Piesold, July 2007, Bulk Sampling Program Road Upgrade Design Summary (REF. NO. NB102-00181/10-1).
- Knight Piesold, 2008, “Mine site infrastructure, pit overburden and waste dumps – 2008 site investigations summary report” (ref NB102-181/24-1), May 4, 2010.
- Knight Piesold, Feb 2009, Bulk Sampling Program Milne Inlet Tote Road Construction Summary, (REF. NO. NB102-181/13-2).
- Thurber, 2011, “2011 Onshore Geotechnical Investigations Summary of Results”, (ref. 19-1605-126), Nov 10, 2011.
- Thurber 2011 report “Initial Geotechnical Recommendations Mary River Mine Site Facilities” (ref 19-1605-126), Nov 7, 2011.
- EBA Engineering Consultants Ltd. (EBA) memo “Foundation Recommendations, Mary River Mine Site Infrastructure”, (File: E14101009.003), September 9, 2010.
- EBA 2008, Mary Rive- Pile Foundations Revision C, E14101009.001.
- Hatch Ltd. H337697-0000-15-124-0004.Geotechnical Data Report –Infrastructure. April 5, 2012.
- Hatch 2013, Geotechnical Design Criteria, H349000-1000-15-122-0001, Rev 0.

4. Regional Geology

Regional geologic mapping is available for the project site from Milne Inlet follow the route of Tote Road (Scott and de Kemp, 1998), which can be used for preliminary design:

- Approximately the first 20 km of the Tote Road from Milne Inlet passes through Precambrian terrane.
- The middle 73 km of the road travels across relatively flat lying Paleozoic rocks.
- The final 14 km of the road to the Mary River mine site passes through Precambrian terrane near the boundary with the Paleozoic units.

The detailed regional geology was described in AMEC 2010 geotechnical Investigation Report (AMEC TC101510, 2010).

5. Geotechnical Data Summary

5.1 Subsoil Conditions

In general, the overburden soils encountered at Milne Port consist of glacial alluvial deposits of cohesionless soils consisting of sand, sand and gravel, and gravel, containing frequent cobbles and boulders. A thin layer of organics at the ground surface is encountered in some locations. The glacial alluvial deposits are found at the ground surface to a depth of 42 m. An average of 9% passing 0.075 mm size (silt and clay content) was recorded in particle size tests from this area. Bedrock has not been encountered at the Site within the low lying area located at the base of the rock ridge.

Vegetation is sparse and consists primarily of a variety of mosses and grasses in areas where surface moisture is present during the thaw season. No shrubs or trees exist in the area and no peat deposits have been observed. Top soil and existing roots shall be removed to a minimum of 150 mm, if required.

The Site is underlain by permafrost, except below large bodies of water where water depths exceed 3 or 4 m. No sub-surface (ground) ice has been observed at the Milne Port site based on the previous geotechnical investigation campaigns. However significant ground ice was found in a deep excavation near the new ore dock and ground ice has been found in the vicinity of the existing Water Building; settlement due to thawing of ground ice is believed to be occurring under the Water Building and the Sewage Treatment Plant.

5.2 Foundation Type and Bearing Capacity

The anticipated foundation option for the infrastructures of Milne Inlet could be summarized in Table 5–1.

Table 5–1: Summary of Preliminary Infrastructures and Foundation Options

No.	Proposed Infrastructures	Potential Foundation Option
1	Rail car rotary tipper building	Shallow foundation (on rock); or Adfreeze pile (on permafrost)
2	Ship loaders	Adfreeze pile
3	Elevated conveyors	Adfreeze pile or shallow foundation
4	Bridges foundations for railroad	Adfreeze pile
5	Conveyor transfer towers and drive houses	Adfreeze pile
6	Ground level yard conveyor and stacker/reclaimer	Rockfill Embankment with shallow foundation
7	Crushing and screening buildings	Shallow foundation
8	Rail workshop	Shallow foundation (possibly on rock)

It should be noted that the above proposed foundation options should be reviewed based on ground investigation results during the next design phase.

5.2.1 Shallow Footings

The following types of shallow foundations are considered applicable for infrastructures at Milne Inlet for pre feasibility design stage.

- Square footing (Footing Length (L)/width (B) =1, with B=1 m to 4 m).
- Rectangular footing (L/B=3, with B =1 m to 4 m).
- Strip Footing (L/B>10, with B=1 m to 3 m).

5.2.2 Bearing Capacity

The allowable bearing capacity of different types of shallow foundation are estimated based on the following assumption.

- The existing subgrade soil is assumed non ice-rich permafrost in this preliminary design stage. It should be noted that, for footing placed on ice-rich soil, the serviceability of the foundation should be checked for secondary creep.
- The proposed shallow foundations at Milne port will be constructed on an engineered fill (granular pad) with a minimum thickness of 400 mm of Non Frost Susceptible (NFS) material. There will be no embedment considered for the foundations at this stage.
- An internal friction angle of 32° and a cohesion of zero are assumed for the soil shear strength parameters. Soil bulk density is assumed 20 kN/m^3.
- The engineered fill is placed and compacted to meet required specifications. Surface drainage is maintained to prevent formation of ice lenses.
- Bearing capacity is estimated based on the generalized foundation equation described in the Canadian Foundation Engineering Manual, 4th Edition.

- A factor of safety of 2.5 applied to the ultimate bearing capacity.

The estimated bearing capacities for different types of shallow foundation are shown in the design charts listed as follows:

- Bearing capacity for square footing: Figure 5-1.
- Bearing capacity for rectangular footing: Figure 5-2.
- Bearing capacity for strip footing: Figure 5-3.

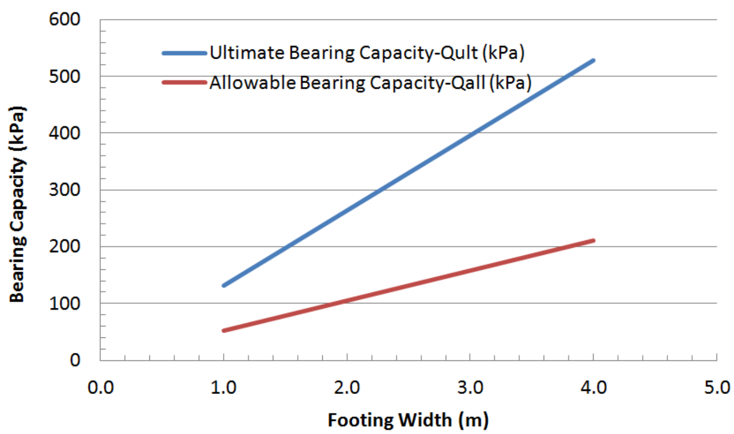


Figure 5-1: Bearing Capacity for Square Footing on 400 mm Granular Engineered Fill (L/B=1 with B =1 m to 4 m)

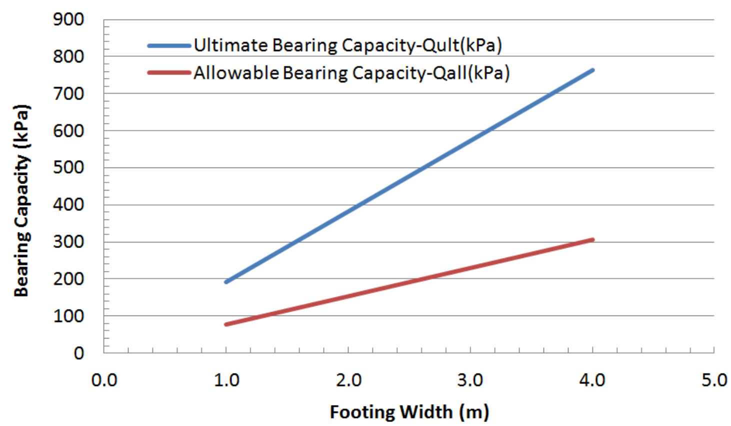


Figure 5-2: Bearing Capacity for Rectangular Footing on 400 mm Granular Engineered Fill (L/B=3 with B =1 m to 4 m)

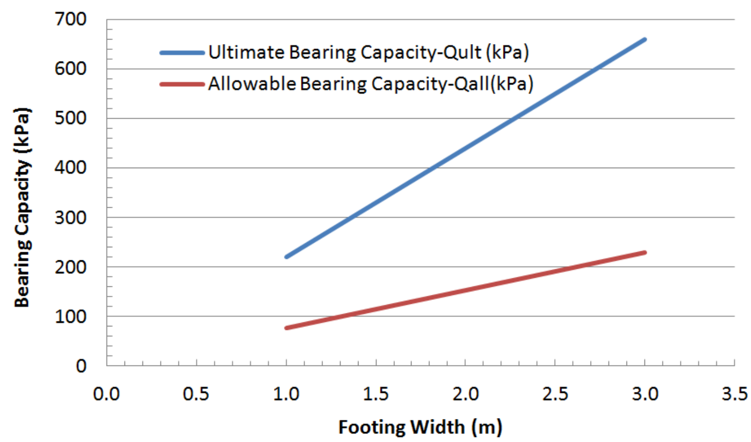


Figure 5-3: Bearing Capacity for Strip Footing on 400 mm Granular Engineered Fill (L/B>10 with B =1 m to 3 m)

5.2.3 Modulus of Subgrade Reaction

5.2.3.1 Building Foundations

Considering the soil conditions at Milne Inlet sites, the modulus of subgrade reaction recommended by Knight Piesold (2007) are considered suitable. Table 5–2 provides the modulus of subgrade reaction for foundations with different widths.

Table 5–2: The Modulus of Subgrade Reaction

Foundation Width (m)	Modulus of Subgrade Reaction (MPa/m)
1.0	66.0
1.5	44.0
2.0	33.0
2.5	26.0
3.0	22.0
3.5	19.0
4.0	16.5

5.2.3.2 Slab on Grade

The building slab at Milne port site will accept loads from heavy loaders, bulldozers, or haul trucks. No stockpile loads are anticipated on slabs. Therefore the maximum effective width of slabs below the trucks are assumed less than 2 m. A modulus of subgrade reaction for slabs on grades can be selected similar to building foundations with a width of 2 m.

Based on the latest field observation, significant ground ice was found in a deep excavation near the new ore dock and ground ice has been found in the vicinity of the existing Water Building, foundation settlement due to thawing of ground ice should be limited by design measures. As such, thermal insulation is recommended for the Milne port buildings. The modulus of subgrade reaction of 20 MPa/m is recommended for preliminary design.

5.2.4 *Sliding Friction Angles*

All the foundations will be founded on granular pad, not on native soils. Consequently the following friction angles and coefficients can be used for sliding of the foundations on granular pad, based on Canadian Foundation Engineering Manual (2006):

- 30° (friction coefficient: 0.58) for cast-in-place concrete.
- 24° (friction coefficient: 0.45) for precast concrete.

5.2.5 *Thermal Insulation Design Consideration*

Based on the test pits advanced during the 2010 investigation of borrow areas close to Milne Inlet, AMEC reported that the thickness of the active zone is anticipated to be between 2 m and 2.5 m. Thurber also indicated that, based on the results of geotechnical investigations carried out in 2006, 2007, 2008 and 2011 in the entire Mary River site, the depth of annual thaw ranges from 0.5 m in poorly drained areas to about 3 m in well drained areas.

For preliminary thermal insulation design at Milne Inlet Site, the following assumptions are applied:

- The temperatures of the heated structures are assumed constant throughout the year. The internal temperature is in a range of at +5°C (lower bound) to +22°C (upper bound).
- The ground temperature below 15m deep from the existing ground surface is -10°C (assumption based on the data from the thermistors installed at the Mine site)

The preliminary thermal insulation recommendations are summarized as follows:

- For the structures with an internal temperature of +5°C, an insulation layer of 125 mm thick is recommended to be placed below the granular fill and the native ground will remain frozen.
- For the structures with an internal temperature of +22°C, the following two insulation configurations are recommended:
  - 250 mm thick insulation layer to be placed below the granular fill.
  - The granular fill will be sandwiched between two insulation layers each with a thickness of 125 mm.

Hatch recommends that thermal analysis shall be carried out for the detail design to confirm the preliminary thermal design and to optimize the thermal insulation configuration, based on the site specific geotechnical investigation data and designed building internal temperatures.

5.3 Embankment Berm for Rail Stacker and Reclaimer Machine

Rail stacker and reclaimer machines are proposed to handle iron ore stockpile at Milne Inlet. Embankment berms for stacker and reclaimer machines are normally subjected to large static and dynamic machine loadings. The stability of these berms and acceptable deformation of machine foundations under working loads are of paramount importance to ensure a safe and cost effective mining operation.

The preliminary geotechnical recommendations for the embankment berm at Milne Inlet are summarized as the following:

- The embankment berm consists of a 200 cm thick compacted rock-fill (Type 8) material underlain a stiff geotextile on the existing ground. The side slope is 1.5H:1V. The maximum height of embankment depends on the design grade at the project site.
- The allowable capacity of the proposed compacted rock-fill embankment is 200 kPa.

It should be noted that the detailed geotechnical engineering assessment shall be carried out to confirm the preliminary design when the design loading and the site specific geotechnical data are available. The geotechnical engineering assessment consists of the following but not limited to:

- Bearing capacity.
- Embankment stability (local and global) under machine loadings.
- Design of geosynthetic reinforcements.
- Foundation deformation under machine loadings.

5.4 Deep Foundations

5.4.1 Adfreeze Piles

Pile foundations in permafrost soil can normally be selected from adfreeze or rock-socketed piles depending on the characteristics of the site and bedrock depth. Since the bedrock depth at the Milne Port site and Railway bridge locations has not been established, for preliminary design stage, only the adfreeze pile option will be studied. In addition, it is assumed that steel pipe piles with nominal diameters ranging from 4” to 12” could be utilized in this project.

5.4.2 Pile Capacity

The capacity of the adfreeze piles can be calculated using the following equation:

$P_a + W = \tau a\ .\pi.d.L$ (for compression) [5-1]

and,

$P_a - W = \tau_a.\pi.d.L$ (for tension) [5-2]

where:

P_a= allowable pile capacity (kN)

W= weight of pile (kN)

d= pile diameter (m)

L= pile embedment length (m) in permafrost (i.e. ignore embedment in active layer)

Also, based on the equation presented in literature for secondary creep, τ_a (kPa) which is the adfreeze shaft stress can be determined using the following:

$$\tau_a = \left[\frac{\frac{\dot{u}_a}{a}.(n-1)}{3^{(n+1)/2}.B}\right]^{\frac{1}{n}} \qquad [5\text{-}3]$$

where:

$\dot{u}_a$= allowable settlement rate (mm/year)

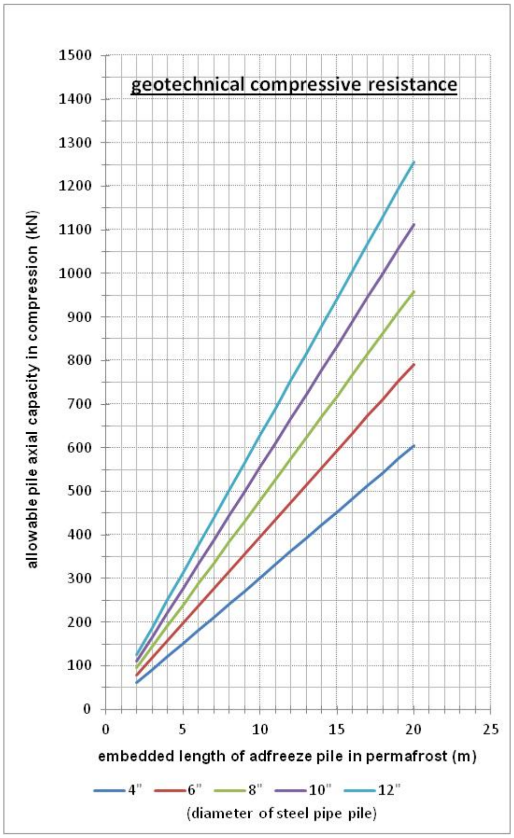
a = pile radius (mm)

B = creep parameter (kPa-n/year)

n = creep parameter (unitless)

It is assumed that the allowable settlement rate is 2 mm/year in the calculations. The creep parameter (n) is also assumed to be equal to 3. Furthermore, with the assumptions of non-saline porewater/ice and an average ground temperature of -5 C, the creep parameter (B) is estimated at 10^{-8} kPa^{-3}/year.

The pile capacity calculation is carried out for pipe piles with diameters of 4", 6", 8", 10" and 12" with embedment lengths ranging between 2 m and 20 m. It is of note that the embedment length corresponds to the length within the permafrost layer (ignoring the length of the pile within the active layer). The allowable pile axial capacities (geotechnical) under compression and uplift (tension) are plotted in Figure 5–4. It should be noted that the weights of the piles (W) have to be be taken into consideration in calculation of the allowable pile capacities in both compression and tension.



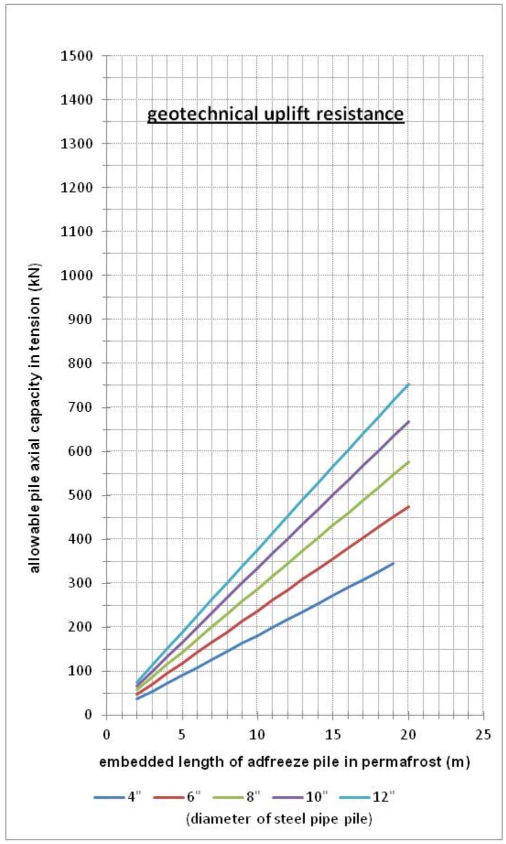


Figure 5–4: Plots of Geotechnical Axial Resistance with Embedded Length of Adfreeze Piles

In order to avoid frost heave, the length of the pile in the active layer should be wrapped with polyethylene film to break the adfreeze bond in the active layer.

It should be noted that Figure 5–4 presents the preliminary geotechnical capacities of adfreeze pile. The structural capacity of the steel pipe pile should be checked by a structural engineer.

6. References

1) Corps of Engineers, U.S. Army. Description and Classification of Frozen Soils. August 1966.
2) Andersland, B.A., Ladanyi, B., 2004, “Frozen Ground Engineering”, Second Edition, ASCE, John Wiley and Sons, Inc.
3) International Permafrost Association, 2005, “Glossary of Permafrost”, The Arctic Institute of North America, The University of Calgary.
4) Canadian Geotechnical Society, 2006, “Canadian Foundation Engineering Manual”, Forth Edition.