RESIDENTIAL FOUNDATION SYSTEMS FOR PERMAFROST REGIONS

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Submitted To:

Canada Mortgage and Housing Corporation

Yellowknife, NWT

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EXECUTIVE SUMMARY

Permafrost underlies all of the Yukon, Northwest and Nunavut Territories and much of the northern portions of the provinces, especially Manitoba and Quebec. Frozen ground conditions can have significant adverse effects on structures in the north. The effects of settlement and frost heaving commonly result in the premature deterioration of residential structures. Problems related to foundation design and construction can be reduced to a minimum if care is taken in the selection of suitable sites and appropriate foundation systems.

This report presents the results of a literature review, interviews and onsite visits to assess feasible foundation systems for residential construction in permafrost regions. The type of foundation system depends on a number of factors, including type and characteristics of the permafrost, subsurface conditions, availability of excavation equipment, availability of skilled labour, and others.

Foundation systems may range from shallow or on-grade footings to piled foundations. The report provides a "decision making tree" (Figure 1.1) to assist stakeholders in determining which foundation system may be appropriate.

RESIDENTIAL FOUNDATIONS FOR PERMAFROST REGIONS

INTRODUCTION

Permafrost underlies all of the Yukon, Northwest and Nunavut Territories and much of the northern portions of the provinces, especially Manitoba and Quebec. The main categories are defined as ranging from "continuous" in the far north to the sporadic permafrost of the "southern fringe".

Frozen ground conditions can have significant adverse effects on structures in the north. The effects of settlement and frost heaving commonly result in the premature deterioration of residential structures. Problems related to foundation design and construction can be reduced to a minimum if care is taken in the selection of suitable sites and appropriate foundation systems.

SELECTION CRITERIA

The following table provides a brief discussion of the primary factors to be considered in the choice of an appropriate foundation system.

Factors to Consider:	**Significance**
Soil/Bedrock Conditions	▪ i.e. coarse or fine grained soils, shallow bedrock
Groundwater Conditions	▪ Groundwater seepage and sloughing may cause difficulties in excavating
Permafrost Condition	▪ Discontinuous or continuous
Ground Temperature	▪ i.e. Warm permafrost (>1°C) or Cold Permafrost (<1°C)
Ice Content	▪ Thaw stable (no excess ice) or thaw unstable (excess ice)
Active Layer Thickness	▪ To determine potential for heaving and depth of excavation for footings
Transportation	▪ Costs and logistics of transporting construction goods and personnel ▪ May effect the duration of the construction period
Materials Availability	▪ Locally available materials are preferable
Equipment Availability	▪ If not available locally, the cost of mobilizing excavating or drilling equipment may be substantial
Labour Market	▪ Local labour is preferred
Cost	▪ Initial cost and lifecycle costs for repair and maintenance
Expected Lifespan	▪ Short (pad and wedge) or long (piles)

Foundation Options

Knowledge of local soil conditions is imperative for determining the potential for ground movements and for deciding on the most appropriate foundation system. As a general rule, coarse-grained sands and gravels tend to contain low to moderate excess ice (i.e. in excess of frozen water in the voids between soil particles). Fine-grained silts and clays tend to contain considerable excess ice especially in the upper 3 to 5 m (10 to 16 ft.). Ice can also exist in bedrock, most commonly in sedimentary deposits and also in cracks and fissures in any rock.

The consequences of thermal degradation in ice-rich permafrost (i.e. due to construction activities or heat from buildings) include reduced foundation capacity, thaw settlement and thaw instability on slopes. The warmer the permafrost, the more readily degradation can occur and the more costly the preservation measures.

In ice-rich soils, differential movements caused by thaw settlement or frost heave can be transferred from the foundation system directly to the structure. Typically, such movements cause deformation to the structure leading resulting in damage to many of its components. Examples of such damage include cracked concrete, masonry, wood and drywall; distorted windows, doors and floors; and separated walls and roofs. As a result, modifications must be made to conventional foundation design to ensure structural stability. Generally, the most common foundation systems attempt to either separate the structure from the active soils beneath (e.g. piles or posts and insulated pads) or float on the active soil and adjust to movements on a continual basis (e.g. pads and wedges or screw jacks).

Data on the available foundation system options for permafrost regions has been obtained from a detailed literature review. Field performance and the associated costs of each system have been evaluated through a combination of field visits and interviews with contractors, housing corporations and individuals within various northern communities. An overall 'decision making tree' (Figures 1.1a) and b) is provided to enable communities, homeowners, builders, and renovators to make informed and appropriate choices in foundation systems.

FOUNDATION SYSTEMS

The decision process is presented in the form of a 'decision making tree' (Figures 1a) through c).

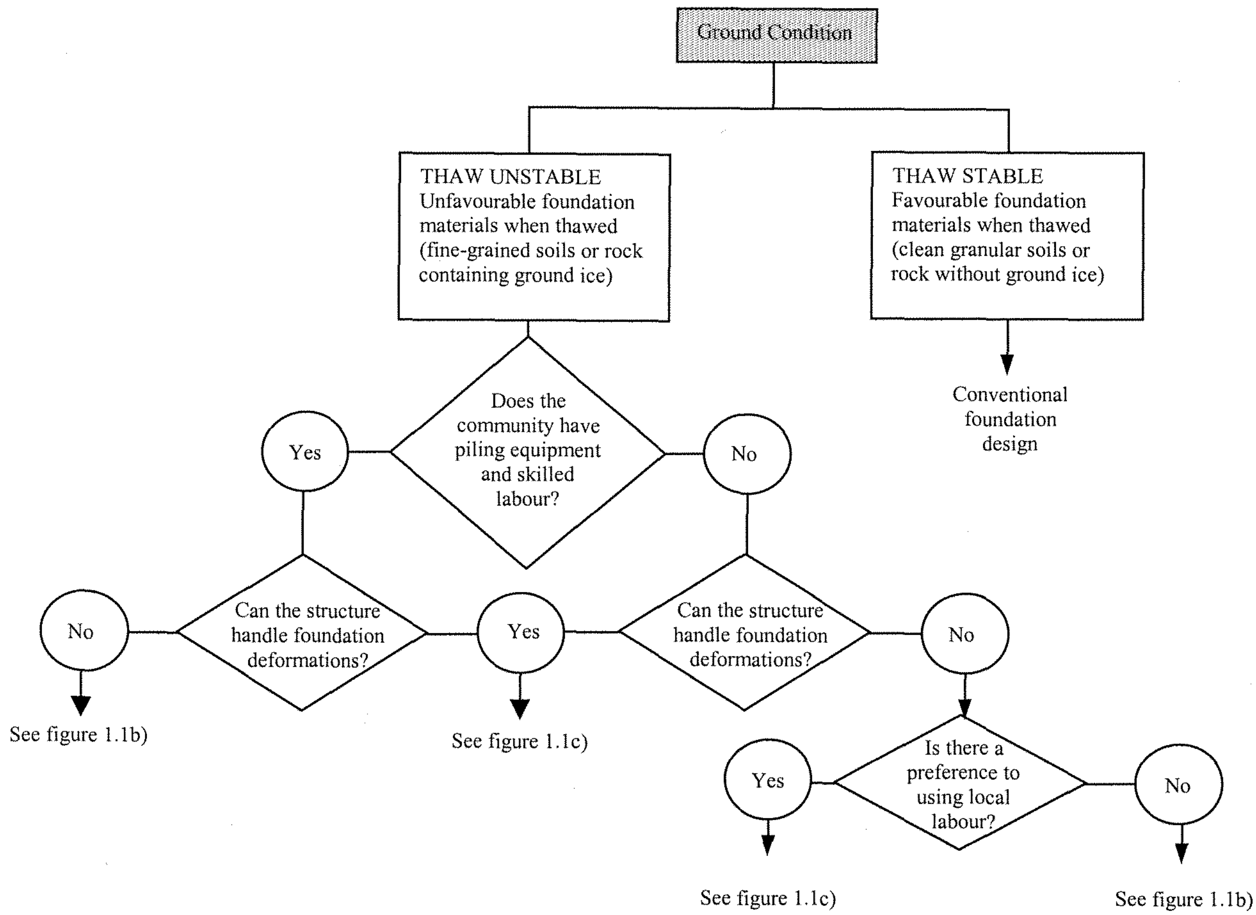

Figure 1a) Decision Making Tree

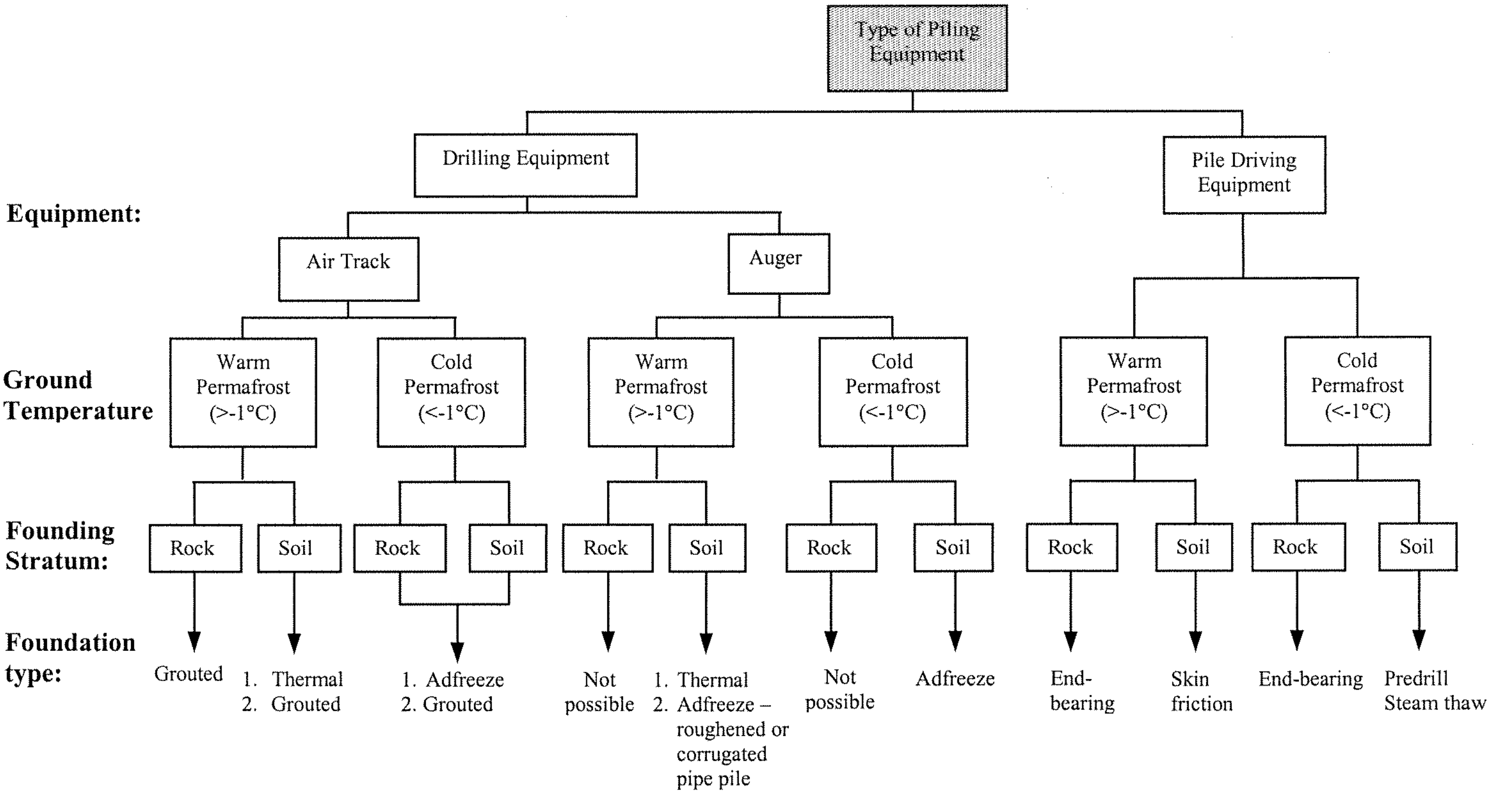

Figure 1b) Decision Making Tree (cont'd)

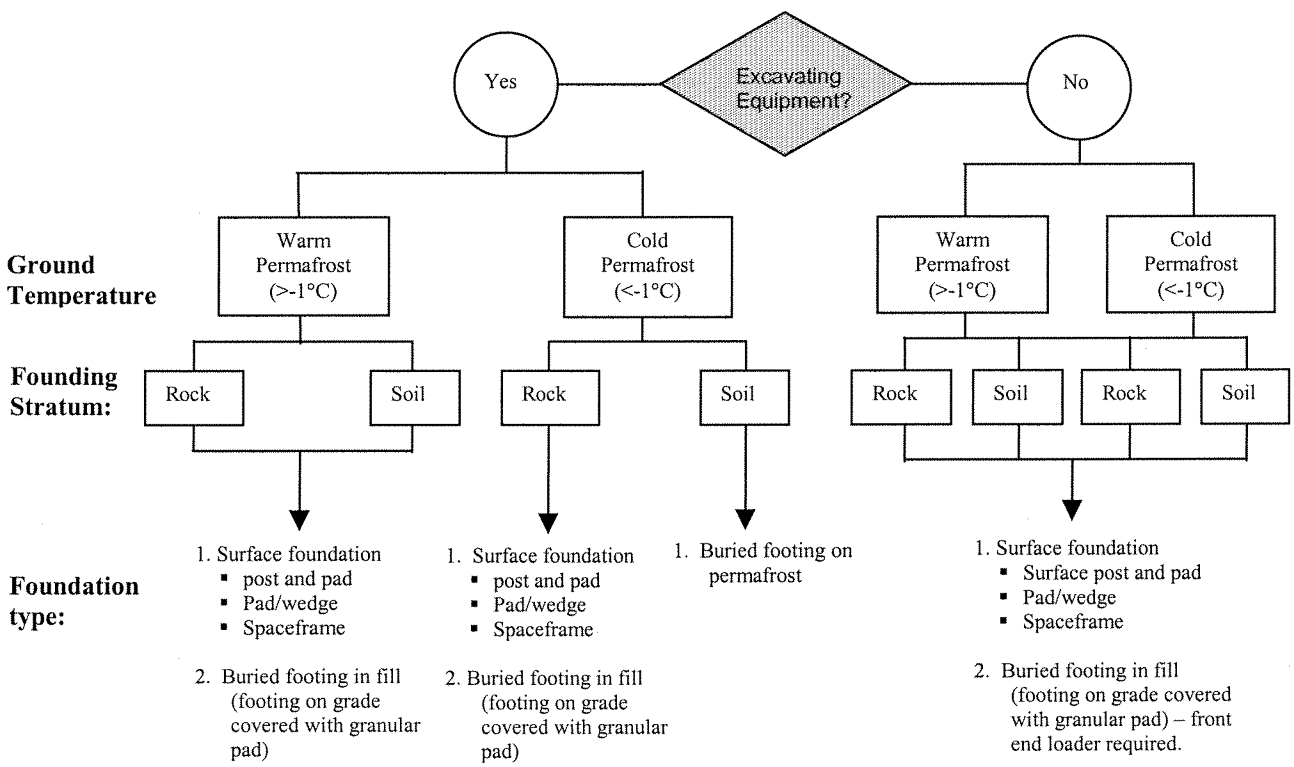

Figure 1c) Decision Making Tree (cont'd)

1a) PADS AND WEDGES

Pads and wedges are the most commonly used foundation system in regions of discontinuous and continuous permafrost. The main beams supporting the building are supported at intervals, typically every 2.5 to 3 m (8 to 10 ft) by pads of horizontally placed timbers that are stacked about 1 m (3 ft) in height to create an air space underneath the building (Figure 2). The air space is necessary to prevent the transmission of heat from the structure into the underlying ground as well as to facilitate releveling of the structure. The pressure treated timber pads are founded on a prepared gravel base or exposed rock outcrop and anchored by steel pins driven into the gravel base. In the event of differential settlement, a pair of wedges provides the adjustment capability. Metal angle iron ties the system to the beam supporting the structure. In some communities, cables tie down the structures to deadmen buried within the gravel pad.

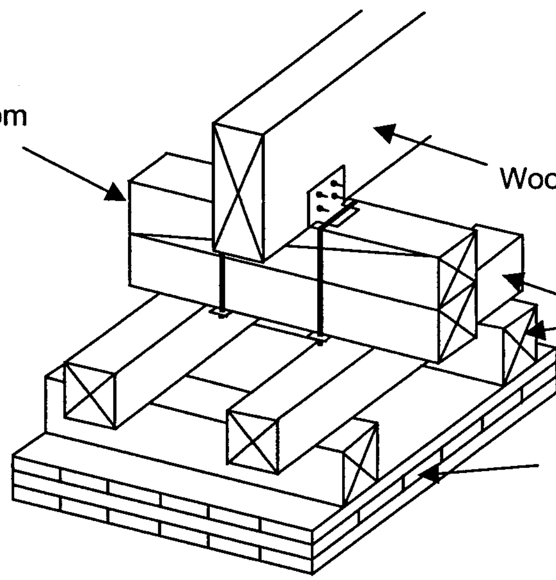

Figure 2 Pad and Wedge Foundation System

1c) POST AND PAD

As with any surface foundation system, the building must be able to tolerate some movement. Pads and posts are generally constructed of pressure treated timber but can be made from a combination of timber, concrete and steel (Figure 3). The pads are placed on or just below the surface of a compacted fill pad. Anchor bolts fasten the posts to the pads to help brace against strong winds and seismic loading. The length of the posts should allow for a minimum air space below the underside of the structure of 0.7m (2 ft 4 in.) to allow any heat from the building to be intercepted. Differential movements resulting from frost heave and thaw settlement can be expected. Extra long anchor bolts are used to fasten the posts to the pads to allow adjustments to be made.

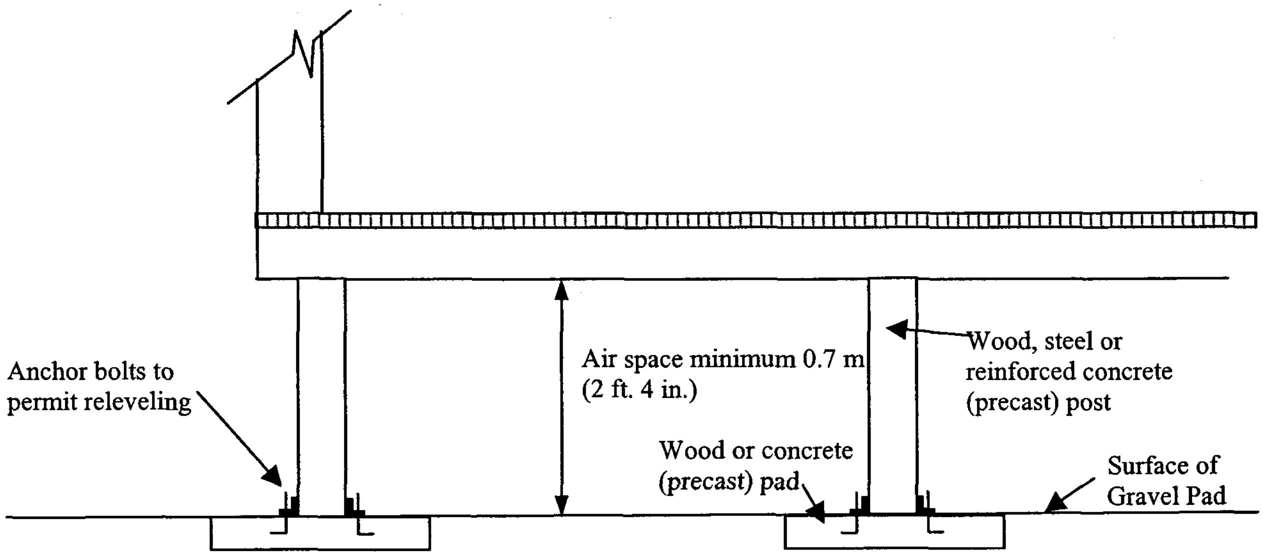

Figure 3 Post and Pad Surface Foundation

1d) MULTIPOINT SPACEFRAME

Spaceframes, an advanced form of surface foundation system has recently gained widespread popularity. Triodetic Building Products of Ottawa is one manufacturer of the patented spaceframe structures (Vangool, 1996). Essentially, these are interconnected tubular steel or aluminum chords that utilize the patented Triodetic joint. This joint allows the assembly of up to ten chords at a single point using specially designed chords and hubs. Figure 4 illustrates the various components of the spaceframe foundation system. The greatest advantage of the spaceframe system is its rigid structure that can tolerate the differential movements of the active soil. A planar structure-to-foundation connection is always maintained, which allows the structure and foundation to behave as a single unit or "block". In essence, differential ground movements affect the unit as a whole and overall tilting can be remedied through adjustable bearing plates.

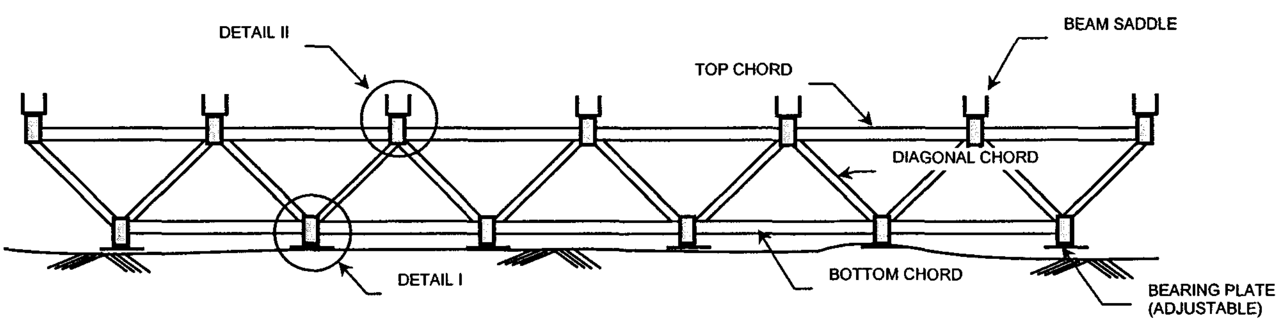

Figure 4 Multipoint Spaceframe

2. FOOTINGS

Footings placed directly on permafrost, sometimes referred to as 'Greenland foundations' or buried pier foundations, are quite common in the arctic. Footings are typically limited to spread footings as opposed to strip footings since the individual footings can usually be adjusted to correct for movement. The foundation may consist of a conventional reinforced concrete footing and pier or may be constructed of a timber or steel post supported on a pressure treated wood pad or concrete footing (Figure 5). Many variations and combinations of structural designs of foundation members are possible.

For sites with ground temperatures warmer than about -2°C, it may not be economical to prevent the permafrost from degrading due to the effects of construction disturbance. Therefore, footings on 'warm' permafrost would only be feasible if the ground was thaw stable (i.e. no excess ice). Sites with ground temperatures colder than -2°C can probably be maintained in the frozen state though insulation may be required for warmer or more ice-rich sites.

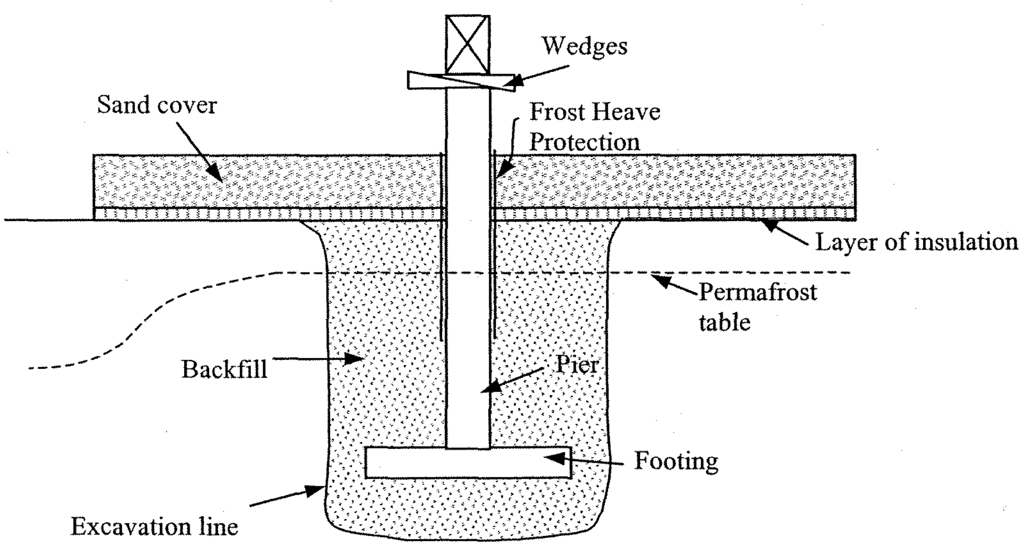

Figure 5 Footings on Permafrost

3. PILES

Pile foundations are considered the most reliable and the preferred foundation system for permafrost regions. The most commonly used piles for residential construction in permafrost are as follows:

- Driven piles
- Sand slurry piles
- Modified sand slurry piles
- Grouted piles
- End bearing piles

Timber and steel are the most common materials used in piling in permafrost regions. Although timber is more readily available, it should be noted that timber may be susceptible to decay. If kept permanently wet or permanently dry, they can have a long life but are prone to decay in a zone of fluctuating water table. Above the water table, they are susceptible to attack by fungi and ants or other wood destroying insects. In this instance, steel piles would be the more appropriate alternative. Given the proper application, timber piles can still be a practical and low-cost foundation system.

Sand slurry piles are the most common pile type used in permafrost regions. In some of the more remote Canadian northern communities the common sand slurry pile consists of a 114 mm (4 ½ in.) pipe installed in a hole with a diameter less than the 50 mm (2 in.) wider than the pile and backfilled with the excavated material. The small size of pile and holes is governed by the limitation of the capacity of the drill equipment, which is normally an airtrack drill rig. The piles are placed open ended so that they can be driven into sloughed material at the bottom of the hole if this occurs.

CONCLUSIONS

When deciding on a foundation system for a residential structure in permafrost, the preliminary step should involve a consideration of the selection criteria listed in Table 1. Once these factors have been evaluated, the decision making tree (Figures 1a through c) may be used as a resource to determine the suitability of the various foundations for a given set of site conditions. For best performance, it is necessary to have an understanding of the soil and permafrost conditions on site and to ensure a quality installation of foundation components.

More than one appropriate foundation system exists for every site and cost will inevitably be the primary deciding factor. It is important to consider not only the initial cost but also the lifecycle costs due to maintenance of the foundation and of the structure in response to foundation movements. While pile foundations may have a higher initial cost, the lifecycle costs may be less than for less sophisticated systems such as pads and wedges, especially when considering the extended lifespan of the structure.

FONDATIONS POUR BÂTIMENTS RÉSIDENTIELS ÉRIGÉES SUR LE PERGÉLISOL
(Résumé)

Rapport présenté à la

Société canadienne d'hypothèques et de logement

Yellowknife (T. N.-O)

par

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Calgary (Alberta)

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FONDATIONS POUR BÂTIMENTS RÉSIDENTIELS ÉRIGÉES SUR LE PERGÉLISOL

INTRODUCTION

Le pergélisol existe dans tous les Territoires du Yukon, du Nord-Ouest et du Nunavut, ainsi que dans la majorité des régions septentrionales des provinces, en particulier le Manitoba et le Québec. Les principales catégories vont du pergélisol permanent dans le Grand Nord jusqu'au pergélisol sporadique en périphérie sud.

Le sol gelé peut exercer d'importants effets défavorables sur les bâtiments du Nord. Le tassement et le soulèvement dû au gel entraînent souvent la détérioration prématurée des bâtiments résidentiels. On peut certes atténuer les problèmes liés à la conception et à la construction des fondations en prenant soin d'arrêter son choix sur des emplacements convenables et des systèmes de fondation appropriés.

CRITÈRES DE SÉLECTION

Le tableau suivant énonce brièvement les principaux facteurs à envisager lors du choix de fondations appropriées.

Facteurs à envisager	Importance
Sol ou roche-mère	• Sols à forte ou fine granulométrie, roche-mère peu profonde
Eau souterraine	• Infiltration d'eau souterraine et éboulement risquant de rendre l'excavation difficile
Pergélisol	• Permanent ou sporadique
Température du sol	• Pergélisol chaud (>1 °C) ou pergélisol froid (<1 °C)
Teneur en glace	• Stable au dégel (aucun surcroît de glace) ou instable au dégel (surcroît de glace)
Épaisseur de la couche active	• Pour établir la possibilité de soulèvement et la profondeur d'excavation des semelles
Transport	• Coûts et logistique du transport de produits de construction et du personnel • Peut influer sur la durée des travaux de construction
Disponibilité des matériaux	• Il est préférable d'opter pour des matériaux offerts dans la localité
Disponibilité du matériel	• Faute de pouvoir en trouver dans la localité, le coût de la mobilisation de matériel d'excavation ou de forage peut être considérable
Marché de la main-d'oeuvre	• Il est préférable de recourir à de la main-d'oeuvre locale
Coût	• Coût initial et coûts du cycle de vie des réparations et de l'entretien
Durée utile prévue	• Courte (assise et cales) ou longue (pieux)

Options en matière de fondations

Il est impératif de connaître la composition du sol de la localité pour déterminer les possibilités de mouvement du sol et décider du système de fondation qui convient le mieux. En règle générale, le sable et le gravier à forte granulométrie contiennent un surcroît de glace variant de faible à modéré (en plus de l'eau gelée dans les vides entre les particules de sol). Par contre, le limon et l'argile à fine granulométrie contiennent un surcroît considérable de glace surtout dans les 3 à 5 m supérieurs (10 à 16 pi). La glace peut aussi exister dans la roche-mère, plus couramment dans les dépôts sédimentaires et également dans les fissures de toute roche.

La dégradation thermique du pergélisol riche en glace (en raison de la construction ou de la chaleur s'échappant des bâtiments) occasionne l'affaiblissement de la capacité des fondations, le tassement dû au dégel et l'instabilité due au dégel sur les terrains en pente. Plus le pergélisol est chaud, plus il risque d'y avoir de dégradation et plus les mesures de préservation risquent de coûter cher.

Dans les sols riches en glace, les mouvements différentiels occasionnés par le tassement dû au dégel ou par le soulèvement dû au gel peuvent être transmis depuis les fondations jusqu'au bâtiment. En général, de tels mouvements ont pour effet de déformer le bâtiment, endommageant par le fait même bon nombre de ses éléments. Ces dommages peuvent s'entendre de la fissuration du béton, de la maçonnerie, du bois et des plaques de plâtre; de la déformation des fenêtres, des portes et des planchers; et de la rupture des murs et du toit. En conséquence, il faut modifier la conception classique des fondations pour en garantir la stabilité structurale. Les fondations les plus courantes visent généralement à dissocier le bâtiment des sols actifs en dessous (pieux ou poteaux et assises isolées) ou à le faire flotter à la surface du sol actif et à procéder continuellement aux rajustements requis selon les mouvements (assises ou cales ou vérins à vis).

Les options de fondations convenant au pergélisol ont été obtenues à partir d'un dépouillement documentaire poussé. La performance sur place et les coûts de chaque système ont été évalués grâce à une combinaison de visites des lieux et d'entrevues en compagnie d'entrepreneurs, de représentants des sociétés responsables de l'habitation et de particuliers de différentes collectivités septentrionales. L'arbre de décision global reproduit (figures 1.1 a) et b)) permet aux collectivités, aux propriétaires-occupants, aux constructeurs et aux rénovateurs de prendre des décisions éclairées et tout indiquées en matière de fondations.

FONDATIONS

Le processus décisionnel est exprimé sous forme d'arbre de décision (figures 1 a) à c)).

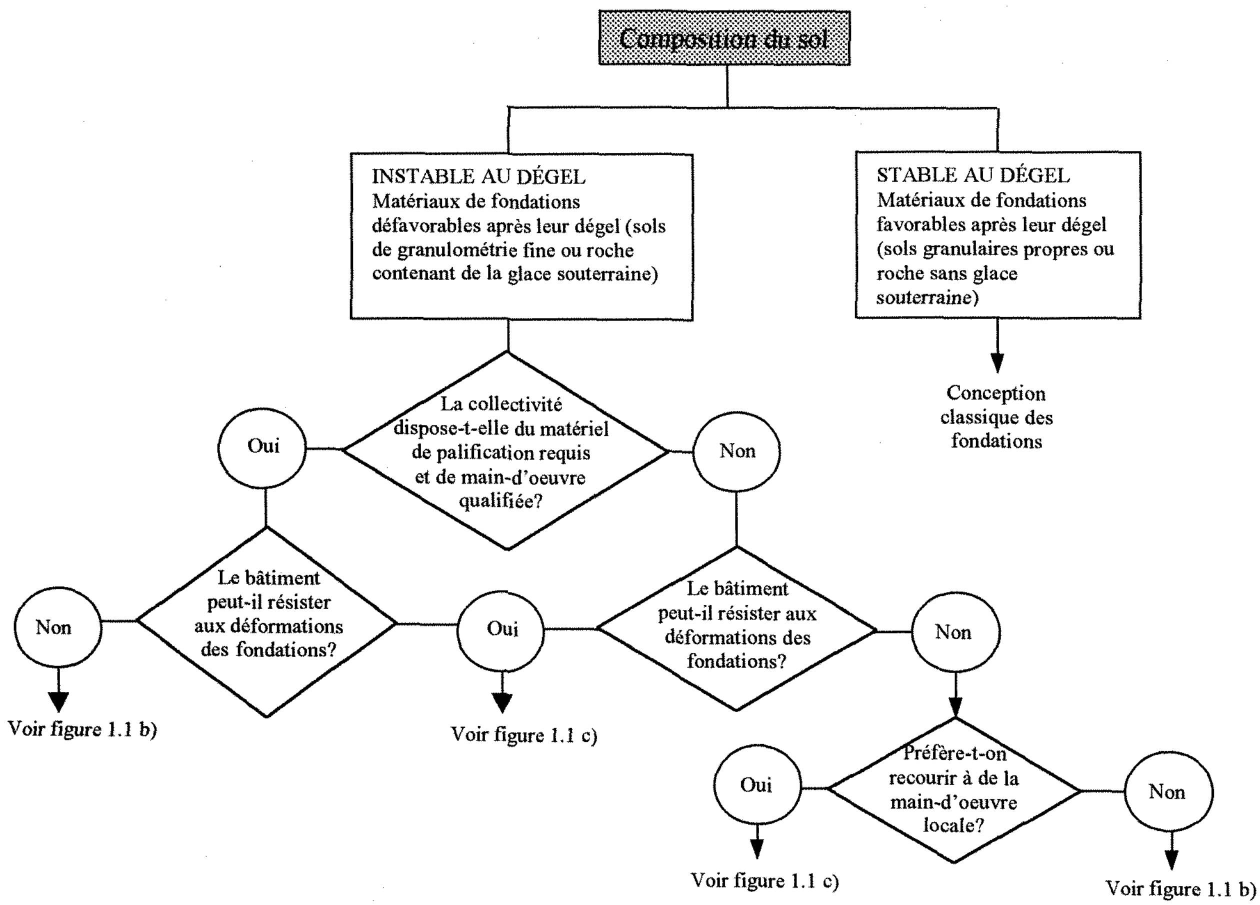

Figure 1 a) Arbre de décision

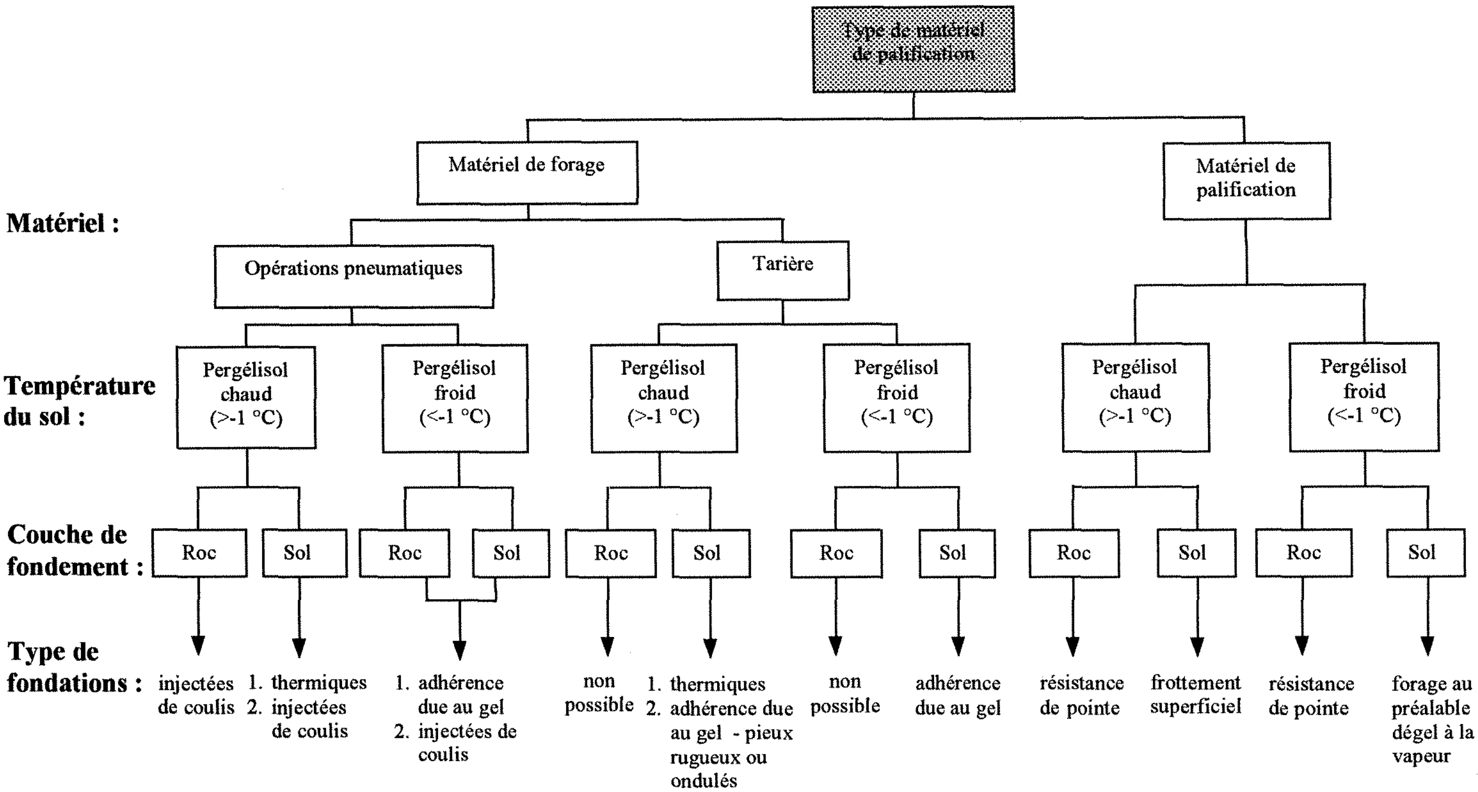

Figure 1 b) Arbre de décision (suite)

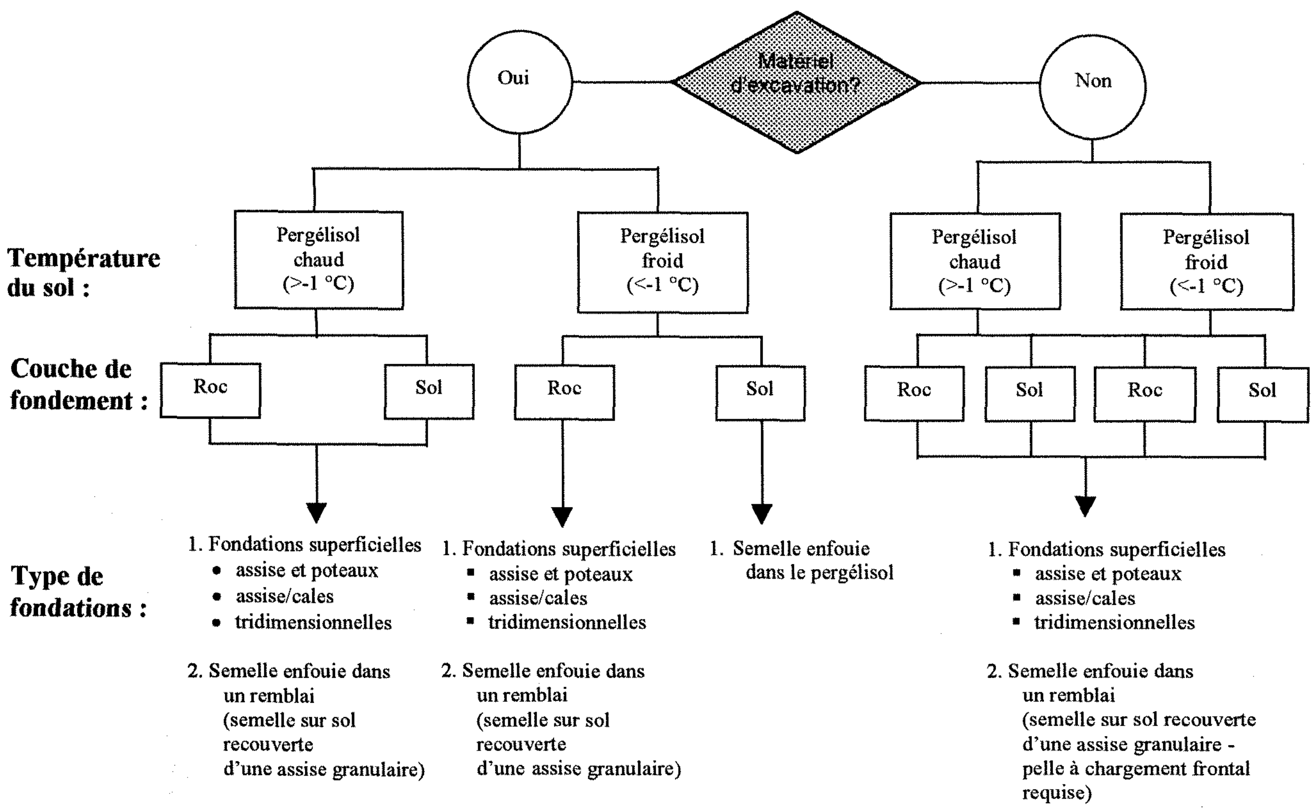

Figure 1 c) Arbre de décision (suite)

1 a) ASSISES ET CALES

Les fondations faisant appel à des assises et à des cales sont les plus répandues dans les zones de pergélisol continu ou sporadique. Les principales poutres soutenant le bâtiment reposent, à intervalles de 2,5 à 3 m (8 à 10 pi), sur des assises d'éléments en bois d'oeuvre horizontaux superposés environ tous les 1 m (3 pi) pour créer un vide d'air sous le bâtiment (figure 2). Le vide d'air est nécessaire pour empêcher la chaleur du bâtiment de se transmettre au sol et pour faciliter la remise de niveau du bâtiment. Les assises en bois d'oeuvre traité sous pression reposent sur une base de gravier préparée ou sur un affleurement rocheux, puis sont ancrées au moyen de chevilles d'acier enfoncées dans la base de gravier. En cas de tassement différentiel, une paire de cales permet d'effectuer le rajustement. Des cornières métalliques assujettissent le système à la poutre soutenant le bâtiment. Dans certaines collectivités, des câbles assujettissent le bâtiment à des palées d'ancrage enfouies dans l'assise de gravier.

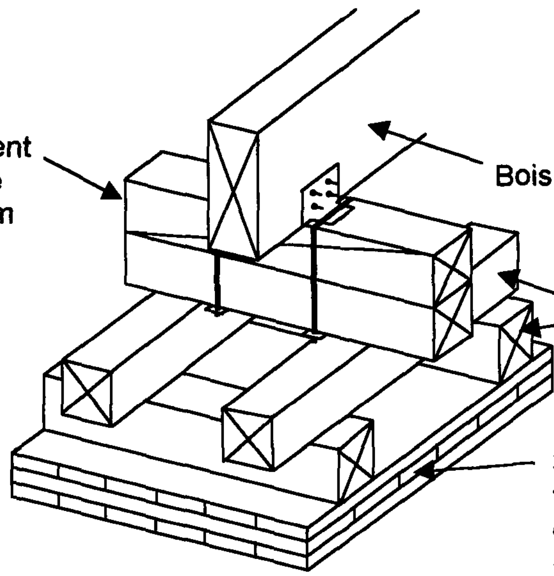

Figure 2 Fondations avec assises et cales

1 c) ASSISES ET POTEAUX

À l'exemple de toutes les fondations superficielles, le bâtiment doit être en mesure de tolérer un certain mouvement. Les assises et poteaux sont généralement constitués de bois d'oeuvre traité sous pression, mais peuvent également être composés de bois d'oeuvre, de béton et d'acier (figure 3). Les assises sont disposées à la surface ou tout juste en dessous d'un remblai compacté. Des boulons d'ancrage assujettissent les poteaux aux assises de façon à permettre au bâtiment de résister aux vents violents et, le cas échéant, à un séisme. La longueur des poteaux doit prévoir, sous la face inférieure du bâtiment, un vide d'air minimal de 0,7 m (2 pi 4 po) pour intercepter toute chaleur provenant du bâtiment. Des mouvements différentiels résultant du soulèvement dû au gel et du tassement imputable au dégel sont à prévoir. Des boulons d'ancrage extra-longs fixant les poteaux aux assises permettent de procéder à des rajustements.

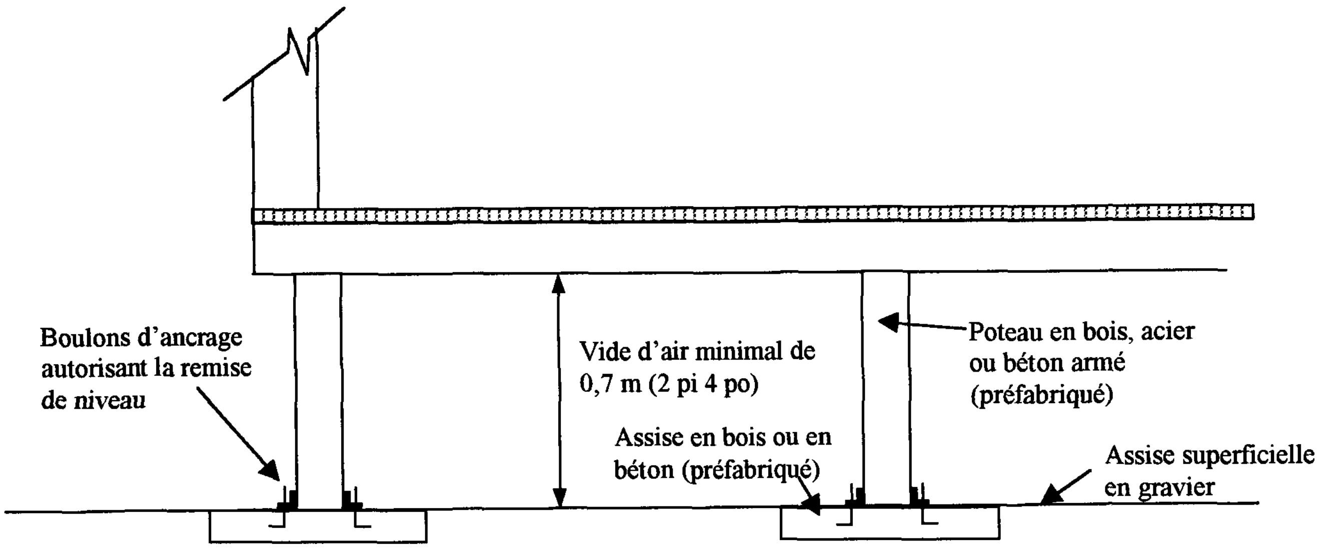

Figure 3 Fondations superficielles à assises et poteaux

1 d) FONDATIONS TRIDIMENSIONNELLES

Les fondations tridimensionnelles, formule évoluée de fondations superficielles, ont ces derniers temps gagné la faveur populaire. L'entreprise Triodetic Building Products d'Ottawa fabrique des fondations tridimensionnelles brevetées (Vangool, 1996). Il s'agit essentiellement de tubulures d'acier ou d'aluminium reliées les unes aux autres par des joints brevetés Triodetic. Ces joints permettent d'assembler jusqu'à dix tubulures à un seul point, à l'aide de membrures et de moyeux de conception spéciale. La figure 4 montre les différents éléments de la fondation tridimensionnelle. Son plus grand avantage réside dans sa structure rigide qui peut tolérer les mouvements différentiels du sol actif. Le raccordement plan entre le bâtiment et les fondations fait en sorte que les deux agissent toujours solidairement. Essentiellement, les mouvements différentiels du sol agissent sur l'ensemble et l'inclinaison générale peut se corriger par les plaques d'appui réglables.

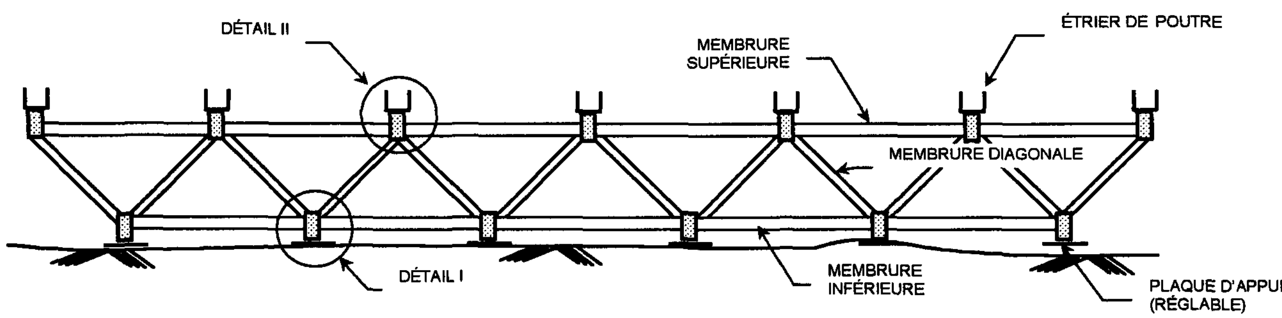

Figure 4 Fondations tridimensionnelles

2. SEMELLES

Les semelles déposées directement sur le pergélisol, parfois appelées fondations sur pieux enfouis, sont d'usage courant dans l'Arctique. On a généralement recours à des semelles élargies plutôt qu'à des semelles filantes puisque les semelles individuelles peuvent se régler suivant le mouvement. La fondation peut être constituée d'une semelle classique en béton armé et d'un pieu, ou de bois d'oeuvre ou d'un poteau d'acier sur semelle de béton ou assise en bois traité sous pression (figure 5). De nombreuses variations et combinaisons de modèles structuraux d'éléments de fondation sont possibles.

Pour les endroits où la température du sol est plus élevée qu'environ –2 °C, il pourrait ne pas être économique d'empêcher le pergélisol de se dégrader en raison des effets de la construction. Par conséquent, les semelles reposant sur le pergélisol « chaud » ne sont réalisables que si le sol est stable au dégel (sans surcroît de glace). Les endroits où la température du sol est plus froide que –2 °C peuvent probablement être conservés à l'état congelé, même s'il faudra sans doute recourir à de l'isolant pour les endroits plus chauds ou plus riches en glace.

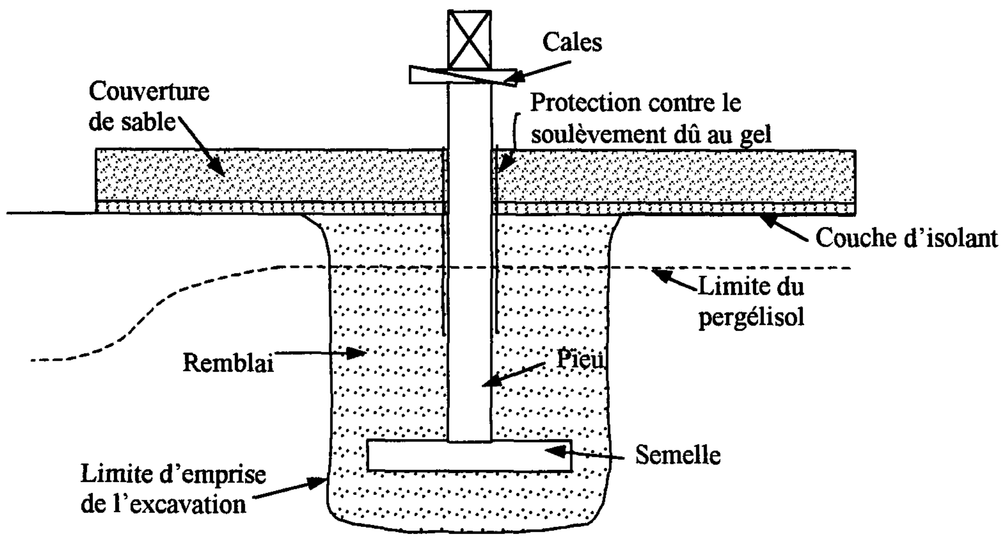

Figure 5 Semelles sur pergélisol

3. PIEUX

Les fondations sur pieux sont considérées comme les plus fiables et constituent le choix de prédilection pour le pergélisol. Les pieux les plus couramment utilisés en construction résidentielle dans les zones de pergélisol sont les suivants :

- pieux enfoncés
- pieux faisant appel à du sable et de la boue
- pieux modifiés faisant appel à du sable et de la boue
- pieux injectés de coulis
- pieux travaillant en pointe

Le bois d'oeuvre et l'acier sont les matériaux qui s'utilisent le plus pour les pieux dans les régions de pergélisol. Bien que le bois d'oeuvre s'obtienne plus facilement, on doit prendre note qu'il est sujet à la carie. Pourvu qu'il soit conservé humide ou sec en permanence, le bois d'oeuvre peut être assorti d'une longue durée utile, mais il est sujet à la carie dans une zone où le niveau de la nappe aquifère fluctue. Le bois d'oeuvre qui se trouve au-dessus de la nappe aquifère est susceptible de subir l'attaque des champignons et des fourmis ou encore d'autres insectes destructeurs. Dans ce cas, des pieux d'acier constitueraient le choix tout indiqué. Employés de façon appropriée, les pieux en bois d'oeuvre constituent toujours un système de fondations pratique et de coût peu élevé.

Les pieux faisant appel à du sable et à de la boue sont le type de pieux les plus utilisés dans les zones de pergélisol. Dans certaines régions éloignées du nord du Canada, les pieux les plus courants consistent en des tuyaux de 114 mm (4 ½ po) disposés dans un trou d'un diamètre de 50 mm (2 po) de moins que le pieu et remblayé au moyen de la matière excavée. Le faible diamètre du pieu et des trous est régi par la limite de la capacité du matériel de forage, qui est souvent une foreuse pneumatique sur chenilles. Les pieux sont laissés ouverts pour pouvoir être enfoncés dans la matière éboulée au fond du trou, le cas échéant.

CONCLUSIONS

Au moment d'arrêter son choix sur des fondations pour un bâtiment résidentiel à ériger sur le pergélisol, il convient avant tout d'envisager les critères de sélection dont fait état le tableau 1. Après avoir évalué ces facteurs, on peut s'en remettre à l'arbre de décision (figures 1 a) à c)) pour déterminer l'à-propos des différentes fondations selon la composition donnée de l'emplacement. Pour obtenir la meilleure performance, il est nécessaire de comprendre la composition du sol et du pergélisol des lieux et de s'assurer d'une installation de qualité des composantes des fondations.

Il existe plus d'un système de fondation approprié pour chaque emplacement et le coût motivera inévitablement le choix. Il importe de considérer non seulement le coût initial, mais aussi les coûts de cycle de vie associés à l'entretien des fondations et du bâtiment à la suite du mouvement des fondations. Quoique les fondations sur pieux coûtent plus cher au départ, les coûts de cycle de vie peuvent être moindres que pour les systèmes perfectionnés comme avec assises et cales, surtout si l'on envisage de prolonger la durée utile du bâtiment.

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1.0 INTRODUCTION

1.1 GENERAL

As the Government of Canada's national housing agency, the Canada Mortgage and Housing Corporation (CMHC) helps to improve the quality, accessibility and affordability of housing in Canada. To help individuals benefit from their housing expertise and make informed decisions, the CMHC has become Canada's largest publisher of housing information. Through the CMHC's initiatives, information on the various foundation systems typically used in northern regions and state-of-the-art research and development are made available to the public.

At the request of Ms. Aleta Fowler, of the CMHC, AGRA Earth & Environmental (AEE) has prepared this report outlining the various foundation options and their appropriateness for use in various northern environments. The scope of work was outlined in a contract dated March 24, 1999.

1.2 PURPOSE

To further help facilitate informed choices based upon particular requirements, a comprehensive, single source on foundation options is needed for individuals involved at all levels in residential construction. The selection and design of foundations in the north requires the consideration of several factors specific to northern conditions. The most important factor is the short-term and long-term impact of the building on the permafrost.

In general, if the permafrost has no excess ice content, thaw stable soil conditions exist and conventional foundation systems can be used. This report is concerned with regions of continuous or discontinuous ice-rich permafrost, where innovations must be made to conventional foundation design to ensure structural stability.

Most structures in the north are built in areas where conventional foundation systems, such as buried concrete foundations with or without basements, are not suitable. The effects of settlement and frost heaving result in the premature deterioration of residential structures. Details of the condition of residential dwellings in communities across the north are contained in Tables 1.1a) to c). These data reveal a large proportion of homes built prior to 1981 in need of major repair. Problems related to foundation design and construction can be reduced if care is taken in the selection of suitable sites and appropriate foundation systems for the site conditions.

1.3 METHODOLOGY

Data on the available foundation system options for permafrost regions has been obtained from a detailed literature review. Field performance and the associated costs of each system have been evaluated through a combination of field visits, case studies, and interviews with contractors, housing corporations and individuals within various northern communities. Where relevant, data gathered from these sources is included in the discussions of the various foundation systems. A complete list of references, site visits, and interview data is contained in Appendices A, B, and C, respectively.

The resulting 'decision making tree' (Figures 1.1a and b) is intended to help facilitate appropriate foundation choices based on individual requirements. Detailed discussions on each foundation option will be discussed throughout the body of this report. It is hoped that this overview of foundation systems for permafrost regions will enable communities, homeowners, builders, and renovators to make informed and appropriate choices in foundation systems.

1.4 DISCLAIMER

In some cases, trade names or specific corporation have been used to describe a particular product. CMHC and its agents do not endorse or necessarily recommend the use of any particular product or service.

2.0 ARCTIC GEOLOGY

2.1 BEDROCK GEOLOGY

The bedrock geology of Canada may be simplified into two major regions - a core of massive, Precambrian crystalline rocks known as the Shield and a surrounding crescent of younger, mainly stratified rocks forming the Borderlands (Bostock, 1970). The Shield is centered on Hudson Bay as shown on Figure 2.1 and the major portion of the Borderlands are found to the north and west. Another small portion of the Borderlands is found southeast of the St. Lawrence River.

The Borderlands can be described as two concentric rings around the Shield. The inner ring consists of lowlands, plains and plateau of predominately flat lying sedimentary rocks. This inner ring is known as the Arctic Lowlands in the north, the Interior Plains to the west and the Appalachian Region in the east. The outer ring consists of discontinuous mountains and plateau, which are deformed. This outer ring is referred to as the Cordilleran Region and consists of folded sedimentary rocks in the eastern part with volcanic strata, massive metamorphic and platonic rocks being more prevalent in the western part (Bostock, 1970).

Due to glaciation, the bedrock geology has a significant relationship with any overlying deposits. The bedrock is commonly a building foundation medium, especially in the Shield, where considerable areas of exposed rock exist.

2.2 SURFICIAL GEOLOGY

The surficial soils in the permafrost region have all been deposited during the Quaternary period, which is characterized by numerous cycles of climate change and glaciation. Although there were several glacial advances and retreats in this period, today's surficial geology has been largely deposited by the latest, Wisconsin glaciation. This glacial stage is thought to have started about 23,000 years B.P. (before present) and have ended between 15,000 and 5,000 B.P. depending on latitude.

The most significant consequence of the glaciation is that the surficial geology is uniquely related to the bedrock geology within each region. The dominant surficial deposits in the Canadian Shield region are tills that have been derived primarily from crystalline and metamorphic rocks. These tills comprise non-plastic sands and silts. In the Interior Plains region, which includes the Mackenzie District as well as Banks and Victoria Islands, the glacial deposits are derived from shales, siltstones and sandstones and tend to be thicker and more fine-grained, including highly plastic clays. In every region there are, of course, more recent fluvial (river) and colluvial (slope movement) deposits that are derived from the local surficial deposits.

An understanding of the local soil conditions is essential in determining the potential for adverse ground movements and deciding on the most appropriate foundation system. Generalized soil conditions for various northern communities have been determined from previous geotechnical reports and are summarized in Appendix D.

3.0 PERMAFROST DISTRIBUTION AND CONDITIONS

3.1 DISTRIBUTION OF PERMAFROST

Permafrost underlies all of the Yukon, Northwest and Nunavut Territories and much of the northern portions of the provinces, especially Manitoba and Quebec. Figure 3.1 shows the complete distribution of permafrost within Canada. The main categories are defined on Figure 3.1 ranging from "continuous" in the far north to the sporadic permafrost of the "southern fringe". When considering the most southerly occurrences it is important to understand the definition of permafrost:

> "soil or rock that remains at or below 0°C (32°F) for at least two years". (NRC, 1988)

The definition based on temperature as opposed to phase change between water and ice is very significant. By this definition, it is important to realize that in cases of saline porewater for example, permafrost may not be frozen solid. In engineering applications, one must realize that frozen strength does not develop until the phase change (to ice) has occurred. After phase change, there is a considerable further increase in strength of frozen soil between 0°C (32°F) and at least -5°C. In saline permafrost, the strength can be significantly less than fresh water permafrost at any given frozen temperature.

The thickness of permafrost is as much as 500 m (1650 ft.) in the far north (Hardy Associates, 1984), decreasing almost linearly with decrease in latitude, as shown in Figure 3.2. In some areas of the discontinuous permafrost zone it is possible to either remove relatively thin permafrost or otherwise work around it. For example, in Hay River, it is possible to extend piles through 8 to 10 m (25 to 35 ft.) of permafrost for support on unfrozen till beneath.

3.2 TEMPERATURE RANGES

As a rough estimate, the mean annual ground temperature within a region tends to be around 2 to 4°C warmer than the mean annual air temperature. Figure 3.3, showing mean annual isotherms, can therefore be used to provide a preliminary indication of ground temperature.

Major exceptions to this rule would be areas where permafrost is advancing in recently exposed river terraces or in coastal communities since the coastal waters are relatively warm. Other exceptions would be related to extremes in vegetation cover, snow cover and of course man-made modifications to the surface boundary conditions. Most construction developments in the arctic will tend to increase ground temperatures and the impact of this on the integrity of the constructed facility must be recognized.

3.3 PERMAFROST TERRAIN FEATURES

There are several distinctive terrain features, exclusive to permafrost regions that indicate particular local or regional terrain conditions. Some of the more significant features that may impact development are identified below along with their potential engineering significance:

- Thermokarst - uneven terrain resulting from the irregular thawing of ice-rich ground and subsequent thaw settlement; lakes typically form in the depressions; indicative of ice-rich fine-grained terrain and generally a degrading permafrost sensitive to disturbance.

- Ice wedge polygons - wedges of ice form in thermal contraction cracks in the ground with the process increasing the ice wedge with time to as much as 3 m (10 ft.) wide at the surface and up to 10 m (30 ft.) deep. The thermal contraction of a large area creates a polygonal pattern of wedges between 15 and 30 m (50 and 100 ft.) across. Polygons can occur in peat or mineral soil. Development must recognize the potential for extreme local concentrations of ice. Polygons usually occur in relatively cold permafrost and therefore are not especially sensitive to disturbance during development.

- Peat plateaus - typically flat-topped areas of relatively dry peat rising above a generally wet peat area. The plateau generally contains significant segregated ice. In more southern permafrost regions, the permafrost is typically only present beneath the plateaus. Development must anticipate the variable and highly sensitive ground ice conditions.

3.4 ICE CONTENTS

As a general rule coarse-grained sands and gravels tend to contain low to moderate excess ice (i.e. in excess of frozen water in the voids between soil particles). Fine-grained silts and clays tend to contain considerable excess ice especially in the upper 3 to 5 m (10 to 16 ft.). Ice can also exist in bedrock, most commonly in sedimentary deposits and also in cracks and fissures in any rock.

In finer-grained soils, ice is often in the form of segregational ice lenses. A complete classification system for ground ice is given by Pihlainen and Johnston (1963). Massive ice, on the order of metres thick, is common in the Mackenzie delta area. Some may be a result of buried ice, however others are extreme cases of segregational ice, as in ice-cored ridges (Dallimore and Wolfe, 1988) and pingos (MacKay, 1973).

The impact of ground-ice on development projects can be significant. Even if the ground is preserved in the frozen state, soil with excess ice exhibits long-term deformations (creep) under sufficiently high sustained loads. This limitation in the load bearing capacity of ice-rich permafrost is particularly significant where the mean annual ground temperatures are warmer than -5 ° C (23°F) or if the pore-ice is saline.

The consequences of thermal degradation in ice-rich permafrost include reduced foundation capacity, thaw settlement and thaw instability on slopes. Again, the warmer the permafrost, the more readily degradation can occur and the more costly the preservation measures.

3.5 ACTIVE LAYER

The layer of soil or rock above the upper surface of permafrost freezes and thaws with the seasons. On average, the thickness of the active layer in regions of continuous permafrost varies between 0.5 m (1 ft. 6 in.) under thick organic materials to 10 m (30 ft.) within exposed rock. In regions of discontinuous permafrost, the depth of the active layer may be greater.

Figure 3.2 indicates an increase in the active layer (zone of seasonal thaw) with decreasing latitude. This is in fact an over-simplification. Certainly mean annual air temperature is an important factor in active layer development; however, vegetation cover and soil water content are also significant. A well-treed area with moss and peat cover may only thaw 0.3 m (1 ft) even in the discontinuous permafrost zone. In contrast a barren terrain in the arctic islands may thaw as much as 2.0 m (6 ft.), especially in the more granular Shield region.

Active layer information must be obtained for each specific site as conditions can vary considerably. By its nature, permafrost is relatively impermeable. Drainage and movement of surface water is therefore confined to the active layer. For this reason, the largely frost-susceptible soils in the active layer are commonly saturated. As this material freezes, water is drawn up from the water table to the colder, drier, fine-grained soil and freezes into ice lenses. The expansion caused by ice lensing is termed 'frost heaving'. It is not uncommon to experience ground surface movements as great as 5-15 cm (2-6 in.) during a seasonal freeze cycle.

It is also important to predict what impact any development will have on the active layer in the long-term. For example, the thickness of the active layer along the south side of a new building will undoubtedly increase as the heat from the sun may be trapped, together with a probable increased reflection off the building.

Any increase in seasonal thaw can have significant impact on many ice-rich deposits. It should be noted that ice is typically most prevalent in the upper 3 to 5 m (10 to 16 ft.) and often there are distinct layers of ice at the base of the active layer.

3.6 TERRAIN SENSITIVITY

The principal aspect of foundation design in permafrost is the preservation of the permafrost. In the colder, continuous permafrost region (-5 to -15 ° C) this is usually less of a challenge than in the warmer discontinuous permafrost. It is, however, possible to cause thermal degradation to some extent by construction disturbance and by direct influence of structures. For example, placing a thin layer gravel cover over a natural mossy surface will dramatically increase the amount of heat absorbed by the ground in the summer. Similarly, if a structure with a floor temperature of 15 to 20° C (60 to 68°F) is constructed on terrain with a pre-construction natural sub-zero surface temperature, the building heat must be intercepted by some means to prevent thermal degradation of the ground.

3.7 CLIMATE EFFECTS

3.7.1 NORMAL CLIMATE FLUCTUATIONS

It is common to reference the Environment Canada - Canadian Climate Normals to obtain mean annual air temperatures. Mean annual temperatures and precipation values for various regions are contained in Tables 3.1a) and b). These data cover the period 1961 to 1990 for most major communities across northern Canada. However, there are considerable variations within that 30 year period. For example, for Yellowknife the published 30 year mean annual temperature is -5.2 ° C (22.6 °F). The individual annual mean temperatures within the period range from -3.6°C (25.5°F) in 1953 to -7.0 °C (19.4°F) in1966 and 1972. This is considered as normal fluctuations, however, the effect of potential extreme warm or cold years should be considered in design, especially for shallow-founded structures. For design purposes, it is common to take the average of the three hottest or coldest indices in the last 30 years to obtain a design extreme index.

3.7.2 CLIMATE WARMING

There is evidence that in some areas of the arctic, mean annual air temperatures are gradually increasing whereas in other areas temperatures are constant or even cooling (Lachenbruch et al, 1988). Numerous studies have related climate warming to the "greenhouse effect" whereby radioactively active gases (carbon dioxide, methane, nitrous oxide and chlorofluorocarbons) in the atmosphere permit greater penetration of the solar radiation yet prevent the reflected long wave radiation from escaping. It is predicted that even if no more atmospheric pollution occurred, there would still be a rise in temperature due to the present buildup of such gases.

Various predictions have been made (Etkin et al. 1988; Etkin, 1989) on the rate of warming that might be anticipated. Assuming current CO_2 emissions and moderate climate sensitivity, these predictions suggest that the mean air temperature may increase by as much as 1°C in the life of most projects (20 – 30 years).

Several authors have discussed the impact of warming on permafrost foundations (Esch and Osterkamp, 1990; Nixon, 1990). Both papers react to the maximum predictions of potential temperature change, 1.0°C/decade, and as such may be an over-reaction. Nevertheless any warming of the permafrost will tend to cause an increase in creep rates in frozen ground and result in some additional thaw settlement. In the longer term, significant reduction in foundation capacity could occur.

It appears there will undoubtedly be a continued warming in the atmosphere. However, the change should be relatively gradual and the ground, especially at depth, will take some time to respond. Therefore, while the impact on foundations in permafrost should not be ignored, one should resist the tendency to become alarmist. In any event, it should be more economical to add insulation or provide some other remedial measures at a later date, if required, than to over-react now and dramatically reduce foundation capacities. It is considered prudent to assume ground temperatures 1°C warmer than present for more critical or sensitive structures.

4.0 TRANSPORTATION SYSTEMS

Transportation of equipment and materials is a key factor in the selection of the appropriate foundation system in the north. Most areas in the Arctic lack local suppliers of building materials such as wood, steel and cement and therefore, these materials must be imported. Transportation options in the north vary depending on geography and weather conditions. For some of the more remote northern communities, the cost of mobilization of personnel, equipment or materials may effectively offset advantages of particular foundation options suited to the local climate and soil conditions. Marshalling and shipping charges can account for approximately 20% of the total construction cost in the high Arctic.

4.1 AIR

Due to the shortness of the ice-free season, air travel is often essential in the shipment of materials or personnel necessary for construction. Air transportation is available to almost all communities in the Yukon, Nunavut and Northwest Territories, and Labrador. Air cargo can be shipped at a charter rate or by weight. Although air transportation is often the most convenient option, costs are not competitive with barge or ship service for bulk freight.

4.2 LAND

The road system in the north consists of a combination of gravel and paved roads, winter roads and ferry crossings. The six ferry crossings linking the road system in the western Arctic normally operate from mid-May to early-November in the South and from June to mid-October at the Northern crossings. Ice bridges are started in mid-December and kept in operation for two to three months. Winter roads are beneficial in providing surface transportation to some communities. These roads are impassable in the summer due to poor drainage and dangers of severe erosion caused when vehicles disturb the thin organic layer above the permafrost (CMHC, 1994).

The main highway route into the Northwest Territories originates at Peace River, Alberta. The highway travels north to Fort Simpson and Wrigley. Winter roads link Inuvik to Aklavik and Tuktoyaktuk: Wrigley to Tulita, Deline, Norman Wells, and Fort Good Hope.

In the Yukon, major centers are linked to the south by the Alaska Highway and to the Mackenzie Delta by the Dempster Highway, which connects to the Alaska Highway.

Road travel in the west, despite available connections, is long. Typical travel times between Edmonton, Alberta and various communities in the western Arctic are:

Hay River	14 hrs
Yellowknife	19 hrs
Wrigley	24 hrs
Whitehorse	27 hrs
Dawson City	34 hrs
Mayo	33 hrs
Inuvik	43 hrs

The central and eastern Arctic, northern Quebec and Labrador have limited road access to the major southern centers. The Trans-Labrador Highway provides a road link between Western and Central regions of Labrador, and with the neighbouring province of Quebec. This highway does not at present extend to coastal region of Labrador.

4.3 WATER

Communities in the western portion of the Northwest Territories are serviced by the Mackenzie River. Navigation problems on the Mackenzie River include a short shipping season (beginning of June to mid-October), ice conditions, low water levels (especially in the Fall), four sets of rapids and decreasing daylight in the fall (CMHC, 1994). As a result, sailing time by freight barge from Hay River to Tuktoyaktuk is approximately 16 days.

Much of the freight carried on the Mackenzie system is transferred to ocean vessels at Tuktoyaktuk for distribution to the Beaufort Sea area and to coastal points and islands as far east as Taloyoak (formerly known as Spence Bay). The Northern Transportation Company Limited (NTCL) is the main carrier.

Communities in the eastern Arctic are serviced by Canadian Coast Guard Sealift with cargo being assembled in Montreal. Private shipping lines also operate in this region and rates are generally on par with the Sealift. The sealift services 15 communities in the Baffin Region plus one in Keewatin. Areas served include Iqaluit, Strathcona Sound, Resolute Bay, Rae Point, Little Cornwallis Island, Eureka and sites in the Foxe Basin and other points as far north as Grise Fjord (CMHC, 1994).

The Keewatin Region is handled by the Northern Transportation Company Limited (NTCL). Barges operate out of Churchill and services six communities. Two communities in the Keewatin (Repulse Bay in the Foxe Basin and Sanikiluaq, on the Belcher Islands, just north of James Bay in Hudsons Bay) are handled separately (Wright, 1999).

NTCL also assembles freight for shipping out of Montreal to the eastern Arctic communities. The eight communities around the south and east of Hudson Bay are served out of the Moosonee by tug and barge. Because of its location, Sanikiluaq is partly served by this service. There is some crossover on service with some of the communities in Nunavut on Hudson Bay.

In Labrador, the Provincial Ferry Service provides passenger and cargo transportation to coastal communities from Goose Bay north to Nain.

4.4 RAIL

The Great Slave Lake Railway runs from Grimshaw, Alberta and then heads north to Hay River, Northwest Territories. Hay River is the staging area for the Mackenzie River barge system.

4.5 DISCUSSION

The logistics of Arctic transportation routes generally favour shipment of construction materials by barge or ship to many communities. This option services the most communities and is the most cost-effective. Due to the length of travel and the short shipping season, goods generally arrive in communities, at least in the Eastern Arctic, in late summer before freezeback. This places further limitations in some regions on the available foundation systems. For example, in areas of Nunavut where shipments arrive in late summer, the construction period can be upwards of 2 years for foundation systems that need to be in place for one freeze thaw cycle prior to loading.

5.0 LABOUR MARKET

Construction in the Arctic generally requires a combination of skilled and unskilled labour. Supervision is also needed in order to ensure a quality installation. Consideration of the required labour and the local labour market is necessary to make an informed decision. Skilled local tradespeople in building construction may be difficult to locate in more remote communities. Where skilled labour needs to be brought into the community for construction, this will be reflected in the overall costs as provision must be made for transportation and subsistence costs.

In the past, housing corporations have fostered 'hands on' learning within the communities. Homes were delivered to communities in 'kits' to be put together within the community. While this practice is not too common anymore, the skills developed while this program was in place should still exist in the communities.

A regional breakdown of education levels and employment in the construction industry for NWT, the Yukon, Nunuvat and northern Labrador is contained in Tables 5.1a-5.1c. Training in the construction and carpentry trades is offered through various colleges such as Arctic College (Nunavut), Aurora College (NWT) and Yukon Colleges. Where appropriately trained local labour is unavailable, prefabricated systems are a viable option. Assembly can typically take place on site with local labour.

6.0 SURFACE FOUNDATIONS

6.1 GENERAL

Differential movements caused by thaw settlement or frost heave, can be transferred from the foundation system directly to the structure. Typically, such movements cause deformation to the structure and can damage many of its components. Examples of such damage include cracked concrete, masonry, wood and drywall; distorted windows, doors and floors; and separated walls and roofs. Generally, the most common foundation systems in the north attempt to either separate the structure from the active soils beneath (e.g. piles or buried footings) or float on the active soil or fill and adjust to movements on a continual basis (e.g. pads and wedges or screw jacks).

The latter surface foundation systems are constructed directly on a prepared gravel base in continuous and discontinuous permafrost regions. These foundation options should only be used to support relatively small or residential structures, heated or unheated, that are able to tolerate some movement. Surface foundations typically incorporate a mechanism to allow for adjustment in the event of differential settlement, which is typically about half of the overall settlement of the structure. Structures need to be maintained or adjusted on an annual or 'as needed' basis. Figure 6.1 outlines the suitability and advantages/disadvantages of the various surface foundation systems.

The non-frost susceptible pad is composed of thaw stable, well-compacted gravel and is constructed on-grade. The pad should be designed to prevent the penetration of thaw into the frost susceptible soil below. As a result, the pad should be approximately 1 m (3 ft.) in height and extend beyond the perimeter of the building by 3 m (10 ft.). To prevent ponding of surface water, the pad should be graded to direct drainage away from the structure.

Ideally, the gravel pad should be placed the year prior to the commencement of construction. This will allow the pad to settle, and adjust to the seasonal movement of the permafrost. If 'soft' ground conditions exist, it may be necessary to provide a geosythetic barrier to isolate the gravel from the fine soils beneath the pad. The geotextile will provide long-term separation of the aggregate base from the subgrade soil.

Although communities rely on local fill sources, care should be taken in the selection of an appropriate fill. Communities such as Gjoa Haven have experienced significant erosion problems due to the sandy nature of the local fill material. Where this occurs, the structure must be jacked up to add more fill. Problems may be complicated by inadequate compaction. As most communities do not have compactors, compaction of the pit run gravel is achieved by a loaded dumptruck. As a result, the gravel pad is often not compacted according to specifications.

Heat flow to the ground must be further reduced by open ventilation between the gravel pad and the underside of the structure in addition to floor insulation. This air gap should be a minimum of 0.7 m (2 ft. 4 in.) to minimize heat transmission to the underlying permafrost, to minimize the potential for snow drifting and to provide sufficient clearance for access to the crawl space and leveling system. In order to ensure good air ventilation, the air space should not be boarded up and should not be used for storage.

Experience has shown that small, light structures placed on surface foundations may be moved laterally by the strong, gusty winds which frequent in the North. Consideration must therefore be given to providing adequate anchorage.

6.2 PADS AND WEDGES

Pads and wedges are the most commonly used foundation system in regions of discontinuous and continuous permafrost. The majority of the communities in which individuals were contacted report pads and wedges as the predominant foundation system.

The main beams supporting the building are supported at intervals, typically every 2.5 to 3 m (8 to 10 ft.) by pads of horizontally placed timbers that are stacked about 1 m (3 ft.) in height to create an air space underneath the building (Figure 6.2). The pressure treated timber pads are founded on a prepared gravel base and anchored by steel pins driven into the gravel base. In the event of differential settlement, a pair of wedges provides the adjustment capability. Metal angle irons tie the system to the beam supporting the structure. Cables are often required to tie down the structure to deadmen buried within the gravel pad.

This foundation system has typically been used in northern permafrost areas for small buildings, which are not likely to suffer damage from a reasonable degree of movement. Homes supported on pads and wedges are shown in Figures 6.3a) and b). The initial cost is low and provided that frequent maintenance is carried out to maintain the home level, this system may be appropriate. Periodic leveling is usually needed, depending on the ground conditions. It may be required every few years for competent thaw stable permafrost but more frequently for ice-rich soils. Although this system is very economical and readily adjusted, adjustments are often not made until extensive damage to the building is evident. Experience has also suggested that releveling may cause damage to the structure due to the concentrated forces exerted on the structure as the wedges are forced under (Duncan, 1994).

Leveling is generally required on the average of every two years to minimize structural damage. Communities in the Yukon Territories have experienced extensive problems with heave and settlement in the past due to poor drainage (i.e. Dawson City). This resulted in frequent levelling needs to minimize damage to the structure. Other northern communities (i.e. Fort Good Hope, NWT and Gjoa Haven, Nunavut) have reported that significant settlement takes place in the first year following construction but stabilizes thereafter. Eventually, the need for maintenance becomes less frequent.

In some applications, this system has been modified to use screwjacks for the adjustment capability instead of the timber cribbing and wedges (Figures 6.4 and 6.5). The screwjack system must be placed on a pressure treated wooden pad. This system facilitates easier adjustment and releveling of the structure.

Although pads and wedges are still commonly constructed, this is no longer the only option, even in the most remote communities. Most communities now have access to the appropriate equipment to allow for more sophisticated and reliable foundation systems to be constructed (i.e. buried footings or piles). It is important to consider the long-term benefits of more permanent foundation systems when considering the initial costs.

6.3 TIMBER SILLS

These are the simplest form of foundation to construct and require no skilled labour. It consists of beams laid along the surface of a compacted pad, or on a stable ground surface (Figure 6.6). The foundation provides an air space between the pad and floor to provide ventilation and to act as a protection from moisture. The air space of 0.7 m (2 ft. 4 in.) normally required for adequate air circulation is not achieved with timber sill foundations. The air space would likely be cut off in winter by snow. Even when used with discretion on cold permafrost, the permafrost table will not come up into the pad and thaw will likely occur.

Thawing of ice-rich soils is an obvious concern due to the increased potential for thaw settlement and subsequent damage to the structure. Of the options available for surface foundations, timber sills are most likely to result in premature structural damage.

This system is able to tolerate reasonable movements. In timber frame construction, the walls are bolted to the sill with extra long bolts to allow for adjustment in response to uneven settlement. Even with the bolts, the buildings may be blown off the sill foundations in strong winds, so buildings need to be anchored to the foundation soils.

6.4 POST AND PAD

As with any surface foundation system, the building must be able to tolerate some movement. Pads and posts are generally constructed of pressure treated timber but can be made from a combination of timber, concrete and steel (Figure 6.7). The pads are placed on or just below the surface of a compacted fill pad. Anchor bolts fasten the posts to the pads to help brace against strong winds and seismic loading. Cross-bracing is also usually applied. The length of the posts should allow for a minimum air space below the underside of the structure of 0.7 m (2 ft. 4 in.) to allow any heat from the building to be dispersed and to minimize snow drifting.

Differential movements resulting from frost heave and thaw settlement can be expected. Extra long anchor bolts should be used to fasten the posts to the pads to allow adjustments to be made.

6.5 SPACEFRAME FOUNDATIONS

Spaceframes, an advanced form of surface foundation system has recently gained widespread popularity, particularly in the Yukon and Northwest Territories. Triodetic Building Products of Ottawa is one manufacturer of the patented spaceframe structures (Vangool, 1996).

Essentially, these are interconnected tubular steel or aluminum chords that utilize the patented Triodetic joint. This joint allows the assembly of up to ten chords at a single point using specially designed chords and hubs.

Figure 6.8 illustrates the various components of the spaceframe foundation system. The greatest advantage of the spaceframe system is its rigid structure that can tolerate the differential movements of the active soil. A planar structure-to-foundation connection is always maintained, allowing the structure and foundation to behave as a single unit. In essence, differential ground movements affect the unit as a whole and overall tilting can be remedied through adjustable bearing plates.

Other advantages offered by using this foundation system include:

- Assembly can be easily carried out by unskilled labour (e.g. a two-man crew can assemble a house frame in two or three days).
- No heavy machinery required.
- Site preparation may involve only leveling or the addition of a gravel layer. Soft ground conditions may necessitate the use of geotextile prior to placing gravel.
- Older structures can be retrofitted with this system.
- Can go for longer without re-adjustment
- Since the structure tilts rather than deforms, less damage to the structure
- Releveling is less destructive to the structure than with other forms of adjustable foundations

Field performance of the Multipoint Spaceframes suggests that the system has solved many of the problems of difficult ground in warm or discontinuous permafrost regions. Observations of several hundred Triodetic foundation frames over a wide variety of soil conditions have indicated that both the initial and long-term displacements are well within acceptable limits (Vangool, 1996).

The limited current experience with spaceframe foundations is mainly in the Yukon and western Northwest Territories where there are significant problems with ice-rich warm permafrost. Residential dwellings in Dawson City, Mayo and Inuvik (NWT) have recently been retrofitted with spaceframes. Feedback from the housing corporations and the homeowners has been positive. The Yukon Housing Corporation, the Yukon Territorial Government and the Northwest Territories Housing Corporation are currently using spaceframes in their projects and are impressed with the performance (Appendix C). Based on their performance, the lifespan of a home supported on a spaceframe is anticipated to be on the order of 70-80 years, typical of quality wood construction.

For an average frame of 8.5 x 12.75 m (28 x 42 ft), the weight of the spaceframe, including timber beams which serve as floor beams to support the existing house, is 4500 kg or 10,000lb. Shipping volume is 4 cubic meters (140 cubic ft) with none of the crates exceeding 2 metres (7 ft) in length. This compact and dense shipping volume is compatible with northern transportation systems.

6.6 COSTS

Estimates of the cost of pad and wedge foundation system have been obtained from the Yukon Territorial Government and the Fort Good Hope Housing Commission. For an average sized home, the cost estimate ranges from $4000-5200 including materials and labour. This estimate should broadly apply to all adjustable foundations constructed of timber. These foundations are typically constructed with local labour within the community and, on average, it takes a two-person crew two days to install.

Estimates of the cost of spaceframe foundation systems have been obtained from the Yukon Territorial Government and the Yukon Housing Corporation. For an average sized residential dwelling, the foundation system will cost approximately $10,000 including shipping to the Yukon. The spaceframe can be assembled by a two-man crew in 2-3 days (unskilled) yielding a labour cost of approximately $2-3000.

It is important to note that even though the timber and concrete surface foundations are less expensive, the lifecycle costs of repair, releveling and shortened lifespan may warrant the choice of more reliable, sophisticated systems (ie. spaceframe, piles, buried footings). Twenty years ago, timber and concrete surface footings were basically the only option in most communities. With the more widespread availability of excavating and drilling equipment, other options are available and should be considered. If equipment is not available, is too expensive, or if extremely difficult ground conditions exist, spaceframes may provide a more viable alternative.

A comparison of the lifespan and lifecycle costs is contained in Table 6.6. The costs of foundations and the associated lifespan of the structure is highly dependent on local soil conditions, groundwater conditions, location and climate. Therefore, rather than approximate values, a relative comparison of the various foundation options is shown in Table 6.6.

7.0 SHALLOW FOUNDATIONS

7.1 GENERAL

Based on community interviews, field visits and a literature review, Figure 7.1 provides an overview of the options and summarizes the suitability and advantages/disadvantages of shallow foundation systems.

As with surface foundations, structures supported on footings must be sufficiently elevated above the site grade by columns such that there is no direct influence of the heat from the structure on the geothermal regime beneath the structure. For the majority of residential structures, the minimum recommended air gap is 0.7 m (2 ft 4 in.) although for larger structures (multi-unit dwellings), this value is increased to 1.0 m (3ft 3 in.), depending on the plan area of the structure.

Special considerations may be required in regions of extreme snow or snow drifting, since accumulation of snow against the base of the structure may impede air flow and heat from the building could influence the ground temperature. For similar reasons, the air space should not be boarded up or used as a storage space.

7.2 FOOTINGS IN OR ON PERMAFROST

Footings placed directly on permafrost, sometimes referred to as 'Greenland foundations' or buried pier foundations, are quite common in the arctic. Footings are typically limited to spread footings as opposed to strip footings since the individual footings can usually be adjusted to correct for movement. The foundation may consist of a conventional reinforced concrete footing and pier or may be constructed of a timber or steel post supported on a pressure treated wood pad or concrete footing (Figure 7.2). Many variations and combinations of structural designs of foundation members are possible.

Pits are excavated through the depth of seasonal thaw and the footings and piers or posts and pads are installed. Soil is backfilled around the posts as rapidly as possible. The posts must project about 1 m (3 ft) above the ground surface. Rigid insulation is then placed on the ground surface and a pad of granular material is placed on the top with the minimum thickness being 300 mm (12 in.) at the edges and 450 mm (18 in.) at the center (Figure 7.3). The fill should be sufficiently thick so that the permafrost table moves up into the pad and the annual frost zone (active layer) will, therefore, occur in the fill where freeze-thaw effects are negligible.

Due to high winds, vertical posts should be cross-braced to provide better stability.

Footings constructed with timber or precast concrete should be placed on a thin leveling course on the frozen foundation stratum. If poured concrete is to be used, either 300 mm of compacted gravel or 50 mm (2 in.) of extruded polystyrene insulation should protect the frozen ground from the heat of the concrete.

The columns should be covered with greased layers of polyethylene, or equivalent within the buried portion to reduce the potential for seasonal heaving. The structural connection between the footing and column should consider the potential heaving forces and seismic loads.

The footing should be placed when the foundation stratum is still frozen and the insulation and sand cover must be placed immediately afterwards. If significant thaw occurs below the footing levels, initial settlement may occur, freezeback may take more than one season, and some frost heave may occur.

Appropriately designed and constructed footings in or on permafrost should experience minimal settlement in the long term (less than 30 mm or 1 1/8 in.). It is typical to assume that differential settlement could be about half of the total settlement of the building. An adjustable wedge system may be incorporated into the design to allow for periodic leveling of the structure.

In regions where boulders or cobbles are encountered within the active layer, a backhoe will be required to excavate to the footing level. If the active layer is not frozen, there may be significant sloughing and seepage problems in cohesionless soils. The excavation walls may be shallow, such as one vertical to 4 horizontal (1V:4H) and therefore the excavation will be large. Pumps may be required to handle seepage.

A problem in numerous remote communities is a lack of proper equipment for excavation, for controlling active layer seepage and even for quality concrete. All of these factors must be considered in selecting a foundation type. Problems with excavation, seepage and sloughing of the sides of the excavation can lead to poor bearing conditions at the base of the footing at the time of construction. Where possible, trenching by mechanical equipment should be avoided and each footing installed individually. The use of a footing pad on well-compacted granular backfill allows construction to proceed immediately as opposed to waiting for the ground to refreeze although some settlement may occur if structural loads are applied prior to freezeback. Where quality concrete is unavailable, pressure treated timber or steel sections may be used.

In regions of shallow but variable bedrock, footings are not viable. Some footings would be based on bedrock while others would be based on frozen overburden. Such a combination of foundation support should be generally avoided in view of the potential for differential movement between foundation types.

The advantage of this foundation is that the footings are installed deep enough so that the bearing surface is below the zone of seasonal heaving and thawing. In more northerly communities, excavation is only required to about 0.3 m (1 ft) until a stable bearing surface on the permafrost is established. Generally only relatively light to moderate column loads can be supported on such footings. Several aspects must be considered in design, namely:

- Soil type, ground temp, salinity and ice contents
- Depth of previous active layer
- Depth of post-construction active layer
- Insulation requirements
- Frost jacking protection on column
- Timing of construction
- Bearing capacity
- Settlement
- Maintenance requirements

7.2.1 GROUND CONDITIONS

For sites with ground temperatures warmer than about -2°C (28°F), it may not be economical to prevent the permafrost from degrading due to the effects of construction disturbance. Therefore, footings on the permafrost would only be feasible if the ground was thaw stable (i.e. no excess ice).

Sites with ground temperatures colder than -2°C (28°F) can probably be maintained in the frozen state though insulation may be required for warmer or more ice-rich sites.

The thickness of the active layer prior to site development is important as it defines the top of the natural permafrost table. In many cases, particularly in fine-grained soils, there can be considerable excess ice at the permafrost table. Since most developments on sites with organic cover tend to deepen the active layer, footings placed on the previous permafrost table could be subject to considerable settlement or failure.

Footings should preferably be placed at much as 600 mm (2 ft) below the design permafrost table. Frost heave protection should be provided on the column or post (Figure 7.4). This may consist of grease and polythene sheets or grease and shrink-wrap surrounding the post through the depth of seasonal thaw. In addition, the foundation should incorporate a means of countering the heaving action. Three of the more common solutions are:

1. To separate the foundation wall or column from the surrounding soil with granular material such as gravel or crushed stone. Uplift forces are lost in shear in the granular materials rather than transmitted to the foundation members

2. The use of anchored columns or walls to resist the uplift forces generated by frost heaving of the soil.

3. The use of insulation. For best protection, the insulation should be placed horizontally adjacent to the structure. This will be discussed in detail in following sections.

7.2.2 INSULATION

The use of insulation around footings can have the beneficial effect of raising the permafrost table, resulting in possible increased bearing capacity and reduced creep settlement. Alternatively, the required footing depth can be reduced with no corresponding change in bearing or settlement. The required amount of insulation can range from 25 to 75 mm (1 - 3 in.) depending on the ground surface temperatures. Bearing capacity and creep settlement potential, being highly temperature dependent in ice-rich soils, are improved by a reduction in seasonal warming. Alternatively, the reduced depth of seasonal thaw means the footing can be raised, reducing excavation costs and, more importantly, reducing the potential for groundwater problems in excavations.

Where fill is being placed on a site, the final fill surface is the new reference surface for any seasonal thaw predictions. Where significant fill thicknesses are required or can be accommodated, it may be possible to raise the footing level considerably. Figure 7.5 illustrates, for a site with a mean ground temperature of –5°C, the base of the footing could be placed at 0.6 m below final grade using 50 mm (2 in.) of insulation instead of almost 2 m (6 ft 6 in.) depth without insulation. In other words, if 0.6 m (2 ft) of fill were being placed on the site, the footings could be placed on the original grade. For sites with considerable water in the original active layer, this can be a definite advantage. In addition, placing footings in a gravel pad placed on top of the original ground creates the least thermal disturbance.

7.2.3 TIMING OF CONSTRUCTION

Ideally footings to be placed on permafrost should be placed prior to the time the thaw reaches the design permafrost table. Depending on alterations to the ground surface and the use of insulation, the design permafrost table may be deeper or shallower than the original permafrost table.

For design conditions that would deepen the permafrost table, the footings would be deeper than the normal permafrost table and can be placed at any time. Excavation may be easier when the active layer is more fully developed except where groundwater or sloughing is a problem. For construction that will raise the permafrost table, ideally the footings would be placed as early as possible in the thaw season. It is important to limit the amount of thaw that occurs beneath the footing level before the site stabilizes to the new surface conditions.

Ideally, footings should be placed together with the insulation and final fill prior to thawing of the soil beneath the footing level. This would be essential for sites with thaw unstable permafrost (i.e. excess ice/water content). For sites with thaw stable soils, the consequences of thaw below the footing may not be as serious. However, the potential for heaving during subsequent freezeback must be considered.

In practice, in many remote communities in the Northwest and Nunavat Territories that are dependent on the late summer sealift for construction materials, the timing of construction is not always that flexible. Where scheduling permits, for projects that will raise the permafrost table, it would be desirable to construct the footings and pad the season ahead of construction of the structure. In this manner thaw settlement and frost heave would be completed and the footings should be permanently stabilized. Complete freezeback should be verified by thermistors installed during construction. Due to the timing of foundation construction and the timing of the sealift in the eastern Arctic, the construction period for the Greenland foundations can be as great as two years.

7.3 FOOTINGS IN FILL

For extremely poor site conditions or other criteria such as flood control, there may be large thicknesses of granular fill placed over the existing grade. Depending on the location and possible use of insulation, it is possible to raise the permafrost up into the fill (Andersland, 1994), as shown in Figure 7.6. The design basis will be on the unfrozen properties of the fill. Insulation requirements will typically be on the order of 50 to 100 mm thick depending on the air temperatures. This system is usually only feasible where the ground temperatures are colder than about –3°C (26.6°F). For nominally compacted fill (only packed with trucks or a cat tractor), the allowable load could be as low as 75 kPa (500 psi). For a thoroughly controlled and tested fill, the bearing capacity can be 250 kPa (1700 psi) or higher depending on quality of material and degree of compaction. This can usually be achieved only with heavy-duty compaction equipment. However, it is unlikely that a typical residential housing unit would require bearing capacities exceeding 250 kPa (1700 psi).

7.4 FOOTINGS ON ROCK

In much of the eastern arctic, bedrock is either exposed or relatively shallow. For relatively high structural loads it is probably feasible to excavate to about 2 m (6 ft) in order to access high bearing capacities. There may be complications such as excess groundwater seepage that could affect the feasibility.

Footings must be placed on the clean, sound rock and are usually keyed into the rock with grouted dowels to provide lateral and uplift restraint. The allowable bearing pressures must be conservatively assessed unless an adequate rock coring and strength-testing program is carried out.

The competency of the rock must be known prior to construction. In some areas, such as in the vicinity of Igloolik, the sedimentary bedrock is highly fractured and can contain considerable ice lenses. Thus, if warming of the bedrock surface was to occur, significant thaw settlement could result. As a general rule, the granitic rocks of the Shield are more competent and provide a stable foundation medium for structures, however, surface rock can be fissured and fractured and contain excess ice.

7.5 STRIP FOOTINGS ON GRADE

In northern Labrador, the most common foundation system is reported to be a perimeter concrete footing with pressure treated wood knee walls. Communities in this region do not have access to drill rigs and the cost of mobilization would be too high to allow for pile foundations. Experience with other systems such as concrete spread footings to slab-on-grade have resulted in relatively large differential settlements.

The concrete footings are constructed on grade with a pressure treated foundation wall tied into the footings by anchor bolts. The footings are covered with fill material for erosion protection. The above ground crawl space typically houses the furnace and experience has shown that a heated crawl space works better than non-heated.

This system was developed in response to local experience and limitations. As aggregate for the footings must be brought in from elsewhere, the volume of concrete is minimized by using pressure treated wood for the foundation walls. Limitations of equipment (i.e. drill rigs) make more sophisticated, reliable piling systems too expensive for local housing. Building inspectors with the Newfoundland and Labrador Housing Commission and the Torngat Regional Housing Association report that while there are settlement problems, the settlement is mainly uniform. As a result, damage to the structure due to foundation movements is less severe than with other methods.

7.6 COSTS

The costs associated with footings are extremely variable and depend on:

Location – costs of material and equipment shipping, availability of skilled tradespeople
Ground conditions – difficulty in excavating
Groundwater conditions – potential seepage and sloughing of excavation
Depth of Active Layer – determines depth of footings

For an average home, twelve to fourteen spread footings are required. Each footing will cost approximately $1000 to install (Appendix C). Labour accounts for approximately 50% of the overall cost but use of local labour within the community will reduce the cost. The Nunavut Territory Housing Corporation reports that workers within the community typically construct Greenland foundations. In some instances, the housing corporation may contract this work out to the hamlet as it usually has the heavy equipment needed for excavation, etc.

The strip footings and foundation wall used exclusively in the communities of northern Labrador are reported to cost approximately $8-9000 for materials and labour for a 100 m^2 (1000 ft^2) home.

8.0 BASEMENTS

It is conventional that basements not be constructed for residential units in permafrost. The reasons for this include the difficulties, and hence, cost of excavating permafrost, and the need to isolate the building heat from the thermally sensitive subgrade soils.

At least two recent projects in Ross River, Yukon have incorporated partial basements. Figure 8.1 shows a photograph of a house with a cut-away section showing the basement structure. The foundation consists of a preserved wood foundation, with the basement floor approximately 1.2 m (4 ft) below grade. The permafrost table is at a depth of 5 m (16 ft) or 3 m (10 ft) beneath the base of the crawl space. The basement floor consists of 200 mm (8 in.) deep joists with fiberglass batting insulation between joists. The joists are supported on 0.6 m (2 ft) high pony walls to form a relatively open air space under the basement floor. Temperature measurements made in March 1998 showed the outside air temperature, basement temperature, and crawl space temperature to be (on average) -7°C (19.4°F), +18°C (64.4°F), and +6°C (43°F) respectively. The ground temperature, approximately 100 mm (4 in.) below the base of the crawl space averaged +0.8°C (33.4°F).

Although the temperatures in the crawl space subgrade are substantially lower than the basement temperature, and the construction of basements has some architectural appeal, it is expected that the building will experience some long-term thaw settlement. The ground temperatures in the community are typically warmer than -1°C (30.2°F). Thus the permafrost is very fragile.

The construction of basements in permafrost regions requires special techniques to ensure the long-term preservation of the permafrost condition. This may include the placement of cooling coils in the subgrade or ventilation of the crawl space under the floor. Where the permafrost is colder, the use of basements may be more feasible because of the higher 'cold sink' capability of the ground.

Several communities in the Northwest Territories have structures constructed with basements. Our Lady of Good Hope church in Fort Good Hope was renovated and a basement constructed in 1954. A 1991 investigation of this national historic site indicated that snow accumulation and ponding in the basement were resulting from excessive cracking of the basement walls. Several structures in Fort Providence have basements with varying reports of performance. The basement at the Hamlet office has had minor problems with seepage into the basement but no settlement problems. Some residential structures constructed with basements in Fort Providence have reported flooding and differential settlement resulting in some structural problems.

Basements or crawl spaces beneath schools have often created problems with greater than expected impact on the ground. In some cases (eg: Igloolik School, old Fort Providence School), thaw around the partial basement for the tank room resulted in flooding and settlement of the floor.

9.0 PILE FOUNDATIONS

9.1 GENERAL

The most commonly used piles for residential construction in permafrost are as follows:

- Driven piles
- Sand slurry piles
- Modified sand slurry piles
- Grouted piles
- End bearing piles

Figure 9.1 provides an overview of the most common pile types and their suitability for various applications.

Timber and steel are the most common materials used in piling in permafrost regions. Experience has shown that steel piles perform well in frozen ground, with only slight corrosion in the active layer. Although timber is more readily available, it should be noted that timber may be susceptible to decay unless pressure treated with a preservative. Structures in Inuvik are currently having problems with rotting wood piles and are now being retrofitted with steel pipe or spaceframes. If kept permanently wet, permanently dry, or frozen, they can have a long life but are prone to decay in a zone of fluctuating water table. Above the water table, they are susceptible to attack by fungi and ants or other wood destroying insects. In this instance, steel piles would be the more appropriate alternative. Given the proper application, timber piles can still be a practical and low-cost foundation system.

A brief discussion of the design principles, installation methods, capacities and suitability is given in the following sections.

It should be noted that these piles have been developed regionally based on a combination of: permafrost, soil type, presence of rock, ground temperature and availability of construction equipment.

9.2 DRIVEN PILES

In Canada driven piles were used extensively in cold permafrost in the construction of the Inuvik townsite (Johnston, 1963) and warmer permafrost in communities along the southern section of Mackenzie River and Great Slave Lake (Pritchard, 1963).

The common types of piles driven are timber (early designs); steel (Pipe and H section preferred in North America) and precast concrete (common in the F.S.U.).

Piles are normally used in warm permafrost with the following guidelines:

- Steel piles (pipe, H section, rails, and sheet piles) driven in fine to coarse grained soil near 0°C (32°F);

- Steel pipe piles driven in undersized holes in warm permafrost in the range from 0 to -1°C (32°F to 30.2°F);
- Steel, wood, and precast concrete piles driven in thawed holes.

Pile driving is most efficient in frozen fine-grained soils where piles can be driven directly. This ensures minimal thermal disturbance and quicker freezeback. Predrilling a small pilot hole, either by dry augering or rotary drilling helps maintain vertical alignment in coarser materials.

Where timber or precast concrete piles are to be used, a hole can be prethawed by steam. The hole may be made smaller than the pile serving as a pilot hole. This may present an acceptable alternative for areas without access to modern drilling and pile driving equipment. In regions of 'warm' permafrost, the time to freezeback after steam thawing may be significant and artificial refrigeration may be required.

9.3 SAND SLURRY OR ADFREEZE PILES

The sand slurry or adfreeze pipe pile is one of the most common pile types in the Canadian cold permafrost, and represents at least 50 percent of the piles installed in Alaska. The major advance in the design of this pile was during the design and construction of the Alyeska Oil pipeline in the 1970's. Since that time this pile has served as the norm in pile design.

The pile design consists of installing a pile in an oversized hole and backfilling the annulus between the soil and pile with a water/sand slurry. The normal pile specifications or procedures for construction, as given by Tobiasson and Johnson (1978); Gosstroi (1969); and Johnston (1981) are as follows:

- Drill a hole with a diameter 100 to 200 mm (4 to 8 in.) greater than the pile diameter for alignment and good sand slurry placement.
- Backfill shall be a water sand slurry at a temperature not to exceed 4°C (39°F)and a consistency of a 150 mm (6 in.) slump concrete.
- Sand shall be a well-graded sand.
- The sand slurry shall be vibrated or rodded to ensure that there is no bridging or voids left along the pile.
- The sand and water used should be saline free as the presence of salts will reduce the adfreeze capacity.
- Initial freeze back may take days to months, depending on the surrounding ground temperatures. Pile loading being must not be allowed until some time after freezeback.
- If the initial ground temperature is >-1°C (30.2°F), the time to freezeback may be significant unless artificial refrigeration is used.

The pile is designed based on shaft friction and is governed by the adfreeze strength at the slurry/pile interface. In ice-poor frozen granular soils end bearing is sometimes taken into account to increase the allowable capacity of vertically downward loaded piles. To improve the end bearing capacity an oversized end plate can be welded to this pipe (Phukan, 1985; Tobiasson and Johnson, 1978). The use of an end plate is common in Alaska where large size drilling equipment is more readily available. It should be also noted that the oversized end plate provides additional anchorage against frost heave.

The major factor governing the capacity of piles in permafrost is ground temperature. The capacity of piles in permafrost is the result of adhesion of the sand slurry pore ice against the steel or the shear strength of the frozen soil. Ground temperatures in permafrost vary by location, annual changes and depth. The distribution of the average ground temperatures across Canada is illustrated by the mean annual air temperature isotherms shown on Figure 3.3. The mean annual ground temperature is about 2 to 4°C warmer than the mean annual air temperature.

In some of the more remote Canadian northern communities, particularly in Nunavut, the common sand slurry pile consists of a 114 mm (4 ½ in.) or 143 mm (5 5/8 in.) hollow structural steel (HSS) pile installed in a hole with a diameter about 50 mm (2 in.) wider than the pile and backfilled with a sand slurry (Figure 9.2). The small size of pile and holes is governed by the limitation of the capacity of the drill equipment, which is normally an airtrack drill rig. In the western Arctic, the more common pile drilling equipment is the larger diameter Texoma-type drill.

The piles are placed open ended so that they can be driven into sloughed material at the bottom of the hole if this occurs. It is not practical to consider piles that are much deeper than 10-12 m (35-40 ft) using the traditional means of installation available (air track) especially in the eastern arctic.

9.4 MODIFIED SAND SLURRY PILES

During the design of the Alyeska pipeline, which passes through 'warm' permafrost areas, it was recognized that the previously discussed sand slurry pipe pile did not have sufficient capacity. To increase the capacity, corrugations were induced into the pipe so that some shear mechanism could be changed from adfreeze bond to shear through the frozen slurry.

Since the construction of the Alyeska pipeline there have been several studies conducted on this subject but no practical guidelines have been published because of the complexity of permafrost conditions and creep behaviour.

The state-of-the-art on modified sand slurry piles can be summarized as follows.

a) It has been found that sand blasting of the plain pipe surface (which is often lacquered) will increase the short-term pile capacity by up to two times. However, because only limited data is available for short-term loading and no data for longterm loading is available, the indicated increase in capacity should be used with caution for long-term conditions.

b) There is considerable published information to show that corrugations or protrusions, such as a weld bead on a pipe pile will increase the pile capacity in both short and long-term load conditions. However, there are no guidelines to assist in designing the protrusions or to estimate the load increase that can be obtained.

c) It appears that the degree of load capacity increase is also a function of backfill type and its density. Dense granular material that exhibits a tendency to dilate under load will result in a greater load increase than fine backfill.

d) Pipe piles with protrusions require larger holes to accommodate the protrusion and sand slurry placement.

e) For many northern communities particularly in the eastern Arctic, the available Air track drill equipment is unable to drill holes large enough to accommodate the protrusion. Larger diameter drill equipment such as the Texoma-type drill is available primarily in the western Arctic.

f) For small loads, a threadbar pile with surface pipe conductor may be a suitable pile (Holubec, 1990). Further study of this pile should be conducted.

Another approach to modifying the performance of sand slurry piles in thaw susceptible and discontinuous permafrost involves the use of load bearing thermosyphons (usually called "Thermopiles"). Thermosyphons are passive heat transfer devices that operate on the simple process of convection through vaporization and condensation. The system consists of a sealed steel cylinder containing a two-phase medium (eg. ammonia or CO_2) and radiator fins. The principle of operation is as follows:

1) The temperature in the ground surrounding the thermosyphon vaporizes the coolant.
2) The vaporized coolant is cooled by convective heat transfer at the radiator fins located at the top of the pile.
3) The condensate travels by gravity down the wall of the pile, thereby removing excess heat and maintaining frozen conditions.
4) The cycle is repeated.

Thermopiles are a low maintenance foundation system, and have been used for many years for institutional and commercial buildings in Alaska, the Yukon, and NWT. The first foundation in Canada to use thermosyphons was the Ross River school in the Yukon. Thermopiles were recently used on an apartment building in Yellowknife (near Bison Holdings). Even as the technology advances, the system is not typically used for residential construction due to its high cost.

Piles appear to be seldom used in areas of thaw susceptible or discontinuous permafrost for residential construction. The Northwest Territories Housing Corporation reports that their homes have experienced severe problems with frost jacking on piles, even when a lubricant is used on the pile through the active layer. In Mayo, piles have been reported to have 'squeezed' right out of the ground (Appendix C). Care should be taken that piles are installed sufficiently deep and in maintaining the frost heave protection on the pile through subsequent freeze-thaw cycles.

9.5 GROUTED PILES

A method of increasing the capacity of a pile in permafrost soil is by replacing the sand slurry with a strong rigid bonding material, such as a cement grout. If a good bond develops between the grout and steel pile, the potential failure surface is translated outward to the grout/soil interface. The pile capacity is increased by the greater area of the failure surface and better bond strength at the grout/soil interface.

The advantages of a cement grout over a frozen sand slurry are:

- high grout strength with no creep in grout
- failure moved to the outside of the grout perimeter
- higher strength between grout and soil interface because of the rough surface produced by drilling.

To date, grouted or cast-in-place piles have been used only on limited occasions in permafrost. Some of the reasons for this are: a) cold temperature grout/concrete was not in common use for foundations, b) concern that heat of hydration may cause excessive thermal disturbance of the permafrost and, c) presence of chlorides in some cements may produce a low strength thaw zone (Weaver and Morgenstern, 1980).

In northern Canada, a special grout pile was developed by identifying and testing two grouts that could be placed in cold permafrost and it would cure to the design strength without additional heating (Holubec and Brzezinski, 1989). This design was developed for the Short Range Radar Stations, which allowed tower anchor pile construction at considerable cost saving. The two identified grouts can be placed in permafrost at about -10°C and will cure to produce a competent grouted pile. These are a Ciment Fondu based grout and Set 45.

In the design of the grouted pile, two pile designs were considered which consisted of a threadbar steel section encased in grout with a surface pipe conductor to provide lateral load capacity and a commonly used 114 mm (4 ½ in.) diameter pipe with 10 mm (3/8 in.) bar welded on the pipe in a spiral configuration. The grouted pile design were tested in Tuktoyaktuk (Holubec, 1990) and in Iqaluit (Biggar and Sego, 1989). Comparing the failure loads or the load at the point of increased deformation, the Iqaluit pile load tests indicated a pile capacity increase nearly 10 times over the smooth pile and the Tuktoyaktuk pile load tests showed a capacity increase of about 3. However, these extra pile capacities may not be of advantage to most residential structures.

9.6 END BEARING PILES

As discussed in the earlier general section, piles are normally designed by ignoring any potential end bearing contribution, the reason being that it is impossible to predict the absence of ice lenses immediately below the base of the pile, especially in ice-rich permafrost regions. There are two exceptions when end bearing is employed in the design of the piles in permafrost, as follows:

9.6.1 PRESENCE OF COMPETENT END BEARING STRATUM

In various regions of the arctic there is a potential for end bearing piles that can be based in some of the following strata:

- ice free bedrock (e.g.: Canadian Shield; some limestones)
- thaw stable granular strata (e.g.: parts of Alaska and Yukon)
- unfrozen till underlying ice-rich deposits (e.g.: Hay River)

The depth to the end-bearing stratum should ideally be within about 12 m (40 ft) below the surface, however, there may still be economical benefits (over adfreeze piles) at greater depths for structures with very heavy loads.

9.6.2 ROCK SOCKETED PILES

Where competent rock is available, piles are typically grouted into a rock socket to ensure good bearing contact between pile and rock. It is common to drill at least 2 m (6 ft 6 in.) into sound rock to ensure more competent rock at the base area (and to ensure the assumed rock is not a large boulder). With the full rock socket grouted, there is greater restraint against uplift and frost heave forces.

Special cold curing grouts are used for grouting the rock socket. Both a Ciment Fondu based ground and Set 45 can be placed in permafrost at about -10°C (14°F) and will cure to produce a competent grouted pile.

9.7 COSTS

As with footings, the cost of pile foundations and installation is highly variable on site location and ground conditions. Typical equipment for permafrost drilling is an air track rig with air rotary heads and down-hole hammers. CANADRILL, out of Iqaluit, services many northern communities with rigs located in various regions of Nunavut. Tundra Drilling, out of Inuvik NWT, services many communities in the western Arctic. Due to the limitations of the drilling equipment particularly in the eastern Arctic, steel pile piles are normally used with a 114 mm (4 ½ in.) outside diameter. If the bedrock is shallow, the piles are grouted into the bedrock. If not, then adfreeze piles are used and the void around the pile is filled with sand slurry.

For a typical home, approximately 12 to 14 steel pipe piles are required but this will depend on the type of floor support system used. A heavily built floor system will require less support (i.e. piles) than a more modest floor system. The number of supports and their spacing is in accordance with the local building codes. On average a home will require two piles to support the entry, and the remainder to support the structure.

The cost per pile is dependent on where the job is and whether air or water freight is used. Typically, a drilling crew consists of three men, and it usually takes four hours per pile plus mobilization and demobilization. It may take longer if problems during construction occur (a drill rod stuck in a hole or a hole caves in) or if particularly tough drilling conditions exist such as in Tuktoyaktuk. If the job is in an extremely remote location, air freight and travel costs can be as high as $15,000. Therefore, depending on the number of piles to be installed or the number of jobs available, the cost per pile can be as low as $700 and as high as $3000. Piling in and around Iqaluit or other major centres typically is in the range of approximately $500/pile (Canadrill). Piling in the western Arctic is typically on the order of $700-$1000/pile (Tundra Drilling Services Ltd.).

Piles are generally reported as the preferred foundation system in many communities (Appendix C) but are often not used due to their cost as compared with pad and wedge foundations. It is important to note that although piles generally cost at least double that of timber surface foundations they require less maintenance and result in longer lifespans of the structure.

10.0 INSULATION MATERIALS

Some form of insulation material is often required in northern development projects as the impact of many types of development is to warm the permafrost. In cases where the permafrost is ice-rich, degradation of the permafrost usually causes excessive settlement or instability on sloping ground.

The type of insulation used varies from natural materials such as peat or wood chips to synthetic materials such as polystyrene or urethane foam. The natural insulations are not likely appropriate for residential development projects even though they are more readily available close to the development site and are generally less expensive. They are also less efficient thermally than the synthetic materials. The synthetic materials are quite expensive and require shipping from distant distribution centres or manufacturing plants.

A general discussion follows on examples of the more common synthetic insulation materials.

10.1 EXTRUDED POLYSTYRENE

The extruded polystyrene board insulation (eg: Styrofoam SM or HI) is the common and very effective insulation material. It should not be confused with expanded polystyrene, bead board, which has quite inferior qualities, especially in a moist environment.

The most notable advantage of the extruded polystyrene is its low thermal conductivity, which has proven to be stable in the long-term. Other synthetic load bearing insulations such as sulphur or urethane foams are not as good in the long-term. Extruded polystyrene has demonstrated a distinct resistance to moisture absorption, which is what causes the loss in insulating value in insulation materials (Olson, 1984).

Extruded polystyrene is not resistant to ultraviolet or hydrocarbons, the latter requiring the use of a suitable impervious membrane. Being only available in rigid board form, a level base must be prepared prior to placement. It is also labour intensive to install, being preferable to use at least two layers with joints staggered.

10.2 URETHANE FOAM

Urethane foam can be produced at variable densities in pre-formed boards or foamed-in-place. Fresh foam can have conductivity lower than the extruded polystyrene, however, it has a considerable capacity to absorb moisture. Numerous attempts have been made to control the absorption using plastic skins and other sealants; however, these have not been completely successful. Most of the data published in this respect have been from the perspective of road insulation that undergoes frequent freeze-thaw cycles. Insulation under floor slabs will often remain largely in the unfrozen state except for some ventilated slab configurations.

A particular advantage of the urethane is the ability to foam-in-place so that surface preparation is reduced. In addition, the shipment of the raw components to the site would usually cost less than the preformed boards.

In spite of the known long-term increase in thermal conductivity, as long as allowance is made for such increase in design, urethane can still be an attractive alternate insulation. It is also common practice to increase the design thickness by as much as 50 mm to allow for an outer layer that may become completely saturated.

TABLES

Table 1.1a) Statistics Canada Census Information (1996 Census)
Labour Market Data for the Northwest Territories and Nunavut

Hamlet, Town, City or Village	Population	Persons with trades or non-university certificate or diploma	Persons who have completed university	Persons in manufacturing and construction industries	Unemployment rate (%)
Aklavik	727	110	25	40	25.4
Arctic Bay	639	70	25	10	19
Arviat	1559	155	45	80	30.5
Baker Lake	1385	165	55	40	16.5
Broughton I.	488	55	10	<10	21.2
Cambridge Bay	1351	265	90	75	7.9
Cape Dorset	1118	150	25	20	12.7
Chesterfield Inlet	337	35	10	<10	26.1
Clyde River	708	80	25	25	28
Colville Lake	90	15	0	<10	<10
Coppermine	1201	170	60	30	15.1
Coral Harbour	669	100	20	10	17.6
Deline	616	85	20	10	25
Detah	190	15	0	<10	23.1
Enterprise	86	20	0	10	----
Fort Good Hope	644	120	25	25	17.3
Fort Liard	512	45	20	45	19
Fort McPherson	878	130	35	45	22.4
Fort Providence	748	150	20	50	31.1
Fort Resolution	536	105	20	40	28.3
Fort Simpson	1257	330	85	80	18.8
Fort Smith	2441	580	230	100	12.2
Gjoa Haven	879	90	20	15	27.3
Grise Fiord	148	25	<10	<10	15.4
Hall Beach	543	45	10	10	21.9
Hay River	3611	830	305	205	12.5
Holman	423	55	15	10	8.6
Igloolik	1174	90	30	45	20.3
Inuvik	3296	715	310	125	13
Iqaluit	4220	760	425	170	10.4
Jean Marie River	53	10	<10	10	33.3
Kimmirut	397	65	20	40	9.4
Kugluktuk	1201	170	60	30	15.1
Lutselk'e	304	30	15	10	13
Nahanni Butte	75	10	10	10	25
Norman Wells	798	255	50	90	5.9
Pangnirtung	1243	115	35	65	16.1
Paulatuk	277	30	10	10	22.2

Hamlet, Town, City or Village	Population	Persons with trades or non-university certificate or diploma	Persons who have completed university	Persons in manufacturing and construction industries	Unemployment rate (%)
Pelly Bay	496	40	10	15	22.6
Pond Inlet	1154	140	30	30	26.3
Rae-Edzo	1662	130	65	35	32.7
Rae Lakes	256	10	10	<10	38.9
Rankin Inlet	2058	355	160	100	13.4
Repulse Bay	559	95	15	<10	14.3
Resolute Bay	198	35	10	10	----
Sachs Harbour	135	25	0	<10	14.3
Sanikiluaq	631	50	10	10	10
Snare Lake	135	10	10	10	27.3
Taloyoak	648	75	20	20	19.1
Trout Lake	68	10	<10	<10	28.6
Tsiigehtchic	162	15	10	10	15.4
Tuktoyaktuk	943	100	35	10	26.9
Tulita	450	75	15	35	23.1
Wha Ti	418	40	10	15	28.6
Whale Cove	301	35	0	<10	19
Wrigley	167	25	10	20	28.6
Yellowknife	17275	3905	2615	735	6.4

Table 1.1a) continued

Table 1.1b) Statistics Canada Census Information (1996 Census)
Dwelling Information for Communities in the Yukon

Hamlet, Town, City or Village	Number of private occupied dwellings	Dwellings constructed before 1981	Dwellings constructed between 1981 and 1996	Dwellings requiring regular maintenace only	Dwellings requiring minor repairs only	Dwellings requiring major repairs
Bear Creek	45					
Burwash Landing	35	10	25	25	10	0
Carcross	85	40	40	40	25	15
Carcross 4	30	10	20	0	10	20
Carmacks	165	75	90	65	55	45
Dawson	495					
Faro	460					
Mayo	130	85	40	50	35	45
Mt. Lorne	145					
Ross River	115	60	55	40	35	45
Stewart Crossing	15					
Tagish	35					
Teslin	70					
Two and One-Half Mile Village	15	10	15	10	10	0
Two Mile Village	35	0	30	10	15	0
Upper Liard	50	25	20	15	20	15
Watson Lake	380					
Whitehorse	7060					

Table 1.1c) Statistics Canada Census Information (1996 Census)
Dwelling Information for Communities in Northern Newfoundland

Hamlet, Town, City or Village	Number of private occupied dwellings	Dwellings constructed before 1981	Dwellings constructed between 1981 and 1996	Dwellings requiring regular maintenace only	Dwellings requiring minor repairs only	Dwellings requiring major repairs
Hebron (and surroundings)	75	35	40	15	30	35
Hopedale	145	65	85	70	30	45
Nain	225	115	110	70	65	90

Table 3.1a) Northwest Territories Climate Normals (1961-1990)

Station	Mean Annual Temperature (°C)	Average Annual Snowfall (cm)	Average Annual Rainfall (mm)
Baker Lake	-12.2	143.5	130.1
Broughton Island	-11.5	36.2	243.4
Byron Bay	-13.9	69.4	49.2
Cambridge Bay	-14.9	73.2	79.6
Cape Dyer	-10.5	102	597.7
Cape Hooper	-11.8	53.2	223.7
Cape Parry	-12	69.8	129.6
Cape Young	---	98.2	77.2
Clinton Point	-10.8	96.3	73.5
Clyde	-12.4	47.2	197.3
Contwoyto Lake	-11.8	128.6	117.5
Coral Harbour	-11.7	152.2	135.1
Dewar Lakes	-13.1	114.4	148
Eureka	-19.9	22.4	53.3
Fort Reliance	-6.8	168/8	139.6
Fort Simpson	-3.7	209.7	164.1
Fort Smith	-3	231.2	153.7
Gladman Point	-15.4	69.2	51.2
Hall Beach	-14.4	98.6	120.1
Hay River	-3.4	194.2	158.5
Inuvik	-9.5	116	175.2
Iqaluit	-9.5	192.9	256.8
Jenny Lind Island	---	69.1	45.3
Lady Franklin Point	---	67.9	50
Longstaff Bluff	-12.5	95.3	118.9
Mackar Inlet	-14.7	86.2	102.6
Mould Bay	-17.7	27.5	92.9
Nicholson Peninsula	---	66.4	45.3
Norman Wells	-6	183.2	148.9
Pelly Bay	-15.1	106.7	125.1
Resolute	-16.6	50.4	97.3
Sachs Harbour	-13.7	49.7	83.8
Shepherd Bay	---	78.6	81.8
Tuktoyaktuk	-10.5	75.4	66.8
Yellowknife	-5.2	154	143.9

Table 3.1b) Yukon Territory Climate Normals (1961-1990)

Station	Mean Annual Temperature (°C)	Average Annual Snowfall (cm)	Average Annual Rainfall (mm)
Burwash	-4	190.6	110.5
Haines Junction	-2.9	154.3	159.8
Komakuk Beach	-11	85	68.9
Mayo	-3.6	201.4	145
Shingle Point	---	125.2	105.8
Teslin	-1.6	190	159.8
Watson Lake	-3.1	256.7	218.9
Whitehorse	-1	159.6	268.8

Table 5.1a) Statistics Canada Census Information (1996 Census)
Labour Market Data for the Northwest Territories and Nunavut

Hamlet, Town, City or Village	Population	Persons with trades or non-university certificate or diploma	Persons who have completed university	Persons in manufacturing and construction industries	Unemployment rate (%)
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Pond Inlet	1154	140	30	30	26.3
Rae-Edzo	1662	130	65	35	32.7
Rae Lakes	256	10	10	<10	38.9
Rankin Inlet	2058	355	160	100	13.4
Repulse Bay	559	95	15	<10	14.3
Resolute Bay	198	35	10	10	----
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Sanikiluaq	631	50	10	10	10
Snare Lake	135	10	10	10	27.3
Taloyoak	648	75	20	20	19.1
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Wha Ti	418	40	10	15	28.6
Whale Cove	301	35	0	<10	19
Wrigley	167	25	10	20	28.6
Yellowknife	17275	3905	2615	735	6.4

Table 5.1b) Statistics Canada Census Information (1996 Census)
Labour Market Data for Communities in the Yukon

Hamlet, Town, City or Village	Population	Persons with trades or non-university certificate or diploma	Persons who have completed university	Persons in manufacturing and construction industries	Unemployment rate (%)
Bear Creek	131	55	0	10	17.6
Burwash Landing	58	20	10	40	---
Carcross	196	50	10	10	28.6
Carcross 4	81	10	0	10	37.5
Carmacks	466	120	25	25	17.3
Dawson	1287	355	135	50	12.9
Faro	1261	350	80	25	5.6
Mayo	324	95	30	10	11.4
Mt. Lorne	399	105	55	40	12.5
Ross River	352	110	10	30	20.5
Stewart Crossing	42	10	0	<10	50
Tagish	69	20	10	<10	33.3
Teslin	189	70	15	10	16.7
Two and One-Half Mile Village	44	15	0	<10	50
Two Mile Village	103	40	0	10	40
Upper Liard	111	30	0	10	36.4
Watson Lake	993	235	70	65	11.4
Whitehorse	19157	4450	2870	1085	9.5

Table 5.1c) Statistics Canada Census Information (1996 Census)
Labour Market Data for Communities in northern Newfoundland

Hamlet, Town, City or Village	Population	Persons with trades or non-university certificate or diploma	Persons who have completed university	Persons in manufacturing and construction industries	Unemployment rate (%)
Hebron (and surroundings)	386	25	15	0	10
Hopedale	591	60	30	10	28.6
Nain	996	130	40	30	22.4

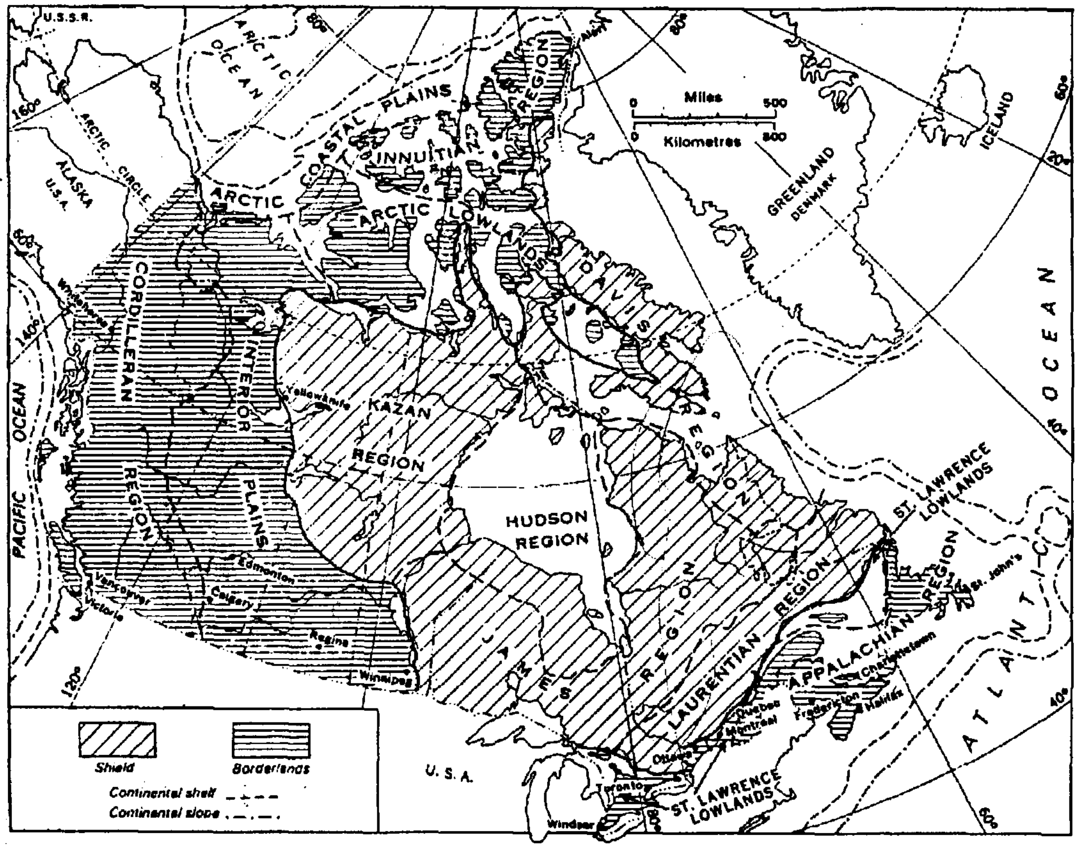
Table 6.1 Comparison of the anticipated lifespan and lifecycle costs of the various foundation options

	Lifespan	Cost		
System		**Materials**	**Labour**	**Maintenance**
Pads and wedges	5	1	1	5
Screwjacks	3	1	1	3
Pad and Post	5	1	2	5
Spaceframe	2	4	2	2
Footings	1	2	4	1
Piles	1	5	5	1

- Rating system:
  Lifespan: 1 – most favourable (>25 years)
  5 - least favourable (<15 years)

  Costs: 1 – least expensive
  2 – most expensive

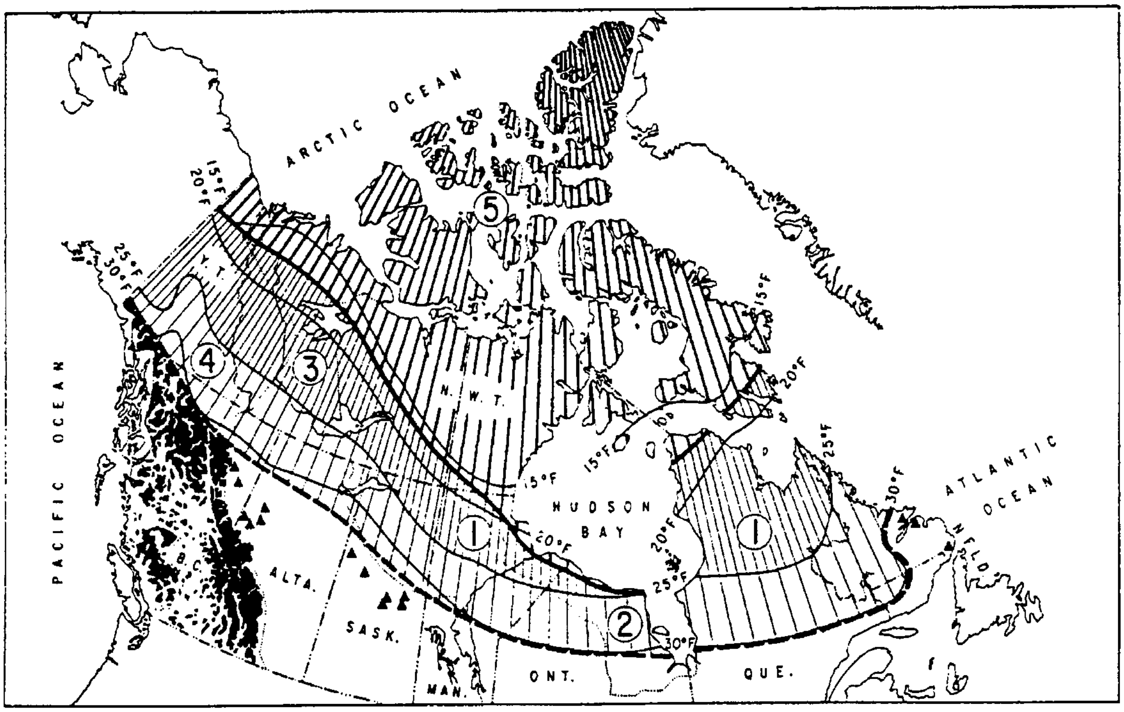
FIGURES



GEOLOGY OF CANADA
(BOSTOCK, 1970)

YX00584

FIGURE 2.1



after Brown 1970

LEGEND

PERMAFROST

- CONTINUOUS PERMAFROST ZONE
- SOUTHERN LIMIT OF CONTINUOUS PERMAFROST ZONE

DISCONTINUOUS PERMAFROST ZONE

- WIDESPREAD PERMAFROST
- SOUTHERN FRINGE OF PERMAFROST REGION
- SOUTHERN LIMIT OF PERMAFROST
- PATCHES OF PERMAFROST OBSERVED IN PEAT BOGS SOUTH OF PERMAFROST LIMIT
- PERMAFROST AREAS AT HIGH ALTITUDE IN CORDILLERA SOUTH OF PERMAFROST LIMIT

CLIMATE

- MEAN ANNUAL AIR TEMPERATURE, °F

PHYSIOGRAPHIC REGIONS

- BOUNDARY OF REGIONS
- 1 PRECAMBRIAN SHIELD
- 2 HUDSON BAY LOWLAND
- 3 INTERIOR PLAINS
- 4 CORDILLERA
- 5 ARCTIC ARCHIPELAGO

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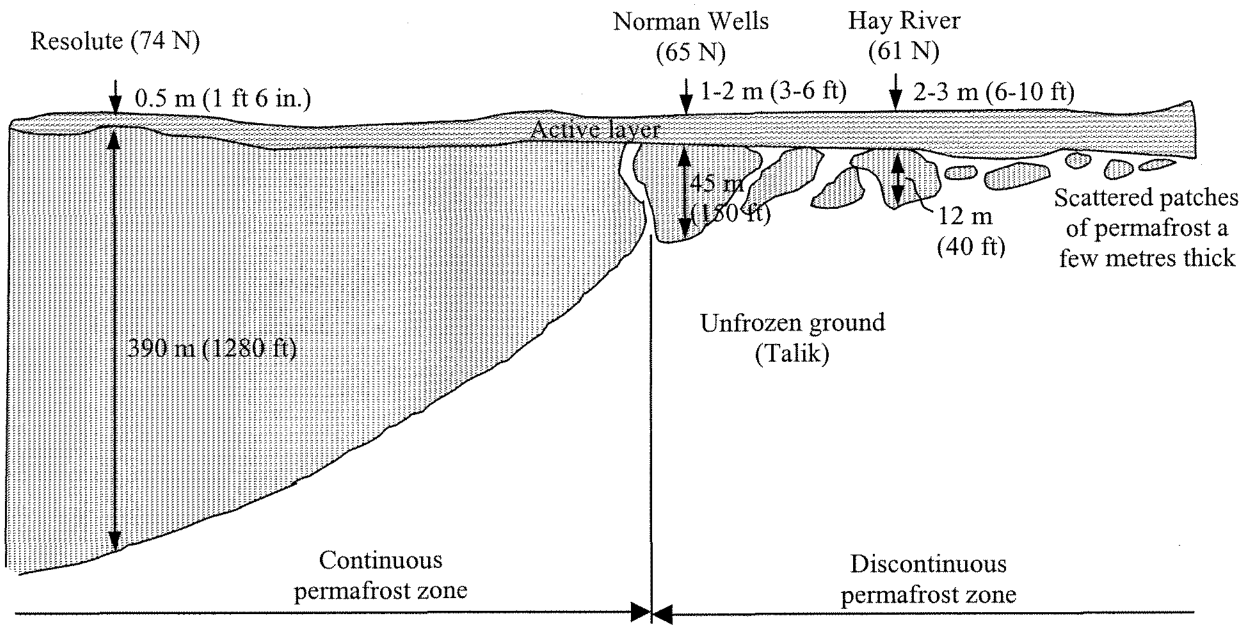
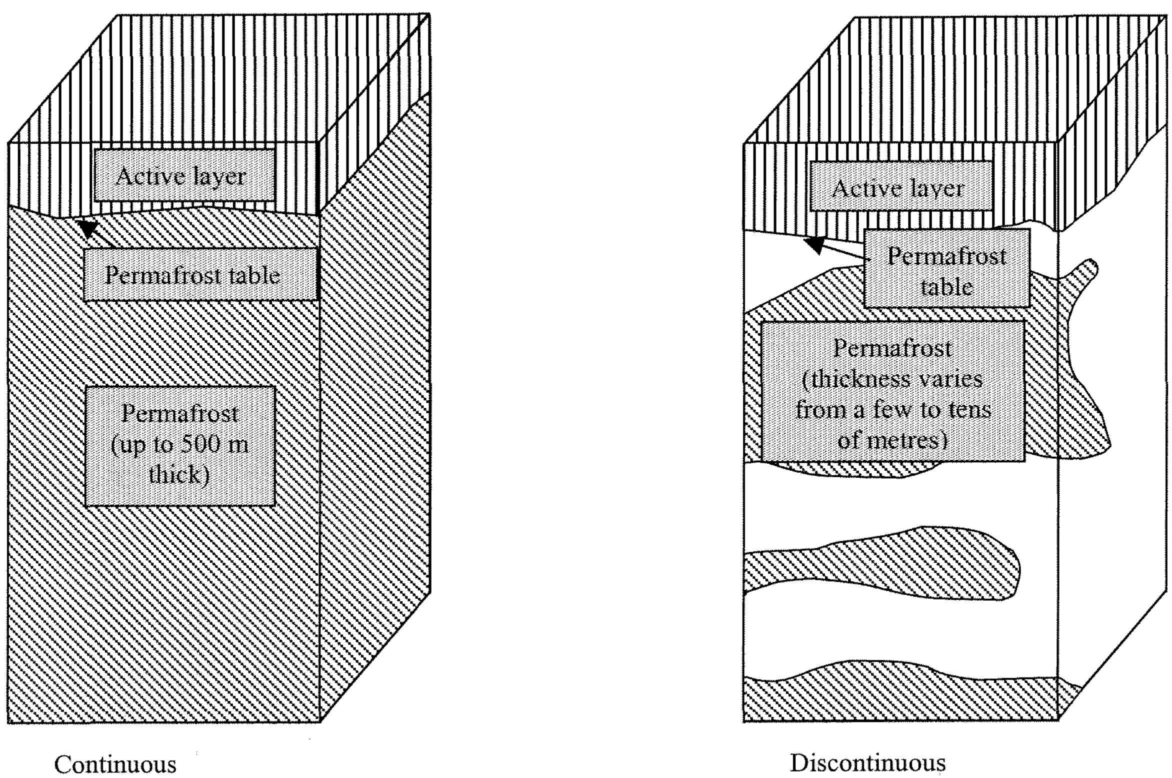
PERMAFROST DISTRIBUTION IN
CANADA
(FROM BROWN, 1970)

YX00584

FIGURE 3.1





b) Typical profiles in permafrost region

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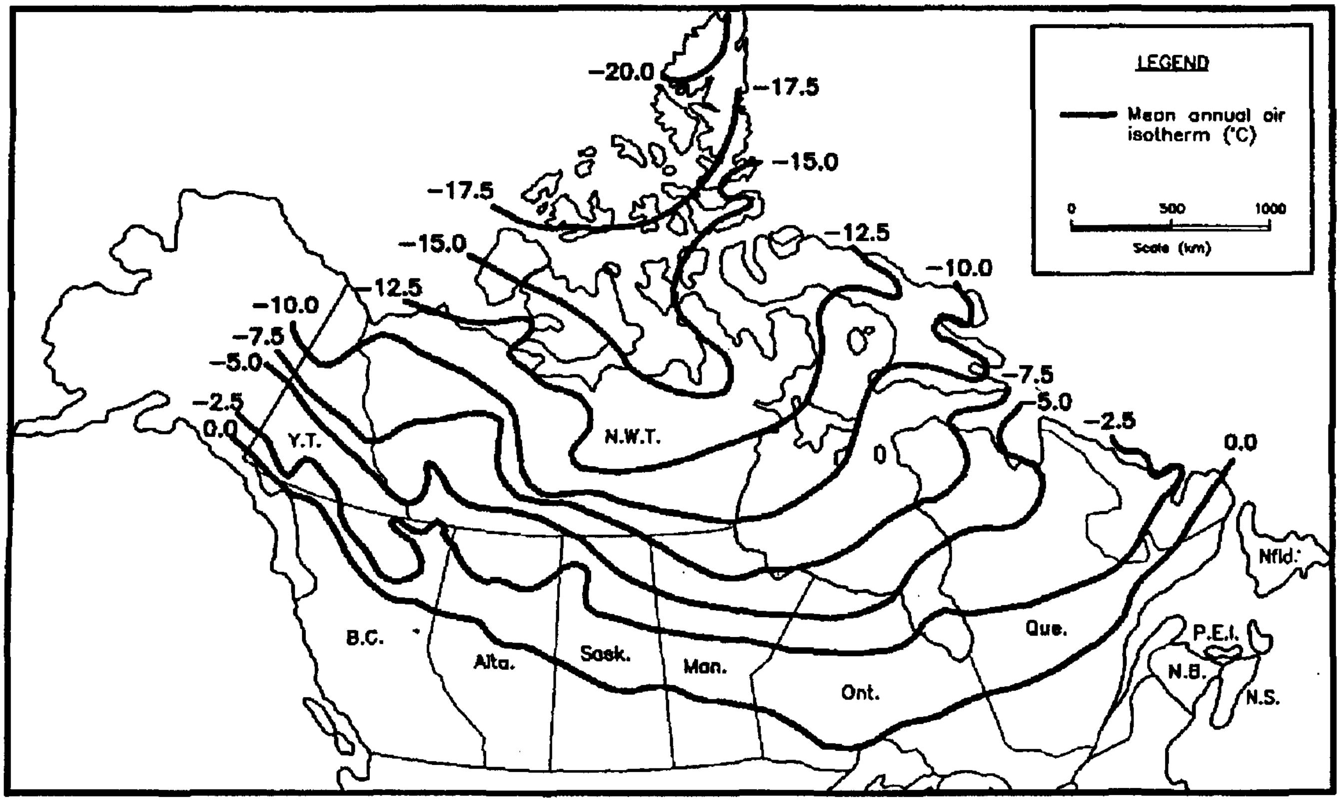
CONTINUOUS AND DISCONTINUOUS PERMAFROST
(after Brown and Johnston, 1964)

YX00584

FIGURE 3.2



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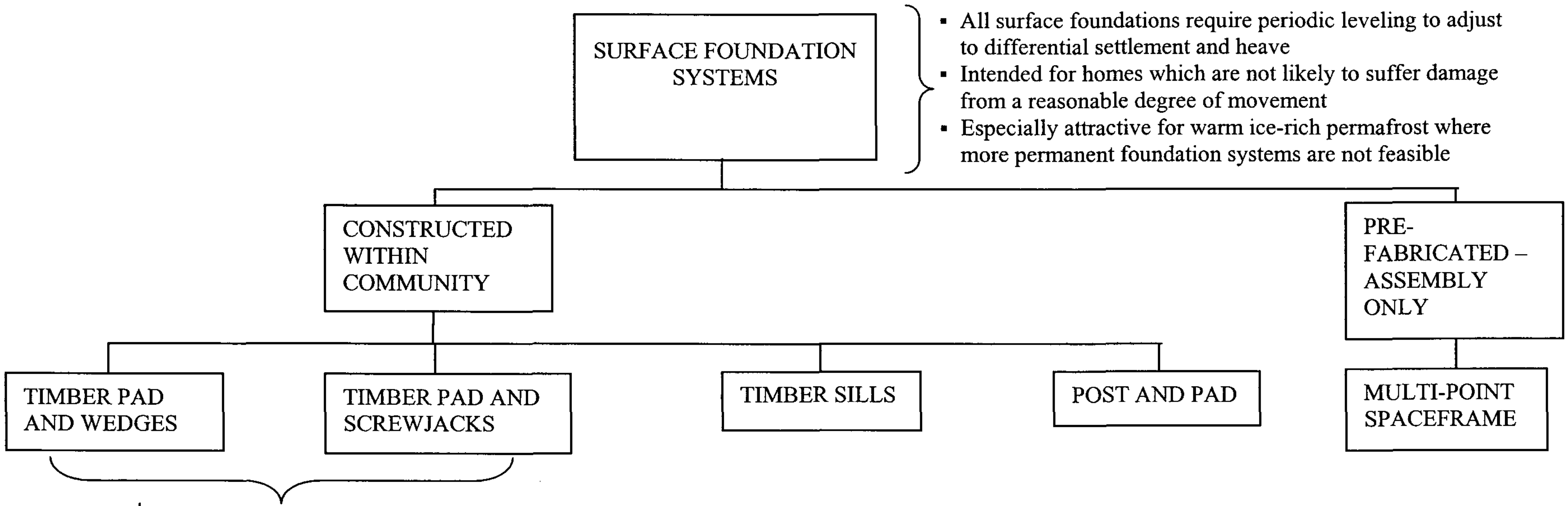
**MEAN ANNUAL AIR TEMPERATURE (°C)-
BASED ON PERIOD 1931-1960
(FROM JOHNSTON, 1981)**

YX00584

FIGURE 3.3



ADVANTAGES:	▪ Easy to construct ▪ Requires no specialized labour or heavy equipment ▪ Initial cost is low ▪ Screwjacks facilitate easier adjustment	▪ Easy to construct ▪ Requires no specialized labour or heavy equipment ▪ Inexpensive	▪ Easy to construct ▪ Requires no specialized labour or heavy equipment ▪ Inexpensive ▪ May be constructed of one or a combination of timber, steel or concrete	▪ Requires no specialized labour ▪ Good for retrofitting ▪ No heavy machinery required ▪ Minimal site preparation required
DISADVANTAGES:	▪ If not properly anchored, buildings may be blown off foundations during strong winds ▪ Shortened lifespan of structure due to movements	▪ shortened lifespan of structure due to movements ▪ If not properly anchored, buildings may be blown off foundations during strong winds ▪ Insuffiecient air space to isolate building heat - only feasible in very cold permafrost (<-10°C)	▪ shortened lifespan of structure due to movements ▪ If not properly anchored, buildings may be blown off foundations during strong winds	▪ Relatively high initial cost ▪ Extends lifespan of structure ▪ If not properly anchored, buildings may be blown off foundations during strong winds

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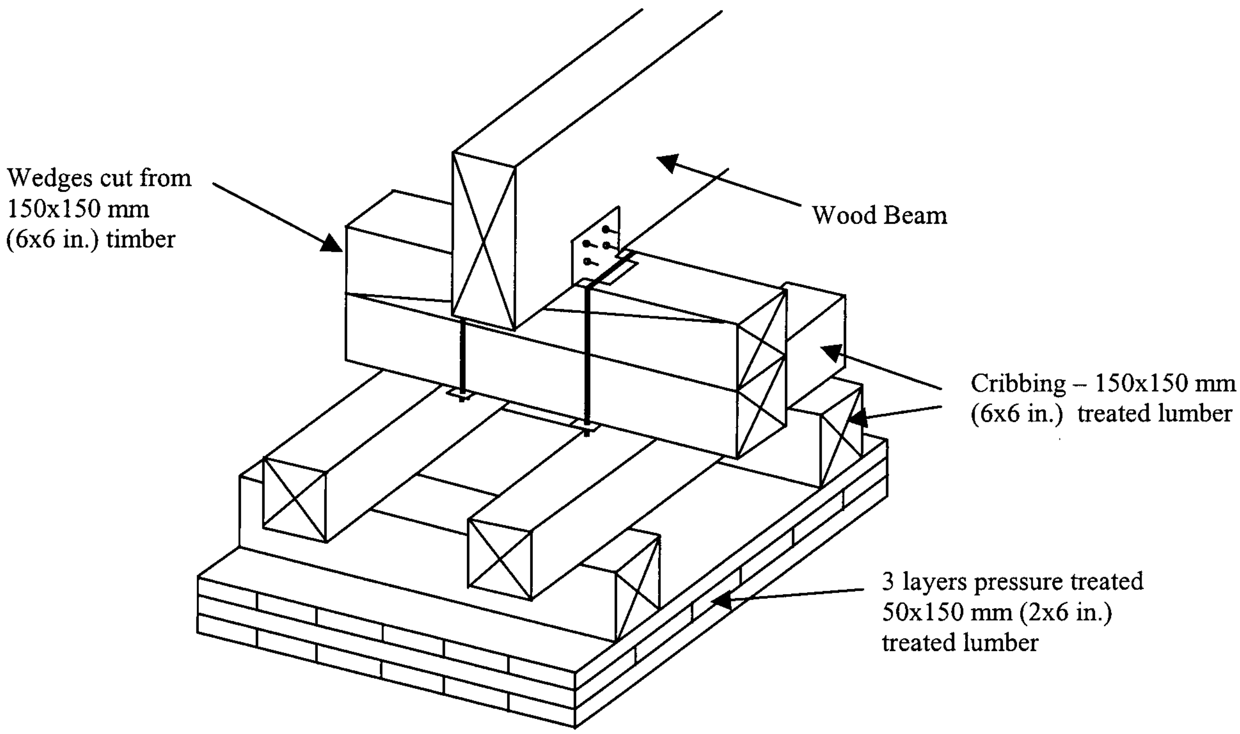
SURFACE FOUNDATION OPTIONS

YX00584

FIGURE 6.1



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WOODEN PAD AND WEDGE SYSTEM

YX00584

FIGURE 6.2

a) Kimmirut

b) Norman Wells

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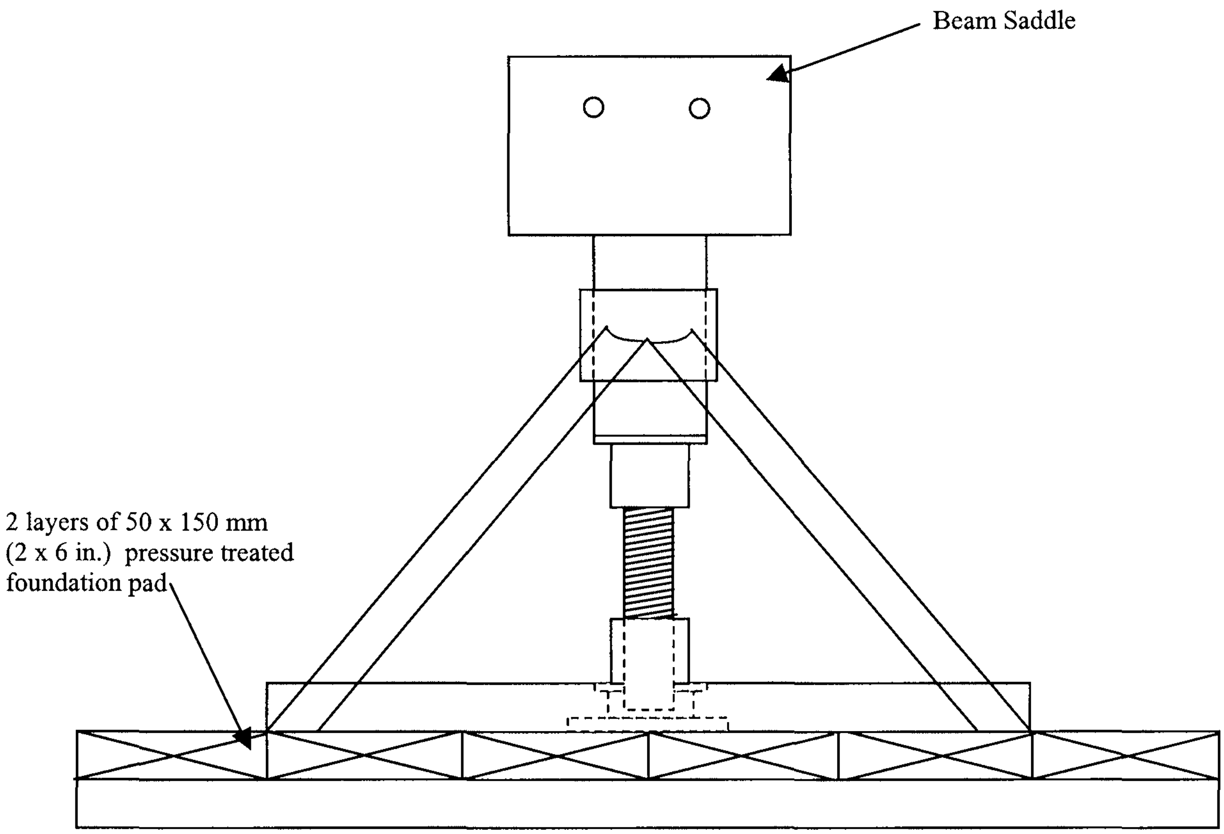
TYPICAL PAD AND
WEDGE FOUNDATIONS

YX00584

FIGURE 6.3



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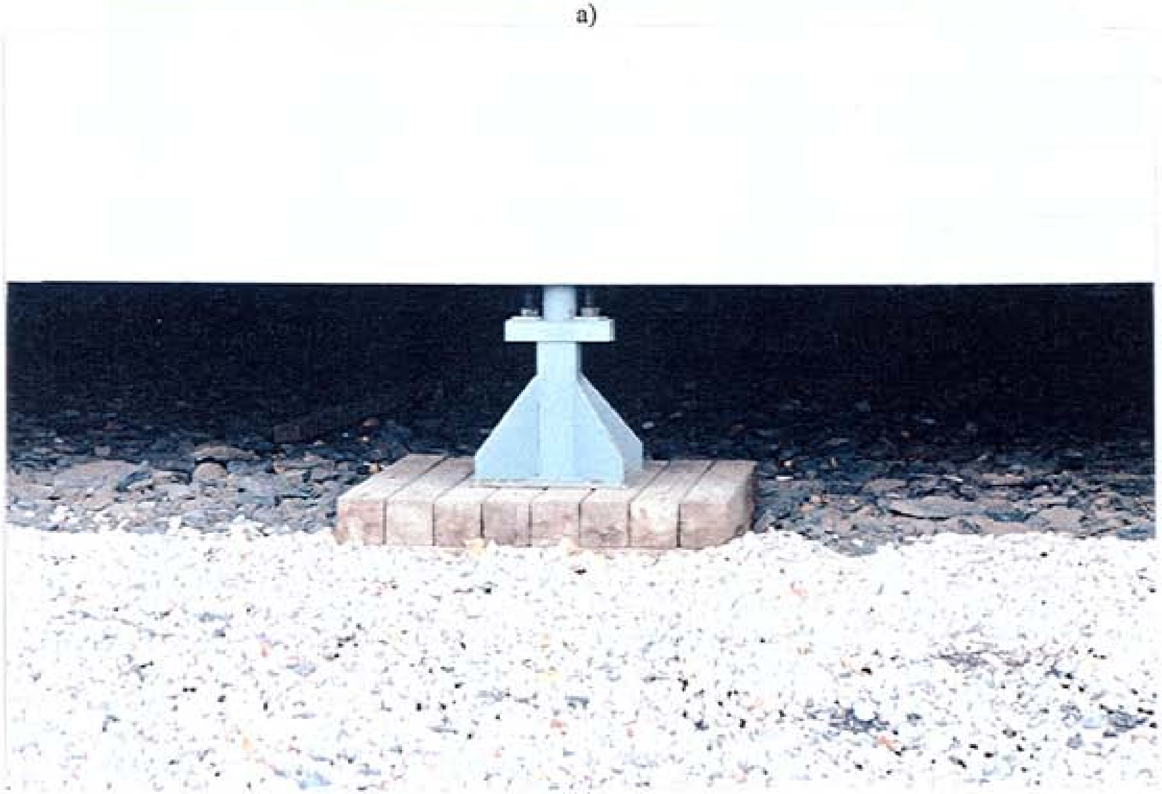
FOUNDATION SCREW JACK

YX00584

FIGURE 6.4

a)



b)

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PAD AND SCREWJACK
FOUNDATION
(Norman Wells)

YX00584

FIGURE 6.5a) and b)

c)

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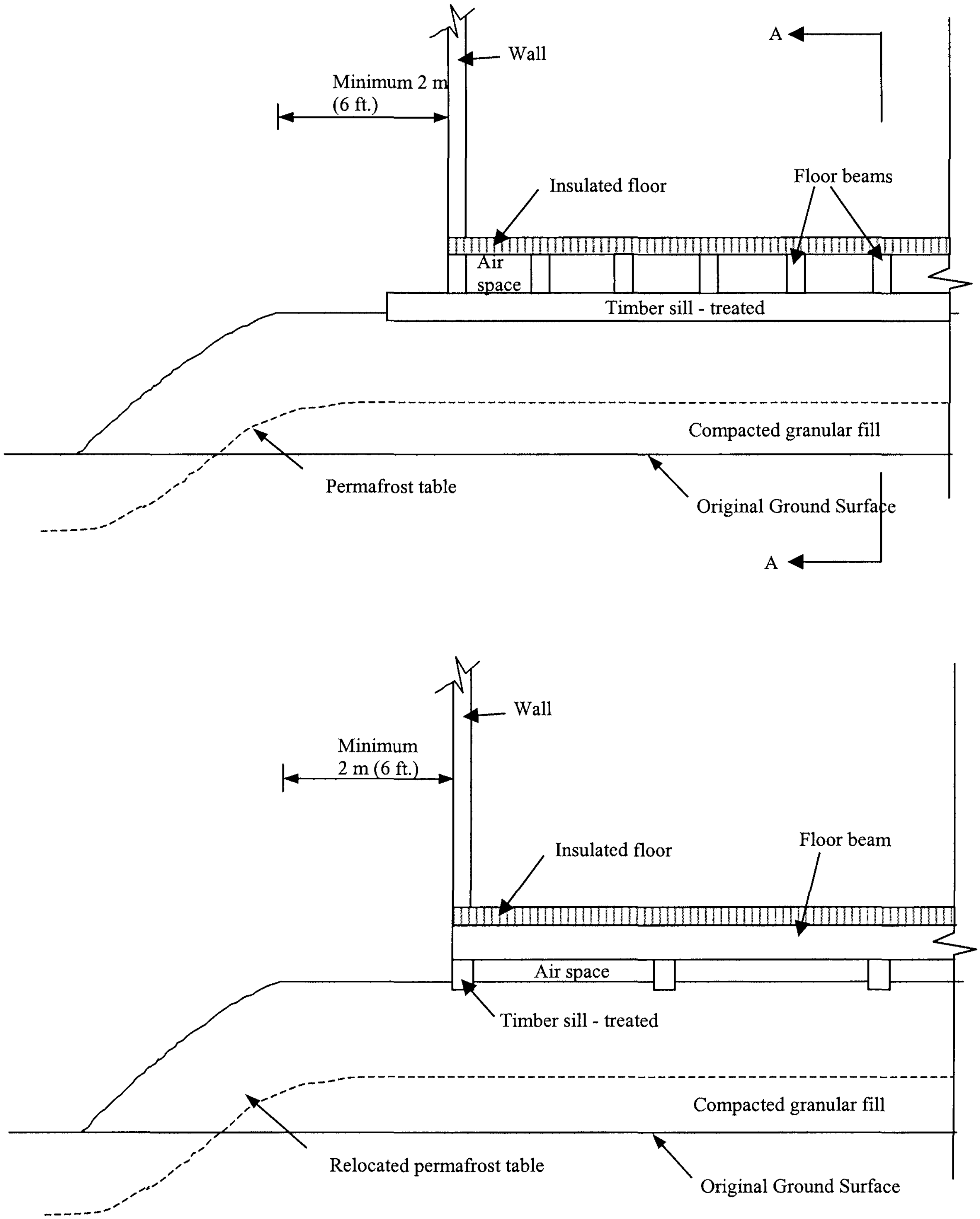
PAD AND SCREWJACK
FOUNDATION
(Fort Rae)

YX00584

FIGURE 6.5c)



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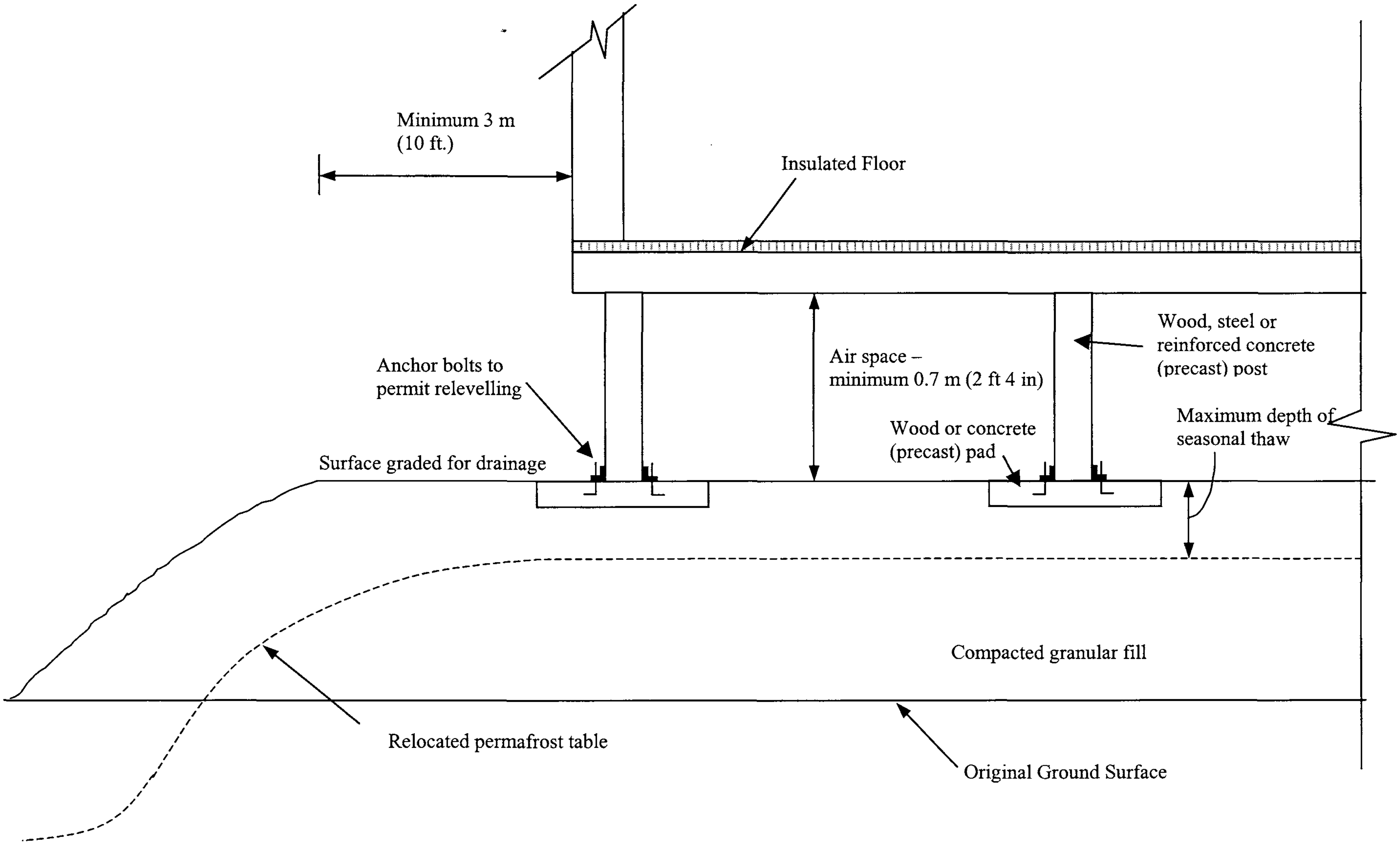
TYPICAL TIMBER SILL SURFACE FOUNDATIONS
(After Johnston, 1981)

YX00584

FIGURE 6.6



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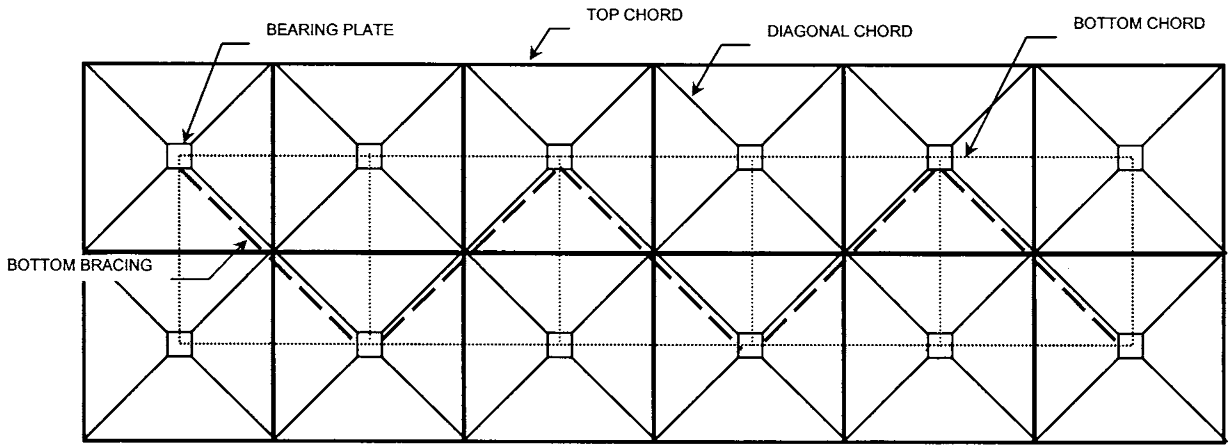
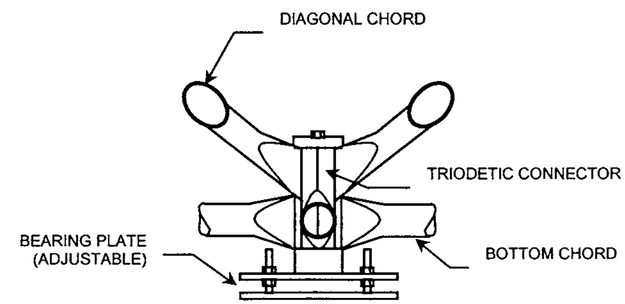
TYPICAL PAD AND POST SURFACE FOUNDATION

YX00584

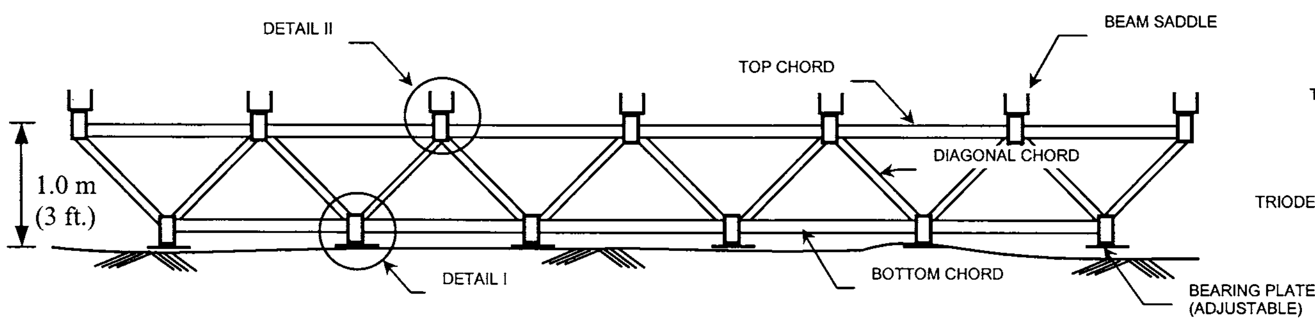
FIGURE 6.7



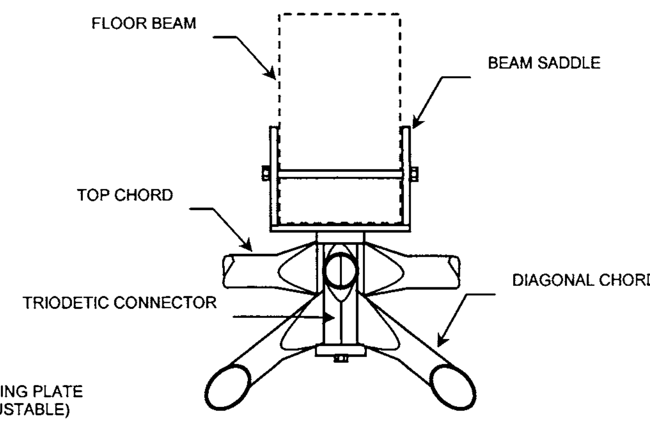
PLAN VIEW



DETAIL I



ELEVATION



DETAIL II

AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

SPACEFRAME SYSTEM
(after Triodetic Building Products)

YX00584

FIGURE 6.8

- FOOTINGS IN OR ON PERMAFROST
  - 'WARM' PERMAFROST (>-1°C)
    - THAW STABLE
      - FOUNDED ON ROCK
        - In areas of shallow bedrock (<2 m)
      - FOUNDED ON SOIL
    - THAW UNSTABLE
      - NOT FEASIBLE
        - Will result in the degradation of the permafrost due to the effects of construction disturbance
  - 'COLD' PERMAFROST (<-1°C)
    - FOUNDED ON SOIL
      - Footings constructed at depth of anticipated post-construction permafrost table, with or without insulation
    - FOUNDED ON SOIL
      - Where bedrock is either exposed or relatively shallow

ADVANTAGES

- An adjustable wedge system may be incorporated into the design to allow for periodic leveling of the structure
- Low material costs
- Effectively resists lateral loading (if posts are cross-braced)
- Can be constructed using one or a combination of timber, steel and concrete (pre-cast or cast-in-place)
- Bearing surface is below the zone of seasonal heaving and settling

DISADVANTAGES

- Typically requires excavating equipment
- Difficult to schedule timing of construction so as not to degrade permafrost
- In cohesionless soils, walls of excavation may be shallow (i.e. 4H:1V) therefore excavation can be quite large
- Problems with groundwater seepage and sloughing into the excavation (may need pumps)
- Depending on the timing of construction and soil type, the construction period can be up to two years

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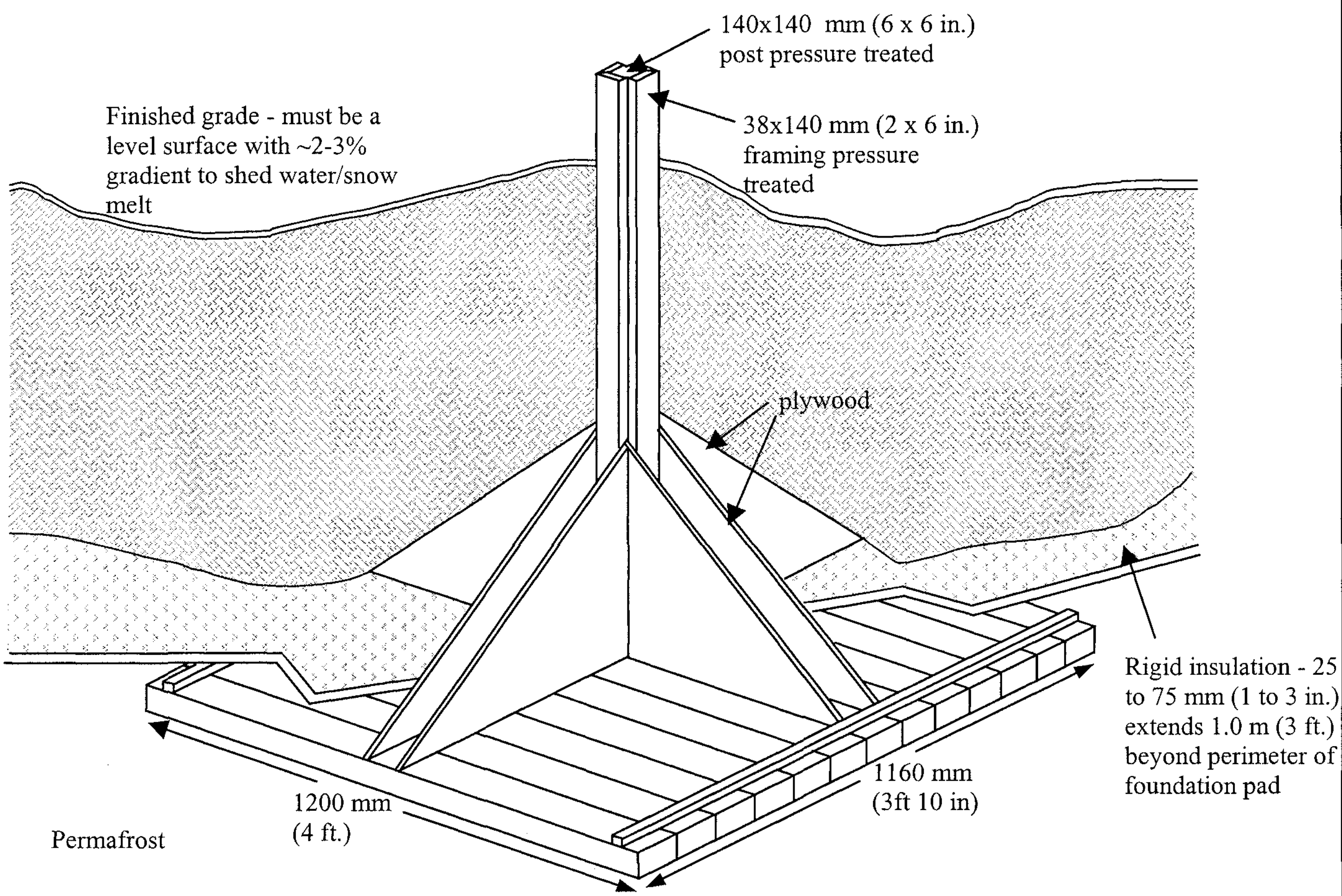
FOOTINGS OPTIONS

YX00584

FIGURE 7.1



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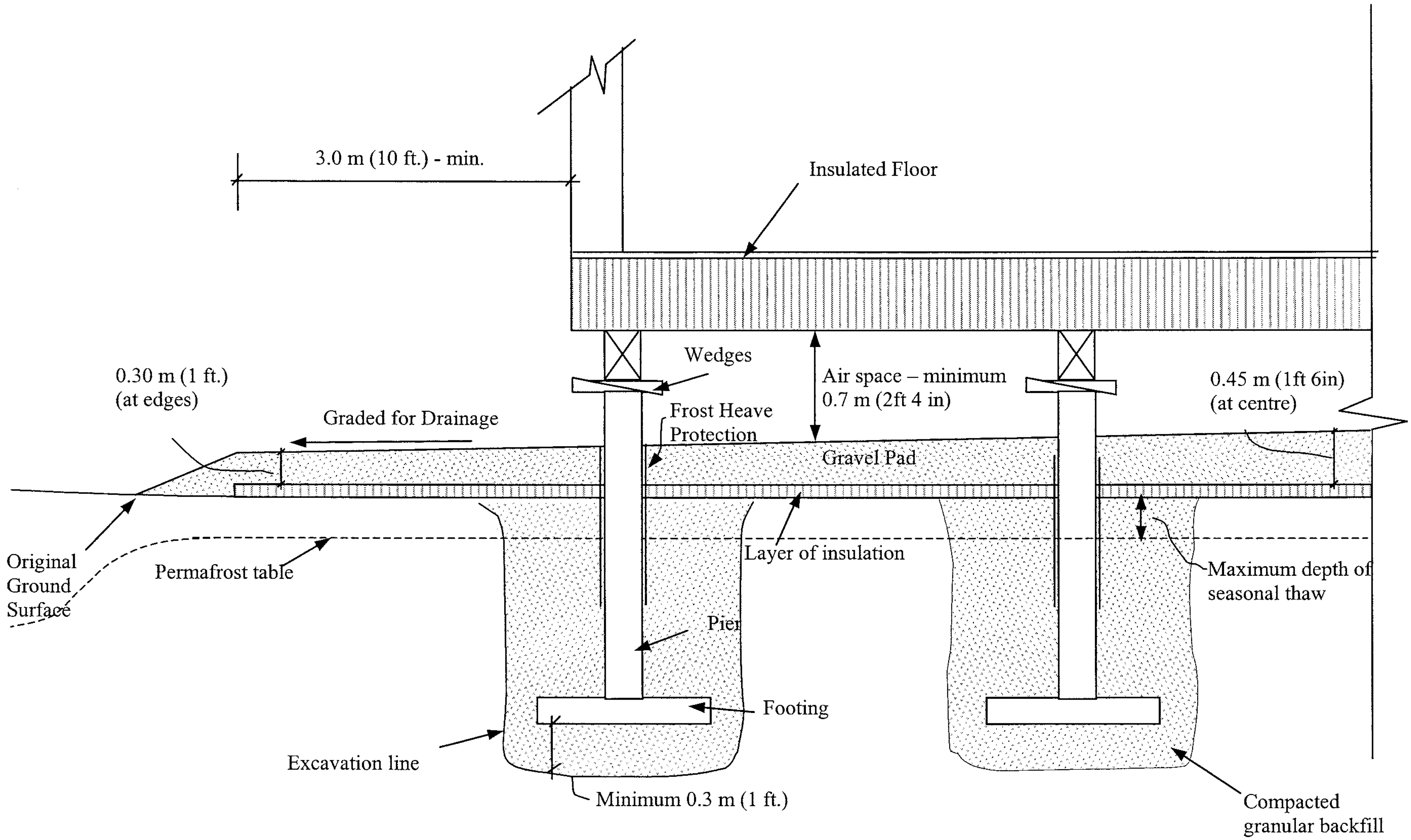
GREENLAND FOUNDATION SYSTEM
(after Genesis Group Ltd.)

YX00584

FIGURE 7.2



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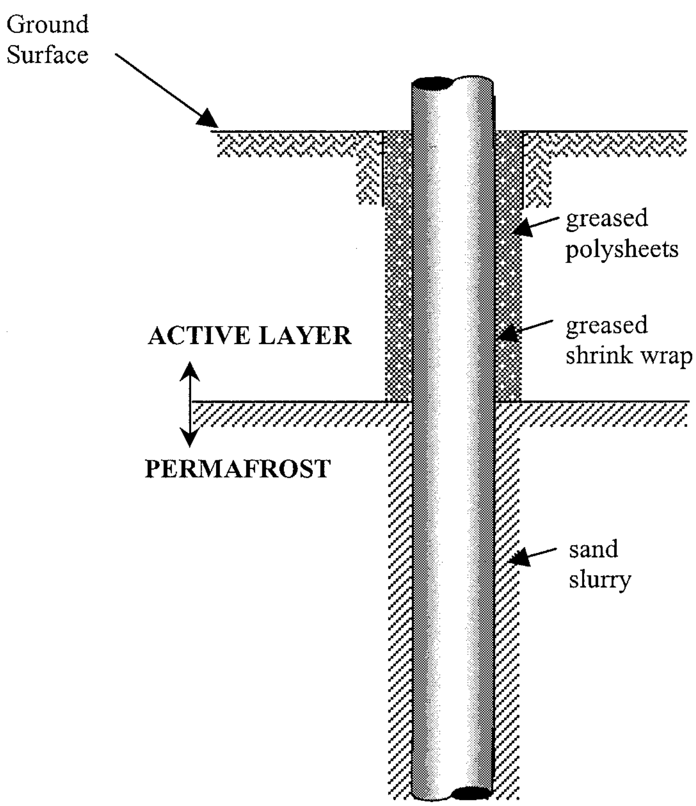
FOOTINGS IN PERMAFROST
(After Johnston, 1981)

YX00584

FIGURE 7.3



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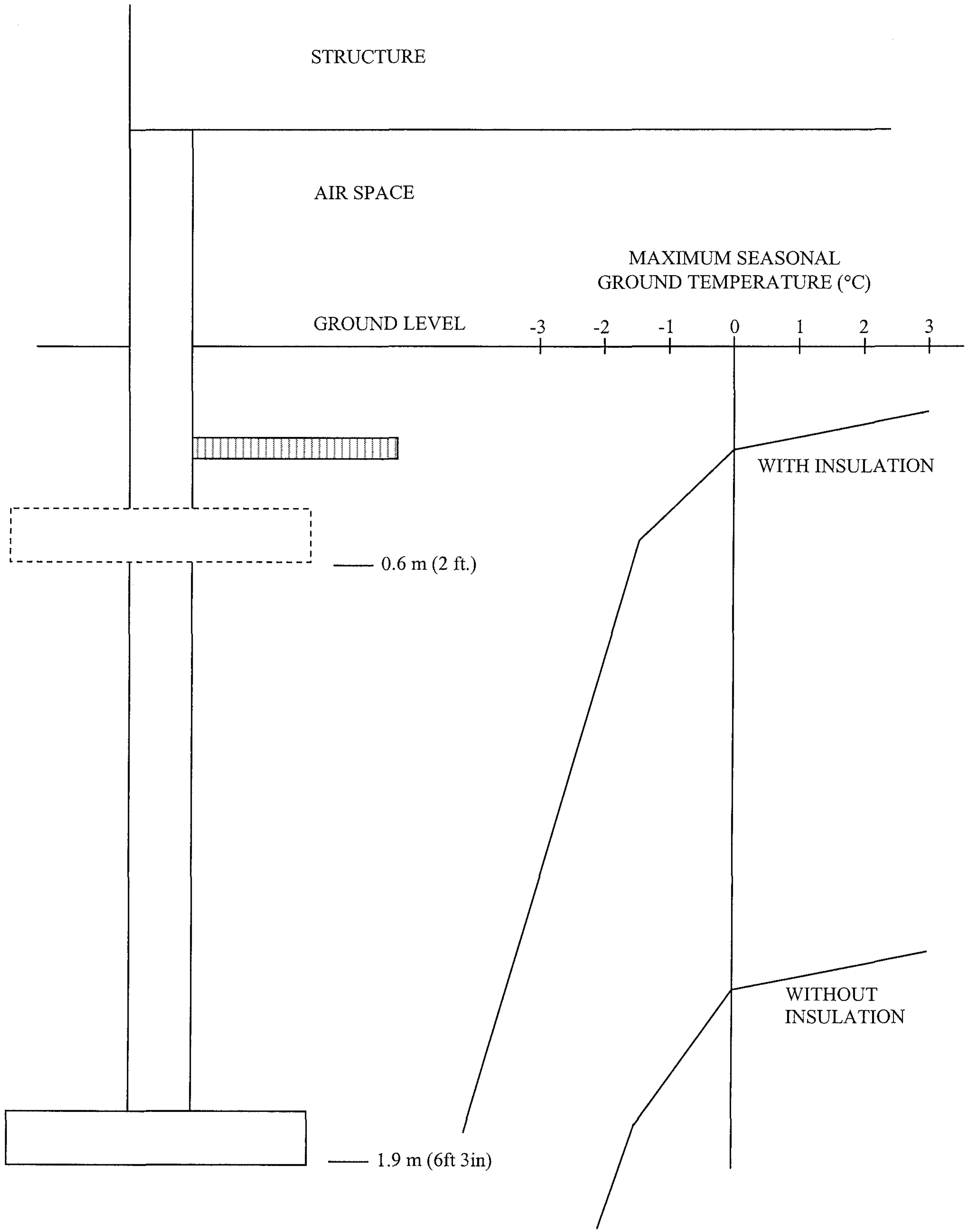
HEAVE ISOLATION

YX00584

FIGURE 7.4



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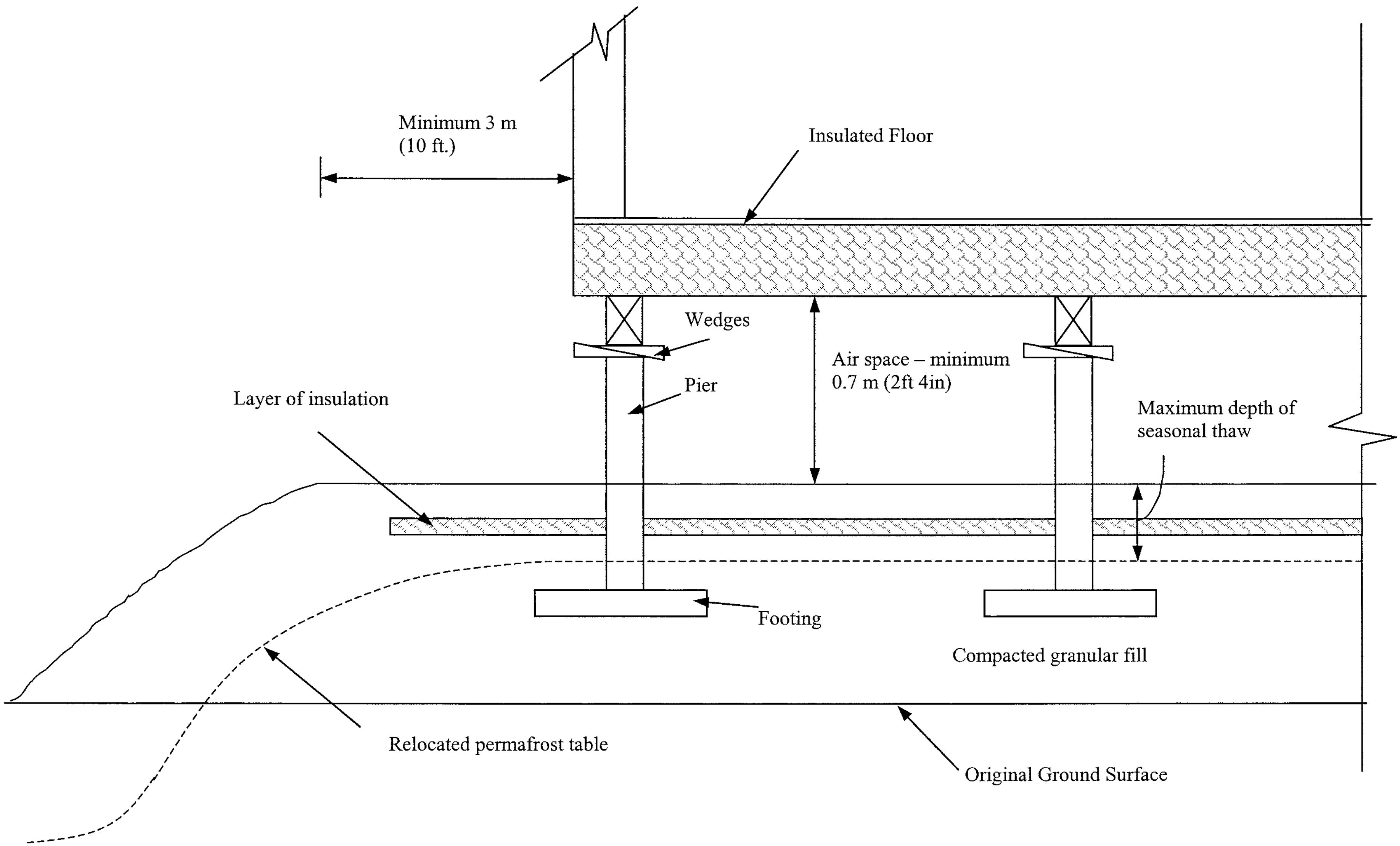
ENGINEERING GLOBAL SOLUTIONS

EFFECT OF INSULATION ON GROUND TEMPERATURE AT FOOTING LEVEL

YX00584

FIGURE 7.5

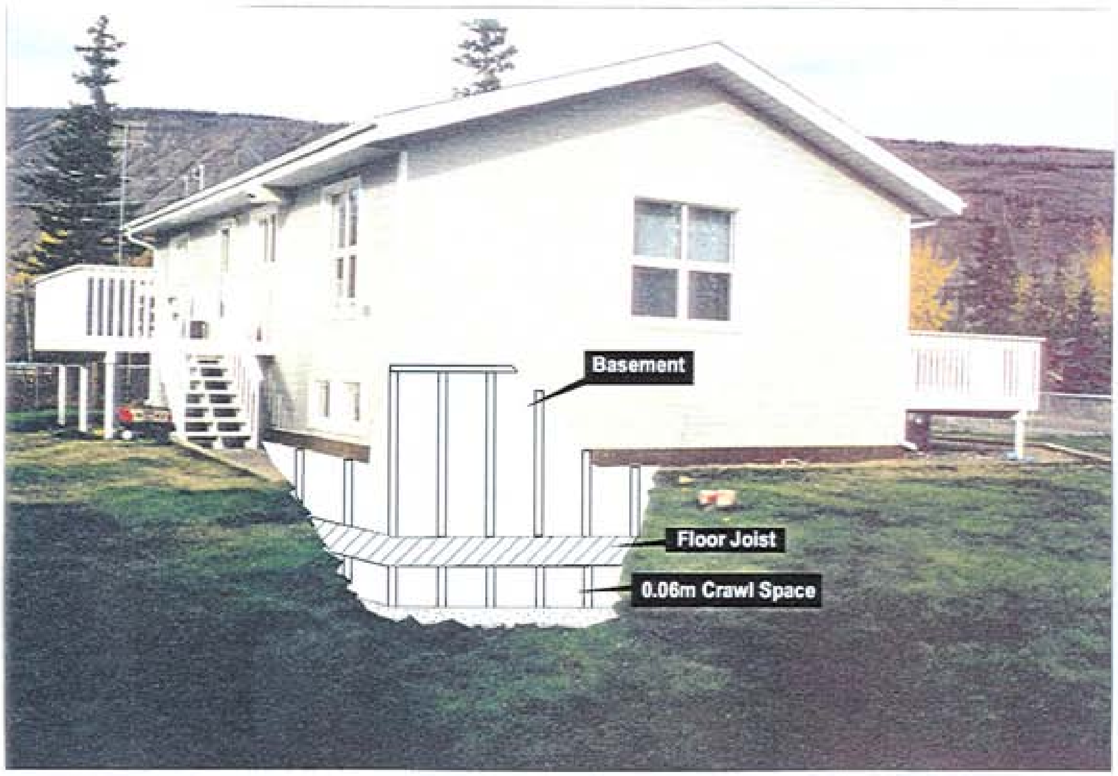


AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

FOOTINGS IN FILL
(After Johnston, 1981)

YX00584

FIGURE 7.6

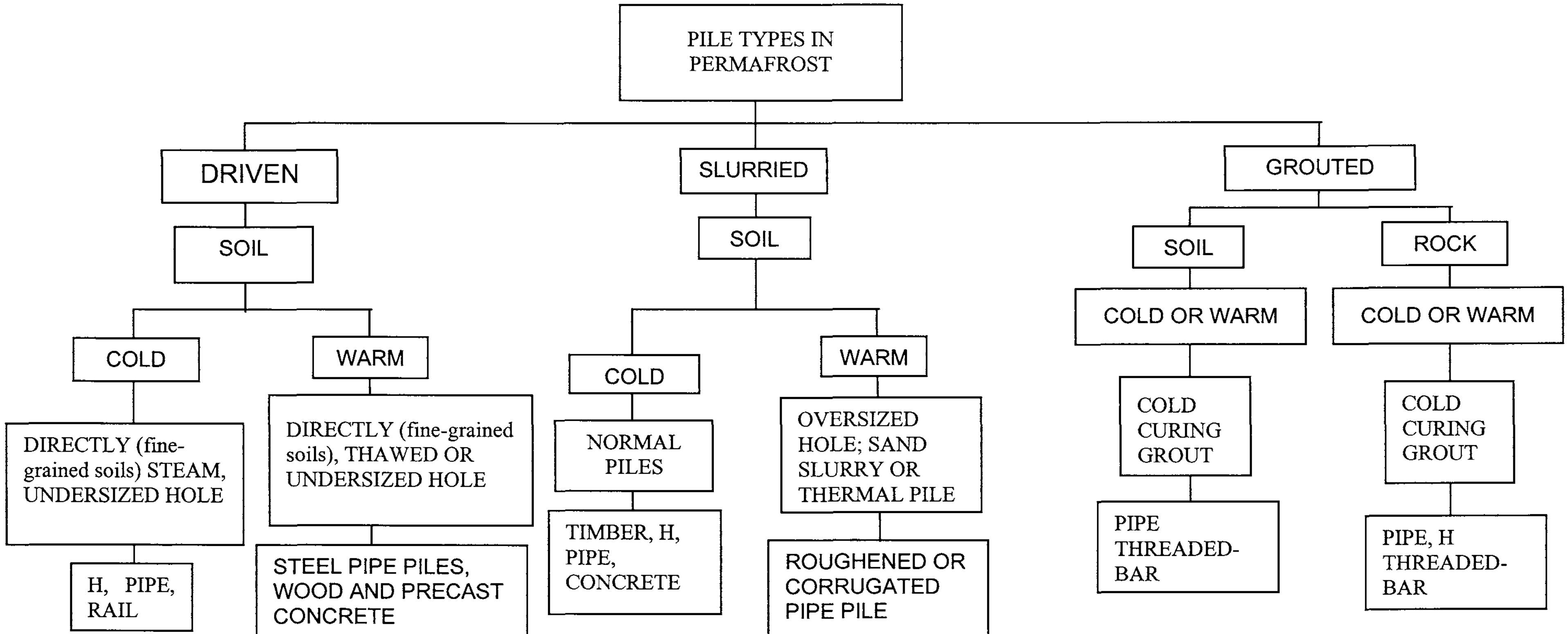


AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

PRESERVED WOOD
FOUNDATION AND
BASEMENT
(Ross River, NWT)

YX00584

FIGURE 8.1



SUITABILITY:

Direct driving ▪ where quick freezeback is required ▪ not for coarse-grained soils ▪ Most efficient in frozen fine-grained soils **Undersize holes** ▪ Expedites pile driving in difficult ground where direct driving may not be possible	▪ Average ground temperature >-1°C ▪ Placement in steamed holes is useful in areas without access to modern drilling and driving techniques	▪ Average ground temperature must be cold (<-1°C) ▪ Depth of active layer is relatively shallow ▪ No end-bearing stratum is encountered at shallow depth	▪ Where average ground temperature is between 0 and -1°C	▪ where a conventional sand slurry pile does not provide adequate strength ▪ not commonly used	▪ Presence of competent end-bearing stratum (ice free bedrock, thaw stable granular strata, or unfrozen till underlying ice-rich deposits) at a depth less than ~12 m

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PILE TYPES IN PERMAFROST

YX00584

FIGURE 9.1

a) Clyde River

b) Kimmirut

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PILE FOUNDATIONS

YX00584

FIGURE 9.2

APPENDIX A

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APPENDIX B

SITE VISITS

LOCATION	DATE VISITED
Kimmirut	March 6, 1999
Clyde River, NT	March 20-23, 1999
Fort Rae	April 16, 1999
Iqaluit, NT	May 4, 1999
Norman Wells, NWT	September 28, 1999
Fort Simpson, NWT	October 1, 1999

Table A.1 Field Visits

APPENDIX C

INTERVIEWS

FOUNDATION DESIGN IN NORTHERN REGIONS

Contact Information: Kevin Hewer
Building Inspector
Yukon Territorial Government
Dawson city
(867) 993-5808

What are the most common foundation systems in use?

DAWSON CITY:

- Discontinuous permafrost

1. Pressure treated pads on a gravel pad (3-4 ft)

- 30″x 30″ pressure treated wood for one story residential structures
- 36″x 36″ pressure treated wood for two story residential structures
- 6″x 6″ timber blocking on top (2 or 3 layers)
- 2″x 10″ floor joist
- open, ventilated crawlspace

Are there any problems with this system?

- Every couple of years, maintenance is needed – hydraulic jack to lift and shim
- Used to have extensive problems with heave and settlement but this has been greatly reduced by the installation of storm drainage reducing surface water
- In 1979, there was a large flood and houses floated away, only held to their land by utilities (levee is now higher to resist 100 yr flood)
- Southern faces of buildings settle more

Have any other foundation systems been tried?

1. Spaceframe on gravel pad

- It appears to work well but is more expensive
- Has limitations on how much movement it can handle – at a certain point, the building will need to be jacked up at the downward end and more fill will be added
- Has concerns about the 6″ diameter pads under the spaceframe (bearing capacity)

What constraints are there to using other systems? (i.e. skilled workers? Excavating and drilling equipment? Fill)

None of these constraints exist. Contractors have appropriate equipment and fill is not an issue in the Yukon.

What are the typical costs for the construction of both the pad/wedge system and the spaceframe?

1. Spaceframe – $10000 for the spaceframe and delivery to the Yukon
   $2-3000 for installation
2. Pad/Wedge - $4-5000

FOUNDATION DESIGN IN NORTHERN REGIONS

Contact Information: Allyn Lyon
Yukon Housing Corporation
(867) 667-3773

What are the most common foundation systems in use?

OLD CROW

1. Pressure treated pads on a gravel pad (3-4 ft)

2. Spaceframe

WHITEHORSE

1. Strip footings

   - 70% of newer construction (last 10-15 years) has full basements. Before that, no machinery and therefore less full basements

MAYO

- Problems with frost lensing
- Not much organic soil

1. Strip Footings

- since there isn't much organic soil, strip footings are pretty much built on grade with a perimeter wall and an interior wall

2. Spaceframe

- Many of the structures supported on strip footings have had serious differential settlement problems and are currently being retrofitted with spaceframe

DAWSON CITY

- 50 homes recently retrofitted with spaceframes

What are the advantages of the spaceframe?

- Impressed with the performance of the spaceframe
- It can go for longer without having to be adjusted
- If other methods aren't adjusted once a year, they jack apart
- Easy to put together

- Lifespan of a home on a gravel pad with strip footings is on the order of 20 – 30 years until it begins to 'jack apart' – Lifespan of a home supported on a spaceframe is on the order of 70-80 years (typical of quality wood construction).

What constraints are there to using other systems? (i.e. skilled workers? Excavating and drilling equipment? Fill)

Many of the smaller communities have no or few experienced and skilled workers. Drilling equipment must be mobilized from Whitehorse or Inuvik. Lots of fill in the Yukon.

What are the typical costs for the construction of both the pad/wedge system and the spaceframe?

Spaceframe – $10000 for the spaceframe and delivery to the Yukon
$2-3000 for installation

Foundation Design in Northern Regions

Contact Information: Albert (Foreman)
Fort Good Hope Housing Commission
(867) 598-2290

What are the most common foundation systems used in your community?

Pads and Wedges

- Pressure treated wood pads placed directly on grade
- Pad dimensions are 3ft x 3ft
- 3 layers of 2x6 underlying either 6x8 or 8x8 timber blocking
- 3 ft. gap between the ground and underside of structure

How has this system performed?

- There is significant settlement on newer homes
- After 2 to 3 years, homes tend to stabilize with very little to no settlement

Are there any other types of foundation systems that have been tried?

- Steel piles have been used on some homes in the past but not on many

How have the pile foundations performed?

There are no settlement problems with the piles but they are generally too expensive for most people in the community

What improvements do you think would work but haven't tried?

None

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Doesn't know about the availability of fill, pads are placed directly on grade
- A portable compressor is used for drilling in pile installation (air track)

What is the typical cost for material and construction of the foundations?

- For a 26ft x 80 ft home (780 ft^2), pad and wedge system costs approximately $5200
- Not able to estimate cost of pile foundation

Foundation Design in Northern Regions

Contact Information: John Penney
Building Inspector
Torngat Regional Housing Association
(709) 896-8126

What are the most common foundation systems used in your community?

Reinforced Concrete Footings

- 90-95% of homes are constructed with reinforced concrete footings on grade
- this foundation system introduced about 10 years ago
- pressure treated knee walls
- furnace in crawl space

How has this system performed?

- This seems to be the only system that works marginally well
- There are relatively large displacements but they are mainly uniform
- Frost heave is always a problem
- Of 29 homes that the Torngat Regional Housing Association built last year, only one is experiencing problems related to foundation movements

Are there any other types of foundation systems that have been tried?

1. Slab-on-grade

- Not been extensively used, too much settlement

2. Concrete Piers

- Piers were installed 12 ft into the ground to get past a muddy layer prevalent in the region
- Significant differential displacement - doors and windows won't open

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Most communities have excavating equipment
- There is no fill material in the region
- Even aggregate for concrete footings must be brought in
- No drilling equipment and the expense of mobilizing drill rigs would be too much to use pile foundations

What is the typical cost for material and construction of the foundations?

- For an 1100 ft^2, the footings would cost approximately $4500

Foundation Design in Northern Regions

Contact Information: Gjoa Haven
Housing Office
(867) 360-6927

What are the most common foundation systems used in your community?

<u>Pads and Screw Jacks</u>

- Rough sawn timber pads (3 x 3ft pad of 2x6)
- Used to be just pads and wedges but screwjacks easier to adjust
- Usually leave in for 1 year before building home

<u>Steel Piles</u>

- Piles generally used on larger homes (2 story)

How have these systems performed?

<u>Pads and Screw Jacks</u>

- Significant settlement takes place in the first year but stabilizes thereafter

<u>Piles</u>

- Work very well

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- CANADRILL has a rig that they move between Spence Bay (Taloyoak) and Gjoa Haven
- The local fill material is very sandy
- Severe erosion problems - sometimes have to go back, jack up the structure and add more fill
- Don't have compactors in most communities and therefore the gravel pad is not compacted according to specifications
- Have trouble with drainage
- The Housing Corporation recently put in new houses but no drainage facilities
- The town had to put in culverts and bill the housing corporation

What is the typical cost for material and construction of the foundations?

- It only takes a day to put in pads and screwjacks but can't estimate the cost

Foundation Design in Northern Regions

Contact Information: Don Jossa
Northwest Territories Housing Corporation
(867) 873-7898

What are the most commonly used foundation system?

Pads and Wedges

- 20 years ago this was the only option

Steel Piles

- Rock-socketed or adfreeze steel piles

Greenland foundations

- There are some Greenland foundations but they are not too common

Strip footings

- In Hay River/Yellowknife, conventional foundations are used (full basements supported on strip footings)

How have these systems performed?

Piles

- Work very well but very expensive
- In Inuvik there are problems with rotting wood piles (steel better). These homes are being retrofitted with spaceframes
- In discontinuous permafrost regions, there is a severe problem with piles jacking up, even with a slip sleeve

Greenland Foundations

- Problems with scheduling so as not to degrade the active layer
- Labour intensive, usually like to install greenland foundations in early spring before the ground gets too soft and problems arise with water and sloughing. In many communities, shipments arrive in late summer so there can be as great as a two year construction period.

Spaceframes

- Appear to work very well
- They are an excellent option where piling is not possible due to discontinuous permafrost
- For retrofitting, spaceframes can be assembled under a jacked up structure

Best Alternatives

- In discontinuous permafrost, spaceframe or other adjustable foundation system
- In continuous permafrost, steel piles

What improvements do you think would work but haven't tried?

The spaceframe seems to have solved the worst problems

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Surface runoff is always a problem
- No site specific geotechnical work done, a 'best guess' is used based on past history in the community
- Although most communities don't have drilling equipment, the NWTHC typically builds homes in groups to minimize the cost of mobilizing a drill rig
- Most communities have access to fill material and have enough heavy equipment to haul the fill. It is mainly pit run gravel compacted using loaded dump trucks
- Aggregate for concrete is not a problem although the gradation is questionable

What is the typical cost for material and construction of the foundations?

- Piling typically costs twice that of a pad/wedge system
- Approximately $1500/pile, most homes require 12 piles ($18000)
- Pads and wedges are constructed within the community, on average it will take a 2 person crew 2 days to install

Foundation Design in Northern Regions

Contact Information: Keith Butler
DIAND
Whitehorse

What are the most commonly used foundation systems?

Whitehorse

- Gravelly, sandy soils
- Generally full basements on strip footings
- 99% are constructed of treated wood

Mayo/Dawson City

- treated wood pads/wedges on a prepared gravel pad
- open ventilated crawl spaces

How have these systems performed?

- In Mayo, results are unpredictable. There are lots of foundation failures where structures have dropped 2-3 ft into the ground (ice lensing) yet in some areas, full basements are possible

- Piles have been used in the past but they squeeze right out of the ground

- Understands that some spaceframes have been used in Mayo and they are performing well

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Obvious constraints in Old Crow (fly-in community)
- Drill rigs can be mobilized
- No problems with fill in all communities

What is the typical cost for material and construction of the foundations?

Doesn't know

Foundation Design in Northern Regions

Contact Information: Holman
Housing Office
(867) 396-4241

What are the most common foundation systems used in your community?

Pads and Screw Jacks

- Used to use timber pads and wedges
- Now use timber pads on gravel with screwjacks, easier to adjust

Steel Piles

- Larger buildings on steel piles

How have these systems performed?

Both systems perform satisfactorily. Piles are much more expensive.

Foundation Design in Northern Regions

Contact Information: Arctic Bay
Housing Office
(867) 439-8833

What are the most common foundation systems used in your community?

<u>Pads and Wedges</u>

- Most homes supported on pads and wedges

<u>Steel Piles</u>

- Newer homes on steel piles

How have these systems performed?

- Both systems work well
- Piles are more expensive but less maintenance

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- CANADRILL has a rig in most communities including Arctic bay. They come in to do the drilling

What is the typical cost for material and construction of the foundations?

Doesn't know.

Foundation Design in Northern Regions

Contact Information: Kugluktuk
Public Works
(867) 982-7255

What are the most common foundation systems used in your community?

Pads and Screw Jacks

Steel Piles

- Generally used in areas of shallow bedrock and where housings budget will allow

How have these systems performed?

Satisfactory

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- CANADRILL has a rig in town
- Lots of fill material left over from runway surfacing
- 2 contractors in town

What is the typical cost for material and construction of the foundations?

?

Foundation Design in Northern Regions

Contact Information:

Steenberg Construction
Iqaluit
(867) 979-6074

What are the most common foundation systems used in your community?

Steel Piles

- drilled steel piles
- elevated structure
- 4-6 ft. into the shallow bedrock in most areas

How have these systems performed?

- Perform well

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- **CANADRILL** has a rig in almost every time

What is the typical cost for material and construction of the foundations?

- Approximately $15000 for a 1000 ft^2 home

Foundation Design in Northern Regions

Contact Information:

Cape Dorset
Public Works
(867) 897-8878

What are the most common foundation systems used in your community?

Pads and Screw Jacks

- Older homes on pads and wedges

Steel Piles

- Drilled steel piles

How have these systems performed?

- Some settlement in the sandy areas
- Most of the region (60%) has relatively shallow bedrock

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Community has air track drill rig

What is the typical cost for material and construction of the foundations?

Doesn't know.

Foundation Design in Northern Regions

Contact Information: Rod Carson
Nunavut Territory Housing Corporation
Cambridge Bay
(867) 983-7297

What are the most common foundation systems used in your community?

Pile Foundations

- Drilled steel piles
- Minimum depth of 8 m

Greenland Foundation

- Typically only need to excavate to 1 foot, then install pad and post.

How have these systems performed?

- Piles work well
- Greenland foundation works well provided there is no high water

Gjoa Haven

- Sandy, erosion problems

Pelly Bay

- Shallow bedrock, few problems

What improvements do you think would work but haven't tried?

Can't think of any

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Mobilize equipment from elsewhere (fly in)
- There is a revolving stockpile in Kugluktuk paid for by the government
- Greenland foundations are typically constructed by workers within the community. The housing corporation may contract this work out to the hamlet.
- The hamlet typically has the heavy equipment needed for excavation, etc.

What is the typical cost for material and construction of the foundations?

- Estimates cost of a piled foundation at $6-10000 dollars for an 1100 ft^2 home

Foundation Design in Northern Regions

Contact Information: Nelson Flynn
Construction Inspector
Newfoundland and Labrador Housing Commission
(709) 896-3988

What are the most common foundation systems used in your community?

<u>Strip footings</u>

- Pressure treated (2 x 6) foundation wall on grade with a reinforced concrete footing
- Footing covered with fill material (for aesthetics)
- Heated crawl space works better than non-heated
- Foundation wall tied into footings by anchor bolts

<u>Piles</u>

How have these systems performed?

- There are settlement problems but strip footings seem to settle uniformly

What improvements do you think would work but haven't tried?

Can't think of any. Quite happy with current design.

What constraints are there to using other systems? (i.e. experienced skilled workers, excavating and drilling equipment, fill?)

- Most communities have excavating equipment
- There is no available fill material, it must be brought in from elsewhere
- Aggregate for footings must be brought in

What is the typical cost for material and construction of the foundations?

- Foundation system costs approximately $8-9000

Foundation Design in Northern Regions

Contact Information: Ed
W & J Construction
Goose Bay
(709) 896-4373

What are the most common foundation systems used in your community?

Strip footings

- Reinforced concrete footing (12 in wide by 8 in deep) on grade
- Footing covered with fill material
- Concrete foundation wall – 4 ft high
- Crawl space normally unheated
- Sometimes wall is constructed to 8 feet for a full basement either with 8 ft concrete wall or 4 ft concrete, 4 ft pressure treated wood
-

How have these systems performed?

- There are settlement problems
- Some minor flooding problems in the crawl space during the spring

What are the permafrost conditions like in Goose Bay?

- Permafrost throughout community
- Sometimes its at 2 feet, sometimes 4 ft.

Foundation Design in Northern Regions

Contact Information: CANADRILL LTD.
Contact: Bronyck
Iqaluit
(867) 979-6031

What type of drilling rigs do they have in the various communities of Nunavut?

- Air track rigs with air rotary heads and down-hole hammers.
- This is typical equipment for permafrost drilling.

For residential construction, what type of pile do they use?

- Typically steel pipe piles with a 4.5" outer diameter.
- If shallow bedrock, then the piles are grouted into the bedrock. If not, then friction piles are used and the void around the pile is filled with sand slurry.

For a typical home (~1000 ft^2) how many piles are generally required?

- This is highly dependent on the type of floor support system used. A heavily built floor system will require less support (i.e piles) than a more modest floor system. The number of supports and their spacing is in accordance with the local building codes.
- For the most average case, 12 to 14 piles are typically used. Usually, two piles support the entry, and the remainder support the structure.

What is the average cost per pile?

- This depends on where the job is, the number of piles, and whether air or water freight is used.
- If the job is at a remote location, air freight and travel costs can be as high as $15000, and depending on the number of piles to be installed or the number of jobs available, the cost per pile can be as low as $700 and as high as $3000.
- For local piling, the typical range is around $500 per pile.

How many workers and man-hours does it take to construct a pile for a residential structure?

- Typically, three men in a crew, and usually takes four hours per pile plus mobilization/demobilization time.
- It may take a longer time if problems during construction occur (e.g. a drill struck in a hole, or a hole caves in).

Foundation Design in Northern Regions

Contact Information:

ENOKHOK CONSTRUCTION.
Contact: Lorrie Serink
Edmonton
(780) 452-5784

What type of drilling rigs do they have in the various communities of Nunavut?

- Air track rigs with air rotary heads and down-hole hammers.
- This is typical equipment for permafrost drilling.
- Maximum diameter of drilled hole is approximately 8″

For a typical home (~1000 ft^2) how many piles are generally required?

- This is highly dependent on the structure and the type of floor support system used.
- Estimates number of piles per home is upwards of 20

What is the average cost per pile?

- When drilling is contracted out, he is typically charged in the range of 1100 to $1500 per pile, depending on conditions and location

For Greenland Foundations, how many are needed per home?

- On average, the same amount of pad and posts are required as per piles (~ 20)

What are the material and labour costs for Greenland Foundations?

- Each footing typically costs approximately $1000 to construct and install
- 50% labour, 50% materials

Foundation Design in Northern Regions

Contact Information: Guy Pemberton
Tundra Drilling Services Ltd.
Inuvik, NWT
(867) 777-4479

What type of pile is generally used for residential construction?

- Used to be timber piles
- Some timber piles that are about 30-40 years old are having problems with rotting
- Timber piles still used for homes but steel piles are definitely becoming more popular
- Usually use 5-6 in. diameter steel pipe pile

For a typical home (~1000 ft^2) how many piles are generally required?

- Generally need approximately 12 piles per home.

What is the average cost per pile?

- Typically $700/pile in and around Inuvik
- In particularly ‘tough’ drilling conditions such as in Tuktoyaktuk, it is usually about $1000/pile

Foundation Design in Northern Regions

Contact Information: Peace Land Drilling
Grand Prairie, Alberta
(780) 538-9875

Have you had any experience with screw pile installation in permafrost?

- **No**
- In more southern regions, screw piles are installed in the winter by predrilling a hole through the depth of permafrost, then screwing it into the competent soils below
- In rock, a small helix is used and the hole is predrilled

Do you think that they could be installed in permafrost?

- Not likely. Even if a ½ inch helix were used, it is likely that the helix would be damaged during installation.
- If installed, they could not be removed
- Testing would first have to be carried out.

Contact Information: Peter Geoffrey
Alberta Anchors
(780) 263-1880

Have you had any experience with screw pile installation in permafrost?

No, haven't heard of any permafrost applications.

Do you think that they could be installed in permafrost?

- Would like to say yes but am not 100 % sure
- Testing would need to be carried out first
- Screw piles with small helix could be designed for the application
- Can predrill a pilot hole, similar to pile driving in permafrost
- Would need a high torque machine
- They have a 25-35,000 ft lb machine but a higher torque may be required to install in permafrost

APPENDIX D

REGIONAL SOIL CONDITIONS

Table D.1 Ground Conditions in Nunavut and Northwest Territories

LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
TULITA (FORT NORMAN)	Discontinuous	▪ Interbedded layers of clay, silt, sand, and clay till. ▪ Thickness of the peat layer in the undisturbed ground seldom exceeds 300 mm	▪ Generally very high in the soils near the surface (top 2 m) but become much lower with depth	Experience suggests rapid degradation of permafrost upon removal of organic surface cover.	
DELINE (FORT FRANKLIN)	Discontinuous ▪ In undisturbed regions, active layer seldom exceeds 400 mm	▪ Peat (average 0.3 m), sand (gravelly, ~1m), clay till, fluvial sand and clay shale	▪ Visible ice seldom observed in clay shale although ice lenses over 25 mm thick have been found		
FORT MCPHERSON	Continuous (depth~100 m) Mean Annual Ground Temp -1.5°C at 7 m	▪ Peat, clayey silt or silty clay overlying soft shale bedrock. ▪ depth to the surface of the shale seldom exceeds 4 m and is often less than 2 meters	▪ Excess ice is almost always found in the surficial soils and clear ice lenses are very often found within the shale		
TSIIGEHTCHIC (ARCTIC RED RIVER)	Continuous (depth~100 m)	▪ Silt and clay, shale encountered below a depth of 10 m.	▪ Ice wedges are present	▪ thawing of ground invariable leads to settlement	
AKLAVIK	Continuous ▪ active layer 0.3 to 0.6 m	▪ Deltaic fine sands, silts and clays ▪ absolute absence of coarser particles ▪ depth to bedrock not known	▪ Ice contents up to 6 times the volume of the soil ▪ Ice lenses of 19 mm in thickness have been observed	▪ severe permafrost problems ▪ transport rig from Inuvik by barge.	▪ adfreeze pipe piles or insulated spread footings
TUKTOYAKTUK	Continuous ▪ depth > 300 m ▪ active layer less than 1 m	▪ Underlain by sands of glaciofluvial origin ▪ may be overlain by up to 2 m of gravelly till ▪ surface covered by 0.5 m of peat in drained areas – 3 m thick in poorly drained areas		▪ patterned ground (polygons) and pingos are common (severe frost action)	

* information in this table has been generalized from available geotechnical investigations in the various communities and discussions with community representatives. The information listed is not representative of the ground conditions throughout the entire community.

LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
PAULATUK	Continuous ▪ depth > 300 m ▪ encountered at approx. 1 m ▪ within the settlement, the permafrost table is at a depth of 1.2 m where free water is usually encountered	Almost entirely composed of gravel and sand			
KUGLUKTUK (COPPERMINE)	Continuous ▪ depth > 300 m ▪ Ground typically thaws to 1.5 m.	▪ bedrock exposures are common. ▪ Around the settlement, bedrock consists of dolerite but to the south, it is shale, sandstone, siltstone and argillite. ▪ Surficial deposits are talus and deltaic sand			
SACHS HARBOUR	Continuous ▪ Depth > 450 m	▪ Shallow soils consist of clayey, sandy, gravelly till containing cobbles and boulders.			
HOLMAN ISLAND	Continuous ▪ depth > 300 m Mean Annual Ground Temp -9°C	▪ Mainly sand and silt with some gravel ▪ rock outcrops are reported on the east side and north of the settlement			
CAMBRIDGE BAY	Continuous ▪ depth > 300 m	▪ Sandy clay till with some gravel and occasional boulders - referred to as boulder clay		▪ patterned ground (polygons) are widespread	

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
FORT GOOD HOPE	▪ on border between continuous and discontinuous <u>Mean Annual Ground Temp</u> -1°C at 7 m	▪ Sands and gravels ▪ may be underlain by clay till with occasional boulders at depths as shallow as 0.5 m (southeast side of community)		▪ groundwater seepage ▪ excavation for footings may result in degradation of permafrost resulting in long freeze back time and settlement.	▪ suitable for pipe piles in augered holes placed 3 x the depth of the anticipated active layer to prevent jacking
IGLOOLIK	▪ continuous ▪ permafrost table at 1 – 2 m <u>Mean Annual Ground Temp</u> -9.5°C	▪ Sand and gravel overlying limestone ▪ Depth to limestone is variable but may be as low as 0.45 m	▪ Ice observed most notably in upper 2 m (AGRA, 1994)	▪ have CANADRILL rig ▪ soil has high salinity ▪ groundwater flow at 1-2m depth ▪ excavation for footings difficult due to gw and boulders ▪ large excavations required due to cohesionless soils ▪ common foundations: spread footings on gravel pad, wooden blocks on gravel pad	▪ steel pile grouted into sound bedrock
INUVIK	▪ continuous ▪ Up to 3 m of seasonal thaw <u>Mean Annual Ground Temp</u> -4 to -5°C at 8 m	▪ mainly peat underlain by gravel. ▪ Clay (or clay till) often encountered under the gravel at variable depths			▪ Adfreeze pipe piles or insulated spread footings
REPULSE BAY	▪ Continuous	▪ Poorly graded gravel with sand overlying bedrock.	▪ No excess ice observed in available logs	▪ Same foundation recommendations	▪ Insulated footings (Greenland foundation)

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
	Mean Annual Ground Temp -10°C at 9 m	▪ Bedrock is generally quite shallow (~0-3 m)		as for coral harbour	▪ Rock socketed piles
CORAL HARBOUR	▪ Continuous ▪ active layer approx. 1 – 1.5 m thick. Mean Annual Ground Temp -7°C in gravelly soils -10° in organic deposits (warmer near ocean shoreline and beneath tundra ponds)	▪ Shallow or exposed bedrock ▪ Bedrock may be overlain by silt and sand with a surface layer of organics		▪	▪ Adfreeze piles imbedded to min 6 m ▪ Where depth to bedrock less than 2 m, footings on bedrock. If bedrock deeper, bedrock socketed piles ▪ Insulated spread footings on permafrost. – install in summer, freezeback in winter.
COLVILLE LAKE	▪ Continuous Mean Annual Ground Temp -2°C at 8 m	▪ Peat overlying a fine to medium sand ▪ Clay till encountered below sand	▪ Contains excess ice and is thaw unstable	▪ Depth of seasonal thaw between 0.3 to 1.5 m ▪ Fill situated 1 km south of community	▪ Timber cribbing on insulated gravel pad, insulated spread footings or adfreeze piles.
SANIKILUAQ	▪ Discontinuous Mean Annual Ground Temp -1.5°C in areas of surface vegetation	▪ Shallow bedrock (~<4 m) ▪ Topsoil underlain by silty sand and gravel with a trace of clay	▪ May be ice rich locally	▪ Patterned ground and shallow thermokarst features Common foundations: ▪ Insulated gravel pad with wood cribs and steel pipe piles in predrilled holes. ▪ Steel piles need to be anchored into bedrock to avoid jacking.	▪ Rock socketed or adfreeze steel piles (depending on depth of bedrock)

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
				▪ Hamlet has a backhoe but no drill equipment as of '87	
WHA TI (LAC LA MARTRE)	▪ Discontinuous <u>Mean Annual Ground Temp</u> -1°C from 2 m to bedrock (variable)	▪ Sand/silt underlain by clay	▪ Occasional zones of excess ice	▪ Most homes have a skirted, unheated crawl space and are founded on gravel pads ▪ Soil too warm and unstable to consider footings or piles based in permafrost. As of 1991, ▪ hamlet has front-end loader with fork lift attachment ▪ D-6 Caterpillar tractor ▪ Dump truck ▪ Concrete mixer	▪ Driven steel piles ▪ Surface foundation
IQALUIT	▪ continuous <u>Mean Annual Ground Temp</u> -5°C at 10 m	▪ silty sand and gravels with cobbles ▪ shallow bedrock in areas	▪ low to no excess ice	▪ Depth of seasonal thaw ~ 2 to 2.5 m	▪ Rock socketed or adfreeze steel piles
QIKIQTARJUAQ	▪ Continuous <u>Mean Annual Ground Temp</u> -8°C at 9 m	▪ interbedded layers of fine sand and silt – trace cobbles and boulders	▪ considerable excess ice locally	▪ depth of seasonal thaw ~ 0.5 to 1.5 m groundwater often observed above permafrost table	▪ insulated spread footings or adfreeze piles as for Clyde River
CLYDE RIVER	▪ Continuous ▪ active layer ~ 0.5 to 2.0	▪ Silty, gravelly sand, occasional cobbles and boulders	▪ Excess ice observed in top 3 to 4 m		▪ insulated spread footings

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
	m Mean Annual Ground Temp -5°C				
PANGNIRTUNG	▪ continuous ▪ active layer 1-2 m deep Mean Annual Ground Temp -7.5°C	▪ silty sand with variable amounts of silt and gravel sized materials ▪ occasional coarse grained gravel to boulder sized materials		▪ have CANADRILL rig ▪ firehall on timber sill ▪ new housing built on adfreeze or end-bearing pile foundations and are performing well	▪ adfreeze best option, will resist hurricane forces
POND INLET	▪ continuous Mean Annual Ground Temp -11	▪ sand and gravel, containing some fines and occasional cobbles and boulders. ▪ Sound bedrock exists at relatively shallow depths in certain areas		▪ have CANADRILL rig ▪ insulated spread footings – need backhoe due to cobbles and boulders, pumps required For seepage.	▪ shallow footings and end-bearing piles recommended ▪ Timber or precast placed on thin leveling course on the frozen foundation stratum for footings ▪ Steel piles socketed into sound bedrock
KIMMIRUT	▪ on border ▪ permafrost generally not reported due to shallow bedrock	▪ generally shallow bedrock overlain by sand and gravel		▪ have CANADRILL rig	▪ rock socketed piles
ARVIAT	▪ continuous ▪ depth of seasonal thaw ~ 1-3 m Mean Annual Ground Temp	▪ predominantly sandy till, occasional cobbles and boulders		▪ piled foundations support 2 story structures ▪ small buildings such as older	▪ Preferred are insulated shallow footings and adfreeze piles.

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
	-5°C at 6 m			housing units, are supported on wood pads on ground surfaces ▪ newer houses , such as the five-plex structure on the west side of the community is supported on piles. ▪ Surface footings not recommended due to the fines content in the insitu soils. ▪ The Qitiqliz school is supported on surface footings consisting of steel beams resting on 4x8 treated timbers	
ARCTIC BAY	▪ Continuous ▪ depth to frozen ground 1m <u>Mean Annual Ground Temp</u> -11°C	▪ black shale underlain by limestone ▪ sandy silt to gravelly silt till may overly bedrock ▪ bedrock exposed in many areas ▪ excavated shale bedrock commonly used for fill	▪ high ground ice content	▪ have CANADRILL rig ▪ granular fill sources within 20 km of hamlet ▪ ice wedge polygons observed ▪ many homes on wood cribbing ▪ newer ones on steel pipe piles placed in pre-drilled holes through a rockfill	▪ Surface footings on insulated gravel pad ▪ Adfreeze or rock socketed steel piles

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LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
				base pad to a depth of 5 m	
KIMMIRUT (LAKE HARBOUR)	▪ continuous ▪ frozen ground at 1 m	▪ bedrock derived (till and talus) overburden on bedrock	▪ no significant excess ice	▪ have CANADRILL drill	▪ adfreeze or socketed steel piles
HAY RIVER	▪ discontinuous <u>Mean Annual Ground Temp</u> -0.4 to 4°C at 6 m	▪ soil profile consists of peat, clay, sand, gravel and clay till		▪ free water in gravel	▪ suitable for steel pipe piles
CAPE DORSET	▪ continuous ▪ active layer less than 2.5 m.	▪ predominantly granular soils varying from silt to cobbles/boulders ▪ soils underlain at variable depth by pre-Cambrian granitic rock			▪ spread footings have been used successively ▪ can be constructed on bedrock where bedrock is shallow (use anchors against uplift) ▪ or spread footings on 1m gravel pad ▪ steel pipe piles in pre-drilled holes
NORMAN WELLS	▪ discontinuous	▪ organic soil overlying till			▪ for small buildings (1 story), gravel pad on wood pads ▪ for larger buildings or where periodic leveling is not acceptable, a pile foundations

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Table D.2 Ground Conditions in the Yukon Territory

LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	ICE CONTENT	COMMENTS	FOUNDATION OPTIONS
ROSS RIVER	Discontinuous zone ▪ Ground temperatures marginally below freezing	▪ Alluvial soils comprising silts through gravel sizes, some organics	▪ Ice contents are variable, but generally increasing with depth	▪ Permafrost table may be as deep as 5 m+ ▪ Long term permafrost degradation could induce settlements of 200 mm or more	▪ On-grade pads ▪ Occasional basements (performance not known)
DAWSON CITY	▪ Discontinuous zone but widespread throughout community. ▪ Generally warm permafrost	▪ Alluvial soils, organic fine soils overlying gravel ▪ Bedrock at approximately 6 m	▪ Ice contents are variable, but generally moderate to high	▪ Long term permafrost degradation and thaw settlement is a persistent problem	▪ Piles into bedrock ▪ Traditional wood cribbing with shims ▪ Some spaceframes
MAYO	Discontinuous zone, but widespread throughout community	▪ Alluvial soils	▪ Variable		▪ Pads and cribs ▪ Some spaceframes
WHITEHORSE	Discontinous zone, but very sporadic within the community	▪ Alluvial gravel deposits along river ▪ Lacustrine silts on upper terraces	▪ Low to none		▪ conventional housing foundations with basements
FARO	Discontinuous zone, but widespread permafrost. ▪ Generally warm	▪ Alluvial gravels and sands with Lacustrine silt at higher elevations over bedrock	▪ Variable	▪ Some areas with no permafrost, main south facing slopes	▪ Frost heave of piles can be design issue
OLD CROW	Continuous zone ▪ Ground temperature colder than -3° C	▪ Lacustrine silts with gravel along river channels ▪ Rock outcrops or colluvium outside channels	▪ Variable		▪ Adfreeze piles for larger homes ▪ Some spaceframes used

* information in this table has been generalized from available geotechnical investigations in the various communities and discussions with community representatives. The information listed is not representative of the ground conditions throughout the entire community.

Table D.3 Ground Conditions in northern Labrador

LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	COMMENTS	FOUNDATION OPTIONS
GOOSE BAY-HAPPY VALLEY	▪ Permafrost sporadic throughout community ▪ Lenses may be present at depths of 20 m or more	▪ Thick glacio-fluvial sand deposits with varying amounts of gravel (trace to some) overlying finer materials such as silt or clay tills ▪ Bedrock at depths of 30 m or more	▪ crawl space is kept unheated to protect permafrost ▪ some settlement problems and flooding in the spring	In all communities: ▪ reinforced concrete footing with pressure treated knee walls ▪ Due to limited materials (fill) and equipment, the current foundation system is the most viable option. ▪ Other systems have been tried but none perform as well. ▪ Of 29 homes built by the Torngat Regional Housing Authority last year, only 1 is experiencing any problems related to foundation movements.
NORTH WEST RIVER	Discontinuous zone ▪ permafrost not evident in top few metres	▪ mainly sand ▪ bedrock at depths greater than 20 m	▪ homes normally built on concrete strip footings on grade with a concrete knee wall	
RIGOLET	Discontinuous zone ▪ permafrost not evident in top 5 m	▪ mixture of sand and gravel ▪ bedrock depth variable	▪ homes normally built on concrete strip footings on grade with a concrete knee wall ▪ foundation cracking and movement very common when installed on poorly draining soils. ▪ Site selection is critical ▪ Very few problems with foundations constructed on coarse soils	
MAKKOVIK	Discontinuous zone ▪ permafrost not evident in top 5 m	▪ mixture of sand and silty clay (possible raised beach). ▪ Bedrock present at surface in many locations	▪ homes normally built on concrete strip footings on grade with a concrete knee wall	
POSTVILLE	Discontinuous zone ▪ permafrost not evident in top 5 m	▪ mixture of sand and silty clay (possible raised beach). ▪ Shells present in overburden at elevations 20 m or more above sea level ▪ Bedrock present at surface in many locations	▪ homes normally built on concrete strip footings on grade with a concrete knee wall	

* information in this table has been generalized from available geotechnical investigations in the various communities and discussions with community representatives. The information listed is not representative of the ground conditions throughout the entire community.

LOCATION	PERMAFROST CONDITION /GROUND TEMP.	GENERALIZED SOIL PROFILE	COMMENTS	FOUNDATION OPTIONS
HOPEDALE	Discontinuous zone ▪ permafrost not evident in top few metres	▪ bedrock at surface throughout community ▪ thin pockets of residual soils (sand and gravel) overlying bedrock	▪ homes normally built on concrete strip footings on grade with a concrete knee wall	
SANGO BAY	Discontinuous zone ▪ permafrost not evident in top 5 m	▪ primarily sand	▪ homes normally built on concrete strip footings on grade with a concrete knee wall	
NAIN	Discontinuous zone ▪ permafrost not evident in top 3 m	▪ thick deposits of sand with fines at lower elevations	▪ severe drainage problems associated with thaw and reluctance for water to penetrate underlying frost layers ▪ most common foundation consists of pressure treated knee wall on reinforced concrete footing (on-grade)	

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