Building foundations on permafrost: Mackenzie Valley, N.W.T.
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NATIONAL RESEARCH COUNCIL

CANADA

BUILDING FOUNDATIONS ON PERMAFROST MACKENZIE VALLEY N.W.T.

BY

JOHN A. PIHLAINEN

JUNE 1951

A JOINT CONTRIBUTION FROM THE
DIRECTORATE OF ENGINEER DEVELOPMENT, CANADIAN ARMY
AND THE DIVISION OF BUILDING RESEARCH

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FOREWORD

Permafrost is so important a factor in relation to building in the north of Canada that the Division of Building Research has looked forward to studying it from the earliest days of its work. It seems clear that one of the principal directions in which the work of the Division should progress is in connection with the special building problems which exist in the north of Canada, many of which are intimately associated with the existence of perennially frozen ground throughout much of this vast area.

The Division therefore welcomed the opportunity of arranging, early in the summer of 1950, jointly with the Directorate of Engineer Development of the Canadian Army, a small expedition to the Mackenzie River Valley. This expedition initiated a study of permafrost in this area with special reference to foundations of buildings in settlements along that great river. The Division was particularly glad to be able to share in this further co-operative venture with a branch of the Canadian Army in view of its many close associations with the Department of National Defence.

The expedition was carried out by four young men. One, Captain J. D. Walker, Royal Engineers, was a visitor in Canada from the British Army, with wide experience in the North; he has since returned to England. Two other members of the party were 2nd lieutenants in the Royal Canadian Engineers spending their third vacation from university work on C.O.T.C. duty: 2nd Lieutenant J. D. Bleaney was studying at Queen's University, and 2nd Lieutenant J. N. Greggain was studying at the University of Saskatchewan.

The fourth member of the party was Mr. John A. Pihlainen, now an Assistant Research Officer with the Division of Building Research, who had had previous experience in the north-eastern part of Canada. Since he was the only one of the party to be continuously engaged on this work, it fell on him to prepare the reports regarding the information collected during the expedition.

This report constitutes the main record and has been prepared by Mr. Pihlainen jointly for the Division and the Directorate of Engineer Development (Lt.-Col. C. E. Brown, Director). Not only did the Directorate assist very materially with the organization and planning of the expedition, but various officers in the Directorate have been of great assistance to Mr. Pihlainen in the preparation of this report.

It is therefore in every sense a joint contribution from the Division and the Directorate. It is, of course, only a preliminary statement since it records the observations of one summer only. It is hoped, however, that it will prove of use and that those who examine it will favour the Division with their comments, criticisms, and suggestions for future publications in this important field.

Acknowledgement must also be made of the fact that funds for the transportation requirements of the expedition were provided through the Associate Committee on Soil and Snow Mechanics of the National Research Council. This Committee is concerned with all aspects of research into the terrain of Canada. It is therefore much concerned with permafrost and was glad to assist financially with this pioneer effort.

Ottawa,
June, 1951.

Robert F. Legget,
Director.

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BUILDING FOUNDATIONS ON PERMAFROST; MACKENZIE VALLEY N.W.T.

by

John A. Pihlainen

PART I INTRODUCTION

More than one-half of the total area of Canada may be called "The North". Largely uninhabited but possessing many potential resources, the full impact of its wealth has yet to be felt.

Gold at Yellowknife, oil at Norman Wells, and radium at Great Bear Lake have brought attention to the Mackenzie River Valley. At the time of these discoveries (and even to-day), many prophesied mass migrations to the northlands. Fortunately, these predictions have not come true for the North is not prepared. The coming years will provide a breathing spell during which scientific investigators may gather information, which will help, when the time comes, in an orderly march to the North.

Foreseeing the importance of this vast part of Canada in strategic and economic considerations of the future, many departments of the Dominion of Canada have accelerated their work in this region. This report concerns the findings of a joint expedition of the Directorate of Engineer Development of the Department of National Defence, and the Division of Building Research of the National Research Council. Both organizations were interested in the construction techniques used for small building foundations on permanently frozen ground (permafrost)*. In addition, the Division of Building Research hoped that the notes collected during the summer would be the beginning of their Northern "Domesday" Book; an ambitious program of particulars on the design, construction details, and services of every building in Canada's North.

From the outset it was realized that the investigations would have to be carried on for a number of years. The 1950 investigations were, therefore, considered exploratory and were to take the form of a small expedition through some particular area of Canada's North. The selection of the Mackenzie River Valley was prompted because it provided numerous small settlements and its water course provided the best and easiest form of transportation throughout the northern area.

THE INVESTIGATIONS OF 1950

The four-man party was assembled in Ottawa during the middle of May. For approximately 4 weeks its members were subjected to intensive briefing on all aspects of the investigations. The party left Ottawa for Edmonton at the beginning of June and flew to Yellowknife on June 15. After a one-week stay at Yellowknife to report on this town's utilities system, the investigators flew to Hay River to join their chartered boat. From Hay River they travelled by boat to Fort Resolution and on July 2

* Definitions for words marked in this way will be found in Appendix C of this Report.

they entered the Mackenzie River. The trip down the Mackenzie River to Aklavik took approximately a month with stops at the principal settlements of Fort Providence, Fort Simpson, Fort Wrigley, Fort Norman (plus a side trip by two members of the party to Fort Franklin on Great Bear Lake), Norman Wells, Fort Good Hope, Arctic Red River, Fort MacPherson (on the Peel River) and Aklavik. From Aklavik the party attempted to visit Port Brabant (Tuk Tuk) but had to turn back 18 miles from their goal. A wind had churned up the Arctic Ocean making travel in their shallow draft river boat very dangerous. The 1950 investigations were completed at Aklavik. A map of the area covered is shown in Fig. 1.

REPORTS

Two types of reports were completed for each settlement. The first, a "Settlement Report", contained a general description of the settlement. Topics such as location, topography, geology and history of the settlement, were covered. The second type, a "Building Report", was an "as constructed" study of every "white man" building in the settlement. Topics covered in this report were location, construction history, sketch plan, photographs, soil and permafrost conditions, foundations, floor, ceiling, wall and roof sections, utilities and notes of failures. (For samples of "Settlement" and "Building" Reports, see Appendices A and B respectively). Over 250 buildings in 12 settlements were reported on in this manner. In addition, approximately 800 terrain and building photographs were taken on the 1400-mile trip.

This report, then, is based on the foundation portion of the 1950 Mackenzie River investigations. It does not cover all the possible types of small building foundations on permafrost but merely reports on those which were encountered in the valley of the Mackenzie River. Part V of this Report contains three charts which outline recommendations for types of construction and foundations for a particular building at a specific site. It must be pointed out that these recommendations cannot be regarded as conclusive as they are based only on the observations of one field trip. They are included as a guide for constructing foundations on permafrost.

To help in understanding the problems of northern foundation construction, a short outline of permafrost precedes the actual foundations report.

PART II GENERAL OUTLINE OF PERMAFROST

The destructive action of perennially frozen ground, or "permafrost", as it is known, has for many years caused engineers much difficulty with building in the North (Fig. 2). Investigation of permafrost conditions up to very recent years was seldom carried out and there was little or no understanding of the behaviour of frozen ground. Consequently, extensive building deformations (measured in feet) caused by settling and heaving, were experienced. Although the existence of perennially frozen ground has been known for some time, extensive research has not been carried out except by the Russians. It is only in the last few years that North American investigations have been started. Much remains to be done, especially with regard to practical foundation problems in Canada's northlands.

Russian and, to a lesser extent, Canadian experience has shown that it is not economical to "fight" permafrost by simply using stronger materials or more rigid structures. Experience has shown instead, that favourable results can be obtained if the basic concepts of permafrost are clearly understood and applied to construction methods.

ORIGIN AND AGE OF PERMAFROST

Permafrost is the result of abnormal ground freezing which subsequent melting has been unable to thaw. The relict nature of permafrost appears to be established for it is generally agreed by most authors that permafrost first appeared in the Pleistocene or Ice Age. It is equally certain that permafrost can form under climatic conditions where the mean annual temperature is below 32°F. Muller (1)^ cites the formation of permafrost in some of the recently built river islands and bars in the Arctic part of Siberia. Perennially frozen ground can also appear in localities where it is not ordinarily expected. For example, some cold storage rooms in England are now underlain by permafrost (2). However, the greater part of permafrost appears to be a legacy from the Ice Age.

OCCURRENCE OF PERMAFROST IN CANADA

Variations in climate, vegetation, soil, topography, and geology, all have marked effects on the permafrost table*. If some thought is given to these numerous factors that affect the growth and continuance of permafrost, it will readily be seen that the mapping of Canada's permafrost area can only be accomplished by extensive boring surveys. These surveys would subdivide the permafrost area into four categories as suggested by Sumgin (3).

1. Isolated small areas where permafrost is found only in peat mounds;

2. Areas of predominantly unfrozen ground with islands of permafrost;

3. Areas of predominantly frozen ground with islands of unfrozen ground (Taliks)*;

4. Areas of continuous permafrost.

^ Numbers in brackets refer to references at the end of the report.

Some observations have been compiled by Major Scott Lynn, D.E.D. These records have served as a basis for the map in Fig. 3 which is tentative and should be used only as a guide.

THERMAL REGIME

The ground in permafrost areas can be separated into two divisions--the upper layer, or active layer, which freezes and thaws seasonally; and the permafrost zone which remains continuously frozen. The depth of the active layer* is dependent on various factors, of which, climate, vegetation cover, type of soil, water content, and topography are a few.

In undisturbed areas, a thermal equilibrium is established, i.e. the insulating power of the vegetation cover and the active layer preserve the permanently frozen ground. This equilibrium is very sensitive to changes and any alteration causes corresponding variations in the depth of the active layer (Fig. 4).

PERMAFROST SURFACE FEATURES

As with the construction of buildings in temperate zones, the importance of site reconnaissance and investigation before the building site is chosen, cannot be overemphasized. Unless the location of the structure is dictated by functional requirements, its exact position should not be set down until the general area has been investigated. A change in location, sometimes less than 100 feet, may avoid construction and settlement difficulties. For example, pile driving at the Indian Day School Teacherage at Hay River showed the absence of permafrost on one corner of the building site. No changes in the design or location of the building were made. As would be expected, the building has settled and heaving has taken place in the vicinity of this corner.

As an aid in primary reconnaissance, the following surface features usually give some indication of subsurface conditions (4).

Vegetation

Thick Moss with Hummocky Tundra or Scrubby Brush

Poor drainage and a high permafrost table.

Spruce, may be Stunted

Poor drainage, wet ground and a high permafrost table.

Land Cleared of Trees and Moss Cover Disturbed

Permafrost table has been lowered. Depending on the length of time that area has been cleared, soil, and drainage conditions, ground may or may not continue to settle. If construction is planned on this type of area, further investigations are essential.

Pine and Fir

Permafrost table is low. Area is usually reasonably well-drained.

Willows

Very low permafrost table with possibility of underground water. Area where fields of surface ice may form.

Birch and Poplar

Low permafrost table or no permafrost, with usually well-drained ground.

Aspen Poplar

Will not grow on frozen ground.

Topography

Valley Lowlands

As permanently frozen ground is usually impermeable, ground-water flows above the permafrost, down ridges into lowlands where there is poor drainage and the possibility of icing conditions.

Ridges

Usually better drained, although as building sites they may be too exposed. Northern slopes being relatively unexposed to the sun have higher permafrost tables.

Ground Relief

The permafrost table generally follows the ground relief.

Flood Plains

Margins of rivers and lakes can be poor building sites as they may have large layers of unfrozen material. The danger here is from flooding and the formation of surface ice.

Soils

Gravels and Coarse Sands

Indicate probable good drainage and low permafrost table.

Fine-Grained Soils

Usually a high permafrost table and because of this poor drainage results.

Rock

Although rock can be permanently frozen, no anxiety should be felt unless thawing weakens its structure.

Climate

In general, the following climatic conditions appear to be favourable for the existence of perennially frozen ground:

(a) A long and cold winter with little snow;
(b) A short and cool summer with light precipitation.

LOCATING THE DEPTH OF THE ACTIVE LAYER

The depth of the active layer is very important in the design and construction of a building. There are two practical field methods for determining this - by "rodding" or by auger boring.

Rodding

In the rodding method, a 1/4- or 1/2-inch sharpened steel rod is driven through the active layer by means of a sledge hammer to refusal. The rod is then turned with a wrench. If the rod turns freely, it has probably been stopped by a rock. If however, a back spring is felt, it may be assumed that the tip of the rod has penetrated for a short distance into the permafrost. The depth of the active layer is then readily determined. Understandably, this method is not effective in soils with boulders or where the permafrost table is very low.

Auger Boring

If hand augers are available, then it would seem more advisable to use this method. In addition to determining the permafrost table, important information such as ground-water level and soil profile is also obtained. With a standard 1 1/2-inch diameter hand earth auger, penetration through seasonally frozen ground* is at times difficult. In permafrost it is practically impossible. Great care must be exercised in judging when the permafrost table has been reached. The usual sign is when the auger does not bite into the soil but merely scrapes very small flakes of the soil. Dropping the auger in the hole produces a muffled metallic clink if it is permafrost - a sharper sound if rock is encountered.

THE DESTRUCTIVE ACTION OF FROZEN SOILS

The destructive action of frozen soils may be divided into two basic types: detrimental frost action, and loss of strength in permafrost on thawing.

These two destructive features can occur individually but very often contribute co-operatively. Both actions must be considered in the design stage.

Detrimental Frost Action

The detrimental effects of frost action may be differential heave, which lifts piles or surface foundations, and settlement during the frost melting period when the subsoil may have little or no bearing strength.

In sandy soils, heaving due to frost action is not great as the only volume change is that of the water in the voids turning to ice. This volume change amounts to approximately 5 per cent. However, in silts or silty clays, volume changes up to 200 per cent may be produced. This is because ice lenses may grow, consisting of horizontal layers of solid ice, varying in thickness up to a foot and in length from an inch to several feet. It can readily be understood that such large volume changes can exert very large forces on foundations.

A further complication arises when the ice lenses melt in the spring. A supersaturated soil with little or no bearing strength is produced by this thawing. The foundations then settle.

The signs of frost heaving* are first felt in the fall and they may continue all winter. Settling of the foundations is usually experienced in the spring. At times the spring settling exceeds the fall and winter heave with the result that doors and windows jam almost all year.

Loss of Strength in Permafrost on Thawing

As would be expected, the thawing of perennially frozen ground, which in an unfrozen condition possesses adequate bearing strength, is not serious. However, even in this favourable subsoil condition it should be remembered that other factors must be considered. For example, in the case of a fine sand, - has the lowering of the permafrost table altered the relative density of the sand and the position of the water table with respect to the footings?

The lowering of the permafrost table, where the bearing strength of the thawed soil is low, is of immediate concern. Even silts, in a frozen state, have high bearing capacities. This fact will be forcibly remembered if one ever has had to bore or excavate this rock-like form of soil. On thawing, because of their very high water content, they are often transformed into semi-liquid or liquid states (Fig. 5).

CONSTRUCTION METHODS IN PERMAFROST

Damage by frost action is not peculiar to Arctic areas. Construction techniques devised in more temperate areas can be used to combat this destructive feature. Descriptions of these techniques lie beyond the scope of this report and, therefore, will not be attempted.

Keeping in mind that the main difficulties with construction on perennially frozen ground arise if this soil thaws and produces an unstable subsoil, two methods of construction are suggested.

Active Method*

The active method of construction is one in which the permafrost is removed. This method is usually carried out when islands of permafrost are encountered (sporadic permafrost*), the perennially frozen ground is very low, or when it has been determined that the permafrost will not form again if removed. Excavation can be carried out by pick and shovel, by drainage after melting with steam, or by exposure to the sun, blasting, and by hydraulic stripping for large areas.

Passive Method*

The passive method of construction is one in which the perennially frozen ground is preserved by not disturbing the thermal régime. For example, if the vegetation cover is removed, (and this is not recommended), an equivalent amount of insulating fill must replace it or the permafrost table will be lowered. If a building is to be placed on this fill, then an additional amount of insulation must be placed to compensate for the heat which will be emitted from the building. For some examples of the passive method of construction in building foundations see Fig. 6.

Generally it will be noted that the active method lends itself to areas of non-continuous permafrost. The passive method would be used in areas of continuous permafrost. The ultimate choice of either method would seem to depend upon:

1. the extent of the permafrost;
2. the properties of the thawed permafrost;
3. the water or ice content of the soil;
4. the general topographic and geologic features of the locality;
5. the type and heating particulars of the building;
6. the economic balance between the cost of excavation and cost of insulation required.

PILES

At the present time, piles appear to be the most economical form of foundation for heavy structures in adverse locations such as low-lying, poorly drained, "muskeg" areas. As would be expected, pile construction techniques in permafrost areas differ from those used in temperate zones and so a short account of placing piles in permafrost follows.

Pile Theory

The basic principle in pile construction on permafrost is to thaw the ground where the pile is to be driven, drive the pile, and then allow the pile sufficient time to "freeze in". The permafrost then grips the pile with what is known as the "adfreezing* strength". When the pile is driven into the thawed ground, it transfers a load to the ground by point bearing. As the pile freezes in, the load is transferred partly by point bearing and partly by adfreezing strength. When the pile is completely frozen in, the load is transferred by adfreezing strength.

Frost Heaving

The upward force on a pile due to frost heaving (see "Destructive Action of Frozen Soils" page No. 6) under select conditions can be very great. Should the adfreezing strength and the loading on the pile be exceeded by this upward force, heaving of the pile will result.

Lowering of Permafrost Table

Non-heaving soils.- The lowering of the permafrost table in non-heaving soils is not generally serious if the change in level is not too excessive. Understandably, the adfreezing strength will be lowered but if the permafrost table remains at the toe of the pile, the load will be transferred by point bearing. If the pile does not penetrate the permafrost then the usual considerations of "pile friction" or loading tests are recommended.

Heaving soils.- The effect of lowering the permafrost table is doubly important in frost-heaving soils. An increase in the depth of the active layer reduces the total adfreezing strength of the pile. In addition, it is quite probable that the frost-heaving force on the pile is increased because of the deeper active layer.

PART III THE MACKENZIE RIVER DISTRICT (5)

The total length of the Mackenzie River System, considered as originating at the headwaters of the Finlay River, is 2525 miles. Its great drainage basin occupies an area of 682,000 square miles or approximately one-fifth of the entire land area of Canada, exclusive of the Arctic Islands. On the North American continent it is exceeded in length and drainage area only by the Mississippi River.

However, the name "Mackenzie River" applies only to that portion of the Mackenzie River System extending from Great Slave Lake to the Arctic Ocean, a distance of over 1000 miles.

SETTLEMENTS OF THE MACKENZIE RIVER DISTRICT

From the time that Alexander Mackenzie made his famous trip to the delta of the Mackenzie River in 1789 to the start of the First World War, the only major economic activity in this vast area was trapping. The fur industry resulted in the establishment of trading posts at approximately 150-mile intervals on the Mackenzie River. The following years have brought no drastic changes. Time has only enlarged the settlements with the arrival of the missions, the Royal Canadian Mounted Police, the Royal Canadian Corps of Signals and officials of various Federal departments.

The only settlement on the Mackenzie River area which did not develop as a result of the fur trade is Norman Wells. It is a plant of the Imperial Oil Company Limited, (oil wells and refinery) of Second World War "Canol" fame. Norman Wells supplies the Mackenzie district with petroleum products, a demand which it can meet by summer operation.

Permafrost Distribution

The approximate southern limit of continuous permafrost is in the vicinity of Fort Simpson (Fig. 3). Permafrost was found in sporadic islands at Fort Resolution, Hay River and Fort Providence. Fort Simpson has no permafrost in the building area, although 20 years ago it occurred continuously at a depth of 18 inches. North of Fort Simpson continuous permafrost can be expected.

BUILDINGS IN THE MACKENZIE RIVER DISTRICT

Buildings in the settlements of the Mackenzie River district divide themselves into functional groups--Hudson's Bay Company buildings, mission buildings, etc. Perhaps the most striking example of this is the "compound" arrangement of the Hudson's Bay Company's older buildings. In this arrangement the store, residence and warehouses are located on the perimeter of a rectangular fenced-in area. Quite frequently, this "boxed-in" area is the Post Manager's vegetable garden. The Hudson's Bay Company's older type of buildings (1926) are usually two-storey frame structures resting on mudsills. These buildings are slowly being replaced by attractive, modern "bungalow" style buildings and the "compound" arrangement is disappearing, (Fig. 27).

By far the largest buildings in the district are those of the missions, Anglican and Roman Catholic. Apart from the church, the mission buildings may consist of a school, hospital, residence and warehouses. They have been constructed mainly of local materials and with native help.

As mentioned before, nearly every settlement has a Royal Canadian Corps of Signals Station. For the past few years frame buildings with concrete basements have been built for married personnel. The earliest of these, with no modifications for permafrost, have showed considerable failures. The latest buildings have been modified slightly but it is too early to say if they are successful.

The most striking buildings that the Canadian Government is constructing are the Indian Day Schools. These are two-storey, flat-roofed frame structures, usually with short concrete piers or concrete blocks for foundations (Fig. 29). The Indian Day Schools consist of one, two or four classrooms depending on the population of the settlement.

Every settlement, except Norman Wells, has its "native" area. The majority of the transient Indians who visit the settlements during the summer months, do not bother to build permanent shelters but merely pitch their tents close to the settlement. The shacks of the resident natives were not investigated.

TYPES OF FOUNDATIONS ENCOUNTERED

Except for steel pipe piles at Norman Wells, the different types of foundations used for structures in the Mackenzie River district are not peculiar to any one settlement. Pertinent statistics on the foundation types are given in Table I, and examples of the different foundations follow a general discussion of Table I.

It is interesting to note that more than half of all foundation types show some failures. This emphasizes the need for further study. The need, however, is for design data and not construction techniques or new types of foundations.

TABLE I

PERTINENT MACKENZIE RIVER DISTRICT PERMAFROST FOUNDATIONS STATISTICS

Type of Foundation	Number Investigated	No Apparent Failure	Apparent Major Failure Due to Frost Heaving	Apparent Major Failure Due to Settling
Mudsills	76	30	30	16
Piles				
Wooden	10	4	3	3
Steel Pipe	25*	9	4	12
Concrete	1	1	0	0
Concrete wall footings	23	10	1	12
Timber pads	19	5	5	9
Timber posts	15	7	8	0
Short concrete piers	7	2	5	0
Concrete pads	6	1	4	1

* All at Norman Wells.

Mudsills

The predominant type of foundation for the district is the timber mudsill. However, as Table I indicates, the frequency with which it appears should not be taken as an endorsement of its effectiveness. The main advantage of the mudsill is that it is a cheap and easy type of foundation to construct. It is, therefore, favoured by the missions, by individual builders and for generally cheaper types of construction, such as warehouses, where cost and ease of construction are of prime importance.

Piles

It is thought that piles form, for the present time, one of the most important permafrost foundation types. Although Table I indicates that steel pipe piles are the most prevalent type, it should be noted that pipe pile foundations were encountered only at Norman Wells. (Pipe is obtained from scrap at practically no cost). At the other settlements, current practice favours using treated native timber.

Concrete Wall Footings

Buildings with concrete basements and concrete wall footings are generally those occupied by the Royal Canadian Corps of Signals and by some Government officials. It will be noted from Table I that more than one-half of these buildings have shown apparent failures. This is mainly due to the fact that only minor modifications for permafrost conditions have been carried out. The designs were adapted from standard designs used elsewhere in Canada.

Other Foundation Types

Timber pads, timber posts, short concrete piers and concrete pads formed the foundations for approximately 25 per cent of the buildings investigated. Their use is not peculiar to any agency building in the North.

EXAMPLES OF DIFFERENT TYPES OF PERMAFROST FOUNDATIONS

The following are examples of the different types of permafrost foundations encountered in the Mackenzie River district. They are arranged in the same order as listed in Table I, that is, the frequency with which they appeared. The examples of "Pile Foundations" are preceded by an account of pile driving techniques used at Yellowknife and Norman Wells.

Timber Mudsill Foundations

Example 1

Building.- Aklavik Power Company Powerhouse, Aklavik, N.W.T.

Soil.- Dark brown silt with a high moisture content. Permafrost encountered approximately one foot below ground level. The site is low-lying and has a grassy cover.

Foundations.- The old portion of the building (constructed in 1946) has two sets of three 8-inch diameter logs running the full length of the building. The wall load is distributed to these sills by 4-inch diameter short logs at right angles and spaced 4 feet on centres. This section of the building has a double floor with 16 inches of sawdust as insulation.

The new portion of the Powerhouse is identical to the old, except that four 8-inch diameter logs are used for the sills. The floor in this section of the building is plain concrete 18 inches deep on a 4- to 5-inch layer of packed sawdust.

The engine beds, in the old portion, have separate foundations from the building. They are on a sawdust packed crib of timbers (10 by 12 inches). The engines in the new section will rest on the concrete floor.

There are no signs of settlement in the building except for the cribbed engine beds which settled 1/2-inch uniformly when first put into operation.

For details of the foundations in the new and old portion of the building as well as details of the engine bed, see Fig. 7.

Example 2

Building.- Bishop's Residence, All Saints Mission (Anglican), Aklavik, N.W.T.

Soil.- Dark brown silt with a high moisture content. Permafrost encountered at approximately 3 feet.

Foundations.- The building was constructed in 1946. The building sills rest on 6-inch diameter logs 3 feet long, laid side by side and at right angles to the sills. The airspace between the floor and ground is approximately one foot. The building is skirted with 1 foot square boxing for its entire perimeter. The floor has two thicknesses of plywood with a linoleum surface and is insulated with full-thick rock wool batts. Seasonal heaving which jams some doors is reported.

PILE DRIVING PROCEDURES

As would be expected, no set rules can be given for pile driving procedures in permafrost. It is hoped that the following descriptions of pile driving at Yellowknife and Norman Wells will help prospective builders in planning their own procedures.

PILE DRIVING AT YELLOWKNIFE

Information on the pile driving procedure used at the Giant Yellowknife Gold Mines Co. Ltd., was obtained by inspection and consultation with their staff (notably Dr. J.D. Bateman). Developed from theory and experience, although not unique, it illustrates admirably how permafrost construction should be carried out, i.e., understanding basic permafrost concepts and applying them to local conditions and materials.

Soil

Permafrost at the Giant Yellowknife property occurs in islands and is not constant in upper or lower limit. In low-lying moss-covered areas, the permafrost table is practically right under the moss while in areas where the surface has been cleared the active layer may be from 2 to 4 feet deep. "Bed-rock is exposed over 30 per cent of the property, the remainder being covered by Pleistocene and recent deposits that are up to at least 110 feet thick, ... Extending through the property, several feet of gravels and sands, as indicated by a large number of diamond drill holes, lie upon the bedrock; and these deposits are overlain by thinly stratified lacustrine clays" (6).

Work Prior to Pile Driving

Whenever it was possible, construction was on bed-rock. However, functional requirements dictated that some of the buildings be constructed on permanently frozen clay.

After the site of a building was chosen, small boxes (approximately 2 feet by 2 feet by 1 foot deep) were built at the proposed location of every pile (Fig. 9). The building area was then backfilled with "mine-muck" fill, (waste rock from mining operations). In this way, the building area was levelled in addition to protecting the moss cover from the tracks of the crawler tractors.

Steam jetting before the piles were driven was accomplished by a pipe 12 feet long, 1 inch diameter, with a 1/4-inch (approximately) nozzle (Fig. 8). The jet was simply propped in place and after three hours of steaming, it sunk the full pile distance in the permafrost (Fig. 9).

Pile Preparation and Driving

The wooden piles driven were either 10-inch round or square depending on availability. All were treated up to the surface with "Osmose" (a wood preservative) and for 2 feet down from the surface were greased and covered with tarpaper. The purpose of this greased collar was to guard against frost heaving. Should the soil exert a force against the pile then the tarpaper collar, and not the pile, would rise. It would be well to note that the effectiveness of this collar is questioned as a permanent solution to frost heaving. Its effectiveness during the first year, if the pile has not frozen in completely, can be understood, but its action after a year or so when dirt has worked into the grease is doubtful.

The soil at Giant Yellowknife on thawing became liquid. Not much force was required for the driving and hence the winch and cable of a D8 "Caterpillar" pushed the piles to the required 12 feet (Fig. 10). (Current practice is to drive the piles into permafrost twice the depth of the active zone, i.e. at Giant Yellowknife - 8 feet in permafrost plus 4 feet in active layer, giving a total of 12 feet). Since the frozen soil is impervious, many of the piles when driven (actually pushed) displaced the liquid soil until some of it oozed out at the top.

Immediately after the piles were driven, they were wedged into their true positions (the wooden guard boxes were found very convenient for this task) and cut off at the desired elevation (Fig. 11). The time required for the piles to freeze in was surprisingly short. This fact was forcibly brought to attention by the following incident.

An attempt was made to drive a pile with a D4 Caterpillar. This was not successful as the D4 was not heavy enough and could not push the pile to the desired depth. Two days later after steaming the pile on one side, a D8 Caterpillar tried to pull put the pile. The attempt was unsuccessful. The pile snapped at the ground line (Fig. 12).

PILE DRIVING AT NORMAN WELLS

The information on pile driving at Norman Wells was obtained from a paper by R. A. Hemstock, entitled "Permafrost at Norman Wells, NWT" and supplemented by inspection and conversation with several members on the staff of the Imperial Oil Company Limited, at Norman Wells.

Soil

The soil at Norman Wells is predominantly a fine frozen silt with some thin layers of gravel and clay. A weak sandstone is encountered at a depth of approximately 40 feet. Permafrost typical of low, poorly drained areas where trees and brush have been cleared but the moss left intact, is encountered at approximately 2 feet from the surface. Clearing off the moss cover has a marked effect on the thermal régime. Ground that at one time (1940) thawed to a depth of 18 inches, with the moss removed has now (1950) thawed to a depth of 13 feet (7).

Work Prior to Pile Driving

Steam jetting at Norman Wells was carried out with a 3/4- to 1-inch pipe about one foot shorter than the desired depth. A steam pressure of 50 to 80 p.s.i. or greater is reported to seem most satisfactory. With respect to steam jetting, Hemstock makes some interesting practical notes:

1. If the ground has dry layers - some water with the steam will speed jetting;

2. Holes may be left up to 3 weeks in summer before driving piles but in freezing weather should not be left more than a week;

3. Except in coarse gravel, special bits - e.g. chisel bits - did not speed jetting;

4. Under favourable conditions, one man can steam jet up to twenty-five 16-foot holes in an 8-hour day;

5. Best results are obtained when a hole is jetted just big enough to take the pile. With experience on different ground types and care in jetting, this may be easily accomplished.

Materials and Equipment

Wooden Piles

The first pile construction at Norman Wells used native spruce because of high shipping costs on imported timber. The piles were from 7 to 10 inches at the butt and some had asphalt-treated collars to help prevent frost heaving. If the piles were driven deep enough (12 to 15 feet) no evidence of heaving, with or without collars, was reported in 1948. Examination of some piles during the summer of 1950 did, however, reveal heaving in a few. This seems to further the proof that a lowering of the permafrost table is occurring. (See "Soil" Section of Pile Driving at Norman Wells page 15).

Steel Piles

Because of the availability of scrap pipe, steel piles have been used exclusively since 1947. They are available free of charge, and are more easily handled and driven than wooden piles. In addition, they may be quickly lengthened, cut or capped by welding as well as being slightly flexible as to position after driving. To help prevent heaving, collars 1 1/2 inches larger than the diameter of the pipe are welded or screwed to the base of the pile.

There has been some speculation on the effects of increased heat flow in steel piles into the permafrost. Hemstock measured this effect at Norman Wells in 1947. For wooden piles, the permafrost level was lowered by 1 inch and for steel piles, 4 inches. The wooden piles supported an unheated building, the steel piles, a water tank. As suspected, the consequences of the heat flow down a pile are negligible for ordinary conditions since the lowering of the permafrost table by a few inches is of no consequence.

Driving

At Norman Wells, Hemstock found that a light fast-drop hammer outfit, mounted on a small crawler-type tractor was most satisfactory. With this type of equipment, piles could be quickly and easily handled and driven, while the machine could move fairly well in the wet soft ground. The steel piles were driven to a depth of 16 feet while the wooden piles were driven from 12 to 15 feet, butt-end first to help prevent frost heaving.

Wooden Pile Foundations

Example 3

Building.- Department of Transport Mess Hall, Kitchen, and Food Stores, Hay River, NWT.

Soil.- Appears to be a sandy grey clay. Permafrost is found at approximately 6 feet below ground surface.

Construction History.- Construction on the building site began during the spring of 1948. The area had been cleared of trees and brush for 6 years. It did, however, need some levelling and no attempt was made to protect the moss cover in these places. During June, 1948, the pile holes in the 5-to 6-foot active layer were made with an 8-inch post-hole auger. Steam jetting in permafrost was carried to a depth of approximately 15 feet. The piles (9-inch diameter at butt) were driven butt-end down and were spaced at 6 feet on centres with the rows of piles at 10 feet on centres. The piles were treated with a wood preservative ("Osmose") and had one layer of tarpaper wound around them at ground level. No grease was used. Some of the difficulties encountered in the pile driving were as follows:

a. Some of the piles "popped up" (i.e. floated). These were re-driven with an extra number of blows;

b. Keeping the piles in line when driving was difficult at times. Frequently a tractor had to be used to pull and keep the piles in alignment.

An unusual feature of this building is the floor. Two pre-fabricated sections of 2- by 6-inch joists and 1-inch tongue and groove flooring have been laid at right angles. Both sections have 2 inches of rock wool insulation. For full details see Fig. 13.

Example 4

Building.- Heating Building of Indian Day School Teacherage, Hay River, NWT.

Soil.- Predominantly a blueish silty clay with layers of fine brown sand varying from 1 to 6 feet. Permafrost is found approximately 8 feet below ground surface and occurs in sporadic islands in the vicinity of the building.

Construction History.- Holes four feet deep were excavated at each pile site during the fall of 1947. Steam jetting and pile driving were carried out in February, 1948. The building was completed and occupied in November, 1948.

Foundations.- Wooden piles, toe diameter 8 inches, were used and driven butt-end first. The length of pile in permafrost was left rough while the portion of the pile in the active layer was greased and enclosed with tarpaper, (no nails were used). Two feet of gravel were placed up to the ground line and the space between the ground and the double concrete floor was filled with peat (Figs. 15 and 16). The chimney for the forced warm air furnace is supported by a special pile. There is no apparent settlement. A sketch section is shown in Fig. 14.

Concrete Pile Foundations

Example 5

Building.- Four-Classroom Indian Day School, Hay River, N.W.T.

Soil.- Predominantly a grey silty clay, occasionally with some sand. At the building site, permafrost is encountered approximately 8 feet below the ground surface. It occurs in sporadic islands in the vicinity of the building.

Construction History.- Twelve to eighteen inches of moss and organic topsoil were removed during December, 1946. The piles were cast in the spring of 1947. Steam jetting and driving were completed by April, 1947. A two-foot gravel mat fill was placed in May, 1947, and the building was finished and occupied by November, 1948 (Fig. 17).

Foundations.- Twelve inches square precast reinforced concrete piles, 28 feet long were used. The piles were cast in a vertical position. Ground was steam thawed to roughly the desired diameter and depth and the piles driven to refusal. There is a 2-foot airspace between the ground and floor which is completely skirted with removable shutters. The floor has a 4-inch concrete slab (plus 2 inches of cinder concrete for heating room) with the usual frame floor on it. Although the specifications called for 2 inches of rock wool, only 1 inch was installed. When the shutters were removed during the winter of 1949-50, the ground floor was so cold that even with heating it could not be occupied. A sketch of the foundations and floor is shown in Fig. 18.

Pipe Pile Foundations

Pile foundations of steel pipe were encountered only at the Imperial Oil Refinery at Norman Wells. Norman Wells is not a typical river settlement. A central heating system is used and steam is carried through steam pipes in utilidors to the buildings. The steam pipes are brought in to the building and distributed to the different rooms under the floor. The skirting around the building and the heat from the steam pipes help to keep the floors warm but also has a marked effect on the thermal equilibrium. Temperatures under heated buildings during the winter were found to range from 60 to 65°F.* Regarding pipe piles, Hemstock remarks, "so far none driven 15 feet or more have heaved or

* Conversation with Mr. Angus Sherwood, Norman Wells, N.W.T.

settled under normal conditions, and examination of foundations erected for two years indicate that they should be satisfactory." Examination during the summer of 1950 showed that the effects of lowering the permafrost table were being felt.

Example 6

Cemesto Quarters.- All 6 buildings are supported by 4-inch steel pipe piles. The deformation pattern is "saucer-shaped" with the walls being, on the average, 2 inches higher than the middle of the floor.

Example 7

Fire Hall.- Utilidor enters east wall. Building has settled 4 inches along east wall.

Example 8

Post Office and Canteen.- The utilidor runs along the side of the building and enters the west wall. The southwest corner of the building has settled about 2 1/2 inches.

Example 9

Block "A" living quarters.- These have had to be jacked and blocked 8 inches in places.

Example 10

Laundry.- The south side where heavy machinery is installed has settled as much as 10 inches.

Example 11

Refinery.- In buildings with heavy machinery, the foundations supporting the floor and machinery are separate. In this building, the pump bases are on 4-inch steel piles driven 14 to 16 feet. The floor joists are 4-inch steel pipe 10-inches on centres, with corrugated galvanized iron sheets on the joists and a 3- to 4-inch concrete floor. The floor is supported by 4-inch steel pipe piles. The floor has settled in places up to 2 inches but this does not affect the operation of the pumps.

Example 12

Boiler House.- This building houses 4 locomotive-type boilers, pumps and generators. Again the boilers have separate foundations from the floor system. The foundation and floor construction is similar to the Refinery except that the boiler base piles are 7-inch steel pipe. The settlement in the building is considerable. The main cause of this is that no provision has been made for drainage of boiler wash water. It simply drains under the building. Measurements of settlement from April 11 to September 5, 1950, showed a maximum settlement of 6 inches for the perimeter of the building and a maximum of 5 inches for the floor (Fig. 19).

Concrete Wall Footings

Example 13

Building.- Department of Transport Family Quarters, Hay River, N. W. T.

Soil.- Sandy grey clay. Permafrost encountered at 4 feet.

Construction History.- The 6-inch covering of moss was stripped from the building site in April, 1947, and excavation of the basement followed in May of the same year. Permafrost was encountered at 4 feet and after a lapse of a month, the permafrost table receded 1 1/2 to 2 feet. This layer was removed and replaced with gravel.

Foundations.- The foundations for the buildings are concrete wall footings 22 inches wide and 10 inches deep. Every 3 feet, a concrete pier was poured to the permafrost level, a distance of 1 1/2 to 2 feet. For details of the foundations, see Fig. 20. There are no signs of settlement on the basement floor or walls but it should be noted that twice the amount of reinforcing steel as called for in the design was used in the basement walls.

Example 14

Building.- Royal Canadian Corps of Signals Radio Station, Hay River, N.W.T.

Soil.- Silty fine sand. Permafrost is encountered approximately 5 feet below the ground surface.

Construction History and Foundations.- Excavation of the basement began in August, 1947. A gravel mat (thought to be 1 foot in thickness) was placed at the bottom of the excavation. The concrete wall footings were 18 inches wide and 12 inches deep. A 5-inch concrete floor and a 9-inch concrete wall were placed for the basement. There is no reinforcing steel in the wall footings, basement floor or walls. The building was completed in December, 1947.

One month after completion, the first cracks appeared on the basement walls and floors. Settlement accelerated during the spring of 1948 to such an extent that the basement floor practically disintegrated and the cracks on the basement walls ranged in size from hairline to 2 inches.

A one-foot layer of sand and gravel was placed on the floor; seven concrete piers, one foot square and 5 feet long, were placed in the middle of the floor where settlement had been most pronounced, and a new 7-inch thick concrete floor was placed. In June, 1950, cracks were noted in this floor.

In March, 1948, an attempt was made to repair the large basement wall cracks by excavating the backfill on the walls and patching with tar and tarpaper. This attempt was apparently not successful as

RCCS personnel reported much seepage through the cracks in the spring. The walls were not backfilled then and it is now possible to look through the cracks to the outside. A sketch of the floor and foundations is shown in Fig. 21.

Example 15

Building.- One-Classroom Indian Day School, Arctic Red River, N.W.T.

Soil.- Moss cover of approximately 6 inches, 1 foot of organic topsoil and silty grey clay with ice lenses (1/4- to 1/2-inch) to at least 5 feet. Permafrost is encountered under the 6-inch moss cover.

Foundations.- Concrete wall footings 2 feet wide and 10 inches deep running for the full perimeter of the building as well as for the main mid-girder. Eight-inch reinforced concrete stub walls carry the building load to the footings. The footings rest on a 1-foot deep shale fill mat. For details of the foundations and floor, see Fig. 22. Excavation for the wall footings was being carried out in July 1950 (Fig. 5) and hence its performance cannot be reported on at this early date.

Timber Pads

Example 16

Building.- Hospital Annex, All Saints Mission (Anglican), Aklavik, N.W.T. (Fig. 23).

Soil.- Dark-brown silt with high moisture content. Permafrost encountered at 2 1/2 to 3 feet below surface at site.

Foundations.- Five 8-inch diameter logs with three split 8-inch diameter logs at right angles. These timber footings are approximately 5 feet square and are spaced at 6 feet on centres (Fig. 24). The ground is relatively undisturbed. There is a 3-foot earth banking. Two vents are provided. The double floor is insulated with 1 thickness of full-thick rock wool batts.

Example 17

Building.- Independent Trader's Store, Aklavik, N.W.T.

Soil.- Dark-brown silt with a high moisture content. Permafrost encountered at approximately 3 feet below ground surface.

Foundations.- The building was constructed during 1938-39 and the surface of the building site was not disturbed. Timber spread-footings, 4 feet square and 8 inches thick were placed on the ground at 8 feet on centres. The building is made level by wooden shims placed under the sills. The building is banked with earth. There is a partial basement which did not show signs of settlement until 3 years ago when water seeped in. Since then, there has been a 3-inch settlement in one portion of this basement. A sketch of the foundations and floor is shown in Fig. 25.

Timber Post Foundations

Example 18

Building.- RCCS Married Quarters (WO I) Norman Wells, N.W.T.

Soils.- Originally the site was muskeg with a slough behind the present RCCS buildings. The slough was drained in 1948 and a 2-foot fill of shale and clay was placed on top of the muskeg. This fill has subsequently settled in some places.

Foundations.- The foundations of this building were to be 13-foot wooden piles. Actually the piles were driven only about 9 feet and hence in this report are considered as posts.

The interesting feature of this building is the false floor arrangement to prevent the heat from the utilidors from disturbing the permafrost table (Fig. 26). How successful this has been cannot be said for certain. There are many cracks and signs of heaving and settling but this could be caused by the fact that the piles were not originally driven deep enough to prevent frost heaving.

Example 19

Building.- R.C.M.P. Single Men's Quarters, Aklavik, N.W.T.

Soil.- Dark-brown silt with a high moisture content. Permafrost encountered at 2 to 3 feet below ground surface.

Foundations.- Ten-inch diameter timber posts, depth thought to be 5 to 6 feet. The 2-foot airspace between the floor and the ground is enclosed by a 2-foot square sawdust-filled boxing. The double shiplap floor is covered with linoleum and is not insulated. Signs of heaving are noted during the winter but they disappear during the summer. The centre of the building is slightly lower than its edges.

Example 20

Building.- Hudson's Bay Company Store, Aklavik, N.W.T.

Soil.- Dark-brown silt with high moisture content. Permafrost is found 2 feet below ground surface.

Foundations.- The foundations were placed during the fall of 1942 and the building was completed in the summer of 1943 (Fig. 27). The building is supported by 8-inch diameter spruce logs, treated with "Cuprenol" and spaced in an 8-foot grid. The posts are 4 feet in the ground and cut approximately 6 inches to 1 foot off the ground. The airspace is enclosed by the siding which has been brought to ground level. The double floor is covered with felt paper and linoleum but has no insulating material. No signs of heaving or settling were noted and the building is reported to be "comfortable" during winter.

Short Concrete Piers

Example 21

Building.- Two-Classroom Indian Day School, Fort Good Hope, N.W.T.

Soil.- Moss cover approximately 6 inches thick; 6 inches to 2 feet of grey clay; 2 feet to 5 feet of silty sand with some boulders. Permafrost encountered at 2 feet. The building site is about a quarter of a mile from the RCCS buildings on a knoll 40 feet high and is underlain by muskeg.

Foundations.- Twelve-inch square concrete posts on 2 feet 8 inches square footings at a depth of 8 feet. The footings have no gravel mat. Special footings were required for the 3 main columns which carry the entire roof (which weighs 4 tons). For details of these special piers, see Fig. 28. The airspace of approximately 1 1/2 feet is skirted and has louvres. The double floor is insulated with 1 thickness of full-thick rock wool batts.

Example 22

Building.- Two-Classroom Indian Day School, Fort Resolution, N.W.T. (Fig. 29).

Soil.- Dark brown silt with a high moisture content. The site is poorly drained, low-lying muskeg. Permafrost was encountered at 2 1/2 feet below ground surface.

Foundations.- Concrete piers approximately 18 inches square at the top, thickening to 2 1/2 feet square at the bottom. There is a 2-foot skirted airspace with shutters 8 by 16 inches every 6 feet. The double floor is insulated with 1 thickness of full-thick glass fibre. The building was constructed in 1949 and there are no apparent signs of settling or heaving.

Concrete Pads

Example 23

Building.- Hudson's Bay Company Residence (Type 12DB), Fort MacPherson, N.W.T.

Soil.- Organic silt for 3 feet then grey clay with patches of gravel. Permafrost is reported at 3 1/2 feet below ground surface.

Foundations.- The building was constructed in 1944 and rests on concrete posts 9 inches square and 5 feet long. These concrete posts are on concrete pads, 2 feet square and 12 inches deep. The spacing is from 8 to 10 feet on centres. The airspace, ranging from 6 inches to 2 feet 6 inches, is skirted with aluminum sheets. There is a partial timber-lined and floored cellar 20 by 12 feet which collects some seepage. A sketch of the foundations and floor is shown in Fig. 30.

Example 24

Building.- Hudson's Bay Company Store and Dwelling, Reindeer Depot, N.W.T.

Soil.- Dark-brown silt with high moisture content. Permafrost is reported to be from 6 inches to 1 foot below ground surface.

Foundations.- Concrete pads 2 feet square and 9 inches deep set on an undisturbed surface. The 3-foot airspace is skirted with loose boarding. The floor is double with full-thick rock wool batts for insulation. The building has shown many signs of movement. Gaps as large as 2 inches between partitions and walls appear during the winter and return almost to normal during the summer.

Miscellaneous Foundations

Example 25

Building.- Royal Canadian Corps of Signals Married Quarters (W.O. II), Aklavik, N.W.T.

Soil.- Dark-brown silt with a high moisture content. Permafrost encountered at approximately 3 feet below ground surface.

Foundations.- The building was constructed in 1949. An unusual feature of this building is that the partial basement is a separate unit from the rest of the building. The building rests on perimeter timber sills while the basement is thought to have its own concrete wall footings. Foreseeing some differential settlement, a steel post with a variable jack was placed in the basement. For details, see Fig. 31.

Some settling of the ground between the timber sills and the concrete basement wall was noted. There are no cracks in the concrete basement walls or floor but the building, in the second floor, has many cracks to show movement of the timber sills.

PART IV CONCLUSIONS

The following conclusions and recommendations are based on a review of ALL the buildings investigated by the 1950 Mackenzie River field studies. The examples of the different types of foundations were chosen to illustrate some, but not necessarily all, of the points mentioned in the conclusions.

GENERAL CONCLUSIONS

In reviewing experience with different types of foundations, it was noted that some considerations were applicable to all foundations. They are as follows:

Site Selection

The selection of the building site by soil surveys has been totally neglected for many buildings in the North. This preliminary step should not be overlooked for it largely determines the type of foundations to be used.

Altering Ground Conditions

It is practically impossible NOT to disturb the thermal equilibrium at a building site during and after construction of the structure. Every effort should be made to minimize this subsequent lowering of the permafrost table and an allowance for it should be made in the design of the foundations.

Surface Foundations

Any type of foundation that rests on the ground surface will prove unsatisfactory if it rests on ground susceptible to frost. The use of satisfactory surface foundations can only be carried out if this unsatisfactory soil is removed and replaced by non-frost action soil or if the unsatisfactory soil is treated with admixtures to eliminate the troublesome frost action characteristics.

Buried Foundations

Foundations that extend into ground that has detrimental frost-action properties depend on the grip with which the permafrost holds them to combat movement. If foundations are not sufficiently embedded in permafrost to overcome frost-action forces, stable foundations should not be expected.

Economics

The economics of "building in the North" are different from those of the more accessible regions and apply to the construction of foundations as well as the superstructures. Transportation and labour costs are high. In addition, the interval during which construction can take place is restricted. In combatting the destructive actions of permafrost, the designer of the foundations and the superstructure should therefore carefully consider:

1. the availability and utilization of local materials;
2. the time when construction can take place to plan an orderly material and work schedule;
3. the use of light-weight building materials to cut transportation costs;
4. the possibility of deviating from conventional building design to produce a more functional arctic dwelling.

CONCLUSIONS REGARDING FOUNDATIONS ON PERMAFROST

To avoid repetition, conclusions on the individual permafrost foundation types discussed have been re-arranged into two broader groupings, surface foundations and buried foundations.

Surface Foundations

Timber Mudsills

1. The timber mudsill is thought to be an unsuitable foundation for large or permanent buildings or for any type of building which has its site in soil susceptible to frost.

2. This type of foundation could be adapted to small, unheated structures but would probably be unsuitable for large ones. The larger the area, the greater are the possibilities of unbalancing the thermal equilibrium (not necessarily over the whole building site but even in a few sections in it) and producing differential movements of the structure.

3. Deterioration of exposed, treated, timber mudsills, in some localities can be expected in as little time as 5 years although a few have lasted 10 years.

4. The frequency with which timber mudsills appear in the Mackenzie River district should not, by any means, be taken as an indication of their effectiveness.

Timber Pad Foundations

1. Essentially, timber pad foundations are similar to timber mudsills. Conclusions 1 to 4 inclusive of "Timber Mudsills" apply to timber pad foundations.

2. Some large buildings favoured this type of foundation, placing the spread footings on the undisturbed ground surface. It is thought that the main reason for this choice was to avoid costly excavation. However, this practice is not recommended especially if the building is heated, for there is no guarantee that the floor of the structure will be insulated well enough to prevent lowering of the permafrost table.

Concrete Pad Foundations

Concrete pad foundations behave in a like manner to timber pad foundations. Their only advantage to timber mudsills and timber pad foundations is their greater durability.

Buried Foundations

Pile Driving

1. The importance of not disturbing the vegetal cover during pile driving cannot be over-emphasized. This is usually very difficult to

achieve unless the area is covered with a layer of gravel to provide a working surface. If the ground at the site is soft, then some consideration should be given to the grading of the gravel used. There is a possibility that if the gravel is poorly graded, the larger sizes may well work their way to the bottom and break up the vegetal cover.

2. Due to the limited data, no definite conclusions on steam thawing have been reached. Steam pressure, size of jet nozzle and duration of steaming are best determined by field trials. Excessive steaming is to be avoided so that the refreezing of the pile will take place in as short a time as possible.

3. The practice of driving wooden piles butt-end first is commended. Frequently this will end the tendency for a pile to "pop up" or float in the thawed soil. An added benefit is the slight reduction in the upward frost heaving force.

4. The present practice of driving piles twice the thickness of the active layer into permafrost shows favourable results. Satisfactory results cannot be expected if subsequent heat losses from a structure increase the thickness of the active layer.

5. Pile driving should precede actual construction of the building by the length of time required for the piles to freeze in. In areas where the permafrost table is low or where permafrost occurs in sporadic islands, it could be carried out during the previous winter. Where permafrost is only a few feet below the surface, piles can be driven a month or less before construction of the building proper.

Pile Foundations

1. Piles are best suited as foundations for buildings with high floor loadings or where the building site is low-lying and poorly drained. When used as foundations for heavy machinery, such as motors, pumps, or boilers, present practice favours that they be separate from the foundations for the rest of the structure. Differential settlement of the structure will thus not normally affect the machinery.

2. When using pile foundations, basements are not usually possible. Partial basements are possible, but extreme care must be exercised so that the thermal régime of the building site is not altered. If a basement is essential, other types of foundations will probably be found more satisfactory.

3. When using piles, it is extremely important that the permafrost table is not lowered later during the life of the building. Ground insulation, such as additional moss covering, an airspace under the floor, building skirting or banking, type and location of heating unit, and floor insulation are important aspects which should be considered along with future use of the structure.

4. There is much reason to doubt the effectiveness of tarpaper and grease collars on piles to reduce frost heaving. They may be effective to a certain extent during the first year, but they are thought to have no value in subsequent years. Thought to be more effective in curbing frost heaving are the "shoes" sketched in Fig. 33.

5. There has been some controversy as to the detrimental effects of heat flow down a steel pile. The results of Hemstock (although limited) show that for buildings under normal conditions, the subsequent lowering of the permafrost table around the pile is so small that it should not affect the performance of the pile.

Timber Posts

On the whole, timber post foundations were found unsatisfactory as they are very susceptible to frost heaving. Because of this, their future use will probably be restricted to areas where permafrost is a few inches under the vegetal cover and, in such areas, for unheated buildings or ones well insulated from the ground.

Concrete Piers

1. Short concrete piers, if not battered, were also found to heave due to frost action. The practice of using concrete posts as supports for the porches of buildings is unsatisfactory. Differential movement of the building and the porch may be so pronounced that entrance doors may become unserviceable.

2. Battered concrete piers appear to give favourable results. They are relatively massive and have been used as supports for extra heavy loads. A batter of 3:1 in the active layer and embedment in permafrost, equal to that of the active layer, have been effective in curbing frost heaving. Modification of these figures (decreased embedment in permafrost) are in order if the depth of the active layer exceeds 3 to 4 feet.

3. As with all types of permafrost foundations, concrete piers will be ineffective if there is a lowering of the permafrost table during or after construction. This effect, even if minimized, is usually unavoidable and must be allowed for in the design of the foundations.

Concrete Pad Footings

1. Relatively more favourable results were observed for buried concrete pad footings. If the footings penetrated permafrost for some distance then fluctuations of the permafrost table would not be felt immediately unless the permafrost table fell below the footings. Frost heaving in these cases is not generally experienced as the pad forms a large anchor or shoe. However, the post that transmits the load to the pad should be well tied in with the pad as it is possible for failure to occur at this junction.

2. Although design data is limited, the rule of thumb to extend the footings in permafrost equal to that of the active layer appears satisfactory. This rule should give favourable results where the permafrost table is high but must be modified for areas of low-lying permafrost.

Concrete Wall Footings

1. Observations of present practice with concrete wall footings seem to indicate that no major modifications of design have been carried out for construction on permafrost. The result of this can be clearly seen in many deformed buildings with concrete wall footings in the Mackenzie River district.

2. Modification of standard design is essential for not only has the insulating vegetal cover been removed but, in cases of basements, the heat source is more difficult to insulate. The usual one-foot gravel mat below the basement floor is insufficient. A substantial gravel fill (3 to 4 feet) with perhaps a false floor, is the type of design that is required.

Miscellaneous Foundations

The view that buildings with satisfactory basements could be constructed by having basement and superstructure on separate foundations was suggested bymany in the field interviews.

1. The chief criticism of this type of design is that if the heating unit is to be in the basement, there will follow a lowering of the permafrost table which will affect the superstructure foundations as well as the basement. If the basement unit is constructed as a rigid reinforced concrete box then it can withstand the preliminary settling that occurs until a new thermal equilibrium is established. The superstructure, in this case, must of necessity be of rigid construction. Not only must it absorb the initial movement but it must withstand the probable increased heaving and settling that the lowering of the permafrost table produces. It is therefore doubted if this type of rigid construction is economically practical. However, it is thought that this design can be modified in the following manner.

2. Much of the failure in the building reported in Example 25 on page 24 can be attributed to the heaving and settling of the mudsills. Surface spread footings would probably react in the same way. The superstructure footings should, therefore, extend into the ground. Since the basement excavation is necessary, the added expense of carrying these footings for 3 or 4 feet below the basement floor is negligible. The reinforced concrete basement floor is placed on a gravel mat as a slab separate from the rest of the structure. A timber wall, with space between it and the excavated side wall, is packed with shavings as insulation. Columns in the basement are equipped with jacks to compensate for any intitial settlement. For details, see Fig. 32.

PART V RECOMMENDATIONS

When a review of the building foundations constructed at the various settlements was made, one interesting feature became evident. In the one thousand miles of river, ending at the Arctic Ocean, with the site conditions at settlements and buildings ranging from gravel to silt, and with varying depth and extent of permafrost, there is no pattern to the foundation types encountered. Construction techniques and details are frequently similar even though ground conditions vary considerably.

The Mackenzie River Investigations of 1950 showed that, with present practice, for every foundation type used there are more unsatisfactory foundations than successful ones. This does not mean, of course, that all of the present types of foundations are unsatisfactory. Since some have been successful, it would seem to indicate that foundation types can be adapted for specific ground conditions. Since soil conditions vary appreciably, the selection of foundations for almost every building presents a separate problem.

While too much importance cannot be attached to the selection of foundations for specific soil conditions it should be borne in mind that the cost and function of the structure can sometimes be the controlling factors in foundation selection. As an extreme example, it would be folly to have mudsill foundations for a large and expensive building resting on frost-susceptible soil. Mudsill foundations on frost-susceptible soil would be quite justifiable, however, for a small, unheated building storing non-perishable items. Economics can, therefore, modify the initial foundation selection.

RECOMMENDED PROCEDURES

Before the foundations for a structure can be selected, conditions at the site must be known thoroughly. Foundation selection should therefore follow the following sequence:-

a. Reconnaissance survey;
b. Site survey;
c. Cost and function study;
d. Foundation selection.

a. Reconnaissance Survey

The first step suggested in choosing the site of a proposed building is to obtain all possible information on topography, drainage, vegetation, permafrost, and housing in the general area where the structure is to be built. While this information is best obtained by field inspection, this is not economically possible in many cases because of the long distances involved. To a limited extent, various government departments may be able to supply information about the areas concerned. In most cases, however, an exhaustive literature survey will have to be carried out.

From the considerations of topography, vegetation, and geology (outlined in Part II, "Permafrost"), supplemented with other local information, one or two preliminary sites can then be chosen. Preference should be given to sites which

(i) Are underlain by bedrock at a convenient distance below the ground surface; or

(ii) Seem to indicate soil which, even if thawed, would provide a suitable foundation material; or

(iii) Are entirely free of permafrost or where permafrost occurs continuously as opposed to locations where it occurs in sporadic islands; and

(iv) Seem to indicate good drainage; and

(v) Show no signs of frost action such as frost mounds*, frost blisters* or frost boiling*; and

(vi) Are not at the foot of slopes as these sites may have groundwater seepages which may result in serious icing* during winter.

While the preceding conditions apply to specific site conditions, the general location of the structure should not be forgotten. The exact position of a building will not often be dictated by its functional requirements although "Radio Range" and "Instrument Landing System" buildings are two notable exceptions. Generally a certain flexibility of location is allowed. The building should of necessity be in the general area of the settlement or in the vicinity of other buildings to which it is related. For convenience, it should be reasonably close to the stores it requires and, if a dwelling, close to the other residences of the settlement.

b. Site Surveys

When the reconnaissance survey has picked out one or, better still, several possible sites, site surveys should be carried out at these locations. For small structures they need not be elaborate and for "cheap" construction may be omitted entirely. For a dwelling, six to nine appropriately placed bore-holes with a hand auger will be sufficient if the permafrost appears to be continuous, and constant in material and depth. If the bore-holes reveal irregularities such as the permafrost existing in sporadic islands and at varying depths, the existence of large ice lenses, or a changing of the soil profile, then additional holes should be bored. Understandably, a boring log must be kept and should record:-

(i) A sketch of the area showing topographic and drainage forms;
(ii) The soil profile;
(iii) The groundwater level;
(iv) The extent of permafrost;
(v) The depth of permafrost;
(vi) The location and size of ice lenses, if any.

Representative samples of the active layer should be taken in addition to determine whether detrimental frost action can be expected. For convenience, grain size has been found to be a satisfactory criterion for recognizing probable frost-susceptible soils. Frost-susceptible soils are those of uniform grading with greater than 10 per cent of the particles finer than 0.02 mm. in size, and those non-uniformly graded with greater than 3 per cent of the particles finer than 0.02 mm. in size (8).

Preference should be given then to sites:-

(i) Having subsoil which, even if thawed, would provide a suitable foundation material, example - gravel;

(ii) Entirely free of permafrost or where permafrost occurs continuously, as opposed to locations where it occurs in sporadic islands;

(iii) Having good drainage;

(iv) Having an active layer with no frost-susceptible soil;

(v) Are not underlain by ice lenses;

c. Cost and Function Study

Before actually selecting the type of foundation it is well to review the cost and function of the building. "Cheap" or temporary structures do not need elaborate foundations. Similarly the function of the structure must not be overlooked. As an example, consider an engine generator building. The foundations of the building can be mud-sills if the engine generator is supported by separate foundations such as piles. Movement of the building is unimportant although differential movement of the engine generator is to be avoided.

d. Selection of Foundations

With this relatively detailed picture of the site, cost and function of the structure, the designer can now start to select the most suitable type of foundation. The primary choice will be governed by ground conditions although the cost and function may modify the choice.

The two ground conditions which will affect the foundation selection are the active layer and the permafrost zone. The active layer, although varying in depth and soil type, will present a standard form of problem, i.e. difficulties arising from frost-susceptible soil. The permafrost zone, however, presents a more complex problem since its depth, extent and thawed properties affect appreciably the choice of construction techniques and foundation types. Accordingly, foundation selection in areas of continuous permafrost and in areas where it occurs in sporadic islands are dealt with separately in the next section. Construction techniques and foundation modifications for the active layer are then given since they are applicable to any permafrost region.

CHARTS FOR

CONSTRUCTION TECHNIQUE AND FOUNDATION SELECTION

After much thought, it was decided to condense the foundation selection recommendations into a self-explanatory graphical form. These recommendations are included in the three charts which follow. It should be borne in mind that they are based on one summer's study. Comments on the form or content of the charts will therefore be welcomed.

The three charts for Construction Technique and Foundation Selection are concerned with the two ground conditions that affect foundations, the permafrost zone and the active layer, as follows:

Chart I - Continuous Permafrost;
Chart II - Sporadic Islands of Permafrost;
Chart III - The Active Layer.

Combined, they attempt to answer the designer's questions on the type of construction and foundations for a particular building at a specific site.

Knowing the extent of the permafrost at the site, the selection of the foundation type is carried out in the following sequence from Chart I or II by considering:

1. The composition of the permafrost;
2. Construction techniques best adapted for the site;
3. The general type of foundation;
4. Cost or importance of the building;
5. Suitable foundation types in order of merit.

Chart III, "The Active Layer", is then applied in a similar manner and the construction technique and foundation type selected from Chart I or II is then modified to suit the conditions of the active layer. The heavy lines on the charts show recommended methods. Thus the charts can be utilized to a certain extent even in the field in the selection of building sites.

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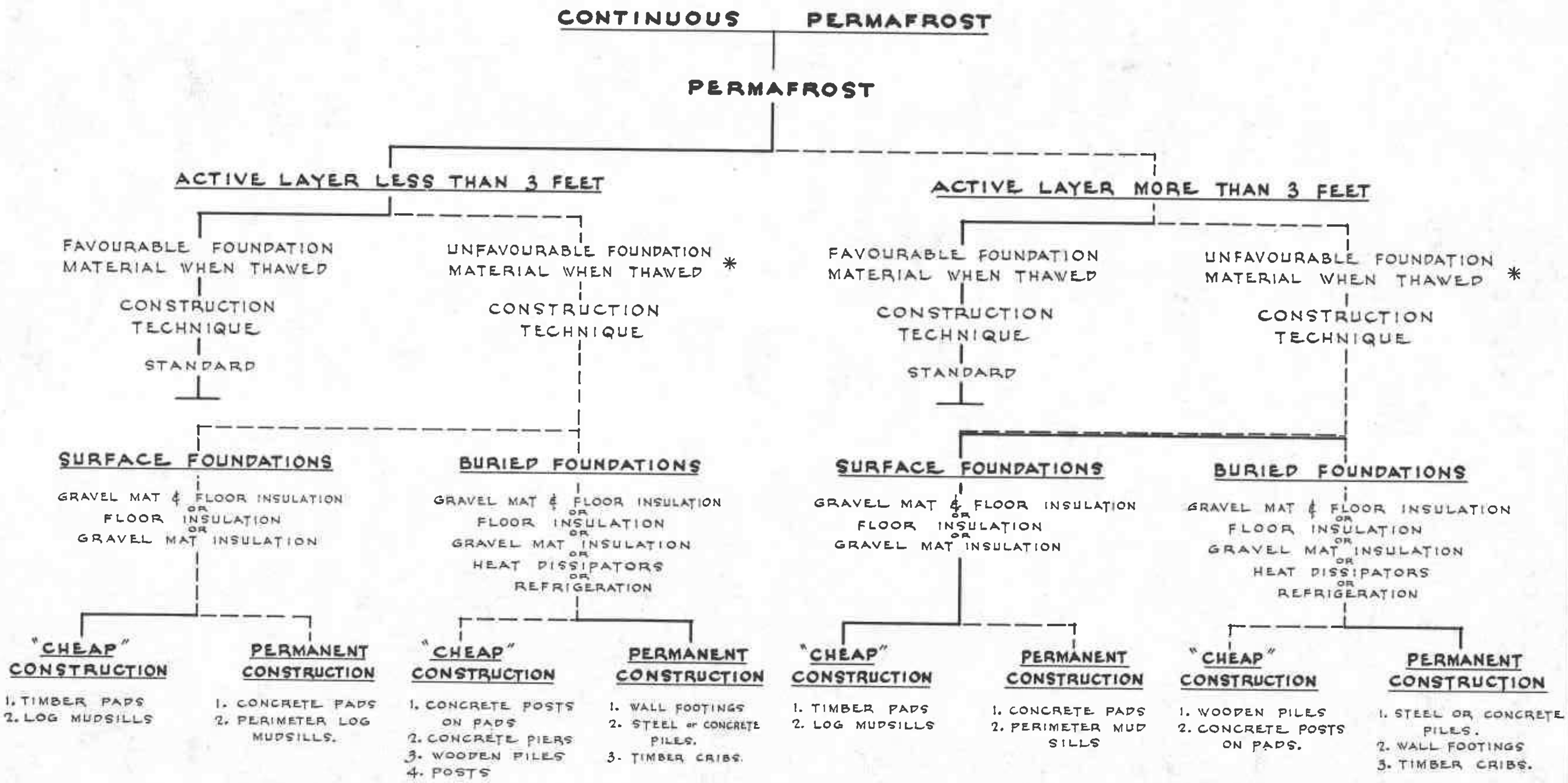
CONSTRUCTION TECHNIQUE AND FOUNDATION SELECTION
CHART I CONTINUOUS PERMAFROST



EVERY EFFORT SHOULD BE MADE TO PRESERVE THE PERMAFROST IN ALL FOUNDATION TYPES.

THIS CHART IS BASED ON A REVIEW OF THE FOUNDATIONS INVESTIGATED IN THE MACKENZIE RIVER DISTRICT DURING 1950. COMMENTS OR SUGGESTIONS WILL BE WELCOMED.

HEAVY LINES SHOW RECOMMENDED PATHS.

DRAWN: J.A.P. & T.N.A.	TRACED: T.N.B.	CHECKED: J.A.P.	APPROVED: R.F.L.	DATE:	SCALE:	TITLE: CHART I CONTINUOUS PERMAFROST	DWG. No. BR 176	SHEET:

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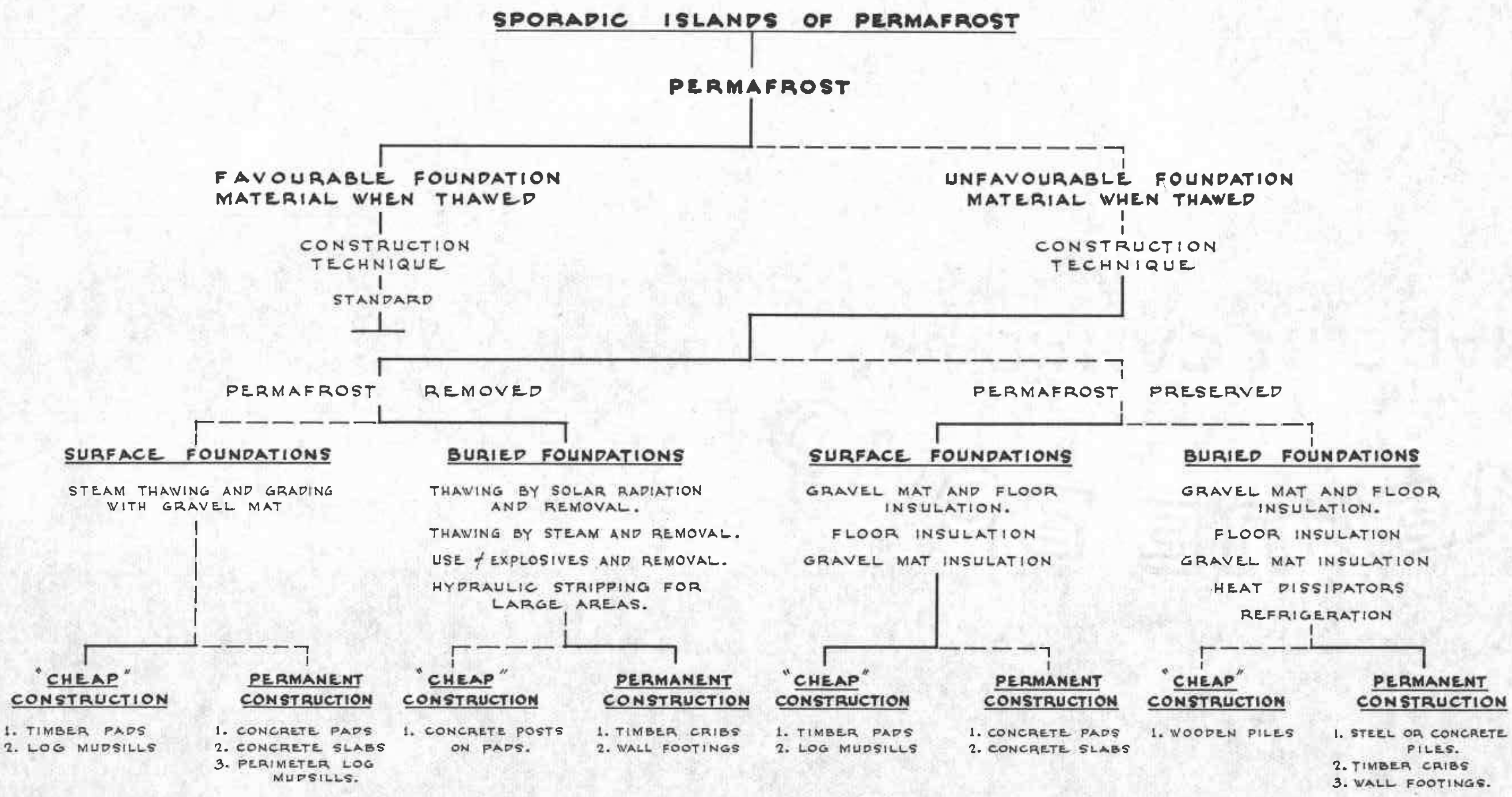
CONSTRUCTION TECHNIQUE AND FOUNDATION SELECTION
CHART II SPORADIC ISLANDS OF PERMAFROST

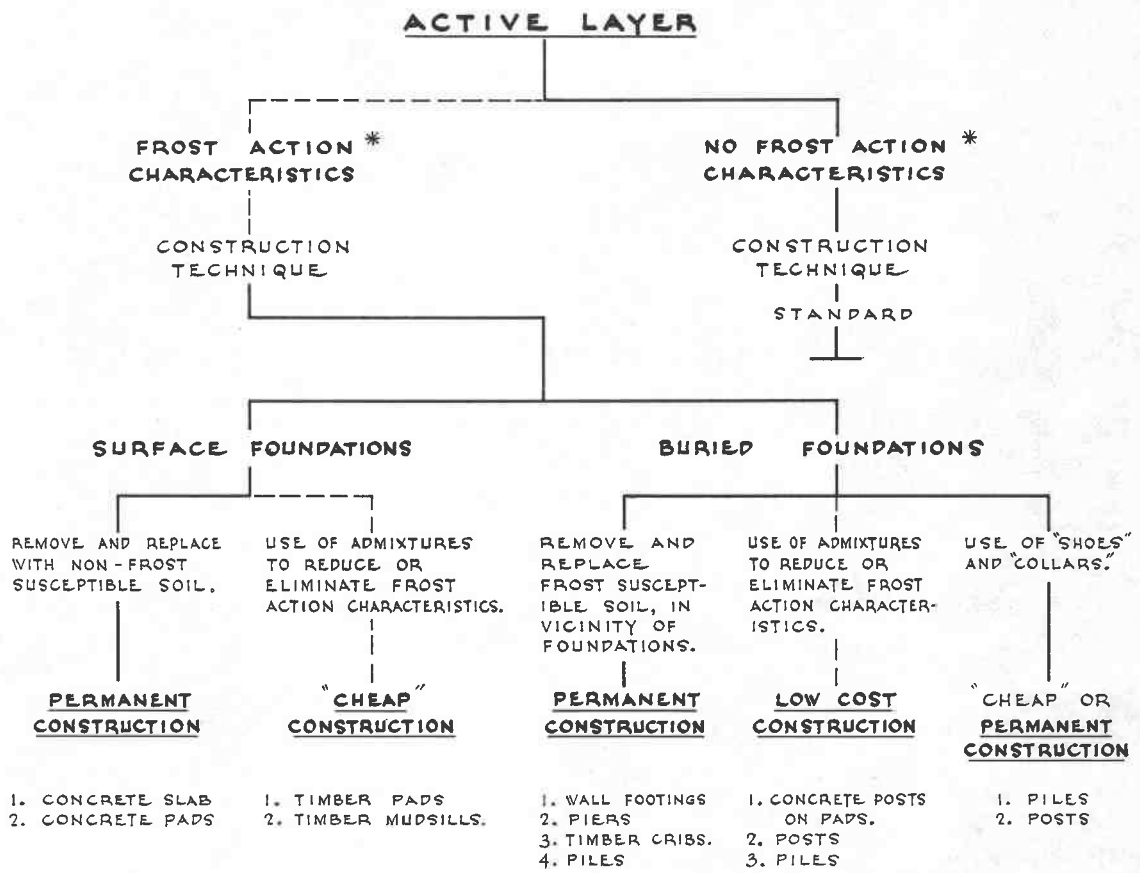


THIS CHART IS BASED ON A REVIEW OF THE FOUNDATIONS INVESTIGATED IN THE MACKENZIE RIVER DISTRICT DURING 1950. COMMENTS OR SUGGESTIONS WILL BE WELCOMED.

HEAVY LINES SHOW RECOMMENDED PATHS.

DRAWN: J.A.P. & T.H.B. | TRACED: T.H.B. | CHECKED: J.A.P. | APPROVED: R.F.L. | DATE: | SCALE: | TITLE: CHART II SPORADIC ISLANDS OF PERMAFROST | DWG. No. BR 177 | SHEET:

CONSTRUCTION TECHNIQUE AND FOUNDATION SELECTION
CHART III ACTIVE LAYER



THIS CHART IS BASED ON A REVIEW OF THE FOUNDATIONS INVESTIGATED IN THE MACKENZIE RIVER DISTRICT DURING 1950. COMMENTS OR SUGGESTIONS WILL BE WELCOMED.

HEAVY LINES SHOW RECOMMENDED PATHS.

* *FOR CONVENIENCE GRAIN SIZE IS A SATISFACTORY CRITERION TO SEPARATE FROST SUSCEPTIBLE SOILS FROM THOSE NOT SUSCEPTIBLE. FROST SUSCEPTIBLE SOILS ARE THOSE OF UNIFORM GRADING WITH GREATER THAN 10% FINER, AND THOSE NON-UNIFORMLY GRADED WITH GREATER THAN 3% FINER, THAN 0.02 MM. IN SIZE.*

DRAWN: T.N.B. & J.A.P.	CHECKED:	TITLE: CHART III ACTIVE LAYER	SCALE:	DWG. No. BR 178	SHEET:
TRACED: T.N.B.	APPROVED: RFL		DATE: 12-4-51		

CONCLUSION

The Division of Building Research of the National Research Council is aware of the fact that much of the information in this report is descriptive. The accumulation of design data in the field of foundations on permafrost is a long-term project which the Division has started only recently. The reader is again reminded that this report is based on information gathered during one summer's field trip. The early publication of the report was prompted because of the expressed need for such information by many members of the engineering profession. It is hoped this paper will prove useful to engineers, especially those actively engaged in "Building in the North". Comments on the report, especially upon the conclusions and recommendations, will be welcomed. The Division of Building Research, by means of its continuing field studies and close contacts with other departments of the Canadian government, as well as those of the United States government, will endeavour to keep Canadian engineers well informed on developments in this field.

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7. Sherwood, A. Letter to R. F. Legget, October 4, 1950. Mr. Sherwood is of the opinion that the present climate does not give the low temperature needed to maintain permafrost. In addition to the example of Norman Wells, he cites the case of Ft. Simpson Island. This island in 1924 had continuous permafrost 30 inches below the ground surface. Now the permafrost occurs in sporadic islands.

8. Casagrande, A. Discussion on frost heaving. Proceedings of the Highway Research Board, Vol. 11, p. 168, 1931.

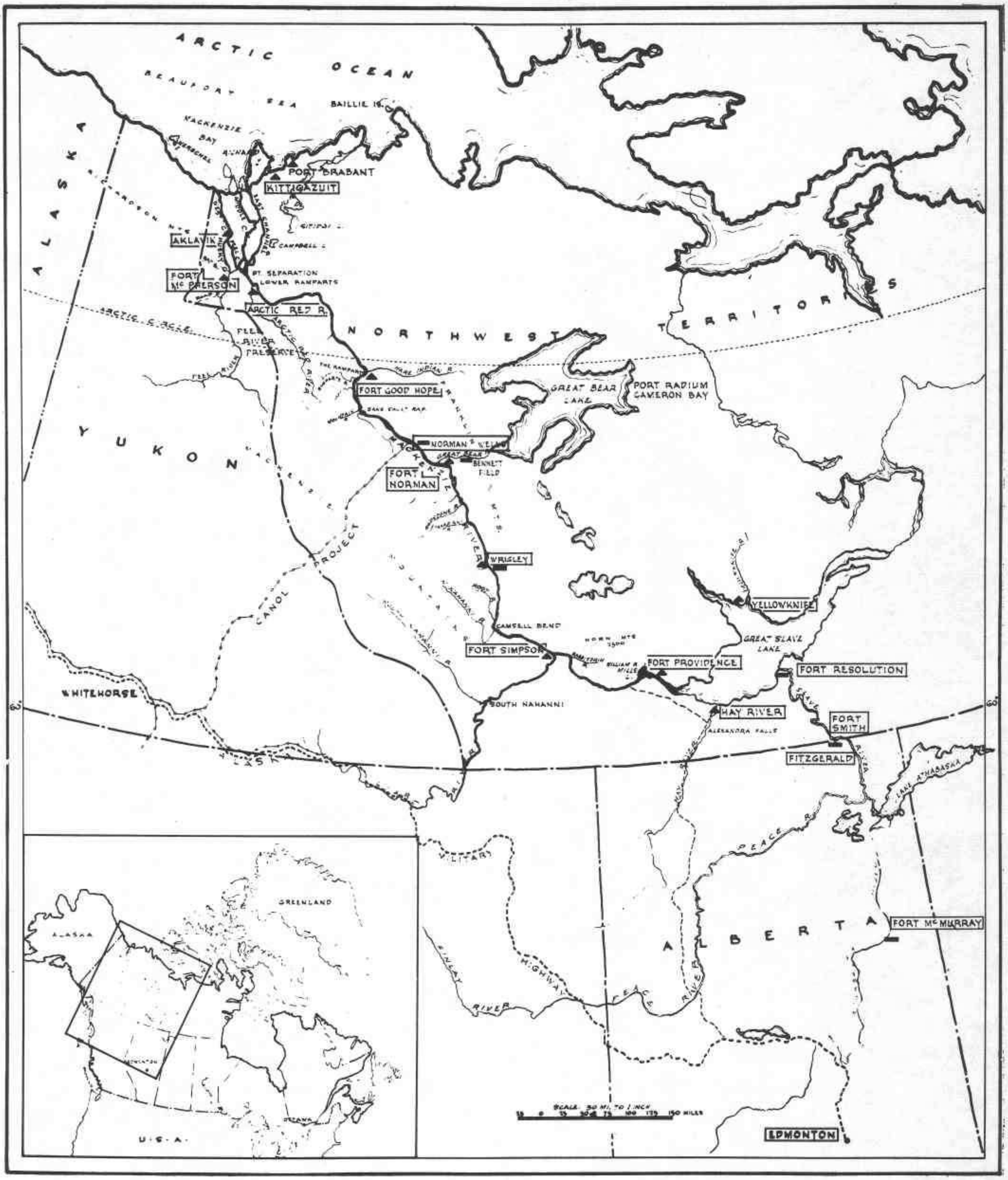
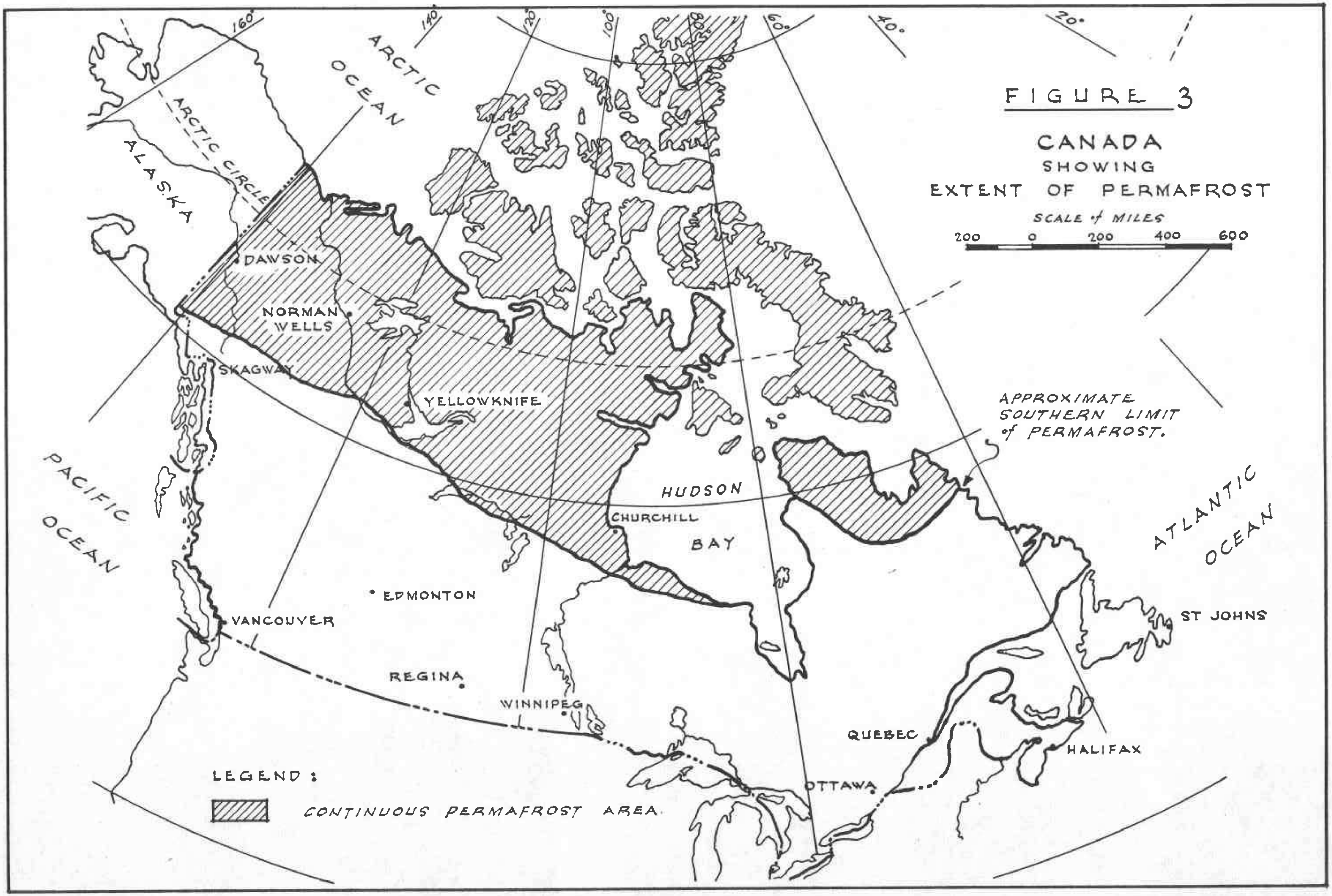


FIGURE 1

A MAP of NORTHWESTERN CANADA SHOWING THE DISTRICT of THE 1950 MACKENZIE RIVER INVESTIGATIONS of FOUNDATIONS ON PERMAFROST.

Fig. 2. Example of the destructive action of permafrost. Settling of the building due to lowering of the permafrost table has caused the centre girder to push out a portion of the concrete wall.



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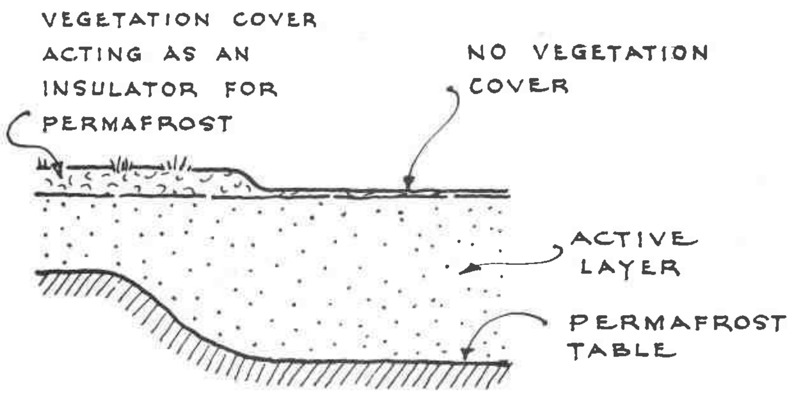


FIGURE 4

VEGETATION COVER ESTABLISHES NEW THERMAL EQUILIBRIUM.

FIGURE 5

EXCAVATION IN PERMAFROST

THE SOIL IS A SILTY CLAY CONTAINING ICE LENSES, PERMAFROST IS ENCOUNTERED SIX INCHES BELOW THE MOSS COVER. THE WATER IN THE TRENCH IS CAUSED BY THE MELTING OF THE ICE LENSES AND MUST BE DRAINED AS PERMAFROST IS IMPERMEABLE.

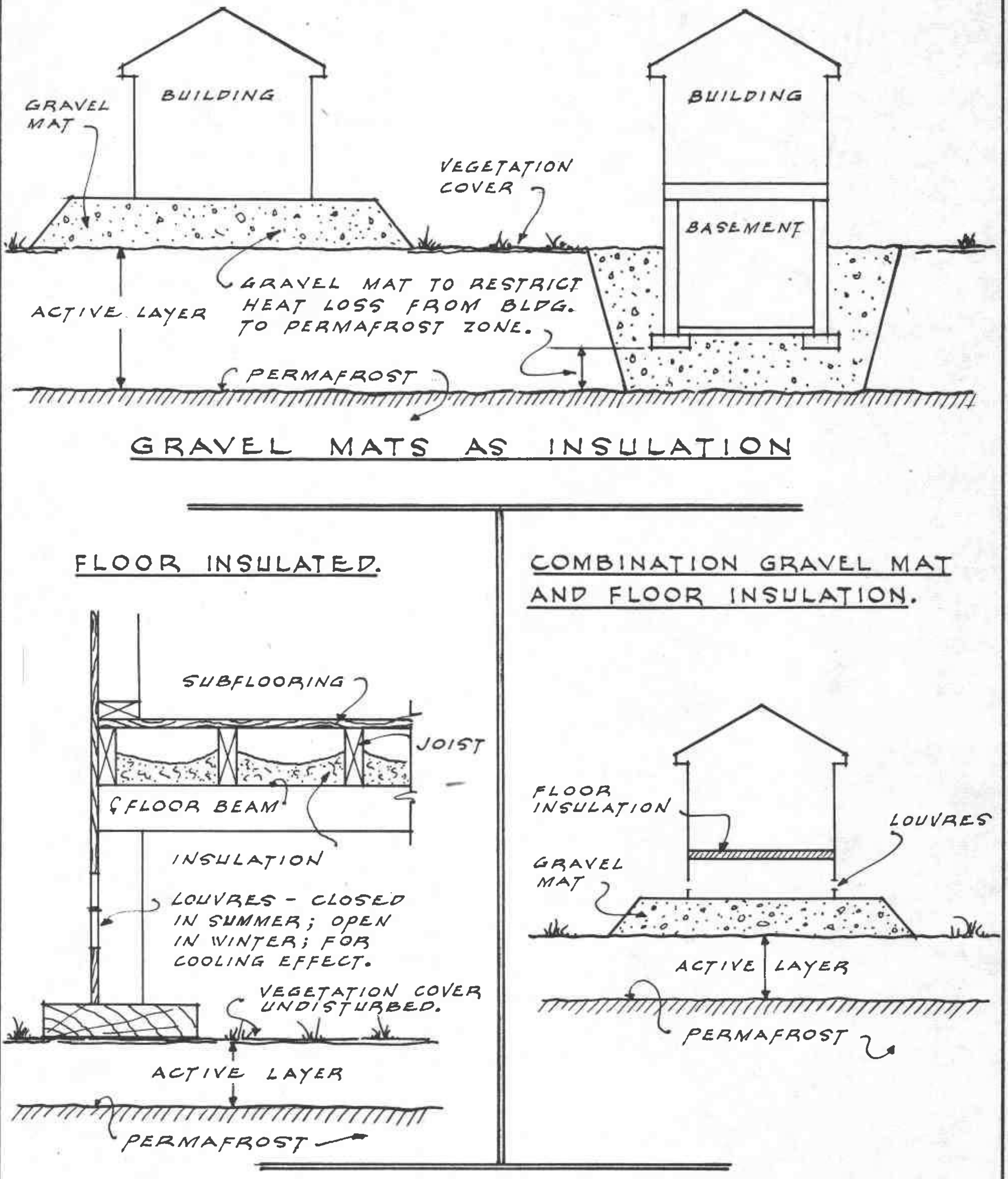
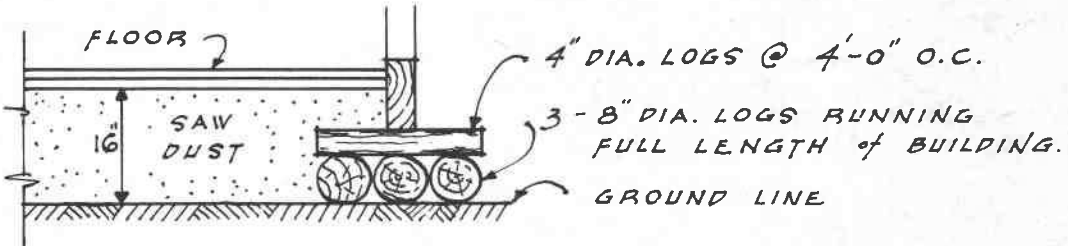
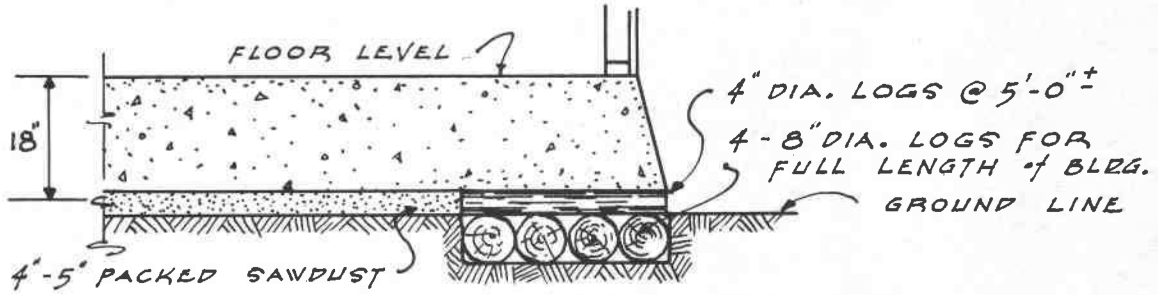


FIGURE 6

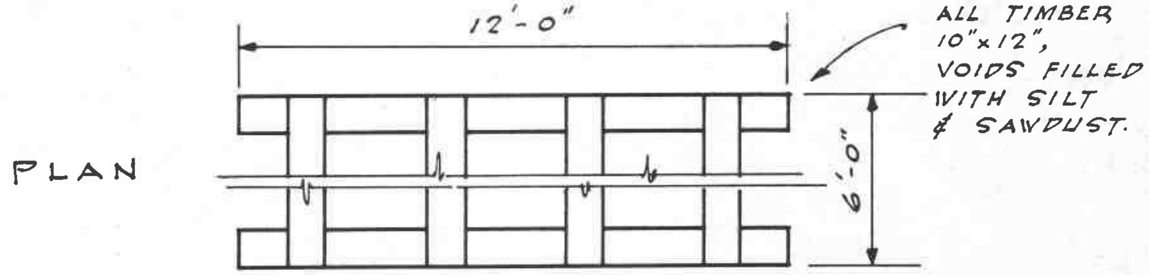
SOME EXAMPLES of CONSTRUCTION BY THE "PASSIVE" METHOD

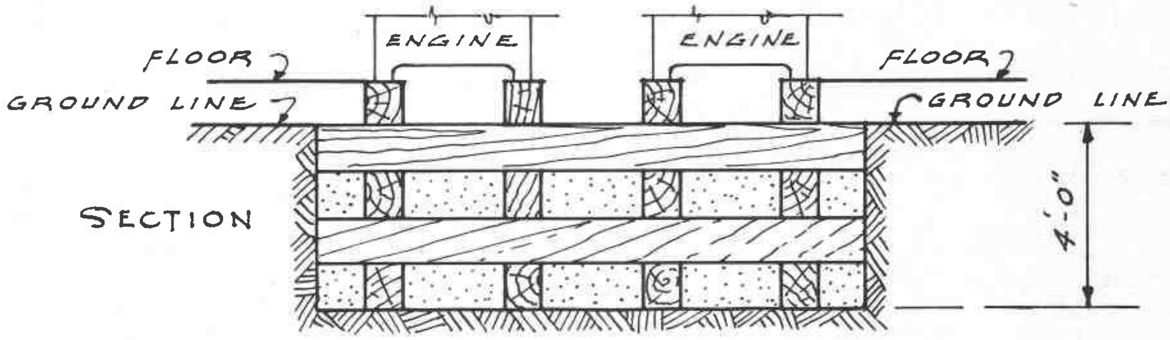


FOUNDATIONS of OLD PORTION of POWERHOUSE



FOUNDATIONS of NEW PORTION of POWERHOUSE





ENGINE BEDS of POWERHOUSE

FIGURE 7

FOUNDATION AND FLOOR DETAILS of AKLAVIK POWER CO. POWERHOUSE, AKLAVIK, N.W.T.

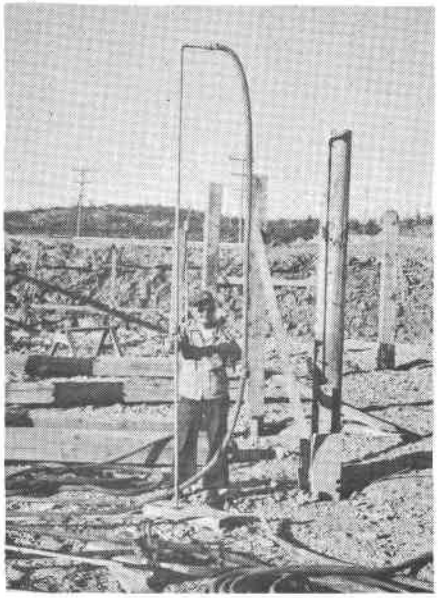


Fig. 8. Steam jetting pipe used at the Giant Yellowknife Gold Mines. The pipe is one inch in diameter with a single ¼-inch (approximately) nozzle.

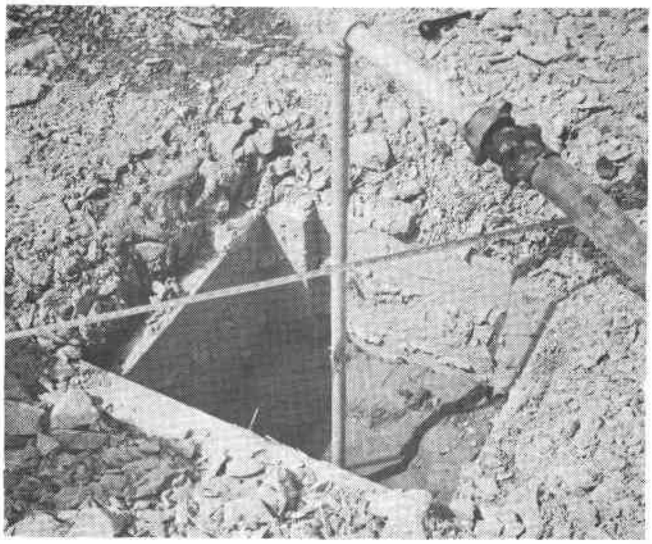


Fig. 9. Close-up of steam jet used at Giant Yellowknife Gold Mines for thawing pile locations. Note liquid nature of thawed soil, pipe "boxing", and protective mine-muck fill.

Fig. 10. Piles at Giant Yellowknife Gold Mines are "pushed" into the thawed soil by means of a D 8 Caterpillar, winch, and cable.

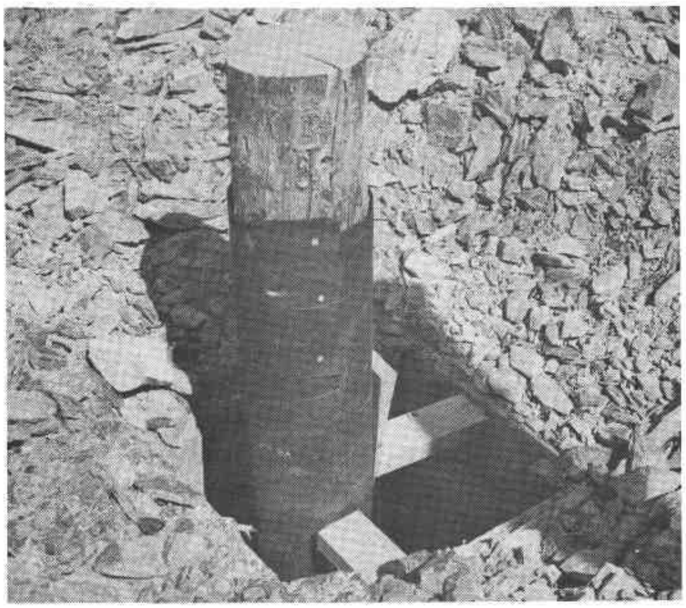


Fig. 11. Close-up of driven pile, cut off to desired elevation and wedged into position. Note tarpaper collar. (Giant Yellowknife Gold Mines, Yellowknife, N. W. T.)

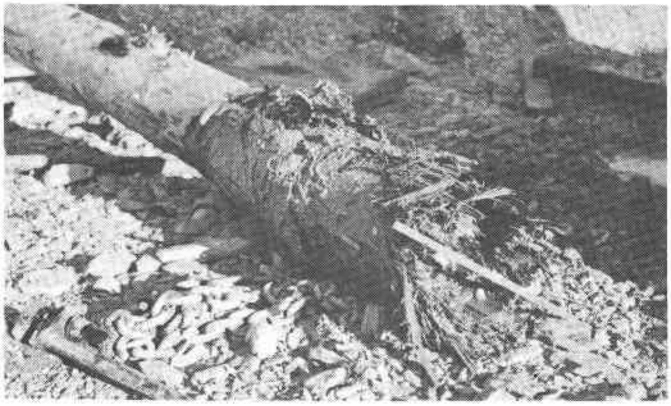


FIGURE 12

AN ATTEMPT WAS MADE TO PULL OUT THIS PILE TWO DAYS AFTER IT WAS DRIVEN. THE PILE FAILED AT GROUND LEVEL. (GIANT YELLOWKNIFE GOLD MINES, YELLOWKNIFE, N.W.T.)

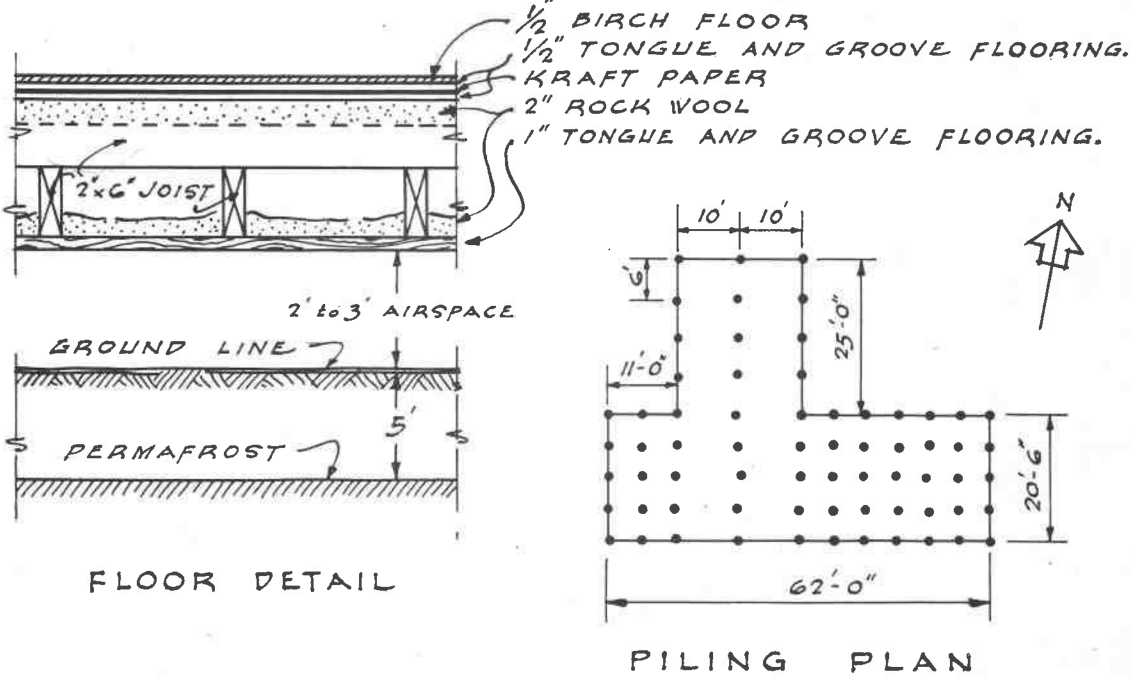


FIGURE 13

DETAILS of THE FOUNDATIONS AND FLOOR FOR THE MESS HALL, KITCHEN AND FOOD STORES of THE DEPARTMENT of TRANSPORT AT HAY RIVER N.W.T.

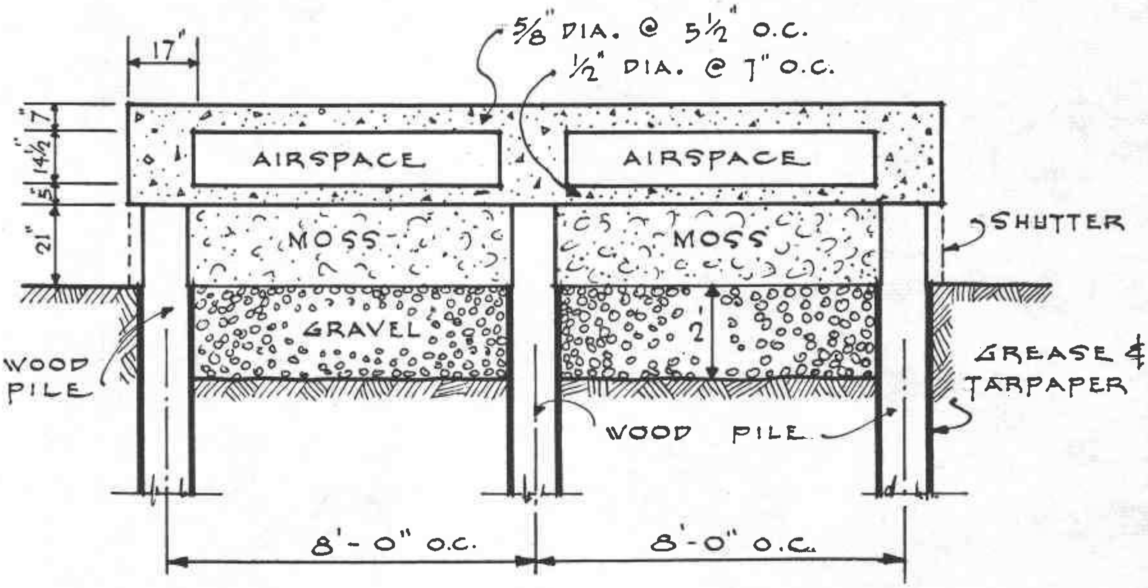


FIGURE 14

DETAILS of FLOOR AND FOUNDATION of THE HEATING BUILDING of THE INDIAN DAY SCHOOL TEACHERAGE, HAY RIVER, N.W.T.

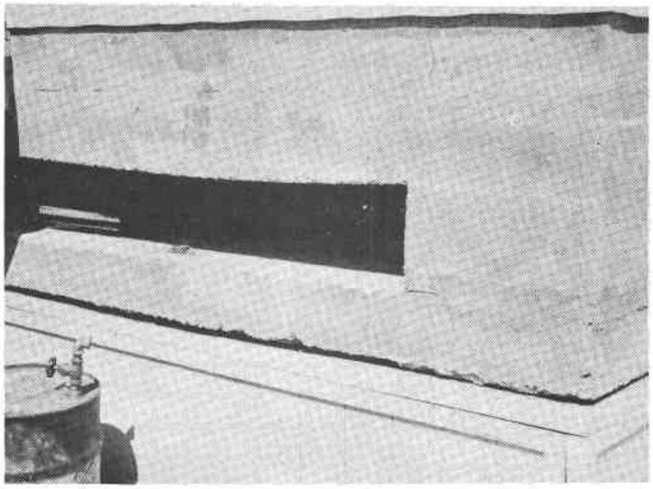


Fig. 15. Double or "false" concrete floor used to minimize heat flow into ground.

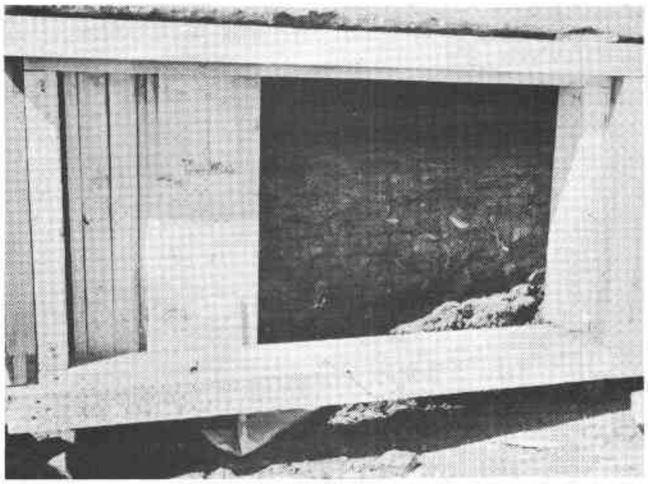


Fig. 16. Shutter removed to show insulation (moss) placed under the building.

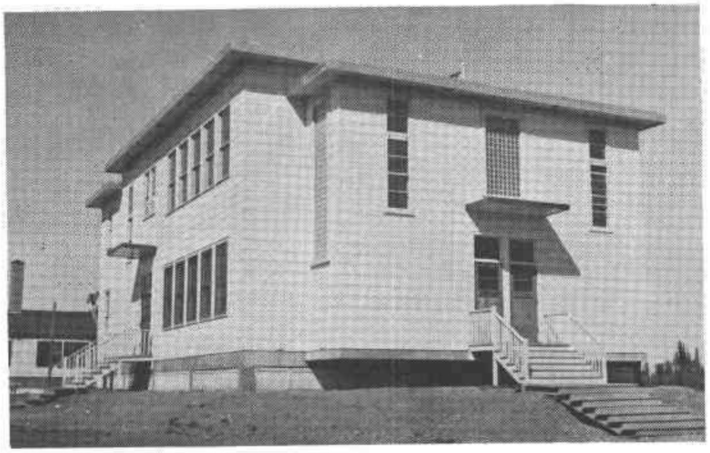
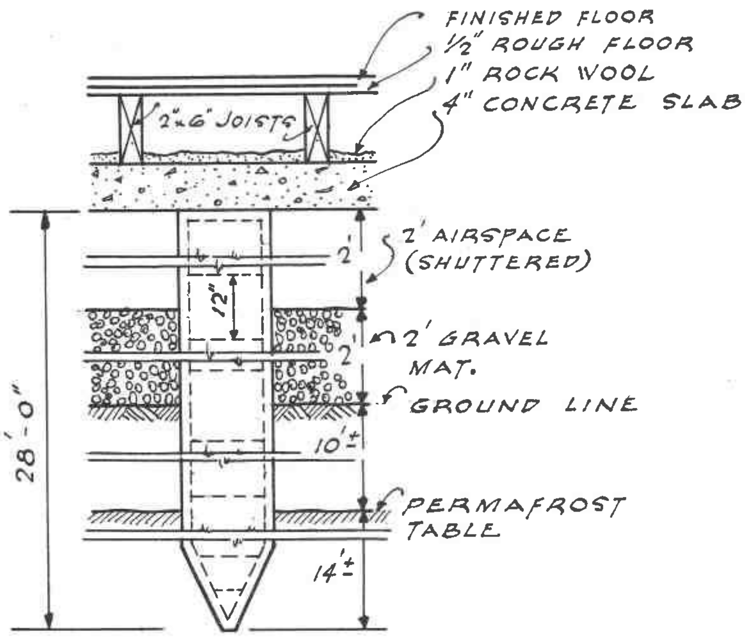
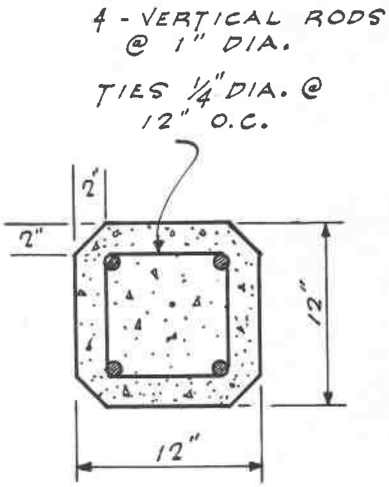


FIGURE 17

VIEW of FOUR - CLASSROOM INDIAN DAY SCHOOL AT HAY RIVER, N.W.T. NOTE TWO FOOT GRAVEL FILL AND SHUTTERS ENCLOSING AIR SPACE UNDER BUILDING.





PLAN of PILE

FIGURE 18

DETAILS of FOUNDATION AND FLOOR of FOUR - CLASSROOM INDIAN DAY SCHOOL AT HAY RIVER, N.W.T.

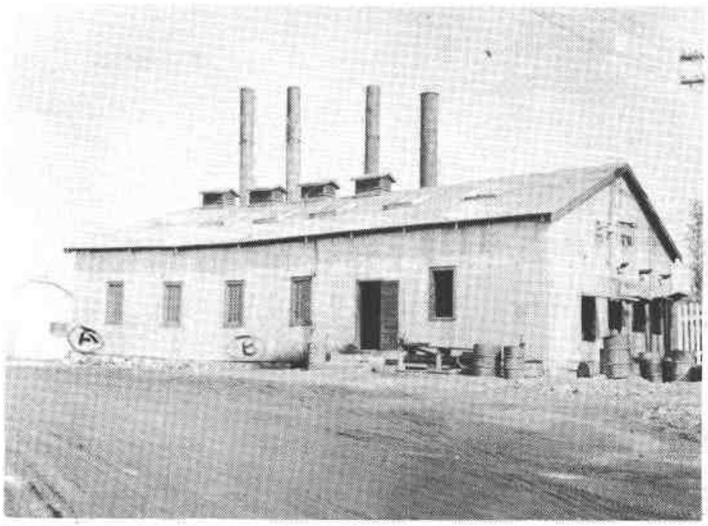


Fig. 19. Boiler house at Norman Wells. The main cause of settlement is that boiler washwater is allowed to drain under the building.

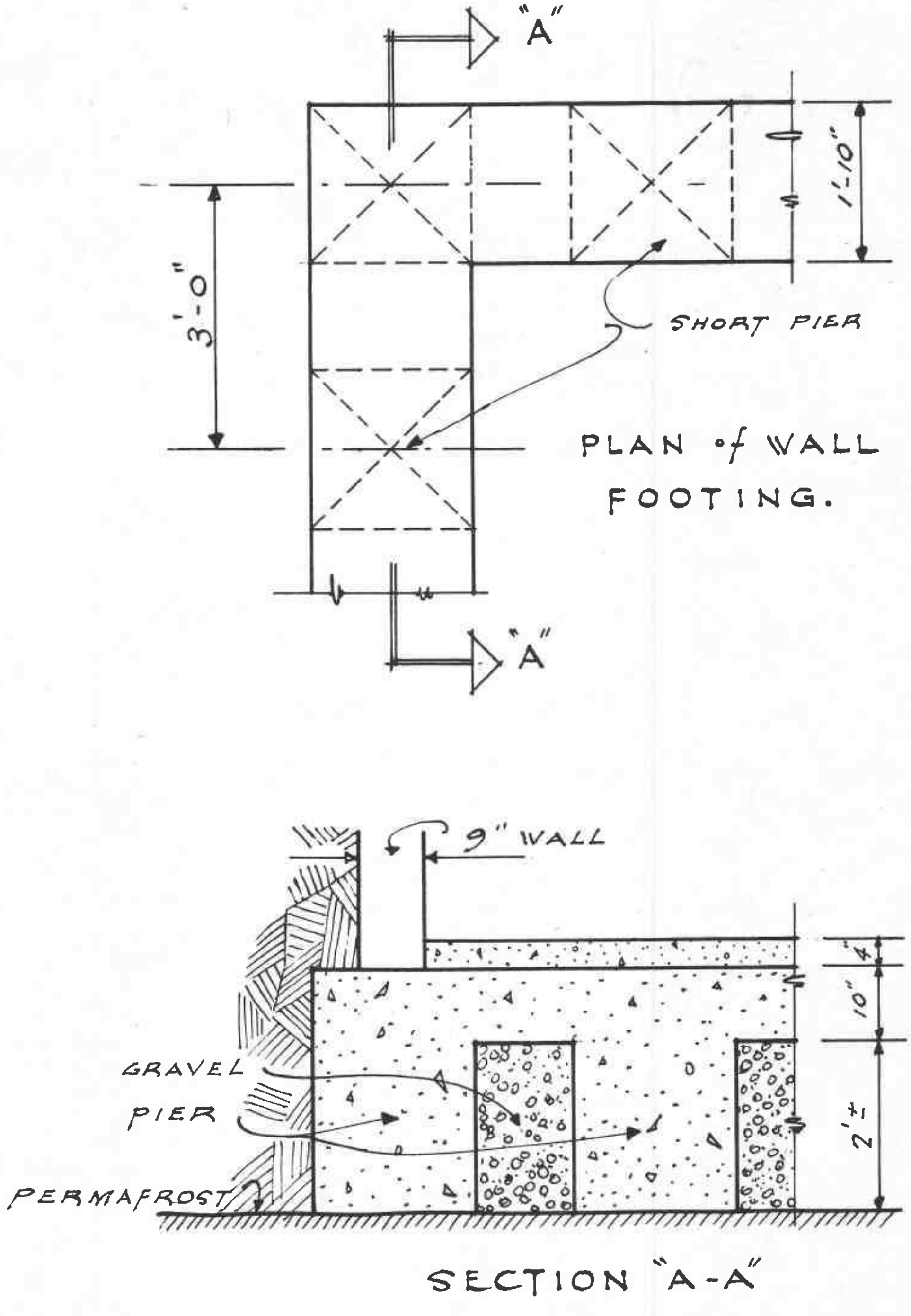


FIGURE 20

DETAILS of FOUNDATION of DEPARTMENT of TRANSPORT FAMILY QUARTERS AT HAY RIVER, N.W.T.

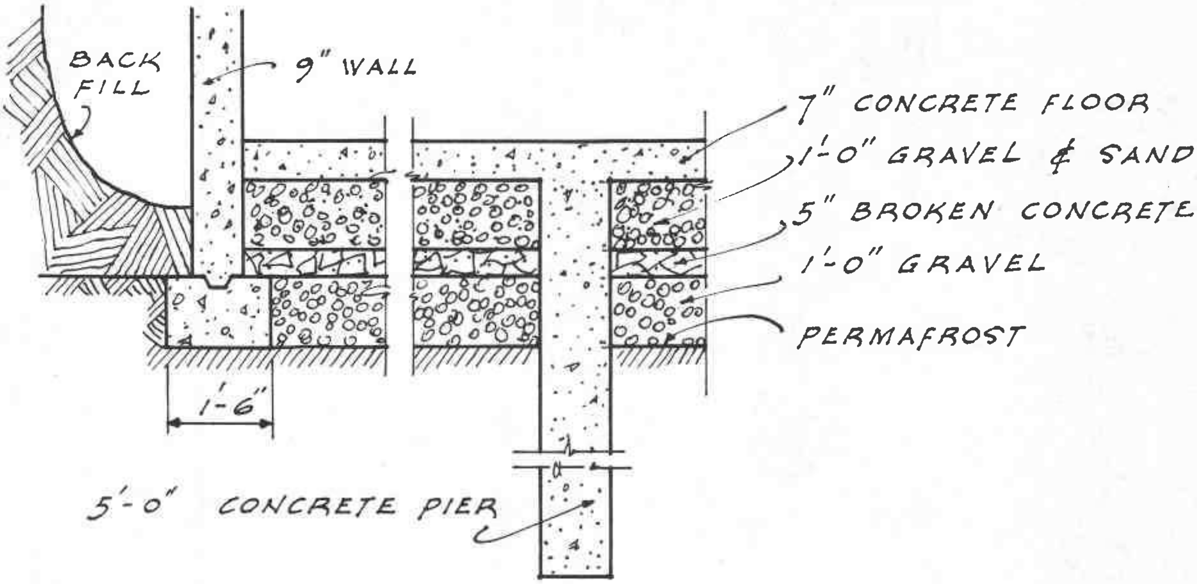


FIGURE 21

DETAILS of FOUNDATION of THE R.C.C.S. RADIO STATION AT HAY RIVER, N.W.T.

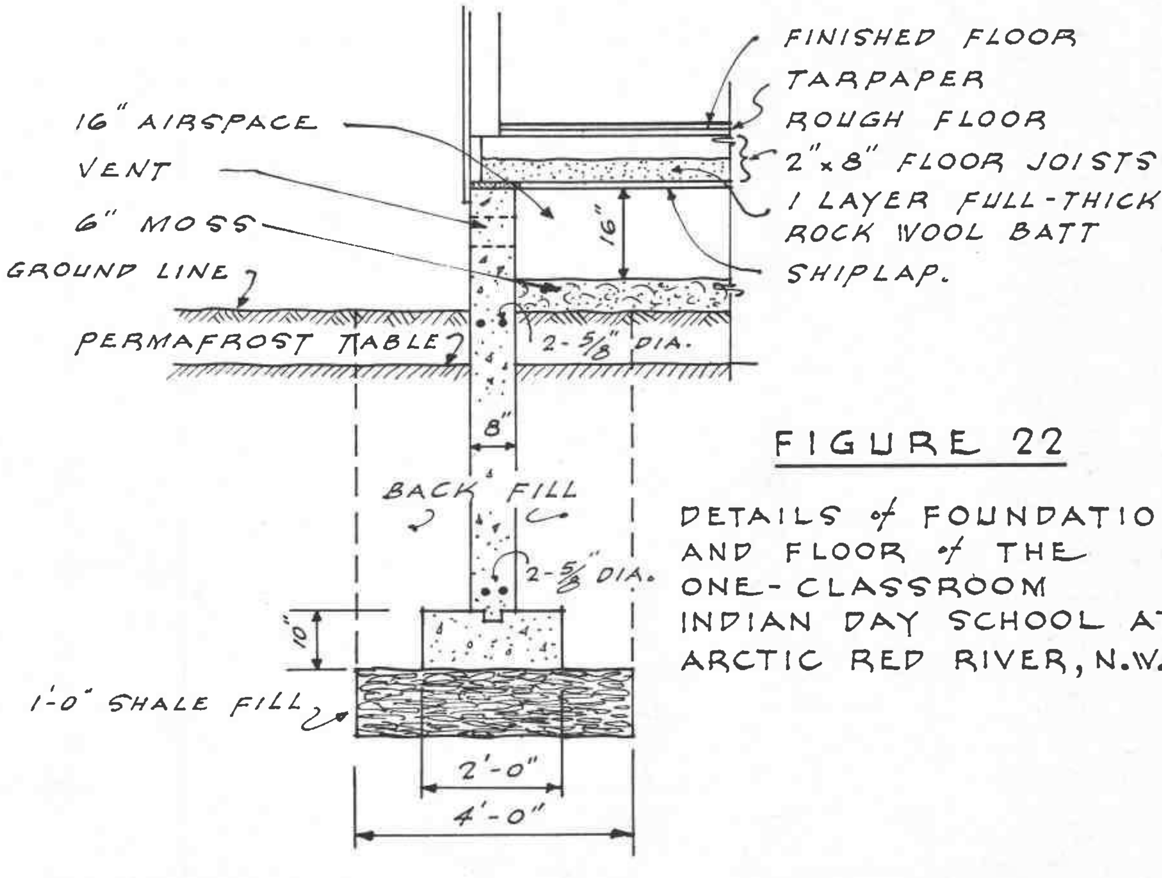


FIGURE 22

DETAILS of FOUNDATION AND FLOOR of THE ONE-CLASSROOM INDIAN DAY SCHOOL AT ARCTIC RED RIVER, N.W.T.

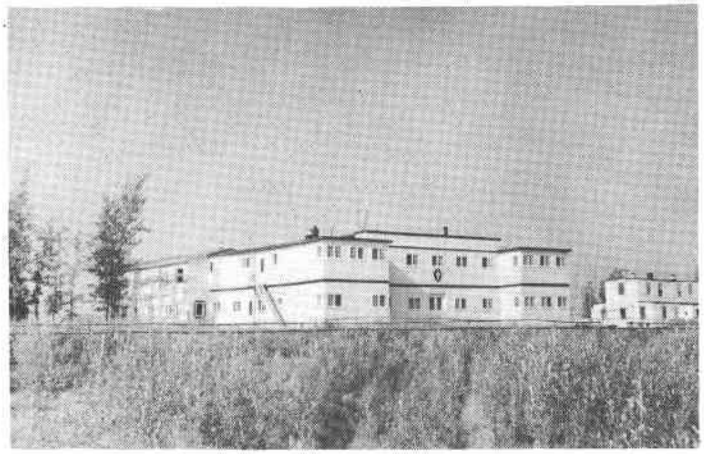


Fig. 23. All Saints Mission Hospital (Anglican), Aklavik, N. W. T. Annex under construction at left.

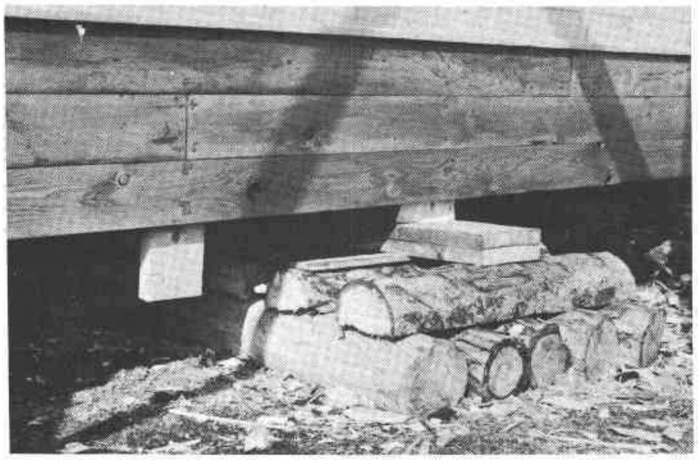


Fig. 24. Timber pad footings used at All Saints Hospital (Anglican) Annex, Aklavik, N. W. T.

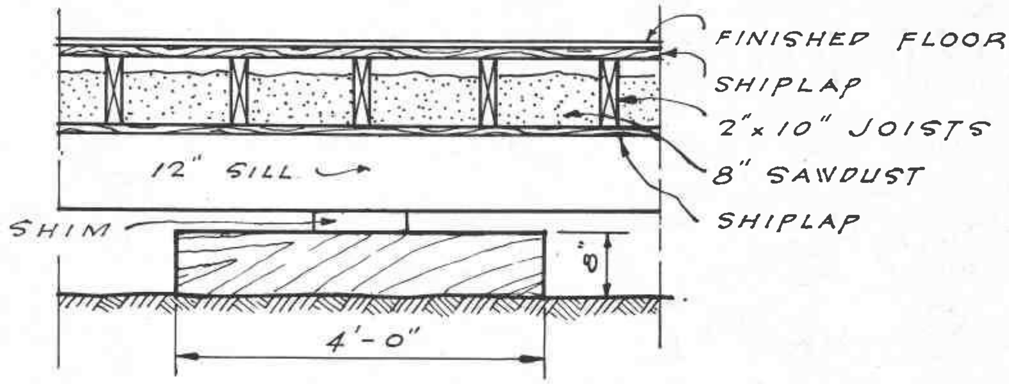


FIGURE 25

DETAILS of FLOOR AND FOUNDATIONS of THE INDEPENDENT TRADERS' STORE, AKLAVIK, N.W.T.

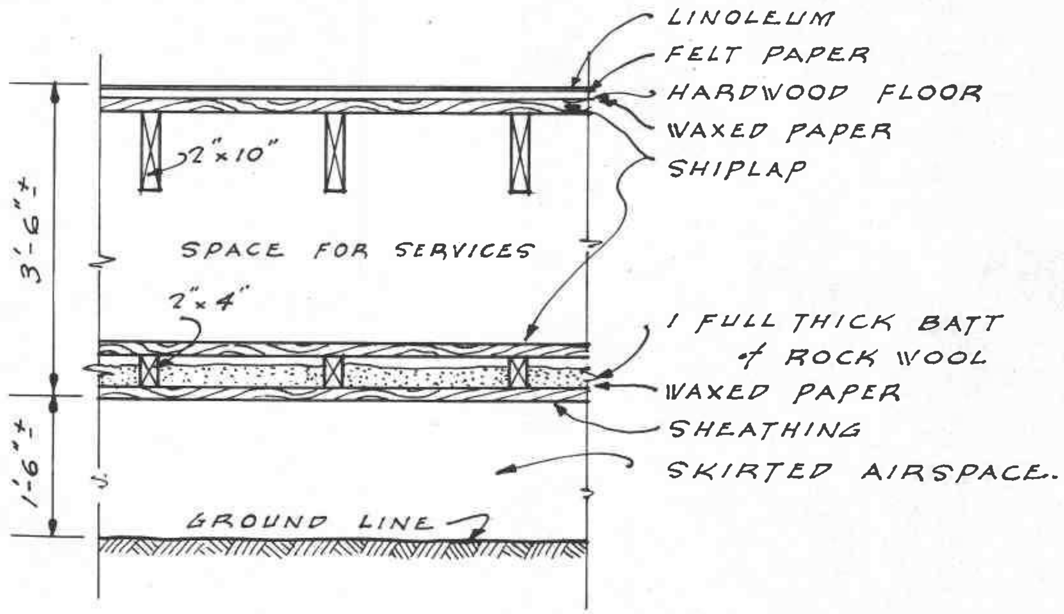


FIGURE 26

DETAILS of FLOOR AND FOUNDATIONS of THE R.C.C.S. MARRIED QUARTERS (WO I) AT NORMAN WELLS, N.W.T.

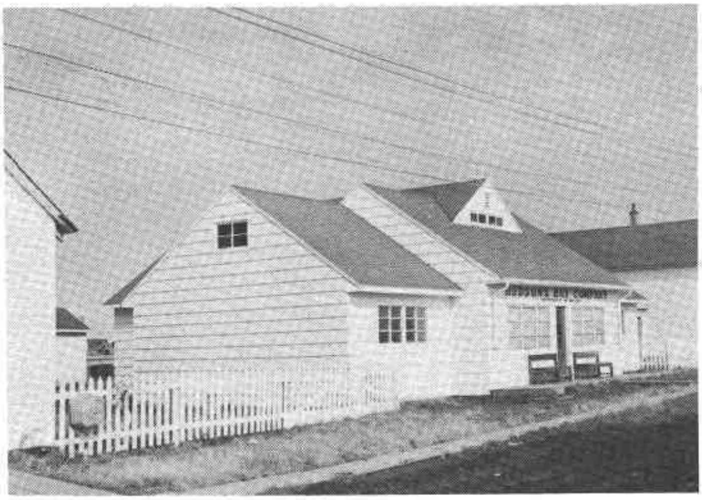
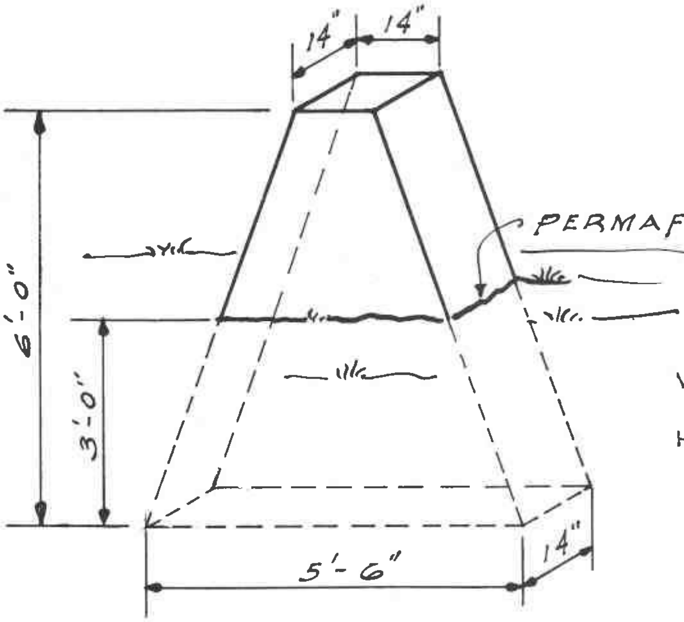


FIGURE 27

HUDSON'S BAY COMPANY STORE, AKLAVIK, N.W.T.



REINFORCEMENT

VERTICAL - 6 - 5/8" DIA. BARS.

HORIZONTAL - 4 - 5/8" DIA. BARS TOP & BOTTOM.

FIGURE 28

DETAILS of SPECIAL CONCRETE PIER USED IN THE FOUNDATIONS of THE TWO-CLASSROOM INDIAN DAY SCHOOL, AT FORT GOOD HOPE, N.W.T.

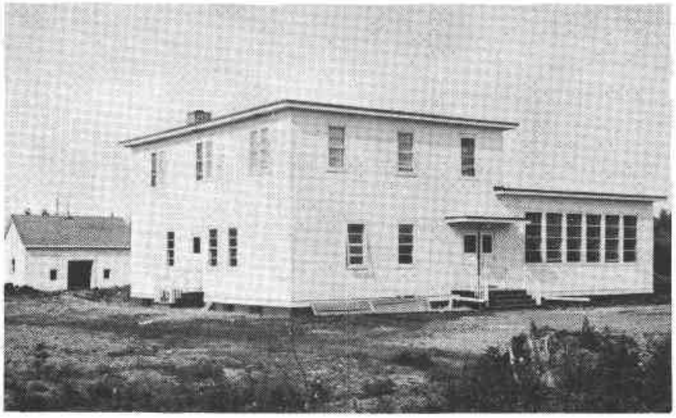


FIGURE 29

TWO-CLASSROOM INDIAN DAY SCHOOL
FORT RESOLUTION, N.W.T.

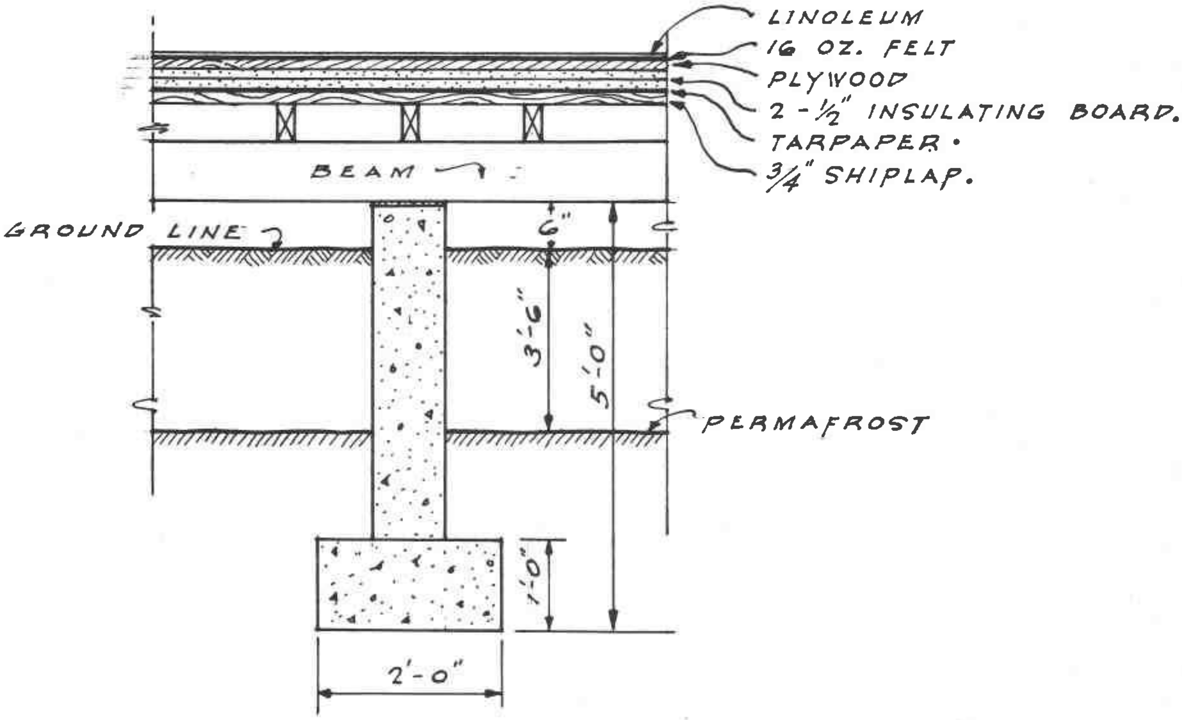


FIGURE 30

DETAILS of FLOOR & FOUNDATION of THE HUDSON'S BAY COMPANY RESIDENCE (TYPE 12DB) AT FORT MAC PHERSON, N.W.T.

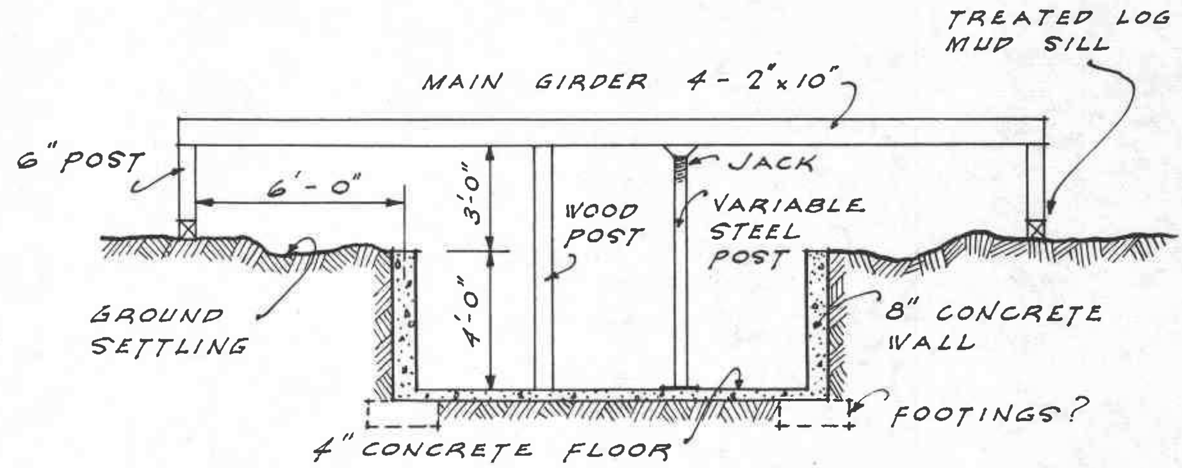


FIGURE 31

DETAILS of FOUNDATION FOR THE R.C.C.S. MARRIED QUARTERS (WO II) AT AKLAVIK, N.W.T.

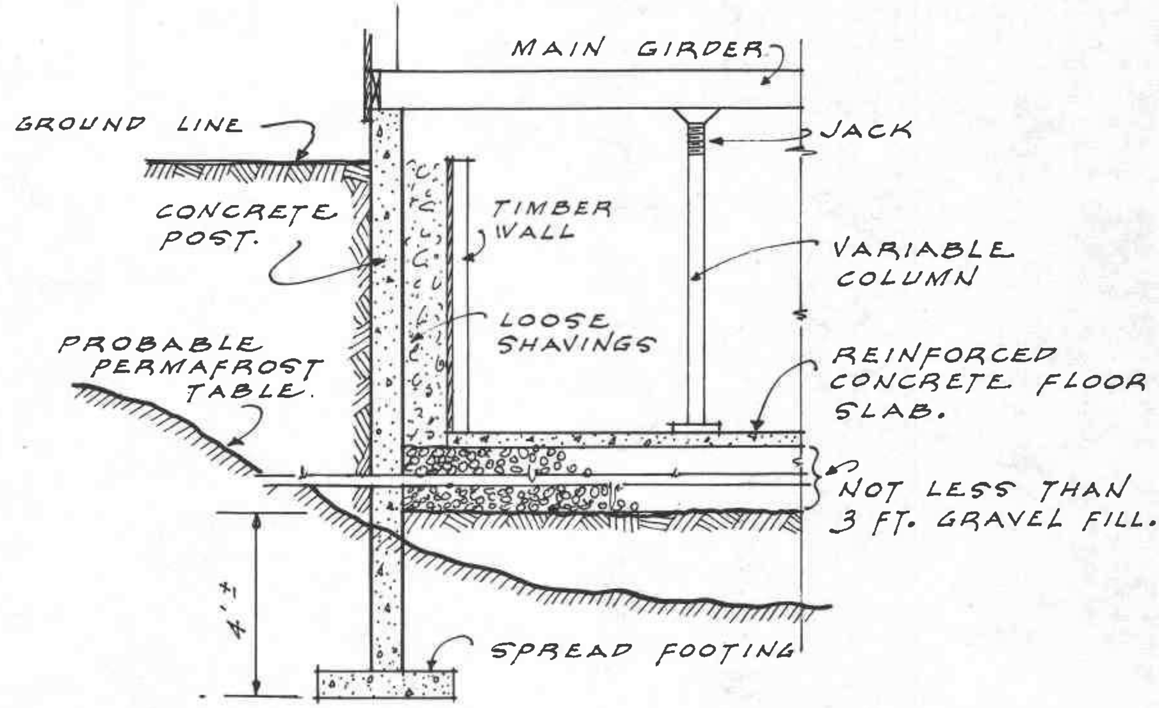


FIGURE 32

DETAILS of SEPARATE BASEMENT AND WALL FOUNDATIONS.

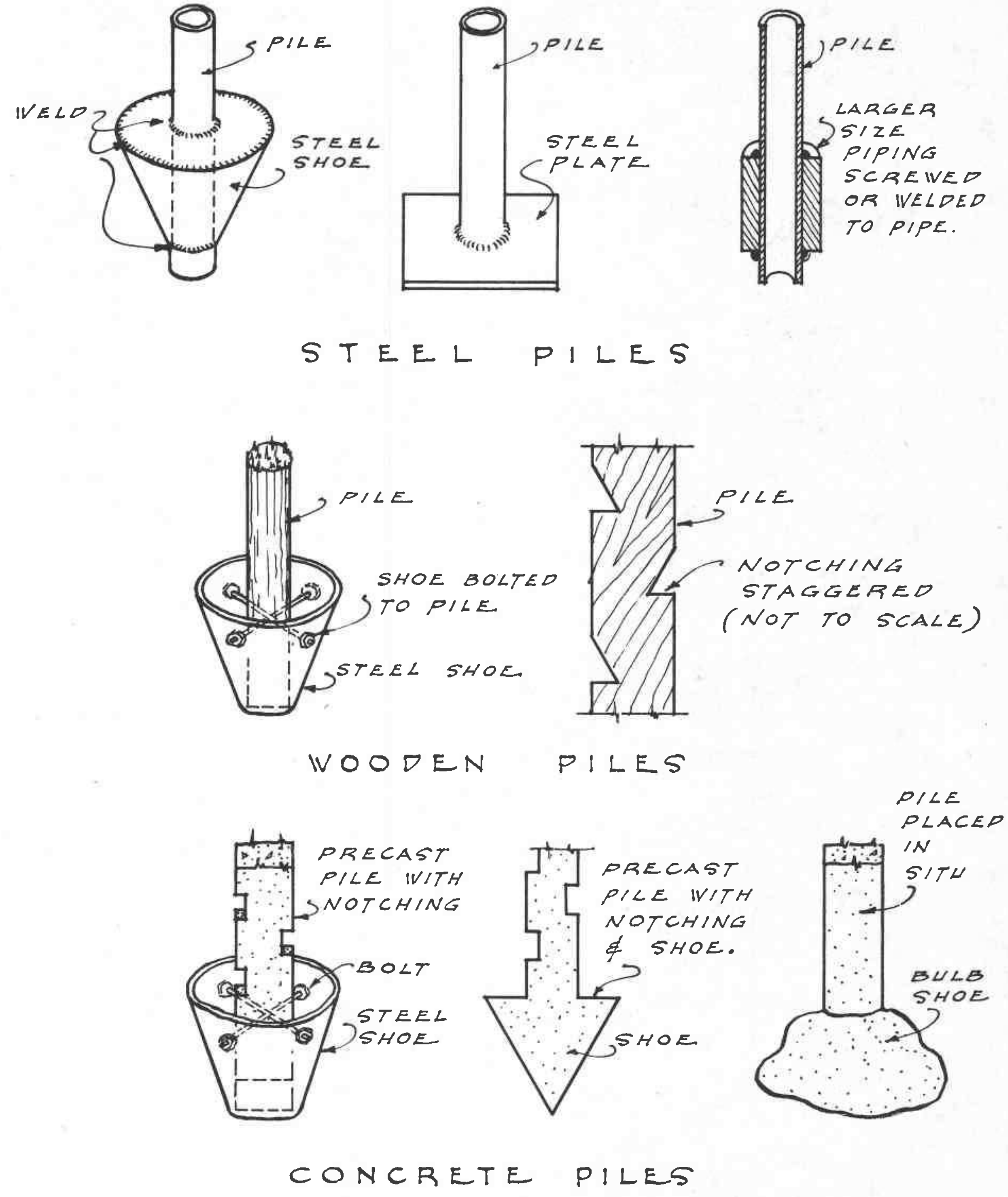


FIGURE 33

SUGGESTED METHODS FOR PREVENTING PILES FROM FROST HEAVING.

APPENDIX A

SAMPLE OF A FIELD SETTLEMENT REPORT

1. **SETTLEMENT:-** Fort MacPherson, N.W.T.

2. **LOCATION:-** Latitude 67° 27'
Longitude 134° 53'

3. **DATE:-** 31 July, 1950

4. **REPORT BY:-** J. D. Walker

5. **PERSONS CONTACTED**

   Mr. Sedgewick - H. B. C. Manager
   Mr. Timmons - Anglican Mission
   Mrs. Smith - Nurse
   Miss Stuart - School-teacher

6. **SITE:-** Fort MacPherson is typical of the river settlements in that it extends along the bank for about a mile. It is situated on the right bank of the Peel River about 25 miles from its junction with the Mackenzie River. It lies due west of Arctic Red River. The buildings are about 80 feet above the river level and consist of the H.B.C. Post, Anglican Mission, Nursing Station, R.C.M.P. Post, an independent trader, a new school under construction and several Indian cabins. The H.B.C. manager maintains a road down the steep scarp to the river and hauls stores by tractor and sled from the boats to the settlement level. The area is closely surrounded by willow and alder trees with spruce trees growing farther back.

   An airstrip was surveyed, towards the end of the war, about 4 miles upstream. The construction camp was built and equipment moved in but the scheme was cancelled.

7. **GEOLOGY:-** The high river bank on which the settlement is built appears to be a "rotten shale" outcrop which can be clearly seen on the river banks. Local reports of small excavations in the building areas indicate a top layer of organic soil and silt for about 2 feet and they grey clay. One excavation encountered gravel at 4 feet.

   The settlement is in the area of the Cretaceous shales and sandstones. According to Camsell (5), the Peel River from about 25 miles above Fort MacPherson flows through "low lying level country underlain by soft sandstones and some conglomerates. Only alluvial sands and clays are exposed below Fort MacPherson".

8. **HISTORY:-** Fort MacPherson is one of the oldest settlements in the Mackenzie District and was the main post for the Arctic coast until Aklavik was established, further north in the delta, in 1912. In 1839 John Bell explored the Peel River and in 1840 established Fort MacPherson (then called Fort Peel) reputedly 4 miles upstream from the present site. Because of flooding they moved in 1842 or 1843

to the new site. At that time the settlement was half Indian and half Eskimo, separated by the H.B.C. Store. Battles were common throughout the country.

The Anglican Mission was established in 1876 and obtained a strong following in that area. The Roman Catholic missionaries arrived in 1890, but they were finally forced to leave in 1895.

The river is not used as a route to the Yukon now but there is a winter trail over the mountains to Old Crow in the Yukon. At the present time there are no Eskimos as far south as Fort MacPherson. The natives are Kutchin or Loucheux Indians living mainly on fish and trapping in the winter. Muskrat is the most plentiful fur in this area.

Population:- Indian 350-400
White 10

APPENDIX B

SAMPLE OF A FIELD BUILDING REPORT

1. BUILDING:- Residence, Mr. A. Sherwood
2. LOCATION:- Norman Wells, N.W.T.
3. DATE:- 23 July, 1950
4. REPORT BY:- J. A. Pihlainen
5. PLANS:- The building was constructed by Mr. Sherwood. No plans are available. Interesting design features are:
   - a. built of native material.
   - b. built with the view of being as independent as possible of Imperial Oil Co. Ltd. camp services.
6. SOIL:- Described by Mr. Sherwood as being a "boulder clay till with ice lenses". Permafrost found 18 inches below the surface of undisturbed muskeg in August.
7. FOUNDATIONS:- Untreated wooden piles driven 13 feet butt-end first. There is no tarpaper collar.
8. FLOOR:- Building on sloping ground. Airspace ± 2 feet at front to ± 0 feet at back. Sides banked with earth. Floor section:- 1-inch sheathing, tarpaper, 2- by 6-inch joists, 6 inches of sawdust between joists and a double floor.
9. WALL:- 1-inch spruce with battens over joints (green spruce used so battens cover shrinkage cracks) 2- by 4-inch studs, 4 inches of sawdust between studs and wall-board.
10. CEILING:- One ply ceiling with veneer.
11. ROOF:- One inch spruce lengthwise on rafters, tarpaper, 2 by 4's laid flat and space filled with sawdust, 1-inch spruce at right angles to first laying and 6-inch battens to cover joints.
12. ATTIC:- No condensation. No ventilation but cracks help.
13. HEATING:- Natural gas cooking stove, and gas heater in living room. Hot water from I.O.L. camp steam.
14. WATER:- From I.O.L. camp but there is a storage tank above the kitchen ceiling.
15. REMARKS:- Only one pile was heaved considerably (SW. corner). This was right after construction. Pile was not sufficiently anchored and heaved approximately an inch. Result is that the ceiling has pulled away from the wall at this location by 1/2 inch.

APPENDIX C

DEFINITIONS (6)

Active Layer	layer of ground above the permafrost which freezes and thaws seasonally.
Active Method (of construction)	method of construction in which the permafrost is thawed or removed from the site.
Adfreezing	the process by which two objects adhere to one another owing to the freezing of the water.
Frost-Blister	a mound or an upwarp of surficial ground caused chiefly by the hydrostatic pressure of groundwater.
Frost-Boil	accumulation of excess water at a place of accelerated spring thawing of ground-ice. It usually weakens the surface and may break through causing a quagmire.
Frost Heaving	an upward force usually manifested by a more or less marked upwarp due to the swelling of frozen ground.
Frost-Mound	an upwarp of land surface caused by the combined action of (1) expansion due to freezing of water, (2) hydrostatic pressure of groundwater, and (3) force of crystallization of ice.
Icing	a mass of surface ice formed during the winter by successive freezing of sheets of water that may seep from the ground from a river or from a spring.
Passive Method (of construction)	method of construction in which the permafrost is preserved by not altering or disturbing the thermal régime of the ground at or in the vicinity of the structure.

Permafrost	a thickness of soil or other surficial deposit or even of bedrock, at a variable depth beneath the surface of the earth, in which a temperature below freezing has existed for over two years.
Permafrost Table	a more or less irregular surface which represents the upper limit of permafrost.
Seasonally Frozen Ground	ground frozen by low seasonal temperatures and remaining frozen only through the winter.
Sporadic Permafrost	permafrost occurring as scattered islands in the area of dominantly unfrozen ground.
Talik	a Russian term for a layer of unfrozen ground between the active layer and the permafrost. Also applies to an unfrozen layer within the permafrost as well as to the unfrozen ground beneath the permafrost.