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PILE CONSTRUCTION IN PERMAFROST[a]

J. A. Pihlainen[1]

SYNOPSIS

General construction problems and practice in permafrost areas, notably Canada, are reviewed. Present design considerations for piles in permafrost involving the preservation of permafrost and the tangential adfreezing strength are summarized. Field operations with piles in permafrost areas including the types of piles used, site preparation, drilling or steam jetting pile locations, pile placing and the refreezing of piles are described.

INTRODUCTION

In the northern part of Canada, the climate is such that a portion of the ground remains frozen throughout the year. Some surface thawing does take place, depending on the locality and the insulating effect of the moss cover but, below this, the ground remains frozen throughout the year. These perennially frozen grounds are known as permafrost. The material in this perennially frozen state may include bedrock, gravel, sand, silt, clay, organic material, and ice. Thus permafrost is not the name of a new material but of the frozen equivalent of materials found in areas further south.

Permafrost is found in about one-fifth of the land area of the world. Almost one-half of the USSR, much of Alaska, and more than one-third of Canada are underlain by permafrost.(1,2) In Canada, almost all of the Northwest Territories, Yukon Territories, and the northern parts of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec and Labrador have permafrost (Fig. 1). The thickness of permafrost in Canada varies with location,

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a. Presented at the October 1958 ASCE Convention in New York, N. Y.

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being naturally deepest in the arctic and thinning out on the southern limits. At Resolute Bay on Cornwallis Island it is approximately 1300 feet thick,(3) at Norman Wells, N.W.T. it is about 150 feet thick,(4) while at Hay River, N.W.T. some patches of permafrost only 5 feet thick have been found(5) (Fig. 1).

Construction Problems in Permafrost Areas

The presence of permafrost or perennially frozen soil at a short distance below the ground surface presents unique difficulties to construction in northern Canada. The three principal properties of permafrost which give rise to these difficulties are its ice content, its thermal sensitivity, and its imperviousness to water.

The ice in a frozen soil acts like a cement, bonding the individual soil particles. The result is a material with considerable, often rock-like, strength. The ice can take the form of layers or lenses ranging from hairline size to 3 and 4 feet in thickness (Fig. 2), or it may be found as coatings over small soil particles as well as boulders. Some of the most spectacular ice deposits occur as chunks, wedges, or blocks buried in perennially frozen ground. The volume of ice in permafrost may be as much as six times that of the soil solids. Thawing of this ice can change perennially frozen soil from a firm bearing material to a slurry with no supporting power. However, all perennially frozen materials do not have these objectionable properties and some coarse-grained soils, as well as bedrock, are favorable foundation materials.

The thermal sensitivity of permafrost makes it a difficult material in which to carry out construction without causing some thawing of the frozen soil.

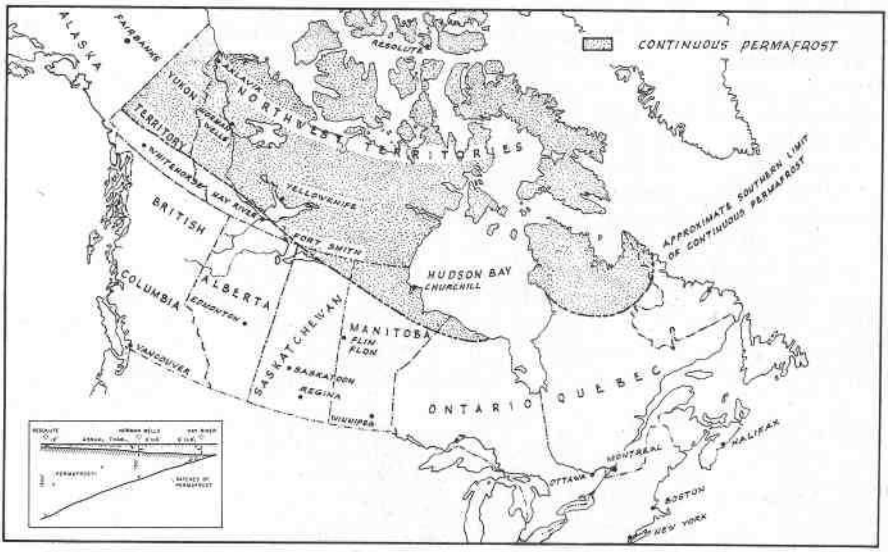


Fig. 1. The distribution of permafrost in Canada.

Permafrost conditions at an undisturbed site are in a delicate state of thermal equilibrium. So delicate is the thermal balance that the permafrost table is ever fluctuating with variations of climate and with the existing type of vegetation. The thermal sensitivity of permafrost is well illustrated by game trails which become slightly depressed paths as the permafrost thaws a little more under this compacted moss than under the surrounding terrain.

It is not strange that the introduction of a building to undisturbed terrain has such a pronounced effect on the permafrost table. Clearing of the trees, brush, and the moss cover start the change in thermal equilibrium. Steam jetting or excavation, and finally the heat losses from a structure complete the thermal disruption. Should the permafrost melt below the foundations of the building, then the building may slowly sink into the ground as the thaw continues. The problem can be described as trying to build a house on a block of ice.

The third, and often neglected, property of permafrost is its imperviousness to water. Rainfall and water from melting snow cannot drain into the ground because of permafrost and tend instead to form stagnant pools and lakes. The poor drainage which results from this fact complicates construction operations and imposes additional problems on the design of buildings in permafrost areas.

As long as water in the summer and snow in the winter provided necessary transportation routes, and buildings were of simple design, the slow and small thaw of permafrost was unimportant. Building foundations consisted mainly of mudsills or timber pads; roads were merely winter hauling trails; and airstrips, if any, were small cleared areas improved by some brush removal.

In recent years, however, much clearing of frozen ground has taken place for road and airfield construction and with the advent of heated basements for

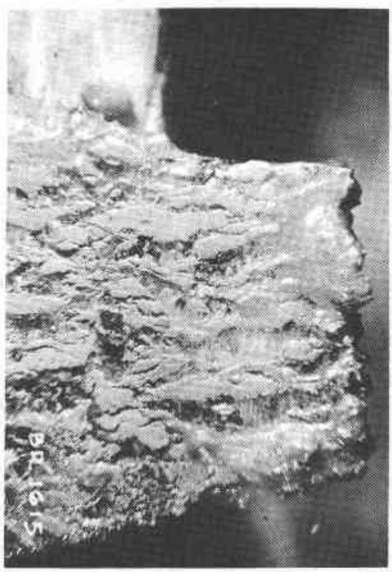


Fig. 2. Split core of Aklavik perennially frozen sandy silt. The volume of ice is three times that of the soil. Darkened portions show ice lenses in one section of the core. (Photographic enlargement twice natural size.)

buildings, the peculiar properties of permafrost have made themselves very evident, especially to engineers. Portions of roads become unserviceable in a matter of months; airstrip construction in some locations has had to be abandoned; and building movements measured in feet have been recorded.

Construction Practice

Early construction practice treated permafrost as a "hard pan". Small buildings were supported by mudsills or pads on the ground surface, larger structures on piers which extended to or slightly into permafrost. Although the bearing capacity of the permafrost was sufficient to distribute the small building loads and the thaw of permafrost was slow and gradual, other faults in this general technique soon forced its abandonment. Frost action frequently moved supporting members up and down as much as 2 feet. In addition, heat loss from a structure would eventually lower the permafrost level and the foundations would settle. These destructive effects, sometimes occurring singly but mostly concurrently, would soon have the structure in distress (Fig. 3).

The difficulties of early construction clearly indicated the need for proper preliminary investigation before the selection and design of foundations in

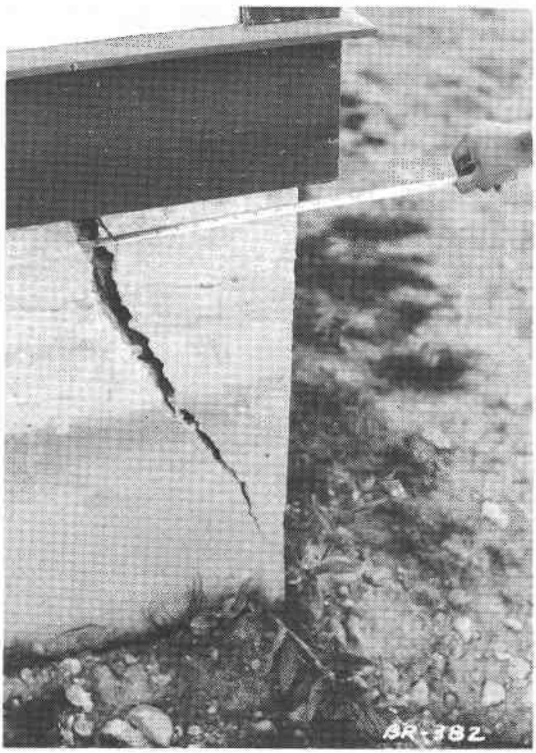


Fig. 3. Crack in foundation wall ranging from 2 inches at top to hairline near ground level.

permafrost areas could safely be attempted. A thorough site survey, with its scope patterned on the importance of the structure, is a prerequisite to foundation selection.

If a site with favorable perennially frozen foundation material is not readily available, then the only recourse is the utilization of the perennially frozen ground which has poor engineering properties. For this type of design, every effort must be made to protect the existing permafrost. Foundation types which disturb natural ground conditions and which allow large heat losses from the structure to the ground are to be avoided. For satisfactory foundation performance, the problem is to estimate the probable thawing of permafrost for the life expectancy of the structure and to design the foundations for these conditions.

For large structures, present construction techniques favor the "embedment" of foundations in permafrost. Embedding the foundations in permafrost provides an anchorage or grip which resists frost action forces and allows for some thawing of the permafrost table without loss of bearing of the foundations. The excavation of perennially frozen soil, however, is costly because of its hard, almost rock-like quality and the fact that on melting most fine-grained soils with high ice contents turn into slurry. The embedment of foundation members by excavation is therefore a difficult and costly operation. An alternative method which provides for anchorage of the foundations in permafrost is to thaw a hole in the ground, and to drive the foundation member sufficiently into the thawed ground so that subsequent refreezing will establish the permafrost table at some distance above the bottom of the member. This is basically the present procedure used for pile foundations in Canadian permafrost areas.

Some Advantages and Disadvantages of Pile Foundations

The principal advantage of pile foundations is that they can be extended with a minimum of effort a sufficient distance into permafrost so that their function should not be impaired by thawing during the life span of the structure. In many cases such as poorly drained sites underlain by fine-grained soils with high ice contents, piles are the only type of foundation that can be used with any hope of success. When local timber is available, the high costs of transportation to the north can be saved. Thus the costs of timber pile foundations can be often justified for smaller structures such as dwellings. This is especially true for large projects where the cost of equipment required is spread over a number of installations.

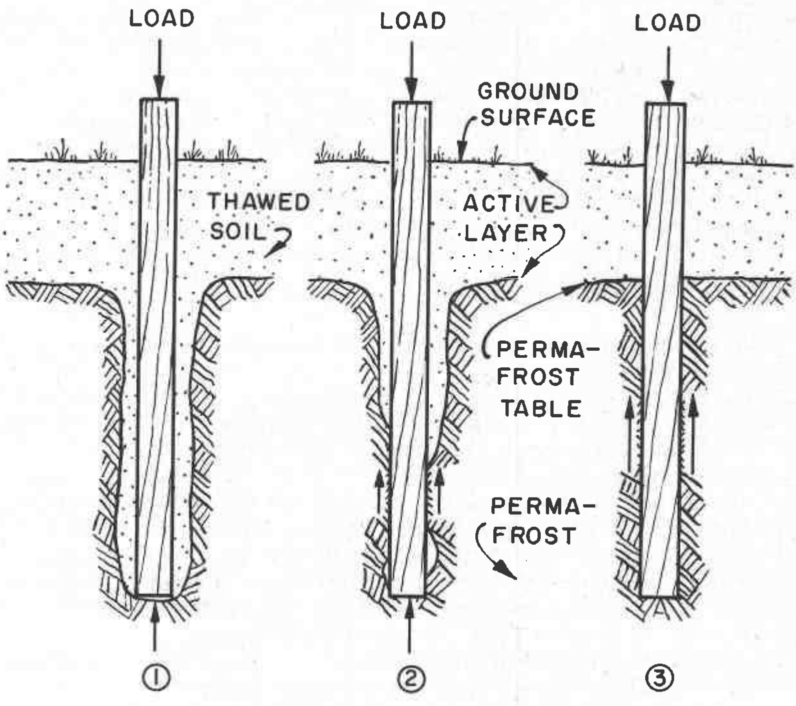
An often-mentioned disadvantage of pile foundations is that basements are not usually possible with this type of foundation. In view of the problems with basement construction in the north,(5) the opinion of many actively engaged in northern construction is that such extra space as is provided by a basement can better be obtained by additions to the superstructure rather than by attempting any excavation under a northern building.

Design Considerations

Present pile construction practice in Canadian permafrost areas is to thaw, or drill holes at, the pile locations, to drive or place the piles, and then allow the piles to refreeze. When a pile is first placed, it transfers its load to permafrost by end bearing. As refreezing begins, the load is distributed partly by the bond between the pile and the frozen soil (tangential adfreezing strength) and partly by end bearing. When the pile is completely frozen the load is thought to be transferred wholly by tangential adfreezing strength (Fig. 4). The tangential adfreezing strength is used not only to distribute the load to permafrost but also to combat frost heaving forces. Accordingly, the design problem is two-fold—first to predict the thawing effect that the structure will have on permafrost during the life of the building, and second to determine what tangential adfreezing strength can be safely assumed for distributing the load to permafrost and combating frost heaving forces.

Preserving Permafrost

The effect of heat losses from a structure during its life span which tend to increase gradually the depth of thaw (and thus reduce the tangential



① IMMEDIATELY AFTER DRIVING, LOAD TRANSFERRED BY POINT BEARING.

② DURING FREEZING, LOAD TRANSFERRED BY POINT BEARING AND ADFREEZING STRENGTH.

③ COMPLETELY FROZEN, LOAD TRANSFERRED WHOLLY BY ADFREEZING STRENGTH.

Fig. 4. Load bearing cycle of pile after steam jetting.

adfreezing strength) is difficult to predict mathematically. Some calculations on the depth of thaw in frozen ground under various surfaces have been made.[6] The correlation of such calculations with the effect of pile supported structures having an open air space between the ground surface and the floor is still required.

It is usual to minimize heat losses to the ground or to preserve permafrost conditions as much as possible. This preservation of permafrost is assisted by keeping the disturbance of the natural vegetative cover to a minimum, by the provision of an air space between the floor of the building and the ground surface through which cold air may circulate during the heating season, and by providing ground insulation in the form of additional moss or dry organic material under the building.

Adfreezing Strength

In anchoring a pile in permafrost, the grip of the frozen soil on the pile is utilized. This grip or tangential adfreezing strength may be defined as the resistance to the force that is required to shear off an object which is frozen to the ground and to overcome the friction along the plane of its contact with the ground.

Russian investigations[7,8,9] have shown that the tangential adfreezing strength depends on:

(i) the texture and density of the soil
(ii) the temperature of the soil
(iii) the moisture content of the soil
(iv) the area of contact, and
(v) the nature of the contact face, i.e. smooth or rough.

Some of these variables are illustrated in Figs. 5, 6, 7 and 8. In general the tangential adfreezing strength:

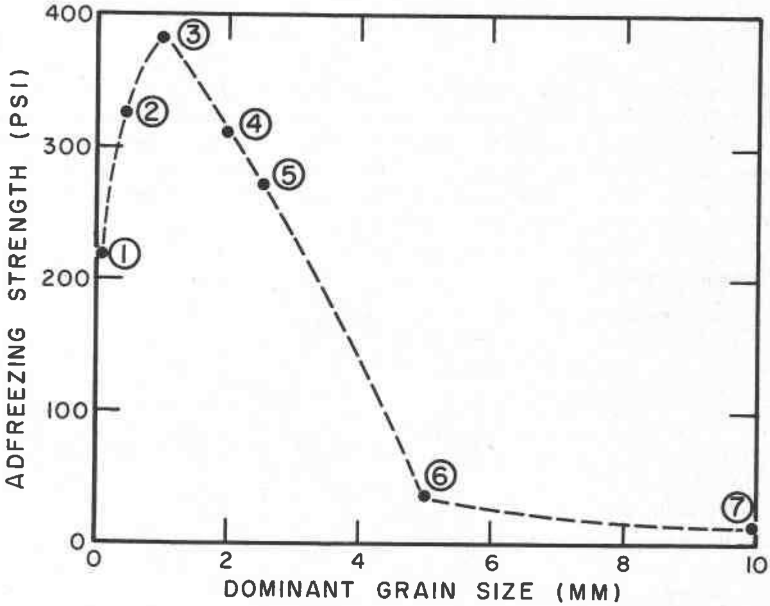
(i) increases as soil density increases, and
(ii) increases as the degree of saturation increases.

Nees[10] conducted model tests on a sandy-silt with 1-1/4-inch standard steel pipe and found that the general trends appeared to be the same but that the model tests yielded much lower values.

Although some information on the values of tangential adfreezing strengths is available, virtually no records are available on frost-heaving forces. This has led to the extensive use of a "rule of thumb" for embedment of piles in permafrost, e.g. embedment or anchorage of piles in permafrost should be equal to at least twice the depth of seasonal freezing and thawing during the life of the building.[1]

Types of Piles

Wooden piles are preferred because of their cost advantage in areas where they can be procured locally; relative conductivities of wood, concrete and steel also favor the use of wooden piles in permafrost. Some precast concrete piles and steel pipe piles have been used but higher costs have curtailed their extensive use. Cast-in-place concrete piles are not used in permafrost areas. The following estimated costs of a 20-ft pile delivered to Inuvik illustrate well the reason for preferring local timber piles.[11]



LEGEND:

No.	TYPE OF SOIL	TEMP (°F)	COEF OF SAT (%)
1	CLAY	26·5	77
2	SAND, FINE	26·5	76
3	SAND, MEDIUM	26·5	78
4	SAND, COARSE TO FINE	26·5	79
5	SAND, COARSE	26·5	97
6	GRAVEL, FINE	26·5	77
7	GRAVEL	26·5	79

(AFTER SUMGIN REF 9)

Fig. 5. Tangential adfreezing strength between wood and various soil textures.

20-ft Pile	Cost
local spruce with preservative	$ 20.00
precast concrete (cast at site)	80.00
creosoted, from Edmonton	100.00

Wooden Piles

Local spruce timbers are most commonly used for piles in the treed permafrost areas. Timber sizes will vary with locality but 20-ft piles with minimum 8-in. tips should be readily available. In the development of the new townsite of Inuvik at the mouth of the Mackenzie River, N.W.T., which is to replace Aklavik, local 20-ft spruce piles were used but in addition spruce piles 40 ft long with 8-in. tips were obtained for special requirements from the Liard River region.

Pile preparation may or may not include the stripping of bark. If a preservative is to be used, stripping of bark and preservative treatment is necessary for that portion of pile which will be in thawed soil. It is very difficult to get a preservative to penetrate spruce by any treatment method, including pressure treatments, except by a diffusion process. With this process the preservative is usually applied to green timber by brush in the form of a slurry. The piles are then stacked closely, covered with waterproof paper to prevent rapid drying, and allowed to stand until the preservative has diffused into the wood. The cost of a 20-ft spruce pile in place at Inuvik, including the cost of the pile, diffusion treatment, handling, steaming and placing the pile, is estimated to be $30 per pile.(12)

Concrete Piles

The use of site precast concrete piles has been limited in permafrost areas because of the high costs of transportation and the need for skilled workmen.

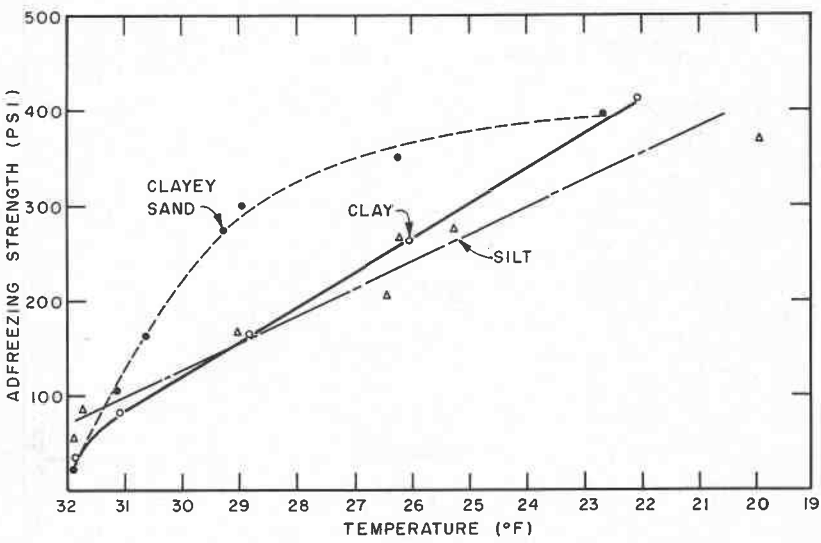


Fig. 6. Effect of temperature on the tangential adfreezing strength for various soil textures.

Cast-in-place concrete piles are not used in permafrost areas because of the problems of curing concrete which is surrounded by permafrost.

Steel Piles

As with concrete piles, steel piles are not in extensive use mainly because of their high cost. They have, however, been used in some communities where steel pipe was available as scrap or surplus, notably Norman Wells, N.W.T. They are easily handled, may be quickly lengthened, cut or capped by welding, and are slightly flexible as to position after driving.(4)

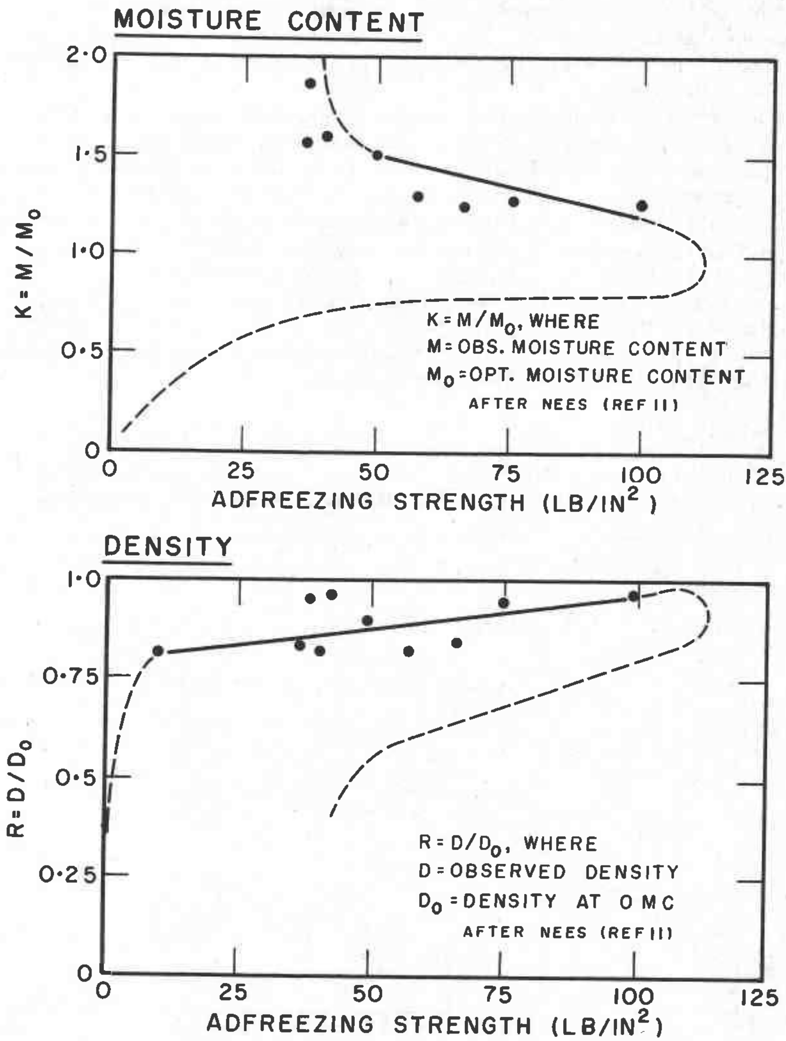
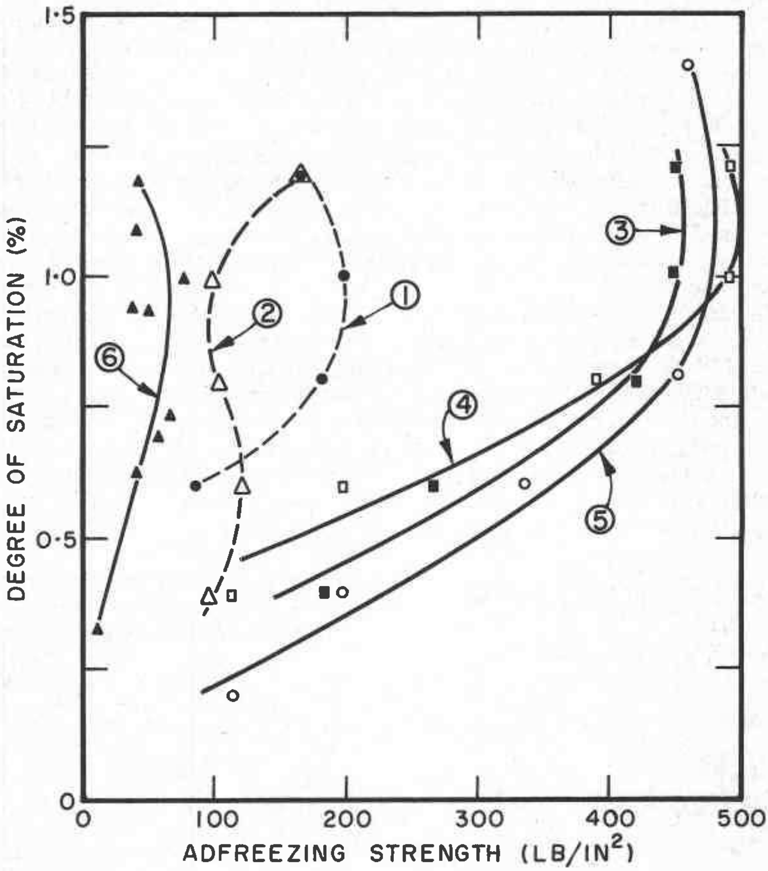


Fig. 7. Effect of moisture content and density on adfreezing strength.



LEGEND:

No.	SOIL	TEMP (°F)
1	CLAYEY	29 - 30
2	SILTY	29 - 30
3	CLAYEY	11 - 15
4	SILTY	11 - 15
5	SANDY LOAM	11 - 15
6	SAND - SILT	18 - 25

(AFTER NEES REF 11)

Fig. 8. Adfreezing strength of various soils to wet wood for varying degrees of saturation.

Site Preparation

Pile-placing operations may involve the use of relatively heavy equipment and the probability of disturbing the natural vegetative cover is great. If it is at all possible, pile-placing equipment should be restricted to the perimeter of the building site where remedial measures, such as the placing of additional organic fill, can be taken to restore the terrain to its original condition.

Frequently this is not possible and some initial disturbance of the organic cover must be accepted. At times, site conditions are so poor for equipment movements that some site preparation is necessary. This generally requires covering the entire building area with a layer of gravel or crushed rock. In some cases this work has been neglected or overlooked with a resulting loss in time and money.

An example of good site preparation is afforded by the pile construction carried out during 1950 by the Giant Yellowknife Gold Mines Co. Ltd., Yellowknife, N.W.T. After the site of the building was chosen, small boxes (approximately 2 ft by 2 ft by 1 ft deep) were built at the proposed location of each pile. 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 from the tracks of the crawler tractors. After the piles were driven, the wooden guard boxes were found to be very convenient for wedging the piles into true positions (Fig. 9).

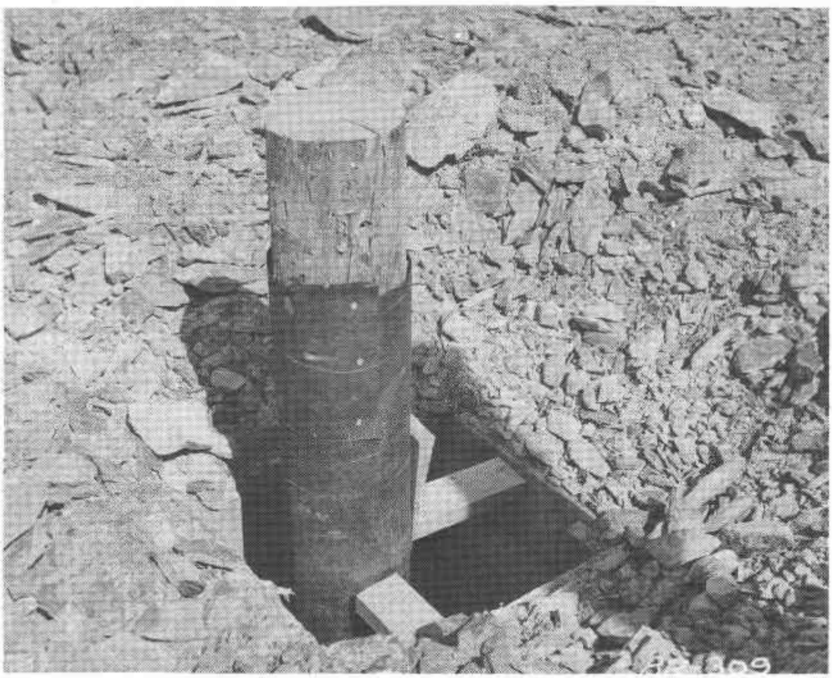


Fig. 9. Close-up of driven pile, cut off to desired elevation and wedged into line, at the Giant Yellowknife Gold Mines, Yellowknife, N.W.T. Tar-paper collar used to reduce evaporation of diffusion type of preservative.

Placing Piles in Permafrost

At present two methods of placing piles in permafrost are used in Canada:

a. Steam jetting (thawing) the permafrost at the pile location and driving the pile, and
b. Drilling and placing the pile in the core hole.

Both methods should be reviewed before a final foundation design is chosen since each method has special merits when considered in relation to final costs and permafrost conditions.

Steam Jetting

Steaming pile locations in permafrost areas is accomplished by advancing a steam jet into frozen ground under its own weight or with help from the person guiding the jet. When the steam jet has reached the desired pile depth it is withdrawn from the hole and the pile is placed in the thawed location. A pile driver then drives the pile to refusal, i.e. to frozen ground.

As would be expected, the mode and efficiency of steam jetting depends upon many variables: the type of steaming equipment that is readily available, the steaming interval, the type of soil, the moisture or ice content of the soil,

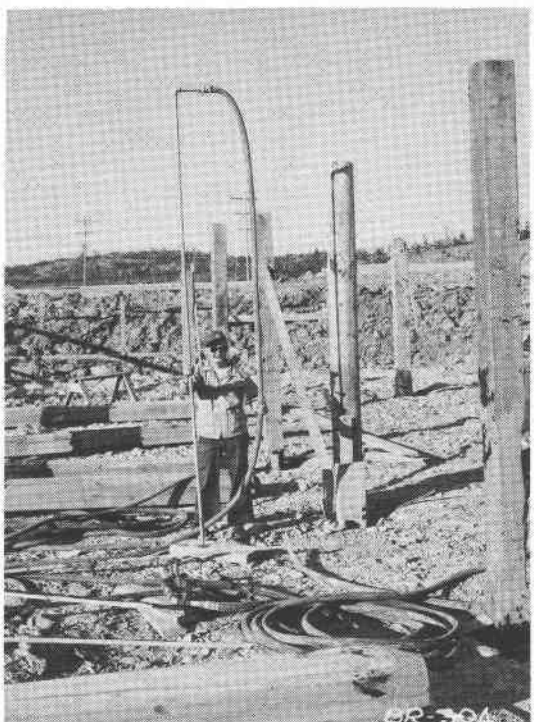


Fig. 10. Steam jet used at Giant Yellowknife Gold Mines, Yellowknife, N.W.T. The pipe is 1 inch in diameter with 1/4-inch nozzle.

and the temperature of the frozen soil. The steaming characteristics of a locality are best determined by field trials.

A steam boiler from 25 to 50 BHP, preferably 50 BHP, is required. Steam pressures from 50 to 120 psi have been used; the higher pressures appear to give better results. At Inuvik in 1958, a 50 BHP oil-fired boiler supplied five 3/4-inch diameter steam jets at 100 psi and used 5 barrels of water per 10-hour day and approximately 12 gallons per hour of fuel oil. Steam jet piping is generally 3/4-in. to 1-1/4-in. pipe, open or slightly crimped to give a better jetting action (Fig. 10). Hemstock(4) has noted that, except in large gravel, special bits such as a chisel bit did not speed jetting. For relatively long piles (longer than 20 ft), a long steam jetting pipe is difficult to handle. In these cases, steam jetting a pile location is started with a short jetting pipe, say 8 ft long, and completed with the longer jetting pipe.

Soils with some ice steam most efficiently for pile driving, i.e. they produce the desired diameter thaw in the shortest time. The rate of thaw in "dry" soils can sometimes be increased by the addition of some water to the thawed hole. Steaming penetration through thick ice is fast but only a small hole slightly larger than the jet is produced. An experienced operator will soon recognize ice formations and will slow down the jet travel in it. Ice lenses in soil, ranging from 1/2 in. to 3 in. in thickness, frequently form ice ledges which reduce the effective diameter of the thawed hole. Working the steam jet up and down beside the pile as it is driven remove these ledges if they impede driving.

One of the hardest materials to thaw by steam jet is frozen organic material. The extremely high ice content solidly bonds the organic particles and fibres. Steaming produces a small hole slightly larger in diameter than the jet and the resulting mat of thawed organic material impedes further thawing. Frequently woody particles such as tree trunks or branches completely stop jet penetration. Several closely spaced holes must then be thawed through the organic material before the desired diameter of thawed hole is produced. If extensive organic deposits occur, the use of jets which direct the steam radially from the pipe may increase steaming efficiency.

The steaming penetration rates for various projects at Norman Wells, Aklavik, and Inuvik have been summarized in Table 1. The rates at Inuvik and Aklavik vary from 3 to 24 ft per hour of steaming with differences attributed mainly to the occurrence of organic material, or boulders as at Inuvik. It will be noted that the steaming penetration rate for Norman Wells of 50 ft per hour of steaming is double the fastest rate for the Aklavik region. The Norman Wells rate is based on trouble-free steaming, when boulders or organic material were not encountered. These steaming penetration rates merely indicate the relative magnitude of this effect so that some first appraisal of the steaming time can be made.

An interesting steam jetting technique was developed at Inuvik, during the summer of 1956. Stones and boulders in the frozen gravel sometimes hindered steam jetting but were most troublesome during pile driving. Stones would frequently be loosened by pile driving and act as wedges deflecting the piles out of line by as much as 3 ft. At times, stones would be forced to the bottom of the hole and the pile could not be driven to full depth.

The steaming technique developed by field trials was to steam the hole to the required depth and diameter with the least possible delay (considering the type of soil). This steaming penetration rate (steam pressure 100 psi) varied from 10 to 94 ft per hour but averaged 40 ft per hour for 70 pile observations.

The steam jet was then left at the bottom of the hole to "bell out" a thawed area into which stones and boulders could be pushed by the pile as it was driven. Various "belling out" times were tried. The average time for 70 successful locations was found to be 18 minutes. Steaming penetration rates including the time for "belling out" varied from 8 to 39 ft per hour for 70 pile locations and averaged 21 ft per hour. The "belling out" steam jetting technique is illustrated in Fig. 11.

Although the term "pile driving" is used in permafrost areas, piles are not driven directly into permafrost. After steaming pile locations, the piles are placed in thawed soil, at times a hole filled with a soil slurry, and pushed, tapped or driven to the depth of steaming. The type of pile placing equipment used varies with availability. At Norman Wells, for light driving to a depth of 16 ft, Hemstock(4) found that a light, drop-hammer mounted on a small crawler-type tractor was most satisfactory. For a small number of piles, a gin pole, fitted with a block and tackle, and a hand-operated winch has been used. At Giant Yellowknife Gold Mines, piles were "pushed" into the thawed soil with the winch and cable of a D-8 caterpillar tractor. Drive weights used have varied from 800 to 2500 lb.

As the piles are forced into the thawed soil, the soil slurry usually oozes out at the top since the surrounding permafrost is impervious. At times, especially if the holes have been oversteamed, the piles "pop-up" or float in the

TABLE 1

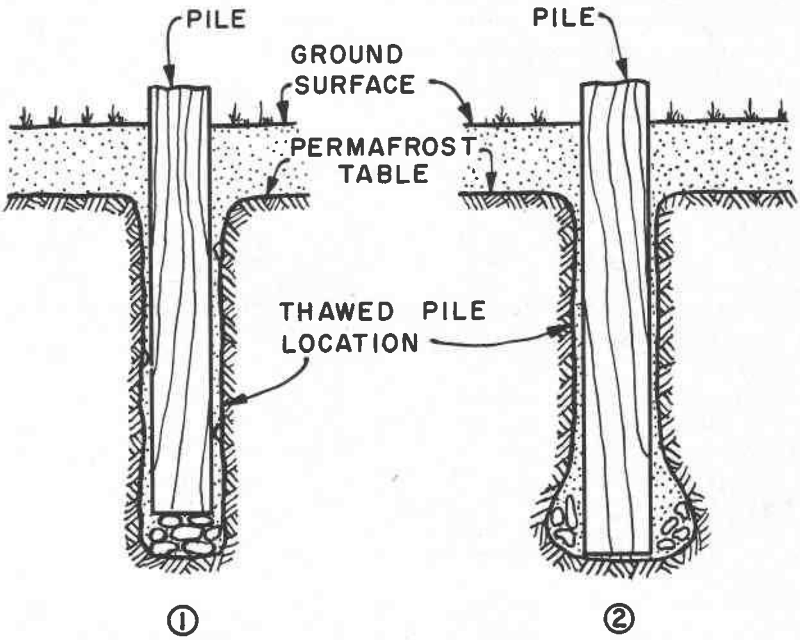
SOME STEAMING PENETRATION RATES AND DETAILS

Location	Predominant Soil	Depth of Steamed Hole (ft)	Steam Pressure (psi)	Steaming Rate (ft/hr)
Norman Wells 1947 [5]	silty clay	16	80-100	50
Aklavik 1952 [19]	silt	18-21	75	24
Aklavik 1953 [20]	silt	20	90	15
Inuvik 1955	fine-grained	20	100	20
	sandy gravel	20	100	10
	organic	20	100	10
Inuvik 1958	gravel	20	100	3-10

soil slurry. This necessitates anchoring or wedging the pile in place and in line until it is sufficiently frozen in.

At Inuvik, pile alignment during driving is difficult because of stones which deflect the piles and the straightening of a considerable number of piles is necessary. Average realignment is about 4 inches although some piles have been straightened as much as 12 inches. The procedure used at Inuvik is to delay re-alignment for about one month after pile driving since wedging is reported to be ineffective immediately after driving. One or two holes, depending on the amount of straightening, are steamed on the side to be moved. For alignments of approximately 6 inches or more, steaming is carried out to the bottom of the pile although usually the steaming depth is approximately two-thirds of the pile length in the ground. The piles are pulled into alignment with a winch and long wooden wedges are inserted to hold the pile in position. Less than 1 per cent of the piles have broken in straightening operations at Inuvik.

The refreezing of piles in permafrost depends upon many variables of which the steaming interval is probably the most important. In general, individual piles or small groups of piles with moderate steaming refreeze



① STONES DEFLECT PILE AND PREVENT DRIVING TO FULL DEPTH.

② STEAM JET LEFT AT HOLE BOTTOM APPROXIMATELY 15 MIN. TO THAW BELL-SHAPED REGION TO WHICH STONES ARE PUSHED BY PILE.

Fig. 11. "Belling out" technique developed at Inuvik for steaming in stony gravels.

sufficiently for construction in a matter of weeks in continuous permafrost. However, large pile areas, especially where steaming is difficult and when re-steaming for pile alignment is necessary, or even smaller groups of piles in areas of sporadic permafrost, may require as much as a year to refreeze before the risk of heaving is over.

The following observation on pile refreezing at Aklavik illustrate the refreezing phenomenon. It should be noted that the results presented here are relevant only to the Aklavik region. In general, longer refreezing intervals can be expected in more southerly locations; shorter intervals for more northerly locations.

The refreezing of four piles at Aklavik was observed during 1953. The piles were each steamed for approximately 1-1/2 hr for a 20-ft depth using steam at 90 psi. Thermocouples were attached to the piles to record temperatures at 2-, 8-, 14- and 20-ft depths. Observations began one or two days after the piles were driven (early July) and continued every second or third day until the middle of September. Table 2 records the refreezing intervals for the various depths.

One of the findings of these observations was the fact that the refreezing of piles in the Aklavik area proceeds in a matter of weeks for moderate steaming. The importance of careful steaming is also emphasized by the results shown in Table 2. Thus at the 20-ft depth, refreezing can occur as late as 39 days after driving, due to oversteaming, although one day or less is the general case. Similarly the range of refreezing times for the 14-ft depth varied from 2 to 28 days. For the 8-ft depth, the time of refreezing was 44 or more days.

Similar refreezing records were collected at Inuvik, during 1955. These results indicated that moderately steamed pile locations were refrozen up to a depth of 11 ft one month after steaming. This is in agreement with the Aklavik refreezing records obtained during 1953. However, the longer steaming intervals observed at Inuvik during 1958 have suggested that at least one winter interval of refreezing should be allowed before construction begins on the piles.

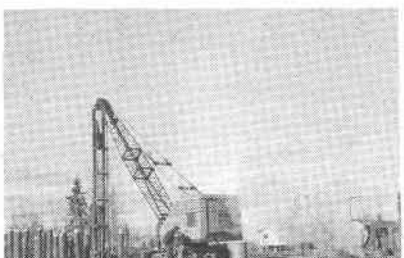


Fig. 12. Piling operations at Inuvik during August 1958. Note gravel pad over building site. Three steam jets are steaming pile locations at building site on right and the pile driver is completing driving at building site on the left.

Drilling Holes for Piles

The main advantages of drilling holes for piles are that disturbance of the perennially frozen condition is kept to a minimum and a reasonably accurate record of the soils and permafrost conditions at each pile location is obtained. These advantages are of particular value for construction in areas where permafrost occurs in "patches" of limited areal extent (commonly referred to as "sporadic permafrost areas"). In these sporadic permafrost areas, the temperature of permafrost is close to the thawing temperature and in some cases, if once thawed, will not refreeze. It may also be uneconomical to destroy the perennially frozen condition and accordingly the future existence of permafrost at each pile location is essential. Drilling the pile locations assures a minimum of disturbance to permafrost. In addition it offers a convenient opportunity to install piping to provide for future refrigeration of pile locations in the event of unanticipated thawing of the foundations.[14,15] The provision of refrigeration piping in steamed and driven piles is difficult since the piping must be protected from damage during driving. In areas of "continuous" permafrost (where permafrost is found everywhere under the natural surface, is relatively thick and has a temperature considerably below thawing) the advantages of drilling are not paramount except when quick refreezing is essential or when the project is large and drilling allows a faster rate of pile installation.

It is probably because of these reasons that drilling pile locations has not been common in the Canadian North. It has been utilized at Inuvik in 1957 for the pile foundations of a powerhouse and large heated oil storage tanks. The large number of piles involved, the close spacing of the piles and the importance of the structures suggested that extreme care was needed in keeping the disturbance of permafrost to a minimum. Drilling, rather than steaming, the pile locations was therefore started during September 1957. Two truck-mounted seismic shot-hole drill rigs drilling 24- and 18-inch diameter holes experienced considerable difficulty with stones and boulders. The procedure developed, although not completely satisfactory, consisted of drilling the frozen stony material with a 20-inch diameter straight blade auger using

TABLE 2

PILE REFREEZING INTERVALS, AKLAVIK 1953

Depth (ft)	Time of Pile Refreezing			
	Pile-1	Pile-2	Pile-3	Pile-4
2	-	-	-	-
8	44 days	> 55 days	> 39 days	> 39 days
14	7 days	28 days	2 days	20 days
20	< 1 day	< 1 day	39 days	1 day

steam to thaw and loosen the stones when drilling became difficult. A commercially available special carbide insert auger performed well in frozen silt and ice although stones did chip and break away the carbide teeth. Drilling a hole to a depth of 26 feet took approximately 1-1/2 to 2 hours.

At Frobisher Bay,(16) in 1958, 24-foot deep holes for piles were drilled with an 18-inch diameter auger but as at East Three, pockets of boulders up to 10-inches diameter caused much difficulty. The drilling procedure at Frobisher Bay consisted of drilling a 2-inch diameter hole at each pile location and steaming the hole prior to augering. However, the boulders caused extensive damage to the auger carbide inserts. Frost cutter and core bits were also used with little or no success.

Explosives were then tried to loosen the boulders. After blasting, the auger was able to excavate the pile location with much more success. The method consisted of drilling three 2-inch diameter holes equally spaced 20 inches from a centre hole at each pile location. The centre hole was left open and the outside holes were loaded with 1-1/8 x 8 inch cartridges of 75 per cent Forcite at 12 inch intervals. These holes were bottom primed with short period caps to give a maximum delay between each hole in the location. Since a collar of 5 feet was maintained on each loaded hole, no surface cracks or caving was apparent.

In contrast to Canadian practice, pile placing in the permafrost areas of Alaska has been carried almost entirely by drilling methods. A typical example of such an operation was during the winter of 1956 when Morrison-Knudsen Inc. drilled 18-inch diameter holes for 30-foot wood piles at Bethel, Alaska.(17) After several field drilling trials they decided to use a special auger equipped with a special drilling head. This tool has four cutting surfaces with square carbide inserts that can be reversed to utilize the other sides. Then the head can be shifted into an upside-down position to provide more cutting surfaces. As frozen silt is highly abrasive, drilling into this frozen soil can cause excessive wear on any cutting heads. After drilling, piles with refrigeration piping attached were lowered into the holes. A sandy-silt slurry was pumped around the piles as backfill and refrigeration equipment froze in the piling.

CONCLUSION

Pile foundations are a potentially excellent foundation type in permafrost areas. Capable of carrying heavier than ordinary building loads, not immediately affected by the gradual thawing of permafrost or by frost action, relatively simple to install, and utilizing local materials, an increase in their present use can be expected. Design considerations of piles in permafrost consists of predicting the effect that the structure will have on permafrost during the life of the building and then to determine what tangential adfreezing strength can be safely assumed for distributing the load to permafrost and combating frost heaving forces. The field techniques of pile construction in permafrost involve many variables, some best determined by field trials. It is hoped that the methods described will help engineers in a first appraisal of the use of pile foundations in permafrost areas.

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