tion in arctic and subarctic regions upon which this paper is based is being made under the supervision of Mr. Henry J. Manger, Engineer, and the general direction of Colonel Walter K. Wilson, Jr., Corps of Engineers, District Engineer, St. Paul District.

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ENGINEERING IN PERMAFROST IN CANADA'S MACKENZIE VALLEY

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Progress in Canada's Northland continues steadily as the vast natural resources are developed to serve the nation. This development brings to the fore many engineering problems, not the least of which is the erection of structures on the permanently frozen ground of the North.

Norman Wells is a small but important oil centre in the lower Mackenzie Valley. From its wells and refinery come the petroleum products to heat, light and power the mining camps, the river transport, and the planes of the whole Mackenzie District. At the refinery the available area for the erection of living quarters, the shops and the refinery consists of a fine frozen silt with occasional thin layers of gravel and clay. Moisture content of the silt may run up to ninety percent. Tests have shown the ground to be frozen to a depth of at least one hundred and forty feet--seasonal thaw may be from one to five feet depending on the ground cover. Yearly mean air temperature averages about twenty-five degrees Fahrenheit.

One of the problems at the refinery is to erect structures on this frozen ground in such a manner that they remain stable. It can easily be seen that thawing of frozen silt with such high moisture content will result in slud with no shear strength whatever. In addition, the problem of frost heaving comes to the fore, the active layer (that is the layer of seasonal freeze and thaw) is very susceptible to frost heaving and the damage to structures is in many cases more evident than that caused by settlement.

The first large expansion of Norman Wells occured during the war when the Canol project was begun. It was in this emergency that many buildings were erected without due regard to foundations. In most cases a fill of silt and dirty gravel from one to three feet thick was run over the muskeg, and on this were put the small pads and posts for the frame buildings. A small town was erected in this manner, the only variations being that in shops and power plants a slab of concrete was poured for a floor directly on the fill.

The first six months after construction proved that permafrost must be dealt with in a different manner. Heat from the buildings caused settling of the interior of the buildings. That is the permanently frozen ground was gradually thawed and due to its very high water content settling was inevitable the four inch concrete floor of the camp boiler house settled thirty inches in the first winter. At the same time these conditions led to a large supply of water under the building and so set up ideal conditions for frost heave around the circumference. Differential movement of fourteen inches in ordinary living quarters was recorded in six months.

Attempts were made during the second summer after erection, to shim up the buildings in the hope that equilibrium had been reached and that further settlement would not occur. However, frost heaving around the outside of the building of course continued and measurements showed too that settlement under heated buildings also went on although at a reduced rate. A total of fifty-two inches settlement under the locomotive type heating boilers was recorded in the two years after construction.

In 1943 several important installations were made at the field, among them the erection of two repressuring stations. The heavy reciprocating machinery and high pressure piping required substantial foundations that would not be subject to heaving or settling. Test pits sunk at the locations selected showed the soil to be a fine silty material with inclusions of ice. Layers of clay and some gravel were encountered below twelve feet. A weak sandstone bedrock occured at about forty feet. No machinery was available to carry the foundations to bedrock, so it was decided to drive wooden piles well into the permafrost, to insulate around the tops of the piles and to pour concrete blocks founded on the piles. The active layer was taken off and work was carried on at the original top of the permafrost to give better drainage of the final job, and to allow greater penetration of the piles. Examination of this foundation after four years, the building was heated for the first eighteen months and unheated after that, showed no measurable movement, and no visible deterioration of any part of the foundation.

Since 1943 all important construction at Norman Wells has been erected on piles. During this time there has been an opportunity to improve the pile driving methods, to study the behaviour of piles and generally devise saticfactory engineering methods for the North.

Since the ground is frozen, holes must be jetted out for piles. Experience showed that the most economical method was to use a steam jet, a three quarter or one inch pipe about one foot shorter than the desired pile depth is used, a steam pressure of fifty to eighty pounds or greater seems most satisfactory. Experience and a careful study of the ground will aid in getting economical results. Some pertinent points for similar conditions are:

1) If the ground has dry layers, some water with the steam will speed jetting.
2) Holes may be left up to three weeks in summer before driving piles, but in freezing weather should not be left more than a week.
3) Except in large gravel special bits, e.g.

chisel bit, did not speed jetting.

4) Under favorable conditions one man can steam-jet up to twentyfive, sixteen foot holes in an eight 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.

Several types and sizes of drop hammers and air hammers were tried. For the particular type of driving required, that is light driving to a depth of about sixteen feet, it was found that a light, fast drop hammer outfit mounted on a small crawler type tractor was most satisfactory. Piles could be quickly and easily handled and driven to refusal in the least possible time. Moreover the machine could move fairly well in the wet, soft muskeg. With this outfit, two men can drive up to thirty wood or steel piles in eight hours.

For the first construction with piles, wood was used exclusively, and because of high shipping costs, native spruce was chosen. Piles were from seven to ten inches at the top, driven butt down to help prevent heaving. Some were driven with the asphalt treated paper "collars" as recommended by Muller, while no treatment was given others. To date none driven twelve feet or more with asphalt collars, and none without asphalt covers with penetration of over fifteen feet have shown any sign of heaving. Piles have heaved up to eight inches in one season where they were not driven far enough into the permafrost for adequate anchorage. As would be expected, this heaving was most noticeable in low, wet areas, while in higher, well drained locations scarcely any heaves have been recorded. As indicated in Fig. 1, frost heaves of piles may be cumulative resulting in movements of twenty or thirty inches in a few years. The rule of thumb recommended by Muller that pile penetration of permafrost be twice the active layer seems to be satisfactory.

A cumulative heave of twenty inches, of a covering box for service lines is shown here. One trestle in the foreground was anchored in permafrost so that it did not move.

FIG. 1

In all construction over the past year and a half, steel piles have been used exclusively, for purely economic reasons. They were available at no cost from scrap pipe, were more easily handled and driven than were wooden piles, and they are slightly flexible as to position after driving. They may be quickly and cheaply lengthened cut or capped by welding. So far none driven fifteen feet or more have heaved or settled, and examination of foundations erected for one year indicate that they should be very satisfactory.

To prevent heaving, collars one and a half inches greater in diameter than the pipe were welded or screwed to the butt of the pile. Pile spacing may be varied to suit the type of construction, in light frame buildings it varied from six to ten feet to fit sill spacing and joints. In spacing piles closer than three feet on centre, greater care must be taken in steam jetting holes to prevent complete thawing of the ground and the consequent long refreezing period.

Wherever possible the piles are extended eighteen to twenty-four inches above the surface of the ground, and the building then erected, thus allowing a clear space under the building for air circulation so that the permafrost level is maintained fairly close to the surface. See Fig. 2.

A light frame building set on steel piles. More piles are shown in the foreground.

FIG. 2

Experiments have been tried with some small buildings, e-g- living quarters twenty-four feet or less in width, in which this space under the building is boxed in and the steam and service pipes run in it. This gives very warm floors and uniform heating of the house and seems satisfactory, if the building is narrow enough so that frost coming in from the sides maintains the permafrost level well above the base of the pile.

Some doubt has been expressed about the use of steel piles, as it was felt that they would carry heat into the ground and so lower the permafrost level. Examination of the frost line around several piles was carried out in August of 1947 and it was found that the permafrost level dropped about one inch around a wooden pile and about four inches around a six inch steel pipe pile. This indicates the greater conduction that could be expected in a steel pile, but does not indicate a dangerous lowering of the frost line. Moreover, temperature records along piles showed that "freezing in" of steel piles after driving is more rapid than the freezing in of wooden piles. At Norman Wells, steel piles were frozen in at the foot in from three to six days.

No pile loading test results have so far been completed, but these tests are presently under way. Indications are that under normal conditions the pile loading is governed only by the strength of the pile under conditions stated above.

Another serious engineering problem is the installation of water, sewer and steam lines in locations where the ground is permanently frozen and has a high water content. It is obvious that buried lines run into high installation and repair costs.

At the Norman Wells site, surface lines have been used almost exclusively although some buried lines were tried. The buried lines did not prove too successful; difficulty was encountered in waterproofing the insulated steam lines which were used to supply steam heat to buildings and at the same time to prevent freezing of water and sewer lines. The first surface lines were laid in an insulated box which in turn was supported on logs or short posts driven into the active layer. As would be expected, a great deal of trouble occurred due to movement, especially heaving of posts driven up to seven feet in the ground. See Fig. 1.

The final method used was to drive single steel piles every seven to nine feet along the line, weld on suitable supports to grade, lay the lines and cover them in with a well insulated box. This method has been very satisfactory, it is not affected by frost heaving, or settlement, repairs are easily and quickly made, and the whole installation can be put in at a fraction of the cost of ditching and laying buried lines.

Some trouble is also encountered in the North in the installation and upkeep of power and telephone lines. Fig. 3 shows power poles which after only two years, have been heaved to the surface by frost action. This case is the most severe in this locality, although there are many instances where power lines have been made dangerously weak by this action, in a matter of three or four years. The only remedy seems to be to drive a pile to anchor in permafrost and fasten the poles to the pile above the ground so that the active layer cannot heave the poles.

Roadbuilding and airport construction are important in the North and of course the effects of permafrost must be carefully considered in both. At Norman Wells, experience showed that the best results were obtained when moss and scrub from both sides of the road were pushed to the centre of the grade, this was packed and over it was placed a filled subgrade, either from the ditches or borrow pits. This method is essentially the same as outlined by Muller; it allows for good drainage, and also causes a rise in the permafrost level in the roadbed. In muskeg areas all stripping of moss and vegetation and subsequent piling in the roadbed should be done in the spring after snow is gone so that machinery can move easily and efficiently on the still frozen ground.

In all construction on permafrost, drainage is of great importance. The natural growth of moss and scrub holds moisture and keeps the permafrost level very near the surface. In any operation this vegetation cover is broken or in many cases cleared away entirely. The resulting lowering of the permafrost level releases large quantities of water which will remain to hamper operations unless there is adequate drainage. If possible, the building area should be cleared at least two years before it is to be used ditches should be provided to carry away excess water. This lowers and stabilizes the frost line and allows for easy work.

The pole line here was heaved out of the ground by frost action. Similar heave is indicated in the short post under the box for service lines along the pole line.

FIG. 3

As in all foundation work the importance of soil testing cannot be overemphasized in permafrost work. Susceptibility to frost heaving is indicated by the grain size determination, and the nature and behaviour of the permanently frozen ground is shown by a test for moisture content.

These and other tests if carefully used will aid in choosing the proper method of attack for any permafrost foundation problem. At locations similar to Norman Wells the following four points are essential.

1) Carry the foundation into permafrost.
2) Assure that the permafrost level is not lowered dangerously.
3) Prevent frost heaving.
4) Provide adequate drainage.

So far test results on soils from Norman Wells are not complete. Records are being kept of air temperatures under several buildings and of temperature at several points along the length of many steel and wood piles. Frost lines under existing buildings are being examined and careful records are being kept of all foundations, roads, etc., in the district. Dry abandoned oil wells are being used to give temperatures of the soil at depth and to determine the lower boundary of the permafrost. A careful analysis of the results of these tests and the proper application will greatly help the engineer in the North to attack and solve the problems presented by permafrost.

REFERENCE

1) "Permafrost on Permanently Frozen Ground and Related Problems", Siemon Muller - Page 96.

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