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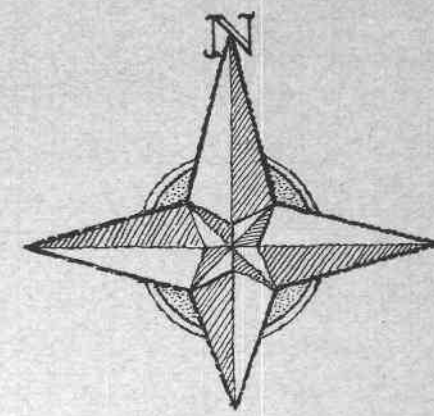
CONSTRUCTION IN PERMAFROST



Obstacles of soil and climate

by H. B. Dickens

Perennially frozen ground or permafrost, as it is more commonly called, is probably the best known and yet least understood feature of the North. Although not a new phenomenon, it is only the relatively recent building of such projects as the Alaska Highway, the Canol Line and the airstrips for the Northwest Staging Route that has made the special problems of construction in permafrost so evident to engineers.

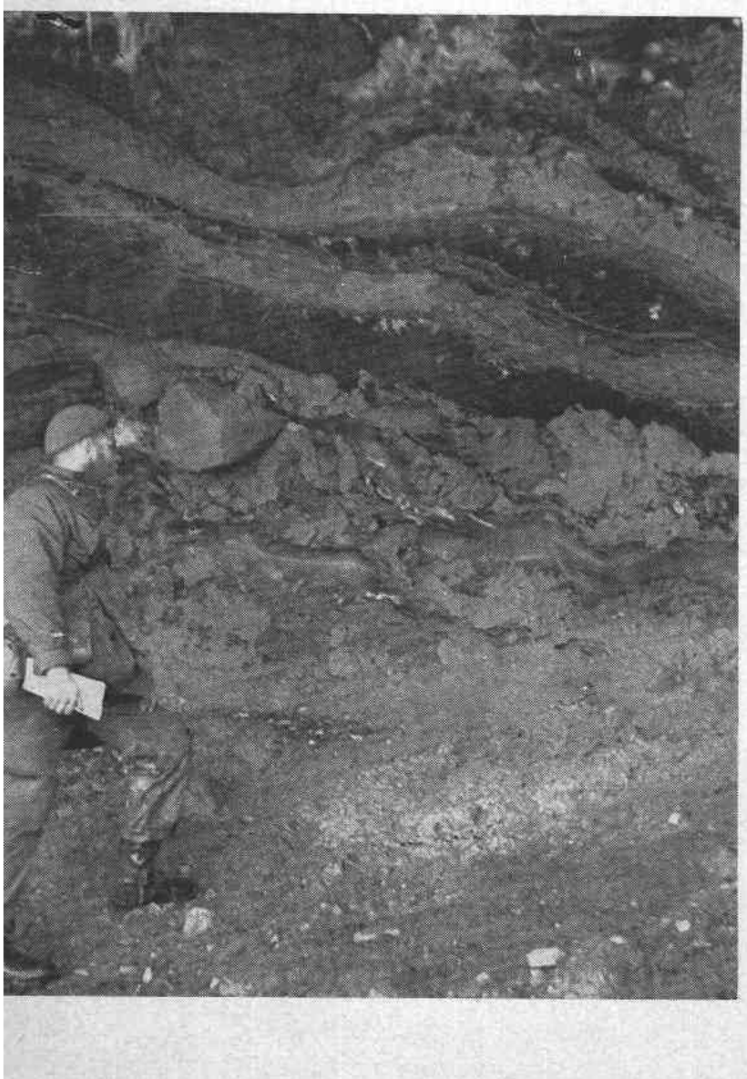
To cope adequately with these problems, the engineer requires a clear appreciation of the basic properties of permafrost, the way in which these properties can change with varying conditions and the implications of such changes to construction.

The word "permafrost" is used to describe that part of the earth's crust where the temperature is below 32°F. The term describes only the thermal condition of the ground and not its composition which may be bedrock, gravel, sand, silt, clay or muskeg, singly or in combination. Thus permafrost is not the name of a new material but is simply the frozen equivalent of the ground as found in warmer climates.

In the case of solid rock, gravel and sand, the frozen condition does not seriously affect the engineering properties of the material. If, however, the ground consists of water-bearing silt or clay, freezing transforms the material to a hard and solid mass. It is to such perennially frozen silt and clay that the name permafrost is popularly applied.

The ground in permafrost areas is normally thought of as two distinct layers: the upper, or active layer, which alternately freezes and thaws with the seasons; and the lower, or permafrost layer, which remains frozen continuously. The depth of the active layer varies with many local factors including soil type, moisture content and vegetative cover in much the same way as depth of frost penetration varies with local conditions in the more southerly areas of Canada. Similarly, foundations located in the active zone are exposed to frost action problems analogous to those encountered in the freezing zone of the soil in more temperate regions. Almost one-half of the


CONTINUOUS PERMAFROST
ALASKA
FAIRBANKS
RESOLUTE
YUKON
TERRITORY
AKLAVIK
NORTHWEST TERRITORIES
NORMAN WELLS
WHITEHORSE
HAY RIVER
YELLOWKNIFE
BRITISH
COLUMBIA
FORT SMITH
HUDSON BAY
CHURCHILL
APPROXIMATE SOUTHERN LIMIT
OF CONTINUOUS PERMAFROST
ALBERTA
EDMONTON
SASKATCHEWAN
MANITOBA
FLIN FLON
VANCOUVER
SASKATOON
REGINA
WINNIPEG
ONTARIO
QUEBEC
MONTREAL
HALIFAX



Melting of permafrost cause of major problems

land area of Canada is underlain by permafrost. Although chiefly confined to the Northwest and Yukon Territories, it does extend into the upper portions of the provinces, particularly into the northern parts of Manitoba and Quebec. As would be expected, the thickness of permafrost increases towards the north, ranging from a few feet in areas such as Hay River to approximately 1300 feet at Resolute in the Far North.

Of major importance to the engineer is knowledge of the southern limit of permafrost in Canada. Unfortunately, this is not a well defined line, as it generally appears on a map. In practice, it consists of a belt of land several hundred miles wide in which areas of continuous permafrost (where the permafrost is found everywhere under the surface) give way to areas of sporadic permafrost (where the frozen ground tends to exist only as scattered patches or islands within the unfrozen material).

It is these latter areas that often pose the most difficult construction problems for the engineer, due mainly to the limited extent of permafrost and consequent difficulty of predicting its occurrence at a specific location, and to its temperature which is generally near 32°F and thus close to melting.

It is the melting of permafrost containing large quantities of ice that gives rise to the major construction problems in permafrost areas. The ice in frozen soil can take the form of layers or lenses ranging from hairline size to 3 or 4 feet in thickness, or can occur as coatings over small soil particles, stones and boulders. Some of the most spectacular ice deposits are found as chunks or wedges buried in the frozen ground.

For soils in a frozen condition, the ice acts like a cement, bonding the individual particles together and producing a soil with considerable strength. When thawed, however, the hard-frozen soil can change to a soft slurry with little or no supporting power.

Knowledge of the ice content of frozen soil is of major importance to the engineer since it provides a measure of the extent to which settlements will occur or trafficability will be affected by thawing. Materials such as frozen rock, gravel, or coarse sand frequently contain little ice and thus impose few problems. Much of northern Canada, however, is underlain by fine-grained soils resulting from glacial action. Such soils generally have high ice contents up to six times that of the soil by volume and if these are to provide suitable support for engineering structures, they must not be allowed to thaw. This is difficult to achieve in view of the extreme sensitivity of permafrost to temperature differences.

The vast area of northern Canada subject to continuous permafrost is shown in the map on the opposite page. The lower pictures opposite show layers of ice or ice lenses uncovered by excavation (right) and naturally exposed (dark layers in picture on left).

In undisturbed areas of permafrost, a delicate condition of temperature equilibrium exists between the top of the permafrost and the ground surface. Any changes in the natural insulating cover such as the stripping of moss can upset this thermal balance of nature and start the permafrost thawing. Even one passage of a tracked vehicle over the natural ground surface will reduce the insulating value of the moss cover sufficiently to cause thawing.

Preservation of the frozen condition during construction and operation of a building or other engineering facility requires not only specific design and construction techniques but also strict discipline and control of all construction operations. In many cases, it is necessary to protect the organic cover prior to beginning work in an area by placing a one- to two-foot gravel layer over all areas that might be disturbed.

A third important and yet often overlooked property of permafrost is its imperviousness to the flow of water. Water cannot percolate through the perennially frozen ground so all water movement tends to occur over or just below the ground surface. This lack of subsurface drainage often results in an excess of surface water even though much of the North is characterized by very low precipitation. If natural drainage is impeded by construction, the accumulated water will accelerate the thawing of the permafrost, with possible serious results.

Since the problems of construction are greatly lessened in rock or granular soils with little ice content, location of such areas is a most important element in northern construction. There are many cases where the increased construction and maintenance costs arising from poor site conditions would more than pay for the most detailed site studies.

The specific requirements of a site survey will vary with the kind of facility under consideration. In all cases, however, the broad objectives are the same, namely, to determine the best available ground conditions and to provide information on which a satisfactory design can be based.

Airphoto interpretation gives promise of greatly aiding both detailed and regional site surveys, but must be supplemented by ground reconnaissance in the final evaluation of the soil, topography, drainage, and vegetation characteristics of a site. Observations of surface features can provide useful clues to the nature of subsurface conditions and, when properly used, can greatly aid the engineer in his preliminary assessment of a site. Actual sampling of the frozen ground to determine its soil and ice profile is still necessary, however, and special techniques have been developed for this purpose*.

Although the siting of engineering facilities on granular materials containing little or no ice per-

Choosing the site is a most important element

mits the use of conventional design and construction techniques, this is not always possible. Where fine-grained materials with high ice contents must be utilized, every effort should be made to preserve the frozen condition of the ground.

The way in which this is achieved in practice will depend on the type of engineering structure. For heated buildings and most enclosures, the ventilation method is commonly used. With this method, the structure is raised above the ground to permit circulation of air beneath, thus minimizing heat flow to the permafrost. The foundations are usually embedded in the perenially frozen ground so that some lowering of the permafrost table can be tolerated without loss of support. Steamed-in piles have proved particularly well suited to this method in fine-graded soils (*Fig. 6 and 7*). Where stones and boulders in the soil make pile placing difficult, however, alternative foundation designs may prove more economical.

Occasionally, surface foundations are used. In such cases, an insulating blanket of gravel is first placed on the undisturbed ground to retard downward heat flow and the building constructed over it. This method must be used with caution since the thickness of gravel required to preserve the permafrost will vary with many local factors and is difficult to predict. With this type of construction, even slight lowering of the permafrost table may cause settlement depending on the soil properties, and in addition, the problem of frost action in the active layer of soil beneath the building may prove serious.

These considerations become particularly critical in road and airstrip construction where the ventilation method, as used with buildings, cannot be applied and an insulating gravel blanket must be relied on to retain the thermal regime. In such cases, the importance of selecting the most favorable site and of keeping disturbance of the surface cover to an absolute minimum in poor soil conditions takes on even greater significance. The only exception to this principle of preserving the frozen condition occurs in the southern areas of permafrost where the frozen ground exists in patches and is close to melting. In these areas, it may be more economical to remove the permafrost by thawing prior to construction and then to build in the normal way.

It is not possible in this brief survey to do more than touch on these major aspects of construction in permafrost. Excavation is one other problem that should be mentioned, however, since it can be both difficult and costly in frozen ground. Normal excavation techniques are much less effective in permafrost. Thus where gravel fill is required, particularly the large amounts needed for roads and airstrips, borrow pits should be located, stripped of vegetation, and allowed to thaw by natural means, well in advance of construction.

Finally, a note about water and sewage facilities. Permafrost imposes difficulties with these by complicating the location of subsurface water supplies and seriously limiting the use of the usual methods of sewage disposal into the soil*. In addition to the foundation stability problem resulting from thawing of permafrost, water and sewer lines cannot be placed below frost level and are therefore subject to freezing hazards. To overcome such difficulties, the utility lines are often placed in heated and insulated boxes called utilidors located above grade and supported in a manner similar to buildings.

In summary, past experience with construction over permafrost has clearly illustrated the costly problems that can arise if site selection is neglected and permafrost ignored. With proper application of present known techniques, and with careful attention to detail at all stages of the work, all types of engineering projects can be successfully carried out in permafrost areas. The cost of such construction is admittedly high by southern standards but reductions can be expected as knowledge of permafrost phenomena and engineering techniques improve and design data become more refined.

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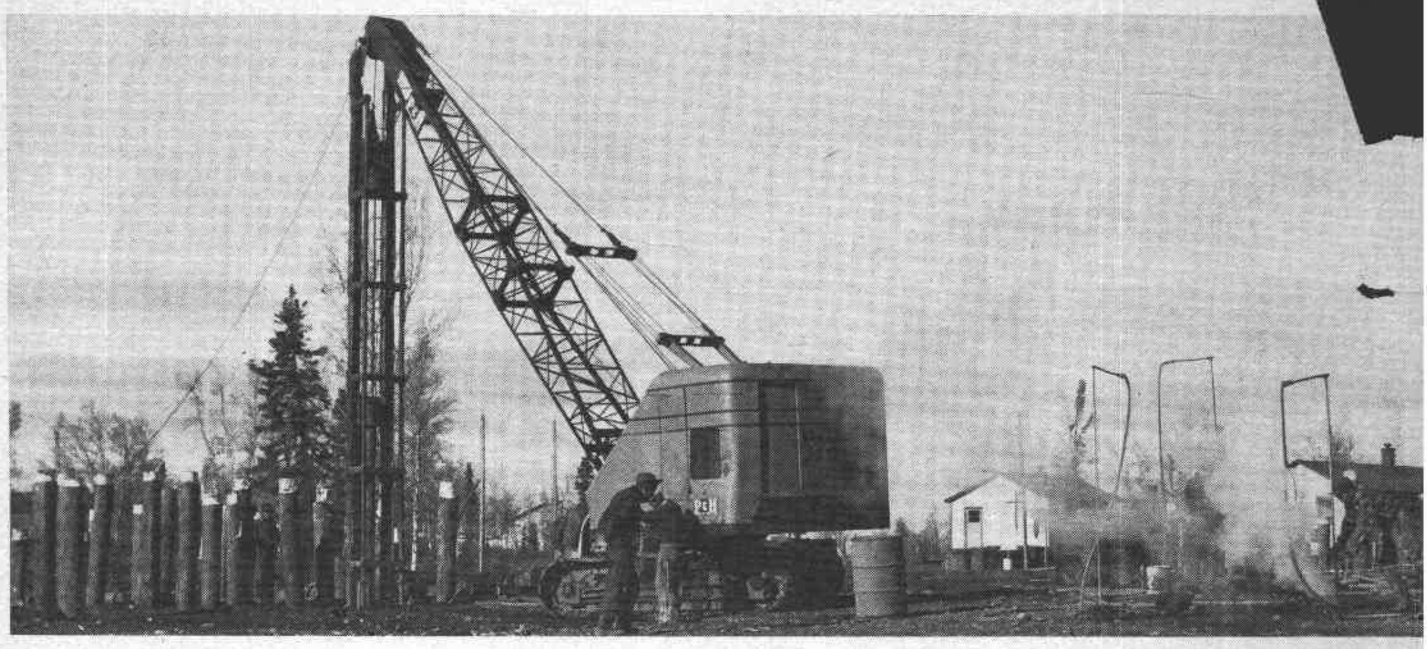
*"Permafrost Investigations at Aklavik (Drilling and Sampling) 1953" by J. A. Pihlainen and G. H. Johnston, Division of Building Research, NRC 3393, January 1954.

*"Water Supply and Sewage Disposal in Perma-frost Areas of Northern Canada" by H. B. Dickens, Division of Building Research, NRC 5169, August 1959.

Thawing of permafrost in Canada's north can be accelerated by actual construction work and by vehicles engaged in the work. For example, the top photograph on the opposite page shows how the natural drainage of the land has been impeded by road construction, forming pools of water at the side. This has the effect of increasing the rate of the thawing. The bottom picture on the opposite page indicates how the passage of a heavy vehicle has disturbed the protective carpet of surface moss and caused a subsidence of the soil beneath. Pile placing in permafrost requires a process of thawing the ground by steam jets and, in the centre picture, this process can be seen in operation on the right. When the ground is sufficiently thawed, piles are driven in the normal way and allowed to freeze in.



The school and hostels at Inuvik (top) shown against the flat background of the Mackenzie Delta
South elevation of the East Hostel at Inuvik showing the playroom and chapel projections (below)

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