## Permafrost aspects of Hudson Bay railroad

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# PERMAFROST ASPECTS OF HUDSON BAY RAILROAD



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Journal of the

SOIL MECHANICS AND FOUNDATIONS DIVISION

Proceedings of the American Society of Civil Engineers

# PERMAFROST ASPECTS OF HUDSON BAY RAILROAD[a]

J. L. Charles[1]

ABSTRACT

A general description of the factors conducive to causing the condition of permafrost, the possible extent of this condition in Northern Canada and its effect on construction and maintenance. Also, recommended practices to contend with problems permafrost presents in connection with such projects, in particular, the Hudson Bay Railroad.

Recent increased activity in the north brought about by such projects as construction of the DEW Line and the Mid-Canada Line, as well as the relocation of the Arctic community of Aklavik has focused much attention upon the subject of permafrost and the problems of building in permafrost areas. It is interesting to note, however, that perpetually frozen soil, now termed "permafrost," was encountered and contended with nearly fifty years ago when construction of the railway was commenced to Hudson Bay. In 1939, the well-known Arctic explorer, Dr. Vilhjalmur Stefansson, making inquiries on behalf of the U. S. Army with respect to permafrost and its probable effect on railway operations in Alaska, turned to the Canadian National Railways for information based on actual experience gained during construction and operation of the Hudson Bay Railway to Churchill. It is this experience that forms the basis for the material in this paper.

Permafrost is not a material, it is a condition. Factors contributing to the occurrence of permafrost are:

1) Altitude and average annual air temperature.

2) Surface covering and its insulating properties.

3) Type and conductivity of sub-soil.

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a. Presented at the May 1959 ASCE Convention in Cleveland, Ohio.

1. Cons. Engr., Canadian National Railways, Winnipeg, Canada.

4) Topography and natural drainage, both surface and sub-surface.

5) Location in relation to rays from the sun.

6) Precipitation.

With local vagaries excepted, permafrost may be expected in regions where the mean annual temperature is a few degrees below freezing - say 25° F. No direct correlation has been found between the presence of permafrost and any particular temperature isotherm, nor can the southern boundary of permafrost be clearly defined but as a rough guide, the southern limit of permafrost in Canada may be assumed to exist as shown in Fig. 1. It should be noted that nearly half of the total area of Canada, including the Arctic Islands, may be underlain by permafrost. The importance of studying this condition in connection with construction and maintenance of engineering facilities in the Canadian Northland cannot therefore be over-emphasized.

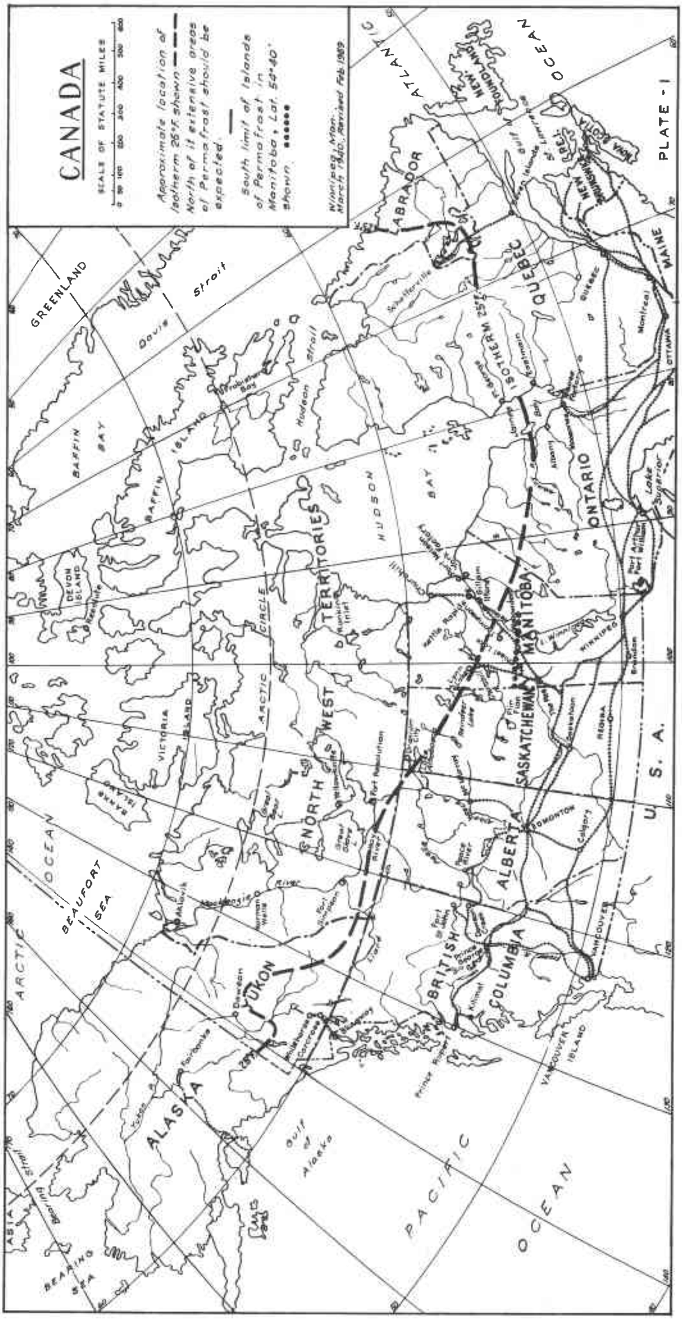
Construction of the Hudson Bay Railway was begun from The Pas, Manitoba, in 1910, to connect the Western Prairies with a seaport on Hudson Bay. The Pas is 340 miles north of the International Boundary between the United States and Canada. Railway mileages are from zero at The Pas, total distance to the port at Churchill is 510 miles.

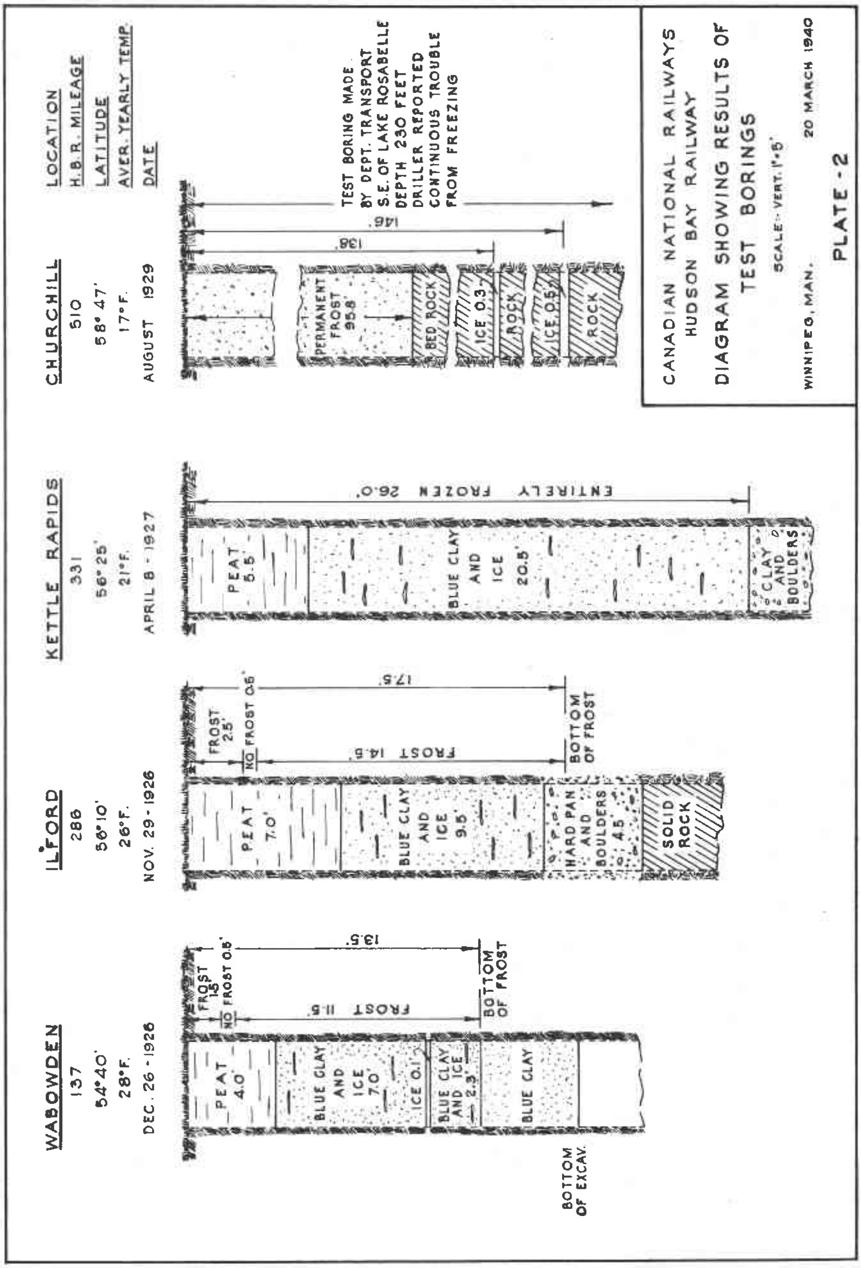
Observations made during construction of the railway showed permafrost to occur in scattered patches or islands as far south as Wabowden, latitude 54°50'. Northward, these islands increase in extent until the Limestone River, latitude 56°30', is reached. From there to Churchill, latitude 58°47', the sub-surface is almost entirely permafrost.

This northerly section traverses the geological formation known as the Hudson Bay Lowlands, a vast area of muskeg, with very little timber, which the Indians call the "Land of Little Sticks"; the "Barren Lands" extend into this territory. Where the subformation is of organic materials covered with surface mosses and there is no accumulation of water, the summer thaw does not penetrate below a depth of 18 inches. On the few low ridges, where materials are fairly dry - clay, gravel or sand - and the covering of vegetation is light, the ground may thaw during the summer to a depth of 5 or 6 feet and under water to 10 feet or even deeper. Fig. 2 shows results of test borings at four principal stations on this Railway. At Churchill, under Lake Rosabelle, frost was not found until borings reached a depth of 42 feet, and in the harbour no frost was encountered within the limits of low-water mark.

The treeless tundra, immediately south of Churchill, is illustrative of the type of country most conducive to the occurrence of permafrost. The average yearly air temperature is 19°F. The area in general is very flat - an elevation of between 50 and 200 feet above sea level - there are numerous shallow lakes and ponds and between them are muskeg hummocks of 5 to 10 feet in height. The entire ground area is covered with a heavy vegetation of mosses, under them are organic materials to a depth of 4 to 18 feet, then glacial drift - grey clay, of fine texture and boulders. Lenses of clear ice, up to 6 inches thick, are found in the layers of both organic materials and drift. The higher ground (hummocks) is entirely frozen excepting for 12 to 18 inches below the surface; whereas the lower ground (hollows), where water accumulates in summer, thaws to a somewhat greater extent.

About one million years ago, the Keewatin ice cap covered this area and extended over the Prairies southerly into North Dakota, depressing the "Lowlands." During and after the last ice retreat, 7,000 to 15,000 years ago,


CANADA
SCALE OF STATUTE MILES
PLATE - I


LOCATION
H.B.R. MILEAGE
LATITUDE
AVER. YEARLY TEMP.
DATE
WABOWDEN
137
54°40'
28°F.
DEC. 26 - 1926
PEAT 4.0'
BLUE CLAY AND ICE 7.0'
ICE 0.1'
BLUE CLAY AND ICE 2.3'
BLUE CLAY
BOTTOM OF EXCAV.
FROST 1.5'
NO FROST 0.5'
FROST 11.5'
13.5'
BOTTOM OF FROST
ILFORD
286
56°10'
26°F.
NOV. 29 - 1926
PEAT 7.0'
BLUE CLAY AND ICE 9.5'
HARD PAN AND BOULDERS 4.5'
SOLID ROCK
FROST 2.5'
NO FROST 0.5'
FROST 14.5'
17.5'
BOTTOM OF FROST
KETTLE RAPIDS
331
56°25'
21°F.
APRIL 8 - 1927
PEAT 5.5'
BLUE CLAY AND ICE 20.5'
CLAY AND BOULDERS
ENTIRELY FROZEN 26.0'
CHURCHILL
510
58°47'
17°F.
AUGUST 1929
PERMANENT FROST 95.8'
BED ROCK
ICE 0.3'
ROCK
ICE 0.5'
ROCK
138'
146'
TEST BORING MADE BY DEPT. TRANSPORT S.E. OF LAKE ROSABELLE DEPTH 230 FEET DRILLER REPORTED CONTINUOUS TROUBLE FROM FREEZING
CANADIAN NATIONAL RAILWAYS
HUDSON BAY RAILWAY
DIAGRAM SHOWING RESULTS OF TEST BORINGS
SCALE:- VERT. 1"=5'
WINNIPEG, MAN.
20 MARCH 1940
PLATE - 2

the elevation of this area raised. Observations show that the elevation above sea-level is continuing to increase. It is interesting to note that several well preserved Walrus skulls and tusks were found in gravel being excavated for ballast from a low esker or beach ridge, 215 feet above and 50 miles inland from the present shoreline of Hudson Bay.

As this tundra is yet in a primitive era in relation to evolution of formation, it is suggested that, the surface may, through time, with improved natural drainage, transform to a more advanced state, perhaps to soil which would produce timber such as the fair stands of spruce presently growing on islands and river banks where there is good drainage. Where ditches have been excavated adjacent to the Railway, black organic materials are exposed in the former lake beds; grasses and weeds will grow in these materials with entirely different characteristics from the mosses of the tundra.

Fig. 3, a sectional diagram, illustrates how observed annual thawing, at water level, of the many lakes and ponds in the region causes over-hang at the shores which periodically fall and increase the water surfaces; this process may result in the joining of a number of lakes and ponds and may lead to the erosion of more and deeper water courses and thus improved drainage for the entire region.

The effect of permafrost in connection with construction and maintenance of the Hudson Bay Railway can best be described by considering the route in two sections: -

A) From the south limit of "patches" or "islands" of permafrost, northerly for a distance of 220 miles to where it becomes general.

Over this section which takes in the Nelson River drainage system, elevation 750 to 450 feet above sea level, the topography varies from extensive flat areas of muskeg to rolling country of the Canadian Shield - rock, with heavy overburden of clay and sand, the latter fairly well timbered with spruce, jack-pine, tamarac, aspen and birch.

Construction was carried out, on this section, from 1912 to 1915. Patches of permafrost were encountered at many locations between Wabowden, Mile 137, and the crossing of the Limestone River, Mile 352, in both clay and organic materials.

Drainage of the muskegs was the first operation. No mechanical equipment was available and to work horses or mules was impractical. Hundreds of miles of ditches were excavated by hand, frozen materials were taken off in layers of about six inches deep as they thawed but in many locations it was essential to effect drainage immediately, then permafrost was actually chopped out with axes.

Where the roadbed was in cut and fill, embankments were built with materials from adjacent cuts, but the length of haul was limited by what was practical with wheelbarrows and small dump cars equipped with double flanged wheels hauled over pole tracks manually, excepting in special locations where a few horses had been left in after the winter freight haul. The balance of the embankments were built with materials, mostly organic, excavated from parallel borrow pits and wheeled, in barrows, into place.

Timber bridges were constructed during winter season, when materials and pile drivers could be hauled in over the frozen terrain. Steam was employed to jet piles through frost. Five cedar piles up to 40 feet long, spaced 3 feet centre to centre in each bent, with distance between bents 14 feet.

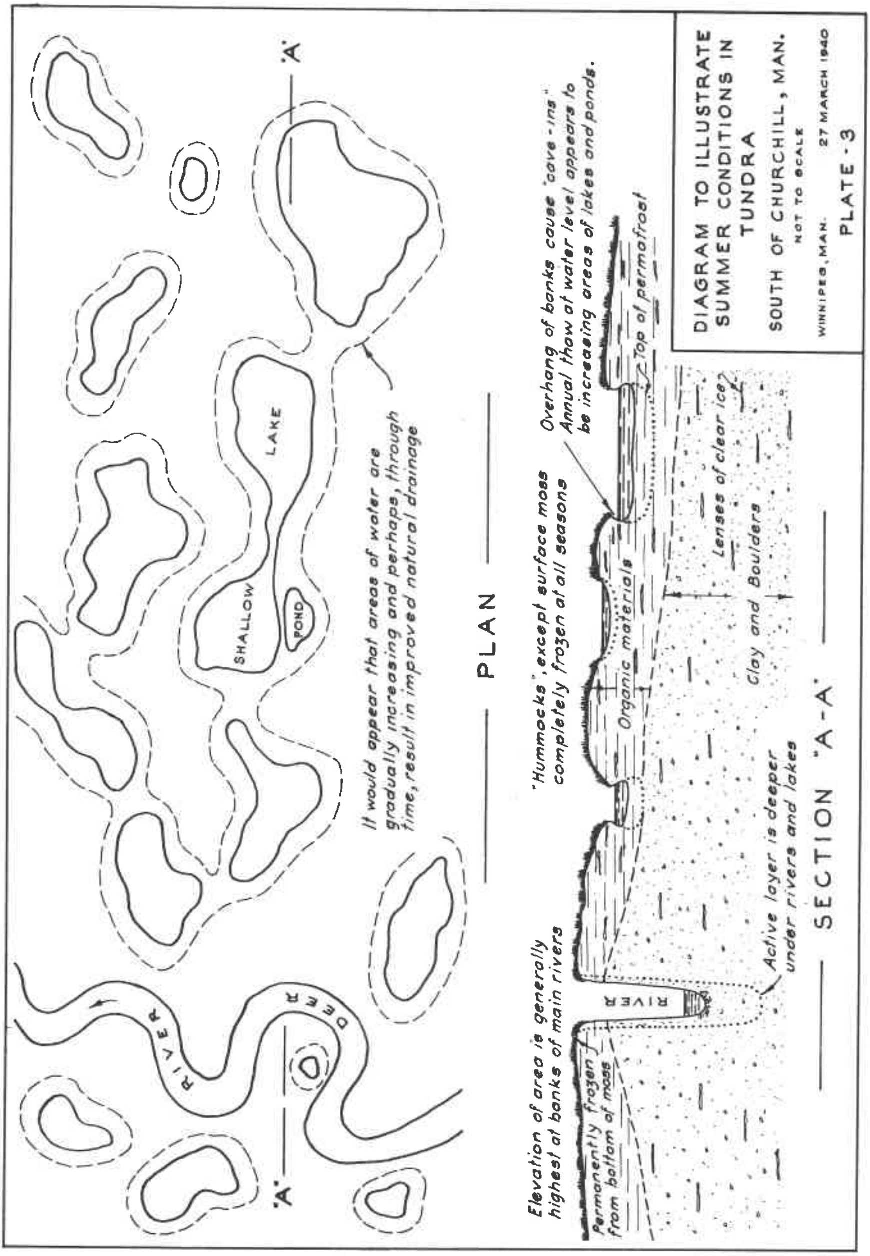


DIAGRAM TO ILLUSTRATE
SUMMER CONDITIONS IN
TUNDRA
SOUTH OF CHURCHILL, MAN.
NOT TO SCALE
WINNIPEG, MAN.
27 MARCH 1940
PLATE - 3
'A'
'A'
DEER RIVER
SHALLOW LAKE
POND
It would appear that areas of water are gradually increasing and perhaps, through time, result in improved natural drainage
PLAN
Overhang of banks cause "cave-ins". Annual thaw at water level appears to be increasing areas of lakes and ponds.
Top of permafrost
"Hummocks", except surface moss completely frozen at all seasons
Lenses of clear ice
Organic materials
Clay and Boulders
Elevation of area is generally highest at banks of main rivers
Permanently frozen from bottom of moss
RIVER
Active layer is deeper under rivers and lakes
SECTION 'A-A'

Track was laid each winter with a "Pioneer" tracklaying machine, when the unconsolidated roadbed was frozen, with temperatures down to 50 degrees below zero. The following summer, embankments were progressively improved with trainfill and the track was ballasted with pit run sand and gravel hauled considerable distances.

Trainfilling and ditching were continued each summer until 1917, when due to wartime conditions further work was suspended and trains were not operated north of Pikwitonei, Mile 214. Beyond there, without maintenance, embankments settled to such an extent that at some locations track was hanging in the air and sink-holes occurred where cuts had been excavated through knolls of frozen organic materials and ice. Removal of surface insulation and exposure to annual thawing caused water to accumulate and aggravate the situation.

In 1926, it was decided to complete the railway to the Bay and to construct a harbour with facilities for trans-shipment of goods, principally grain, between rail and ocean freighters. The initial requirement was to rehabilitate the 330 miles of track laid and facilities built prior to the suspension of construction. As it was customary to use untreated ties during construction, a large percentage had to be replaced and heavy programmes of ditching, trainfilling and rebuilding of timber bridges were necessary. Fortunately, draglines and other mechanical equipment had become available and they could be moved in by rail. Conditions were much easier than during original construction when all supplies had to be hauled in by teams during winter as there was no summer transport other than on foot.

Extensive surveys were carried out to plan more effective drainage. Draglines were moved out on pads as much as three miles to commence excavation of off-take ditches, up grade, to the track and then parallel side ditches. A large percentage of these excavations were of organic materials although some parts were through clay and occasionally solid rock. Much was permafrost, this was usually excavated in layers of from 6 to 12 inches deep as they thawed after exposure; however, in critical locations where the necessity for drainage was urgent, explosives were used, but efficiency factor of explosives in blasting frozen materials is comparatively low.

In connection with the ditching, hundreds of the original culverts were renewed and additional ones installed. Selection of culvert sites is of great importance; if it is at all possible they should not be placed on permafrost. Where this is not practicable, it is necessary to excavate well below grade and backfill immediately with dry material, preferably sand or gravel, before thawing begins. A mat of old bridge stringers, laid with a good camber, should then be placed as a foundation for the culvert.

For such locations, experience has shown the most servicable type of culvert to be a cedar box, with solid floor, constructed of 10" × 10" or 12" × 12" timbers. These structures are flexible and will function even if they become distorted. In northern latitudes, a life of thirty or more years may be expected for exposed untreated cedar; under water, it will last almost in perpetuity. Due to the possibility of settlement and other movement of a culvert placed on permafrost, use of treated timber would not appear to be economical. As an alternative, corrugated iron pipe is now available.

There are no unusual features in maintaining and operating this section of railway. It is important, however, that drainage ditches are re-excavated periodically, say every ten years, to prevent accumulation of water against the slopes of embankments. Cuts, particularly those excavated through permafrost, must be kept well drained, and berms should be built at the toe of slopes of embankments and up to two feet above high water level at locations where total drainage is not practicable. Snowfall is not heavy and temperatures are not lower than encountered on the Trans-Continental Lines in Canada; however, winters are longer.

B) From the Limestone River northerly - where permafrost is general - to Churchill, a distance of 160 miles.

Here the railway runs almost due north over the low watershed between the Nelson River and the Churchill River - a vast area of muskeg, with hundreds of shallow lakes and ponds. Opinions had been expressed that it would not be practicable to construct and maintain a railway there.

Surveys and soil tests, during the winter of 1926-27, showed this to be incorrect. As transport was by dog teams, weight of supplies and equipment had to be kept to a minimum. No drill equipment could be carried so it was necessary to actually chop test-holes to ascertain the depth of organic materials overlying the glacial drift. The greatest depth found was 18 feet. Lenses of clear ice up to 6 inches thick were cut through in both the organic and glacial materials.

Further reconnaissance was made during the following summer by a small party walking across country packing the bare essentials. This confirmed observations made under winter conditions that, almost the entire area was under laid with permafrost and that, generally the annual thaw of the "active" layer extended only to a depth of one to two feet from the surface.

At the same time, the mouth of the Churchill River, a natural harbour, was surveyed with respect to development of a harbour.

As results of these surveys were favourable in comparison with alternatives which had been previously studied, it was decided that, the railway should be constructed to Churchill and a seaport be developed there.

Plans were made to commence location surveys early in November, 1927. In this territory, winter is much more favourable for ground surveys and to search for granular materials for trainfill and ballast. Dogs were, as yet, the only practical means of forward transport, also, aerial photographs and photogrammetry had not become available.

Plans were also made for construction to be commenced in January 1928 and to closely follow the location surveys as they advanced. All supplies and materials, required for the following summer, had to be freighted in and distributed along the route. This was done with horses, hired for the winter from prairie farms; it had to be completed and the teams taken out before Spring break-up.

Originally, all bridges were of the pile trestle type and were built during the same winter, in order that materials and equipment could be hauled from site to site over the frozen ground. Piles were driven into the permafrost with the aid of stream jets. It looked odd to see bridges standing alone with no approach embankments but this avoided delays to grading and tracklaying.

To ensure that permafrost would remain in this condition and future maintenance of track and structures would be the minimum, it was decided to design the railway roadway to be almost entirely embankment and make as few cuttings as practicable.

Initial grading was restricted to minor levelling of the surface mosses etc., just sufficient to permit track to be laid.

Three good deposits of sand and gravel - eskers or beach ridges - were located, the farthest from the line was six miles. Tracks were laid into these pits and power shovels, cars and fuels etc., were placed in them before Spring break-up. Then granular materials were excavated, loaded, distributed and tracks were progressively lifted, commencing from each pit to the main line, then each way along it, until connected with work being carried on from pits to the south and north. When the lifts from the respective pits were completed, the main track was on a roadbed almost entirely embankment, composed of sand and gravel.

As stated above, grading prior to tracklaying was restricted to minor levelling of surface mosses and ditches excavated only where it was essential to drain shallow lakes and ponds; the final roadbed was on undisturbed permafrost. The covering of sand and gravel embankments does not appear to have affected the permafrost below, and may have even assisted in perpetuating this condition.

Track was laid into Churchill 29th March 1929; so this most northerly section of railway has been in operation for 30 years.

Maintenance of track is comparatively light; there is very little settlement, very few weeds grow, life of ties and timber structures is considerably longer than in southern areas and some of the original untreated ties are still in service. As renewals are required, treated ties are being installed and it is expected they will have a lift of fifty years.

Although high winds prevail on the tundra, very few snow drifts accumulate on the track; as the rails are 3 to 4 feet above the general ground elevation, winds clear them. Operation of a snowplow is seldom necessary.

One exception to the good features of maintaining a railway on the tundra is that piles in timber trestles are subject to a very irregular heaving. Piles in the same bent are sometimes affected very differently; one pile may remain in position but the one next to it may heave considerably. Another feature is, piles which heave may remain up or may settle again.

Care in pre-steaming holes, about the diameter of the piles, to thaw just sufficient permafrost to permit the piles to be driven - butt down - will reduce the possibility of heaving; if it does occur it is not too serious a situation as timber bridge decks can be surfaced periodically by cutting heaved piles, and/or, by shimming to take up settlement.

The axiom we follow is - (i) wherever practicable avoid excavations in permafrost, (ii) do not disturb the natural surface insulation and, (iii) endeavor to retain the permafrost condition.

Where topography prevents this axiom to be followed, difficult construction situations may arise. Some of these are best illustrated by reference to the more recent construction of the following branch lines from the main Churchill Railway.

## Sherridon to Lynn Lake, 144 Miles, 1952-1953

This line, constructed to serve the mining community of Lynn Lake, was built through rolling country of the Canadian Shield, between latitude 55° and 57°. Some hills had heavy overburdens of varved clay and/or organic materials, within "islands of permafrost," where the railway gradients necessitated making excavations.

These cuts in permafrost were mostly excavated in layers by bulldozers, as materials progressively thawed after exposure. However, where time was limited, explosives were necessary to break up some of the deeper cuts, for materials to be handled with power shovels. All cuts in permafrost were excavated to additional depth - 2 feet to 3 feet below sub-grade - to permit more ballast to be used in such locations and finally the sides were widened to very flat slopes.

Sipiwesk to Thompson, 31 Miles, 1957

This branch line, located between latitude 55°25' and 55°45', turns off from the Hudson Bay Railway at Mile 200 and runs north-westerly through territory similar to the Lynn Lake Line. Although it is within the Canadian Shield, there is generally heavy overburden. It is well timbered with spruce, aspen, jackpine, birch and willows.

Permafrost was encountered in a number of cuts, through varved clay and bands of ice. Very flat side slopes were necessary to prevent materials from sliding and obstructing drainage ditches in the bottom of these cuts. As time was limited to meet a deadline for track to be laid to a new mine site, these cuts were only excavated to a depth of one foot below normal sub-grade.

The following Spring, 1958, as the permafrost thawed, clay worked up through the ballast and caused serious track problems. These were not overcome until sections were removed to permit excavations to be deepened to at least three feet below sub-grade. These excavations were then back-filled with granular materials, drainage ditches improved, and the track relaid. There is now no difficulty in maintaining a reasonably good surface.

At one location where it was necessary to make a cutting through organic materials, in permafrost condition, additional time was taken to excavate to a depth of five feet below sub-grade and backfill immediately with comparatively dry clay - granular materials were not available at the time. When track was laid, it was given a normal lift of ballast and it remained in surface.

This branch line was constructed to serve a property being developed by the International Nickel Company. This project included a major mining and refining plant and relative townsite. "Islands" of permafrost presented serious foundation problems in connection with some buildings and services in the townsite. Fortunately there are extensive ridges of sand and gravel, within five miles, available for back-filling excavations made in permafrost below sub-grade. Excavations to solid rock were made for foundations of all heavy plant structures.

To provide power for this project the Manitoba Hydro-Electric Board is constructing the Kelsey Generating Station, on the Nelson River, 50 miles north of Thompson. Extensive and deep permafrost was encountered during excavation of the spillway, this caused difficulties in removing such a large volume of frozen layers of clay, silt and ice, which when exposed, became almost fluid.

Optic Lake to Chisel Lake, 52 Miles, 1958-1959

This line, currently under construction to serve a new mine being developed by the Hudson Bay Mining and Smelting Company, runs in a general east-west direction between latitude 54°40' and 54°50'. General characteristics are low hills of exposed rock with muskegs between, excepting at the easterly end, where there is considerable overburden of glacial drift.

This may be considered as the extreme southerly limit of permafrost in Northern Manitoba, only a few small isolated patches are being encountered where heavy surface mosses cover poorly drained organic materials.

## CONCLUSION

Based on observations during a period of nearly fifty years, in railway location, construction and maintenance in territory where permafrost occurs, the following general recommendations are submitted:

1) Before ground surveys are commenced to establish a location for a proposed railway, air photos should be analyzed and interpreted to indicate where permafrost may occur and to what extent and to locate possible deposits of granular materials.

2) Air photographs and photogrammetry should also be used to aid in selection of the best route. Careful consideration of drainage features is particularly important.

3) In territory where permafrost occurs in comparatively small isolated areas - "Islands" - such areas should be avoided to the extent practicable in relation to distance and ruling gradients etc.

4) Permafrost on a side-hill slope can become very troublesome.

5) Where it is not practicable to avoid excavating in permafrost for construction of a railway roadway, excavations should be extended to a depth of 3 feet to 5 feet below sub-grade, then backfilled immediately with comparatively dry materials preferably granular if available within reasonable hauling distance.

6) Sides of cuts in permafrost should be excavated to very flat slopes, as a precaution against materials sliding and obstructing drainage ditches.

7) Drainage is always important, this especially so in areas of permafrost. Off-take ditches should be excavated and well maintained to prevent accumulation of water against side-slopes of embankments, particularly where they are built on permafrost, as water in contact with it will cause thawing.

8) Special care is necessary in selecting sites for bridges and culverts and type of structure with respect to site conditions. Whereas first class foundations are essential for rigid type structures, such as steel bridges on concrete sub-structures, it is not so serious if some distortion occurs in a timber trestle or a cedar box culvert; they will remain functional.

9) Cross section area of culverts should be comparatively large to facilitate cleaning in event of an accumulation of ice.

10) In areas where permafrost is general and there are no great changes in topography, such as the tundras, design the location to obtain a roadway to be entirely embankment, if practicable to do so.

11) Relative telegraph and telephone lines should be erected on tripods of cedar poles, set on the surface.

Excavations should be restricted to off-take ditches and minor levelling on the railway right-of-way just sufficient to permit track to be laid. Then the track should be lifted by trainfill, to build up embankments on undisturbed permafrost.

Finally, when constructing where permafrost is general, preserve this condition, build on it, do not excavate into it, except for essential drainage to prevent accumulation of water and relative thawing.

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