Frost Action and Railroad Maintenance In the Labrador Peninsula

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Prior to 1950 engineering activity in the Labrador Peninsula was confined to a few of the more accessible areas and was limited in scope. A full-scale demonstration of many of the engineering problems associated with this little-known region has been provided by the Quebec North Shore and Labrador Railway, a 360-mi railroad constructed between 1950 and 1954 to serve the new iron mining district in the interior of the peninsula. Experience since 1954 has shown that the operating conditions imposed by a rigorous winter climate, particularly the necessity to carry a heavy tonnage during a relatively short shipping season, requires an unusually high standard of railroad maintenance.

This paper describes some of the manifestations of frost action which have proved troublesome from the standpoint of railroad maintenance in the Labrador Peninsula and also reports the results obtained from a number of ground temperature installations. The data show values recorded for frost penetration under various conditions of exposure, including cut and embankment sections of the railroad subgrade, undisturbed snow and natural ground cover, an ice-covered automobile parking lot, and an iron ore stock pile.

On the basis of the ground temperature data it is concluded that a snow-vegetative cover is one of the more important variables controlling the depth of frost penetration. Removal or disturbance of these media permits deep penetration of frost (as much as 6 or 7 ft) in a snow-covered cut section and more than 10 ft in an exposed embankment.

A consideration of the physiography of the Labrador Peninsula suggests that in the terrain traversed by the Quebec North Shore and Labrador Railway, climate, groundwater conditions, vegetative cover, and the distribution of frost-susceptible soils are fairly representative of conditions throughout much of the region.

● THE LABRADOR PENINSULA has emerged in recent years as an important producer of iron ore and the site of several rapidly growing centers of population. A significant factor in this transformation has been the Quebec North Shore and Labrador Railway, which links the new mining town of Schefferville with Sept-Iles, a seaport on the north shore of the Gulf of St. Lawrence.

The Q.N.S. & L. Railway was constructed between 1950 and 1954 (1) and was the first major engineering project to be undertaken in the area. Located for its entire 360-mi length through undeveloped and unsettled territory (2), little advance information on soil or climatological conditions was available. Under these circumstances, there was speculation concerning construction and maintenance difficulties which might result from the combination of a severe climate and the type of terrain usually dismissed as 'muskeg'. Of particular interest was the depth of seasonal frost penetration and the degree to which local soils might be susceptible to frost action. Difficulties with permafrost were expected to affect the mining operations at Schefferville and, to a lesser extent, the construction and maintenance of the railroad. Also largely a matter of conjecture was the effect of sustained below-freezing air temperatures on ore-handling operations.

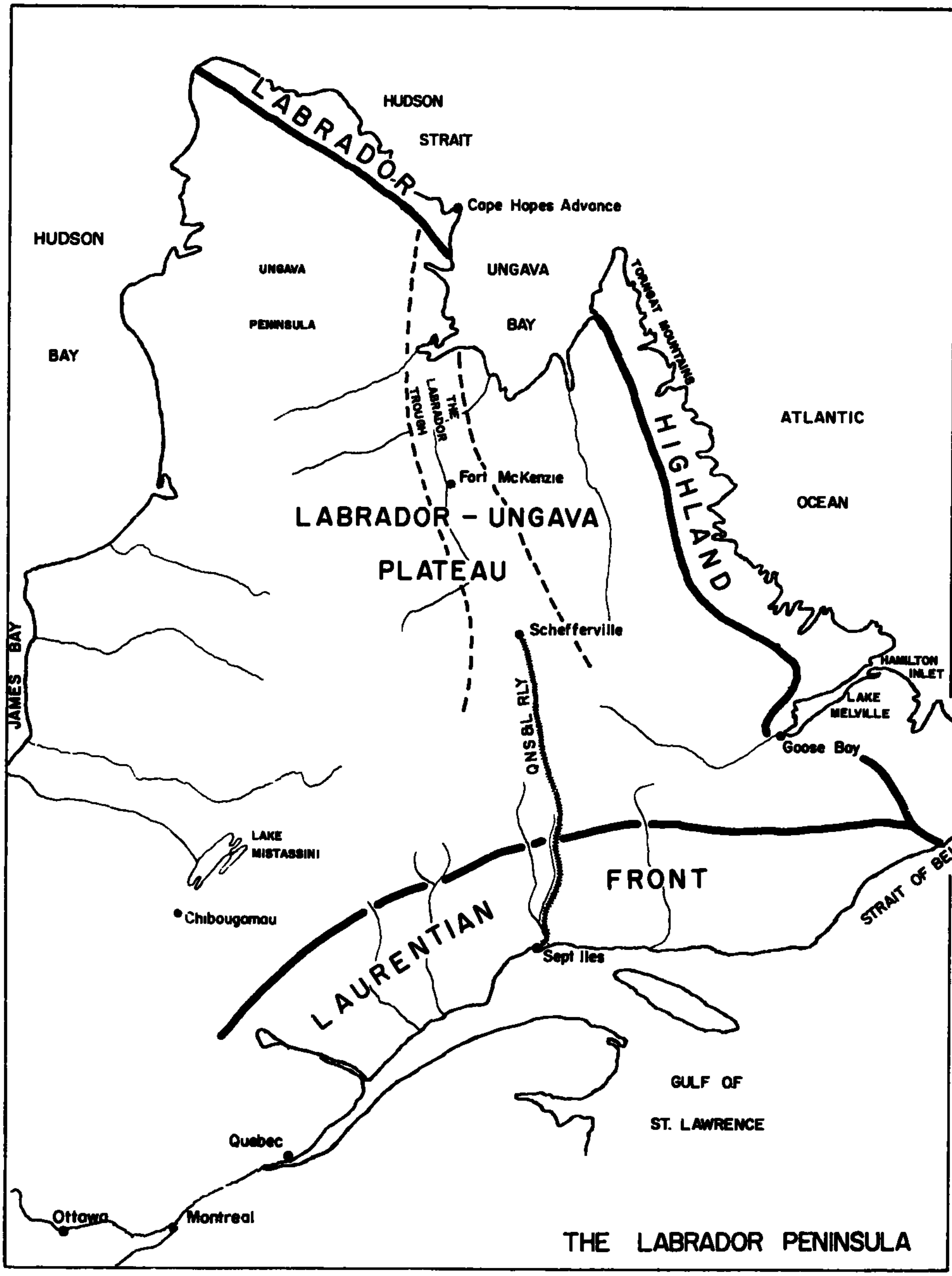

Figure 1.

Although efforts were made during construction to exclude from the railroad subgrade such obviously frost-susceptible soils as silts, some differential frost heaving was foreseen and a better understanding of the thermal regime within the roadbed was considered desirable. To this end, several ground temperature installations were made and attention was given to the accumulation of climatological data and to the classification of soils.

Since operations started in 1954 the railroad has carried approximately 36 million tons of iron ore. Difficulties associated with the handling of frozen material at present limit the rail shipment of ore to the period between early May and late November, or an average season of 200 days. During the winter months the railroad remains in service to permit movement of passengers and freight, but traffic is light. The number of trains passing a given point in each 24-hr period during the summer is approximately 16, 7 of which are loaded ore trains; in winter, traffic averages one train per day. Performance of the roadbed under these operating conditions has provided useful information concerning the nature and extent of problems associated with frost action. It is believed that similar problems are likely to be encountered over much of the Labrador Peninsula.

PHYSIOGRAPHY

Among the more important of the external variables which influence frost action are: climate, particularly air temperature, precipitation, and wind; topographical location and degree of exposure; the nature and depth of surface cover; and ground water conditions. Because some of these factors are also prime considerations in railroad location, the physiography of the Labrador Peninsula is a subject which deserves special attention.

The peninsula is usually regarded as a section of the Laurentian Upland Province of the Canadian Shield (3), and is essentially a plateau with an average elevation of 1,500 to 2,000 ft. Severe dissection by deep, glaciated valleys is a feature of the edge of the plateau and local relief in the coastal areas is in the order of 2,000 ft. On the basis of landscape, surface materials and climate, the region may be divided into three physiographic subsections (4) as follows (see Fig. 1):

1. The Laurentian Front.
2. The Labrador-Ungava Plateau.
3. The Labrador Highland

The Laurentian Front

The physiographic subsection known as the Laurentian Front extends from the Saguenay River in the west to the Strait of Belle Isle in the east. Rarely more than a few miles inland, the steep, south-facing Laurentian Escarpment rises abruptly from the coastal lowland and defines the southern margin of the dissected edge of the interior plateau.

Stratified sands, silts and silty clays comprise the bulk of the sediments of the coastal lowland, with sand as the dominant surface material. Banded silty clays are generally associated with river terraces and are exposed in many river bank slopes.

North of the Laurentian Escarpment, the rough terrain of the dissected region extends inland for as much as 100 miles. It is an area of active erosion in which the deep, glaciated valleys of the numerous south-flowing rivers are conspicuous features. As a result of glacial and post-glacial derangement of drainage, a number of broad valleys are occupied by misfit streams or chains of elongated lakes.

Generally, surface soils in the river valleys are stratified sands and gravels of fluvio-glacial origin, although silt and silty sand may be encountered in isolated terrace remnants. Close to the northern margin of the Laurentian Front, coarse-textured gravel occurs in extensive outwash deposits.

The maritime climate of the north shore of the Gulf of St. Lawrence is not unduly severe; the mean January and July daily temperatures at Sept-Iles being 5 F and 60 F, respectively. A useful measure of the magnitude and duration of below-freezing air temperatures is the freezing index or the cumulative total of degree days below 32 F.[1] On the basis of mean monthly temperatures, the freezing index for Sept-Iles in the period 1945-1957 has varied between 2,100 (1950-51) and 3,350 (1949-50), with an average of 2,700. Temperature conditions throughout the remainder of the Laurentian Front are considerably more severe than those prevalent in the coastal lowland. The

[1] In this use, the degree day is defined as the difference, in degrees Fahrenheit, between the mean daily air temperature for a given day and 32 F. When mean daily air temperatures exceed 32 F, degree-days are subtracted from the cumulative total.

freezing index is probably between 3,500 and 4,000 for much of this region, a range comparable with that experienced in southern Manitoba.

The mean annual total precipitation at Sept-Iles for the same period (1945-57) has been 42 in. Heaviest monthly precipitation occurs in July and amounts to approximately 4.5 in. A second peak of precipitation occurs during the winter months when moist air from the Gulf of St. Lawrence comes into contact with the Laurentian Escarpment. The average snowfall at Sept-Iles is 165 in., more than 100 in. of which falls during the months of December, January, and February. The Laurentian Front thus experiences a snowfall which is one of the heaviest in Canada. In the lower reaches of the river valleys, an annual snowfall of 200 in. is to be expected: the corresponding figure for the southern rim of the plateau is about 135 in.

The Labrador-Ungava Plateau

Geological exploration in the physiographic subsection known as the Labrador-Ungava Plateau has been most intense in the narrow belts of folded sedimentary and volcanic rocks which are known to be mineralized (5). These structural units, of which the Labrador Trough is at present the most important, differ physiographically from the remainder of the plateau.

The Labrador Trough is a belt of parallel rock ridges and valleys with axes oriented in a north-northwest, south-southeast direction. It extends southward from the west side of Ungava Bay approximately 400 mi and has a maximum width of some 50 mi.

With the exception of the Labrador Trough and other less prominent belts of folded rocks, the Labrador-Ungava Plateau may be described as a relatively flat plain, veneered by glacial till and characterized by eskers and other granular landforms. The most striking feature is the extent to which the landscape is dominated by bodies of water, with lakes and expanses of open bog occupying as much as 50 percent of the terrain over broad areas.

"Muskeg," a popular descriptive term in this region, is generally used in connection with swampy ground of the widely-distributed "string-bog" variety. A typical bog of this type has the appearance of a shallow pool covered by a network of narrow, roughly parallel bands of moss or grassy vegetation. Closer examination usually reveals that the bands are stable, rather than floating, and that string-bogs are terraced; a slight difference in elevation being maintained between the water levels on opposite sides of individual bands. Water-deposited sediments are a feature of many lakeshore areas and frequently underlie string-bogs. The vertical profile exposed by excavation normally comprises 1 or 2 ft of silty organic material underlain by from 1 to 3 ft of silt. This, in turn, overlies a sandy glacial till. The presence of silt does not appear to be essential to the development of string-bogs, but in situations where it is absent, till of a finer texture is usually encountered.

A continuous mat of waterlogged vegetation is often associated with shallow depressions and flat-lying areas. A distinguishing feature of this type of swampy ground is the presence of low shrubs and stunted trees in addition to the grasses and moss of the string-bogs. Timbered bogs of this type are usually underlain by a few feet of fibrous organic matter and the prevailing glacial till. In the terrain traversed by the Q.N.S. & L. Railway, the depth of organic material has rarely been found to exceed 4 or 5 ft.

The region most seriously affected by waterlogged organic terrain occupies the central and south-eastern section of the plateau. Here, a system of large lakes embraces the headwaters of all the important rivers. Other areas affected include the gently sloping terrain on the Pleistocene sediments east of James Bay, and the permafrost area about Ungava Bay.

The climate of the Labrador-Ungava Plateau is rigorous. Mean annual temperature and total precipitation in the south are 26 F and 35 in., respectively. The corresponding figures for the northwest are 16 F and 13 in. (6). Snowfall accounts for approximately 40 percent of the total precipitation. Summer seasons are cool with cloudy skies and lengthy periods of intermittent light rain.

Winter temperature conditions at Schefferville are typical of those which prevail over a broad area. Due to the more continental climate of the interior, they do not differ markedly from those experienced in the Ungava Bay region. Average indices at Schefferville and Fort McKenzie are 5,200 and 5,500, respectively, comparable with the value of 5,700 for Cape Hopes Advance on Hudson Strait.

Schefferville lies in a region of sporadic permafrost and experiences an average annual snowfall of 130 in. North of this point, however, a pronounced decrease in precipitation occurs and is accompanied by a significant increase in the incidence of permafrost.

The Labrador Highland

This physiographic subsection known as the Labrador Highland embraces two areas which are separated geographically by Ungava Bay. The larger area extends from the eastern shore of Ungava Bay to the Strait of Belle Isle; the smaller area includes a narrow strip along the south shore of Hudson Strait.

Although a number of distinct physiographic units are recognized, this region may be regarded as the Atlantic counterpart of the Laurentian Front, because it, too, comprises the rough terrain of the dissected edge of the plateau. The continuity of the cliffed coastline is broken by deep glacial troughs or fiords and by the steep valleys of numerous small streams. The Hamilton River drains an extensive area of the interior plateau and discharges into Lake Melville; it is the only river of importance associated with the Labrador Highland. South of Lake Melville and Hamilton Inlet, the fiord-type of dissection in which glacial troughs are not occupied by major rivers, gives way to the glaciated river-valley type of dissection which is characteristic of the Laurentian Front.

The only unconsolidated materials of importance in this generally rocky area are to be found in the Lake Melville basin. Here, post-glacial emergence and erosion have produced elevated beach ridges and terraces in sands and silty clays.

The climatic extremes within the Labrador Highland are fairly well represented by winter conditions at Goose Bay, with an average freezing index of 3,400 and a mean annual snowfall of 130 in., and at Cape Hopes Advance where the freezing index is 5,700 and the mean annual snowfall amounts to 60 in. As might be expected, the Atlantic coast experiences more moderate temperature conditions and heavier snowfall than the adjacent plateau.

FROST PENETRATION AND GROUND TEMPERATURES

To those engaged in construction and maintenance activities in severe climates, recurring frost damage to highway and airfield pavements and the differential frost heaving of railroad track are important considerations. In addition to information on soil and ground water conditions, the solution of many of the problems involved requires a knowledge of the thermal regime beneath undisturbed ground and in earth fills.

Ground temperature measurements undertaken by the Q.N.S. & L. Railway were expected to yield data which would permit a rational approach to maintenance problems involving frost action (7). Among the more important questions on which information was sought were the following:

1. The depth and rate of frost penetration beneath the railroad subgrade in both cut and embankment sections under normal winter operating conditions.
2. The rate at which the upper surface of the frozen zone might be expected to thaw during the spring and summer months and the depth and date at which the residual frost leaves the ground.
3. The effect of typical vegetative cover and undisturbed snow on frost penetration.

Ground Temperatures at Milepost 266

The site chosen for the railroad installation was 266 mi north of Sept-Iles at an elevation of 1,650 ft above sea level. Terrain and climatic conditions in this area are typical of those prevailing over much of the southern part of the Labrador-Ungava Plateau. Within a 600-ft section of the railroad right-of-way, twelve remote-reading

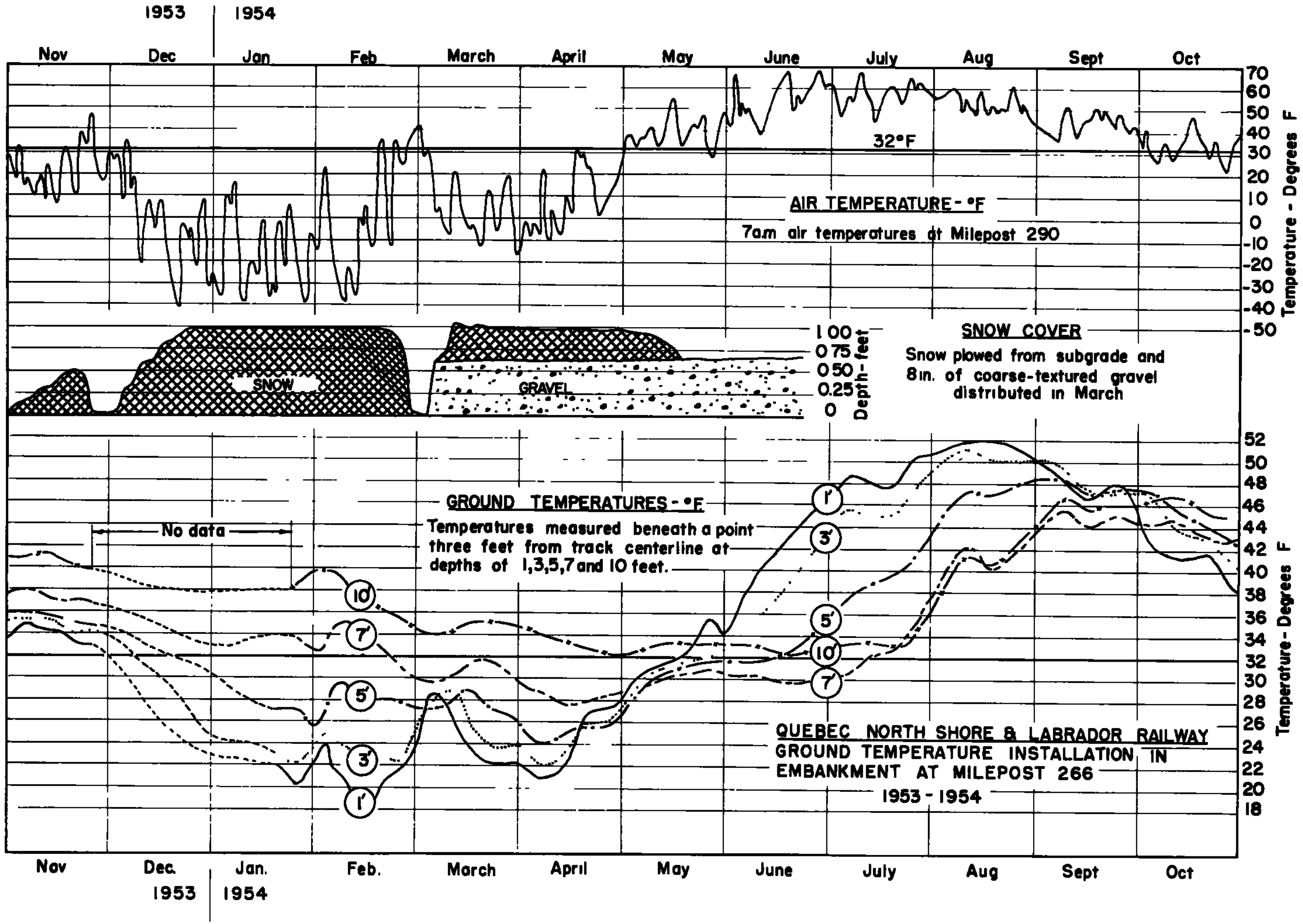
1953
1954
Nov
Dec
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
32°F
AIR TEMPERATURE - °F
7a.m air temperatures at Milepost 290
Temperature - Degrees F
SNOW COVER
Snow plowed from subgrade and 8in. of coarse-textured gravel distributed in March
SNOW
GRAVEL
Depth - feet
GROUND TEMPERATURES - °F
Temperatures measured beneath a point three feet from track centerline at depths of 1,3,5,7 and 10 feet.
No data
QUEBEC NORTH SHORE & LABRADOR RAILWAY
GROUND TEMPERATURE INSTALLATION IN EMBANKMENT AT MILEPOST 266
1953 - 1954
Temperature - Degrees F
Nov
Dec.
Jan.
Feb.
March
April
May
June
July
Aug
Sept
Oct
1953
1954

Figure 2.

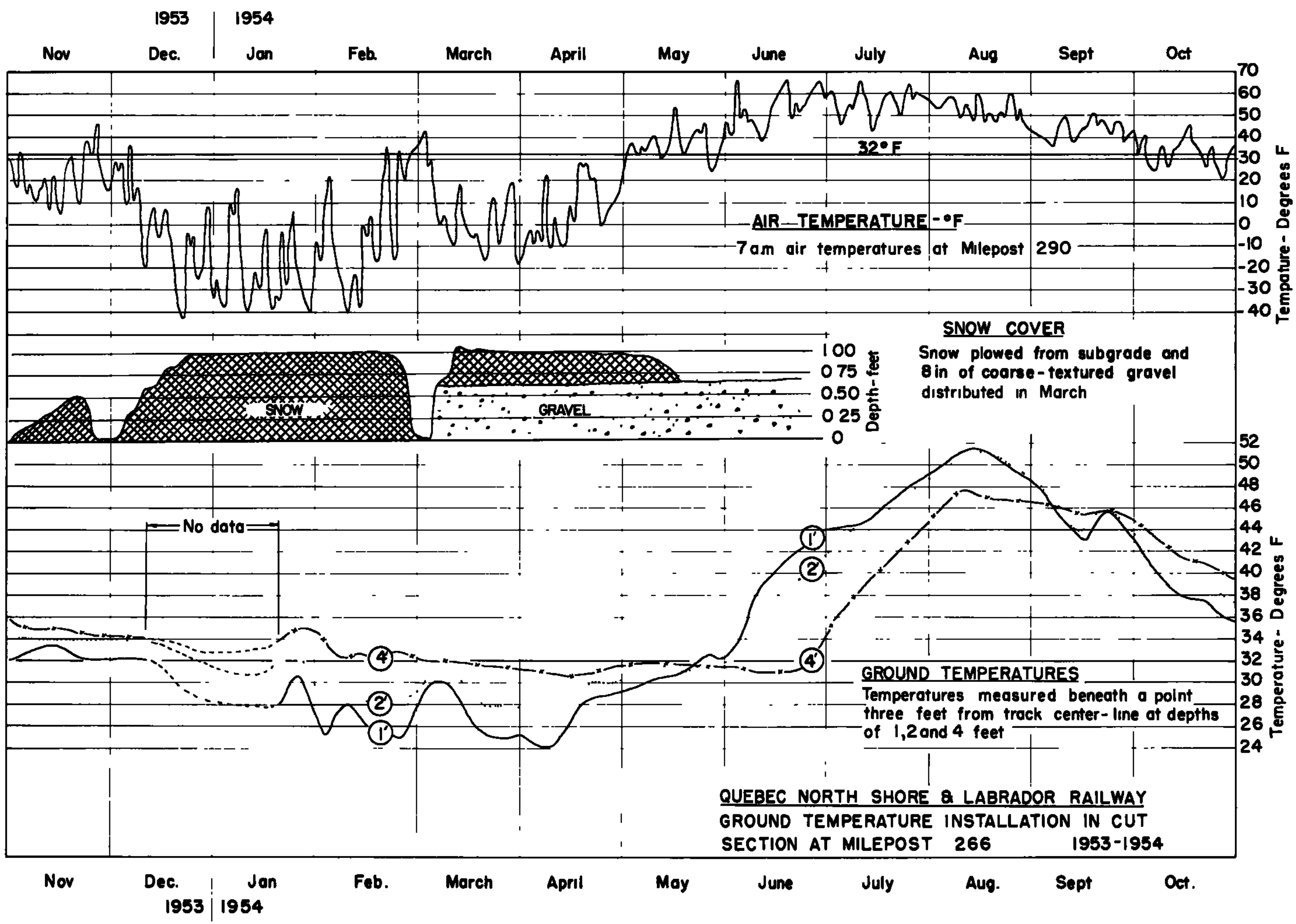
1953 | 1954
Nov
Dec.
Jan
Feb.
March
April
May
June
July
Aug
Sept
Oct
32°F
AIR TEMPERATURE - °F
7 a.m air temperatures at Milepost 290
Temperature - Degrees F
SNOW COVER
Snow plowed from subgrade and 8 in of coarse-textured gravel distributed in March
SNOW
GRAVEL
Depth - feet
1.00
0.75
0.50
0.25
0
No data
1'
2'
4'
GROUND TEMPERATURES
Temperatures measured beneath a point three feet from track center-line at depths of 1, 2 and 4 feet
Temperature - Degrees F
QUEBEC NORTH SHORE & LABRADOR RAILWAY
GROUND TEMPERATURE INSTALLATION IN CUT SECTION AT MILEPOST 266 1953-1954

Figure 3.

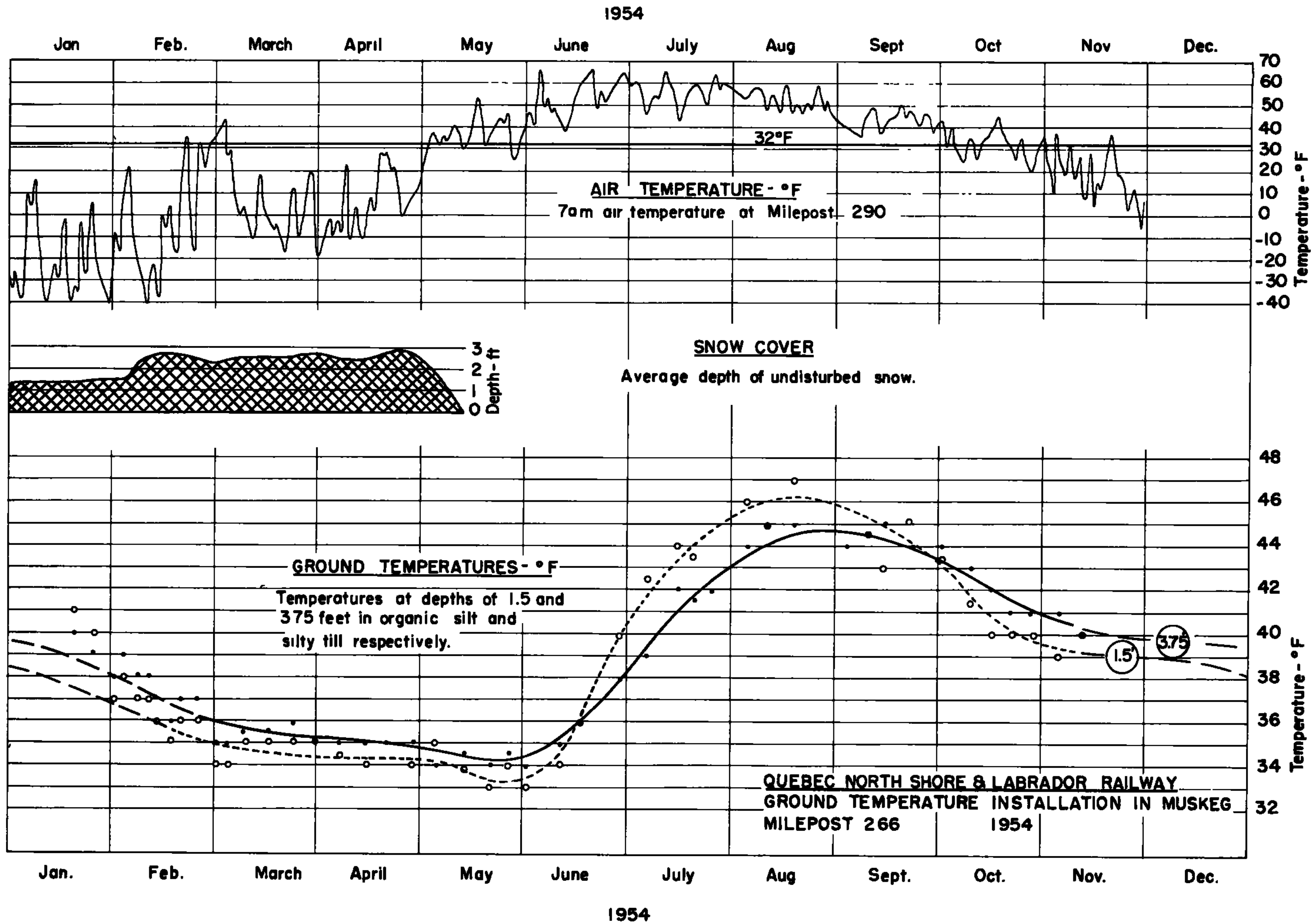
1954
Jan
Feb.
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec.
70
60
50
40
30
20
10
0
-10
-20
-30
-40
Temperature - °F
32°F
AIR TEMPERATURE - °F
7am air temperature at Milepost 290
3
2
1
0
Depth - ft
SNOW COVER
Average depth of undisturbed snow.
48
46
44
42
40
38
36
34
32
Temperature - °F
GROUND TEMPERATURES - °F
Temperatures at depths of 1.5 and 375 feet in organic silt and silty till respectively.
3.75
1.5
QUEBEC NORTH SHORE & LABRADOR RAILWAY
GROUND TEMPERATURE INSTALLATION IN MUSKEG
MILEPOST 266 1954
Jan.
Feb.
March
April
May
June
July
Aug
Sept.
Oct.
Nov.
Dec.
1954

Figure 4.

mercury-bulb thermometers were installed; six in an embankment with a height of 16 ft (Fig. 2), four below subgrade in a 6-ft cut (Fig. 3) and two beneath a typical "muskeg" type of vegetation adjacent to the roadbed (Fig. 4).

Grading operations in the vicinity of Milepost 266 were completed early in October 1953. Excavation of the cut involved a silty glacial till, but borrow material with a more sandy texture was used as fill for the embankment. Thermometer bulbs were installed in the sides of trenches excavated during the third week in October and track was laid on October 30. Because the completed grade was not used as a road prior to the laying of track, the ground temperature sites were at no time exposed to the effects of construction traffic.

With respect to the surface on which track was originally laid, temperatures were measured at depths of 1, 3, 5, 7, 10, and 13 ft in the embankment and 1, 2, 4, and 6 ft in the cut section. In each case, thermometer bulbs were located beneath a point 3 ft from the track centerline, and were therefore close to the ends of ties. Thermometer bulbs under "muskeg" cover were located at depths of 1.5 and 3.75 ft below natural ground. These bulbs measured temperatures in organic silt and in silty glacial till, respectively. As a result of drainage measures associated with the roadbed, the vegetative cover and organic subsoil were slightly drier than would have been the case in an undrained string-bog or muskeg area.

Thermometer bulbs were equipped with Bourdon-tube type indicators, with dials calibrated from -20 F to +80 F. A 30-ft capillary tube extension between each bulb and its indicator was insensitive to temperature variations along its length and permitted indicators to be housed in weatherproof shelters. Thermometers were checked in an ice bath prior to installation, and the degree of accuracy expected was approximately ± 2 F.

Air temperature conditions during September and October 1953 were mild and the period was one of unusually light precipitation. The depth of frost penetration below subgrade on October 30 was approximately 4 in. Snowfall in November provided a maximum cover of about 6 in., which was entirely removed by heavy rain on November 25.

Access difficulties made it impossible to secure regular ground temperature observations from Milepost 266 before the end of January 1954. After January 20, however, records were obtained at intervals of approximately one week.

The occasional air temperature observations made at Milepost 266 are of little value as an indication of climatic conditions and have been discarded in favor of a daily record of early-morning air temperatures at Milepost 290. In connection with snow cover conditions, it is important to note that snow was plowed from the track. Prior to the end of January, the effect of this operation was to produce a 12-in. cover of compact snow over the thermometer bulbs in both embankment and cut section. Compaction increased during February, when observations were made at 4-day intervals and snow cover suffered some trampling underfoot. Thermometer bulbs in the muskeg installation were protected and snow cover was truly undisturbed.

After the period of moderate air temperatures which occurred between February 27 and March 3, all snow beyond the ends of ties was bladed from the roadbed. Coarse-textured, pit-run gravel was then distributed from ballast cars to a depth of some 8 in. (To facilitate dumping of gravel during the winter months, the material (average moisture content 6 percent) was deliberately frozen before loading. Hauling operations were usually suspended when air temperatures exceeded 15 F.) Although this material was eventually to serve as sub-ballast, its immediate function was to improve the stability of the skeletonized track structure. Under the altered surface conditions, snowplow operations restricted the depth of snow cover to about 3 in. for the remainder of the winter. This is less than one-half the cover provided under normal circumstances, as the top of the usual ballast section lies 2 in. below the upper surface of the ties.

Assuming that the "frost line" coincides with the position of the 32 F isotherm, the depth of frost penetration (and "thaw penetration") at any date may be interpolated from ground temperature curves (Fig. 5). A high degree of accuracy is desirable in the measurement of temperatures, however, if the position of the frost line is to be determined with any precision. Despite the limitations of the instruments used, the

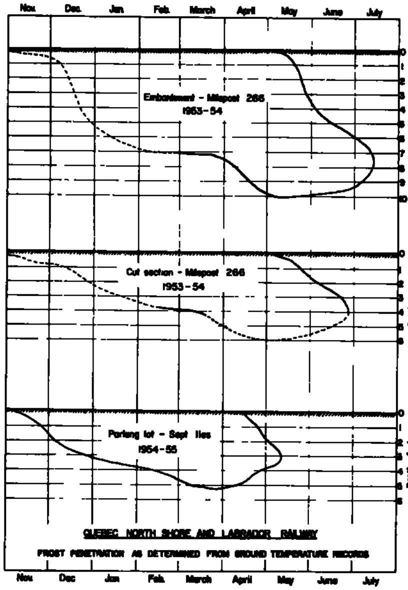

Figure 5.

ground temperature records are believed to give a reliable indication of conditions below subgrade at Milepost 266 during 1954. Experience has shown that the embankment and cut sections are not subject to serious frost heaving.

With regard to the original objectives of this ground temperature study, the following conclusions may be briefly stated:

1. In the sandy glacial till which forms the usual roadbed material in the southern part of the Labrador-Ungava Plateau, a winter of average severity and a minimum snow cover may result in frost penetration to a depth of 6 ft in a typical cut section and 10 ft in a high embankment. Although the coldest air temperatures generally occur in January, frost penetration tends to continue until the end of April.

2. The frost line appears to retreat from the surface of a cut section at a fairly uniform rate of 1 ft in 14 days. In the case of an embankment, however, the melting of snow cover on side slopes is followed by a rapid thawing of the soil to a depth of about 3 ft. Below this, the frost line retreats at a rate comparable with that for a cut section. When deep frost penetration occurs in a high embankment, frozen ground may be encountered at a depth of 7 ft as late as mid-July. Similarly, below subgrade in a cut section, the presence of frozen ground at a depth of 4 ft is to be expected at the end of June.

3. Frost penetration in organic soil with a high moisture content (natural moisture contents commonly exceed 200 percent) is unlikely to exceed 1.5 ft when 2 to 3 ft of undisturbed snow overlie the typical surface cover of mossy vegetation. At shallow depths, the lowest temperatures occur late in May and are probably due to the infiltration of rain and melt water. Midsummer temperatures close to the surface are highest in August and appear to be about 5 deg lower than the maximum temperatures at corresponding depths below the railroad subgrade. This temperature difference is attributed to the insulating effect of vegetation and to evaporation from the surface of the poorly-drained organic soil.

Ground Temperatures at Schefferville

During the fall of 1953, the Division of Building Research of the National Research Council, in cooperation with the Iron Ore Company of Canada, initiated a program of ground temperature measurements at Schefferville (7). The original installation employed a number of mercury-bulb thermometers connected to either remote-reading indicators or automatic recorders. This installation was relocated in 1954 and since that time has provided a record of ground temperature variations beneath an unpaved roadway which is cleared of snow during the winter, and beneath an adjacent area upon which snow is allowed to accumulate. Both installations involve a very coarse-textured, well-drained, glacial till. Under these conditions, frost penetration beneath the snow-cleared surface has been found to exceed 15 ft. Undisturbed snow with a depth of 30 to 36 in. apparently limits frost penetration to about 11 ft.

Ground Temperatures at Sept-Iles

To supplement the data available from Milepost 266 and Schefferville, a third ground temperature installation was made at Sept-Iles during the fall of 1954. Apart from their

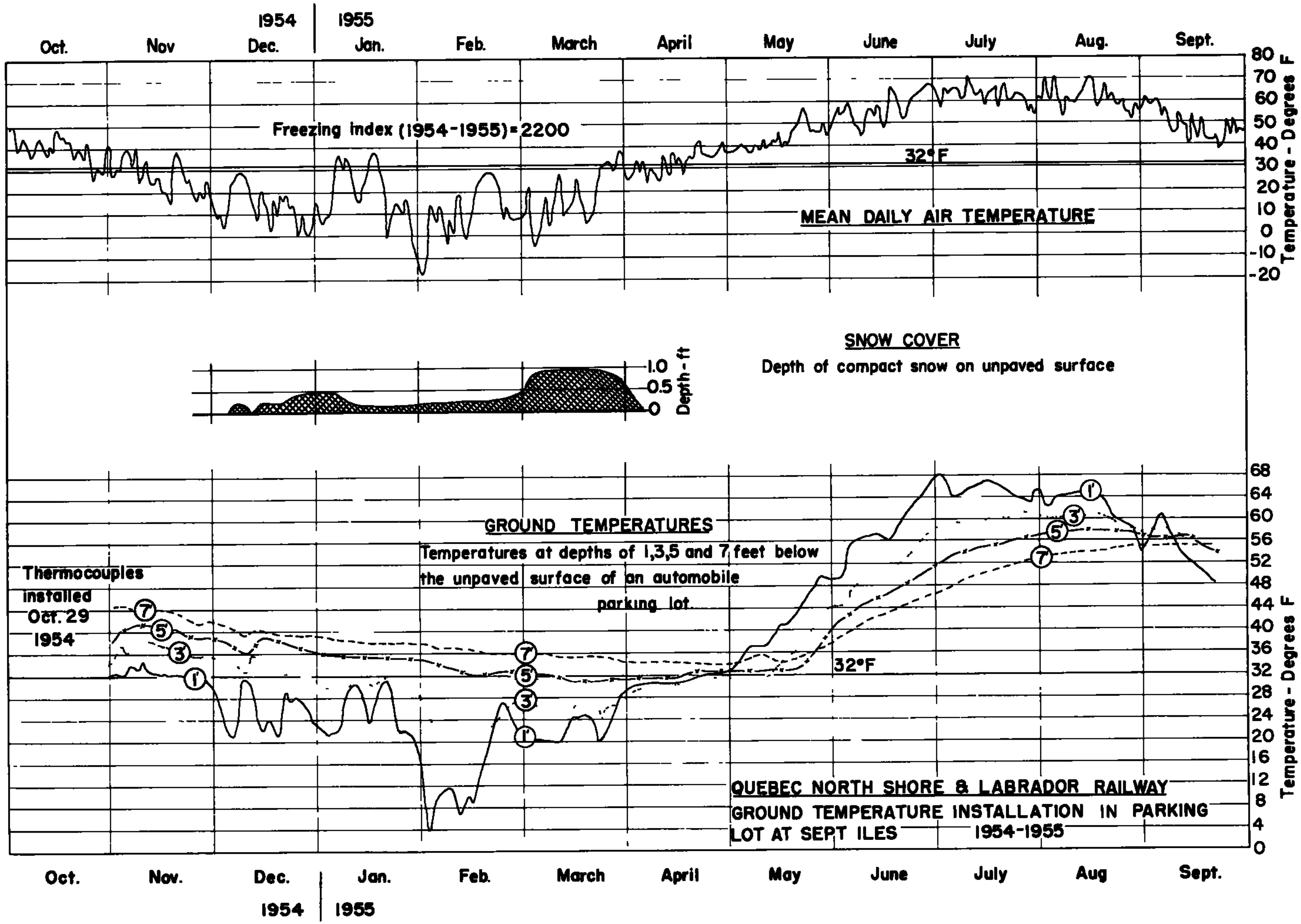
1954
1955
Oct.
Nov
Dec.
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Freezing index (1954-1955)=2200
32°F
MEAN DAILY AIR TEMPERATURE
80
70
60
50
40
30
20
10
0
-10
-20
Temperature - Degrees F
SNOW COVER
Depth of compact snow on unpaved surface
1.0
0.5
0
Depth - ft
GROUND TEMPERATURES
Temperatures at depths of 1,3,5 and 7 feet below the unpaved surface of an automobile parking lot.
Thermocouples installed Oct. 29 1954
7
5
3
1
32°F
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
Temperature - Degrees F
QUEBEC NORTH SHORE & LABRADOR RAILWAY
GROUND TEMPERATURE INSTALLATION IN PARKING LOT AT SEPT ILES 1954-1955
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
July
Aug
Sept.
1954
1955

Figure 6.

value to the Q.N.S. & L. Railway, it was hoped that the results might prove useful in the town of Sept-Iles, a rapidly expanding community interested in new housing developments and the installation of water mains and sewers. The predominant surface soils in the area are recent beach deposits of medium and coarse-textured sand. Field moisture contents are in the order of 6 percent.

Seven copper-constantan thermocouples were installed at 1-ft intervals beneath the unpaved surface of a busy automobile parking area (Fig. 6). Temperature measurements were made using a potentiometer indicator with a temperature-graduated scale and a range from -25 F to +125 F. The limit of error for this instrument was in the order of 1 F.

Whenever possible, ground temperature observations were made daily from November 1954 to September 1955. Although heavy snowfalls were cleared from the surface, an accumulation of compact snow and ice developed during the winter months. The freezing index for the winter of 1954-55 was 2,200.

Conclusions based on the ground temperature observations at this installation include the following:

1. In the absence of snow cover, frost penetration in well-drained sand is likely to exceed 5 ft, even during a relatively mild winter.
2. Maximum frost penetration occurs late in March and the thaw is completed at a depth of 3 ft early in May (Fig. 5).
3. At depths of 1 and 2 ft, ground temperatures are readily affected by fluctuations in air temperature.

In March 1955, thermocouples were installed in five holes drilled at right angles to one of the sloping faces of an iron ore stockpile at Sept-Iles. The short period of observation coincided with the retreat of the frost line from a depth of 4.5 ft. Because it was necessary to discontinue observations at the end of April, the results are inconclusive. However, it is of interest to note that frost penetration in iron ore with at least 2 ft of undisturbed snow cover was only slightly less than in sand with a shallow cover of ice and compact snow. Specific gravity of the iron ore is generally between 3.8 and 4.2. The field moisture content in the vicinity of the ground temperature installation was approximately 12 percent.

Apart from providing useful data concerning the depth of frost penetration, ground temperature measurements in the Labrador Peninsula indicate that a snow-muskeg cover is one of the controlling variables in frost penetration. Removal or disturbance of these media permits deep frost penetration in coarse-textured soils and leads to the development of ground ice in frost-susceptible soils. Similarly, changes in the nature and depth of surface cover above frozen ground may delay the complete thawing of frost or ground ice. The following examples suggest that changes in the thermal regime can be produced by both natural and artificial means:

1. In undisturbed muskeg areas, ice lenses have been encountered in excavations made for communication-line poles as late as mid-September. The development of string-bogs on potentially dry slopes has been attributed to the effect of this type of ground ice. In a region of high precipitation, the presence of frozen ground during the summer months creates waterlogged conditions which are conducive to the spread of mossy vegetation (8).
2. During construction of the railroad, excavation of a shallow cut at Milepost 245 in September 1953 exposed frozen silt containing numerous ice lenses, some of which were as much as 3 in. thick. To remove all of the frozen, but rapidly thawing, material it was necessary to drill and blast to a depth of 6 ½ ft below subgrade. A haulage road used by tractors during the two previous winters crossed the railroad right-of-way at this location and is believed to have contributed to the development of massive ground ice through the removal of snow and vegetative cover.

RAILROAD MAINTENANCE

Frost action affects the roadbed of the Q.N.S. & L. Railway in a number of ways, follows:

1. Differential heaving of track.
2. Reduction in load-carrying capacity of the subgrade during the thawing period.
3. Icing conditions.
4. Sloughing of cut and embankment slopes.

Maintenance forces are occupied with one or more of these manifestations of frost action for many months each year.

Frost Heaving

The fact that ore-hauling operations are restricted to the period between May and November alleviates, to some extent, the seriousness of heaved track. Nevertheless, because a typical frost heave involves distortion of only a few feet of track, the abrupt change in rail elevation must be reduced by shimming rails for some distance on either side of the heave. Ground temperature observations suggest that when shimming operations are undertaken in mid-winter (for example, in February), the inevitable clearing and compaction of snow cover may serve to intensify frost action.

Experience has shown that the more serious heaves (in excess of 5 in. and , exceptionally, as much as 12 in.) occur on the interior plateau and involve silt, silty sand, or silty glacial till. The most troublesome of these frost-susceptible soils are generally associated with lakeshore areas where long sections of shallow embankment alternate with shallow cuts in silty sand or silty glacial till.

Performance in embankment sections is generally good when the depth of fill is at least 5 ft. The high moisture content of the organic subsoil is effective in retarding frost penetration and prevents the formation of ice lenses in the underlying silt. When serious frost heaving does occur in shallow embankment sections it can often be correlated with the presence of buried stumps or erratic boulders.

Because highly frost-susceptible soils are often encountered beneath the organic surface cover, pronounced heaving occurs when the roadbed is at grade. This condition is realized at the ends of cut sections, where maintenance requires early shimming during the winter and the adjustment of shims as the frost leaves the ground. Fortunately, although heaves of this type vary in magnitude, they occur at the same location each year and their cause is relatively easy to determine. Excavation and backfilling may therefore be undertaken with some assurance that the condition will be relieved.

During construction, cut sections in silty soils were often rendered impassable to heavy traffic and in a few instances it was necessary to resort to such doubtful expedients as corduroy. Moderate heaving (3 to 5 in.) is common in these cuts and is particularly objectionable because the location of heaves varies from year to year. Subsurface conditions are conducive to the formation of water pockets and the freezing of impounded water is responsible for one form of ground ice. Ice segregation may also occur in the silty soil underlying the buried timber. Two factors believed to contribute to the severity of frost heaving in these situations are (a) heavy rainfall during the weeks preceding the onset of the freezing season, and (b) deep side ditches that encourage the penetration of frost.

Maintenance difficulties, and the lengthy periods during which slow train speeds must be imposed, warrant consideration of large-scale remedial measures in troublesome cut sections. In the case of one such cut, the relocation of 6,000 ft of track has been undertaken—an operation involving 47,000 cu yd of excavation.

Efforts are being made to obtain a permanent improvement of frost heave conditions through (a) drainage improvements, (b) excavation and backfilling, and (c) widening cuts and embankments and using crusher-run gravel as train-fill or sub-ballast. The short maintenance season (only slightly longer than the 200-day operating season) severely limits the volume of work that can be accomplished annually. Therefore, temporary measures for control of frost heaves are important at present.

Admixtures used to date include sodium chloride, calcium chloride, and spent sulfite liquor. The results achieved by these treatments are difficult to evaluate, inasmuch as drainage improvements and the lifting of track have also contributed to the performance of the roadbed. However, all three admixtures are believed to have been effective in reducing the amount of heave. Injection of spent sulfite liquor is undoubtedly the m durable form of treatment. However, it involves the use and transportation of specialized equipment, a matter of some importance on a single-track railroad with heavy traffic.

Subgrade Support

The length of time required for complete thawing of the roadbed to take place has been determined by ground temperature measurements and confirmed by excavation. Loss of subgrade support for the track structure during the spring and summer months is caused by excessive moisture in the roadbed and becomes apparent in pumping ties, fouled ballast, and rough track. Thawing of segregated ice accounts for isolated soft spots in the roadbed, but heavy rainfall and the presence of frost are the principal offenders. A steady improvement in this condition is being realized through the use of deep ballast sections that reduce the load on the subgrade. The occurrence of frost boils has been almost entirely eliminated in this way.

Icing Conditions

In the river valleys of the Laurentian Front, rocks tend to be jointed and fissured. Water seeping toward the roadbed causes ice to accumulate in side ditches and eventually to block culverts and over-run the track. Use of heating cables is justified in the more serious situations, such as those involving tunnels. Permanent improvements are possible in many cases through collection and diversion of surface waters. Thawing of culverts at the end of the winter frequently requires use of steam.

Sloughing of Slopes

Cut slopes in the banded silty clays associated with the north shore lowland of the St. Lawrence are particularly prone to slough. Ice lenses develop in the silty strata and sloughing begins with the first periods of bright sunshine in the spring. Cut slopes tend to become more stable from the standpoint of sloughing as a weathered surface layer develops. The weathered crust does not support the growth of ice lenses to the same extent as the parent material and is more tolerant of vegetation. Use of a blanket of granular material has been found to be beneficial in preventing sloughing in cases where seepage does not occur along the sand-clay interface.

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