Design and performance of the Inuvik, N.W.T., airstrip

G.H. Johnston

Geotechnical Section, Division of Building Research, National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R6

The Inuvik airfield was constructed between 1956 and 1958 on a site underlain by frozen fine-grained soils containing considerable quantities of ice. Its design and performance were therefore of considerable concern. The airfield consists of an embankment of rock fill constructed on the undisturbed ground surface to a thickness sufficient to prevent, or minimize, thawing of the frozen subgrade soils: from 2.5 to 4.2 m, and averaging about 3 m. The airfield was paved with asphaltic concrete in 1969.

Ground temperatures were measured at several locations in the subgrade and the embankment from 1958 to 1974. All temperature observations showed that the permafrost table moved up at least 0.6 m into the fill after construction was completed in 1958 and remained at about the same level in subsequent years, even after paving. The airstrip has performed extremely well to date and has required little maintenance work.

La piste d'atterrissage d'Inuvik a été construite entre 1956 et 1958 sur un lit de sol à grain fin gelé contenant des quantités considérables de glace. Sa conception et son comportement ont donc été un sujet de préoccupation considérable. La piste d'atterrissage consiste en un remblai de roches construit sur une surface de sol intact à une profondeur suffisante pour empêcher, ou minimiser, le dégel du sous-sol gelé: de 2,5 à 4,2 m pour une profondeur moyenne d'environ 3 m. La piste d'atterrissage a été couverte d'un béton asphaltique en 1969.

Les températures du sol ont été mesurées à divers endroits sous le niveau du sol et dans le remblai de 1958 à 1974. Toutes les observations de la température ont montré que la surface du pergélisol a monté d'au moins 0,6 m dans le remblai après que la construction fut terminée en 1958 et est restée à peu près au même niveau au cours des années suivantes, même après le pavage. La piste d'atterrissage a eu un excellent comportement jusqu'à maintenant et n'a pas nécessité beaucoup de travaux d'entretien.

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Introduction

Inuvik is located on the east side of the Mackenzie River Delta (68° 21′ N, 133° 44′ W) in the continuous permafrost zone. The site was selected following a detailed survey of the Delta area in 1954 (Merrill *et al.* 1960) and development of the new town began in 1955. The need for a major airfield was an important consideration and, following careful investigation of several potential locations by Transport Canada, a site was chosen about 12 km south-east of the town early in 1956.

The site selected for the airport had several desirable features. Cuts and excavation of frozen ground were not needed to meet longitudinal and transverse grade requirements because of the relatively flat terrain and no drainage problems were anticipated. Large lakes that could be used by float planes were nearby and a road could easily be constructed to the town. Although there was no granular borrow material in the immediate vicinity, the only rock outcrops in the area were located adjacent to the site, a most important factor since unlimited quantities of good fill material could be obtained from a quarry in the bedrock.

As is true throughout the region, the site is underlain by permafrost and ice-rich frozen soils. The design and ultimate performance of this major facility were, therefore, of considerable concern. The airfield was designed by Transport Canada to prevent or minimize thawing of the underlying frozen ground and consists of a thick embankment of rock fill placed on the undisturbed ground surface. Work started in late 1956, and construction of a gravel-surfaced runway, taxiway, and parking apron was completed late in 1958 (Figure 1). All traffic surfaces were covered with asphaltic concrete pavement in 1969.

In co-operation with Transport Canada the Division of Building Research, National Research Council of Canada, installed ground temperature cables during construction in 1957 and again in 1969, when the pavement was placed, to monitor the performance of the fill. Design and construction aspects and the results of observations made during the period 1957 to 1974 are presented in this paper.

Site Conditions

Climate

Weather observations have been made at Aklavik, located in the Delta about 56 km west of Inuvik, from about 1926 to 1962. Early in 1957, a weather station was established at the Inuvik airport. Monthly and annual averages of daily mean air temperature and precipitation for the two stations are given in

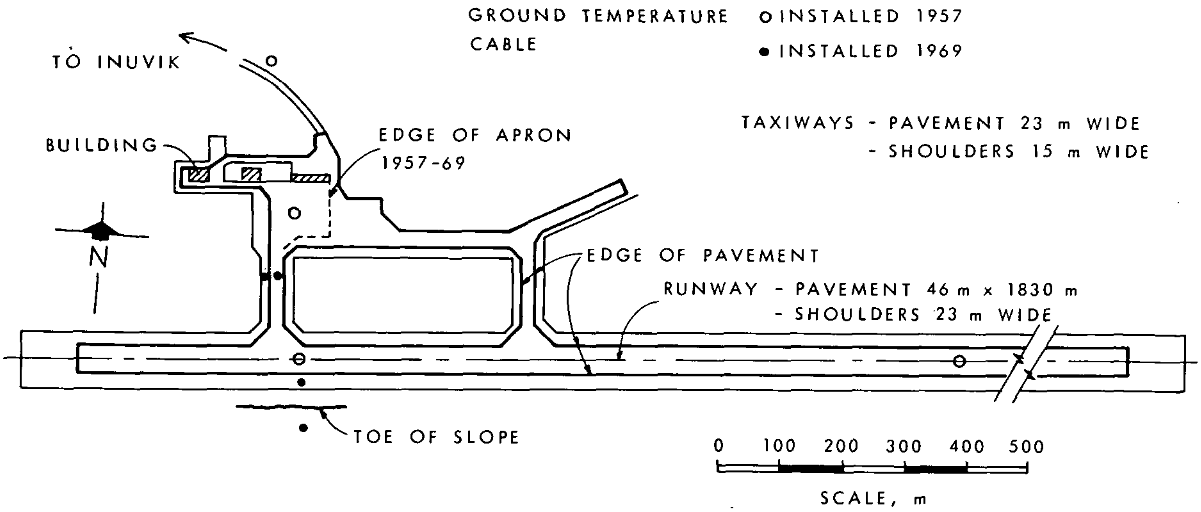


FIGURE 1. Plan showing general layout of the Inuvik, N.W.T., airstrip.

Table 1. The extreme maximum and minimum values of air temperature recorded at Aklavik and Inuvik, were 34 and −52°C and 32 and −57°C, respectively.

Average values of the air freezing and thawing indices for Aklavik during the period 1949 to 1959 are 4460 and 1255 degree days Celsius (DDC) respectively (Thompson 1966). Average values of the air freezing and thawing indices at Inuvik for the period 1958 to 1974 are 4825 and 1190 DDC, respectively. Annual maximum, minimum, and mean air temperatures and annual air thawing and freezing indices for Inuvik are provided for the same period (Figure 2).

On the average there are about 105 frost-free days at Aklavik each year and about 95 at Inuvik. The average number of days having thawing temperatures at Inuvik during the 1959 to 1974 period was 133.

Terrain

The airport site slopes gently from north to south, and was originally covered with a sparse tree growth of stunted spruce and a ground-cover of moss, small shrubs, and other plants. The active layer varied in thickness from about 45 to 120 cm. Two small shallow lakes lay on the runway alignment, one at the east end, the other under the north shoulder near the west end. Both were filled in during construction.

Several test pits were excavated by hand to depths of from 2.5 to 4.5 m prior to construction. The general soil profile for the site consists of a layer of organic material, varying in thickness from 0.1 to 2.4 m, underlain by a brown silt with varying amounts of sand, clay, and stones. This layer, ranging in thickness from 1.5 to 3.3 m, was underlain by a gray silty gravel with some sand and clay. About 1.5 m of this material was exposed in the test pits, but its total thickness was not determined.

The peat is composed of a mixture of fine particles and fibres with some larger woody particles. Stones ranging in size from 2.5 to 15 cm and an occasional boulder of 45 to 60 cm occur in the silt and silty gravel strata. The range and average values of pertinent soil properties are given in Table 2. Although bulk densities were not determined for the mineral soils at the airport, they would have average values ranging from 1840 to 2160 kg/m^3 since the materials were similar to those found on the Inuvik townsite (Pihlainen 1962).

In general, frozen peat in the active layer was well

TABLE 1. Average values of air temperature and precipitation for Aklavik and Inuvik, N.W.T.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Air temperature (°C)													
Aklavik (1929-50)	-28	-27	-22	-12	-1	9	13	10	3	-6	-19	-27	-9
Inuvik (1958-74)	-31	-27	-25	-14	-1	11	14	10	3	-9	-22	-28	-10
Precipitation (mm)													
Aklavik (1929-50)	14	12	10	13	12	20	35	36	23	22	19	11	227
Inuvik (1958-74)	22	8	8	12	17	24	39	42	18	29	22	13	254

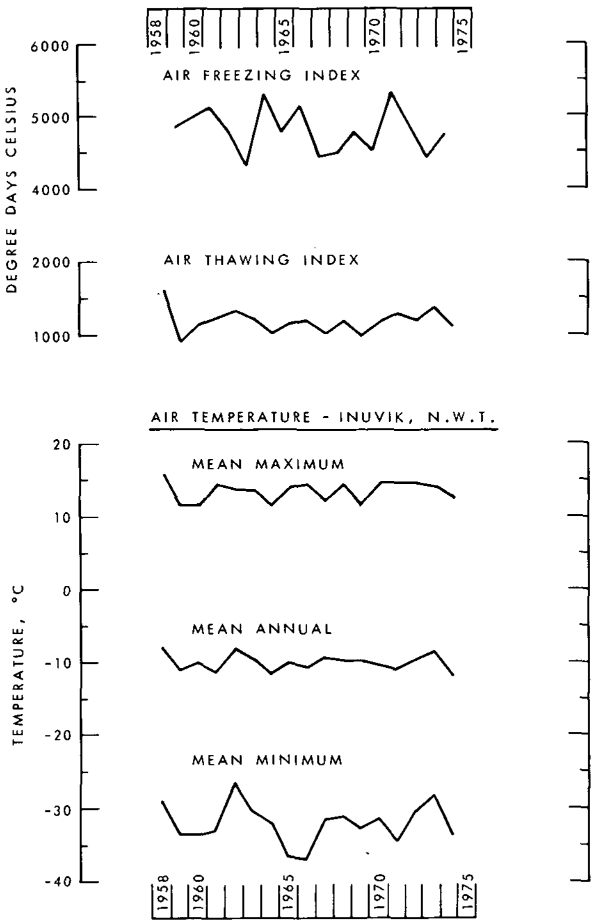


FIGURE 2. Inuvik air temperatures and freezing and thawing indices, 1958-74.

bonded by ice, usually not discernible by eye, with hair-line ice lenses occurring throughout the material. Occasional ice lenses 5 cm thick and random ice masses from 15 to 40 cm thick, with soil inclusions, were encountered in the peat below the permafrost table. Below the peat, the matrix of silt with sand, stones, and clay was well bonded by ice not visible to the eye. Horizontal ice lenses up to 2.5 cm thick occurred throughout this layer, but they decreased in size and concentration with depth. Layers of ice up to 60 cm thick, with silt inclusions 1 to 7.5 cm, were frequently found near the top of this stratum. Ice contents of the underlying gray silty gravel with sand and clay were generally low. It was well bonded by ice but contained random horizontal ice lenses up to 4 mm thick.

Bedrock was not encountered in any of the test pits. The airport is located in the Campbell Lake Dolomite Upland — a rather small area recognized as a distinctive tectonic element in the sedimentary complex of north-western Canada. The outcrops adjacent to the airport (from which the fill material was obtained) consist of rocks that are the oldest known in the area (Norris 1973). These are interbedded, gray to pale red, silty dolomites (dated by paleomagnetism as late Precambrian), gray and green shale, and light gray quartzite.

Design

The site selected was the best of any investigated in the area and had many favourable features. The subgrade soils contained large quantities of ice, however, and thus settlement, bearing capacity, and stability problems could arise if significant thawing were to occur. Furthermore, seasonal freezing and thawing of these frost-susceptible materials could introduce the detrimental effects of frost action. To avoid or minimize these problems, it was highly desirable that an embankment of non-frost-susceptible material be designed and constructed to prevent or control degradation of the underlying permafrost. Fortunately, large quantities of excellent fill material could be obtained from the quarry located about 0.8 km west of the airfield.

When design was undertaken in the mid 1950's, all sources of information and previous experience with road and airstrip construction in permafrost areas

TABLE 2. Range and average values of soil properties

	w %	Plasticity LL/PI %	Clay <0.002 mm	Silt 0.002 to 0.06 mm	Sand 0.06 to 1.2 mm	Gravel >1.2 mm
Peat	276-836 (545)[1]	—	—	—		—
Brown silt	19-92 (34)	27-36 (31)[2] / 9-16 (11)	12-29 (21)	28-53 (40)		18-60 (39)
Silty gravel	7-23 (16)	20-52 (35)[3] / 7-22 (15)	10-60 (28)	24-40 (31)		12-66 (41)

[1]Average values given in brackets.
[2]Stones larger than 13 mm removed.
[3]Tests made on fines passing #60 sieve.

were reviewed. For the conditions at the Inuvik site it was apparent that a substantial fill would be needed to prevent thawing of the underlying frozen ground. The "modified Berggren formula" (Aldrich 1956; Aldrich and Paynter 1953) was used to predict the thickness of fill required.

For design purposes it was considered that the climate at Inuvik would be similar to that at Aklavik. A review of the Aklavik weather records indicated that the mean annual air temperature was about $-9°C$ and that the thawing season lasted about 140 days. It was estimated that the maximum air thawing index would be about 1350 DDC and the average wind speed about 14 km/h. Little information was available on the correlation of the air thawing index and the thawing indices for various types of surfaces. Based primarily on observations made in Alaska, values for a surface correction coefficient (*n*-factor) for thawing ranged from 1.2 to 2.0, but 1.4 appeared realistic for a gravel (crushed rock) surface and 1.8 for an asphalt surface (Carlson 1952; Carlson and Kersten 1953; U.S. Army 1954).

The rock fill could be treated as a single homogeneous layer and it was estimated that the compacted shale would have a dry density of 2240 kg/m^3 and a moisture content of from 2.5 to 5 per cent. Appropriate thermal conductivities for the material were selected from Kersten (1949), and the volumetric heat capacity and latent heat were calculated based on these physical properties.

Using the modified Berggren equation it was estimated that a gravel-surfaced fill at least 3.6 m thick or an asphalt-covered fill at least 4.2 m thick would be required to prevent thawing of the underlying permafrost. It was considered impracticable and too costly to construct such a thick fill initially, particularly when a paved surface would probably not be required for several years. During that period the ground thermal regime would adjust and stabilize greatly and, should thawing and settlement occur, the gravel surface could be maintained by regular grading and addition of fill. Based on a careful assessment of all factors, including observations on road and similar embankments, it was decided that the minimum fill thickness permitted would be 2.4 m. To satisfy grade requirements, however, the average thickness of the embankment actually constructed was about 3 m; at some locations the completed fill was about 4.2 m thick.

Construction and Maintenance History

Construction equipment was mobilized during the summer of 1956 and brought to Inuvik by barge in September when the contractor moved to the site. During the winter of 1956-57 the quarry was opened, the road to the townsite was completed, access roads around the airfield were built, and the sparse tree cover was cleared by hand.

Placement of fill began in late March 1957. Original specifications called for the rock to be crushed (150-mm material was the largest size allowed). Drilling and blasting procedures produced good fragmentation and a wide range of sizes, however, and quarry-run material was used for much of the main fill.

Disturbance of the ground-cover was not permitted and movement of construction equipment around the site was closely controlled and confined to the haul roads. An initial layer of rock up to 1 m thick was placed over the entire area by end-dumping. Material was then added in layers about 0.3 m thick. The fill was hauled by large trucks and spread by bulldozers. Good compaction was achieved when the construction equipment travelled over each layer of fill and through the use of various types of compactors and rollers. By the end of August 1957, approximately 1.8 m of fill had been placed (Figure 3) and the various sizes of crushed material required for the surface course were being stockpiled. By December 1957, most of the main fill had been placed for the 1520-m long runway, the west taxiway, and the parking apron.

Early in 1958, it was decided to extend the runway to 1830 m by additions to both the east and west ends. During 1958 the extensions were constructed and the surface course placed over the entire airfield.

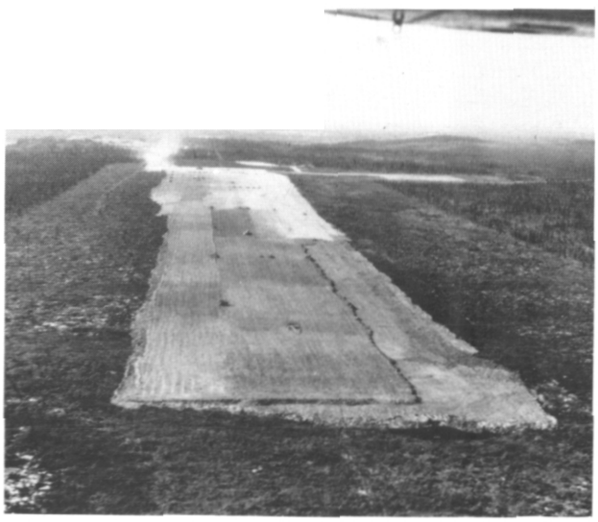


FIGURE 3. Air view to west of runway under construction, August 1957. Note small lake in foreground being back-filled; shadings on runway indicate different types of rock fill (shale, dolomite, quartzite) from quarry in distant background.

All work was completed by the fall of that year. The runway is 46 m wide, with shoulders 23 m wide. Typical sections are shown in Figure 4. The taxiway is 23 m wide, with 15 m shoulders.

At the west end, where the small pond was filled in, about 200 m of the north half of the runway settled slightly shortly after construction was completed. This was corrected by adding about 8 cm of material in July 1959. No further movements of this section have been observed. Minor settlement of the north shoulder and slope of the runway near the east end also occurred in the early years, but to date it has not required remedial work.

During the summer of 1969, the parking apron was enlarged, the existing airfield surface was scarified and covered with an additional 7 to 10 cm of well-compacted crushed rock (maximum size 4 cm), and a 9-cm thick asphalt pavement was laid on the runway, taxiway, and apron. In subsequent years the parking apron was enlarged again and another taxiway (east) constructed; both are paved (*see* Figure 1).

About 1970, a depression approximately 15 m wide began to form at the junction of the original (west) taxiway and the apron. By 1974, the centre of the depression had settled about 0.5 m. It is believed that water that had collected in the area bounded by the runway, the taxiways, and the apron was draining to the west through the fill, causing thawing and settlement to occur. In 1974, the pavement was removed from this section, compacted fill was added to bring it back to grade, and the area was repaved. In addition, a ditch was excavated to ensure drainage of the water to the east and north and thus eliminate ponding.

Over the years, routine maintenance grading of the gravel surface has been carried out during the summer. Before the airfield was paved in 1969, a compacted snow surface was maintained during the winter so that ski- as well as wheel-equipped aircraft could use it. The snow was compacted using rollers, drags, and graders to provide a smooth and firm surface, usually to a depth of 10 to 15 cm, although for a month or so during some winters it might have been 25 to 30 cm thick. Excess snow was removed by graders and blowers. When the snow began to melt in the spring it was graded off the runway.

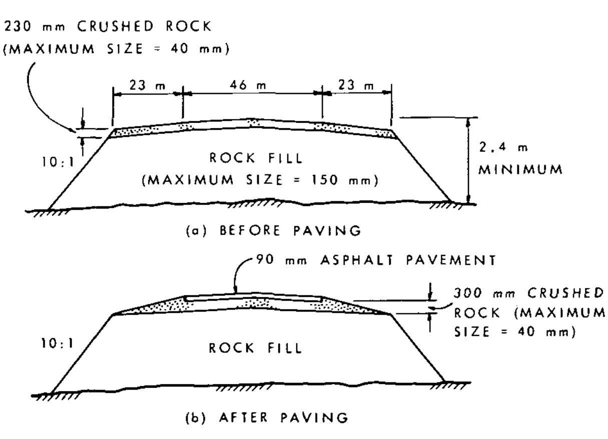


FIGURE 4. Typical sections, Inuvik runway.

The paved surfaces are kept clear of snow and ice by plows, blowers, and power brushes. Snow on the gravel shoulders is compacted, however, and varies in thickness from 5 to 7.5 cm.

Instrumentation

Ground temperature cables were installed at four locations in March 1957 prior to construction. All were placed in carefully backfilled, hand-dug test pits, with thermocouples spaced at various intervals to a depth of 4.5 m below the original ground surface. At each depth, three thermocouples were inserted in holes drilled 15 cm into the wall of the test pit. One cable was located in an undisturbed area north of the parking apron to serve as a reference, another on the apron, and two were on the runway centre-line near the west and east ends. The last three also measured temperatures at various levels in the embankment; three sensors were placed at each level as the fill was constructed.

Four more cables were installed when the airfield was paved in 1969. One was placed to a depth of 4.5 m in a drill hole located in an undisturbed (but tree-cleared) area south of the runway to replace the previous datum cable. Disturbance caused by unanticipated activity in the vicinity of both cables, however, was such that neither could be considered as a suitable undisturbed reference. Another cable was installed at the centre of the south runway shoulder opposite the west taxiway, with thermocouples placed at various intervals in the fill and to a depth of 4.5 m below the original ground surface.

Two short thermocouple cables were installed on the west taxiway in 1969. One was placed on the centre-line, with sensors at the asphalt surface and at various levels to a depth of 91 cm below the surface. The second was installed adjacent to it at the centre of the west shoulder, with sensors placed at various levels from 12 to 107 cm below the gravel surface. The location of all thermocouple cables is shown (*see* Figure 1).

Field Observations and Discussion

Beginning in 1957, ground temperatures were measured two or three times a month throughout the year. Occasionally, observations were missed or had to be discarded for periods of one to three months because of equipment malfunction or because observers were not available. Temperatures on the short taxiway cables were measured continuously by a strip chart recorder starting in August 1969. All observations were terminated late in 1974.

The annual thaw pattern and variation in subgrade temperatures at two depths on the runway centre-line at the west end for the period 1958 to 1974 are shown in Figure 5. Also shown is the depth of compacted snow on the runway in the years prior to paving in 1969. The embankment at this location was about 2.5 m thick, the minimum permitted for the airfield. Similar plots (not shown) were obtained for the apron and east-end runway centre-line sites. The maximum thaw depths were determined each year from temperature measurements at the apron and all runway sites (Figure 6). Ground temperature envelopes show the average maximum, minimum, and mean temperatures for the ten-year period before, and the five-year period after, paving at each of the sites (Figure 7).

An examination of Figure 6 shows that the permafrost table rose into the fill following construction in 1958. Within four to five years it stabilized at from 0.6 to 0.8 m above the original ground surface. After the pavement was placed in 1969, the depth of thaw increased somewhat at all sites, but the permafrost table remained above the original ground surface. The greatest increase occurred under the runway centre-line at the west end site. The thaw depths at the apron and east end runway centre-line, where the fill

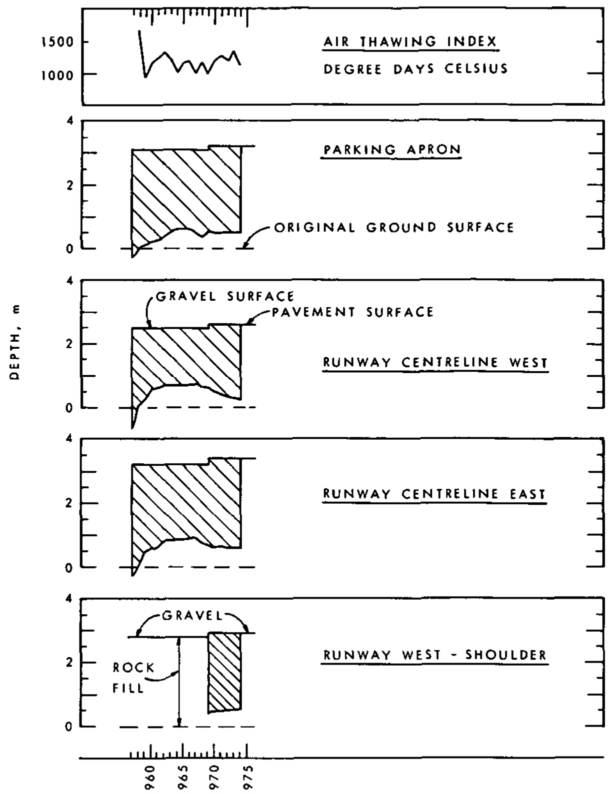
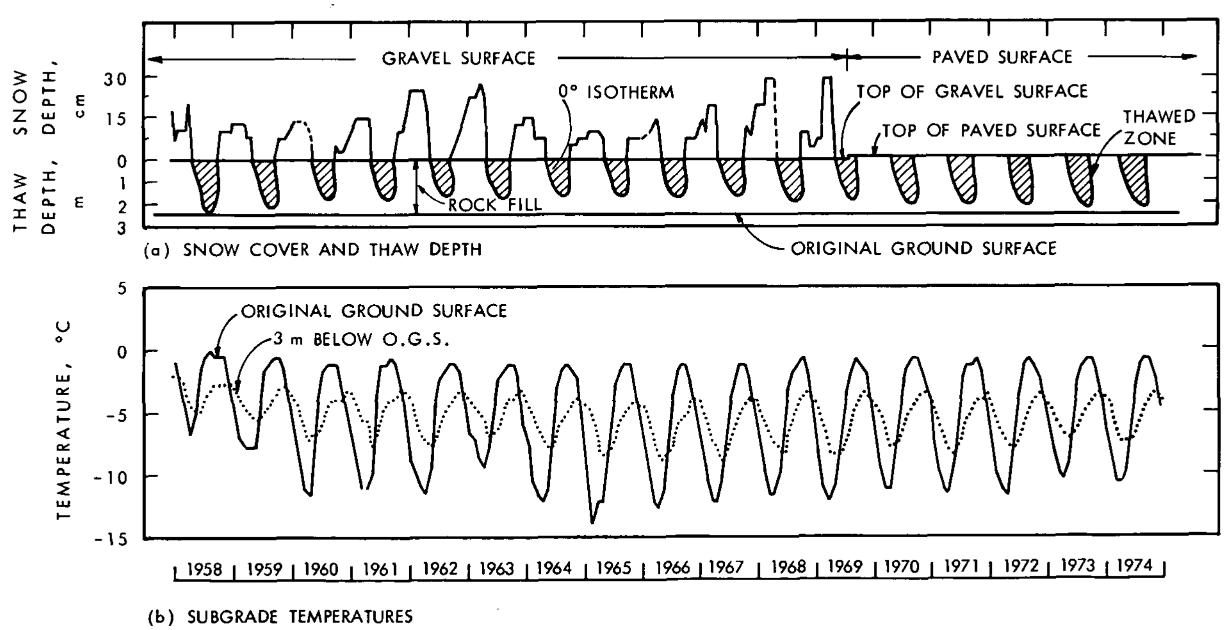


FIGURE 6. Maximum annual thaw depths, Inuvik airstrip.



(b) SUBGRADE TEMPERATURES

FIGURE 5. Snow cover, thaw depth, and subgrade temperatures — runway centre-line, west end, Inuvik airstrip.

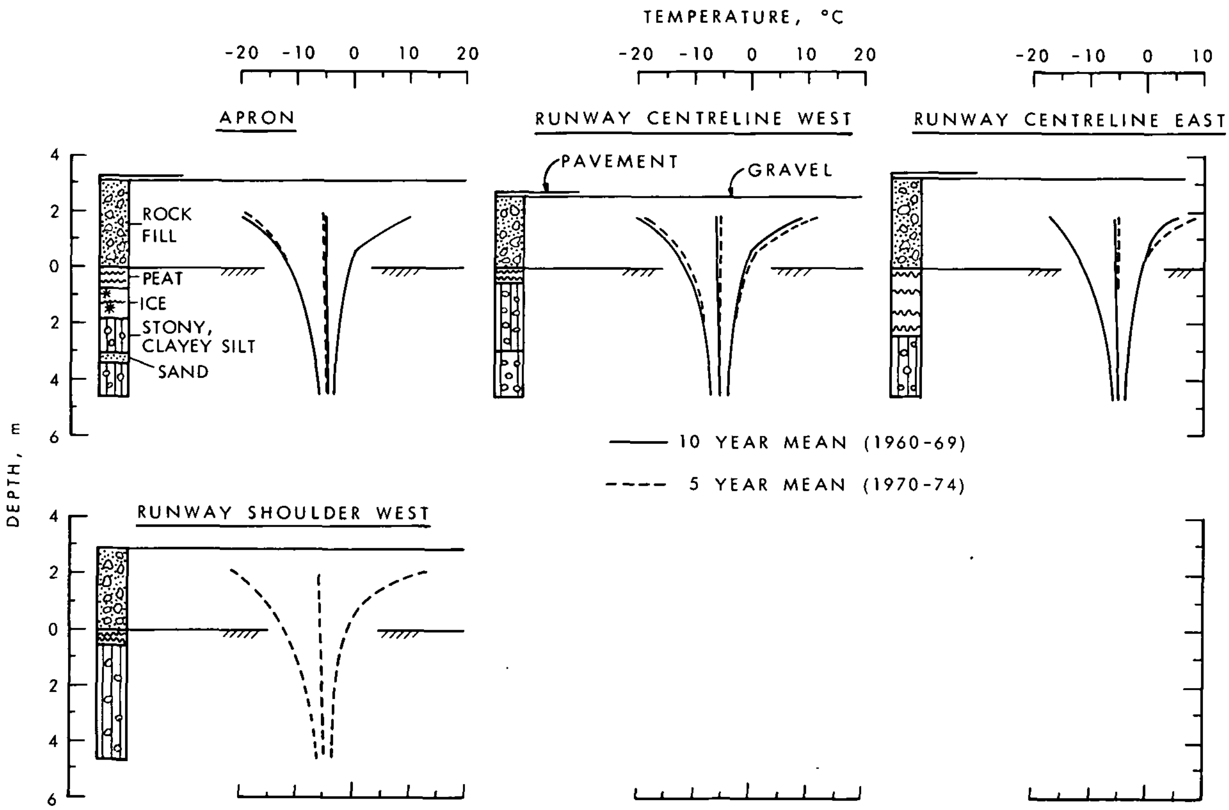


FIGURE 7. Ground temperature envelopes, Inuvik airstrip.

is 3.0 to 3.4 m thick, were greater than those at the west-end site where the fill is about 2.5 m thick. During the period 1969 to 1974 the depths of thaw measured under the gravel shoulder (where the fill is about 3 m thick) and the adjacent west-end centreline site were about the same.

A comparison of the ten- and five-year mean temperature envelopes (*see* Figure 7) indicate a slight warming trend, i.e. an increase in the depth of thaw, at the two runway sites after the airfield was paved. On the other hand, a cooling trend is indicated at the apron site. The envelopes are based on mean values determined from observations made two or three times per month, with gaps of from one to three months (mainly in the winter) in some years. Although a comparison of ten- and five-year means may not be truly representative, they do give some indication of the changes that have occurred in the ground thermal regime.

The differences in the depth of thaw and ground thermal regime that may be seen when comparing the four sites on the airfield are not readily explained. A number of factors could influence the results considerably. For example, differences in the type (shale, quartzite, dolomite) and physical and thermal properties (moisture content, grain-size, density, conductivity) of the rock fill actually placed in layers at each location, the properties of the compacted snowcover on the runway and shoulders, the time and method of snow removal and the pattern of snow melt and dissipation (filtration) of the resulting water through the rock fill in the spring and early summer in the years prior to paving, the generally subtle yet significant differences in albedo between sites (whether gravel or pavement), and the use of the site (the apron would be subjected to oil spills and to more traffic much different from that of the runway sites) are probably the more important factors. Unfortunately, insufficient observations were made and little information is available that would help in assessing the influence of these and other factors.

Values of the air, gravel, and pavement freezing and thawing indices and n-factors computed from them during the five-year period 1970 to 1974 are given in Table 3. Air temperatures were obtained from the Inuvik weather station located at the airport; ground temperatures were measured continuously (every 6 min) at the cables installed on the west taxiway. A thermocouple placed in the asphalt about 5 mm below the surface was used to determine

TABLE 3. Thawing and freezing indices and n-factors

	Freezing			Thawing		
	Period days	Index DDC[1]	n_f[2]	Period days	Index DDC[1]	n_t
	1969-70			1970		
Air	216	4523	—	121	1193	—
Gravel	239	4329	(0.96)	124	1591	1.33
Pavement	224	4248	0.94	134	2117	1.77
	1970-71			1971		
Air	239	5334	—	135	1293	—
Gravel	239	4997	(0.94)	149	1928	1.49
Pavement	229	4955	0.93	149	2342	1.81
	1971-72			1972		
Air	238	4884	—	112	1204	—
Gravel	218	4310	(0.88)	120	1603	1.33
Pavement	208	4313	0.88	140	2136	1.77
	1972-73			1973		
Air	243	4428	—	137	1372	—
Gravel	229	4018	(0.91)	149	1840	1.36
Pavement	219	4083	0.92	159	2325	1.70
	1973-74			1974		
Air	219	4757	—	133	1121	—
Gravel	216	4845	(1.02)	139	1659	1.48
Pavement	214	4509	0.95	139	2121	1.89
Five-year averages						
Air	231	4785	—	128	1237	—
Gravel	228	4500	(0.94)	136	1724	1.40
Pavement	219	4422	0.92	144	2208	1.79

[1]DDC = Degree days Celsius.
[2]Values of n_f in brackets do not take into account a compacted snow layer on the surface that varied in thickness from 0 to 5 cm during the freezing period.

the pavement surface temperature. That of the adjacent gravel shoulder was calculated by extrapolating the temperatures measured at several points from about 12 cm (the highest) to 105 cm below the surface. The manner in which the air, gravel, and pavement thawing indices accumulated each summer is shown in Figure 8.

The freezing n-factor is virtually the same each year for both the gravel and pavement surfaces, due in large part to the effect of the thin layer of compacted snow on the gravel surface and to the fact that there is a long period of twilight and darkness at this latitude and hence little or no incoming radiation during the winter. The thawing n-factor for the gravel surface was obtained from extrapolation of ground temperatures and therefore is subject to some error. This error would be very small, however, because of the large number of observations made on each of the closely-spaced sensors in the cable. As would be expected, the thawing n-factors vary annually for the five-year measurement period, which covers a reasonable range for the Inuvik climate. The average values of 1.4 and 1.8 for the gravel and pavement surfaces respectively can be considered representative of the conditions at this site.

It is apparent that the modified Berggren equation overestimated the thickness of fill required. As with any predictive method, much depends on the selection of appropriate values (or range or combination of them) for the various parameters. The original values used for the climatic variables were based mainly on Aklavik records. Observations made at Inuvik in subsequent years indicate that the climate there is somewhat cooler than that at Aklavik. Similarly, values for the properties of the fill materials are important, but can be estimated only within certain limits. Unfortunately, in this case no detailed information on material properties was obtained. Never-

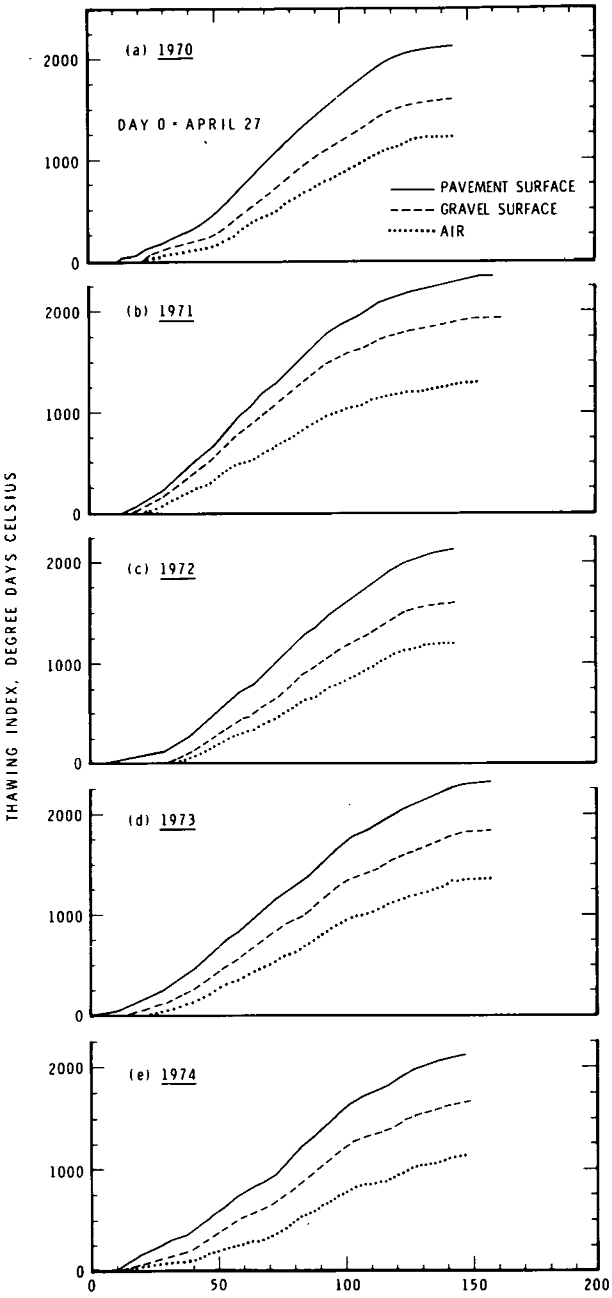


FIGURE 8. Cumulative air, gravel, and pavement thawing indices, 1970-74, Inuvik airstrip.

theless, although the original prediction was conservative, the use of the modified Berggren equation was reasonably successful.

Conclusion

Observations have shown that the Inuvik airstrip, built in a remote area on ice-rich frozen ground, has performed extremely well. No more than routine maintenance has been required. The permafrost table has risen and remained in the embankment (placed on the undisturbed ground surface) and thawing of the underlying frozen ground has been prevented, even after the surface was paved. Although based on rather limited experience and information, the decisions taken during planning, design, and construction of this major facility have been fully justified by its successful performance.

Acknowledgements

The co-operation and assistance received from Transport Canada personnel during the initial construction period and in subsequent years is gratefully acknowledged. Special thanks must go the Inuvik Weather Station observers who carried out the manual measurements of ground temperatures for many years, often under adverse conditions. Appreciation must also be expressed to members of the Inuvik Research Laboratory, and especially to J.C. Plunkett of the Division of Building Research, for their assistance.

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