# Challenge of Permafrost Degradation Impact on Airport and Road Pavements

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Paper prepared for presentation
at the Innovation in Geotechnical and Materials Engineering Session

Of the 2018 Conference of the
Transportation Association of Canada
Saskatoon, SK

## ABSTRACT

A large part of northern Canada is in the discontinuous or scattered and discontinuous permafrost zone. It has been observed at airports and on roads, that due to disintegrating permafrost the pavements in the above zones exhibit rapidly progressing degradation.

This paper describes cases where pavement failures due to melting or melted permafrost were investigated. Large settlements or slippage of airport pavements were observed. The pavements became very rough, posing a safety hazard to moving aircraft, particularly on runways. Similar settlement may occur on aprons and taxiways. In some cases airport buildings, including terminal buildings, may differentially settle/heave and require urgent expensive repairs. Relocation of buildings and airside groundside facilities may be necessary.

Three cases are described in this paper where airport and road pavements exhibited serious problems due to permafrost degradation. It presents the method of investigation of permafrost presence and condition including visual condition inspection, geotechnical investigation and laboratory testing, temperature monitoring using thermistors and extent of permafrost using OhmMapping. The considered methods of addressing the issue of pavement failures included identifying the location and severity of the problem, addressing the drainage issues, emergency pavement repairs, soil replacements and pavement insulation, structural repairs using geosynthetics, and reconstruction including soil improvement or replacement, and relocation.

## 1.0 INTRODUCTION

Numerous airport and road pavements in the northern latitudes of Canada and in Alaska, were constructed numerous years ago. At the time of the original construction of these pavements the depth of the seasonally frozen soils (active layer) was relatively shallow, and underlying the active layer were soils that were permanently frozen (permafrost). Due to the presence of the permafrost layer underlying the pavement structure, the design of these pavements initially assumed that the subgrade soils would have significantly higher bearing capacities. However, over the life of these pavements the thickness of the active layer has increased drastically, and in some locations the permafrost has completely melted [1, 2]. The melting of the permafrost layers has in turn resulted in the reduction of the bearing capacity of the subgrade soils, drastic deformation and settlements of pavements, and a reduction in the service life of the pavements [1, 2].

Due to the rapid, and severe deterioration of these pavements, they are requiring significantly more maintenance and earlier than anticipated pavement rehabilitation. Additionally, the extents of the rehabilitation required for the pavements is typically far more extensive, and sometimes up to full reconstruction, due to the fact that the pavements were originally designed using subgrade bearing strength values that are significantly higher than the actual bearing strengths of the soils after the permafrost layer has degraded [1].

In addition to the challenging ground conditions at these northern latitudes, the cost for construction in these areas is also significantly greater than equivalent construction at southern latitudes. These pavements are often located in remote areas and the number of qualified contractors undertaking construction projects is very limited. Additionally, the quantity and variety of suitable materials for construction are also limited, and therefore the cost for construction tends to be very high.

Difficult ground conditions and high construction costs require that customized and unique approaches have to be taken for the design of the rehabilitation of pavements constructed with similar ground and permafrost conditions. During pavement rehabilitation design it needs to be ensured that the reliability of pavement performance is not compromised and that the safety of the travelling public is ensured.

This paper includes three locations where airport and road pavements exhibited serious problems due to permafrost degradation. It presents the method of investigation of permafrost presence and condition including pavement visual condition inspection, roughness surveys, geotechnical investigation and laboratory testing, temperature monitoring using thermistors and extent of permafrost using an Ohm Meter. The considered methods of addressing the issue of pavement failures due to permafrost degradation includes identifying the location and severity of the problem, addressing the drainage issues, emergency pavement repairs, soil replacements and pavement insulation, structural repairs using geosynthetics, and reconstruction including soil improvement or replacement, and relocation.

## 2.0 DISTRESS MANIFESTATIONS DUE TO DEGRADING PERMAFROST

Golder has carried out visual inspections on numerous pavements in areas where the permafrost is known to be degrading and is generally scattered and discontinuous. Examples of Airports pavements constructed on permafrost which is now deteriorating, where Golder has carried out investigations include the following

- Case 1 - Yellowknife Airport, Yellowknife, Northwest Territories;

- Case 2 - Hay River Airport, Hay River, Northwest Territories; and
- Case 3 - Thompson Airport, Thompson, Manitoba.

The primary distresses that were identified on the pavements during our visual condition inspections included the following:

- High severity depressions/settlements and frost heaves at localized areas;
- High severity cracking, including faulting and stepping;
- Localized patches which crack shortly after, typically with one year, of the patch being placed;
- Ponding on and ice accumulation on the pavement surface;
- Poor pavement surface roughness characteristics.

Figure 1 shows an example of high severity settlement that was observed on a runway pavement at Yellowknife Airport. Also, shown in Figure 1 is the cracking that may be observed in the granular shoulders. This type of cracking is typically observed in areas with ice rich soils due to degrading permafrost layers. Figure 2 shows an example of high severity cracking that can typically be observed in pavements that were constructed on permafrost layers that have since degraded or are degrading. Figure 3 shows a large area of ponding water that was observed on the runway pavement at Yellowknife Airport, and Figure 4 shows a large area of ponding water and severe depression that was observed on the apron pavement at Thompson Airport. Figure 5 shown severe tilting of one of maintenance building at the same airport due to permafrost degradation.

The examples above are for airport pavements; however, similar issues are observed on road pavements in these areas as well. Figure 6 shows an example of a road pavement in the Yellowknife area, exhibiting extreme deformations due to permafrost degradation. The section has shown in the photograph been closed and a new road section had to be constructed.

In addition to pavement deterioration, buildings constructed in area of scattered and discontinuous permafrost are susceptible to rapid and significant deterioration as the permafrost layers begin to degrade and the depth of the depth layer increases. Typically, the degradation of the layer does not occur uniformly, but rather may occur at some locations more rapidly than others. The non-uniform permafrost degradation results in differential settlement of the building foundation, and cracking in the building walls.

## 3.0 INVESTIGATION METHODS TO EVALUATE SITE PERMAFROST CONDITIONS

In addition to completing a visual condition inspection to identify distresses that would be typical of permafrost degradation, there are methods that can be used to identify the distribution of permafrost underlying existing infrastructure and/or areas for proposed new infrastructure. Examples of other investigations that may be carried out to evaluate site permafrost conditions include the following:

- Carrying out a detailed review of historical information, particularly information regarding the conditions of infrastructure over time, construction and maintenance history, and roughness survey;

- Carrying out pavement visual condition inspection;
- Carrying out a borehole investigation; and
- Carrying out geophysical investigations, in particular OhmMapping.

The objective of carrying out a geophysical survey would be to delineate areas of sporadic or degraded permafrost, to compare subsurface conditions in the area of existing facilities, and in the area of proposed new facilities. During the geophysical investigation, ground resistivity information is collected using the capacitively-coupled electrical resistivity imaging (C-CERI) method. The C-CERI method measures the electrical resistivity of the subsurface, both laterally and vertically, to infer structure and material composition of the subsurface. Typically, grain-size, porosity, soil-type, temperature, ice content, water saturation and total dissolved solids (TDS) concentration are the primary factors controlling resistivity. Increasing ice content or permafrost normally increases resistivity significantly, whereas increased water content tends to lower resistivity. Therefore, measurement of variations in the electrical properties of near-surface soils using electrical geophysical survey methods often enables effective mapping of the effects related to the presence or absence of permafrost.

Figure 7 below presents an example of C-CERI data collected along a highway in a region of discontinuous permafrost during winter in northern Canada. The cross-section presents a colour contour map of resistivity in terms of lateral distance and depth, where cool colours represent lower resistivity and warm colours represent higher resistivity. The upper 3 m of the subsurface consists of higher resistivity seasonally frozen road fill materials. Between 3 to 8 meters below ground surface, there are zones of lower and higher resistivity observed. The higher resistivity zones are attributed to increased ice content (permafrost) while the lower resistivity zones are attributed to increased water content (melted permafrost).

The OhmMapper survey instrument is a C-CERI system designed to measure ground resistivity without the use of electrodes traditionally employed in conventional direct current resistivity systems. The OhmMapper system consists of an ungrounded transmitter, a receiver array of up to five receivers and a data logger. The transmitter and receiver array are commonly pulled along the ground by hand or with a small vehicle to allow collection of near-continuous data. Data are recorded by means of a digital data logger connected to the receiver array and are positioned in real-time by a global positioning system (GPS) receiver. Multiple receivers provide varying depths of investigation to enhance vertical resolution. Figure 8 displays a typical field configuration for the OhmMapper being towed by a person on foot.

Investigation depth is largely controlled by the transmitter-receiver separation and the electrical properties of the ground; increasing the distance between the transmitter and receiver increases penetration depth while an increase in ground conductivity tends to reduce the depth to which the signal can penetrate. Maximum depth of investigation for the OhmMapper instrument is generally between 10-20 meters, but may be as little as 5 m in highly conductive ground conditions. Because the instrument needs to be towed along the surface of the ground, deployment of the OhmMapper in areas not sufficiently cleared of obstacles such as trees, tree stumps, ditches and significant bodies of water is inadvisable due to the likelihood of damage to the instrument.

The scope of the geotechnical investigations should be sufficient to characterize site conditions and define ground temperatures and water levels in non-permafrost areas. Ground temperature data is especially important in areas like Thompson where permafrost is commonly warm (ground temperature >1°C) and susceptible to thawing as a result of site clearing and improvements. Typical elements of a geotechnical field investigation should include:

- Installation of thermistor casings (typically 25mm-50mm PVC or HDPE) to allow for measurement of ground temperature. Once a thermistor casing is installed ground temperatures can be periodically measured by airport personnel using portable thermistor cables or a data acquisition system can be installed with wireless or satellite uploading of data to allow remote monitoring at critical locations.

- Installation of piezometers to allow for measurement of groundwater level in non-permafrost areas.

- Determination of blow count using conventional split spoon sampling techniques.

- Collection of undisturbed samples (e.g., Shelby tube) in unfrozen silt and clay, including field measurement of undrained shear strength using a Torvane similar field equipment.

- Collection of frozen core samples (e.g. Geoprobe, auger coring, or refrigerated coring).

- Measurement of shear strength in unfrozen silt and clay (e.g. field vane shear).

- Geotechnical Index Tests, including measurement of index properties (e.g. moisture content, Atterberg limits, unit weight, particle size distribution, frost classification, and pore water salinity).

- Frozen soil testing where applicable including frozen bulk density and thaw strain.

In order to address appropriately address the infrastructure deterioration due to degrading permafrost, it is critical to carry out detailed site investigations to delineate the extents and depths of permafrost. The information gathered during the field investigations will then be used to developed design strategies that should be implemented to address the deficiencies in the existing infrastructure at the affected sites.

## 4.0 PAVEMENT TREATMENT TO ADDRESS DETERIORATION DUE TO PERMAFROST DEGRADATION

The repairs of pavements experiencing deterioration due to permafrost degradation can be divided into three major categories, as follows:

- Emergency pavement repairs;

- Pavement structural rehabilitation; and

- Drainage improvements.

The emergency repairs would be needed to be carried out to address the areas that exhibit significant pavement roughness due to either depressions or settlements, or due to very high severity cracking. Emergency repair treatments of the critical areas typically involve milling of the asphalt layers, full depth or partial, and then placement of a new asphalt overlay.

For the purpose of undertaking structural repairs of existing pavements, typically the methods used to address permafrost and spring thaw weakening are described below [1, 2, 3, 4, and 5]:

1. Providing complete frost protection by installing non-frost susceptible material to the depth of seasonal thaw. Normally, economic and practical considerations control the limit of the depth of treatment to a maximum of 1.8 m (6 feet). This method also addresses the potential for future frost heaving and improves the structural support for the pavement;

2. Accept a reduced subgrade strength where the pavement structure should have a sufficient support capacity during the seasonal permafrost thaw period. If this method is used, differential frost heaving should still be anticipated; and

3. Installing insulating panels – the panels are placed beneath the pavement structure to protect against further degradation of permafrost. This method may lead to some problems and should be carefully considered on a site specific basis and some pavement engineers are skeptical about its application. This approach is also very expensive.

4. Relocation of the pavement to an area where the permafrost has already melted.

Pavement designs that have previously been developed for existing pavements that cannot be relocated are detailed below:

1. Reconstruction - Full width reconstruction of the roughest sections of pavement, to a depth of seasonal frost penetration. The removed existing soil and old backfill materials should be replaced with new granular material. The materials recovered from the existing pavement structure can be re-used, provided they meet gradation requirements and are free of contamination. Insulation was not recommended to be installed in this alternative. This alternative would be considered to be the most effective from a technical perspective and provides the best long-term solution. However, it is also the most expensive and may have a drastic impact on operations of an airport or road due to the extent of excavation and backfilling, and the associated time required to carry out the construction.

2. Cement Stabilization - Remove the existing pavement structure full width and stabilize the existing soils with Portland cement. Then place a new pavement structure. Insulation was not recommended to be installed in this alternative. It should be anticipated in this alternative that some frost heaving will very likely still occur and some settlement may also occur. Since the cement treated layers may not be durable in a frost heaving environment, this alternative would not be recommended without undertaking a detailed geotechnical investigation and some pilot-scale trials.

3. Geogrid (Pillow) Structure - Remove the existing pavement structure and the top of the existing soil to a predetermined depth. The depth should be based on the required pavement design from structural design analysis and the results of the soil consolidation tests. Place a layer of biaxial geogrid and then 150 mm of granular base material above it. Then place a second layer of the biaxial geogrid. The double geogrid and granular ‘sandwich’ acts as a reinforced support layer for the pavement. Place the remaining part of the pavement structure. Insulation was not recommended to be installed in this alternative. Although in this alternative some frost heaving should be anticipated, this alternative offers high flexibility and should provide sufficient durability. It also would be the most cost effective than the other two alternatives described above.

In addition to carrying out the pavement rehabilitation or relocation, it is critical for future pavement performance that the pavement surface and subsurface drainage should be reviewed, and any required improvement should be implemented. As a minimum, the existing ditches along the pavement edge should be sufficiently deep and any overgrown vegetation within the ditch should be removed. The pavement surface grade and the ground surface grade towards the ditches should be sufficient to allow for positive drainage of surface water towards the ditches.

It is considered to be preferable to install subdrains along the pavement edge. The depth of the subdrains should be a minimum 0.5 m below the bottom of the pavement structure. Additionally, consideration should be given to the installation of double subdrain system, with one network of subdrains being at a lower depth than the other subdrain network. It is also critical that there are enough outlets taking the subsurface water to the ditches.

Finally, it is recommended winter snow removal procedures should be updated to moving snow piles from plowing to a further distance away from the pavement edge. Snow acts as an insulating layer on the ground surface, which in turn results in more rapid deterioration of permafrost. The location of the snow piles should be considered carefully. This simple maintenance fix can remove the insulating layer in the winter, allow deeper freezing depths, and reduce the rate of pavement deterioration.

Dealing with buildings tilting due to permafrost melting is outside the scope of this paper, although Golder also provides foundation recommendations for buildings affected by the permafrost degradation.

## 5.0 CASE STUDIES

Case 1 – Yellowknife Airport. The surveyed pavement roughness is shown in Figure 9. The analysis indicated two locations on Runway 10-28 where the survey roughness was in the excessive and unacceptable zones. The thermistor measurements clearly indicated that the permafrost is either melting or melted. Examples of the readings are shown in Figures 10 and 11. It was recommended to carry out an emergency repair be carried out at both locations and a pavement rehabilitation be carried out in the near future. This should include pavement subsurface drainage system installation.

Case 2 – Hay River Airport. Similar to Case, 1, the thermistors measurements clearly indicated that the permafrost was melting or melted. Since the pavement roughness was good in the keel zone and poor only in the non-keel zone, mainly near pavement edges, only minor emergency repairs were required. It was also recommended that pavement rehabilitation be carried out in the near future. This should include reconstruction of the pavement subsurface drainage system.

Case 3 – Thompson Airport. The OhmMapping survey indicated the new locations suitable to airside facilities relocations. Due to severity of the permafrost degradation in the apron area and the settlements and tilting of the building, it was decided to relocate the Airport Terminal Building, the apron and the access road to a new location where the impact of any permafrost degradation would be minimized. For localized areas where some minor settlements of airside facilities could be anticipated, the use of geosynthetics was recommended.

## 6.0 CONCLUSIONS

A large part of northern Canada is in the discontinuous or scattered and discontinuous permafrost zone. Due to global warming and changing the type of the ground surface, the depth of the active layer has increased steadily and currently the permafrost can be considered to be melting or has already melted. This has resulted in significant differential settlement of the pavements. Also, since the soils under the pavements are occasionally also frost susceptible, differential frost heaving is also observed. This results in pavement roughness and pavement cracking.

In this paper the authors have detailed the investigation methodologies that should be used to identify whether the infrastructure deficiencies are due to the degradation of permafrost, and to delineate the extent of permafrost and the depths of the active layer. The information gathered from these investigations is critical to develop suitable treatment and rehabilitation designs to address the deficiencies in the existing infrastructure at the affected sites.

The considered methods of addressing the issue of pavement failures due to permafrost degradation includes identifying the location and severity of the problem, addressing the drainage issues with sometimes dual subdrains, emergency pavement repairs, soil replacements and pavement insulation, structural repairs using geosynthetics, and reconstruction including soil improvement or replacement, and relocation.

## 7.0 REFERENCES

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2. Guy Dore and Hannele K. Zubeck, “Cold Regions Pavement Engineering”, ASCR Press, McGraw Hill, 2009.

3. Orlando B. Anderson and Branko Ladanyi, “Frozen Ground Engineering”, Second Edition, ASCE, John Wiley & Sons, Inc., 2004.

4. Public Works Canada, Architectural and Engineering Services, Air Transportation, ‘Manual of Pavement Structural Design’, ASG-19 (ak-68-12), July 1992.

5. U.S. Department of Transportation, Federal Aviation Administration, Advisory Circular AC No: 150/5320-6E, “Airport Pavement Design and Evaluation”, Date: 9/30/2009.

# FIGURES

**Figure 1. Severe settlements in the non-keel zone of runway pavement at Yellowknife Airport and cracking in granular shoulder.**

**Figure 2. Severe transverse crack on runway at Hay River Airport.**

**Figure 3. Water ponding in a deep depression on runway pavement at Yellowknife Airport.**

**Figure 4. Water ponding in a deep depression on apron pavement at Thompson Airport.**

Figure 5. Severe tilting of a maintenance building due to permafrost degradation.

Figure 6. High severity pavement deformations on a road in the Yellowknife Area.

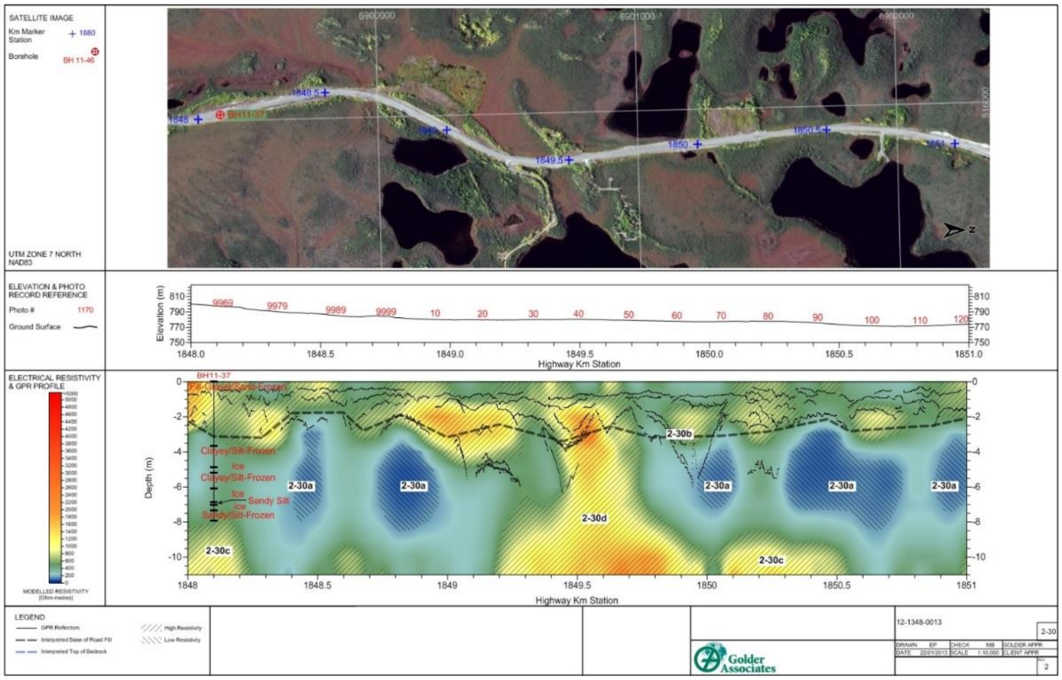

Figure 7. Example of Interpreted C-CERI Resistivity Survey Data to Delineate Permafrost

Figure 8. Example of investigated aggregates.

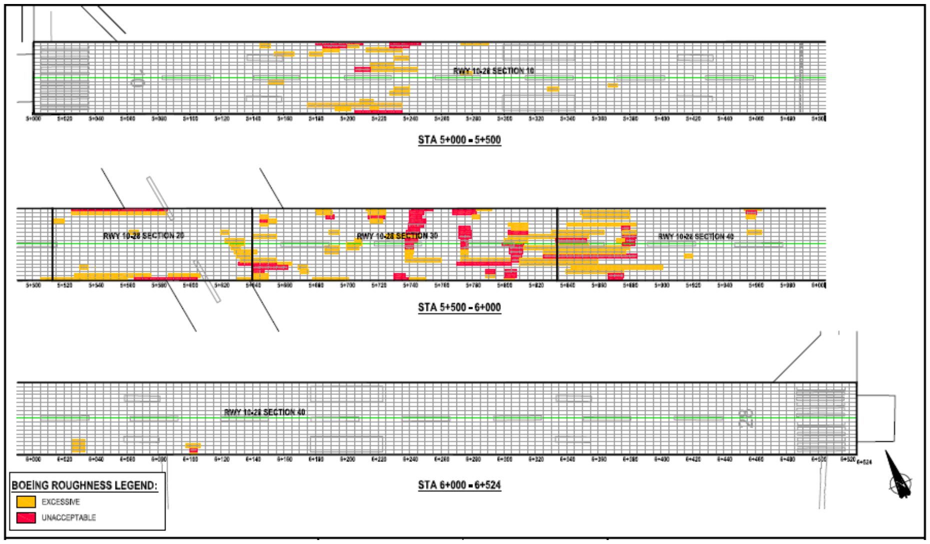

**Figure 9. Roughness analysis results on Runway 10-28.**

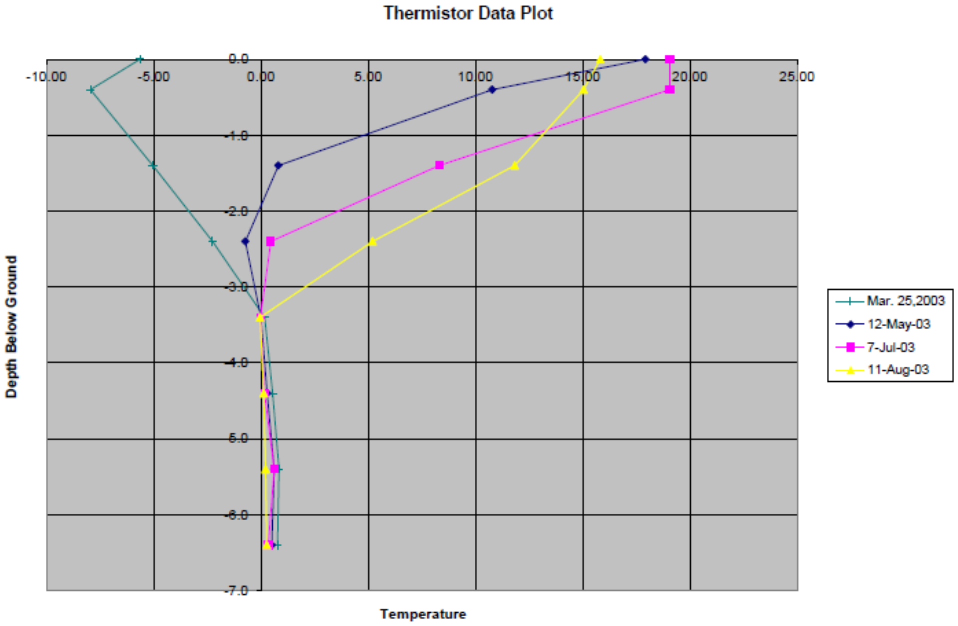

**Figure 10. Example of thermistor readings on Runway 10-28.**

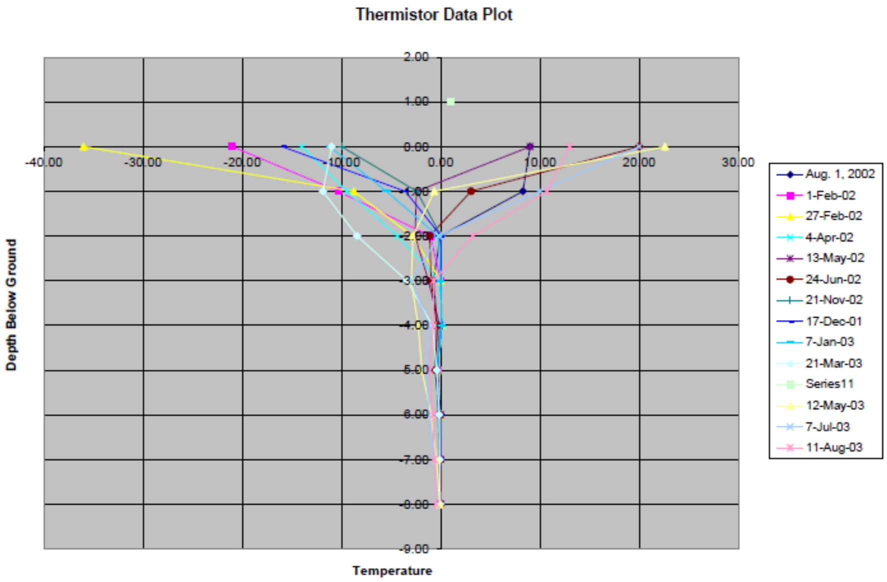

Figure 11. Example of thermistor readings on Runway 10-28.