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SVALBARD AIRPORT GEOTECHNICAL STUDY: ENGINEERING METHODOLOGY AND RESULTS

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Abstract

The Svalbard Airport runway has experienced continual distress in the form of settlement depressions resulting in an uneven pavement surface, which has a significant impact on aircraft operations. A geotechnical study, contracted by Luftfartsverket (The Norwegian Civil Aviation Authority), was initiated in 1993 to define the cause of the problem and develop potential rehabilitation alternatives. This paper provides an overview of the study conducted. Attention is given to the techniques used during the site investigation, geotechnical instrumentation, and analysis. The proposed rehabilitation alternatives include: insulating additional areas, raising the runway grade, removal of ice-rich soil and replacement with thaw-stable gravel, continuation of patching and overlaying, and painting the runway surface white.

Introduction

The Svalbard Airport is northwest of the town of Longyearbyen, located on the island of Spitsbergen which is north of mainland Norway (Figure 1), at approximately 78° north latitude.

Since its construction during the 1973 to 1975 summer seasons, approximately one-third of the 2200 m long paved runway has been adversely affected by thaw-settlement. The on-going settlement, which has been attributed to permafrost degradation in the cut sections, has resulted in the need to patch and/or overlay the runway a number of times since it was completed. The design thickness of the initial lift of asphalt placed when the surface was paved in 1975 was 60 mm. The asphalt thickness measured during the site investigation was as much as 350 mm which provides some indication of the settlement that has occurred. The settlement depressions typically have a diameter of 10 to 40 m.

Unfortunately, the available surface settlement survey data, as compiled by others, is incomplete. Recent surface elevation data for the entire runway is not available. The runway surface elevation data gathered by two independent agencies may each have used diffe-

Figure 1. General Location Plan.

rent survey datum from that used on the original runway design drawings. Additionally, they only cover the area in which settlement has been noted in the past. The survey data is suitable for determining the recent relative movement of the runway; however, the difference in elevation datum precludes the determination of the absolute settlement that has occurred over a longer period of time.

Site investigations and in situ ground temperature measurements have been performed at the airport. The University Courses on Svalbard (UNIS) is now assisting with ground temperature data collection for input to a ground temperature database. Luftfartsverket initiated this long-term study in an attempt to better understand the problem at hand and to develop potential rehabilitation concepts. This paper intends to provide an overview of the study conducted.

Site conditions & airport history

Svalbard Airport is located a short distance northwest of Longyearbyen. The paved runway lies on a relatively flat coastal plain in an east-west direction (Figure 2). Isfjorden (ocean) is located immediately north of the runway, while south of the runway, steeply sloping foothills rise to an upland plateau known as Platåberget. These hills provide a source of surface and groundwater flow towards the runway. This water is channeled into two major drainage courses that cross beneath the runway through corrugated steel culverts. Cut-off ditches have been constructed on the uphill side of the runway to intercept runoff from the slope.

The coastal plain where the runway is situated is underlain by coarse to fine-grained soil. According to Tobiasson (1978) the soil underneath the runway ranges from being relatively dry to ice-rich, and contains ice lenses. Peat bogs, up to 0.5 m in thickness are believed to have existed at some locations along the runway; however, it is understood that the existing peat and tundra surface was removed prior to construction. Tobiasson also states that "Samples of permafrost below the runway revealed that it contained numerous ice lenses up to 50 mm thick, but no massive ice". It has also been reported that, in some locations beneath the runway, the soil contains about 70 percent ice by volume.

The runway was constructed with approximately one-third to one-half of its area in cut and fill; the remainder of the area is an embankment fill. Fill thickness overlying the native soil varies from 1.1 to 4.0 m, depending on the location along the runway. The thinner fill sections are located within the areas in which cut and fill was used during the original construction. The sections constructed as a cut with subsequent thin fill thickness placed are located from approximately Station 1540 to Station 1850 and from Station 2300 to Station 2830. The sections with minimum fill are the sections that have experienced the most settlement distress.

The runway has been affected by settlement depressions since construction was completed in 1975. The resulting unevenness of the runway has required ongoing remedial maintenance to provide a relatively smooth runway surface. The most recent asphalt overlay program was completed in August 1997. Polystyrene insulation was placed at the two major

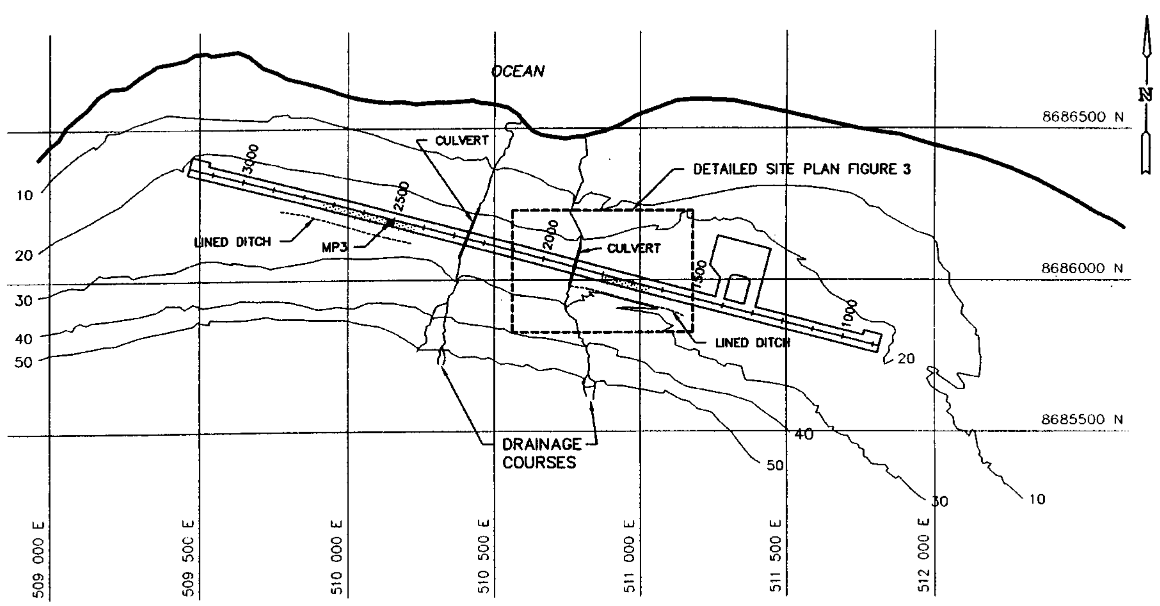

Figure 2. Svalbard Airport Site Plan.

problem areas in 1989: Stations 1700 and 2500 (Figure 2). Other mitigation measures used by Luftfartsverket include the construction of cut-off ditches on the uphill side of the runway.

A study was initiated to determine the cause of the settlement depressions and propose potential rehabilitation solutions. A site investigation was conducted to address the following issues:

- assemble detailed stratigraphic information, including moisture content, salinity, grain size distributions, ice content, and bulk density,
- monitor ground temperature below the runway surface, and
- examine ground water conditions.

Site investigation

FIELD WORK AND INSTRUMENTATION INSTALLATION

Six boreholes were drilled at the Svalbard Airport using an Atlas Copco ROC 701 air-track drill rig contracted from Store Norske Spitsbergen Kulkompani AS (SNSK). The borehole locations, as numbered EBA1 through EBA6, are presented in Figure 3. (Instanes A/S drilled one borehole (MP3) at the western section of the runway).

The principal two boreholes, EBA1 and EBA2, were drilled on the runway for the purpose of assessing the stratigraphy and to install permanent ground temperature cables. The remaining four boreholes, EBA3 through EBA6, were drilled along the southern edge (uphill) of the runway to study ground water conditions. Slotted standpipes were installed in the latter four boreholes for this purpose.

Boreholes EBA1 and EBA2 were drilled to depths of 10.3 m and 15.3 m respectively. EBA1 was selectively located in the insulated section of the runway, while EBA2 was located in the non-insulated section. EBA3 through EBA6 ranged in depths from 5.5 m to 7.4 m. Undisturbed samples were obtained for the first time where soil conditions were suitable using a 75 mm diameter permafrost core barrel. The undisturbed samples obtained allowed the determination of ice content, particle size distribution, Atterberg limits, bulk density and salinity. Disturbed samples were also obtained from the air-circulated cuttings where coarse-grained soil was encountered.

Dataloggers, housed on the south side of the runway, were connected to the ground temperature cables. The first ground temperature data were recorded on April 28, 1994.

GROUND TEMPERATURE CABLES

The ground temperature cables installed were custom manufactured. Each cable was composed of 12 Fenwall thermistors connected to a 20 conductor, 24 gauge cable. The thermistors were enclosed in custom manufactured polyurethane moulding for protection purposes. Amphenol connectors were used to connect the ground temperature cables to the dataloggers.

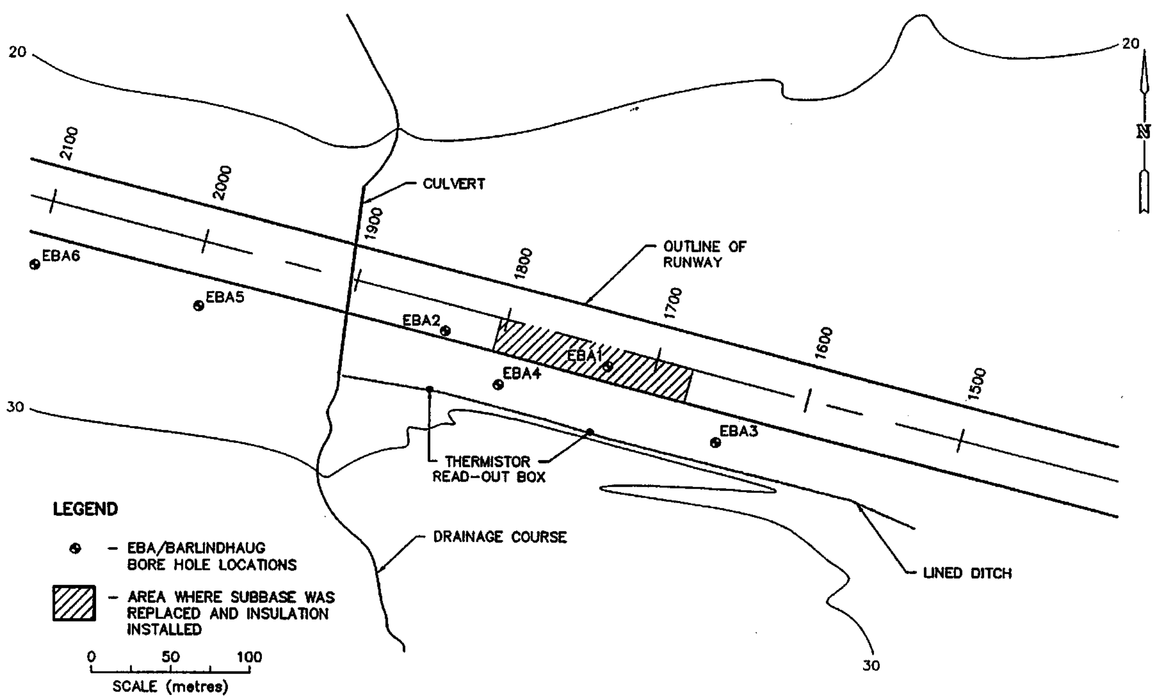

Figure 3. Borehole Location Plan.

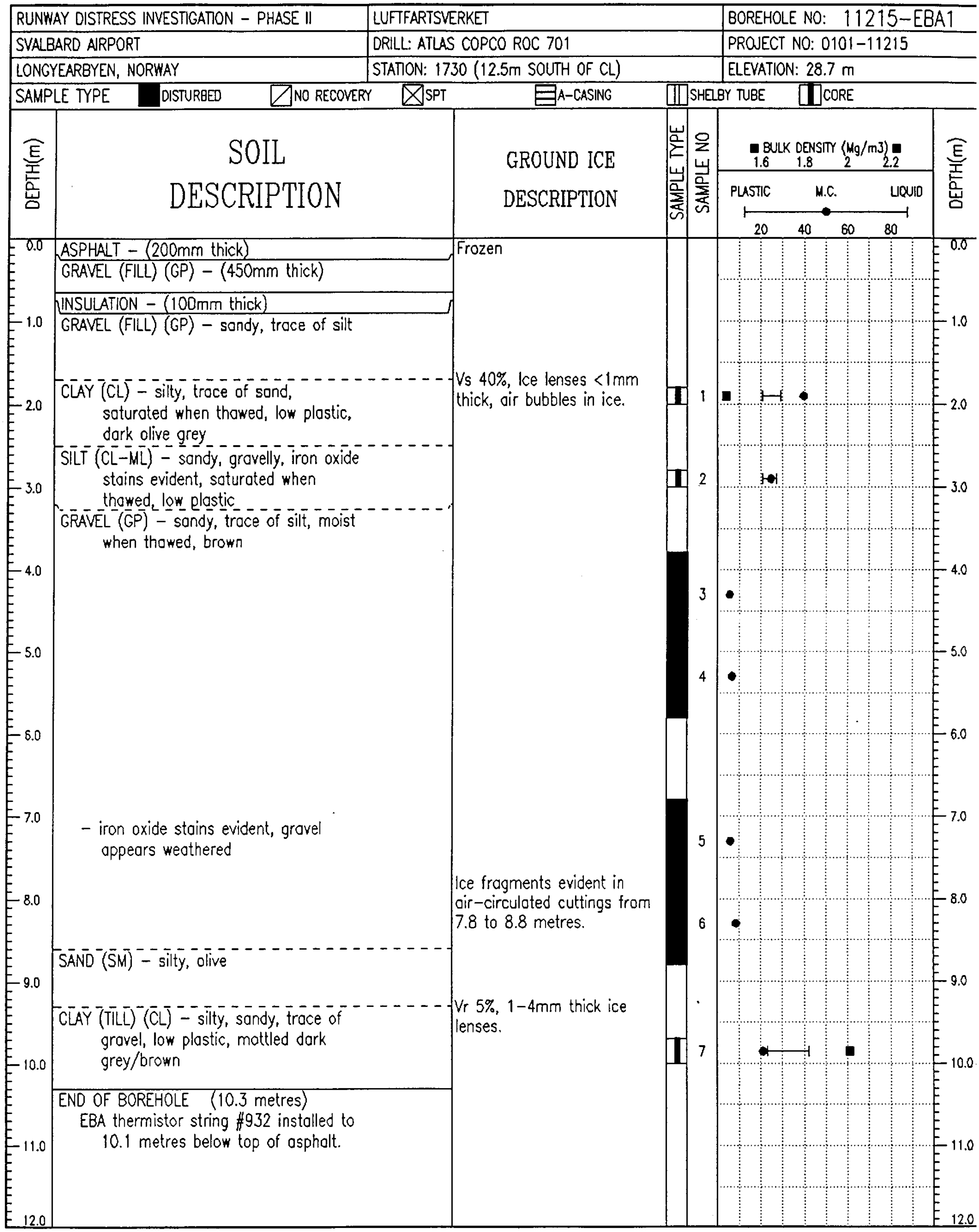

Figure 4. Borehole Log EBA1.

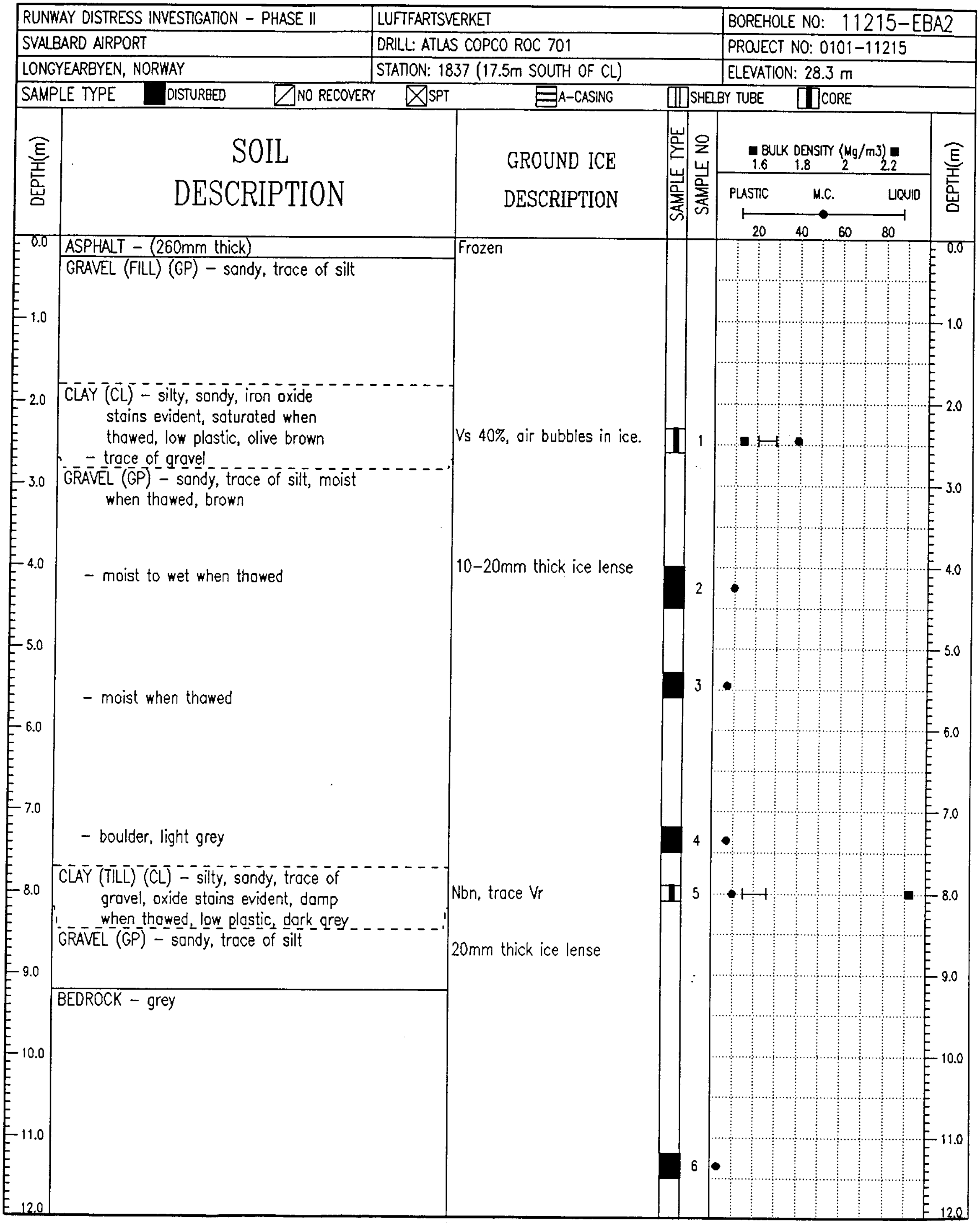

Figure 5. Borehole Log EBA2.

The ground temperature cables were calibrated using an ice-water bath. The temperature of the bath was measured with a thermometer accurate to 0.01°C. Individual correction factors were calculated for each thermistor.

Dataloggers

Lakewood Systems Ltd. manufactured the 16 channel dataloggers used to monitor and record ground temperatures. Optional 5.2 amp. hour lithium batteries were included in the dataloggers to supplement the built-in 1 amp. hour batteries. The Lakewood datalogger has an A/D resolution and an A/D accuracy of 1/8191 (13 bits) and 1/4095 (12 bits) respectively. The storage resolution is 1/16383 (14 bits), and the total impedance is 1 Megaohm. The manufacturer has guaranteed an operating range of -40°C to +75°C, but the datalogger has been successfully tested to lower temperatures in the field.

In the spring of 1995, it was found that the datalogger in the non-insulated area had stopped collecting data. No data was collected from January 31, 1995 to September 26, 1995 as a result of this breakdown. Based on previous experience from North American arctic projects, it was assumed that the malfunction was caused by a static surcharge in the datalogger. This is the result of the blowing snow in the dry arctic climate passing across the datalogger housing. Static electricity build-up was later prevented by the addition of a braided grounding cable connected to a grounding rod.

The boreholes and shallow surface trench in which the cable lead was placed were supposed to be sealed with asphalt under a separate maintenance contract after the ground temperature cables were installed. However, this work was not immediately conducted. Surface water therefore drained down the holes and came in contact with some of the individual thermistors during days of heavy rainfalls, creating temperature spikes of a few degrees in the recorded data. These readings were manually removed from the final data set. The boreholes were sealed for the first time in August 1997.

Soil conditions

The soil condition below the runway surface are known to be highly variable. Borehole logs for EBA1 and EBA2 are shown in Figures 4 and 5.

Both EBA1 and EBA2 were characterized by asphalt that varied from 220 mm to about 350 mm in thickness. This is significantly greater than the initial construction thickness of 60 mm and is a result of the numerous asphalt overlays that have taken place over the years.

A 1.7 m layer of granular fill was observed underneath the paved runway in Borehole EBA1. Extruded polystyrene insulation (100 mm thick) was encountered at 0.65 m below the asphalt surface. The granular fill overlays a 0.7 m layer of ice-rich silty clay, which in turn overlays a 0.7 m layer of silt. The silt is underlain by gravel.

The conditions for Borehole EBA2 were quite similar to that of EBA1. In the case of EBA2, granular material was observed to 1.8 m below the asphalt. The gravel is followed by 0.9 m of ice-rich silty clay, which is underlain by gravel.

Ice lenses typified the clay stratum observed below the gravel fill. Ground ice is present in the form of thin stratified, segregated ice lenses. As much as 40% of the core volume recorded is present as ground ice. The clay is considered silty and of low plasticity (CL).

Results

Temperature Measurements

Ground temperature data have been downloaded every 3 to 5 months since the dataloggers were installed on April 28, 1994. Ground temperature profiles for EBA1 and EBA2, as used in the analysis conducted in 1994, are shown in Figures 6 and 7.

The presence of the insulation in the vicinity of EBA1 results in a quite different temperature profile in comparison to EBA2. The maximum annual thaw front in the insulated area extends to just below the insulation and therefore does not reach the ice-rich silty clay located at 1.8 m depth. The insulation installed is performing well. This is readily apparent when comparing the settlement that has occurred in the insulated and non-insulated areas.

The seasonal thaw front in the non-insulated area extends to 2.5 m, well beyond the surface of the ice-rich soils found at 1.8 m depth. The site investigation and temperature measurements obtained show that runway settlement is due to thawing of the ice-rich soils.

The installation of insulation has prevented thaw settlement. However, the insulation may have drawbacks as it affects the thermal gradient directly below the asphalt. The asphalt surface overlying the insulated sections may incur additional thermal cracking when compared to the non-insulated area. Differential icing of the pavement surface has resulted due to differential heat flow through the pavement structure. However, this is deemed to be a minor problem for the operation of the airport.

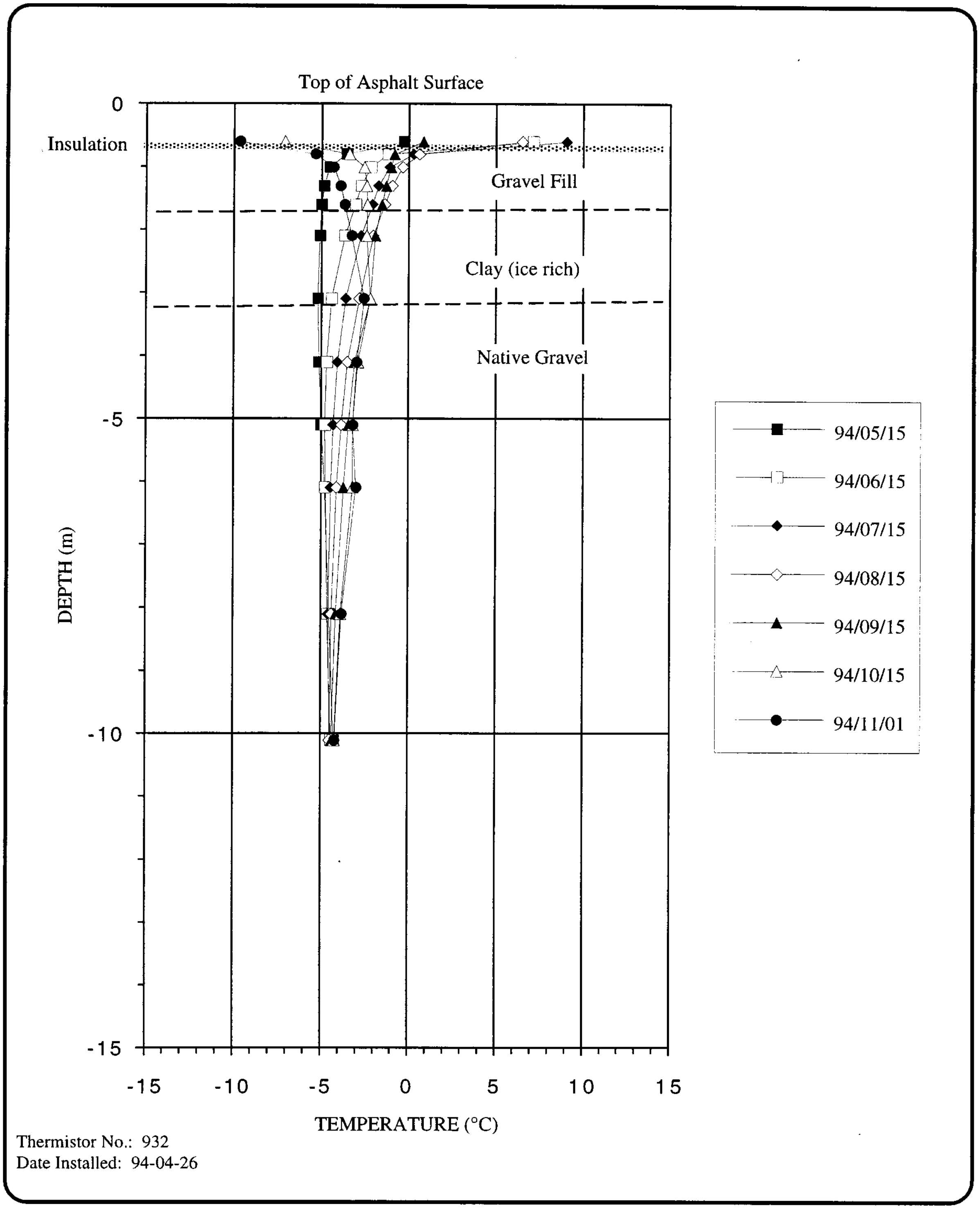

Figure 6. Ground Temperature Profile (EBA1).

THERMAL ANALYSIS

Since it was readily apparent that the surface settlement was caused by thawing of the ice-rich soil, it was necessary to identify the mode of heat transfer. Two possible mechanisms causing thaw were identified:

- Heat conduction from the ground surface.
- Combination of heat conduction and mass heat transfer due to water seeping underneath the runway causing enhanced thaw.

A finite element geothermal program was used to model the thermal regime in the vicinity of Boreholes EBA1 and EBA2. The program models conductive heat transfer, taking phase change into account, in order to determine subsurface thermal gradients. Input parameters include meteorological data used to determine surface temperatures and site specific soil properties determined during the site investigation. The meteorological data used in the analysis is summarized in Table 1.

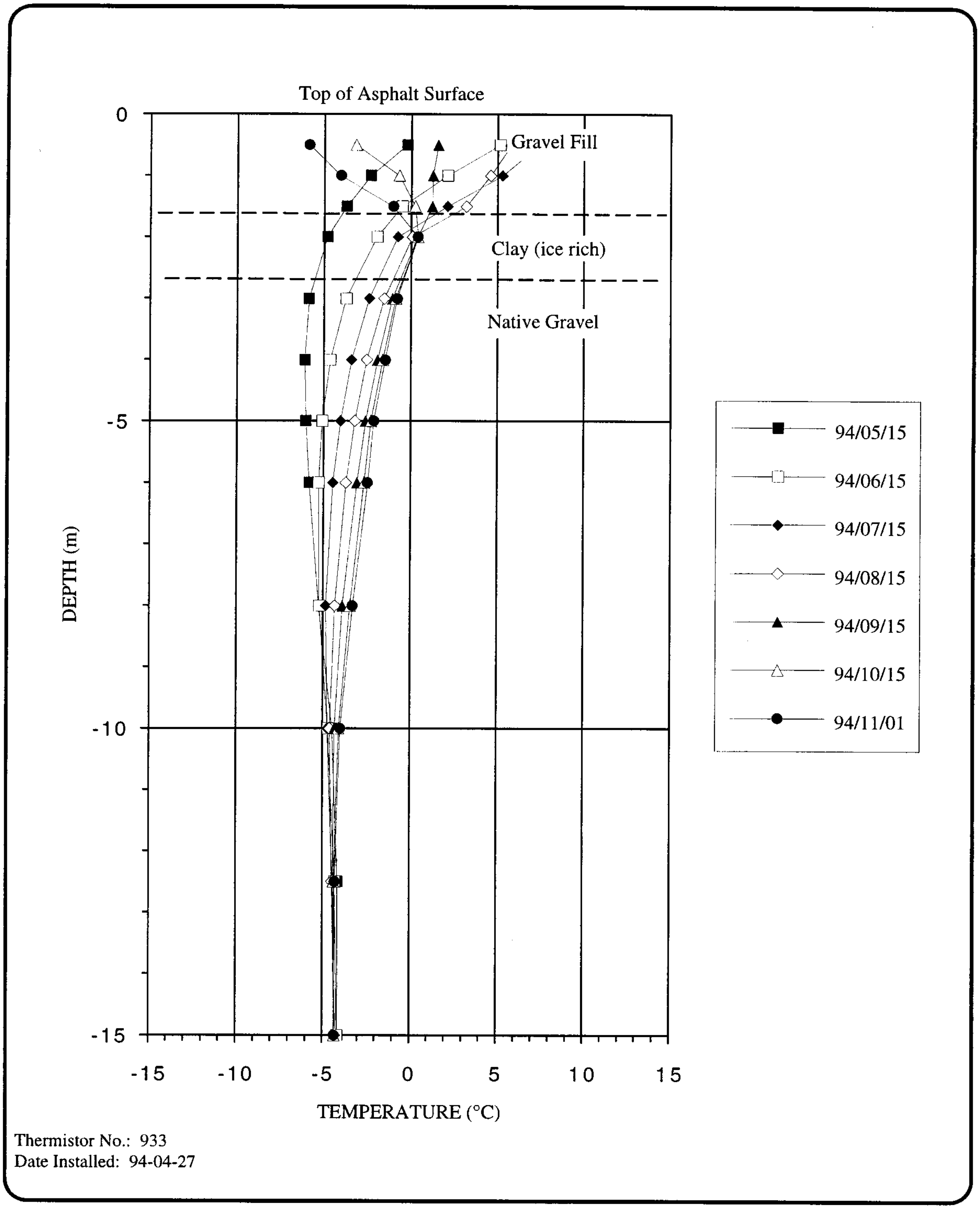

Figure 7. Ground Temperature Profile (EBA2).

The hypothesis for the thermal analysis was that if it is possible to predict temperatures under the runway using solely a conductive model, this would mean that water infiltration is not a significant contribution to the settlement. On the other hand if the observed temperatures under the runway could not be predicted using a conductive model, then the water infiltration would be suspected as a contributor to the settlement.

An initial thermal analysis was conducted using meteorological data from 1961 to 1990 to determine an initial ground temperature profile. Then site specific air temperature data from 1992, 1993 and 1994 were applied. The analyses were then conducted to simulate the conditions determined at the insulated (EBA1) and non-insulated (EBA2) locations. The predicted ground temperature profiles were compared to the ground temperature measurements obtained from one thaw season between May and November, 1994.

Table 1. Metheorological data used in thermal analyses

METEOROLOGICAL DATA USED IN THERMAL ANALYSES

Month	Air Temperature (°C) 1961-90	1992	1993	1994	Wind Speed (km/h)	Daily Solar Radiation (W/m^2)
January	-15.3	-12.7	-17.0	-16.8	20.5	0.0
February	-16.3	-17.7	-16.5	-16.3	18.4	0.9
March	-15.8	-11.3	-16.5	-9.5	16.6	29.0
April	-12.4	-6.6	-14.6	-6.6	15.1	118.0
May	-4.4	-2.6	-3.6	-3.9	14.0	217.9
June	1.8	3.2	2.4	3.1	15.1	225.5
July	5.8	6.0	7.8	5.2	16.9	171.1
August	4.8	4.6	6.5	3.5	15.5	93.4
September	0.4	3.0	-0.1	0.5	15.1	36.4
October	-5.5	-8.2	-8.8	-8.3[1]	18.7	3.9
November	-10.3	-6.8	-2.1	-8.0[1]	21.6	0.0
December	-13.3	-12.2	-11.3	-	21.2	0.0
Mean Annual	-6.7	-5.1	-6.1			

[1] estimated from air temperature data, thermistor strings EBA1 and EBA2

Figures 8 and 9 illustrate that the predicted ground temperatures are within 0.5°C of the measured values. Thaw depths predicted by the model are 0.2 m and 0.4 m less than the measured depths at EBA1 and EBA2, respectively. The lesser predicted thaw depths than those measured can be partially explained by the fact that the finite element program does not model the progressive thaw-settlement and consolidation of the soil which results in a downward movement of the upper soil surface on which the boundary conditions are applied. In addition the resulting change of the thermal properties as the soil consolidates are not taken into account by the thermal model.

The agreement between the predicted and measured ground temperatures indicate to the authors that the conductive heat transfer model was appropriate to explain the observed behaviour, and that water flow beneath the runway did not provide a significant contribution to the thawing process.

Rehabilitation alternatives

The site investigation and subsequent analysis have determined that runway settlements are due to progressive thawing of ice-rich soil. Runway settlements may be eliminated if the thaw front is prevented from reaching the ice-rich soil. The following rehabilitation alternatives have been suggested:

Insulation Alternative

The area in the vicinity of Borehole EBA1 had extruded insulation (100 mm thick) installed at a 0.69 m design depth below the runway. This insulation has prevented further thaw settlement where installed. Extending insulation to other problem areas should therefore eliminate further settlement problems.

Care must be taken at transition zones between non-insulated and insulated areas to reduce differential heat flux through the runway surface. Accordingly, it has been determined that transition zones extending 8.5 m, in which the thickness of the insulation is systematically reduced, will be required for this purpose.

Specifying cold weather asphaltic cement can further prevent thermal cracking. Such cold weather asphalt techniques have been developed as part of the Canadian Strategic Highway Research Program (C-SHRP).

Drawbacks to the insulation alternative include high costs and disruption of air traffic for at least one summer.

Remove and Replace Alternative

An alternative to using insulation to keep the ice-rich permafrost frozen would be to remove it completely down to the underlying frozen gravel stratum. This

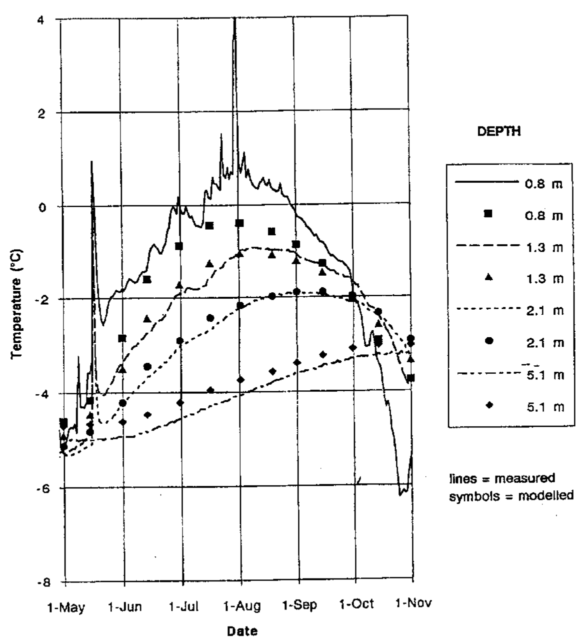

Figure 8. EBA1 Modeled and Measured Temperature Profiles.

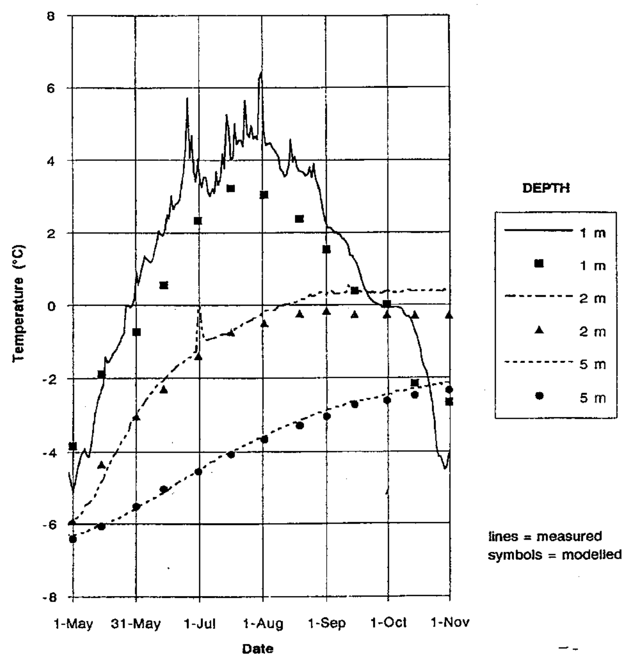

Figure 9. EBA2 Modeled and Measured Temperature Profiles.

alternative is more applicable to the western problem area in which it is anticipated that the ice-rich soil layer will be thinner than in the eastern problem area (based on the original construction drawings and a limited amount of field data).

It is anticipated that the amount of ice-rich soil which would need to be over-excavated will vary along the runway. The ice-rich soil which underlies the previously placed granular fill could be up to 1.4 metres thick in places, resulting in an excavation depth in excess of 3 m. As with the use of insulation, this option will require significant capital outlay and the runway will have to be closed for at least one summer construction season. This option does eliminate the differential icing associated with insulated pavements.

Raised Grade Alternative

Raising the runway grade by the addition of thaw stable gravel is another rehabilitation solution. The addition of thaw stable gravel would add sufficient thermal insulation to prevent the thawing of the problematic ice-rich soils. An estimated 1.5 m of thaw stable material is required.

The raised grade option could also incorporate the insulation alternative. A 50 mm thickness of extruded polystyrene insulation placed directly on the existing pavement will reduce the amount of thaw stable gravel required by 0.5 m.

It is expected that the raised grade alternative would probably require less construction time than the two previous options discussed. A drawback to the raised grade alternative is additional costs associated with the adjustment and replacement of technical airport facilities such as runway lights and navigational aids.

Painting Alternative

Previous attempts to paint the runway white showed that the thaw front was reduced by an average of 0.4 m. However, painting the entire runway white will not solve the problems associated with thaw settlement, but will rather slow the rate of thaw. In other words, this alternative would not solve the problem, but would reduce the problems at hand.

The painting alternative would introduce new maintenance issues to make sure that the runway remains white all the time.

Patch/Overlay Alternative

This final alternative involves continuing what has been done in the past. Thaw settlement would be further monitored, and asphalt patching/overlays would be utilized as required. This alternative does not require any significant investments, and the runway would be taken out of service for short periods of time.

Conclusions

Thaw settlement occurring on the Svalbard Airport has prompted Luftfartsverket to initiate a long-term geotechnical study. The study has determined that the thaw settlement observed on the runway are due to permafrost degradation of a layer of ice-rich soil. Finite element analysis has shown that the ground temperature distribution agrees well with the geothermal model. This indicates that the thaw settlements observed do not relate to mass heat transfer from the flow of water underneath the runway.

Luftfartsverket have chosen the excavate and insulate alternative and construction is expected to begin as early as the summer of 1998.

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References

Tobiasson, W. (1978). Construction on Permafrost at Longyearbyen on Spitsbergen. In *Third International Conference on Permafrost*, Vol. 1, pp. 885 - 890.