DEVELOPMENT OF AN AUTOMATED ROAD SUBSURFACE FROST PROBE NETWORK FOR QUÉBEC

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ABSTRACT

All road administrations that are responsible for management of a road network are confronted with the same challenge – to assure users of a safe and reliable network.

To preserve the road network in good condition, the Ministère des Transports du Québec (MTQ) limits truck loads during spring thaw, for a period varying according to the harshness of the previous winter. To determine the extent of this period, the frost depth is the decision parameter.

In the past, the MTQ has deployed glycol frost probes in the pavement at multiple locations on the road network. Regular reading of these probes allows mapping of frost depth in Québec. However, this task represents a risk and necessitates a lot of resources.

With the goal of completely eliminating manual readings, the MTQ has deployed an automatic road data collection system (SCDR, or système automatique de collecte de données routières) for instrumentation of the Québec road network with electronic thermal profile sensors.

The comparative analysis of data for replacement of manual readings with automatic measurements proved conclusive.

This article also describes the developments that allowed manufacturing of the new electronic frost probe (sensor).

1. ISSUES

Increased water content in pavement foundations weakens them and renders them vulnerable to heavy traffic during thaws.

2. SOLUTION

The chosen solution is to limit heavy vehicle loads. To mitigate the impacts on road transportation, the permitted load for heavy equipment is reduced temporarily during spring thaw for a variable period, which must be determined a few weeks in advance[1].

3. DETERMINATION OF THE DURATION OF LOAD RESTRICTIONS

The harsh weather conditions of Québec winters require the imposition of load limits on road carriers during thaws to preserve pavement integrity. To determine the heavy vehicle load restriction period during thaws, the MTQ is installing tube-shaped frost probes in the pavement at multiple locations on the road network. These probes indicate the frost depth under the pavement. Frequent readings of these probes allow tracking of changes in frost depth and, especially, the thaw cycles, which then allows the MTQ to determine the load restriction start and end dates[2].

Figure 1 – *Thaw zones*

4. MANUAL METHOD

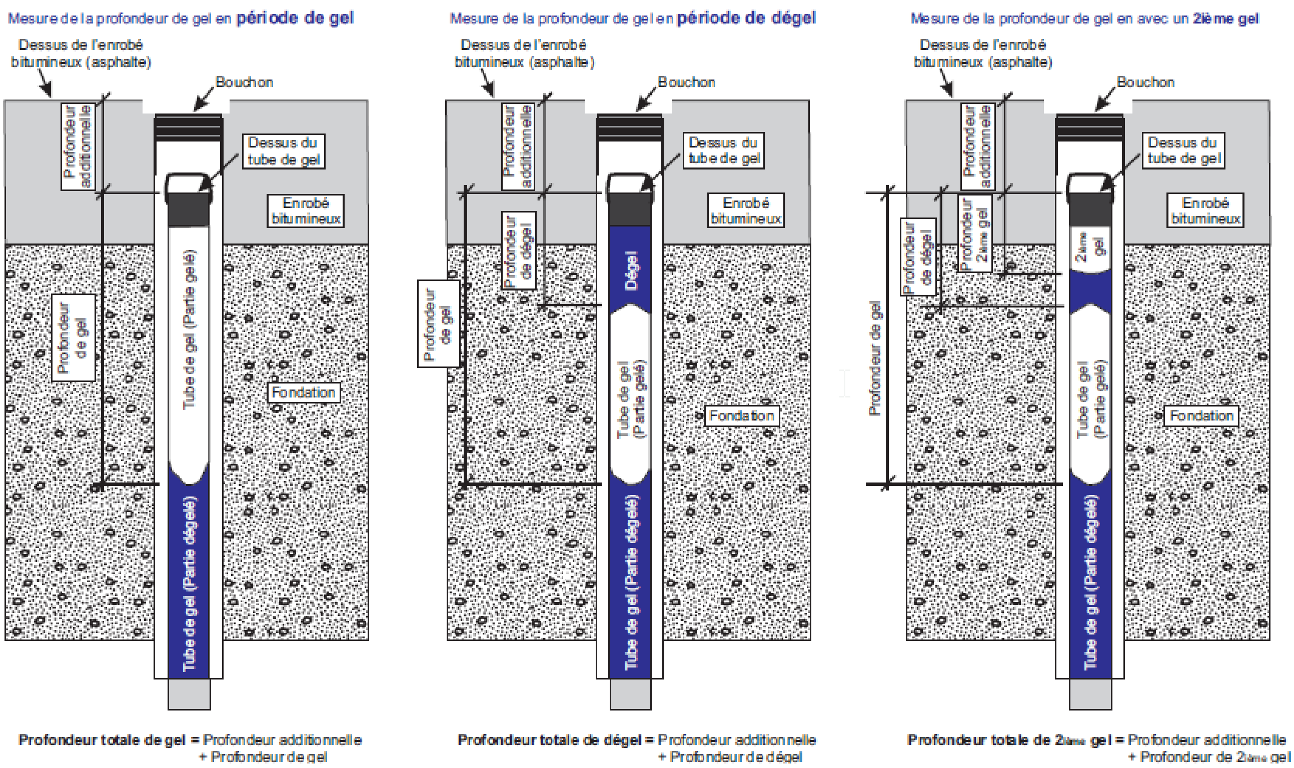
In the past, the MTQ deployed a network of 90 glycol frost probes, which require manual reading about once a week in the spring. This type of installation necessitates temporary road closing, installation of signs and use of vehicles with impact attenuators to protect the workers. The glycol frost probes will no longer be used by 2015, due to the new automated frost depth measuring method.

The glycol frost probe measuring method is presented below (see table for translation). Blue glycol indicates a thawed zone and white glycol indicates a frozen zone.

Reading frost and thaw depths

Frost depth measurement during frost			Frost depth measurement during thaw			Frost depth measurement with 2nd frost		
Top of hot-mix asphalt Additional depth Frost depth	Plug Top of frost probe Frost probe (frozen part) Frost probe (thawed part)	Hot-mix asphalt Foundation (subsurface)	Top of hot-mix asphalt Additional depth Thaw depth Frost depth	Plug Top of frost probe Thaw Frost probe (frozen part) Frost probe (thawed part)	Hot-mix asphalt Foundation (subsurface)	Top of hot-mix asphalt Additional depth 2nd frost depth Thaw depth Frost depth	Plug Top of frost probe 2nd frost Frost probe (frozen part) Frost probe (thawed part)	Hot-mix asphalt Foundation (subsurface)
Total frost depth = Additional depth + Frost depth			**Total frost depth** = Additional depth + Frost depth			**Total frost depth** = Additional depth + 2nd frost depth		

Relevé des profondeurs de gel et de dégel



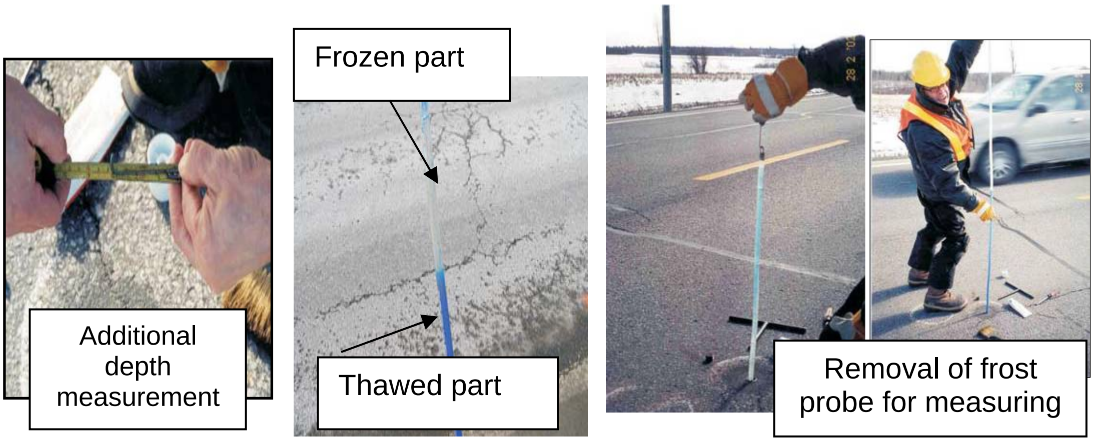


Figure 2 – *Glycol frost probe manual measuring method*

Method change objectives

- Workers' safety
- Data reliability
- Productivity
- Increased sampling rate
- Cost

The manual reading operations for the glycol frost probes proved dangerous and costly. They represented about $225,000 per year and required a lot of time, the equivalent of nearly 9 full-time jobs to take the readings and maintain the equipment.

5. AUTOMATED METHOD – NEW APPROACH

The new electronic frost probes with automatic reading provide data every 10 minutes all year round, without the necessity of human intervention. Each probe is linked to a road weather station and the data is transmitted to the MTQ's offices in real time by means of an automatic road data collection system, known as SCDR. Figure 3 shows a frost probe with automated reading.

The validity of the automated frost depth measuring method was evaluated over a period of several years by comparing the data obtained by the glycol frost probes (the manual system) with the data obtained by the automated frost probes. The results of the comparisons confirmed the relevance and reliability of the data obtained with the automated frost probes and made it possible to consider eliminating the use of glycol frost probes.

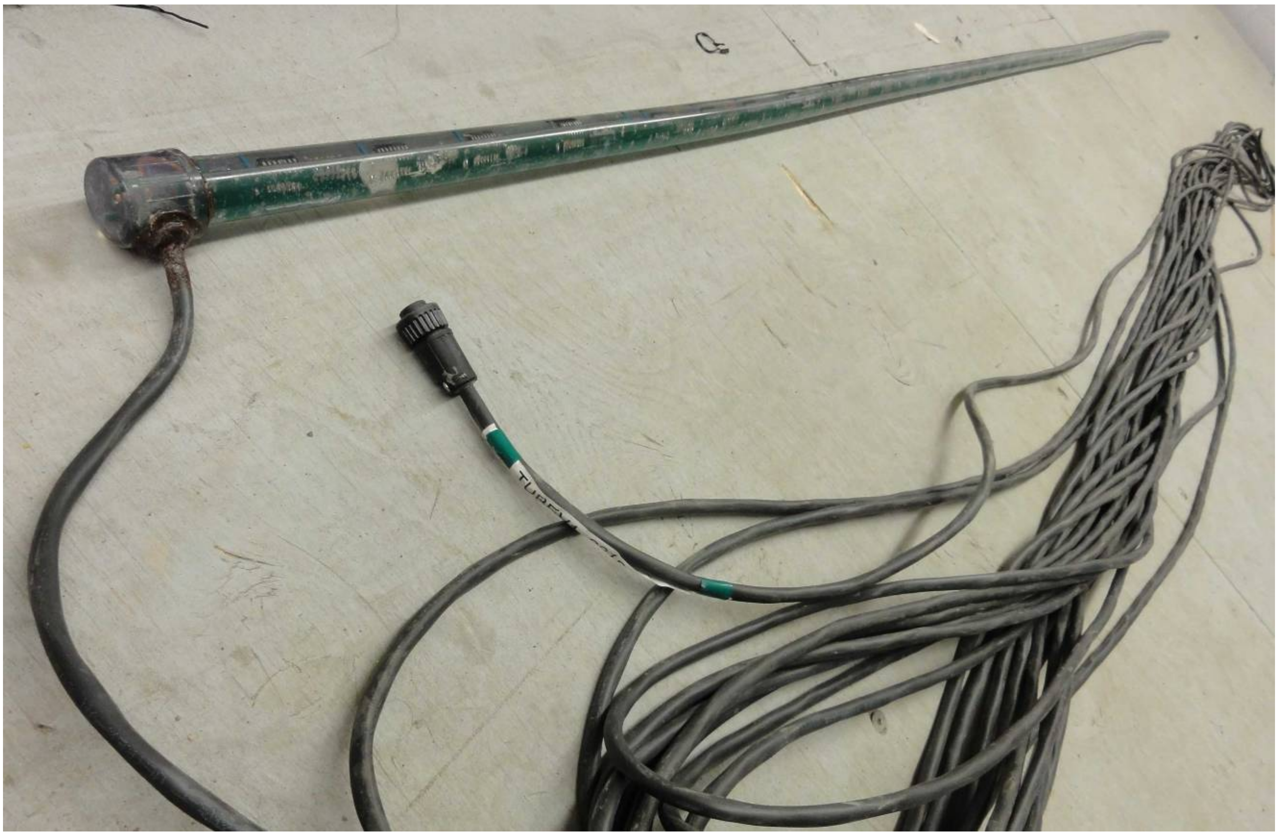


Figure 3 – *Frost probe with automated reading*

6. ROAD DATA COLLECTION SYSTEM (SCDR)

6.1 Network of road weather stations

For automated measuring of the frost depth on the MTQ road network, automated frost probes were added to all 36 MTQ road weather stations. A second construction phase allowed the addition of 13 stations equipped with automated frost probes to complete the provincial network, bringing the number of stations to 49. The latitudes associated with the stations extend between 45.0º and 50.6º North latitude. Figure 4 shows the location of the road weather stations on the MTQ network.

Figure 4 – *Location of the MTQ's 49 road weather stations*

6.2 Automatic road data collection system (SCDR)

The road data collection system is a real-time computerized data acquisition system, which collects a variety of operational data concerning the provincial road network. The measurements coming from the road weather stations are collected via telecommunications links connecting the central computer servers to the field station sites. All the data collected is stored and archived in a central database. In particular, it includes pavement structure temperature data collected by the frost probes.

The SCDR data is provided to the system's many users and to the MTQ's different partners, such as Environment Canada (Weather Service). The teams assigned to winter maintenance, snow removal and deicing also have access to the system's data to facilitate and optimize their operations.

7. COMPONENTS OF THE ROAD WEATHER STATIONS

The road weather stations are located on the roadside throughout the territory served by the MTQ. They are equipped with a variety of sensors for atmospheric and road weather variables.

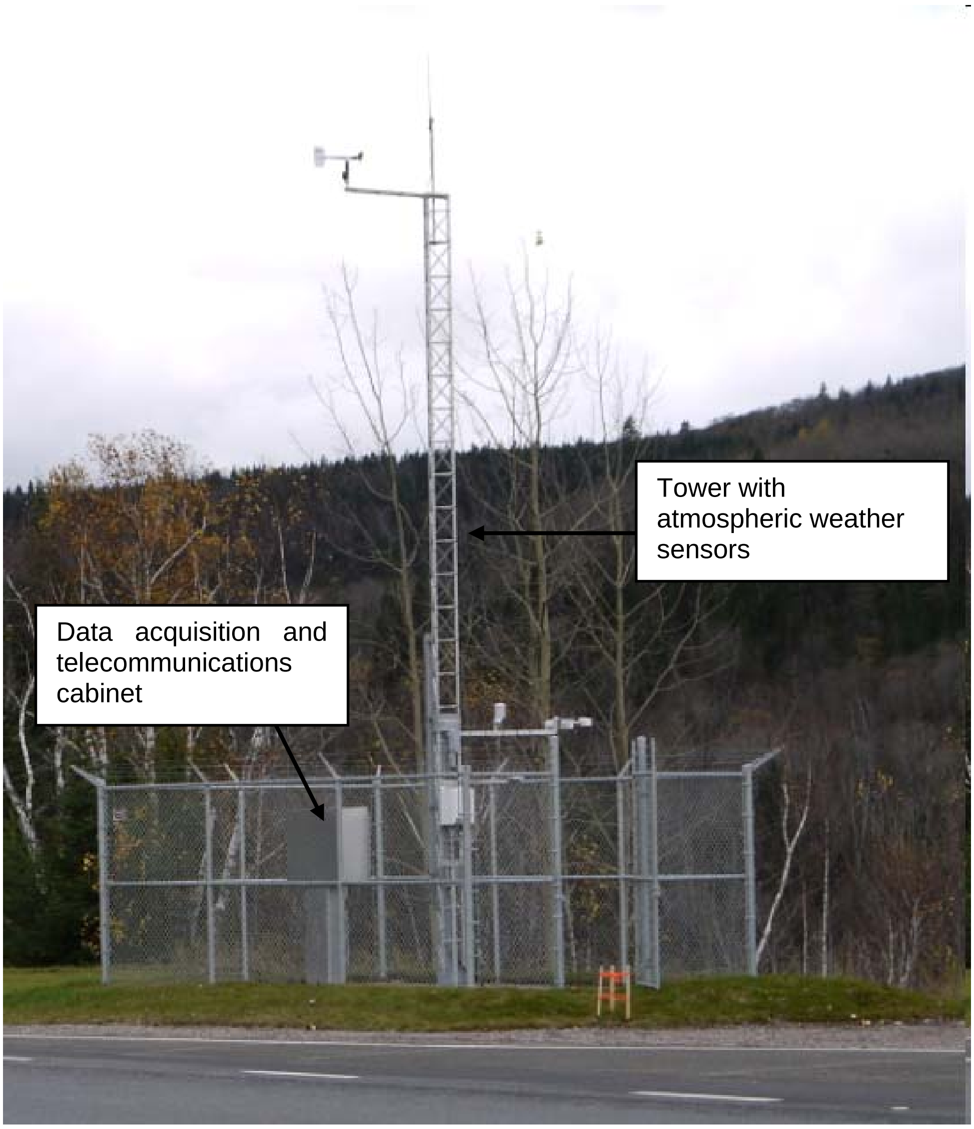


Figure 5 – *Typical MTQ road weather station*

7.1 Sensors

7.1.1 Atmospheric sensors

- Anemometer (wind speed and direction)
- Ambient air temperature sensor
- Relative humidity sensor
- Barometric pressure sensor
- Visibility distance and precipitation type sensor
- Infrared radiation sensor

7.1.2 Pavement sensors

- Surface temperature sensor
- Automated frost probe (thermal profile sensor for subsurface temperature)
- Smart surface condition sensor (pavement condition, brine freezing point)
- Infrared radiation sensor

7.1.3 Cameras

- View of the weather conditions on the road and pavement (certain stations)

The data from the different sensors is read and stored by a data acquisition unit located on the station site and connected to the road data collection system (SCDR) by telecommunications links, as indicated. In this manner, data is transmitted every 10 minutes for consultation and archiving by means of the SCDR system.

8. FROST PROBES WITH AUTOMATED READING

8.1 Working principle

The pavement structure temperature is determined by an electronic component called a “thermistor”.

- The thermistor’s electrical resistance varies very precisely according to the temperature variation.
- The thermistors are placed in series at precise distances along the entire length of the tube. They are read sequentially by the frost probe’s printed circuits and establish the pavement structure temperature at different depths. There are 18 thermistors in a 3 m probe.

Thanks to these probes, the soil temperature under the pavement is measured at 18 points at depths ranging from 5 cm to 300 cm. The thermistors used in the new frost probes are shown below.

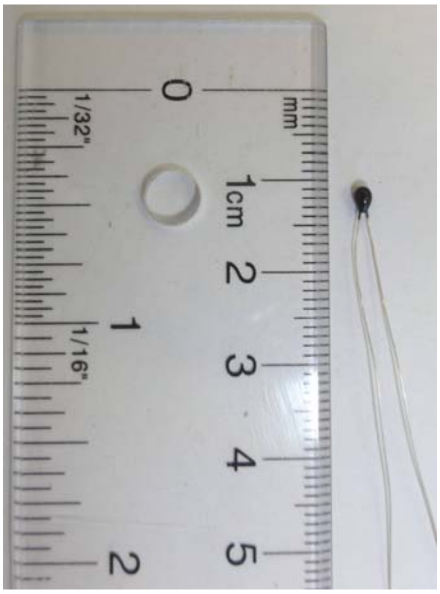


Figure 6 - *Thermistor*

8.2 Installation

Figure 7 - *Installation of the frost probe in the pavement*

A hole a little over 3 m deep (at the centre of the left-hand image) is made by a truck equipped with a hole borer. The frost probe is placed precisely 1 cm under the surface and 40 cm from the centre of the lane. The signal cable, usually 60 m long, is passed through a groove cut in the asphalt and connected to the roadside weather station via underground conduits. The groove and the openings are filled with an epoxy sealant.

8.3 Maintenance and replacement

The automated frost probes do not necessitate any special maintenance and it is not possible or necessary to remove them once they are installed in the pavement. When a new pavement course is applied, a new frost probe is installed to preserve the temperature measurements at the right depths relative to the pavement surface.

8.4 Sensor design and manufacturing

Four-layer printed circuits with electronic components were designed to allow sequential reading of 18 thermistors by the weather station data acquisition unit. Each frost probe contains 10 interconnected 30-cm printed circuits.

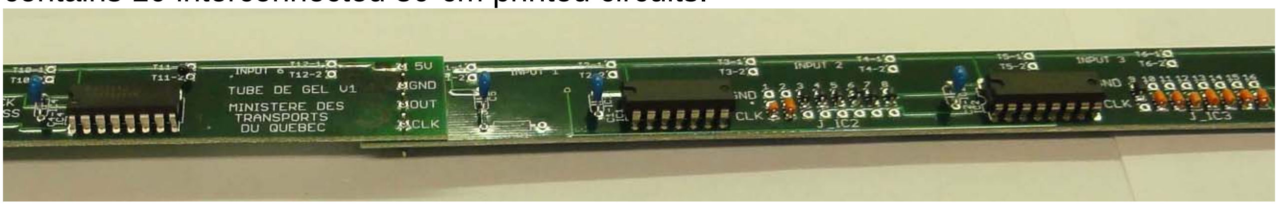


Figure 8 - *Example of printed circuits*

The electronics are placed in a PVC tube, which is then filled with epoxy. The electronics thus are protected against blows and short-circuits caused by water infiltration.

Several criteria were used to select the epoxy:

- pot life greater than 20 minutes;
- low viscosity;
- absence of shrinkage during hardening;
- amber colour or colourless;

- low polymerization temperature (exothermic reaction).

Complete sealing of the probe’s tube was very difficult to obtain and required repeated trial and error attempts.

When the two epoxy components are mixed, the chemical reaction releases a lot of heat. Construction of a support proved necessary, because the PVC tubes were subjected to deformation.

Figure 9 – *Frost probe manufacturing support*

8.5 Measurement precision

Several tests made it possible to determine that the precision of the temperature measurement provided by the frost probe is ± 0.1°C. This precision is sufficient to determine the load restriction periods during a thaw.

During manufacturing, tests are performed to ensure that all the probes installed in the territory are functional and precise.

9. CONCLUSION

The automated road subsurface frost probe network deployed by the MTQ will allow complete elimination of the manual readings of the former network of 90 glycol frost probes. This will protect the road network during the freeze-thaw cycle by facilitating the choice of load restriction periods for heavy vehicles. It was possible to add frost depth data collection to the road weather station infrastructures. The information is available virtually in real time (10-minute delay). This “intelligent transportation” system has achieved the objectives of improving workers’ safety, data reliability and productivity, while reducing recurring costs.

REFERENCES

1. Road Vehicle Load and Size Limits Guide, Gouvernement du Québec, Ministère des Transports du Québec, May 2013.
2. Seasonal Load Restriction in Canada and Around the World. Canadian, Strategic Highway Research Program, Ottawa, Ontario, Canada, Sept. 2000.