

A Case Study on the Performance of High Load Polystyrene as Roadway Insulation in Edmonton, Alberta, Canada

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ABSTRACT

In 2008, The City of Edmonton reconstructed a portion of St. Albert Trail, a major arterial roadway in northwest Edmonton. The roadway passes under an existing Canadian National Railway trestle, where it encounters frost susceptible soils. Since there was the possibility that frost heaving could adversely affect the clearance height beneath the trestle, the reconstruction of the roadway incorporated high load extruded polystyrene insulation to prevent frost penetration and heaving of the roadway. The polystyrene insulation was placed below the pavement in thicknesses ranging from 50mm to 100mm. During construction, the City took the opportunity to instrument the roadway with several thermistor strings, placed both above and below the various thicknesses of insulation, as well at various depths in the native soil. The thermistor data was used to calibrate a finite element model developed in GeoStudio's Temp/W. The resulting temperature model of the local soils and climatic conditions was used to predict frost penetration through the various thicknesses of insulation and the City's standard roadway structures. This information will be used on future roadway projects, to optimize the thicknesses of insulation used on other roadways in the Edmonton area. This case study documents two and a half years of temperature profile monitoring, the development of the temperature model and some initial results.

INTRODUCTION

Polystyrene has been used as roadway insulation in cold regions for decades, to attenuate frost penetration under roadways and to allow for a reduced pavement structure (Penner, [3]). It is also increasingly being used in the far north to protect infrastructure from permafrost degradation due to climate change (Beaulac & Dore, [1]). Although polystyrene is a relatively costly material, only thin amounts are often needed to provide adequate frost protection. This often makes it a more cost effective option than many other alternatives (Gandhal, [2]).

This case study investigates the performance of a section of roadway where polystyrene insulation was installed during the reconstruction of St. Albert Trail, where it passes under an existing Canadian National Railway (CNR) trestle in northeast Edmonton, Alberta. The concern was that since the roadway would be constructed on soils identified as being frost susceptible, frost heaving could seasonally affect the clearance height beneath the trestle. This concern prompted the use of insulation as a mitigation measure.

Portions of St. Albert Trail were reconstructed with polystyrene insulation, ranging from 50mm, to 75mm and then 100mm in thicknesses. In addition, a section with the standard uninsulated roadway cross section was monitored for comparison purposes. Styrofoam High Load Extruded Polystyrene Insulation manufactured by The Dow Chemical Company was the insulation used. A series of thermistor strings connected to data loggers were then installed beneath all four roadway sections. The placement of the field instrumentation took place in September and October of 2008.

This report documents the field program and gives preliminary results of the performance of the selected polystyrene insulation material based on field observations over a span of two and a half years. Thermal models were also developed using GeoStudio's Temp/W and compared to the actual temperature data collected from the thermistors.

PRELIMINARY FIELD INVESTIGATION

The test site area selected for this study consisted of approximately 137 metres of St. Albert Trail, north of 126 Avenue. The location of this site is shown in Figure 1. Two preliminary geotechnical investigations were performed by AMEC Earth and Environmental in June and July of 2008. During the first investigation, in June of 2008, test pits were dug to a depth of approximately 1.0 metre. In these test pits, medium to high plastic lacustrine clay over low plastic silty clay to clayey silt was encountered. The low plastic silty clay/clayey silt extended to the termination depth of the test pits. In July 2008, an additional three test pits were completed further north down the road. These test pits were advanced to a depth of 1.5 metres. In all three of these test pits, low to medium plastic clay till was encountered near the surface to the completion depth. The lacustrine clay and the glacial clay tills encountered in this area are considered to have moderate frost susceptibility.



Figure 1. Project Site Location: St. Albert Trail and 126 Avenue, Edmonton

INSULATION AND ROAD STRUCTURE

Styrofoam Highload 40 Extruded Polystyrene insulation was selected for this project. It has a nominal R-value of $0.88 \text{ m}^2 \bullet^\circ\text{C/W}$ and the list of the insulation's other thermal properties is summarized in Table 1.

Property & Test Method	STYROFOAM™ Highload 40 - Value
Thermal Resistance per 25mm ASTM C518, C177 @ 25°C ($\text{m}^2 \bullet^\circ\text{C/W}$)	0.88
Maximum Use Temperature (°C)	74
Coefficient of Linear Expansion, ASTM D696 ($\text{mm/m} \bullet^\circ\text{C}$)	6.3×10^{-2}

Table 1. Thermal Properties of STYROFOAM™ Highload 40 Insulation

Various thicknesses of Styrofoam were installed along a section of St. Albert Trail, where it passes beneath a CNR trestle. The thickest cross section of insulation was 100mm. It was installed in one long run of approximately 50 metres in length, centered beneath the CNR trestle. The insulation thickness was then stepped down to 75mm and then 50mm, installed in approximately 20 metre runs both northwards and southwards from the 100mm section. A plan of the insulation layout is shown below in Figure 2.

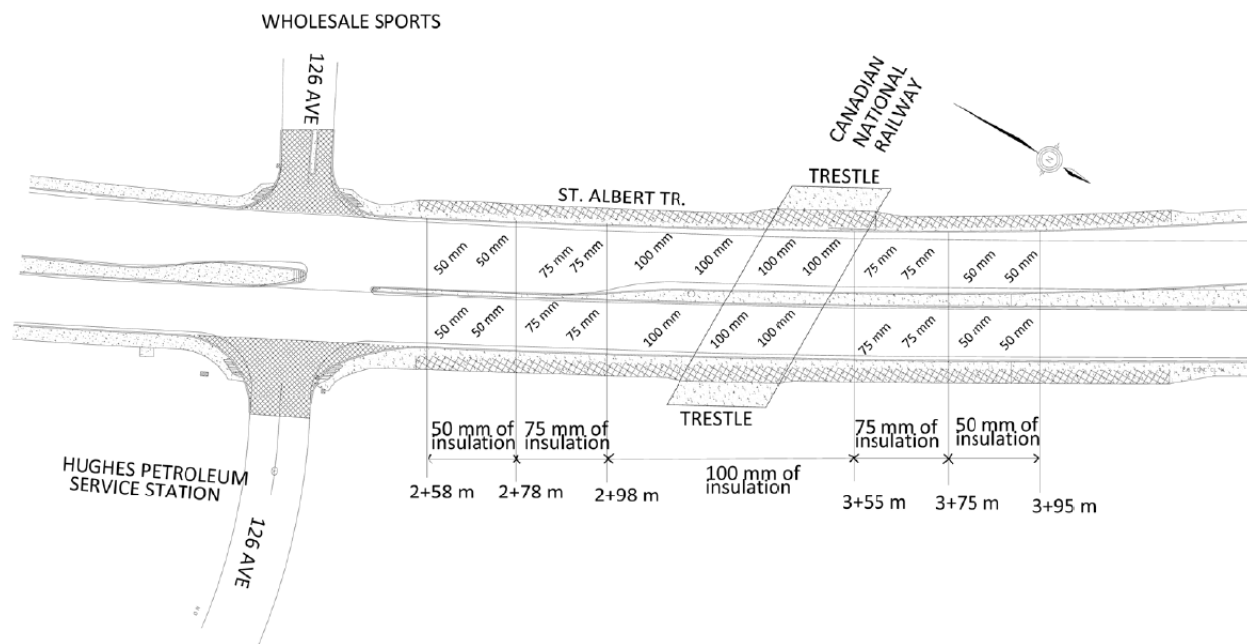


Figure 2. Insulation Layout

THERMISTOR INSTALLATION AND LOCATIONS

The thermistors were installed in the northbound lanes of St. Albert Trail, north from the intersection at 126 Avenue to the railway trestle. A total of eight thermistor strings were installed; two beneath each roadway cross section. The duplication of thermistor strings was for redundancy purposes in the event that a primary string was ever damaged. Since we had two additional data loggers available at this time, six of the eight thermistor strings were actually monitored, but thermistor strings KW2 & KW4 were not monitored. The thickness of insulation, the locations of each of the thermistor strings and the location of a crack corresponding to the edge of the insulation is shown in Figure 3.

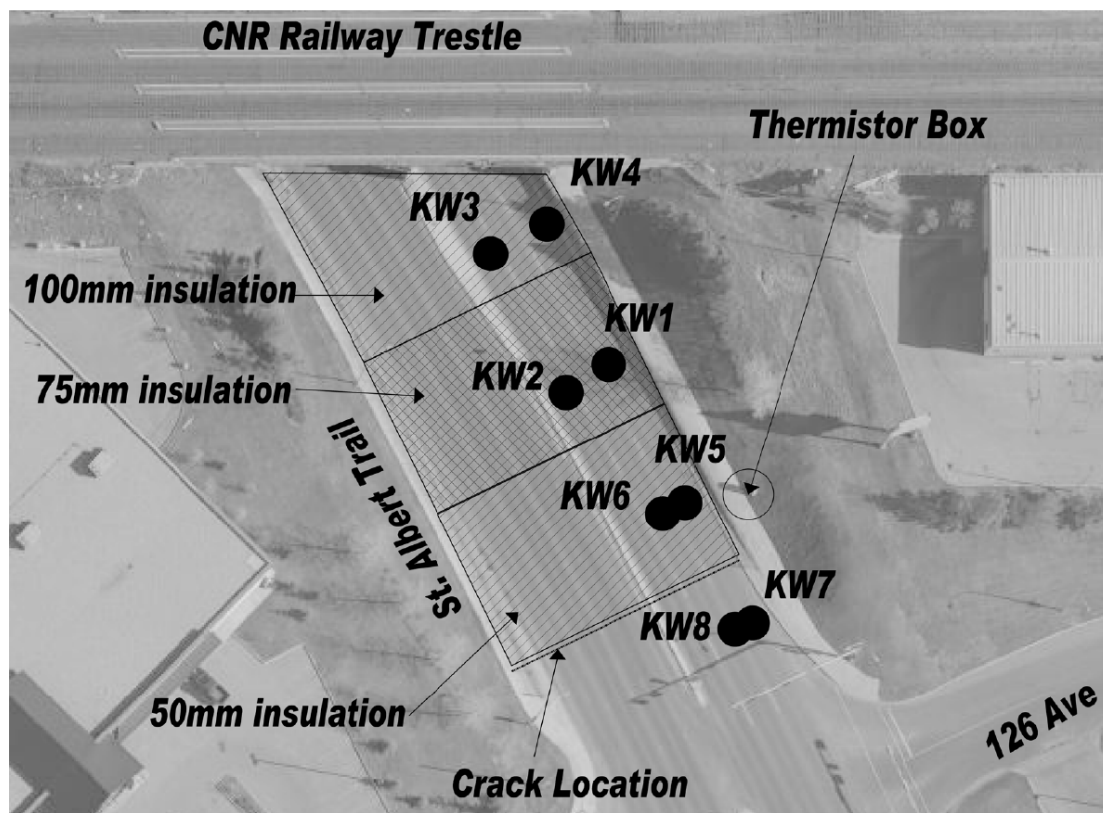


Figure 3. Thermistor, Insulation and Frost Heave Crack Locations

The thermistors were installed prior to the completion of roadway construction. First, a horizontal PVC pipe was placed and the thermistor strings were strung through the pipe to their present locations. The PVC pipe for the installation of the thermistor strings was placed within the course gravel portion of the drainage blanket layer, just above the lower geotextile layer. The PVC pipe was approximately 900mm to 1000mm below the ground surface. At the required thermistor locations, the granular base and bedding sand was hand excavated and the insulation and geotextile cut out to locate the PVC pipe with the thermistors. Hand-augered holes were then hand drilled and the thermistor strings were placed vertically into the holes and backfilled with the hole cuttings. The

backfilled holes were hand tamped using a long rod to ensure the soil around the thermistor beads was compacted and no voids existed. Figure 4 shows a typical cross section of the roadway that was constructed.

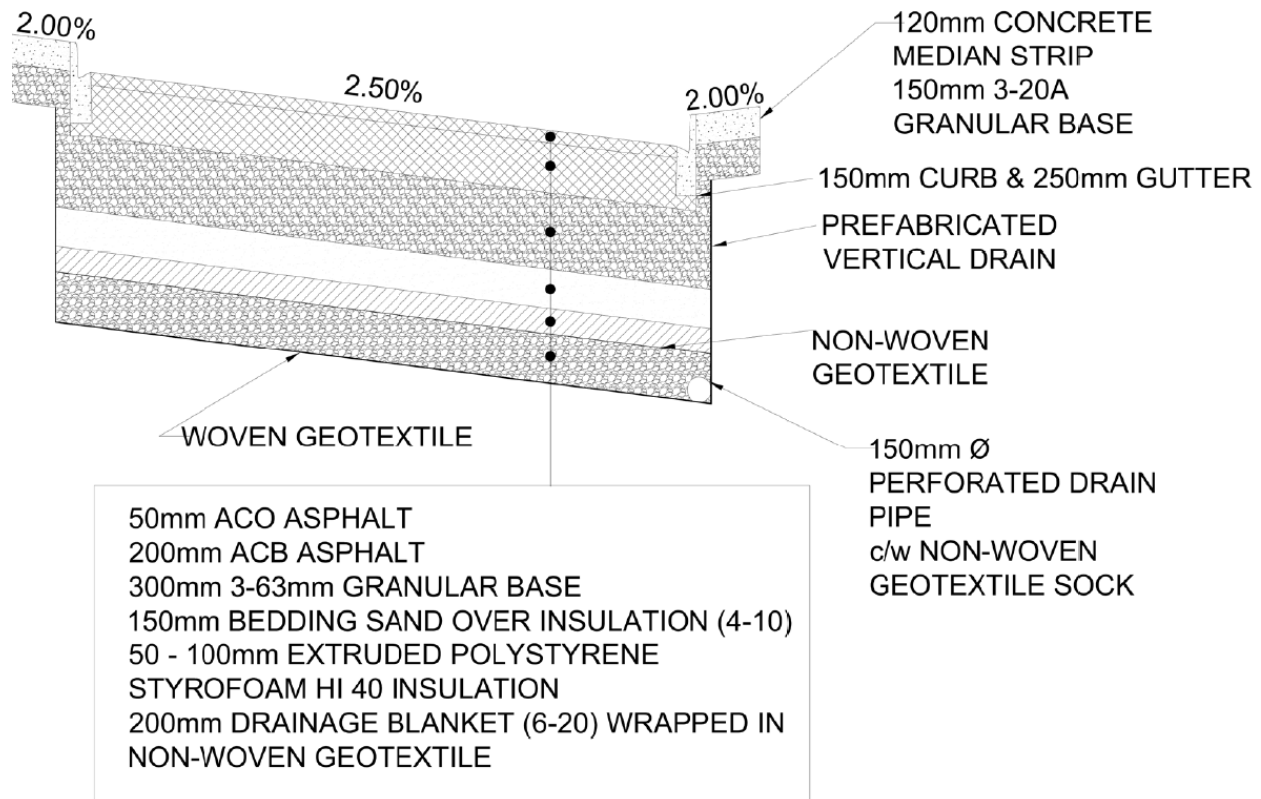


Figure 4. Typical Roadway Cross Section (Northbound Lane)

After the placement of the thermistors, the run out portion of each thermistor string was pulled out and the cut out portion of insulation was replaced with one thermistor bead placed on top of the insulation. The PVC pipe and the run out portion of the thermistor strings were then buried with medium grained bedding sand to provide protection for the thermistor strings during and after the completion of construction and to maintain homogeneity within the pavement structure. Typical photos of the installation are shown in Figures 5 & 6.



Figure 5. Thermistor Installation



Figure 6. Fly out Thermistor Bead

All the thermistor strings were led to an equipment cabinet, supplied and placed by EPCOR, which was located on the east side of the road near thermistors KW6 and KW7. The thermistor strings were then connected to RX16MLT 16 channel thermistor string data loggers supplied by Lakewood Systems Ltd. of Edmonton, Alberta and placed in the EPCOR cabinet. The data loggers and thermistors were calibrated and programmed to take temperature readings every six hours; at 0:00h (midnight), 06:00h, 12:00h and 18:00h.

Each thermistor string had a total of 13 active sensor beads spaced at 100mm to 200mm apart from one another. The top bead on each thermistor string was located 0.7m below the pavement surface. The deepest thermistor beads were located at depths ranging between 1.85m and 2.7m below the final pavement surface.

AMBIENT TEMPERATURE RESULTS

The past two winters had quite drastic temperature swings from week to week and even day to day. A record low temperature of -31.7°C was set on March 10, 2009; -12°C lower than the previous record. There was also a prolonged cold streak from mid December to mid January 2009, where temperatures were generally between -20°C and -30°C . The Degree days below 0°C for 2009 and 2010 were measured to be 1167.7 and 1070.2 respectively. The long term average measured by Environment Canada at the Edmonton City Centre Airport, between 1971 and 2000, is 1229.2 Degree Days below 0°C . While this shows that the air temperatures for the two years measured were both slightly warmer than the historical average, they were still both fairly representative of a typical winter in the region.

Ambient air temperatures were originally being measured inside the EPCOR cabinet housing the data loggers, but warming of the interior of the cabinet by solar radiation resulted in temperatures higher than the true ambient temperatures. Therefore in 2010, an exterior solar shielded thermistor lead was installed to eliminate this problem.

Year(s)	Degree days below 0 °C	Data Source	Solar Shield?
2008/2009	1167.7	City of Edmonton	No
2009/2010	1070.2	City of Edmonton	Yes
1971 to 2000 (Average)	1229.2	Environment Canada	N/A

Table 2. Degree Days Below 0°C

SUBSURFACE TEMPERATURE RESULTS

Within the project area where no insulation was present, frost penetrated to a depth of approximately 1.6m below the pavement surface during the winter of 2008/2009 and approximately 1.5m below the pavement surface during the winter of 2009/2010. Figures 4 through 7 show a condensed data set collected from the thermistor strings with 0mm, 50mm, 75mm and 100mm of insulation. The dark line at a depth of 0.7m shows the temperature just above the insulation while the other three lines show the temperature data directly below the insulation and at two deeper depths.

The recorded temperature data showed that 100mm and even 75mm of insulation was more than adequate to prevent frost penetration into the subgrade soils. In the section where 50mm of insulation was installed, frost just penetrated through the insulation. The coldest temperature recorded immediately below the 50mm of insulation in thermistor KW5 was -1.5°C, but the frost penetrated less than 10cm below the 50mm of insulation.

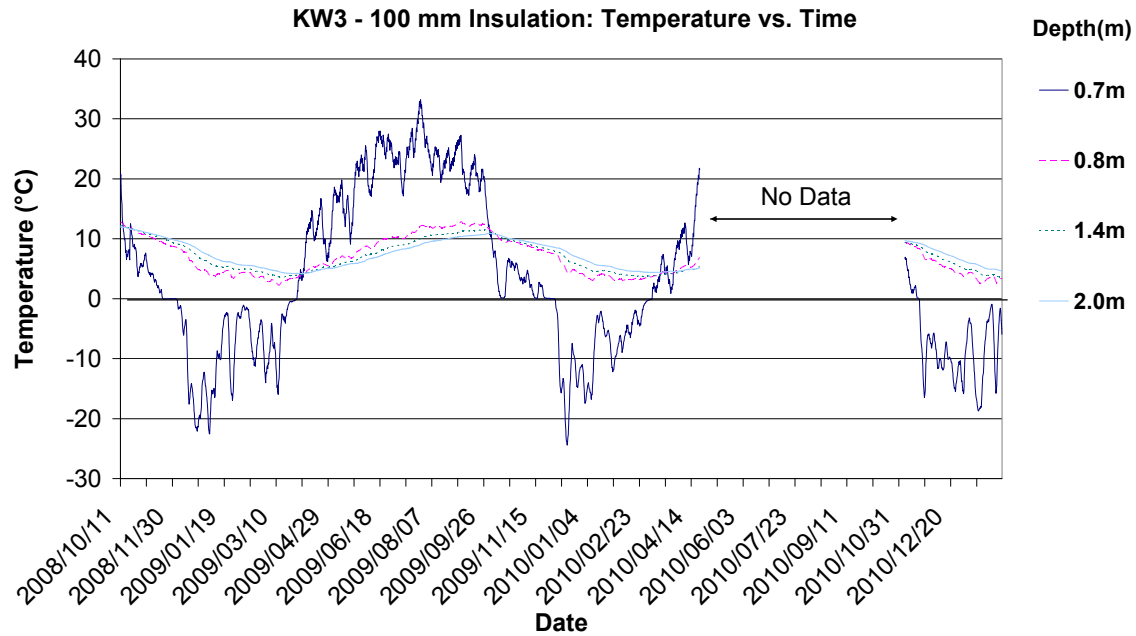


Figure 7. 100 mm Insulation: Temperature vs. Time

No temperature data was recorded during the summer of 2010 as the data logger was removed for scheduled maintenance.

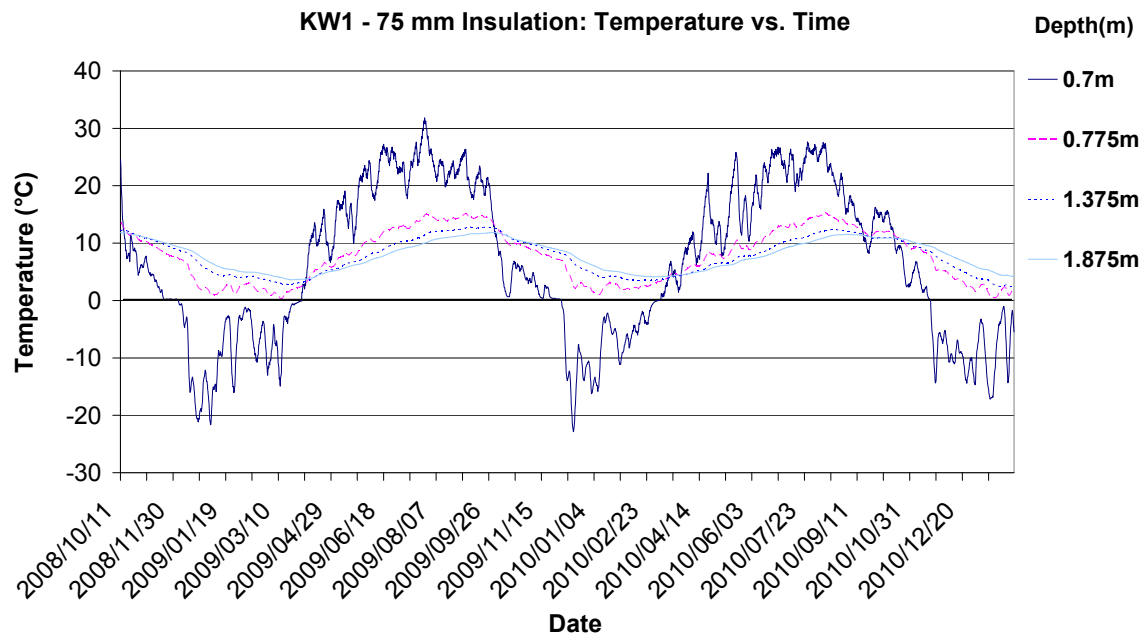


Figure 8. 75 mm Insulation: Temperature vs. Time

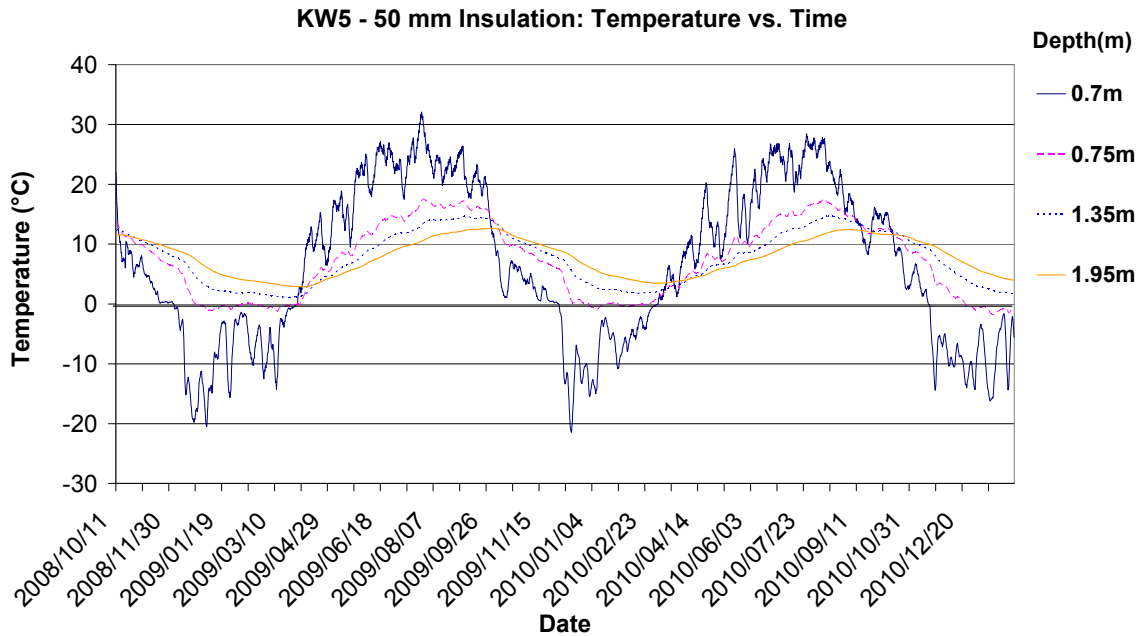


Figure 9. 50 mm Insulation: Temperature vs. Time

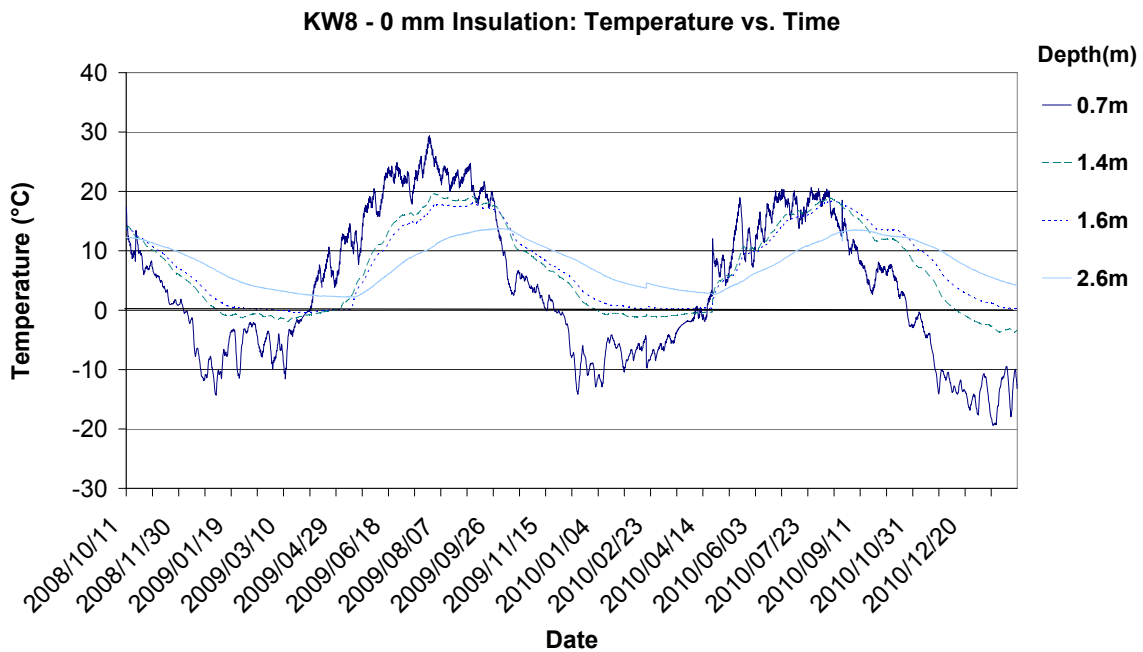


Figure 10. No Insulation: Temperature vs. Time

FIELD OBSERVATIONS

During the winter of 2010/2011, several transverse cracks developed along the roadway within the project area. A survey was carried out which confirmed that the cracks corresponded approximately to the ends of the insulated road section. One large

transverse crack formed across all of the northbound and southbound lanes, south of the railway trestle. A vertical displacement of approximately 5mm was noted on the northbound lanes, with the higher side being the uninsulated road section. The heaving of the uninsulated side was due to the penetration of frost into the subgrade surface, which would have still been present in the subgrade soils during the field observation in April, 2011. A much smaller transverse crack was also noted at the end of the insulated section of roadway north of the trestle, but only in the southbound lanes. The location of the large crack on the south side of the CNR trestle, in relation to the thermistor locations and the insulation limits is shown on Figure 3. Figure 9 shows a photo of the crack located along the south edge of the insulated section.



Figure 11. Crack due to Frost Heave

GEOTHERMAL MODELLING

Geothermal modelling was performed using GeoStudio's Temp/W program for 0mm, 50mm and 100mm of insulation. The purpose of the modelling was to characterize the thermal properties of the soil, insulation and pavement structure using actual thermistor data to provide a basis for future predictive roadway thermal modelling.

In order to simplify the model, the entire pavement structure was combined into one region. The total pavement structure was made to be 1 metre in thickness, including the drainage blanket. The insulation was placed within the centre of the pavement structure region. In order to obtain an accurate temperature profile, the soil region was extended to a depth of 10m below the ground surface. At this depth the temperature is reasonably consistent throughout the year, and by extrapolating from the thermistor readings obtained with depth, a temperature of 9°C was chosen for the bottom temperature boundary condition at a depth of 10m.

The thicknesses of the insulation is very thin relative to the total thicknesses of the other materials present within the model, therefore an interface material model was used to

represent the insulation in the model. An interface material is drawn as a line and the thickness cannot be dictated. Therefore the thermal conductivity of the insulation was decreased for the 100mm of insulation, to simulate the increased thickness and higher insulative properties of the thicker insulation layer. Table 3 below shows the material parameters used in the analysis and Figure 11 shows the schematic of the computer analysis.

	Material Model	Unfrozen/Frozen Thermal Conductivity (kJ/days/m/°C)	Unfrozen/Frozen Volumetric Heat Capacity (kJ/m³/°C)	Vol. W/C (m³/m³)
Pavement	Simplified Thermal	100/ 108	2520/2620	0.01
Soil	Simplified Thermal	147/ 160	1925/1875	0.2
Insulation 50mm	Interface	0.78	N/A	0
Insulation 100mm	Interface	0.65	N/A	0

Table 3. Thermal modelling material parameters

The models were run using both a steady state and transient state analysis. For the steady state analysis, a temperature of 1°C was used for the top boundary condition (ambient air temperature). For the transient analysis, a function was used to replicate the actual ambient air temperature measured with time, as obtained from the thermistors. The models were then run to simulate 1 year (365 days) of elapsed time. To confirm the models accuracy, models were created for two winters: October 2008 to October 2009 and from October 2009 to October 2010.

To obtain convergence, the model was set-up to save the results every 30 days, so an exact date when the maximum frost depth was achieved in the model was not obtained. However, the 30 day range of dates in which the maximum frost depth was reached in the Temp/W model, corresponded well with the actual dates obtained from the thermistor data. Table 6 shows a summary of this data.

Scenario	Maximum Frost Depth	Date the Maximum Frost Depth was Reached in Temp/W Model	Date the Actual Maximum Frost Depth was Reached
No Insulation	~1.6 m	Between Feb. 15, 2009 and Mar. 17, 2009	Mar. 13, 2009
50 mm Insulation	Just below insulation	Between Dec. 16, 2008 and Jan. 15, 2009	Dec. 25, 2008
100 mm Insulation	Just above insulation	Between Nov. 15, 2008 and Dec. 17, 2008	Nov. 20, 2008

Table 4. Comparison of model frost depth with actual

Figure 13 shows the advance of the frost line within the subgrade soils with time. The data shown again demonstrates that the Temp/W model corresponded well with the actual data obtained from the thermistors.

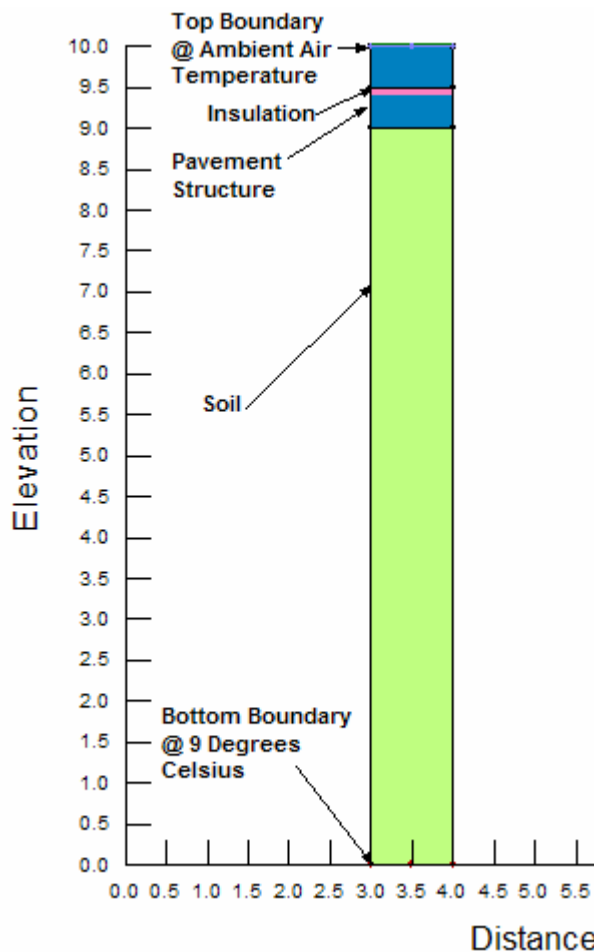


Figure 12. Geothermal Model

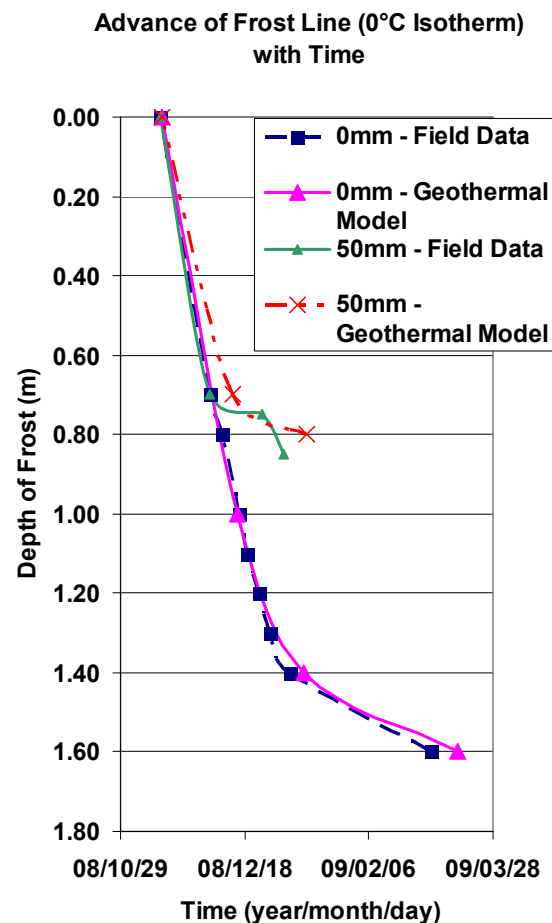


Figure 13. Advance of Frost Line with Time

CONCLUSIONS

The extruded polystyrene insulation worked well in insulating the soils from frost penetration. Some frost penetration into the underlying subgrade soils was evident when 50mm of insulation was used. From the research program completed here, 75 mm of insulation was found to completely prevent frost penetration into the subgrade soils for typical Edmonton temperatures, pavement structure and soil types. Therefore 100mm of insulation is probably overly conservative for the conditions typically encountered in Edmonton. On the other hand, 50mm of insulation did allow some frost penetration to occur, but the amount of frost heaving was measurably less than an adjacent uninsulated portion of roadway. For less critical roadway sections, 50mm of insulation may prove to be an economical compromise if the risk from small amounts of frost heave can be tolerated.

The geothermal model developed using GeoStudio's Temp/W program, accurately predicted the depth and time of frost penetration for several insulation scenarios. The model will be useful in helping to predict frost penetration and insulation requirements for other similar roadway projects in the Edmonton area.

During the course of this program, problems with differential icing were not observed between the insulated and uninsulated portions of the roadway. This may be due in part to an aggressive sanding and salting program on this major urban arterial roadway. The transverse cracking of the asphalt encountered at the transition between the insulated and uninsulated portions of the roadway does suggest that additional experimentation is required to develop a transition design which minimizes or eliminates this problem. Past experience has shown that creating a gradual transition zone where the insulation thickness is decreased by smaller, 25 mm increments may be helpful in mitigating the cracking due to frost heave near the insulation limits.

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