EDMONTON EXPERIENCE WITH BOTTOM ASH AND OTHER INSULATING MATERIALS FOR MITIGATION OF FROST HEAVE INDUCED DAMAGE IN PAVEMENTS

Author: David A. Field, P.Eng., EBA
Co-Authors: Tony Ruban, P.Eng., EBA
Art Johnston, P.Eng., EBA
Daryl Nixon, P.Eng., EBA
Don Lewycky, P.Eng., City of Edmonton Engineering

Paper prepared for presentation
at the Successful Mitigation of Frost Heave Session
of the 2011 Annual Conference of the
Transportation Association of Canada
Edmonton, Alberta

ABSTRACT

Edmonton, Alberta, has extensive areas of lacustrine silt and clays, formed during the last period of glaciation. The upper few metres of these sediments are typically relatively dry and stable. Where shallow groundwater is present or deeper cuts are performed for new roadway construction, the silts and clays are weak and saturated, exhibiting severe frost heave in winter along with loss of strength upon thawing.

The use of polystyrene insulation has been used to insulate the subgrade and mitigate the potential for frost heave of subgrade and associated damage of overlying pavement structures. Construction of several roadway projects in these lacustrine silts and clays have used an insulating layer of bottom ash in lieu of polystyrene insulation. Where grades are flat and drainage is poor, it can be a challenge to construct a roadway section bearing on the saturated silts as they quickly lose strength with construction equipment traffic and provide an unstable platform for layout of the insulation sheets. Bottom ash has proven to be an effective stabilization layer in addition to providing insulating properties as it drains well and has angular particle sizes which provide a stable working platform when placed on top of the exposed silt.

This paper presents case histories of several roadway projects in Edmonton comparing the design, cost and performance of roadway projects constructed with polystyrene, bottom ash and alternate frost heave mitigation strategies. Thermal modeling was used to evaluate the insulating properties of bottom ash and proposed alternate subgrade concepts. Advantages and limitations of each frost heave mitigation strategy are presented to provide a basis for comparison and to aid in selection for design of new roadway sections in similar environments. Pavement design considerations are also discussed.

1.0 BACKGROUND

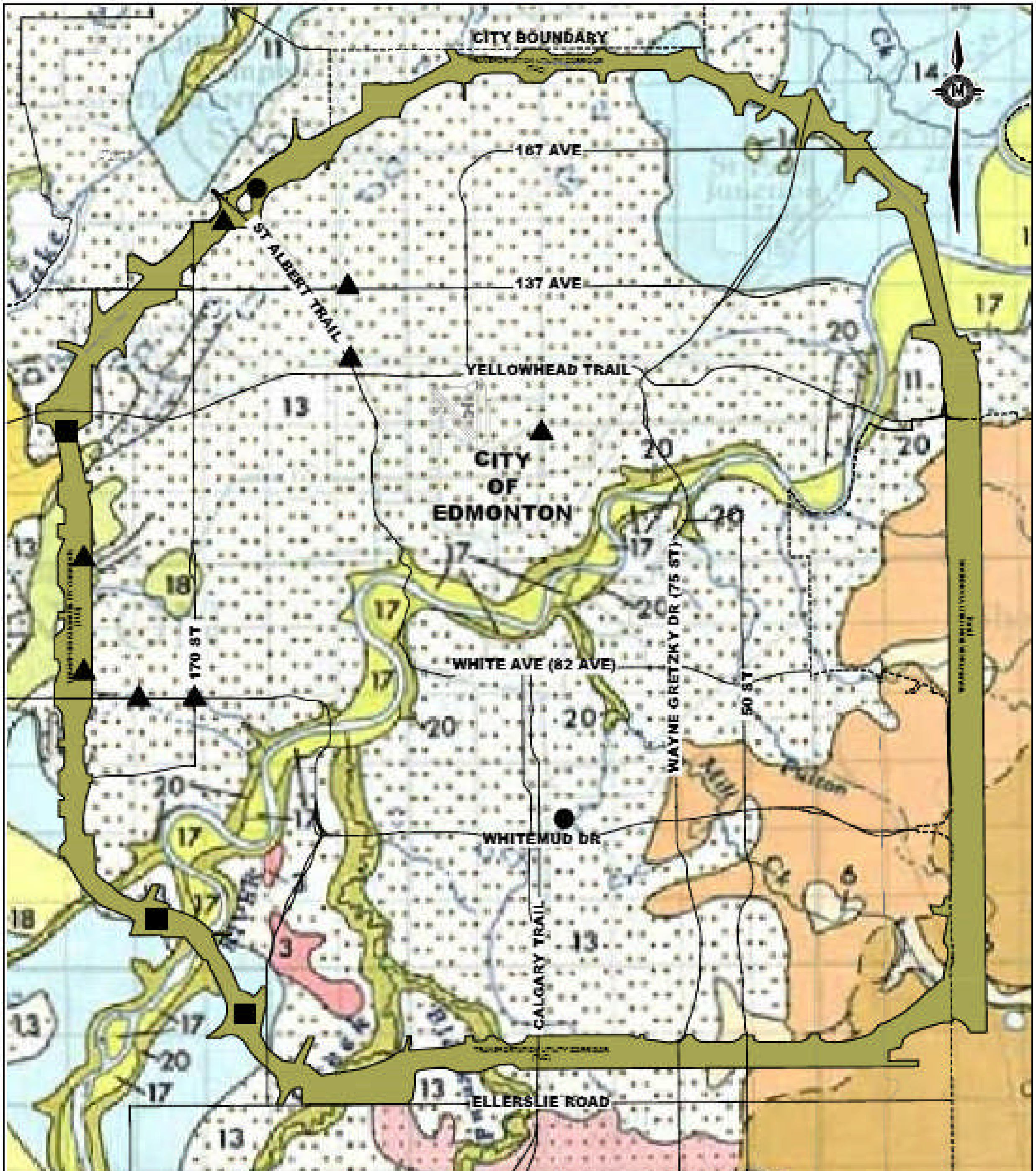
Edmonton, Alberta, has extensive regions of lacustrine deposits, formed at the end of the last period of glaciation. These soils consist of layers of silt, clay and fine sand that was deposited in a saturated condition and have not been consolidated, aside from drying out over time. Typically, the upper few metres of these soils are dry and stable. At depth, the soils are weak due to their high moisture content. Where shallow groundwater is present or deeper cuts are performed for new roadway construction, the soils lose strength upon disturbance. Pavements constructed above these soils exhibit frost heave in winter, damaging the pavement structure due to deformation and loss of strength of subgrade upon thawing in the spring.

The most extensive areas of these weak frost-sensitive soils are along the western side of the city, as shown on Figure 1, the surficial geologic map of Edmonton[1]. This figure also shows the location of projects where frost heave mitigation have been implemented. In the early 1980s, as major development of this region took place, damage of newly constructed pavements was noted after a few seasons, especially after spring thaw. Field surveys measured heaving up to 300 mm. The City of Edmonton undertook investigation to delineate regions of subgrade susceptible to frost heaving and to determine a cost-effective means of building pavement sections above these materials that would resist damage related to frost heaving.

Frost heave occurs when cold penetrates beneath the pavement section and the water within the subgrade soil freezes and expands. In a saturated silt or fine-grained sand and silt soil, thin lenses of ice will form as the water in the soil freezes. Given the availability of water in the subgrade, with continued cold temperatures, additional lenses of ice form as capillarity draws groundwater up from a greater depth. Over the course of a typical winter, significant heaving can occur due to the build-up of these ice lenses. When the frost melts, the pavement experiences loss of subgrade support and breaks down. Photo 1 shows a core taken from a frozen silt soil exhibiting severe ice lensing. Photo 2 shows the same core upon thawing.

Regions of frost-susceptible silt can be defined through a borehole or backhoe pit exploration program. Photo 3 shows the appearance of these weak silts upon excavation. Photo 4 illustrates a measured frost heave of approximately 200 mm measured at the end of a winter season.

[1] Surficial Geologic Map of Edmonton, Map 143, Research Council of Alberta. Bayrock, L.A., Hughes, G.M. 1972.



LEGEND

- 11 - LACUSTRINE SAND AND SILTY SAND
- 13 - LACUSTRINE SILT AND CLAY
- 18 - LAKE AND SLOUGH DEPOSITS, SILT AND CLAY

▲ - POLYSTYRENE ■ - BOTTOM ASH ● - OTHER

FIGURE 1

SURFICIAL GEOLOGY OF EDMONTON AND LOCATIONS OF ROADWAY MEASURES TO MITIGATE FROST HEAVE

[1] Research Council of Alberta
Map 143, Bayrock L. A.; Hughes, G.M. 1972
May 2011

Photo 1: Ice Lenses in a Core of Frozen Silt Showing Frost Heave Mechanism

Photo 2: Loss of Strength upon Thawing

Photo 3: Exposing Weak Saturated Silt Layer

Photo 4: Frost Heave of 200 mm

2.0 TRADITIONAL APPROACHES TO MITIGATE FROST HEAVE

Three basic conditions must be present to promote frost heaving and to allow for ice lensing to occur:

- The soil must be frost susceptible and have the ability to "wick" water. This means that the soil must allow for easy transport of porewater through capillary action to the freezing zone while remaining saturated so that upon freezing, the voids expand and create ice lenses that continue to grow as freezing penetrates. Silt and low plastic clays and mixtures of silt, clay, and fine sand are the most frost susceptible (typically lacustrine soils). High plastic clays are less frost susceptible, and clean granular soils are the least frost susceptible.

- Temperatures must be sufficiently cold for the subgrade to freeze. The colder the temperatures and the length of time that cold is applied, drives the frost deeper into the subgrade.

- The subgrade soils must have sufficient water available at the depth of freezing for ice lenses to develop.

Traditionally, efforts to mitigate frost heave in pavement subgrade have addressed the elimination of one or more of the above conditions through the following approaches:

- Raise the grade line using non frost-susceptible fill or remove and replace the frost-susceptible soils with non-frost-susceptible soils to the maximum depth of freezing.

- Insulate the subgrade soil from freezing by incorporating a layer of insulation (typically extruded polystyrene foam insulation or bottom ash) beneath the pavement structure, which maintains temperatures above freezing within the subgrade.

- Provide drainage of the subgrade by raising grades or installing a capillary break to prevent water from being available to frost-susceptible subgrade.

The local winter climate (typically expressed as degree days) controls the maximum depth of freezing. The specific degree days for the project locale are used to evaluate the effectiveness of insulation and required thickness to reduce expected maximum frost penetration into the subgrade. Environment Canada maintains the National Climate Data and Information Archive which provides freezing temperature data for most of the country.

2.1 Granular Replacement

Granular soils drain well and have sufficient pore volume that upon freezing, the expansion due to formation of ice is accommodated within the pores maintaining the original soil volume. Granular soil needs to be adequately clean to prevent fine grained soil particles from retaining capillary moisture and causing volume change upon freezing. A granular soil having less than 5 percent fines is considered non frost-susceptible. Within the City of Edmonton, a frost depth penetration of approximately 2.4 m is estimated. A typical full-depth granular subgrade is illustrated on Figure 2.

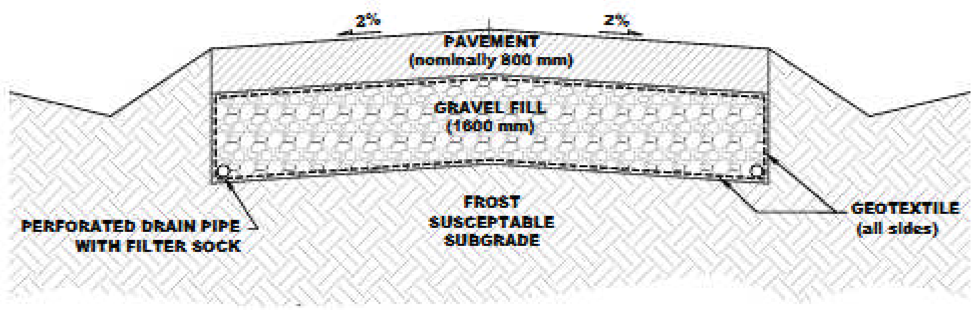


FIGURE 2
TYPICAL GRANUALR REPLACEMENT SECTION

Roadway Section	Typical Section	Construction Notes
99 Avenue and Gateway Boulevard		Deep replacement with granular
NW Anthony Henday Drive, near St. Albert Trail	1600 mm clay or sand 600 mm granular drainage	
Whitemud Drive – 111 Street to 99 Street	350 mm of asphalt 300 mm of gravel 150 mm of cement stabilized subgrade	Replacement of frost-susceptible soils with granular backfill.

2.2 Insulated Pavement

The use of insulation can be effective in maintaining subgrade temperatures above freezing over the course of winter. Ridgid extruded polystyrene foam insulation is the most common, given its ability to withstand applied loads of up to 100 kPa and its closed cell structure which prevents absorption of water. Insulation is manufactured in sheets available in increments of 25 mm thick. The sheets are usually placed above a levelling course of a sand or fine gravel with the pavement section bearing above. Polystyrene has traditionally been used in areas where the gradeline could not be raised and frost-susceptible material could not be removed and replaced.

A typical roadway embankment and pavement section using polystyrene is shown below on Figure 3 and would include a subcut of 600 mm to 900 mm below subgrade elevation. This would be followed by placement of a woven geotextile, backfill with granular fill or re-cycled concrete to stabilize the underlying subgrade. Then place 75 mm to 100 mm of polystyrene insulation board topped with the roadway pavement structure.

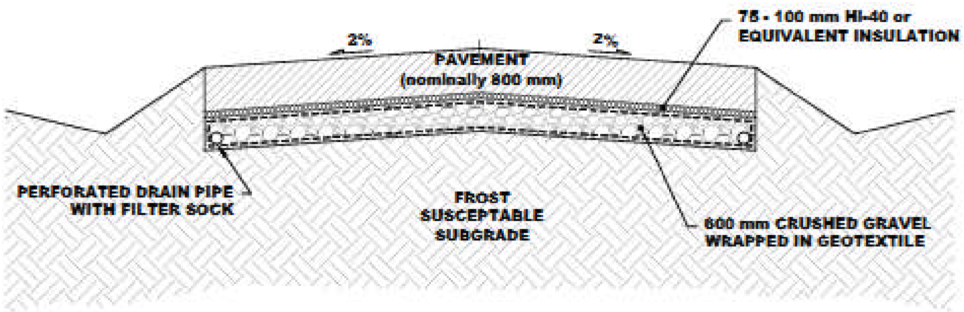


FIGURE 3
TYPICAL INSULATED SUBGRADE SECTION

Photo 5 shows the installation of granular base course directly on polystyrene insulation sheets. It can be a challenge during construction to provide a flat surface for the insulation sheets to be place on. Large rocks or dips in the surface can damage the sheets upon applying fill and subsequently compacting. The sheets must also be placed carefully during periods of windy weather to avoid them being blown out of alignment.

Photo 5: Base Course Being Placed on Polystyrene Insulation

Roadway Section	Typical Section	Centerline Length	Construction Notes
Whitemud Drive 170 Street to SW Anthony Henday	250 mm asphalt 300 mm gravel 25 mm to 100 mm Styrofoam HI 150 mm cement stabilized subgrade	~ 2 km	
St. Albert Trail, North of Yellowhead Trail	250 mm asphalt 300 mm 63 mm granular base 150 mm bedding sand 50 mm to 100mm Styrofoam HI	137 m	40 m of 50 mm insulation 40 m of 75 mm insulation 57 m of 100 mm insulation 150 mm perforated lateral drain
137 Ave under CN/ CP Rail	250 mm of asphalt 300 mm of 3-83 gravel 150 mm of 4-10 bedding sand 25 mm to 75 mm Styrofoam HI 200 mm of 6-20 gravel 150 mm cement stabilized subgrade	360 m	60 m of 25 mm insulation 60 m of 50 mm insulation 240 m of 75 mm insulation 150 mm perforated lateral drain
118 and Rexall Place	300 mm of asphalt 300 mm gravel 150 mm of cement stabilized subgrade		Existing subgrade drainage system on site. Granular material is drained by the system.

3.0 BOTTOM ASH INSULATION ALTERNATIVE

In the western part of Edmonton, saturated silt layers are encountered near surface. In any area where a roadway gradeline falls below natural grade or shallow groundwater is present, some extraordinary measures are required to construct roadway subgrade and to prevent ice lensing and heaving in the saturated lacustrine deposits. Constructing subgrade is also challenging because the saturated silts lose strength quickly upon excavation and disturbance by construction equipment. Some form of stabilization is typically required in order to facilitate passage of construction equipment.

The use of bottom ash wrapped in geo-synthetic fabric directly on top of the saturated silt has been used to provide both a stabilizing layer and to act as insulation to mitigate frost heave. Bottom ash is a by-product of burning coal for electrical power generation. It is the ash or cinders left behind in the boilers after burning pulverized coal. The material is lightweight and has previously been used to improve the thermal properties of fillcrete. Bottom ash particles are angular and when bladed onto soft ground, provide a surface capable of supporting construction traffic.

In Edmonton, bottom ash has been used in fillcrete as sand-sized aggregate. The use of bottom ash was recognized as providing an insulating property, helping to prevent frost from being conducted through the fillcrete to buried utilities. Bottom ash has also been used in Saskatchewan successfully as a sub-base layer to replace pit-run gravel, a scarce resource in that region. Benefits of using bottom ash were: similar performance to conventional granular materials, ease of handling and compaction, low bulk density, and non-susceptibility to frost heave. The University of Alberta evaluated the thermal conductivity of bottom ash through laboratory testing in 1991.

EBA used technology usually applied to thawing of permafrost to evaluate the potential of bottom ash for use as an insulating layer to prevent frost from penetrating the subgrade. Based on that analysis, the City of Edmonton constructed an instrumented test section of bottom ash to confirm the constructability of bottom ash and to measure the depth of frost penetration over the course of a winter. EBA used frost penetration data obtained from thermocouples installed in that trial section of bottom ash, current meteorological data from the Edmonton Municipal Airport, and computer modelling to determine the in-situ insulation properties of the bottom ash. After the in-situ materials were characterized, pavement layers were added to the computer model and depth of frost penetration was calculated for several years of various cold temperatures based on historic Edmonton winters. The results of that analysis indicated that the bottom ash was of sufficient insulating capacity and could be used in lieu of extruded polystyrene to prevent the frost from reaching the silt subgrade.

The pavement was constructed on top of the bottom ash in 1998 and the thermistor strings were again monitored over the following winter. The depth of frost penetration was in close agreement with the predicted frost penetration depth as shown in Figure 4. Over the following 12 years, the roadway has continued to perform well and there has been no frost heaving on this section. Additionally, there were no thermal transverse cracks observed. The City of Edmonton and Alberta Transportation have recognized the cost savings and superior performance of the bottom ash section of roadway and have continued to construct roadways using bottom ash as a stabilizing and insulating layer in this part of Edmonton.

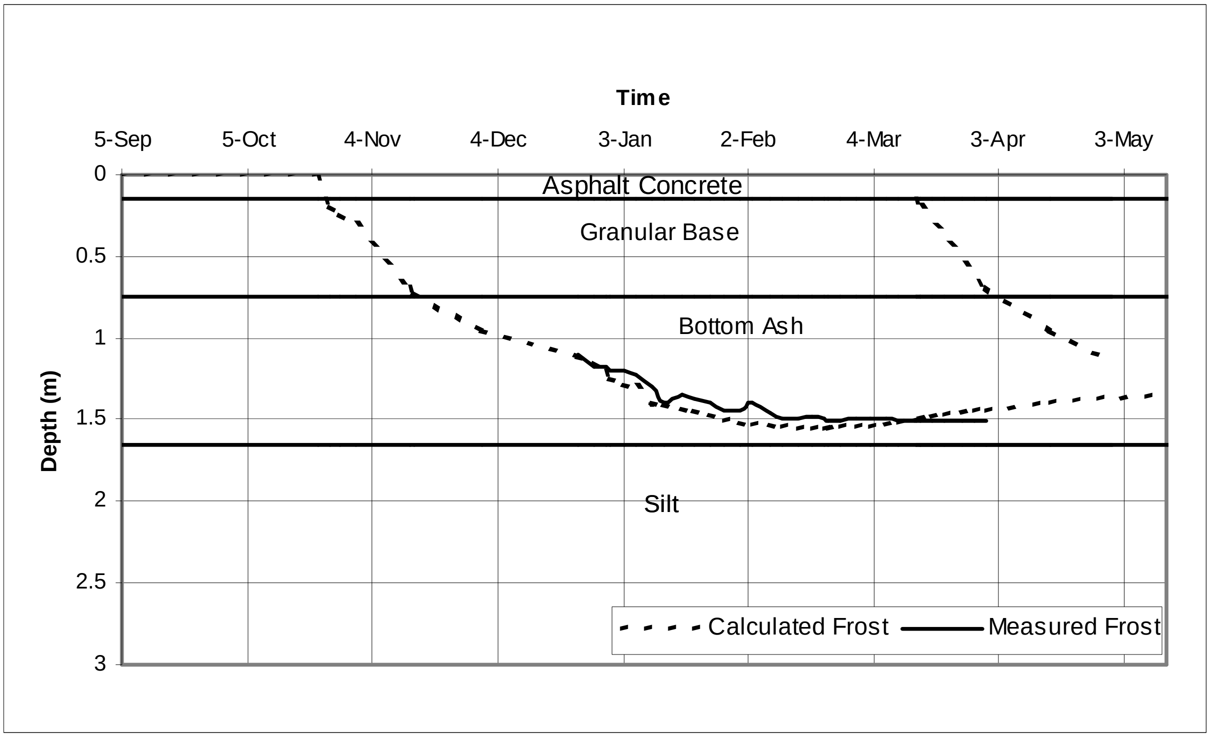


Figure 4: Anthony Henday Drive – Comparison of Calculated and Measured Frost Depth

In order to construct a layer of bottom ash successfully, an understanding of its unique properties and challenges as a construction material is necessary. Bottom ash is typically delivered with high moisture content on-site, as it is removed from the power plants by a water flush. In a roadway application, bottom ash is typically placed as a 1 m thick layer, directly beneath the pavement structure. Because of the higher bearing strength of bottom ash compared to clay or silt subgrade, a slight reduction in the thickness of the pavement structure can occur to offset the cost of the bottom ash. A medium weight geotextile is typically used as a separator between the underlying subgrade soil and the bottom ash layer. Figure 5 shows a typical section of a bottom ash insulated pavement.

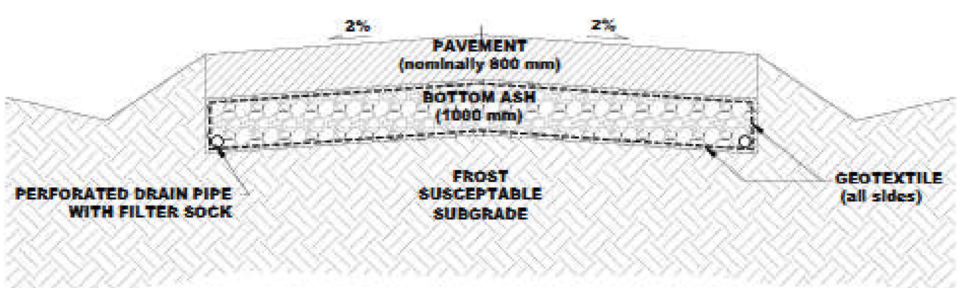


FIGURE 5
BOTTOM ASH STABILIZATION / INSULATION

Bottom ash can be placed in a single lift and compacted by smooth drum steel wheel equipment. The as-delivered water content should be between 25% and 28% to ensure suitable placement. The bottom ash should be protected from drying out before it is covered by a granular base course. Dry bottom ash has minimal internal stability and will displace easily under vehicle wheel loading. Photo 6 shows a layout of bottom ash being bladed onto geotextile above weak silt subgrade.

Photo 6: The Construction of a Bottom Ash Layer Directly on Weak Silt Subgrade

Environmental tests conducted on bottom ash have indicated that bottom ash has high concentrations of heavy metals, especially boron. Lead is also noted at slightly elevated concentrations. Leachate tests on water from the bottom ash have indicated that the leachate is not toxic; however, the leachate from the bottom ash should be controlled. It may be required to obtain environmental approval to use the bottom ash.

The following sections of roadway have been constructed using bottom ash:

Roadway Section	Typical Section	Centerline Length	Construction Notes Performance
Anthony Henday Drive S. of Yellowhead Trail		~1 km	
SW Anthony Henday Drive North Saskatchewan River to Terwillegar Drive	1000 mm bottom ash	3.6 km	
NW Anthony Henday Drive	280 mm asphalt 500 mm gravel 1100 mm bottom ash	~3 km	150 mm perforated lateral drain

4.0 OTHER STRATEGIES FOR FROST HEAVE MITIGATION

The use of a select layer of high plastic clay can provide an effective insulating layer above saturated frost-susceptible subgrade, provided that the select materials remain relatively dry and unsaturated. This can be achieved by creating a continuous capillary break layer of clean granular materials beneath the select subgrade fill. The capillary break layer would need to be constructed of sufficient thickness to maintain effective drainage to prevent water from migrating upwards into the overlying fill. The thickness of the select clay fill needs to be adequate to prevent freezing of the capillary drainage layer. Where stable subgrade is present, typically 300 mm of clean granular material is adequate to construct a capillary break. Where stabilization of weak subgrade must also be provided, a 600 mm thickness of granular fill would be typical.

The use of a geosynthetic drainage layer can also be considered to provide a capillary break. The construction of an effective geosynthetic capillary break could be problematic above weak, saturated silts given the need to provide stabilization to allow for passage of construction equipment and the challenge of maintaining a planar surface of the geosynthetic layer to achieve effective drainage.

Suitable, select low to non-expansive fill would consist of materials classifying as F2 or F3 under the US Army Corps of Engineers frost heave susceptibility classification system. These materials are typically moderately plastic clays with liquid limits above 35 and granular soils with up to 20% fines. The thickness of the select layer needs to be adequate to prevent the capillary break layer from freezing. Figure 6 shows a typical section for a capillary break and low frost heave replacement subgrade.

For roadway installations where some seasonal distortion can be tolerated, the frost-susceptible silt can be removed and replaced with a layer of low to medium plastic clay without using a capillary break. This approach is easier and cheaper to construct but will be subject to expansion upon freezing during winter. The use of suitable clay will prevent the formation of ice lenses and more severe frost heaving. Damage of pavement can be minimized by recognizing this seasonal movement and isolating the pavement from features that would not heave, such as granular fill around culverts or structure foundations.

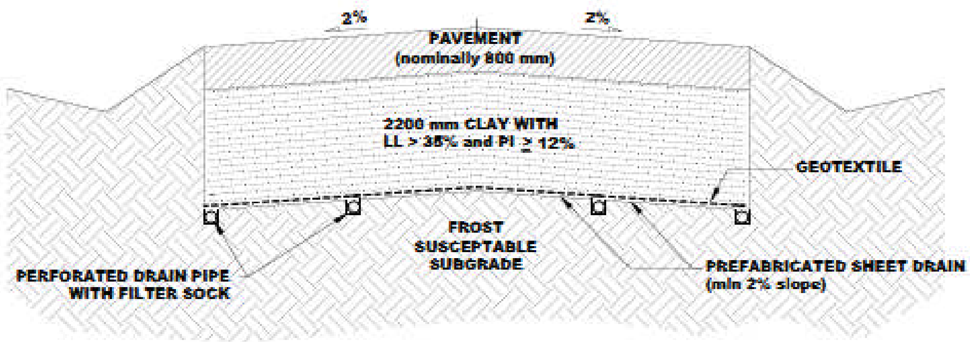


FIGURE 6
CAPILLARY BREAK AND
LOW FROST HEAVE REPLACEMENT

5.0 PAVEMENT DESIGN CONSIDERATIONS

Several aspects of pavement design can be influenced by specific frost mitigation strategies. For example, in terms of structural design a deep granular replacement provides the additional benefit of enhancing the pavement structure foundation. This often enables the reduction of asphalt concrete and/or granular layer thickness. For other treatments such as bottom ash, specific subgrade support conditions should be evaluated to determine an appropriate subgrade modulus for the bottom ash layer to use as part of the basis for pavement structural design.

With respect to pavement performance, materials selection (and specifically asphalt binder selection) can be significantly influenced by the type of frost mitigation treatment selected. In Edmonton, selection of a binder providing a relatively high reliability of low temperature performance is essential to minimizing the potential for low temperature induced transverse cracking. This is particularly important when dealing with performance based smoothness specifications because of the significant influence transverse cracking has on ride quality. Current asphalt binder selection protocols, developed for colder climates such as Western Canada, assume that during cold periods the pavement temperature is higher than the ambient air temperature. This is due to heat resonating from the subgrade underlying the pavement structure. Depending on the frost mitigation treatment used, this temperature differential between the warmer asphalt concrete and the ambient air temperature can be reduced and even eliminated. Therefore, an asphalt binder that may provide acceptable low temperature performance in a conventional pavement may be prone to significant low temperature induced transverse cracking when used for an insulated pavement. This is due to the insulation's effectiveness in keeping the heat from the ground contained beneath the insulation layer subjecting the pavement to a more extreme thermal regime in response to weather fluctuations. Anecdotal evidence indicates this has occurred in Edmonton, particularly where polystyrene foam insulation has been used.

Another performance related observation of pavements incorporating rigid extruded polystyrene insulation is that in specific weather conditions, these pavements may "ice" sooner or more severely than non-insulated pavements. This can, in certain instances, have an impact on road safety given that surface conditions may change significantly with the transition from non-insulated to insulated sections. The tendency for pavements insulated with bottom ash to experience early icing has not been observed; however, a rigorous comparison of the relative icing tendencies between non-insulated, foam insulated and bottom ash insulated pavements has not been performed.

6.0 CONCLUSIONS

Deep subgrade replacement with granular non frost-susceptible materials is an effective means of mitigating frost heave beneath pavements. The availability and pricing of suitable granular materials can make this an expensive option. Replacement with high plastic clay is another option that has been used and is more cost effective but can result in some minor heaving.

The use of polystyrene insulation is an effective means to prevent freezing and subsequent heave and damage of pavements constructed above frost-susceptible subgrade. Transverse cracking of pavements can occur due to thermal shock of the pavement associated with the abrupt temperature gradient created by the insulation. Choosing a more appropriate asphalt binder can help address this effect. Icing of insulated pavements is also a consideration.

Bottom ash can provide an effective insulating layer above frost-susceptible soils. It can also function as a means to facilitate stabilization of weak saturated soil. The cost effectiveness of bottom ash is dependent on local availability and pricing. The contractor needs to be aware of special handling requirements of bottom ash and the need to evaluate heavy metal content and environmental risk.

Installation of a granular capillary break layer above frost-susceptible soils can allow the use of moderately plastic clay and clayey sand fill to construct a frost-resistant layer and mitigate frost heaving. The constructability of this composite section can be a challenge. The long-term performance of a capillary break is contingent on building and maintaining effective drainage to prevent saturation of the select fill over the lifetime of the project. If the drainage system fails, the subgrade will be subject to frost heaving and may require reconstruction.

REFERENCES

[1] Surficial Geologic Map of Edmonton, Map 143, Research Council of Alberta. Bayrock, L.A., Hughes, G.M. 1972.

[2] Use of Bottom Ash as a Sub-base Insulation Layer. Paper prepared for presentation at the Soils and Materials Investing in New Materials Products and Processes Session, 2005 Annual Conference of the Transportation Association of Canada (unpublished).