Innovative Approach to Establish Transitions Between Two Materials of Different Frost Susceptibilities Under Rigid Concrete Pavement at Montreal-Pierre Elliott Trudeau International Airport

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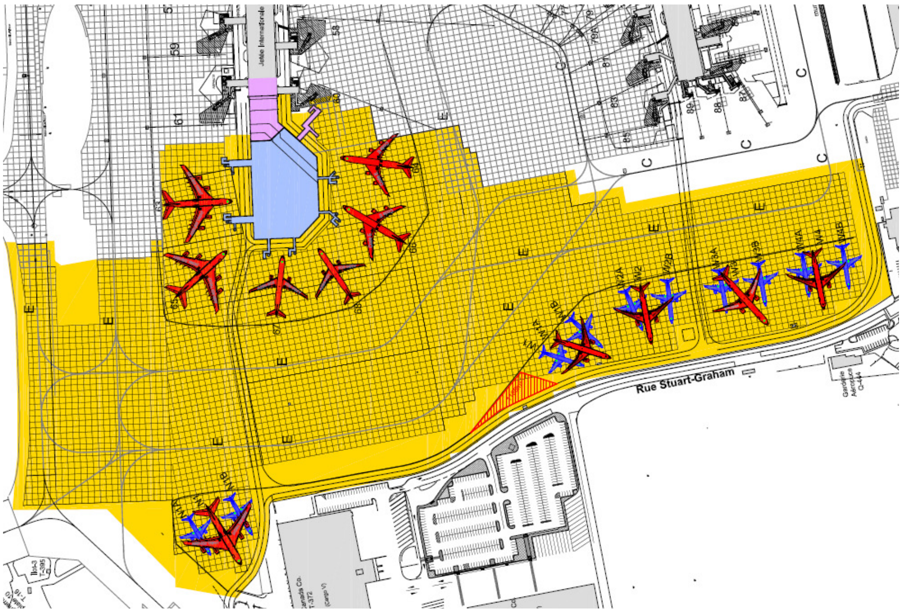
Abstract: Natural soils at the site of Montreal-Pierre Elliot Trudeau International Airport are not easily reusable as trench backfill for laying underground infrastructure (sewers, fuel pipeline) since they generally have a high proportion of fine particles (< 80 µm) along with a high water content, making them difficult to compact. Previously, it was common practice to fill trenches with a stone screening containing more than 15% fine particles (< 80 µm) so as to mimic as much as possible the frost behaviour of the existing natural soil. However, this process raised another issue, as during the rainy season, these materials (stone screening) became easily saturated and thus unstable, leading to subgrade's instability. Given this recurring problem, especially in the fall, ADM decided in 2012 to fill these infrastructure trenches with crushed stone close to a 0-20 mm calibre or 0-56 mm calibre so as to ensure the stability of the materials laid. As a result, the frost susceptibility of the crushed stones in these trenches was completely different from that of the surrounding natural soils. This lecture will present the innovative approach put forward by the authors to design an appropriate transition between these two materials, for a rigid concrete pavement, using the SSR model for frost heave calculation used by Quebec's Department of Transportation (MTQ) in its "CHAUSSÉE 2" software.

1 Introduction

Due to an average annual increase of 6.5% of international flights in the last 5 years and due to some congestion issues at the West end of the existing tarmac, Aéroports de Montréal (ADM) which manages Montreal-Pierre Elliott Trudeau International Airport and Montréal-Mirabel International Airport is undergoing a major enlargement of its international installation in Montreal. These projects include the West extension of the tarmac which is shown in figure 1. The tarmac's pavement will be a 400 mm thick concrete pavement where many underground infrastructures (sewers and fuel pipeline) extensions were planned underneath the concrete pavement.

FIGURE 1

West Extension of Montréal-Trudeau Airport



Even with a 400 mm thick concrete pavement, differential heave due to frost susceptible soils can hinder the performance of a concrete pavement or even cause major cracking.

In the last 5 to 10 years, a lot of new developments have been found in the knowledge of the behaviour of frost susceptible soils and in frost heave prediction.

The present paper will show how these new developments have been used in a innovative way to design transition between 2 materials of different frost susceptibility so that concrete pavement would behave more adequately.

2 Project description

Montreal-Pierre Elliott Trudeau International Airport is undergoing a major enlargement of the installation, with one of these projects being the West Extension of the tarmac to enable the addition of 6 new gates for large aircrafts.

This extension represents a surface of 65,000 m² (26,000 m³ of concrete) which incorporated the following items:

- Demolition of 3 existing buildings.
- Demolition of existing old concrete slabs (old tarmac) and crushing for reuse.
- Demolition and removal of existing utilities.
- Recycling of base aggregates of old tarmac.
- Reconstruction and extension of underground infrastructures (sewers and fuel pipelines).

- Construction of granular sub-base and base.
- Construction of concrete pavement of 400 mm in thickness.

The pavement design was as follows:

TABLE 1

PAVEMENT STRUCTURE

Elements	Thickness	Specifications
Concrete	400 mm	Flexural strength of 5,0 MPa
Upper base: 0-40 mm calibre crushed stone	200 mm	Compacted to 100% Modified Proctor
Intermediate base: 0-40 mm calibre crushed stone	200 mm	Compacted to 98% Modified Proctor
Lower base: recycled crushed concrete	200 mm	Compacted to 98% Modified Proctor
Sub-base: 0-20 mm calibre crushed stone	300 mm	Compacted to 98% Modified Proctor

Under this 1.3 m thick pavement, native soils constituting the sub-grade is composed of either sand and silt or silty clay of high plasticity. Both of these materials are frost susceptible soils with similar behaviour.

3 Trench backfilling and past experience

Native soils at the site of Montreal-Pierre Elliott Trudeau International Airport are not easily reusable for backfilling the trenches for the underground infrastructures (sewers and fuel pipeline, etc.) because the 2 deposits found on site have a high proportion of fine particles (< 80 µm) along with a high water content making them not compactable to 95% Modified Proctor.

Prior to 2012, it was the common practice to backfill trenches with a “dirty” stone screening containing more than 15% of fine particles (< 80 µm) so that it would match as much as possible the frost susceptibility of existing surrounding native soils.

However, this process raised another problem during the rainy season (like in the fall). These materials (stone screening) would become easily saturated and in this instance, leading to instability of the sub-grade.

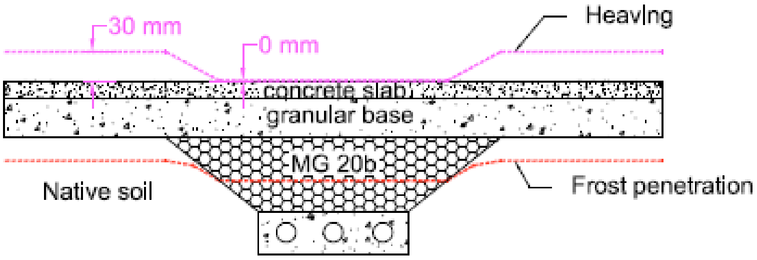
Given this recurring problem each fall, ADM decided in 2012 that all trenches should be backfilled with crushed stone that would be close to 0-20 mm calibre or 0-56 mm calibre so as to ensure the stability of the materials laid. As a result, the frost susceptibility of the crushed stone in these trenches was completely different from that of the surrounding native soils. To minimize the effect of differential heave on the concrete pavement, transition would have to be designed between these 2 materials.

4 Behaviour of concrete pavement under differential heave

Differential heave in a concrete pavement can be simulated in the following sketch showing the behaviour of the pavement under such movement.

FIGURE 2

Differential frost heave under pavement with 2 materials with different frost susceptibility



If we look transversely at a longitudinal trench where materials in the trench don't heave (or very lightly) and where surrounding natural soils heave, we can consider the concrete pavement as a 400 mm thick beam of 1 m in width (since it is a very long trench) and with a length that would vary with the geometry of the trench with or without transition.

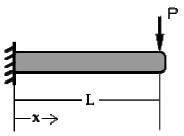
That been said, the flexural strength of concrete would be obtained under a maximum moment of 133 kN • m.

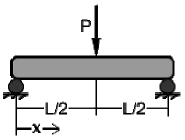
$$M = \frac{\delta I}{y} = \frac{5000\,\frac{\text{kN}}{\text{m}^2} * 5.33\text{x}10^{-3}\text{m}^4}{0.2\text{m}} = 133\ \text{kN} \bullet \text{m}$$

M: Flexural moment in the beam
δ: Stress at lower (or upper) fiber = flexural strength of concrete = 5,0 MPa (5 000 kN/m²)
γ: Distance between lower (or upper) fiber and neutral axis = h/2 and thickness/2 = 0.2 m
I: Inertial moment of section : $bh^3/12 = 5.33\text{x}10^{-3}\ \text{m}^4$

Since we should apply a safety factor to avoid any cracking of the concrete, we will use only 80% of the flexural strength, so 4 MPa (5 MPa x 0.8). If we use this safety factor, the tolerable maximum moment applied to the beam would be of 107 kN•m.

Two models could be used to establish what would be the maximum displacement under this maximum moment. We could use a cantilever beam or a beam on 2 supports.





$$\gamma_m = \frac{PL^3}{3EI} = \frac{MI^2}{3EI}$$

$$M_{max} = \frac{PL}{4} \text{ et } \gamma_m = \frac{PL^3}{48EI}$$

γ_m: Permissible displacement (m)
P: Applied force (kN)
L: Length of lever arm (m)
M: Flexural moment applied to the beam
M_{max}: 106.7 kN•m
E: Elasticity module: 30,000 MPa (30 000 000 kN/m^2)
I: Inertial moment of section: $bh^3/12 = 5.33\text{x}10^{-3}$ m^4

So if we want to limit the stress in the concrete to 4.0 MPa, the maximum displacement for a cantilever beam would be, for example, of 8 mm for a 6 m long beam. The displacement would be the same for a beam with 2 supports.

Cantilever beam

$$y_m = \frac{106{,}7\text{kN}\bullet\text{m} * 6^2\text{m}^2}{3 * 30\ 000\ 000\frac{\text{kN}}{\text{m}^2} * 5{,}33\text{x}10^{-3}\text{m}^4} = 0{,}008 \text{ m}$$

Beam with 2 supports

$$106{,}7\text{kN}\bullet\text{m} = \frac{\text{P x } 12\text{m}}{4} \quad \text{et} \quad y_m = \frac{35{,}57\text{kN x } 12^3\text{m}^3}{48 \text{ x } 30\ 000\ 000\frac{\text{kN}}{\text{m}^2}\text{ x } 5{,}33\text{x}10^{-3}\text{m}^4} = 0{,}008 \text{ m}$$

If we apply this for different lengths of lever arm, the maximum displacement tolerable not to exceed a stress of 4.0 MPa in the concrete would be of:

TABLE 2

LEVER ARM LENGTH VS MAXIMUM DISPLACEMENT

Lever arm length (m)	Max. displacement (mm)	Lever arm length (m)	Max. displacement (mm)
6	8	11	27
7	11	12	32
8	14	13	38
9	18	14	44
10	22	15	50

These calculations state that concrete pavement should not be subjected to differential heave higher than the maximum displacement is this table.

For this purpose, we will use this table to establish the length that the transition should have when we encounter 2 types of material with different frost susceptibility.

5 Innovative approach using SSR Model

5.1 SSR Model

Frost heave related damage to pavement is associated to pavement cracking due to surface deformation which will also affect riding comfort. As we understand it, the cracking and surface deformation is linked to frost heave but, we should say, mostly to differential heave. Since differential heave is difficult to calculate, usually total heave serves as an indicator of pavement performance to frost.

Many researchers (Konrad (1998), Gustavsson (1999) and Doré (2005)) have led us to say that total frost heave should be limited to certain values (30-100 mm) so that differential heave would be limited to acceptable values.

Two models of frost heave prediction (Saarrelainen (1992) and Konrad (2001)) are presented in the book entitled *“Cold Region Pavement Engineering”* (ASCE Press, 2009). Quebec’s Department of Transportation (MTQ) retained the SSR Model (Saarrelainen (1992)) for frost heave calculation which they have incorporated in their pavement design software called “CHAUSSÉE 2” in use since 2006.

5.2 Innovative approach

Since total frost heave can be calculated, the frost transition can be designed using the calculated differential frost heave under different situations (natural soils that heave and backfilled trench that does not heave).

If we look at the proposed pavement structure (Table 1) and we use the following hypothesis, so that the software CHAUSSÉE 2 can be used easily:

- Thermal characteristics of concrete are similar to asphalt.
- Thermal characteristics of 0-40 mm caliber crushed stone are similar to 0-56 mm caliber crushed stone.
- Default values of software used for native soils Segregation potential (SP_o) are:
  - “fine” SM (30 to 50% of fine particles (< 80 µm)) for silty sand or sand and silt = 4.0 mm²/°C • h.
  - CH for silty clay of high plasticity = 1.5 mm²/°C • h.
- Dorval Freezing Index:
  - normal → 972 °C • D
  - 20-year design → 1256 °C • D

With these assumptions, a 20-year design (1256 °C • D) will give us:

TABLE 3

CALCULATED FROST DEPTH AND TOTAL HEAVE FOR PROPOSED PAVEMENT

Type of soil	Classification	Frost depth	Total heave
Silty sand or sand and silt	"Fine" SM	1,845 m	31 mm
Silty clay of high plasticity	CH	1,688 m	28 mm

Now if we want to limit the differential heave to the values listed in Table 2, we will have to use transition so that the differential heave will not induce tensile stress higher than 4.0 MPa.

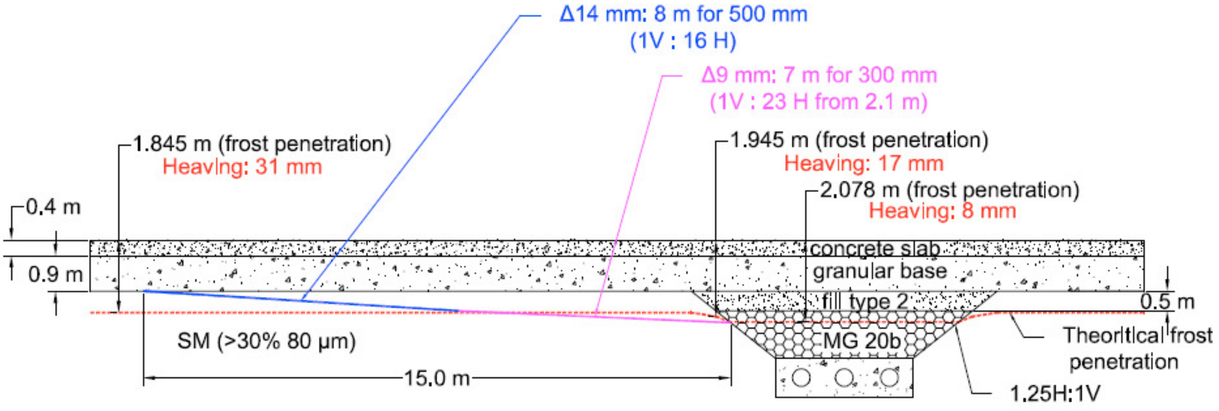
6 Presentation of innovative solution

To simplify the design of these transitions, the worst case scenario where we have the highest heave has been used. This is when we are in presence of silty sand or sand and silt.

Also, it was decided by ADM that the trenches would be backfilled with crushed stones of 0-20 mm caliber which contains less than 10% of fine particles (< 80 µm) and that a top layer of 0.5 m of the trench would be backfilled with a type 2 backfill which by specifications, contains 8 to 17% of fine particles. This situation showed the following heave and frost penetration.

FIGURE 3

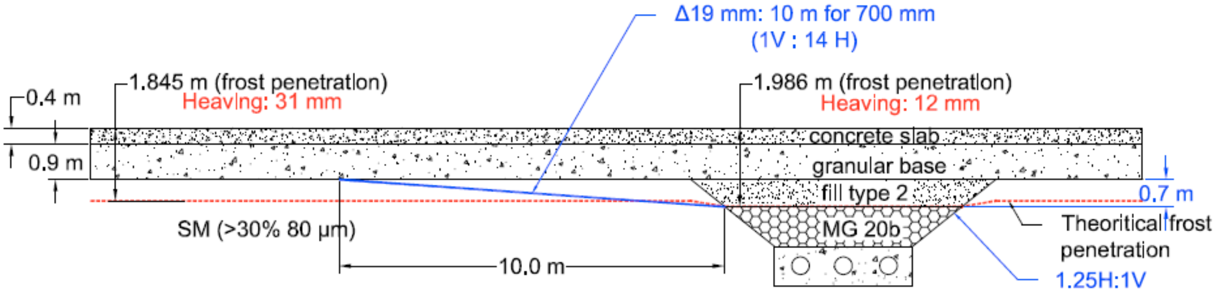
TRENCH FOR FUEL PIPELINES (INITIAL DESIGN)



Since the frost depth was more than 1.8 m (pavement structure of 1.3 m and Type 2 backfill of 0.5 m), it was decided to increase the thickness of Type 2 backfill to 0.7 m to increase the heave directly over the trench therefore decreasing the differential heave as shown hereafter.

FIGURE 4

TRENCH FOR FUEL PIPELINE (PROPOSED CHANGES)

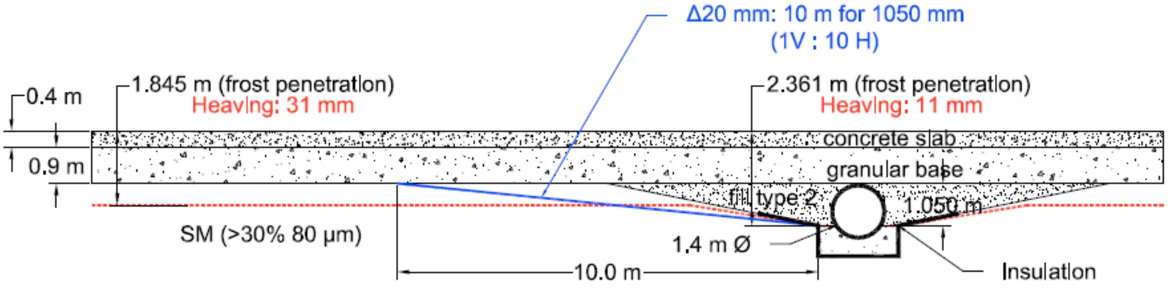


So since we now have a differential heave of 19 mm, the lever arm length would need to be 10 m so that the flexural strength of concrete is not more than 4.0 MPa. In the final, this cross-section was retained.

Other situations were looked at, like shallow sewer pipes. The first situation presented in the figure n° 5 shows that the transition 14 H : 1 V would remain the solution, since the differential heave would be of 20 mm.

FIGURE 5

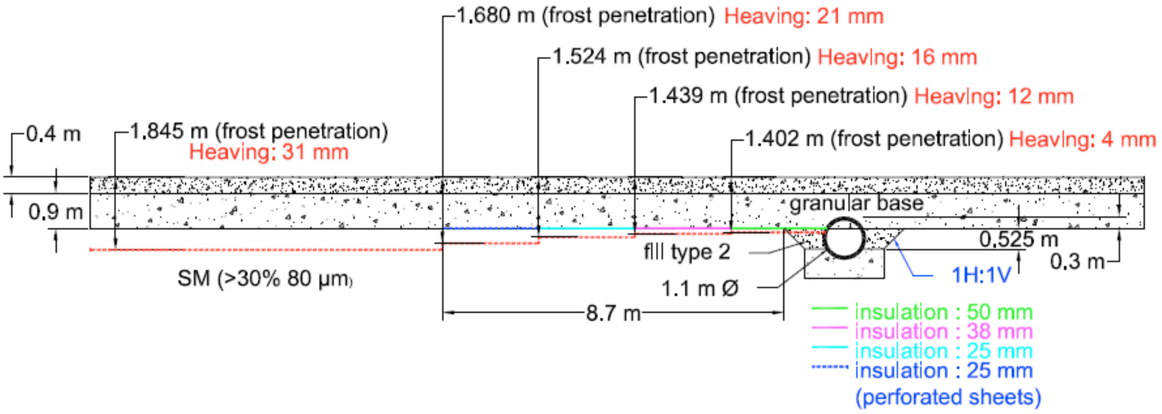
TRENCH FOR SEWER LINES (TRANSITION FINAL DESIGN)



The last case (Figure 6) was when the top part of the sewer pipes would even enter into the pavement structure. In this case, the only way to respect the permissible differential heave was to use thermal insulation under the pavement on different thickness to achieve a decrease of the differential heave as we are moving away from the sewer pipe, as shown on figure 6.

FIGURE 6

TRENCH FOR VERY SHALLOW SEWER LINES



This solution was not retained because of its cost and finally, for simplicity toward the contractor, all transitions were designed to 14 H : 1 V from a depth of 2.0 m.

7 Conclusion

Differential heave cannot be calculated directly but when the existing soils and material conditions are known, the calculated total heave can be used to evaluate the potential differential heave of the pavement.

As we could also see, concrete pavement does not need such a large differential heave to reach a flexural moment that can cause cracking. The innovative way of using the SSR Model to evaluate heave under different conditions served us well to design adequate transition between 2 materials of different frost susceptibility.

All of these transition designs were done in a short period, prior to the bid by contractor. If sufficient time would have been available, specialized testing to determine the true Segregation potential (SP_o), instead of MTQ's default value, could have given a better appreciation of the frost heave and therefore an optimal transition design.

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