Construction Engineering Department
1100, Notre-Dame Street West
Montreal, Quebec
H3C 1K3
Telephone (514) 396-8490
Fax (514) 396-8584

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M. Jack Tutino
Vice-president
Alliance Designer Products
225, Bellerose Boulevard West
Laval, Quebec
H7L 6A1
Tel : (450) 624-1611
Fax : (450) 624-1622
Email : jack@alliancegator.com

Subjects	**Initial characterization of soils and processes of solid paving stone and slab sections** Phase # 1.0 to 6.0 - Budget #2A (2015-08-27) and services offered (2015-09-15) **&** **Monitoring of instrumented patio sections** Phase # 1.0 to 5.0 - Budget #2B (2015-08-27) and services offered (2015-09-15)

Sir,

We are pleased to provide you with this report regarding the installation, three-year follow-up and initial characterization of soils and sections of concrete pavers and slabs that make up residential patios and that have been developed using the traditional method and the Gator Base system.

We hope that this document will meet your expectations and that we will have the opportunity to collaborate with you again in your future work.

Please accept, Sir, our best regards.

Michel Vaillancourt, P. Eng., Ph.D.
Professor – Construction Engineering Department

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1.0 INTRODUCTION

Following the approval of budget #2A and #2B of 2015-08-27 and the service offer of 2015-09-15, construction work was orchestrated by your company to build residential patios made of concrete pavers and slabs, and more specifically, to evaluate the building methodology for these patios. In particular, two (2) methodologies are used: the traditional method (TM) and the Gator Base system (GBS).

These in-situ tests follow laboratory work commissioned by Alliance Designer Products to characterize the Gator expanded polypropylene (EPP) panel base and compare the GBS with the TM. This work is presented in the report *“TECHNICAL REPORT ON THE CHARACTERIZATION OF GATOR BASE EXPANDED POLYPROPYLENE PANEL (EPP) AND STUDY OF THE MECHANICAL BEHEVIOR OF A TRADITIONAL ICPI APPLICATION VS A GATOR BASE PEDESTRIAN APPLICATION”* written in November 2014.

The objective of this mandate is to validate the results obtained in the laboratory on real sites. The aspects studied on site concern the thermal behaviour of the systems as well as their load-bearing capacity and resistance to deformation. Laboratory tests have shown that for the same thickness, the GBS was much more insulating than the TM. In addition, these tests also showed that the GBS was better able to distribute loads. In order to compare the thermal behaviour of the two systems, thermocouples will be implemented to continuously monitor the external and internal temperatures of the systems. In addition, elevation surveys at the end of construction and annual surveys thereafter will make it possible to monitor the movements on the surface of the patios.

As such, the approach used by the Laboratoire sur les chaussées et les matériaux bitumineux (LCMB) of the École de technologie supérieure (ÉTS) was to:

- Implement the necessary instrumentation to take temperature readings under the sections of concrete pavers;
- Sample soils to perform their physical, mechanical and thermal characterizations in the laboratory;
- Evaluate the mechanical behaviour of soils and of both systems using on-site characterization tests;
- Evaluate the thermal behaviour of both systems using temperature readings;
- Conduct topographic (or profile) surveys of the concrete pavers sections over the years to quantify their potential degradation;
- Prepare a report presenting the results.

2.0 DESCRIPTION OF SITES, SECTIONS AND INSTRUMENTATION

Three (3) sites in Quebec have been selected by your company to install the patios developed according to the two (2) systems and thus begin their initial characterization. These sites are located precisely in the backyard of the residences of the: A) 67, Roxton Crescent in Montreal West, B) 114, Daigneault Street in the City of Chambly and, C) 204, Dufferin Avenue in the City of Hampstead in Montreal. In the report, sites are identified by their address numbers, 67, 114 and 204 respectively. For each site, the residential patio is divided into two (2) sections of the same size: one developed using the traditional method (TM) and the other using the Gator Base System (GBS). In addition, the area of each section was chosen by your customer and your company. Table 1 shows the area of the patios, the sections developed according to the two (2) processes and the date of their completion for each of the sites. In addition, Table 2 describes the composition of each of the sections of solid paving stones. Each section is supported by a geotextile that covers the existing soil.

Table 1 Patio area, sections and date of construction per site

Element \ Site	67	114	204
Area Patio (m^2)	4,5 x 6,7 (14.75 x 22')	4,3 x 4,3 (14 x 14')	3,7 x 3,7 (12 x 12')
Area Section TM (m^2)	4,5 x 3,4 (14,75 x 11')	4,3 x 2,1 (14 x 7')	3,7 x 1,8 (12 x 6')
Area Section GBS (m^2)	4,5 x 3,4 (14,75 x 11')	4,3 x 2,1 (14 x 7')	3,7 x 1,8 (12 x 6')
Date of construction	2015-09-11	2015-09-10	2015-09-16
Measure in ( ) in feet 1' = 0,3 m			

Each section is instrumented with three (3) thermocouples to evaluate its thermal behaviour. The three (3) thermocouples, inserted into ducts[1] , are placed in the infrastructure soil. Figure 1 illustrates a typical case concerning the positioning of thermocouples and ducts under patio sections. Two (2) thermocouples are placed together under the geotextile and the other thermocouple (x1) is placed 6" (150 mm) deeper.

[1] IPEX type PVC conduit with 1/2" inside diameter to protect thermocouples from weather and punching.

Table 2 Thickness of the materials composing each section per site

Site	67		114		204	
Element \ Section	TM	GBS	TM	GBS	TM	GBS
Covering	Slabs ** 19 mm (3/4")	Slabs ** 19 mm (3/4")	Pavers *** 60 mm (2 3/8")	Pavers *** 60 mm (2 3/8")	Pavers *** 60 mm (2 3/8")	Pavers *** 60 mm (2 3/8")
Expensed polymer panel (or Gator base panel)	---	20 mm (3/4")	---	20 mm (3/4")	---	20 mm (3/4")
Bedding sand compacted	25 mm (1")	13 mm (1/2")	25 mm (1")	13 mm (1/2")	25 mm (1")	13 mm (1/2")
Compacted (0/20 mm) crushed stone (GBS only)	150 mm (6")	---	150 mm (6")	---	150 mm (6")	---
Geotextile	Very thin					
Compacted (0/20 mm) crushed stone	---	≈ 50 mm (2")	---	---	---	---
Total thickness	194 mm (7 3/4")	102 mm (4")	235 mm (9 1/4")	93 mm (3 21/32")	235 mm (9 1/4")	93 mm (3 21/32")

** Squares slabs 24" x 24" x 3/4" thick.
*** Pavers of three dimensions (or areas) different but of the same thickness 2 3/8".
1" = 25,4 mm

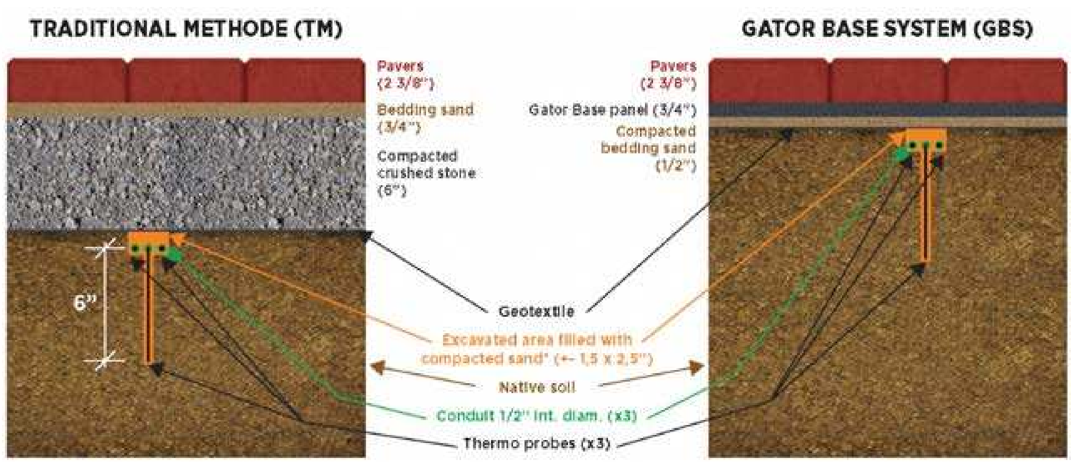

Figure 1 Typical case of the positioning of thermocouples and ducts under the sections of concrete pavers / slabs (profile view)

The thermocouples are placed in the central part and in the longitudinal direction of a section in order to be as far away as possible from the perimeter of the patio, at least 0.9m (3') away. This provision will limit the impact of the surrounding soil (and of the other section) on the temperature readings or more precisely, on the thermal behaviour of each section. Finally, the thermocouples are connected to a temperature acquisition box. Figures 2, 3 and 4 illustrate the location of the house, sections, thermocouples (T_x), ducts (=) and temperature acquisition boxes (B_x or CR_{xx}) for each site.

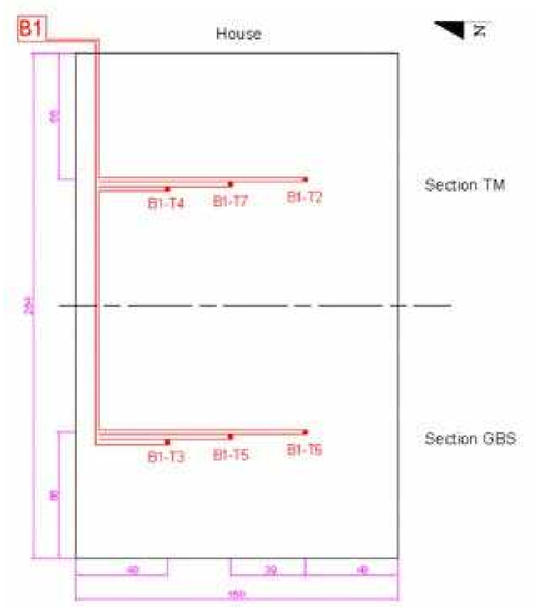

Figure 2 Location of the house, sections, thermocouples, ducts and box at 67 Roxton Crescent in Montreal West (dimensions in inches).

Picture 1 67 Roxton Crescent in Montreal West - Backyard patio position 308° N.W. Surrounded by house wall and air conditioning unit and a cedar hedge at the back and opposite side of the house.

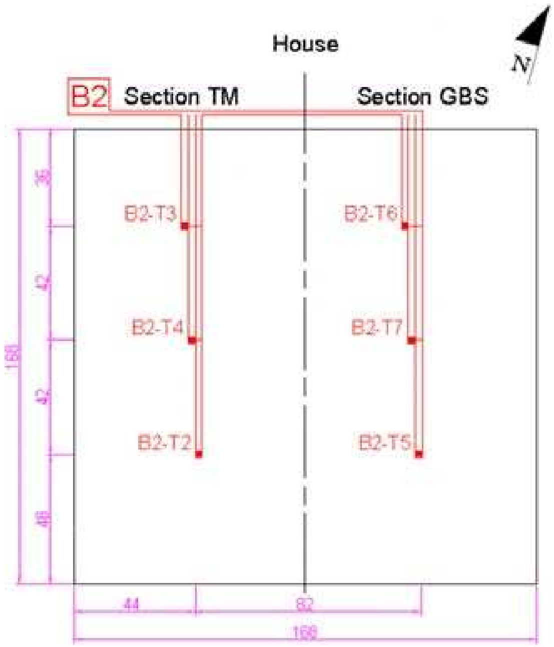

Figure 3 Location of the house, sections, thermocouples, ducts and box at 114 Daigneault Street in the City of Chambly (dimensions in inches).

Picture 2 114, Daigneault Street in the city of Chambly - Backyard patio position at 145° S. E. The balcony of the house is open on 3 sides.

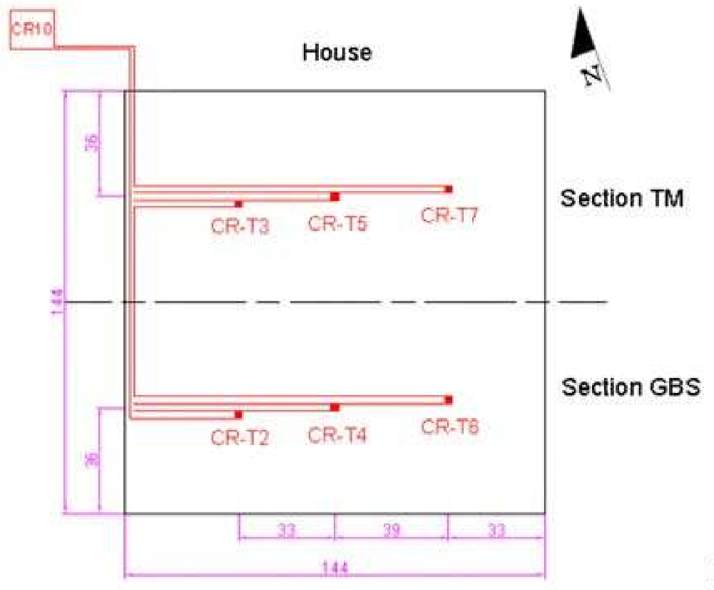

Figure 4 Location of the house, sections, thermocouples, ducts and box at 204 Dufferin Avenue in Hampstead (dimensions in inches).

Picture 3 204 Dufferin Avenue in Hampstead - Backyard patio position 206° SW surrounded by a house side hedge and mature trees in the back.

3.0 SOIL SAMPLING

Following the removal of turf and topsoil (GBS) and the complete excavation (TM) of the sections on the residential property, several soil samples were taken manually. These samples were taken to obtain materials for the tests of: 1) Gradation and Proctor (GP_x), 2) Density (MV_x), and 3) Segregation potential evaluated with a freezing cell (CG_x). The sampling locations for each site are shown in Figures 5, 6 and 7. A total of nine (9) samples were taken. In addition, the GP_x and MV_x samples were used for the tests of: 4) Water content, 5) Consistency limits, and 6) Compaction (or oedometric consolidation).

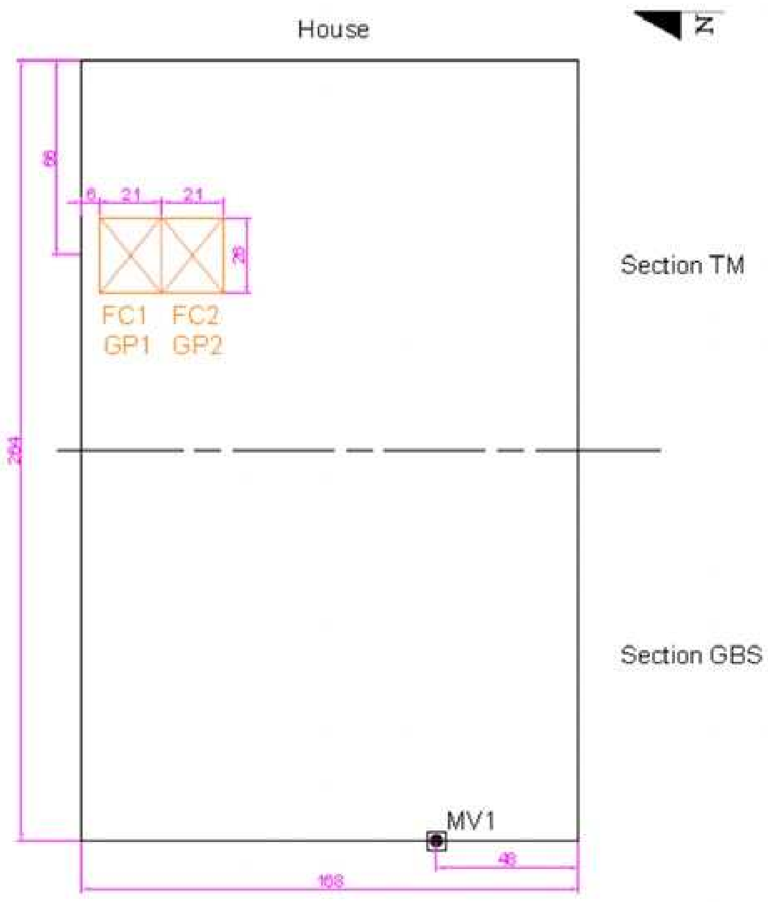

Figure 5 Sample locations at 67 Roxton Crescent in Montreal West.

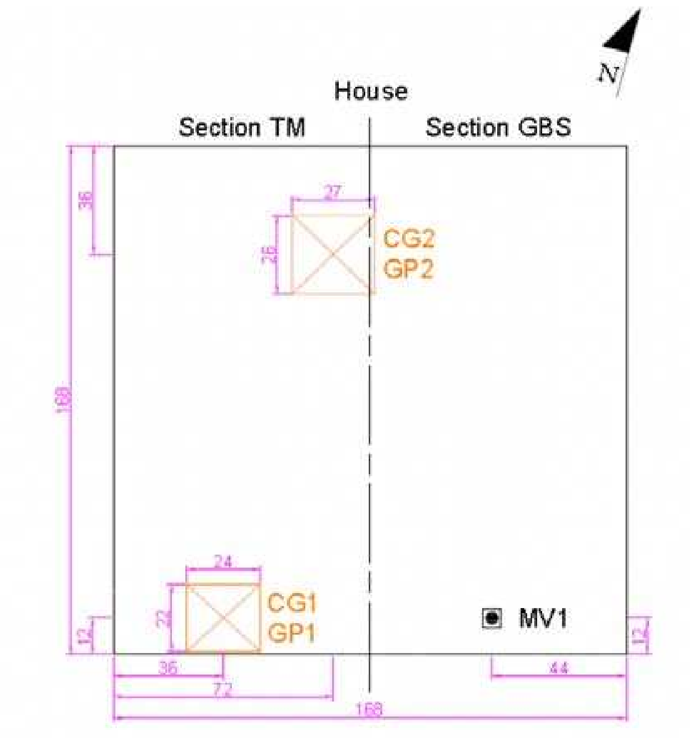

Figure 6 Sample locations at 114 Daigneault Street in Chambly.

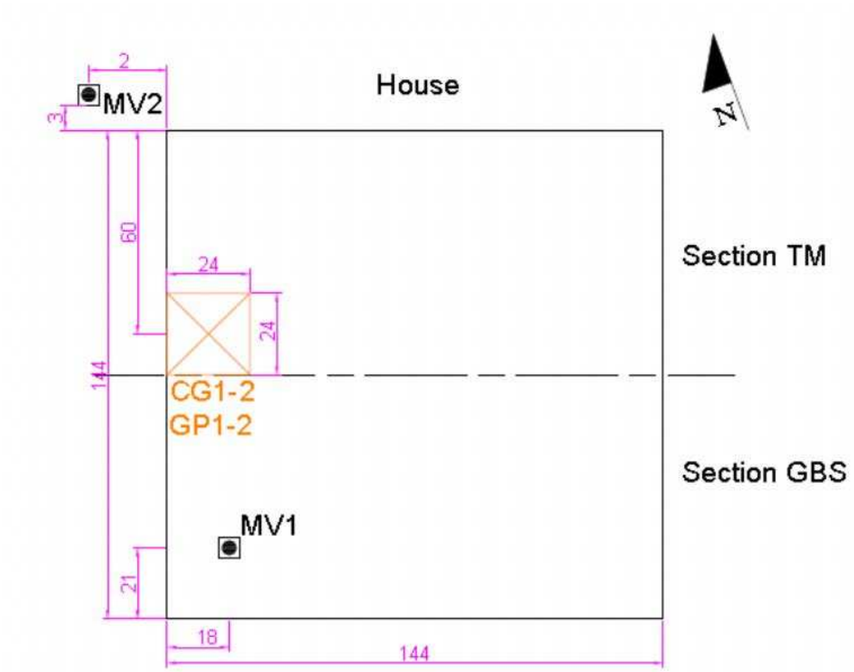

Figure 7 Sample location at 204 Dufferin Avenue in Hampstead.

4.0 CHARACTERIZATION TESTS

4.1 Introduction

This section presents all the characterization tests that have been performed, on site or in the laboratory, on soils and sections of concrete pavers. These tests allow us to know the physical and/or mechanical properties of these elements. The tests were carried out according to the following standards:

- Determination of the density with the sand-cone method (ASTM D1556/D1556M) ;
- Light dynamic variable energy penetrometer (Panda) (no standard) ;
- Light Falling Weight Deflectometer (LFWD) (no standard) ;
- Particle size analysis by sieving (ASTM C136, LC 21-040, NQ 2560-040) ;
- Gradation analysis by sedimentation (ASTM C136, LC 21-040, NQ 2501-025) ;
- Determination of the water content (ASTM D4959, BNQ 2501-170, LC 21-201) ;
- Consistency limits (ASTM D4318, CAN/BNQ 2501-090, CAN/BNQ 2501-170);
- Oedometric compaction/consolidation (ASTM D2435, LC 22-301) ;
- Determination of segregation potential (ASTM D5918, LC 22-331);
- Proctor standard/normal (ASTM D 698, CAN/BNQ 2501-250).

4.2 Field Tests

Following the excavation, a sand cone test(s) was performed to determine the density (MV) of the uncompacted (in situ) soil in place (SNC). In some cases, the MV was determined on the soil in place after being compacted (SC) using a vibrating plate. The steps of the sand cone test are as follows: 1) making a hole in the ground, 2) weighing the recovered soil, 3) filling the hole with calibrated sand, and 4) weighing the sand required for filling, which allows to know the volume of the hole and then the MV of the soil in place (in situ). The density test results for each site are shown in Table 3. Considering the dry density values calculated using the results of the sand cone tests (Table 3) and the moisture content determined in the laboratory, and the optimal dry density values determined using the Proctor test (Table 9), the degree of soil compaction at sites 67, 114 and 204 is 82%, 71% and 74 to 78%, respectively.

Table 3 Results of soil density tests in place (in situ) for MV and GBS sections.

Test	Measured parameter	Material [A]	Depth of the survey (m) [B]	Site		
				67	114	204
Sand cone	Density in situ (ρ, kg/m³)	SNC	0 à 0,15	1 669 (1)	N. D.	1 581 (1)
		SC	0 à 0,15	ND	1 375 (1)	1 612 (1)
	Dry density (ρd, kg/m³) [C]	SNC	0 à 0,15	1 357	N. D.	1 195
		SC	0 à 0,15	N. D.	1 066	1 127

A SNC: Uncompacted soil; SC: Compacted soil with a vibrating plate.
B From the bottom of the excavation.
C Considering the water content determined in the laboratory (value given in Table 9).
(X) Number of completed tests indicated with exponents and in parentheses.
N. D. Not available

For each site, variable energy light dynamic penetrometer tests (Panda, PA_x) were performed (Figures 8, 9 and 10). These tests were first performed on uncompacted soil (CNS), then on compacted soil (SC) and finally on compacted crushed stone (PCC). The Panda consists of a metal rod that is driven into the ground (or stone) by manual beating in order to know the peak strength of the material as a function of depth and thus, to know the mechanical strength of the material. The peak strength varies according to the type of soil and its rigidity. With this device, it is therefore possible to define the stratigraphy (location of the different layers) of a site according to its peak strength. In addition, the resistance at the tip of the ground can be converted into mechanical resistance (resilient module, Mr).

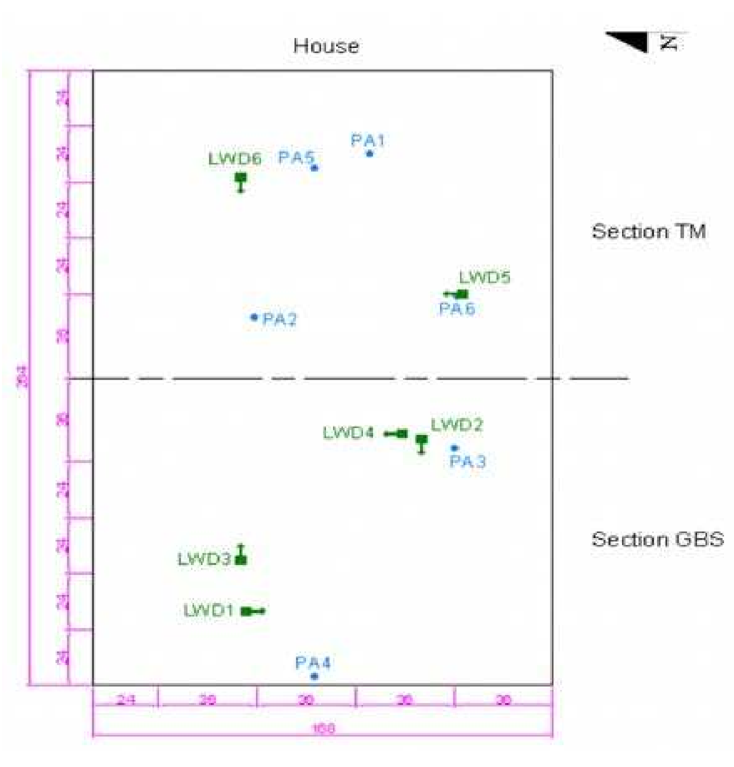

Figure 8 Location of the Panda (PA) and LFWD (LWD) trials at 67 Roxton Crescent in Montreal West.

Figure 9 Location of the Panda (PA) and LFWD (LWD) trials at 114 Daigneault Street in Chambly.

The values of Mr CNS, SC and PCC as a function of depth for each site are given in Tables 4 to 6.

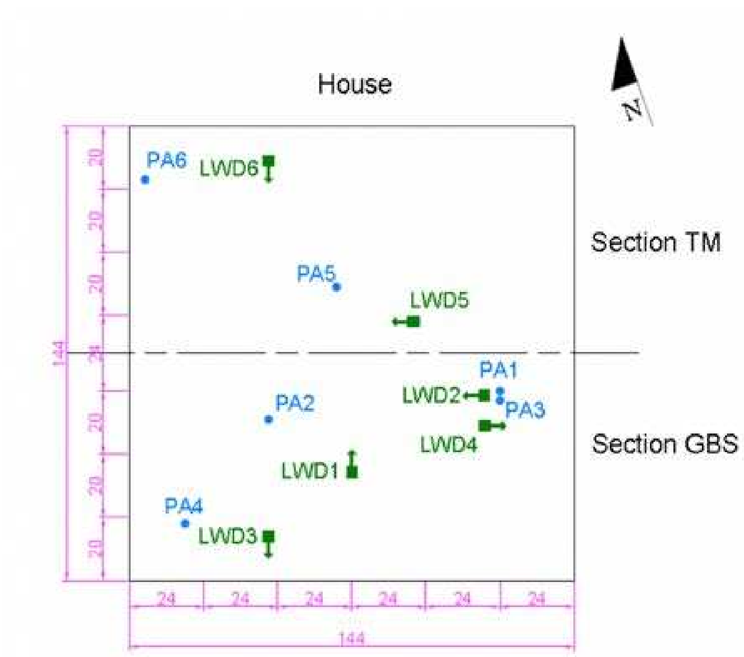

Figure 10 Location of the Panda (PA) and LFWD (LWD) trials at 204 Dufferin Avenue in Hampstead.

Table 4 Panda test results at uncompacted soil (SNC) at TM and GBS sections.

<table>
<tr><th rowspan="3">Test [A]</th><th rowspan="3">Measured parameter</th><th rowspan="3">Material</th><th rowspan="3">Depth of the survey (m) [B]</th><th colspan="6">Site</th></tr>
<tr><th colspan="2">67</th><th colspan="2">114</th><th colspan="2">204</th></tr>
<tr><th>TM PA1</th><th>GBS PA3</th><th>TM PA1</th><th>GBS PA3</th><th>TM PA5</th><th>GBS PA1</th></tr>
<tr><td rowspan="12">Panda</td><td rowspan="12">Resistance at tip converted into resilient module (Mr in MPa)</td><td rowspan="12">SNC</td><td>0,0 à 0,1</td><td rowspan="2">38</td><td rowspan="2">32</td><td rowspan="2">25</td><td rowspan="2">27</td><td rowspan="9">50</td><td rowspan="4">41</td></tr>
<tr><td>0,1 à 0,2</td></tr>
<tr><td>0,2 à 0,3</td><td rowspan="7">29</td><td rowspan="7">38</td><td rowspan="3">38</td><td rowspan="3">41</td></tr>
<tr><td>0,3 à 0,4</td></tr>
<tr><td>0,4 à 0,5</td><td rowspan="4">53</td></tr>
<tr><td>0,5 à 0,6</td><td rowspan="7">44</td><td rowspan="7">46</td></tr>
<tr><td>0,6 à 0,7</td></tr>
<tr><td>0,7 à 0,8</td></tr>
<tr><td>0,8 à 0,9</td><td rowspan="4">51</td></tr>
<tr><td>0,9 à 1,0</td><td rowspan="2">50</td><td rowspan="3">112</td><td rowspan="2">71</td></tr>
<tr><td>1,0 à 1,1</td></tr>
<tr><td>1,1 à 1,2</td><td>46</td><td>88</td></tr>
<tr><td colspan="10">A Two (2) tests were carried out, the results of which are displayed for each of the sites.
B From bottom of excavation for the two (2) sections: TM et GBS.</td></tr>
</table>

Table 5 Panda test results at compacted soil (SC) at MV and GBS sections.

<table>
<tr><th rowspan="3">Test [A]</th><th rowspan="3">Measured parameter</th><th rowspan="3">Material</th><th rowspan="3">Depth of the survey (m) [B]</th><th colspan="6">Site</th></tr>
<tr><th colspan="2">67</th><th colspan="2">114</th><th colspan="2">204</th></tr>
<tr><th>TM PA5</th><th>GBS PA4</th><th>TM PA2</th><th>GBS PA4</th><th>TM PA5</th><th>GBS PA2</th></tr>
<tr><td rowspan="12">Panda</td><td rowspan="12">Resistance at tip converted into resilient module (Mr in MPa)</td><td rowspan="12">SC</td><td>0,0 à 0,1</td><td rowspan="5">37</td><td rowspan="4">50</td><td rowspan="5">42</td><td rowspan="4">37</td><td rowspan="2">37</td><td rowspan="2">34</td></tr>
<tr><td>0,1 à 0,2</td></tr>
<tr><td>0,2 à 0,3</td><td rowspan="3">48</td><td rowspan="2">46</td></tr>
<tr><td>0,3 à 0,4</td></tr>
<tr><td>0,4 à 0,5</td><td rowspan="6">71</td><td rowspan="3">48</td><td rowspan="8">52</td></tr>
<tr><td>0,5 à 0,6</td><td rowspan="3">42</td><td rowspan="3">46</td><td rowspan="7">52</td></tr>
<tr><td>0,6 à 0,7</td></tr>
<tr><td>0,7 à 0,8</td><td rowspan="5">51</td></tr>
<tr><td>0,8 à 0,9</td><td rowspan="3">34</td><td rowspan="4">51</td></tr>
<tr><td>0,9 à 1,0</td></tr>
<tr><td>1,0 à 1,1</td><td rowspan="2">51</td></tr>
<tr><td>1,1 à 1,2</td><td>51</td></tr>
<tr><td colspan="10">A Two (2) tests were carried out, the results of which are displayed for each of the sites.
B From bottom of excavation for the two (2) sections: TM et GBS.</td></tr>
</table>

With the exception of the site at 114 Daigneault Street and by comparing the results of the Panda tests in Tables 4 and 5, it can be seen that compacted soil (SC) has essentially the same mechanical characteristics as uncompacted soil (SNC). This can be explained by the high water content of the soils. These water contents are higher than those considered optimal for compaction (ref. Proctor tests: additional details in section 4.3). However, this can be mainly due to the low density of soils that are clayey and reworked. In addition, the low compaction energy provided by the small vibrating plates is not very effective for soil densification. By comparing the results of the tests in Tables 4 and 5 with those in Table 6, it can be seen that from 0.0 to 0.2 m, the mechanical strength (Mr) increases considerably. Mr goes from an average value of 50 MPa to an average value of 113 MPa due to the installation of the PCC despite its thickness of 0.150 m (6”). It should be mentioned, however, that this value of 113 MPa is relatively low for a compacted PCC layer that should be around 300 MPa. The low compaction energy and low capacity of infrastructure soils explain this difference.

Table 6 Panda test results for compacted crushed stone (PCC) at MV sections.

<table>
<tr><th rowspan="3">Test [A]</th><th rowspan="3">Measured parameter</th><th rowspan="3">Material</th><th rowspan="3">Depth of the survey (m) [B]</th><th colspan="6">Site</th></tr>
<tr><th colspan="2">67</th><th colspan="2">114</th><th colspan="2">204</th></tr>
<tr><th>PA5</th><th>PA6</th><th>PA7</th><th>PA8</th><th>PA6</th><th>PA7</th></tr>
<tr><td rowspan="12">Panda</td><td rowspan="12">Resistance at tip converted into resilient module (Mr in MPa)</td><td rowspan="12">PCC</td><td>0,0 à 0,1</td><td rowspan="2">71</td><td rowspan="2">71</td><td rowspan="2">71</td><td rowspan="2">71</td><td rowspan="2">75</td><td rowspan="2">71</td></tr>
<tr><td>0,1 à 0,2</td></tr>
<tr><td>0,2 à 0,3</td><td rowspan="5">34</td><td rowspan="10">37</td><td rowspan="2">34</td><td rowspan="3">32</td><td rowspan="2">34</td><td rowspan="3">34</td></tr>
<tr><td>0,3 à 0,4</td></tr>
<tr><td>0,4 à 0,5</td><td rowspan="3">44</td><td rowspan="3">48</td></tr>
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<tr><td>0,6 à 0,7</td></tr>
<tr><td>0,7 à 0,8</td><td>46</td><td rowspan="5">51</td><td rowspan="3">46</td><td rowspan="5">52</td></tr>
<tr><td>0,8 à 0,9</td><td rowspan="4">38</td></tr>
<tr><td>0,9 à 1,0</td></tr>
<tr><td>1,0 à 1,1</td><td rowspan="2">51</td><td rowspan="2">51</td></tr>
<tr><td>1,1 à 1,2</td></tr>
<tr><td colspan="10">A Two (2) tests were carried out, the results of which are displayed for each of the sites.
B From the surface of compacted crushed stone (PCC) only for section TM because section GBS does not have a PCC with a thickness of 2” (0,051m).</td></tr>
</table>

At each stage of construction, for each layer, the modulus of rigidity (or carrying capacity in MPa) was measured using the LFWD (Light Falling Weight Deflectometer), i.e.: on compacted soil (SC), compacted crushed stone (PCC), expanded polymer panels (PPE) and slabs (D) or concrete pavers (PU). For each site, the location of the LFWD tests is shown in Figures 8, 9 and 10. The LFWD test consists of dropping a given mass of a known height onto an aluminum plate (100 mm to 150 mm in diameter) that rests on the surface to be tested. The plate is perforated in its center where a geophone rests on the surface to measure the deflection of the surface following the fall of the mass. In addition, a sensor measures the force (in kN) (or stress in kPa) generated by the falling mass on the surface. From retro-calculation software and deflection and force measurements, it is possible to estimate the modulus of rigidity of the material(s) constituting the structure under load. The deflection measured at the surface includes the deflections of each of the layers of the structure deformed by the impact. The module obtained is global and represents the module of the structure and not the module of the surface. The results of the LFWD tests for the sections developed using the traditional method (TM) and the Gator Base System (GBS) are presented in Tables 7 and 8, respectively.

Table 7 LFWD test results for sections developed using the traditional method (TM).

Test [A]	Statement elevation (m) [B]	Measured parameter	Site		
			67	114	204
LFWD	0,000 : at SC's level	Force (kN)	101 (2)	45 (1)	91 (2)
		Deflection (mm)	4,744 (2)	1,288 (1)	4,100 (2)
		Rigidity modulus (MPa)	**6 (2)**	**9 (1)**	**6 (2)**
	0,127 : at PCC's level	Force (kN)	105 (2)	108 (2)	105 (2)
		Deflection (mm)	1,502 (2)	1,585 (2)	1,560 (2)
		Rigidity modulus (MPa)	**19 (2)**	**18 (2)**	**18 (2)**
	0,168 ou 0,203 [C] : at D or PU's level	Force (kN)	8,0 (3)	N. D.	8,1 (6)
		Deflection (mm)	0,007 (3)		0,003 (6)
		Rigidity modulus (MPa)	**4 443 (3)**		**9 315 (6)**

A Number of tests carried out and validated is indicated by exhibiting and in parentheses.
B From bottom of excavation (SC: compacted soil, PCC: compacted crushed stone and PU: plains pavers).
C Although the level is the same, elevation varies due to the different thickness of the covering: slabs (D) or plain pavers (PU).
** High deflection (mm) generating a modulus of weak rigidity (MPa).
N. D. Not available

Table 8 LFWD test results for sections constructed with the Gator Base System (GBS).

Test [A]	Statement elevation (m) [B]	Measured parameter	Site		
			67	114	204
LFWD	0,000 : at SC's level	Force (kN)	101 (2)	45 (1)	91 (2)
		Deflection (mm)	4,744 (2)	1,288 (1)	4,100 (2)
		Rigidity modulus (MPa)	**6 (2)**	**9 (1)**	**6 (2)**
	0,033 ou 0,084 [C] : at PPE's level	Force (kN)	101 (2)	93 (2)	93 (2)
		Deflection (mm)	2,332 (2)	5,101 (2)	5,101 (2)
		Rigidity modulus (MPa)	**11 (2)**	**5 (2)**	**5 (2)**
	0,093 ou 0,109 [D]: at D or PU's level	Force (kN)	7,9 (4)	N. D.	8,0 (8)
		Deflection (mm)	0,010 (4)		0,007 (8)
		Rigidity modulus (MPa)	**3 088 (4)**		**4 061 (8)**

A Number of tests carried out and validated is indicated by exhibiting and in parentheses.
B From bottom of excavation (SC: compacted soil, PPE: expensed polymer panel and D: slabs or PU: plains pavers).
C For section du 67, Roxton, it was necessary to add about 50 mm of PCC due to over-excavation.
D Although the level is the same, the elevation varies due to the placement of about 0,050m of PCC and the different thickness of the slabs / plain pavers.
** High deflection (mm) generating a modulus of weak rigidity (MPa).
N. D. Not available

The LFWD results obtained for both systems indicate very low infrastructure soil (SC) capacity for each site. Indeed, global modules below 30 MPa are considered low in road construction. Remember that this test provides an overview of the overall rigidity of the structure. The addition of the PCC and PPE layer does not change the results. The reversible modulus obtained in the PCC layer by means of the penetrometer is 72 MPa. With the LFWD we obtain at best 19 MPa. This shows that it is the capacity of the infrastructure soil that governs. With the addition of concrete elements (paving stones and slabs) the overall rigidity increases more than significantly. In fact, the load-bearing capacity of both systems is obtained by the paved surface.

The difference in modulus observed at the surface between site 67 and site 204 for both systems is explained by the contact surface mobilized during the test. The deflection obtained on the slabs is greater because the mobilized surface is larger. This produces a lower contact stress, but which is felt over a greater depth. The size of the stress bulb is proportional to the contact surface of the load. Figure 11 shows this principle. As shallow soils extend over a large depth, the recorded deflections are larger and therefore the recorded moduli are smaller.

Similarly, the difference in rigidity observed between TM and GBS for slabs and paving stones is explained by the fact that GBS has taken over loads over a larger area. GBS PEPs distribute loads over a larger area and offer a reduced contact stress, but which acts over a greater depth. This larger deflection suggests a lower stiffness. This is the case since there are more weak soils mobilized with PEPs than with granular foundation.

LFWD results on the surface of site 114 are not available due to a failure of the LFWD device at the time of testing.

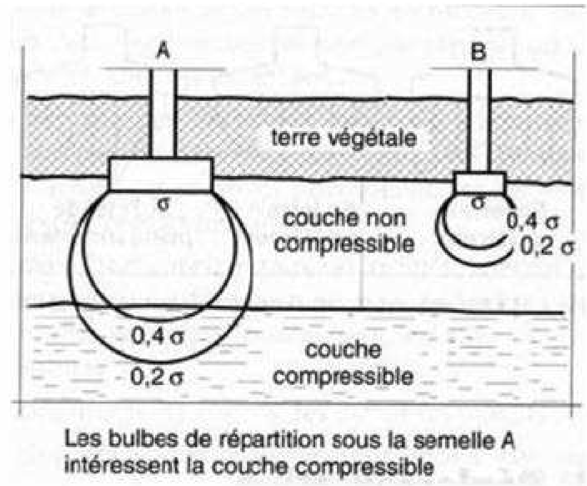


Figure 11 Principle of the bulb of stresses through different soil layers for the same load.

4.3 Laboratory Tests

The nine (9) soil samples (presented in Section **3.0 Soil Sampling**) were transported to our laboratory for examination and characterized using geotechnical tests. All laboratory test results are presented in Table 9.

The water contents (%w) determined on the soils of the three (3) sites varies from 21 to 40%. These %w values are higher than the optimal values (20 to 26%) for compaction that are determined using the standard (or normal) Proctor test.

On each of the soils, gradation analyses by sieving and sedimentation tests were carried out (Table 9). A graphical representation of the results of these tests is shown in Figures 12, 13 and 14.

Laboratory analyses allow soils to be classified according to the Unified Soil Classification System (USCS). This classification system groups soils according to aggregate size and consistency. The soils encountered are inorganic clays with medium to high plasticity (LC) (Table 9).

In addition, the consolidation test determines that the effective consolidation stress (σ´p) of the soils at sites 67 and 114 is 135 and 87 kPa, respectively. So, if the soil is subjected to a higher stress σ´p, it will have a so-called high settlement. In particular, these soils have a relatively low mechanical resistance comparable to soft clays.

A priori, based on soil grain size and the proportion of fine particles (U.S. Corps of Engineers, USCE criteria), it is possible to estimate their susceptibility to frost. To this end, for all soils, the potential for frost damage and the loss of bearing capacity during thawing are very convincing because they are classified as gel materials. This statement was clarified using the segregation potential tests (Table 9).

Finally, it is important to note that the clay soils present on the sites came from fairly heterogeneous fill and that the results of the laboratory tests represent the average of the characteristics of these soils.

Table 9 Results of all laboratory tests.

Test	Measured parameter		67	114	204
Water content *	w (%)		21^{GP1} 23^{MV1}	35^{GP1} 35^{GP2} 29^{MV1}	32^{GP1} 40^{MV1} 34^{MV2}
Standard (or normal) Proctor	Optimum water content (w_{opt}, %)		20	25	26
	Optimum dry density ($\rho_{d\ opt}$, kg/m^3)		1 660	1 500	1 520
Gradation analyses	by sieving	Soil class**	inorganic clays with medium plasticity (CL)	inorganic clays with high plastici-ty (CH)	inorganic clays with high plastici-ty (CH)
	by sedimentation				
Consistency limits	of liquidity (w_l, %)		37	55	54
	of plasticity (w_p, %)		22	28	25
Index	of plasticity (Ip = wp - wl, %)		15	27	29
Oedometric consolidation	Soil density (ρ, kg/m^3)	initial	1 790	1 860	Not retained for analysis
		final	2 080	1 840	
	Soil dry density (ρ_d, kg/m^3)	initial	1 400	1 420	
		final	1 650	1 420	
	Water content (w, %)	initial	28	31	
		final	26	29	
	Saturation degree (%)	initial	74	83	
	Effective consolidation stress (σ´p, kPa,)		135	87	
Cone Penetrometer	Shear resistance (kPa)		Unrealized ***	Unrealized ***	
Segregation potential	Water content (w, %)		36	44	
	Setting up the sample : overload pressure (kPa)		20 - 25	60	
	Frost heave susceptibility (SPo, mm^2/°C*day)		8,5 : <12 Negligible	92,9 : 75-200 High	

* For this test, the sample number is indicated by exponent.
** It is necessary to refer to the consistency limits in order to properly classify the soil.
*** Due to the presence of stones, vegetable and organic materials. This does not allow to adequately per form the test.

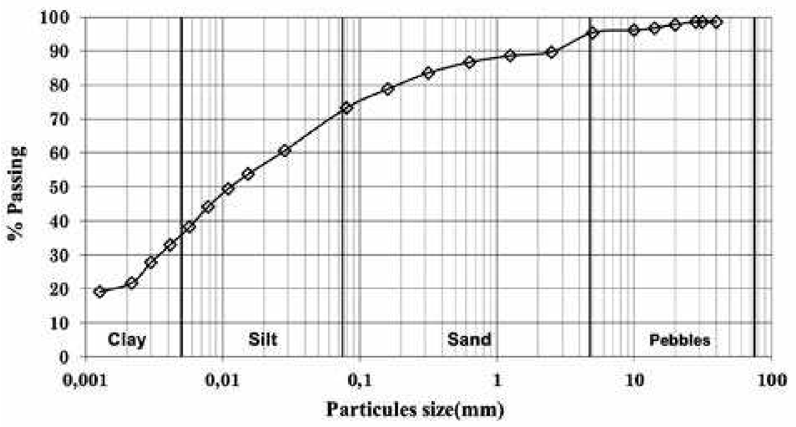


Figure 12 Results of sieving and sedimentation analysis for the soil at 67 Roxton Crescent in Montreal West.

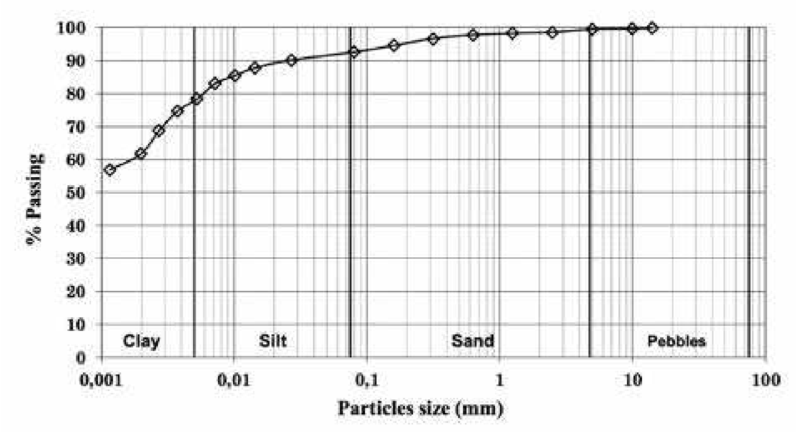


Figure 13 Results of sieving and sedimentation analyses for the soil at 114, Rue Daigneault in Chambly.

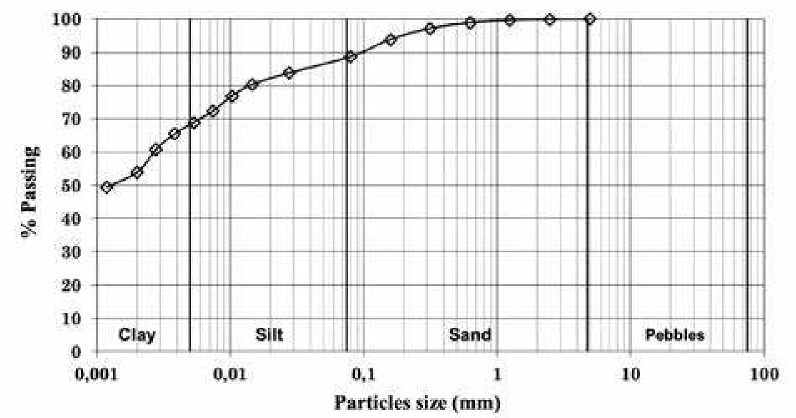


Figure 14 Results of sieving and sedimentation analyses for soil at 204 Dufferin Avenue in Hampstead.

4.4 Conclusion

The sites investigated consist of backfill soils from construction excavations. The site and laboratory tests present the characteristics of these soils at the location where these tests were performed and samples were taken. Results may therefore vary from one location to another for the same site.

Density tests (MV) with sand cone and standard (or normal) Proctor laboratory tests reveal that soils have a low level of compaction (71 to 82%). In addition, laboratory tests for determining water content reveal that soils contain a lot of water (21 to 40%). Laboratory tests of consistency limits, particle size analyses by sieving and sedimentation classify soils as inorganic clays with medium (LC) to high (CH) plasticity. Also, these tests classify these soils as possibly gelling materials. Although both are clay, the CL at site 67 is not very frost sensitive while the CH at site 114 is very frost sensitive. However, based on the nature of the backfill observed at each site, these soils (CL and CH) can be considered as gelling.

The site tests of the light dynamic variable energy penetrometer (Panda) and Light Falling Weight Deflectometer (LFWD) show that the existing infrastructure soils, exclusively clay backfill soils for the three sites, have low mechanical strength. The LFWD results show that the larger the contact surface of the load with the ground, the deeper the stress is felt and the greater the deflections. This confirms the low load-bearing capacity of infrastructure soils and explains the lower stiffness values expressed in global modulus.

5.0 TEMPERATURE READINGS

5.1 Introduction

Thermal instrumentation was installed at the three study sites to study the insulating potential of the Gator Base System (GBS) expanded polyethylene (EPP) panels. The assumption is that the 19 mm thick GBS with EPP insulates as well as a 150 mm granular foundation. The objective of the site instrumentation is to demonstrate this insulating potential in the application of solid paving stone patios.

For each of the sites, the instrumentation, i.e. the seven (7) thermocouples and the acquisition box, made it possible to identify: A) the ambient air temperature or outside temperature (T_{air}, x1), B) the ground temperatures under the crushed stone for the TM section ($T_{on\ TM\ soil}$, x2) and under the sand bed for the GBS section ($T_{on\ GBS\ soil}$, x2) and C) the ground temperature at 150 mm depth for the TM section ($T_{150\ mm\ TM\ soil}$, x1) and for the GBS section ($T_{150\ mm\ GBS\ soil}$, x1). Here, the presentation and analysis of temperature readings is done one site at a time (§ 5.2, 5.3 and 5.4). Before proceeding to the presentation and analysis of the results, it is important to note that the environmental conditions, namely the presence of snow (insulating power), trees, shrubs and dwellings (creation of shade and heat transfer), have a significant impact on the thermal performance measured on the sites for each section.

5.2 Temperature readings at 67 Roxton Crescent in Montreal West

For Site 67, cold weather temperature readings from September to April for the entire duration of the survey, from September 24, 2015 to December 19, 2018, are shown in Figure 15. Figure 15 shows that the temperatures recorded for the TM section (red color lines), as well as the ambient temperature (T_{air}, blue dotted line), vary more than those recorded for the GBS section (green color lines). Overall, for this site, the GBS is more insulating than the MV. However, it should be noted that the thermocouple recording the temperature at 150 mm below the TM section did not record a temperature. This is a hazard of this type of installation. The temperature variation is much more stable with GBS than TM. In addition, the GBS temperatures go very little below zero, so very little frost. Additional details regarding the surveys at Site 67 are presented in Tables 10 and 11, including means and standard deviations.

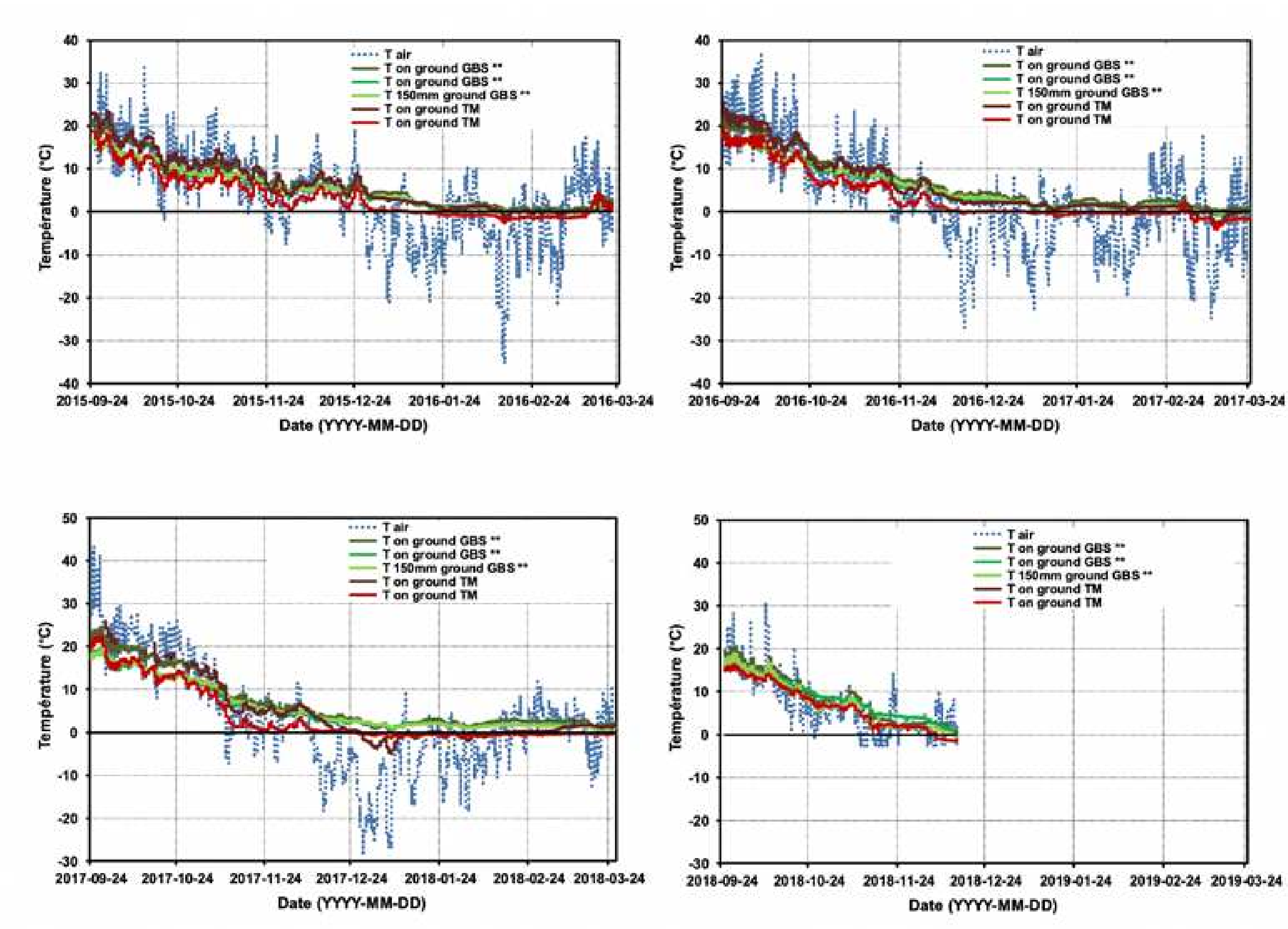


Figure 15 Temperature readings during the cold period at 67 Roxton Crescent in Montreal West

Figure 16 shows the temperatures recorded from September 24, 2015 to December 19, 2018, for the warm periods of the year, from April to September. Again, the temperatures recorded for the TM section vary more than those recorded for the GBS section. This means that the GBS section offers better thermal insulation. Overall, for this period, the temperatures associated with the GBS are lower than those of TM.

These results must be qualified, however, because the layout of the patio to the various elements of the yard (house, furniture, air conditioning, shrubs, hedges, fence, etc.) can have an effect on air movement and sun exposure leading to localized temperature variations that have an impact on the measurements.

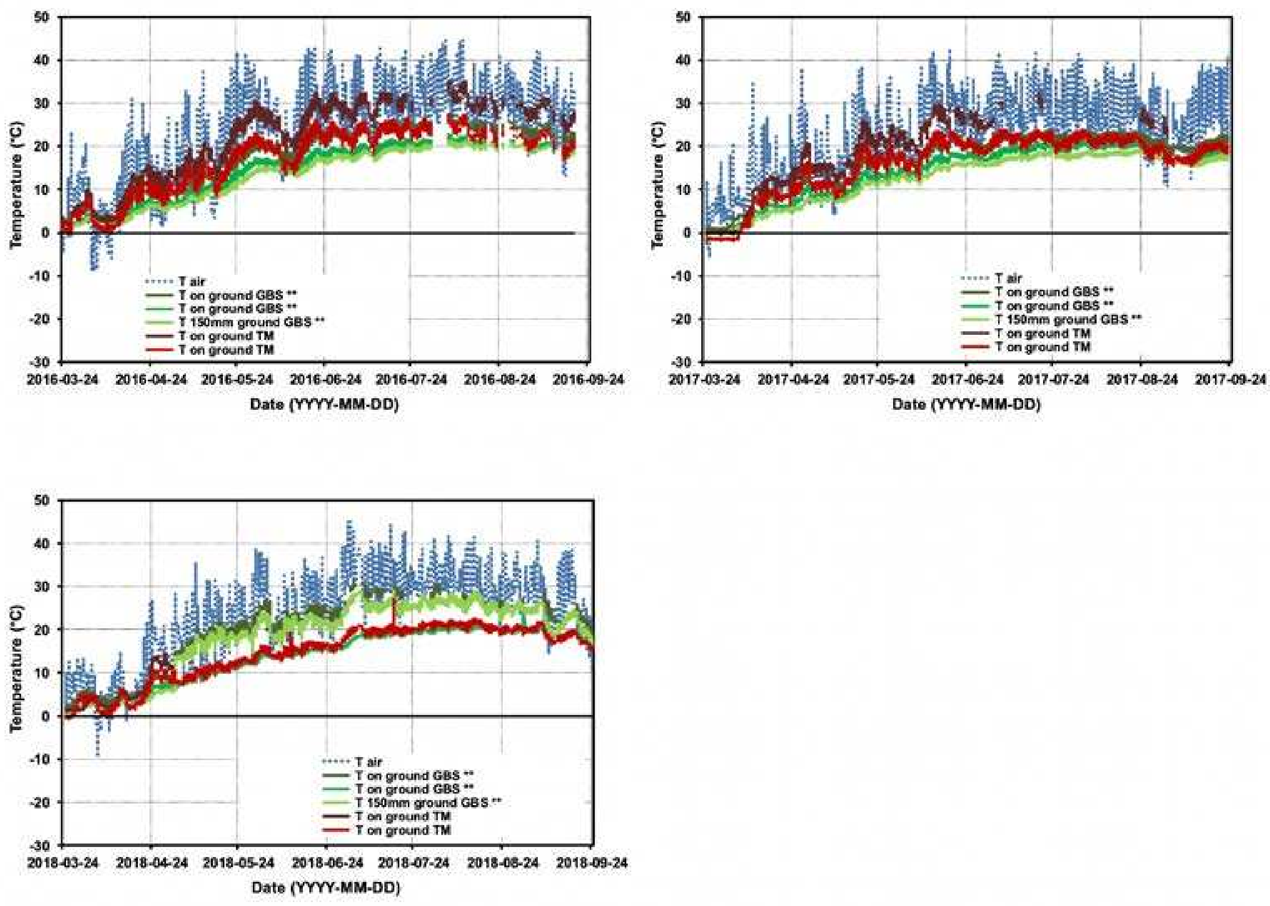


Figure 16 Temperature readings during the hot period at 67 Roxton Crescent in Montreal West.

Table 10 Summary of temperature readings taken during cold periods at 67 Roxton Crescent in Montreal West.

Periods	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2 *	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7 *	$T_{on\ ground\ GBS}$ T3 **	$T_{on\ ground\ GBS}$ T6 **	$T_{150\ mm\ ground\ GBS}$ T5 **
Analysis 1st cold period 2015-09-24 to 2016-03-24	MIN	-35,3	-1,6	-2,6	r. t. i.	-0,4	-1,0	-0,5
	MAX	33,6	23,5	18,9	r. t. i.	20,9	16,5	16,7
	Extended (Max-Min)	68,9	25,1	23,4	r. t. i.	22,9	17,5	17,2
	Standard devia. (σ)	10,2	6,0	4,9	r. t. i.	5,4	4,6	4,7
	Average	3,3	6,2	3,4	r. t. i.	6,4	4,9	5,1
Analysis 2nd cold period 2016-09-24 to 2017-03-24	MIN	-27,0	-3,6	-4,3	r. t. i.	-0,02	-0,9	-0,5
	MAX	36,6	25,6	20,0	r. t. i.	22,2	18,5	18,7
	Extended (Max-Min)	63,6	29,3	24,2	r. t. i.	22,2	19,42	19,1
	Standard devia. (σ)	10,6	6,7	5,7	r. t. i.	6,0	5,1	5,2
	Average	2,3	5,9	3,3	r. t. i.	6,6	5,1	5,4
Analysis 3rd cold period 2017-09-24 to 2018-03-24	MIN	-28,7	-5,1	-1,3	r. t. i.	0,5	0,47	0,29
	MAX	43,3	25,9	22,5	r. t. i.	24,4	19,4	19,18
	Extended (Max-Min)	71,9	31,0	27,0	r. t. i.	23,9	23,2	18,89
	Standard devia. (σ)	12,1	5,7	6,4	r. t. i.	6,5	5,3	5,46
	Average	2,6	3,1	3,6	r. t. i.	6,9	5,5	5,7
Analyse 4th cold period 2018-09-24 to 2018-12-14	MIN	-2,6	r. t. i.	-1,6	r. t. i.	0,6	1,2	-0,4
	MAX	30,8	r. t. i.	16,5	r. t. i.	20,3	16,8	18,8
	Extended (Max-Min)	33,4	r. t. i.	18,0	r. t. i.	19,7	15,7	20,9
	Standard devia. (σ)	6,5	r. t. i.	5,2	r. t. i.	5,6	4,7	5,6
	Average	6,7	r. t. i.	6,6	r. t. i.	8,5	8,6	7,2

* Inadequate temperature reading (r. t .i) because it is very similar to that of T_{air}.
** Advantage section GBS, compared to TM, because 51 mm of 0-20 mm crushed stone was added to the design originally planned to fill one on excavation.

Tableau 11 Summary of temperature readings taken during hot periods at 67 Roxton Crescent in Montreal West

Periods	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2 *	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7 *	$T_{on\ ground\ GBS}$ T3 **	$T_{on\ ground\ GBS}$ T6 **	$T_{150\ mm\ ground\ GBS}$ T5 **
Analysis 1st hot period 2016-03-24 to 2016-09-24	MIN	-8,6	0,6	-0,9	r. t. i.	1,9	0,5	0,4
	MAX	44,6	35,0	27,4	r. t. i.	27,2	22,7	21,2
	Extended (Max-Min)	53,3	34,4	28,3	r. t. i.	25,3	22,2	20,8
	Standard devia. (σ)	10,9	9,6	7,7	r. t. i.	7,6	6,8	6,6
	Average	22,8	20,8	16,4	r. t. i.	16,7	13,5	12,6
Analysis 2nd hot period 2017-03-24 to 2017-09-24	MIN	-5,93	-0,46	-1,94	r. t. i.	0,55	-0,41	-0,51
	MAX	42,64	32,32	23,84	r. t. i.	23,78	21,62	19,16
	Extended (Max-Min)	48,58	32,77	25,78	r. t. i.	23,23	22,03	22,03
	Standard devia. (σ)	8,88	8,90	6,94	r. t. i.	6,59	6,23	5,93
	Average	21,9	16	15,9	r. t. i.	16,5	14	12,7
Analysis 2nd hot period 2018-03-24 to 2018-09-24	MIN	-9,58	r. t. i.	-0,64	r. t. i.	1,34	1,07	0,56
	MAX	45,21	r. t. i.	27,21	r. t. i.	32,32	25,80	29,02
	Extended (Max-Min)	54,79	r. t. i.	27,85	r. t. i.	30,98	24,73	28,45
	Standard devia. (σ)	10,23	r. t. i.	6,62	r. t. i.	8,79	6,48	8,74
	Average	21,1	r. t. i.	14	r. t. i.	15,6	13,4	17,8

* Inadequate temperature reading (r. t .i) because it is very similar to that of T_{air}.
** Advantage section GBS, compared to TM, because 51 mm of 0-20 mm crushed stone was added to the design originally planned to fill one on excavation.

Following the measurements and observations made on this site. It is clear that the GBS system acts as an isolated structure, i.e. with warmer ground temperatures in winter and cooler in summer.

5.3 Temperature readings at 114 Daigneault Street in Chambly

For Site 114, cold weather temperature readings from September to April for the entire duration of the survey, from September 24, 2015 to December 19, 2018, are shown in Figure 17. In addition, Figure 18 shows the temperatures for the periods from April to September and for the entire duration of the surveys. Tables 12 and 13 summarize the temperature readings for Site 114 during cold and warm periods, respectively. On this site it can be seen that the temperatures at the surface of the infrastructure ground and at 150 mm depth are very similar for both systems, for both cold and hot periods. These results confirm the superior insulating power of the GBS compared to the much thicker TM.

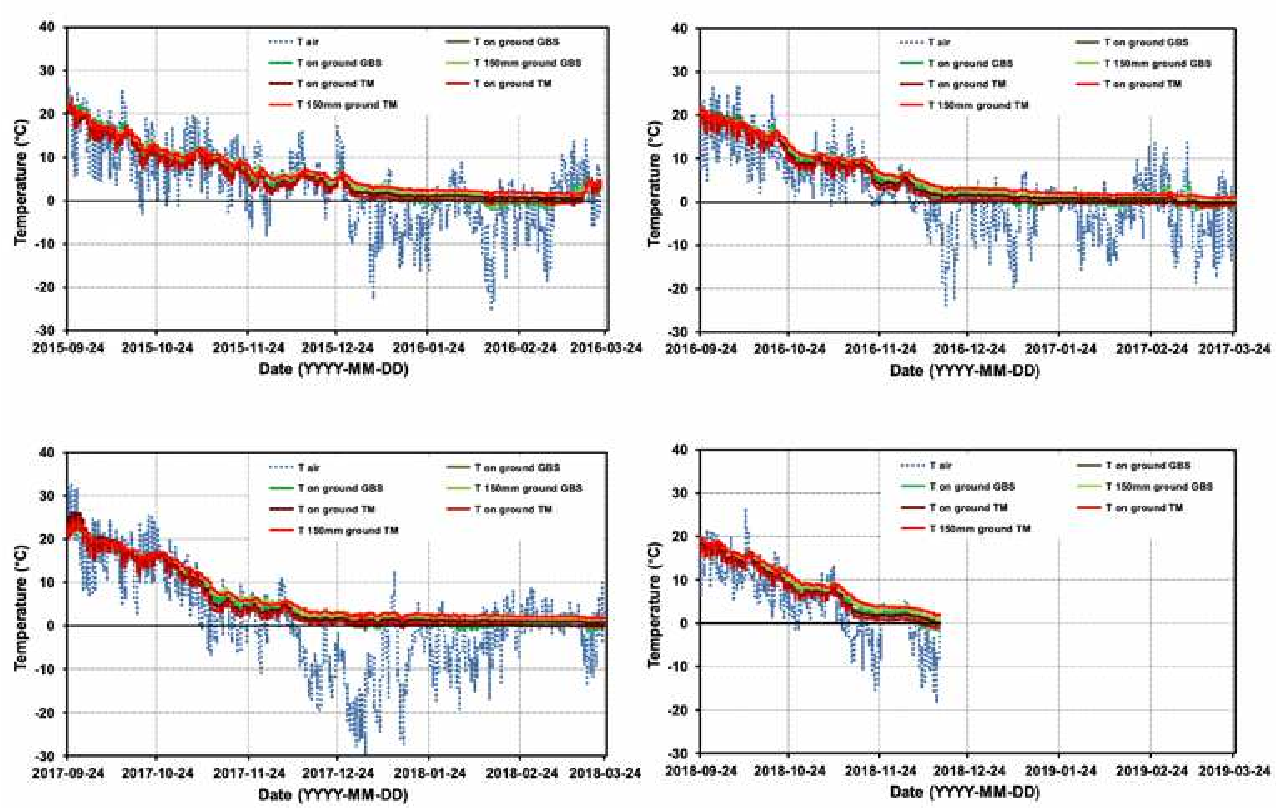


Figure 17 Temperature readings during the cold period at 114, Rue Daigneault in Chambly.

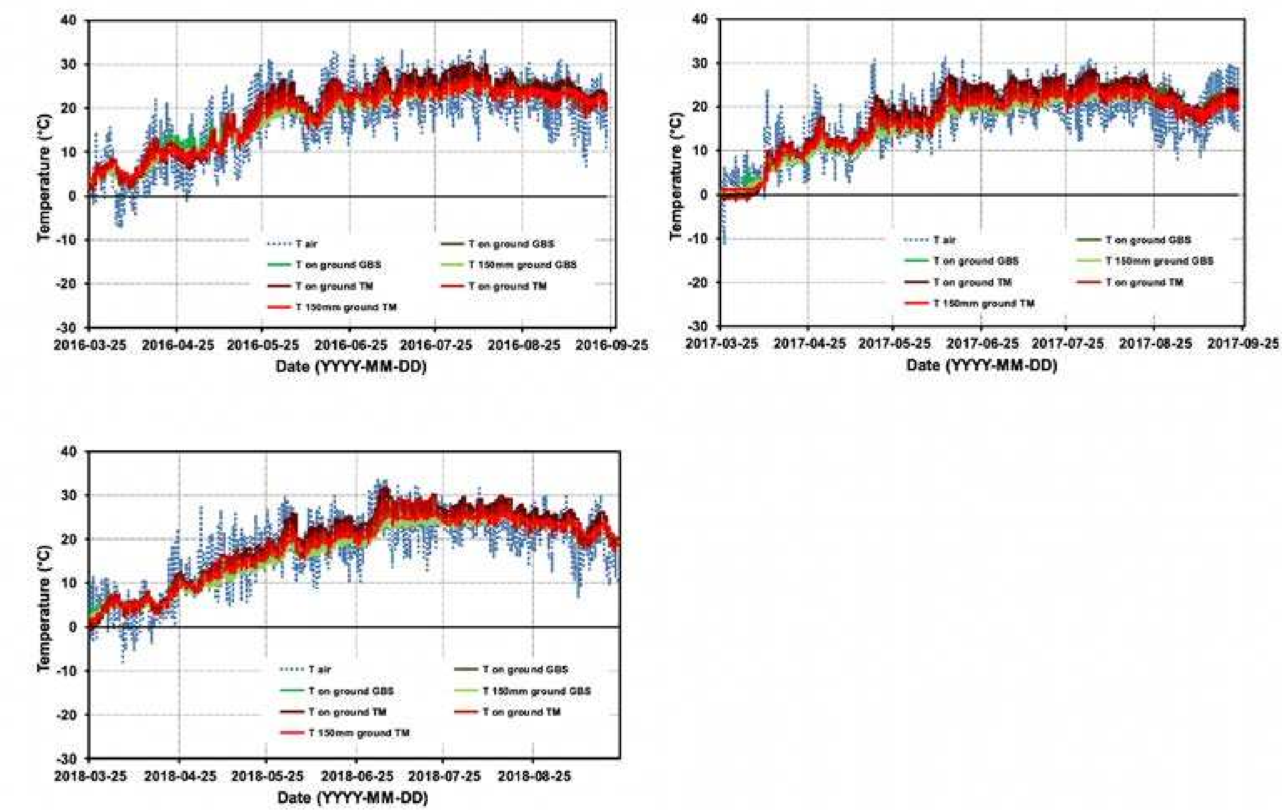


Figure 18   Temperature readings during the warm period at 114, Rue Daigneault in Chambly

Tableau 12 Synthesis of temperature readings during cold periods at 114, Rue Daigneault in Chambly.

Periods	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7	$T_{on\ ground\ GBS}$ T3	$T_{on\ ground\ GBS}$ T6	$T_{150\ mm\ ground\ GBS}$ T5
Analysis 1st cold period 2015-09-24 to 2016-03-24	MIN	-25,5	-0,4	-1,3	0,8	-1,1	-2,0	-1,6
	MAX	26,1	22,6	23,8	22,5	23,0	23,9	22,0
	Extended (Max-Min)	51,6	23,0	25,1	21,7	24,1	26,2	23,6
	Standard devia. (σ)	8,2	5,3	5,8	5,4	5,6	5,9	5,7
	Average	8,3	11,1	10,2	11,2	10,8	10,5	10,5
Analysis 2nd cold period 2016-09-24 to 2017-03-24	MIN	-23,9	-0,7	-1,5	0,6	-0,7	-2,0	-1,1
	MAX	26,9	22,2	20,7	22,1	21,6	20,1	20,7
	Extended (Max-Min)	50,7	22,9	22,2	21,5	22,3	22,4	21,9
	Standard devia. (σ)	8,3	5,9	6,1	5,9	6,2	6,1	6,1
	Average	1,6	5,0	4,1	6,4	5,3	5,0	5,9
Analysis 3rd cold period 2017-09-24 to 2018-03-24	MIN	-30,7	-0,2	-0,8	1,3	-0,2	-1,5	-0,4
	MAX	33,0	26,1	24,6	23,5	25,6	24,4	22,5
	Extended (Max-Min)	63,7	26,4	25,4	22,3	25,8	25,9	22,9
	Standard devia. (σ)	10,8	7,0	6,9	6,6	6,7	6,7	6,5
	Average	0,9	5,6	4,8	6,9	6,0	5,5	6,4
Analysis 4th cold period 2018-09-24 to 2018-12-14	MIN	-18,6	-0,4	-1,3	1,6	-0,5	-1,8	-0,4
	MAX	26,6	18,9	17,8	20,0	18,2	18,9	19,0
	Extended (Max-Min)	45,2	19,4	19,1	18,4	18,7	20,6	19,3
	Standard devia. (σ)	7,6	5,7	5,8	5,4	5,6	5,7	5,4
	Average	4,1	7,5	6,7	9,4	7,9	7,9	8,9

Tableau 13 Synthesis of temperature readings during hot periods at 114, Rue Daigneault in Chambly.

Periods	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7	$T_{on\ ground\ GBS}$ T3	$T_{on\ ground\ GBS}$ T6	$T_{150\ mm\ ground\ GBS}$ T5
Analysis 1st hot period 2016-03-24 to 2016-09-24	MIN	-7,4	1,8	0,9	3,0	1,8	1,5	1,9
	MAX	33,5	30,3	27,5	26,6	28,8	27,9	25,3
	Extended (Max-Min)	40,9	28,5	26,6	23,6	27,0	26,4	23,4
	Standard devia. (σ)	8,3	8,1	7,1	7,0	7,5	7,0	6,8
	Average	17,0	19,1	18,2	17,9	18,2	18,1	17,1
Analysis 2nd hot period 2017-03-24 to 2017-09-24	MIN	-11,4	-0,5	-1,6	0,4	-0,7	-1,3	-0,6
	MAX	31,4	28,6	26,3	24,5	27,3	26,2	23,0
	Extended (Max-Min)	42,9	29,1	27,9	24,1	28,0	27,4	23,6
	Standard devia. (σ)	6,9	7,6	7,1	6,7	7,2	6,6	6,5
	Average	16,5	18,4	17,0	16,8	17,3	16,6	15,8
Analysis 3rd hot period 2018-03-24 to 2018-09-24	MIN	-7,9	0,4	-0,8	1,2	0,9	1,3	0,9
	MAX	34,0	31,7	29,5	25,9	28,8	28,7	25,8
	Extended (Max-Min)	41,9	31,3	30,3	24,7	27,9	27,4	24,9
	Standard devia. (σ)	8,2	8,2	7,7	7,3	7,5	7,5	7,2
	Average	17,4	19,5	18,2	17,8	18,0	18,1	16,9

5.4 Temperature readings at 204 Dufferin Avenue in Hampstead

For Site 204, the results obtained for the total duration of the surveys are incomplete. Indeed, the data acquisition system has failed and the few attempts made to correct this problem have been unsuccessful. Nevertheless, the results are presented in Figures 19 and 20, and the same trend can be observed as at site 114, i.e. very similar temperatures for both systems.

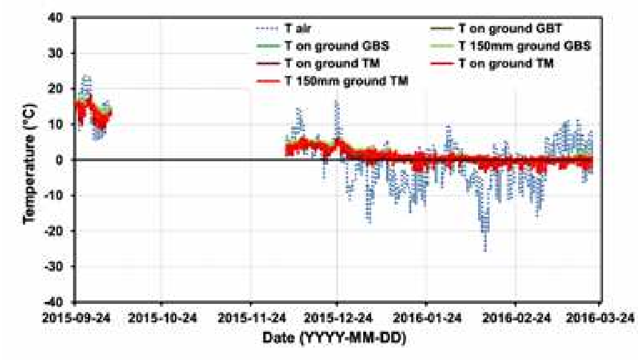


Figure 19 Temperature readings during the cold period at 204 Dufferin Avenue in Hampstead.

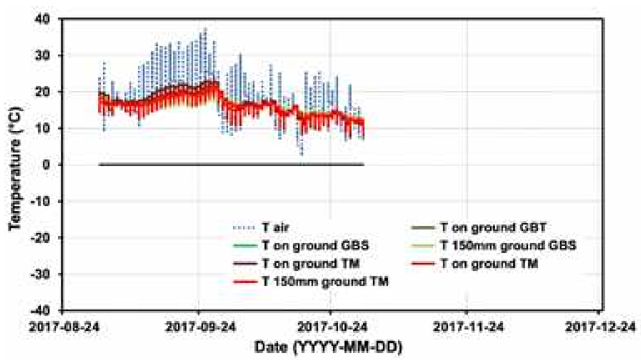


Figure 20 Warm weather temperature readings at 204 Dufferin Avenue in Hampstead.

Tables 14 and 15 provide a summary of the temperature readings available for Site 204. These tables indicate that the temperatures recorded for the GBS section (green color values) vary just a little more than those recorded for the TM section (red color values).

Table 14 Synthesis of cold period temperature readings at 204 Dufferin Avenue in Hampstead.

Period	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7	$T_{on\ ground\ GBS}$ T3	$T_{on\ ground\ GBS}$ T6	$T_{150\ mm\ ground\ GBS}$ T5
Analysis cold period 2015-09-24 to 2016-03-24	MIN	-26,0	-3,5	-4,0	-3,1	-3,7	-3,8	-3,5
	MAX	23,7	18,3	18,1	16,9	18,5	17,8	17,3
	Extended (Max-Min)	49,7	21,8	22,1	20,0	22,2	21,6	20,8
	Standard devia. (σ)	7,8	4,1	4,1	4,2	4,4	4,4	4,4
	Average	-0,87	2,1	1,8	2,6	2,3	2,5	2,9

Table 15 Synthesis of hot weather temperature readings at 204 Dufferin Avenue in Hampstead.

Period	Measure	T_{air} T1	$T_{on\ ground\ TM}$ T2	$T_{on\ ground\ TM}$ T4	$T_{150\ mm\ ground\ TM}$ T7	$T_{on\ ground\ GBS}$ T3	$T_{on\ ground\ GBS}$ T6	$T_{150\ mm\ ground\ GBS}$ T5
Analysis hot period 2017-09-24 to 2017-11-24	MIN	2,5	7,8	7,8	8,6	9,8	9,2	9,1
	MAX	37,2	23,7	23,0	21,7	20,7	22,2	22,0
	Extended (Max-Min)	34,7	15,8	15,2	13,1	11,0	13,0	12,8
	Standard devia. (σ)	5,9	3,2	2,8	2,4	2,0	2,4	2,3
	Average	17,3	16,4	15,6	16	16,1	15,9	16,1

5.5 Section's Conclusion

In the 2014 report, the R value for EPP was 0.6319 m^2*K/W for 25.4 mm thickness or 3.617 $hr*°F*ft^2/BTU$ per inch thickness in the imperial system. According to Berraha et al (2016), the value of R for well compacted dry crushed stone is 0.098 m^2*K/W or 0.559 $hr*°F*ft^2/BTU$ per inch of thickness. The value ratio R (R_{PPE}/R_{0-20}) is equal to the inverse of the thicknesses (e_{0-20}/e_{PPE}), i.e. around 6.5.

The temperature readings taken at the three (3) sites show that the difference between the TM and GBS sections is negligible. To this end, it can be stated that the section developed with the Gator Base System (GBS) made of expanded polymer (EPP) panels has a similar thermal resistance to the section built using the traditional method (TM) developed with compacted crushed stone (PCC) and this for a thickness more than 6 times less.

6.0 TOPOGRAPHIC SURVEYS

6.1 Introduction

These elevation surveys were conducted to compare the structural capacity of the Gator Base system (GBS) with the traditional method (TM). The objective is to demonstrate that the two systems are equivalent for use as a patio. In order to carry out topographic (or profile) surveys of the sections of plain paving stones, a total robotic station was used. In addition, ropes, coloured chalk and a digital camera were required.

6.2 Position and Readings

To date, six (6) topographic surveys have been conducted, one immediately following the construction of the sections, the others at six-month and one-year intervals over a three-year period. The surveys conducted at the end of the freeze period were optional to contractual commitments. Table 16 shows the date of the readings. Profile surveys are carried out by squaring each of the patios. The number of points (point surveys) is the same for each section of the patio at the same site. Figures 21, 22 and 23 illustrate the location of the profile points (point surveys) completed at each site.

Table 16 Date of completion of the surveys by site

Site / Readings	67	114	204
1st reading	2015-09-24	2015-09-24	2015-09-25
2nd reading	2016-03-22	2016-03-22	Not realized due to material storage and snow
3rd reading	2016-09-19	2016-09-19	2016-09-19
4th reading	2017-10-31	2017-10-31	2017-10-31
5th reading	2018-05-07	Not realized due to material storage and snow	2018-05-07
6th reading	2018-12-14	2018-12-14	2018-12-14

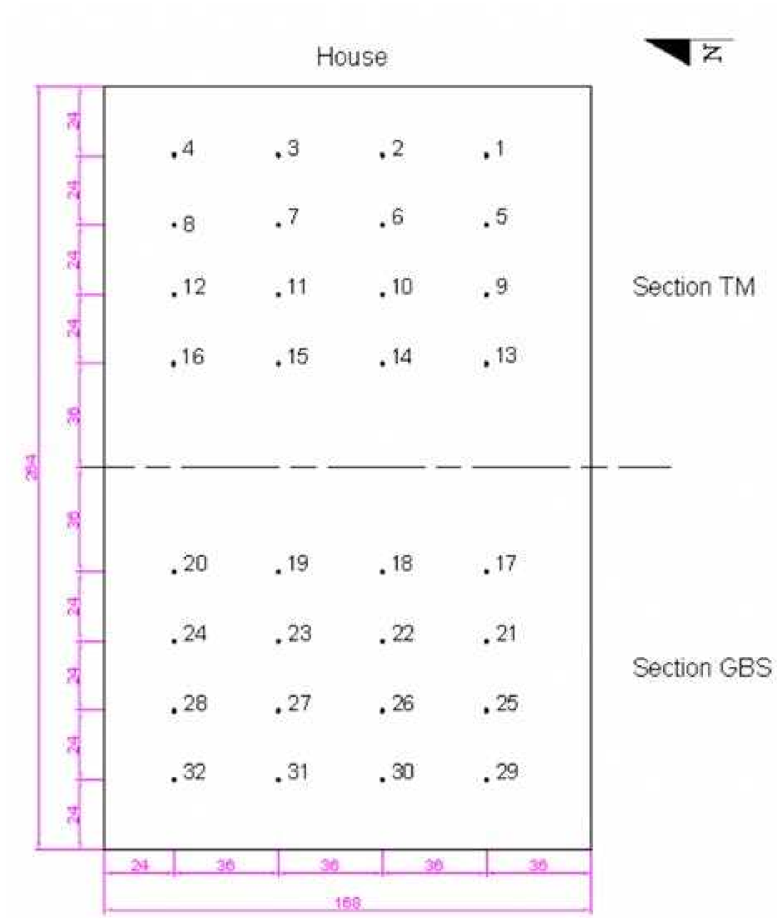


Figure 21 Location of spot profile surveys at 67 Roxton Crescent in Montreal West.

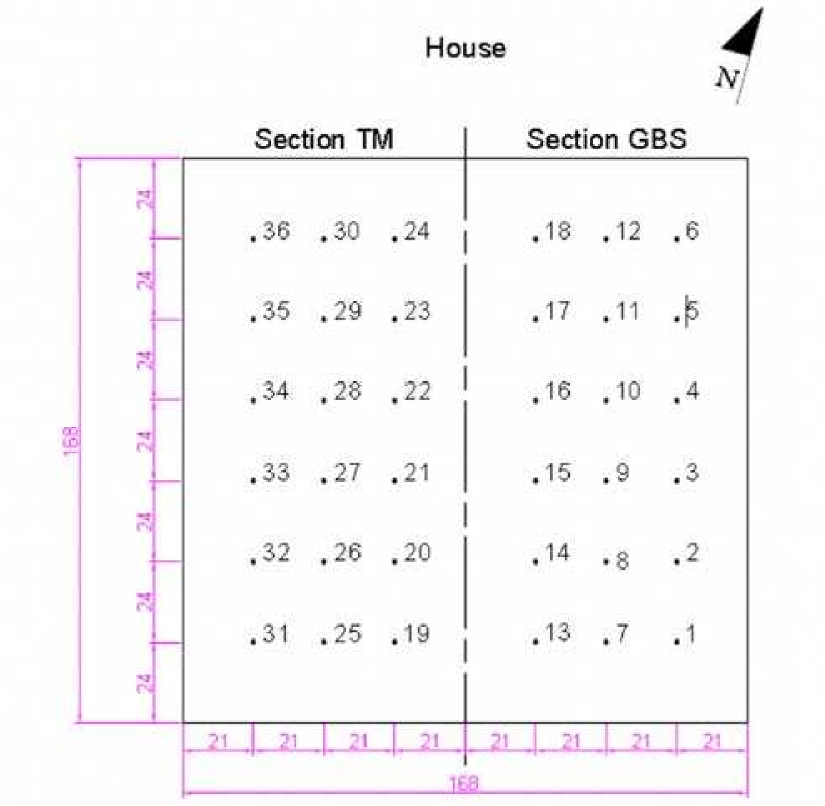


Figure 22   Location of spot profile surveys at 114 Daigneault Street in Chambly.

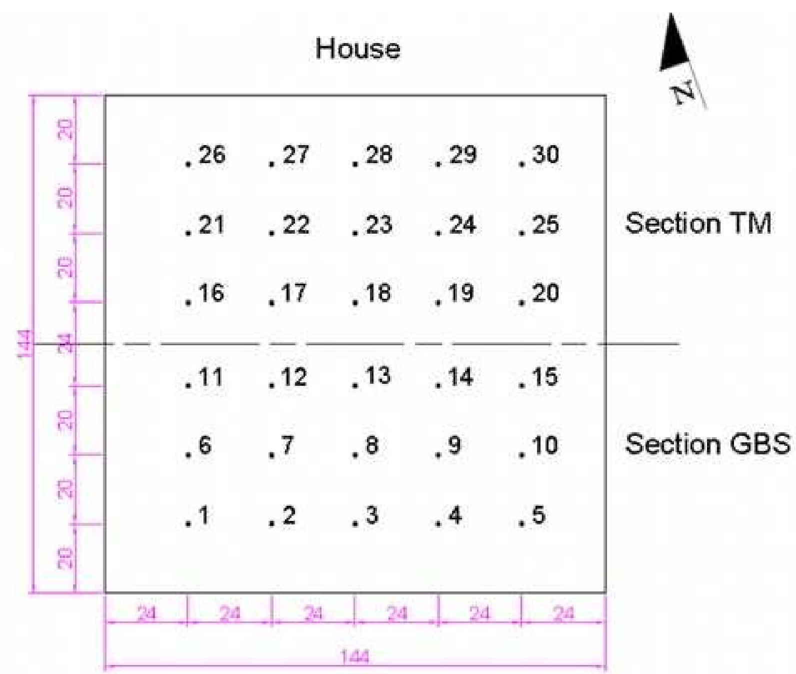


Figure 23   Location of spot profile surveys at 204 Dufferin Avenue in Hampstead.

6.3 Initial profile of the sections and analysis of the results

The analysis of the results is done in a relative way, i.e. the surface deformations for each of the sites are evaluated on the basis of the initial surface. Using the 1st survey, the initial profile of the sections can be established. Figures 24, 25 and 26 illustrate the initial profile of the sections for each site. The elevation value of the sections is relative to the arbitrary elevation, but it allows appreciating the high and low points & slopes used during the construction of the sections. In addition, it allows following the fluctuations of the surface at each reading and this always in relation to the initial elevation. For all sites, the elevation analysis reveals that water flow on the surface of the paving stones will necessarily occur towards the GBS sections (Figures 24, 25 and 26).

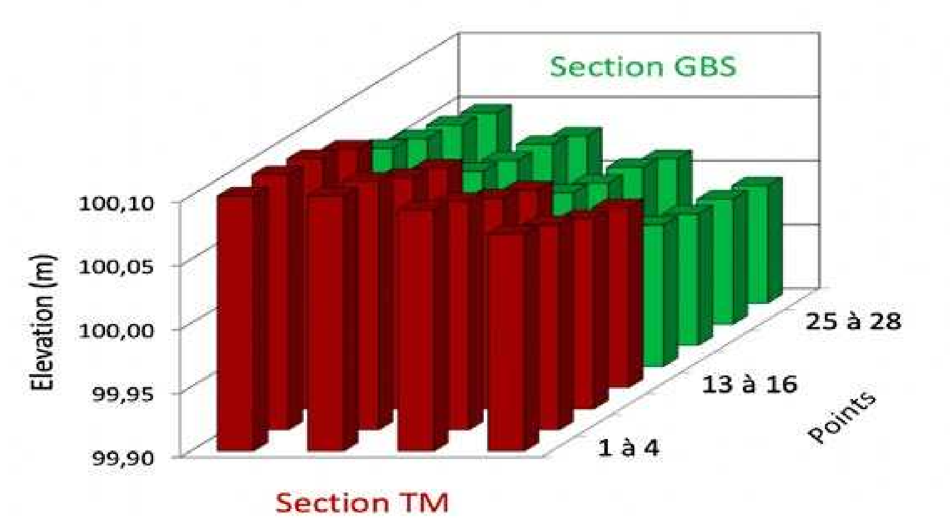


Figure 24 The initial profile of the sections at 67 Roxton Crescent in Montreal West.

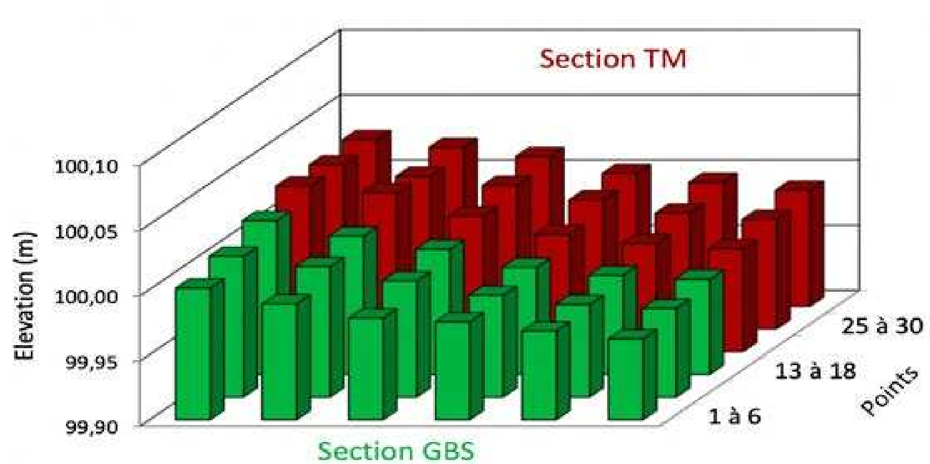


Figure 25 The initial profile of the sections at 114, Rue Daigneault in Chambly.

Figure 26 The initial profile of the sections at 204 Dufferin Avenue in Hampstead.

6.4 Evolution of the section profile for site 67 from fall 2015 to fall 2018

From the 1st survey (Sept. 2015) and the 3rd survey (Sept. 2016) of the same site, it is possible to verify, after one year, the evolution of the profile of a patio after the first winter when the uplift is at its maximum. Figure 27 A shows the (Δ) elevation variations with a 3D approach. We can see the location of the deformations. Although interesting, this representation does not allow the amplitude of the deformations to be correctly assessed. Figure 27 B shows the same 2D results. We can see better the amplitude of the deformations. Positive values of Δ indicate a lifting of the patio while negative values indicate a subsidence. Figure 28 shows all the 2D surveys for site 67. The other results for this site are presented in the appendix.

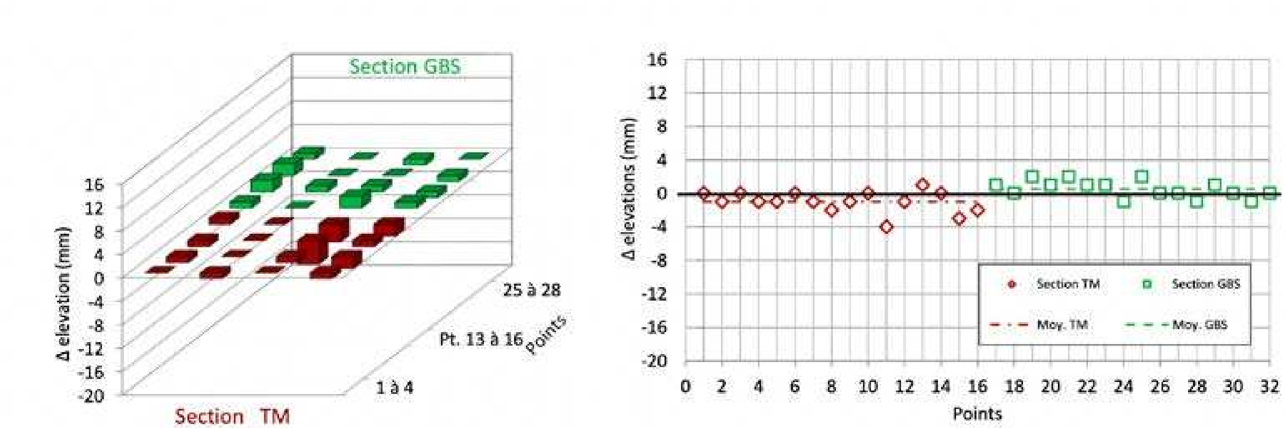


Figure 27 Elevation differences between Sept. 2015 and Sept. 2016 at 67 Roxton Crescent in Montreal West: A) 3D representation; B) 2D representation

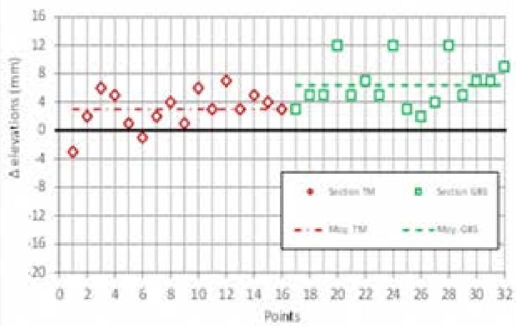
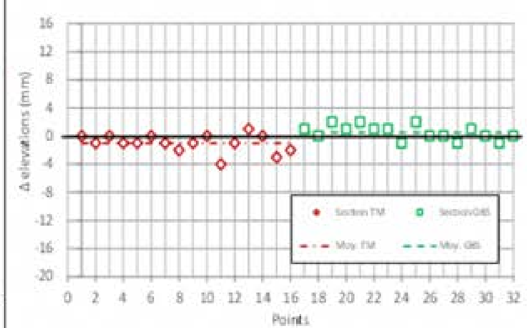
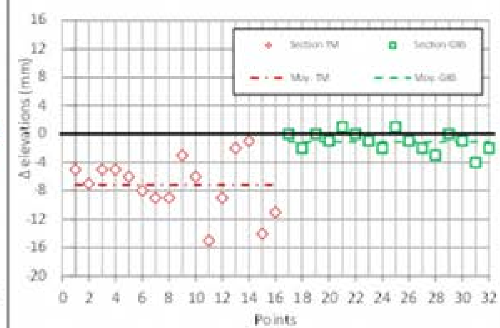
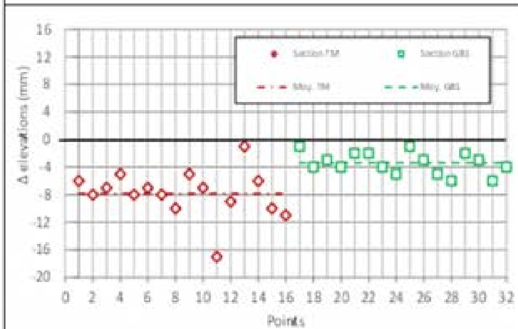
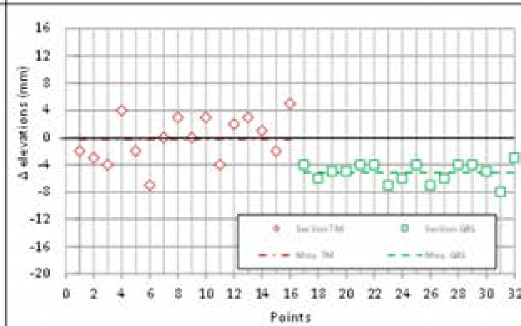
Reading / Site	March 22, 2016	September 19th, 2016	October 31, 2017
67			
	May 7, 2018	December 14th, 2018	
			

Figure 28 Elevation Differences for the entire survey period at site 67, Roxton Crescent in Montréal West

An analysis of the results on site 67 shows a slight lifting of the GBS section in spring 2016, maximum 12 mm. In the fall of 2016, the patio was restored and deformations are low. Thereafter, from autumn 2017 to autumn 2018, it is rather the TM section that records the most significant deformations up to 16mm, while the GBS section is rather stable with deformations below 8mm. The temperature data presented in Figure 14 indicates that there was no freezing under the GBS section and very little under the TM section. However, water may have infiltrated and frozen between the paving stones or slabs and PEPs. In addition, there is a gradual decrease from one survey to the next for both systems. This settling may be due to the consolidation of the infrastructure soils under the patio. These soils are heterogeneous and made of clay of average plasticity that can deform over time.

6.5 Evolution of the section profile for site 114 from fall 2015 to fall 2018

Analysis of the elevation data for site 114, presented in Figure 29, shows very small deformations, in the order of 4 mm of settlement for both systems. For this site, spring 2018 data are missing. In the fall of 2018, there was heavy precipitation, cold and early frost, as shown in Figure 16. This may explain the 4 mm to 6 mm lifts observed for both systems.

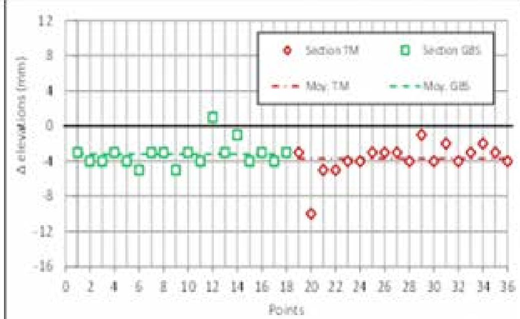
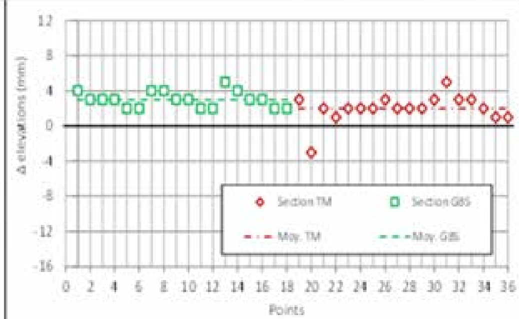
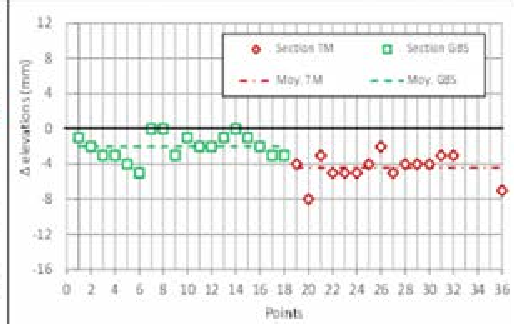
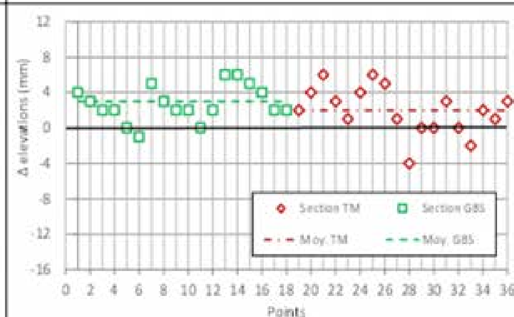
<table>
<tr><th>Reading / Site</th><th>March 22, 2016</th><th>September 19th, 2016</th><th>October 31, 2017</th></tr>
<tr><td rowspan="3">114</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>May 7, 2018</td><td>December 14th, 2018</td><td></td></tr>
<tr><td>N. D.</td><td>
</td><td></td></tr>
</table>

Figure 29 Elevation deviations for the entire survey period on site 114 Daigneault Street, Chambly

6.6 Evolution of the section profile for site 204 from fall 2015 to fall 2018

Analysis of the elevation data for site 114, presented in Figure 30, shows very similar behaviour to what is observed at site 114. Although no surveys could be conducted in the spring of 2016 due to the presence of snow and stored materials, the fall 2016 and 2017 and spring 2018 surveys show very little deformation. GBS is more stable with deformations less than 4 mm (except for a point at 7 mm). The TM fluctuates a little more but the deformations remain below 6 mm (except for two points at 8 mm and 10 mm). As with the previous site, there is a gradual decrease in the surface area from one survey to the next due to the consolidation of the infrastructure soils.

However, in the fall of 2018 there was heavy rainfall, cold and early frost. This may explain the uprisings observed during this period. For the GBS section, the average elevation is reduced from -2 mm (spring 2018) to +1 mm in autumn 2018, a differential of 3 mm. For the TM section, the average elevation is reduced from -6 mm in spring 2018 to +5 mm in autumn 2018, a differential of 11 mm.

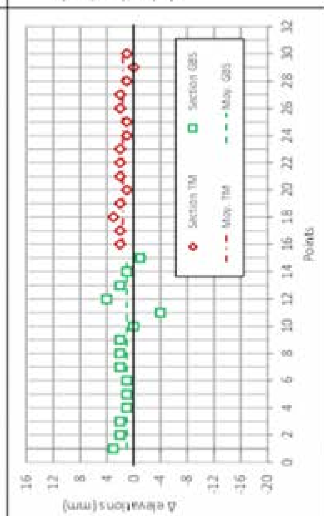
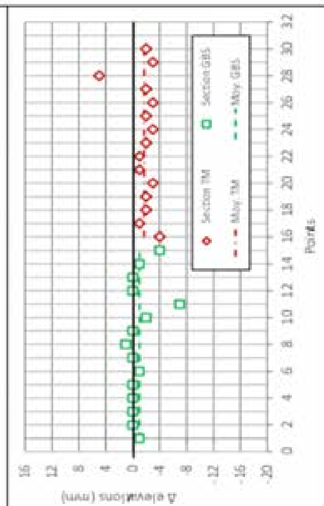
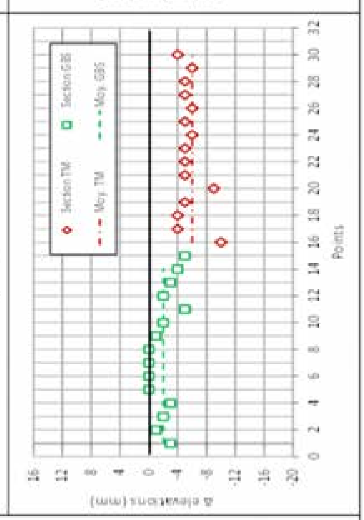
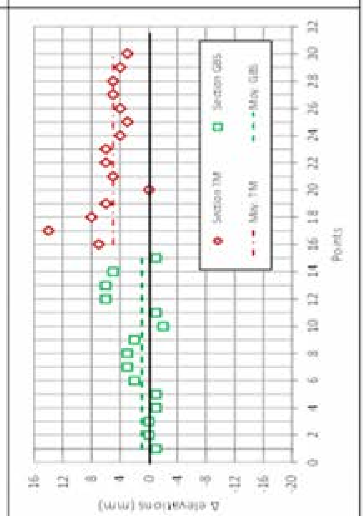
Reading / Site	March 22, 2016	September 19th, 2016	October 31, 2017
204	N. D.		
	May 7, 2018	December 14th, 2018	
			

Figure 30 Elevation deviations for the entire survey period at 204 Dufferin Avenue in Hampstead

6.7 Section's Conclusion

Simultaneous analysis of the three sites under study in relation to the temperature readings shows that the deformations observed at all sites for both GBS and TM systems are relatively low. Some consolidation of infrastructure soils can be observed from one survey to another. Deformations are always lower and more stable on GBS sections than on TM sections. The small fluctuations and amplitudes of the deformations of the Gator Base system indicate a better load distribution. Since the GBS itself is less loaded due to its lower thickness, it is less demanding on infrastructure soils and generates less consolidation deformation than TM. Similarly, the live loads applied to the patio surface are better distributed and generate less point deformations.

In the fall of 2018, heavy rainfall and early freezing caused upheavals on all sites and sections except the GBS section of site 67. The observed uprisings are always greater for TM sections than for GBS sections. This shows that the GBS performs better in wet and frozen conditions.

7.0 CONCLUSION

Site and laboratory tests revealed that the infrastructure soils in place under the sections (backfill) are inorganic clays, medium to highly plastic (LC to CH), have a very low density, contain a lot of water, have a low mechanical strength similar to firm to soft clays, and are gel-like. These soils can settle by consolidation under low load. Overall, these are not good soils for construction.

The temperature measurements show almost identical behaviour for the two systems studied. Both systems provide equivalent frost protection and limit frost impacts on infrastructure soils. However, given the low thickness of the GBS compared to the TM, the insulating power of the GBS per millimetre of thickness is much higher than that of the TM. In addition, GBS appears to provide better surface drainage, which limits differential movement on the surface of the infrastructure soil if there is frost.

Elevation readings show better performance of the GBS. Long-term settlements are lower due to the lower load transmitted to the ground by the system. Indeed, the TM has a 150 mm thick layer of crushed stone that applies a load of 300 kg per additional square metre compared to the GBS. In addition, the surface area of the PEPs allows for a better distributed load transfer that limits point movements and therefore offers a more even surface area than the TM.

In conclusion, these two systems are at least equivalent, otherwise the GBS is superior in terms of surface drainage, resistance to consolidation settling and surface evenness quality.

8.0 STUDY LIMITATIONS

This report is intended only for the client for whom it was prepared. The information contained herein is given to the best of our knowledge and in the light of the data available at the **École de technologie supérieure** at the time of writing.

This report should be considered as a whole and none of its parts can be used in isolation. Any use that a third party may make of it or any decision based on its content made by such third party is the responsibility of the latter.

The conclusions and recommendations presented in this report are based on our current understanding of the project.

It is important to note that a geotechnical study consists of a point sampling of a site and that the recommendations made are based on the results obtained at the survey locations only. It is then assumed that these soil conditions are representative of the entire stratigraphy of the site.

We hope that this report will be to your complete satisfaction. Feel free to contact us for more information.

Michel Vaillancourt, ing., Ph.D.
Professor – Construction engineering department

ÉCOLE DE TECHNOLOGIE SUPÉRIEURE

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