Report No. 4956-00-01

GEOTECHNICAL STUDY

Reconstruction of the Québec City Armoury

ARCOP/DFS/STGM Consortium of Architects

File No. 4956-00
November 2014

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION

A team of geotechnical, environmental, and soils and materials engineering consultants from Laboratoires d'Expertises de Québec ltée (hereinafter "L.E.Q. ltée") was contracted by the ARCOP/DFS/STMG consortium of architects to conduct a geotechnical study as part of the project to rebuild the Québec City Armoury, located at 805 Avenue Wilfrid-Laurier, in Québec City.

A preliminary geotechnical study was conducted by the firm Qualitas in 2009 as part of that project. The purpose of this new geotechnical study was therefore to examine the nature of the soils on site, to determine some of their physical and mechanical properties, and to measure the depth of the underground water table and bedrock in order to issue specific recommendations with regard to the reconstruction and expansion of the fire-damaged building.

This report provides all of the fieldwork and laboratory results as well as comments and recommendations with regard to the project's integration with the types of soil found on the site under study.

2.0 RECONNAISSANCE METHOD

2.1 Fieldwork

On-site reconnaissance was carried out by L.E.Q. ltée technical staff on May 23, 24, 27 and 28, 2013. The borehole program was prepared by representatives of BPR Inc.

2.1.1 Boreholes

A total of thirteen boreholes, identified as F-1 to F-13, were drilled to depths that varied from 2.70 to 4.58 metres using a track-mounted Envirotrack corer that was equipped with all of the accessories required to collect soil and rock samples. More specifically, boreholes F-1 to F-8 were drilled inside the building's main room, whereas boreholes F-9 to F-13 were drilled on the existing building's projected expansion site. Drilling was achieved with NW-type tubing and washing.

A standardized 50.8-millimetre (outside diameter) split spoon was used to recover soil samples for the purposes of visual description and laboratory analysis. During the sampling operations, standard penetration trials were conducted in accordance with standard NQ 2501-140. Once the bedrock was reached, samples were collected using an NQ-type diamond-toothed corer.

Observation tubes made from bottom-perforated 19-millimetre PVC pipes were inserted in boreholes F-1 to F-5 and F-7 to F-13 in order to subsequently measure groundwater levels. Borehole F-6 was set up as an observation pit to sample groundwater for the environmental component of this study, which is the subject of a separate report.

2.1.2 Surveying and levelling

The boreholes were positioned by L.E.Q. ltée technical staff based on a preliminary location map provided by a BPR Inc. representative on an electronic storage device. It should be noted that the position of certain boreholes had to be slightly altered in order to avoid interfering with the significant number of underground services on the site. The plan's borehole locations were determined on the basis of on-site reference points. Geodetic elevation of the land surface at the borehole site was measured by L.E.Q. ltée staff using an elevation benchmark identified as 23L1035 located on the front facade of the existing Armoury building, which indicated 90.87 metres of elevation. The position of each borehole is presented in Location Plan No. 4956-00-01 in Appendix "B".

2.1.3 Geophysical survey

Multichannel Analysis of Surface Wave (MASW) and seismic refraction surveys were conducted on May 21, 2013 by technical staff from Géophysique GPR International Inc. in Longueuil, Québec. The purpose of these geophysical surveys was to calculate the seismic shear wave velocity for the unconsolidated deposit and rock distributions on the site under study in order to determine its Site Class, as required by the *National Building Code of Canada 2010* to calculate the seismic loads in consideration of the building's reconstruction and expansion.

2.2 Laboratory work

All samples collected from the site were taken to our laboratory in Québec City, where a visual examination of each sample was conducted by Mr. Louis Morin, engineer. Unconfined compressive strength and density were determined for four rock samples.

All soil and rock samples not used in the analyses will be kept in storage for a period of three months as of the issue date of this report. After this period has expired, the samples will be destroyed unless otherwise notified by a representative of the ARCOP/DFS/STGM consortium.

2.3 Data presentation

The borehole reports, which are presented in Appendix "A", contain all of the information collected during the fieldwork operations. The location plan in Appendix "B" provides the borehole locations. Lastly, the report from Géophysique GPR International Inc., which contains results of the geophysical survey, is provided in Appendix "C".

3.0 NATURE AND PROPERTIES OF SOILS AND MATERIALS

This section provides a summary of the nature and certain properties of the materials encountered in the borehole drilling process. Soil stratigraphy is summarized in Table 1 below, and presented in greater detail in each of the drilling reports provided in Appendix "A".

TABLE I

SOIL STRATIGRAPHY SUMMARY

Stratigraphy	Boreholes and depth (m)						
	F-1	F-2	F-3	F-4	F-5	F-6	F-7
Asphalt	0.00-0.03	0.00-0.03	0.00-0.03	0.00-0.03	0.00-0.03	0.00-0.02	0.00-0.06
Concrete	0.03-0.40	0.03-0.28	0.03-0.39	0.03-0.37	0.03-0.35	0.02-0.37	0.06-0.18
Fill	0.40-3.23	0.28-1.93	0.39-1.45	0.37-2.44	0.35-2.14	0.37-2.44	0.18-2.08
Bedrock	3.23	1.93	1.45	2.44*	2.14	2.44	2.08
End of the borehole	4.53	3.81	3.05	4.58	4.12	4.12	4.53

* Approximately 300 millimetres of friable rock were found on the bedrock surface.

TABLE I (CONT'D)

SOIL STRATIGRAPHY SUMMARY

Stratigraphy	Boreholes and depth (m)					
	F-8	F-9	F-10	F-11	F-12	F-13
Asphalt	0.00-0.03	0.00-0.07	0.00-0.08	0.00-0.08	0.00-0.08	0.00-0.09
Concrete	0.03-0.38	---	---	---	---	---
Fill	0.38-0.53	0.07-1.15	0.08-0.61	0.08-0.61	0.08-1.50	0.09-2.02
Granular soil generated from alterations of the bedrock**	---	---	---	---	---	2.02-2.32
Bedrock	0.53	1.15	0.61	0.61	1.50	2.32
End of the borehole	3.34	3.20	2.70	3.10	3.17	3.80

**Grain size equivalent to sandy silt; a small amount of gravel.

Fill material compactness in all boreholes was loose to very dense. Standard "N" penetration varied from 4 to 83 strikes to drive the split spoon over a course of 300 millimetres. Brick and cinder debris were also noted in this material. Olfactory evidence of contamination was noted in some areas.

A visual examination of the bedrock has revealed that it is generally composed of clayey limestone. In some areas, shale beds less than 1 metre thick were found between the limestone banks. Calcite veinlets were also found. The RQD rock quality designation index measured along the centerline of the core samples varied from 0% to 100%, which indicates that rock quality varies from very poor to excellent. Generally speaking, however, the rock is of average quality. It should also be noted that, in some areas, the rock was of high quality right from the surface, whereas more fractured and lesser quality layers were noted on other surface areas.

The stratification dip measured on the collected rock samples varied from 50° to 65°. Unconfined compressive strength tests performed on four rock samples yielded respective results of 59.7, 95.9, 104.9 and 131.3 MPa, whereas density for those four samples was measured respectively at 25.8, 26.5, 27.0 and 27.2 kN/m³.

4.0 GROUNDWATER

The depth of the underground water table was measured in the observation tubes or pits that had been placed in the boreholes. The values obtained from the most recent measurement taken on June 7, 2013 are summarized in Table II below. Geodetic elevations for the groundwater level measurements are listed in the right-hand column in Table II.

TABLE II

GROUNDWATER DEPTH

Borehole	Groundwater depth (m)	Corresponding geodetic elevation (m)
F-1	> 2.68	< 87.66
F-2	2.51	87.83
F-3	1.52	88.83
F-4	3.33	87.00
F-5	2.26	88.09
F-6	> 4.12	< 86.22
F-7	3.00	87.35
F-8	1.66	88.70
F-9	1.81	88.28
F-10	1.92	87.34
F-11	2.06	88.17
F-12	> 3.17	< 89.54
F-13	2.76	88.61

It should be noted that groundwater levels may vary significantly with the seasons, amounts of precipitation and alterations of the physical environment such as the topography, the addition of trench drains, etc. It is important to point out that the water level measurements presented above probably reflect a buildup of drill water in the boreholes (rock), which is a common occurrence with low-permeability materials. The level of the underground water table is probably much deeper that what these measurements would indicate.

5.0 SPECIAL CONSIDERATIONS

5.1 Environmental aspect

The environmental characterization of the soils and groundwater was not included in this contract. Furthermore, soil and groundwater descriptions are only provided to cover the geotechnical aspect of the file, which is an essential consideration in the design of plans and technical specifications as well as the project's execution. The soil and groundwater descriptions presented in this report cannot be used to draw conclusions from an environmental perspective. A report on the environmental aspect of the project, however, will be issued by L.E.Q. ltée in the near future. The report will bear identification number 2499-00-01.

5.2 Formation of ochre deposits

The existence of conditions conducive to the formation of iron ochre deposits in the groundwater that could block the building's foundation drain was not investigated in this study, as this subject was not included in this contract. It is therefore recommended that the owner conduct his own investigation before laying the building's foundations. In this regard, it may be relevant to examine the functioning of the existing building's drainage system before making a decision.

6.0 COMMENTS AND RECOMMENDATIONS

6.1 General considerations

Public Works and Government Services Canada (PWGSC) plans to rebuild the Québec City Armoury, which was damaged in a fire in 2008. The main room will be rebuilt and may include a basement. The building will also be expanded on the southern and western sides of the existing building. A one-level underground parking garage will be built under the addition to the southern side of the building.

Based on the information collected from boreholes F-1 to F-13, under the layer of asphalt and/or concrete, the site under study is covered with fill material 0.53 to 3.23 metres thick. This fill material generally rests directly on the bedrock. In some areas, a thin layer of granular soil generated by the rock alteration can be found between the fill and bedrock. The rock has been identified as clayey limestone, with shale beds less than 1 metre thick, of generally average quality but occasionally showing more fractured surface layers of varying thicknesses.

Groundwater depth measurements varied from 1.52 metres to more than 4.12 metres on June 7, 2013 at geodetic elevations of 86.22 metres to less than 89.54 metres. The water observed in the observation tubes or pits is most likely a buildup of drill water in the boreholes.

The site under study is currently occupied by the existing Armoury, which is no longer in use. The outside perimeter of the building consists of a paved (asphalt) yard or parking lot. The site's topography does not show any particular differences in levels, other than an ascending 1.5- to 2.5-metre embankment at the parking lot located at the site's westernmost boundary.

6.2 Potential rock swelling caused by pyrite

It should be noted that the bedrock is likely to contain pyrite. No chemical analyses were conducted in this study to validate this likelihood. However, a high swelling potential was determined in the preliminary geotechnical study conducted by the firm Qualitas in 2009. Thus, given that the nature of the bedrock is the same as that which was identified in the preliminary study, for a concrete slab resting near the rock surface (in the case of a basement, for example), measures will have to be taken to prevent any reactions that could result in heaving caused by pyrite. One measure commonly used is the installation of a bituminous membrane directly on the sound bedrock in order to cut off the supply of oxygen that is required for rock swelling to occur. The alternative option of placing a thin concrete cushion on the bedrock does not seem appropriate because of the risk of concrete sulphation caused by the sulphuric acid created by the eventual oxidation reaction of the pyrite in the rock.

6.3 Factored geotechnical resistance at ultimate limit states (ULS)

Given the shallow depth of the bedrock, it is very likely that the building's foundations will rest almost completely on the rock surface.

Considering that the foundations of the projected building will rest directly on the bedrock, the bearing capacity of the rock was determined in accordance with ULS standards based on the results of compression test trials conducted on bedrock core samples.

Results of the unconfined compressive strength tests varied from 59.7 to 131.3 MPa. Based on the lowest of those values, geotechnical resistance at ULS calculated using the following equation is equal to:

$$\begin{aligned} Q_{ult}\ (ULS) &= 3\ K_{sp} \times q_u \\ &= 3 \times 0.1 \times 59.7\ MPa \\ &= 17.9\ MPa \end{aligned}$$

By introducing a performance factor of 0.5, we obtain:

$$Q_{ult}\ (Factored\ ULS) = 17.9 \times 0.5 = 8.95\ MPa$$

We can therefore consider a geotechnical resistance at ULS of 8,950 kPa for a foundation footing that is well-seated on the sound bedrock cleared of any loose particles with water or air pressure or steel bars. This value appears very high, however, and does not take into account the shale beds in the solid bedrock, shale being a rock of lesser quality than limestone. For this reason, and based on the existing literature, a geotechnical resistance at ULS of 1,000 kPa should be considered.

However, based on discussions with a representative of BPR Inc., which is responsible for the new building's design, loads up to 2,000 kPa are applied locally on the foundations of the existing Armoury building without affecting its integrity. Thus, for that reason and at the designer's discretion, a geotechnical resistance at ULS of 2,000 kPa could be used in the building's design. This opinion is supported by the fact that settlement has been recorded under the building's current loads.

6.4 Geotechnical reaction at serviceability limit states (SLS)

In the case of foundation elements resting on the bedrock, the geotechnical reaction at SLS, or the admissible bearing capacity, does not apply where an admissible settlement of 25 millimetres is considered. Before that much settlement occurs in the rock, a rupture would have already occurred. The design criterion will therefore be based on the geotechnical resistance at ULS. Any settlement below this stress level will be negligible.

Very fractured or very friable rock will have to be excavated; otherwise the admissible bearing capacity will have to be reduced to 500 kPa for foundation elements of any size and for total and differential settlement of less than 25 and 19 millimetres respectively.

Where the bedrock is at a lower level than the foundation base, the foundations cannot rest on the fill material found at the borehole sites. As a result, this fill material will have to be removed from the entire thickness and surface of the construction area until the bedrock is cleared. A controlled backfill can then be used to bring the land up to the level determined to seat the footings. The backfill must be composed of a compactible granular borrow, such as MG-112 sand, as defined in standard NQ 2560-114. This material must be applied in layers of no more than 300 millimetres, with each layer densified to at least 95% of the full density obtained in the modified Proctor (M.P.) test. From a distance of 300 millimetres from the edge of the footings, we recommend that the controlled backfill be given a slope equal to or softer than 1.0 horizontally and 1.0 vertically (1.0 H:1.0 V), to ensure adequate distribution of the loads under the footings. A controlled backfill built in this manner can provide an admissible bearing capacity of 150 kPa for total settlement of less than 25 millimetres.

Furthermore, on a controlled backfill, footings must rest on an MG-20 granular cushion, as defined in standard NQ 2560-114. At a minimum thickness of 200 millimetres, the cushion must be densified to at least 95% of M.P.

Since the footings could overlap on different materials (rock and controlled backfill) in certain areas, it is essential that the transition between the rock and the backfill is sufficiently gradual to minimize the impact of differential settlement. In addition, the building's design will have to take into account this settlement, and the appropriate structural measures will have to be taken to that effect.

6.5 Site Class

The sector's Site Class was determined on the basis of Table 4.1.8.4.A of the *National Building Code of Canada 2010*. Based on shear rate measurements, this sector belongs to the type "A" Site Class, as defined by Géophysique GPR International Inc., on page 4 of their report, which is presented in Appendix "C".

6.6 Excavation

Based on the observations at the borehole sites, the excavation slopes to observe in the unconsolidated deposits must meet the requirements set forth in the *Safety Code for the construction industry*, most recent edition, issued by the Commission de la santé et de la sécurité du travail (CSST), on the condition that the bottom of the excavations be located above the underground water table.

Should there ever be a need to excavate material beneath the water table, the water table should be lowered; otherwise the slopes will have to be softened. The bottom of the excavation pits must be kept dry during the entire period required to complete the work. Based on the borehole groundwater measurements, despite the

fact that the underground water table is probably located much deeper than what the measurements indicate, it is not impossible that water trapped in the bedrock could seep out during the excavation work. Given that any permeability in a rock mass is largely due to cracks, the seepage could be more or less significant depending on the size of the crack openings in the rock mass. This seepage must be controlled with the appropriate equipment.

Excavations inside the sound bedrock, if need be, could be carried out with a slope set at 1.0 horizontally and 10.0 vertically (1.0 H:10.0 V). However, the fractured or altered rock may require softening of the slopes to ensure the stability of the pit walls. Based on the observations at the borehole sites, the bedrock appears to be of sufficiently good quality to make excavation difficult. In our opinion, excavation of the bedrock will require the use of a jack hammer or explosives. In the event that explosives are required, precautions should be taken to avoid damage to surrounding buildings. This point is all the more important given the age of the existing building.

As the work is being carried out, periodic inspections of the excavation pits should be carried out to ensure the stability of the pit walls. The presence of soft materials or permeable layers that allow water to flow locally may affect pit wall stability. The appearance of signs of instability, such as cracks in or at the tops of the walls could require softening of the slopes, according to the recommendations of a geotechnical engineer, and/or the use of a protective casing in the trenches to ensure worker safety. It will also be necessary to take into consideration the inclination of the rock strata and its orientation with regard to the trench axis in order to prevent the risk of rock blocks slipping to the bottom of the trench. According to the geological chart of Ministère des Ressources naturelles du Québec for the Québec City region, compiled by P. St-Julien in 1995, the stratification orientation in that sector is north 110°. In addition, the stratification dip measured on the borehole rock samples

varied from 50° to 65°. Based on the chart mentioned above, the stratification dip is oriented in the northeast direction.

Given that the bedrock will, in all likelihood, serve as the resting point for the footings, its surface must be adjusted to provide a horizontal surface that is cleared of all loose particles using water or air pressure or a steel bar. The footings could then be poured directly onto the cleaned up bedrock.

6.7 Frost protection

In order to provide the foundations with adequate protection against the effects of frost, we recommend that they be located at least 1.80 metres below the landscaped surface of the property or that they be adequately insulated.

Furthermore, installing a drain with a proper outlet at the resting point of the foundations is recommended. In addition, landscaping of the area surrounding the building should be designed to keep runoff water from the construction work away from the building, thereby reducing the amount of water trickling towards the drains.

6.8 Slab on grade

At no time may a slab on grade for the projected building rest on the fill material encountered at all of the borehole sites. This material must be excavated to the full thickness and surface area of the slab and be replaced with controlled backfill, following the exact procedure recommended in section 6.4.

Furthermore, the slab on grade must rest on a cushion of MG-20 granular material, as defined in standard NQ 2560-114. At a minimum thickness of 150 millimetres, this material must be compacted to at least 95% of M.P.

6.9 Backfilling

Exterior backfilling of the foundation walls must be carried out by laying a frost-resistant granular material such as CG-14 sand, in accordance with standard NQ 2560-114. This material must be placed in successive layers of no more than 300 millimetres, and each layer must be densified to at least 95% of M.P. under the civil engineering structures (slabs, sidewalks, borders, etc.) and at least 90% of M.P. under grass-covered surfaces.

6.10 Parking lots

6.10.1 Presence of fill material

The presence of fill material does not impede the construction of a parking lot, as long as the nature and compactness of the materials is evaluated. The fill material on the site under study could be kept and used for the parking lot, as long as it is redensified to at least 90% of M.P. for the infrastructure and of a sufficiently high environmental quality for it to be reused.

6.10.2 Road structure

The road structure of the access lanes and parking lots will either rest on fill material that may be frost-sensitive in some areas or on the bedrock. According to a representative of BPR Inc., the western sector of the site will be used as an

unloading dock for heavy vehicles, whereas the other access lanes and parking lots will be used by light vehicles.

We would like to emphasize that the soils located below the infrastructure line are subject to the effects of frost to a depth of 2.00 metres from the road surface. Materials that contain significant proportions of silt and clay are susceptible to heaving by their very nature, unless the foundation is insulated or the frost-sensitive materials are replaced by frost-resistant materials. As a result, an adequate transition between two different materials beneath the infrastructure line is essential to ensuring proper road surface behaviour to reduce the risk of cracks forming in the asphalt and to provide a smooth and comfortable ride for users.

Given the nature of the materials encountered at the borehole sites, we recommend that the road structure be built with the various layers detailed in Table III below:

TABLE III

PROPOSED ROAD STRUCTURE

Layer	Material	Thickness (mm)	Compactness (%)
Asphalt	To be determined by the designer		
Upper base	MG-20 crushed aggregate	200[1] 300[2]	98
Sub-base	MG-112 granular material	300[3] 600[4]	95

1- For light traffic;
2- For heavy traffic;
3- For infrastructure composed of rock;
4- For infrastructure composed of fill material.

The road structure proposed above is submitted for reference purposes only, and was selected on the basis of a general knowledge of the base thicknesses used regionally and adjusted to the foundation soils identified. It is recommended that this road structure be validated using road design software by factoring in the projected traffic density. In the case of the indoor parking garage, since this area will be heated, the road structure presented in Table III could be used (without the sub-base).

As for the surface of the infrastructure, it should be graded in such a way that would allow any water that could penetrate the road structure to drain off.

All materials to be used in the road structure must meet the standards set forth in the most recent edition of Tome VII on materials, published by the Ministère des Transports du Québec, or the standards prescribed in standards BNQ and NQ that apply to this construction.

7.0 LIMITATION OF THIS STUDY

This geotechnical study report is intended exclusively for the client for whom it was prepared. The information it contains is provided to the best of our knowledge and in light of the data available to L.E.Q. ltée at the time it was drafted. This report must be considered as a whole and no individual portions may be used separately. Any use of this report by a third party, or any decision made by a third party on the basis of the content of this report, is the responsibility of that third party.

Furthermore, it is important to specify that a geotechnical study is based on spot sampling of a given site. As a result, the environmental, geological, hydrogeological and/or geotechnical conditions between sampling points may differ from the actual conditions obtained from soundings, which provided the conditions on the basis of which our comments and recommendations were issued. In addition, the time factor must be considered, since from the moment the soundings are conducted, conditions may change due to natural facts or direct or indirect human intervention on or at some distance from the site.

L.E.Q. ltée requests that it be informed in writing of any changes in the location, nature or design of the project in order to assess the situation and, if necessary, amend the comments and recommendations presented in this report. In addition, as the project is carried out, we recommend that a geotechnical engineer be notified and allowed to inspect the excavation pits and, if applicable, adjust the comments and recommendations drawn from the soundings conducted in this geotechnical study.

We remain available to provide any additional information.

LABORATOIRES D'EXPERTISES DE QUÉBEC LTÉE

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Québec City, November 28, 2014

LM/mm

Distribution:

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APPENDIX "A"

Borehole Reports
Boreholes F-1 to F-13

GENERAL

EXPLANATION OF THE BOREHOLE RECORD FORM

FV-1003 (2011-05)

The object of the Borehole Record is to assemble all the field and laboratory data regarding the soil, bedrock and ground water conditions obtained during the investigation at each borehole.

PROFILE

Elevation: This column gives the elevation of boundaries between various geological strata. The elevation refers to the datum given in the general heading.

Description: Each geological stratum is described using the standard classification given below.

The proportion of each constituent part of the soil as defined by the grain size range is denoted by the terms given below. The compactness of granular soils is defined by the Standard Penetration Value and the consistency of cohesive soils by the shear strength.

Classification	Particle sizes
Clay	smaller than 0.002 mm
Silt	0.002 to 0.08 mm
Sand	0.08 to 5.00 mm
Gravel	5.00 to 80 mm
Cobbles	80 to 300 mm
Boulders	larger than 300 mm

Descriptive terms	Proportion
"trace"	1 to 10%
"some"	10 to 20%
Adjective (e.g. gravelly, silty)	20 to 35%
"and" (e.g. sand and gravel)	35 to 50%

Compactness	Standard Penetration Test "N" Value (blows per 0.3 m)
Very loose	0 to 4
Loose	4 to 10
Medium or compact	10 to 30
Dense	30 to 50
Very dense	over 50

Consistency	Shear strength (kPa)
Very soft	less than 12
Soft	12 to 25
Firm	25 to 50
Stiff	50 to 100
Very stiff	100 to 200
Hard	over 200

Degree of plasticity	Liquid limit
Low	less than 30%
Medium	between 30 and 50%
High	more than 50%

Stratigraphy: In this column the hatching symbols follow the symbols of the United Soil Classification System. The basic soil types are designated by the following symbols:

GROUND WATER

The depth to ground water level as measured in the borehole is given in this column. The observation dates are given in the graph column at the right.

SAMPLES

Condition: The location, length and condition of each sample is shown in this column. The sample condition is defined by the symbols in the general heading.

Number & type: Each sample of the borehole is designated by the number as shown in this column. The sample type is also shown by a symbol that refers to the legend given in the general heading.

Recovery: Soil sample and rock core recoveries are given in percent of the penetration of the sampler. The sample length is equal to the distance from the top of the sample to the cutting edge irrespective of whether the lower part of the sample is lost.

R.Q.D.: The Rock Quality Designation is obtained by summing up the total length of core recovered but counting only those pieces of core which are 10 cm in length or longer, given in per cent of the core run.

$$\text{R.Q.D.} = \frac{\Sigma \text{li} \geq 10 \text{ cm}}{\text{Lcr}}$$

TESTS

Laboratory tests and results of *in-situ* tests are shown in this column at their corresponding depths.

Standard Penetration Test Values, commonly designated as "N" values, are given in this column. This value is obtained by dropping a 63,5 kg hammer onto the drill rods from a height of 760 mm. The number of blows necessary to produce the penetration of the last 305 mm of the 51 mm standard split spoon sampler is regarded as the "N" value.

GRAPH

Any pertinent observations noted during drilling and in the laboratory are given in the column. Also shown graphically are the results of Atterberg limits and moisture content tests as well as those of the 51 mm cone dynamic penetration test when performed. This latter penetration test consists in the continuous driving of a 51 mm diameter 60 degrees cone under constant energy, generally 475 joules, and thus differs from the Standard Penetration Test.

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-1
Elevation: 90,34 m
Date: 2013-05-23

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed ☒ Good ▨ Lost ■

Sample type
CF Split spoon sampler
CR Diamond core
LA Wash sample
TA Auger sample
TM Thin-wall sampler
PS Fixed piston sampler

Symbols
▼ Groundwater level
Ach Chemical analysis
Ag Grain size analysis (sieving)
Sed Grain size analysis (sedimentation)
Wc Natural water content
Wl Liquid limit
Wp Plastic limit

Hydrocarbures
Odour
No non-existent
Li Light
Mo Moderate
Pe persistent
Visual aspect
No non-existent
Sc scattered
Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	visual Aspect
	90,34									
	90,31	Asphalt. (0.03 m)								
	89,94	Concrete. (0.40 m)								
		Fill: Grayish-brown gravel, some sand, trace of silt. Compact.				1-VR			In	In
1										
						2-CF	8	N=17	In	In
	88,53	(1.81 m)								
		Fill: Brown silt, some sand and gravel, trace clay, becoming brownish-gray at 3.03 m. Presence of rock fragments. Loose.								
2						3-CF	41	N=6	In	In
						4-CF	62	N=5 ACH DUP	In	In
3										
	87,11	(3.23 m)				5-CF	75	N=50/50mm Refusal	In	In
		Bedrock: Gray clayey limestone. Ill-defined stratification dip. Fair quality.				6-CR	87		In	In
		7-CR Qu = 59,7 MPa γ = 25,8 kN/m³				7-CR	100	RQD=57%	In	In
4										
	85,81	(4.53 m)								
		End of drilling.								
5										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-24	> 2,68
2013-05-27	> 2,68
2013-06-07	> 2,68

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des materiaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-2
Elevation: 90,34 m
Date: 2013-05-23

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Hydrocarbures
Odour
- No non-existent
- Li Light
- Mo Moderate
- Pe persistent

Visual aspect
- No non-existent
- Sc scattered
- Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	visual Aspect
	90,34									
	90,31	Asphalt.								
	90,06	(0.03 m)								
		Concrete.				1-CF	42	ACH DUP	Le	In
		(0.28 m)								
		Fill: Gray gravel, some sand, trace of silt to silty. Compact.				2-CF	30	N=13	Le	In
1										
	89,12	(1.22 m)								
		Fill: Grayish-brown sandy gravel, trace to some silt. Presence of rock fragments.				3-CF	41	N=83 ACH	Le	In
	88,41	(1.93 m)				4-CF	60	N=50 pour 100 mm	Le	In
2		Bedrock: Gray clayey limestone. Presence of calcite veinlets. Ill-defined stratification dip. Fair to excellent quality.				5-CR	100	Refusal	In	In
						6-CR	72	RQD=53%	In	In
3										
						7-CR	100	RQD=100%	In	In
	86,53	(3.81 m)								
		End of drilling.								
4										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-24	1,77
2013-05-27	2,31
2013-06-07	2,51

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-3
Elevation: 90,35 m
Date: 2013-05-24

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed ☒ Good ▨ Lost ■

Sample type
CF Split spoon sampler
CR Diamond core
LA Wash sample
TA Auger sample
TM Thin-wall sampler
PS Fixed piston sampler

Symbols
▼ Groundwater level
Ach Chemical analysis
Ag Grain size analysis (sieving)
Sed Grain size analysis (sedimentation)
Wc Natural water content
Wl Liquid limit
Wp Plastic limit

Hydrocarbures
Odour
No non-existent
Li Light
Mo Moderate
Pe persistent
Visual aspect
No non-existent
Sc scattered
Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater Cond	Samples No et type	Rec (%)	Tests	Odour	Visual Aspect
	90,35								
	90,32	Asphalt.							
		(0.03 m)							
	89,96	Concrete.							
		(0.39 m)			1-CF	0		In	In
		Fill: Brownish-gray silt, some gravel and sand, trace of silt. Very loose.			2-CF	30	N=4	In	In
1									
	89,13	(1.22 m)							
		Fill: Gray gravel and sand, trace of silt. Presence of concrete debris (15%).			3-CF	41	N=50/80 mm Refusal ACH	Le	In
	88,90	(1.45 m)							
		Bedrock: Gray clayey limestone. Presence of a layer of shale at a depth of approximately 2 metres. Presence of calcite veinlets. 50° stratification dip. Very poor to fair quality.			5-CR	96	RQD=14%	In	In
2									
					6-CR	100	RQD=62%	In	In
3	87,30	(3.05 m)							
		End of drilling.							
4									

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-27	1,34
2013-06-07	1,52

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-4
Elevation: 90,33 m
Date: 2013-05-23

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
CF Split spoon sampler
CR Diamond core
LA Wash sample
TA Auger sample
TM Thin-wall sampler
PS Fixed piston sampler

Symbols
Groundwater level
Ach Chemical analysis
Ag Grain size analysis (sieving)
Sed Grain size analysis (sedimentation)
Wc Natural water content
Wl Liquid limit
Wp Plastic limit

Hydrocarbures
Odour
No non-existent
Li Light
Mo Moderate
Pe persistent
Visual aspect
No non-existent
Sc scattered
Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	Visual Aspect
	90,33									
	90,30	Asphalt. (0.03 m)								
	89,96	Concrete. (0.37 m)				1-CF	21		In	In
1		Fill: Gray gravel, some sand. Presence of rock fragments.				2-CF	21	N=35 ACH	Le	In
	89,11	(1.22 m)								
2		Fill: Brown gravelly silt, some sand, trace of clay. Presence of rock fragments. Loose.				3-CF	33	N=9	In	In
						4-CF	38	N=4	In	In
	87,89	(2.44 m)								
		Friable grey rock.				5-CF	35	N=48/50 80 mm	In	In
	87,66	(2.67 m)				6-CR	80	Refusal	In	In
3		Bedrock: Gray clayey limestone. Presence of a very fractured passage between 3.40 and 3.80 metres. 50° stratification dip. Very poor to fair quality.				7-CR	100	RQD=57%	In	In
						8-CR	43	RQD=0%	In	In
4						9-CR	79	RQD=61%	In	In
	85,75	(4.58 m)								
		End of drilling.								
5										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-23	2,46
2013-05-27	3,34
2013-06-07	3,33

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-5
Elevation: 90,35 m
Date: 2013-05-24

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed ☒ Good ▨ Lost ■

Sample type
CF Split spoon sampler
CR Diamond core
LA Wash sample
TA Auger sample
TM Thin-wall sampler
PS Fixed piston sampler

Symbols
Groundwater level
Ach Chemical analysis
Ag Grain size analysis (sieving)
Sed Grain size analysis (sedimentation)
Wc Natural water content
Wl Liquid limit
Wp Plastic limit

Hydrocarbures
Odour
No non-existent
Li Light
Mo Moderate
Pe persistent
Visual aspect
No non-existent
Sc scattered
Sat Saturated

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	Visual Aspect
	90,35									
	90,32	**Asphalt.**								
		(0.03 m)								
	90,00	**Concrete.**								
		(0.35 m)				1-CF	19		In	In
	89,74	**Fill: Gray gravel, some sand, trace of silt. Presence of rock fragments.**								
1		**(0.61 m)**				2-CF	46	N=22 ACH	In	In
		Fill: Brown sandy silt, some gravel becomming gray starting at a depth of 1.22 metres. Presence of rock fragments. Compact to dense.				3-CF	57	N=37	In	In
2						4-CF	100	N=50/150 mm Refusal ACH	Le	In
	88,21	**(2.14 m)**								
		Bedrock: Dark gray shale becomming a clayey limestone at a depth of 2.59 metres. Ill-defined stratification dip. Poor to good quality.				5-CR	100	RQD=26%	In	In
3										
						6-CR	100	RQD=82%	In	In
4										
	86,23	**(4.12 m)**								
		End of drilling.								
5										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-27	2,07
2013-06-07	2,26

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-6
Elevation: 90,34 m
Date: 2013-05-27

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Hydrocarbures
Odour
- No non-existent
- Li Light
- Mo Moderate
- Pe persistent

Visual aspect
- No non-existent
- Sc scattered
- Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater Cond	Samples No et type	Rec (%)	Tests	Odour	Visual Aspect
	90,34								
	90,32	v							
		(0.02 m)							
	89,97	Concrete.							
		(0.37 m)			1-CF	0		In	In
		Fill: Gray gravel and silt, trace of clay. Presence of rock fragments. Loose.			2-CF	25	N=4 ACH	In	In
1									
	89,12	(1.22 m)							
		Fill: Gray silt, some gravel to gravelly, trace of clay. Presence of rock fragments. Loose.			3-CF	20	N=6	In	In
2					4-CF	23	N=5 Refusal ACH	In	In
	87,90	(2.44 m)							
		Bedrock: Gray clayey limestone. Presence of a 150 mm layer of shale at a depth of approximately 3 metres. 60° stratification dip. Very poor to fair quality.			5-CR	100	RQD=0%	In	In
3					6-CR	100	RQD=32%	In	In
					7-CR	84	RQD=67%	In	In
4									
	86,22	(4.12 m)							
		End of drilling.							
5									

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-28	> 4,12
2013-06-07	> 4,12

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-7
Elevation: 90,35 m
Date: 2013-05-27

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Hydrocarbures
Odour
- No non-existent
- Li Light
- Mo Moderate
- Pe persistent

Visual aspect
- No non-existent
- Sc scattered
- Sat Saturated

Depth (m)	Elev (m)	Description	Str	Groundwater	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	Visual Aspect
	90,35									
	90,29	Asphalt.								
	90,17	(0.06 m)								
		Concrete.				1-CF	23		In	In
		(0.18 m)								
		Fill: Gray gravel, some sand to sandy amd some silt. Loose.				2-CF	7	N=8	In	In
1										
	89,13	(1.22 m)								
		Fill: Brown gravelly silt, trace of clay. Presence of rock fragments.				3-CF	25	N=5 ACH	In	In
	88,52	(1.83 m)								
		Fill: Gray gravel and sand, trace of silt. Presence of rock fragments.				4-CF	80	N=50/100 mm Refusal	In	In
2	88,27	(2.08 m)								
		Bedrock: Dark gray shale becomming a clayey limestone at a depth of 3.14 metres. Presence of a very fractured passage between 3.14 and 3.61 metres. 55° stratification dip. Very poor to fair quality.				5-CR	83	RQD=49%	In	In
3										
						6-CR	83	RQD=0%	In	In
4						7-CR	100	RQD=54%	In	In
	85,82	(4.53 m)								
		End of drilling.								
5										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-28	3,00
2013-06-07	3,00

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-8
Elevation: 90,36 m
Date: 2013-05-24

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Hydrocarbures
Odour
- No non-existent
- Li Light
- Mo Moderate
- Pe persistent

Visual aspect
- No non-existent
- Sc scattered
- Sat Saturated

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests	Odour	Visual Aspect
	90,36									
	90,33	Asphalt. (0.03 m)								
	89,98	Concrete. (0.38 m)				1-CF	40	N=50 pour 150 mm Refusal	In	In
	89,83	Fill: Grayish-brown gravel, some sand. (0.53 m)								
1		Bedrock: Dark gray shale becomming a clayey limestone at a depth of 1,53 metres. Very fractured until 1.53 metres deep. 50° stratification dip. Very poor to excellent quality.				2-CR	67	RQD=0%	In	In
2						3-CR	100	RQD=89%	In	In
3						4-CR	100	RQD=100%	In	In
	87,02	(3.34 m) End of drilling.								
4										

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-27	1,53
2013-06-07	1,66

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-9
Elevation: 90,09 m
Date: 2013-05-27

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests
	90,09							
	90,02	Asphalt.						
	89,92	(0.07 m)						
	89,86	Fill: Gray gravelly sand, trace of silt.				1-CF	56	N=17
		(0.17 m)						
		Fill: Brown sand, trace of silt.				2-CF	46	N=21 Refusal
1		(0.23 m)						
	88,94	Fill: Brown gravelly sand, trace of to some silt. Presence of ashes (<2%). Compact.						
		(1.15 m)				3-CR	100	RQD=33%
		Bedrock: Gray clayey limestone. Presence of thin, approximately 100 mm layers of dark gray calcareous shale. 60° stratification dip. Poor quality.						
2						4-CR	100	RQD=35%
						5-CR	100	RQD=32%
3								
	86,89	(3.20 m)						
		End of drilling.						
4								

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-28	1,77
2013-06-07	1,81

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-10
Elevation: 89,26 m
Date: 2013-05-28

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests
	89,26							
	89,18	Asphalt.						
	89,08	(0.08 m)						
	88,96	Fill: Gray gravelly sand, trace of silt.				1-CF	51	N=17 Refusal
	88,65	(0.18 m)						
		Fill: Brown sand, some silt.						
		(0.30 m)						
1		Fill: Brown graveley sand, some silt.				2-CR	87	RQD=50%
		(0.61 m)						
		Bedrock: Gray clayey limestone. Presence of calcite veinlets. 65° stratification dip. Poor to excellent quality.						
2		3-CR Qu = 95,9 MPa γ = 27,2 kN/m³				3-CR	100	RQD=33%
	86,56	(2.70 m)						
		End of drilling.						
3								

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-28	1,76
2013-06-07	1,92

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-11
Elevation: 90,23 m
Date: 2013-05-27

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests
	90,23							
	90,15	Asphalt.						
	90,05	(0.08 m)						
	89,95	Fill: Gray gravelly sand, trace of silt.				1-CF	57	N=21 Refusal
	89,62	(0.18 m)						
		Fill: Brown sand, trace of silt.						
1		(0.28 m)				2-CR	28	RQD=0%
		Fill: Gravelly sand, some silt. Presence of brick debris (1%).						
		(0.61 m)						
		Bedrock: Gray clayey limestone. Very fractured until 1.51 metres deep. 55° stratification dip. Very poor to fair quality.				3-CR	100	RQD=42%
2								
						4-CR	100	RQD=57%
3	87,13	(3.10 m)						
		End of drilling.						
4								

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-05-28	2,05
2013-06-07	2,06

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-12
Elevation: 92,71 m
Date: 2013-05-28

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests
	92,71							
	92,63	Asphalt.						
	92,48	(0.08 m)						
	92,38	Fill: Grey sand and gravel, trace of silt.				1-CF	57	N=41
		(0.23 m)						
		Fill: Brown sand, trace of silt.						
1		(0.33 m)				2-CF	67	N=30
		Fill: Brown gravelly sand, trace of silt.						
	91,41	(1.30 m)				3-CF	100	N=50/50mm Refusal
	91,21	Probable fill: Gravel, some sand, trace of silt.				4-CR	100	RQD=0%
		(1.50 m)						
2		Bedrock: Gray clayey limestone. Very fractured until 1.65 metres deep. 50° stratification dip. Very poor to fair quality.				5-CR	100	RQD=62%
		5-CR Qu = 104,9 MPa γ = 27,0 kN/m³				6-CR	100	RQD=74%
3								
	89,54	(3.17 m)						
		End of drilling.						
4								

Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-06-07	>3,17

LABORATOIRES D'EXPERTISES de Québec ltée
Ingénierie des sols et des matériaux

BOREHOLE LOG

Number: 4956-00
Hole #: F-13
Elevation: 91,37 m
Date: 2013-05-28

Project: Reconstruction of the Québec City Armoury
Location: Québec (Québec)

Equipment used: Envirotrack
Casing si NW
Hammer weight: 63,5 kg
Drop: 760 mm

Sample condition
Disturbed | Good | Lost

Sample type
- CF Split spoon sampler
- CR Diamond core
- LA Wash sample
- TA Auger sample
- TM Thin-wall sampler
- PS Fixed piston sampler

Symbols
- Groundwater level
- Ach Chemical analysis
- Ag Grain size analysis (sieving)
- Sed Grain size analysis (sedimentation)
- Wc Natural water content
- Wl Liquid limit
- Wp Plastic limit

Depth (m)	Elev (m)	Description	Str	Ground water	Samples: Cond	Samples: No et type	Samples: Rec (%)	Tests
	91,37							
	91,28	Asphalt. (0.09 m)						
		Fill: Gray sand and gravel, trace of silt. Compact.				1-CF	57	N=19
	90,67	(0.70 m)						
1		Remblai: Grayish-brown sand and gravel, trace of silt. Presence of ashes (<2%). Compact.				2-CF	67	N=10
	90,06	(1.31 m)						
		Fill: Brownish-black silt, some sand and gravel. Loose.				3-CF	100	N=7
	89,45	(1.92 m)						
2	89,35	Fill: Gray sand, some gravel. (2.02 m)				4-CF	100	N=25,50/100 mm
	89,05	Brown sandy silt, some gravel similar to deconsolidated rock. (2.32 m)				5-CR	100	RQD=0%
		Bedrock: Gray clayey limestone. Very fractured until 2,50 metres deep. 57° stratification dip. Very poor to poor quality.				6-CR	100	RQD=31%
3		7-CR Qu = 131,3 MPa γ = 26,5 kN/m³				7-CR	100	RQD=48%
	87,57	(3.80 m)						
4		End of drilling.						

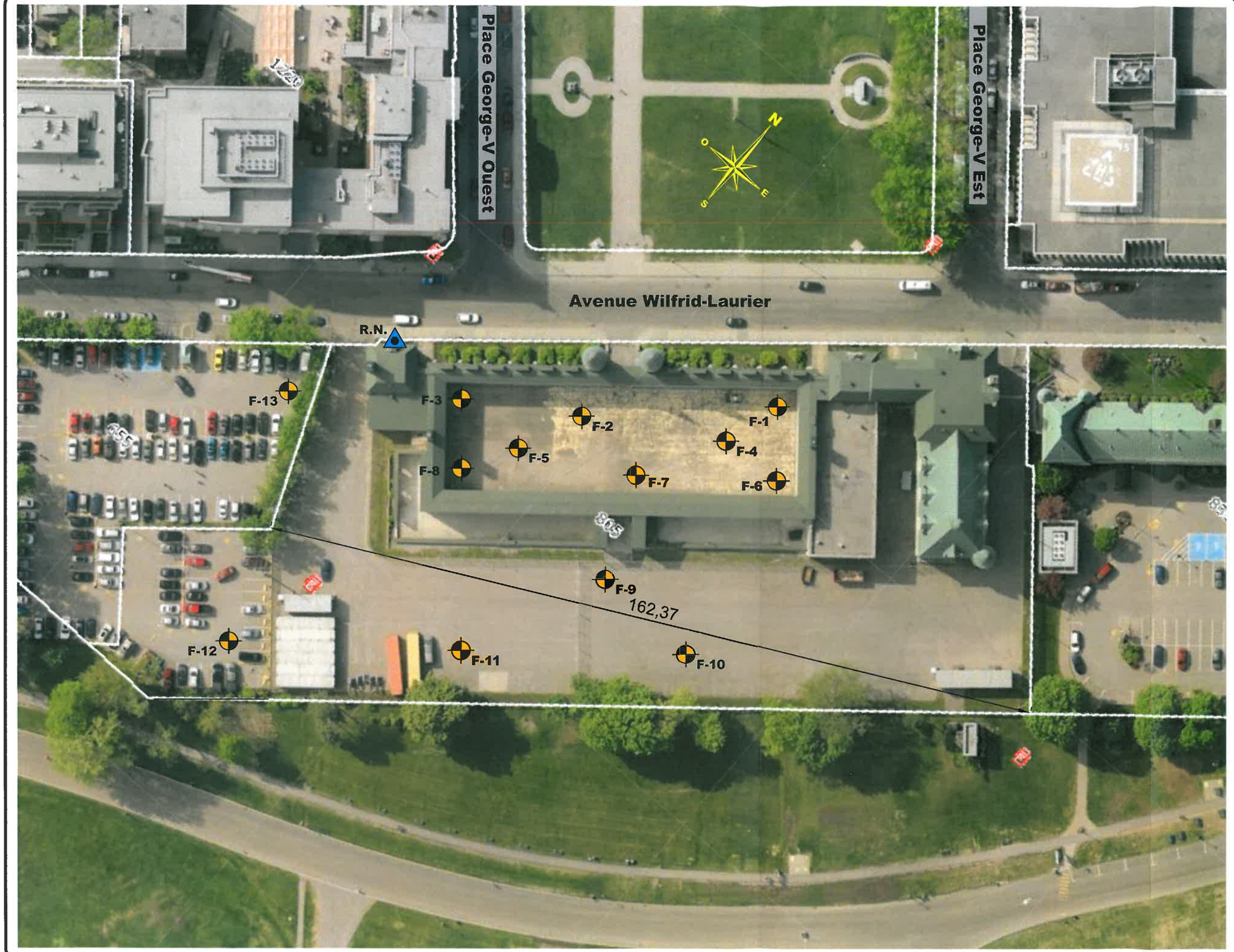
Notes

An open 19 mm diameter tube was left in the borehole to determine groundwater level.

Date	Depth (m)
2013-06-07	2,76

APPENDIX "B"

Borehole Locations
Drawing No. 4956-00-01



Legend:

F-1 Borehole

R.N. Benchmark no 23L1035, Geodetic elevation: 90,87 m

Prepared for:

ARCOP/DFS/STGM Consortium

Prepared by:

LABORATOIRES D'EXPERTISES DE QUÉBEC LTÉE
Géotechnique, environnement et ingénierie des sols et matériaux

Seal:

INGÉNIEUR · ENGINEER
R. JUNEAU
21791
QUÉBEC

Project Title:

Reconstruction of the Québec City Armoury

Drawing Title:

Borehole locations

Author:	Scale:	Project No.:
D.S.	1:750	4956-00
Verified:	Date:	Drawing No.:
R.J.	November 2014	4956-00-01

APPENDIX "C"

Levés MASW
Rapport de la firme Géophysique GPR International inc.

GÉOPHYSIQUE GPR INTERNATIONAL INC.

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Le 4 juin 2013

Transmis par courriel: lmorin@legitech.com
Notre réf : M-13619

M. Louis Morin, ing.
Laboratoires d'Expertises de Québec Ltée
2320 rue de Celles
Québec QC G2C 1X8

Objet: Levés de MASW et de sismique réfraction pour la catégorie d'emplacement
805, Avenue Wilfrid-Laurier est, Québec

[Dossier: 4956-00]

Cher Monsieur,

Nous vous transmettons par la présente les résultats obtenus suite à la réalisation des levés géophysiques du 21 mai 2013, dans le stationnement arrière du Manège militaire Voltigeurs de Québec.

Le 13 mai 2013, Laboratoires d'Expertises de Québec Ltée mandatait Géophysique GPR International inc. pour effectuer des levés de MASW et de sismique réfraction dans le but de mesurer les vitesses de l'onde de surface pour en calculer les vitesses de l'onde sismique de cisaillement pour les dépôts meubles et le roc. À partir de ces résultats, la valeur de V_{S30} a pu être calculée afin d'identifier la catégorie d'emplacement. La localisation régionale du site est présentée à la figure 1, alors que la figure 2 illustre avec plus de détails la localisation du dispositif d'acquisition sismique. MM. Charles Trottier, M.Sc., phys. et Lamine Bah, M.Sc.A., géol. ont vu à la réalisation des levés sismiques sur le terrain.

Les sections qui suivent présentent brièvement le principe de la méthode, puis les résultats émanant des calculs.

Levés de type MASW

Principe de la méthode

La méthode "MASW" (*Multi-channel Analysis of Surface Wave*) est dérivée de la méthode d'auscultation "SASW" (*Spectral Analysis of Surface Wave*). Elle consiste d'abord à mesurer l'onde de Rayleigh (une onde de surface), dont la vitesse de propagation est dispersive en fréquence et principalement dépendante des ondes de cisaillement (ou S) et en partie de l'onde de compression (ou P) des matériaux. On en déduit ensuite la distribution de la vitesse sismique de l'onde de cisaillement en profondeur. Le MASW est une méthode qui opère dans le domaine des fréquences plutôt que du temps, ce qui la rend plus robuste au bruit sismique environnant, comme en milieu urbain. La méthode MASW est considérée comme "active", puisque les signaux sismiques sont induits à des lieux et moments connus et contrôlés par rapport au dispositif de géophones. De nature similaire, la méthode ESPAC (*Extended Spatial Autocorrelation*) ou MSM (*Microtremor Survey Method*) est considérée "passive", utilisant des sources lointaines qui produisent des "signaux" de plus basses fréquences. Elle peut aussi être appliquée à des enregistrements sismiques "actifs".

Les propriétés de dispersion sont mesurées comme des changements de vitesses de l'onde de Rayleigh (V_R) en fonction des fréquences. L'énergie de l'onde de surface décroît exponentiellement en fonction de la profondeur. Les ondes de surface de basses fréquences se propagent plus profondément et sont davantage influencées par les vitesses sismiques de cisaillement des matériaux plus profonds, que celles de plus hautes fréquences. L'inversion de la courbe de dispersion de l'onde de Rayleigh permet de calculer un sondage de la vitesse sismique de l'onde de cisaillement (V_S) en fonction de la profondeur. La figure 3 présente le mode opératoire de base sur le terrain pour un levé de type MASW. La figure 4 illustre les étapes types des résultats d'acquisition et de traitement de la méthode. Une description plus détaillée de la méthode est présentée par *Multi-channel Analysis of Surface Waves*, Park, C.B., Miller, R.D. et Xia, J., Geophysics, Vol. 64, No. 3 (May-June 1999); pp. 800–808. Pour la méthode passive, on peut se référer à *Shear Velocity Profiles Obtained from Microtremor Array Data with an Example from Direct Fitting of SPAC Curves*, Asten, M.W., 2007, Proceedings of the 20th SAGEEP Conference, Denver, Environmental and Engineering Geophysical Society; ou aussi : *The Microtremor Survey Method*, Okada, H., S.E.G., Geophysical Monograph Series No. 12.

Mise en place des dispositifs de levés

L'espacement entre les géophones était de 3 mètres pour le dispositif principal et de 1 mètre pour le dispositif secondaire centré sur le dispositif principal, utilisé afin d'obtenir une meilleure résolution des couches supérieures. Une masse de 80 lb ("weight drop") a été utilisée comme source sismique. Les points d'impact ont été réalisés aux deux

extrémités des dispositifs. La méthode MASW permet la réalisation d'un sondage de vitesses de l'onde sismique de cisaillement issue de l'intégration horizontale de près de la demi-longueur du dispositif d'acquisition sismique en surface. Le sondage de V_S doit être considéré comme localisé vers le centre du dispositif d'acquisition.

Le roc étant connu à faible profondeur, des mesures de sismique réfraction ont également été réalisées, utilisant le dispositif d'acquisition sismique principal de MASW.

Traitement des levés de MASW

Les principales étapes du traitement incluent l'inspection et l'édition des données brutes ; fenêtrage temporel ; transformation en spectrogrammes des enregistrements sismiques ; identification du mode fondamental de dispersion de la vitesse de phase ; et inversion numérique menant au sondage de vitesses de l'ondes de cisaillement (V_S) des matériaux ayant permis la construction des ondes de Rayleigh (V_R). Ces étapes ont été réalisées avec le logiciel SeisImagerSW™ d'OYO. La précision de la restitution de V_S, à partir de la mesure de V_R serait normalement de l'ordre de 15 % ou mieux.

Traitement des levés de Sismique Réfraction

La méthode de sismique réfraction, qui opère dans le domaine du temps, permet le calcul des profondeurs des réfracteurs, de même que celui de leurs vitesses sismiques respectives. Dans le cas présent, les levés ont été réalisés pour permettre les calculs des vitesses sismiques de l'onde de compression (P) et de cisaillement (S) du roc, afin de pallier à une limitation de la méthode MASW lorsque le roc est peu profond.

La séquence de traitement se résume par : identification des temps d'arrivées des tirs (ébranlements) de directions opposées ; régression linéaire des demies différences de délais d'arrivées d'ondes sismiques de directions opposées pour obtenir les vitesses sismiques recherchées (Hobson-Overton). Les logiciels MK-6 (de ABEM) et SeisImager/2D (de OYO) ont été utilisées.

Résultats

Les résultats des mesures de sismique réfraction sont présentés à la figure 5, par les régressions linéaires des demies différences de délais des tirs de directions opposées, pour les ondes de compression (P) et de cisaillement (S) dans le roc. Les vitesses sismiques calculées sont de V_P = 4056 m/s et de V_S = 2240 m/s. Il s'agit vraisemblablement des vitesses sismiques du roc sain (rapport de Poisson de σ = 0,28). Étant donné que l'onde réfractée est de nature évanescente à partir de l'interface du

réfracteur, les vitesses mesurées par sismique réfraction sont représentatives des vitesses les plus élevées de la portion supérieur du roc.

La figure 6 illustre les valeurs de V_S calculées par MASW en fonction de la profondeur, ainsi que la valeur calculée par sismique réfraction, assumée constante en profondeur.

Le calcul de la vitesse moyenne fait usage de la moyenne harmonique plutôt que de la moyenne arithmétique pour tenir compte de l'effet de délais cumulatifs pour chaque tranche de matériel considérée. Ainsi, la valeur de V_{S30} représente la vitesse de l'onde de cisaillement d'une couche équivalente d'un matériel homogène entre la surface et 30 mètres de profondeur.

Le Tableau 1 présente le calcul de la valeur de V_{S30} pour le terrain actuel, utilisant les résultats de MASW et de sismique réfraction. Cette valeur est de 1623,5 m/s, correspondant à la catégorie d'emplacement "A".

Une évaluation sommaire de la profondeur du roc (sain) par sismique réfraction montre un léger pendage du sud-ouest vers le nord-est. De l'extrémité sud-ouest vers le centre du dispositif sismique, le roc (sain) serait à une profondeur de l'ordre de 2 mètres. Il plongerait toutefois jusqu'à près de 3,5 à près de 5 mètres de profondeur, vers l'extrémité nord-est du dispositif sismique.

CONCLUSION

Dans le cadre d'une étude géotechnique pour la reconstruction et l'agrandissement du Manège militaire Voltigeurs de Québec, Laboratoires d'expertises de Québec Ltée a mandaté Géophysique GPR International inc. pour calculer les vitesses sismiques de l'onde de cisaillement des dépôts meubles et du roc, afin d'identifier la catégorie d'emplacement. Les méthodes de sismique réfraction et de MASW ont été utilisées.

Étant donné la faible profondeur du roc et le gradient d'impédance sismique très élevé, le sondage de V_S par MASW a été limité en profondeur. Le résultat de sismique réfraction a été utilisé pour compléter la colonne stratigraphique jusqu'à 30 mètres de profondeur pour le calcul de la valeur de V_{S30}. La valeur de V_S du roc obtenue par sismique réfraction a été extrapolée jusqu'à 30 mètres. L'hypothèse raisonnable de continuité en profondeur de la qualité mécanique du roc a été considérée.

La valeur de V_{S30} obtenue pour le terrain actuel est de 1624 m/s, correspondant à la catégorie d'emplacement "A" (V_{S30} > 1500 m/s) selon le code national du bâtiment (cf. Tableau 4.1.8.4.A).

Des résultats sommaires de calculs de sismique réfraction suggèrent que la portion sud-ouest du dispositif sismique montrerait un roc (sain) de l'ordre de 2 mètres de profondeur. Par contre, la portion nord-est présenterait un roc (sain) à des profondeurs de l'ordre de 3,5 à près de 5 mètres. Selon le Commentaire J, #100 du CNB, les catégories d'emplacements "A" et "B" ne peuvent pas être considérées si il y a plus de 3 mètres de matériaux meubles entre le roc et la portion inférieure des fondations.

Il est à noter que d'autres informations géotechniques recueillies sur le site ; y compris la présence de sols liquéfiables, d'argiles sensibles, de haute teneur en eau, etc. peuvent conduire à une révision de la catégorie d'emplacement, telle que fournie dans ce rapport, laquelle est basée sur la valeur calculée de V_{S30}.

Les valeurs de V_S calculées et présentées dans ce rapport sont représentatives de l'état in-situ des matériaux et n'ont pas été corrigées pour les contraintes totales et effectives.

Ce rapport a été rédigé par Jean-Luc Arsenault, ing., M.Sc.A.

Espérant le tout à votre satisfaction, veuillez agréer, cher Monsieur, l'expression de nos sentiments les meilleurs.

Jean-Luc Arsenault, ing., M.Sc.A.
Chargé de projets
(Numéro de membre de l'O.I.Q.: 45316)

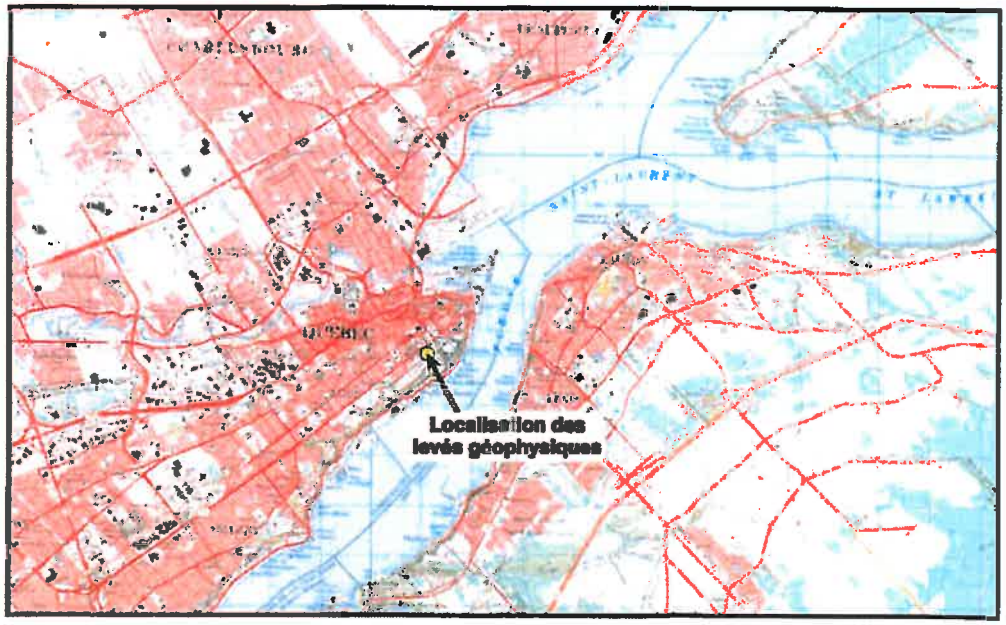


FIGURE 1
Localisation régionale du site
(Source : feuillet topographique 21 L/14)

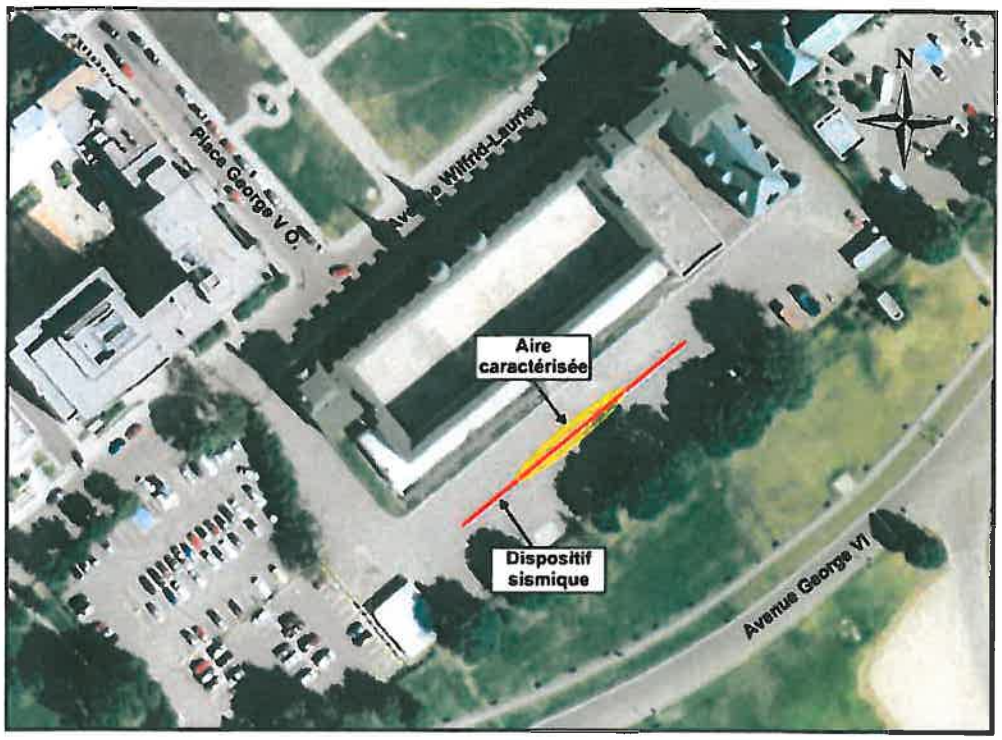


FIGURE 2
Localisation du dispositif sismique
(Source : *Yahoo! maps*)

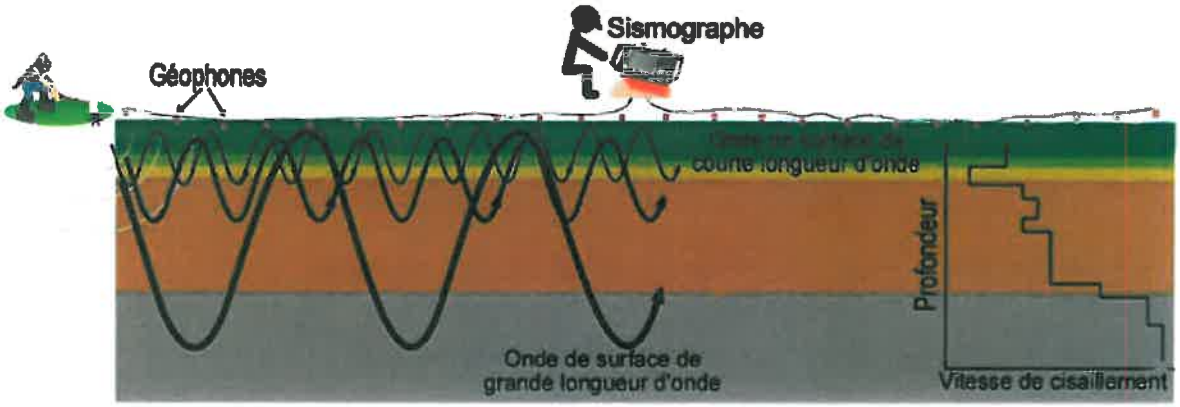


FIGURE 3
Croquis du principe de base de la méthode MASW

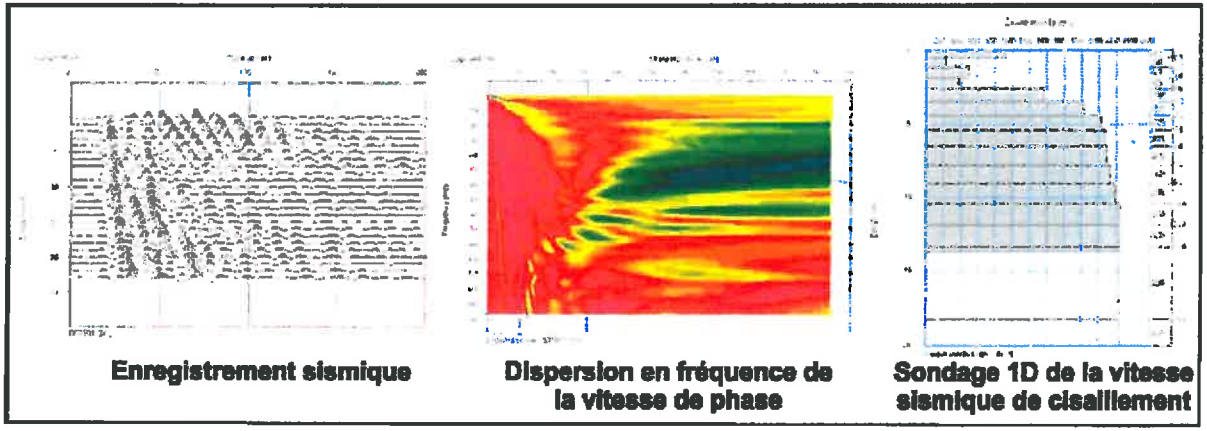
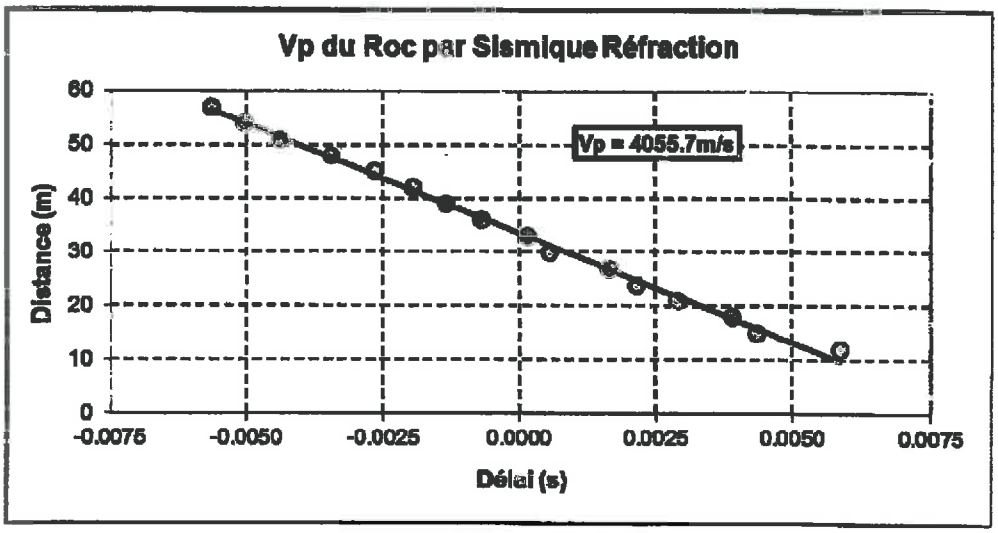


FIGURE 4
Exemple d'enregistrement sismique (MASW/ESPAC) brut, de la dispersion en fréquence de la vitesse de phase et d'un modèle 1D résultant de la vitesse de cisaillement en profondeur



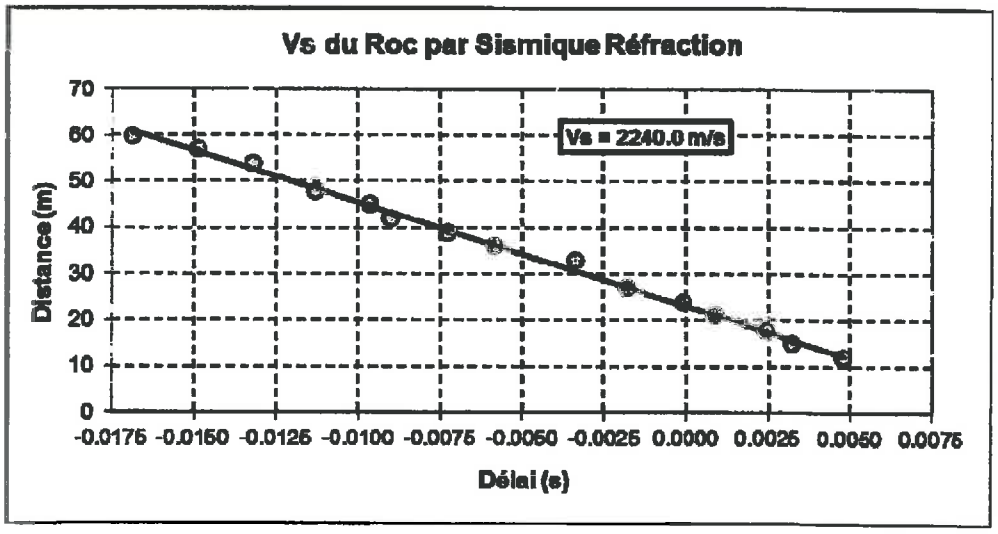


FIGURE 5
V_P et V_S du roc par sismique réfraction

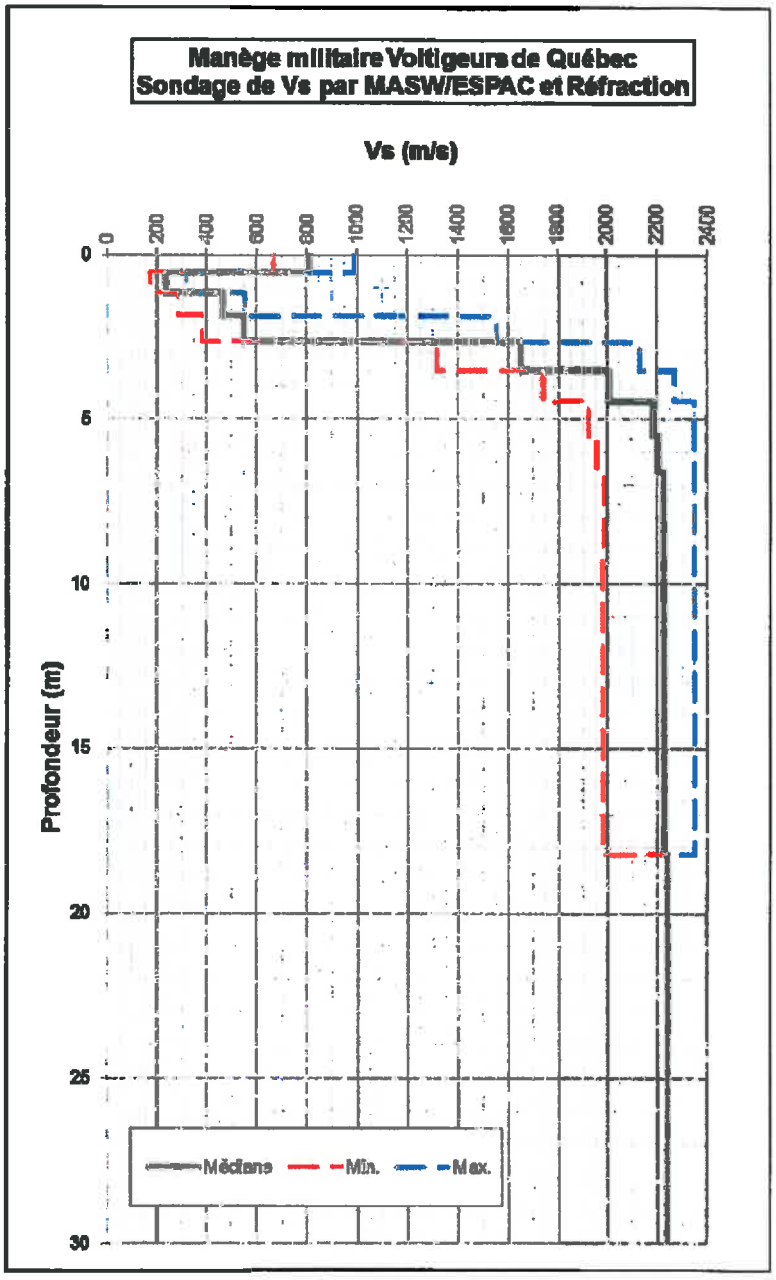


FIGURE 6
Sondage de V_S

TABLEAU 1
Calcul de la valeur de V_{s30} du terrain actuel

Profondeur	Vs			Épaisseur	Épaisseur cumulée	Délai pour Vs méd.	Délai cumulé	Vs moy. à prof. donnée
	Min.	Médiane	Max.					
(m)	(m/s)	(m/s)	(m/s)	(m)	(m)	(s)	(s)	(m/s)
0.00	666.1	810.9	989.5					
0.54	169.3	235.9	314.5	0.54	0.54	0.000661	0.000661	810.9
1.15	283.8	464.7	555.4	0.62	1.15	0.002620	0.003281	351.7
1.86	375.7	550.6	1552.9	0.70	1.86	0.001509	0.004790	387.3
2.64	1319.2	1650.9	2132.6	0.78	2.64	0.001422	0.006212	424.7
3.50	1742.3	2008.7	2267.7	0.87	3.50	0.000524	0.006736	520.1
4.45	1919.6	2184.8	2351.0	0.95	4.45	0.000472	0.007208	617.5
5.48	1958.1	2204.6	2351.0	1.03	5.48	0.000471	0.007679	713.8
6.59	1986.6	2227.1	2351.0	1.11	6.59	0.000505	0.008184	805.7
7.79	2057.0	2240.0	2371.4	1.20	7.79	0.000537	0.008721	893.2
9.07	2160.8	2271.9	2414.8	1.28	9.07	0.000570	0.009291	975.8
10.43	2240.0	2305.1	2417.6	1.36	10.43	0.000599	0.009889	1054.3
11.87	2240.0	2351.0	2437.8	1.44	11.87	0.000626	0.010515	1128.7
13.39	2240.0	2347.3	2454.7	1.53	13.39	0.000649	0.011163	1199.7
18.21	2240.0	2240.0	2240.0	4.82	18.21	0.002054	0.013217	1378.0
30.00				11.79	30.00	0.005262	0.018479	1623.5

Vs30 (m/s) =	**1623.5**
Catégorie :	**A***

* : Les catégories d'emplacement A et B ne peuvent être considérées si il y a plus de 3 mètres de matériaux meubles entre le roc et la portion inférieure des fondations.