VIII

Appendix VIII
Down-Hole Seismic Surveys and Electrical Soundings

Terratech

APPENDIX VIII

Down-Hole Seismic Surveys and Electrical Soundings

Report by Geophysics GPR International Inc. # M-05043 dated April 2005

Report by Geophysics GPR International Inc. # M-05128 dated November 2005

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Our ref. : M-05043

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Montreal QC H2Z 1Z3

Subject: **Down-hole seismic surveys at Lévis, QC – Rabaska Project**

Dear Sir,

Please find attached two (2) bound copies and one copy not bound of the final report with regard to the above mentioned subject.

We hope everything is to your satisfaction. Do not hesitate to contact us for any further information.

Yours truly,

Jean-Luc Arsenault, Eng., M.A.Sc.

JLA/vsg

Enclosure

ISO 9001

DOWN-HOLE SEISMIC SURVEY
RABASKA PROJECT, LÉVIS QUÉBEC

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1. INTRODUCTION

In March 2005, Terratech mandated Geophysics GPR International Inc. to execute two down-hole seismic surveys at the Rabaska project site in Lévis, Québec (Can.). The purpose of this survey was to provide the seismic shear wave velocity of the soil and the rock, as well as the dynamic elastic properties. This work was required to complement the methane storage tanks site feasibility studies. The survey location is presented in figure 1.

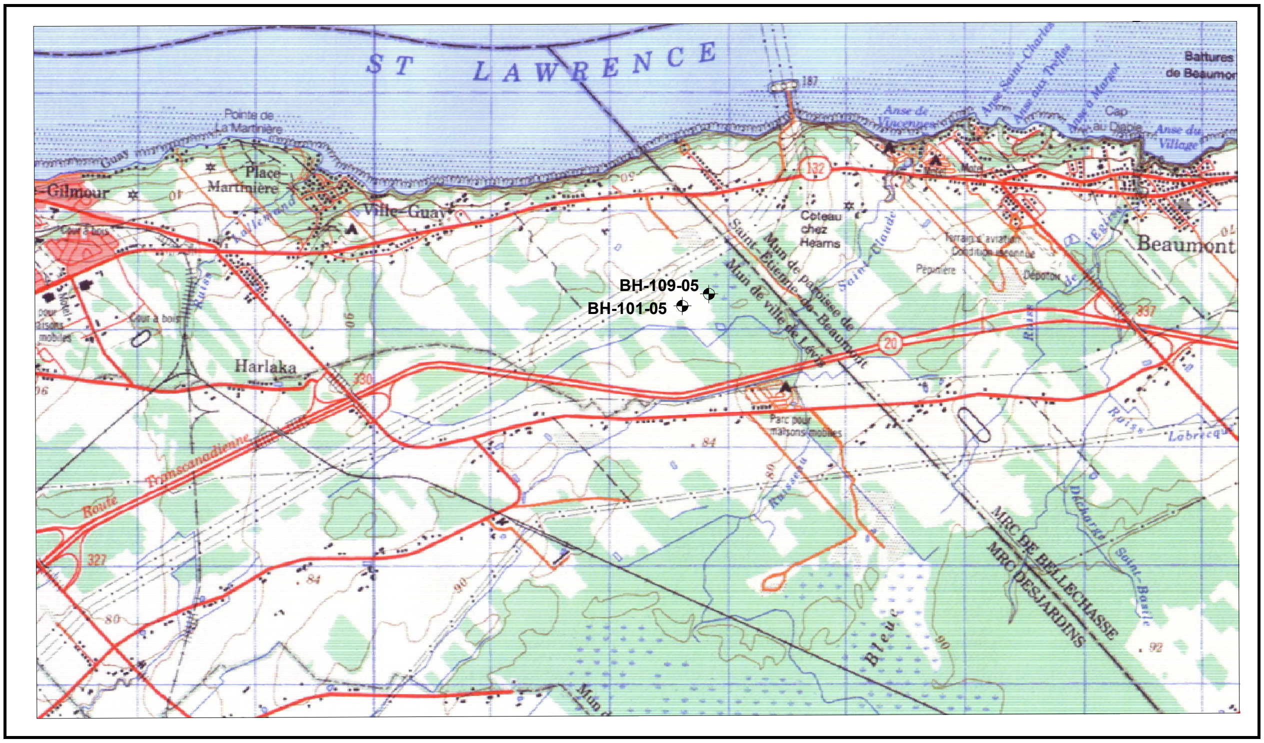

FIGURE 1
Approximate survey location

2. METHODOLOGY

This section briefly presents the field procedures and interpretation methods used for the down-hole seismic surveys. The field work was executed on the 3th of April, 2005 by Mr. Daniel Campos (Jr. Eng., M.A.Sc.), Mr. Benoit Maillé (Sr. Tech.) and Mr. Bao Nguyen (Tech.) The boreholes investigated (BH-101-05 and BH-109-05) are about 25 meters deep and are distanced by about 250 meters as seen on figure 1. These boreholes were previously performed by Terratech.

The down-hole seismic survey was executed using a surface seismic source and an in-hole seismic receiver. Figure 2 shows a schematic diagram of the set-up.

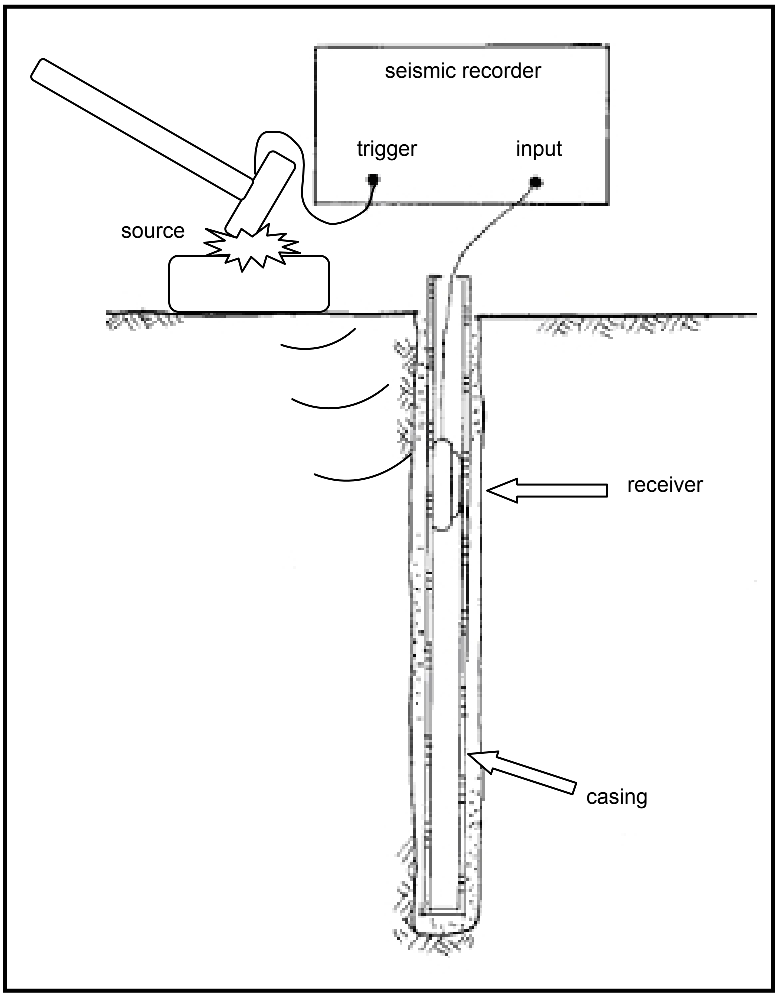

FIGURE 2
Schematic diagram of the down-hole seismic survey

The boreholes had 2.5" inner diameter PVC casing. These boreholes were used to measure the seismic wave arrivals with a 3D geophone, held in firm contact with the casings by lamellar springs. The seismic records were acquired with a Terraloc Mark VI seismograph from ABEM. In order to have a good resolution and to be sure to record some eventual very slow shear waves, the sampling interval was set to 50 µs. Thus, every record was 185 ms long, and a pre-trig delay of 10 ms ensured to always record the entire seismic signal at the geophone.

Compression “P” and shear “S” waves were produced by hitting a 10 pound sledgehammer vertically on a steel plate and laterally on a wooden beam that was coupled to the ground using metal studs. To facilitate the picking of the shear “S” wave arriving time, the wooden beam was hit on both extremities in order to obtain inverse polarities of the wave signal. An impact switch was used to trigger the seismic recorder. Seismic records were produced every 1.0 meter along the borehole. The travel time from the source to each receiver (geophone) are determined by measuring the elapsed time from the time break to the seismic wave manifestation within the record. The distance between each geophone location was then divided by the time elapsed for the different seismic waves travel time, to obtain local seismic velocities in function of depth. The down-hole method presents the advantages of being free from the seismic velocities inversion in depth, as well as not being affected by refraction effects in opposition to the crosshole method.

The "P" wave velocity is not polarizable, and depends mainly on volumetric elastic ratio of the constituent soil particles and pore water. The "S" wave has the advantage to be inverted, and its velocity depends more on the structural elasticity of the material, which is influenced by the size, form and tightness of the particles.

<u>Mechanical dynamic moduli</u>

The main objective of the down-hole seismic survey was to provide the in situ measurement of the shear wave velocity of the rock, and also to evaluate the dynamic elastic properties of the overburden and rock. Two types of seismic waves were required for this purpose. These are the compressional wave velocity ("Vp") and the shear wave velocity ("Vs"). The propagation of this second seismic wave is always slower than the one produced by the compression action by almost a factor 3 to 6 in the case of an unconsolidated material. Both seismic waves are assumed to propagate into an isotropic material according to its elastic mechanical parameters and density as shown below:

$$Vp = \sqrt{\frac{E(1-\nu)}{\rho(1-2\nu)(1+\nu)}}$$

and

$$Vs = \sqrt{\frac{E}{2\rho(1+\nu)}}$$

where :

Vp	:	seismic compressional wave
Vs	:	seismic shear wave
E	:	Young modulus
υ	:	Poisson ratio
ρ	:	density of the material

Knowing the "Vp", "Vs" and the density of the material, one can directly derive its elastical properties (Poisson ratio, Young, bulk and shear moduli).

The Poisson ratio is determined directly from the compressional and shear waves data. It is expressed by the ratio of transverse strain to longitudinal strain. Its dynamic determination can be noted as:

$$\nu = \frac{Vp^2 - 2Vs^2}{2(Vp^2 - Vs^2)}$$

The Poisson ratio usually varies from 0.05 for a very hard and rigid rock, to 0.48 for a soft and poorly consolidated material, the value 0.5 being characteristic of a non-solid (liquid) material where "Vs" is non-existent.

The Young, bulk and shear moduli require the material density (ρ). Their dynamic determination can be expressed as follows:

The Young modulus is the uniaxial stress-strain ratio. It is also sometimes known as the stretch modulus or modulus of elasticity, and can be calculated as:

$$E = \frac{\rho Vp^2(1+\nu)(1-2\nu)}{(1-\nu)} = 2\rho V_S^2(1+\nu)$$

The bulk modulus, also known as the incompressibility modulus, is the stress-strain ratio under simple hydrostatic pressure (pressure change on volumetric dilatation). Its dynamic evaluation can be obtained by the following equation:

$$K = \frac{E}{3(1-2\nu)}$$

The shear modulus is the stress-strain ratio for a simple shear. It is also known as the rigidity modulus and its dynamic value is obtained by:

$$G = \rho Vs^2 \quad \text{or} \quad G = \frac{E}{2(1+\nu)}$$

Nevertheless, all of these mechanical moduli are named "dynamic moduli" as opposed to the usual "static moduli" measured from laboratory tests. Dynamic moduli are then generally higher than static ones. The dynamic moduli of elasticity are also the instantaneous deformation moduli under the natural state of stress. The main differences between the dynamic and the static tests are the time factor of the load and the low strain level applied to the material.

3. DOWN-HOLE SEISMIC SURVEY RESULTS

BH-101-05

The borehole BH-101-05 was 25.63 m deep while the surveys were carried-out. The rock surface was 9.65 m deep, according with the boring logs. Figure 3 present a seismogram constructed with some seismic records from this borehole, showing the P and S waves with increasing time with depth. A possible deeper "reflector" also shows up, with a decreasing time with depth. It could be located at approximately 33 m deep.

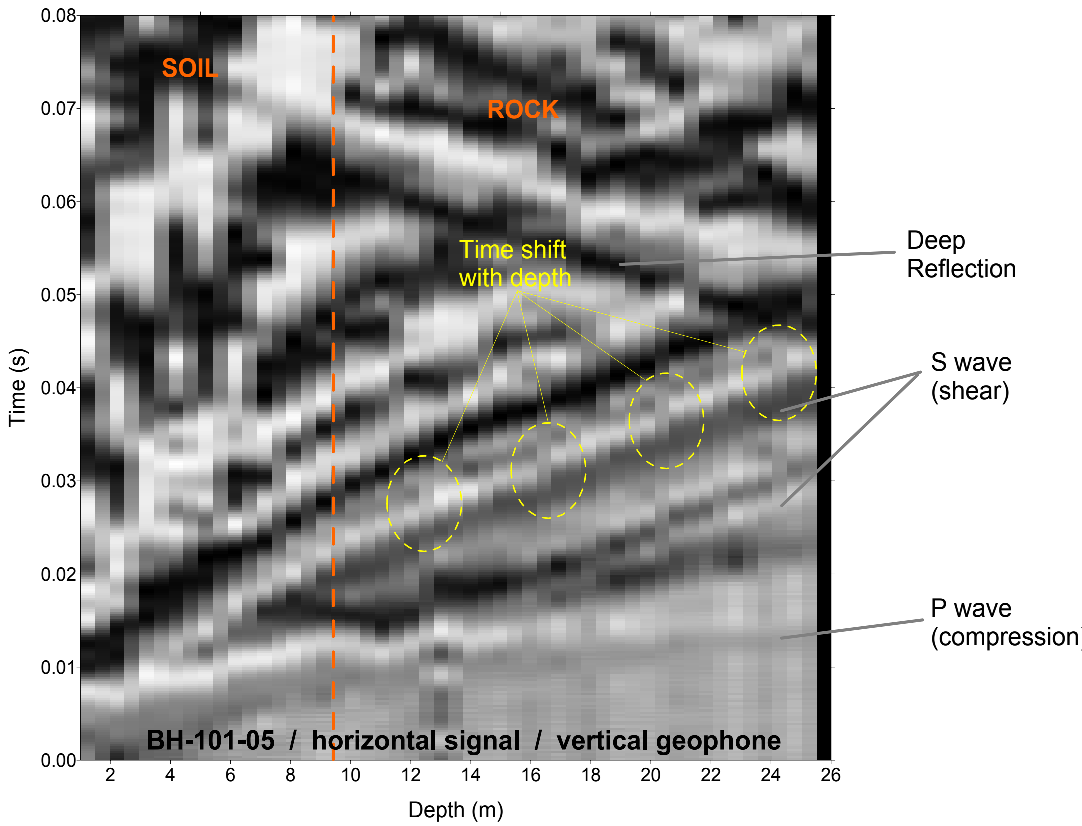

FIGURE 3
Seismogram (Th-Rv) from BH-101-05

The measured seismic velocities are presented at the table 1. For the dynamic moduli calculations, we assumed two material densities that could be within a reasonable range for the surface sediment (1900 kg/m^3), and for the rock (2600 kg/m^3).

The "Vp" values are generally low, but in agreement with the range of velocities previously measures in the area by seismic refraction. The evolution of these velocities with depth, describes roughly the main trends expressed from the RQD values. Within the overburden, the very high “Vp” value of 2851 m/s at 2.2 m deep could be explained by the presence of frozen soil, as the thaw period was not completed while the surveys were performed.

TABLE 1

Seismic velocities measured and calculated dynamic moduli at BH-101-05

Depth (m)	Vs (m/s)	Vp (m/s)	Vol.mass.* (kg/m3)	Poisson	G dyn. (GPa)	E dyn. (GPa)	K dyn. (GPa)
2.2		2851	1900				
3.7	492	1924	1900	0.46	0.46	1.35	6.42
5.2	490	1387	1900	0.43	0.46	1.30	3.05
6.2	512	1096	1900	0.36	0.50	1.35	1.62
7.2	523	1246	1900	0.39	0.52	1.45	2.26
8.2	548	1428	1900	0.41	0.57	1.61	3.11
9.2	676	1570	1900	0.39	0.87	2.41	3.52
10.2	779	1894	2600	0.40	1.58	4.41	7.22
11.2	727	3710	2600	0.48	1.37	4.07	33.96
12.2	841	3564	2600	0.47	1.84	5.40	30.58
13.2	979	3363	2600	0.45	2.49	7.24	26.08
14.2	1230	3691	2600	0.44	3.93	11.31	30.18
15.2	1045	3475	2600	0.45	2.84	8.23	27.62
16.2	593	3184	2600	0.48	0.91	2.71	25.15
17.2	724	2944	2600	0.47	1.36	4.01	20.72
18.2	779	2645	2600	0.45	1.58	4.58	16.09
19.2	669	2194	2600	0.45	1.16	3.37	10.97
20.2	843	1677	2600	0.33	1.85	4.92	4.85
21.2	783	1668	2600	0.36	1.59	4.33	5.10
22.2	757	1643	2600	0.37	1.49	4.07	5.03
23.2	684	2370	2600	0.45	1.22	3.54	12.98
23.7		3076	2600				

* : “assumed” density values.

The principal information from this survey is probably the very low shear wave velocity of the mudstone-shale (very severely fractured to fractured, from the boreholes logs). The “Vs” values are oscillating around 800 m/s. It reached more than 1000 m/s between 13 and 16 m deep, but it also matched the higher RQD value (93 %) calculated from the drill core. Similarly, the lower “Vs” values generally also matched the low RQD values.

The calculated Poisson ratios are generally as high in the overburden as in the rock. The dynamic shear modulus (“G”) range around 1.5 GPa, with the exception between 14 and 16 m deep, were it could range from 2.5 to 4 GPa.

BH-109-05

The borehole BH-109-05 was 25.98 m deep while the surveys were carried-out. The rock surface was 7.26 m deep, according with the boring logs. Figure 4 presents two seismograms constructed with some seismic records from this borehole. The “S” waves were recognized clearly, with increasing time with depth. The P waves were more difficult to recognize at this site. As noticed at the BH-101-05 site, a possible deeper “reflector” also shows up (on the vertical geophone seismogram), and It could be located at approximately 27 m deep.

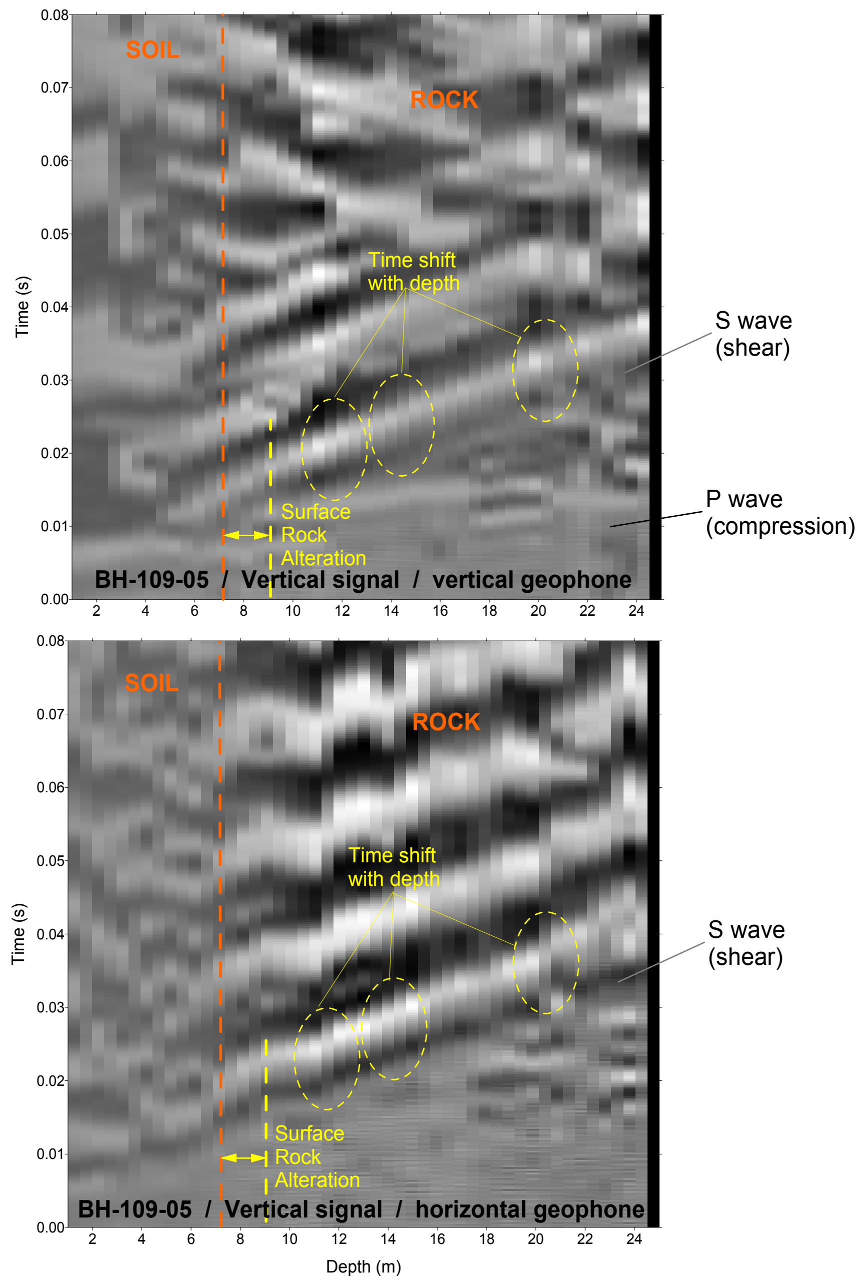

FIGURE 4
Seismogram (Tv-Rv and Tv-Rh) from BH-109-05

The measured seismic velocities are presented at the table 2. Similarly to the BH-101-05, for the dynamic moduli calculations, we assumed two material densities that could be within a reasonable range for the surface sediment (1900 kg/m^3), and for the rock (2600 kg/m^3).

The “Vp” values were difficult to be clearly recognized for this site. Nevertheless, even if they could reveal a real degree of uncertainty for the rock, they presented some low values for the superficial part of the rock; a “Vp” between 2800 and 3200 m/s between 11 and 19 m deep; and average (and extrapolated value) of 3377 m/s for greater depths.

TABLE 2

Seismic velocities measured and calculated dynamic moduli at BH-109-05

Depth (m)	Vs (m/s)	Vp (m/s)	Vol.mass.* (kg/m3)	Poisson	G dyn. (GPa)	E dyn. (GPa)	K dyn. (GPa)
2.3	286		1900		0.16		
5.3	444		1900		0.38		
6.3	507		1900		0.49		
7.3	552		1900		0.79		
8.3	578	2070	2600	0.46	0.87	2.53	9.98
9.3	705	1749	2600	0.40	1.29	3.62	6.23
10.3	768	1938	2600	0.41	1.54	4.32	7.72
11.3	823	2256	2600	0.42	1.76	5.02	10.88
12.3	856	2847	2600	0.45	1.90	5.52	18.53
13.3	688	2889	2600	0.47	1.23	3.62	20.07
14.3	735	3132	2600	0.47	1.41	4.13	23.64
15.3	778	3677	2600	0.48	1.58	4.65	33.05
16.3	808	3082	2600	0.46	1.70	4.97	22.43
17.3	735	2855	2600	0.46	1.41	4.12	19.31
18.3	698	2861	2600	0.47	1.26	3.72	19.60
19.3	771	3377	2600	0.47	1.54	4.55	27.59
20.3	708	3377	2600	0.48	1.30	3.85	27.92
21.3	1154	3377	2600	0.43	3.46	9.93	25.04
22.3	1210	3377	2600	0.43	3.80	10.85	24.58
23.3	971	3377	2600	0.45	2.45	7.14	26.38

* : “assumed” density values.

The shear wave velocities measured in the rock were very low. They were in the range of 800 m/s, except between 20 and 23 m deep, where it happened to be of the order of 1200 m/s. The corresponding dynamic shear modulus “G” (assuming a material density of about 2600 kg/ m^3) was of the order of 1.5 GPa.

The calculated Poisson ratios for the rock are generally very high, presenting similarities as expected for the overburden. They could be varying between 0.40 and 0.48, which is not a standard range for a rock, and even not for a glacial till or clay. Nevertheless, even if these values are significantly high, they seem to match with Poisson ratios previously calculated (using ASTM specification crosshole surveys) for a Quebec city South shore municipality’s shales, at few tens of kilometers of the investigated site.

4. CONCLUSION

The down-hole geophysical surveys carried out at the potential Lévis site (in two boreholes) revealed that the rock (a mudstone with thin layers of shale, very severely fractured to fractured) presents normal, and even high seismic velocities for its seismic compressional nature ("Vp"), but some very low values for its shear seismic waves velocities ("Vs"). Generally, as well as for BH-101-05 as BH-109-05, the representative shear wave velocity appeared to be of the order of 800 m/s, which is very low for a sound sedimentary rock. The average value was usually lightly exceeded where the RQD values where high, but it still remained low.

The shear modulus "G" was estimated considering a hypothetic but realistic volumetric mass of 2600 kg/m^3. The "G" general values for BH-101-05 and BH-109-05 calculated could be of the order of 1.5 GPa, which is low for a sedimentary rock.

This report was prepared by Daniel Campos, Jr. Eng. M.A.Sc., and it was approved by Jean-Luc Arsenault, Eng., M.A.Sc.

Jean-Luc Arsenault, Eng., M.A.Sc.
Project manager

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