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Transmitted by email: matthew.firestone@landrichomes.com
Our Ref.: GPR-21-03368

Mr. Matthew Firestone
Project Manager
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Subject: **Shear Wave Velocity Sounding for the Site Class Determination**
1765 Montreal Road & 9 Beckenham Lane, Ottawa (ON)

Dear Sir,

Geophysics GPR International inc. has been mandated by Landric MTL Road Property inc. to carry out seismic shear wave surveys on a property located north-east of the Montréal Road and Beckenham Lane corner, in Ottawa (ON). The geophysical investigation used the Multi-channel Analysis of Surface Waves (MASW), the Spatial AutoCorrelation (SPAC), and the seismic refraction methods. From the subsequent results, the seismic shear wave velocity values were calculated for the soil and the rock, to determine the Site Class.

The surveys were carried out on November 5th, 2021, by Mrs. Karyne Faguy, B.Sc. geoph. and Mr. Dominic Déraps, tech. geoph. Figure 1 shows the regional location of the site and Figure 2 illustrates the location of the seismic spreads. Both figures are presented in the Appendix.

The following paragraphs briefly describe the survey design, the principles of the testing methods, and the results presented in tables and graphs.

MASW PRINCIPLE

The *Multi-channel Analysis of Surface Waves* (MASW) and the *SPatial AutoCorrelation* (SPAC or MAM for *Microtremors Array Method*) are seismic methods used to evaluate the shear wave velocities of subsurface materials through the analysis of the dispersion properties of the Rayleigh surface waves ("ground roll"). The MASW is considered an "active" method, as the seismic signal is induced at known location and time in the geophones' spread axis. Conversely, the SPAC is considered a "passive" method, using the low frequency "signals" produced far away. The method can also be used with "active" seismic source records. The SPAC method allows deeper Vs soundings, but generally with a lower resolution for the surface portion. Its dispersion curve can then be merged with the one of higher frequency from the MASW to calculate a more complete inversion. The dispersion properties are expressed as a change of phase velocities with respect to frequencies. Surface wave energy will decay exponentially with depth. Lower frequency surface waves will travel deeper and thus be more influenced by deeper velocity layering than the shallow higher frequency waves. The inversion of the Rayleigh wave dispersion curve yields a shear wave (V_S) velocity depth profile (sounding).

Figure 3 schematically outlines the basic operating procedure for the MASW method. Figure 4 illustrates an example of one of the MASW/SPAC records, the corresponding spectrogram analysis and resulting 1D V_S model.

INTERPRETATION

The main processing sequence involved data inspection and edition when required; spectral analysis ("phase shift" for MASW, and "cross-correlation" for SPAC); picking the fundamental mode; and 1D inversion of the MASW and SPAC shot records using the SeisImagerSW™ software. The data inversions used a nonlinear least squares algorithm.

In theory, all the shot records for a given seismic spread should produce a similar shear-wave velocity profile. In practice, however, differences can arise due to energy dissipation, local surface seismic velocities variations, and/or dipping of overburden layers or rock. In general, the precision of the calculated seismic shear wave velocities (V_S) is of the order of 15% or better.

More detailed descriptions of these methods are presented in *Shear Wave Velocity Measurement Guidelines for Canadian Seismic Site Characterization in Soil and Rock*, Hunter, J.A., Crow, H.L., et al., Geological Surveys of Canada, General Information Product 110, 2015.

SURVEY DESIGN

The seismic acquisition spreads were laid out on the 1765 Montreal Road property, with geophone spacing of 2.5 metres for the main spread, using 24 geophones (Figure 2). Two shorter seismic spreads, with geophone spacing of 0.2 and 0.5 metre, were dedicated to the near surface materials. The seismic records were produced with a seismograph Terraloc Pro 2 (from ABEM Instrument), and the geophones were 4.5 Hz. An 8 kg sledgehammer was used as the energy source with impacts being recorded off both ends of the seismic spreads.

The seismic records counted 4096 data, sampled at 1000 µs for the MASW surveys, and 40 µs for the seismic refraction. The records included a pre-trigged portion of 10 ms. A stacking procedure was also used to improve the Signal / Noise ratio for the seismic records.

The shear wave depth sounding can be considered as the average of the bulk area within the geophone spread, especially for its central half-length.

RESULTS

From seismic refraction (V_P), the rock depth was calculated between 2.2 and 2.9 metres (± 1 metre). The V_S for the upper portion of the rock was calculated to 1450 m/s. These results were used as initial parameters for the basic geophysical model, prior to the MASW dispersion curves modeling and inversions.

The MASW calculated V_S results are illustrated at Figure 5. Some very low to low seismic velocities values were calculated from the surface to approximately 1 metre deep. Due to the high gradient of seismic impedance between the rock and the overlaying materials, and the shallow rock, the calculated valid V_S values did not exceed 21 metres deep. The deeper valid V_S values were extrapolated to 30 metres to allow the $\overline{V}_{S30}$ calculation.

The $\overline{V}_{S30}$ value results from the harmonic mean of the shear wave velocities, from the surface to 30 metres deep. It is calculated by dividing the total depth of interest (30 metres) by the sum of the time spent in each velocity layer from the surface down to 30 metres, as:

$$\bar{V}_{S30} = \frac{\sum_{i=1}^{N} H_i}{\sum_{i=1}^{N} H_i / V_i} \quad | \quad \sum_{i=1}^{N} H_i = 30\ \mathrm{m}$$

(N: number of layers; H_i : thickness of layer "i" ; V_i : V_S of layer "i")

Thus, the $\bar{V}_{S30}$ value represents the seismic shear wave velocity of an equivalent homogeneous single layer response, between the surface and 30 metres deep.

The calculated $\bar{V}_{S30}$ value of the actual site is 860.9 m/s (cf. Table 1), corresponding to the Site Class "B".

In the event the foundations would be 4.5 metres or more below the rock surface, the $\bar{V}_{S30}$* value would be greater than 1500 m/s, allowing the use of the Site Class "A" (cf. Table 2).

CONCLUSION

Geophysical surveys were carried out to identify the Site Class for a property located north-east of the Montréal Road and Beckenham Lane corner, in Ottawa (ON). The seismic surveys used the MASW and the SPAC analysis, and the seismic refraction method to calculate the $\overline{V}_{S30}$ value. Its calculation is presented at Table 1.

The $\overline{V}_{S30}$ value of the actual site is 861 m/s, corresponding to the Site Class "B" ($760 < \overline{V}_{S30} \leq 1500$ m/s), as determined through the MASW and SPAC methods, Table 4.1.8.4.A of the NBC, and the Building Code, O. Reg. 332/12. Some very low to low seismic values were calculated from the surface to approximately 1 metre deep.

In the event the foundations would be 4.5 metres or more below the rock surface, the $\overline{V}_{S30}$* value would be greater than 1500 m/s, allowing the use of the Site Class "A".

It must be noted that other geotechnical information gleaned on site; including the presence of liquefiable soils, very soft clays, high moisture content etc. (cf. Table 4.1.8.4.A of the NBC) can supersede the Site classification provided in this report based on the $\overline{V}_{S30}$ value.

The V_S values calculated are representative of the in situ materials and are not corrected for the total and effective stresses.

Hoping the whole to your satisfaction, we remain yours truly.

Jean-Luc Arsenault, M.A.Sc., P.Eng.
Senior Project Manager

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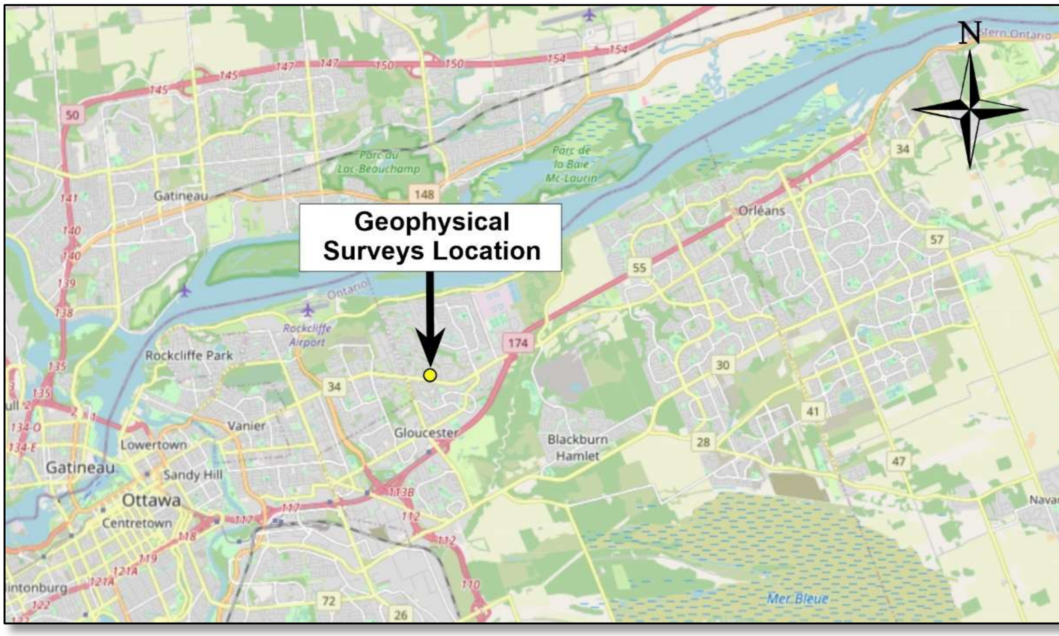

Figure 1: Regional location of the Site
(source: *OpenStreetMap©*)

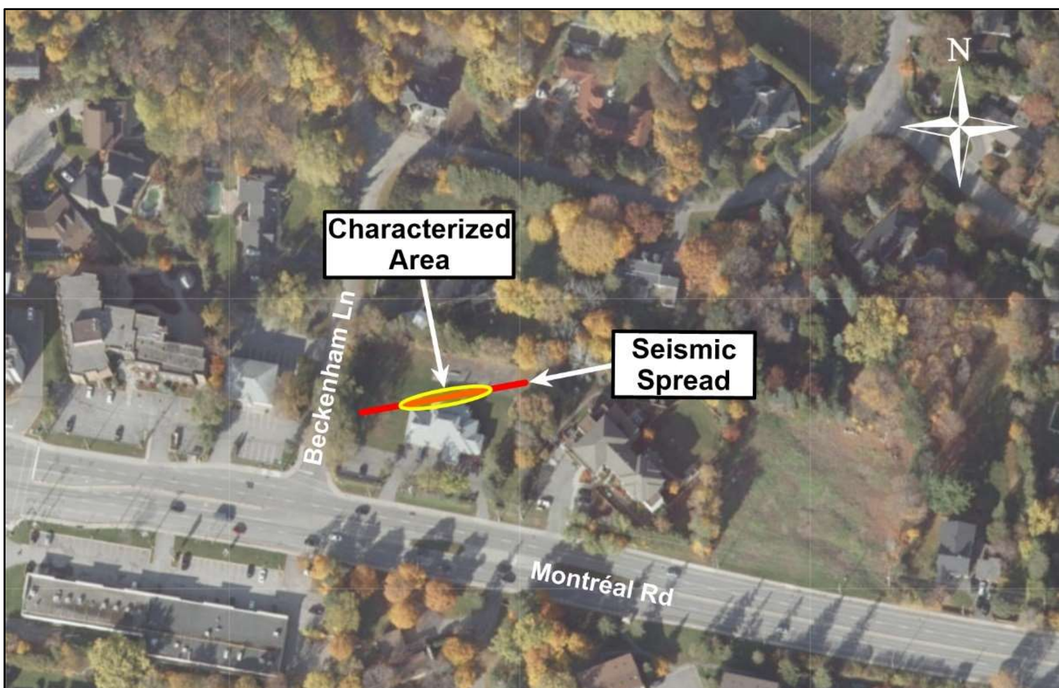

Figure 2: Location of the seismic spreads
(source: *geoOttawa*)

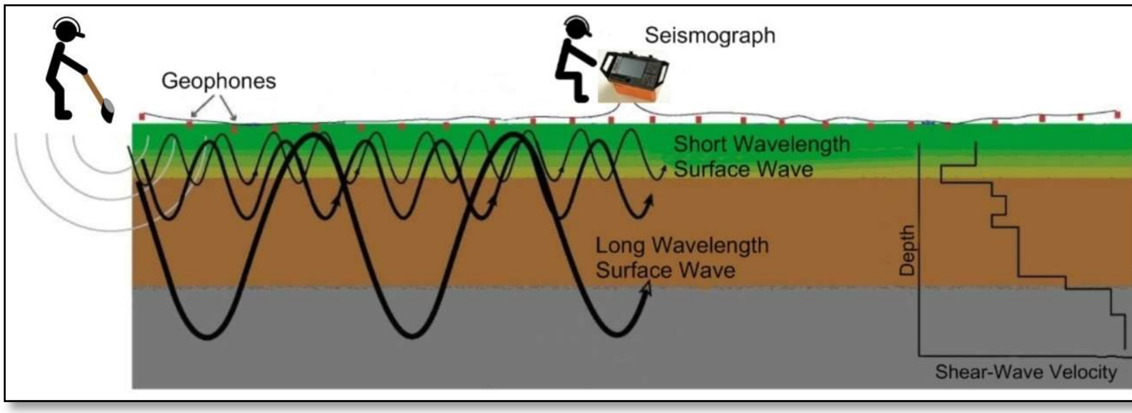

Figure 3: MASW Operating Principle

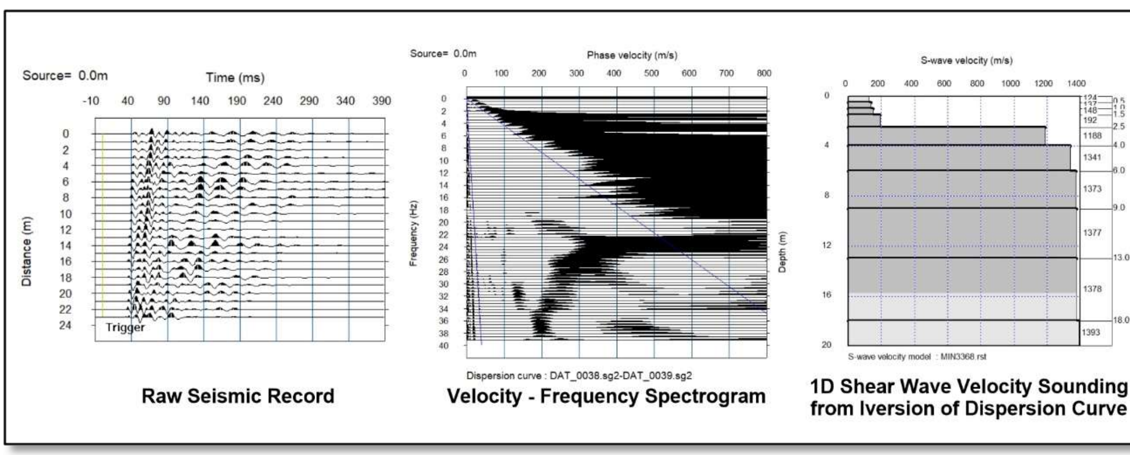

Figure 4: Example of a MASW/SPAC record, Phase Velocity - Frequency curve of the Rayleigh wave and resulting 1D Shear Wave Velocity Model

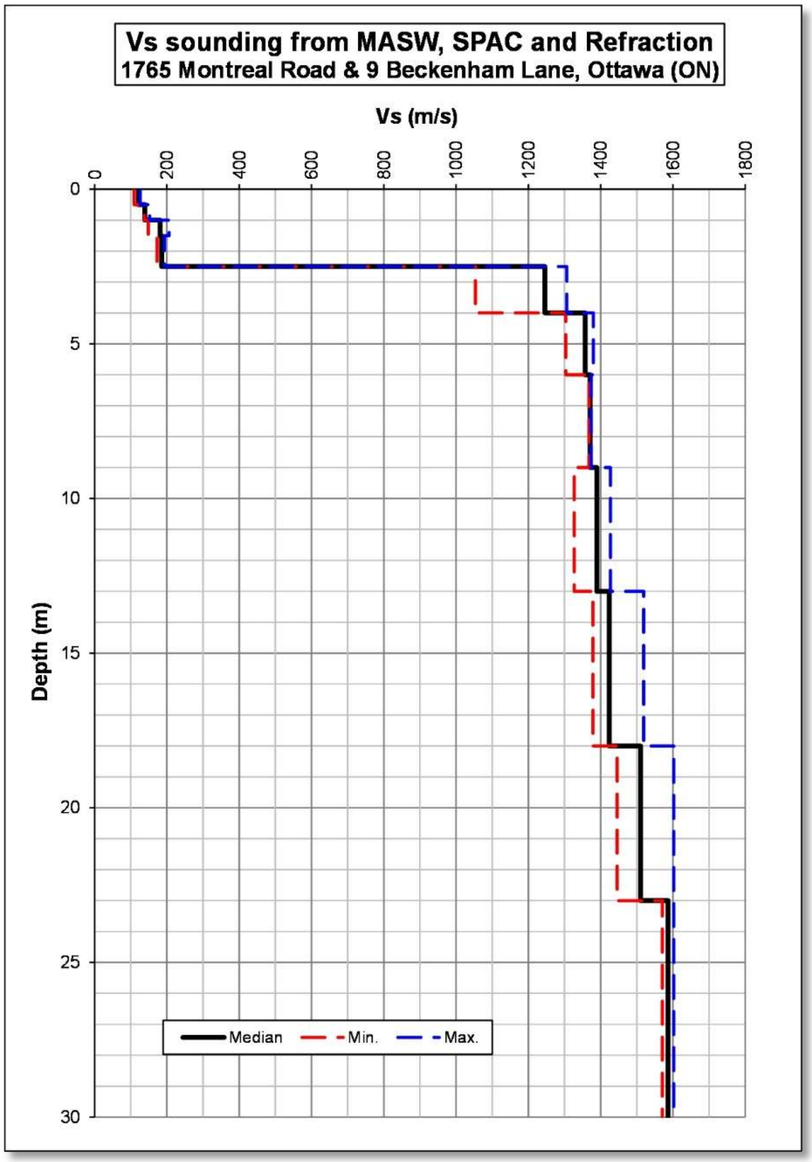

Figure 5: MASW Shear-Wave Velocity Sounding

TABLE 1
V_{S30} Calculation for the Site Class (actual site)

Depth	Vs			Thickness	Cumulative Thickness	Delay for Med. Vs	Cumulative Delay	Vs at given Depth
	Min.	Median	Max.					
(m)	(m/s)	(m/s)	(m/s)	(m)	(m)	(s)	(s)	(m/s)
0	**109.3**	**121.9**	**126.3**	**Grade Level (November 5th, 2021)**				
0.5	**137.3**	**138.5**	**152.5**	0.50	0.50	0.004101	0.004101	121.9
1.0	**148.7**	181.3	206.1	0.50	1.00	0.003610	0.007711	129.7
1.5	**173.1**	185.3	193.3	0.50	1.50	0.002758	0.010469	143.3
2.5	1053.5	1245.5	1306.1	1.00	2.50	0.005396	0.015865	157.6
4.0	1303.5	1357.4	1379.7	1.50	4.00	0.001204	0.017070	234.3
6.0	1367.5	1370.7	1373.8	2.00	6.00	0.001473	0.018543	323.6
9.0	1326.9	1389.1	1426.8	3.00	9.00	0.002189	0.020732	434.1
13.0	1378.5	1423.8	1519.1	4.00	13.00	0.002879	0.023611	550.6
18.0	1445.3	1510.4	1602.4	5.00	18.00	0.003512	0.027123	663.7
23.0	1570.7	1586.5	1602.4	5.00	23.00	0.003310	0.030433	755.8
30				7.00	30.00	0.004412	0.034845	860.9

V_{S30} (m/s)	**860.9**
Class	**B**

TABLE 2
Limit for the Site Class A (4.5 meters below the rock surface)

Depth	Vs			Thickness	Cumulative Thickness	Delay for Med. Vs	Cumulative Delay	Vs at given Depth
	Min.	Median	Max.					
(m)	(m/s)	(m/s)	(m/s)	(m)	(m)	(s)	(s)	(m/s)
0	109.3	121.9	126.3	**Limit for the Site Class A (foundations 4.5 metres in the rock)**				
0.5	137.3	138.5	152.5					
1.0	148.7	181.3	206.1					
1.5	173.1	185.3	193.3					
2.5	1053.5	1245.5	1306.1					
4.0	1303.5	1357.4	1379.7					
7.0	1367.5	1370.7	1373.8					
9.0	1326.9	1389.1	1426.8	2.00	2.00	0.001459	0.001459	1370.7
13.0	1378.5	1423.8	1519.1	4.00	6.00	0.002879	0.004339	1382.9
18.0	1445.3	1510.4	1602.4	5.00	11.00	0.003512	0.007850	1401.2
23.0	1570.7	1586.5	1602.4	5.00	16.00	0.003310	0.011161	1433.6
37.0				14.00	30.00	0.008824	0.019985	1501.1

V_{S30}* (m/s)	**1501.1**
Class	**A**