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Our Ref.: GPR-21-03366

Mr. Matthew Firestone
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Subject: **Shear Wave Velocity Sounding for the Site Class Determination**
98-100 Bearbrook Rd, Ottawa (ON)

Dear Sir,

Geophysics GPR International inc. has been mandated by Landric Bearbrook Property inc. to carry out seismic shear wave surveys at 98 - 100 Bearbrook Road, in Ottawa (ON). The geophysical investigation used the Multi-channel Analysis of Surface Waves (MASW), the Spatial AutoCorrelation (SPAC), and the seismic resonance method. From the subsequent results, the seismic shear wave velocity values were calculated for the soil, to determine the Site Class.

The surveys were carried out on November 4th, 2021, by Mr. Alexis Marchand and Mr. Dominic Déraps, tech. 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 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. The SPAC method generally allows deeper Vs soundings. Its dispersion curve can then be merged with the one of higher frequency from the MASW to calculate a more complete inversion.

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 geophones' sets were spread out on the backyards of 98 - 100 Bearbrook Road (Figure 2). The main seismic spread used 24 geophones, spaced 3.0 metres apart. A second seismic spread, with 1.0 metre geophone spacing, was dedicated to the shallow materials.

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 seismic records were produced with a seismograph Terraloc Pro 2 (from ABEM Instrument), and the geophones were 4.5 Hz. A 9 kg sledgehammer was used as the energy source with impacts being recorded off both ends of the seismic lines.

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 resonance (using V_P), the rock was calculated at approximately 36 metres deep.

The MASW calculated V_S results are illustrated at Figure 5. It must be noted that some low seismic velocities were calculated from the surface to 13 - 15 metres deep.

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:

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

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

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

The calculated $\overline{V}_{S30}$ value for the actual site is presented at Table 1. It is 170.3 m/s, corresponding to the Site Class "E".

In the case the foundations would be at 8.0 metres deep, the $\overline{V}_{S30}*$ value would be 201.5 m/s, corresponding to the Site Class "D" (cf. Table 2).

CONCLUSION

Geophysical surveys were carried out at 98-100 Bearbrook Road, in Ottawa (ON), to identify the Site Class. The seismic surveys used the MASW and the SPAC analysis, and the seismic resonance method, to calculate the $\overline{V}_{S30}$ value. This calculation is presented at Table 1.

The $\overline{V}_{S30}$ value of the actual site is 170 m/s, corresponding to the Site Class "E" ($\overline{V}_{S30} \leq$ 180 m/s), as determined through the MASW and the SPAC analysis, Table 4.1.8.4.A of the NBC, and the Building Code, O. Reg. 332/12.

If the foundations would be at 8.0 metres deep, the $\overline{V}_{S30}$* value would be 202 m/s, corresponding to the Site Class "D" (180 < $\overline{V}_{S30} \leq$ 360 m/s).

It must be noted that some low seismic velocities were calculated from the surface to 13-15 metres deep. A geotechnical assessment of the corresponding materials could be required for the potential of liquefaction, the degree of clay sensitivity, and other critical parameters.

It must also 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.

P.Eng.

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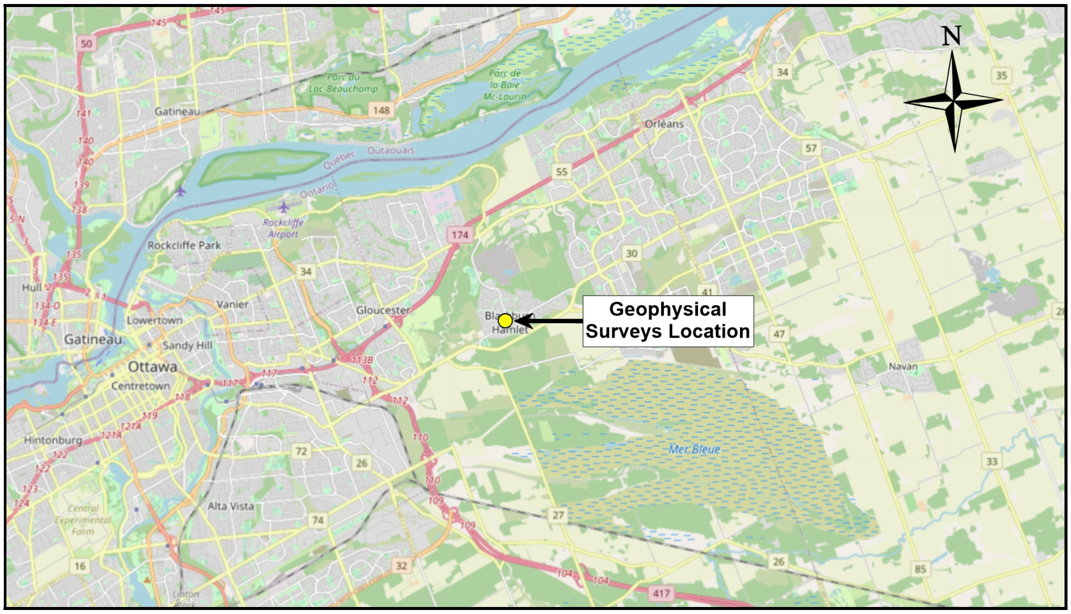

Figure 1: Regional location of the Site
(source: *OpenStreetMap©*)

Figure 2: Location of the Seismic Lines
(source: *GeoOttawa*)

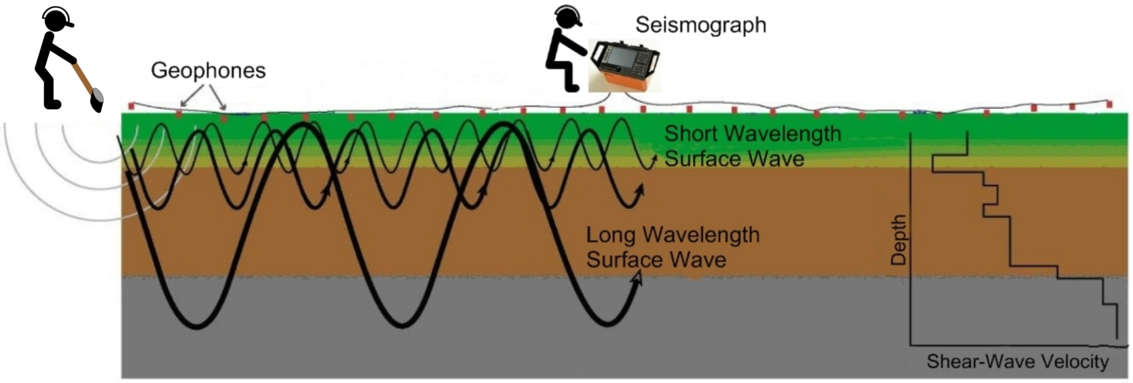

Figure 3: MASW Operating Principle

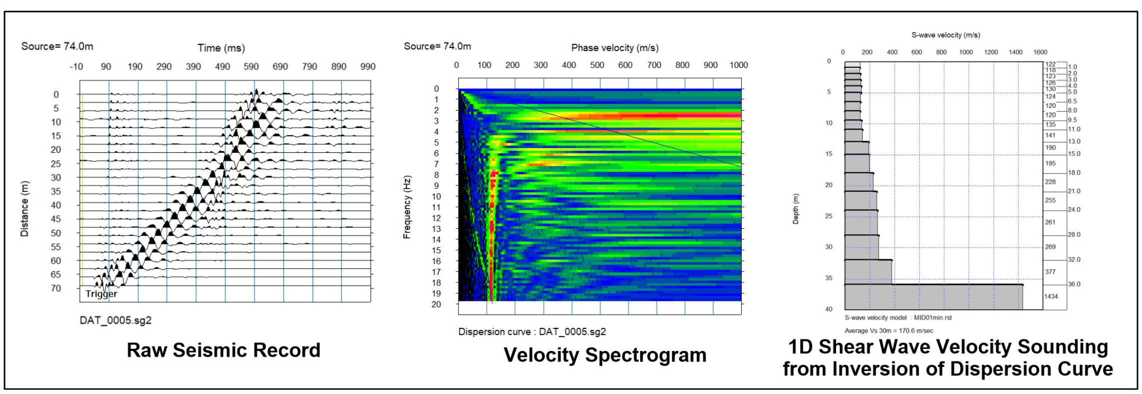

Figure 4: Example of a MASW/SPAC record, Rayleigh wave Velocity - Frequency Dispersion Curve and resulting 1D Shear Wave Velocity

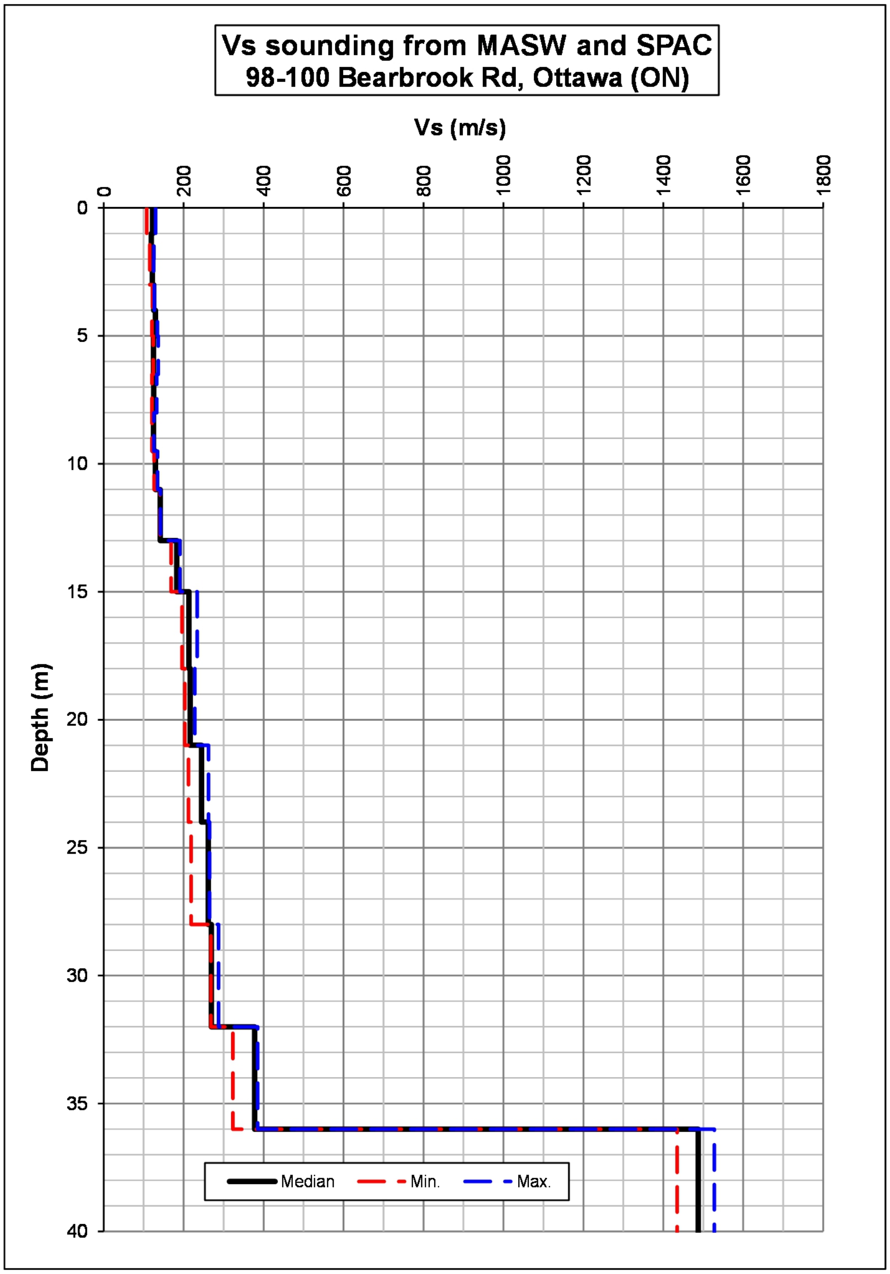

Figure 5: MASW Shear-Wave Velocity Sounding

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	**107.4**	**122.5**	**129.9**	Grade Level (November 4th, 2021)				
1.0	**115.4**	**118.9**	**125.6**	1.00	1.00	0.008160	0.008160	122.5
2.0	**115.5**	**122.0**	**125.3**	1.00	2.00	0.008409	0.016570	120.7
3.0	**121.9**	**125.3**	**126.9**	1.00	3.00	0.008199	0.024768	121.1
4.0	**120.9**	**129.3**	**134.6**	1.00	4.00	0.007981	0.032749	122.1
5.0	**123.9**	**124.5**	**136.5**	1.00	5.00	0.007735	0.040484	123.5
6.5	**120.7**	**124.8**	**132.8**	1.50	6.50	0.012050	0.052533	123.7
8.0	**120.7**	**124.3**	**125.7**	1.50	8.00	0.012016	0.064550	123.9
9.5	**126.0**	**129.5**	**135.1**	1.50	9.50	0.012071	0.076620	124.0
11.0	**140.8**	**141.4**	**142.1**	1.50	11.00	0.011585	0.088205	124.7
13.0	**168.5**	182.6	190.7	2.00	13.00	0.014140	0.102346	127.0
15.0	195.7	213.0	233.9	2.00	15.00	0.010956	0.113301	132.4
18.0	203.0	216.5	228.2	3.00	18.00	0.014085	0.127386	141.3
21.0	212.0	244.9	262.5	3.00	21.00	0.013854	0.141240	148.7
24.0	218.8	261.5	265.0	3.00	24.00	0.012252	0.153492	156.4
28.0	268.1	269.5	287.4	4.00	28.00	0.015294	0.168786	165.9
30	323.0	377.4	385.4	2.00	30.00	0.007421	0.176207	170.3

Vs30 (m/s)	**170.3**
Class	**E (1)**

TABLE 2

V_{S30}* considering the foundations at 8 metres deep

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	107.4	122.5	129.9	**Considering the foundations at 8 metres deep**				
1.0	115.4	118.9	125.6					
2.0	115.5	122.0	125.3					
3.0	121.9	125.3	126.9					
4.0	120.9	129.3	134.6					
5.0	123.9	124.5	136.5					
6.5	120.7	124.8	132.8					
8.0	**120.7**	**124.3**	**125.7**					
9.5	**126.0**	**129.5**	**135.1**	1.50	1.50	0.012071	0.012071	124.3
11.0	**140.8**	**141.4**	**142.1**	1.50	3.00	0.011585	0.023656	126.8
13.0	**168.5**	182.6	190.7	2.00	5.00	0.014140	0.037796	132.3
15.0	195.7	213.0	233.9	2.00	7.00	0.010956	0.048751	143.6
18.0	203.0	216.5	228.2	3.00	10.00	0.014085	0.062836	159.1
21.0	212.0	244.9	262.5	3.00	13.00	0.013854	0.076690	169.5
24.0	218.8	261.5	265.0	3.00	16.00	0.012252	0.088942	179.9
28.0	268.1	269.5	287.4	4.00	20.00	0.015294	0.104236	191.9
32.0	323.0	377.4	385.4	4.00	24.00	0.014842	0.119078	201.5
36.0	1434.4	1487.1	1527.5	4.00	28.00	0.010598	0.129676	215.9
38.0				2.00	30.00	0.001345	0.131021	229.0

Vs30* (m/s)	**201.5**
Class	**D (1)**

(1) Some low seismic velocities were calculated from the surface to 13-15 metres deep. A geotechnical assessment of the corresponding materials could be required.