FRONTWAVE
GEOPHYSICS

SHEAR WAVE VELOCITY TESTING
FOR SEISMIC SITE CLASSIFICATION
141-153 PLAINS ROAD WEST, BURLINGTON, ONTARIO

Submitted to:

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File No. F-24223

September 12, 2024

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1 INTRODUCTION

Frontwave Geophysics Inc. was retained by AAA Architects Inc. to carry out a geophysical investigation for a proposed development at 141-153 Plains Road West in Burlington, Ontario.

The objective of the survey was to determine site class (designation) for seismic site response based on average shear wave velocity value measured in the upper 30 m (V_S30). The multi-channel analysis of surface waves (MASW) method was used to obtain shear wave velocity profile.

The fieldwork was conducted on September 11, 2024. The location of the MASW survey line is shown in Figure 1.

This report describes the basic principles of MASW, survey design, interpretation method, and presents the results of the investigation in the chart and table format.

2 INVESTIGATION METHODOLOGY

Overview

The Multi-channel Analysis of Surface Waves (MASW) is a seismic method widely applied to produce shear wave velocity (V_S) profiles. It is based on the dispersive nature of Rayleigh or Love surface waves in layered media. Surface waves with longer wavelengths propagate deeper in the subsurface, hence, their phase velocity is more influenced by the elastic properties of deeper layers. The velocity of surface waves depends mainly on the shear wave velocity of the medium. The distribution of surface waves phase velocities as a function of wavelength (or frequency) can be visualized as a dispersion curve. The inverse problem is then solved by modelling the experimental data with a theoretical dispersion curve; the model parameters are typically limited to layer thickness and shear wave velocity with an assumption of horizontally layered strata. As a result of the inversion, a shear wave velocity depth profile is obtained. Figure 2 illustrates the overall procedure of the MASW method.

Two approaches different in data acquisition and processing can be implemented. The active method involves using artificial sources (e.g., sledgehammer, drop weight) to generate seismic energy, whereas the passive method utilizes energy generated by natural sources (wind, waves, microseismicity) and human activities (mostly vehicle traffic). The energy that can be generated with easily accessible active sources such as sledgehammers is typically concentrated within a relatively high frequency range, and the maximum depth of penetration for active surveys is limited to approximately 15-30 m, depending on the mass of the source and geology of the site. Ambient vibrations registered with the passive acquisition are usually of lower frequency and provide better resolution at greater depths. When survey logistics allow, the active and passive source methods are combined for obtaining well-resolved dispersion images over a wide frequency range, thus increasing the depth of investigation while retaining high resolution at shallow depths.



Legend

MASW Location of MASW survey line (46 m geophone spread)

Image: Google Earth 2022

Date:	2024-09-12
File No:	F-24223
Title:	Survey location plan
Location:	141-153 Plains Rd W, Burlington, ON

Figure: **1**

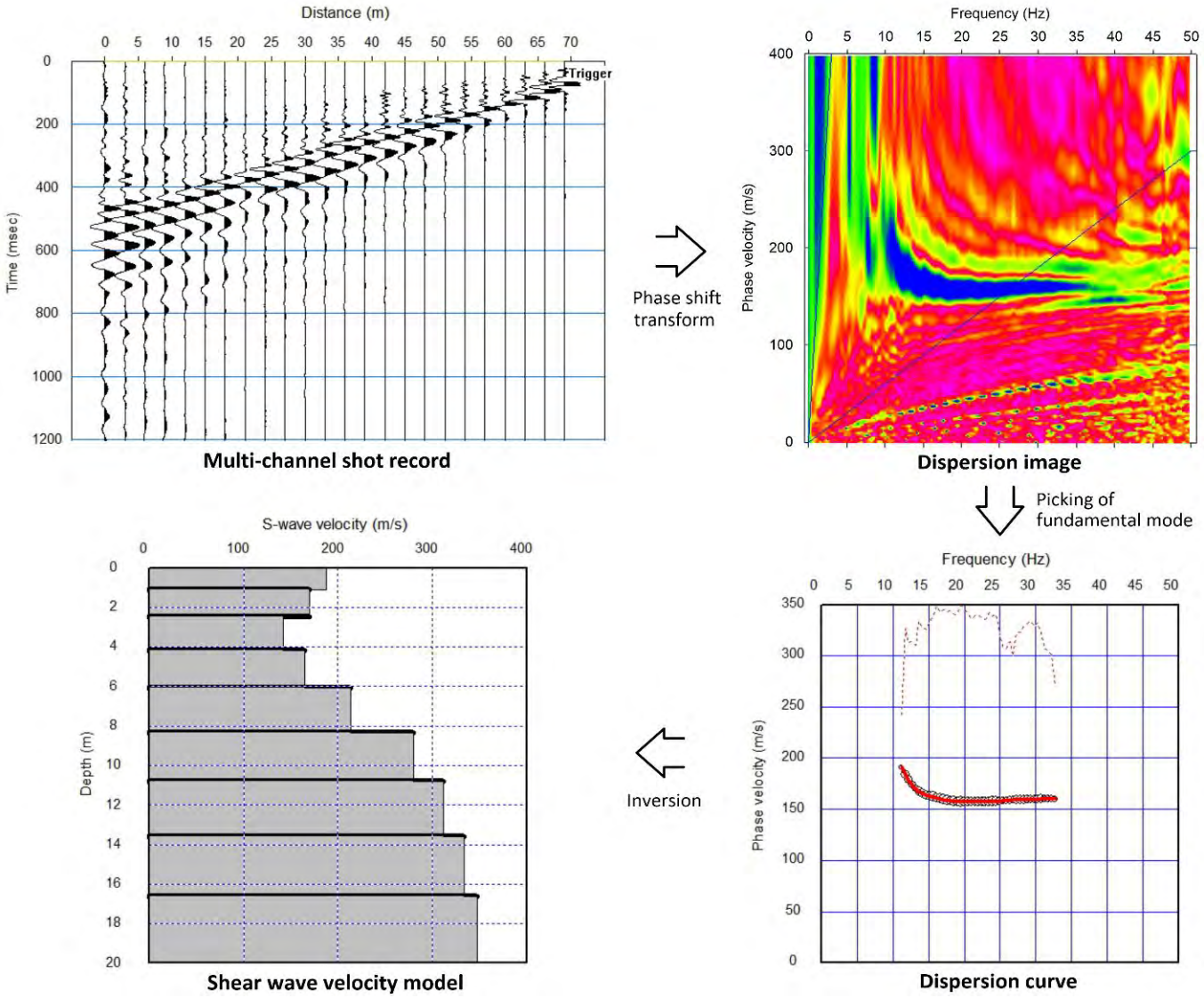


Figure 2 *The procedure of MASW data processing using the SeisImager SW software package.*

Survey Design

The acquisition layout consisted of 24 receivers in a linear array (spread), connected with a multicore cable to P.A.S.I. Gea-24 seismograph. 4.5 Hz natural frequency vertical geophones were used for this survey. To optimize sampling of different wavelengths, two sets of measurements were conducted with spread lengths of 23 m and 46 m (1 m and 2 m spacing between geophones, respectively). Data collected with longer spreads provide a greater depth of investigation, whereas data collected with shorter geophone spacings ensure better resolution in the uppermost few meters of the subsurface.

An 8-kg sledgehammer was used as an energy source for active acquisition. Shots were executed at three to five locations per spread: two shots close to the ends of the spread, and one to three

shots within the spread. A total of 8 shot records was collected. The record length was set to 1500 ms with a 0.05 ms sampling interval.

For passive acquisition, a linear 24-channel array with 2 m spacing between geophones was used. Ambient wavefield was recorded for 10 minutes with a sampling interval of 2 ms.

Interpretation

A dispersion curve is obtained from each field record by converting the shot gather into a dispersion image and then identifying and picking the fundamental mode. A shear wave velocity profile is obtained through inversion of the dispersion curve by modelling the subsurface as a horizontally layered medium with the model parameters limited to the number of layers, their thickness and shear-wave velocity.

ZondST2D software package was used for processing, picking and inversion of the MASW data.

Some variability among the dispersion curves and resulting models obtained from different shot records is always observed due to lateral velocity variations, near and far field effects, different signal-to-noise ratio, etc. Combining independent inversion results from multiple shot records improves the estimation of the actual shear wave velocity and provides an assessment of uncertainty. The results of the interpretation are presented in the form of the average shear wave velocity profile; the observed variability of the MASW data is reported as upper and lower bound velocity profiles.

Accuracy of the results

The accuracy of MASW generally depends on the complexity of the subsurface and specific site conditions (noise levels, topography, etc.). Lateral velocity variations and steeper bedrock topography increase the dispersion uncertainty. The presence of high velocity contrast layers such as bedrock will require the use of a-priory information to optimize model parameters for more accurate results. Hence, if the a-priory information is not available (e.g., when the data are overly noisy to carry out refraction analysis), the accuracy decreases.

The uncertainty of the resulting S-wave velocity depth profile is evaluated using the upper and lower bound velocity profiles. In practice, it means that the MASW data can be used to provide reliable site classification if the calculated upper and lower bound V_S30 values fall into the same site class range.

3 RESULTS

The collected surface wave data were of fair quality; overall, the dispersion images of the active and passive data covered a frequency range of approximately 10 to 80 Hz. Example shot record and MASW dispersion images obtained at this site are presented in Figure 3.

Due to adverse ground surface conditions (asphalt pavement), it was not possible to perform a refraction analysis on the collected data. Borehole data provided by the client indicated that the depth to bedrock at this site was greater than 15.2 m.

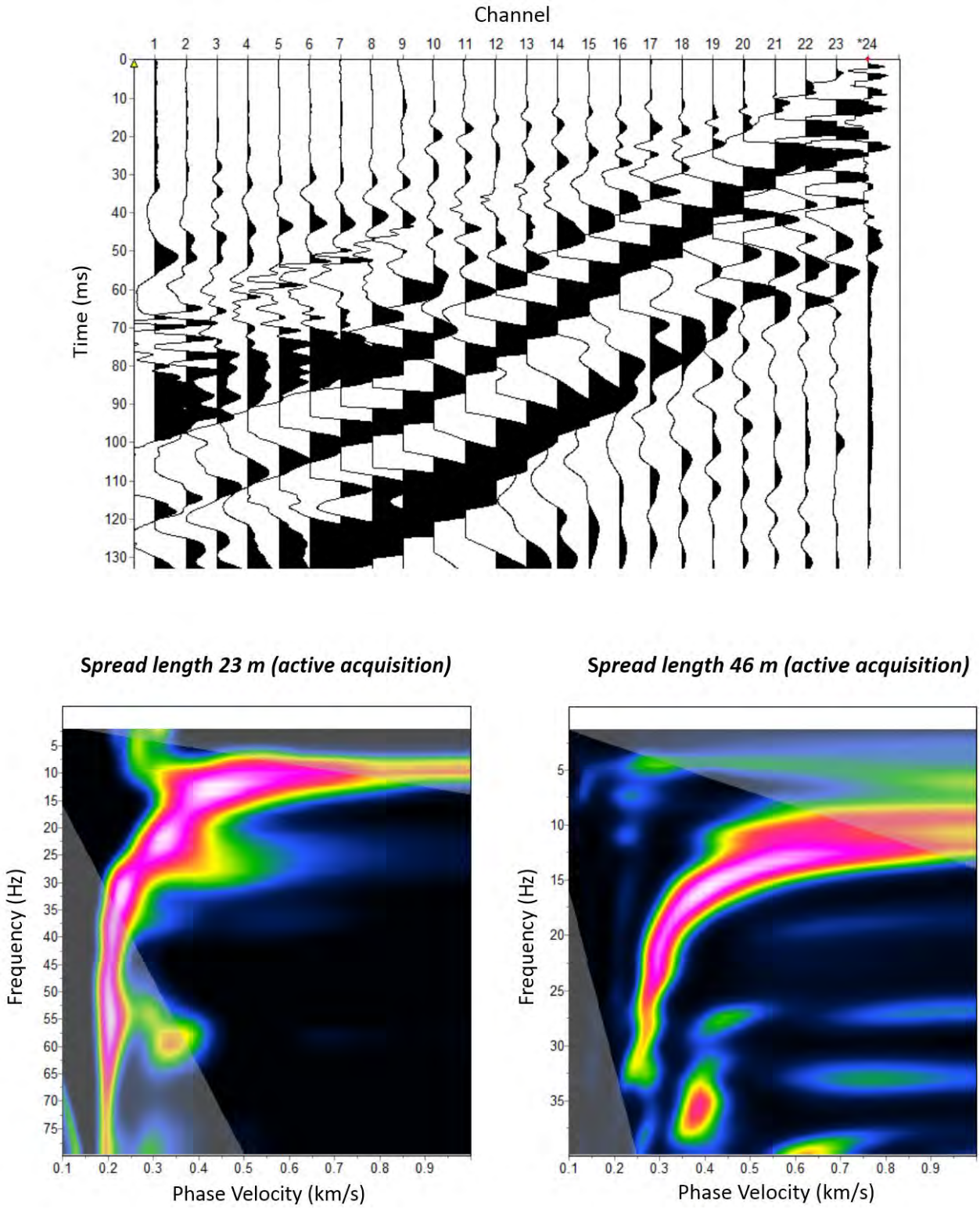


Figure 3 *Example shot record (top) and MASW dispersion images (bottom).*

The results of the MASW sounding are presented in Figure 4. The average shear wave velocity profile from the active shot records and passive data is plotted in the chart as a solid line. The dashed lines represent the upper and lower bound S-wave velocity profiles.

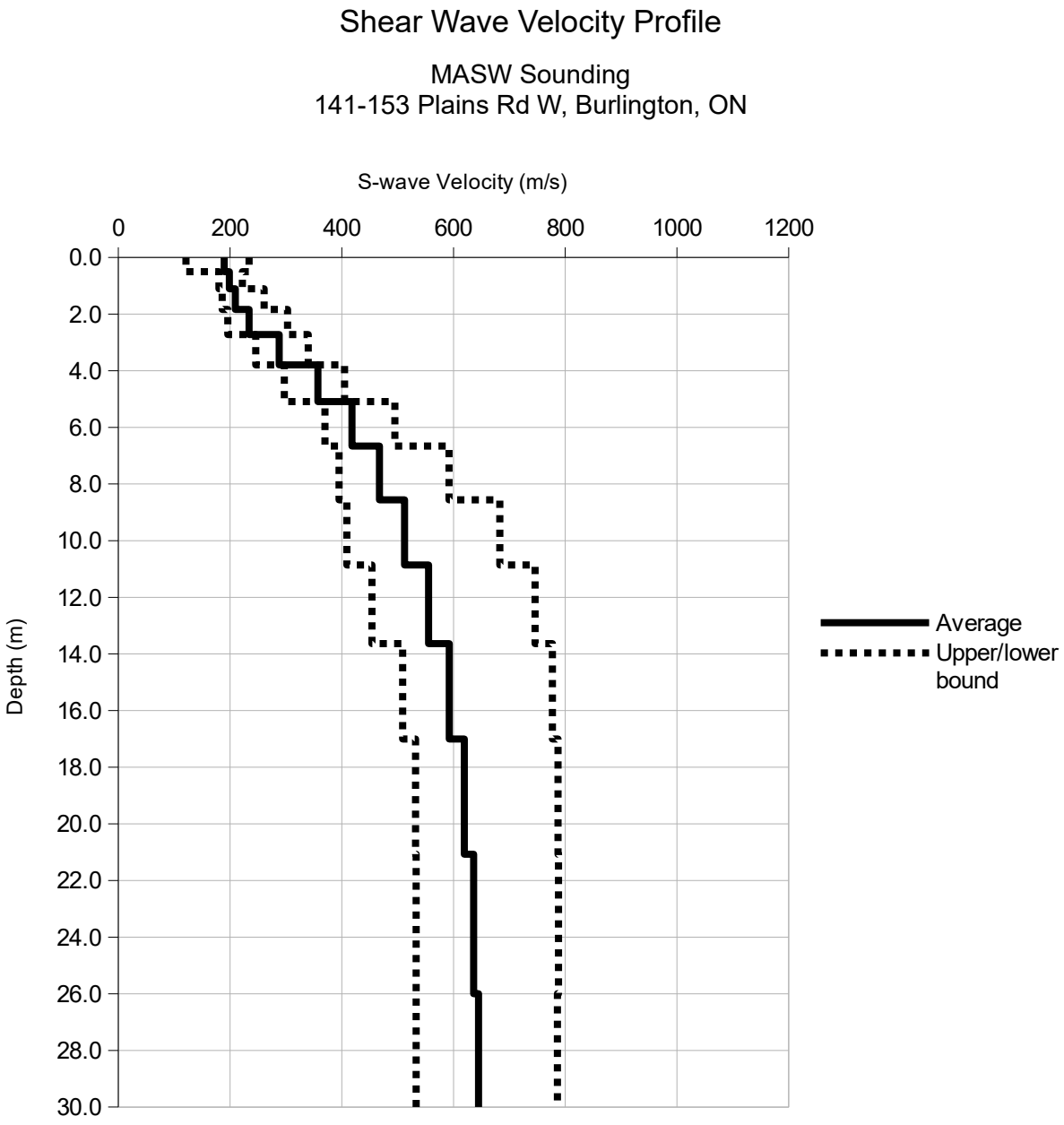


Figure 4 *Shear wave velocity profile from MASW sounding.*

The tabulated shear wave velocity model is presented in Table 1.

Table 1 *Shear wave velocities from MASW sounding.*

Depth Interval (m)		S-wave Velocity (m/s)
From	To	
0.0	0.5	190
0.5	1.1	199
1.1	1.8	210
1.8	2.7	234
2.7	3.8	288
3.8	5.1	357
5.1	6.7	418
6.7	8.6	468
8.6	10.9	512
10.9	13.6	555
13.6	17.0	592
17.0	21.1	619
21.1	26.0	636
26.0	30.0	645

The average shear wave velocity within the upper 30 meters (V_S30) is defined as the travel-time weighted average velocity from surface to a depth of 30 m and calculated using the following formula:

$$V_S30 = 30 / \Sigma (d/V_S),$$

where d is the thickness of any layer and V_S is the layer S-wave velocity. In other words, V_S30 is calculated as 30 m divided by the sum of the S-wave travel times for each layer within the topmost 30 m.

The calculated V_S30 values are presented in Table 2.

Table 2 *V_S30 values from MASW sounding.*

Depth Range (m)	Minimum V_S30 (m/s)	Average V_S30 (m/s)	Maximum V_S30 (m/s)	NBC 2015 Site Class	NBC 2020 Site Designation
0 to 30	392	**470**	585	**C**	**X_{470}**

The V_S30 values obtained from the MASW sounding varied from 392 m/s to 585 m/s with an average of 470 m/s.

Based on the Site Classification for Seismic Site Response (Table 4.1.8.4.-A) of the National Building Code of Canada 2015 (NBC 2015), the investigated area is in **Site Class C** ($360 < V_S30 \leq 760$ m/s).

Based on the Sentence 4.1.8.4.(2b) of the National Building Code of Canada 2020 (NBC 2020), the **Site Designation** is **X_{470}**.

4 CLOSURE

Shear wave velocity testing involving the multi-channel analysis of surface waves (MASW) method was carried out for a proposed development at 141-153 Plains Road West in Burlington, Ontario.

The average shear wave velocity (V_S30) value calculated from in situ shear wave velocity measurements was **470 m/s**. Based on the Site Classification for Seismic Site Response (Table 4.1.8.4.-A) of the National Building Code of Canada 2015 (NBC 2015), the investigated area is in **Site Class C** ($360 < V_S30 \leq 760$ m/s). Based on the Sentence 4.1.8.4.(2b) of the National Building Code of Canada 2020 (NBC 2020), the **Site Designation** is $\mathbf{X_{470}}$.

We hope you find this report satisfactory. Should you have any questions or require additional information, please do not hesitate to contact the undersigned.

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