Technical Report

Geophysical Survey
Eastern Busway Alliance,
Feb-April 2023.

Project:	**EBA1117**
Client:	**Eastern Busway Alliance**
Location:	**Pakuranga, Auckland**
Date:	**22th April 2023**
Technical Staff:	**Matt Watson** **Kirsty Hamlin**

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APPENDIX - DIGITAL DATA

1.0 Introduction

ScanTec Ltd was requested by Eastern Busway Alliance to carry out a geophysical survey to assist with a geotechnical investigation in the vicinity of Pakuranga Creek.

The scope of the survey work included;

- Horizontal Vertical Seismic Ratio (HVSR) testing to provide 1D Shear wave velocity profiles.
- Geomagnetic measurements to identify the extent of basalt lava
- Sub-bottom profile (SBP) measurements in Pakuranga Creek to identify the depth to bedrock and identify the presence of basalt lava.

Survey work was carried out during February, March and April, 2023

2.0 Survey methodology

2.1 Horizontal Vertical Spectral Ratio (HVSR) Methodology

Seismic testing was carried out at this site using HVSR (horizontal vertical spectral ratio) technique. Equipment used included a SARA 3-axis, 3-channel, 24-bit seismograph with a dynamic range of 144dB between 0.1Hz and 10Hz.
Specifications : https://syy.com.tr/upload/pdf/geobox-eng-7044.pdf

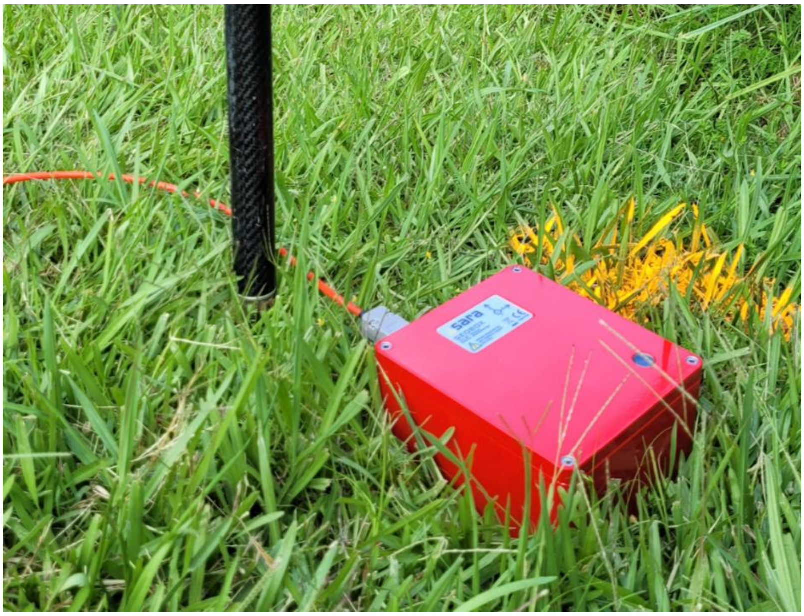
The positions for each HVSR location were collected using Polaris GNSS receiver, SKYNET East Tamaki base station. Accuracy 0.02m horizontal and vertical.

HVSR (Horizontal Vertical Spectral Ratio) is a relatively recently developed variation on the MASW technique, and uses passive seismic signal (ambient background noise) enhanced by sledge hammer blows to determine shear wave velocity profiles at individual locations along a predefined survey line. At each location data is recorded over 15-30minutes duration by a high sensitivity 3-axis seismograph. This technique is useful if the layout of the site prevents the use of long survey lines (necessary for MASW) which extend beyond the required limits of the survey.

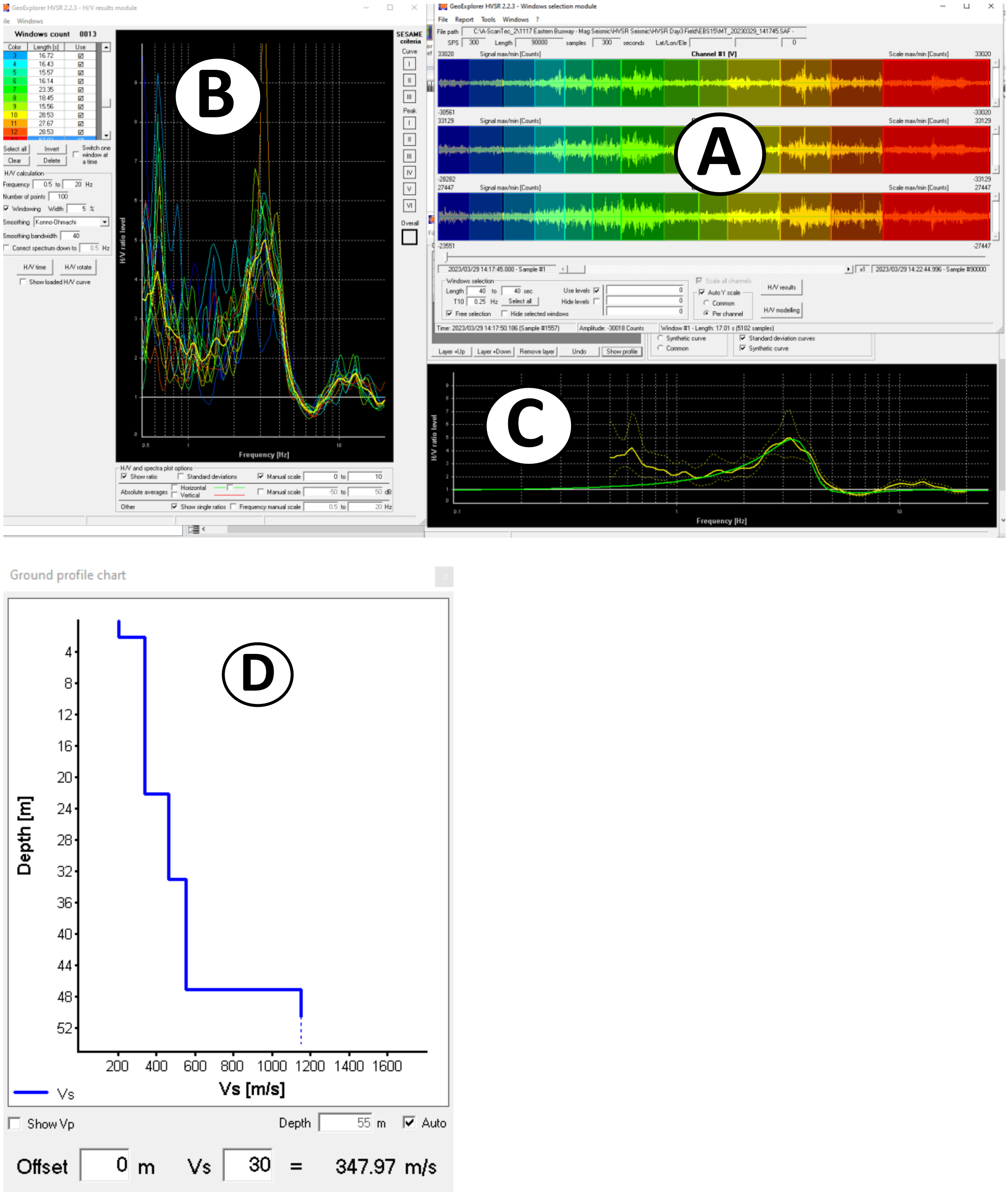
Data Processing and Analysis

HVSR data was processed using SARA GeoExplorer software (2019). Processing involves sampling multiple windows of data for each location to obtain a population of H/V ratios for statistical analysis and to calculate the HVSR curve (or ellipticity curve) for each reading position. A synthetic ellipticity curve is generated for a particular stratigraphic model and the shear wave velocity profile is determined for each seismograph location.

Shear wave velocity readings and stratigraphic depths are then used to construct a contour map for the site. The average shear wave velocity to a depth a 30m (Vs30) is also provided.



(Above) HVSR equipment in use. Seismograph has 3 long stainless steel spikes which are pushed into ground to couple with soil.



(Above) Example of HVSR processing carried out for each of the 16 HVSR locations.
The above data is from EBS15.

A – analysis of the waveforms, sampling of time windows
B – graphing H/V ratios for statistical analysis, and generation of synthetic ellipticity curve
C – Modelling of synthetic ellipticity curve to generate a 1D shear wave velocity profile
D – Generating the 1D shear wave velocity profile

2.2 Sub-Bottom Profiling (SBP) methodology

A Syqwest SBP with 24bit ADC controller were used for SBP data acquisition. Specifications: syqwestinc.com/products/sub-bottom-profilers/stratabox.

Depth resolution is 0.10m (@10Hz frequency). Transmission power levels selectable between 0.3kW and 1kW.

The 10KHz transducer was mounted in the middle of the vessel. Measurements were synchronized with the RTK GNSS data. Measurements were recorded at a boat speed of between 1-2knots. Multiple runs were recorded over some lines using different acquisition settings to obtain optimum results. SBP line locations are shown on Figure 1.

Output power and receiver gain levels had to be carefully controlled due to the very shallow water. SBP coverage is generally limited to water depth greater than approximately 2m. Below 2m water depth, depending on the geological conditions at each specific site, it is very difficult to achieve good results as the initial reflection from the seabed overloads the signal.

Time variable gain (TVG) and bottom ramp functions were used to optimise the gain settings and minimise the ringing effect due to the very shallow water.

SBP data processing

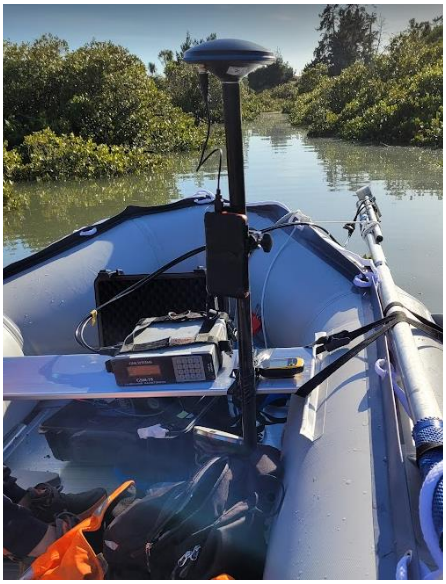
All measurements were processed using REFLEX-W seismic processing software, RADAN 6.5 and SURFER v10. Data processing involved;

- Positional offset and tidal corrections
- converting from SEG-Y to DZT format
- high and low pass frequency filtering
- linear gain ramp
- horizontal background removal
- predictive deconvolution
- manual digitisation of seismic reflections / sedimentary layers and bedrock.

Positional and height datum

RTK GNSS positioning was carried out using Polaris S100 GNSS receiver with cellular link to the SKYNET, East Tamaki base station. Positional and elevation data are presented in NZTM / NZVD (2016). Corrections were made for survey pole length, position on the vessel (offset) and depth of sonar / SBP transducers. Nominal positional accuracy was 0.02m for static measurements on land and between 0.05m-0.08m for kinematic marine measurements within creek and mangrove areas. Decrease in PDOP was experienced within some mangrove areas due to vegetation canopy and reduction in satellite visibility.

(Above) Pakuranga Creek, main channel North of the bridge, at low tide.



(Above) Magnetometer and SBP surveys in progress, Pakuranga Creek.

2.3 Geomagnetic Survey methodology

Geomagnetic field measurements were recorded using a GMS-19 magnetometer and used to investigate the extent of the basalt lava flow. See specifications below.

Gem Systems GSM-19 https://www.gemsys.ca/rugged-overhauser-magnetometer/

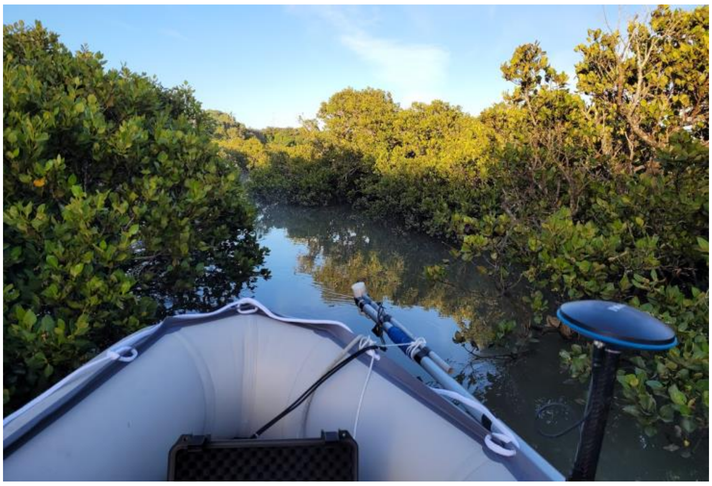
Sensitivity: 0.022 nT @ 1 Hz,
Resolution: 0.01 nT
Absolute Accuracy: +/- 0.1 nT
Dynamic Range: 20,000 to 120,000 nT
Gradient Tolerance: Over 10,000 nT/m
Sampling Intervals: 60+, 5, 3, 2, 1, 0.5, 0.2 sec
Operating Temperature: -40°C to +50°C

GPS positions collected using Polaris GNSS receiver, SKYNET East Tamaki base station. Accuracy range (HV) during kinematic survey 0.05-0.08m. Static reading (HV) accuracy 0.02m.

Basalt found within the Auckland volcanic field contains the strongly magnetic mineral magnetite, and therefore deflects the geomagnetic field as it passes over lava flows. This can be detected by the magnetometer, and used to determine the presence or absence of basalt lava, and also estimates of thickness.

Measurements were recorded in the survey boat by placing the magnetic sensor on an aluminium pole extending in front of the boat, to keep it away from any onboard magnetic interference from ferrous metals. The sampling interval for the measurements was 0.5seconds, synchronized with the GPS equipment.

During the survey, the boat was taken as far along the mangrove channels as physically possible, before the channel became impassable due to being too overgrown with mangroves. The boat was then reversed to a suitable turning area. The extent of the magnetometer measurements is shown on Figures 1, 6.



(Above) Magnetometer survey in progress along narrow channel in Mangrove forest. This photo is taken at high tide, approximately 20m before the navigable limit of this creek section.

3.0 Results and interpretation

3.1 HVSR (Seismic) Results

The locations of the measurements are shown on Figure 1 (see attached A3 sheets). Seismic stations EBS1 to EBS16 are marked by the red triangles.

The Vs30 rating, which is the average shear wave velocity to a depth of 30m, is shown as Figure 2.

For each seismic station, a 1D shear wave (Vs) velocity profile is generated. These are shown as figures 3 to 4. S-wave and P-wave velocities are shown by the blue and red lines respectively.

The confidence of Vs interpretation for HVSR decreases with depth, and although indicated, the boundaries shown below approximately 40m depth are indicative only.

Analysis of data

- The lowest interpreted shear wave velocity is 150m/s, in the upper soil layer. This was commonly observed at the majority of seismic stations.
- The range of Vs30 readings was between 299m/s (EBS01) and 438m/s (EBS07).
- Velocity inversion occurs in EBS07 and EBS08, where a thin basalt layer (Vs 550m/s) is interpreted to overlie weak sedimentary formations (Vs 400m/s).
- Generally, Vs values for this site would be considered to be low for Auckland, indicating weak sediments overlying weathered East Coast Bays (ECB) formation.
- Comparing Vs with borehole logs indicates that there is no significant change in Vs at the top of the ECB formation, measured using HVSR technique. This implies that a deep weathering profile exists, and the shear wave velocity does not change significantly between alluvial or Tauranga Group sediments and weathered ECB.
- In the Vs models, the velocity increase (Vs >1000m/s) indicates un-weathered sedimentary formations. This occurs in all cases below 30m. The minimum depth was 35m, EBS02. As mentioned above, the confidence of Vs interpretation decreases with depth, so the actual depth indicated should be indicative only.

3.2 Sub-bottom Profile (SBP) Survey Results

SBP readings were recorded on March 24th 2023. This was selected as the measurement day due to the spring tide (3.5m) which provides increased water depth for the SBP transducer. Weather for the survey was fine with light winds.

The locations of the measurements is shown on **Figure 5** (see attached A3 sheets). Survey lines extend to the north and south, with no data coverage beneath Ti Rakau Bridge.

Difficulties were anticipated before the survey due to the minimal water depth at this location, which often prevents good data quality due to the transducer being to close to the seabed. These concerns were communicated at the proposal stage of the project, and the decision was to attempt to collect data. Generally, the SBP data collected on site was useable only in the deeper parts of the main channel. In the shallow E-W tributaries, the water depth even at spring high water was insufficient for the SBP equipment to operate successfully.

Reflections from bedrock were interpreted in the main channel, which range between -6.5m and -11.5m (NZVD 2016) see Figure 5 inset. The data was digitised, tidal corrections applied, elevations determined using standard velocity for saturated alluvial sediments, and gridded to form a contour map (Figure 5).

In the location of Ti Rakau Bridge, bedrock elevation interpreted on SBP is approximately 3.5m deeper than indicated on the borehole logs (DH408-413). This is likely to be caused by the extensive weathering profile of the ECB formation. The SBP reflection interpreted as bedrock is likely to be a less weathered siltstone/sandstone boundary within the ECB.

There are very few strong SBP reflections within the sediments above the ECB formation. This is likely to be related to insufficient contrast in material properties, which results in a very low reflection coefficient.

Basalt would have provided a strong reflection coefficient, resulting in very clear signal returns. No reflections were observed in the SBP data within the main (N-S) channel that can be interpreted as basalt.

Along the E-W SBP line, where basalt was possible, the data quality was compromised due to extremely shallow water depth (0.8m to 1.5m at high tide), so we are unable to use this line for evaluation of the presence of basalt.

3.3 Geomagnetic Survey Results

Marine geomagnetic readings were recorded on March 23rd. This was selected as the measurements day due to the spring tide (3.5m) which would allow increased access into narrow channels within the area of mangroves. Land geomagnetic measurements were also recorded on March 23rd 2023.

The locations of the measurements are shown on Figure 6, which included trying to get the survey boat as far as possible up the tributary streams within the mangrove forest. The extent of coverage were limited to the navigable channels for the boat.

Data coverage on this site is sparse, which makes interpretation difficult. Typically magnetic data is collected in a grid over the required survey area, however this was not possible at this site due to mangroves, road, buildings etc.

Figure 7 shows the data with a contour map and graphs indicating the Total Magnetic Field strength (TMF) in units of nano-Tesla (nT).

Observations:

- A negative geomagnetic anomaly is likely in the vicinity of Chinatown due to the presence of basalt lava. This means that TMF levels will *decrease* towards areas of basalt or increase in basalt thickness.
- In the eastern part of the marine survey TMF levels indicate that basalt is present. This is indicated by the dashed line on Figure 7 and Figure 8
- Very low TMF values are observed in the SE channel, adjacent to Chinatown. This is interpreted as a high probability of a thin basalt lava flow in this area or basalt rubble within alluvial sediments.
- Basalt is also interpreted on the NE land line (Magnetic Line 3), which is either a thin lava flow or basalt rubble layer.
- Basalt rubble is interpreted to be present on Lines 1 and 2. Higher levels of background interference on these lines were present due to the proximity to the road.
- No basalt is interpreted in the main Pakuranga Creek area, however isolated ferrous metal objects (metallic waste) are present on the seabed. Most of these were filtered out during the data processing stage.
- Ti Rakau bridge caused high levels of magnetic disturbance

4.0 Summary

Geophysical measurements were used to assist with a geotechnical investigation of the Pakuranga Creek area for the Eastern Busway Alliance.

A combination of marine sub-bottom profiling (SBP), marine and land geomagnetic, and Horizontal-Vertical Spectral Ratio (HVSR) techniques were used.

A total of 16 HVSR seismic measurements were recorded and 1D shear wave velocity profiles were calculated, which indicate Vs increasing from 150m/s for near surface formations to unweathered bedrock of approximately 1000-1200m/s.

Vs30 calculations for each station show a range of between 299m/s and 438m/s. 1D Vs profiles indicate that there is a deep weathering profile in this area with generally low shear wave velocities (<400m/s) for weathered ECB formation.

A thin layer (0.5m to 3m maximum) of basalt is interpreted at HVSR stations EBS07 and EBS08. The basalt may exist either as a thin in-situ lava flow or basalt rubble layer. Geomagnetic measurements in the eastern part of the site correlate with the HVSR results, indicating a thin basalt lava flow present.

SBP coverage was limited to the main channel only, and depths were provided to the bedrock. Unfortunately, the water depth (even at spring high tide) was too shallow for the transducer to operate correctly in the E-W channel leading towards Chinatown, so no bedrock reflections were identified in the data due to signal saturation.

Bedrock RL determined from the SBP measurements in the main channel ranged between 6.5m and 11.5m (NZVD 2016), with the lowest points in the vicinity of Ti Rakau Rd, and becoming shallower to the South and North.

Please let me know if you have any questions related to this technical report, or require further information or clarification.

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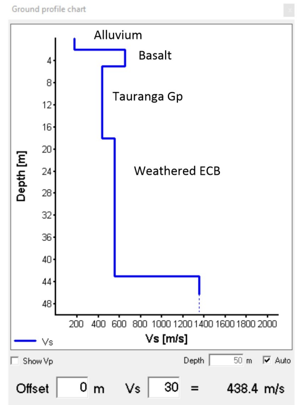
Figure 1 - Geophysical survey extent

Thin layer of basalt is interpreted, near surface.
1.5m thickness (EBS 08) - possibly a rubble layer
3m thickness (EBS 07)
Very low shear wave velocity
for underlying sedimentary units



Shear wave velocity profile, EBS 07

Lowest shear wave velocities observed in this region.

Thin layer of basalt or rubble is interpreted.

STATION		Vs30 (m/s)	Notes	E (Mt Eden 2000)	N (Mt Eden 2000)
EBS1	day1	299.18		411334.429	794920.105
EBS2	day1	301.41		411332.671	794934.505
EBS3	day1	355.65		411360.579	794935.451
EBS4	day1	331.47		411363.118	794911.031
EBS5	day1	332.76		411399.554	795072.504
EBS6	day1	350.73		411421.608	795098.064
EBS7	day1	438	Basalt 3m layer	411542.136	795074.595
EBS8	day1	421.68	Basalt 1.5m layer	411531.549	795085.43
EBS9	day2	380.61		411454.869	794856.815
EBS10	day2	330.08		411407.394	794873.795
EBS11	day2	369.72		411304.845	794901.075
EBS12	day2	307.25		411207.301	794933.368
EBS13	day2	311.84		411274.081	794973.623
EBS14	day3	358.7		410968.44	795019.512
EBS15	day3	380.61	possible basalt	411047.205	795067.495
EBS16	day3	377.88		411105.231	795156.191

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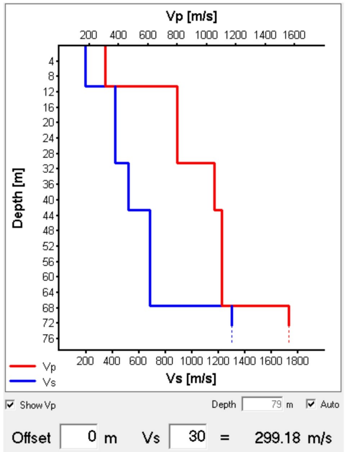
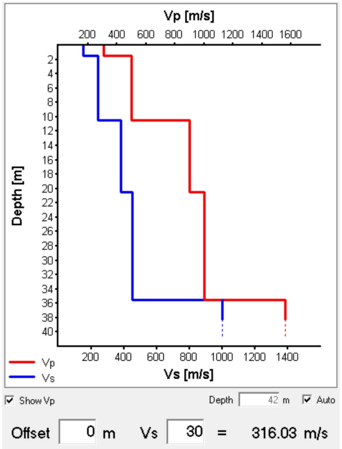
Figure 2 - HSVR Seismic Shear Wave Velocity, Vs30 Results

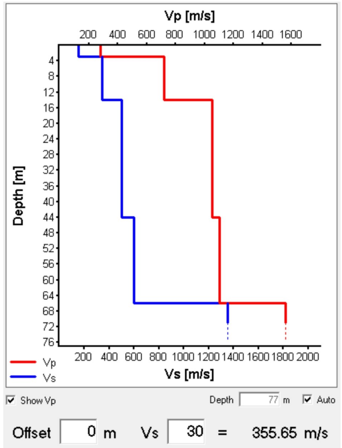
EBS 01 (HVSR 1D Vs Profile)



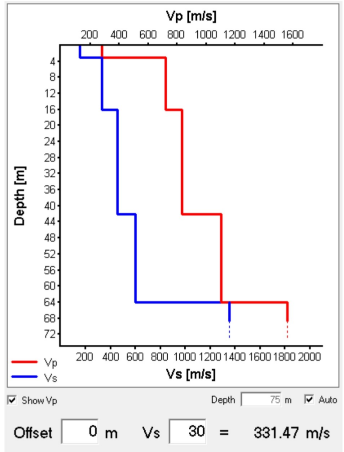
EBS 02 (HVSR 1D Vs Profile)



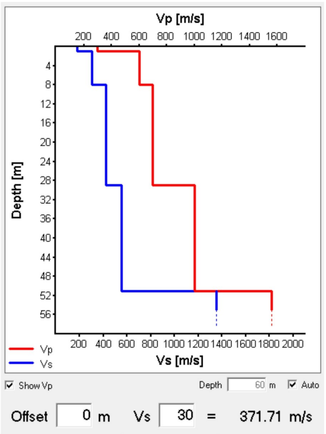
EBS 03 (HVSR 1D Vs Profile)



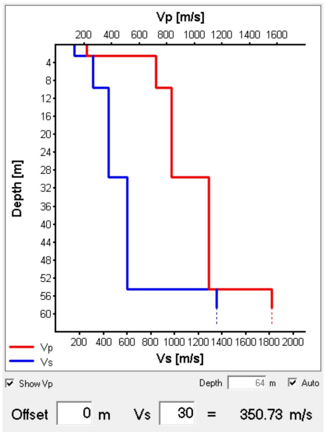
EBS 04 (HVSR 1D Vs Profile)



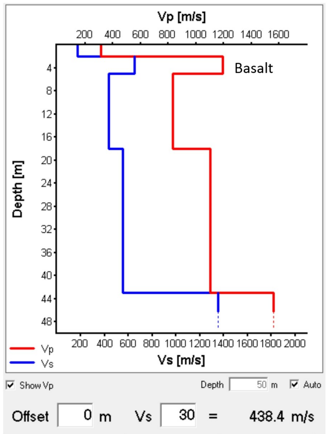
EBS 05 (HVSR 1D Vs Profile)



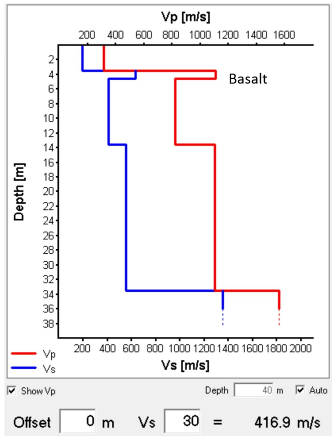
EBS 06 (HVSR 1D Vs Profile)



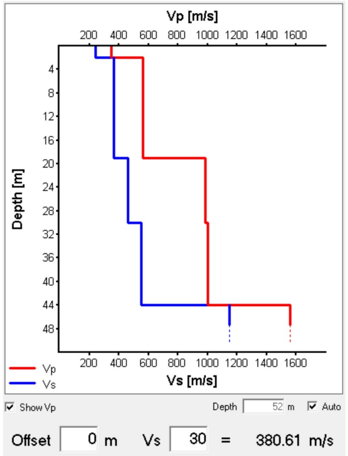
EBS 07 (HVSR 1D Vs Profile)



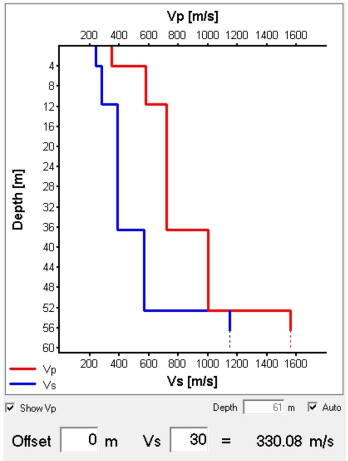
EBS 08 (HVSR 1D Vs Profile)



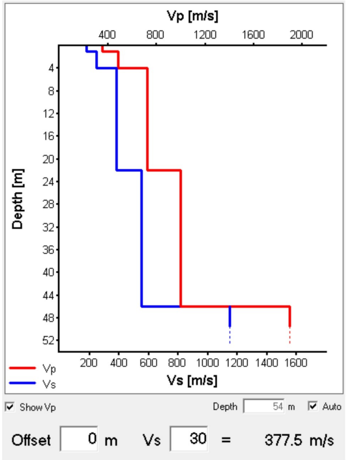
EBS 09 (HVSR 1D Vs Profile)



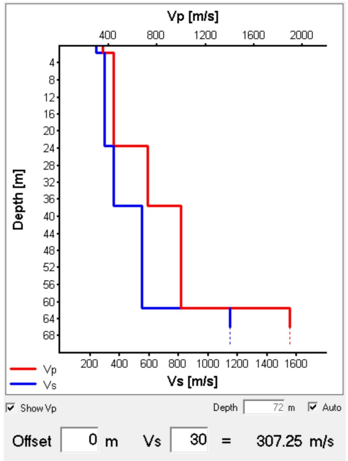
EBS 10 (HVSR 1D Vs Profile)



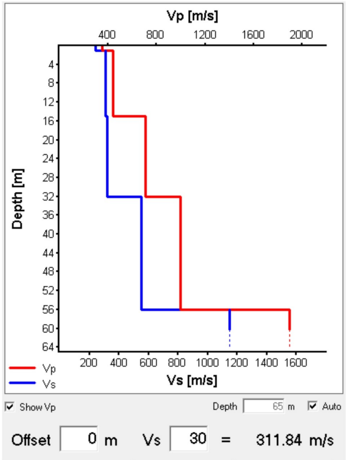
EBS 11 (HVSR 1D Vs Profile)



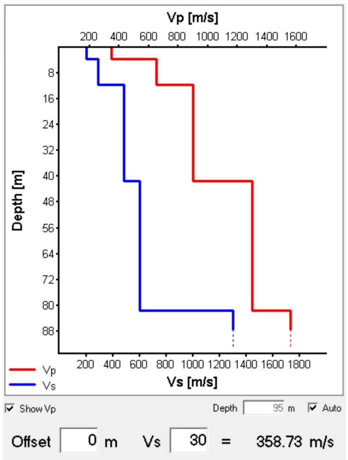
EBS 12 (HVSR 1D Vs Profile)



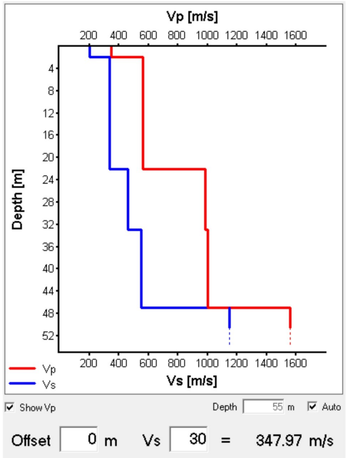
EBS 13 (HVSR 1D Vs Profile)



EBS 14 (HVSR 1D Vs Profile)



EBS 15 (HVSR 1D Vs Profile)



EBS 16 (HVSR 1D Vs Profile)

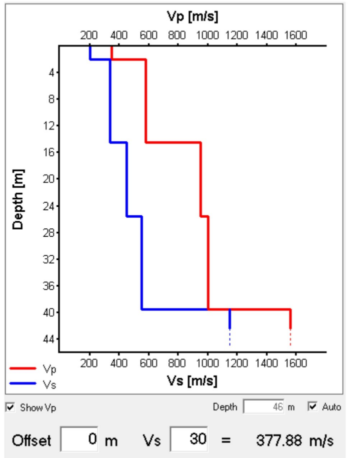


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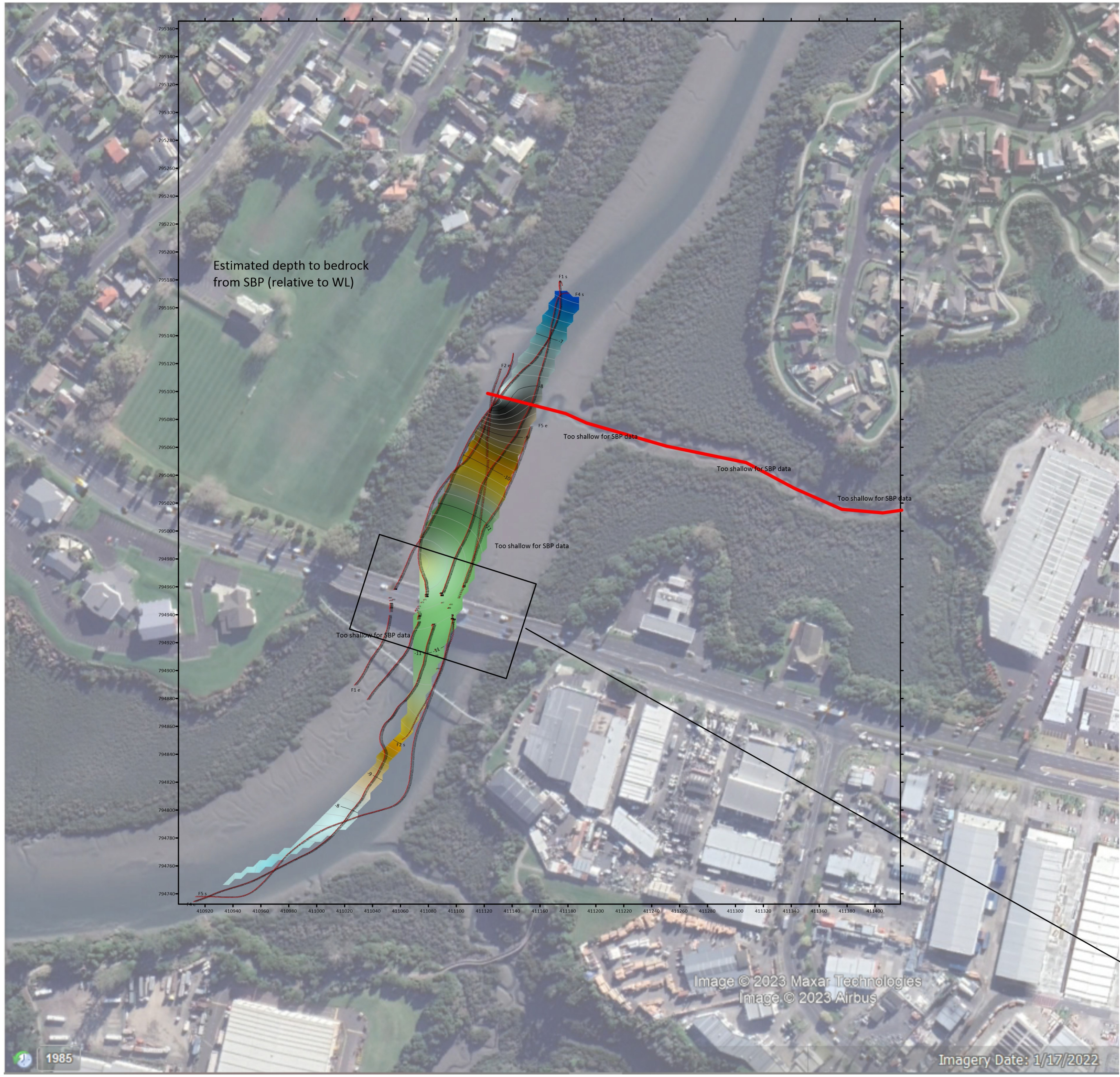
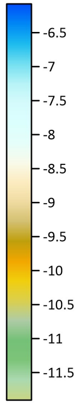
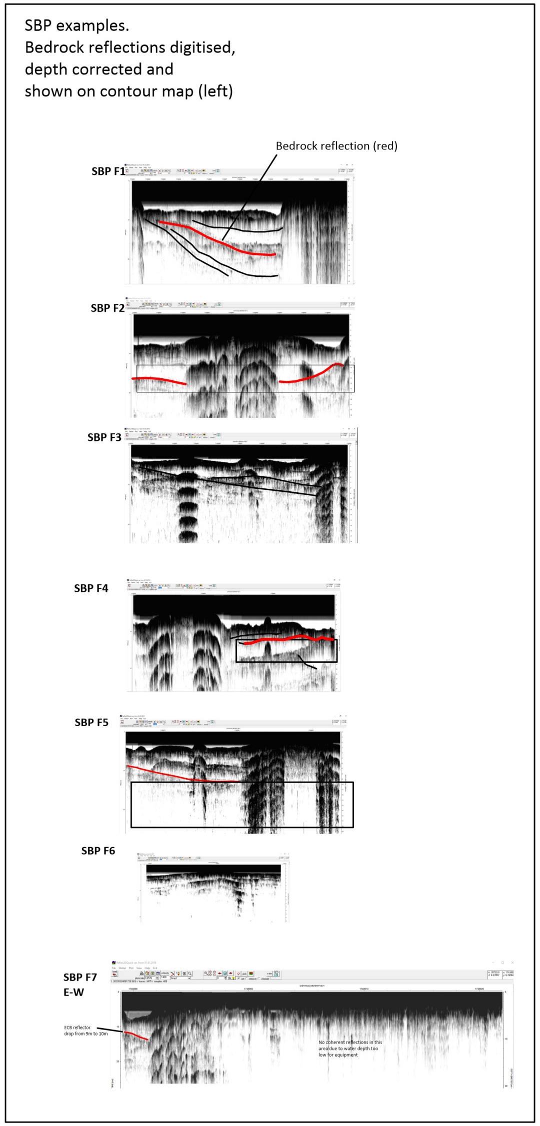
Figure 4 - HSVR Seismic Shear Wave Velocity, Vs30 Results





Elevation of SBP reflection interpreted as bedrock. NZVD 2016



SBP bedrock reflections can be compared to BH logs in this area.
They are **approximately 3.5m** deeper than the ECBF level indicated on DH408 to DH413
This is possibly due to the extensive weathering profile of the ECBF, and that the SBP does not respond to the weathered upper surface of the ECB.

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Figure 5 - Sub-Bottom Profile (SBP) Results

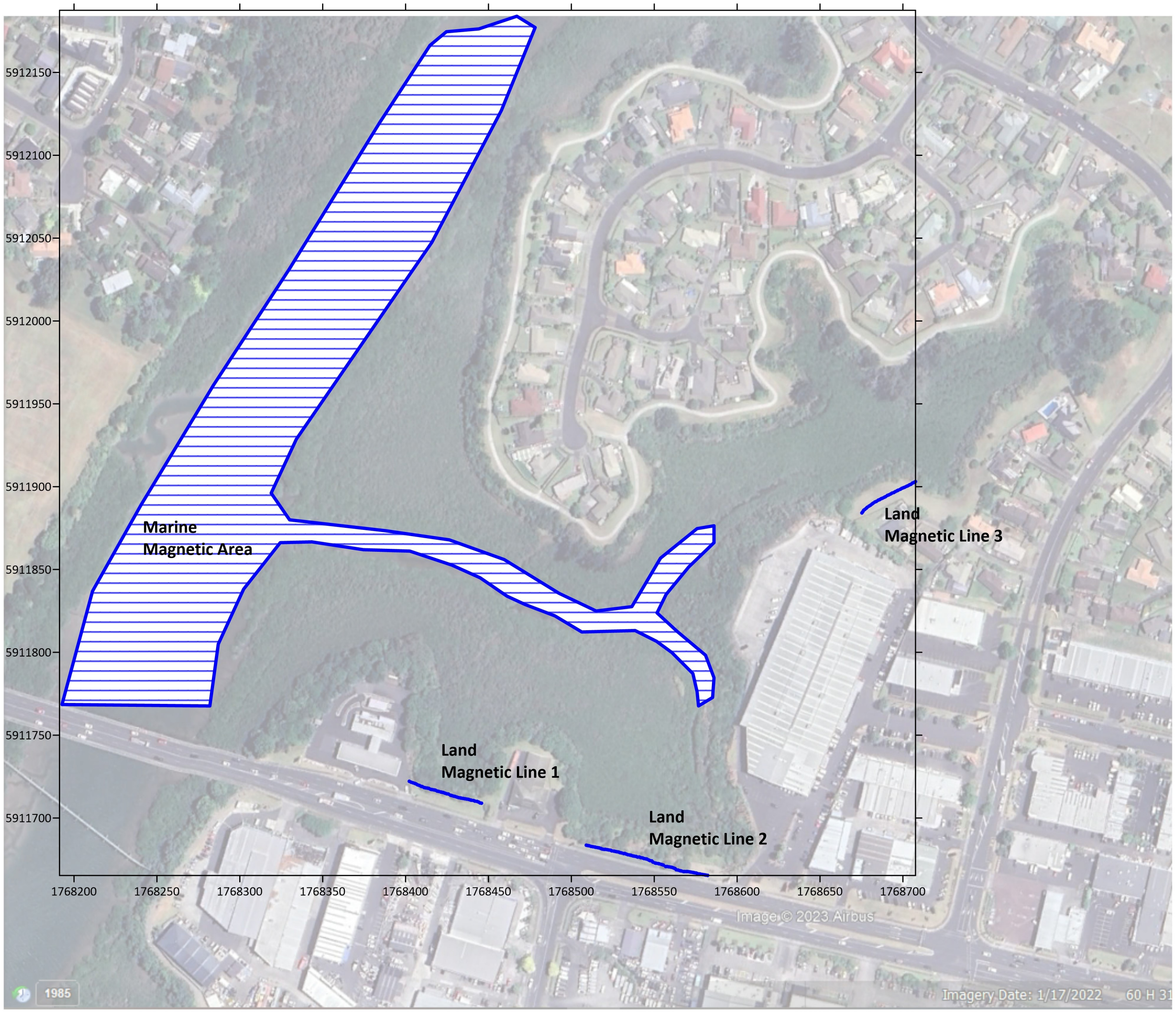

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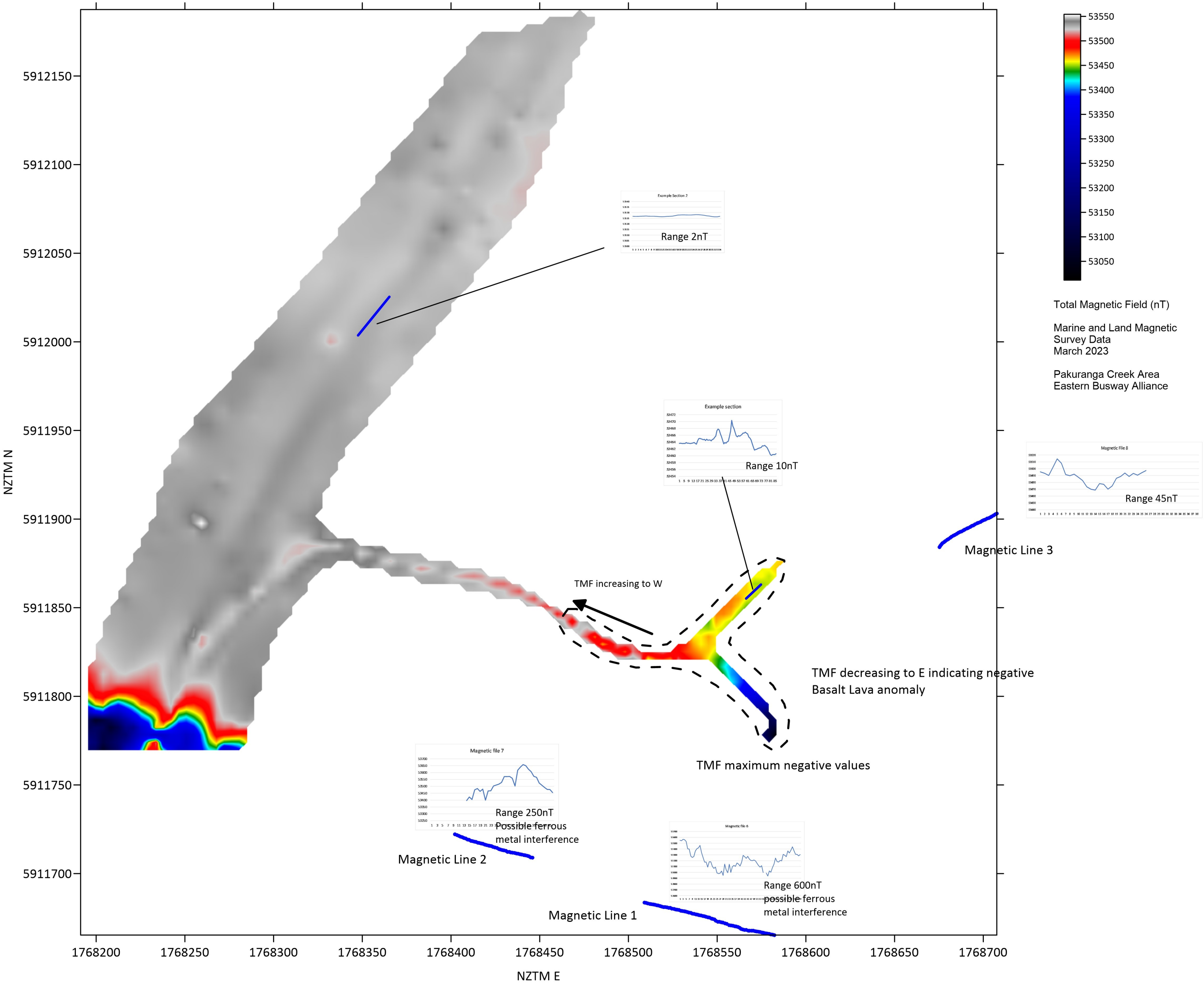
Figure 6 - Land and marine magnetic measurements to define extent of basalt lava flow: Survey Extent



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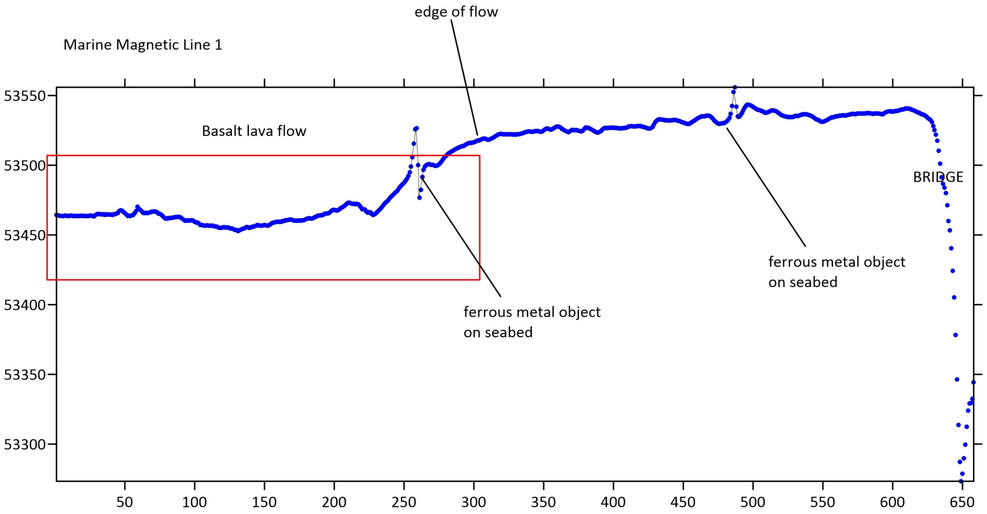
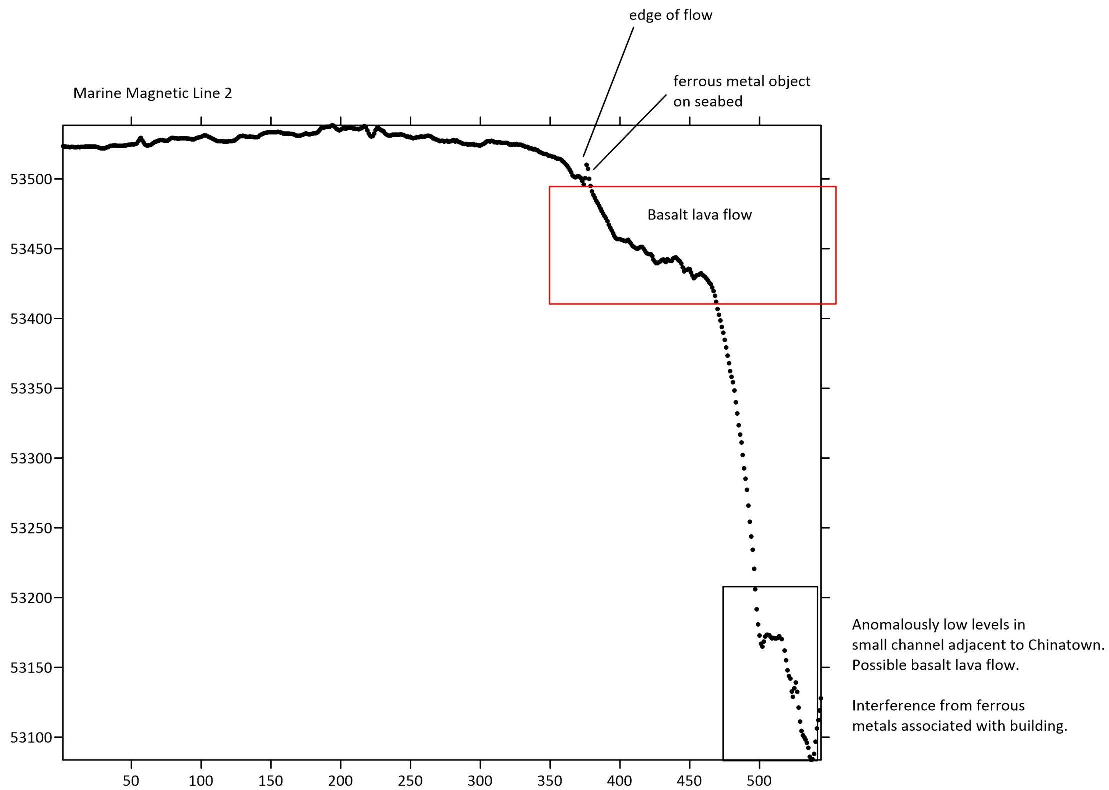
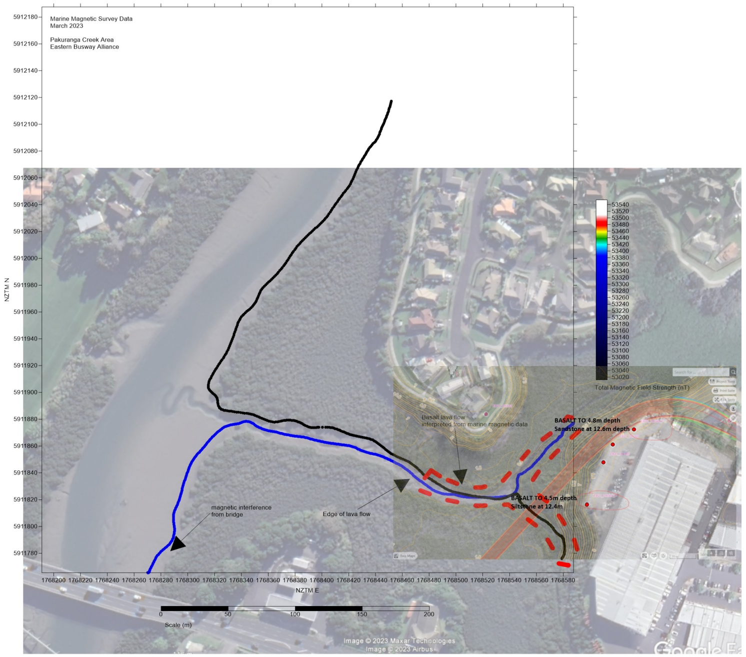
PROJECT	Geophysical Survey
DATE	March-April 2023
PERSONNEL	MW, KH
EQUIPMENT	SBP / magnetometer / HVSR
CONTACT 1	matt@scantec.co.nz
CONTACT 2	021-376-644

Figure 7 - Land and marine magnetic measurements to define extent of basalt lava flow: Results







CLIENT Eastern Busway Alliance
PROJECT Geophysical Survey
DATE March-April 2023
PERSONNEL MW, KH
EQUIPMENT SBP / magnetometer / HVSR

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Figure 8 - Sub-Bottom Profile (SBP) Results

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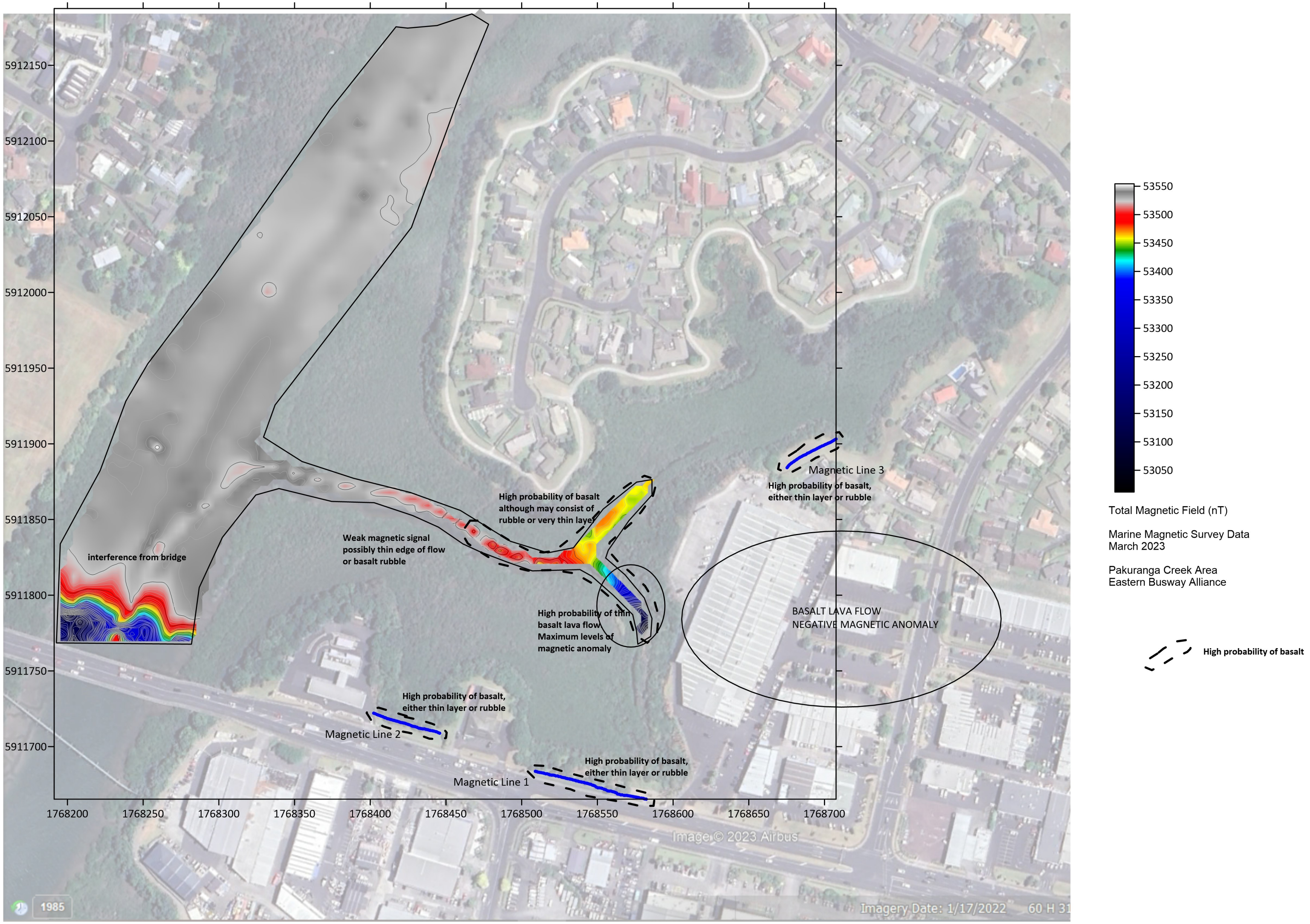

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Figure 9 - Land and marine magnetic measurements to define extent of basalt lava flow: Interpretation

REPORT ON:

DOWNHOLE SEISMIC TESTING

PROJECT:

EASTERN BUSWAY

CLIENT:

EASTERN BUSWAY ALLIANCE

5 REEVES ROAD PAKURANGA
AUCKLAND 2010

220679

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1 INTRODUCTION

Eastern Busway Alliance (the Client) engaged Resource Development Consultants Ltd (RDCL) to conduct a geophysical investigation using the downhole seismic technique. The purpose of the investigation was to measure shear wave velocity (Vs) and compressional wave velocity (Vp) in one existing drillhole.

The drillhole had 50 mm internal diameter PVC grouted in place.

The testing was conducted as part of a geophysics investigation of the site of a designed bridge on the proposed Eastern Busway.

1.1 UNDERSTANDING OF THE PROJECT

RDCL understands the Client required seismic velocity data for geotechnical and structural engineering designs for a bridge. The bridge is along the proposed Eastern Busway, around Ti Rakau Drive between Chinatown across the mangroves to the Mobil Station.

The client wished to define the depth to rock head, weathered rock and "good" rock and thickness of overlying soils. To accomplish these goals RDCL proposed downhole seismic testing in one drillhole and a seismic refraction tomography (SRT) survey.

This report details results of the downhole seismic testing. Hole parameters are given in Table 1 below.

TABLE 1 – DRILLHOLE PARAMETERS

ID	Depth	Northings (NZTM)	Eastings (NZTM)	Water Level (m)	Date Started	Date Completed
DH332	33.0	NR	NR	4.9 – 5.1	07/02/23	08/02/23

A draft geotechnical borehole log was provided to RDCL by the Client. A simplified geological summary of the log is given in Table 2 below. This summary was used in part to define geophysical velocity layers.

TABLE 2 – SIMPLIFIED GEOLOGICAL SUMMARY OF GEOTECHNICAL LOG

From (m)	To (m)	Material
0.0	10.25	Silty Clay with some Sand & Peat
10.25	14.55	Silty Sand – Silt/Sandstone weathering horizon
14.55	20.65	Slightly weathered Siltstone & Sandstone
20.65	33.0	Slightly weathered Sandstone & some Siltstone.

2 SCOPE OF WORK

The scope of work for the project included:

- Acquisition of downhole seismic data in one drillhole.
- Data processing.
- Delivery of a technical summary report.

2.1 TERMS OF REFERENCE

This investigation employed geophysical methods and therefore the findings presented here are the result of the measurement and interpretation of seismic (acoustic) signals. As such any results derived from the geophysical investigation should be taken in the context of and in reference to the complete ground investigation. Reasonable skill and care were taken to ensure that the results are accurate and reliable, including reference where appropriate to published date from this and/or other sites. However, as with other indirect methods there is a possibility of localised inconsistencies and inaccuracies within the results.

3 GEOPHYSICAL SURVEY

Data was acquired in DH332 on the 22nd of February 2023.

3.1 SURVEY RATIONALE

Downhole seismic testing was used to provide an indication of variation in compressional wave velocity (Vp) and shear wave velocity (Vs) downhole. By measuring the difference in arrival times of the compressional and shear waves at known depths, the velocities can be calculated.

Key to the survey is accurate identification of shear waves. This was achieved by utilising the fact that shear waves can be polarised. By striking a shear beam in opposing directions, polarised shear waves are created. Seismic traces can then be superimposed allowing the polarisation to be observed, and shear waves to be therefore distinguished from the coda ("tail") of the earlier arriving compressional waves.

3.2 DATA ACQUISITION METHOD

3.2.1 ACQUISITION SYSTEM

Acquisition of downhole seismic data was conducted using a Geometrics Geode seismograph addressing a tri-axial Geostuff BHG-3 downhole clamping geophone.

Tests were spaced at 1 metre intervals from 2 m below ground level to the bottom of the drillhole.

3.2.2 SEISMIC SOURCE

Shots were:

- Produced by a sledgehammer for seismic signal generation ("shots").
- Stacked (three shots) to improve signal to noise ratio.
- Horizontally polarised "shear" wave shots were acquired in opposite directions by striking a shear beam weighted by a vehicle (to improve coupling). The shear beam was orientated to align with the orientation of one of the transverse components of the tri-axial geophone sensor.
- Vertical compressional wave shots (P wave) were acquired by striking a metal plate with a sledgehammer placed at a known distance from the drillhole collar.

3.2.3 Acquisition Parameters

Acquisition parameters were typically:

- Record length - 500 ms
- Delay - 0 ms
- Sample interval - 62.5 µs
- Acquisition filters - OUT

3.2.4 Positional Control

Positional control downhole was obtained using 0.5 m interval marks on the geophone cable. Downhole measurements were made relative to ground level during acquisition.

- Therefore, downhole positional accuracy is likely to be of the order of ±0.05 m.

Horizontal offsets to the shear beam and P-wave plate were measured using a tape measure.

- Therefore, positional accuracy is likely to be of the order of ±0.05 m.

3.2.5 Verticality

Drillhole verticality was assumed, and no travel time corrections are applied associated with variations in verticality. This is a direct ray path method.

3.2.6 Quality Assurance

There are three main field-testing QC steps.

- Before data acquisition seismic channels are checked for signal to noise interference. This is used to assess poor drillhole wall coupling or external noise on site (unwanted sound). This is commonly referred to as a noise shot.
  - A noise shot is recorded at surface, to assess signal to noise ratio and to confirm electronic systems are functioning and correct timing and trigger errors.
  - A noise shot is also recorded at depth, typically at a mid-point in the drillhole. This confirms in-hole signal to noise ratio, ensures the tool is functioning after deployment and assesses the frequency characteristics of the noise.

- Every shot interval has stacked signal shots of three shots per test depth. Each shot is checked for timing errors and poor coupling before being saved to the data sets. Shots were stacked in field to improve signal to noise ratios.
- Shear wave seismic shots are recorded in opposing directions to establish a polarised shear wave. Polarised shear waves reduce the chances of tube waves being confused with shear wave arrivals.

3.2.7 Resolution Limitations

Layer velocities were defined based on changes in arrival time slopes and geological intervals detailed in the drillhole log. Velocities are calculated from calculating the slope from the Tx curves (time depth). It is usually not appropriate to calculate interval velocities using just two points (over successive measurements) as large errors in velocity are likely (ASTM – D7400-08).

3.3 Data Processing

Data processing consisted of:

- Phase 1 – Initial processing and data filtering.
- Phase 2 – First break picking and shear wave picking.
- Phase 3 – Data presentation and calculation of interval velocities.

3.3.1 Phase 1 – Initial Processing

Raw data files were imported into an RDCL proprietary Python script. The script undertook the following generalised processes:

- Split of channels 1, 2 and 3 (data orientated in the vertical, north and east components).
- Sort into left, right and vertically polarised shots.
- Deletion of unrequired traces.
- Correct assignment of depth geometry from header.
- Merge of traces into separate gathers for left, right and vertical polarised shots.
- Bandpass-filtering.
- Visual assessment of traces.

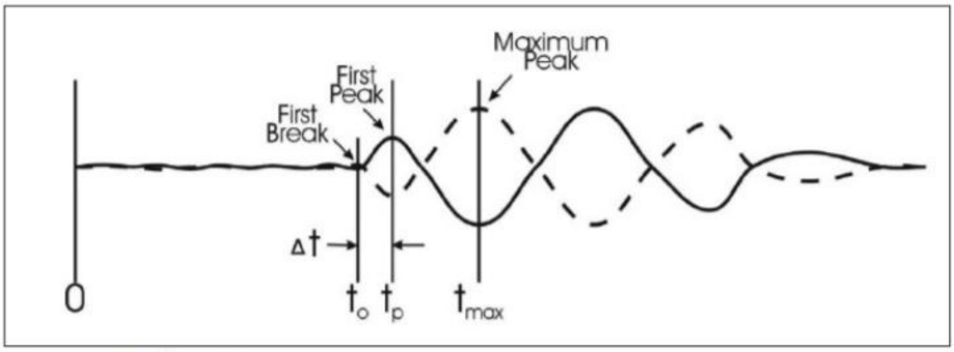
3.3.2 Phase 2 – Arrival Time 'Picks'

Gathers were subsequently imported into the Seisimager Pickwin module software for picking. Shear wave arrival times were manually picked by identifying waves that were polarised. Where shear waves could not be reliably identified, a gap was left and that data was not picked. Shear wave identification may be affected by:

- Decreases in signal to noise ratio.
- Interference from tube waves.
- Disturbance by the coda of the P-wave arrivals.

For the purposes of this survey shear waves were picked at three separate locations on each trace (Schematic 1) and interval/layer velocities calculated using the three picking methods.

SCHEMATIC 1 - SHEAR WAVE VELOCITY PICKING



The three methods are called:

- First Break.
- First Peak.
- Maximum Peak.

Three methods of shear wave picking were used to reduce and assess the uncertainty in the shear wave velocity interval/layer calculations.

Compressional wave arrivals were picked from the vertically polarised shots at the first break. Arrival times were then exported.

3.3.3 PHASE 3 – VELOCITY CALCULATIONS

Arrival times were imported into an RDCL proprietary Python script for presentation and calculation of interval velocities and layer velocities. Intervals were defined from changes in slope in the arrival time data and the drillhole log provided to RDCL.

Geometric corrections were made to the travel times for shot/collar horizontal offsets and any casing stick up.

4 RESULTS

Compressional and shear wave velocities were measured in DH332 to a depth of 31.0 m bgl. Data cannot be collected to the end of hole depth due to the length of the tool.

4.1 DATA PRESENTATION

Velocity layers were assigned based on (in decreasing order of importance):

- Gradient changes observed in the S-wave t-x curves.
- Gradient changes observed in the P-wave t-x curves.
- Changes in geology observed in the drillhole.

4.2 NOTES

Signal to noise ratios in the shear wave data were reasonable. Polarisation was generally good, although poor in some individual shots. Several phase reversals and some noisy shots complicated picking, and some depth levels were not picked.

The seismic signals show a distinct character from approximately 11 – 16 m bgl which may be related to the sand/siltstone weathering horizon. This section displays the fastest shear wave velocity in the hole, with a velocity inversion at 17.9 m. This is unexpected, as usually less weathered, more competent rock (i.e. from 14.55 m down) would have faster velocities.

It is also noteworthy that there is no clear velocity change associated with the logged rockhead at 14.55 m bgl.

Shear wave velocity values were recorded in the range of 90 - 491 m/s (Figures 1 – 3). Data are summarised in Table 3.

Signal to noise ratios in the compressional wave data were good. P wave velocities were mostly recorded at ~1,600 m/s from the 4.55 m boundary to end of hole. This coincides with the recorded water level at 5 m. As P wave velocity in water is ~1,500 m/s, P wave velocities recorded are probably a measure of water velocity of the saturated formation. In that case the velocity of the unsaturated formation may be less than 1,500 m/s and has not been measured.

Compressional wave velocities are given in Figure 4 summarised in Table 4.

TABLE 3 –DH332 SUMMARY OF SHEAR WAVE VELOCITIES

		Average S-Wave Velocity (m/s)			
From (m)	To (m)	First Break	First Peak	Max Peak	Pick Method Average
0.00	4.55	112	107	90	103
4.55	12.50	167	182	238	196
12.50	17.90	467	492	356	438
17.90	24.40	280	267	253	266
24.40	32.00	436	386	290	371

TABLE 4 – DH332 SUMMARY OF COMPRESSIONAL WAVE VELOCITIES

From (m)	To (m)	Average P-Wave Velocity (m/s)
0.00	4.55	460
4.55	10.25	1,641
10.25	17.90	1,673
17.90	23.80	2,220
23.80	32.00	1,556

4.3 ARRIVAL TIMES

For completeness arrival times are tabulated in Appendix C. These values may be used to calculate velocities over different intervals than that defined in this report.

4.4 COMMENT

Measured compressional and shear wave velocities fall within the expected ranges for the logged materials (Reynolds, J.M. (2011).

5 REFERENCES

- Geometrics (2014). http://www.geometrics.com/geometrics-products/seismographs/download-seismograph-software/#SeisImager/2D
- Reynolds, J. M. (2011). An introduction to applied and environmental geophysics. John Wiley & Sons.

7 LIMITATIONS

- This report has been prepared for the particular purpose outlined in the project brief and no responsibility is accepted for the use of any part in other contexts or for any other purpose.
- This investigation employed geophysical methods and therefore the majority of the findings presented here are the result of the measurement and interpretation of seismic (acoustic) signals. As such any results derived from the geophysical investigation should be taken in the context of and in reference to the complete ground investigation. Reasonable skill and care was taken to ensure that the results are accurate and reliable, including reference where appropriate to published data from this and/or other sites. However, as with other indirect methods there is a possibility of localised inconsistencies and inaccuracies within the results.
- Ground conditions assessed in this report are inferred from data provided by the Client, published sources, site inspection and the investigations described. Variations from the interpreted conditions may occur, and special conditions relating to the site may not have been revealed by this investigation, and which are therefore not taken into account. No warranty is included either expressed or implied that the actual conditions will conform to the interpretation contained in this report.
- No responsibility is accepted by Resource Development Consultants Ltd for inaccuracies in data supplied by others. Where data has been supplied by others, it has been assumed that this information is correct.
- Groundwater conditions can vary with season or due to other events. Any comments on groundwater conditions are based on observations at the time.
- This report is provided for sole use by the Client and is confidential to the Client and their professional advisors. No responsibility whatsoever for the contents of this report shall be accepted for any person other than the Client.

8 CLOSURE

We trust this meets your current needs. Should you wish to discuss any aspect of the contents of this document please contact the undersigned at +64 4 282 1564.

Faithfully,

O. Gibson

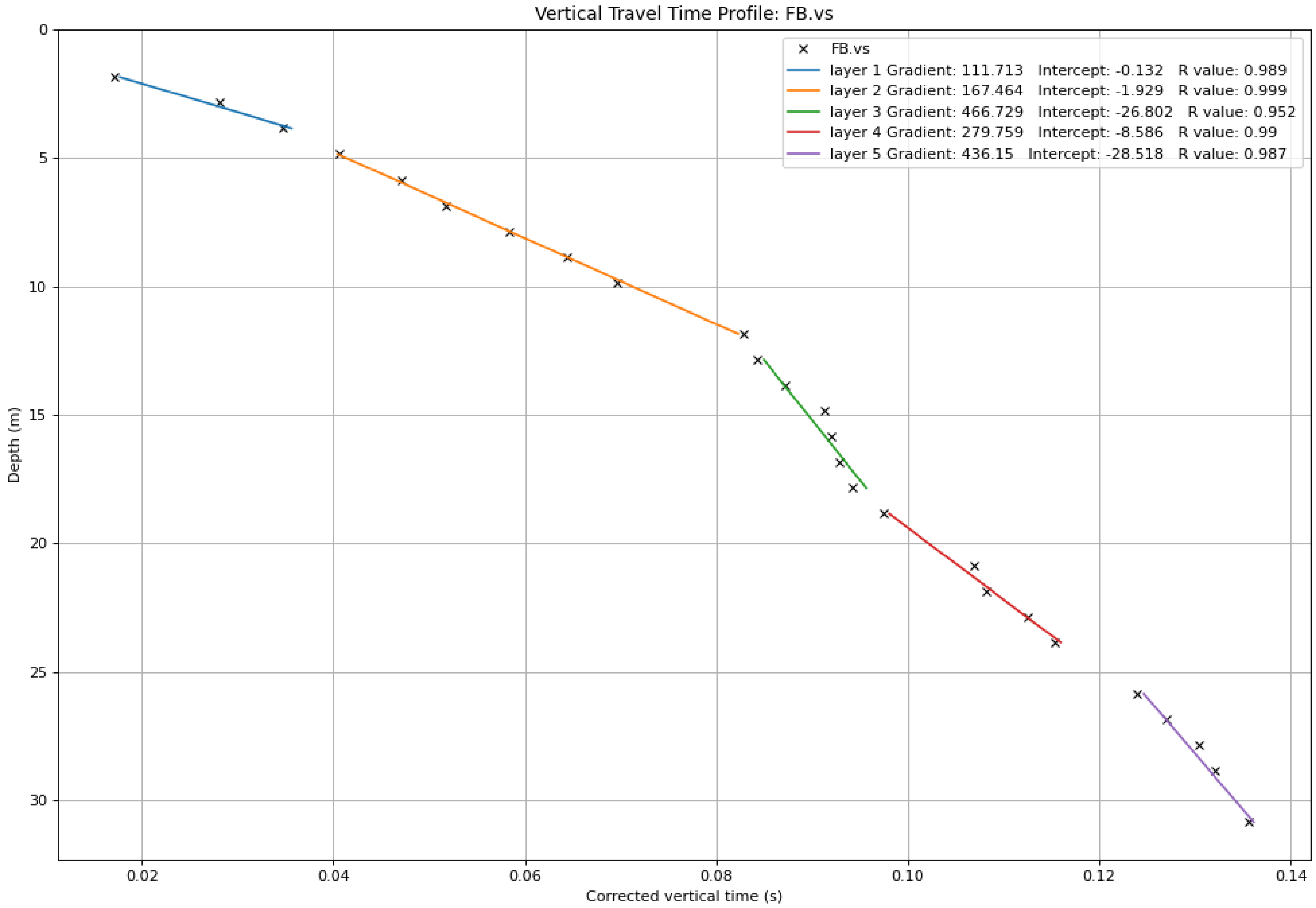
Alistair Stronach
BSc, MSc
Geophysicist

O Gibson
BSc, MRes, FGS
Principal Geophysicist

Attached:

Figures	1 – 6
Appendix	A - C

FIGURES



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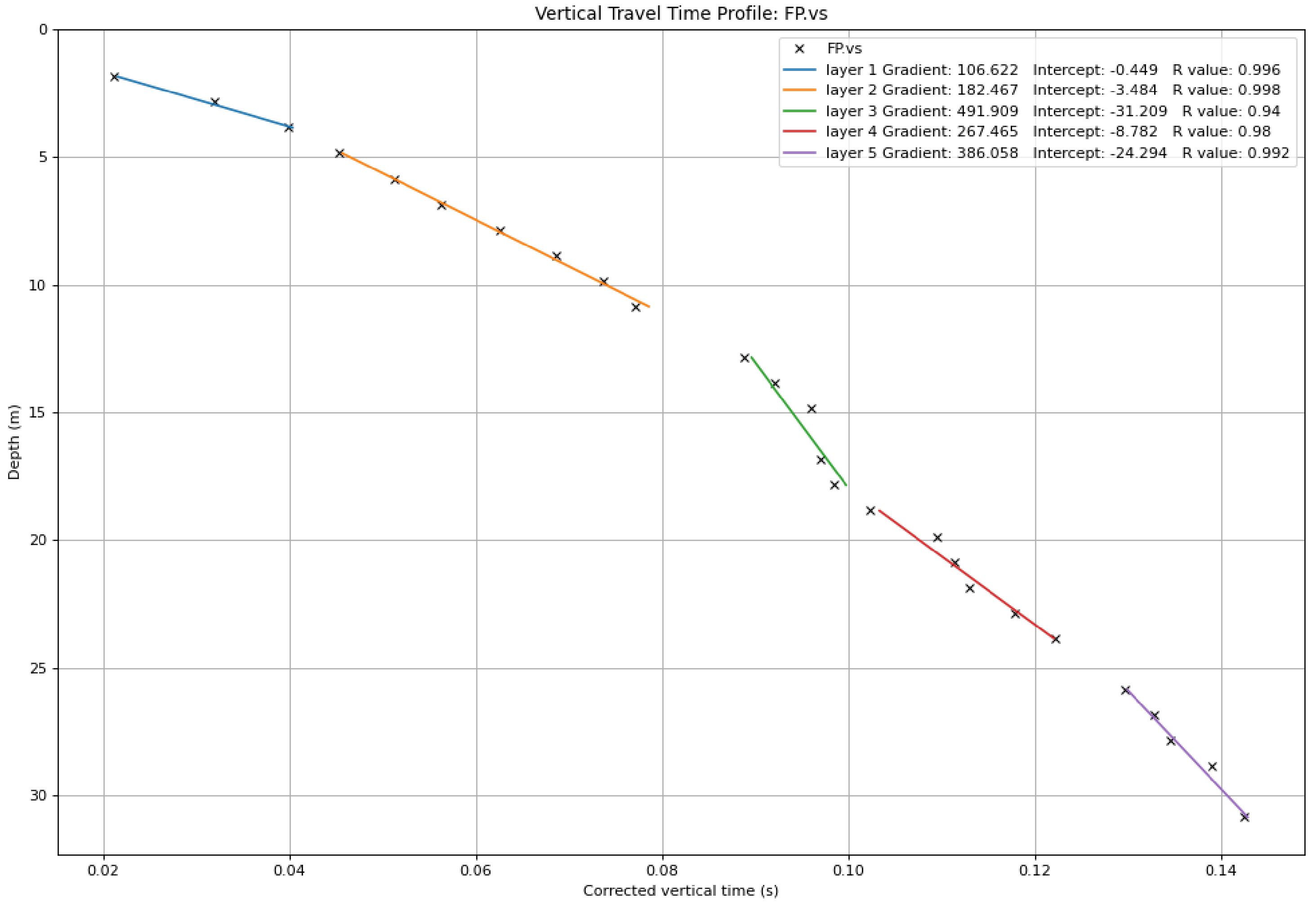
	CLIENT	Eastern Busway Alliance	CHECKED BY	OG	DATE	27/02/23	01



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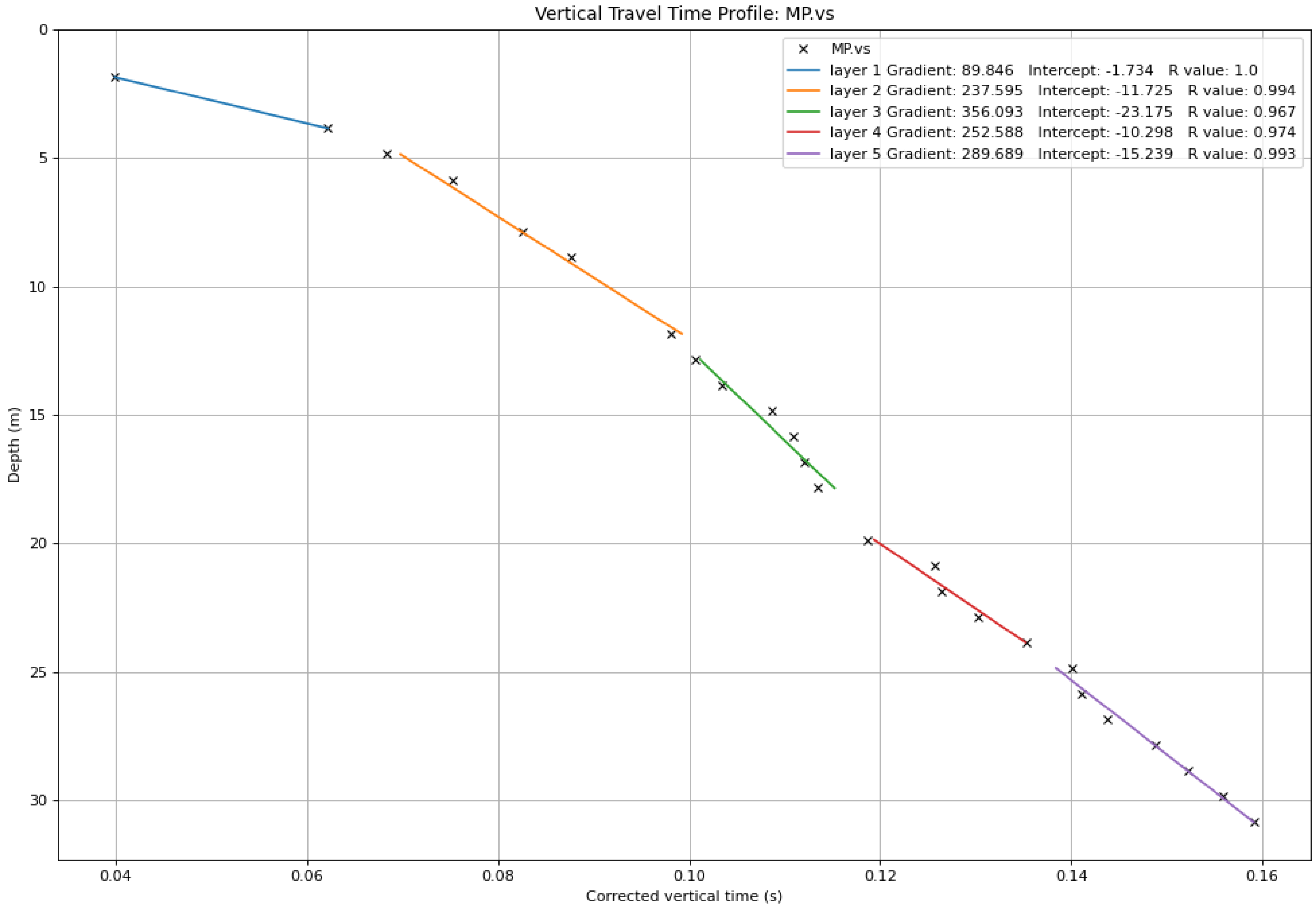

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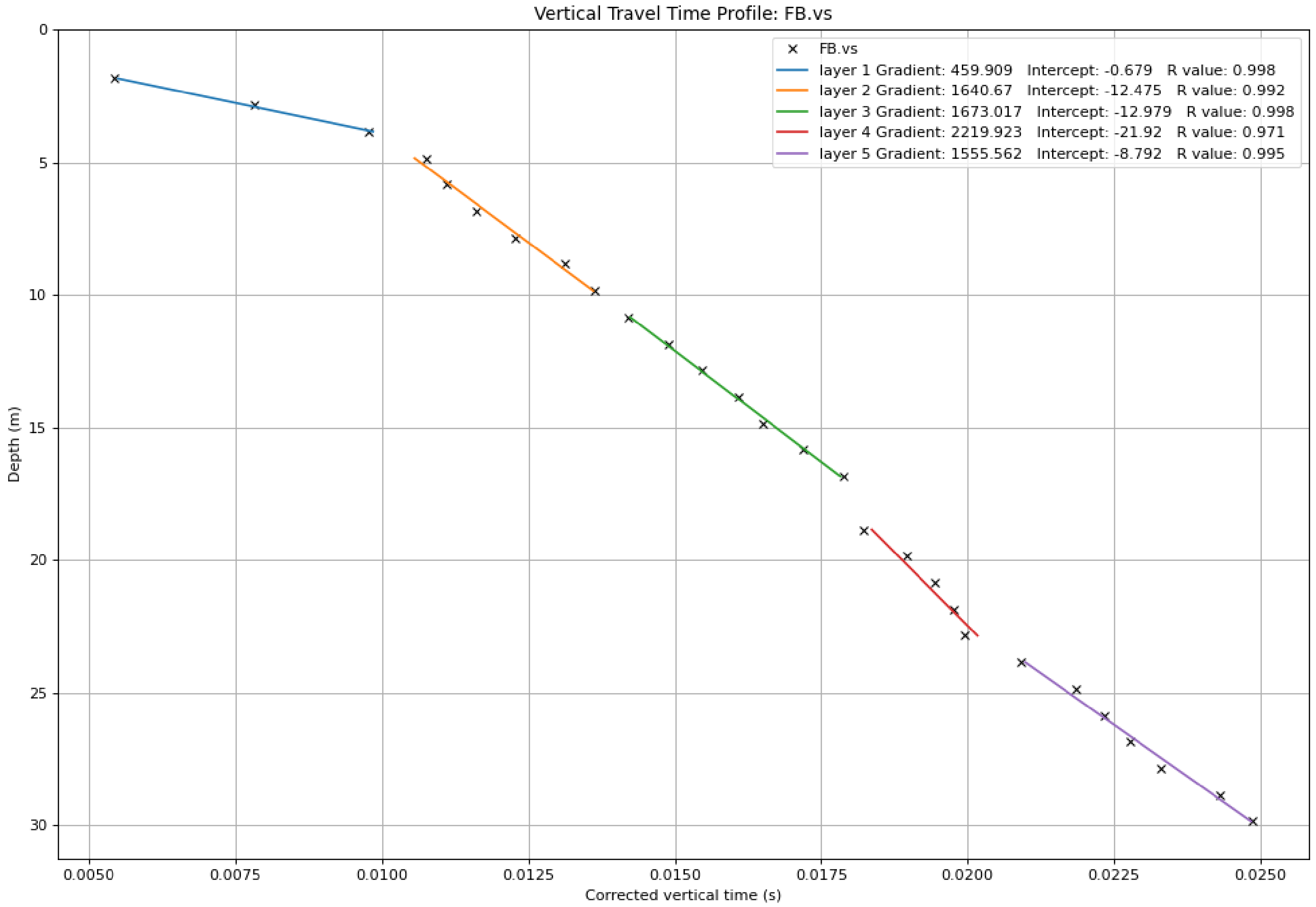

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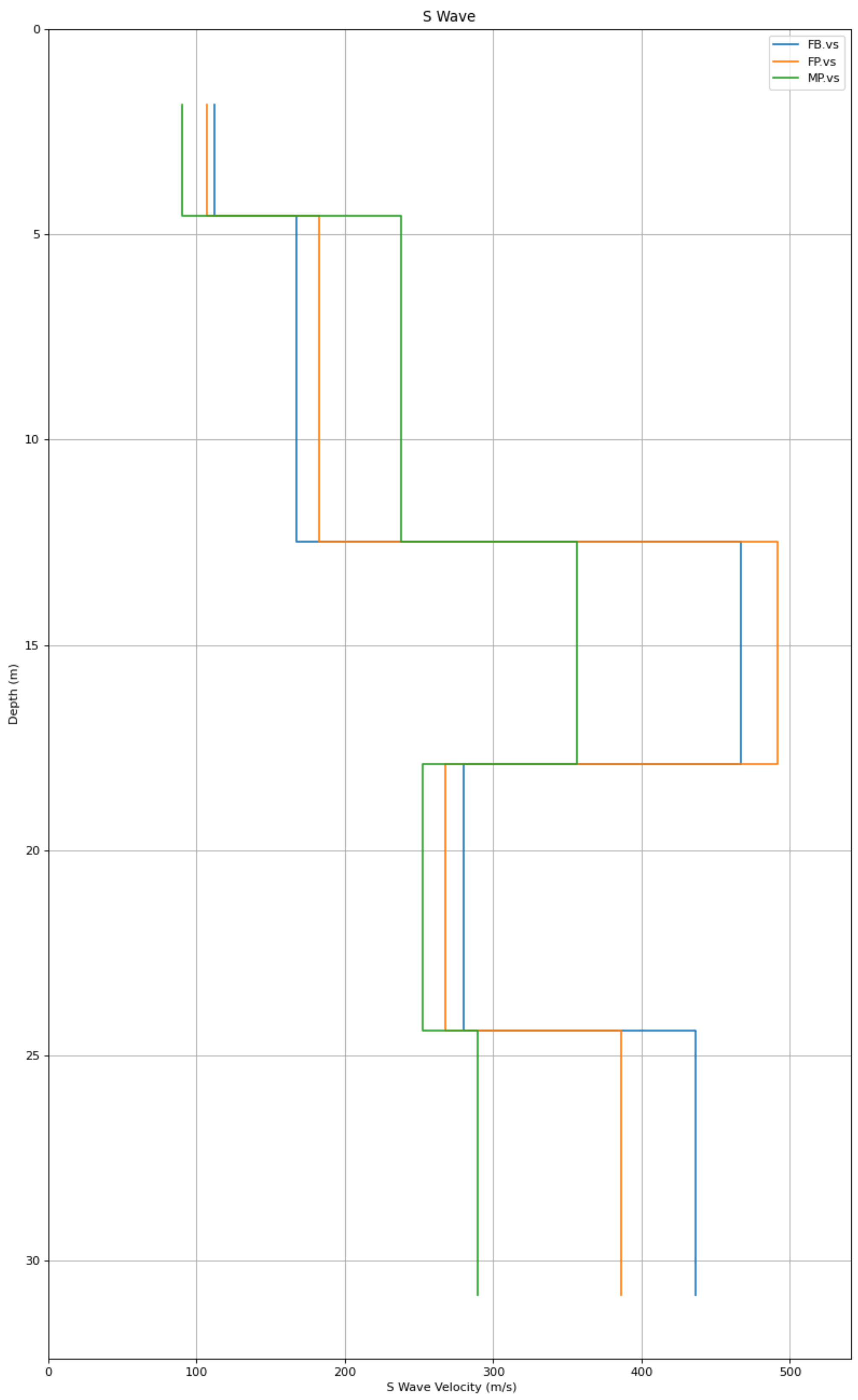
PROJECT	Eastern Busway Downhole Seismic Testing	DRAWN BY	AS	DATE	27/02/23	FIG
CLIENT	Eastern Busway Alliance	CHECKED BY	OG	DATE	27/02/23	04



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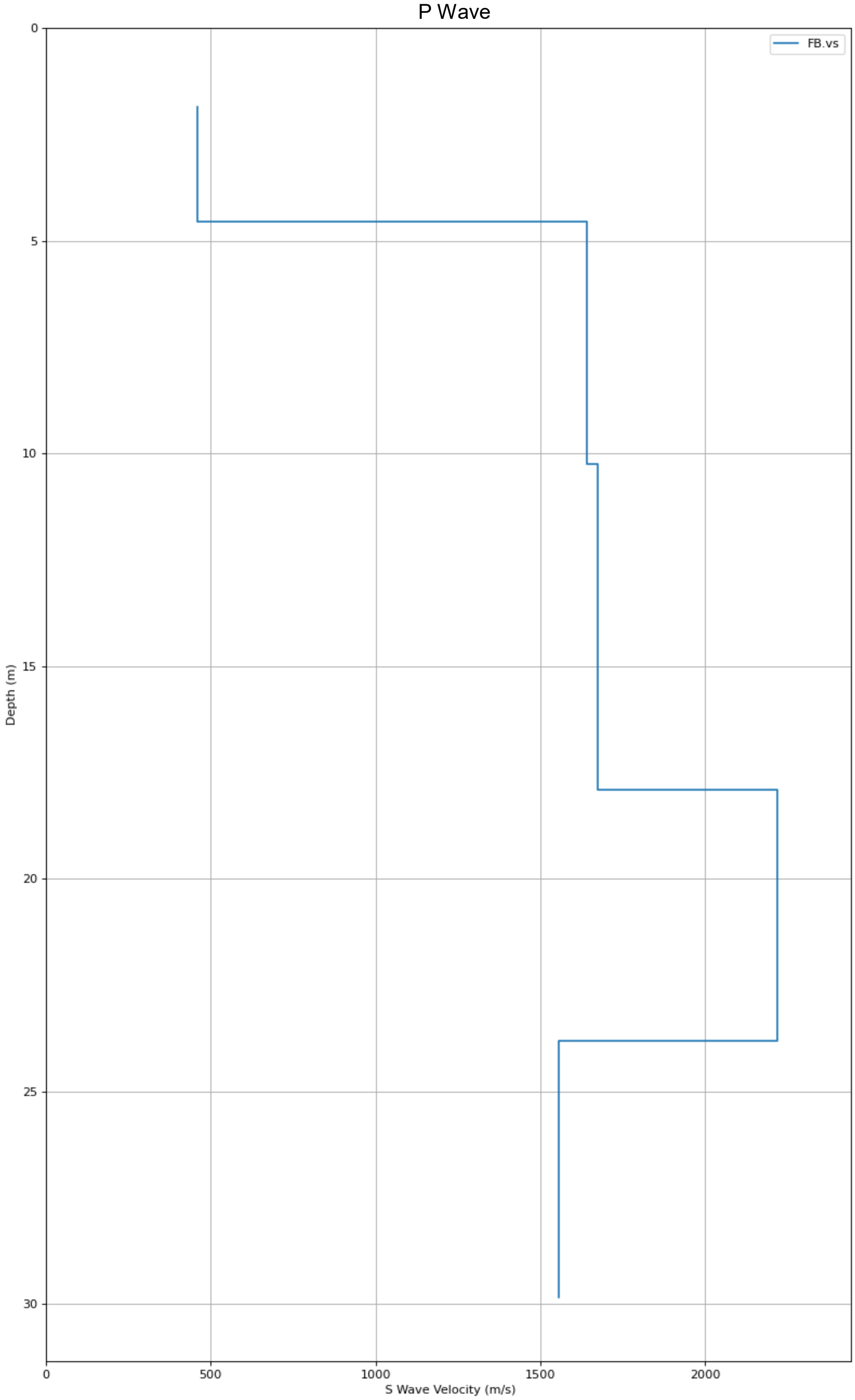
CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679	Figure No.	05



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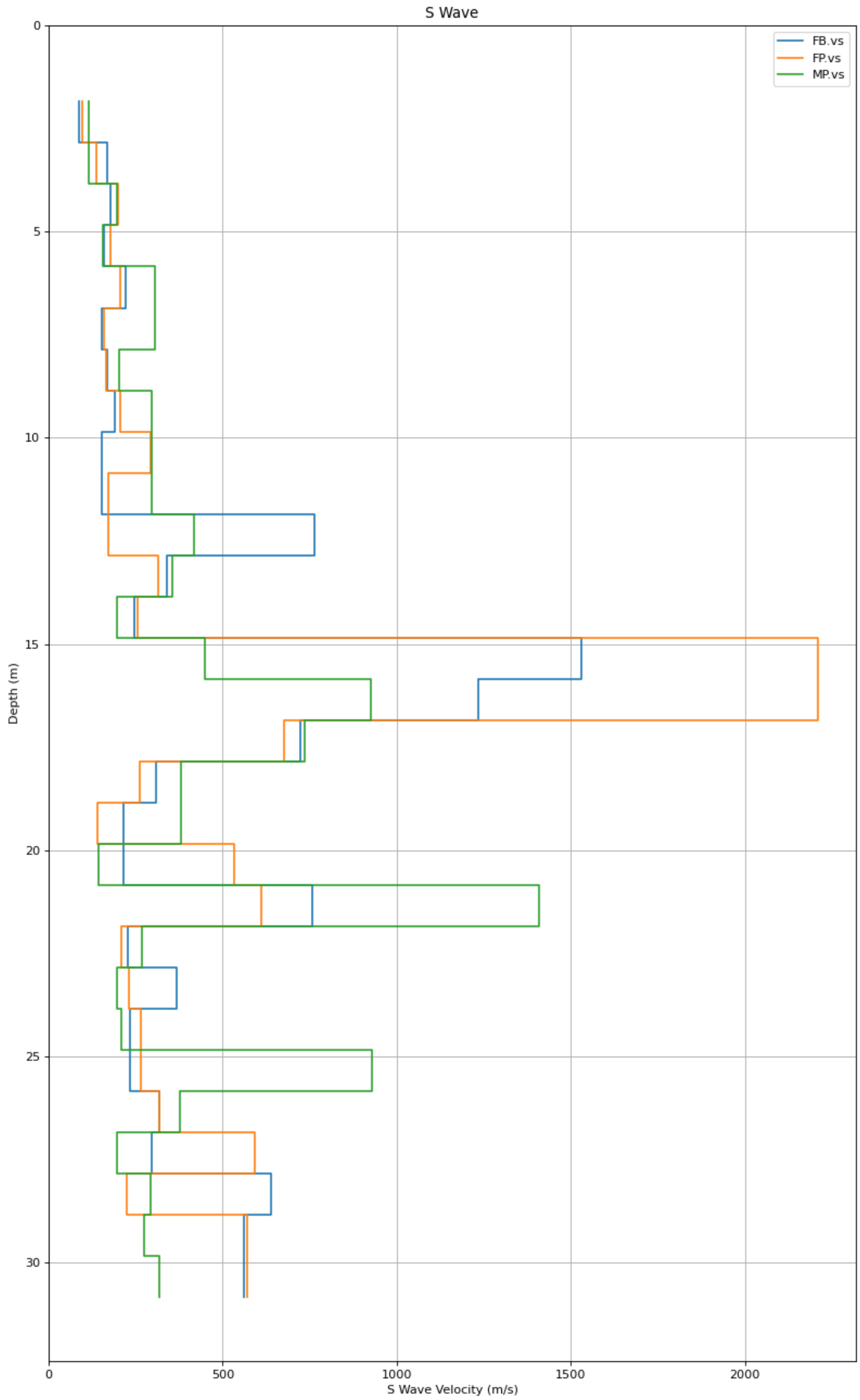
DRAWN BY	AS	DATE	27/02/23	CLIENT	Eastern Busway Alliance		
CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679	Figure No.	06

APPENDIX A – INTERVAL VELOCITIES



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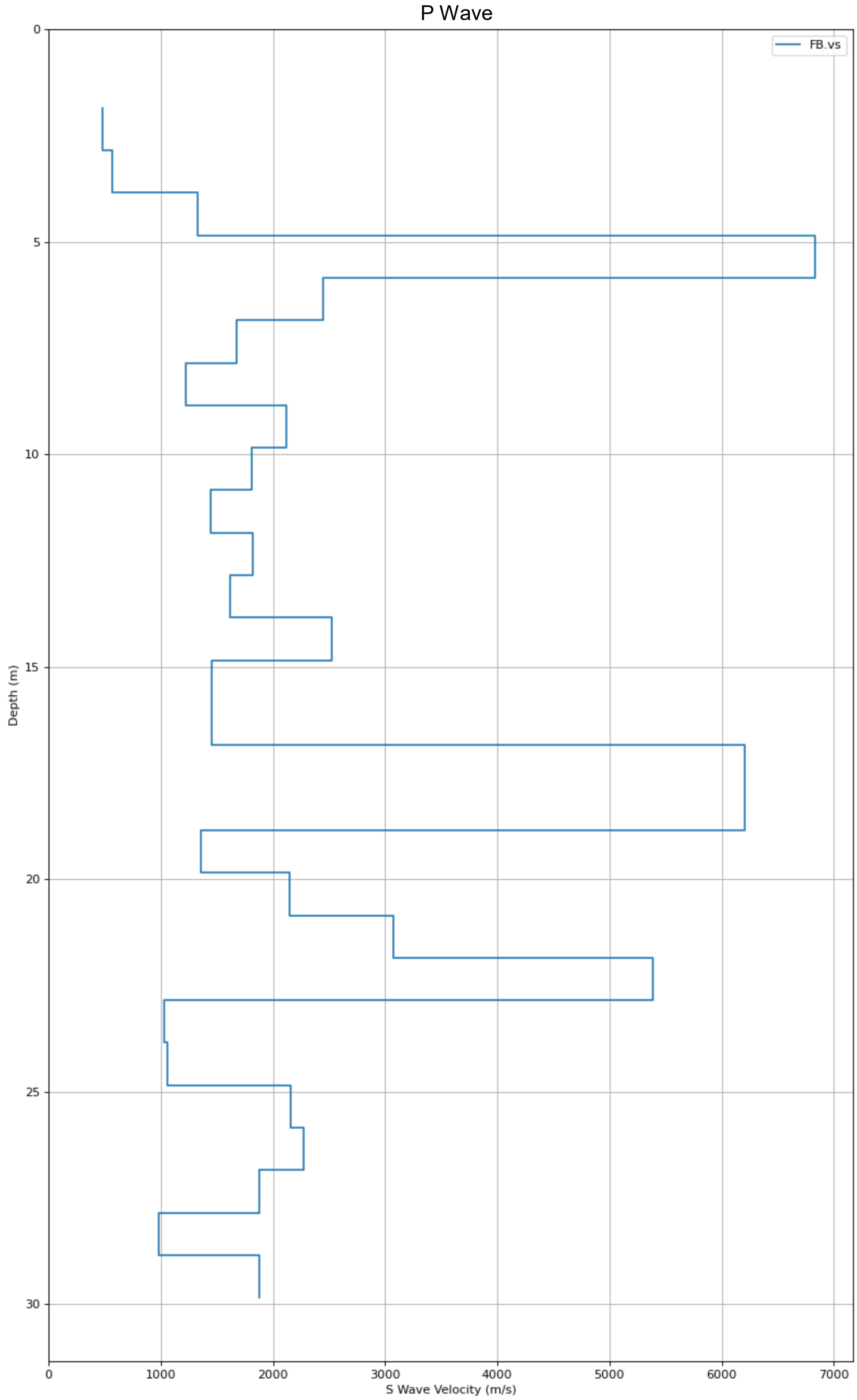
CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679 — Figure No. A1



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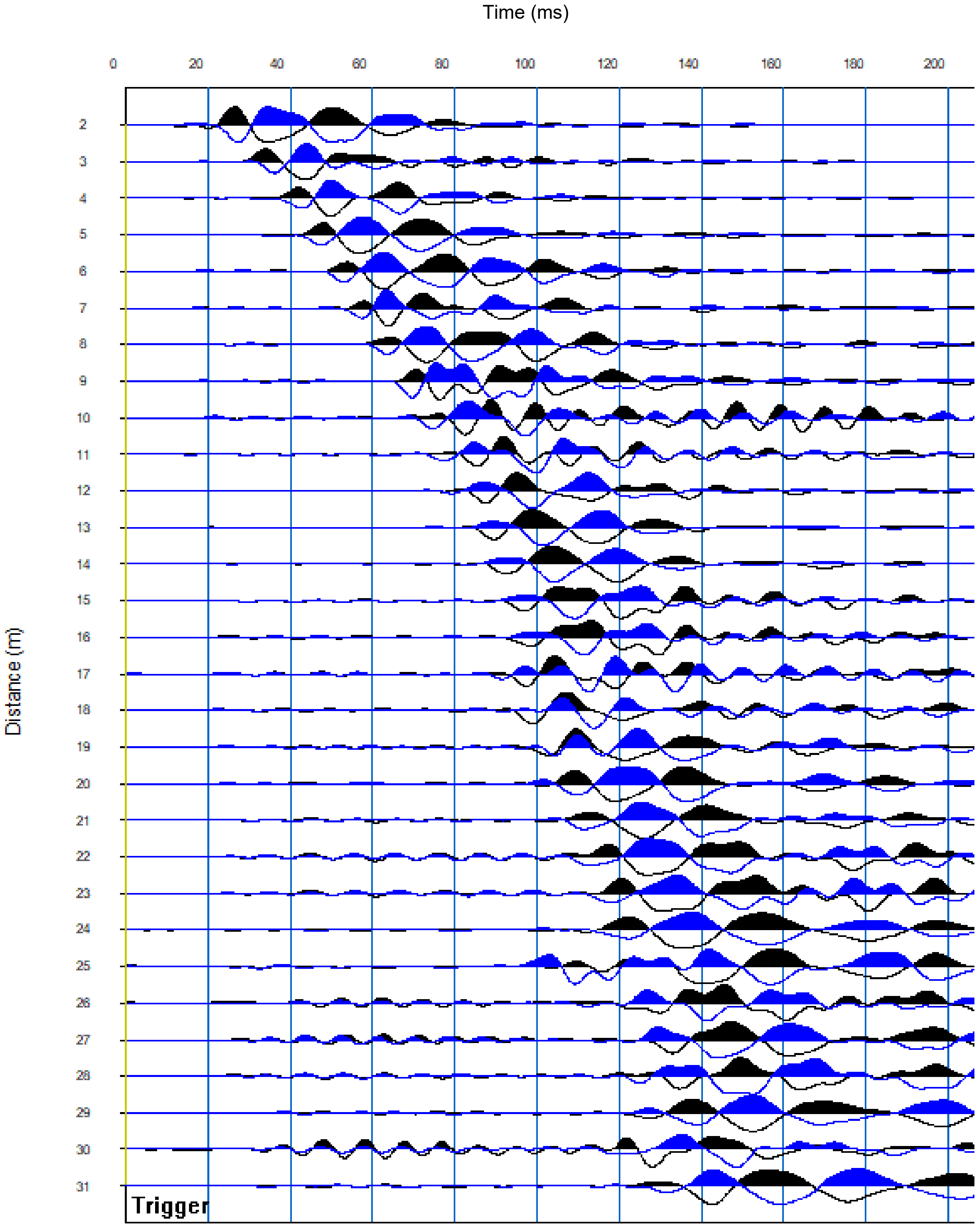
				PROJECT	Eastern Busway Downhole Seismic Testing	
DRAWN BY	AS	DATE	27/02/23	CLIENT	Eastern Busway Alliance	
CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679	Figure No. A2

APPENDIX B – TRACE GATHERS



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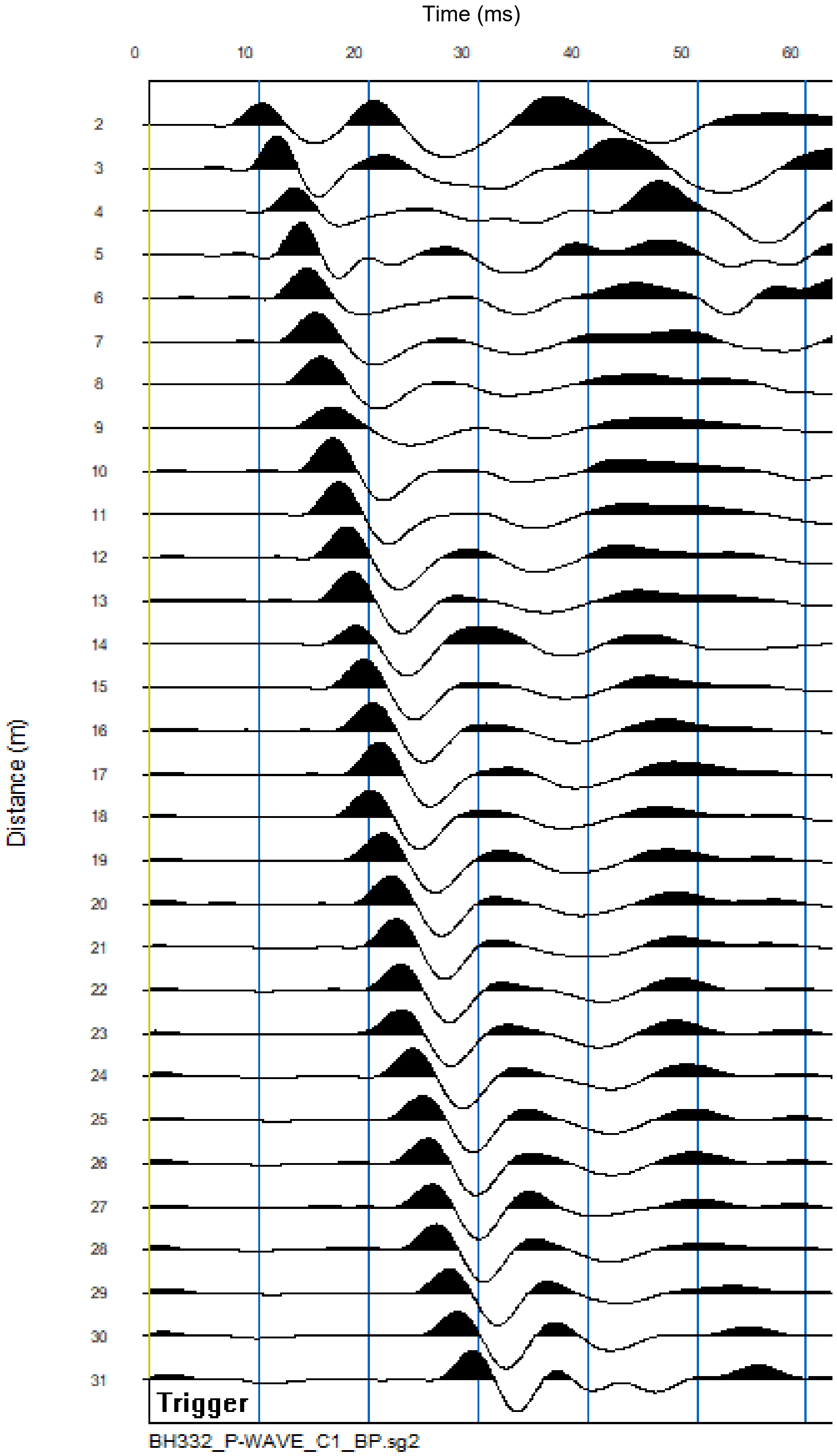
CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679	Figure No. B1



RDCL				TITLE	DH332 Compressional Wave Trace Gather		
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CHECKED BY	OG	DATE	27/02/23	PROJECT No.	220679	Figure No.	B2

APPENDIX C – TABULATED ARRIVAL TIMES

TABLE C1 – DH332 SHEAR & COMPRESSIONAL WAVE ARRIVAL TIMES

Vs – First Break		Vs – First Peak		Vs – Max Peak		Vp – First Break	
Depth (m)	Arrival Time (ms)	Depth (m)	Arrival-Time (ms)	Depth (m)	Arrival Time (ms)	Depth (m)	Arrival Time (ms)
1.85	0.0172	1.85	0.0212	1.85	0.0399	1.85	0.0054
2.85	0.0282	2.85	0.0319	3.85	0.0621	2.85	0.0078
3.85	0.0347	3.85	0.0398	4.85	0.0683	3.85	0.0098
4.85	0.0407	4.85	0.0453	5.85	0.0753	4.85	0.0108
5.85	0.0471	5.85	0.0512	7.85	0.0826	5.85	0.0111
6.85	0.0517	6.85	0.0562	8.85	0.0877	6.85	0.0116
7.85	0.0584	7.85	0.0626	11.85	0.0982	7.85	0.0123
8.85	0.0643	8.85	0.0687	12.85	0.1006	8.85	0.0131
9.85	0.0697	9.85	0.0736	13.85	0.1035	9.85	0.0136
11.85	0.0828	10.85	0.0771	14.85	0.1086	10.85	0.0142
12.85	0.0842	12.85	0.0888	15.85	0.1109	11.85	0.0149
13.85	0.0872	13.85	0.092	16.85	0.112	12.85	0.0155
14.85	0.0913	14.85	0.096	17.85	0.1134	13.85	0.0161
15.85	0.092	16.85	0.097	19.85	0.1187	14.85	0.0165
16.85	0.0929	17.85	0.0985	20.85	0.1257	15.85	0.0172
17.85	0.0943	18.85	0.1023	21.85	0.1264	16.85	0.0179
18.85	0.0975	19.85	0.1094	22.85	0.1302	18.85	0.0182
20.85	0.1068	20.85	0.1113	23.85	0.1353	19.85	0.019
21.85	0.1082	21.85	0.113	24.85	0.1401	20.85	0.0194
22.85	0.1126	22.85	0.1178	25.85	0.1411	21.85	0.0198
23.85	0.1153	23.85	0.1221	26.85	0.1438	22.85	0.02
25.85	0.1239	25.85	0.1297	27.85	0.1489	23.85	0.0209
26.85	0.1271	26.85	0.1328	28.85	0.1523	24.85	0.0219
27.85	0.1304	27.85	0.1345	29.85	0.1559	25.85	0.0223
28.85	0.132	28.85	0.1389	30.85	0.1591	26.85	0.0228
30.85	0.1356	30.85	0.1424			27.85	0.0233
						28.85	0.0243
						29.85	0.0249