THURBER ENGINEERING LTD.

September 24, 2021 File No.: 29681

Baptist Housing
#125 – 6165 Highway 17A
Delta, BC V4K 5B8

Attention: Mr. Dayle Krahn, EDAC

GEOTECHNICAL DESIGN REPORT FOR INGLEWOOD CARE CAMPUS REDEVELOPMENT

Dear Dayle:

Thurber Engineering Ltd. (Thurber) has been retained by Baptist Housing to provide geotechnical engineering services for the proposed Inglewood Care Campus Redevelopment project located at Taylor Way and Inglewood Avenue in the District of West Vancouver, BC. We understand that the project is in the development permit stage and that Baptist Housing requires a geotechnical report as part of the submission. This report is a revision to our previously issued report dated April 15, 2021. The purpose of this revision is to include additional geophysical work that was completed on site.

This letter summarizes the anticipated subsurface conditions and provides our geotechnical recommendations based on the results of a thorough desktop study, geotechnical test hole investigation, and geophysical testing program. We understand that the project is being designed in accordance with the requirements of the 2018 British Columbia Building Code (BCBC).

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. PROJECT AND SITE DESCRIPTION

The project site is comprised of the existing Inglewood care campus with several existing care facility buildings and three residential properties that are occupied by existing houses and small structures. The overall project site is approximately rectangular in shape with dimensions of 180 m (north-south) by 110 m (east-west) and is bordered by Burley Drive to the west, Inglewood Avenue to the south, Taylor Way to the east, and the existing North Shore Jewish Community Centre to the north. We understand that the existing care facility buildings are generally at-grade with only small portions of the building footprint having a basement level. We further understand that the existing residential houses may have partially buried basement levels that are expected to be less than 1 m below grade.

The site topography is generally crowned in the middle of the site and slopes downward towards the north and south at a gradient of approximately 5% and an overall elevation change in the order of 3 m from the middle of the site to the north and south property lines. To the west of Burley Drive the topography slopes up at a gradient of approximately 25%. The existing Brothers Creek is located under the parking lot between the north property line and the Jewish Community Centre.

Thurber has been provided with architectural drawings that were prepared by ZGF Architects LLP (ZGF). The drawings indicate that the project involves the demolition of the existing multi-storey care facility structures and the three existing residential houses to facilitate construction of a new multi-tower care facility constructed over a common 1 to 2 level below-grade parking structure. We understand that the demolition and construction will be completed in the following two 2 phases:

- Phase 1 – demolition of the residential houses and construction of the western portion of the new facility. The lowest parking level for Phase 1 is currently designed at El. 67.5 m geodetic.

- Phase 2 – demolition of the existing care facility after the care facility operations, residents, and personnel are relocated into the Phase 1 building and construction of the rest of the new facility. The lowest parking level for Phase 2 is currently designed at El. 64.0 m. Construction of the lowest parking levels will require either a) underpinning of the Phase 1 parking level, or b) constructing the western Phase 2 foundation walls during construction of Phase 1.

2. SUBSURFACE CONDITIONS

2.1 Surficial Geology

Published surficial geology mapping (Geological Survey of Canada Map 1486A) indicates that the site is located near the border of the following two geological units:

- Capilano Sediments (Cc) consisting of raised deltaic and channel fill, medium sand to gravel up to 15 m thick deposited by proglacial streams and commonly underlain by silt to silty clay loam. In this location, we anticipate that very dense Vashon Drift deposits (glacial till-like) soils underlie the Capilano Sediments.

- Tertiary Bedrock (T) including sandstone, siltstone, shale, conglomerate, and minor volcanic rocks; where bedrock is not exposed it is covered by glacial deposits and colluvium.

2.2 Thurber Geotechnical Investigation

Thurber completed a geotechnical investigation on November 19, 2020 that consisted of 5 solid stem auger test holes labelled AH20-01 to AH20-05. The test holes were advanced to depths ranging from 5.1 m to 10.1 m below existing site grades. Standard Penetration Tests (SPT) were completed within each of the test holes. Thurber personnel were on site to log the subsurface soil and groundwater conditions and to collect disturbed soil samples for laboratory testing. The approximate locations of the test holes are shown on that attached Figure 1.

The results of the investigation, along with the laboratory test results, are presented on the attached test hole logs. These logs provide complete, detailed descriptions of the conditions encountered and should be used in preference to the generalized soil descriptions below.

The subsurface conditions generally consist of the following, which are presented with increasing depth:

- Fill: A surficial layer of fill consisting of asphalt/limestone underlain by variable sand, silty sand, sandy silt, silt, gravel, and some organics was encountered in each of the test holes. The fill ranged from about 0.2 m to 1.5 m thick.

- Silt: The fill material is underlain by 0.8 m to 1.9 m of firm to hard silt, which was observed in each of the test holes except for AH20-05. The natural water content of the silt ranged from approximately 20% to 40%.

- Sand: Compact to dense sand with some silt and gravel was encountered in each of the test holes. The thickness of this deposit ranged from about 0.8 m to 6.4 m and was thickest at AH20-01.

- Silty Sand / Sandy Silt (Till-Like): This deposit was observed in each of the test holes except in AH20-02 at the north-east corner of the site. Although not observed during the investigation, we anticipate that occasional cobbles and large boulders may be encountered within this deposit.

- Sandstone / Siltstone Bedrock: Weathered bedrock was encountered at each of the test holes at depths ranging from 4.0 m to 8.8 m below existing site grades, which corresponds to approximately El. 66.4 m to El. 73.7 m geodetic. The surface of the bedrock generally slopes downward from the northwest to the southeast. The bedrock in this vicinity is known to range from extremely weak (R0) to weak (R2) but may contain localized harder inclusions.

Perched groundwater was observed at various depths over the low-permeability silt and the till-like sandy silt / silty sand layers at each of the test holes except for AH20-05. We expect that the perched groundwater will be influenced by periods of significant rainfall and snowmelt. We do not expect that the regional groundwater level will be encountered at the depth of the proposed below-grade parking levels.

2.3 Geophysical Testing

Thurber coordinated the completion of two geophysical site investigation programs that were conducted by ConeTec Investigations Ltd. (ConeTec), which took place on February 6, 2021, and May 6, 2021. The geophysical site investigations consisted of a total of 9 Seismic Refraction Tomography (SRT) lines labelled SRT21-01 to SRT21-09 and 9 Horizontal to Vertical Spectral Ratio (HVSR) tests located around the site. In addition, the seismic data was also processed using the Multichannel Analysis of Surface Waves (MASW) technique to create a shear wave velocity profile at the east side of the site. The approximate locations of the SRT, HVSR, and MASW locations are shown on the attached Figure 1 and are further detailed on the attached ConeTec reports.

The primary purpose for completing the geophysical investigation was to evaluate the variation of the dense to very dense till-like soils / bedrock to assist with the architectural design layout of the below-grade levels such that the excavation / blasting of bedrock can be optimized. The geophysical investigation provides a 2-dimensional soil stiffness profile (either via compression wave velocity or shear wave velocity) with depth chart along the SRT lines and a 1-dimensional soil stiffness versus depth chart at the HVSR locations.

Based on the geophysical interpretation report provided by ConeTec, the depth to the very dense till-like soil / bedrock is generally consistent with the results of the geotechnical investigation. The geophysical interpretation indicates that the very dense till-like soil / bedrock generally slopes downward from about El. 73 m at the northwest corner of the site to about El. 70 m at the northeast and southwest corners of the site and drops off to about El. 63 m at the southeast corner of the site. The variation of the anticipated very dense till-like soil / bedrock surface is provided in the ConeTec report.

3. GEOTECHNICAL DISCUSSION AND RECOMMENDATIONS

Based on our understanding of the project and the anticipated subsurface conditions, we consider that the proposed development is feasible to be constructed on shallow strip and pad foundations on the very dense till-like deposits and/or the sandstone / siltstone bedrock.

We consider that the key geotechnical consideration for the project is the excavatability of the glacial till-like deposits due to the potential for large boulders and the rippability of the bedrock, which may require blasting. In addition, within the southeast portion of the site, the depth to the very dense till-like soil / bedrock may be below the base of the proposed parkade level which may require sub-excavation and replacement with lean mix concrete or high-quality crushed gravel structural fill to provide a consistent bearing surface.

The sections below provide our geotechnical design recommendations.

3.1 Seismic Site Classification and Liquefaction Assessment

Table 4.1.8.4.A of the 2018 BCBC provides guidelines for seismic site classification based on "average" shear wave velocity, SPT N_{60}-value, or undrained shear strength in the top 30 m soil profile. Based on the results of the geotechnical investigation and geophysical testing, and the expectation that proposed building will be constructed either on or within 3 m of the bedrock surface, we consider that the site should be classified as Site Class B as per the 2018 BCBC.

Table 1 provides the spectral accelerations for the baseline Site Class C that should be converted to Site Class B values by the Structural Engineer based on Tables 4.1.8.4-B through 4.1.8.4-I of the 2018 BCBC.

Table 1: Spectral Accelerations for Site Class C for 5% Damping and 2% / 50 Years Probability (2475 Year Return Period)

Sa (0.05)	Sa (0.1)	Sa (0.2)	Sa (0.3)	Sa (0.5)	Sa (1.0)	Sa (2.0)	Sa (5.0)	Sa (10.0)	PGA	PGV
(g)										(m/s)
0.429	0.651	0.805	0.806	0.712	0.404	0.247	0.079	0.028	0.350	0.525

Based on the inferred in situ density of the subsurface soil conditions and anticipated depth to groundwater, we consider that the site will not be susceptible to liquefaction during the 2018 BCBC 2475 Year Return Period design earthquake.

3.2 Site Preparation

Initial site preparation of the building areas should involve the demolition of the existing buildings (as per the construction Phases), removal of any asphalt, topsoil, poor-quality fill, and natural soils / bedrock down to the foundation level.

We anticipate that the base of the excavation will consist of either very dense glacial till-like soil or bedrock. We anticipate that cobbles and large boulders may be encountered during excavation, which may require splitting. Furthermore, the upper portion of the bedrock is expected to consist of rippable sandstone, however the bedrock is anticipated to become harder with depth and inclusions may also be encountered which would require drilling and/or blasting.

3.3 Excavation Shoring Requirements

Due to the depth of excavation required to construct the proposed building, and the expectation that construction lay-down areas will be required, and site access/egress is to be maintained during the phased development, vertical excavation shoring will be required. Given the subsurface conditions, we consider that the most appropriate excavation and shoring system should consist of a combination of temporary, unsupported side slopes (where feasible), conventional reinforced shotcrete with temporary tie-back anchors within overburden soils, and rock bolts within the harder bedrock.

Temporary side slopes should be no steeper than 1H:1V (Horizontal to Vertical) within fill materials and the undisturbed natural silt and sand soils. The temporary side slopes can be steepened to 0.75H:1V within glacial till-like soils. The exposed soils should be covered with polyethylene sheeting held down with weld wire mesh that is pinned to the top, middle, and bottom of the slope to provide protection from erosion due to rainfall and surface runoff.

Where glacial till-like soils are present, the excavation shoring will likely consist of approximately 100 mm thick shotcrete with reinforcing mesh / reinforcing steel and tie-back anchors with lengths of approximately 8 m to 12 m that are spaced in the order of 1.5 m vertically and 1.8 m horizontally. Where bedrock is encountered below the glacial till-like soils, the 100 mm thick shotcrete will have to overlap with the interface of the bedrock. Below this level, the lengths and spacing of the tieback anchors and the extent of the shotcrete can likely be reduced depending on the quality of the bedrock and the spacing/orientation of the rock discontinuities and jointing. If during field review the bedrock is found to be sufficiently strong, there is a potential the pattern spacing of the anchors could be eliminated and replaced with spot bolting of the rock where discontinuities, unfavourable joint sets, and significant seepage within the bedrock are encountered.

During Phase 1 of the excavation, the west side of the existing care facility will need to be underpinned. However, since the below-grade portion of Phase 2 is deeper than Phase 1, additional underpinning of the east side of Phase 1 will be required during the Phase 2 excavation. We strongly suggest that, if feasible, the below-grade foundations and foundation walls along the western side of Phase 2 be constructed during the Phase 1 construction works to reduce and/or eliminate the need for the additional underpinning.

The permanent building walls can be constructed tight to the excavation shoring; however, we note that unless special provisions are made to recess the temporary anchor heads, the structural engineer will have to allow for the anchor heads to embed into the permanent building walls, which may also affect the offset of the walls from the property lines.

With a robust shoring design constructed by a suitable contractor, we estimate that ground movements could be in the order of 20 mm to 25 mm. We recommend that pre-construction and post-construction surveys be completed to confirm the magnitude of the movements and to document any distress to nearby infrastructure caused by the excavation. In addition, ongoing survey monitoring of the excavation shoring will be required on an approximately weekly basis and slope inclinometers may need to be installed to monitor the performance of the excavation shoring system.

Baptist Housing will be required to obtain encroachment agreements with the neighbouring property owners (such as the District of West Vancouver) to allow for the temporary tie-back anchors. The agreements should also document how damage to existing infrastructure will be repaired.

3.4 Foundation Design

Provided that the site is prepared in accordance with our recommendations, conventional strip and spread footings can be designed using the Serviceability Limit State (SLS) bearing pressure and factored Ultimate Limit State (ULS) bearing resistance presented in Table 2.

Table 2: SLS Bearing Pressure and ULS Bearing Resistance

Foundation Soil	SLS Bearing Resistance* (kPa)	Factored ULS Bearing Resistance** (kPa)
Crushed Gravel Structural Fill over Bedrock	150	250
Very Dense Till-Like Soil	400	750
Bedrock or Lean Mix Concrete over Bedrock	1000	1000

* SLS Bearing Pressure based on limiting total post-construction settlement to 25 mm and differential settlement to 20 mm over a horizontal distance of 10 m.

** Geotechnical resistance factor of 0.5 used as per Canadian Foundation Engineering Manual, 2006

The SLS bearing pressure and ULS bearing resistances provided are based on strip footings with a maximum width of 3 m and spread footings with a maximum dimension of 5 m. If larger footing sizes are required, Thurber should be provided with the structural loads to provide updated recommendations.

Foundations should be designed with a minimum dimension of 600 mm for pad footings and 450 mm for strip footings. The foundations should also be buried at least 450 mm below finished grade for frost protection purposes.

The sliding of foundations can be resisted by friction at the interface between concrete and the foundation soils. A factored coefficient of friction of 0.35, based on a resistance factor of 0.5 as per the Canadian Foundation Engineering Manual, 2006, can be used for design.

3.5 Drainage and Backfill Considerations

The slab-on-grade should be underlain with an underslab drainage layer consisting of a minimum 150 mm thick layer of 19 mm clear crushed gravel to provide a capillary break and prevent water from contacting the slab-on-grade. In addition, perimeter and underslab drains should be placed at the foundation elevation of the building. The underslab drains should be installed at approximately 15 m horizontal centre-to-centre spacing. The perimeter and underslab drains should be comprised of minimum 100 mm diameter perforated PVC pipe that discharge into a suitable municipal drainage system. The perimeter drain should be surrounded with at least 150 mm of 19 mm clear crushed gravel that is either wrapped in filter cloth or covered with 150 mm of birds-eye gravel.

We note that hydraulic conductivity of the glacial till-like soil is expected to be very low and that the bedrock is expected to be impermeable except for jointing in the bedrock. As such, infiltration of water into the glacial till-like soil or bedrock should not be considered.

If the proposed buildings are constructed tight to the temporary excavation shoring walls, the perimeter drainage will need to be installed on the interior of the building. Therefore, to prevent the build-up of hydrostatic pressures on the exterior of the foundation walls, a drainage mat must be placed between the excavation shoring wall and the foundation wall and weep holes should be installed at approximately 1.5 m centre to centre spacing to hydraulically connect the drainage mat to the underslab drainage system.

The backfill required to achieve the finished grade elevation (likely required only if the foundation walls are not constructed tight to the excavation shoring walls) should consist of free-draining, well-graded, granular 75 mm minus sand and gravel that is placed and compacted to at least 98% of the material's Standard Proctor Maximum Dry Density (SPMDD). Backfilling of walls (if required) should not occur until walls are adequately braced (e.g. suspended slab constructed or internal wall bracing placed).

The finished grade around the building should be sloped such that surface runoff is carried away from the building. In addition, where possible, the surface treatment adjacent to the building should consist of impermeable materials such as concrete sidewalks or asphalt to reduce the potential for infiltration of runoff into the perimeter drainage system.

The purpose of the drainage and backfill provisions is to prevent the build-up of hydrostatic pressures against the underside of the slab-on-grade and foundation walls. The requirement for water-proofing and/or damp-proofing are the responsibility of the Architect or Building Envelope consultant.

3.6 Lateral Pressures against Foundation Walls

Lateral earth pressures against the below-grade foundation walls under static and seismic conditions will be dependent of the actual the soil / bedrock depths encountered. We have completed our analyses based on the conservative assumption that bedrock is below the base of the excavation. If, during demolition of the existing buildings, the depth to the bedrock surface is confirmed, and if significant cost savings can be realized, we can provide revised lateral pressures for the structural design.

The magnitude of the lateral pressures depends on whether the foundation walls are "yielding" or "non-yielding". "Yielding" walls are defined as walls that are able to rotate at least 0.005H, and "non-yielding" walls are defined as walls that are unable to rotate at least 0.005H, where H is the overall height of the wall. The attached Figure 2 and Figure 3 provide lateral earth pressures for "yielding" and "non-yielding" walls, respectively. The structural engineer should determine if the foundation walls are "yielding" or "non-yielding" and use the appropriate figure for the design.

3.7 Asphalt Pavement Design

We expect that asphalt pavement will be required for drive aisles, and that these areas will be accessed by larger vehicles, such as fire, garbage, and loading trucks. Given these loading conditions, we recommend that the following asphalt pavement design be used:

- Minimum 85 mm of asphalt pavement placed in two lifts. The asphalt can be reduced to 65 mm only if utilized by lightly loaded passenger vehicles, over;
- Minimum 225 mm thick layer of 19 mm minus Crushed Granular Base, as defined by the Master Municipal Construction Documents (MMCD) compacted to at least 95% of the material's Modified Proctor Maximum Dry Density (MPMDD), over;
- Minimum 300 mm thick layer of Select Granular Subbase, as defined by the MMCD, compacted to at least 95% MPMDD, over;
- Competent subgrade consisting of 75 mm minus crushed gravel structural fill, very dense till-like soil, or bedrock.

Thurber should be contacted to review the exposed subgrade surface prior to fill placement as well as to complete compaction testing of the subbase and road base materials.

4. ADDITIONAL GEOTECHNICAL WORK

4.1 Excavation Shoring Design

Thurber should be provided with the architectural, structural, and civil design drawings after the development permit is approved by the District of West Vancouver. We will complete the required engineering analyses and prepare the excavation shoring design drawings based on the location and depth of the required excavation to provide temporary support during construction. We expect that the excavation shoring will consist of a combination of temporary side slopes, conventional shotcrete and anchors, and rock bolts.

4.2 Geotechnical Field Review During Construction

Thurber should be contacted to complete geotechnical field review during construction to verify that the subsurface soil and groundwater conditions are consistent with our design assumptions and that the intent of our recommendations is being followed. Geotechnical field review, including those outlined below, are required to fulfil the obligations specified in the Letters of Assurance, which are required by the District of West Vancouver for occupancy permitting.

Thurber should be contacted to review the following:

- Review site stripping and subsurface conditions after demolition of the existing buildings to verify the depth and quality of the anticipated sandstone bedrock;

- Review the installation of the temporary excavation shoring elements, including proof and performance testing of the temporary tie-back anchors and rock bolts;
- Review foundation preparation prior to placing rebar and pouring concrete;
- Review underslab and perimeter backfill materials prior to placement; and
- Complete compaction testing of backfill materials, including asphalt pavement section.

5. CLOSURE

We trust this information meets your present needs. If you have any questions, please contact the undersigned at your convenience.

Yours truly,
Thurber Engineering Ltd.

Paul Wilson, M.Eng., P.Eng.
Review Engineer

PROFESSIONAL
PROVINCE OF
C. D. S. TENCH
34664
BRITISH COLUMBIA
ENGINEER

Sept 24, 2021

Conrad Tench, P.Eng.
Senior Geotechnical Engineer

Attachments
- Statement of Limitations and Conditions
- Figure 1: Site Location Plan
- Figure 2: Lateral Earth Pressures for Yielding Walls
- Figure 3: Lateral Earth Pressure for Non-Yielding Walls
- Test Hole Logs (5)
- ConeTec Investigations Ltd.: “Presentation of Site Investigation Results, Taylor Way, West Vancouver Geophysical Report” dated February 17, 2021
- ConeTec Investigations Ltd.: “Presentation of Site Investigation Results, Taylor Way, West Vancouver Geophysical Report” dated May 19, 2021

STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

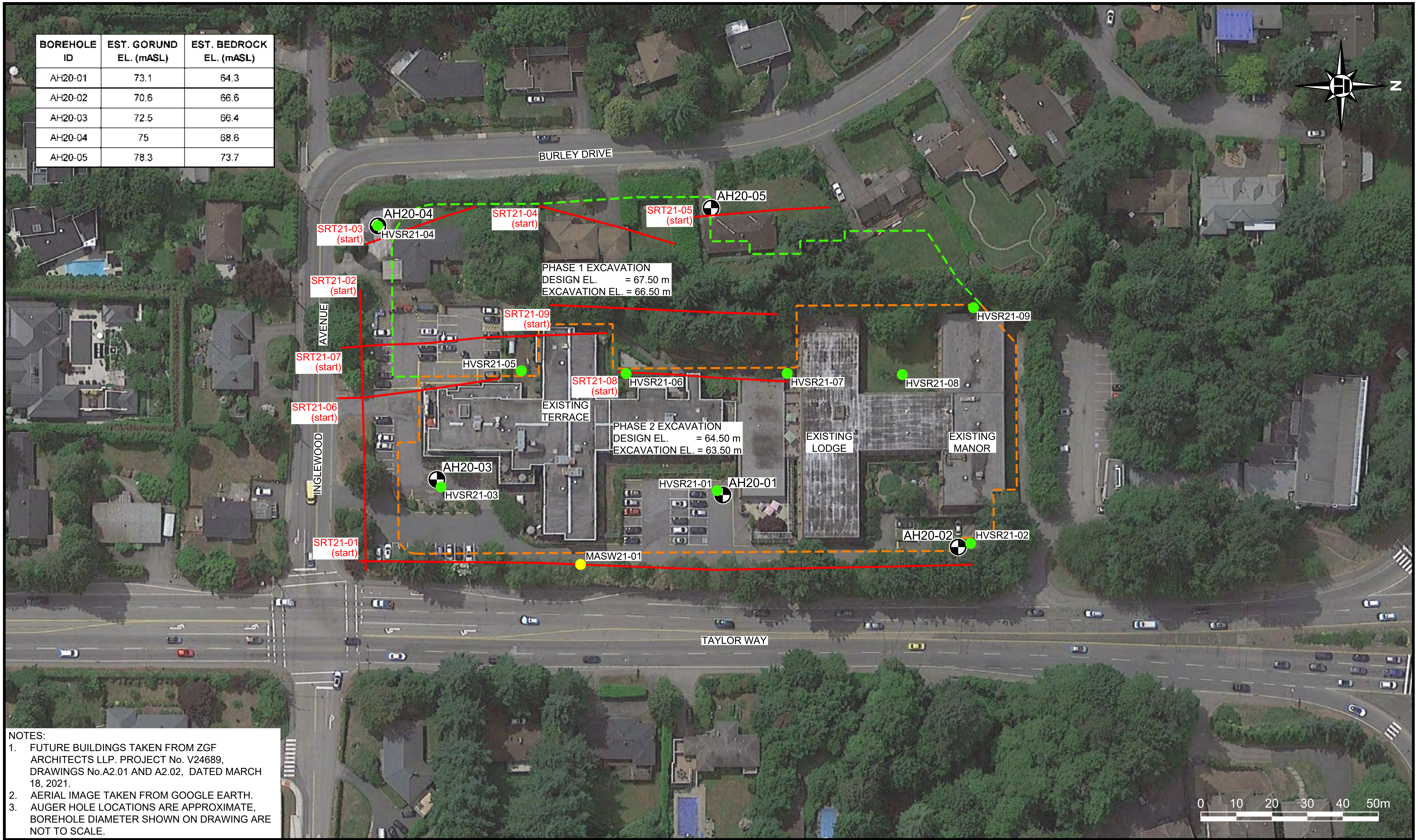
6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

BOREHOLE ID	EST. GORUND EL. (mASL)	EST. BEDROCK EL. (mASL)
AH20-01	73.1	64.3
AH20-02	70.6	66.6
AH20-03	72.5	66.4
AH20-04	75	68.6
AH20-05	78.3	73.7



NOTES:
1. FUTURE BUILDINGS TAKEN FROM ZGF ARCHITECTS LLP. PROJECT No. V24689, DRAWINGS No.A2.01 AND A2.02, DATED MARCH 18, 2021.
2. AERIAL IMAGE TAKEN FROM GOOGLE EARTH.
3. AUGER HOLE LOCATIONS ARE APPROXIMATE, BOREHOLE DIAMETER SHOWN ON DRAWING ARE NOT TO SCALE.

LEGEND:

◐ AUGER HOLE
● HVSR LOCATION
● MASW LOCATION
▭ PROPOSED PHASE 1 EXCAVATION
▭ PROPOSED PHASE 2 EXCAVATION
— GEOPHYSICAL LINE

THURBER ENGINEERING LTD.

CLIENT
BAPTIST HOUSING

SITE LOCATION PLAN

INGLEWOOD CARE CAMPUS REDEVELOPMENT WEST VANCOUVER, BC

DESIGNED	DRAWN	APPROVED
JM	MOM/RRS	

DATE	SCALE
SEPT. 23, 2021	1:1000

PROJECT No.	FIGURE No.	REV.
29681	1	0

CANCEL PRINTS BEARING EARLIER NUMBER

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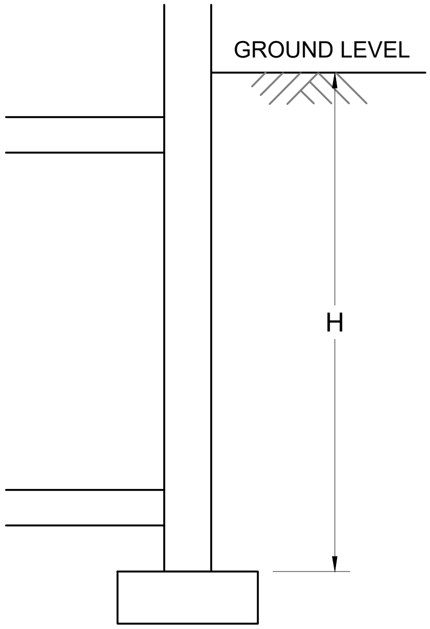
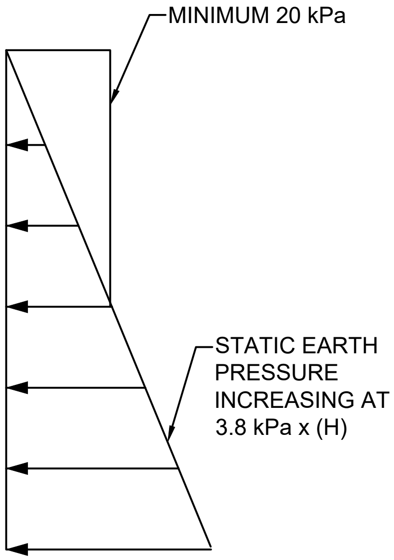
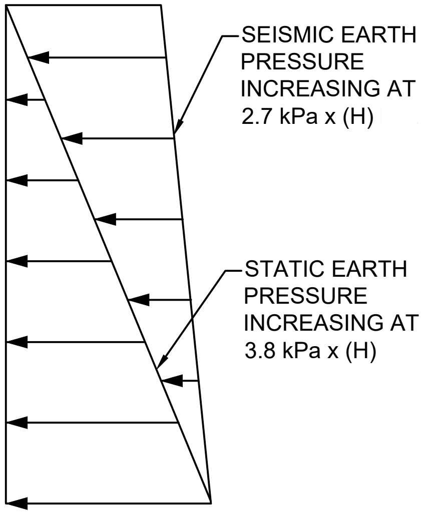


TYPICAL FOUNDATION WALL



STATIC EARTH PRESSURE



SEISMIC AND STATIC
EARTH PRESSURES

NOTES:

1. ALL METRIC UNITS ARE (m) AND (kPa).
2. THE PRESSURES GIVE IN THIS DIAGRAM ARE UNFACTORED.
3. APPLICABLE ONLY IF THE BASEMENT WALL IS COMPLETELY ABOVE WATER TABLE.
4. PRESSURES SHOW ARE SUITABLE FOR BASEMENT WALLS AND RETAINING WALLS ABLE TO ROTATE AT LEAST 0.005H

THURBER ENGINEERING LTD.

CLIENT
BAPTIST HOUSING

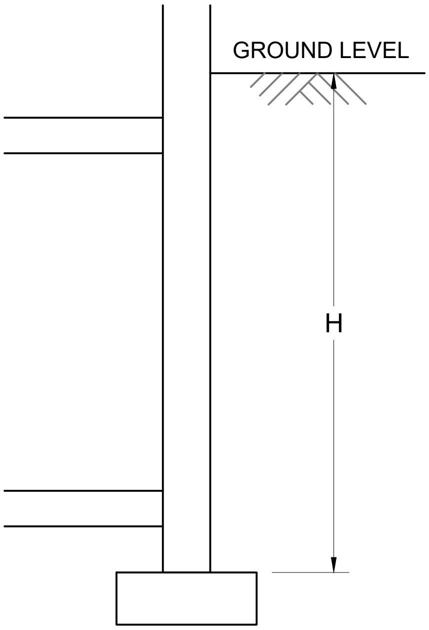
LATERAL EARTH PRESSURE
FOR YIELDING WALLS

INGLEWOOD CARE
CAMPUS REDEVELOPMENT
WEST VANCOUVER, BC

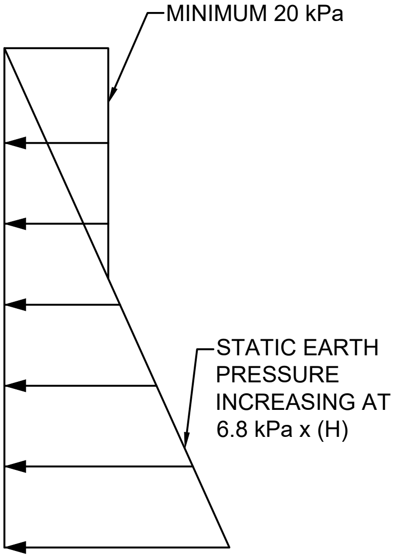
DESIGNED	DRAWN	APPROVED
CDT	MOM	

DATE	SCALE
APRIL 14, 2021	N.T.S.

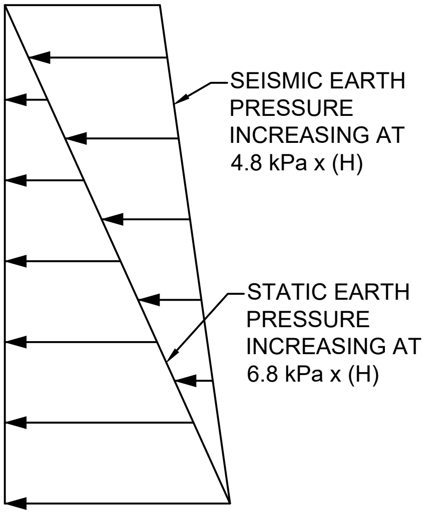
PROJECT No.	FIG. No.	REV.
29681	2	0



TYPICAL FOUNDATION WALL



STATIC EARTH PRESSURE



SEISMIC AND STATIC EARTH PRESSURES

NOTES:

1. ALL METRIC UNITS ARE (m) AND (kPa).
2. THE PRESSURES GIVE IN THIS DIAGRAM ARE UNFACTORED.
3. APPLICABLE ONLY IF THE BASEMENT WALL IS COMPLETELY ABOVE WATER TABLE.
4. PRESSURES SHOW ARE SUITABLE FOR BASEMENT WALLS AND RETAINING WALLS ABLE TO ROTATE AT LEAST 0.005H

THURBER ENGINEERING LTD.

CLIENT
BAPTIST HOUSING

LATERAL EARTH PRESSURE
FOR NON - YIELDING WALLS

INGLEWOOD CARE
CAMPUS REDEVELOPMENT
WEST VANCOUVER, BC

DESIGNED: CDT
DRAWN: MOM
APPROVED:
DATE: APRIL 14, 2021
SCALE: N.T.S.
PROJECT No.: 29681
FIG. No.: 3
REV.: 0

Sheet 1 of 2

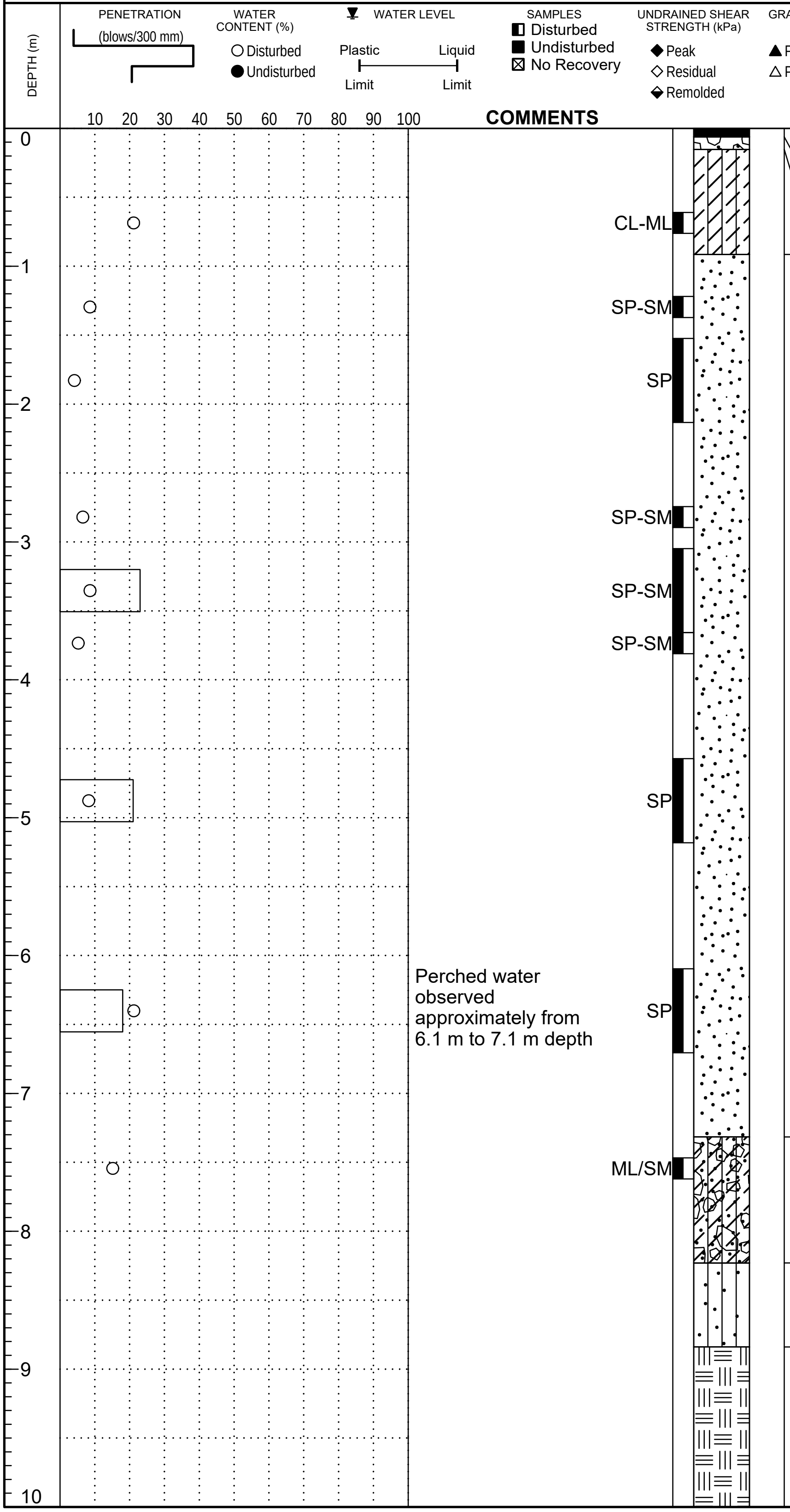
LOG OF TEST HOLE

TEST HOHOLE NO.
AH20-01

LOCATION: N 5464763, E 490165 (Est.)

TOP OF HOLE ELEV: 73.1 m (Est.)
METHOD: Solid Stem Auger
DRILLING CO.: Southland Drilling Co. Ltd.
INSPECTOR: RIG/JM

CLIENT: Baptist Housing
PROJECT: Inglewood Care Campus Redevelopment
DATE: November 19, 2020
FILE NO.: 29681
REVIEWED BY: CDT



Perched water observed approximately from 6.1 m to 7.1 m depth

SOILS DESCRIPTION

ASPHALT (63 mm thick).

Brown-grey GRAVEL (ROADBASE).

Hard, grey-brown, moist, clayey SILT.
- mottled grey-brown silt between 0.2 and 0.3 m depth

Compact, grey-brown to grey, moist SAND with a trace to some silt and a trace of gravel.

- a trace of cobbles at 5.5 m depth

Dense, brown, moist, sandy SILT to silty SAND with some gravel and clay (TILL-like).

Compact, brown, moist, sandy SILT.

Dense to very dense, grey, weathered SILTSTONE / SANDSTONE.

ELEVATION (m): 73, 72, 71, 70, 69, 68, 67, 66, 65, 64

LOG OF TEST HOLE (COORDS + EL. EST.) 29681.GPJ THURBER_MOM.GDT 18/2/21- THURBER MOM.GLB

Sheet 2 of 2

LOG OF TEST HOLE

TEST HOLE NO. **AH20-01**

LOCATION: N 5464763, E 490165 (Est.)

TOP OF HOLE ELEV: 73.1 m (Est.)

METHOD: Solid Stem Auger

DRILLING CO.: Southland Drilling Co. Ltd.

INSPECTOR: RIG/JM

CLIENT: Baptist Housing

PROJECT: Inglewood Care Campus Redevelopment

DATE: November 19, 2020

FILE NO.: 29681

REVIEWED BY: CDT

DEPTH (m)

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed

Plastic Limit ├──┤ Liquid Limit

WATER LEVEL

SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
⬖ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✖ GASTECH reading
✕ PID reading

ELEVATION (m)

10 20 30 40 50 60 70 80 90 100

COMMENTS

SOILS DESCRIPTION

End of hole at required depth.
Hole open to 8.5 m depth.
Borehole backfilled in accordance with BC Reg. 39/2016.

DEPTH (m): 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

ELEVATION (m): 63, 62, 61, 60, 59, 58, 57, 56, 55, 54

Sheet 1 of 1

LOG OF TEST HOLE

TEST HOLE NO. **AH20-02**

LOCATION: N 5464830, E 490174 (Est.)

TOP OF HOLE ELEV: 70.6 m (Est.)

METHOD: Solid Stem Auger

DRILLING CO.: Southland Drilling Co. Ltd.

INSPECTOR: RIG/JM

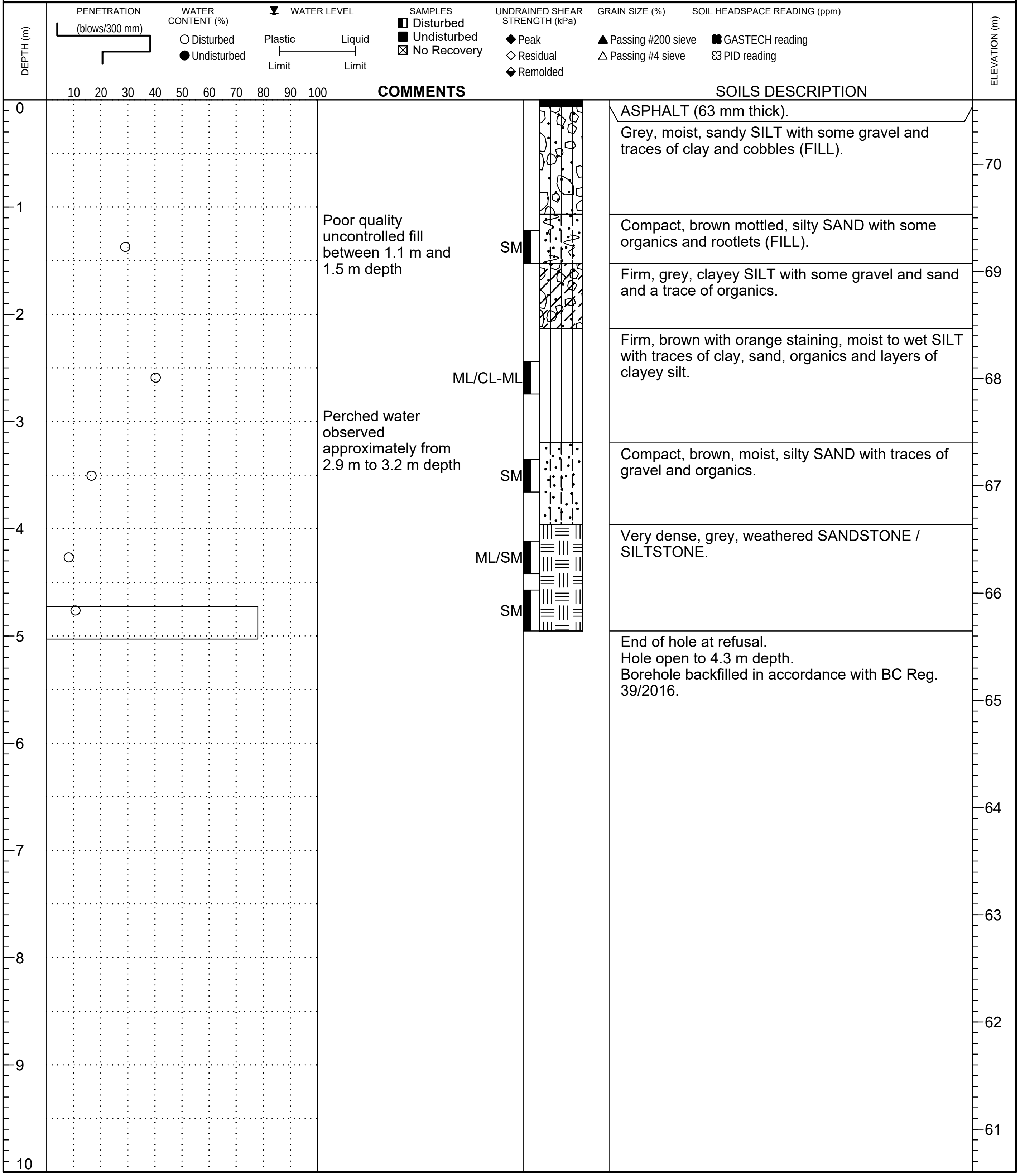
CLIENT: Baptist Housing

PROJECT: Inglewood Care Campus Redevelopment

DATE: November 19, 2020

FILE NO.: 29681

REVIEWED BY: CDT



COMMENTS

Poor quality uncontrolled fill between 1.1 m and 1.5 m depth

Perched water observed approximately from 2.9 m to 3.2 m depth

SOILS DESCRIPTION

ASPHALT (63 mm thick).

Grey, moist, sandy SILT with some gravel and traces of clay and cobbles (FILL).

Compact, brown mottled, silty SAND with some organics and rootlets (FILL).

Firm, grey, clayey SILT with some gravel and sand and a trace of organics.

Firm, brown with orange staining, moist to wet SILT with traces of clay, sand, organics and layers of clayey silt.

Compact, brown, moist, silty SAND with traces of gravel and organics.

Very dense, grey, weathered SANDSTONE / SILTSTONE.

End of hole at refusal.
Hole open to 4.3 m depth.
Borehole backfilled in accordance with BC Reg. 39/2016.

Sheet 1 of 1

LOG OF TEST HOLE

TEST HOLE NO. **AH20-03**

LOCATION: N 5464682, E 490157 (Est.)

TOP OF HOLE ELEV: 72.5 m (Est.)

METHOD: Solid Stem Auger

DRILLING CO.: Southland Drilling Co. Ltd.

INSPECTOR: RIG/JM

CLIENT: Baptist Housing

PROJECT: Inglewood Care Campus Redevelopment

DATE: November 19, 2020

FILE NO.: 29681

REVIEWED BY: CDT

PENETRATION (blows/300 mm)

WATER CONTENT (%): ○ Disturbed ● Undisturbed; Plastic Limit ⊢—⊣ Liquid Limit

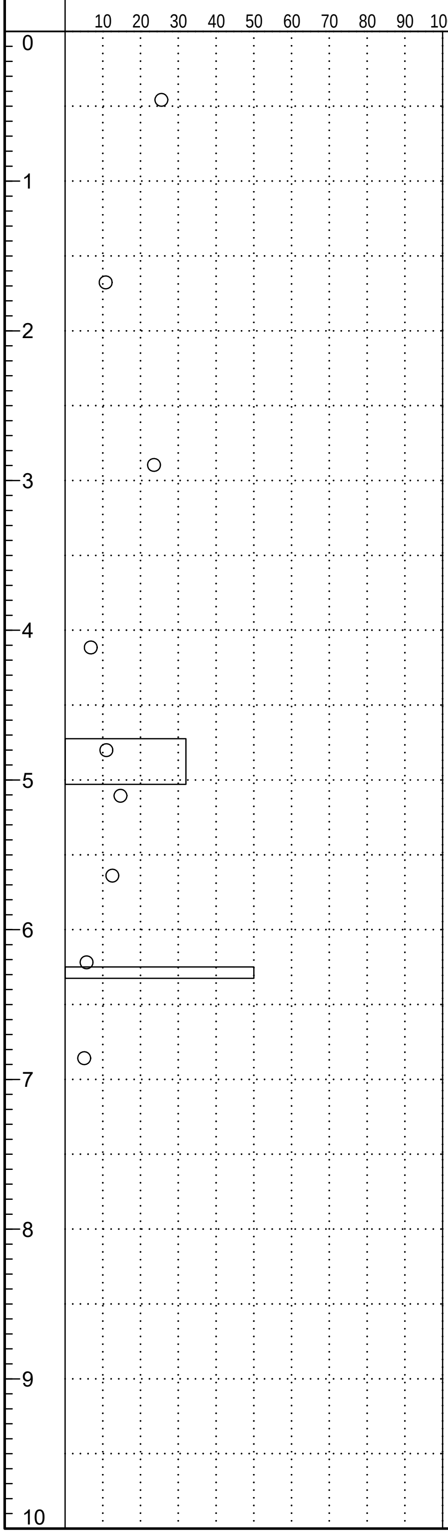
WATER LEVEL

SAMPLES: ◧ Disturbed ■ Undisturbed ☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa): ◆ Peak ◇ Residual ◆ Remolded

GRAIN SIZE (%): ▲ Passing #200 sieve △ Passing #4 sieve

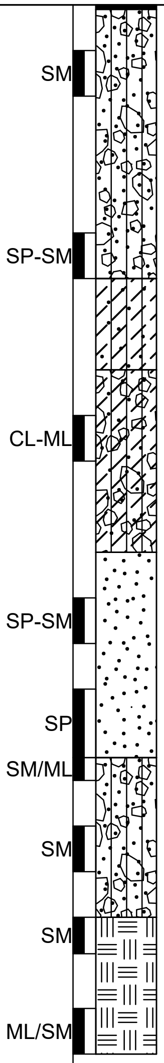
SOIL HEADSPACE READING (ppm): ✖ GASTECH reading ⌘ PID reading



COMMENTS

Poor quality uncontrolled fill between 0.1 m and 1.1 m depth

Perched water observed approximately from 4.9 m to 5.0 m depth



SOILS DESCRIPTION

ASPHALT (50 mm thick).

Compact, dark brown, moist, silty SAND to sandy SILT with some gravel and traces of organics and wood fibre (FILL).

- brown to orange, silty SAND below 1.1 m depth

- 300 mm thick layer of gravelly SAND at 1.5 m depth

Compact, brown, moist SILT with some clay and sand and a trace of gravel.

Hard, brown, clayey SILT with some sand and gravel.

- 300 mm thick layer of grey, sandy SILT at 3.4 m depth

Dense, grey-brown, moist to wet SAND with a trace to some gravel and a trace of silt.

Dense, brown to brown-grey, moist, sandy SILT to silty SAND with some gravel (TILL-like).

Very dense, grey, weathered SILTSTONE / SANDSTONE.

End of upon auger refusal.
Hole open to 5.2 m depth.
Borehole backfilled in accordance with BC Reg. 39/2016.

ELEVATION (m): 72, 71, 70, 69, 68, 67, 66, 65, 64, 63

Sheet 1 of 1

LOG OF TEST HOLE

TEST HOHOLE NO.
AH20-04

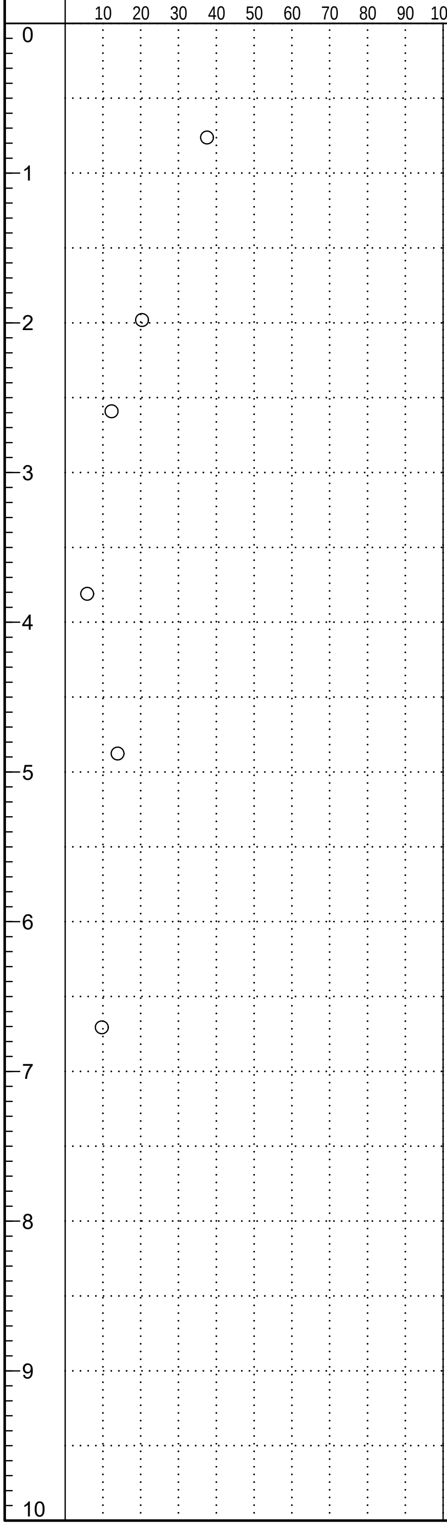
LOCATION: N 5464662, E 490086 (Est.)

TOP OF HOLE ELEV: 75.0 m (Est.)
METHOD: Solid Stem Auger
DRILLING CO.: Southland Drilling Co. Ltd.
INSPECTOR: RIG/JM

CLIENT: Baptist Housing
PROJECT: Inglewood Care Campus Redevelopment

DATE: November 19, 2020
FILE NO.: 29681
REVIEWED BY: CDT

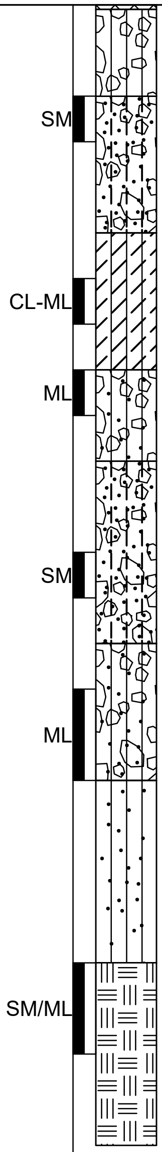
PENETRATION (blows/300 mm)
WATER CONTENT (%) ○ Disturbed ● Undisturbed
Plastic Limit ├──┤ Liquid Limit
WATER LEVEL
SAMPLES ◧ Disturbed ■ Undisturbed ☒ No Recovery
UNDRAINED SHEAR STRENGTH (kPa) ◆ Peak ◇ Residual ⬖ Remolded
GRAIN SIZE (%) ▲ Passing #200 sieve △ Passing #4 sieve
SOIL HEADSPACE READING (ppm) GASTECH reading PID reading



COMMENTS

Poor quality uncontrolled fill between 0.1 m and 0.6 m depth

Perched water observed approximately from 0.9 m to 1.2 m and from 1.4 m to 1.5 m depth



SOILS DESCRIPTION

Limestone fill.

Dark brown, moist SILT with some organics and gravel (FILL).

Compact, orange-brown, moist, silty SAND with some gravel and a trace of organics (FILL).

- 300 mm thick SAND layer at 1.2 m depth

Very stiff, grey-brown, clayey SILT with a trace of gravel.

Compact to dense, grey-brown, moist, sandy SILT with some gravel and a trace of clay.

Compact to dense, grey-brown, moist SAND with some silt and gravel.

Dense, brown to grey-brown, moist, sandy SILT with some gravel and a trace of clay (TILL-like).

Dense, grey-brown, moist, sandy SILT with a trace of gravel.

Very dense, weathered SILTSTONE / SANDSTONE.

End of hole at required depth.
Hole open to 5.5 m depth.
Borehole backfilled in accordance with BC Reg. 39/2016.

ELEVATION (m)
74
73
72
71
70
69
68
67
66

Sheet 1 of 1

LOG OF TEST HOLE

TEST HOLE NO.
AH20-05

LOCATION: N 5464755, E 490079 (Est.)

TOP OF HOLE ELEV: 78.3 m (Est.)
METHOD: Solid Stem Auger
DRILLING CO.: Southland Drilling Co. Ltd.
INSPECTOR: RIG/JM

CLIENT: Baptist Housing
PROJECT: Inglewood Care Campus Redevelopment

DATE: November 19, 2020
FILE NO.: 29681
REVIEWED BY: CDT

DEPTH (m)

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed
Plastic Limit
Liquid Limit

WATER LEVEL

SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
⬖ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

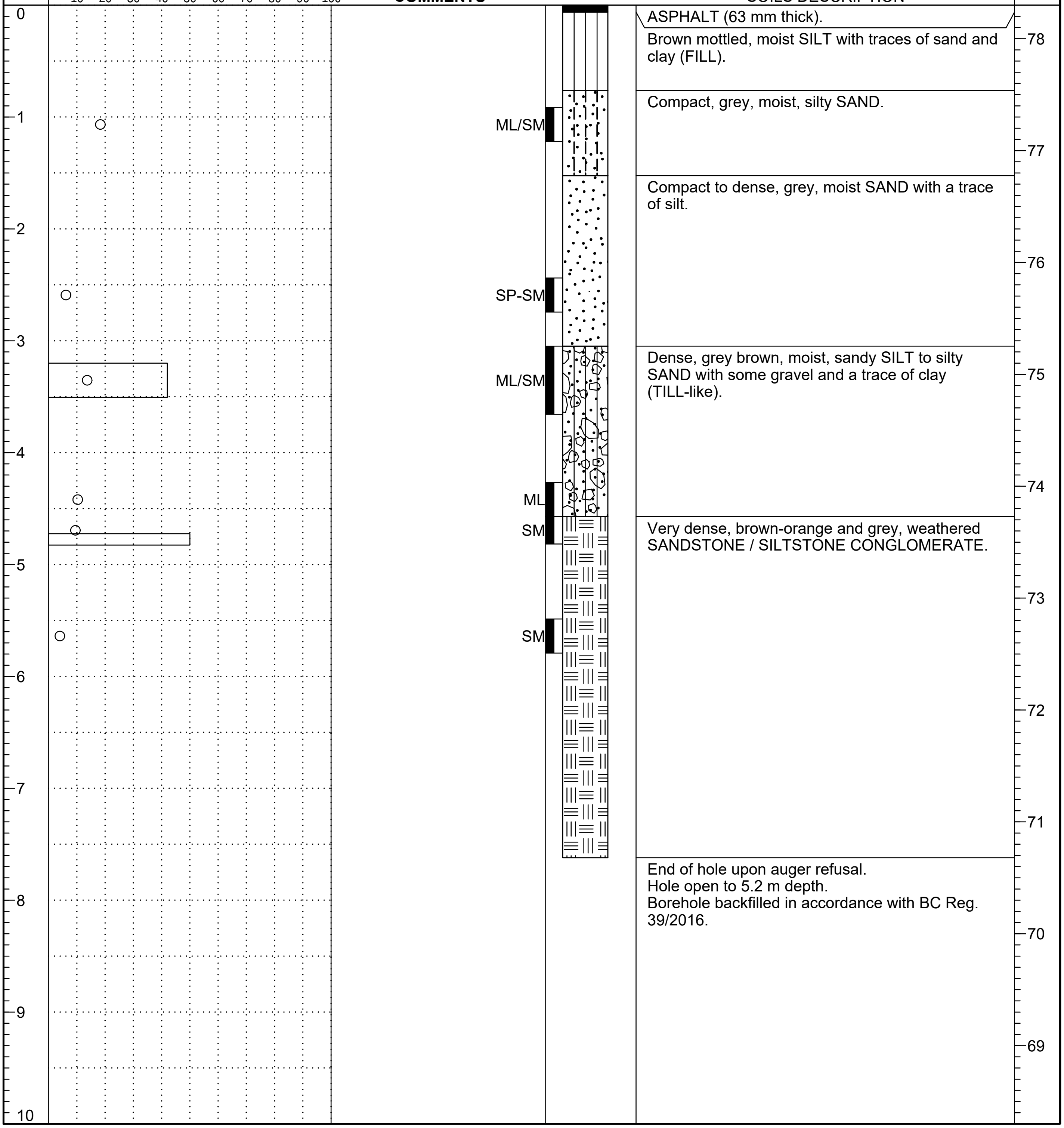
SOIL HEADSPACE READING (ppm)
✖ GASTECH reading
✕ PID reading

ELEVATION (m)

10 20 30 40 50 60 70 80 90 100

COMMENTS

SOILS DESCRIPTION



ASPHALT (63 mm thick).

Brown mottled, moist SILT with traces of sand and clay (FILL).

Compact, grey, moist, silty SAND.

Compact to dense, grey, moist SAND with a trace of silt.

Dense, grey brown, moist, sandy SILT to silty SAND with some gravel and a trace of clay (TILL-like).

Very dense, brown-orange and grey, weathered SANDSTONE / SILTSTONE CONGLOMERATE.

End of hole upon auger refusal.
Hole open to 5.2 m depth.
Borehole backfilled in accordance with BC Reg. 39/2016.

LOG OF TEST HOLE (COORDS + EL. EST.) 29681.GPJ THURBER_MOM.GDT 18/2/21- THURBER MOM.GLB

PRESENTATION OF SITE INVESTIGATION RESULTS

Taylor Way, West Vancouver Geophysical Report

Prepared for:

Thurber Engineering Ltd.

ConeTec Job No: 21-02-21901

Project Start Date: 06-Feb-2021
Project End Date: 06-Feb-2021
Report Date: 17-Feb-2021

Prepared by:

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Introduction

The enclosed report presents the results of the geophysical site investigation program conducted by ConeTec Investigations Ltd. for Thurber Engineering Ltd. at the Taylor Way, West Vancouver Project. The program consisted of 5 Seismic Refraction Tomography (SRT) tests around the perimeter of the property, as well as 4 Horizontal to Vertical Spectral Ratio (HVSR) tests incident with previously drilled boreholes. The purpose of the investigation was to determine depth to bedrock around the site. The seismic data was also processed using the Multichannel Analysis of Surface Waves (MASW) technique to create a shear wave velocity profile (Vs) for the purpose of calculating a Vs30 for the site.

Project Information

Project	
Client	Thurber Engineering Ltd.
Project	Taylor Way, West Vancouver
ConeTec project number	21-02-21901

Coordinates		
Test Type	Collection Method	EPSG Number
SRT, MASW, HVSR	RTK as-built survey and estimates from site measurements	32610

Acquisition Procedure

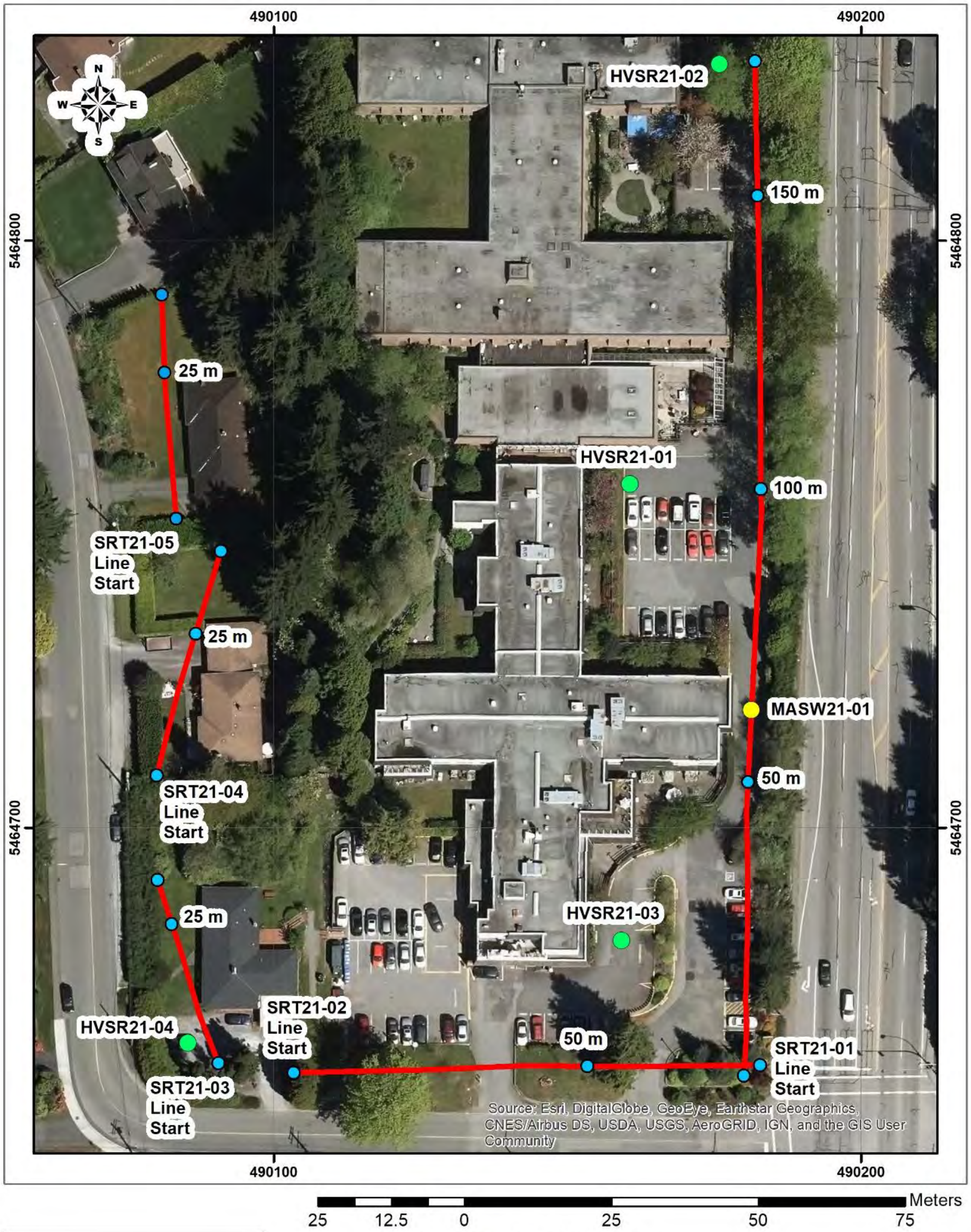
The SRT dataset were acquired using the equipment outlined in the table below. A static receiver array was used for each profile. Each array consisted of up to 48 channels, where geophones were placed every 1-2 m along the survey lines. A sledgehammer was used as a seismic source. The first reading was gathered at the 0 m station and then data was recorded every 3-6 m through each profile. Each source location had a minimum of 3 shots collected and stacked to produce the seismic record.

HVSR data was collected by placing the 3-component seismograph flat on the ground next to an adjacent borehole. A 15 minute reading was taken while the instrument was protected from rain and traffic.

Equipment Used for MASW and SRT Testing on this Project				
Seismograph(s)	Geophones	Coupling Mechanism	Trigger Style	Seismic Sources
2 x Geometrics Geode 24	48 x Geospace 4.5 Hz vertical	Aluminium pucks	Piezoelectric trigger	10 lb sledgehammer with aluminium plate

Equipment Used for HVSR Testing on this Project			
Seismograph	Coupling Mechanism	Trigger Style	Seismic Sources
Tromino 3-Component Seismograph	Flat base	Timed trigger	Passive Sources

Thurber Engineering Ltd. - Taylor Way



Legend

- ▬ SRT21-01
- ▬ SRT21-02
- ▬ SRT21-03
- ▬ SRT21-04
- ▬ SRT21-05
- ● MASW21-01
- ● HVSR Locations

ConeTec Job Number: 21-02-21901
Survey Date: 06/02/2021
Unit: meters
Map Scale 1:850
Coordinate System: NAD 1983 CSRS UTM Zone 10N
Projection: Transverse Mercator
Vertical Datum: CGVD28 HT_2.0

CONETEC

Data Analysis and Quality

The SRT data quality for this project was good throughout but got better the further away the readings were taken from Taylor Way. Heavy traffic was the main source of noise but was mitigated by timing the readings with pauses in traffic and by taking multiple stacks to improve the signal to noise ratio. Post processing techniques were also used to improve the signal quality. Example time domain traces and first break picks are included in the appendices of this report.

A 1D MASW plot was created from the SRT21-01 data in order to calculate Vs30. The longest array possible was used to support the deepest possible depth of investigation. This positioned the reading over a relatively deep section of sediment which improved data quality but produced a lower Vs30 calculation than other locations would. Example Coherent surface wave energy in the 18 – 40 Hz band allowed the determination of a 1D Vs model to 22 meters deep. An estimate of Vs30 was made assuming the material between 22-30 m has equal shear wave velocity as the material immediately above it. Overtone images and time domain traces are included in the appendices of this report.

The HVSR data quality collected on this project was very good. The 3 readings taken on the pavement of the property showed definitive H/V peaks while the fourth reading on the driveway of a nearby home was inconclusive. The main source of noise was due to nearby heavy traffic, but this was mitigated by taking 15-minute readings, allowing noisy sections to be removed from the processed data set.

Results

Inverted compression wave velocity (Vp) test results are included in the appendices of this report. SRT pdf profiles and csv data files are included in the release of this report. SRT21-01 - 02 were grouped into profiles with common horizontal and vertical scales to aid comparison. SRT21-03 - 05 used different scaling to better present the data.

A refractor was clearly seen in every section and the top of bedrock was estimated to have a compression wave velocity of 1500 m/s, consistent with weathered rock. A 2-layer starting model was used to invert the SRT data assuming constant overburden and bedrock velocities. The compression wave velocity ranged from 300-4000 m/s and the depth of investigation ranged up to approximately 15 m. A dashed purple line denotes interpreted bedrock on the SRT profiles. A discontinuity on SRT21-01 was noticed around 90 m along the line. A sharp change in the depth of the bedrock resulted in contrasting depths of investigation between each half of the line. The shallow depth of investigation on the latter half of the line is caused by near surface bedrock. The seismic signal travels faster and stays in the ground for much less time resulting in a diminished depth of investigation.

Inverted shear wave velocity (Vs) test results and a Vs30 calculation table are included in the appendices of this report. MASW pdf profiles and csv data files are included in the release of this report. The processed dispersion curve showed a coherent signal ranging from 18-40 Hz. Shear wave velocity ranged from 250 - 1400 m/s and the depth of investigation was about 22 m.

The depth to bedrock information garnered from nearby boreholes were used as an input for proximal HVSR locations. The depth input for each curve was used to generate a synthetic H/V curve. The model parameters were then adjusted to fit the synthetic curve to the measured curve. Using this technique, an estimate of bulk Vs could be generated. Future HVSR locations on this site can use this bulk Vs to estimate depth to bedrock at difficult to access locations. Unfortunately, HVSR21-04 could not be interpreted because the peak was unreliable. The estimated bulk Vs was 260 m/s. Measured resonant frequencies ranged from 7-12 Hz. The HVSR summary and quality reports are included in the appendices of this report.

Closure

Thank you for the opportunity to work on this project. The equipment used and the field procedures followed complied with current accepted practice standards. This report has been prepared under my supervision and I have reviewed and approved the content.

ConeTec Investigations Ltd.

I. A. WEEMEES

18-Feb-2021

Ilmar Weemees, P. Eng.

M. S. K. KOOTCHIN
45293

2021-Feb-18
Matvei Kootchin, P. Geo.

Limitations

3rd Party Disclaimer

This report titled “Taylor Way, West Vancouver”, referred to as the (“Report”), was prepared by ConeTec for Thurber Engineering Ltd. The Report is confidential and may not be distributed to or relied upon by any third parties without the express written consent of ConeTec. Any third parties gaining access to the Report do not acquire any rights as a result of such access. Any use which a third party makes of the Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. ConeTec accepts no responsibility for loss, damage and/or expense, if any, suffered by any third parties as a result of decisions made, or actions taken or not taken, which are in any way based on, or related to, the Report or any portion(s) thereof.

Client Disclaimer

ConeTec was retained by Thurber Engineering Ltd. to collect Seismic Refraction data to provide depth to bedrock measurements, MASW to provide Vs30 and HVSR to provide resonant frequency measurements (“Data”) which is included in this report titled “Taylor Way, West Vancouver”, which is referred to as the (“Report”). ConeTec has collected and reported the Data in accordance with current industry standards. No other warranty, express or implied, with respect to the Data is made by ConeTec. In order to properly understand the Data included in the Report, reference must be made to the documents accompanying and other sources referenced in the Report in their entirety. Other than the Data, the contents of the Report should not be relied upon in any fashion without independent verification and ConeTec is in no way responsible for any loss, damage or expense resulting from the use of, and/or reliance on, such material by any party.

The seismic refraction method is a non-intrusive test that utilizes seismic wave propagation to image the subsurface. The geophysical property that is measured in seismic refraction is seismic velocity, usually the compressional wave (P-wave) velocity. P-waves propagate at the highest velocity of any seismic waves and are therefore commonly used to pick the first breaks of waves that propagate through earth materials. The first break picks (Figure 1) can be used with travel time equations to determine the depth to a refractor such as bedrock or to discriminate between geological layers.

Refracted seismic waves involve energy that travels through a lower velocity layer and enters a higher velocity medium (refractor) near the critical angle. The seismic waves travel in the high velocity medium along the refractor surface. Since seismic waves move faster in the high velocity medium than the lower velocity layer above it, the wave refracted along that surface will overtake the direct wave. This refracted wave then becomes measured as the first arrival at all subsequent geophones (Figure 2). The velocity of the refracted layer can be computed from the travel time difference of first arrivals given a known distance between the geophones. The time when the refracted wave overtakes the direct arrival is called the “critical distance”, and can be used to estimate the depth to the initial refractor.

The field methods used for refraction seismic testing involve laying out a seismic cable, attaching a number of geophones (usually 24 or more) to it and connecting it to a seismograph. For a two dimensional test, surface geophones are placed in a linear array along a survey line at a known separation. A series of recordings (shots) are collected at known offsets from the either end of the array as well as a number of known locations within the array. The information recorded is called a shot trace and is represented in the time domain (Figure 1). These traces are used to pick the first arrival and the amalgamation of these picks are plotted together to form the shot break (Figure 3). For detailed analysis, frequent shot records collected throughout the array help better constrain the modelled seismic velocity of the medium.

The depth of investigation is directly related to the ground conditions of the medium being surveyed, though there are a couple parameters of the survey design that can be changed to modify the depth or resolution of the survey. One parameter that can be changed is the length of the array. The depth modelled is typically between one-third and one-fifth of the spread length, where a longer spread size corresponds to deeper investigation. A more powerful source can also improve the depth of investigation as energy attenuation becomes a factor, by providing cleaner data to pick from. A sledgehammer source is sufficient in the tens of meters, whereas a larger sources are needed for deeper investigation. Parameters directly related to resolution are the separation distance between geophones and the separation distance between recordings. Reducing the separation distance of the geophones will create better vertical and horizontal resolution in the finished product. Similarly, more frequent recordings (smaller recording spacing) will provide more data to work with and lead to a model with better resolution.

Interpretation of the seismic data first requires picking the first breaks from the time domain record. From these picks a host of characteristics can be determined, such as; the number of layers present, the velocity of each layer, and the traveltime taken to travel from a given refractor to the surface and the thickness of each layer. This data is inverted to create a final subsurface model. ConeTec uses Rayfract® Standard 3.33, created by Intelligent Resources Inc., for the analysis and inversion of the refraction data.

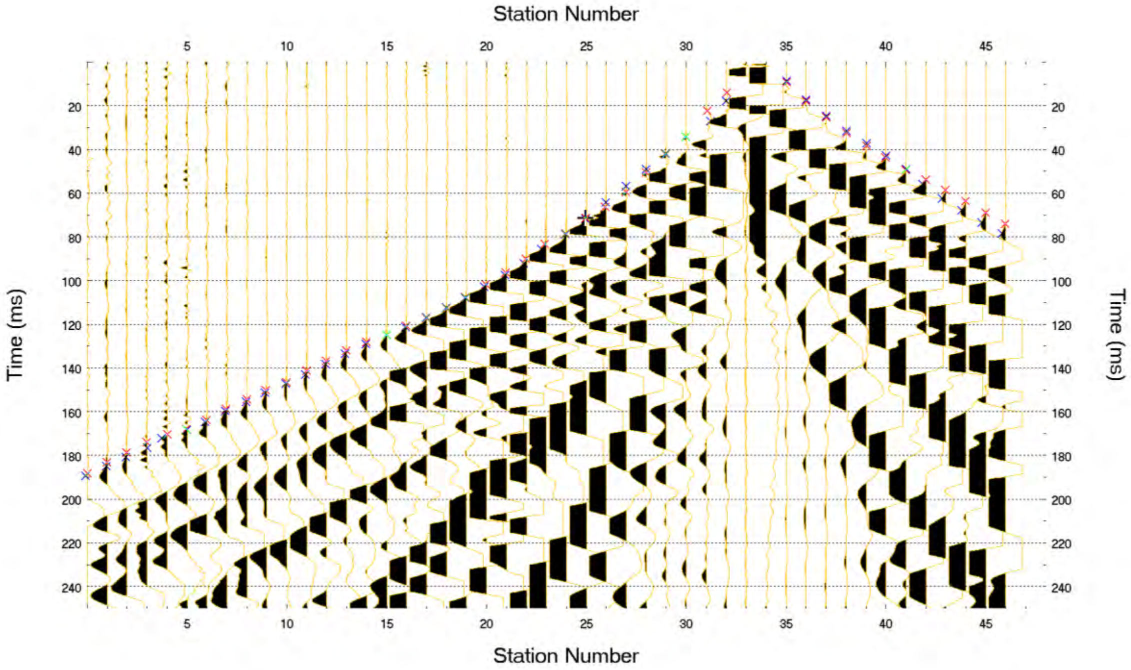


Figure 1. Typical refraction time domain record (shot trace) with picks.

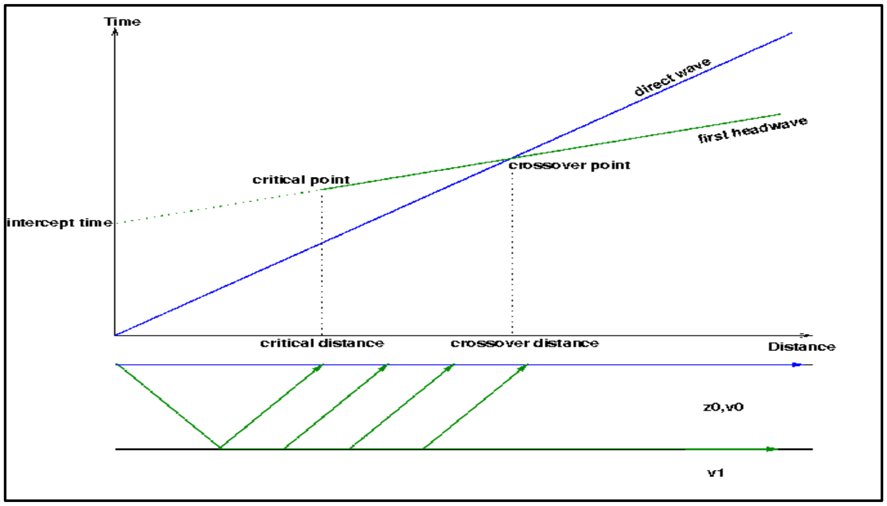


Figure 2. (1) Propagating seismic waves (bottom) and related travel time diagram (top) of the direct (blue) and the first refracted phase (green).

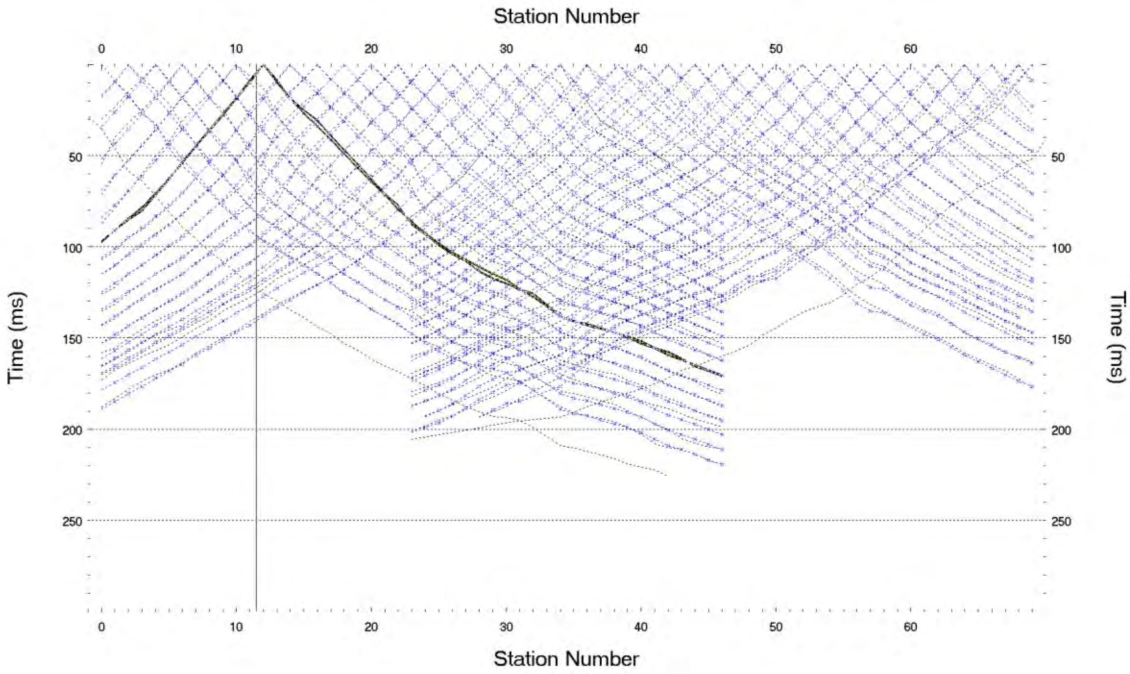


Figure 3. Typical refraction time domain shot breaks record.

The equipment, field procedures, and analysis software used by ConeTec Investigations Ltd. all conform to the currently accepted best practices for near surface refraction testing. It should be noted that the refraction method is not able to determine a lower velocity layer below a higher velocity layer, also known as a velocity reversal. The method may also be insensitive to thin layers immediately above high velocity layers, which is referred to as the hidden layer problem. The results of geophysical testing are always interpretative to a certain extent and should be confirmed by drilling or other intrusive testing. While efforts have been made to provide the best possible information ConeTec Investigations Ltd. does not warranty this report to be free from errors or inaccuracies.

References

ASTM D5777, 2011, “Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation”, ASTM, West Conshohocken, US

Brueckl, E., 1987, The interpretation of traveltime fields in refraction seismology, Geophysical Prospecting, volume 35, pp. 973-992.

Greenhalgh, S.A. and Whiteley, R.J., 1977, Effective application of the seismic refraction method to highway engineering projects, Australian Road Research, volume 7, No. 1, pp. 3-20.

Palmer, D., 2009, Maximising the lateral resolution of near-surface seismic refraction methods, Exploration Geophysics, volume 40, pp. 85-98. (copublished in Butsuri-Tansa and Mulli-Tansa)

Schuster, G.T. and Quintus-Bosz, A., 1993, Wavepath eikonal traveltime inversion: Theory, Geophysics, volume 58, pp. 1314-1323.

Watanabe, T., Matsuoka, T., and Ashida, Y., 1999, Seismic traveltime tomography using Fresnel volume approach, Society of Exploration Geophysicists Meeting, Houston, Texas, Expanded Abstracts.

White, D.J., 1989, Two-dimensional seismic refraction tomography. Geophysical Journal, volume 97, pp. 223-245.

Rayfract website: http://www.rayfract.com

Multichannel analysis of surface waves (MASW) is a non-intrusive in-situ test that uses the principles of elasticity and surface wave dispersion to determine the variation of shear wave velocity with depth at a site. The observation that surface waves (Rayleigh waves) of different wavelengths propagate at different phase velocities in non-ideal media, is called dispersion. This is a direct result of the fact that surface waves of different wavelengths propagate along the surface to varying depths, and hence, if material stiffness changes with depth (as is the case with most non-ideal materials), then an appropriately selected wavelength band will reflect such changes in the velocity of propagation.

The field methods for surface wave testing are very similar to other surface seismic data collection methods. Surface geophones are placed in a linear array along a survey line at a known separation (typically one metre). A series of recordings (shots) are collected with a known in-line source offset from the array. Each shot gather is represented in the time-offset domain and shows the amplitude of wave propagation through the array (refer to Figure MASW-1). For detailed frequency analysis, multiple records with different shot offset distances are collected to help better define the broad spectrum frequency-phase velocity response of the medium. Two-dimensional cross sections can be collected by moving the geophone array a small distance (typically two meters) along the line and repeating the shots at set offsets.

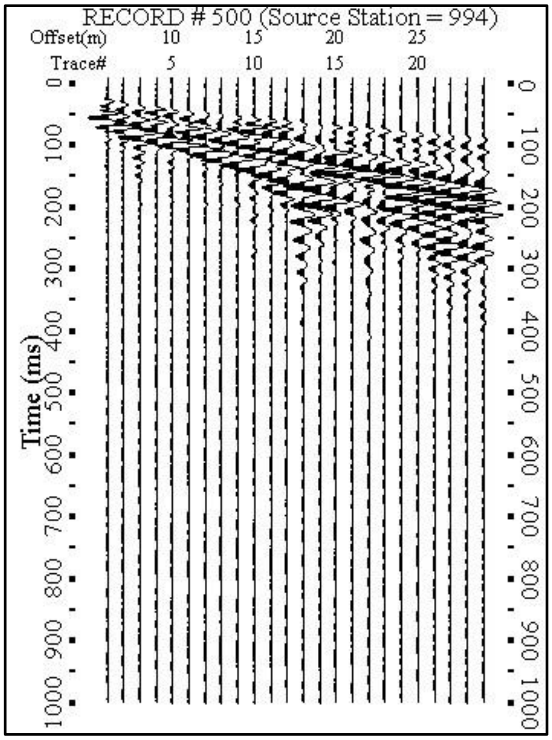


Figure MASW-1. Typical MASW time domain record (shot gather)

Given that surface wave velocity is closely related to the shear wave velocity and the wavelength related to depth, the surface wave results can be used to develop a profile of shear wave velocity versus depth through a process referred to as inversion. The program used to perform the inversion is SurfSeis 4.0, developed by the Kansas Geological Survey. In SurfSeis, the raw time domain traces are transformed to the frequency domain to create what is referred to as an overtone image as shown in Figure MASW-2. The overtone image displays the amplitude of the primary surface wave mode and any potential higher modes. A dispersion curve is fitted to the overtone image, and the inversion process is then used to determine the most appropriate shear wave velocity profile. The parameters used for the inversion of the dispersion data are provided in the data release folder in an Excel table.

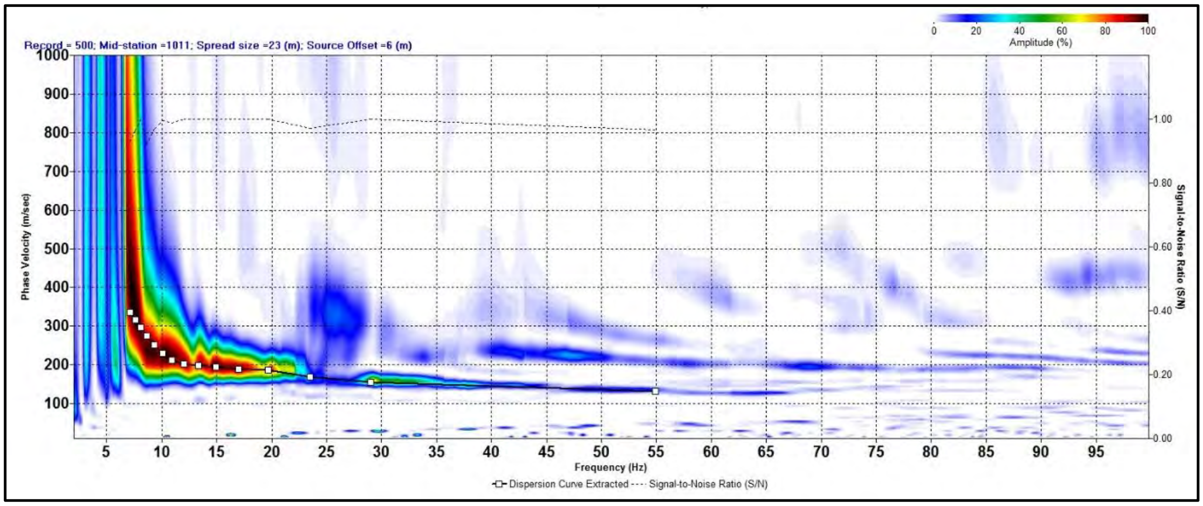


Figure MASW-2. Overtone image and a picked dispersion curve

For each test location, a 1D shear wave velocity profile comprising of a number of velocity layers of variable thickness (refer to Figure MASW-3) is provided . For 2D testing a series of 1D tests are combined to produce a shear wave velocity cross section.

The depth of investigation is related to the ground conditions and the amount of energy delivered by the surface wave source. The surface wave method uses Rayleigh waves that travel horizontally along the ground surface to a depth of about one wavelength. The actual depth of sampling of the ground is considered to be one-half to one-third of the Rayleigh (surface) wave wavelength. The wavelengths measured by the equipment will be a function of the frequency of the source and the velocity of the surface waves through the ground. As the depth of investigation increases, there will be less certainty in terms of layer boundaries and velocity values.

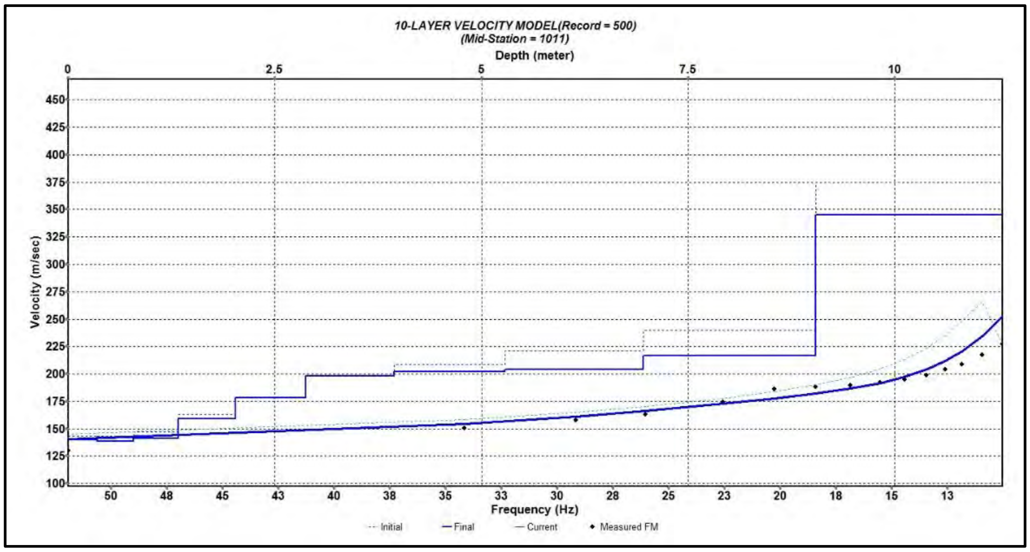


Figure MASW-3. 1D inversion result with fitted dispersion curve

The equipment, field procedures, and analysis software used by ConeTec all conform to the currently accepted best practices for MASW testing. The results of geophysical testing are always interpretative to a certain extent and should be confirmed by drilling or other intrusive testing.

References

Miller, R.D., Xia, J., Park, C.B., and Ivanov, J.M., 1999, Multichannel analysis of surface waves to map bedrock, Kansas Geological Survey, The Leading Edge, December, p. 1392-1396.

Park, C.B., Miller, R.D., and Xia, J., 1998b, Ground roll as a tool to image near-surface anomaly: 68th Ann. Internat. Mtg. Soc. Expl.Geophys., Expanded Abstracts, p. 874-877.

Park, C.B., Miller, R.D., and Xia, J., 1999, Multichannel analysis of surface waves: Geophysics, v. 64, n. 3, pp. 800-808.

Park, C.B., Miller, R.D., Xia, J., and Ivanov, J., 2007, Multichannel analysis of surface waves (MASW)-active and passive methods: The Leading Edge, January.

SurfSeis website: http://www.kgs.ku.edu/software/surfseis/index.html

Xia, J., R.D. Miller, and C.B. Park, 2000a, Advantages of calculating shear-wave velocity from surface waves with higher modes: [Exp. Abs.]: Soc. Expl. Geophys., p. 1295-1298.

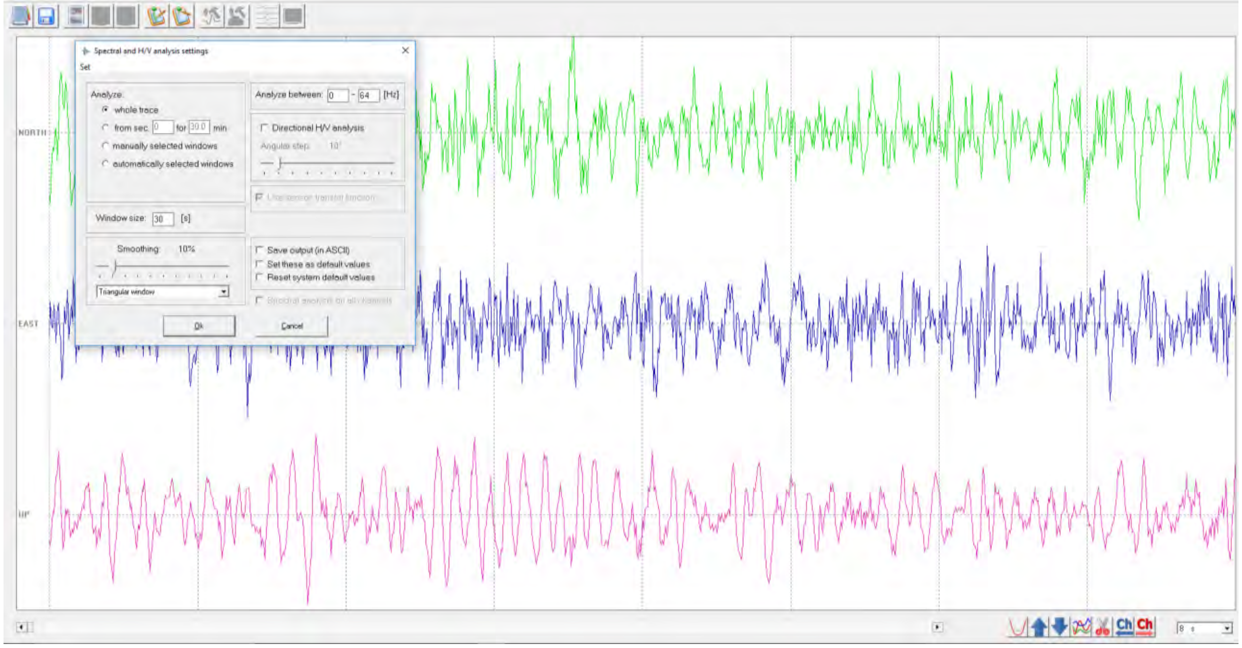
Xia, J., Miller, R.D., Park, C.B., and Ivanov, J., 2000b, Construction of 2-D vertical shear-wave velocity field by the Multichannel Analysis of Surface Wave technique, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 2000), Washington D.C, February 20-24, p. 1197-1206.

The horizontal to vertical spectral ratio (HVSR) method is a passive seismic technique that can be used to measure site period, estimate sediment thickness or the depth to bedrock. HVSR uses the ratio of the average horizontal and vertical component amplitude spectrums to generate a spectral ratio curve with a peak at the fundamental resonance frequency (f_0). A low frequency multi-component seismograph is used to measure the horizontal and vertical components of ambient seismic noise. These elastic waves are created naturally by sea and wind action but can also be produced at higher frequencies through anthropogenic sources such as vehicle traffic or industrial activity. The HVSR method is best suited to sites with a sharp contrast in acoustic impedance at the sediment-bedrock interface.

A measure of the site period or resonant frequency can be important in determining how a site will respond during an earthquake. In instances where multiple peaks are measured in the spectral response, the peak with the highest amplitude is considered the site period. If multiple peaks are near the same amplitude, then multiple site periods will be reported. If a velocity profile is known, the HVSR data can be used to estimate depth to bedrock. This information is often used to produce depth to bedrock plan view maps over large areas. The reverse is also true where if the depth to bedrock is known then an average velocity of the overburden can be estimated.

Prior to collecting data, a measurement location is selected to avoid heavy traffic, industrial noise and artificial ground surfaces such as asphalt, pavement, or cement or as directed by the client. If many readings will be taken across a site, then the seismometer will be placed in a common orientation for each reading. Typically, spikes attached to the bottom of the sensor are used to couple it to the ground. Good coupling, where the ground tightly holds on to the spikes, is essential for high quality data. After the equipment is coupled, it is levelled using the built-in level. Data is typically recorded with a sampling frequency of 128 Hz. In general, longer readings can detect lower frequencies, down to a limit of 0.1 Hz. Lower frequency data typically correspond to deeper investigation depths. A 15 to 20-minute reading will be able to measure frequencies down to the 0.5 Hz range with a depth of investigation of 100 meters or more. Once the reading has started the user walks away and waits for the reading to complete.

The passive seismic data is analyzed using software developed by MoHo s.r.l. An example HVSR time domain record is shown in Figure HVSR-1.



Spectral and H/V analysis settings

Set

Analyze:
● whole trace
○ from sec 0 for 30.0 min
○ manually selected windows
○ automatically selected windows

Analyze between: 0 - 64 [Hz]

☐ Directional H/V analysis
Angular step: 10°

☑ Use sensor transfer function

Window size: 30 [s]

Smoothing: 10%
Triangular window

☐ Save output (in ASCII)
☐ Set these as default values
☐ Reset system default values

☐ Spectral analysis on all channels

Ok
Cancel

Figure HVSR-1. Typical HVSR time domain record

Post processing typically includes band-pass filtering to remove high frequency noise and spectral smoothing. The software computes the average spectrums of the horizontal and vertical components over a user-specified time window. After selecting processing parameters, a series of windows are used to analyse the data (Figure HVSR-2). These windows include the H/V stability, the amplitude spectra, and the H/V curve. The H/V stability window shows the signal response of the sensor over time and is used to edit out noise. Amplitude spectra show the amplitude of certain frequency bands for each orthogonal sensor and are used to compare the response of each component and to help differentiate peaks that are stratigraphic in origin from anthropic. The H/V curve shows the ratio between the horizontal readings and the vertical readings and the standard deviations. It is used to determine the site period for the reading by locating the H/V peak.

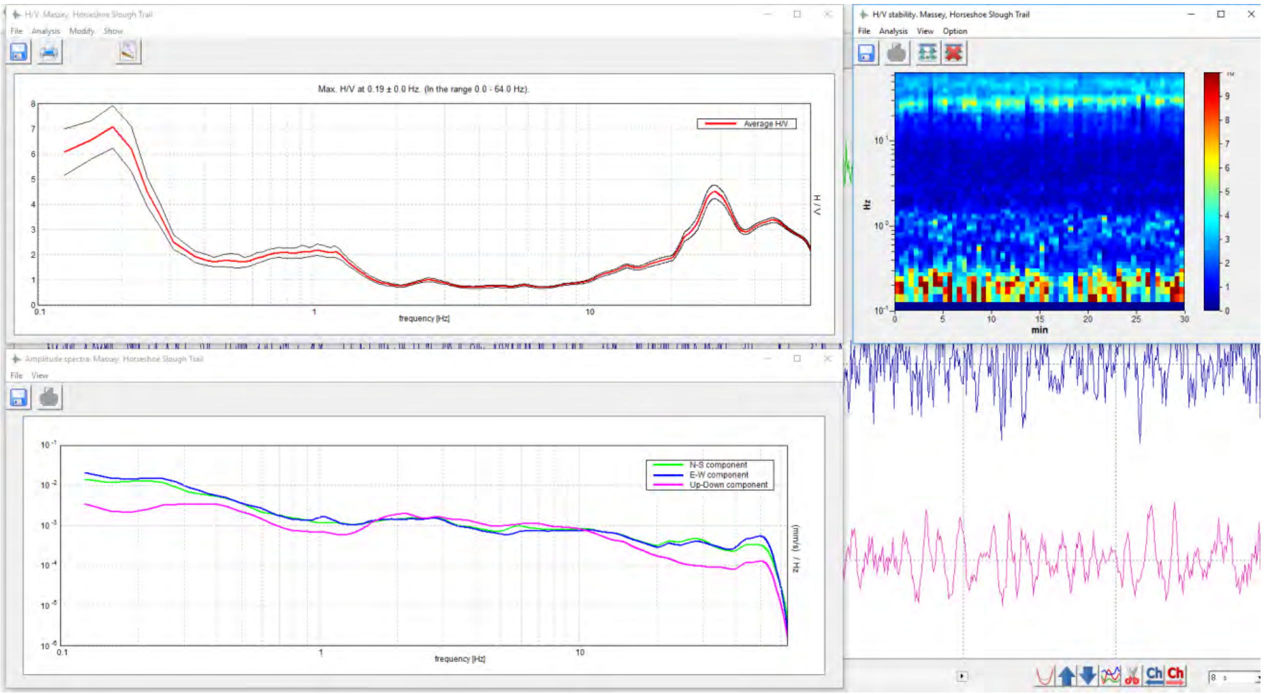
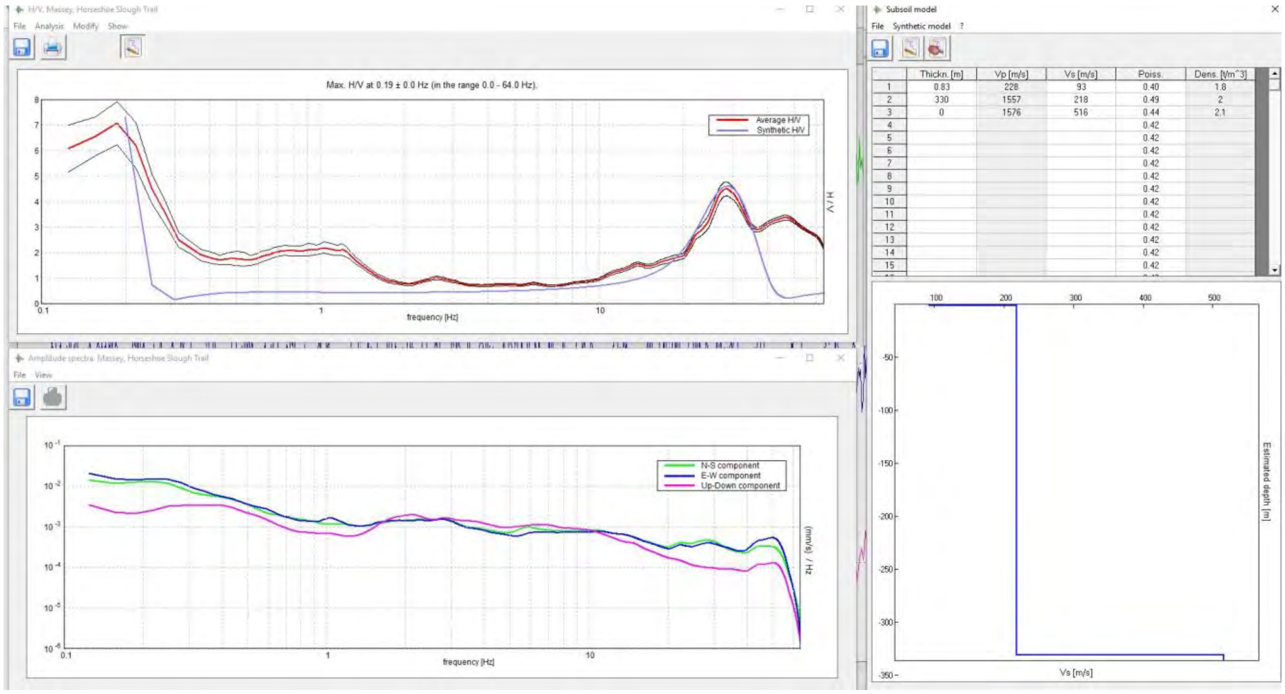


Figure HVSR-2. H/V processing windows

If the purpose of the test is to determine shear wave velocity or layer thickness, then the next step is to fit a model to the H/V curve. The model is built in a table containing Vs, Vp, layer thickness, Poisson's ratio and density (Figure HVSR-3). If a layer thickness or Vs is known, the remainder of the table can be populated to create a model that fits the H/V curve.



	Thickn. [m]	Vp [m/s]	Vs [m/s]	Poiss.	Dens. [t/m^3]
1	0.83	228	93	0.40	1.8
2	330	1557	218	0.49	2
3	0	1576	516	0.44	2.1
4				0.42	
5				0.42	
6				0.42	
7				0.42	
8				0.42	
9				0.42	
10				0.42	
11				0.42	
12				0.42	
13				0.42	
14				0.42	
15				0.42	

Figure HVSR-3. H/V processing windows with modeled data

For each test location, a site period value is provided. Lower frequencies require longer reading times to collect statistically significant values. Ground conditions, reflector topography, velocity contrast between layers and site noise can all have significant impacts on the reading quality. As lower frequencies are recorded there will be less certainty in terms of period. Likewise, if the site period is translated to shear wave velocity or layer thickness, there will be less certainty in those values as the depth of investigation increases.

The equipment, field procedures, and analysis software used by ConeTec are in general accordance with the SESAME (2004) guidelines. The results of geophysical testing are always interpretative to a certain extent and should be used as a part of a larger site investigation.

References

SESAME European Research Project WP12 – Deliverable D23.12 (2004), Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations Measurements, Processing and interpretation: European Commission – Research General Directorate
Project No. EVG1-CT-2000-00026 SESAME

The following appendices listed below are included in the report:

- SRT Summary and Results
- MASW Summary and Results
- Vs30 Calculation Table
- HVSR Summary and Results
- SRT Time Domain Traces and Breaks
- MASW Time Domain Traces and Overtone Images

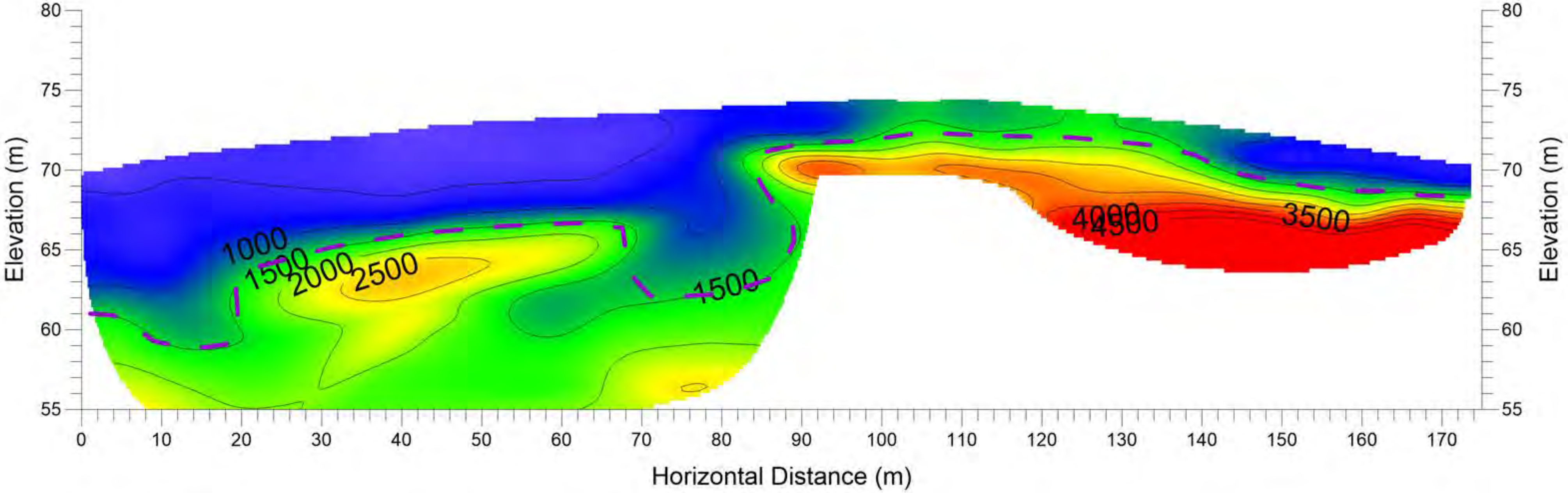
SRT Summary and Results

Job No: 21-02-21901
Client: Thurber Engineering Ltd.
Project: Taylor Way, West Vancouver
Start Date: 06-Feb-2021
End Date: 06-Feb-2021

SEISMIC REFRACTION TEST SUMMARY

Section ID	Date	Source Type	Geophone Spacing (m)	Shot Spacing (m)	Section Length (m)	Array Length (m)	Start of Section Northing[1] (m)	Start of Section Easting (m)	End of Section Northing (m)	End of Section Easting (m)
SRT21-01	06-Feb-2021	Sledgehammer	2.0	6.0	174	94	5464658	490180	5464830	490182
SRT21-02	06-Feb-2021	Sledgehammer	2.0	6.0	82	82	5464658	490102	5464660	490184
SRT21-03	06-Feb-2021	Sledgehammer	1.0	3.0	33	33	5464660	490090	5464692	490080
SRT21-04	06-Feb-2021	Sledgehammer	1.0	3.0	39	39	5464709	490080	5464747	490091
SRT21-05	06-Feb-2021	Sledgehammer	1.0	3.0	38	38	5464753	490083	5464791	490081

1. Coordinates were collected with a differential GPS in datum NAD83/UTM Zone 10 North.



— Interpreted Bedrock Surface

* Vertical Exaggeration of 2:1

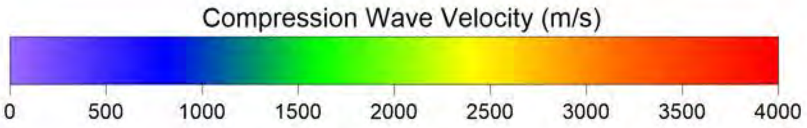
THURBER ENGINEERING LTD.

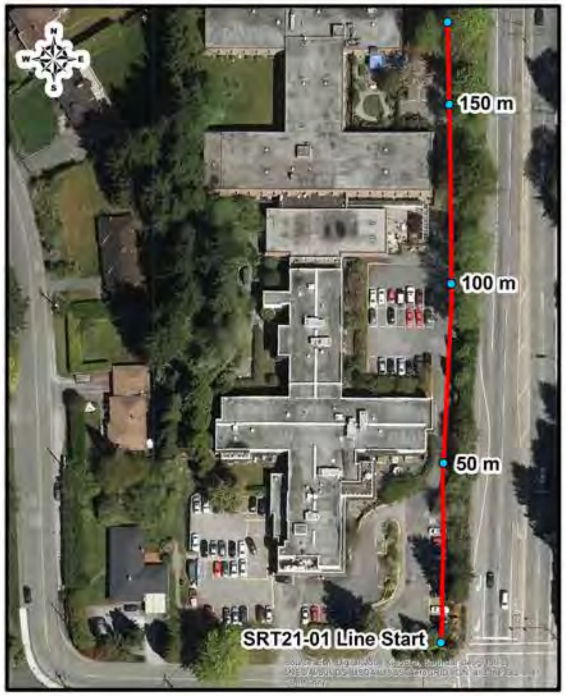
Taylor Way, West Vancouver

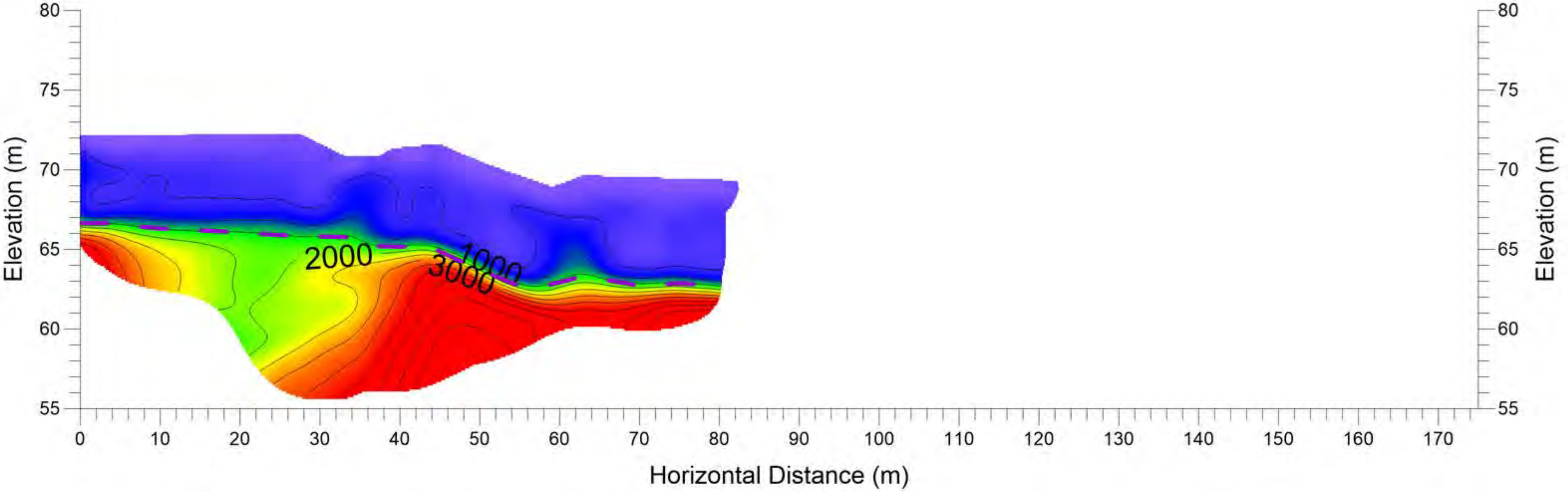
CONETEC

FIGURE 1
SRT21-01: 0 to 174 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-FEB-2021
SURVEY DATE(S)	06-FEB-2021
CONETEC JOB NUMBER	21-02-21901







— Interpreted Bedrock Surface

* Vertical Exaggeration of 2:1

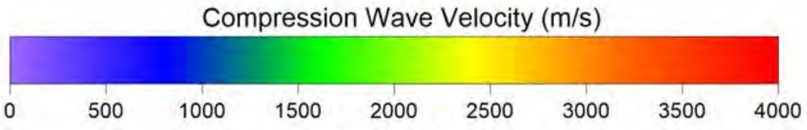
THURBER ENGINEERING LTD.

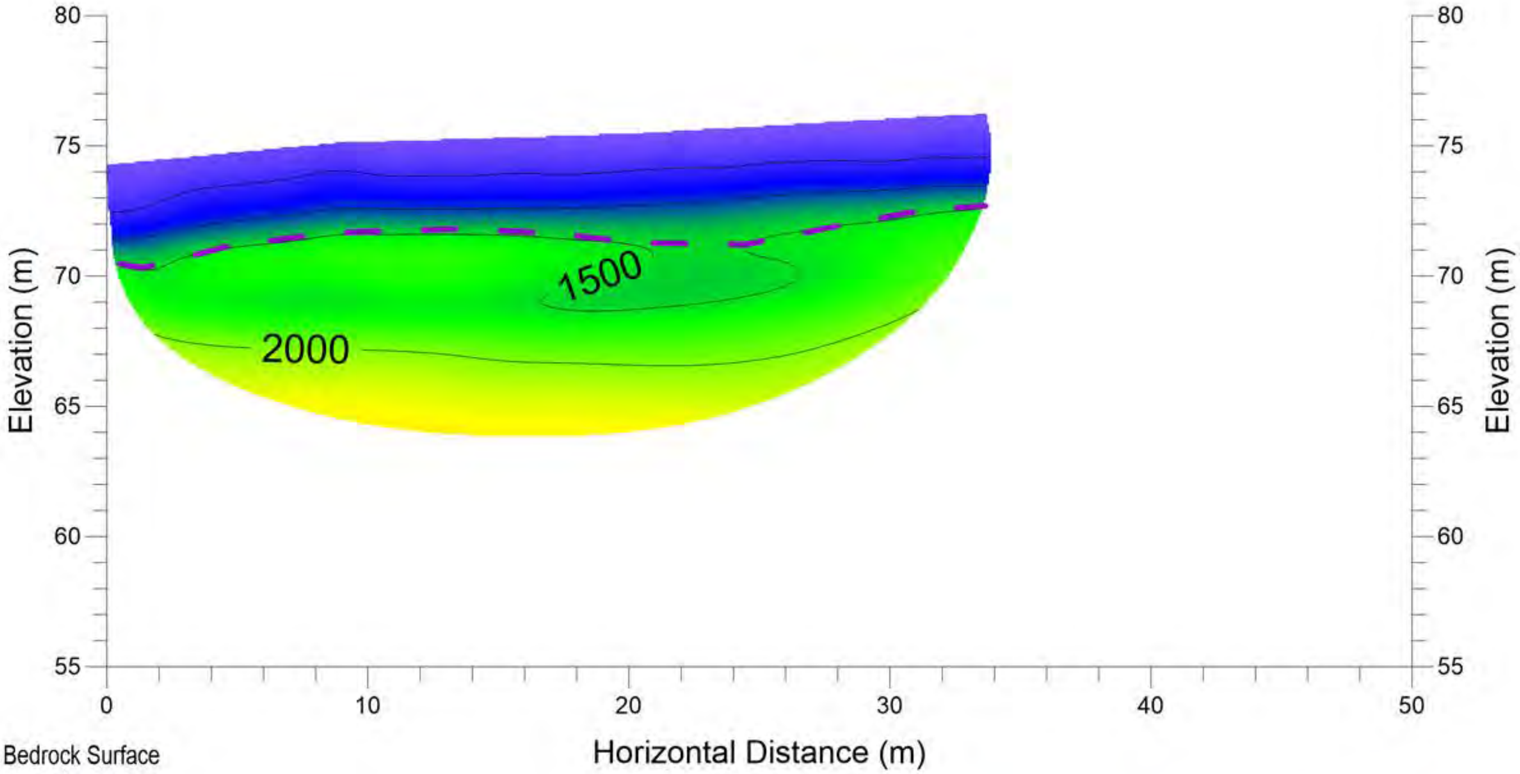
Taylor Way, West Vancouver

CONETEC

FIGURE 2
SRT21-02: 0 to 82 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-FEB-2021
SURVEY DATE(S)	06-FEB-2021
CONETEC JOB NUMBER	21-02-21901





Interpreted Bedrock Surface

* Vertical Exaggeration of 1:1

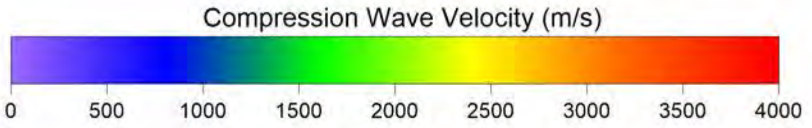
THURBER ENGINEERING LTD.

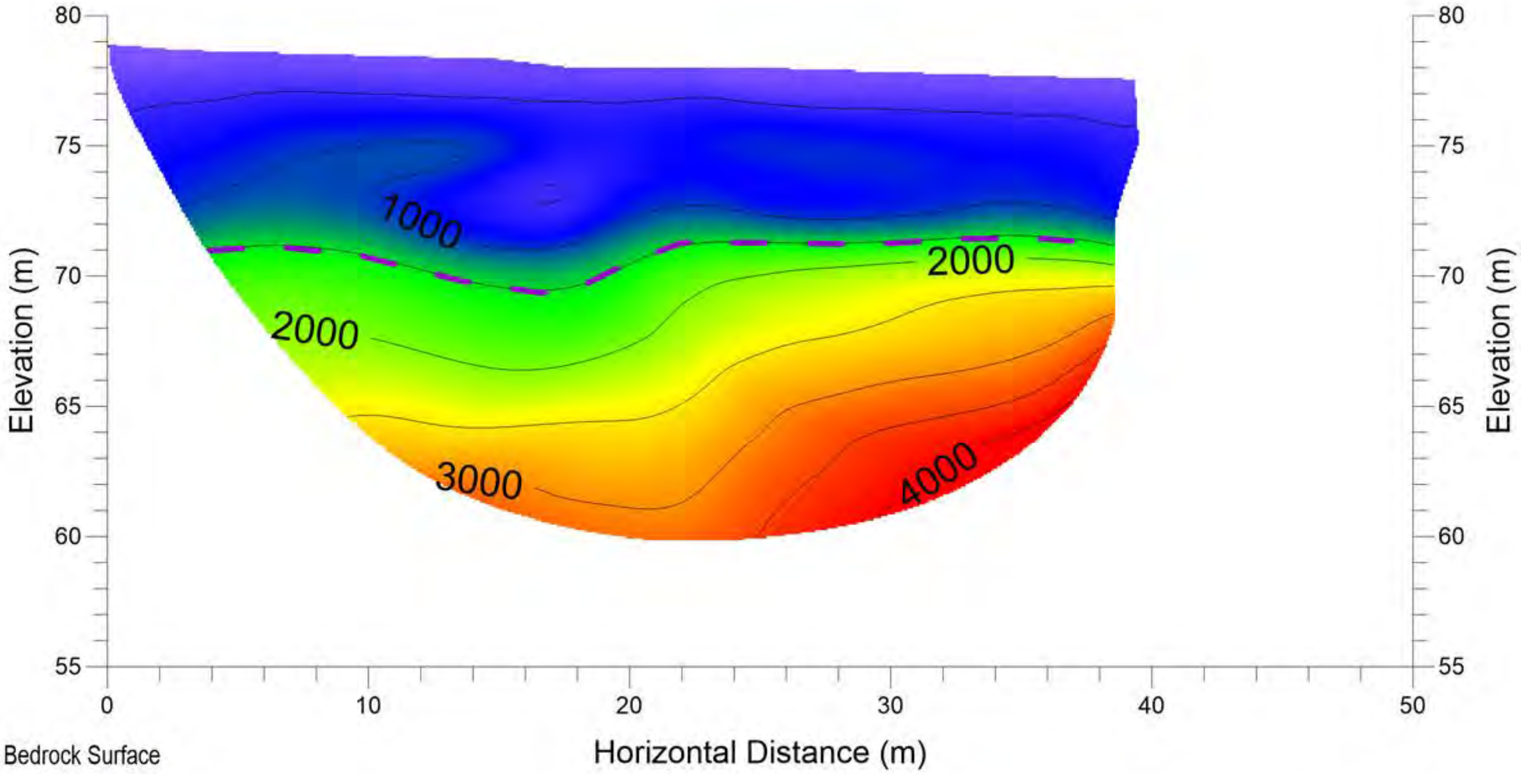
Taylor Way, West Vancouver

CONETEC

FIGURE 3
SRT21-03: 0 to 33 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-FEB-2021
SURVEY DATE(S)	06-FEB-2021
CONETEC JOB NUMBER	21-02-21901





— Interpreted Bedrock Surface

* Vertical Exaggeration of 1:1

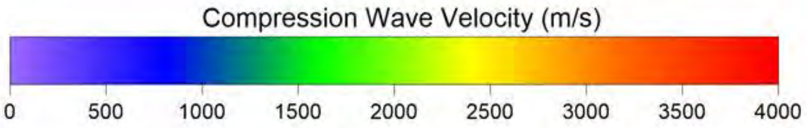
THURBER ENGINEERING LTD.

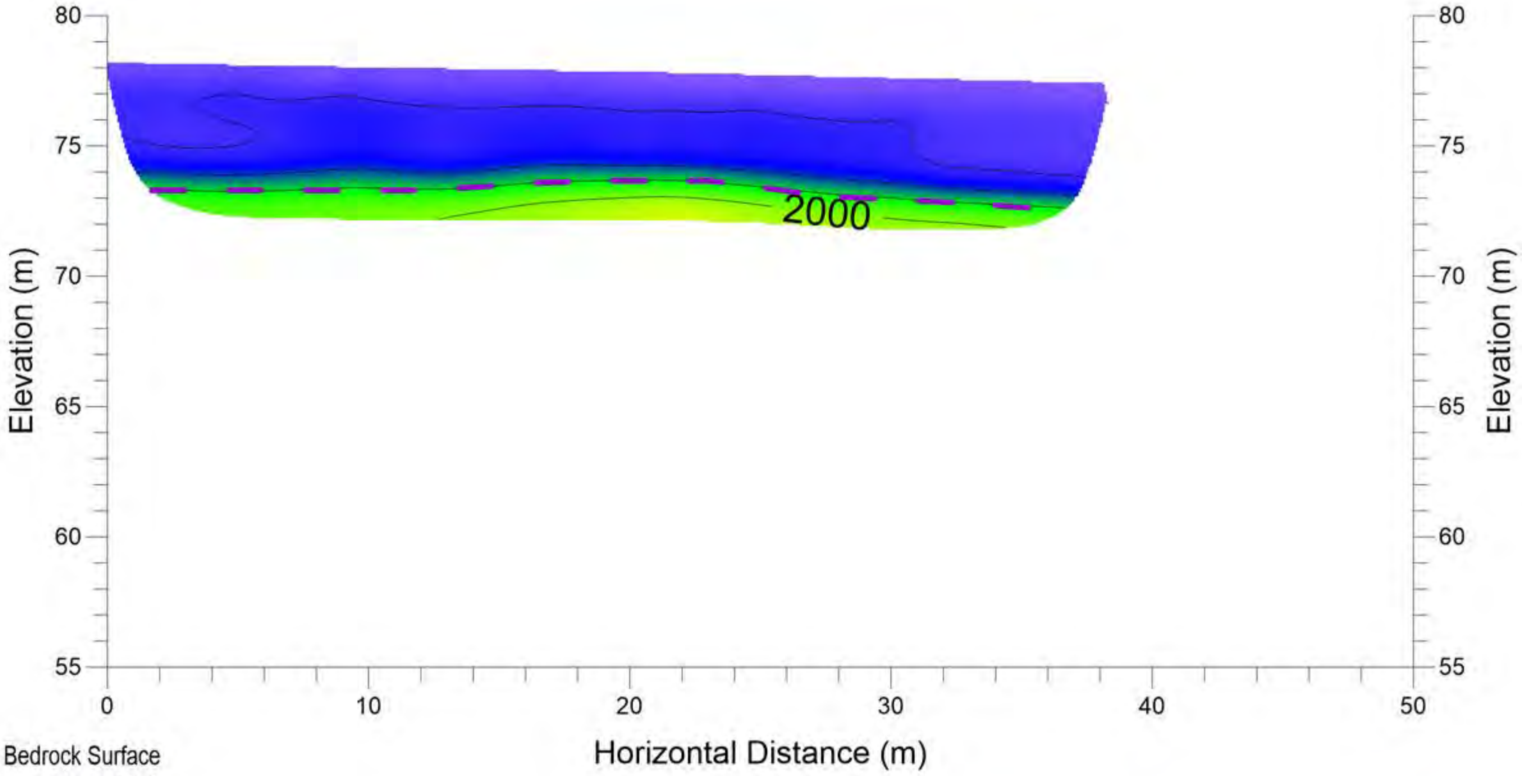
Taylor Way, West Vancouver

CONETEC

FIGURE 4
SRT21-04: 0 to 39 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-FEB-2021
SURVEY DATE(S)	06-FEB-2021
CONETEC JOB NUMBER	21-02-21901





Interpreted Bedrock Surface

* Vertical Exaggeration of 1:1

THURBER ENGINEERING LTD.

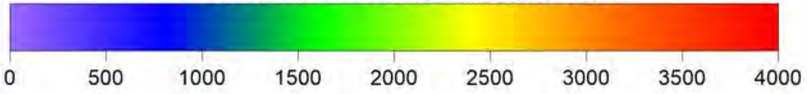
Taylor Way, West Vancouver

CONETEC

FIGURE 5
SRT21-05: 0 to 38 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-FEB-2021
SURVEY DATE(S)	06-FEB-2021
CONETEC JOB NUMBER	21-02-21901

Compression Wave Velocity (m/s)



MASW Summary and Results

Job No:	21-02-21901
Client:	Thurber Engineering Ltd.
Project:	Taylor Way, West Vancouver
Start Date:	06-Feb-2021
End Date:	06-Feb-2021

1D MASW TEST SUMMARY

Sounding ID	Date	Active Source	Geophone Spacing (m)	Array Length (m)	Northing[1] (m)	Easting (m)	Refer to Notation Number
MASW21-01	6/Feb/21	Sledgehammer	2	66	5464720	490181	1,2

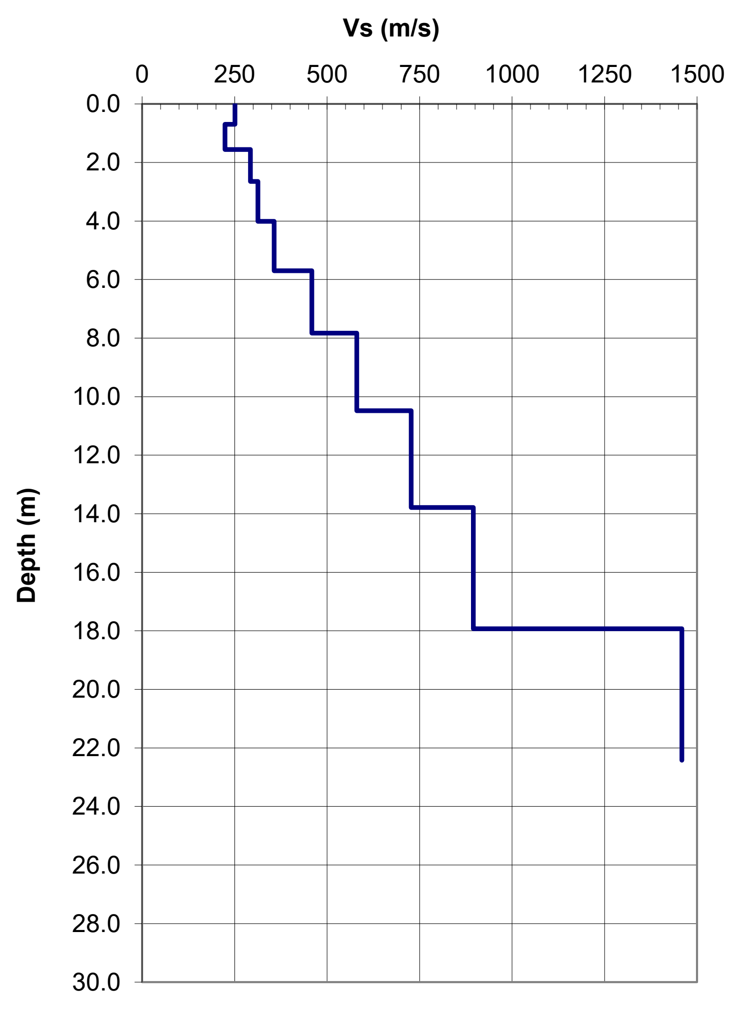
1. Coordinates are in NAD 83 UTM Zone 10 North.

2. Coordinates were interpolated from physical site measurements and RTK GPS measured coordinates

Job No:	21-02-21901
Client:	Thurber Engineering Ltd.
Project:	Taylor Way, West Vancouver
Sounding ID:	MASW21-01
Date:	06-Feb-2021

1D MASW SHEAR WAVE VELOCITY TEST RESULTS

Layer	Layer Thickness (m)	Depth of Bottom of Layer (m)	Vs (m/s)
1	0.70	0.70	251
2	0.86	1.56	224
3	1.09	2.65	293
4	1.36	4.01	313
5	1.69	5.70	357
6	2.13	7.83	459
7	2.65	10.48	580
8	3.31	13.79	727
9	4.14	17.93	895
10	4.49	22.42	1459



Vs30 Calculation Table

Job No: 21-02-21901
Client: Thurber Engineering Ltd.
Project: Taylor Way, West Vancouver
Sounding: MASW21-01
Date: 06-Feb-2021

VS30 CALCULATION

Layer Number	Layer Thickness (m)	Layer Bottom (m)	Vs (m/s)	Equivalent Vertical Travel Time (s)
1	0.70	0.70	251	0.00279
2	0.86	1.56	224	0.00384
3	1.09	2.65	293	0.00372
4	1.36	4.01	313	0.00435
5	1.69	5.70	357	0.00473
6	2.13	7.83	459	0.00464
7	2.65	10.48	580	0.00457
8	3.31	13.79	727	0.00455
9	4.14	17.93	895	0.00463
10	4.49	22.42	1459	0.00308
11	7.58	30.00	1459	0.00520
Total Vertical Travel Time for 30m (s)				0.04609
Average Travel Time Weighted Shear Wave Velocity (m/s)				651

Notes: Yellow filled cells indicate projected shear wave velocity

HVSR Summary and Results

Job No: 21-02-21901
Client: Thurber Engineering Ltd.
Project: Taylor Way, West Vancouver
Start Date: 06-Feb-2021
End Date: 06-Feb-2021

HVSR TEST SUMMARY

Sounding ID	Date	Location ID	Reading Length (min)	Resonant Frequency (Hz)	Interpreted bulk Vs (m/s)	Known depth to contrasting Vs layer (m)	Northing (m)	Easting (m)	Refer to Notation Number
HVSR21-01	06/Feb/2021	Near AH20-01	15	7.94 ± 0.06	255	8.8	5464759	490161	1,2
HVSR21-02	06/Feb/2021	Near AH20-02	15	12.19 ± 0.99	185	4.0	5464830	490176	1,2
HVSR21-03	06/Feb/2021	Near AH20-03	15	12.31 ± 0.11	265	6.1	5464681	490159	1,2
HVSR21-04	06/Feb/2021	Near AH20-04	15	NA	NA	6.4	5464663	490085	1,2,3

1. Coordinates were surveyed using an RTK GPS. Coordinates are in NAD 83 UTM Zone 10 North
2. Interpreted bulk Vs values were generated from known depth to bedrock and HVSR results.
3. Insufficient data quality for interpretation.

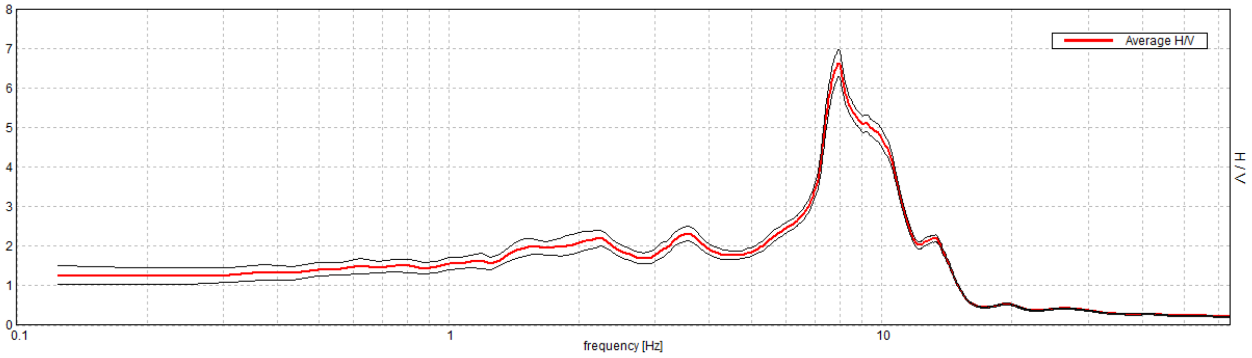
TAYLOR WAY, WEST VANCOUVER HVSR21-01

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/02/21 11:33:46 End recording: 06/02/21 11:49:46
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

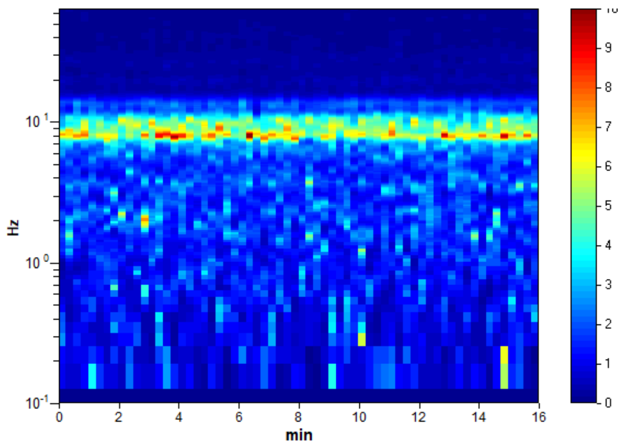
Trace length: 0h16'00''. Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 10%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

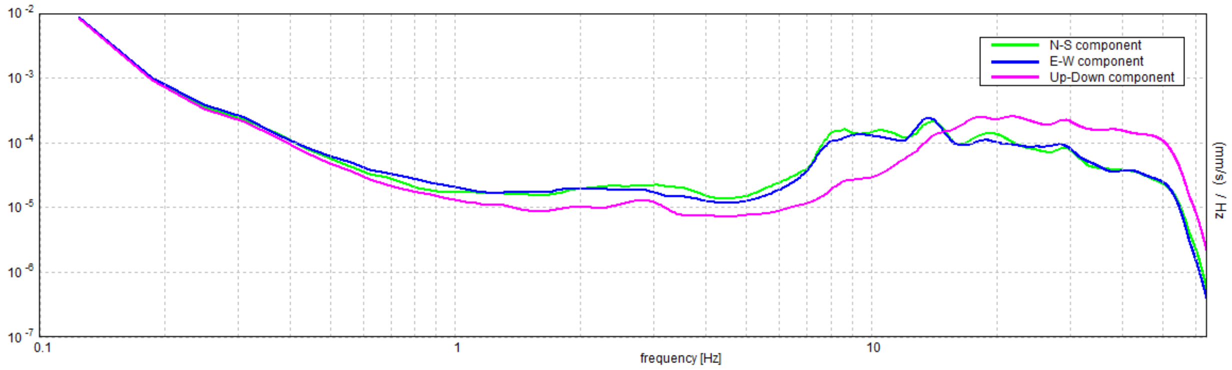
Max. H/V at 7.94 ± 0.06 Hz. (In the range 0.0 - 64.0 Hz).



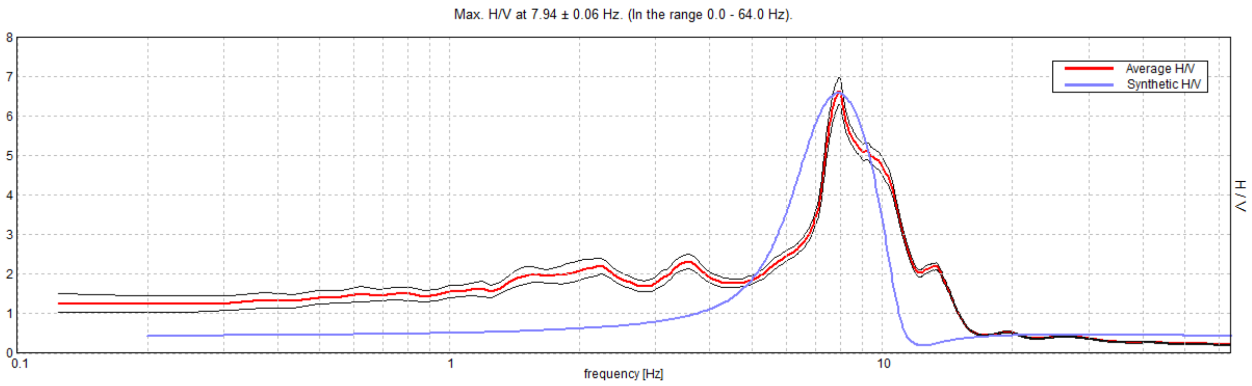
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

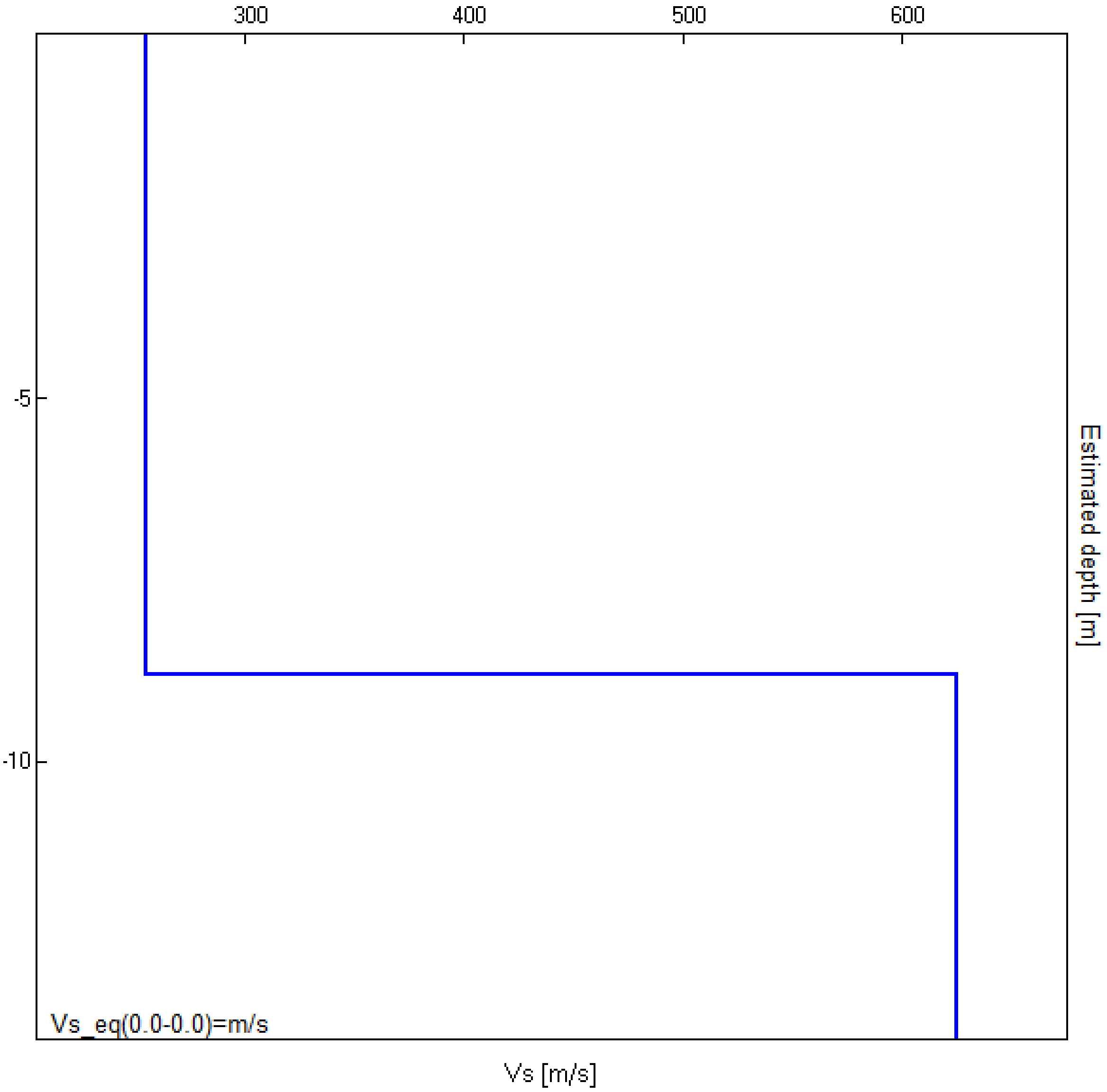


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
8.80	8.80	255	0.40
inf.	inf.	625	0.40

Vs_eq(0.0-0.0)=m/s


300
400
500
600
-5
-10
Estimated depth [m]
Vs_eq(0.0-0.0)=m/s
Vs [m/s]

[According to the SESAME, 2005 guideline.]

Max. H/V at 7.94 ± 0.06 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	7.94 > 0.67	OK	
$n_c(f_0) > 200$	7620.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 192 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	6.938 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	11.063 Hz	OK	
$A_0 > 2$	6.61 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.0075| < 0.05	OK	
$\sigma_f < \varepsilon(f_0)$	0.0595 < 0.39688	OK	
$\sigma_A(f_0) < \theta(f_0)$	0.3421 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$					
Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

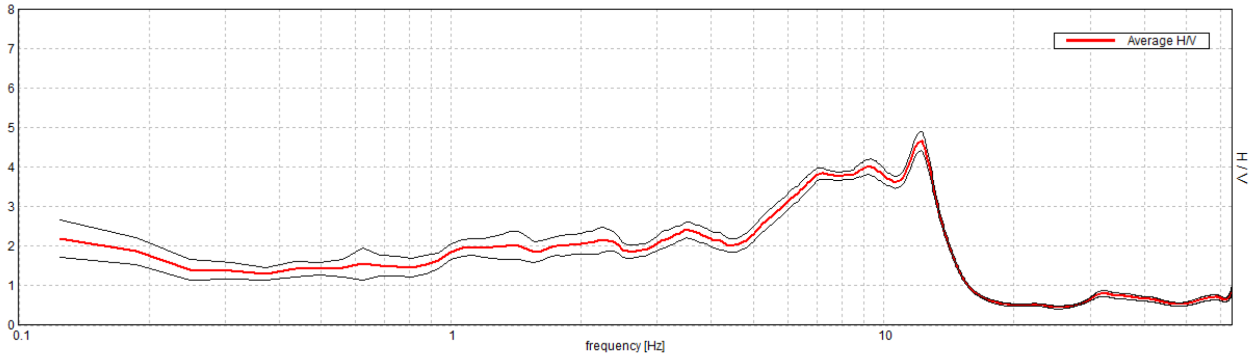
TAYLOR WAY, WEST VANCOUVER, HVSR21-02

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/02/21 12:20:51 End recording: 06/02/21 12:36:51
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

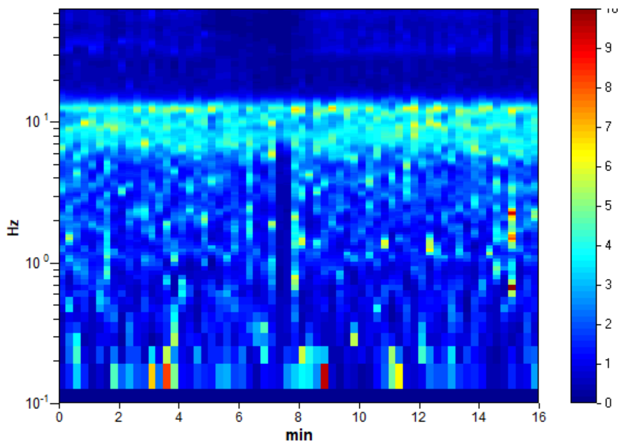
Trace length: 0h16'00''. Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 10%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

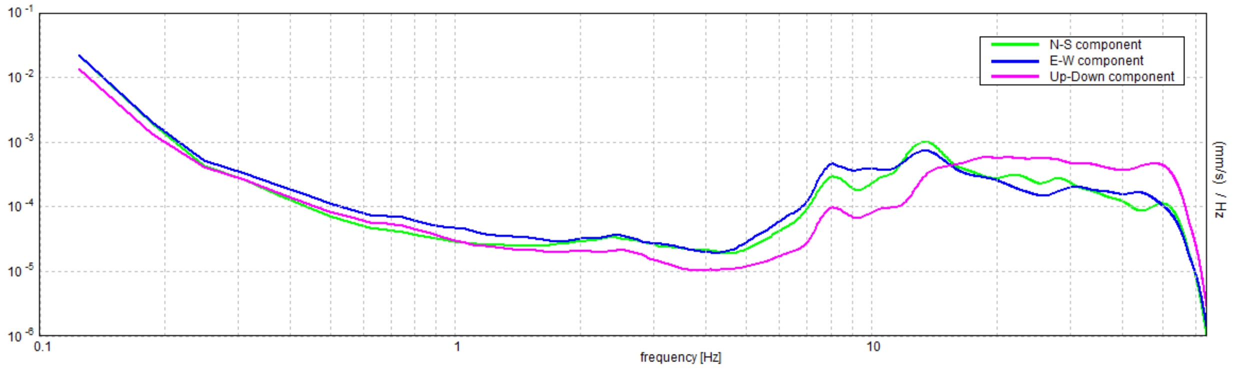
Max. H/V at 12.19 ± 0.99 Hz. (In the range 0.0 - 64.0 Hz).



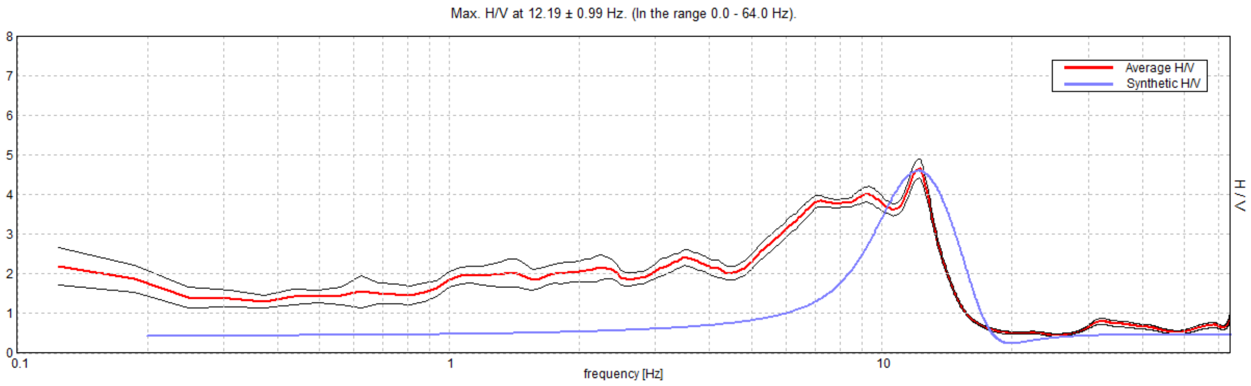
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

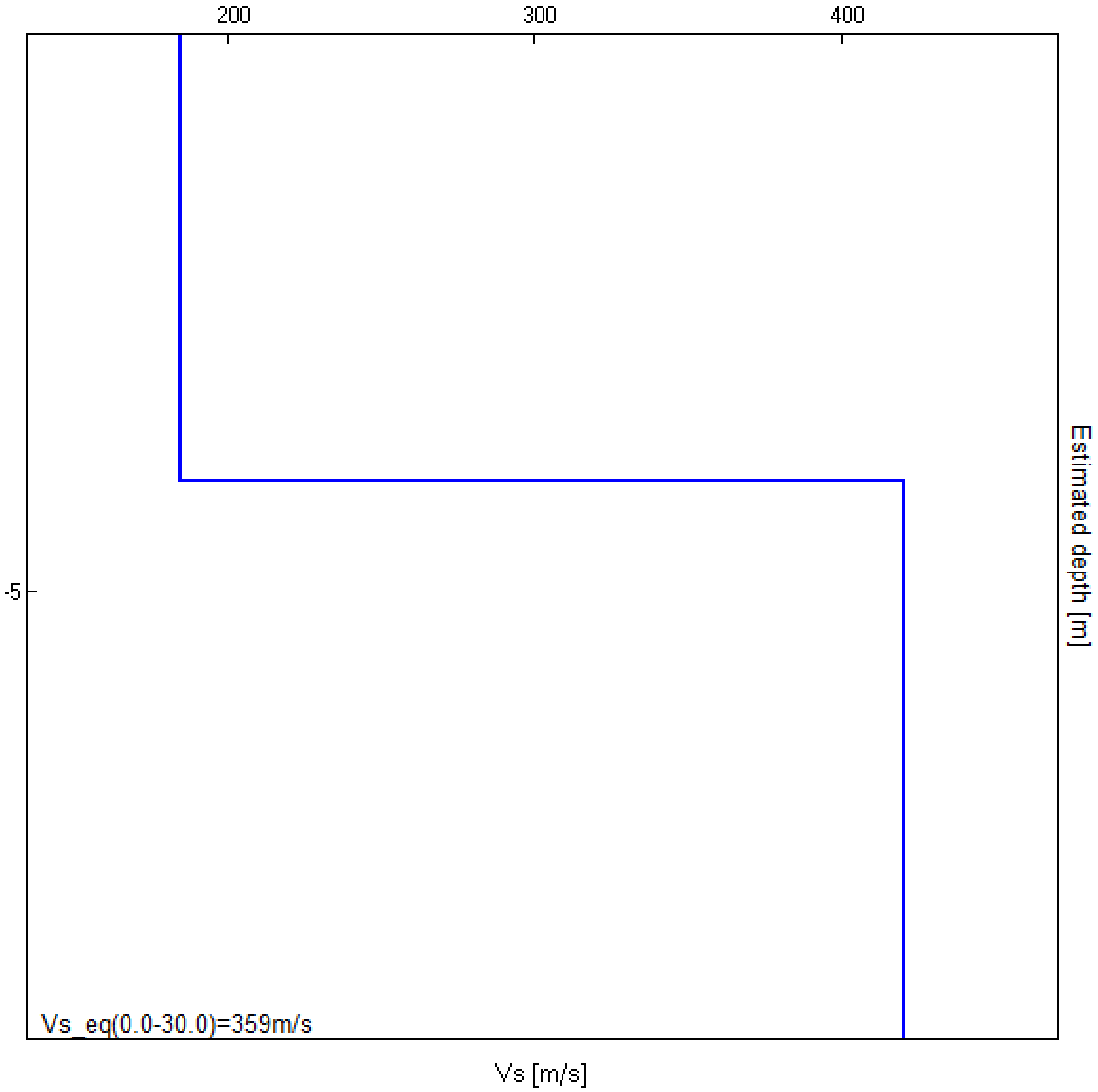


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
4.00	4.00	185	0.40
inf.	inf.	420	0.40

Vs_eq(0.0-30.0)=359m/s


200
300
400
-5
Estimated depth [m]
Vs_eq(0.0-30.0)=359m/s
Vs [m/s]

[According to the SESAME, 2005 guidelines.]

Max. H/V at 12.19 ± 0.99 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	12.19 > 0.67	OK	
$n_c(f_0) > 200$	11700.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 294 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0] \mid A_{H/V}(f^-) < A_0 / 2$	5.0 Hz	OK	
Exists f^+ in $[f_0, 4f_0] \mid A_{H/V}(f^+) < A_0 / 2$	13.875 Hz	OK	
$A_0 > 2$	4.65 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	$\lvert 0.08135 \rvert < 0.05$		NO
$\sigma_f < \varepsilon(f_0)$	0.99145 < 0.60938		NO
$\sigma_A(f_0) < \theta(f_0)$	0.2406 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$

Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

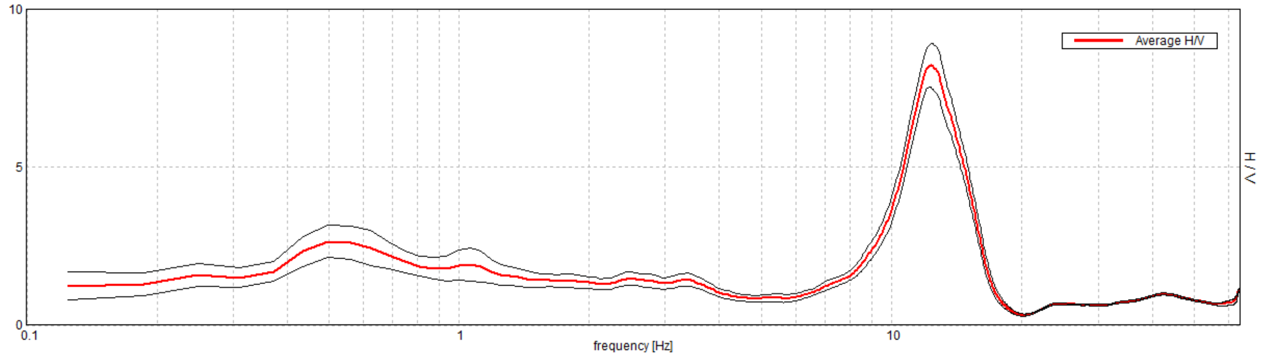
TAYLOR WAY, WEST VANCOUVER, HVSR21-03

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/02/21 12:59:26 End recording: 06/02/21 13:15:26
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

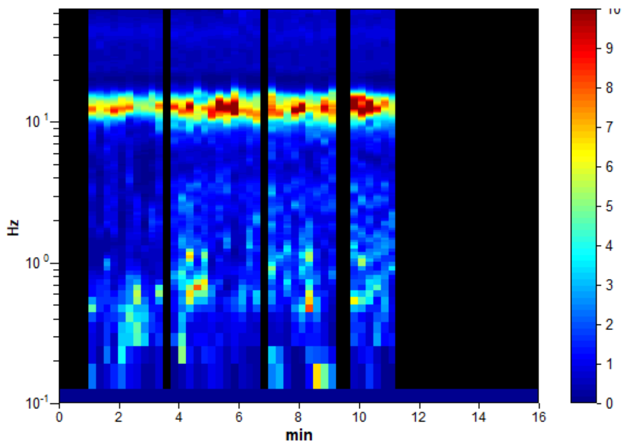
Trace length: 0h16'00''. Analyzed 58% trace (manual window selection)
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 10%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

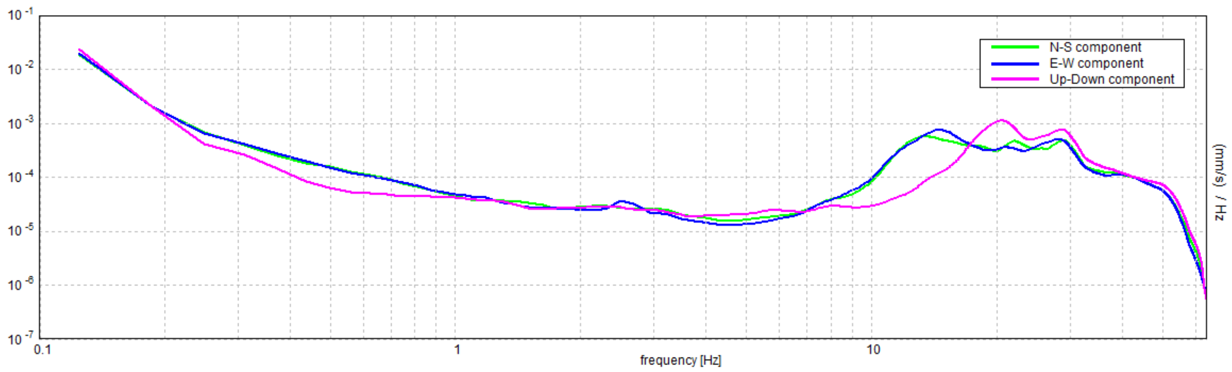
Max. H/V at 12.31 ± 0.11 Hz. (In the range 0.0 - 64.0 Hz).



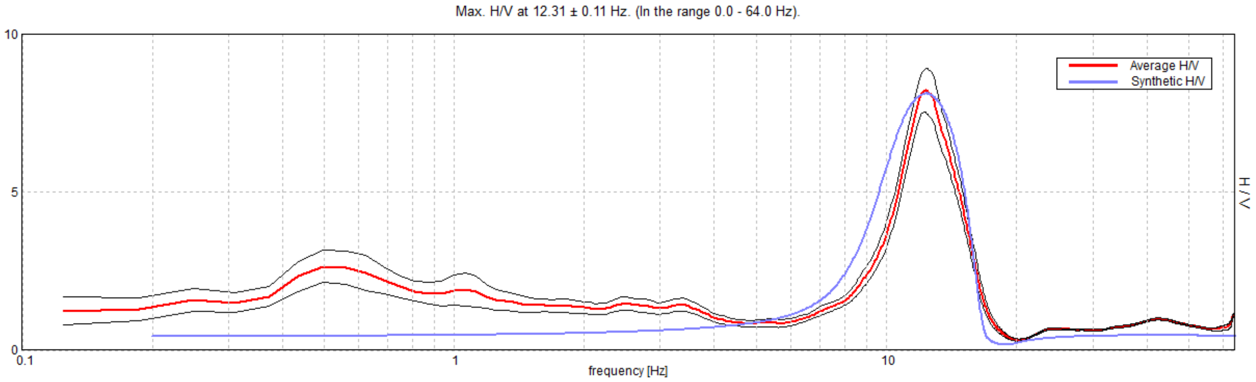
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA



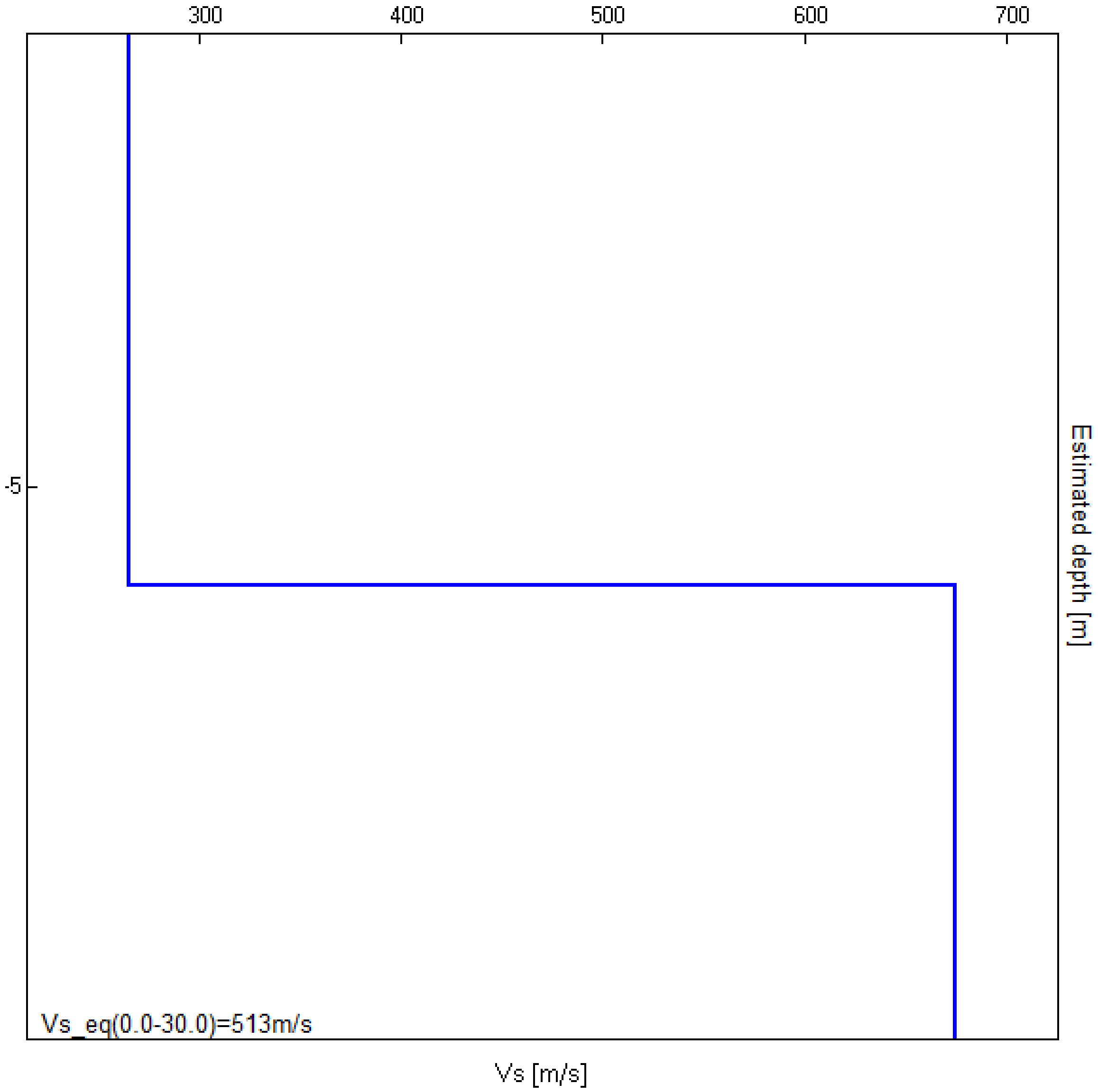
EXPERIMENTAL vs. SYNTHETIC H/V



Max. H/V at 12.31 ± 0.11 Hz. (In the range 0.0 - 64.0 Hz).

Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
6.10	6.10	265	0.40
inf.	inf.	675	0.40

Vs_eq(0.0-30.0)=513m/s


300
400
500
600
700
-5
Estimated depth [m]
Vs_eq(0.0-30.0)=513m/s
Vs [m/s]

[According to the SESAME, 2005 guidelines.]

Max. H/V at 12.31 ± 0.11 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	12.31 > 0.67	**OK**	
$n_c(f_0) > 200$	6833.4 > 200	**OK**	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 296 times	**OK**	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	10.188 Hz	**OK**	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	15.313 Hz	**OK**	
$A_0 > 2$	8.22 > 2	**OK**	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.00871| < 0.05	**OK**	
$\sigma_f < \varepsilon(f_0)$	0.10727 < 0.61563	**OK**	
$\sigma_A(f_0) < \theta(f_0)$	0.6936 < 1.58	**OK**	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$

Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

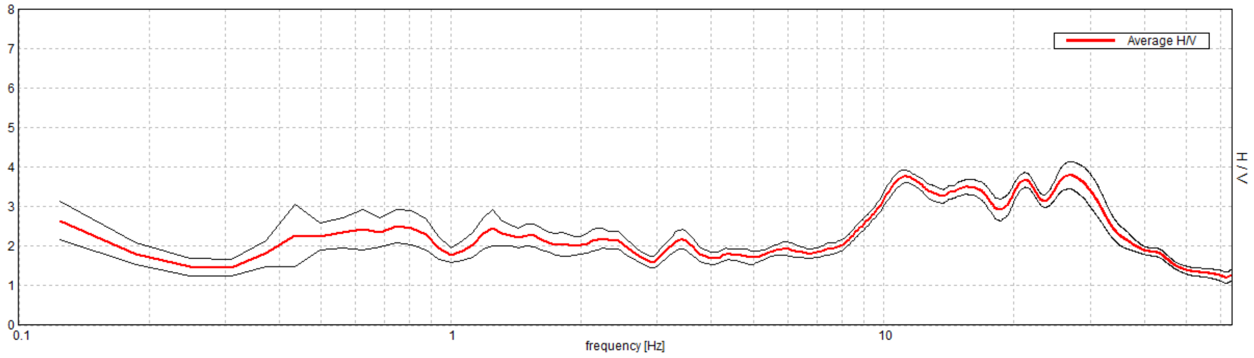
TAYLOR WAY, WEST VANCOUVER HVSR21-04

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/02/21 14:52:43 End recording: 06/02/21 15:08:43
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

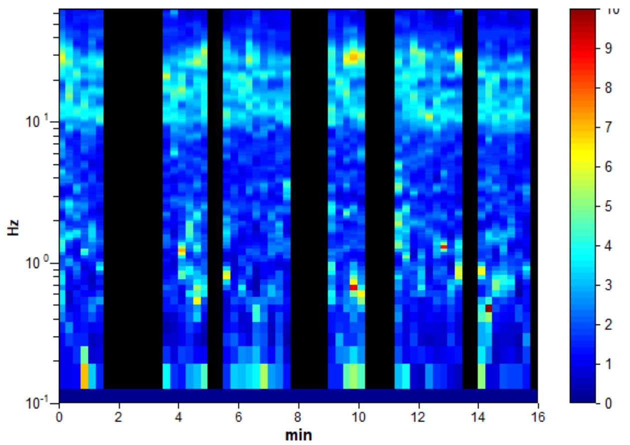
Trace length: 0h16'00''. Analyzed 66% trace (manual window selection)
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 10%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

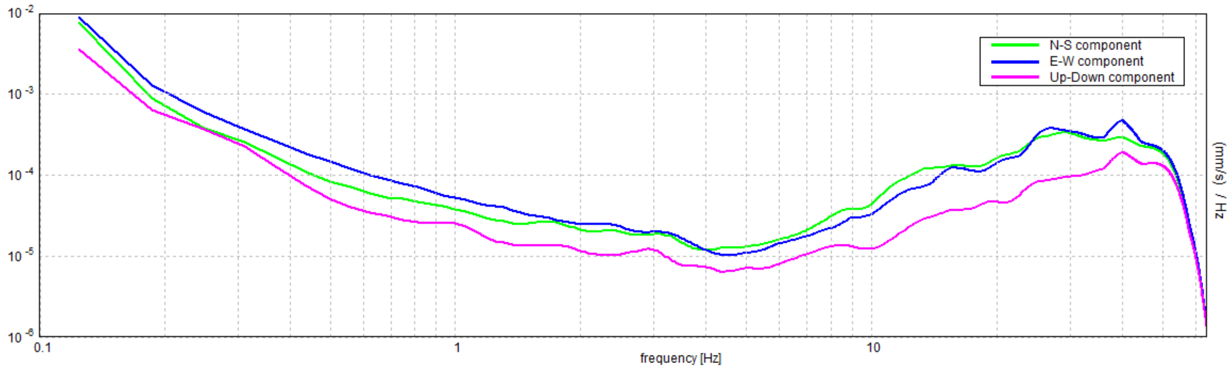
Max. H/V at 26.88 ± 0.46 Hz. (In the range 0.0 - 64.0 Hz).



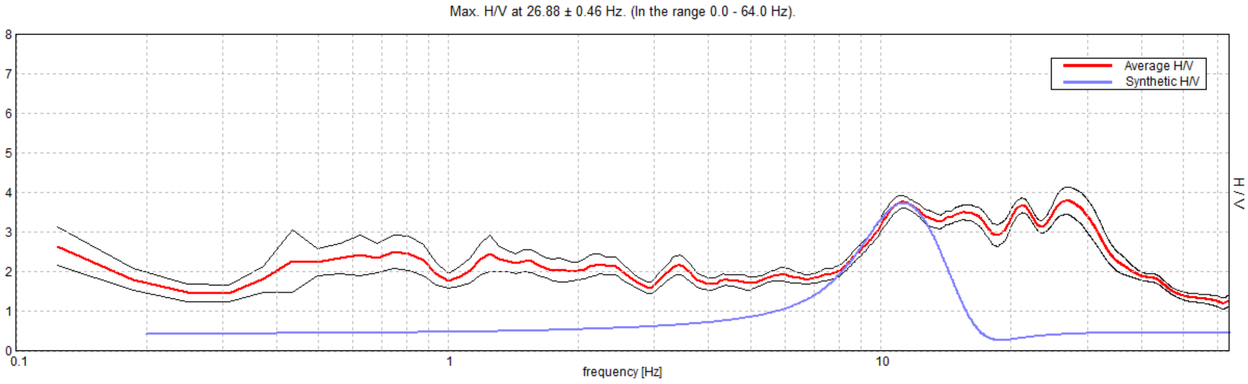
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

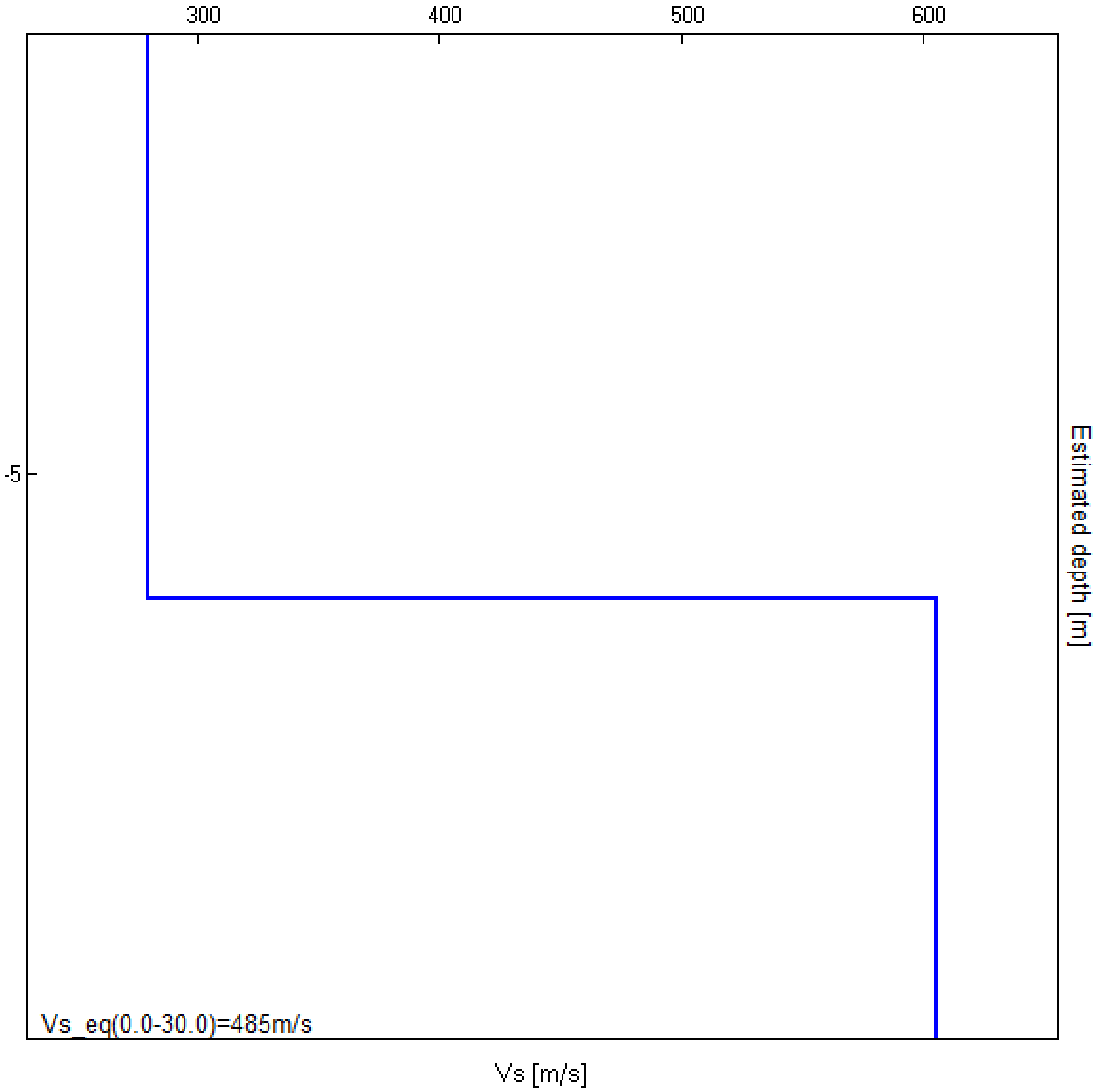


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
6.40	6.40	280	0.40
inf.	inf.	605	0.40

Vs_eq(0.0-30.0)=485m/s


300
400
500
600
-5
Estimated depth [m]
Vs_eq(0.0-30.0)=485m/s
Vs [m/s]

[According to the SESAME, 2005 guidelines.]

Max. H/V at 26.88 ± 0.46 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	$26.88 > 0.67$	OK	
$n_c(f_0) > 200$	$16931.3 > 200$	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 646 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

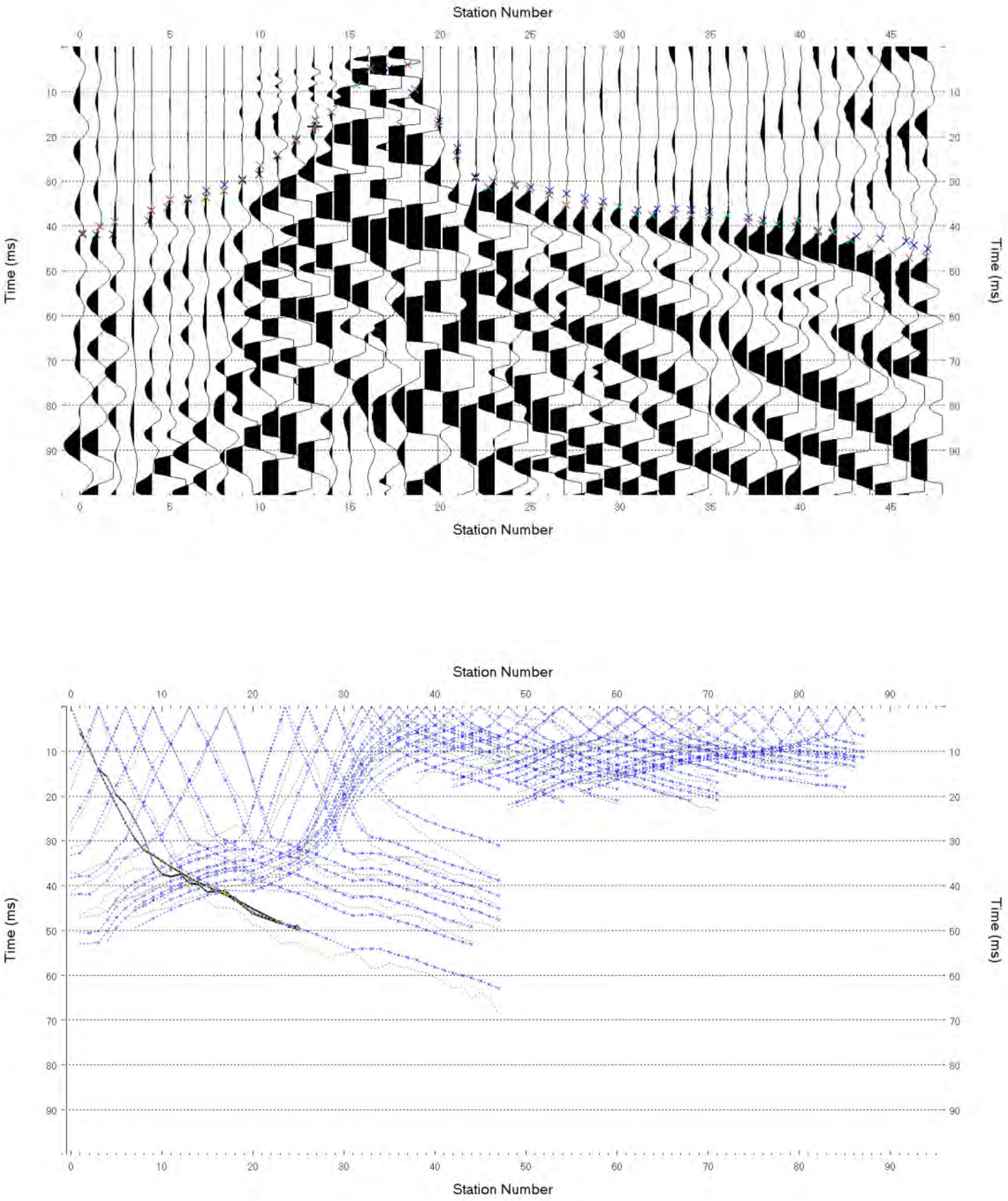
Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	7.25 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	39.875 Hz	OK	
$A_0 > 2$	$3.80 > 2$	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	$\|0.01729\| < 0.05$	OK	
$\sigma_f < \varepsilon(f_0)$	$0.46461 < 1.34375$	OK	
$\sigma_A(f_0) < \theta(f_0)$	$0.3444 < 1.58$	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

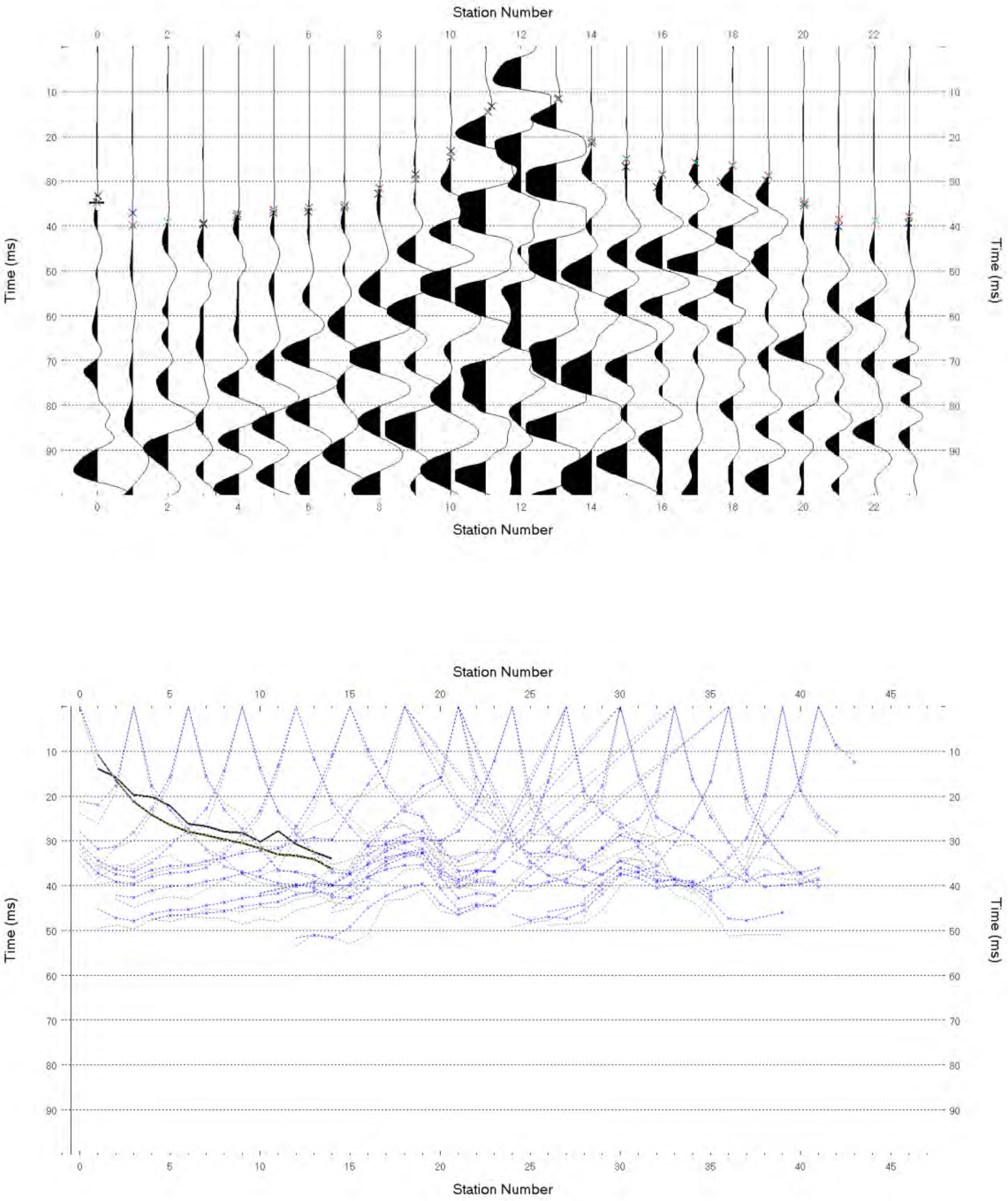
Threshold values for σ_f and $\sigma_A(f_0)$

Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	$0.25\ f_0$	$0.2\ f_0$	$0.15\ f_0$	$0.10\ f_0$	$0.05\ f_0$
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

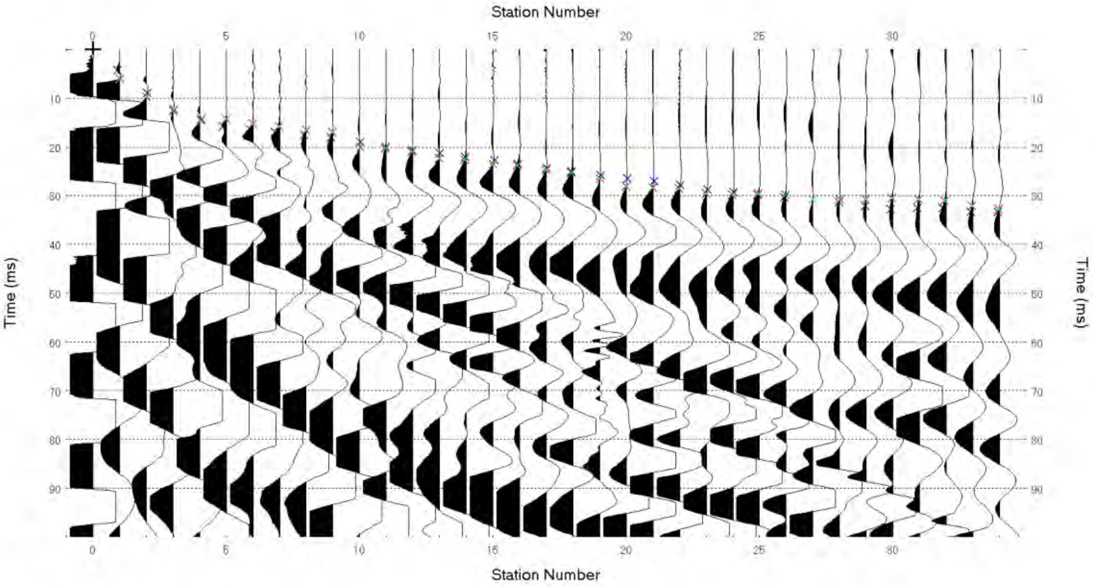
SRT Time Domain Traces and Breaks

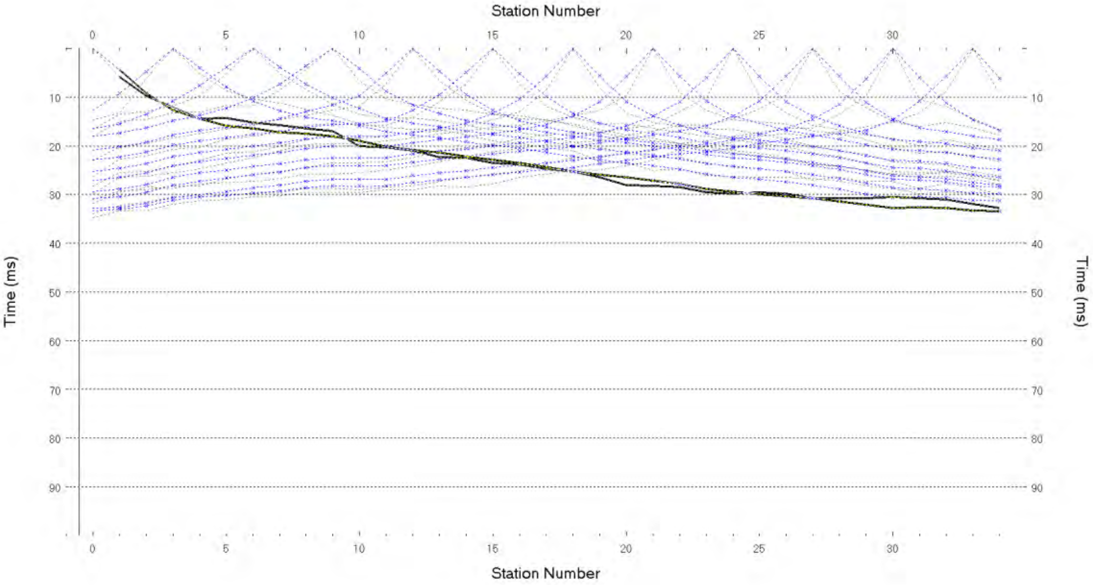


SRT21-01: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of all picks into a shot break profile (bottom).

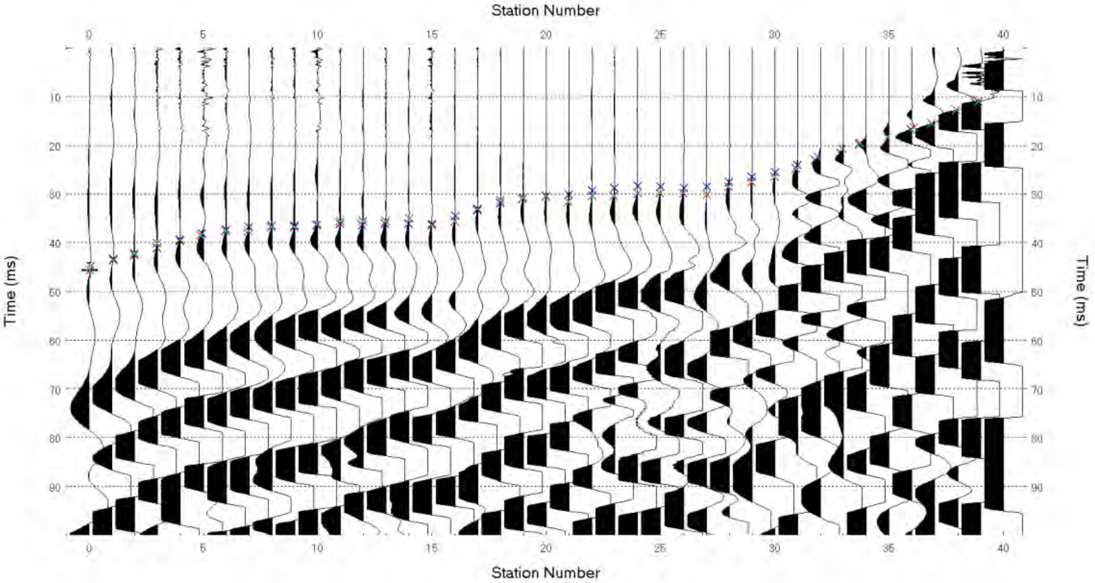


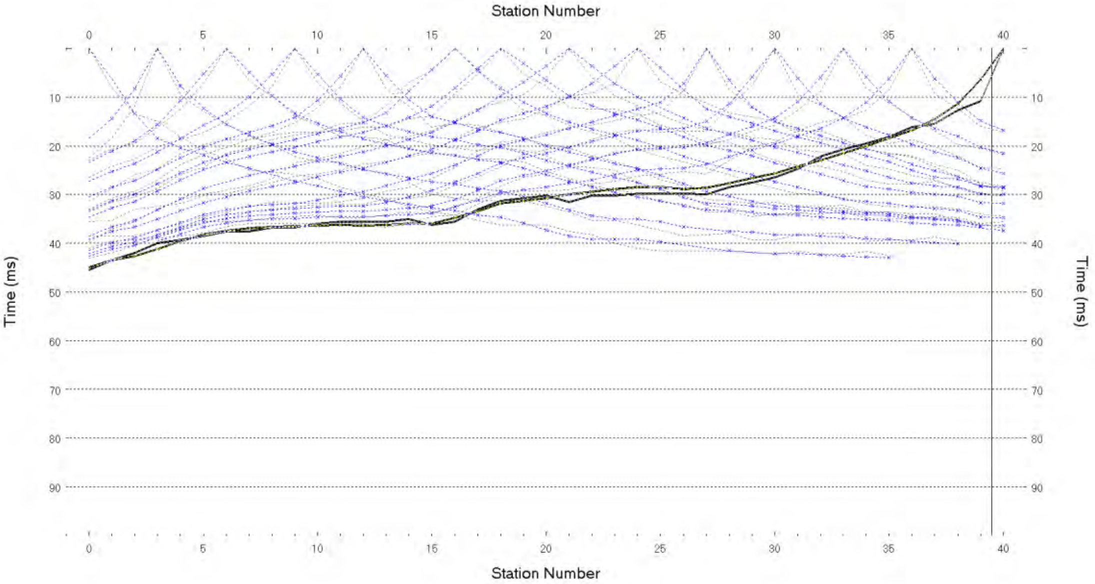
SRT21-02: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of all picks into a shot break profile (bottom).



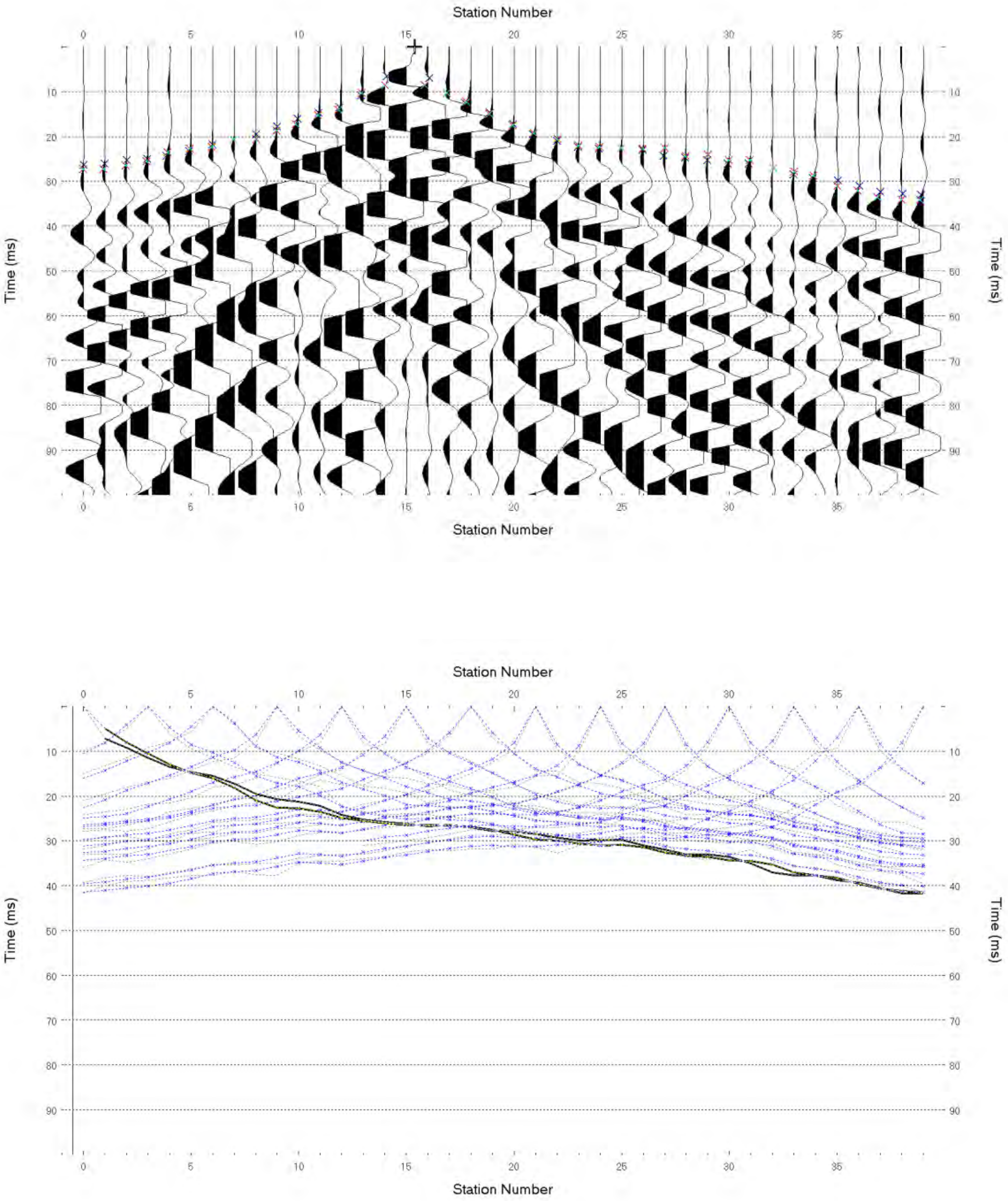


SRT21-03: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of all picks into a shot break profile (bottom).



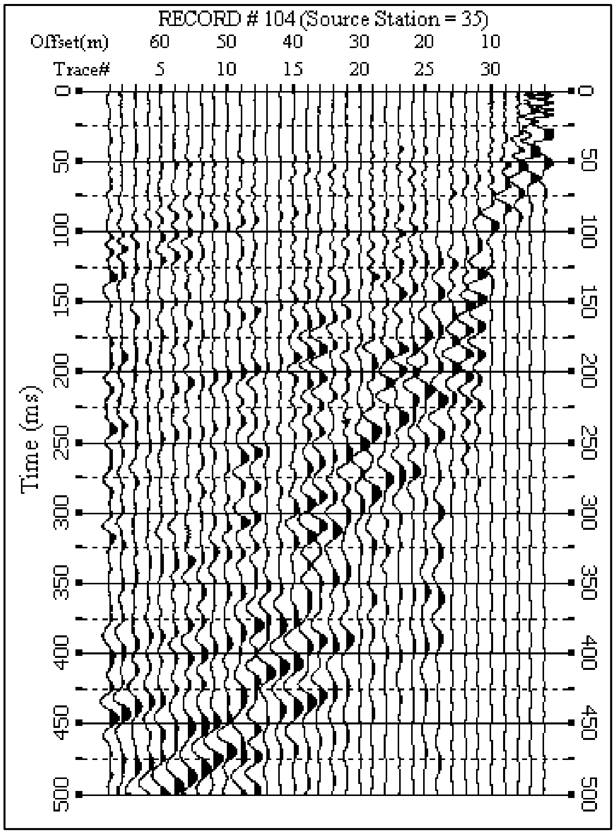


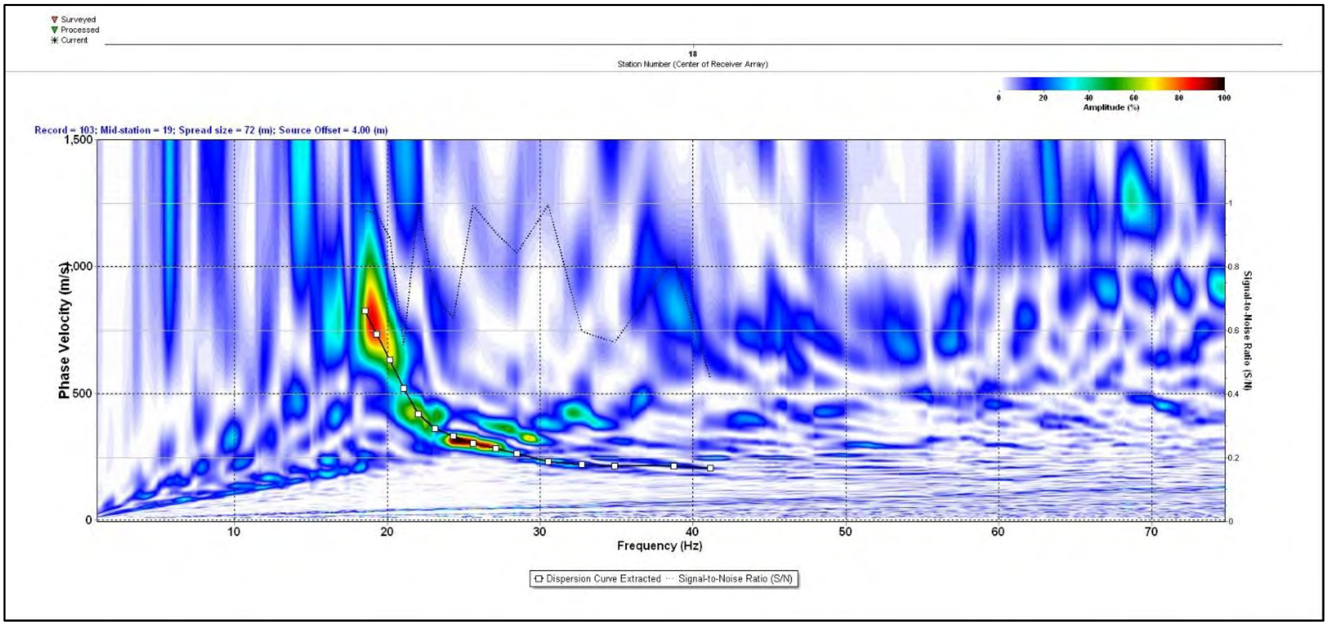
SRT21-04: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of picks into a shot break profile (bottom).



SRT21-05: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of picks into a shot break profile (bottom).

MASW Time Domain Traces and Overtone Images





MASW21-01: Example time domain trace (top) and overtone image with picked dispersion curve (bottom).

PRESENTATION OF SITE INVESTIGATION RESULTS

Taylor Way, West Vancouver

Prepared for:

Thurber Engineering Ltd.

ConeTec Job No: 21-02-21901.02

Project Start Date: 06-May-2021
Project End Date: 06-May-2021
Report Date: 19-May-2021

Prepared by:

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www.conetec.com
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Introduction

The enclosed report presents the results of the geophysical site investigation program conducted by ConeTec Investigations Ltd. for Thurber Engineering Ltd. at 725 Inglewood Avenue, West Vancouver, BC on the project titled *Taylor Way, West Vancouver*. This is the second visit to the site and consisted of 4 additional Seismic Refraction Tomography (SRT) lines and 5 passive seismic readings to provide estimates of depth to bedrock. The passive seismic dataset was analyzed using the Horizontal to Vertical Spectral Ratio (HVSR) to estimate depth to bedrock where SRT lines were not possible.

Project Information

Project	
Client	Thurber Engineering Ltd.
Project	Taylor Way, West Vancouver
ConeTec project number	21-02-21901.02

Coordinates		
Test Type	Collection Method	Coodinate Reference System
SRT, HVSR	Estimated from site measurements and satellite imagery.	NAD83 (CSRS) Horizontal Projection: UTM Zone 10 North Vertical Datum: CGVD28 HT_2.0(v70)

Line start and end coordinates were estimated from site measurements to known objects (curbs, trees and roadways) and satellite imagery, while station spacing was measured in the field with a tape. These measurements were used to generate Easting and Northing coordinates for each geophone location along each line. The elevation component for each station was then extracted from a publicly available Digital Elevation Model provided by the District of West Vancouver open data portal: https://mapping.westvancouver.ca/OD/dbo_OPENDATA_FILES_list.php?page=list
An overview map, showing all the work completed to date, is included in the appendices of this report.

Acquisition Procedure

The SRT dataset were acquired using the equipment outlined in the table below. A static receiver array was used for each line and each array using up to 48-channels with geophones placed every 2 meters along the survey lines. For line SRT21-07 a geophone spacing of 1 meter was used. A sledgehammer was used as a seismic source vertically impacting a thick aluminum plate on the ground. The first reading was gathered at the 0-meter station and then data was recorded every 4 meters (2 meters for SRT21-07) through each profile. Each source location had a minimum of 3 impacts collected and stacked to produce the seismic record. Passive seismic readings were collected using an ultra-low frequency 3-component seismograph and 16 minute record lengths.

Equipment Used for Seismic Testing on this Project				
Seismograph(s)	Geophones	Coupling Mechanism	Trigger Style	Seismic Sources
2 x Geometrics Geode 24	48 x Geospace 4.5 Hz vertical	Aluminium pucks/spikes	Piezoelectric trigger	10 lb sledgehammer
Tromino	3-component (internal)	Spikes and flat base	Internal timer	Passive

Data Analysis and Quality

The SRT data quality for this project was good, except for SRT21-09, and a clear first break refraction arrival is apparent on each seismic line. Traffic along Taylor Way was the main source of noise but was mitigated by timing the readings with pauses in traffic and by taking multiple stacks to improve the signal to noise ratio. Post processing techniques were also used to improve the signal quality. Example time domain traces and first break picks are included in the appendices of this report.

For line SRT21-09, a clear and consistent first break refraction was not observed. Most readings along this line appear to be corrupted by near time arrivals of unknown origin or cause. Due to the inconsistent nature of the data observed along SRT21-09 a full analysis was not completed to minimize the cost to the client.

The passive seismic data quality for readings HVSR21-06, 08 and 09 were sufficient for HVSR analysis and depth to bedrock modeling; however, this was not the case for readings HVSR21-05 and 07. The passive seismic method is very sensitive to near surface coupling, so it is likely that data quality at locations HVSR21-05 and 07 suffered as a result. Similarly, the overburden thickness on this site is thin such that peaks in the H/V spectral curve would occur in the 5-20 Hz frequency band. This frequency band overlaps with anthropogenic noise sources which are also apparent in readings HVSR21-05 and 07 and detrimental to data quality and interpretability.

Results

Inverted compression wave velocity (Vp) results are included in the appendices of this report. High resolution PDF profiles and CSV data files are included in the digital release. SRT cross sections were plotted at the same scale as the previous report, with the same project title, to aid in comparison. A 2-layer starting model was used to invert the SRT data assuming constant overburden and bedrock velocities with upper limits of 1000 and 4000 m/s respectively. The inverted compression wave velocity ranged from 300-4000 m/s. For profiles SRT21-06 to 08 a refractor was clearly observed and is interpreted as the transition between overburden sediments and bedrock. On the PDF cross sections, a dashed purple line denotes this interpreted transition.

From the HVSR dataset, 2-layer shear wave (Vs) velocity models were produced by fitting synthetic H/V spectral curves to the measured H/V spectral curves. Model input data used a constant overburden Vs value of 285 m/s (taken from previous MASW data on site), Poisson’s ratio of 0.35 and density of 1750 kg/m^3. The half-space was estimated to have a Vs range of 730-775 m/s, Poisson’s ratio of 0.41, and density of 2200 kg/m^3. Half-space velocity was adjusted for each model to match the amplitude of the synthetic H/V curve to the measured H/V curve. A summary table of the HVSR results are presented in the appendices of this report, along with detailed reports of the HVSR analysis and modeling.

Closure

Thank you for the opportunity to work on this project. The equipment used and the field procedures followed complied with current accepted practice standards. This report has been prepared under my supervision and I have reviewed and approved the content.

ConeTec Investigations Ltd.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
I. A. WEEMEES

19-May-2021

Chris Hermiston, GIT

Ilmar Weemees, P. Eng.

Limitations

3rd Party Disclaimer

This report titled “Taylor Way, West Vancouver”, referred to as the (“Report”), was prepared by ConeTec for Thurber Engineering Ltd. The Report is confidential and may not be distributed to or relied upon by any third parties without the express written consent of ConeTec. Any third parties gaining access to the Report do not acquire any rights as a result of such access. Any use which a third party makes of the Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. ConeTec accepts no responsibility for loss, damage and/or expense, if any, suffered by any third parties as a result of decisions made, or actions taken or not taken, which are in any way based on, or related to, the Report or any portion(s) thereof.

Client Disclaimer

ConeTec was retained by Thurber Engineering Ltd. to collect Seismic Refraction and Passive Seismic data to provide depth to bedrock estimates (“Data”) which is included in this report titled “Taylor Way, West Vancouver”, which is referred to as the (“Report”). ConeTec has collected and reported the Data in accordance with current industry standards. No other warranty, express or implied, with respect to the Data is made by ConeTec. In order to properly understand the Data included in the Report, reference must be made to the documents accompanying and other sources referenced in the Report in their entirety. Other than the Data, the contents of the Report should not be relied upon in any fashion without independent verification and ConeTec is in no way responsible for any loss, damage or expense resulting from the use of, and/or reliance on, such material by any party.

The seismic refraction method is a non-intrusive test that utilizes seismic wave propagation to image the subsurface. The geophysical property that is measured in seismic refraction is seismic velocity, usually the compression wave (P-wave) velocity. P-waves propagate at the highest velocity of any seismic waves and are therefore commonly used to pick the first breaks of waves that propagate through earth materials. The first break picks (Figure SRT-1) can be used with travel time equations to determine the depth to a refractor such as bedrock or to discriminate between geological layers.

Refracted seismic waves involve energy that travels through a lower velocity layer and enters a higher velocity medium (refractor) near the critical angle. The seismic waves travel in the high velocity medium along the refractor surface. Since seismic waves move faster in the high velocity medium than the lower velocity layer above it, the wave refracted along that surface will overtake the direct wave. This refracted wave then becomes measured as the first arrival at all subsequent geophones (Figure SRT-2). The velocity of the refracted layer can be computed from the travel time difference of first arrivals given a known distance between the geophones. The time when the refracted wave overtakes the direct arrival is called the “critical distance”, and can be used to estimate the depth to the initial refractor.

The field methods used for refraction seismic testing involve laying out a seismic cable, attaching a number of geophones (usually 24 or more) to it and connecting it to a seismograph. For a two dimensional test, surface geophones are placed in a linear array along a survey line at a known separation. A series of recordings (shots) are collected at known offsets from the either end of the array as well as a number of known locations within the array. The information recorded is called a shot trace and is represented in the time domain (Figure SRT-1). These traces are used to pick the first arrival and the amalgamation of these picks are plotted together to form the shot break (Figure SRT-3). For detailed analysis, frequent shot records collected throughout the array help better constrain the modelled seismic velocity of the medium. The test equipment and procedures are in general accordance with the current ASTM D5777 standards.

The depth of investigation is directly related to the ground conditions of the medium being surveyed, though there are a couple parameters of the survey design that can be changed to modify the depth or resolution of the survey. One parameter that can be changed is the length of the array. The depth modelled is typically between one-third and one-fifth of the spread length, where a longer spread size corresponds to deeper investigation. A more powerful source can also improve the depth of investigation as energy attenuation becomes a factor, by providing cleaner data to pick from. A sledgehammer source is sufficient in the tens of meters, whereas larger sources are needed for deeper investigation. Parameters directly related to resolution are the separation distance between geophones and the separation distance between recordings. Reducing the separation distance of the geophones will create better vertical and horizontal resolution in the finished product. Similarly, more frequent recordings (smaller recording spacing) will provide more data to work with and lead to a model with better resolution.

Interpretation of the seismic data first requires picking the first breaks from the time domain record. From these picks a host of characteristics can be determined, such as; the number of layers present, the velocity of each layer, and the travel time taken to travel from a given refractor to the surface and the thickness of each layer. This data is inverted to create a final subsurface model. ConeTec uses Rayfract® Standard 3.33, created by Intelligent Resources Inc., for the analysis and inversion of the refraction data. For more information about Rayfract®, refer to http://rayfract.com/.

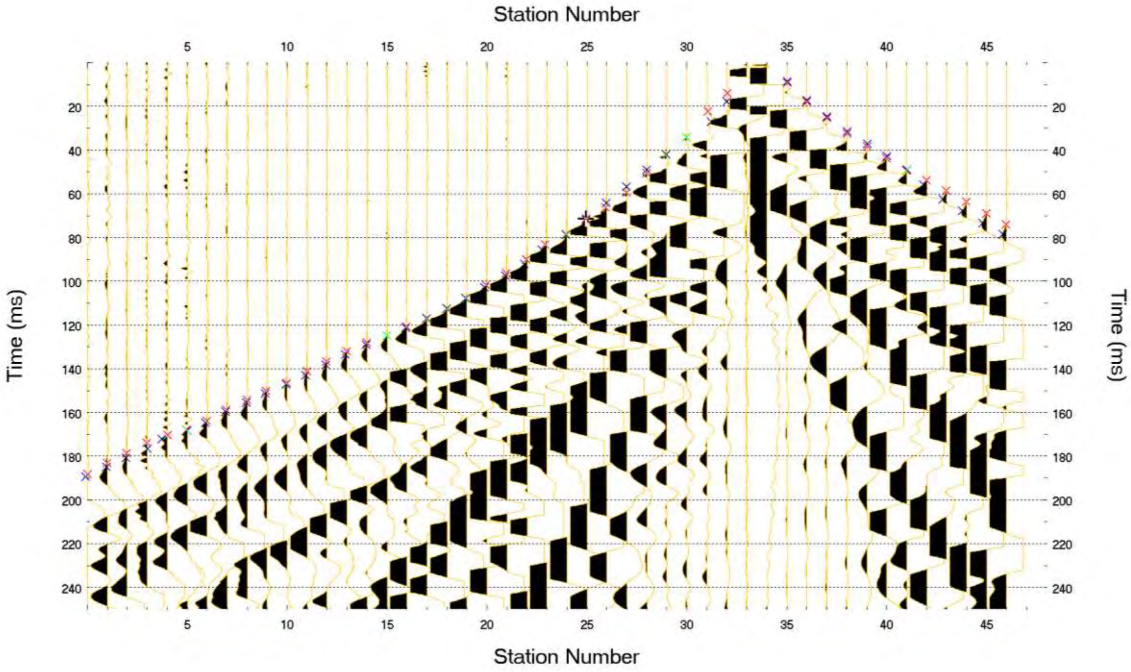


Figure SRT-1. Typical refraction time domain record (shot trace) with picks.

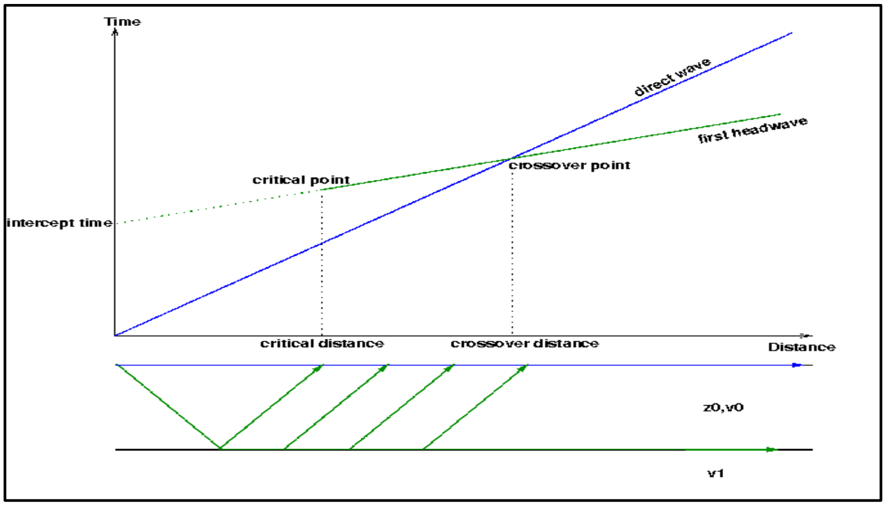


Figure SRT-2. Propagating seismic waves (bottom) and related travel time diagram (top) of the direct (blue) and the first refracted phase (green).

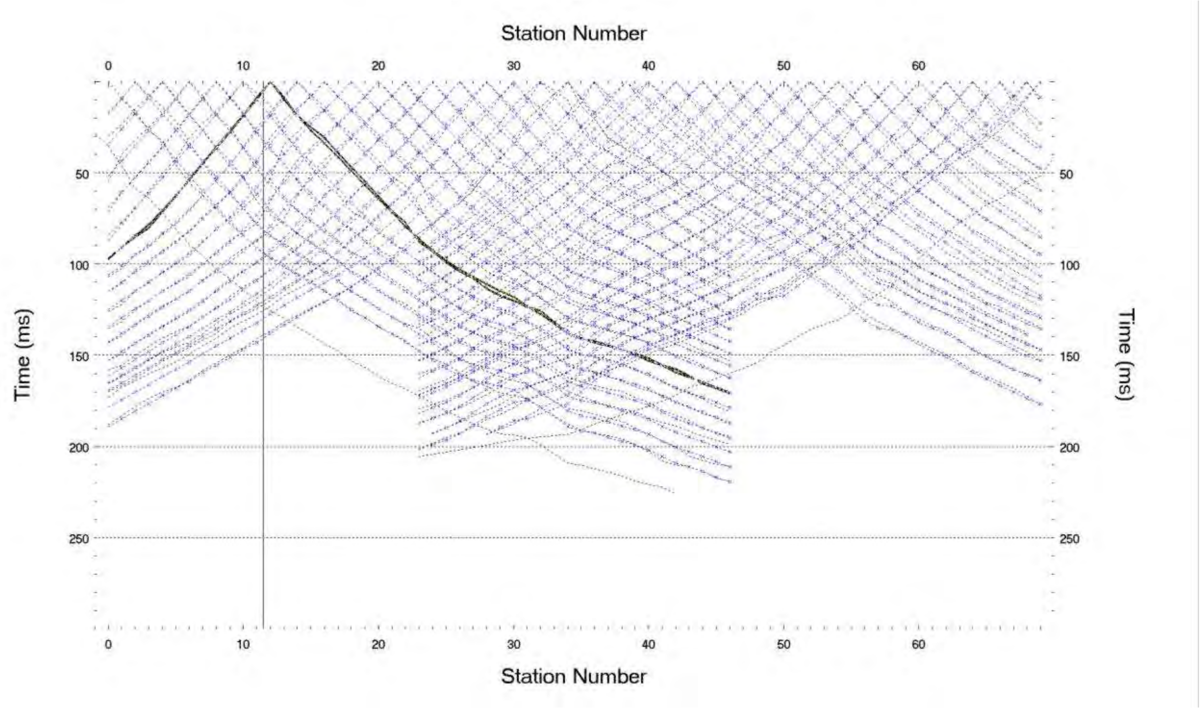


Figure SRT-3. Typical refraction time domain shot breaks record.

The equipment, field procedures, and analysis software used by ConeTec all conform to the currently accepted best practices for near surface refraction testing. It should be noted that the refraction method is not able to determine a lower velocity layer below a higher velocity layer, also known as a velocity reversal. The method may also be insensitive to thin layers immediately above high velocity layers, which is referred to as the hidden layer problem. The results of geophysical testing are always interpretative to a certain extent and should be confirmed by drilling or other intrusive testing. While efforts have been made to provide the best possible information, ConeTec does not warranty this report to be free from errors or inaccuracies.

References

ASTM D5777-18, 2018, "Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation", ASTM International, West Conshohocken, PA. DOI:10.1520/D5777-18.

Brueckl, E., 1987, The interpretation of traveltime fields in refraction seismology, Geophysical Prospecting, volume 35, pp. 973-992.

Greenhalgh, S.A. and Whiteley, R.J., 1977, Effective application of the seismic refraction method to highway engineering projects, Australian Road Research, volume 7, No. 1, pp. 3-20.

Palmer, D., 2009, Maximising the lateral resolution of near-surface seismic refraction methods, Exploration Geophysics, volume 40, pp. 85-98. (copublished in Butsuri-Tansa and Mulli-Tansa)

Schuster, G.T. and Quintus-Bosz, A., 1993, Wavepath eikonal traveltime inversion: Theory, Geophysics, volume 58, pp. 1314-1323.

Watanabe, T., Matsuoka, T., and Ashida, Y., 1999, Seismic traveltime tomography using Fresnel volume approach, Society of Exploration Geophysicists Meeting, Houston, Texas, Expanded Abstracts.

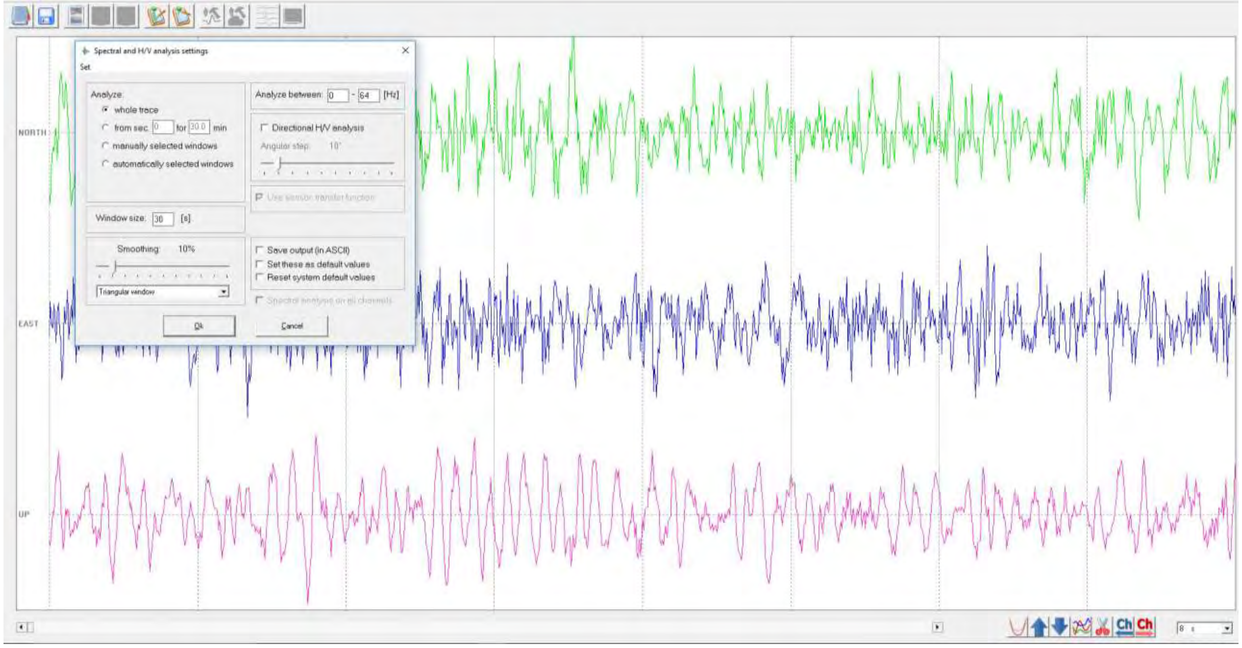
White, D.J., 1989, Two-dimensional seismic refraction tomography. Geophysical Journal, volume 97, pp. 223-245.

The horizontal to vertical spectral ratio (HVSR) method is a passive seismic technique that can be used to measure site period, estimate sediment thickness or the depth to bedrock. HVSR uses the ratio of the average horizontal and vertical component amplitude spectrums to generate a spectral ratio curve with a peak at the fundamental resonance frequency (f_0). A low frequency multi-component seismograph is used to measure the horizontal and vertical components of ambient seismic noise. These elastic waves are created naturally by sea and wind action but can also be produced at higher frequencies through anthropogenic sources such as vehicle traffic or industrial activity. The HVSR method is best suited to sites with a sharp contrast in acoustic impedance at the sediment-bedrock interface.

A measure of the site period or resonant frequency can be important in determining how a site will respond during an earthquake. In instances where multiple peaks are measured in the spectral response, the peak with the highest amplitude is considered the site period. If multiple peaks are near the same amplitude, then multiple site periods will be reported. If a velocity profile is known, the HVSR data can be used to estimate depth to bedrock. This information is often used to produce depth to bedrock plan view maps over large areas. The reverse is also true where if the depth to bedrock is known then an average velocity of the overburden can be estimated.

Prior to collecting data, a measurement location is selected to avoid heavy traffic, industrial noise and artificial ground surfaces such as asphalt, pavement, or cement or as directed by the client. If many readings will be taken across a site, then the seismometer will be placed in a common orientation for each reading. Typically, spikes attached to the bottom of the sensor are used to couple it to the ground. Good coupling, where the ground tightly holds on to the spikes, is essential for high quality data. After the equipment is coupled, it is levelled using the built-in level. Data is typically recorded with a sampling frequency of 128 Hz. In general, longer readings can detect lower frequencies, down to a limit of 0.1 Hz. Lower frequency data typically correspond to deeper investigation depths. A 15 to 20-minute reading will be able to measure frequencies down to the 0.5 Hz range with a depth of investigation of 100 meters or more. Once the reading has started the user walks away and waits for the reading to complete.

The passive seismic data is analyzed using software developed by MoHo s.r.l. An example HVSR time domain record is shown in Figure HVSR-1.



Spectral and H/V analysis settings

Set

Analyze:
● whole trace
○ from sec. 0 for 30.0 min
○ manually selected windows
○ automatically selected windows

Window size: 30 [s]

Smoothing: 10%

Triangular window

Analyze between: 0 - 64 [Hz]

☐ Directional H/V analysis

Angular step: 10°

☑ Use sensor transfer function

☐ Save output (in ASCII)
☐ Set these as default values
☐ Reset system default values

☐ Spectral analysis on all channels

Ok
Cancel

Figure HVSR-1. Typical HVSR time domain record

Post processing typically includes band-pass filtering to remove high frequency noise and spectral smoothing. The software computes the average spectrums of the horizontal and vertical components over a user-specified time window. After selecting processing parameters, a series of windows are used to analyse the data (Figure HVSR-2). These windows include the H/V stability, the amplitude spectra, and the H/V curve. The H/V stability window shows the signal response of the sensor over time and is used to edit out noise. Amplitude spectra show the amplitude of certain frequency bands for each orthogonal sensor and are used to compare the response of each component and to help differentiate peaks that are stratigraphic in origin from anthropic. The H/V curve shows the ratio between the horizontal readings and the vertical readings and the standard deviations. It is used to determine the site period for the reading by locating the H/V peak.

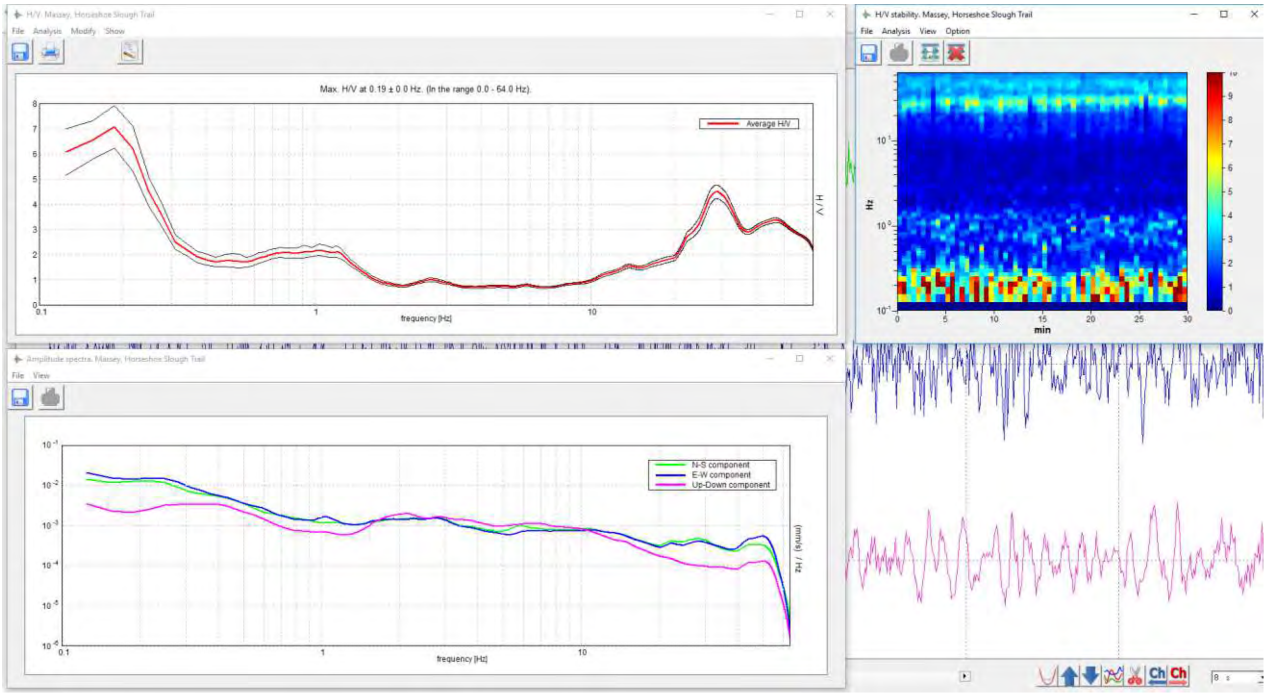
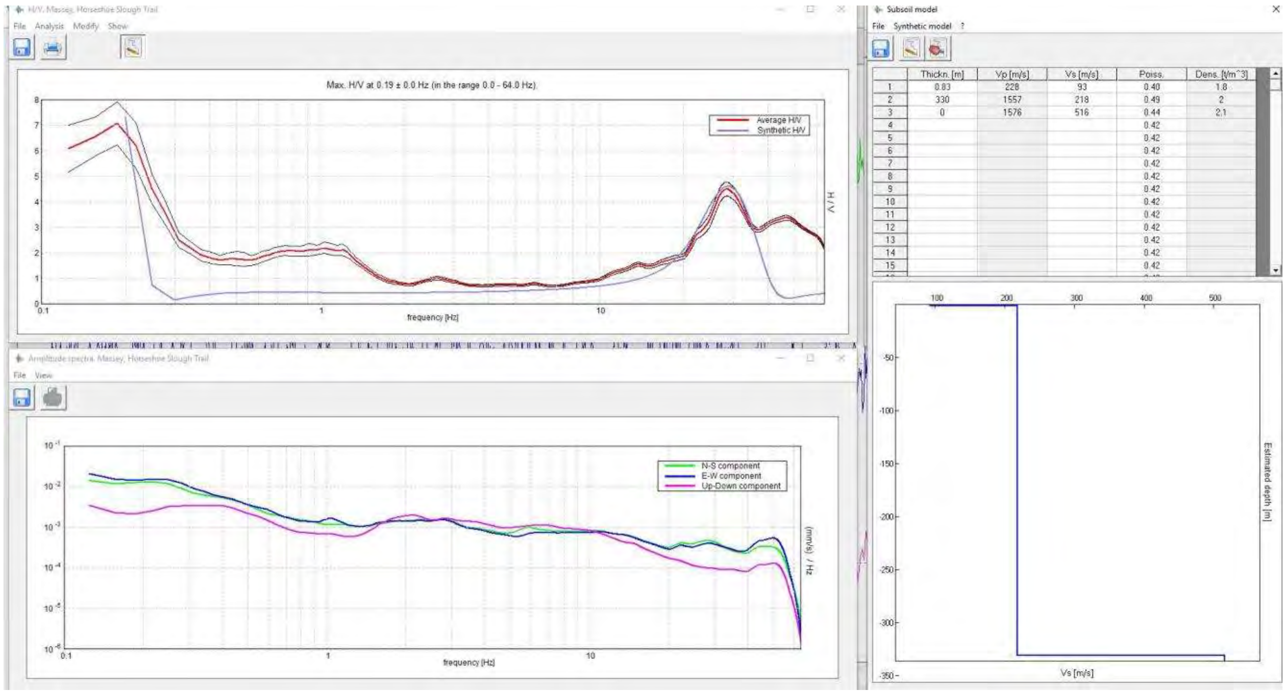


Figure HVSR-2. H/V processing windows

If the purpose of the test is to determine shear wave velocity or layer thickness, then the next step is to fit a model to the H/V curve. The model is built in a table containing Vs, Vp, layer thickness, Poisson's ratio and density (Figure HVSR-3). If a layer thickness or Vs is known, the remainder of the table can be populated to create a model that fits the H/V curve.



	Thickn. [m]	Vp [m/s]	Vs [m/s]	Poiss.	Dens. [t/m^3]
1	0.83	228	93	0.40	1.8
2	330	1557	218	0.49	2
3	0	1576	516	0.44	2.1
4				0.42	
5				0.42	
6				0.42	
7				0.42	
8				0.42	
9				0.42	
10				0.42	
11				0.42	
12				0.42	
13				0.42	
14				0.42	
15				0.42	

Figure HVSR-3. H/V processing windows with modeled data

For each test location, a site period value is provided. Lower frequencies require longer reading times to collect statistically significant values. Ground conditions, reflector topography, velocity contrast between layers and site noise can all have significant impacts on the reading quality. As lower frequencies are recorded there will be less certainty in terms of period. Likewise, if the site period is translated to shear wave velocity or layer thickness, there will be less certainty in those values as the depth of investigation increases.

The equipment, field procedures, and analysis software used by ConeTec are in general accordance with the SESAME (2004) guidelines. The results of geophysical testing are always interpretative to a certain extent and should be used as a part of a larger site investigation.

References

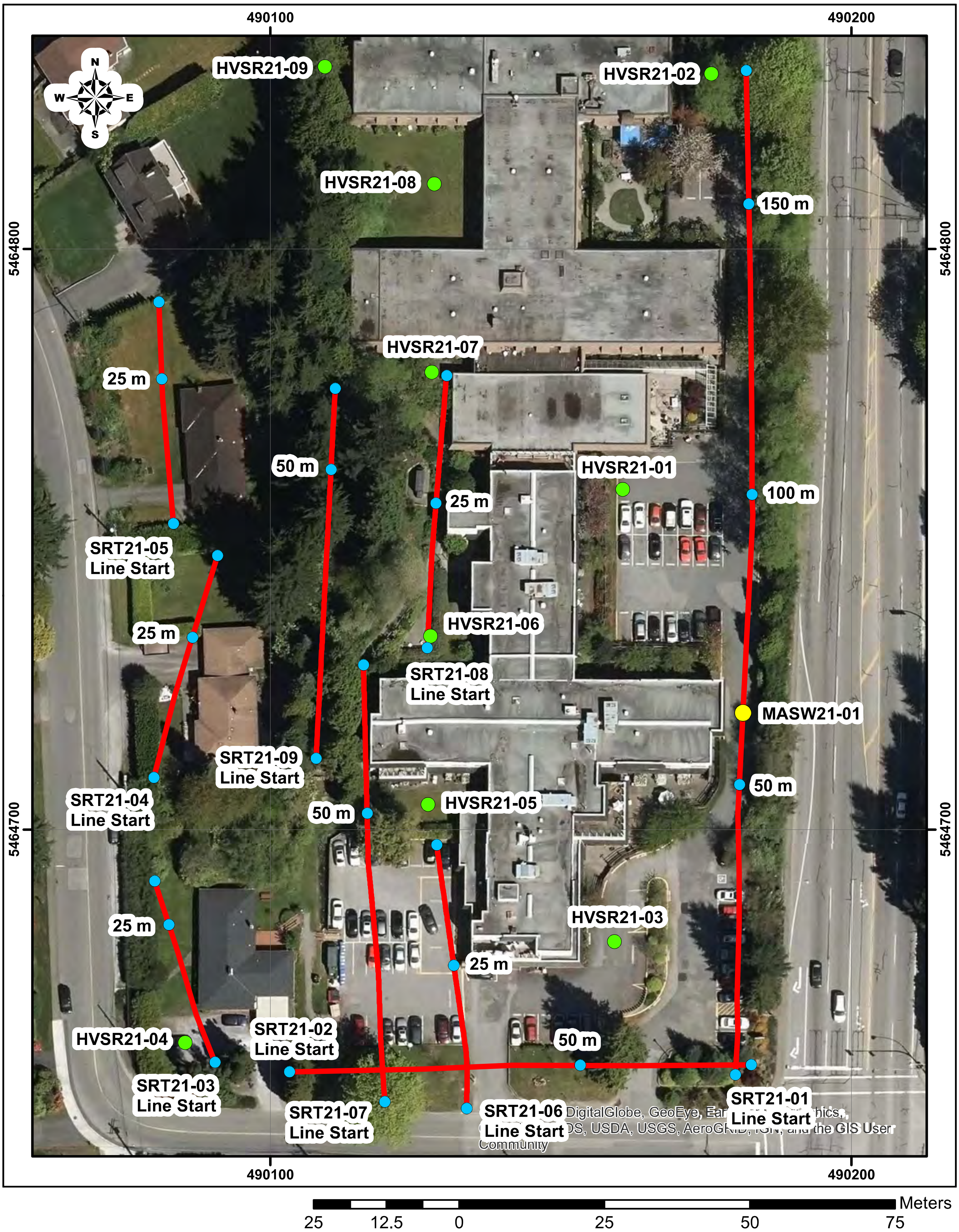
SESAME European Research Project WP12 – Deliverable D23.12 (2004), Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations Measurements, Processing and interpretation: European Commission – Research General Directorate
Project No. EVG1-CT-2000-00026 SESAME

The following appendices listed below are included in the report:

- Overview Map
- SRT Summary and Results
- HVSR Summary and Results
- SRT Time Domain Traces and Breaks

Overview Map

Thurber Engineering Ltd. - Taylor Way



Legend

● HVSR Location

● MASW21-01

— Seismic Line

ConeTec Job Number: 21-02-21901
Survey Date: 06-Feb-2021 and 06-May-2021
Unit: meters
Map Scale 1:850
Coordinate System: NAD 1983 CSRS UTM Zone 10N
Projection: Transverse Mercator
Vertical Datum: CGVD28

ConeTec

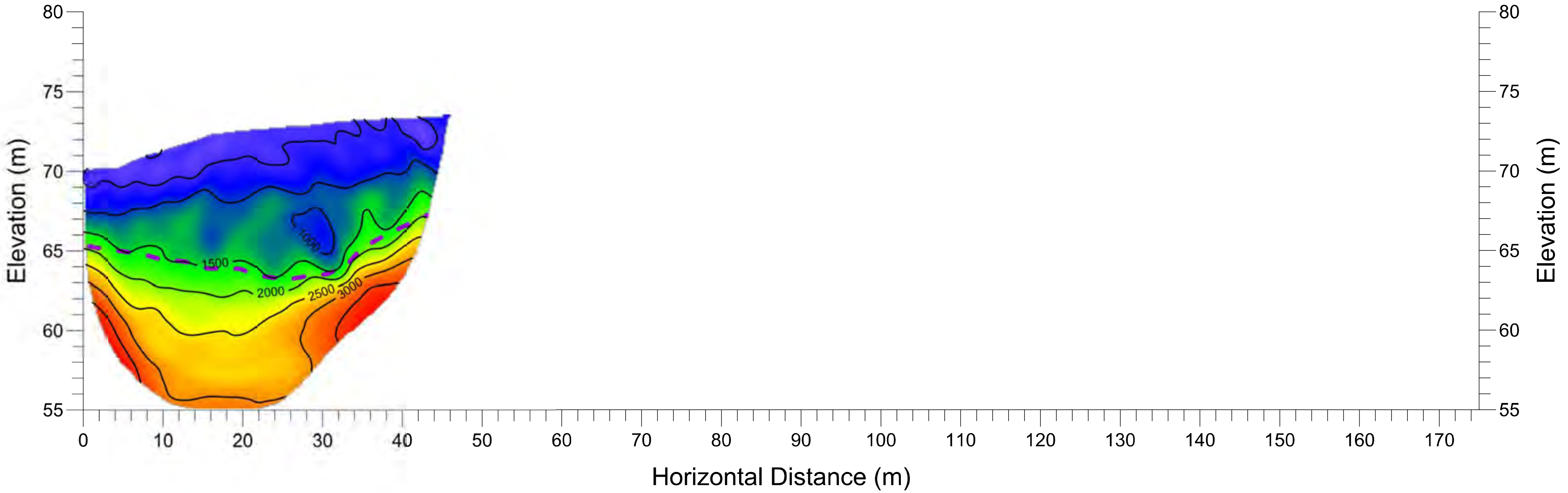
SRT Summary and Results

Job No: 21-02-21901.02
Client: Thurber Engineering Ltd.
Project: Taylor Way, West Vancouver
Start Date: 06-May-2021
End Date: 06-May-2021

SRT TEST SUMMARY

Section ID	Date	Source Type	Geophone Spacing (m)	Shot Spacing (m)	Section Length (m)	Array Length (m)	Start of Section Northing[1] (m)	Start of Section Easting (m)	End of Section Northing (m)	End of Section Easting (m)	Refer to Notation Number
SRT21-06	06-May-2021	Sledgehammer	2.0	4.0	46	46	5464652	490134	5464698	490129	
SRT21-07	06-May-2021	Sledgehammer	2.0	4.0	74	74	5464653	490120	5464728	490116	
SRT21-08	06-May-2021	Sledgehammer	1.0	2.0	48	48	5464731	490127	5464779	490130	
SRT21-09	06-May-2021	Sledgehammer	2.0	4.0	64	64	5464712	490108	5464776	490111	2

1. Coordinates were estimated from field measurements and satellite imagery and are referenced to NAD83(CSRS) UTM Zone 10 North
2. SRT21-09 data quality not sufficient for analysis



Interpreted Bedrock Surface

* Vertical Exaggeration of 2:1

THURBER ENGINEERING LTD.

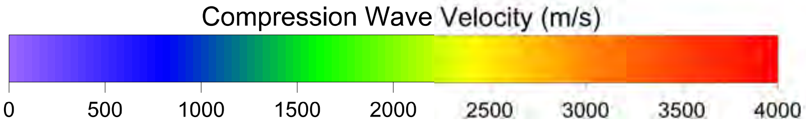
Taylor Way, West Vancouver

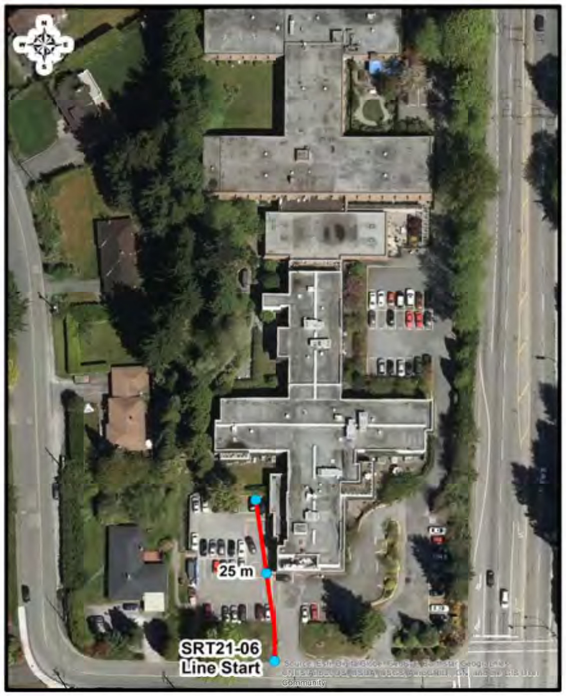
CONETEC

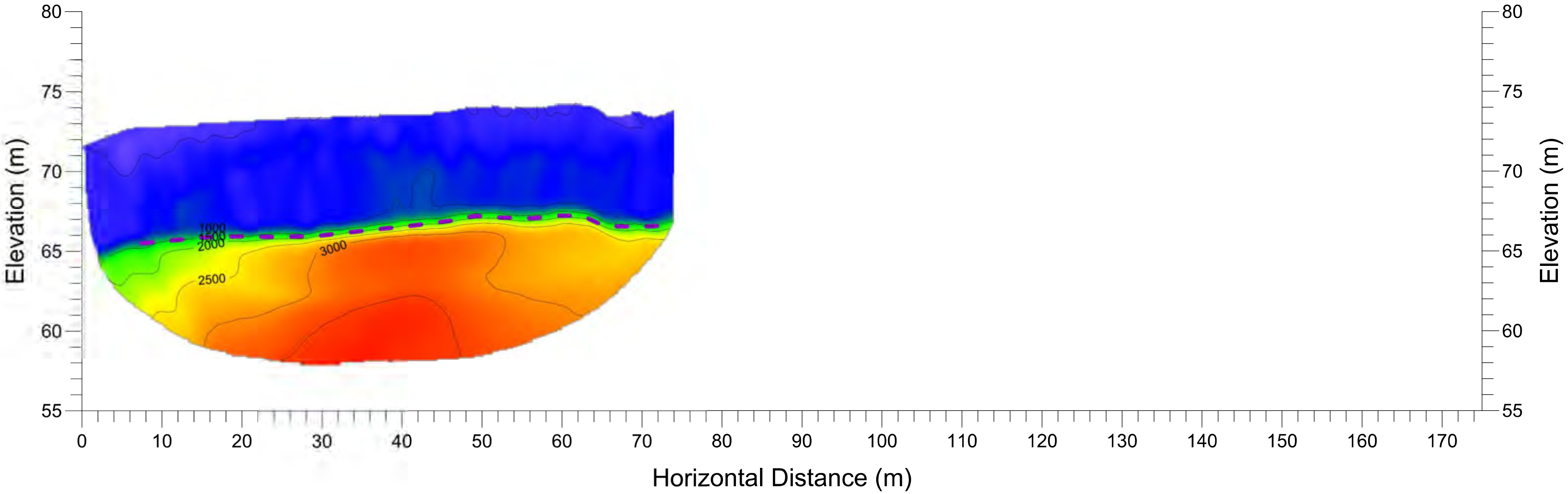
FIGURE 6

SRT21-06: 0 to 46 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-MAY-2021
SURVEY DATE(S)	06-MAY-2021
CONETEC JOB NUMBER	21-02-21901







— Interpreted Bedrock Surface

* Vertical Exaggeration of 2:1

THURBER ENGINEERING LTD.

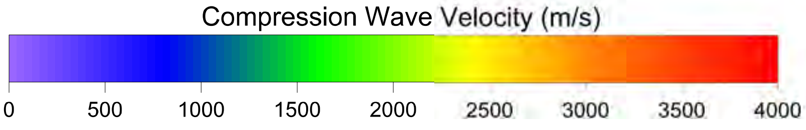
Taylor Way, West Vancouver

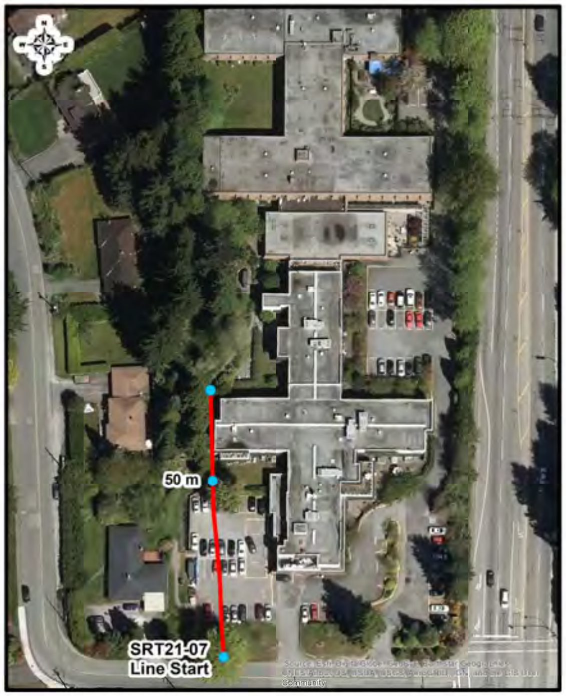
CONETEC

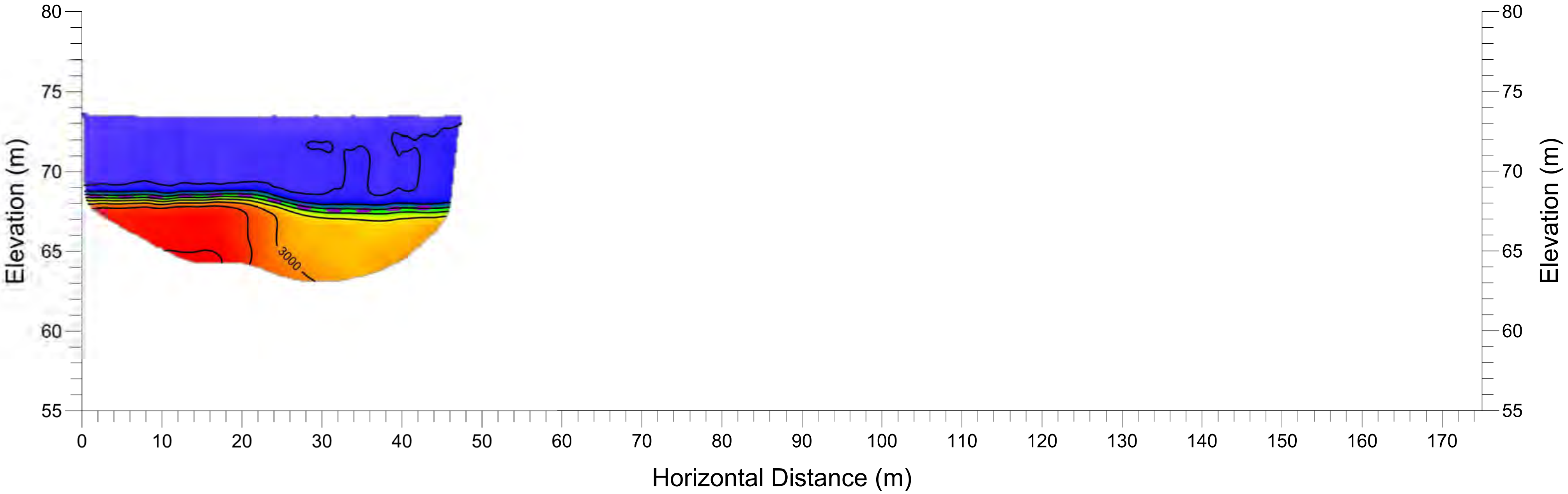
FIGURE 7

SRT21-07: 0 to 74 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	17-MAY-2021
SURVEY DATE(S)	06-MAY-2021
CONETEC JOB NUMBER	21-02-21901







— Interpreted Bedrock Surface

* Vertical Exaggeration of 2:1

THURBER ENGINEERING LTD.

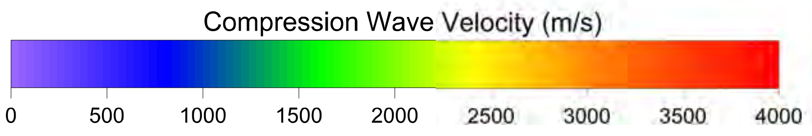
Taylor Way, West Vancouver

CONETEC

FIGURE 8

SRT21-08: 0 to 48 m

INFORMATION TABLE	
HORIZONTAL DATUM	NAD 83 CSRS
PROJECTION	UTM Zone 10 North
VERTICAL REFERENCE	CGVD26 HT_2.0
DATE(S) ISSUED / REVISED	18-MAY-2021
SURVEY DATE(S)	06-MAY-2021
CONETEC JOB NUMBER	21-02-21901



HVSR Summary and Results

CONETEC

Job No: 21-02-21901.02
Client: Thurber Engineering Ltd.
Project: Taylor Way, West Vancouver
Start Date: 06-May-2021
End Date: 06-May-2021

HVSR TEST SUMMARY

Sounding ID	Date	Location	Reading Length (min)	Resonant Frequency (Hz)	Estimated Overburden Vs (m/s)	Estimated Depth to Half-space (m)	Estimated Half-space Elevation (m)	Reliable H/V Curve	Clear H/V Peak	Northing[1] (m)	Easting[1] (m)	Surface Elevation[2] (m)	Refer to Notation Number
HVSR21-05	06-May-2021	HVSR21-05	20	-	-	-	-	-	-	490127.1	5464704.3	73.5	3
HVSR21-06	06-May-2021	HVSR21-06	16	18.0 ± 0.01	285	4.5	69.0	Y	Y	490127.5	5464733.3	73.5	
HVSR21-07	06-May-2021	HVSR21-07	16	-	-	-	-	-	-	490127.7	5464778.7	73.5	3
HVSR21-08	06-May-2021	HVSR21-08	16	11.94 ± 1.74	285	6.0	67.6	Y	N	490128.2	5464811.1	73.6	
HVSR21-09	06-May-2021	HVSR21-09	16	9.81 ± 0.39	285	8.5	65.4	Y	Y	490109.4	5464831.3	73.9	

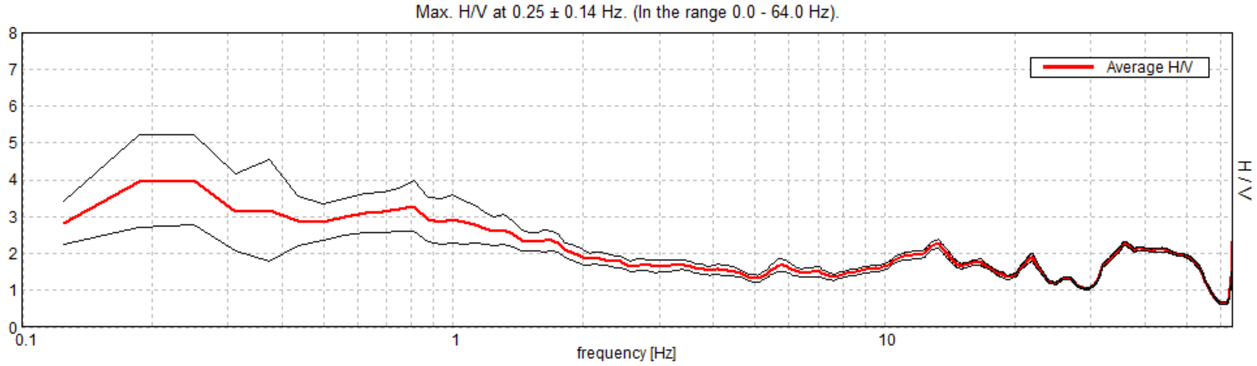
1. Coordinates were collected using consumer-grade GPS device with datum: NAD83(CSRS) UTM Zone 10 North
2. Surface elevation at the time of testing and referenced to vertical datum CGVD28 HT_2.0
3. Data quality not sufficient for modeling and interpretations

WEST VAN, HVSR21 05

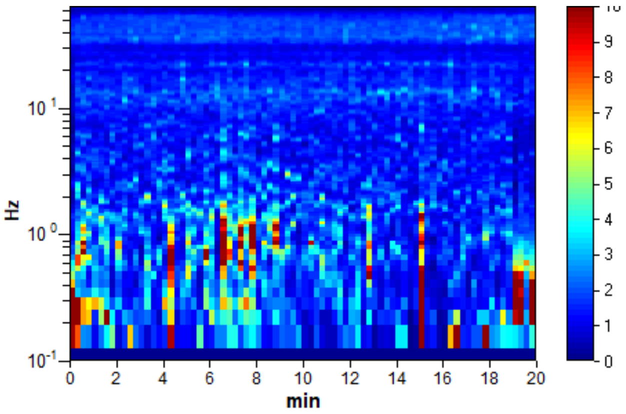
Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/05/21 16:25:07 End recording: 06/05/21 16:45:07
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

Trace length: 0h20'00". Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 7%

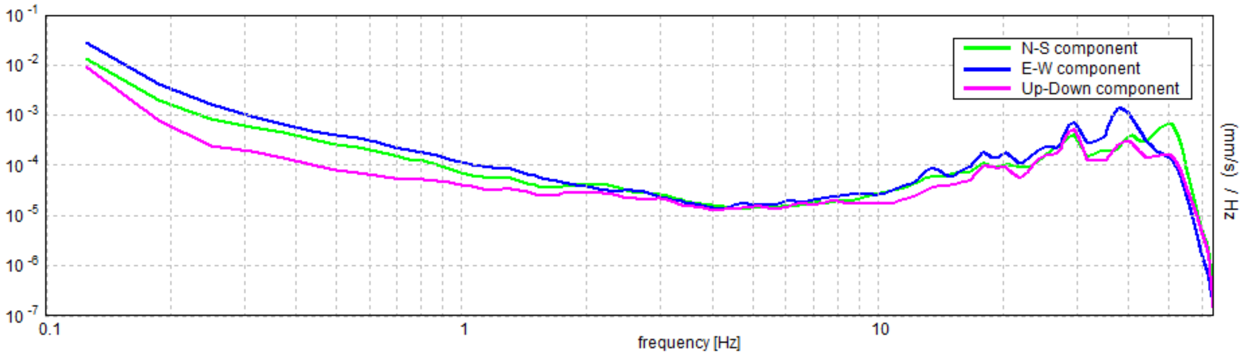
HORIZONTAL TO VERTICAL SPECTRAL RATIO



H/V TIME HISTORY



SINGLE COMPONENT SPECTRA



[According to the SESAME, 2005 guidelines. **Please read carefully the *Grilla* manual before interpreting the following tables.**]

Max. H/V at 0.25 ± 0.14 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$\mathbf{f_0 > 10 / L_w}$	0.25 > 0.67		NO
$\mathbf{n_c(f_0) > 200}$	300.0 > 200	OK	
$\mathbf{\sigma_A(f) < 2}$ **for** $\mathbf{0.5f_0 < f < 2f_0}$ **if** $\mathbf{f_0 > 0.5Hz}$ $\mathbf{\sigma_A(f) < 3}$ **for** $\mathbf{0.5f_0 < f < 2f_0}$ **if** $\mathbf{f_0 < 0.5Hz}$	Exceeded 0 out of 7 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists $\mathbf{f^-}$ **in** $\mathbf{[f_0/4, f_0] \mid A_{H/V}(f^-) < A_0 / 2}$	0.063 Hz	OK	
Exists $\mathbf{f^+}$ **in** $\mathbf{[f_0, 4f_0] \mid A_{H/V}(f^+) < A_0 / 2}$			NO
$\mathbf{A_0 > 2}$	4.00 > 2	OK	
$\mathbf{f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%}$	|0.54343| < 0.05		NO
$\mathbf{\sigma_f < \varepsilon(f_0)}$	0.13586 < 0.05		NO
$\mathbf{\sigma_A(f_0) < \theta(f_0)}$	1.223 < 2.5	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$

Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

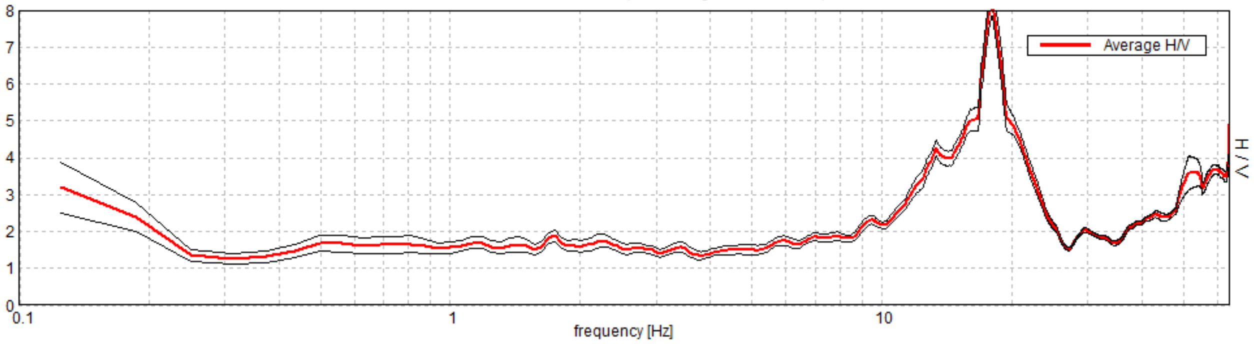
WEST VAN, HVSR21 06

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/05/21 16:53:56 End recording: 06/05/21 17:09:56
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

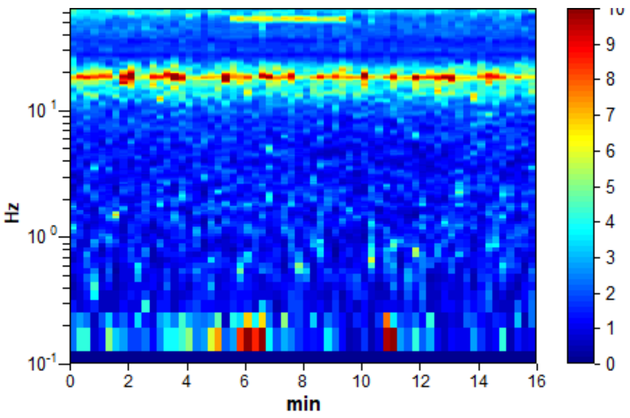
Trace length: 0h16'00''. Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 7%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

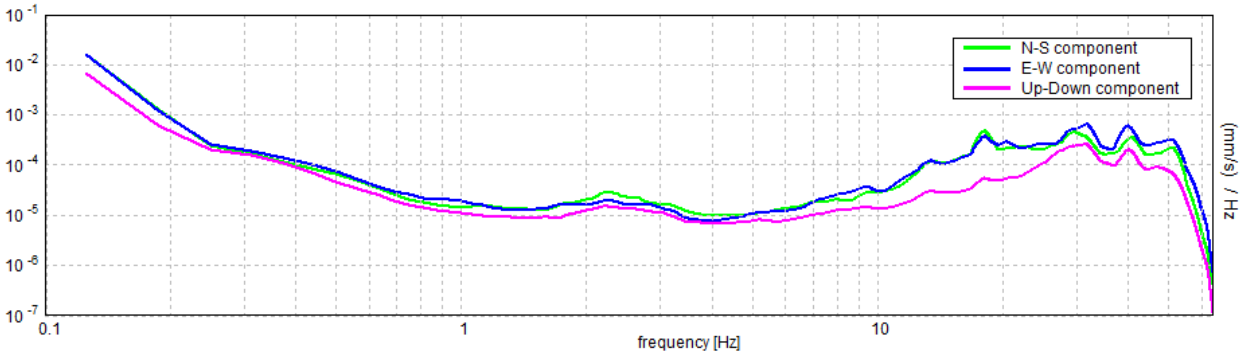
Max. H/V at 18.0 ± 0.0 Hz. (In the range 0.0 - 64.0 Hz).



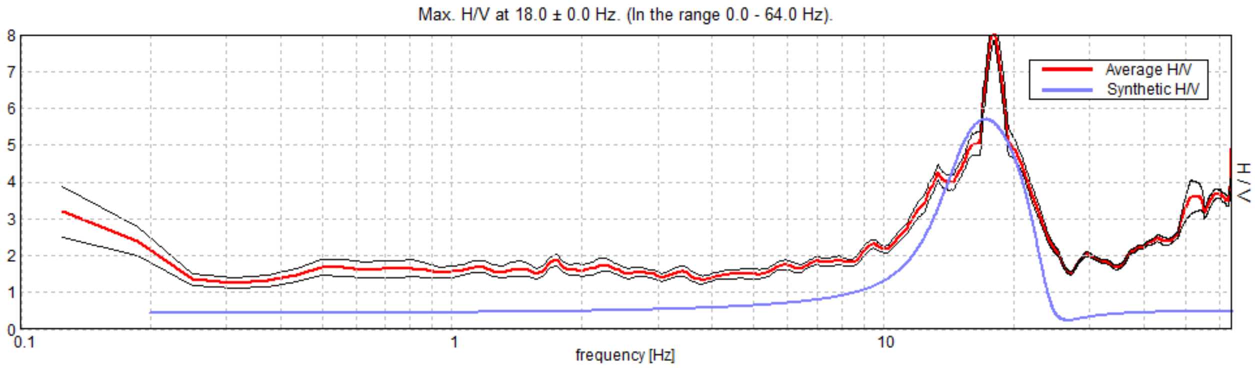
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

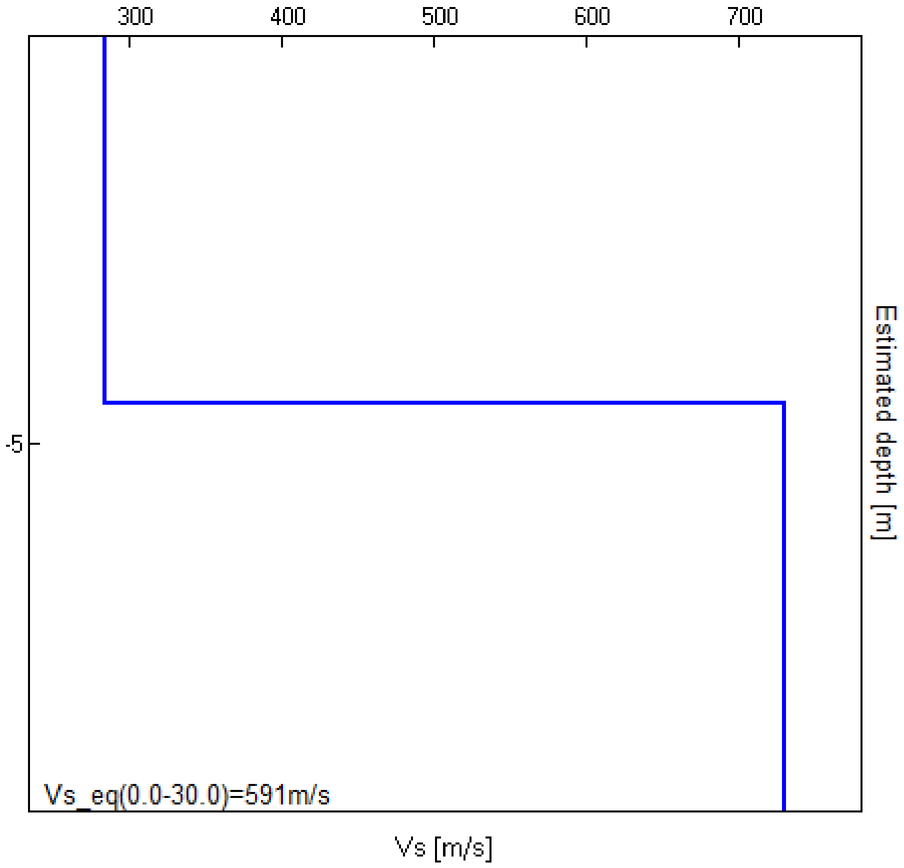


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
4.50	4.50	285	0.35
inf.	inf.	730	0.41

Vs_eq(0.0-30.0)=591m/s



[According to the SESAME, 2005 guidelines. **Please read carefully the** *Grilla* **manual before interpreting the following tables.**]

Max. H/V at 18.0 ± 0.0 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	18.00 > 0.67	OK	
$n_c(f_0) > 200$	17280.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5$Hz **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5$Hz**	Exceeded 0 out of 433 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	14.688 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	21.438 Hz	OK	
$A_0 > 2$	8.24 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.0| < 0.05	OK	
$\sigma_f < \varepsilon(f_0)$	0.0 < 0.9	OK	
$\sigma_A(f_0) < \theta(f_0)$	0.4016 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

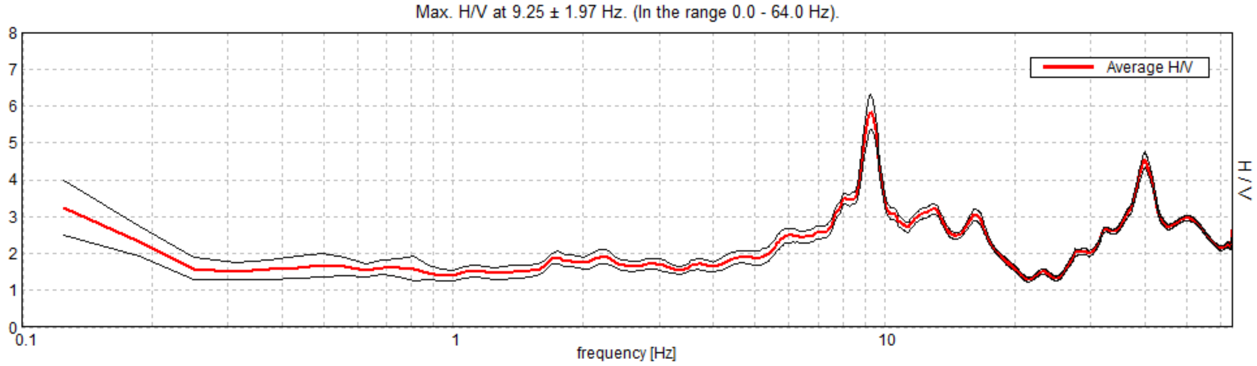
Threshold values for σ_f and $\sigma_A(f_0)$					
Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

WESTVANTHURBER, WV HVSR21 07

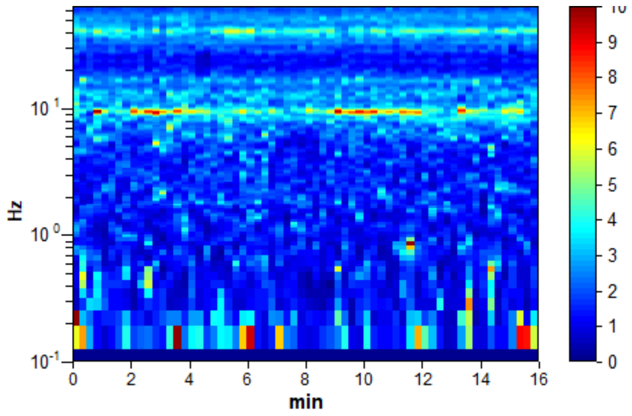
Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/05/21 17:18:46 End recording: 06/05/21 17:34:46
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

Trace length: 0h16'00". Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 7%

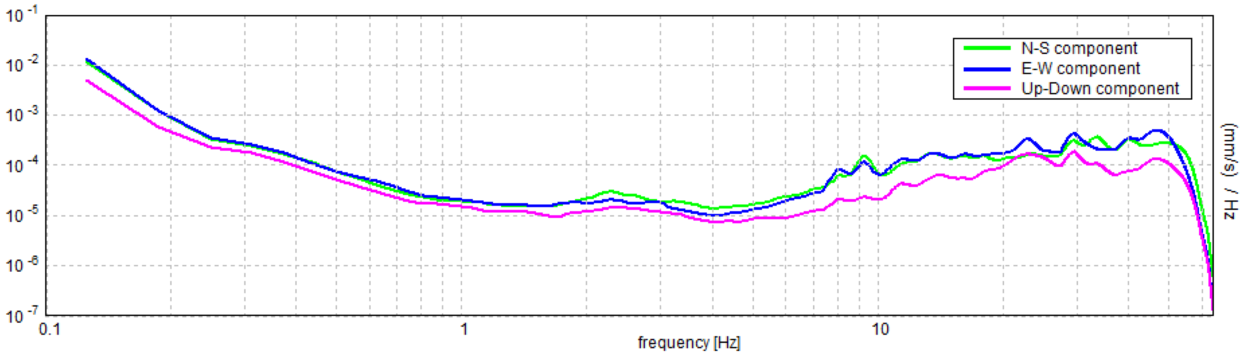
HORIZONTAL TO VERTICAL SPECTRAL RATIO


Max. H/V at 9.25 ± 1.97 Hz. (In the range 0.0 - 64.0 Hz).

H/V TIME HISTORY



SINGLE COMPONENT SPECTRA



[According to the SESAME, 2005 guidelines. **Please read carefully the *Grilla* manual before interpreting the following tables.**]

Max. H/V at 9.25 ± 1.97 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	9.25 > 0.67	OK	
$n_c(f_0) > 200$	8880.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 223 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	7.563 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	10.75 Hz	OK	
$A_0 > 2$	5.84 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.21263| < 0.05		NO
$\sigma_f < \varepsilon(f_0)$	1.9668 < 0.4625		NO
$\sigma_A(f_0) < \theta(f_0)$	0.4679 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$

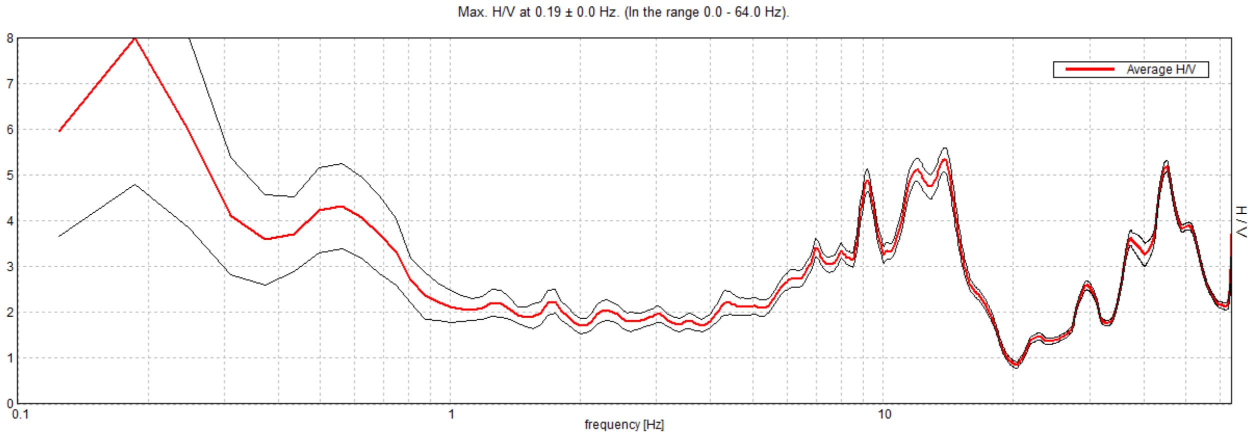
Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

WESTVANTHURBER, WV HVSR21 08

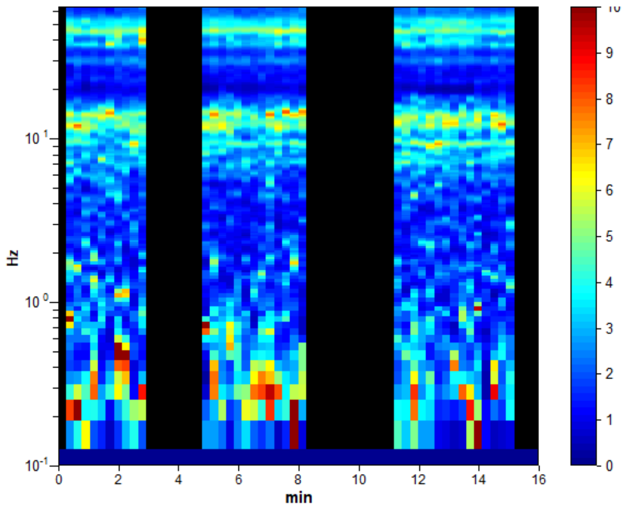
Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/05/21 17:41:30 End recording: 06/05/21 17:57:30
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

Trace length: 0h16'00". Analyzed 63% trace (manual window selection)
Sampling rate: 128 Hz
Window size: 16 s
Smoothing type: Triangular window
Smoothing: 7%

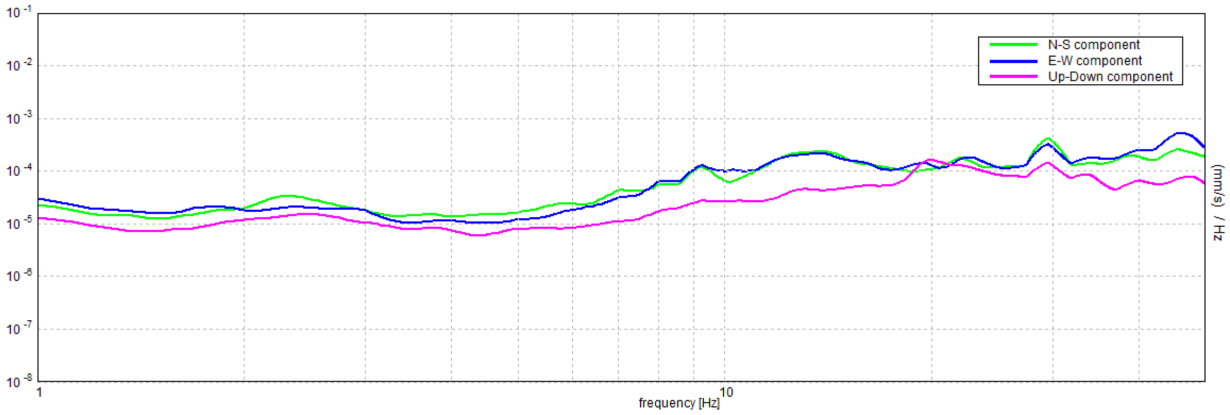
HORIZONTAL TO VERTICAL SPECTRAL RATIO



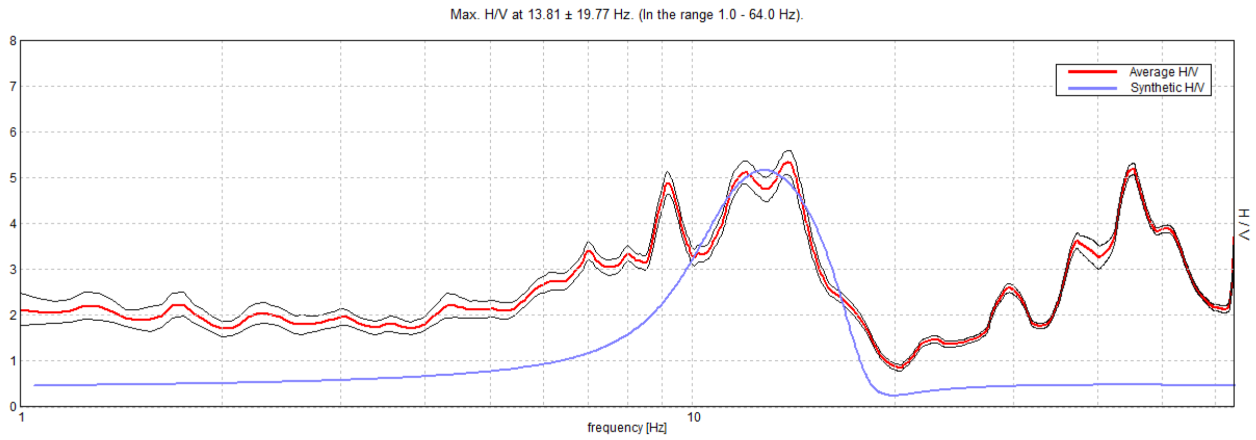
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

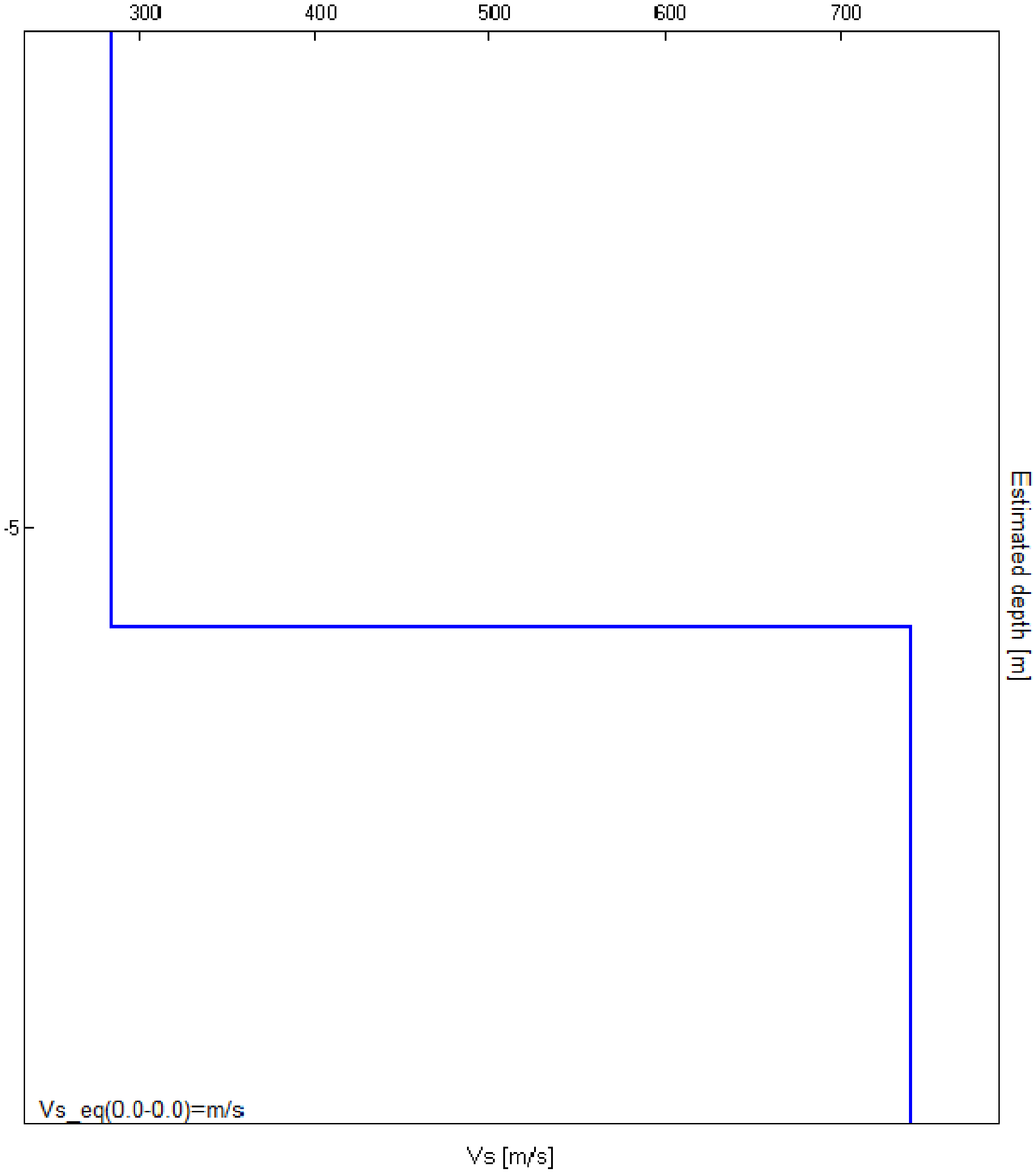


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
6.00	6.00	285	0.35
inf.	inf.	740	0.42

Vs_eq(0.0-30.0)=561m/s


300
400
500
600
700
-5
Estimated depth [m]
Vs_eq(0.0-0.0)=m/s
Vs [m/s]

[According to the SESAME, 2005 guidelines. **Please read carefully the *Grilla* manual before interpreting the following tables.**]

Max. H/V at 11.94 ± 1.74 Hz (in the range 1.0 - 50.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	11.94 > 0.63	OK	
$n_c(f_0) > 200$	7258.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 288 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	6.563 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	16.0 Hz	OK	
$A_0 > 2$	5.36 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.14561| < 0.05		NO
$\sigma_f < \varepsilon(f_0)$	1.73821 < 0.59688		NO
$\sigma_A(f_0) < \theta(f_0)$	0.3144 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

Threshold values for σ_f and $\sigma_A(f_0)$

Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

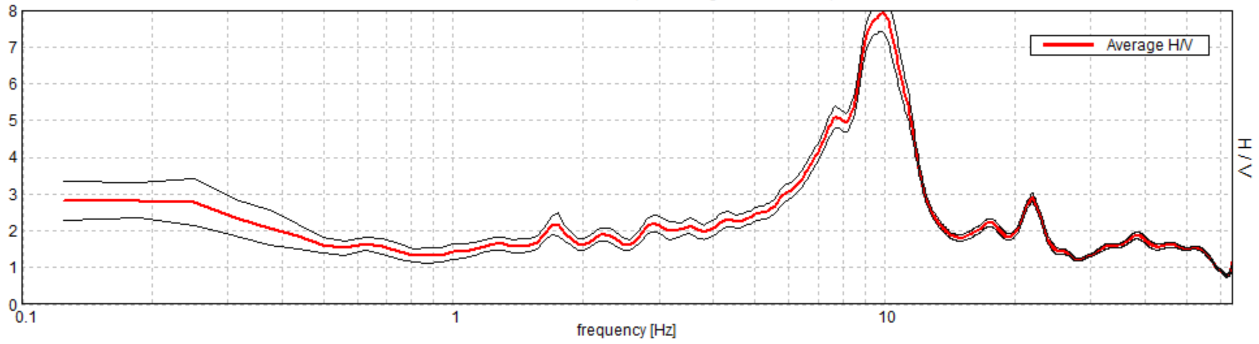
WEST VAN, HVSR21 09

Instrument: TZ3-0084/02-19
Data format: 32 byte
Full scale [mV]: 51
Start recording: 06/05/21 18:02:45 End recording: 06/05/21 18:18:45
Channel labels: NORTH SOUTH; EAST WEST ; UP DOWN
GPS data not available

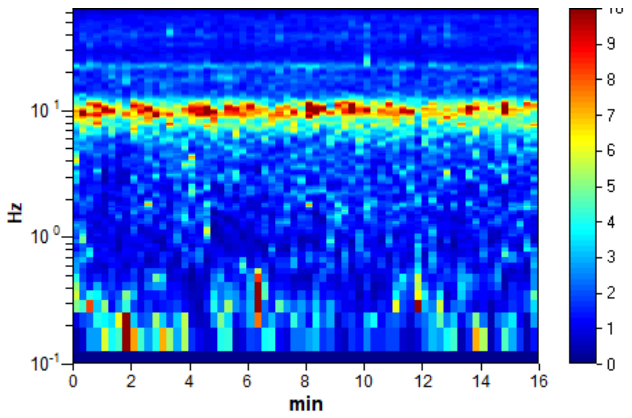
Trace length: 0h16'00". Analysis performed on the entire trace.
Sampling rate: 128 Hz
Window size: 15 s
Smoothing type: Triangular window
Smoothing: 7%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

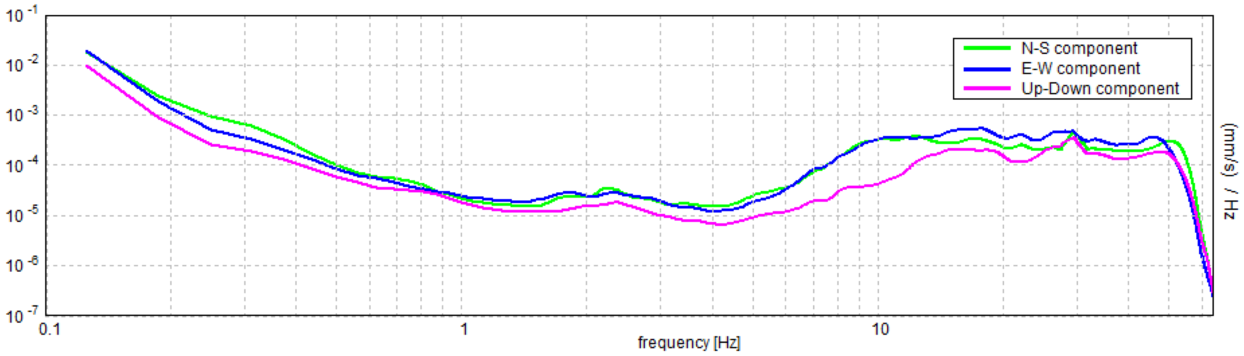
Max. H/V at 9.81 ± 0.37 Hz. (In the range 0.0 - 64.0 Hz).



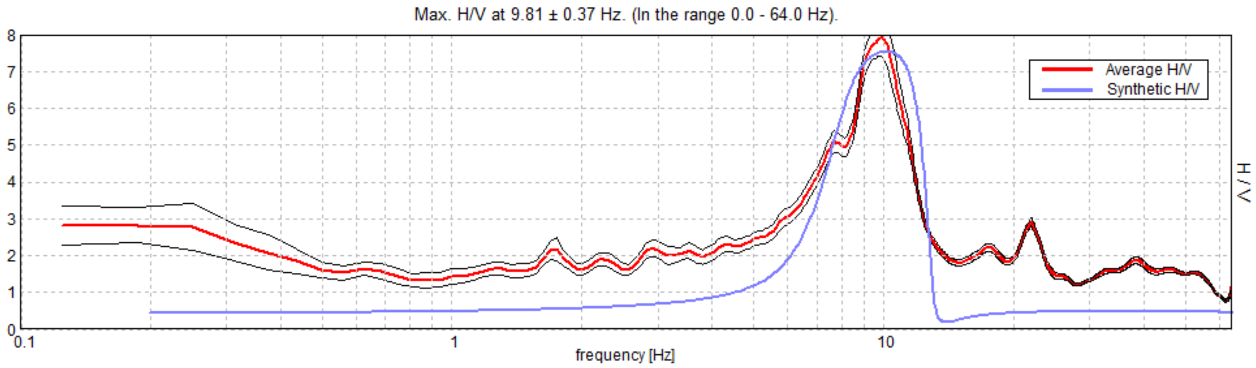
H/V TIME HISTORY



SINGLE COMPONENT SPECTRA

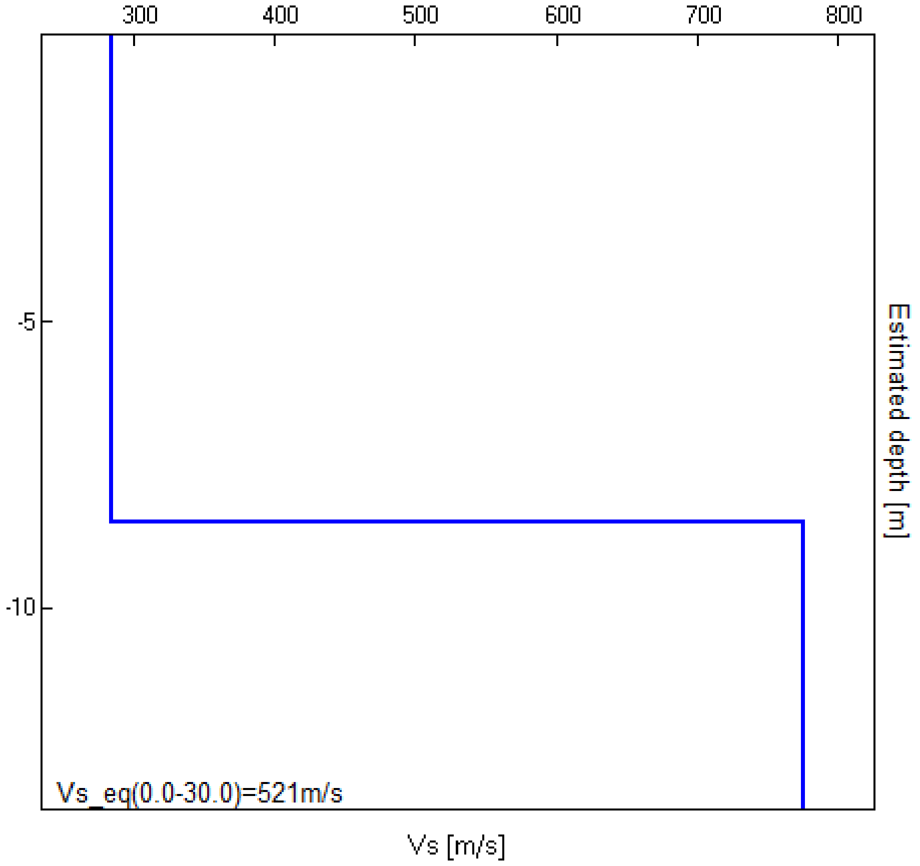


EXPERIMENTAL vs. SYNTHETIC H/V



Depth at the bottom of the layer [m]	Thickness [m]	Vs [m/s]	Poisson ratio
8.50	8.50	285	0.35
inf.	inf.	775	0.41

Vs_eq(0.0-30.0)=521m/s



[According to the SESAME, 2005 guidelines. **Please read carefully the** *Grilla* **manual before interpreting the following tables**.]

Max. H/V at 9.81 ± 0.37 Hz (in the range 0.0 - 64.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

$f_0 > 10 / L_w$	9.81 > 0.67	OK	
$n_c(f_0) > 200$	9420.0 > 200	OK	
$\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5Hz$ **$\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5Hz$**	Exceeded 0 out of 236 times	OK	

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

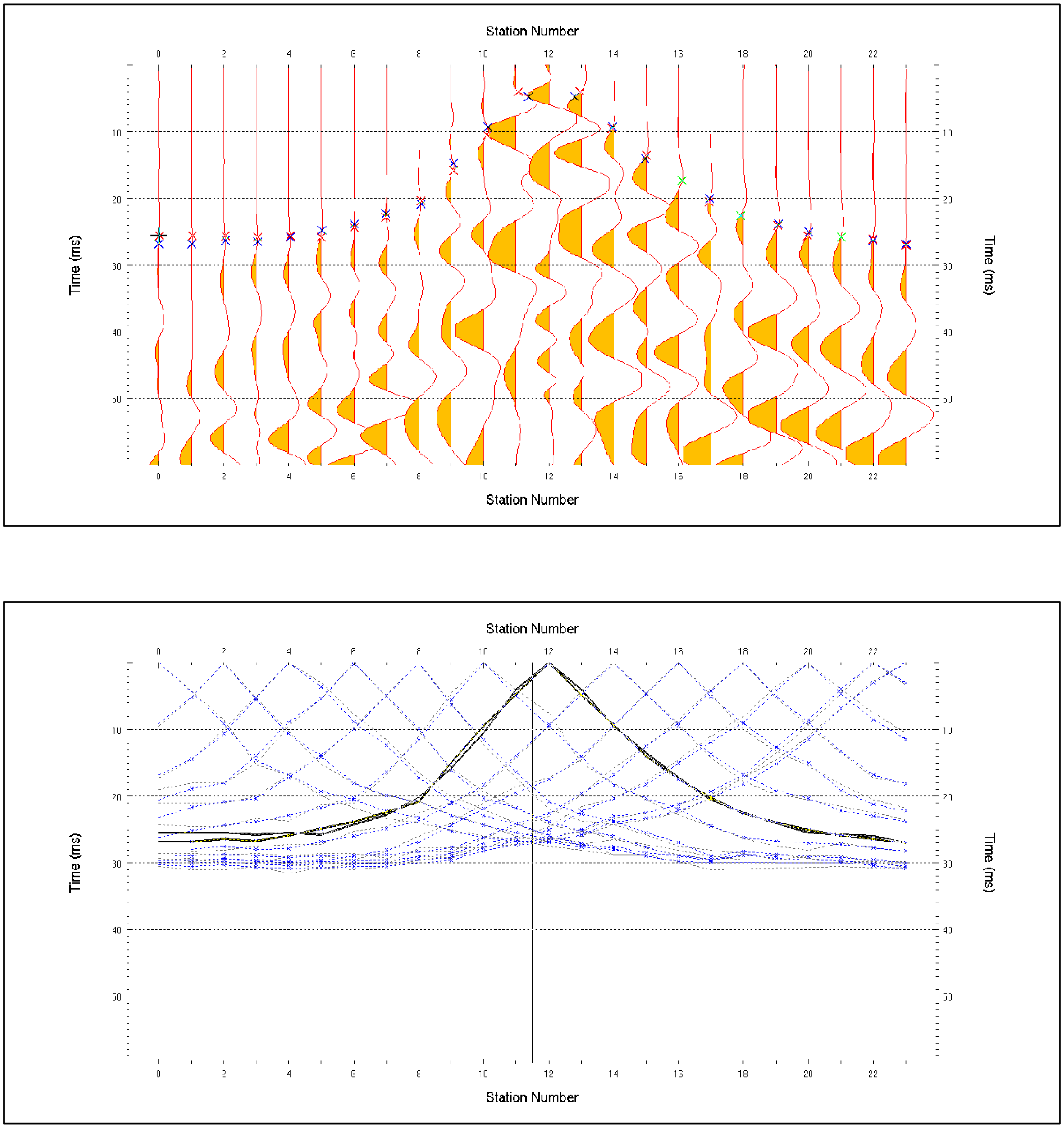
Exists f^- in $[f_0/4, f_0]$ | $A_{H/V}(f^-) < A_0 / 2$	6.813 Hz	OK	
Exists f^+ in $[f_0, 4f_0]$ | $A_{H/V}(f^+) < A_0 / 2$	11.938 Hz	OK	
$A_0 > 2$	7.92 > 2	OK	
$f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$	|0.03733| < 0.05	OK	
$\sigma_f < \varepsilon(f_0)$	0.36627 < 0.49063	OK	
$\sigma_A(f_0) < \theta(f_0)$	0.4844 < 1.58	OK	

L_w	window length
n_w	number of windows used in the analysis
$n_c = L_w n_w f_0$	number of significant cycles
f	current frequency
f_0	H/V peak frequency
σ_f	standard deviation of H/V peak frequency
$\varepsilon(f_0)$	threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
A_0	H/V peak amplitude at frequency f_0
$A_{H/V}(f)$	H/V curve amplitude at frequency f
f^-	frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
f^+	frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
$\sigma_A(f)$	standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
$\sigma_{logH/V}(f)$	standard deviation of log $A_{H/V}(f)$ curve
$\theta(f_0)$	threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$

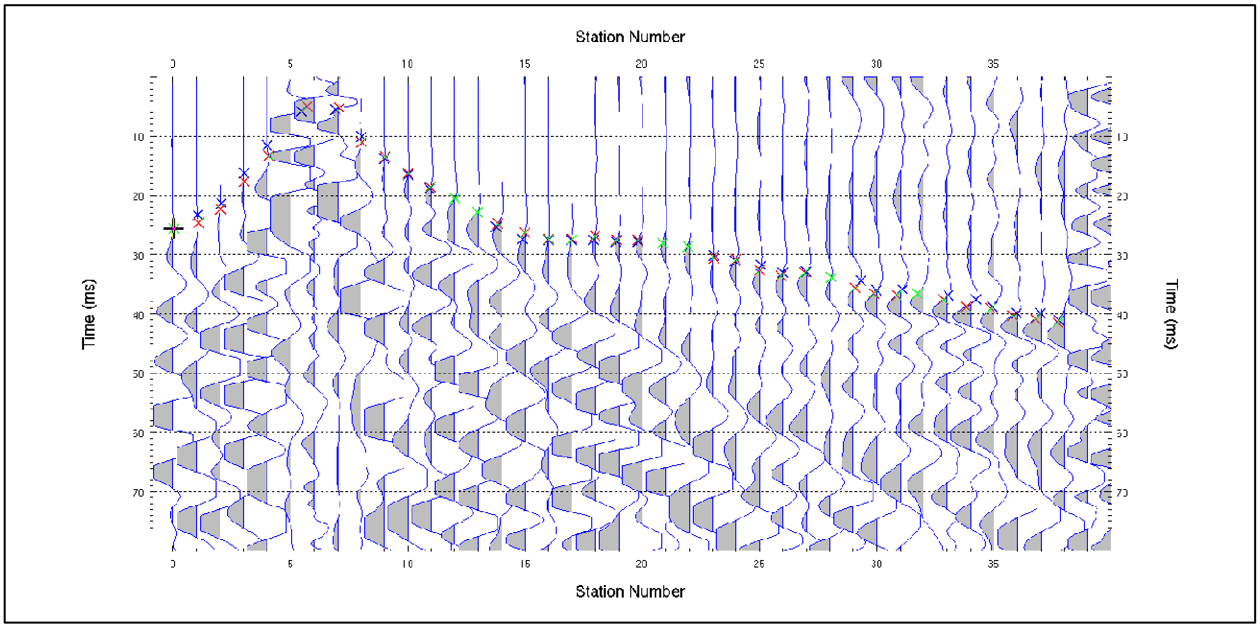
Threshold values for σ_f and $\sigma_A(f_0)$

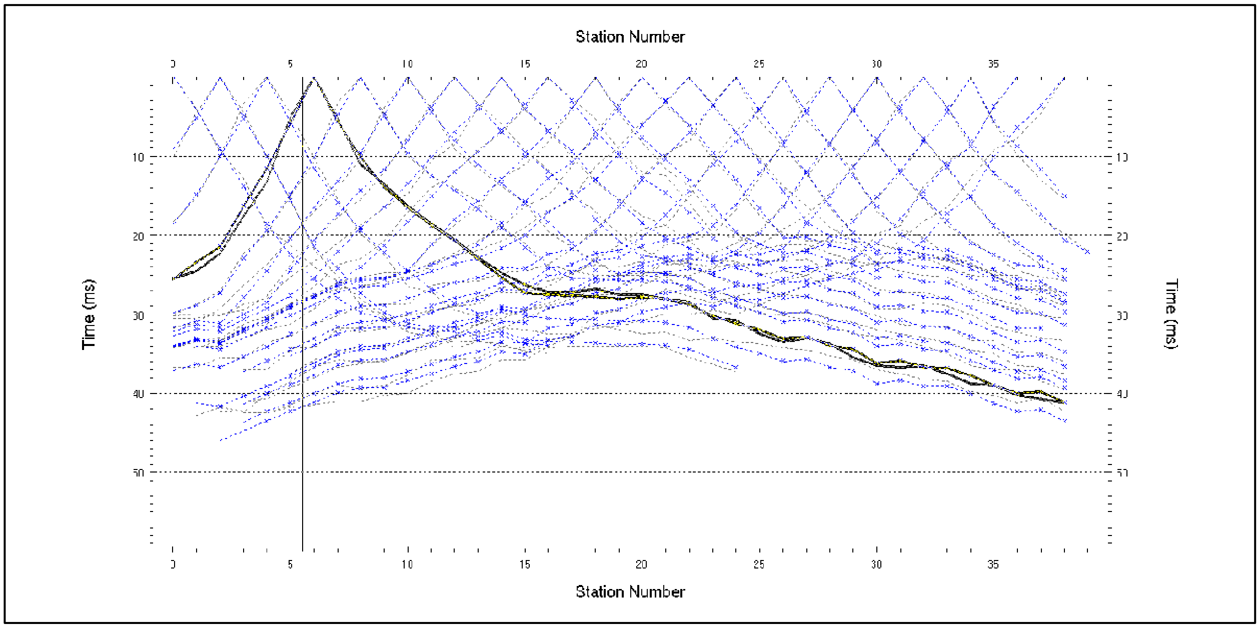
Freq. range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon(f_0)$ [Hz]	0.25 f_0	0.2 f_0	0.15 f_0	0.10 f_0	0.05 f_0
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
log $\theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

SRT Time Domain Traces and Breaks

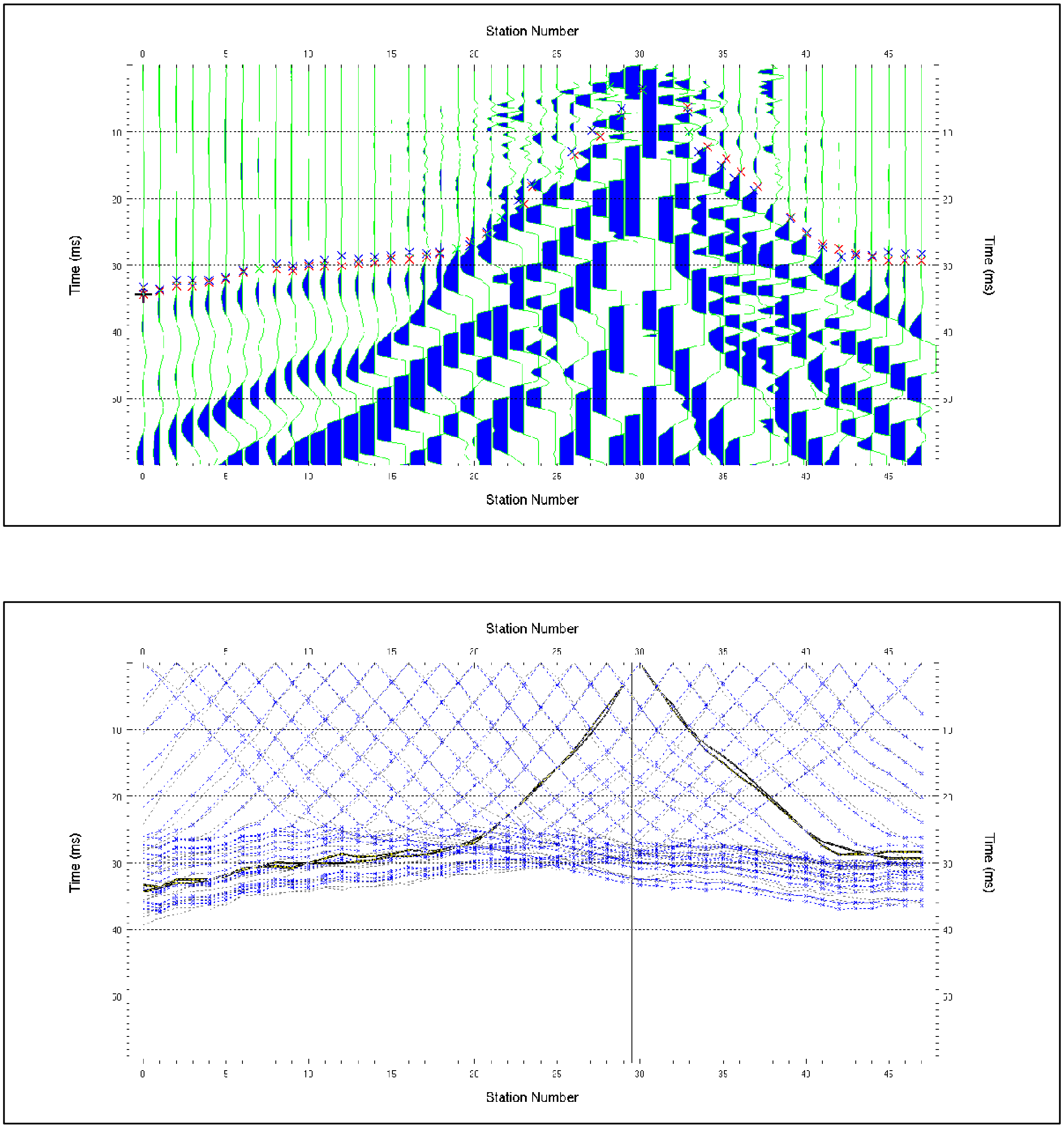


SRT21-06: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of all picks into a shot break profile (bottom).

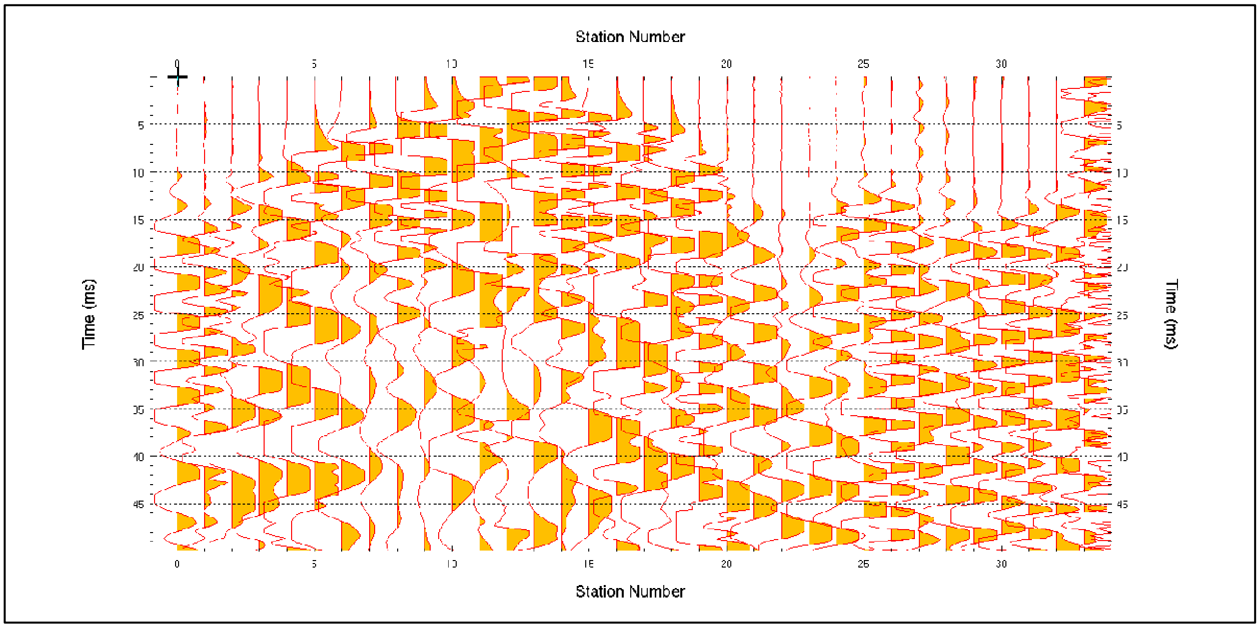




SRT21-07: Example time domain trace (top) with user and modeled picks (red and blue x's) and an amalgamation of all picks into a shot break profile (bottom).



SRT21-08: Example time domain trace (top) with user and modeled picks (red and blue x’s) and an amalgamation of all picks into a shot break profile (bottom).



SRT21-09: Example time domain trace with uninterpretable data.