Analysis of MASW Data
For 2-D S-Velocity (Vs) Cross Section (Line4)

Park Seismic
Geotechnical Seismic Investigation

Sample Full MASW Report

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Report

To

Anonymous Company

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Summary

- MASW data from "**LINE4"** are processed for **1-D and 2-D shear-wave velocity (Vs) profiles**.
- First, the original fifty nine (59) records of 120-channel acquisition with 4-m receiver spacing are rearranged to produce **a set of 24-channel-equivalent roll-along records (43 of them). The roll-along data set with a relatively long source offset (X1=12dx) was chosen for production analysis to account for relatively deep bedrock (e.g., ≥ 20 m) indicated from preprocessing results.**
- This "roll-along" rearrangement has been made for two reasons: (1) to prepare a data set with the same source-offset (X1) and receiver spread length (L) to ensure the consistency in near-field effects of surface waves, and (2) to produce a 2-D Vs cross section.
- This rearranged data set is processed to produce individual dispersion images, which are then stacked to produce one dispersion image of the highest signal-to-noise (SN) ratio. **Then, one fundamental-mode dispersion curve (M0) has been extracted from this stacked image that is used to produce the 1-D Vs profile, which represents the velocity (Vs) variation with depth through the lateral averaging of the subsurface material for the entire surface distance covered by this roll-along data set (i.e., total 336-m distance between 94-m and 430-m surface locations).**
- **According to this 1-D Vs profile, the overburden has velocities approximately in 150 m/sec – 250 m/sec corresponding to soft – relatively stiff soil. A slight velocity inversion is observed within the overburden at its second half of thickness. The overburden is then underlain by a bedrock of Vs ≈ 900 m/sec at about 27-m depth. Considering relatively low Vs, the bedrock appears to be in highly weathered condition and not a competent rock.**

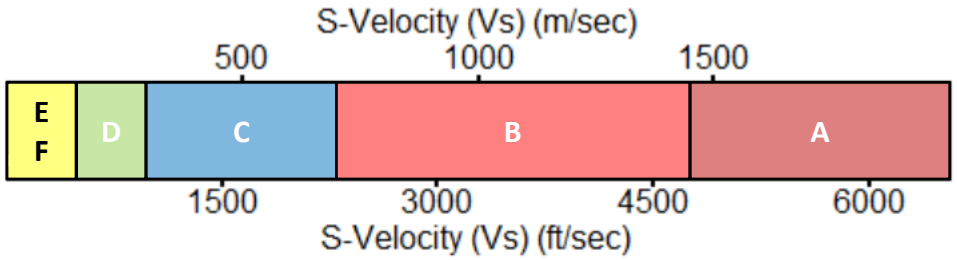
Summary (cont'd)

- From this 1-D Vs profile, the average Vs for top 30-m depths (i.e., $Vs^{30\text{-}m}$) is calculated as **$Vs^{30\text{-}m}$ = 252 m/sec**, which puts the site into **class D ("Stiff Soil")** according to the seismic site classification codes adopted by **National Earthquake Hazard Reduction Program (NEHRP) and the International Building Code (IBC)**. The classification table is presented after summary.
- ***However, dispersion patterns observed in the stacked dispersion image showed extremely low signal-to-noise (SN) ratio at frequencies lower than about 5 Hz, which corresponds to an analysis depth of about 20 m. Therefore, the evaluation of bedrock depth (Zbd) and its velocity (Vs-bd) may not possess a high reliability.***
- Separate dispersion curves were extracted from the individual dispersion images processed from the roll-along data set. The curves were used to produce the **2-D Vs cross section, which indicates that, in general, bedrock depths are approximately between 20-m and 50-m. However, considering that the lowest frequency of dispersion observed with sufficient energy was about 5 Hz, which corresponds to the maximum investigation depth (Zmax) of about 20 m, bedrock depths deeper than 20 m are less reliable. Bedrock velocities are observed approximately in 700 m/sec ≤ Vs ≤ 1000 m/sec. However, due to the same uncertainties in dispersion curve picking at the lowest frequencies (e.g., ≤ 5 Hz), bedrock velocities could be under-estimated. Overburden velocities are approximately in ~150 m/sec ≤ Vs ≤ ~300 m/sec corresponding to those of soft-stiff soil. Significant velocity inversions are observed within the overburden, especially right above bedrock with an approximate thickness of 10-m.**

Summary (cont'd)

- **Separate (and independent) evaluation of bedrock velocities (Vs and Vp)** has been attempted based on the **"Frequency-Summation (FRQ-Sum)"** method. This method, when effective, generates a summed curve in which the last two peaks represent Vs and Vp of bedrock, respectively. The effectiveness of this method varies significantly depending on the velocity structure of the site as well as acquisition parameters such as source offset (X1), receiver spread length (L), etc. ***The last peak at 3540 m/sec is interpreted as Vp of the bedrock. Then, the next peak at the lower phase velocity of 1660 m/sec is interpreted as Vs of bedrock. These two values give a Poisson's ratio of 0.359 (i.e., POS ≈0.359). These results of Vs and Vp are in contrast to those from line 5 that did not show any other peak at phase velocities higher than 1660 m/sec and therefore the peak (1660 m/sec) was previously interpreted as Vp. Now, it is apparent that the peak represents Vs, not Vp, for both lines. The possible reason for this discrepancy is explained in the last page by comparing average dispersion images from both lines. They show that S-wave refraction dominated over P-wave refraction in both lines. The latter (P-wave refraction) is almost completely missing in line 5, while it takes minor energy in line 4 occurring over a very narrow band of about 55-60 Hz.***
- **Overall data quality** as judged from signal-to-noise ratio (SN) of dispersion images was "**fair – good**."
- ***Considering all theoretical aspects of MASW analysis, the order of confidence level for analyzed parameters is the velocity (Vs) of overburden (Vs-ob), bedrock depth (Zbd), bedrock S-velocity (Vs-bd), and bedrock P-velocity (Vp-bd) with the first (i.e., Vs-ob) having the highest confidence.***
- ***For this particular data set, the approximate levels are estimated as 95% (Vs-ob), 90% (for Zbd ≤ 20 m) and 70% (for Zbd > 20 m), 70% (Vs-bd from 1-D and 2-D profilings), and 90% (Vs and Vp from FRQ-Sum).***

Seismic Site Classification ($Vs^{30\text{-}m}$ or $Vs^{100\text{-}ft}$)



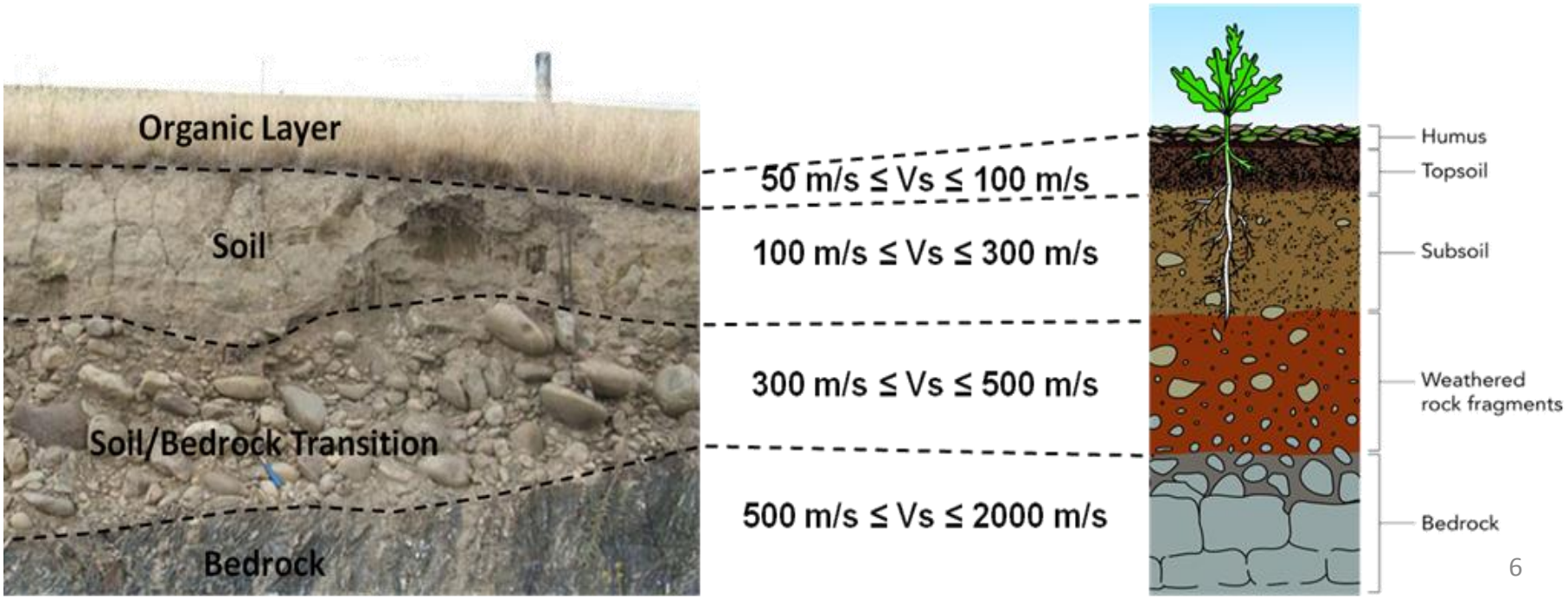
NEHRP* Seismic site classification based on shear-velocity (Vs) ranges.

Site Class	S-Velocity (Vs) (ft/sec)	S-Velocity (Vs) (m/sec)
A (Hard Rock)	> 5,000	**> 1500**
B (Rock)	2,500 – 5000	**760 – 1500**
C (Very Dense Soil and Soft Rock)	1,200 – 2,500	**360 – 760**
D (Stiff Soil)	600 – 1,200	**180 – 360**
E (Soft Clay Soil)	< 600	**< 180**
F (Soils Requiring Add'l Response)	< 600, and meeting some additional conditions.	**< 180, and meeting some additional conditions.**

*** National Earthquake Hazard Reduction Program (www.nehrp.gov)**

Table of Typical Near-Surface Materials and "Approximate" Seismic Velocity (Vs)

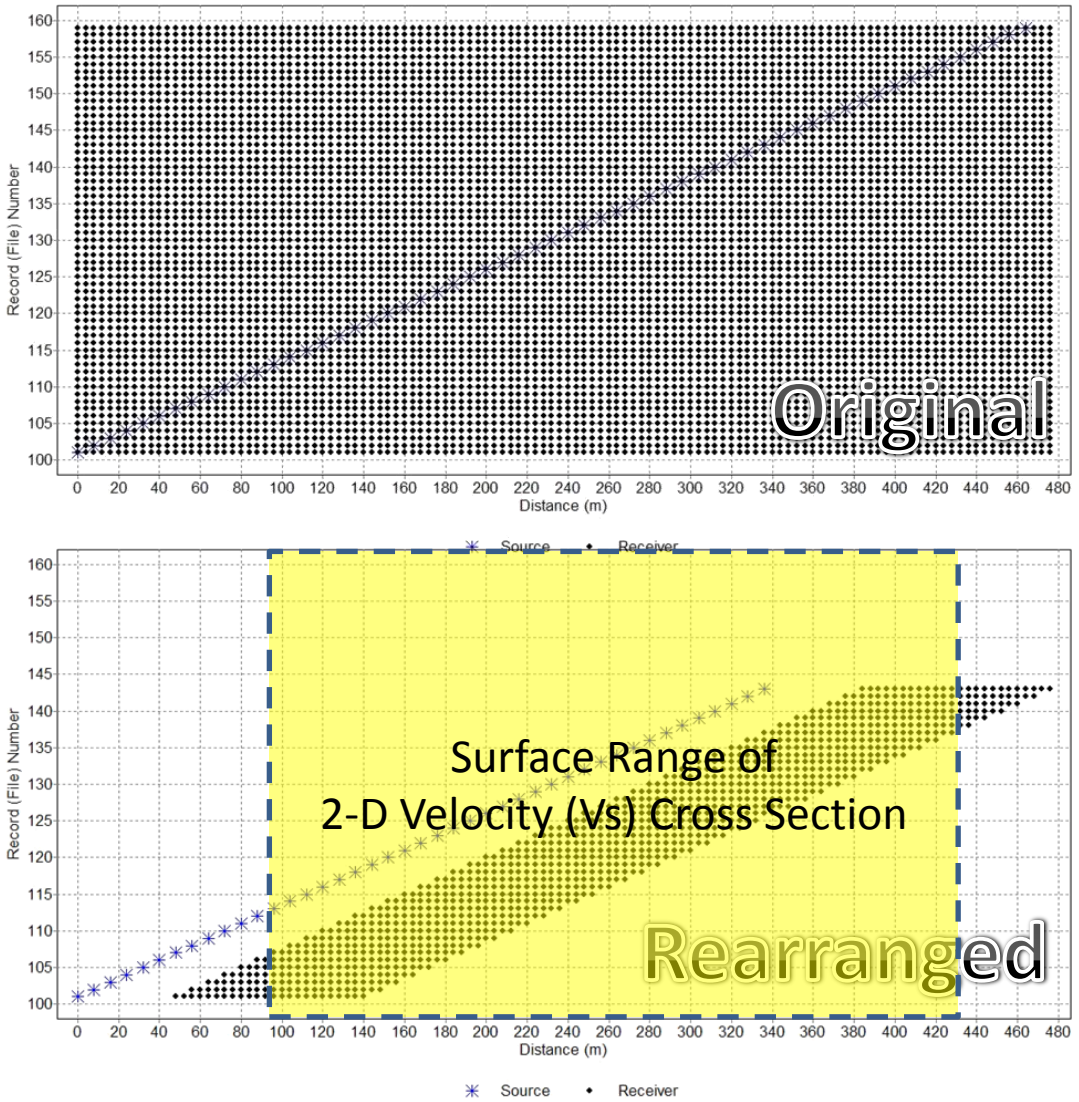
- Vs ≤ 100 m/s – **"extremely soft" soil**
- 100 m/s ≤ Vs ≤ 200 m/s – **"soft" soil**
- 200 m/s ≤ Vs ≤ 300 m/s – **"stiff" soil**
- 300 m/s ≤ Vs ≤ 500 m/s – **"weathered" zone**
- 500 m/s ≤ Vs – **"rock"**
- 1000 m/s ≤ Vs – **"competent" rock**



Data Arrangement for Processing

The source/receiver (SR) configuration of the original data set is displayed on top. There were total fifty nine (59) records of 120-channel acquisition with 4-m receiver spacing.

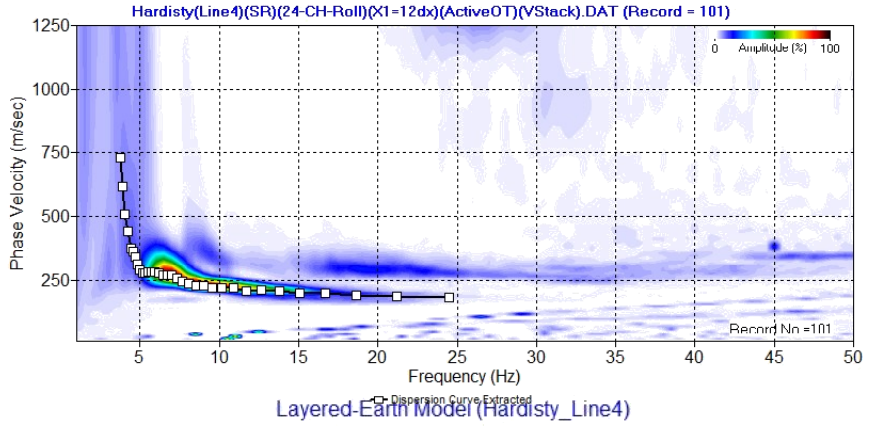
Then, this data set is rearranged to produce forty three (43) 24-channel equivalent roll-along records, SR configuration of which is shown at the bottom. A relatively long source offset of X1=12dx was chosen for the roll-along data set to account for relatively deep bedrock (e.g., ≥ 20 m) indicated from preprocessing results. The configuration shows range of the receiver-spread mid-point, which is the range of the final 2-D Vs cross section, will be in 94.0 – 430.0 m (total distance of 336 m) as indicated by the yellow box on the chart.



1-D Shear-Velocity (Vs) Profile

All forty three (43) roll-along records' dispersion images are stacked and one fundamental-mode (M0) dispersion curve is extracted from the stacked image (shown below). A 1-D shear-velocity (Vs) profile of **10-layer** model is obtained from the extracted curve and displayed at the bottom. Numerical values of velocity (Vs) are presented in the table.

Dispersion



1-D Vs Profile

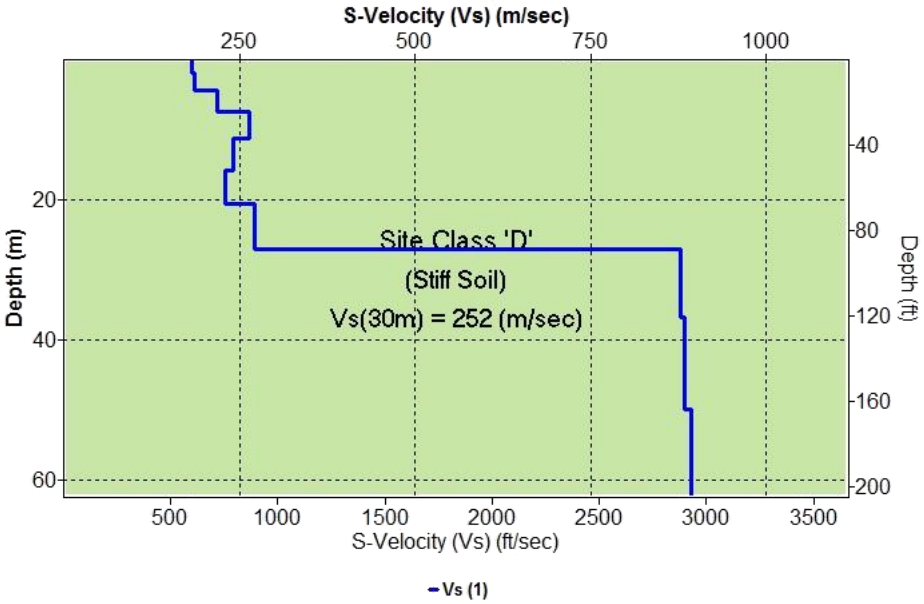


Table of Vs Values

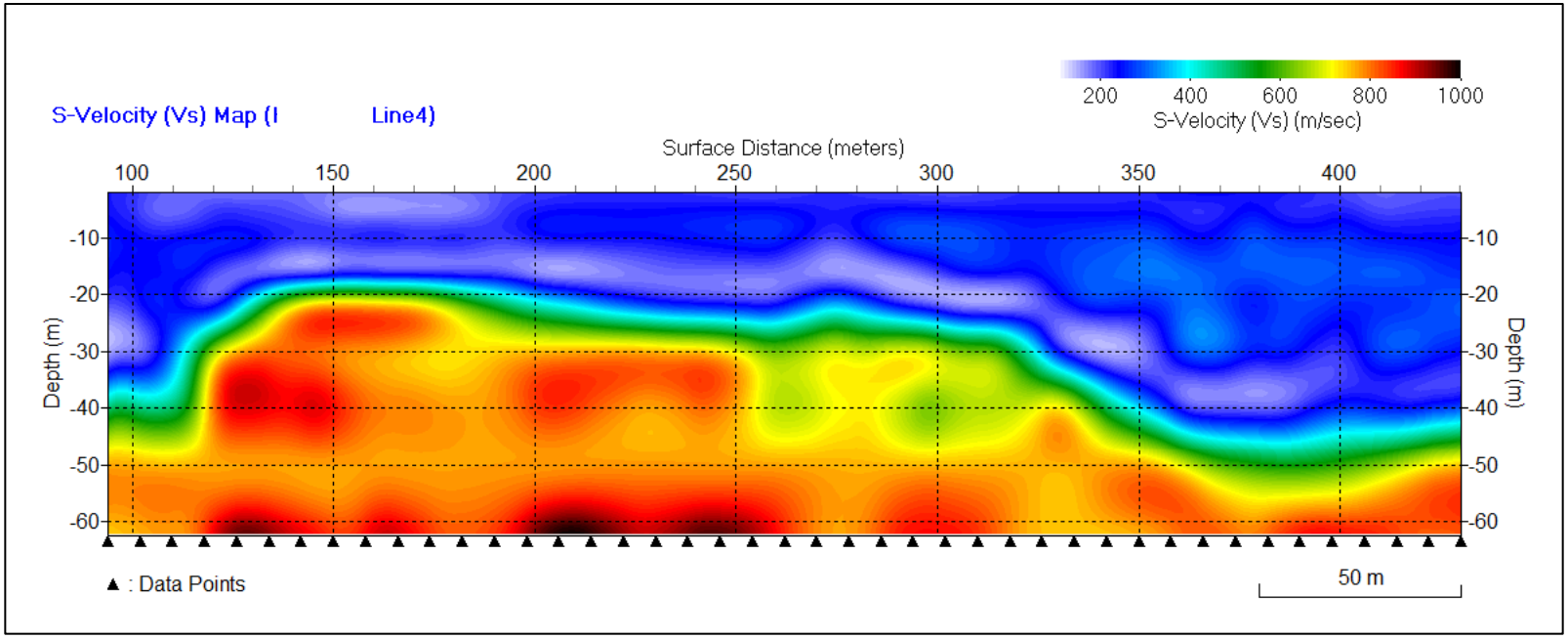
No.	Depth (m)	Final Vs (m/sec)
1	1.938	**182.04**
2	4.36	**186.88**
3	7.388	**219.23**
4	11.173	**264.58**
5	15.904	**240.54**
6	20.588	**230.63**
7	27.022	**270.74**
8	36.765	**878.1**
9	50	**882.89**
10	**HS***	**893.67**

*HS: half space

2-D Shear-Velocity (Vs) Cross Section

All forty three (43) dispersion curves analyzed from the 24-channel roll-along records are used to produce the 2-D shear-velocity (Vs) cross section shown below. **A velocity (Vs) scale of 100 - 1000 m/sec** was used for the color scheme shown on top of the section.

In general, bedrock depths are approximately between 20-m and 50-m. However, considering that the lowest frequency of surface waves observed in most of dispersion images was about 5 Hz, which corresponds to the maximum investigation depth (Zmax) of about 20 m, bedrock depths deeper than 20 m are less reliable. Bedrock velocities are observed approximately in 700 m/sec ≤ Vs ≤ 1000 m/sec. However, considering uncertainties in dispersion curve picking at the lowest frequencies (e.g., ≤ 5 Hz), bedrock velocities could be under-estimated. Overburden velocities are approximately in ~150 m/sec ≤ Vs ≤ ~300 m/sec corresponding to those of soft – stiff soil. Significant velocity inversions are observed within the overburden, especially right above bedrock with an approximate thickness of 10-m for most of the mapped areas.

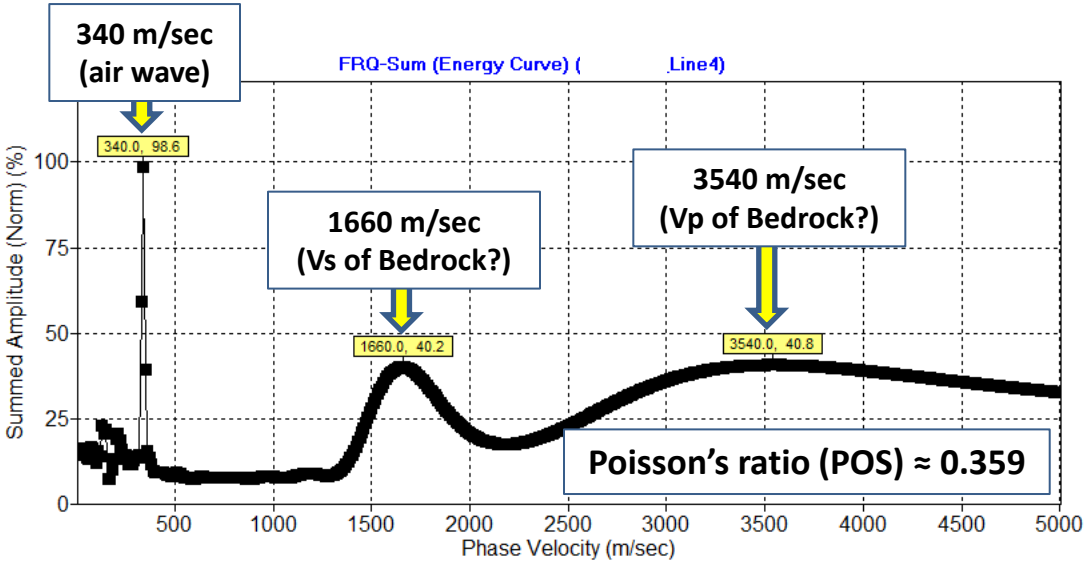


Evaluation of Bedrock Velocities (Vs or Vp)

Approximate evaluation of bedrock velocities (Vs and Vp) has been attempted based on the "frequency-summation (FRQ-Sum)" method that sums all the energy in the stacked dispersion image along the frequency axis. This method, when effective, generates a summed curve in which the last two peaks represent Vs and Vp of bedrock, respectively. The effectiveness of this method varies significantly depending on the velocity structure of the site as well as acquisition parameters such as source offset (X1), receiver spread length (L), etc.

The last peak at 3540 m/sec is interpreted as Vp of the bedrock. Then, the next peak at the lower phase velocity of 1660 m/sec is interpreted as Vs of bedrock. These two values give a Poisson's ratio of 0.359 (i.e., POS ≈0.359). The strongest peak at the lowest phase velocity of 340 m/sec is interpreted as energy from air waves.

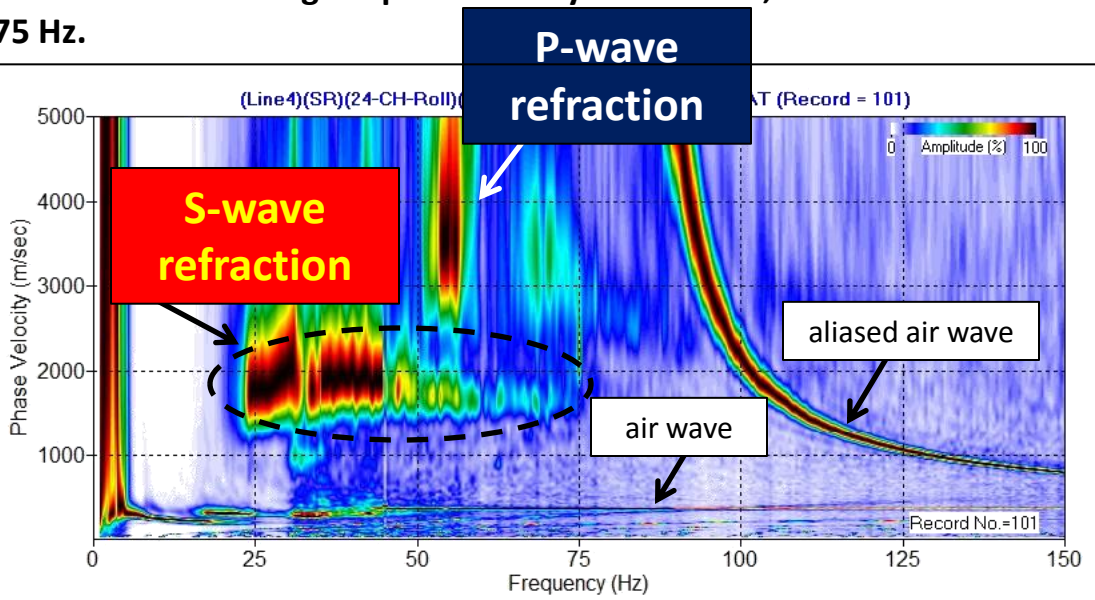
These results of FRQ-Sum analysis are in contrast to those from line 5 that did not show any other peak at phase velocities higher than 1660 m/sec and therefore the peak (1660 m/sec) was previously interpreted as Vp. Now, it is apparent that the peak represents Vs, not Vp, for both lines. The possible reason for this discrepancy is explained in the next page by comparing average dispersion images from both lines. They indicate that S-wave refraction dominated over P-wave refraction. The latter (P-wave refraction) is almost completely missing in line 5, while it takes minor energy in line 4 occurring over a very narrow band of about 55-60 Hz.



Average Dispersion Images (Line 4 and Line 5)

The two dispersion images from lines 4 and 5 show similar features except that the line 4 shows the possible P-wave refraction from bedrock, which was not apparent on the line 5. The P-wave refraction indicates that its wavefield possesses a very narrow-banded nature taking frequencies only in 55-60 Hz, whereas the S-wave refraction takes a broad band in 25-75 Hz.

Line 4



Line 5