Nanometrics Posthole Seismometers

World Class Performance

Contents

Figures

Summary

The Nanometrics Trillium 120 Posthole (Trillium Posthole) seismometer is designed for subsurface installation to optimize seismic performance while minimizing the cost and logistics of site setup. This paper features an analysis of installation techniques in typical environments, and for each of these environments, provides compelling results from independent and internal studies that illustrate the advantages of buried instruments such as the Trillium Posthole.

Performance of the Trillium Posthole versus World Class Vault Instruments

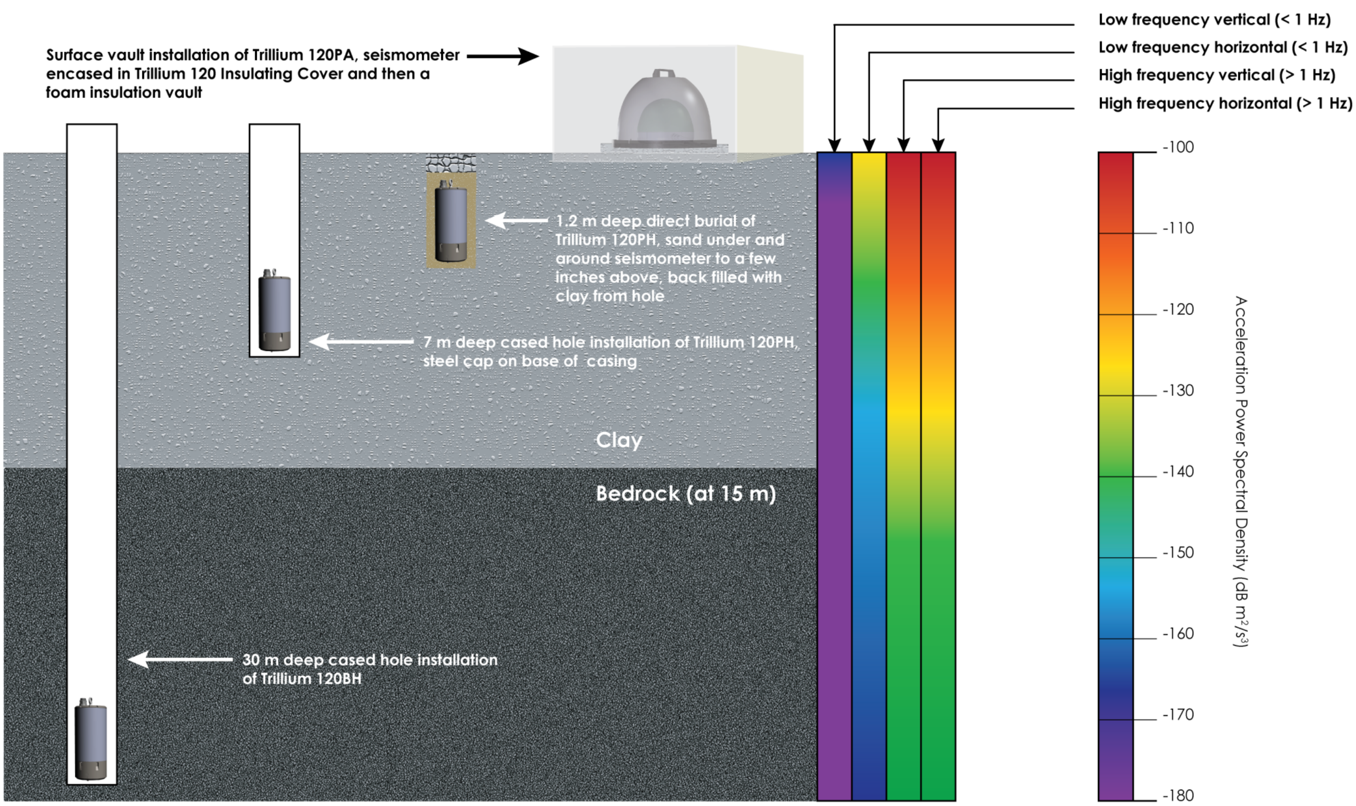
The PSD plot in 0 illustrates the self-noise of the Trillium Posthole. In this installation, two Trillium Posthole seismometers, a Trillium 240 seismometer, and a Trillium 120PA seismometer were installed side-by-side on a granite block resting on sedimentary bedrock (limestone and shale). 0 clearly demonstrates the comparable performance of the Trillium Posthole to world-class vault instruments.

Variation in Noise with Depth

A four seismometer installation was performed at Nanometrics in Kanata, Ontario, Canada. This installation includes a surface vault installation of a Trillium 120PA, a 1.2 m direct burial installation in clay of a Trillium Posthole, a 7 m cased hole installation in clay of a Trillium Posthole, and a 30 m cased hole installation in bedrock of a Trillium 120 PH.

Figure 1 is an illustration of this installation with a graphical spectrum of low and high frequency noise levels at the various depths. See Figure A2 for the low frequency PSD plot of this installation and Figure A3 for the high frequency plot.

Figure 1 Spectral analysis of installation at Nanometrics Inc.



The low frequency PDS plot of the Nanometrics installation (see Figure A2) shows that

- Vertical performance is good, even in a noisy environment (thick sediment, in the middle of a city), independent of depth and geology. The surface vault is about 3dB noisier than the buried and borehole installations.
- Tilt noise on the horizontal channels markedly decreases with depth within the sediment layer, which can be seen by comparing the buried and borehole installations to the surface vault installation (System 4) as follows:
  - The Trillium 120PA surface vault installation (System 4) is affected by tilt noise.
  - The 1.2 m Trillium Posthole installation (System 3) has similar performance to the surface vault at long periods, and lower noise above 0.1 Hz.
  - The 7 m cased hole Trillium Posthole installation (System 2) has significantly less tilt noise than the surface vault.
  - The 30 m cased hole Trillium Posthole installation (System 1) in bedrock has minimal tilt noise and is approaching the vertical noise level.

The high frequency PSD plot (Figure A3) shows that

- In a 7m deep hole, from 2 to 50 Hz, there is a -6dB benefit to burying the seismometer within the sediment layer.
- There is a -30 to 40 dB benefit in drilling to bedrock. This is because the amplitude of locally generated high-frequency noise varies inversely with the velocity of the medium (quartzite bedrock at 5000 m/s versus clay at 100 m/s).
- Above 50 Hz, performance improves with depth, even within the sediment layer, because high-frequency surface waves do not penetrate very deep into the sediment layer.

Installation Examples

This paper illustrates three types of installation, each of which show how depth and site conditions affect noise performance.

Shallow Bedrock Installation

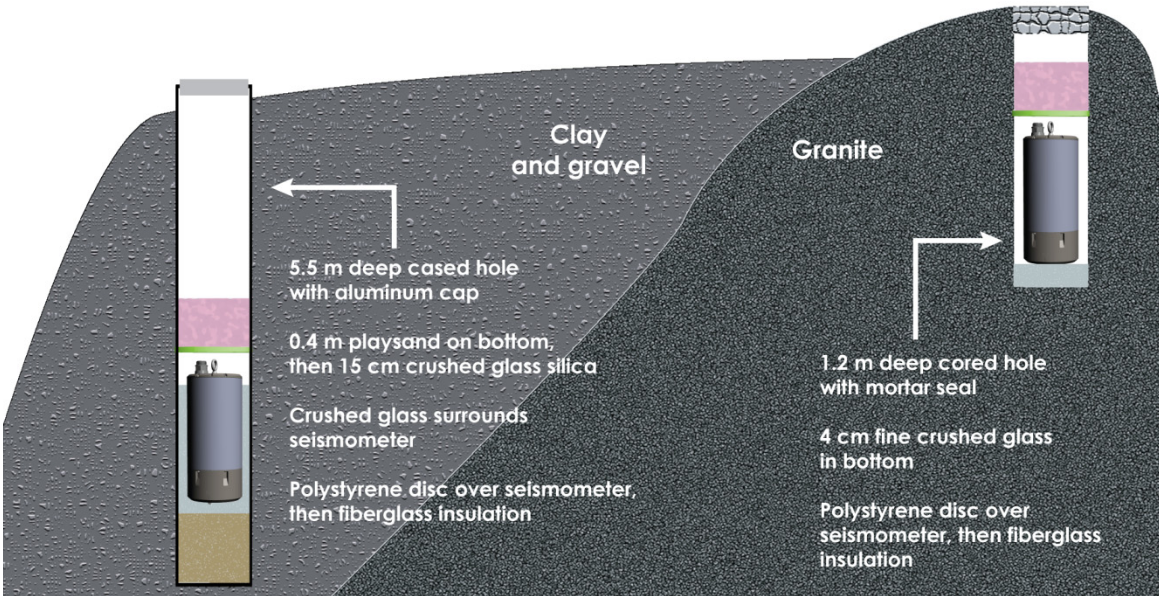
An excellent site for a posthole installation is on bedrock covered by a few feet of soil. Installation is as simple as digging a hole to bedrock, installing the seismometer and backfilling the hole. The seismometer does not need to be level as long as it is within its self-leveling tilt range. The soil will provide excellent insulation and keep the seismometer at a near-constant temperature year-round.

Example: Albuquerque Seismological Laboratory (ASL), Snake Pit Cored Holes Installation, Albuquerque, NM

This installation included two Trillium Posthole seismometers (see Figure 2):

1. The first seismometer was installed in a 1.2 m hole cored into an exposed granite outcrop. The bottom of the hole was covered in a 4 cm layer of fine crushed glass, and the top end was insulated and sealed with mortar.
2. The second seismometer was installed in a 5.5 m cased hole augured into clay and gravel fill. A 40 cm layer of fine sand filled the bottom of the hole and a 15 cm layer of crushed glass silica was added on top of the sand to form a base for the seismometer. The hole was insulated and covered with an aluminum cap.

Figure 2 Trillium Posthole Granite and clay installations at ASL, Snake Pit Cored Holes



Using the Nanometrics 7 m and 30 m borehole installations as benchmarks, the data plot (see Figure A4) for this installation shows that

- The vertical channel for both seismometers tracks the NLNM.
- The horizontal channels for the seismometer in sediment (System 2 in Figure A4) are similar to the Nanometrics 7 m borehole installation (see Figure A2 and Figure A3), though the tilt noise at the Snake Pit Cored Holes installation is slightly lower because the bedrock is shallower.
- The horizontal channels for the seismometer in bedrock (System 1 in Figure A4) are similar to the Nanometrics 30 m borehole into bedrock (see Figure A2 and Figure A3), though tilt noise is slightly higher at the surface in the Snake Pit Cored Holes installation versus the deeper Nanometrics installation.

Thick Sediment Installation

Where bedrock cannot be reached economically, shallow burial is still a very effective deployment method.

Example: PASSCAL Instrument Center Installation at the Rio Grande Flood Plain, Socorro, NM

The PASSCAL (Program for Array Seismic Studies of the Continental Lithosphere) installation described here consists of a sediment installation on the Rio Grande flood plain where the water table is less than a metre below the surface.

In this installation, four Guralp Systems CMG-3T seismometers were installed; two by direct burial in shallow holes of one metre or less that were dry when dug and filled with sand, and two in buried vaults. A fifth seismometer, a Trillium Posthole was also installed by direct burial in an augured hole where it was completely submersed in water. The hole was 1.5 m deep with a pipe fitted into the hole to prevent the walls from collapsing. Sand was poured around the seismometer to approximately half its height. Vermiculite filled the hole from the water line to the top of the pipe.

The PSD plot (see Figure A5) of this installation shows that

- Horizontal noise performance of the Trillium Posthole seismometer is similar to the others and somewhat lower on the verticals.

- Horizontal noise of all of the seismometers is limited by the site, -130 to -140 at 100s, which is very similar to the surface and direct burial installations at Nanometrics (see Figure A2 and Figure A3).

Downhole Installations

There is a level of site noise inherent to thick sediment environments, due to surface waves and resonances within the sediment layer. This can be mitigated by drilling down, away from the surface, towards or into the bedrock. Such holes (down to 100 m) may require a casing to prevent the sides from collapsing on the sensor and preventing eventual sensor removal. The Trillium 120 Posthole is suitable for installation in such cased holes where it can be placed at the bottom of the hole. There are two suitable methods for installing the Trillium Posthole in a cased hole, either with or without sand around the seismometer. Each method has pros and cons that must be weighed, based on the specific circumstances of the installation.

In a downhole installation using sand, a small quantity of sand is poured at the bottom of the hole, the seismometer is lowered onto it, then a measured quantity of sand is poured to fill up the volume around the seismometer and cover the top with no more than a few inches of sand. (Excess sand on top of the seismometer makes it hard to extract later.)

See *Example: Albuquerque Seismological Laboratory (ASL), ANMO Seismic Observatory 100 m Borehole Installation,* Albuquerque, NM on for a description of a borehole installation with sand.

If a hard, flat surface can be prepared at the bottom of the hole (with self-leveling concrete, or a metal cap on the bottom of the casing string), then sand is not required to stabilize the seismometer and the sensor can be placed on its 3 feet at the bottom of the hole. The seismometer should not touch the side of the hole. If the casing is a close fit to the seismometer, air will form a viscous boundary layer and prevent any convection cell from forming in the space beside the instrument.

See the *Variation in Noise with Depth* section of this document and refer to the 7 m Trillium Posthole and 30 m Trillium Posthole installations at Nanometrics for examples of downhole installations without sand.

Example: Albuquerque Seismological Laboratory (ASL), ANMO Seismic Observatory 100 m Borehole Installation, Albuquerque, NM

In this installation, a Trillium Posthole was installed in a large diameter borehole of approximately 100 m depth. After setting the seismometer on sand at the bottom of the hole, a measured quantity of sand was poured down the hole to fill the space around the seismometer and to cover the top of the seismometer.

The PSD plot of this installation (see Figure A6) shows that

- The Trillium Posthole long-period vertical performance is superior to the reference seismometer, a KS-54000 from Geotech Instruments.
- The horizontal performance on both seismometers is similar to the vertical performance, down to 100 s.

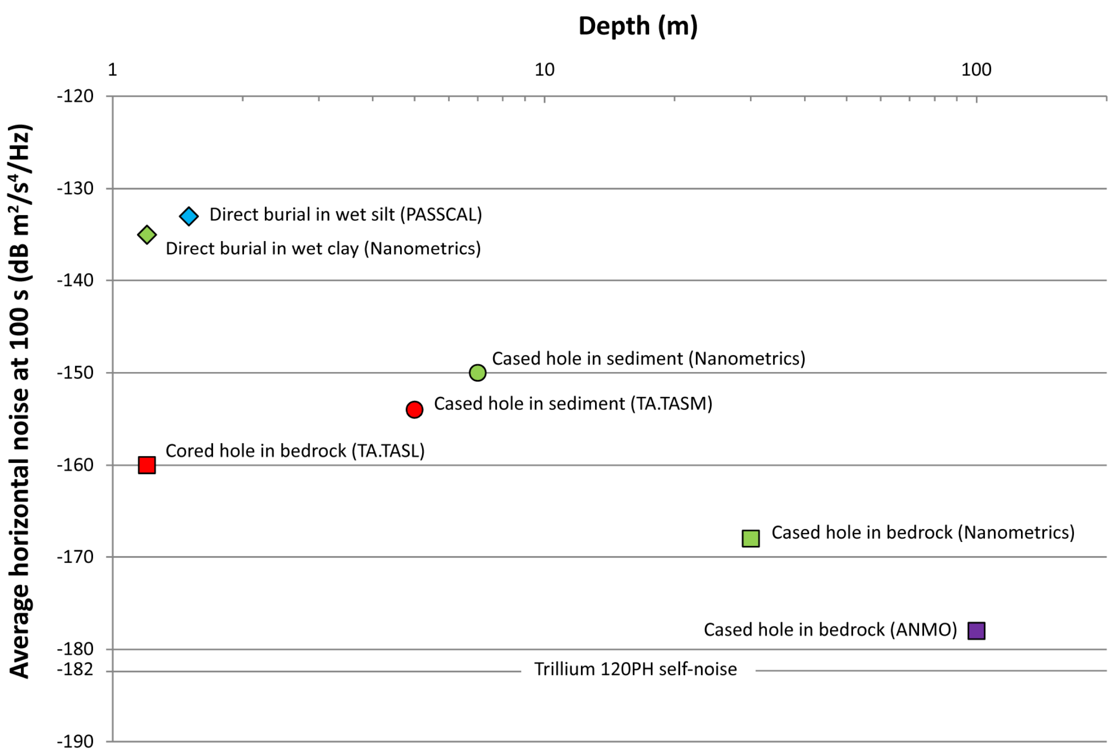
Summary of Tilt Noise versus Depth

The following plot summarizes results for horizontal background signal ("tilt noise") versus depth for all of the featured installations. PSD values at 100 s are averaged across all horizontal channels for instruments at a given depth at each site, as a measure of ground tilt motion.

Based on this sample of sites, results for tilt noise versus depth are remarkably consistent for similar installations at different locations.

The main independent variable is the geology, in particular, the seismic velocity of the medium in which the seismometer is emplaced. The Snake Pit Cored Holes 1.2 m hole (see Figure 2) is the outlier in the group because it was drilled into exposed bedrock, whereas the other shallow holes were in sediment.

Figure 3 Performance plot of Trillium Posthole seismometers at featured installation sites



Conclusion

The installations featured in this paper have illustrated several benefits inherent in the Nanometrics Trillium Posthole seismometer. The most significant benefits are that

- The Trillium Posthole offers comparable performance to the world's highest performing vault seismometers.
- There are inherent noise field benefits associated with installing a seismometer in a downhole environment that are not available to vault instruments, specifically
  - Horizontal noise is significantly suppressed in downhole environments and changes depending on the type of geology.
- True leveling is made possible by the motorized, stacked axes design of the Nanometrics Trillium Posthole seismometer. This design offers a method of separating the noise inherent in horizontal axes from the vertical axis.
- Trillium Posthole seismometers can operate closer to cultural noise.
- A Trillium Posthole installation in a secure location and environment will provide the same data as a remote location.

Appendix A: PSD Plots of Trillium Posthole Installation

Figure A1 Comparative PSD plot for Trillium 120 Posthole installed on pier at Nanometrics Inc.

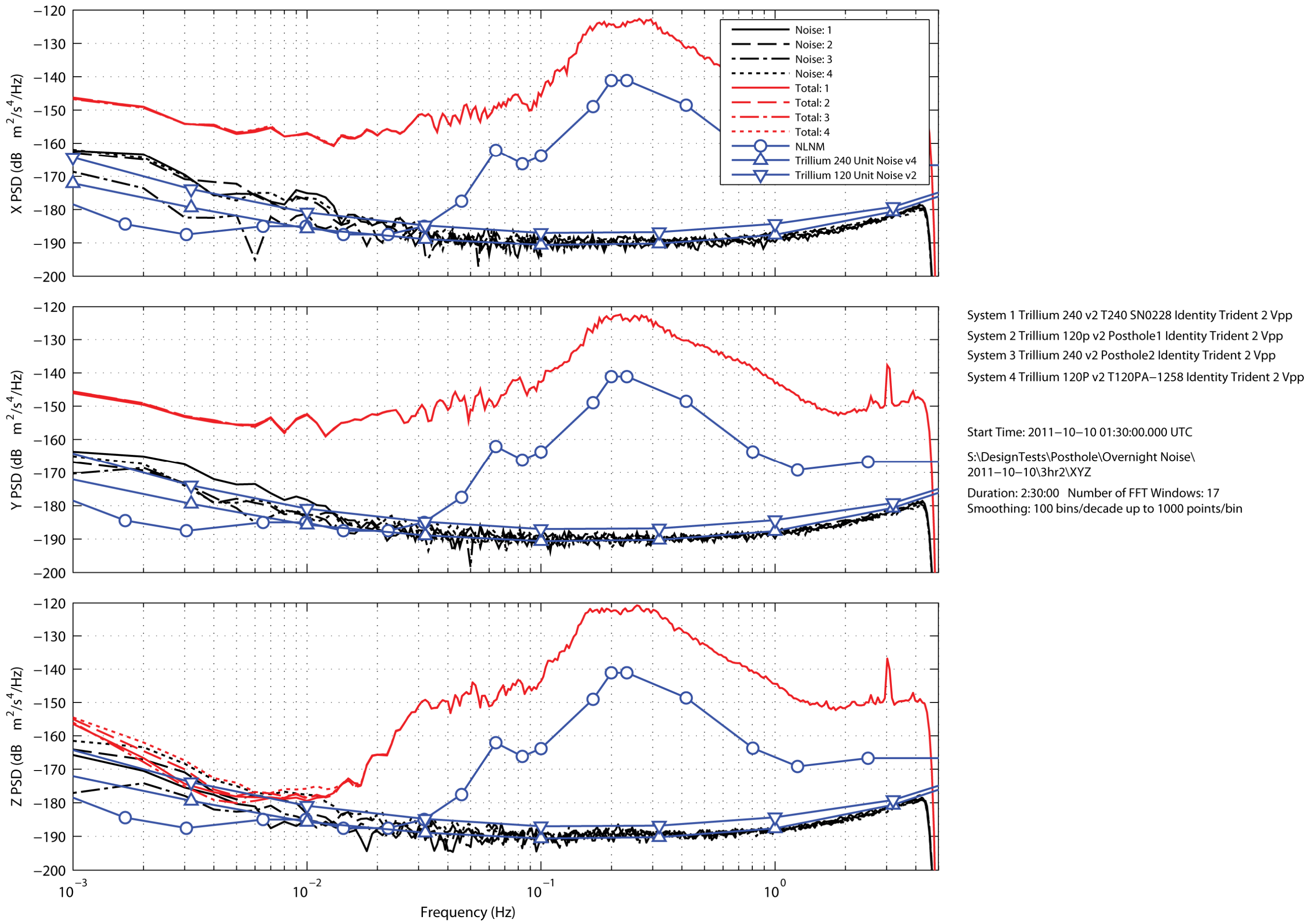


Figure A2 Low frequency PSD plot of a four seismometer installation at Nanometrics Inc.

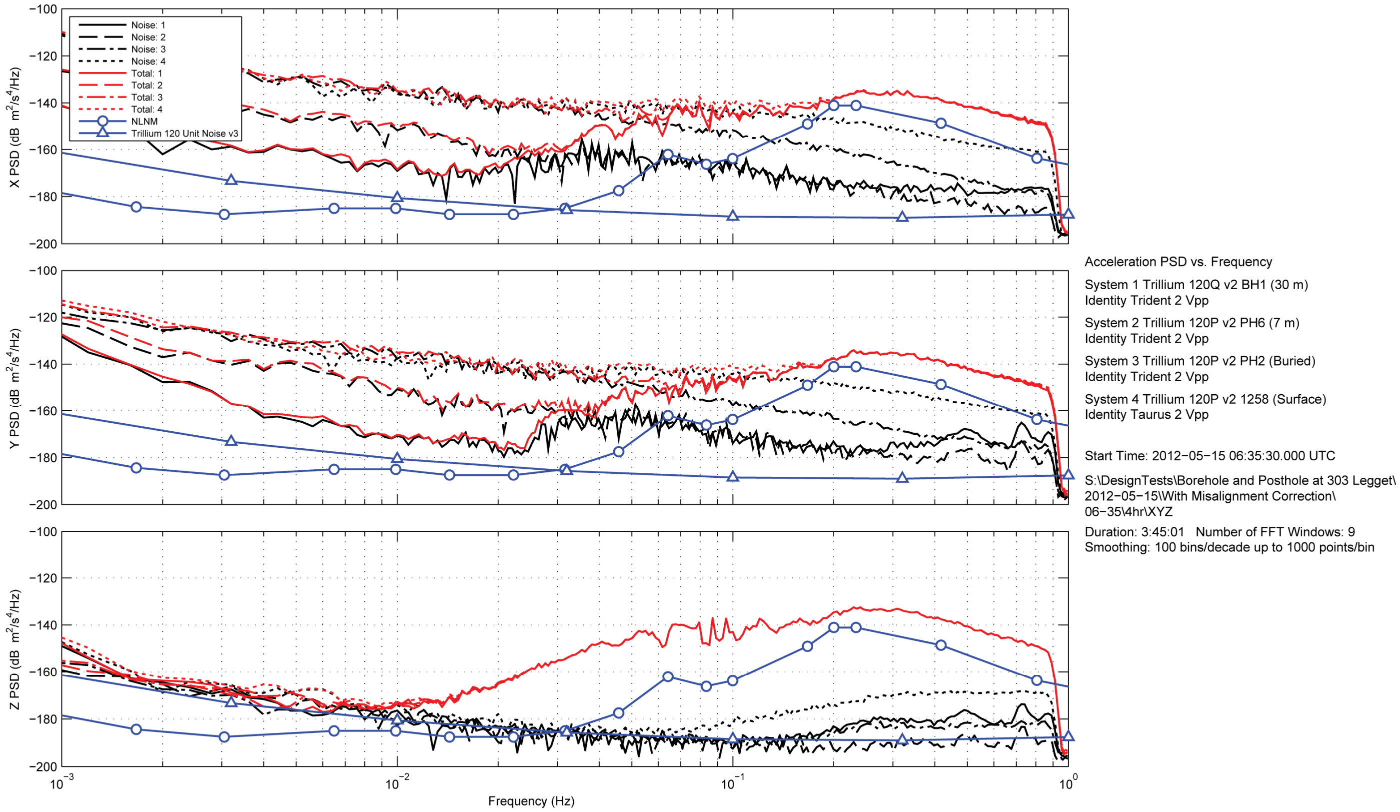


Figure A3 High frequency PSD plot of a four seismometer installation at Nanometrics Inc.

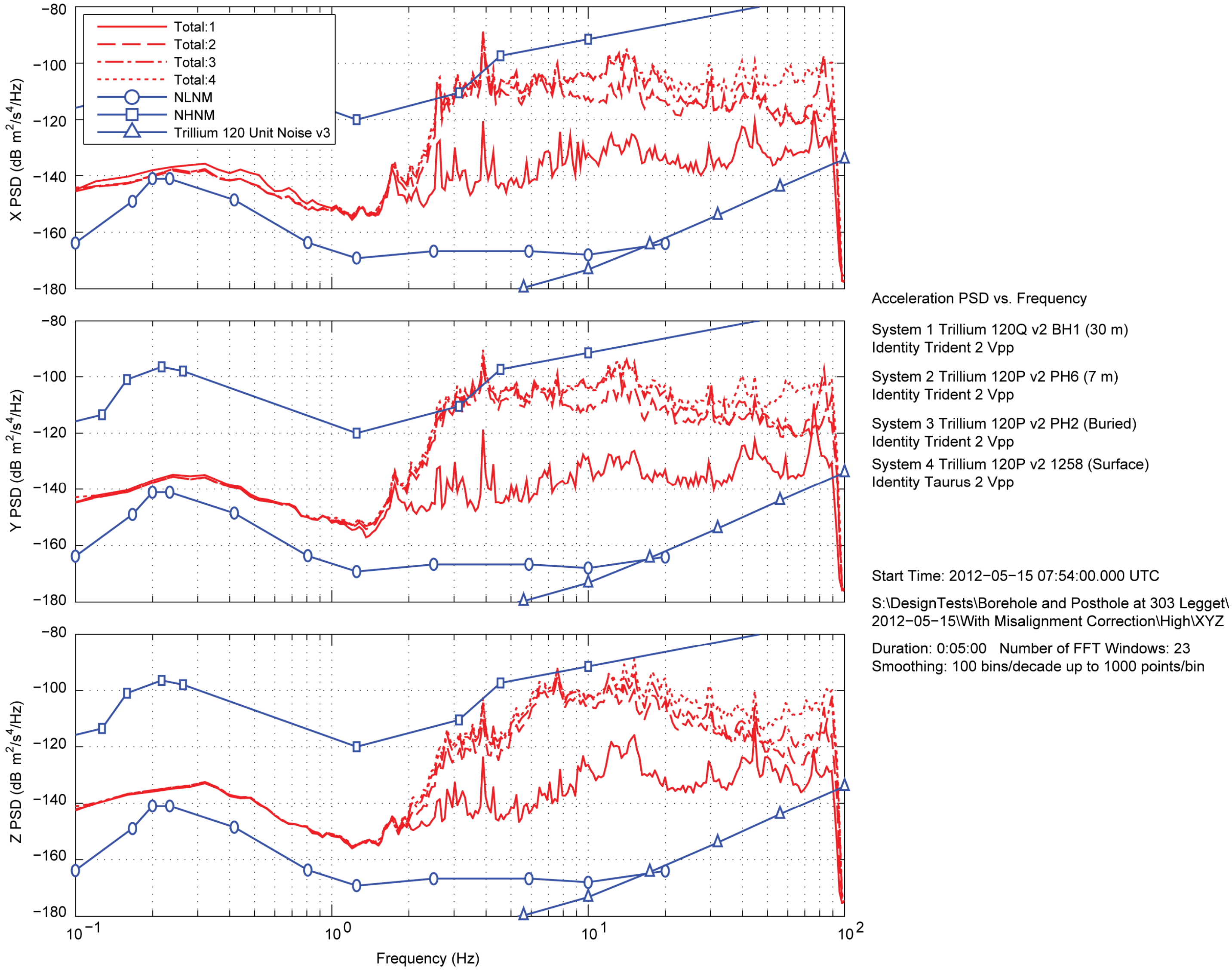


Figure A4 PSD plot for ASL installation at Snake Pit Cored Holes, Albuquerque, NM

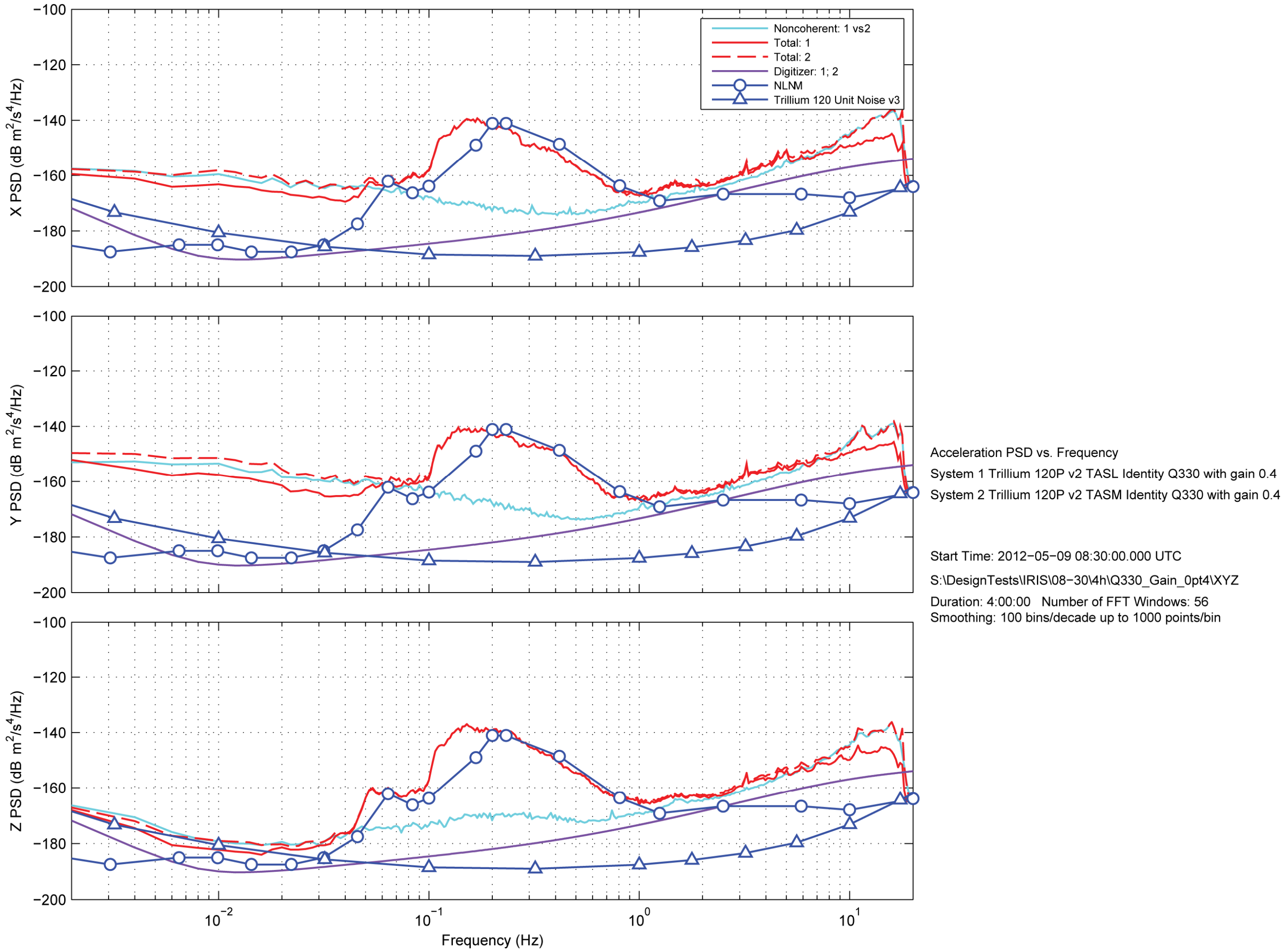


Figure A5 PSD plot for PASSCAL installation, Rio Grande flood plain, Socorro, NM

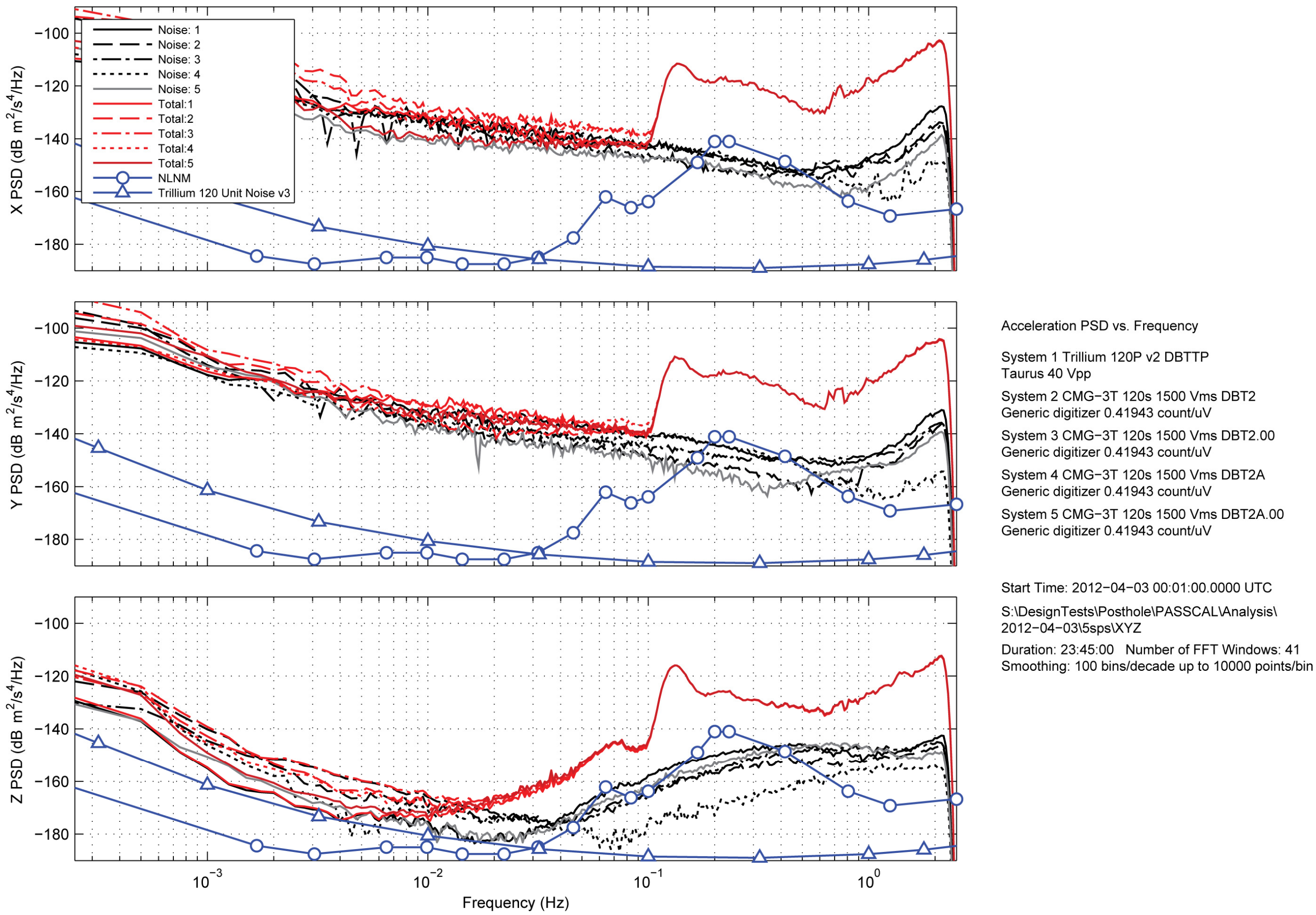
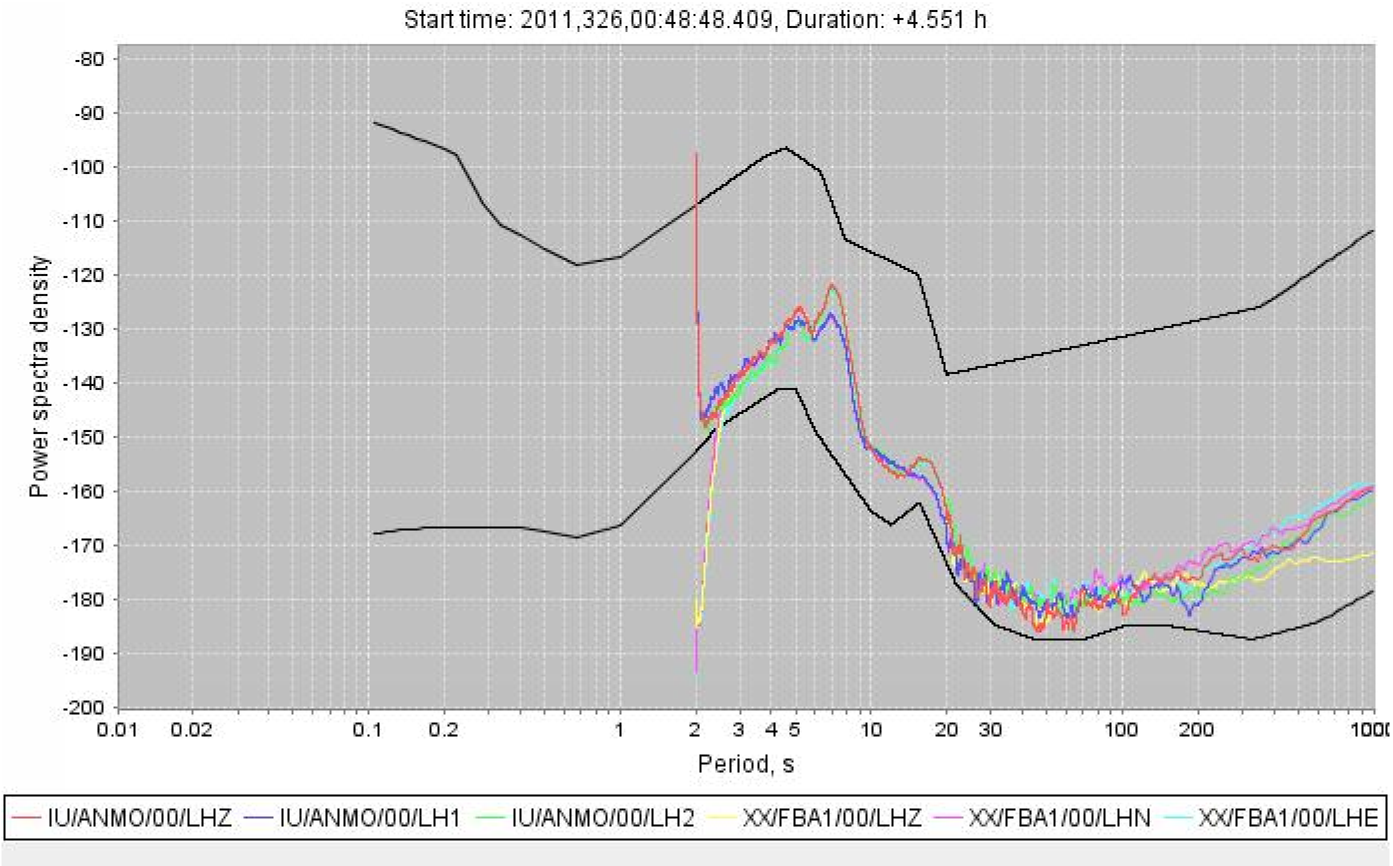


Figure A6 PSD plot for ASL installation at ANMO Seismic Observatory



KS-54000	**Trillium Posthole**	
Z = red	Z = yellow	
H1 = dark blue	N = pink	• Horizontals not oriented true north and east
H2 = green	E = light blue	

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Tim Parker of PASSCAL for providing details on the PASSCAL Trillium Posthole installation at the Rio Grande flood plain near Socorro, NM.

References

Ackerly, N. (2012) PASSCAL Evaluation of Trillium Posthole

Hutt, C. and Ringler, A. (2011) Brief Summary of Nanometrics Trillium Posthole Seismometer Noise Tests

Sleeman, R., van Wettum, A. and Trampert, J. (2006) Three-Channel Correlation Analysis: A New Technique to Measure Instrumental Noise of Digitizers and Seismic Sensors, Bulletin of the Seismological Society of America, Vol. 96, No. 1, pp. 258-271.

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