Comparison Study between Vault Seismometers and a New Posthole Seismometer

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Abstract

Surface vault broadband seismometers have typically yielded good results on the vertical, but have been unreliable and noisy on the horizontal. There are several reasons for this issue, including inherent problems with surface tilt noise and thermal stability. A comparison study was undertaken between the highest performing vault seismometers and a new broadband Posthole seismometer in a down-hole installation, at different depths and in various environments at stations in North America ranging from remote locations in Alaska to a noisy urban area. In the remote and urban studies, a spectral analysis was conducted and PSD plots were generated, the results of which will be provided in detail in the paper. This paper will discuss all of the results from these installations as well as the various installation techniques at these locations.

Trillium Posthole

The Trillium Posthole Seismometer is a very broadband seismometer designed for down-hole deployments. The instrument is housed in a stainless steel enclosure incorporating a high-pressure marine grade connector making it ideally suited to uncased, buried installations.

An advanced, internal leveling system allows the unit to operate over a tilt range of ±5 degrees (±10 degrees is also an option). The axis stack is mechanically levelled to ensure that the vertical axis does not couple horizontal noise.

The Trillium Posthole is ideal for local, regional and tele-seismic studies having a response flat to velocity from 120 seconds to 150 Hz and a self noise below the NLNM at 100 seconds. Operators will appreciate the low power consumption, remote mass centering and robust no-mass lock design inherent in all Trillium seismometers.

The Nanometrics Trillium Posthole seismometer is designed for subsurface installation to optimize seismic performance while minimizing the cost and logistics of site setup. Two models of the Trillium Posthole are available; model 17435 features a ±5° tilt range and a diameter of 5.64 inches, while model 17162 features a ±10 degree tilt range and a diameter of 6.77 inches.

For specifications, see the Trillium Posthole data sheet at http://www.nanometrics.ca/products/trillium-posthole

Performance

A four seismometer installation was performed at Nanometrics in Kanata, Ontario, Canada, which is situated in a business park of a busy urban area. 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 Posthole.

Figure 1 is an illustration of this installation with a graphical spectrum of low and high frequency noise levels at the various depths. Figure 2 provides the low frequency PSD plot of this installation and Figure 3 provides the high frequency plot.

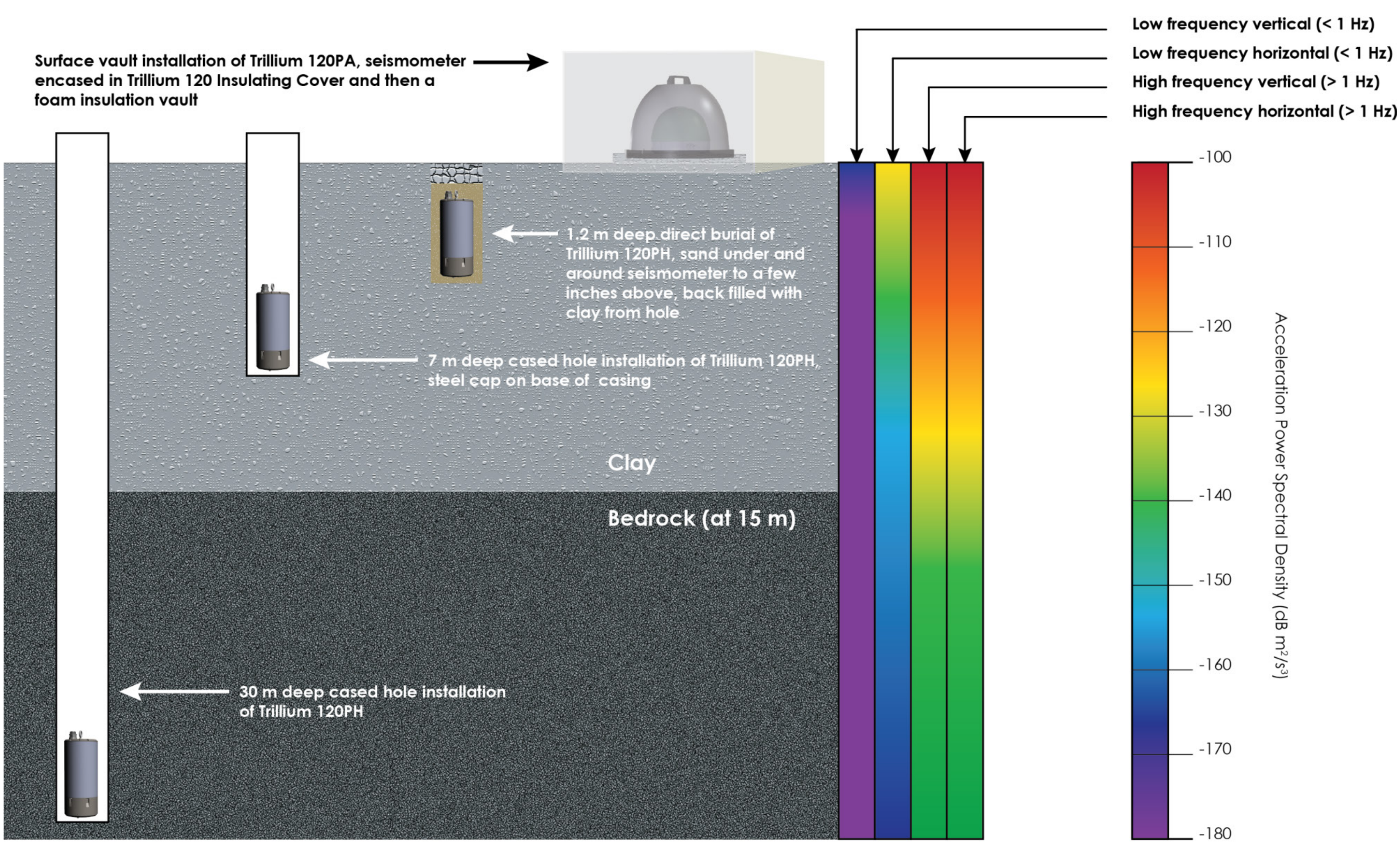

Figure 1 Spectral analysis of installation at Nanometrics Inc.

The low frequency PSD plot (Figure 2) of the Nanometrics installation 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 3 dB 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.

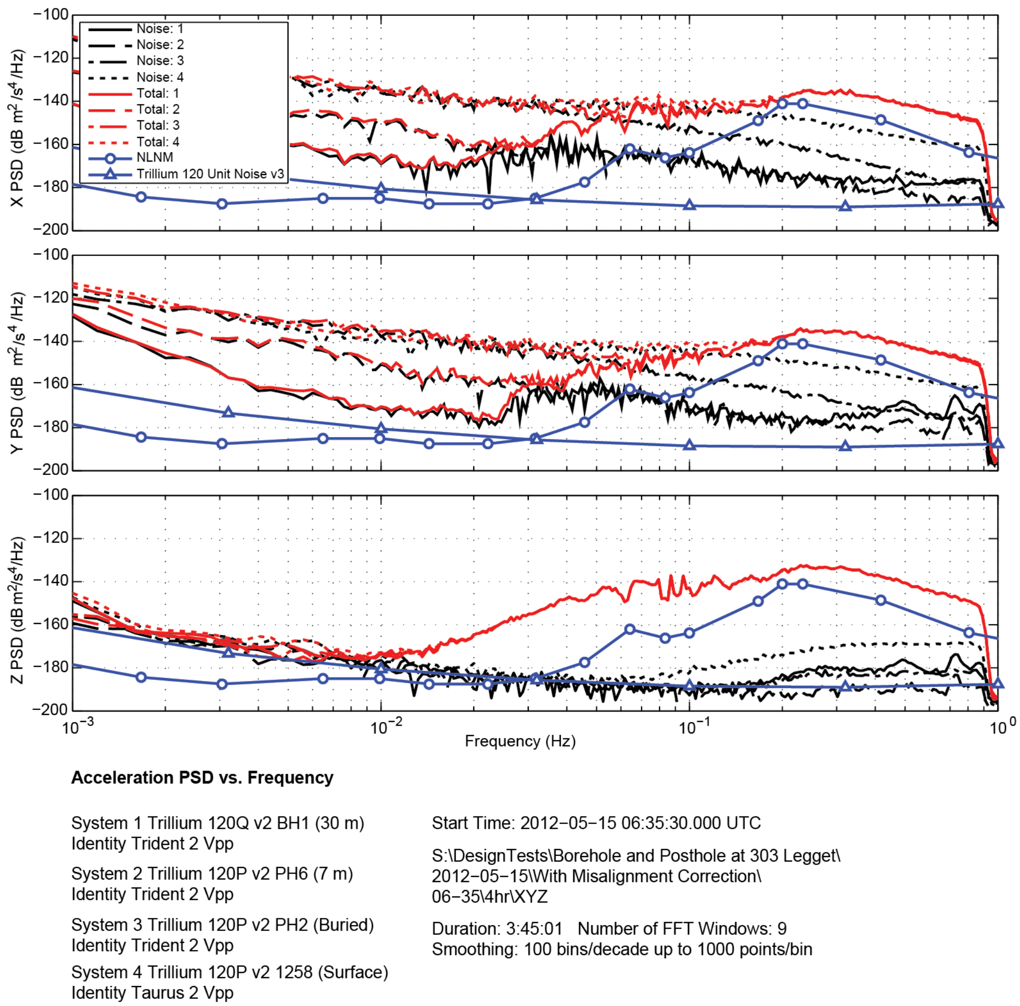

Figure 2 Low frequency PSD plot of a four seismometer installation at Nanometrics Inc.

The high frequency PSD plot (Figure 3) shows that

- In a 7 m deep hole, from 2 to 50 Hz, there is a -6 dB 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.

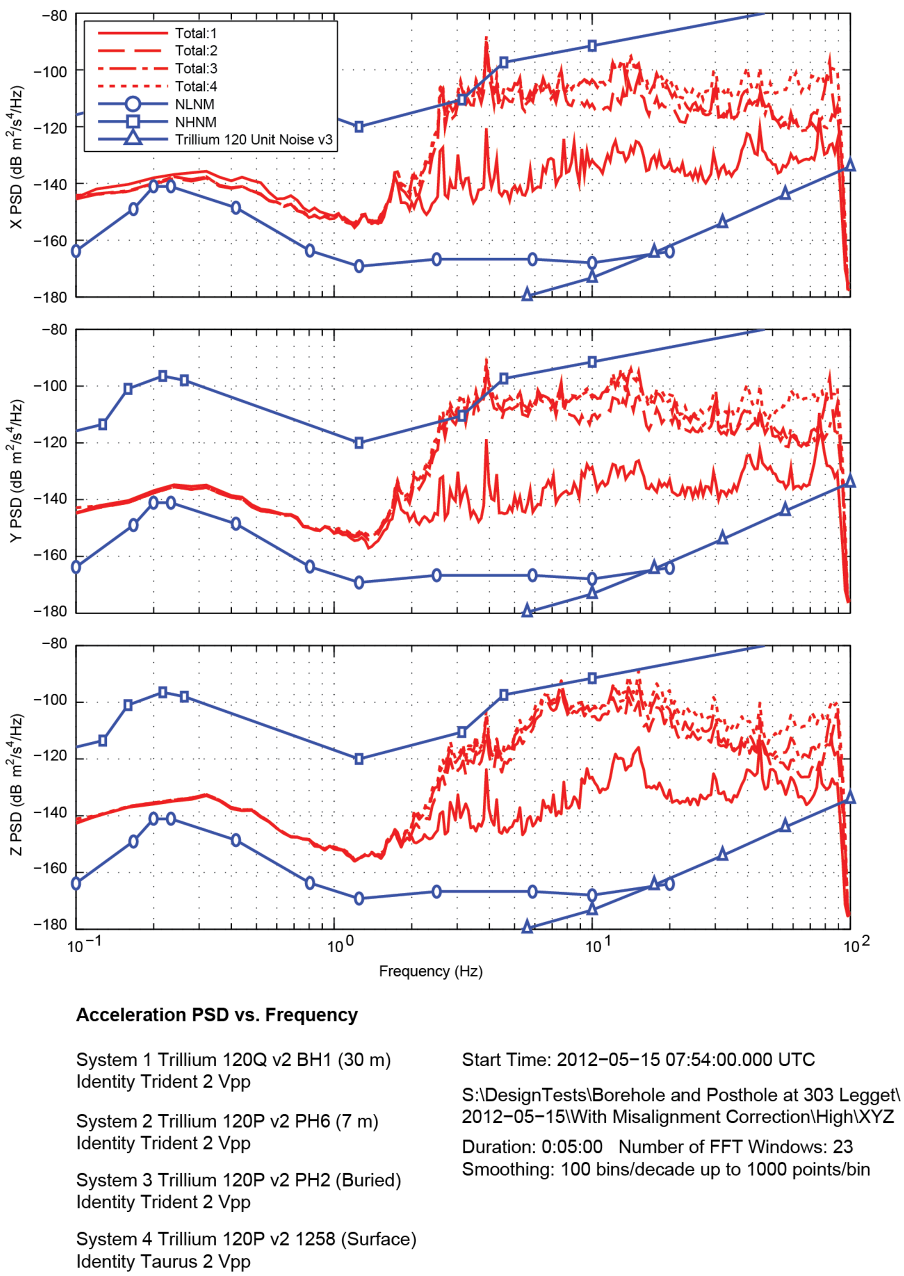

Figure 3 High frequency PSD plot of a four seismometer installation at Nanometrics Inc.

Figure 4 illustrates a typical transportable array (TA) vault installation, while the 5.5 m Trillium Posthole installation in Figure 5 shows an actual installation at the TA.POKR.01 test station. Comparing the two illustrations, it is obvious to see that the effort, complexity, and footprint involved in a vault installation far outweigh that of a posthole installation.

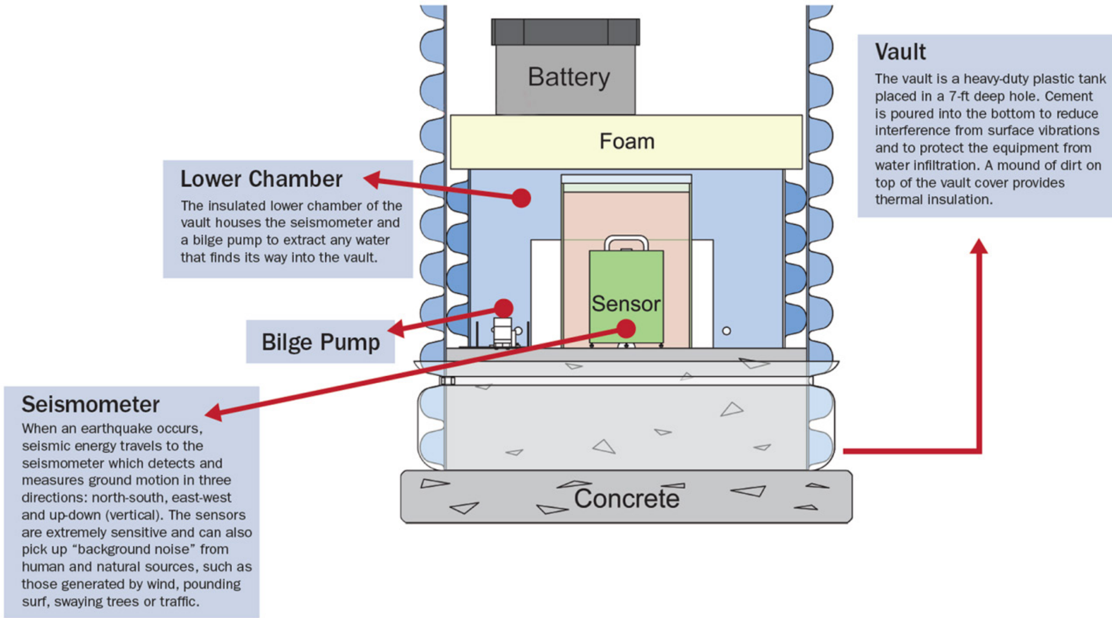

Figure 4 Actual TA.POKR.01 test installation installed at 5 m, with typical posthole seismometer installation in granite

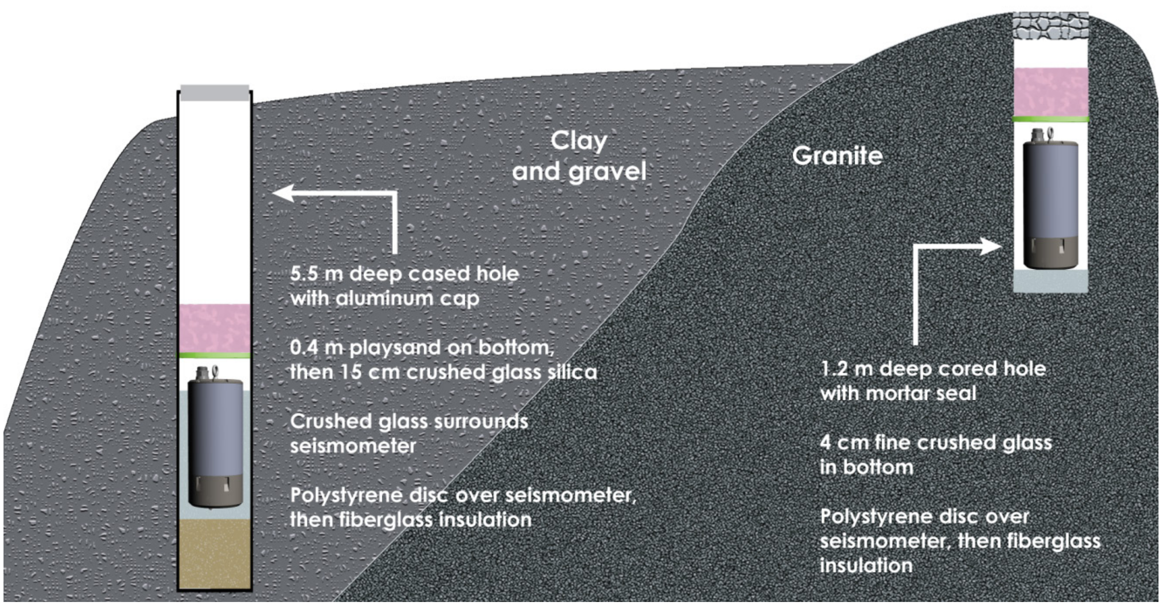

Figure 5 Actual TA.POKR.01 test installation installed at 5 m, with typical posthole seismometer installation in granite

Real-world Results

The M7.7 earthquake experienced on October 28, 2012 in Haida Gwaii, British Columbia (see Figure 6) provided real-world results in the comparison of the vault and posthole installations at the transportable array near Fairbanks, Alaska.

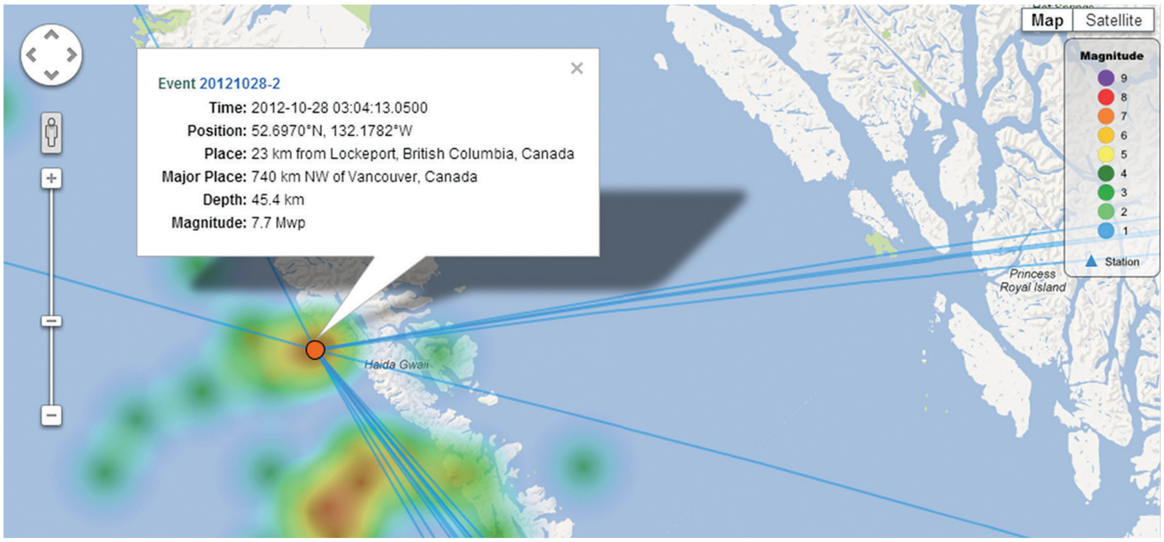

Figure 6 Nanometrics Athena Event Cataloging and Notification software identifying the Haida Gwaii M7.7 event

Figure 7 shows an acceleration spectrogram of the event. The right side of the spectrogram is the POKR surface vault installation and the left side is the POKR.01 posthole installation at 5 m depth. Both sides show the period leading up to and including the M7.7 event. Both sides also show quiet on the vertical channel leading up to the event; however, the Trillium Posthole shows revolutionary results with quiet on both horizontal channels as well, at only 5 m depth, as witnessed by the dark blue spectrum on the plots below.

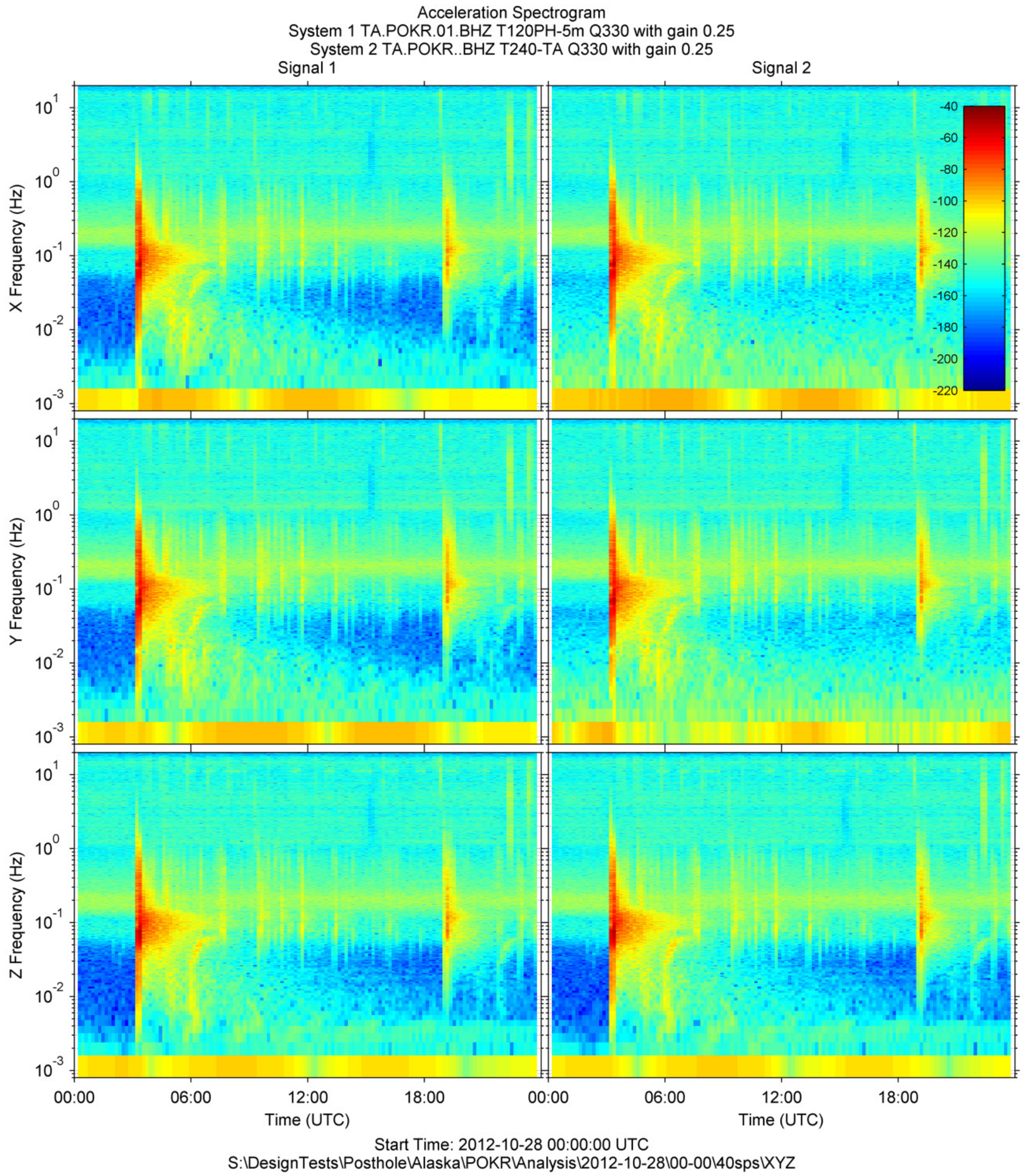

Figure 7 Acceleration spectrogram showing Haida Gwaii M7.7 event recorded by POKR Trillium 240 surface vault installation and POKR.01 co-located Trillium Posthole at 5 m depth

Conclusion

The measurements from the Haida Gwaii event and from the other installations featured in this paper show significantly improved noise performance benefits associated with installing a seismometer in a down-hole environment that are not available to vault instruments; including significantly decreased horizontal noise. Posthole installations at just 5 m depth show clear advantages over surface installations; this is amply demonstrated by the POKR installation, particularly during the M7.7 event at Haida Gwaii. Throughout all installations, the Trillium Posthole is performing to its specification of -181 dB. The urban location at Nanometrics provided similar performance to a surface vault installation in a remote location. The results from these studies indicate that it is now possible to get beneath the noise and keep assets secure, even in noisy urban locations.

The Trillium Posthole has successfully identified clear benefits in all areas of seismometer installation, from reduced noise, to increased security, to decreased footprints. 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 down-hole environment that are not available to vault instruments, specifically:
    - Horizontal noise is significantly suppressed in down-hole 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.

Acknowledgements

Bob Busby, Incorporated Research Institutions for Seismology (IRIS), for providing his installation reports and diagrams of the Trillium Posthole installation at the TA.POKR and TA.POKR.01 stations near Fairbanks, Alaska.

NIck Ackerley, Nanometrics Inc., for providing his November 2012 report, Evaluation of Broadband Seismometers in Alaska, examining the installation methods of several seismometers, including the Trillium Posthole at the HDA/POKR stations.

About Nanometrics

Nanometrics Inc. is a world-class provider of precision instrumentation, network technology and software applications for seismological and environmental research. Nanometrics products are employed for the study and monitoring of regional, national and global seismicity; natural resource exploration; environmental data communications; and other scientific applications. Deployed in over 100 countries on every continent, Nanometrics real-time and portable systems are utilized by the world's leading scientific institutions, universities, corporations and test ban treaty monitoring organizations.