Temporary Broadband Seismic Station Deployments in the 21st Century

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Summary

Truly portable broadband (BB) seismic instrumentation becomes viable only when the superiority of direct burial and purpose-built instrumentation is embraced. Direct comparisons of shallow vaults with pier-style instruments versus direct burial, using specific tests, analysis of IRIS PASSCAL supported experiments, and reviews of the IRIS archived portable BB datasets, provide evidence that it is the best approach for temporary station installations. Modern instrumentation that is self aware and reports complete instrument response can also contribute to a trouble-free and successful portable BB station deployment. Many of the method's shortcomings for obtaining quality temporary field observations of long-period seismic wave fields are related to field methods developed to handle the limitations of older BB systems on offer from vendors, instead of reengineering the seismic system for the very general, yet field-specific, use case.

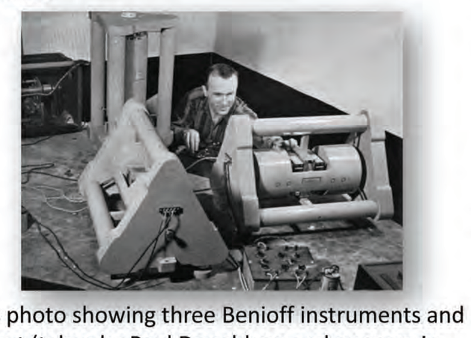
We compare shallow vault deployments with traditional pier-style instruments to shallow posthole type deployments through PSDs PDF plots and other routine metrics for establishing station quality. We discuss embracing community standards for easy and accurate exchange of metadata, exploiting self-aware instrumentation for fewer metadata reporting issues and less analyst time troubleshooting metadata issues. The applications of these new instrument designs and new *modus operandi* is advantageous for early earthquake warning, rapid earthquake aftershock studies and volcanic hazards responses.

From first century China to today

132 AD

Photo by Houfeng Didong of modern replica of Zhang Heng's seismoscope

1930s

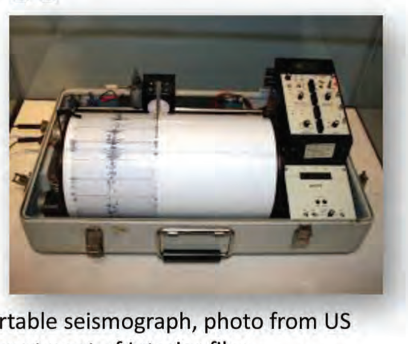


1930s photo showing three Benioff instruments and Don Leet (taken by Paul Donaldson and appears in *Geophysics* at Harvard, *Ishii et al (2015)*

From the first seismic instrument invented by Zhang Heng in AD132, we now have global coverage and very broadband measurements with increasing numbers of stations and denser arrays, but not in the density needed to significantly advance understanding and imaging of the complex structure in the Earth's interior and crust with passive recording techniques. This is partly a limitation of the number of stations available but also because of the time and effort required to deploy pier-style broadband sensors. The energy sector however routinely deploys tens of thousands of channels of systems for active source imaging in frequency ranges and signal amplitudes that don't require the construction of piers, vaults or even burial that broadband seismic sensors do for recording quality data sets.

Direct burial of new purpose-built broadband instruments reduces the time and money required for successfully deploying stations. It enables researchers to install more instruments for the same budget and obtain a higher quality data set over conventionally deployed pier-type instruments in temporary vaults. Used in a GSN-type station, they can reduce the cost of construction (shallow cased boreholes are less expensive than large vaults) while providing increased reliability as most vaults still require protection of the instruments from water. Deep seismic boreholes deployments have proven superior to large surface vaults and for temporary deployments of instruments near the surface, shallow boreholes are proving superior to vaults now that there are sensors that are designed for the purpose of either cased borehole or direct burial.

1970s



Portable seismograph, photo from US Department of Interior files

2016

Broadband GSN station Hong Kong Po Shan (HKPS)Photo courtesy of GSN

2016

Fully integrated portable broadband/digitizer system deployed at the South Pole, Antarctica, photo courtesy IRIS PASSCAL Instrument Center

The vault problem

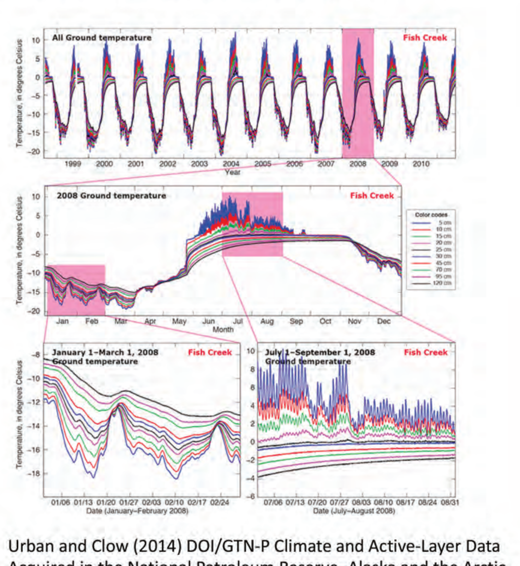
Broadband studies require low noise recordings of both vertical and horizontal channels, which is difficult and costly to accomplish with a pier-style instrument in a temporary surface vault deployment. Researchers try to meet these requirements but are constrained by limitations of pier-type instruments: vault engineering, purchasing of disposable vault materials, transportation of the materials to create temporary vaults and many hours to construct. The problem is compounded when working in remote or environmentally challenging environments.

The challenges related to the sensor are temperature stability, air circulation, pier stability, security and water intrusion. It's also difficult to create a consistent vault build quality with non-professional staff, which compounds the near-surface seismic noise challenge. Temporary vault construction involves many hours of planning, materials gathering and finally constructing on site. After the experiment the vault materials are often discarded.

Using purpose-built broadband sensors and direct burial techniques or shallow cased boreholes eliminates failure because of water intrusion issues. Direct burial uses the mass of the earth to mitigate diurnal temperature changes and creates a stable environment for less tilt and better ground coupling.

Photos courtesy of the NSF SAGE facility PASSCAL

Depending on latitude, altitude, soil type, water content and shading, burying the top of the sensor to a depth of .7-1 meter will limit the diurnal temperature change to < 1 °C.



Urban and Clow (2014) DOI/GTN-P Climate and Active-Layer Data Acquired in the National Petroleum Reserve–Alaska and the Arctic National Wildlife Refuge, 1998–2011(USGS Publications)

The cost of logistics adds to the cost of instrument ownership

11,543 portable broadband station deployments since facility creation, a huge investment of time and money!

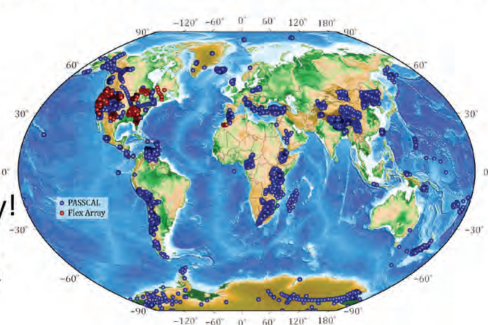
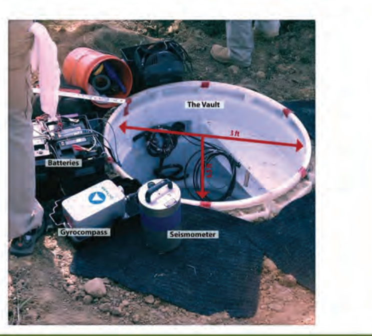


Figure courtesy Bruce Beaudoin IRIS PASSCAL Instrument Center

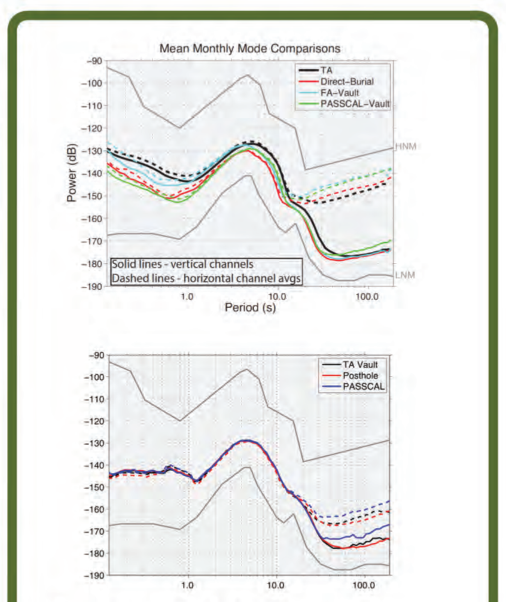
The NSF Earthscope Transportable Array project budgeted over $8,000.USD to install every vault, for 2,000 installations! These systems also required $3,000.USD for remediation after the recording period was over. Roughly $22million USD!



Studies comparing shallow vaults to direct bury

Until recently, the USA's National Science Foundation (NSF) portable instrument pool consisted of only traditional pier-style BB seismic sensors, requiring researchers to construct vaults. The sensors were not designed for the typical use case of a portable broadband experiment, and this caused both data loss and lower data quality even though much effort was put into engineering improvised vaults. Vendors now provide purpose-built instrumentation for both this research application and the observational facility use case. This NSF portable instrument facility is replacing the failed instruments with posthole type direct bury instrumentation. Recent analysis of deployments by Sweet (2015) has demonstrated direct burial techniques have lower installation noise in the low frequency range when compared to the temporary PASSCAL-type vault deployments and comparable to Earthscope Transportable Array deployments (which are installed 1 meter deeper) by comparing their noise performance by using PSD probability density functions (McNamara & Buland, 2004).

Trillium 120PH posthole sensor



Sweet et al.,2015

Studies comparing direct bury vs borehole vs vault

- Comparison study between vault, PH (Nanometrics 2013)
- Quantifying benefits of shallow posthole installations (RESIF 2015)
- Comparative noise performance of portable broadband sensor emplacements (IRIS/PASSCAL 2014)
- Borehole tests at USGS Albuquerque Seismological Laboratory (Bob Hutt 2014)
- Data quality of collocated portable broadband seismometers using direct-burial and vault emplacement Aderhold, et al.,2015

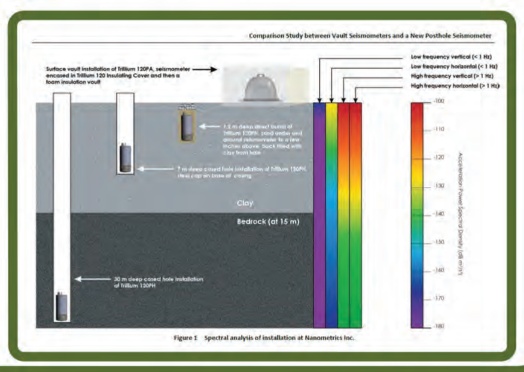


Figure 1 Spectral analysis of installation at Nanometrics Inc.

21st century broadband seismic instrumentation

Meridian 120PH and Compact 120PH are fully integrated digital seismometers featuring a Trillium 120PH seismometer or a Trillium Compact sensor paired with a 24-bit digital recorder inside a waterproof, stainless steel vessel. The all-in-one design simplifies and ruggedizes the deployment, making this instrument ideal for large transportable arrays and many other applications where portability and rapid deployment are important.

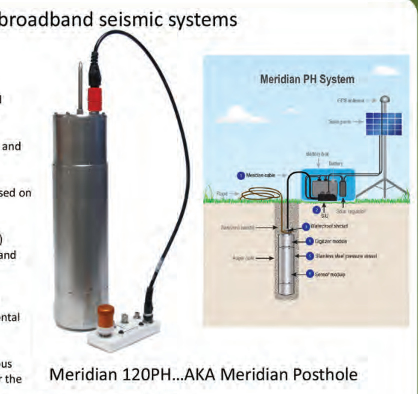
Data is retrieved via a waterproof data cartridge from the IP68 rated surface interface unit (SIU) or telemetered to a network operations center. The Meridian systems are based on polar-proven direct burial type sensors that have been deployed for over 3 years in polar environments. There are over 40 deployed in Antarctica presently and the Meridian development is now being tested, the next logical step in reducing the cost, volume and weight of polar-rated seismic stations. Cost of seismic equipment and volume of enclosures could be reduced by ~30% over the systems deployed in Antarctic multi-year stations today.

Winter over LiFePO4 Rechargeable System and integrated BB seismic system

Figure courtesy of GEOICE project PASSCAL

Nanometrics Integrated broadband seismic systems

- Small size
- Rugged digitizer and cabling
- IP68, direct buriable
- Lightning and static discharge hardened
- Secure data, sealed data cartridge with industrial SD media
- Redundant data storage (data cartridge and downhole store)
- Self-aware metadata
- Response file generated on demand based on current configuration
- Allows for a unit tilt range of ±5° or ±10°(120PH) or ±2.5° or ±10° (Compact)
- Provides motorized automatic leveling and mass centering that can be remotely initiated(120PH)
- Leveling system that levels the internal seismometer to true vertical and horizontal orientation
- There is no mass lock
- Required power recording in autonomous mode - 1.4W for the 120PH and .9W for the Compact



Meridian 120PH…AKA Meridian Posthole

A pressure vessel ideally suited to uncased or cased posthole installations that

- Is made of stainless steel with a fully waterproof detachable cable entrance designed for continuous submersion.
- Posthole 120 is 143 mm (5.63 in.) outside diameter that allows for installations in narrow cased hole environments. Compact is 97mm (3.87 in.) outside diameter.
- Has a centered eyebolt in the end cap for attaching a lifting chain or strain relief cable
- The eyebolt has a load rating of 590 kg (1300 lb)

Exceptional performance that makes them ideal for teleseismic, regional, and local studies by Providing

- An extended low frequency range useful out to beyond 1000 seconds (120PH)
- Low sensitivity to both tilt and temperature(120PH). Recentering is rarely required after the initial installation.
- The ability to resolve Peterson's new median-noise model (NLNM) down to a 200 second period(120PH)
- A wide dynamic range with a clip level of 16.6 mm/s up to 10 Hz and 0.17 g above 10 Hz(120PH)
- A symmetric triaxial arrangement of the sensing elements that ensures uniformity between vertical and horizontal outputs
- The ability to remotely select either the raw (UVW) or resulting horizontal-vertical (XYZ) outputs allows for the calibration of each axis separately.

Digitization, featuring

- An intuitive Web interface accessible via Ethernet connection
- True 24-bit performance
- Dual sample rates of up to up to 2000 sps—(only in streaming mode), 500sps maximum for continuous archiving mode
- Advanced bandpassed triggering
- Data retrieval via a removable SD™ card in MiniSEED and SEGY file Formats or from the store via the local Ethernet
- Event peak ground motion statistics: acceleration, velocity, and displacement
- Acquisition and data management of high precision GPS data (BINEX)
- Comprehensive real-time communications options include SeedLink support
- Data Latency as low as 1 second

Meridian Compact 120PH

Researchers using direct burial instrumentation

Photos courtesy of the NSF SAGE facility PASSCAL

Conclusions

- New instrumentation is available that is purpose built for portable broadband deployments via direct burial. This instrumentation has become "best practice" for seismic facilities.
- Simple direct bury installation techniques rival the best efforts of well-funded facility temporary vault at a small fraction of the cost and time.
- Studies looking at noise performance, comparing instrumentation and these techniques, suggest more consistent and lower-noise installations.
- To increase station density, integration of the digitizer can reduce the amount of effort involved with deploying a larger number of stations, specifically reducing the meta-data efforts and mistakes, features stated to be extremely important to advance imaging of structures by researchers by enabling great numbers of deployments with the same logistics.