A New Range of Direct Bury Instruments, From Very Weak to Strong Motion Sensors

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Abstract

The endeavor to make weak and strong motion sensors deployable in any terrestrial environment continues with the Cascadia series and over 200dB of dynamic range. The new Horizon broadband sensor will work both in a direct burial application or as a robust pier instrument. Boreholes are recognized as the quieter environments for the lowest noise observatory class instruments and the new T360 based instruments can be deployed in direct burial environments which is unprecedented. The experiences of support facilities in large deployments of broadband seismometers in continental scale rolling arrays proves the utility of packaging new sensors in corrosion resistant casings and designing in the robustness needed to work reliably in temporary deployments. Integrating digitizers and other sensors decreases deployment complexity, decreases acquisition and deployment costs, increases reliability and utility. We'll discuss the informed evolution of broadband pier instruments into the modern seismic systems that enable economic densification of monitoring arrays along with supporting new ways to approach geoscience research in a field environment.

Drawbacks of Most Modern Broadband Seismometers

Designed for deployments in temperature controlled vaults with dry, stable piers, a single and limiting use case.

- Cases and connectors made of corrodible materials
- Cases not robust enough to mitigate atmospheric pressure changes
- Cases not designed for pressures of immersion or for contact with other materials such as sand and soils
- Cases not designed with magnetic shielding
- Limited cold temperature tolerance
- Limited tilt tolerance and dynamic range (more than before but still not enough in EQ zones)
- Majority not deployable in smaller boreholes (<150mm diameter)
- Majority are not "smart" sensors, only analog outputs
- Most have poor electrical transient protection
- Most are designed and treated as a stand-alone instrument and not as a fully integrated part of a seismic station system
- Most can not report their own SOH, metadata, responses and identification
- Have limited and inadequate vendor support

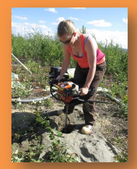
Discussion-Seismology applications evolved, the user community grew and researchers were awarded significant support through funding agencies. Instrumentation development has lagged and researchers have been improvising solutions that solved problems in deploying instruments in a greater range of conditions, in larger numbers and requiring less logistical support. Vendors are working on improving their designs for greater capability while reducing the costs of fielding and operating these systems in any terrestrial environment.

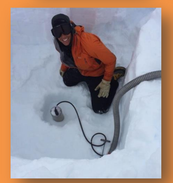
(Pictures below are courtesy of the PASSCAL Instrument Center and IRIS web archives unless noted otherwise)

Temporary vaults using pier type instruments

Temporary vaults, time consuming to build, vary in quality and rarely are waterproof

Posthole instruments using augured holes





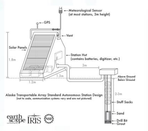
Blue cylinder is improvised pressure case for pier instrument

STS-2 with GRSN Shielding

Photo courtesy of Neil Ziegelman, Albuquerque Seismological Laboratory

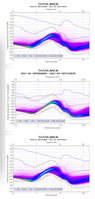
US Array TA station evolution from left to right, all figures, photos and data from IRIS Web Services

TA Vault based design used for first 8 years with pier style instruments, many stations had water damage



Alaska station design based on cased holes and ***posthole*** type sensors, this station design change lowered horizontal noise floors significantly

TA Station F25K Christian River, AK, USA- Sensor T120PH



Examples of NEW Integrated Seismic Systems

Meridian based systems with integrated digitizers…if you still want all telemetry options and modern tilt tolerant broad and midband instuments in rugged containers sutiable for any terrestial environment.

- Rugged and compact digitizer and cabling
- IP68, direct buriable instrument, or installed in rudimentary vault, pier, cased hole
- Electrical transients hardened
- Redundant data, Sealed data cartridge with industrial SD media and internal media backup
- Self-aware metadata, response file generated on demand based on current configuration
- Allows for a unit tilt range of ±5° or ±10°(120PH option) 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
- Power required recording in autonomous mode 1.4W 120PH and .9W Compact

Pressure vessel ideally suited to uncased or cased posthole installations

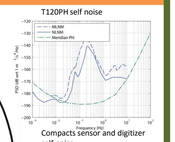
- Made of stainless steel with a fully waterproof detachable cable designed for continuous submersion.
- Posthole 120 is 143 mm (5.63 in.) OD, Compact is 97mm (3.87 in.) OD.
- Has a centered eyebolt or alignment fitting in the end cap for attaching a lifting chain or strain relief cable

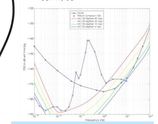
Exceptional performance that makes them ideal for teleseismic, regional, and local studies by providing:

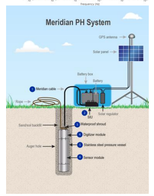
- An extended low frequency range useful out to beyond 1000 seconds (120PH)
- Low sensitivity to both tilt and temperature(120PH). Re-centering is rarely required after the initial installation.
- The ability to resolve Peterson's new median-noise model (NLNM) down to a 200 second period(120PH)
- A wide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

Digitizer Features:

- An intuitive Web interface accessible via Ethernet connection
- True 24-bit performance
- Dual sample rates of up to up to 2000sps in streaming mode, 500sps maximum for continuous archiving mode
- Advanced bandpassed triggering
- Data retrieval via a removable SD™ card or local Ethernet in MiniSEED and SEGY file Formats
- 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







Examples of NEW Integrated Earthquake Early Warning Systems

The Cascadia series of instruments are the combination of proven high-performance strong motion and weak motion seismic sensors into a single integrated modular unit that can be installed as a single instrument. Cascadia provides several advantages for installation as well as improved performance. Several options can be considered, incorporating a variety of physical form-factors, seismometer technology, and accelerometer signal range selections.

Form-factors:

- Compact posthole 97mm(3.8") diameter
- Auto-leveling full Posthole 143mm(5.75") diameter
- Observatory-class Borehole 143mm(5.75") diameter

Seismometer technology:

- Compact Broadband - 120s (in compact form-factor)
- Compact 10° tilt-range - 20s (in compact form-factor)
- Observatory-class – 120s (in full posthole or borehole)
- GSN-class – 360s (in full posthole or borehole)

Accelerometer range:

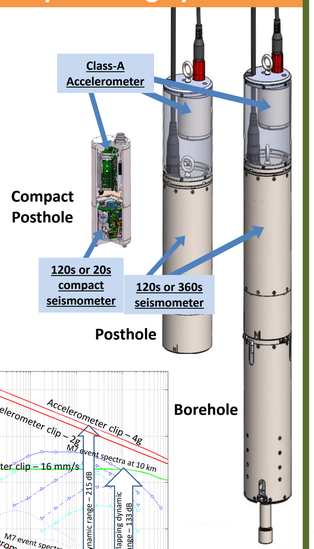
- Dynamic selection of signal range: ±4g, ± 2g, ± 1g, ± ½g, ± ¼gThe

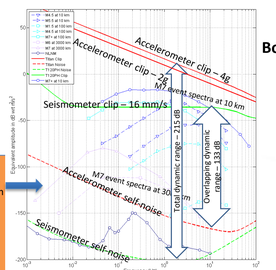
Site and installation improvements

- Two sensors managed as one
- Bore or dig one hole, whether shallow or deep borehole
- Manage one cable (compact form-factor)
- Level and align once
- Electronic leveling bubble on digitizer GUI
  - Easily manipulate the compact posthole in a dark hole
  - Check vertical orientation of sensor at any time remotely
  - Observe verticality of borehole casing during installation

Performance and operational improvements

- Always on-scale: local large magnitude as well as very weak signals recorded with the high combined dynamic range of the two sensors
- All six channels precisely aligned
- Surface noise (cultural, temperature, tilt) reduced, even with shallow burial

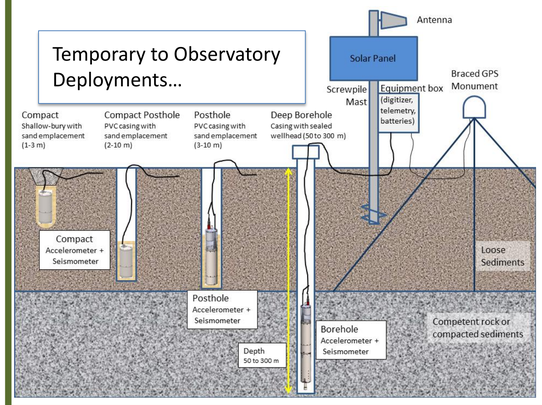




Graphical view of combined sensor dynamic range, showing maximum recordable signals (clip level), minimum discernable signals (self-noise floor), typical earthquake spectra at various magnitudes and distances, the Peterson New Low Noise Model, and the overlapping and total dynamic ranges. One example is shown: a Titan 4g accelerometer combined with a Trillium 120 Posthole. Other options can be considered, e.g.: GSN-class 360s seismometers, configuring the accelerometer to 2g and for high density arrays at a lower cost a Titan 4g combined with a Trillium Compact 120 second PH.

4g Class A Accelerometer + Observatory Class 120s Seismometer

Station Options: Near-Surface, Posthole, Borehole, Icehole, Snowhole!



The multi-use station design comprises power, telemetry, digitizer/data logger, seismic sensors and possibly other sensors such as high-rate GPS/GNSS instrumentation. Three options are considered for the site:

Near-surface:
Direct-bury, typically to 1m, in an uncased hole, backfilled with sand. The 6-channel sensor is a Class-A accelerometer integrated with a compact 120s broadband seismometer in a compact posthole form factor.

Posthole:
PVC or steel-cased hole 3-10m, backfilled partially with sand. The 6-channel sensor is a Class-A accelerometer integrated with an auto-levelling 120s or 360s broadband seismometer in a full posthole form factor.

Borehole:
Steel-cased dry borehole drilled 50-300m. The 6-channel sensor is a Class-A accelerometer integrated with an auto-levelling 120s or 360s broadband borehole seismometer with a motorized holelock.

Trillium Horizon, an example of a new direct bury VBB Sensor, will work on a wet or flooded pier too!

Sensor/Digitizer Integration Benefits

The seismic signal digitizer is a key component of a integrated station, where specific advances are focused on delivering multiple data streams tailored for the different uses of the station data, as well as optimizing the cost and convenience of installation and operation.

Installation and configuration:
Tight integration between the seismometer and digitizer can enable rapid, convenient installation and reduce errors.

- Use the seismometer's electronic leveling bubble displayed on digitizer web GUI while sensor is powered up

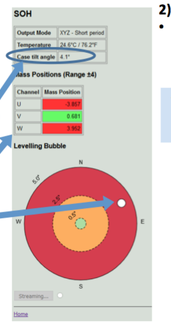
1) Start leveling process

- Power up system
- Access web GUI
- Go to Sensor SOH page
- Use short-period mode
- Observe tilt and bubble (tilted 4.1°, NE direction)

Tilt out of range at 4.1°

Mass positions out of range

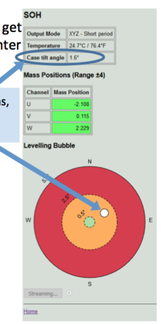
Bubble indicator outside the 2.5° range



2) Level sensor

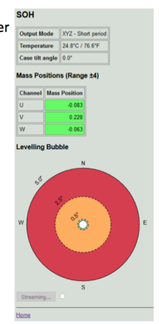
- Tilt sensor to get bubble to center

Tilt, mass positions, bubble in range but not perfect

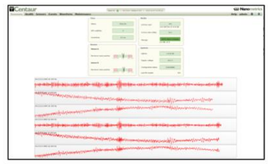


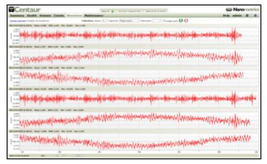
3) Complete

- Bubble at center
- Tilt near zero
- Mass positions near zero



- The digitizer real-time waveform display and Status Summary pages quickly confirms everything is working





- Response management: the digitizer automatically constructs station response files in RESP, dataless SEED format that includes the sensor and digitizer responses based on digitizer/sensor configurations.