Field Calibration of Seismic Instruments

Geoffrey Bainbridge, Bruce Townsend, Marián Jusko

Nanometrics Inc.

INTRODUCTION AND MAIN RESULTS

Initial calibration can be done in a laboratory using specialized test equipment, but to check calibration of instruments over their lifetime in the field requires different processes. We discuss two particular challenges: site response and temperature sensitivity:

Side-by-side calibration using a portable reference sensor works well in a vault, but is problematic for a borehole site, since site response is different at the surface versus at depth. A solution is to install a permanent reference sensor downhole, co-located with the primary sensor. We present data from the Taiwan DSO Network showing high coherence and response matching for pairs of downhole instruments.

Sensitivity can vary due to temperature dependence of permanent magnets used in force-feedback sensors. This small effect can be characterized, and corrected if desired by periodically updating sensitivity metadata, using modern seismic sensors that include an internal temperature reporting capability.

SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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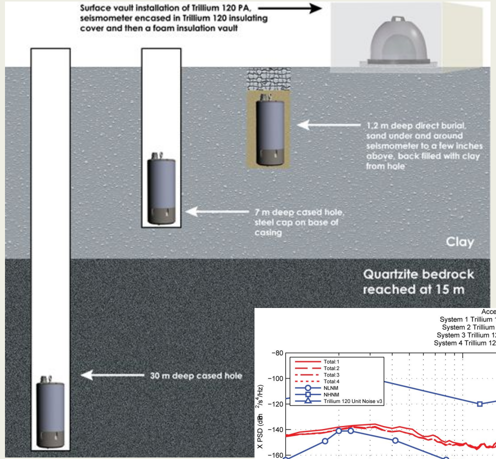
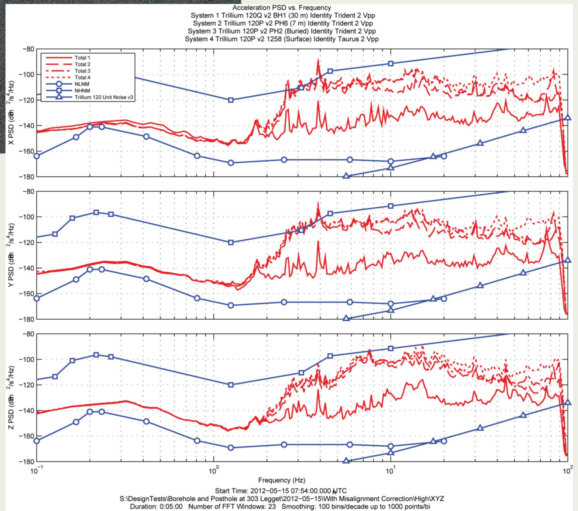
Site Response

2012 study at Nanometrics Ottawa site:
Four T120 seismometers were deployed at different depths in surface clay layer (0, 1, 7 m) and quartzite bedrock (30 m).

- Earth transfer function varies 40 dB for frequencies above 2 Hz. It is important to characterize this!
- The difference in site response prevents comparison of instrument transfer functions between different depths. We need a second instrument down the borehole for this.



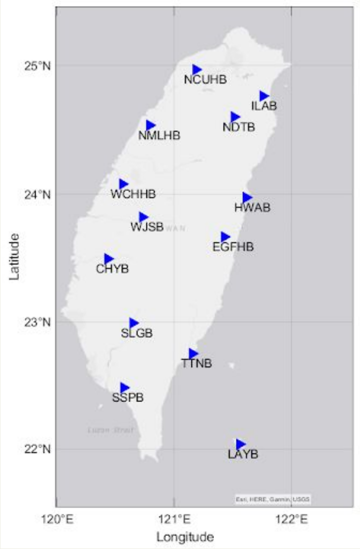


Two-Sensor Borehole Instrument

Nanometrics Cascadia 120 Slim Posthole combines a strong-motion sensor (Titan accelerometer) and a weak-motion sensor (Trillium 120 seismometer), aligned together in a single 104 mm diameter package for downhole installation.

The Taiwan Central Weather Administration has deployed 13 Cascadia 120 Slim Posthole instruments in their Downhole Seismic Observation Network.

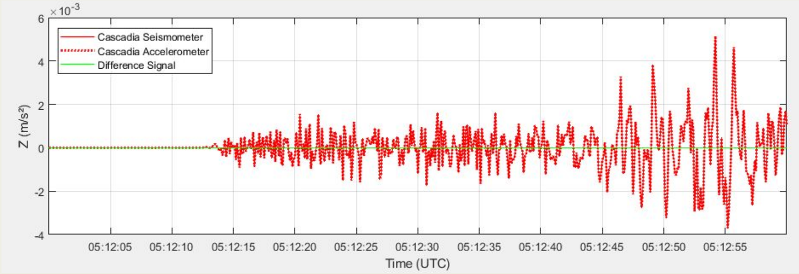
The main objective is combined strong and weak motion sensing. Another benefit is to cross-check operation and accuracy of two different types of instrument co-located in the same hole.



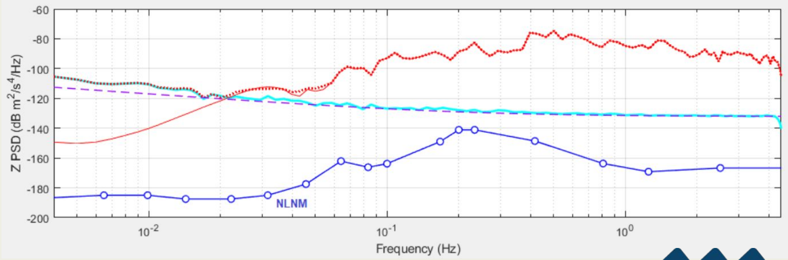
Comparing Downhole Sensor Signals

Record of M6.3 earthquake (Yilan 2021-10-24) at DSON station SSPB, 260 km away from epicenter

- Response-corrected acceleration:
  - Difference signal in green is close to flat line.
  - Peak difference is only 0.46% of peak signal, from combined response errors of two Centaur digitizers + two sensors (Trillium 120 and Titan)



- PSD coherence analysis:
  - Shows non-coherent noise (light blue) 60 dB below peak of total signal = 99.9% coherence. Noise matches the Titan noise specification (dashed line). The difference signal above is coherent with ground motion and is due to small differences in the sensitivity of the two systems.



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Temperature Effect

Two recent presentations at AGU 2024 identified minor change in sensitivity with temperature: +0.12 % per °C for Trillium seismometers

- George Slad: Application of a Seismic Sensor Temperature Testbed at Sandia National Laboratories
- Tomofumi Shimoda: Absolute sensitivity calibration of broadband seismometers under various ambient temperatures

This type of temperature dependence exists for all manufacturers' instruments that use a magnet and coil

- Includes broadbands, force-feedback accelerometers, and geophones
- Exact temperature dependence depends on magnet material

Effect is due to temperature coefficient of magnets used for force feedback

Higher temperature
→ lower magnet strength
→ weaker feedback
→ higher sensitivity to ground motion

Factory calibration is done at room temperature of +24 °C

- Change of +0.12 % per °C is minor for moderate temperatures
- More significant at extreme temp., e.g. -5% at -18 °C

Temperature Calibration

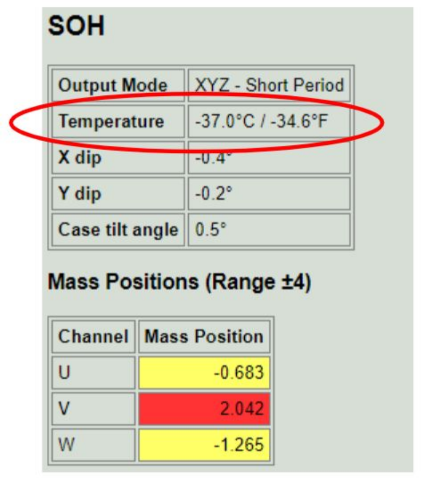
This is a subtle effect that is difficult to measure.

- Measurement requires a reference that is not temperature-sensitive
- Shake table using laser interferometer can be stable within 1 to 10 ppm per °C

Temperature sensitivity can not be measured in the field

- In electrical self-calibration, temperature effect cancels because calibration input and feedback constant both vary with magnet strength.
- In side-by-side comparison, reference seismometer has temperature dependence. So do geophones and piezo sensors.

Proposal: Use known temperature sensitivity for the sensor type, measure temperature in the field, and calculate the sensitivity correction factor.



SOH

Output Mode	XYZ - Short Period
Temperature	-37.0°C / -34.6°F
X dip	-0.4°
Y dip	-0.2°
Case tilt angle	0.5°

Mass Positions (Range ±4)

Channel	Mass Position
U	-0.683
V	2.042
W	-1.265

Temperature Correction

Nanometrics sensors report temperature on SOH (State Of Health) web page – see screenshot below. Temperature is accurate within ±1 degree.

Temperature coefficient of magnets is inherent to the alloy composition, therefore very consistent. Same magnet material is used in all Nanometrics sensors, now and historically. **Use +0.12 % per °C for all.**

Sensitivity correction formula:

- **Sens (T) = Sens (T_cal) * (1 + 1.2e-3*(T - T_cal))**
- T_cal is the temperature where the sensitivity was last calibrated, typically room temperature for shake table or factory calibration

Process:

- Monitor temperature in field via periodic checks of sensor SOH.
- Calculate new sensitivity for new metadata epoch when change becomes significant, e.g. +/-10 °C from start of current epoch.

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