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# Improving Metadata Accuracy Within Seismic Networks

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## Overview:

Modern seismology analysis techniques require an accurate translation between the seismic record and ground motion at the receiver site. This translation is made possible through station metadata, which includes station coordinates, channel orientation, sample rate, digitizer gain, and seismometer response. Without this critical information, it is not possible to accurately estimate event location and event magnitude.

Today's seismometers have proven to be stable in terms of calibration. Unfortunately this stability has led to the pervasive practice of copying metadata from station to station, rather than individually calibrating each station channel. This hazardous practice can sometimes lead to the propagation of errors across entire networks.

This study focuses on seismic channels from stations using the Geotech S-13 seismometer that have digital archives at the IRIS Seismology Data Management Center. It covers data holdings from 2000 until current day. This study shows that most stations estimate channel response based on a 'standard' estimate, rather than an individual calibration. In some cases, these estimates are incorrect resulting in inaccurate reporting of event magnitude exceeding 35%.

We have developed a compact calibration system that enables networks to quickly calibrate these channels in order to reduce measurement errors.

## Incorrect Assumptions:

Part of the problem with assumed calibration is the misinterpretation of manufacturer specifications. Such is the case of the Geotech S-13. **(Figure 1)** The specifications call out an instrument sensitivity of 629 V-sec/m , but this value represents response of an UNLOADED seismometer without any damping resistor. **(Figure 2)** When configuring the seismometer with a damping ratio of 0.707, sensitivity falls by 36% to 395 V-sec/m. **(Figure 3)** Unfortunately, the open-circuit generator response number has propagated across a significant number of stations, meaning that calculations based on data from these stations will under-report magnitude by approximately 36%.

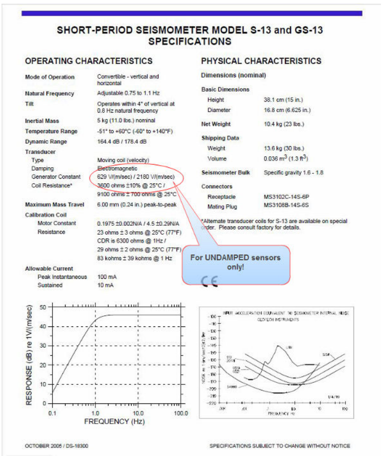


**FIGURE 1: Geotech Specifications for the S-13 seismometer**: The seismometer specification for sensitivity is a nominal open-circuit value. This is not specifically called out and can lead to incorrect calibration if taken at face value.



## Data under Study:

We extracted metadata from IRIS Seismology Data Management Center representing available data holdings in which the S-13 short-period seismometer was the instrument used for the seismic channel. The metadata describe 314 channels of digital data holdings within the IRIS DMC. This common short-period, electromechanical seismometer still represents 154 digitized channels listed as "active" across at least three networks.

## Generic Calibrations can result in incorrect sensitivity:

In analyzing the metadata for the channels using the S-13 seismometer, the first thing to note is how many channels appear to be using a 'generic' calibration. **(Figure 4)** The metadata for the 314 channels have only five channels possessing unique gain values not shared by other channels within the database. By routinely copying channel response, it is possible to propagate response and gain errors from one station to another.

The creation of a metadata file, be it XML or dataless Miniseed, is not trivial, so common practice is to modify a template by changing the station name, network name, and station coordinates. It is common to use an existing channel as a template then "copy and paste". However if incorrect assumptions are made regarding the response of the instrument, errors can easily propagate across the network. When the 314 channels were examined, 70 channels (22%) published the incorrect sensitivity of 629 V-sec/m within their official station metadata. **(Figure 5)**

## How many are out of tolerance?

22 percent of the studied channels showed incorrect sensitivity. However there are an additional 81 channels (26%) where the channel gain is unknown because pre-amplifier response has been convolved within the stated gain of the seismometer within the metadata. Some channels even include the digitizer within the same parameter. By combining the individual channel circuit gains into a single parameter within the metadata, the instrument response cannot be easily evaluated. Thus, only about 52% of the channels can be considered as likely within tolerance. The rest remain in a state of unknown calibration. **(Figures 6, 7)**

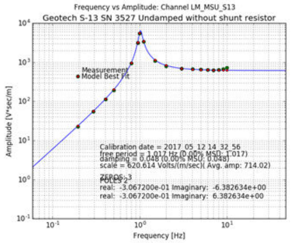


**FIGURE 2: Open-circuit Response of the S-13.** The open-circuit instrument response matches the spec-sheet generator constant, but does not reflect real-world operating conditions.

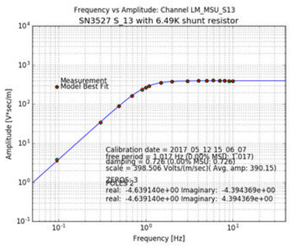


**FIGURE 3: Response of S-13 when equipped with shunt resistor.** When damping ratio is set to 0.707, Sensitivity drops to a nominal value of 395 V-sec/m.

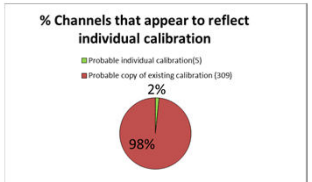


**FIGURE 4: Unique calibrations in the metadata.** Only five out of 314 channels exhibit unique metadata indicating individual calibration of the channel.

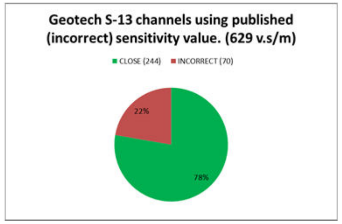


**FIGURE 5: Percentage of channels using incorrect sensitivity value.** 78% of the channels are "close", in that they vary from 346 to 444 V-sec/m, which is +-12% of the nominal value.

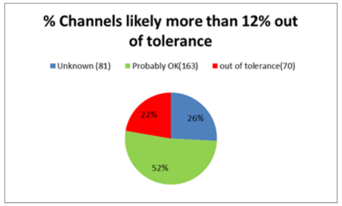


**FIGURE 6: Distribution of channels in terms of probable "in-tolerance" condition.**

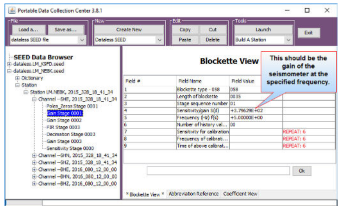


**FIGURE 7: Examining metadata via PDCC:** Note the presence of multiple gain stages. Pre-amplification gain should always be input into Gain Stage 0003, rather than being convolved into the seismometer gain.

## Calibration variance of the S13 Seismometer

We wanted to understand just how much variation in sensitivity is found within a typical Geotech S-13 seismometer. For that answer, we turned to IRIS/PASSCAL who loaned us their S-13 instrument pool for calibration. **(Figure 8)** We then used our "Mass Displacement Tracking" (MDT) calibration methodology to precisely calibrate the seismometers to measure the sensitivity variation.

Mean sensitivity for the instrument pool was 395.0 V-sec/m **(Table 1)** . The stated "new" factory sensitivity with .707 damping is 400 V-sec/m (per verbal conversation with Geotech), which correlates with our tests and demonstrates that the sensitivity of the S-13 varies little with time. It is therefore likely that out-of-tolerance channels can be rectified by applying this mean sensitivity to the metadata. However, both resonance frequency and damping ratio must first be physically verified for each channel.

These 29 seismometers were manufactured approximately thirty years ago, and their performance should reflect any typical S-13 still being used within active stations throughout the various networks.

| | |
|---|---|
| Sample size: 29 Geotech S-13 seismometers | |
| Mean sensitivity: | 395.0 V-sec/m |
| Stdev: | 8.70 V-sec/m |
| Stdev percentage: | +-2.2% of mean |
| Minimum sensitivity: | 369.8 V-sec/m |
| Maximum sensitivity: 4 | 10.3 V-sec/m |

**Table 1: IRIS/PASSCAL S-13 sensitivity variance**

**FIGURE 8: IRIS/PASSCAL S-13 instrument pool**

## Validating the calibration:

We have developed an inexpensive calibration system "in a backpack", that can be used on any electromechanical seismometer to quickly and accurately calibrate the seismic channel. **(Figure 9)** The Mass Displacement Tracking (MDT) calibration method can be applied wherever one can optically track the seismometer mass, and it has been used successfully on the S-13 as well as various models of seismometers throughout the states of the Former Soviet Union. The system uses a common signal generator to excite the seismometer, and a surplus industrial laser position sensor to optically track mass displacement. By comparing mass displacement to seismometer signal output at various frequencies, it is possible to accurately determine the seismometer response.

As an illustration of the accuracy of the calibration method, a Geotech S-13 was co-located with a reference broadband seismometer in which ambient noise was used to check the response against both instruments. Within the operating band of 8 seconds to 20 Hz, the newly-calibrated S-13 tracked the reference seismometer within 2 dB at all frequencies. **(Figure 10)**

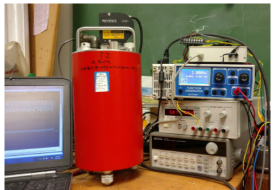

**FIGURE 9: MDT Calibration system.** The system consists of a precision laser position sensor, the station digitizer and a quality signal generator.

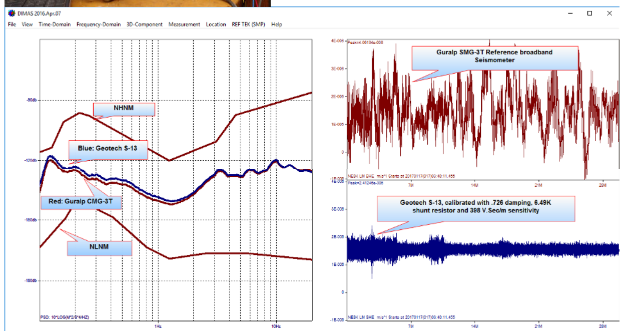


**FIGURE 10: Co-location of calibrated S-13 with reference CMG-3T.** Co-location and resulting PSD of seismic energy from .125Hz to 20Hz demonstrate less than 2db difference at all frequencies.

### Abstract

Seismic station metadata includes such parameters as location, digitizer parameters and sensor calibrations. Accurate metadata are essential for effective nuclear explosion monitoring, allowing researchers to analyze vast amounts of seismic data throughout the world. Yet, our research demonstrates problems with the accuracy of seismic station metadata, particularly calibration metadata. Observed errors in calibration metadata include unknown, outdated, and incorrect parameters, as well as inappropriate calibration applications. Incorrect station parameters are often propagated within a network.

For example, a review of metadata from Geotech S-13 stations archived at the Incorporated Research Institutions for Seismology Data Management Center revealed that many calibration tables list erroneous sensitivities arising from misapplication of the factory calibration sheet. This error is propagated by routine copying of the assumed standardized response. In addition, our work across networks of the Former Soviet Union shows that calibrations are often unknown following conversion from analog to digital recording, and sensor orientations and coordinates are sometimes incorrect.

We have developed a field-portable system to calibrate electromechanical sensors, thus improving station calibration metadata accuracy. This technique is available to assist networks with calibrations and vetting of station metadata to help produce high quality scientific data for accurate seismic hazard and CTBT monitoring.

### Acknowledgements:

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