SEISMIC SENSOR COMPONENT EVALUATION

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ABSTRACT

Sandia National Laboratories tested and evaluated seismic sensors from Geotech Instruments, LLC (Garland, Texas) and Güralp Systems Limited (GSL) (Aldermaston, United Kingdom). The sensors evaluated were Geotech model GS21A, a single component short-period vertical borehole seismometer and GSL model CMG-3V, also a single component short-period vertical borehole seismometer.

Both the Geotech GS21A and the Güralp CMG-3V tests included side-by-side testing to determine:

- Sensor self noise
- Seismometer response
- Seismometer sensitivity
- Calibration capability

Response and self-noise mathematical models were developed.

OBJECTIVE

Introduction

Sandia National Laboratories tested and evaluated seismic sensors from Geotech Instruments, LLC (Garland, Texas) and Güralp Systems Limited (GSL) (Aldermaston, United Kingdom) for possible use in the United States Atomic Energy Detection System (USAEDS). Testing was performed using the system requirements for the USAEDS. Since some USAEDS seismic stations may be included in the International Monitoring System (IMS), some testing was performed using IMS requirements. The sensors evaluated were Geotech model GS21A, a single component short-period vertical borehole seismometer and GSL model CMG-3V, also a single component short-period vertical borehole seismometer.

Evaluations Performed

Tests included side-by-side coherence analysis to determine sensor self noise, seismometer response, seismometer sensitivity, and calibration capability. The results of these evaluations were compared to relevant AFTAC and IMS application requirements or specifications.

RESEARCH ACCOMPLISHED

Geotech GS21A Short-period Vertical Borehole Seismometer

Testing of the GS21As was performed during January-February 2004, at the Sandia National Laboratories Facility for Acceptance, Calibration and Testing (FACT) Site, Albuquerque, NM. Two GS21A seismometers were provided for testing; serial numbers 273 and 302. Two GS13 seismometers were positioned as references. Data were recorded on a Quanterra Q4128 data logger with external preamplifiers.

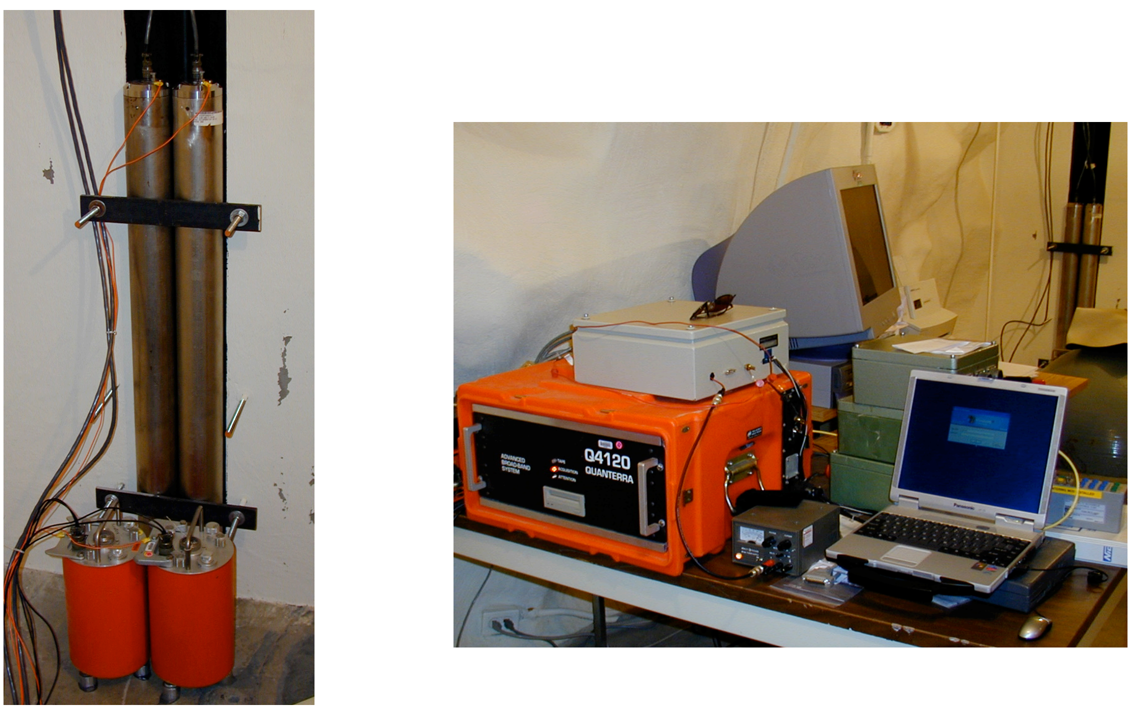

Figure 1. Geotech GS21A Installation

The GS21A seismometers were configured as single vertical axis, short-period borehole seismometers. The sensitivity of the GS21A's was 1311 v/m/s (1834.7 v/m) at 1 Hertz.

The following tests were conducted on the GS21As. This is the basic set of tests as outlined in the Sandia Ground-based Monitoring R and E Technology Report: *Test Plan for the Evaluation of Seismic Sensors for Ground-based Geophysical Monitoring, 3 March 2003*.

1. **Seismic Sensor Characterization**
   1.1 Response Model Development

2. **Seismic Sensor Signal Performance Tests**
   2.1 Seismic Sensor Self-Noise (SSSN)
   2.2 Seismic Sensor Response Verification (SSRV)

Geotech GS21A SP Seismometer Response Model Development

The GS21A response was developed using the GS21A response parameters measured by Geotech and the Sandia Seismometer Response Model software. The Geotech GS21A has the response indicated in the figures below.

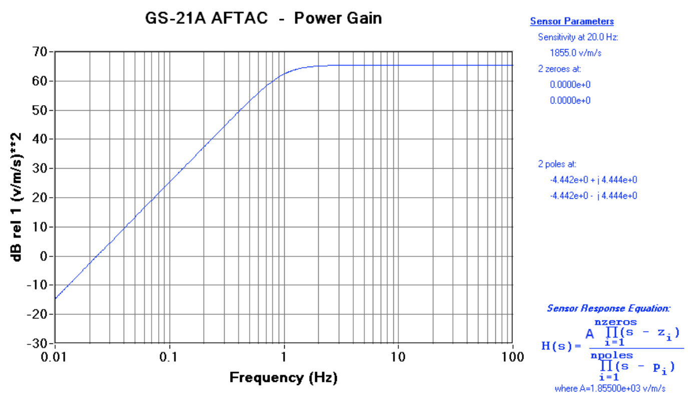

Figure 2. Geotech GS21A Gain Plot

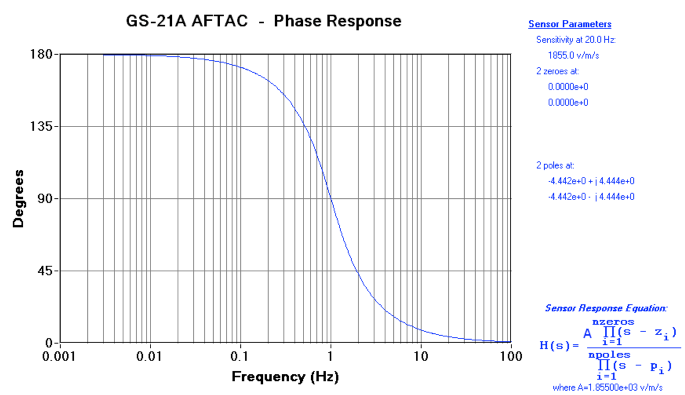

Figure 3. Geotech GS21A Phase Plot

A magnet-coil, spring-mass passive seismometer can be characterized by measuring specific seismometer parameters and calculating others. Characterization of a GS21 seismometer is outlined in the GS21 Operation and Maintenance Manual. Parameters that need to be determined include main coil resistance, spring-mass natural frequency, main coil generator constant, seismometer open circuit damping, main coil critical damping resistance and calibration coil motor constant.

Specific GS21A Seismometer Response

Purpose: The purpose of the seismometer response test was to characterize the overall response of the GS21A seismometer.

Configuration: Measure the GS21A response parameters using procedures from the GS21 Operation and Maintenance Manual or use the Geotech Seismometer Calibration data sheets.

Evaluation: A GS21A response model was developed using the response parameters measured by Geotech and the Sandia Seismometer Response Model software. A nominal GS21A response model was calculated. Damping resistance for 0.707 damping was calculated. Termination resistance for the DB24 ITN test was determined from the parallel combination of the coil resistance and 0.707 damping resistance.

Results: The calculated response for the two GS21As under test is shown in the figure below.

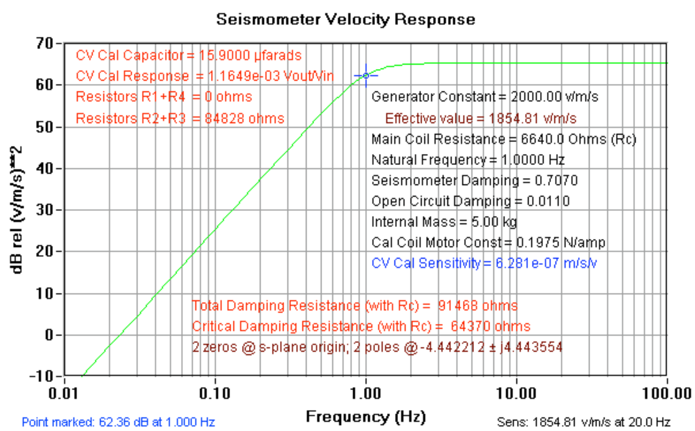

Figure 4. Geotech Specific GS21A Response Plot

GS21A Seismic Sensor Self-Noise (SSSN)

Purpose: The purpose of the seismometer self-noise test is to determine the seismometer self-noise in the presence of low seismic background signals.

Configuration: Two seismometers are installed side-by-side or stacked vertically in specially designed seismic vault fixtures. The seismometer outputs are connected to a data acquisition system that samples the data synchronously. Data are acquired during low seismic backgrounds.

Evaluation: A noise-power coherence analysis computation provides the noise-floor of the seismometer for a low seismic background stimulus.

Results: The GS21A's self-noise is plotted below. The theoretical noise floor was experimentally verified between 1 – 5Hz. The plot extends into the other areas of the passband of interest as verification of the worst possible case for seismometer noise. The DWR's self-noise limits the ability to record the seismometer noise in these areas. It is believed that the seismometer's theoretical noise model is a closer approximation in these frequency bands. This is shown in the figure below.

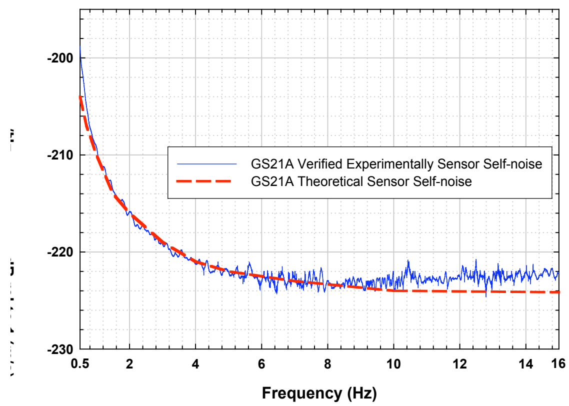

Figure 5. Geotech GS21A Self-noise Plot

<u>**GS21A Seismic Sensor Response Verification (SSRV)**</u>

<u>Purpose:</u> The purpose of the seismometer response verification test is to verify the seismometer response using seismic background signals and a reference seismometer.

<u>Configuration:</u> Two seismometers, (1) a characterized reference seismometer and (2) the seismometer under test, are installed side-by-side or stacked vertically in specially designed seismic vault test fixtures. The seismometer outputs are connected to a data acquisition system that samples the data synchronously. Data are acquired during moderate seismic backgrounds.

<u>Evaluation:</u> The data are converted from each seismometer to equivalent ground motion using the seismometers mathematical response model for each seismometer. If the seismometer response model is correct, the response calculations in earth-motion units will be identical.

<u>Results</u>: After converting the data to ground motion for both the reference and the GS21A the data were nearly identical (to within 0.2 dB). This result verifies that the sensor response model is accurate. The overlaying corrected data in earth units for each seismometer is shown below.

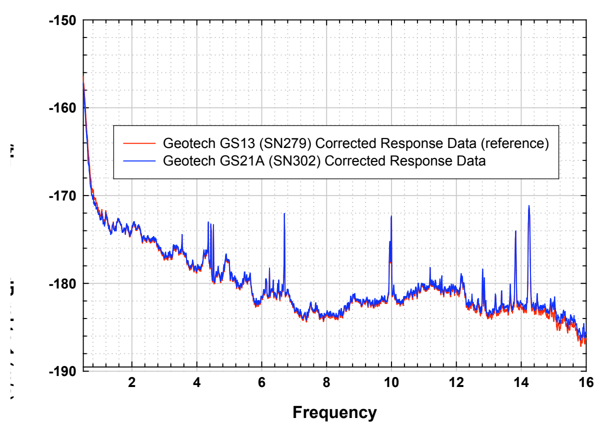

Figure 6. Geotech GS21A SSRV Plot

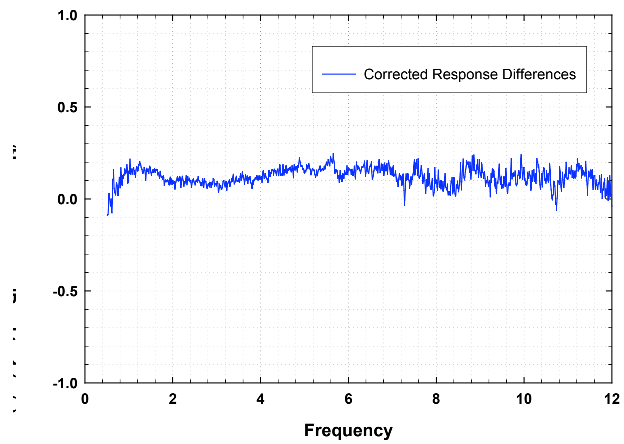

Figure 7. GS21A GS13 Corrected Response Difference Plot

Güralp CMG-3V Short-period Vertical Borehole Seismometer

The GSL CMG-3V short-period vertical borehole seismometer was manufactured by Güralp Systems Limited (GSL) (Aldermaston, UK). The sensor has a flat response from 30 seconds to 50 Hertz. GSL provided two CMG-3V seismometers for evaluation.

Testing is being performed at the Sandia National Laboratories FACT site.

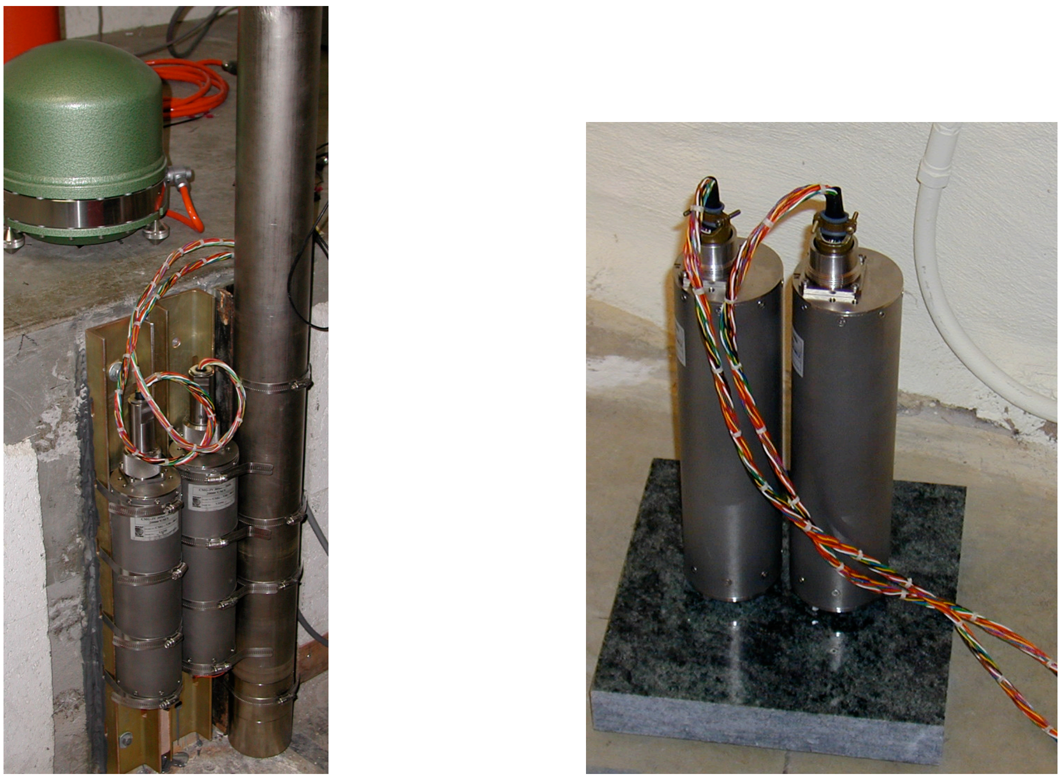

Figure 8. CMG-3V Testing at FACT site

Sandia will evaluate the overall technical performance of the GSL CMG-3V short-period vertical borehole seismometer component of the Güralp instrumentation. GSL CMG-3V tests include side-by-side testing to determine sensor self noise, seismometer response, seismometer sensitivity, and calibration capability. The results of these evaluations will be compared to relevant AFTAC and IMS application requirements or specifications.

CONCLUSIONS AND RECOMMENDATIONS

GS21A Seismometer Response:
Utilizing the parameters that Geotech provided for the seismometers under test and the Sandia Seismometer Response Model software a determination of the GS21A seismometer responses was developed.

Seismic Sensor Self-noise (SSSN) Test:
The Geotech GS21A theoretical noise model was experimentally verified between 1 – 5Hz. Extensions into the other areas of the passband of interest were calculated as the worst possible case for seismometer noise. It is believed that the seismometer's theoretical noise model is a closer approximation in these frequency bands.

Seismic Sensor Response Verification (SSRV) Test:
The theoretical seismometer responses for the GS21A seismometers under test were verified. The GS21A responses where verified to a reference Geotech GS13 seismometer.

REFERENCES

Kromer, Richard P. Townsend, Toby O., Ground-based Monitoring R and E Technology Report, 'Test Plan for the Evaluation of Seismic Sensors for Ground-based Geophysical Monitoring', 3 March 2003.

Townsend, Toby O. Kromer, Richard P., Ground-based Monitoring R and E Technology Report, 'A Technique for Measuring the Self-noise of Ultra Low Noise Seismometers within Modern Seismic Systems', 15 February 2004.