Remote Calibration Procedure and Results for the CTBTO AS109 STS-2HG at YBH

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Abstract

Berkeley Digital Seismic Station (BDSN) YBH, located in Yreka, CA, USA, is certified as Auxiliary Seismic Station 109 (AS109) by the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty organization (CTBTO). YBH, sited in an abandoned hard rock mining drift, houses a Streckeisen STS-2HG triaxial broadband seismometer (the AS109 sensor)and a co-sited three-component set of Streckeisen STS-1 broadband seismometers and a Kinemetrics Episensor strong motion accelerometer (the BDSN sensors). CTBTO requested that we preform a remote calibration test of the STS-2HG to verify its response and sensitivity. The remote calibration test was done successfully on June 17, 2013 and we report here on the procedure and results of the calibration.

The calibration of the STS-2HG (s/n 30235) was accomplished using two Random Telegraph (RT) stimuli which were applied to the triaxial U,V,W component calibration coils through an appropriate series resistance to limit the drive current. The first was a four hour RT at 1.25 Hz (to determine the low-frequency response) and the second was a one hour RT at 25 Hz (to determine the high-frequency response). The RT stimulus signals were generated by the Kinemetrics Q330 data logger and both the stimuli and the response were recorded simultaneously with synchronous sampling at 100 sps. The RT calibrations were invoked remotely from Berkeley. The response to the 1.25 Hz RT stimulus was used to determine the seismometer natural period, fraction of critical damping and sensitivity of the STS-2HG sensors and the response to the 25 Hz RT stimulus was used to determine their corresponding high-frequency response. The accuracy of the sensitivity as determined by the response to the RT stimuli is limited by the accuracy of the calibration coil motor constant (2 g/A) provided on the factory calibration sheet.

As a check of the accuracy of the sensitivity determined from the response to the RT stimuli, we also compare the ground motions inferred from the STS-2HG with the corresponding ground motion inferred from the co-sited STS-1's and the Episensor strong motion accelerometer using seismic signals which have adequate signal-to-noise ratios in passband common to both instruments.

Factory Calibration

The data from the factory calibration sheet for YBH AS109 STS-2HG (s/n 30235), dated May 28, 2002, are:

The sensitivity of all three (U,V,W) sensors in the triaxial seismometer are Gs = 20,000+/-200 V/(M/S) and the maximal axes deviation is <0.6 degrees.

For the low-frequency end (0.00586-0.10547 Hz), the response is a linear 2nd order high-pass filter:

Comp	Ts (sec)	hs
U	120.38+/-0.71	0.7064+/-0.075
V	120.33+/-0.70	0.7045+/-0.041
W	120.56+/-0.71	0.7062+/-0.049

For the high-frequency corner (1-100 Hz), the optimized response is given by 4 zeros and 9 poles (in Hz) (corrected for ground motion instead of calibration coil excitation):

Comp	Zeros
U,V,W	-73.5+/-68.29i, -2.411, -2.411
U	-30.45
V	-28.41
W	-28.54

Comp	Poles
U,V,W	-1629.7+/-433.7i
U,V,W	-1514..0+/-1825.5i
U,V,W	-72.34
U	-75.90, -14.01+/-63.07i, -2.465
V	-2.460, -14.76+/-62.82i, -69.43
W	-70.46, -14.24+/-63.42i, -2.452

Gs and Gc

The signal coil generator constants:

Comp	Gs (V/(M/S))
U	19882.1
V	19856.3
W	20110.9

were determined via comparison of the ground motions inferred from the STS-2HG and from the co-sited Kinemetrics Episensor for the first 30 seconds of the P-wave signal from the 2013.144 Mw 8.3 Sea of Okhotsk earthquake (0.5-2 Hz 6PBP filtered for good SNR). The Episensor was used as the reference because it is calibrated to an accuracy of order 0.1 percent and its calibration is easily checked via tilting.

The calibration coil motor constants:

Comp	Gc (N/A)
U	1.89010
V	1.90105
W	1.88767

were then determined via comparison of the stimulus and response signals using 56 minutes of a 1 Hz @ -30 dB sinusoid calibration signal starting at 2013.294.2042. The RMS stimulus current applied to the calibration coils was 8.265 uA and the calibration coil motor constants were determined from the ratio of the RMS U,V,W ground motion velocities to the RMS stimulus current. The SNR of the STS-2HG response signals was improved significantly via removal of the correlated seismic ground motions recorded by the co-sited YBH STS-1s.

Ts and hs

The natural period (Ts) and fraction of critical damping (hs) of the U,V,W component sensors in the STS-2HG:

Comp	Ts (sec)	hs
U	120.19	0.716
V	120.19	0.710
W	120.27	0.715

were determined from the response to a four hour Random Telegraph (RT) stimulus calibration signal (1.25 Hz @ +/-78mV) and the variance reduction was 99.936%. For the analysis, the stimulus and Z,N,E responses were recorded at 100 Hz and then decimated to 1 Hz and the Z,N,E responses were rotated to the U,V,W coordinate frame. The in-house program seiscal was used in the analysis. seiscal uses a adaptive migrating grid search algorithm to determine the Ts and hs which maximizes the variance reduction between the calculated and observed responses to the calibration stimulus.

HF Response

Analysis of the high frequency response characteristics of the STS-2HG was limited by the 40 Hz FIR anti-aliasing filters used in the data logger at the highest available sampling rate of 100 Hz). The trend in the amplitude and phase responses in the 10-40 Hz range are consistent with the factory calibration responses.

Discussion

The calibration procedures described here require:

- A co-sited reference sensor with a known calibration,
- Simultaneous recording of the stimulus, response and reference sensor signals.

The high-frequency response of the STS-2HG has a peak at approximately 70 Hz and a significant response that extends to 100+ Hz. Accurate analysis of the high-frequency response requires recording of the stimulus and response signals with a bandwidth of at least 80 Hz and preferably 100+ Hz. The Kinemetrics Q330 data logger, which records the STS-2HG has a maximum sampling rate to 100 Hz.

Conclusions

The STS-2HG (s/n 30235) has been in operation at YBH for more than a decade and during that time the measured low-frequency response and sensitivity of the U,V,W sensors has not changed significantly from the values reported on the Streckeisen factory calibration sheet.

The calibration coil motor constant given by Streckeisen is Gc = 2 N/A. The Gc values determined here are approximately 5 % below the factory reported values. It is crucial that the correlated component of the seismic signals from the reference sensor be removed from the response signals in order to obtain accurate results.