Jahrestagung der Deutschen Geophysikalischen Gesellschaft (DGG), Braunschweig, 4. - 7. März, 2019

Quest for Optimal Seismometer Installation : Experiments with three STS-6A Seismometers at BFO

R. Widmer-Schnidrig[(1)], P. Duffner[(1)], T. Forbriger[(1)], A. Ringler[(2)] and R. Freudenmann[(3)]

(1) Black Forest Observatory (BFO) KIT Karlsruhe and Stuttgart University
(2) Albuquerque Seismological Laboratory, USGS, Albuquerque, New Mexico, U.S.A.
(3) Streckeisen GmbH, Pfungen, Switzerland

Motivation

The Streckeisen STS1 seismometers in the global seismic network (GSN) are the most sensitive sensors for longperiod seismic observations in the Earth's normal mode band. In fact the STS1 defines the low noise models (NLNM and GSN noise model) at frequencies in the millihertz range. Unfortunately some of these instruments deteriorate from aging and can no longer be maintained. They are out of production since years and maintenance is no longer supported by the manufacturer. The global seismological community for this reason is in search of a capable replacement for the STS1.

To evaluate the performance of the newest candidate to replace the STS1 seismometer we have constructed a new concrete pillar in the rear of the BFO mine behind the dual airlock and drilled three shallow boreholes in this pillar, each 160cm deep and 20cm in diameter. Following the procedure by ASL/USGS we installed one of three STS6A in a closed bottom 17.5cm diameter stainless steel pipe in the borehole and establish the mechanical contact with the surrounding rock by loosely poured, fine coal slag. The seismometer with its 15cm diameter sits in the dry interior of the pipe and is surrounded and held in place by more fine coal slag. Initially, the other two STS6As were installed on top of the pillar and shielded similar to standard vault seismometers.

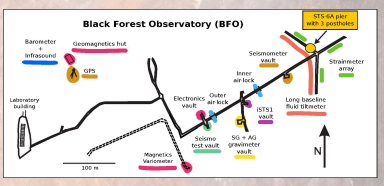


Fig. 1: Map of the BFO mine observatory: behind the dual air-lock is the seismometer vault with the STS-1 and STS-2 seismometers. In the very back and next to the N300E strain meter is the new pier with the three boreholes wher the STS-6As are deployed.

References

Harrison, J. C., Cavity and topographic effects in tilt and strain measurements. J. Geophys. Res. (1976).
Zürn W. and Widmer R., On noise reduction in vertical seismic records below 2 mHz using local barometric pressure. GRL (1995).
Zürn W., Exß J. et al., On reduction of long-period horizontal seismic noise using local barometric pressure. GJI (2007).
Zürn W. and Wielandt E., On the minimum of vertical seismic noise near 3 mHz. GJI (2007)

Acknowledgements

We thank David Kyle Jones for the help with the drilling of the boreholes. ASL/USGS for providing the tools and hardware to drill the boreholes. Walter Zürn for numerous discussions.

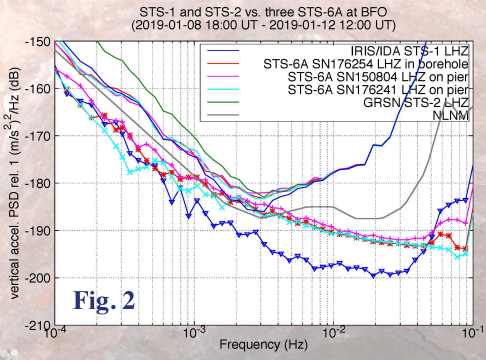


Fig. 2: Signal PSDs (solid lines) and self-noise (lines with symbols).

Vertical components

In Fig.2 power spectral densities of the vertical acceleration and the sensor self-noise are shown. Outside the minimum of the NLNM (1.5 - 4 mHz) the STS-6 can resolve vertical ground noise at BFO. However inside this band the STS-1Z detects lower signal powers and the STS-6A seems to be limited by its self-noise.

Below 1 mHz signal levels of the STS-1Z and STS-6A are indistinguishable, and in agreement with the SG-056 gravimeter: all of them sense the atmospheric pressure noise. However for the latter sensor a barometric correction with one real regression coefficient (-3.5 nm/s^2/hPa) leads to a reduction of the noise level while such a correction is inefficient with both STS-1Z and STS-6A, except for very pronounced pressure disturbances like in Fig. 3.

We use a Sleeman 3-channel correlation analysis to estimate sensor self-noise. At 3mHz it is -190dB for the STS-1Z while only -185dB for the STS-6A. Since a signal PSD level of -185dB is often reached at BFO this shows that the STS-6A cannot resolve ground noise.

Compared with the STS-2Z the STS-6A is a clear improvement in terms of sensor-self-noise: the STS-2Z could only compete with the STS-1 down to 8 mHz while the STS-6A only lags behind the STS-1 in a narrow frequency band around 3 mHz.

For the vericals we did not see an improvement upon installation in the boreholes. This finding may be a result of the shielding provided by the dual air-lock at BFO and may not be applicable to installations elsewhere.

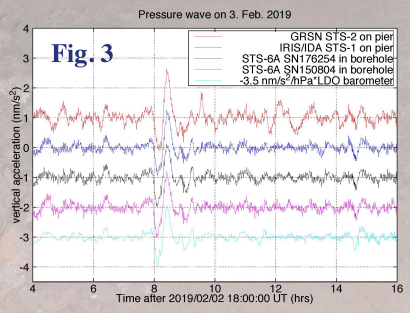
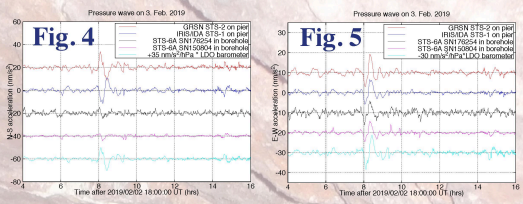


Fig. 3: Band-passed (3600s - 100s) filtered vertical accelerations and scaled (-3.5 nms^{-1}/hPa) outside air pressure.



Figs. 4, 5: Band-passed (3600s - 100s) filtered horizontal accelerations showing the response due to an atmospheric pressure wave: N-S on fig. 4, E-W on fig. 5. Bottom trace is scaled outside air pressure.

Horizontal components

Since accelerations are generally larger on horizontal components than on verticals due to the additional contribution from atmospheric pressure induced ground tilts, sensor self-noise is not an issue: all involved sensors can resolve horizontal ground noise at BFO: STS-1, STS-2 and STS-6A.

The challenge with horizontal components is how to reduce the so called cavity effect: the mechanism by which large scale strain fields deform sensor vaults and thereby lead to very local tilts of the seismometer piers. In the seismometer vault at BFO the N-S component of the STS-1 and the STS-2 are installed on opposite sides of the vault: one pillar is built against the N-wall, the other against the S-wall. The response of these two sensor components to outside air pressure fluctuations is 180 degrees out of phase (Fig. 4) - an observation which can be explained by the cavity effect.

Since the STS-6A is conceived as a borehole/posthole instrument we drilled shallow boreholes and made an effort to position the holes along the symmetry axis of the tunnel. In fact, the combination of installing the sensors in boreholes and siting the boreholes along the symmetry axis of the tunnel has led to significant reduction in sensitivity to outside air pressure fluctuations. During the passage of a storm front the barometric noise was clearly reduced on both N-S and E-W components of the sensor installed in boreholes (Fig. 6) while during the passage of a single (plane?) pressure wave only the N-S component showed a clear reduction with respect to the vault instruments STS-1 and STS-2 (Fig. 4). However, for the same pressure wave the signal amplitude was the same on all E-W components, irespective of vault or borehole installation (Fig. 5). At this point it is unclear if this observation is due to the propagation direction of the pressure wave, the topography near BFO, or a combination of both.

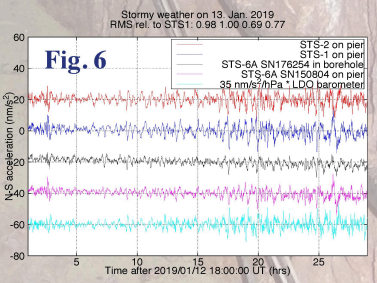


Fig. 6: Band-passed (3600s - 100s) filtered horizontal N-S accelerations covering the passage of a windy weather front. The bottom trace is the scaled outside air pressure.