| Topic | Recommendations for seismometer deployment and shielding |
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## 1 Intention of this information sheet

This information sheet summarizes the most relevant considerations for the proper installation of broadband seismometers. An annotated example of proper shielding is provided as well as references to literature and internet resources.

There is no single solution to the installation of seismic stations. The best solution in your case will depend on the specific conditions of your observational sites and the targeted signals. Comprehensive discussions on seismometer installation and site selection are provided by Wielandt in Chapter 5 and by Trnkoczy et al. in Chapter 7 of this manual.

Temporary field installations for short period observations may put other demands on seismometer installation than permanent installations for broadband observations. For sensitive shortperiod observations you will primarily seek sites without local vibrational sources. High-resolution broadband observations on the other hand require careful thermal shielding and protection against air-pressure variations, since forces due to unwanted sensitivities to temperature and pressure decrease not as rapidly with increasing signal-period as the inertial forces due to ground motion do. For permanent installations you might be able to build a seismometer vault, while you have to make compromises regarding sites for temporary installations. Use the guidelines below when seeking the best solution for your specific case.

## 2 Location: site selection

- Prefer sites which are far away from noise sources like cars, industry, large buildings, tall poles (which can vibrate in the wind), room heaters and air-conditioners (which produce thermal variations), high-current power supply lines (which produce magnetic fields).
- Check whether you need a mains power supply, telephone or computer network connection, free view to the sky for GPS reception or solar panels. Site selection might be limited due to these requirements.
- Prefer subsurface locations (vaults, cellars, tunnels, underground shelters, etc). The overburden will provide thermal shielding. In addition this keeps the instruments at a distance to noise sources like air-pressure and passing cars which generate ground motion by surface loading.
- Avoid locations affected by air drafts. They will undermine your efforts to provide thermal shielding.
- If possible, your seismometer should be installed in a dedicated room all by itself.

- When selecting older cellars or cellars in estate buildings in particular for installation, be alarmed if non of the goods stored therein are placed on the ground directly. There is a potential risk of occasional flooding.

## 3 Protection

In particular for temporary installations, when usually compromises must be made during site selection, you should consider a few additional protection measures:

- **Protection against animals**: Free field installations should be protected against damage by animals. There are known cases of seismic installations being destroyed by cattle in stampede. For some unknown reason sheep and similar animals like to bite signal cables. Mice have been observed to occupy the subsurface cavity around buried seismometers building nests in the thermal insulation.
- **Protection against humans**: While it may appear obvious to protect the installation against vandalism (e.g. solar panels should be considered an attractive swag) also well-meaning persons might endanger the instruments. Loose cables on the floor are a trip hazard. Consider that curious fellows might like to pull at cables entering holes or boxes. Somebody might pull a power supply plug in the need of a free socket in good faith. All technical equipment (recorders, batteries, etc.), except the actual sensor, should be installed in a solid box which can serve as a means of transportation as well as a barrier to protect the installation.

## 4 Coupling

The best seismometer does not serve you well, if it is not rigidly coupled to the ground. You should consider the following:

- The feet of the instrument must have a stable position on the ground. Avoid rough surfaces or surfaces covered with dust or sand. Slightly hit the pier with a hammer to make the feet settle in a stable position. Strong-motion instruments should be bolted to the ground (but not broadband sensors).
- Ensure a direct coupling to the base rock. Do not install seismometers on a buried boulder. It can move independently from base rock and sometimes show resonances.
- Use concrete piers for permanent installations or deployments in unconsolidated sediments.
- In unconsolidated sediments you might prefer to bury the instrument, if the instrument is suitable for this.
- Avoid membranes. Badly coupled floors of cellars or plastic containers can tilt the instrument due to air-pressure variations. For long-period horizontal instruments you might like to install warp-free baseplates (see Chapter 5, section 5.5.3).
- Forces should only be exerted at the feet of the seismometer. Make sure that cables and insulation material cannot exert additional forces on the instrument. The cable should be lead around the seismometer in a big loop and fixed to the ground with additional weights.

# 5 Shielding

## 5.1 Unwanted sensitivities and protective shielding measures

Unfortunately seismometers are not only sensitive to inertial acceleration. You have to shield them against environmental influences which you do not like to observe. Items are sorted by priority:

***Thermal shielding*** is a must. Typical coefficients of thermal expansion or temperature coefficients of suspension springs (even for thermally compensated alloys) are in the order of $10^{-6}$ $K^{-1}$ to $10^{-5}$ $K^{-1}$. To resolve the signal of the permanently excited free oscillations at a level of $10^{-12}$ g, temperature variations of the sensing device must be kept below a level of $10^{-6}$ K. Therefore, wrap the instrument and containers around the instrument with a soft wool-like material or synthetic fleece which does not exert mechanical forces. In installations with high ambient humidity, synthetic fleece or polyester stuffing with stronger fibres should be preferred. Thin fibres can collect condensed ambient humidity which can result in a collapse of the spaces between fibres, thus increasing heat conductivity in the long run. Fill also gaps beneath the instrument. This prevents convective heat transport.
Further wrap the instrument with a reflective foil (available for first-aid kits) to prevent radiative heat transport.

Effective measures for thermal shielding are also subsurface installations, burying the instrument and anything which helps to prevent air drafts.

For temporary installations thermal shielding by covers made from Polystyrene have proven effective (pers. comm. Jörn Groos). Besides their positive thermal effect such covers are easy to install and can be used to protect the sensor mechanically during shipment and when burying the instrument.

***Shielding against air-pressure*** variations is essential for long-period observations. Variations of the buoyancy force on the proof-mass of vertical component sensors are caused by variations of air-density due to meteorological air-pressure variations. The amplitude of such forces can easily exceed the amplitude of the tides, if the instrument is not shielded appropriately. The susceptibility to air-pressure for an unshielded seismometer pendulum made of brass and aluminium is approximately 1500 nm $s^{-2}$ $hPa^{-1}$. To resolve the signal of the permanently excited free oscillations at a level of $10^{-12}$ g, variations of air-pressure inside the instrument must be kept at a level below $10^{-5}$ hPa. Although broadband seismometers are supplied with an air-tight casing you should install an additional air-tight container with a warp-free design (see below) for highly sensitive installations. Otherwise the deformation caused by variation of air-pressure on the casing of the seismometer can result in tilt. Gravity coupled this way into the horizontal components easily exceeds inertial acceleration at large signal periods.

***Magnetic shielding*** is required for high-resolution long-period observations. All temperature compensated suspension springs are susceptible to magnetic fields. For many broadband seismometers variations of the ambient magnetic field must be smaller than $10^{-2}$ nT to allow resolution of the permanently excited free modes. In particular at sites, where man-made magnetic fields due to large DC currents (e.g. tramway supply currents) have to be expected, a passive permalloy or active magnetic shield is advisable.

***Humidity*** can cause corrosion and leakage currents. Therefore, keep your instruments dry. Use tight containers, plastic bags and desiccant to protect sensors and electronics. If you install the electronic components in a plastic bag, the excess heat of the electronics can put the surface temperature above the dewpoint.

***Electromagnetic interference*** caused by strong fields must be avoided. Maintain a distance between signal cables and AC mains power cables. Use differential signal transmission wherever possible. Twisted pairs of signal cables improve immunity against electromagnetic fields. Avoid loops of signal cables which might act like pickup coils.

***Lightning induced overvoltage***. Long analog cables make your instruments vulnerable to lightning damage. Avoid long signal cables and consider to place your seismometer's feet on glass or perspex plates.

## 5.2 GRSN shielding: An illustrated and annotated case example

The sequence of Figures. 1 to 7 illustrates the shielding method commonly applied in the German Regional Seismic Network (Wielandt and Widmer-Schnidrig, 2002, GRSN). This type of shielding is now commercially available (Stoll, 2008). The GRSN is one of the most sensitive broadband networks and a comparably large number of its stations are able to detect the background free oscillation at a level of $10^{-11}$ $ms^{-2}$ (Kurrle and Widmer-Schnidrig, 2006). The type of shielding used in this network is understood to be one of the essential factors to maintain this high quality.

**Figure 1** The seismometer (an STS-2 in this case; see DS 5.1) is placed on a polished gabbro plate (actually a raw gravestone obtained from a stonemason). The gabbro plate sits on three nuts or lead plates on the actual seismic pier in a subsurface vault. The gabbro plate is part of an air-pressure shield and serves as a practically non-deformable base plate. Electronic cables pass through a hole in the stone which is sealed with glue. The seismometer is aligned to north, the alignment rod points (in case of the STS-2) to east.

**Figure 2** Some kind of synthetic wool, polyester stuffing, or fleece material is gently wrapped around the seismometer. The gap between the gabbro plate and the casing of the instrument is also filled with fleece to prevent air convection. Be careful to keep the thermal insulation loosely fitting. The fleece must not exert forces on the seismometer casing.

**Figure 3** A stainless steel container (actually a large cooking pot) is placed upside down on a rubber gasket on the gabbro plate. It is screwed down onto the plate to provide an air-tight shielding. Air-pressure variations are thus attenuated by at least 40 dB. Pressure acting on the surface of the shielding may deform the steel container but not noticeably the gabbro plate. Deformations of the steel container do not affect the seismometer. This way a stable levelling of the horizontal components is maintained. It is advisable to place some desiccant inside the steel container to capture remaining humidity and reduce the risk of corrosion.

**Figure 4** A second layer of stuffing or fleece is wrapped around the steel container. Other than in this picture it is recommendable to wrap the gabbro plate too. The fleece again serves as a thermal insulation and prevents air drafts from acting directly on the surface of the instrument. Synthetic stuffing fleece with stronger fibres is preferable for this outer layer. The stronger fibres are able to maintain the structure of the fleece even when exposed to high humidity.

**Figure 5** The whole installation is wrapped with a reflective foil which can be obtained as a part of first-aid kits. The reflective foil reduces radiative and convective heat transport and therefore is part of the thermal insulation. Again it is recommended to extend the foil over the gabbro plate down to the surface of the pier. Ensure that no air-draft can pass underneath the foil. Tape it to the pier or put some heavy items on its edges.

**Figure 6** In this example an active magnetic shielding is added to the installation. The cubic frame supports three pairs of coils. A fluxgate magnetometer is used together with an active electronic feedback and the coils in order to maintain a constant magnetic field inside the cube. Such measures are recommended in magnetically polluted environments. In the case of this example the station (STU, Germany) is located in the city area of Stuttgart. The tramway produces large DC currents of varying magnitude in the subsurface. They induce magnetic fields which would be strong enough to limit the seismometer in its long-period seismic detection capability.

**Figure 7:** This picture shows the actual seismometer for station STU, which is associated with the GRSN (http://www.szgrf.bgr.de/station_map.html) and GEOFON (http://geofon.gfz-potsdam.de/geofon/) networks.

## 6 Recommended readings

Scientific literature on technical aspects of seismometer installation is comparably rare. Uhrhammer and Karavas (1997) describe installation considerations at the Berkeley Seismological Laboratory. McMillan (2002) presents those of Albuquerque Seismological Laboratory. Havskov and Alguacil (2004) describe power supply and lightning protection issues besides general sensor installation topics. The effect of air pressure shielding is discussed by Zürn and Wielandt (2007). Wielandt and Widmer-Schnidrig (2002) present installation methods in the GRSN and Klinge et al. (2002) describe noise conditions achieved in this network. Holcomb *et al.* (1998) studied the positive effect of sand in borehole installations. A warp-free baseplate is described by Holcomb and Hutt (1992).

Studies of background noise conditions in existing networks can serve as a reference of what can be achieved in comparable environments. Section 7.2 of Chapter 7 may serve as an example, also for potential site selection. Peterson (1993) and Berger et al. (2004) provide reference levels for low-noise limits obtained in the Global Seismic Network. Widmer-Schnidrig (2003) demonstrates that the NLNM (Peterson, 1993; see Fig. 4.7 in Chapter 4) is biased by the STS-1 (see DS 5.1) self-noise at periods smaller than 1 mHz. Webb (2002) gives a quantitative reference of global noise conditions on land and on the sea floor as well as descriptions of typical unavoidable sources of seismic noise. Groos and Ritter (2009) provide an in-depth study of noise conditions in an urban environment.

To provide optimal conditions for seismic observations you require a basic understanding of non-seismic noise sources and how to avoid them (see, e.g., Chapter 4 as well as in Chapter 7 Fig. 7.5, Section 7.2 and Sections 7.4.3 to 7.3.5 with many Figures). Forbriger et al. (2010) provide a concise summary of considerations for high-resolution broadband installations. They further describe possible limitations due to magnetic field induced noise. Cavity effects which can amplify tilt and strain noise are studied by Emter and Zürn (1985) and Gebauer et al. (2010). Zürn and Widmer (1995) demonstrate the gravitational effect of the atmosphere on long-period vertical component observations and suggest potential countermeasures. Zürn et al. (2007) study tilt-noise induced on horizontal components by surface loading due to barometric pressure.

Do not hesitate to contact other network and station operators. Many of them will be willing to share their experience regarding seismometer installation (in particular if you are willing to share your data). A good point to start are the internet sites of major seismic networks. Some recommended sites are

**http://www.ldeo.columbia.edu/~ekstrom/Projects/WQC.html**
The Waveform Quality Center at Lamont-Doherty Earth Observatory provides routine waveform quality control results and noise level estimates for many stations in the Global Seismographic Network (GSN) which can serve as a reference for comparable installations.

**http://earthquake.usgs/gov/regional/asl/**

Albuquerque Seismological Laboratory provides the USGS Open File Reports on their web-site (McMillan, 2002, e.g.).

**http://seismo.berkeley.edu/**

UC Berkeley Seismological Laboratory operates the Berkeley Digital Seismic Network and other deployments and has published guidelines for the installation of seismometers (Uhrhammer and Karavas, 1997).

**http://ida.ucsd.edu/index.html**

The Project IDA operates a significant part of the Global Seismic Network. They feature quality control and low noise studies (Berger et al., 2004).

**http://geofon.gfz-potsdam.de/**

Part of Chapter 7 is a field report of the GEOFON network (http://geofon.gfz-potsdam.de/geofon/manual/welcome.html).

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