Evaluation of Installation Methods for STS-2 Seismometers

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1 INTRODUCTION

In the course of the planned upgrade of the Gräfenberg Array (GRF) from Streckeisen STS-1 seismometers with 20s free period to STS-2 seismometers with 120s free period the question of how best to install the sensors has to be reconsidered.

While it was understood early on that the Streckeisen STS-1 seismometers needed elaborate shielding in order to reach their full potential (Wielandt and Streckeisen 1982) it took 10 years of experimenting before a satisfactory and widely accepted method was established (Holcomb and Hutt 1992). Because some of the experience gained with the shielding of the STS-1 entered the design of the casing of the STS-2 it was not clear what kind of additional shielding was needed for getting best results with the STS-2. Since the first STS-2s have been deployed starting with the GRSN in 1991 different types of insulations were tried and it became apparent that the data quality at low frequencies can be markedly improved by extensive shielding of the sensors (e.g. Hanka 2000). How best to do this is the focus of this paper.

The STS-1s presently operated by the GRF Array are installed on warp-free base plates (Holcomb and Hutt 1992) and operated under slight vacuum because otherwise both the vertical and horizontal components would respond more strongly to variations in the ambient air pressure: the vertical component due to buoyancy and the horizontal component due to tilts produced by the deformation of the seismometer casing. In contrast to the STS-1 the STS-2 has a sealed casing such that variable air pressure should not lead to any buoyancy forces on the sensor masses. Air pressure fluctuations will however deform the casing which would adversely affect horizontal components if the casing did not have a warp-free design. Since this warp free design does not completely remove pressure induced tilt Wielandt (Wielandt and Widmer-Schnidrig 2002) proposed a shielding designed for the particular needs of the STS-2 seismometer (Fig. 1). The German Regional Seismic Network (GRSN) is so far the only network which has adopted this shielding and starting in 1992 the original method of installing the seismometers is slowly being replaced by the new shielding. So far nine installations have been converted. In the following we give a brief discussion of the most important aspects of the new shielding and compare the data of the GRSN network with data from other networks to demonstrate the efficiency of the new shielding.

We only discuss low-frequency data covering the normal mode band. Because seismic data at frequencies below the microseism peak ($f < 50\text{mHz}$) generally exhibit a red noise spectrum implying that stations which perform well in the normal mode band generally do so also at higher frequencies. Thus the findings of this study are at least relevant for the frequency band covered by surface waves and long-period body waves. At frequencies above 1Hz industrial noise is often the primary source of noise but this noise source can not be addressed with shielding of the sensor but only with a suitable site selection.

2 THE STUTTGART SHIELDING

This shielding proposed by Wielandt consists of a thick gabbro plate and an upside down stainless steel cooking pot which are screwed together to provide a hermetically sealed environment. The space under the stainless steel pot not occupied by the seismometer is filled with fiber wool to suppress thermal convection in the immediate surrounding of the sensor. The outside of the pot is again covered with insulating fiber and both the inner and outer fiber layers are each covered with a heat reflecting blanket to maximize thermal stability.

For convenience and because it was designed, first built and installed at the Stuttgart Institute of Geophysics, we shall subsequently call this shielding “Stuttgart shielding”. Stuttgart shielding protects seismometers from humidity, reduces temperature and atmospheric pressure fluctuations and – as we shall try to demonstrate below – contributes to the very quiet low-frequency data produced by seismometers shielded in this way.

A detailed description of the Stuttgart shielding is given in Wielandt and Widmer-Schnidrig (2002, page 77) and a pictures of the different stages of the STU installation was published on the web (Forbriger 1998).

2.1 Protection from Humidity

Since the first STS-2 seismometers were installed 15 years ago it has been noticed that the O-rings of the STS-2 casing do not provide an adequate barrier for humidity. In a specifically set up recent experiment Streckeisen could detect humidity leaking into the sensor casing after a matter of hours (E. Wielandt, pers. comm., 2005). Too much humidity inside the STS-2 can lead to corrosion which in turn can raise sensor self-noise. A concrete example is the GRSN station TNS prior to the installation of the Stuttgart shield. Humidity entering the TNS STS-2 has lead to high-frequency spikes in the data from July to October 2001. Apart from the signal degradation due to corrosion careful protection from humidity reduces the effort needed to service the sensor and increases its life time.

2.2 Temperature Stability

Both thermal radiation and convection are being suppressed by the Stuttgart shield. This same effect can also be achieved with different insulation techniques as implemented in other networks. Be-
Fig. 1. Schematic drawing of the Stuttgart shielding of the STS-2 as it is implemented in the GRSN (Wielandt and Widmer-Schnidrig 2002). The gabbro plate is square measuring 40 cm on the sides and is 12 cm thick. Only the top surface of the gabbro plate is polished to provide an easily sealable contact with the cooking pot. The gabbro plate weights approx. 50 kg. The cooking pot is made from stainless steel, holding 25 liters and measures 33 cm in height and 32 cm in diameter.

Beyond the insulation the high heat capacity of the gabbro base plate also leads to an additional passive, thermal stabilization of the sensor from below.

### 2.3 Air pressure

The hermetically sealed Stuttgart shield reduces the amplitude of the air pressure fluctuation that reach the seismometer. In spite the fact that the STS-2 casing was designed such that the deforming parts of the casing are mechanically decoupled from the seismic sensors, a reduction of the external pressure fluctuations still leads to a reduction of the stresses which have to be absorbed by the casing and hence to a further reduction of pressure induced tilts.

In contrast to the aluminum pressure vessel used by the GEOFON network (Hanka 2000), whose base plate is only about three times thicker than its cover, the Stuttgart shield contains a very large structural asymmetry consisting of a 12 cm thick gabbro base plate with high rigidity and a comparatively soft cover (stainless steel cooking pot with 4 mm thick walls). This large asymmetry implies that as ambient pressure varies only the cover deforms but the base plate, on which the sensor rests, remains essentially level. Horizontal component recordings should benefit in particular from this aspect of the design (see below).

### 3 DATA EXAMPLES

To carry out experiments which unambiguously show the effect of the Stuttgart shield is difficult as it would require to record for several weeks and at the same location multiple STS-2s with and without the Stuttgart shield. We pursue a different strategy here and try to learn about the merits of different installation techniques based on the data recorded by the different networks over the last years.

The pitfalls of this approach are clear: since no two installations are identical and since many factors contribute to the overall quality of a station it is problematic to attribute a difference in noise level to a single aspect of the installation such as the shielding of the sensor. The benefit of the approach are, that we can draw conclusions based upon recordings from many more stations and a much longer time span than would be realistically possible in the case of a dedicated experiment. Of course any interpretation must be done with great care.

We base our study on data recorded by different seismic networks which operate STS-2 seismometers. The only network which uses the Stuttgart shield is the GRSN and even in this network only 9 out of 18 stations are equipped with it.

In order to study the effect of the Stuttgart shield it would in principle also be possible to compare data from a particular station before and after its shielding. However this approach is problematic too, since for example in the case of station BFO at the time of the installation of the Stuttgart shield also the STS-2 was replaced.

### 3.1 Vertical Component Noise: Detecting the Hum

At quiet observatories the background free oscillations of the Earth (a.k.a. hum) consisting of permanently excited fundamental spheroidal modes can be detected in times devoid of any large quakes. The modes which make up the hum span the frequency band 2-7 mHz and every one of them has a nearly constant $\text{rms}$ amplitude of $\sim 1$ nGal over 100 $\mu$Hz band width. So far this signal could be detected with superconducting gravimeters, with spring gravimeters and with both STS-1 and STS-2 Streckeisen seismo-

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Table 1. Hum detections in the GRSN. At the three stations BSEG, CLZ and HLG it is not known what kind of seismometer shielding is in place “GE Al-pot” refers to the hermetically sealable aluminum pot developed and used by the GEOFON network. The station MOX was equipped with the Stuttgart shield in June 2005. No data suitable for a search of the hum are so far available from GEC2 and NOTT.
Since the hum is a global phenomenon of nearly constant amplitude in space and time it can be used as a test signal to judge the quality of the vertical component of a station. In an ongoing investigation of the processes which lead to the excitation of the hum D. Kurrle (pers. comm., 2005) has inspected long-period data from over 140 stations equipped with STS-2s: GEOFON and partner networks, IRIS, BDSN, F-Net, SDSNet and could identify the hum at only 7 non-GRSN stations: WLF (Luxemburg), UGM (Indonesia), PSZ (Hungary), BRANT, BALST, SULZ (Switzerland) and WTTA (Austria). These stations all belong either to the GEOFON or the SDSNet. We attribute the fact that no STS-2 in either the IRIS, BDSN or F-net show the hum to the fact, that in these three networks the STS-2s stand essentially naked on the piers, covered with at most a Styrofoam box (pers. communication for IRIS and F-net staff).

In the remaining part of the paper we shall concentrate exclusively on the networks whose STS-2 are suitably installed to detect the hum at least at a subset of stations. These are the GRSN, GEOFON and SDSNet networks, for which we know quite well how the sensors are shielded.

The seven only hum detections out of 63 GEOFON and SDSNet stations should be compared with the 75 percent yield for the GRSN stations with Stuttgart shielding (7 out of 9)!

Inspecting the GRSN network only (table 1) we note that there does not exist a perfect correlation between hum detections and the Stuttgart shield: BRG and TANN are the only stations without the Stuttgart shield that see the hum whereas stations BUG and IBBN don’t see the hum in spite of the Stuttgart shield. At station STU the hum could be seen back in 1996 whereas in 2005 the hum has drowned in noise. At TANN the STS-2 is shielded with a GEOFON aluminum pot that rests on a gabbro base plate. In Moxa (MOX) the STS-2 is a Stuttgart shield since summer 2005 with the effect that the long-period noise level has been reduced by ~3dB but the hum does not emerge from the noise yet. Since the superconducting gravimeter at the same station sees the hum a replacement of the STS-2 seismometer is currently being considered.

We conclude that unless there is a hidden and so far unknown aspect of the seismometer installation apart from the Stuttgart shield by which the GRSN network is distinct from other broadband seismic networks, the hum detection at the majority of stations covered with the Stuttgart shield speaks clearly for the efficiency of the latter to reduce vertical component noise levels.

### 3.2 Horizontal Noise: comparing Streckeisens at BFO

While it is well documented that for the vertical component the STS-1 has a lower self-noise than the STS-2 (e.g. Berger et al. 2004) so that the STS-2 cannot resolve Earth noise over the same large frequency band as the STS-1, we show here that for the horizontal component both STS-1 and STS-2 perform equally well down to the frequencies of the lowest seismic modes even at very quiet sites.

In Fig. 2 E-W component spectra of the 2004 Sumatra event recorded with STS-1 and STS-2 seismometers at BFO are compared. Above 0.5 mHz the STS-2 spectrum exhibits a slightly lower noise level than the STS-1 which is installed on a warp-free base plate. Taken together with the fact that the E-W component of the STS-1 at BFO was among the quietest stations of the GSN in the long-term noise study of Berger et al. (2004) and even defined their GSN noise model at several frequencies, these two studies suggest that selected and suitably installed STS-2 seismometers can produce horizontal component spectra of comparable quality as the STS-1, even at very quiet sites. Whether they actually resolve Earth noise would require a coherence analysis.

### 3.3 Comparison of Networks: The 2004 Sumatra Event

A robust method to judge the quality of low-frequency seismic data is to inspect a deterministic signal such as a large quake. While amplitudes of mode peaks in signal spectra may vary across a network a robust measure is to identify the last modes which can be clearly detected above the noise at the low-frequency end of the spectrum. In the case of the 2004 Sumatra event the best stations can detect all modes down to the football mode \(\psi_S\) at 0.3 mHz and hence the frequency band between 0.1 and 1.2 mHz is a suitable band to inspect.

**GEOFON:** in this network mostly STS-2 seismometers are used. Because of the large weight of the Gabro base plate and the related high costs for transportation GEOFON has developed its own method of shielding the seismometers. This shield consists of a 3 cm thick aluminum base plate and an upside-down aluminum pot with ~1cm thick walls. Efforts have been undertaken to create an air-tight shield and while the two parts can be tightly screwed together the only potentially leaky part is the feed through of the seismometer cable. Still the shield protects the seismometer from humidity, and reduces ambient temperature and pressure fluctuations. Vertical and horizontal component spectra of the 2004 Sumatra event are shown in fig. 5 and fig. 6. The only two stations in these figures with a Stuttgart shield are RGN and STU. They are affiliated with both the GEOFON and the GRSN networks. The vertical component spectra are of comparable quality as for the GRSN (fig. 3). The “football mode” \(\psi_S\) is visible at only few stations while the mode \(\psi_T\) can be seen at the large majority of stations. Comparing the horizontal components the difference between the GRSN and the GEOFON networks is huge in the given frequency band: while the peaks of the toroidal modes \(\psi_T\) and \(\psi_S\) can be seen at nearly all GRSN stations (fig. 4) these modes are largely missing in the GEOFON spectra. The excellent signal-to-noise ratio in the horizontal spectra of the GRSN station MOX and the GEOFON station SOP, which at the time of the Sumatra event were both operated without the Stuttgart shield shows that at selected sites excellent spectra can also be recorded without a Stuttgart shield. However, fig. 6 suggests that such sites are an exception.

**SDSnet:** The swiss seismic network (Bür et al. 2000) is equipped...
with 27 STS-2 seismometers and thus constitutes a broad-band network with one of the highest station densities. The shielding of the sensors consists of a square housing made of four walls with outside dimensions of 120 by 120 cm and 80 cm high. The inside of the walls is covered with Styrofoam and the remaining space is filled with small Styrofoam spheres. A wooden plate which is also covered on the inside with Styrofoam rests on top of the walls and completes the insulation (P. Zweifel, pers. comm., 2005). Thus the sensors are not shielded from ambient air pressure fluctuations and rest rest directly on the pier. Spectra of the Sumatra quake are assembled in fig. 7 and 8.

A peculiarity of the SDSnet is that the output of the STS-2 seismometer is high-pass filtered prior to digitization in order to remove the tidal signal and any DC offset. The effect of this filter has been removed from the spectra in fig. 7 and 8 to allow direct comparisons with the other networks.

The quality of the spectra is highly variable within the network with the quietest stations being comparable with the least noisy stations of the GRSN and GEOFON networks. Three out of 27 stations of the SDSnet see the hum: BRANT, SULZ and BALST.

The horizontal component spectra as a whole are considerably less noisy than GEOFON spectra but not as quiet as the GRSN spectra. One possible reason for the comparatively high horizontal noise on the GEOFON stations maybe related to the GEOFON aluminum shield whose bottom differs not by much in stiffness from its top so that a change in ambient air pressure leads to a warping of the base plate and possibly a tilting of the seismometer. Since the STS-2s in the SDSnet are installed directly on the concrete pier they do not suffer from this kind of tilt induced by the shielding.

3.4 Noise Studies from the Literature

In the recent comprehensive study of the performance of the Global Seismic Network (GSN) vertical component noise levels from the different sensors used by the GSN were compared and the STS-2 fared surprisingly poorly in comparison with the STS-1 (Berger et al. 2004, fig. 9). While at BFO the difference in noise levels between these two sensors was estimated to be 5dB at 3 mHz (Widmer-Schnidrig 2003) the difference in the GSN is at least 12dB. The reason for the comparably poor performance of the STS-2 in the GSN is probably related to the fact the GSN mostly uses the STS-2 as auxiliary sensor to record high frequency signals which the STS-1 does not provide and that shielding of the seismometers primarily affects the performance at long periods, which in the case of the GSN are covered by the STS-1. Until very recently the STS-2s in the GSN were deployed with only minimal protection (B. Hutt, pers. communication, 2005).

4 CONCLUSION

We have demonstrated that there exist considerable differences in the quality of low-frequency seismic STS-2 data from network to network. Assuming that these network wide differences can be attributed to the particular way in which the sensors are shielded within a network, the data presented speak very much in favor of the Stuttgart shield.

Comparing GRSN, GEOFON and SDSnet spectra a similar picture seems to emerge as was found by Holcomb and Hutt (1992) in their work on how best to install STS-1 seismometers. They found that horizontal seismometers installed in evacuated containers perform very poorly unless the base plate of the container has a warp-free design of some sort. A non-warping base plate can be achieved by cementing the base plate to the pier or else by using a warp-free design such as discussed in Holcomb and Hutt (1992). In particular they found that horizontal component performance of a sensor in a sealed container with a flexible base plate is worse than if the container is vented. This in agreement with the observation that the horizontal component spectra of the SDSnet show higher signal-to-noise ratio than the GEOFON stations, whose base plate doesn't seem to be stiff enough to withstand the stresses from ambient pressure fluctuations without warping. The gabbro base-plate of the Stuttgart shield on the other hand seems stiff enough to qualify in this context as warp free.

At least at BFO where STS-1 and STS-2 are installed next to each other a direct comparison is possible and the horizontal components of the two sensors performed equally well with the STS-1 installed on a warp free base plate and the STS-2 under a Stuttgart shield. Thus for horizontal components the shielding does not just reduce noise levels but actually allows to reach the quality of the STS-1.

For the vertical components we have used hum detection as a criterion and the result speaks very clearly for the Stuttgart shield: 75% of the STS-2s covered with the Stuttgart shield detect the hum while the hum can only be detected at 12% of the SDSnet and GEOFON stations. We don’t know of any station where the STS-2 sits naked on the pier and the hum can be detected.

Are there reasons that speak against the Stuttgart shield? We don’t know of any. When compared with the price of an STS-2 seismometer the costs of the Stuttgart shield seem negligible.

APPENDIX A: HOW TO BUILD YOUR OWN STUTTGART SHIELD

At least in Germany, the gabbro plate can be ordered from manufacturers of grave stones. Its dimensions are 40 by 40 by 12 cm and weighing approximately 50 kg. Only the top surface of the gabbro plate needs to be polished to provide an easily sealable contact with the cooking pot. The cooking pot is made from stainless steel, holding 25 liters and measures 33 cm in height and 32 cm in diameter. The connectors for the STS-2 are produced by www.fischerconnectors.com and a DBEE 105A038-130 sealed socket to be mounted on the outside of the gabbro plate and a WSO 105A038-130 plug to connect to the STS-2 are needed. Feed the wires connecting the plug and the socket through intersecting 18 mm diameter holes drilled into the gabbro plate from the front and from above. The socket is glued onto the front hole of the gabbro plate such that the cable from the host box can be plugged into it. Weld eight stainless steel angle irons evenly spaced onto the outside of the cooking pot flush with the rim. Glue threaded studs into holes that are drilled into the top surface of the gabbro plate. Place these holes such that the studs meet the angle irons. If the studs are long enough to reach through holes in the angle irons then the pot can be firmly screwed down onto the gabbro plate. A rubber seal placed between the gabbro plate and the rim of the upside down cooking pot completes the setup. Note that further insulation layers need to be placed inside and outside the pot to reduce convection and heating by radiation (see fig. 1 and Forbriger (1998)). Some Silicagel to absorb residual humidity may also be placed under the cooking put as a safeguard against corrosion.
Fig. 3. Vertical component linear amplitude spectra of the 2004 Sumatra event recorded by STS-2 (LHZ channel) of the GRSN network. GRFO is the IRIS/GSN station at the Gräfenberg Array equipped with a KS-54000 borehole seismometer. Record length is 108 hours. All spectra are normalized to unit maximum amplitude. No instrument correction has been applied. Station codes are given on the right and the location of theoretically predicted spheroidal and toroidal modes are given along the top.

ACKNOWLEDGMENTS

M. Tyderle for producing the Stuttgart shields deployed in the GRSN. We thank the network operators for collecting and freely distributing high quality seismic data: GRSN (SZGRF, Erlangen, Germany), GEOFON (GFZ, Potsdam, Germany), SDSnet (ETHZ, Switzerland), BDN (UC Berkeley, California), IRIS (Seattle, Washington), and F-Net (Tsukuba, Japan). Wiley-Vch publishers granted permission to reproduce figure 1.

REFERENCES


Fig. 5. Same as fig. 3 but for the vertical components of the stations from GEOFON and its partner networks. RGN and STU are the only stations in this figure which have the Stuttgart shield. Station and network codes are given on the right of the spectra.

Fig. 6. Same as fig. 4 but for the E-W components of the stations from GEOFON and its partner networks. RGN and STU are the only stations in this figure which have the Stuttgart shield.
Fig. 7. Same as fig. 3 but for the vertical components of the Swiss SDSnet.

Fig. 8. Same as fig. 4 but for the E-W components of the Swiss SDSnet.