A Summary of STS-2 Low-Noise Installation Methods Tested at the USGS Albuquerque Seismological Laboratory

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In the quest for lower noise data from seismometer installations, the USGS Albuquerque Seismological Laboratory (ASL) has studied various techniques for installing STS-2 seismometers. The objective was to find ways to improve long period (LP) noise performance of the vertical component in the hope of approaching the LP noise level of the STS-1 vertical seismometer. Previous tests of installation methods have shown that it is difficult to improve horizontal LP noise performance unless one installs the seismometer at some depth (3 to 100 meters or more). However, it is far too easy to increase horizontal LP noise when trying to decrease vertical LP noise. For example, if one installs the seismometer in a sealed chamber on a base plate that is also part of the pressure containment vessel, the base plate can bend in response to air pressure changes, resulting in increased LP horizontal noise compared to that achieved with no sealed chamber. We therefore concentrated on improving the LP noise of the vertical component while not degrading the performance of the horizontal components.

Previous to these studies, which began in 2005, the "standard" installation method used in many cases was to either install the STS-2 with no cover at all, or to install it with a simple air shield (see Figure 1).

Figure 1. "Standard" STS-2 installation method with simple air shield.

As part of this investigation, we explored several methods to isolate the STS-2 from environmental effects, especially temperature and air pressure variations, to attempt to improve the LP performance of the vertical component. Several methods were tried as shown in Figures 2-7. Results are presented in Figure 8, Figure 10, and Figure 10. A summary is presented in Table 1 at the end.

Sealed Steel Isolation Chamber with Thick Steel Base

Figure 2. Sealed steel isolation chamber with 4-inch thick base plate. Steel chamber is covered with loose Styrofoam balls for insulation. Additional box is added on the outside for protection from air currents in vault.

The steel isolation chamber shown in Figure 2 was a configuration used for testing the idea of pressure isolation. It is not intended for use in a normal installation, as the 4-inch thick steel base plate is much too heavy to handle in normal operations. A very thick base was chosen for this test to make sure that it would not bend (warp) as a result of barometric pressure changes, thus causing excessive horizontal LP noise.

STS-2: Granite Base (Similar to German Method)

Advantages:

- Reduces LP noise
- Protects seis connector (but not host box connector) from environment

Disadvantages :

- More expensive than standard install (parts ~$1500)
- More effort (5” thick granite plate ~100 lbs)

Figure 3. Granite base plate with semi-sealed cable entrance, fiberglass wool insulation around sensor, and stainless steel cooking pot to seal against vault environment.

The installation method shown in Figure 3 is approximately the same method used in the German Regional Seismic Array (GRSN). See Borman (2002). One may purchase a pre-manufactured granite base plate assembly from Lennartz Electronic: http://www.lennartz-electronic.de/MamboV4.5.2/index.php

One difference between the ASL-designed granite base plate and the German-designed version is that the German version is completely pressure sealed, while the ASL design is not. The ASL version passes the original orange seismometer cable through a sealing device, but air is not prevented from flowing through the interior of the cable jacket along the individual conductors. ASL therefore recommends installing a drying agent (dessicant) inside the chamber to keep the air dry as long as possible. However, we suspect that after several years, the dessicant will become saturated and will need to be replaced to keep the air dry around the seismometer.

STS-2 on Warpless baseplate, sealed

- STS-2 on steel "warpless" base plate, sealed with steel jar. All steel is powder coated for rust proofing.
- Gets covered with foam pellets in inner foam box around jar + outer foam box to shield inner one. Important to insulate seis with blanket or other cover!
- Advantages: Reduced LP noise, protects seis and connector (new design), provides magnetic shielding, seis orientation, external level adjust
- Disadvantages: More expensive (~$4000), more effort (~150 lbs)

Figure 4. Steel isolation chamber with "warpless" base plate design.

This ASL design (Figure 4) is similar to the original ASL test design with the 4-inch thick steel base plate. The difference is that the base plate on which the seismometer sits is a "warpless" design that does not also act as part of the pressure vessel. The warpless base plate design helps prevent an increase in horizontal LP noise. For drawings of the warpless base plate and sealed chamber design, contact ASL.

This design is completely sealed against barometric pressure changes, because the orange cable does not pass through. Instead, it plugs into a sealed connector installed in a steel ring above the base, which is internally connected to the seismometer via a pigtail cable. This ASL design is the same as the original German design in this regard. If the chamber is sealed with a small amount of dessicant inside, there will be no need to change dessicant periodically because there is no exchange of air with the outside.

Insulating Cover and Round Air Shield

Figure 5. STS-2s with polar fleece insulating covers and round PVC tubes for air shields.

In Figure 5:
Top Left: STS-2 inside round PVC tube air shield.
Top Right: With polar fleece insulating cover installed over seismometer.
Bottom Left: Three STS-2s installed on granite pier in ASL tunnel, along with the reference STS-2 installed in steel isolation chamber with warpless base plate (blue cover in rear right of photo).
Bottom Right: All round PVC air shields covered, additional air shield sides (white) installed around test pier. A cover was also installed over the entire assembly during testing. The two round yellow objects with dark covers in the bottom right of this photo are air shields covering two STS-1 horizontal instruments. A vertical STS-1 instrument is located on the floor of the vault just below this photo.

Granite Base Plate with Cable Entry Groove

Figure 6. Granite base plate with square cable entry groove.

In Figure 6:
Top Left: STS-2 on 3-inch thick granite base plate with polar fleece insulating cover in place.
Top Right: Aluminum cooking pot (painted green) secured down to granite base plate with brass hold-down brackets. There is a flat rubber gasket between the cooking pot and the granite base plate.
Bottom Left: Round air shield covers entire assembly. One may also use a square foam box as an air shield.
Bottom Right: Orange cable for seismometers enters through a square rubber piece that fits down into a square groove in top of granite base plate. This cable entry method avoids the need for a pigtail cable and connector, but it results in a chamber that is not air tight (like the method shown in Figure 3). This means that dessicant placed inside the chamber to keep that space dry should be replaced every two to three years.

STS-2 Installed In Sand

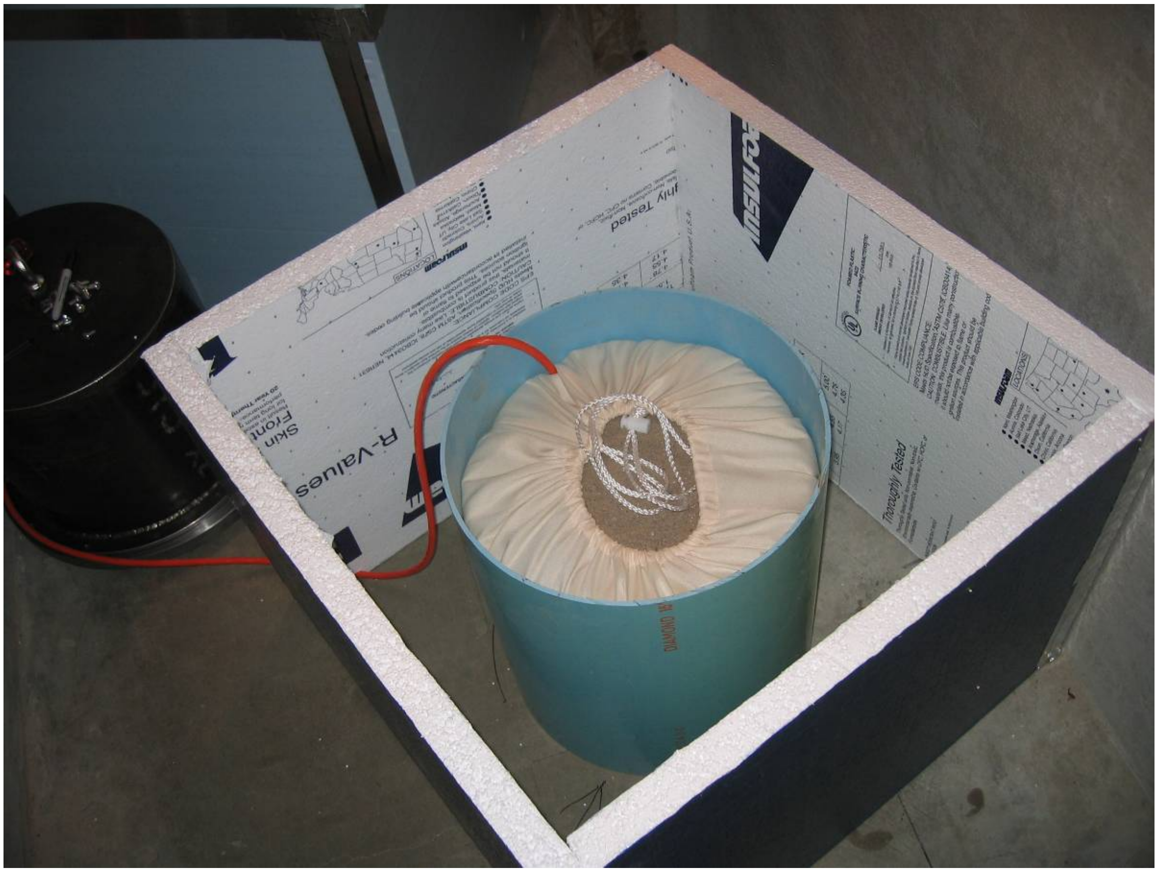

Figure 7. STS-2 installed under a cloth laundry bag filled with playground sand.

The installation method shown in Figure 7 was also evaluated. Test data indicated that the vertical component was very quiet with this method (probably because of the excellent thermal stability provided by the sand), but it sometimes results in elevated horizontal LP noise levels when atmospheric pressure is changing (such as when the wind is blowing). Figure 8 illustrates this problem.

In Figure 8, the top trace is air pressure, the next three traces are the NS, EW, and Z traces from an STS-2 installed with sand around it, and the bottom three traces are the NS, EW, and Z traces from an STS-2 installed in a steel enclosure with warpless base plate. All traces have been band pass filtered from 0.001 Hz to 0.05 Hz. The total amount of time represented is approximately 3.5 days. In the rightmost portion of the plot (roughly the last 15 hours), the sand was removed from the first STS-2, resulting in much lower noise on the two horizontal components (comparable with the two horizontal components of the second STS-2). Note that, before the sand was removed from the first STS-2, the horizontal noise was much higher than on the second STS-2. The daily periods of high levels of horizontal LP noise on the first STS-2 correspond to daily periods of increased air pressure fluctuations during daylight hours.

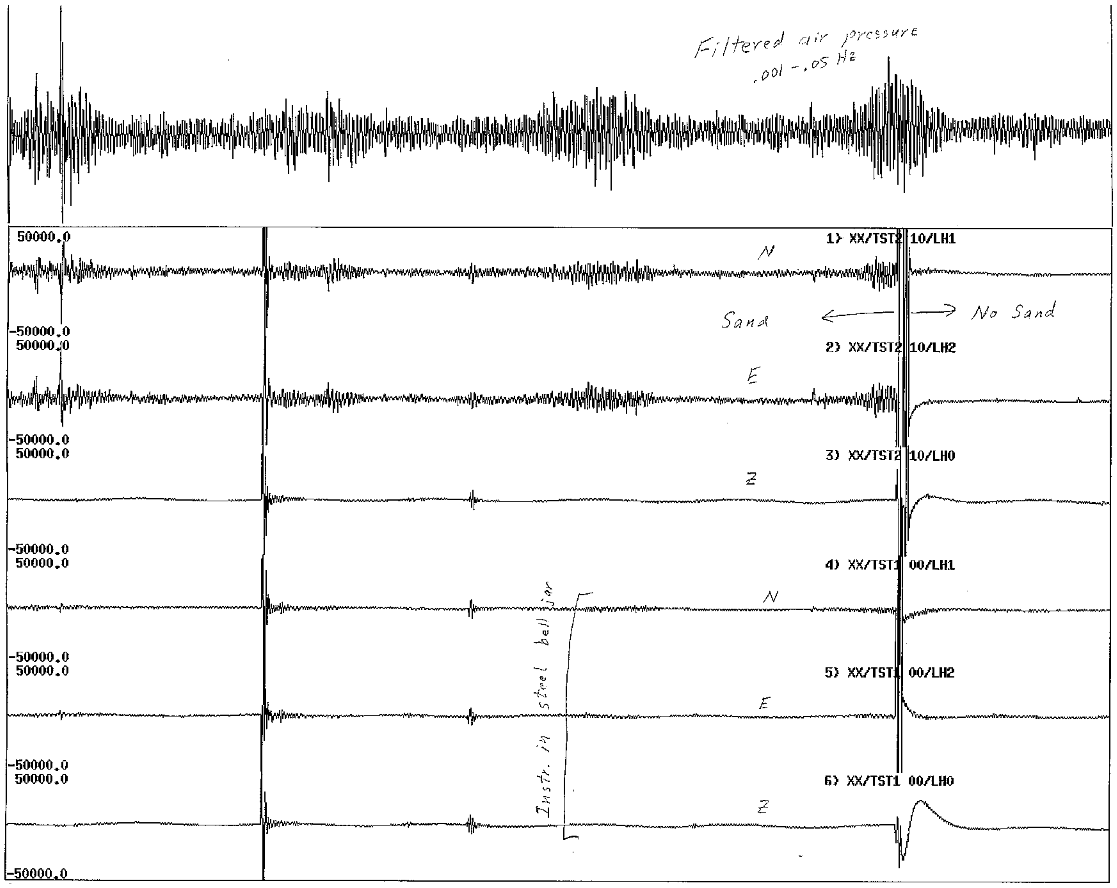

Figure 8. STS-2 horizontal LP noise comparison with sand *versus* no sand.

The vertical LP noise level of an STS-2 when surrounded by sand is much improved over the "standard" method shown in Figure 1, and is about the same as for the other installation methods shown. This is thought to be due to increased thermal stability.

ASL does not recommend using the sand method unless it can be shown (in the user's particular situation) that horizontal LP noise is not increased when the seismometer is covered with sand, compared with the "standard" method.

Results

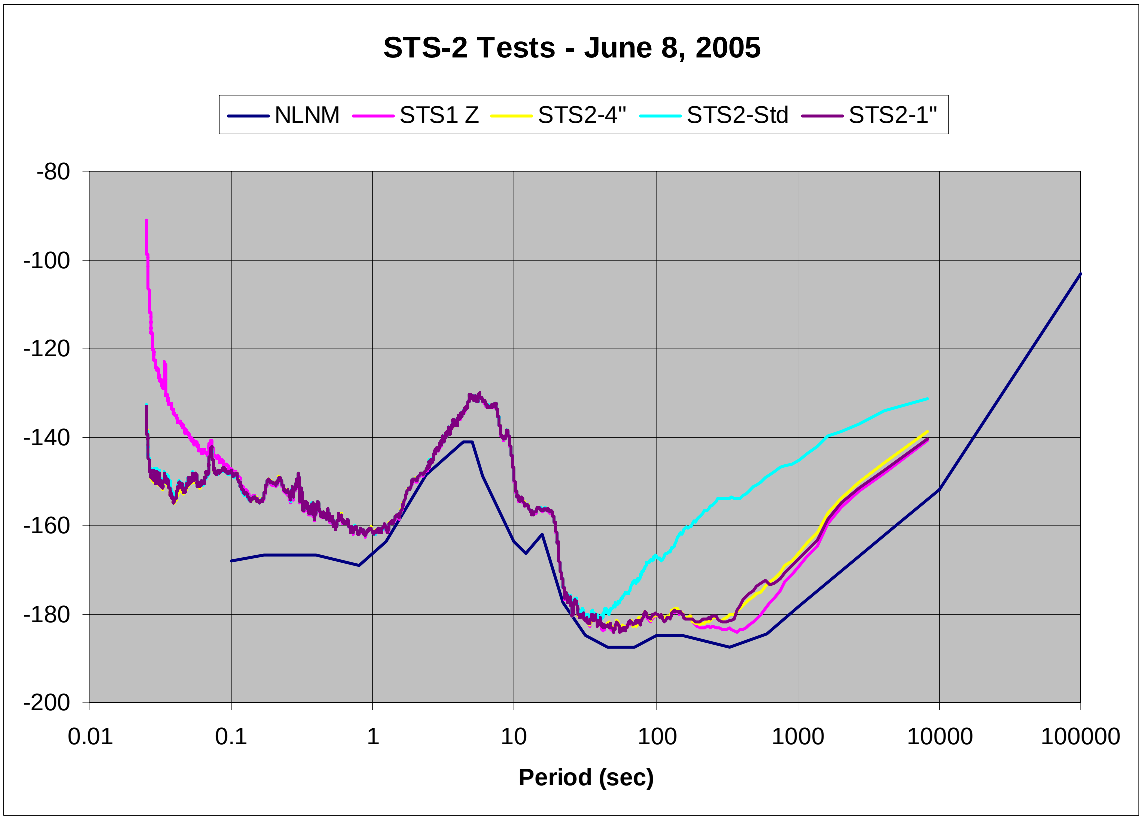

Figure 9. Power spectral densities of vertical noise levels observed for some of the installation methods presented in this document.

In Figure 10, we present vertical power spectral densities (PSDs) for some of the installation methods described.

- Dark blue: **NLNM** = USGS New Low Noise Model.
- Magenta: **STS1 Z** = Noise PSD for the STS-1 vertical.
- Yellow: **STS2-4"** = Noise PSD for STS-2 vertical in sealed steel chamber on 4-inch thick steel base plate (Figure 2).
- Cyan: **STS2-Std** = Noise PSD for STS-2 vertical installed using "standard" method shown in Figure 1.
- Purple: **STS2-1"** = Noise PSD for STS-2 vertical in sealed steel chamber on 1-inch thick steel base plate (similar to method shown in Figure 2, but with much thinner base plate).

We see that both of the STS-2 vertical components installed in a sealed steel chamber exhibit LP noise levels very close to that of the STS-1 vertical component, and much lower noise than an STS-2 installed in a simple air shield box.

Although all of the results are not shown, the other installation methods described in this document (Figure 3, Figure 4, Figure 5, Figure 6), all have the same reduced noise levels as those achieved by the steel chamber method (Figure 2). None of the installation methods presented above result in any detectable increase in horizontal LP noise levels, except for the sand method shown in Figure 7.

We calculated the seismometer self noise of the STS-2 by comparing four STS-2 seismometers. Three STS-2s were installed with polar fleece covers and round PVC air shields (Figure 5) and one was on a warpless base plate in a sealed steel chamber (Figure 4). The self noise of a seismometer is the incoherent signal produced by that seismometer (when compared to two other seismometers installed on the same pier). That is, we remove the common (coherent) signals between three sensors, under the assumption that all three should be producing the same signal resulting from ground motion. This self noise calculation represents the total noise contributed by both the instrument and the installation method. We see in Figure 10 that the self noise of the STS-2 compares quite favorably with that of the STS-1 for frequencies higher than about 0.003 Hz (period shorter than about 333 seconds). Two of the three STS-2 seismometers used for this noise calculation were installed as shown in Figure 5 and one was installed as shown in Figure 4.

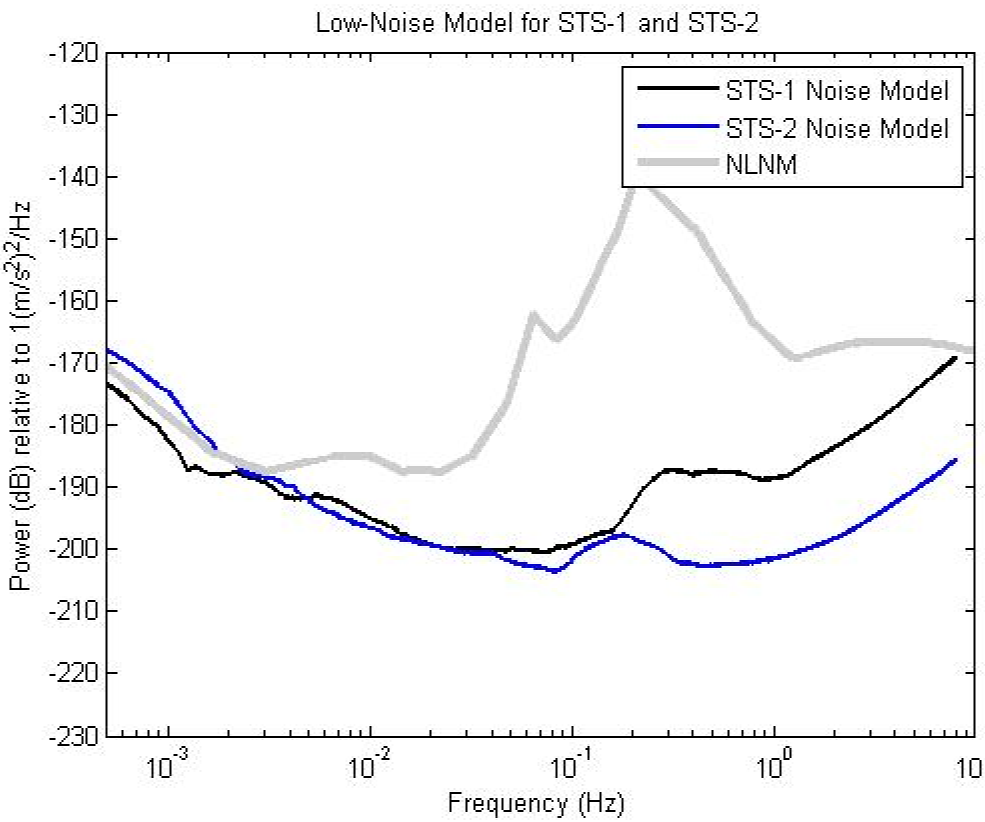

Figure 10. Self noise of STS-1 and STS-2 seismometers, calculated from side-by-side vertical component data.

Conclusions

Any of the STS-2 installation methods shown in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6, will result in both vertical and horizontal LP noise levels roughly equivalent to those of well-installed STS-1 seismometers. The installation method chosen will be a function of vault conditions, budget, and personal preference.

The common component of these installation methods is the use of an insulating cover on the seismometer (polar fleece cover or equivalent) and placing a close-fitting air shield around the seismometer (but not touching the seismometer) to reduce the effects of air motion in the seismometer vault. Isolation of the seismometer from air pressure variations and from the vault environment is achieved by the methods shown in Figure 2 (sealed steel isolation chamber with thick steel base), Figure 4 (steel isolation chamber with warpless base), and the German Regional Network (referenced in Figure 3). The methods shown in Figure 3 (thick granite base with semi-sealed cable entrance) and Figure 6 (granite base with semi-sealed cable entrance via square groove in granite base) help keep the seismometer and cable clean and dry, but do not provide pressure isolation. If your seismometer vault is clean and dry, you may wish to consider the simple method shown in Figure 5 (polar fleece insulating covers and close-fitting air shields only).

A summary of STS-2 installation methods, costs, weights and dimensions, type of shielding provided, and LP vertical noise improvement to be expected is given in Table 1. Contact Bob Hutt bhutt@usgs.gov or Adam Ringler aringler@usgs.gov for further information.

References:

Borman, P. (Editor, 2002). New Manual of Seismological Observatory Practice (IASPEI), volume 1, section 7.4, page 67. ISBN 3-9808780-0-7. Published by GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany.

Table 1: Summary of STS-2 installation methods, costs, weights and dimensions, type of shielding provided, and long period noise improvement to be expected.

Method	Approx. Cost (US Dollars)	Weight & Dimensions	Shielding provided	Z noise improvement over "Standard" method	H noise improvement over "Standard" method
Figure 1: "Standard" (simple air shield)	$5	< 1 kg, 60x60x60 cm	Air movement, minimum thermal	None	None
Figure 2: Sealed steel isolation chamber with thick steel base	$3000	Base: 131 kg, 45.7 cm diam x 10 cm thick Cover: 30 kg, ~35cm diam x 35cm high. Outer foam air shield: 74x74x64 cm	Pressure Air motion Thermal Magnetic Humidity	Better	None
Figure 3: Thick granite base with sealed cable entrance, stainless steel cooking pot for cover	$1500	Base: 50 kg, 38x38x12.7 cm. Cover: 4 kg, 36 cm diam x 33 cm high. Outer foam air shield: 50x50x50 cm	Air motion Thermal Humidity	Better	None
Figure 4: Steel warpless baseplate, steel cover, sealed	$6,200	Base: 90 kg Cover: 28 kg Overall dimensions: 48 cm diam x 38 cm high. Outer foam air shield: 74x74x64 cm	Pressure Air motion Thermal Magnetic Humidity	Better	None
Figure 5: Insulating cover and close-fitting round PVC air shield	$100	4 kg, 38 cm diam x 38 cm high	Air motion Thermal	Better	None
Figure 6: Granite base with square cable entry groove, aluminum cooking pot for cover	$1500	Base: 30 kg, 37x37x7.6 cm Cover: 3.4 kg, 36 cm diam x 36 cm high	Air motion Thermal Humidity	Better	None
Figure 7: PVC tube filled with sand over seismometer, foam air shield	$110	PVC tube: 4kg, 38x38 cm. Sand: 22 kg	Air motion Thermal	Better	Worse