UC Berkeley Seismographic Station

Guidelines for Installing Broadband Seismic Instrumentation

Under Construction!

Introduction

In this installation guideline, rather than trying to cover all aspects of the installation procedures in detail, we will concentrate on those aspects which have the largest impact on the overall performance of a seismic station housing a broadband seismometer. The two aspects of the installation which most influence the overall performance of the broadband seismometer are the construction of the seismic pier and the application of thermal insulation around the sensor and pier. As an example, we also cover some details about the installation and the operating characteristics of the BDSN broadband station recently (March 1997) installed on the Farallon Islands (68 km west of Berkeley).

When a potential site for a broadband seismic station is found, it is informative to deploy a portable broadband sensor recorded by a 24-bit resolution data logger at the site for a few days in order to measure the low-frequency background noise. This is an important step because the low-frequency noise level can not be reliably predicted from the high-frequency noise level. A quiet short-period site will not necessarily be a low-noise broadband site.

PSD Background Noise Measurement

Once a potential site for a broadband seismic station has been found we always set out a portable broadband station (a broadband sensor and a 24-bit resolution data logger) and record for a few days to get an indication of the background noise levels. When a suitable place for the broadband seismometer has been found (roughly level and large enough for the sensor and the insulating box), the loose surface material is removed using a back hoe and/or a shovel and the exposed rock is cleaned off using a geologic hammer and a wire brush in order to get a clean and stable surface. Figures 1 and 2 show an example of a temporary installation of a broadband seismometer at a potential broadband site near Hopland.

Figure 1. Example of a placing a broadband seismometer on a rock outcropping. A hole was dug into the side of a hill and the loose weathered material was removed until an approximately level and flat piece of solid rock, large enough to hold the seismometer, was exposed.

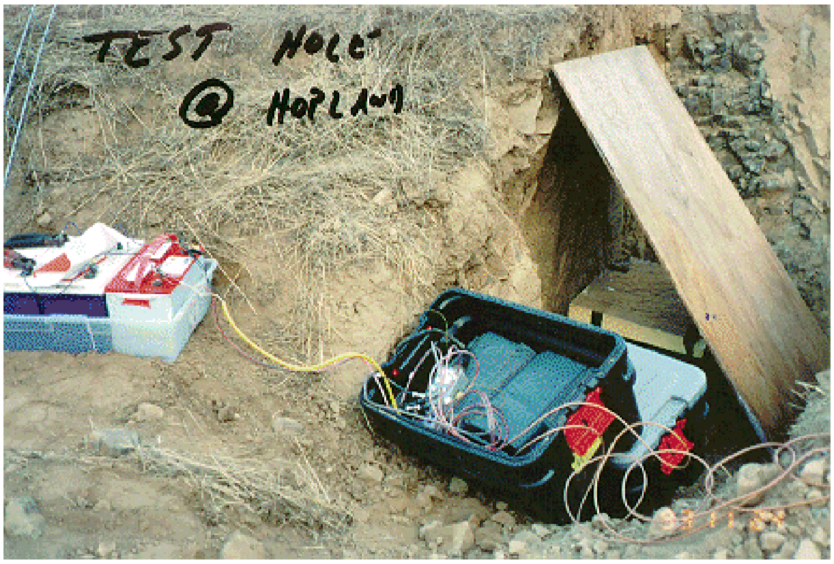

Figure 2. After setting up the seismometer it was covered with an insulating box (built from insulating foam as described below) to help provide thermal stability. A piece of plywood was also placed as a shade over the thermal insulation to minimize exposure to direct sunlight. The data logger and batteries are also visible in the figure. Be sure that the insulating box is not touching the seismometer. It generally takes about a half-day for the seismometer to become stable after it is set up and operating.

Typically, three or more potential sites in an area are investigated when looking for a new site for a broadband station and noise tests are done at two or more of these sites. We prefer sites which are on public lands with nearby power and telephone and away from significant sources of cultural noise (roads, highways, railroads, etc). Sites with minimal exposure to direct sunlight are also preferred for thermal stability. The best BDSN sites we have found are in abandoned hard rock mining drifts in relatively remote locations.

Vandalism is also a concern so we look for sites that offer some degree of security and are not generally visible from public roads or paths. While searching for a site is a time consuming endeavor, it is necessary in order to achieve the best performance from the broadband seismographs.

The power spectral density (PSD) of the background noise is determined and compared against other stations. An example of a PSD analysis of the low-frequency background noise is shown in Figure 3 where we were interested in the low-frequency noise levels in a drift into the side of a hill in the Livermore area (55 km SE of Berkeley). Figure 4 provides a comparison with the BDSN station JRSC. In both figures, the PSD units are in dB relative to 1 (m/s**2)**2/Hz.

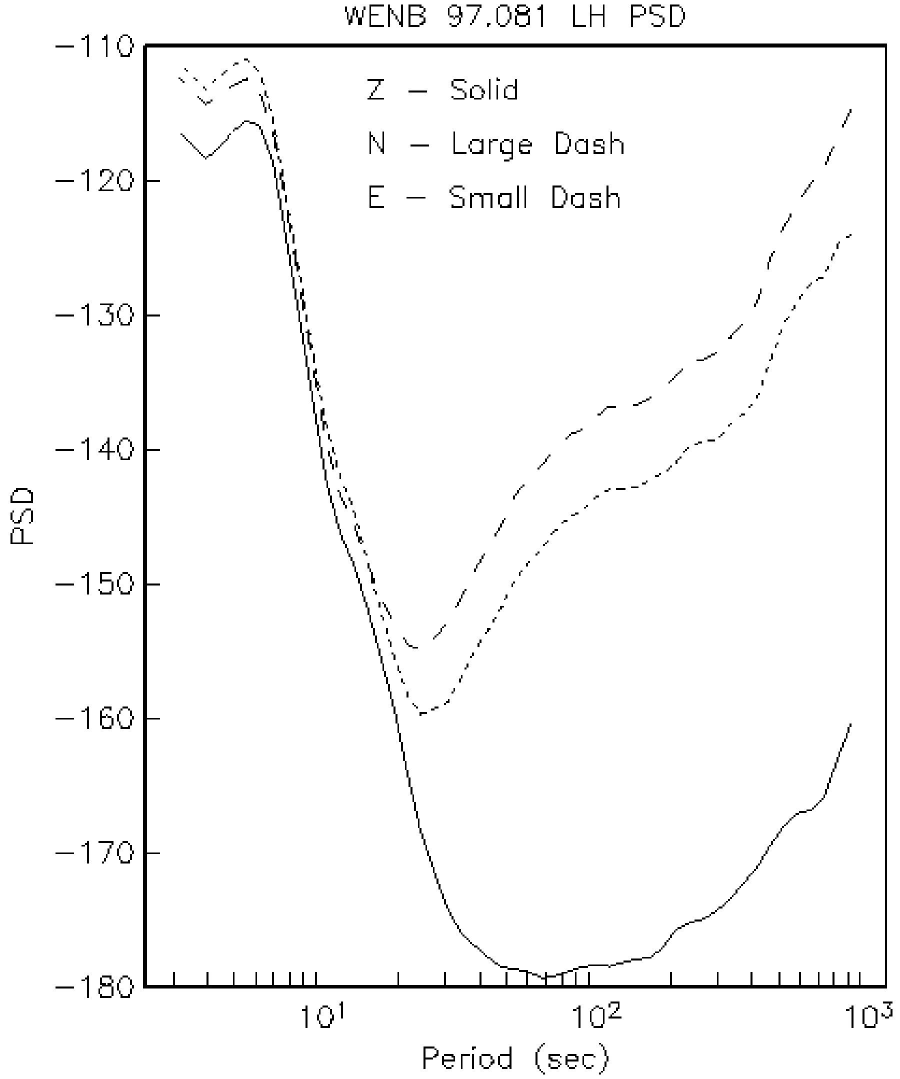

Figure 3. PSD background noise, recorded using a Streckeisen STS-2 broadband seismometer and a Quanterra Q4120 data logger, at a proposed BDSN broadband station site.

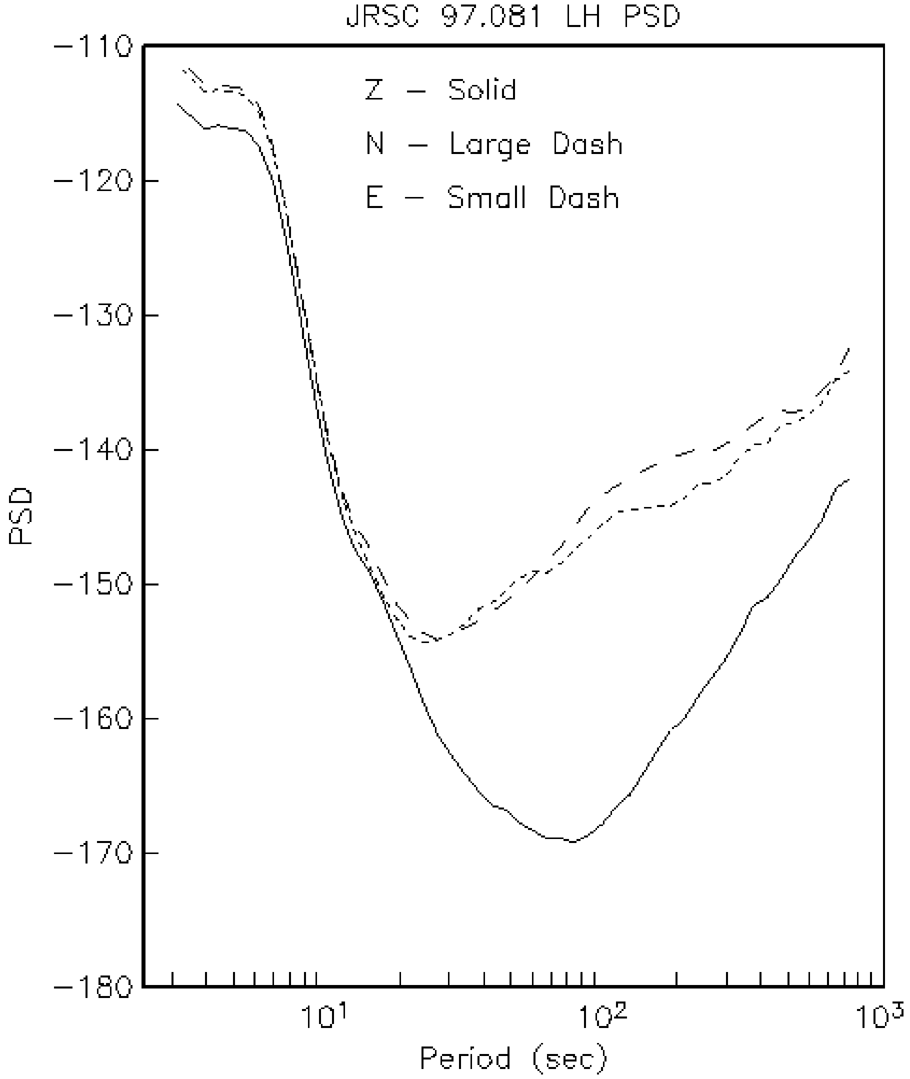

Figure 4. The PSD background noise level recorded at BDSN station JRSC, which also houses an Streckeisen STS-2 seismometer, is given for comparison with Figure 3.

Note that the noise levels on the horizontal components in the two PSD figures are similar while the vertical components differ substantially at long-periods. The vertical component noise PSD at the proposed BDSN site is very low primarily because the back of the drift (100m from the entrance), where the temporary instrument was installed, has a very stable temperature. As will be discussed below, thermal stability is necessary in order to obtain the best performance from a broadband seismometer.

Construction of the Seismic Pier

Typically, the broadband seismometer is capable and responsive to nanoradian tilts. As a practical matter, a human hair placed under the corner of a level football field would cause such a tilt. Site selection on low porosity, hard rock is therefor critical. Any unconformity beneath, or within the pier will add to the ambient noise. Clay soils which swell in contact with moisture, or micrometer air pores within sand are capable of causing tilts. While construction or structural piers are often built upon compacted gravel, sand, or dirt, these underlying materials are cable of causing the seismic pier to reactively tilt and thus increase ambient noise.

Traditionally concrete consists of varying amounts of portland cement, rock aggregate, sand, water and reinforcing steel. Normally these materials are combined in proportions to achieve the desired strength, at an optimal cost. Considering that the seismic pier bears less than twenty kilograms seismometer mass, and consists of perhaps a cubic meter of volume; strength and costs are therefore not of concern.

The primary concern is that the pier affect neither the response of the earth or the seismometer. The concrete pier should simply hold, and grossly level the seismometer. In this regard, the concrete mixture should be as homogeneous as possible. Steel reinforcing (re-bar), wire mesh, and rock aggregates all have different coefficients of thermal expansion and should not be used in a seismic pier. A rich mixture of 50 percent portland cement and 50 percent sieved sand will produce a very hard, smooth surfaced pier. This mixture, and absence of reinforcing material is contrary to traditional concrete.

When constructing the form for the pier, be sure that any gaps in the form are relatively small as the concrete mix flows readily and it will tend to leak out of gaps in the form, particularly so when it is vibrated to remove entrained air. Also, be sure that there is a gap, about 4 inches or so in width, around the perimeter of the pier at its base so that no other concrete (either the vault floor or walls) comes into contact with the pier. This gap is needed to minimize any contact with the pier which can potentially induce tilts.

When mixed, the portland cement and sand should have the approximate consistence of toothpaste. After pouring into the form, the mixture should be vibrated to remove entrained air. Without vibration, the entrained air will respond, expanding and contracting with passing regional pressure cells, resulting in high frequency noise spikes. Concrete vibrators are available from tool/equipment rental shops.

Concrete strength is normally specified as 28-day cure. Since we are not really interested in strength, a 28 day cure time is misleading. The rich concrete mixture actually sets up extremely fast and the pier becomes hard enough to hold the seismometer, without indentation due to the pointed feet of the seismometer, in less than 24 hours. As the concrete cures, heat is generated from hydration of the portland cement. Approximately 80 percent of the heat will be expelled within the first 14-28 days. This could affect the settling of the seismometer duing that period. We have not found the moisture from curing concrete to be a problem on the sensors, probably due to the highly reactive mixture of cement and sand that we use.

An example of a newly constructed pier at the BDSN station at Parkfield (PKD) is shown in Figure 5.

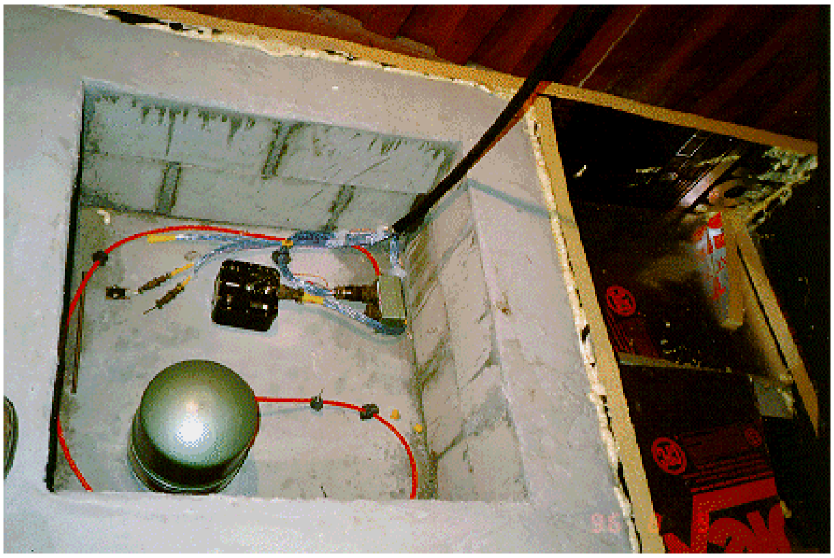

Figure 5. After the pier was poured and had set, a concrete wall was constructed around the pier using hollow concrete construction block filled with the same concrete mix used in the pier construction. This extra concrete wall is basically used to increase the thermal mass which is insulated by the foam box in order to lengthen the thermal time constant of the insulated pier/seismometer system. Installed on the pier are a Streckeisen STS-2 broadband seismometer (and control box) and a Kinemetrics FBA-23 strong motion accelerometer. The strong motion accelerometer is anchored to the pier to enable recording of +/-2g full-scale accelerations. Note that the STS-2 cable is laid out to minimize coupling of noise to the STS-2 when the cable reacts to temperature changes. We have found that cable induced noise can be minimized by suspending the cable from above and draping it onto the pier.

Thermal Insulation of the Broadband Seismometer

Of all the things that can be done when installing a broadband seismometer, thermal insulation has perhaps the biggest impact on the overall performance of the seismometer and it has the added advantage of being both inexpensive and easy to install. The objective is to achieve a thermal time constant of sufficient length to significantly attenuate the diurnal thermal signature.

The insulation of choice is semi-rigid polyisocyanuratic foam board with aluminum foil facers on both sides. This insulation has a nominal R-value of 8.7 per inch, it comes in 4x8 foot sheets and it is widely available in a number of thicknesses up to 4 inches. We usually use 2 inch thick sheets of the insulation because they are readily available at local lumber yards. The 2 inch sheets have an R value of 17.4 and they are easy to cut using hand tools. We use expanding polyurethane resin, which comes in spray cans, to glue the sheets into an insulating box and to glue the box to the pier in order to minimize conductive, radiative, and convective sources of heat transfer. An example of insulating the pier is shown in Figure 6.

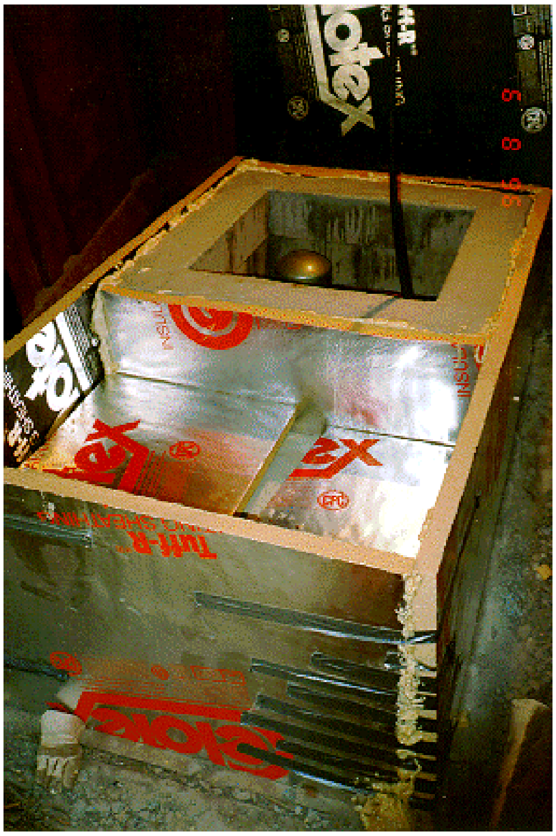

Figure 6. Installing foam insulation at the BDSN station at Parkfield (PKD). The pier was made sufficiently large to house a set of 3 Streckeisen STS-1 seismometers but we currently have installed a Streckeisen STS-2 seismometer on the rear half of the pier. The 2 inch foam insulation is held together by tape temporarily until the liquid foam used at all joints in the foam insulation box solidifies. A second layer of the 2 inch foam and a top (4 inches thick) were added after this photograph was taken. A liquid foam bead is applied along all seams in the foam to glue it together into a rigid box. Note that the top is also glued on and when a seismometer needs to be serviced, the top of the foam box is cut on a bevel so that it can be removed and later glued back in place. This is done because the goal is to minimize all forms of heat transfer including convection of air through the foam insulating box and it is practical because the instruments are very reliable and rarely need servicing.

Insulating just the seismometer with a 4 inch thick foam box will result in a thermal time constant of order 1000 seconds, limited ultimately by heat conduction through the pier. To achieve a longer time constant, we increase the thermal inertia by insulating the entire exposed portion of the pier with a 4 inch foam box. The effectiveness of insulating the pier as well as the seismometer is demonstrated in Figure 7.

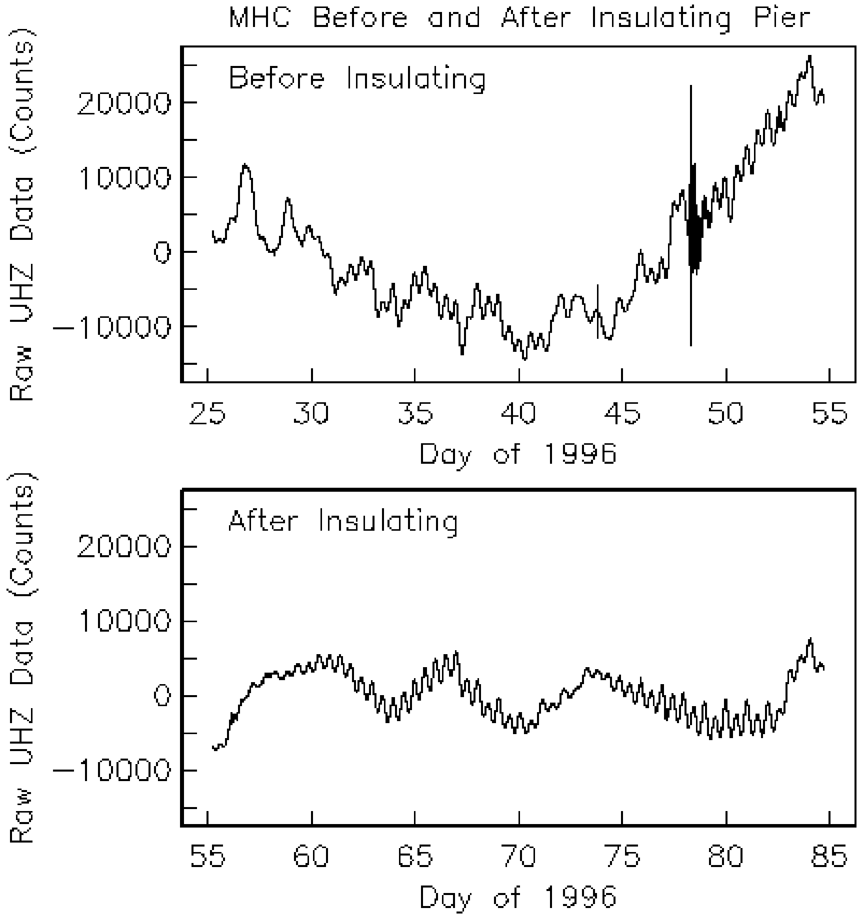

Figure 7. The vertical Streckeisen STS-1 seismometer signal recorded at BDSN station Mt. Hamilton (MHC) where the upper trace is before insulating the pier and the lower trace is after insulating the pier. The records are each one month long and the vertical scales are the same. The thermal time constant for the MHC insulated seismometer/pier is 2 days. Note that the dominantly diurnal thermal signal, present in the upper trace, is highly attenuated in the lower trace. The relatively high-frequency signal present on both traces is the semi-diurnal gravitational tides. The upper trace also shows the 96.048 06:00 UT Mw 8.2 Irian Jaya earthquake. For reference, 1 digital count is equivalent to, at periods shorter than 360 seconds (the natural period of a STS-1 seismometer), a ground velocity of 0.259 nanometers/second.

Typical broadband seismometers dissipate 1-2 watts of heat and typical accelerometers dissipate a few milliwatts of heat. Owing to their low power dissipation, they can be heavily insulated, without an excessive rise in the operating temperature. Be aware that if you contemplate insulating to high R values (greater than 80, say) you should either monitor the temperature rise of the seismometer or calculate the theoretical temperature rise for the pier and insulation geometry to insure that the seismometer will not be subjected to temperatures which exceed its normal operating range.

The temperature sensitivity of a 24-bit resolution data logger is typically about 2 percent as large as the temperature sensitivity of a broadband seismometer. Thus, the data logger does not need nearly as stable of a temperature environment as does the broadband seismometer. The more stable the temperature of the data logger, however, the better its resolution (a Quanterra data logger in a very stable temperature environment can actually achieve 25+ bits of resolution). A data logger typically dissipates 10-20 times as much heat as the broadband seismometers. Because of its high heat dissipation, we do not consider it a good idea to apply significant insulation around a data logger located in a nominally room temperature environment because its internal heat dissipation will rapidly raise the temperature beyond the data loggers operating range.

Installation of a BDSN Broadband Station on the Farallon Islands

In January 1997, we installed Guralp CMG-40T and a Quanterra Q4120 data logger equipped BDSN station on the Farallon Islands. The installation proved to be quite a logistical challenge owing to its remote location (with access via helicopter and boat) and to the restrictions imposed by its status as the Farallon National Wildlife Refuge (with limited site visitations and construction). We were interested in the site because its unique geographical location, on the Pacific plate west of the major fault systems in the San Francisco Bay Area, enhances the network geometry of the BDSN stations in the Bay Area. Normally, multiple trips are definitely the way to go, although there is a cost in added travel time. Since our permit only allowed one visitation to the island, we spent considerable time in preparation, and installed the FARB station in a single 4 day trip (2 men working 12-14 hour days):

Day 1. Travel and select location of seismometer, establish telemetry configuration.

Day 2. Prepare local outcrop for pier by removing weathered layer and grossly leveling, pour 2 inch thick leveling pier, install recorder and power cables.

Day 3. Install and orient seismometers (Guralp and FBA) install conduits for signal cables and power, begin covering seismometers, wire and fuse battery bank.

Day 4. Continue covering seismometers, adding thermal mass, and return travel.

A block diagram of the equipment installed at the Farallon Islands is shown in Figure 8. Owing to the remote and relatively inaccessible location of FARB, we purposely designed and built some redundancy into power supply and communication circuits.

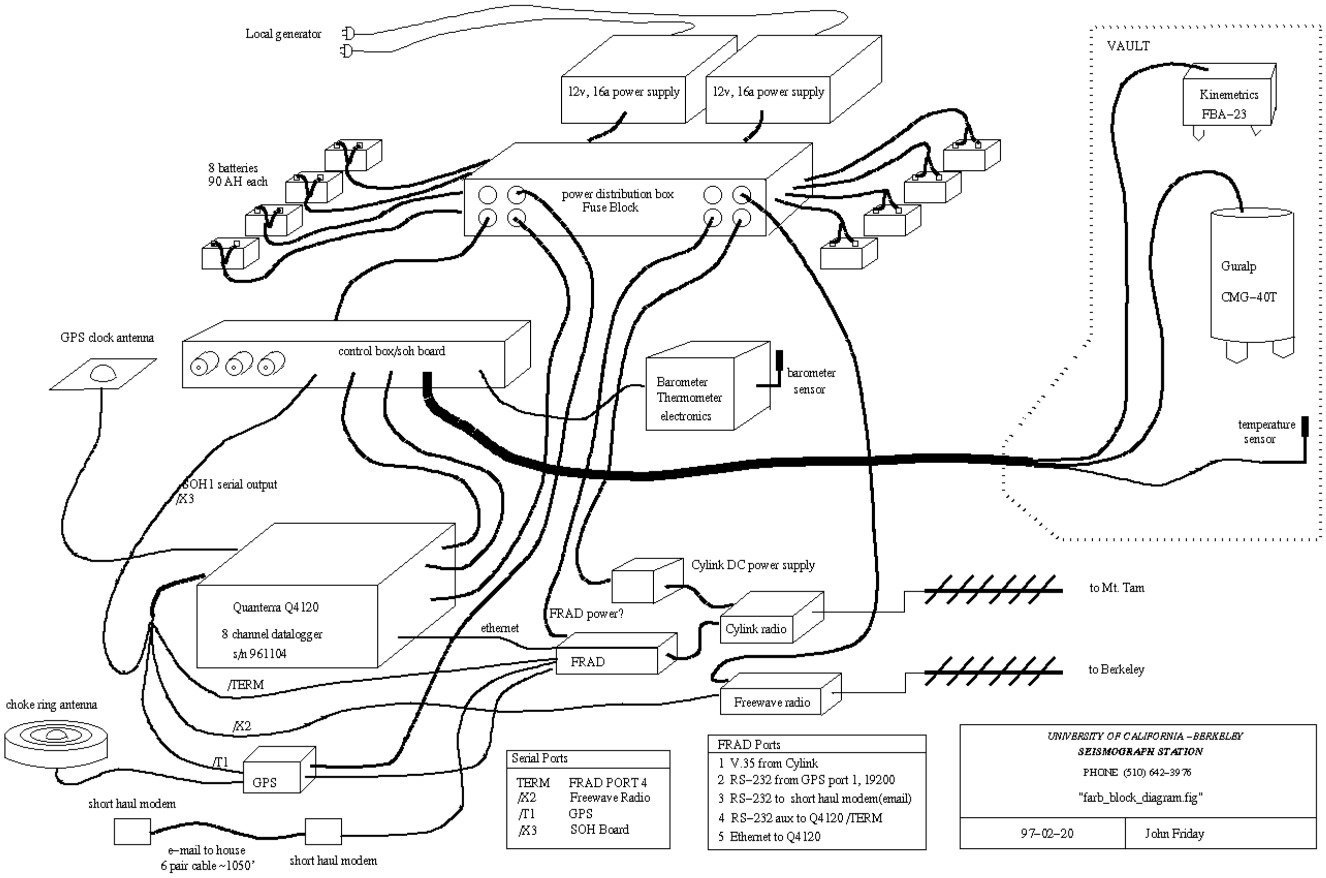

Figure 8. A block diagram of the hardware installed at the Farallon Islands BDSN station (FARB). Note the redundancy build into the power supply and communications components. The communications circuitry has five communications channels, an ethernet connection and 4 serial port connections, over the frame relay telemetry. The ethernet connection to the Quanterra Q4120 data logger enables full access to the capabilities of the data logger. The serial ports are used: for V.35 from the Cylink spread spectrum radio, for console port access to the Q4120, for a data and command link to the Ashtech GPS receiver (part of the Bay Area Regional Deformation (BARD)) network, and to provide email connectivity for the personnel stationed on the island.

Supplies to construct the station were ferried by helicopter and by boat. Two people spent 4 days on the island constructing the station. Once the equipment and supplies were unpacked, the installation proceeded in an orderly manner with the data logger and all associated hardware (except the seismic sensors and antennas) being assembled in a rack enclosure and placed inside an existing building. Power is supplied by an existing 13 kw diesel generator, and since there is no phone service to the island, a spread spectrum radio communication link to Berkeley was installed to support frame relay communications that is used for two-way communications with the station. We wanted an overall installation that was as reliable and as redundant as we could make it and towards this goal, we duplicated the power supply (with a large bank of batteries) and communications systems (there was an existing spread spectrum communications link set up for the DGPS station that we had installed previously on the island). Figure 9 shows the equipment rack which we located in an existing building on the island. Note that the rack and its components are securely anchored to prevent overturning in the event of strong ground motions. In makes no sense to install a broadband station which includes a strong motion accelerometer and then not securely anchor the equipment.

Figure 9. The completed BDSN Farallon Islands (FARB) equipment rack and battery installation. The Quanterra Q4120 data logger is strapped to the top of the rack and the batteries are to the left of the rack in a restraining enclusure on the floor. The equipment in the rack, from top to bottom, is: the Cylink spread spectrum radio; the seismometer control pannel, the Freewave spread spectrum radio and the frame relay access device (FRAD), the Ashtech GPS receiver, the power supply distribution equipment, and finally the duplicate power supplies.

The seismic pier was constructed on a rock hillside among foundation blocks that once supported several water tanks. The weathered part of the rock was chipped away until an approximately 1 meter square roughly level area was obtained for siting the pier. The form for the pier was a ring cut from one of the plastic barrels used to transport the equipment to the island. The ring was cut from the central part of the barrel such that the closed end of the barrel can slip over it to form an enclosure once the concrete pier was constructed. After the concrete set, the Guralp CMG-40T was installed, and a 4 inch thick insulation box was constructed to fit over the barrel. After testing the telemetered data at Berkeley to verify that the CMG-40T was operational, the barrel enclosure and insulation were installed. The enclosure was then covered with an estimated 1000 kilograms of rock, glued together with the expanding polyurethane foam, to form a massive thermal shield around the seismometer. A picture of the completed seismometer installation is shown in Figure 10.

Figure 10. The completed BDSN Farallon Islands (FARB) seismometer installation. The sensor was nestled in among foundation blocks which once held several water tanks. The rock covering the seismometer enclosure, the pile of smaller rocks in the center of the figure, acts both as thermal insulation and as camouflage for the installation.

Along with the seismic signals, we also record the temperature of the seismometer and the relative barometric pressure at a 1 Hz rate with 24-bit resolution. We have started installing thermistors and barometers at all new BDSN stations and the existing BDSN stations in order to allow reduction of the ambient noise levels in the seismic band via cross-correlation with the seismometer temperature and differential pressure. The temperature data is also a good indication of the effectiveness the thermal insulation around the seismometer. For example, Figure 11 compares the Z-component seismic, the pressure, and the temperature. Note that the seismometer temperature varies by only a few tenths of a degree Celsius (C) per day. This is sufficiently stable for a broadband 30 second period seismometer. The effectiveness of the insulation and rock mass around the seismometer is measured by how much the peak-to-peak (P-P) temperature fluctuates. The seismometer temperature varied 0.325 degrees C P-P when the air temperature variation was 7.0 degrees C P-P (measured at the San Francisco Buoy, 16 km ENE of FARB). Thus the insulation and rock around the seismometer attenuated the diurnal temperature fluctuations by 13.3 dB. For comparison, the seismometer temperature at the most stable BDSN station (Yreka, YBH), housing a set of Streckeisen STS-1 seismometers (360 second period) in an abandoned hard rock mining drift, varies by less than 30 millidegrees C P-P in two months.

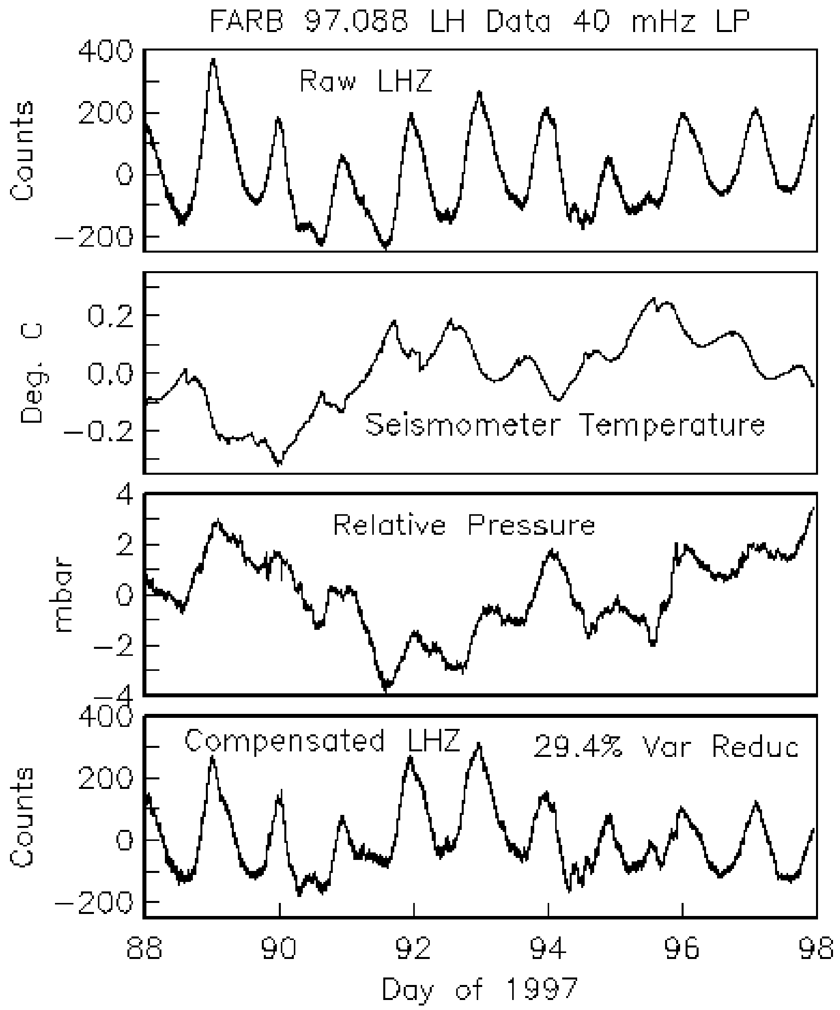

Figure 11. Compares the raw LHZ (1 Hz) FARB Z-component Guralp CMG-40T signal with the relative seismometer temperature, the relative pressure, and the LHZ data compensated for the linearly correlatable effects of temperature and pressure for a 10 day interval starting 97.088. The variance reduction is 29.4 percent for the LHZ compensated data when it is low-pass filtered at 25 seconds to remove the majority of the microseismic background noise. For reference, 1 digital count is equivalent to, at periods shorter than 30 seconds (the natural period of a CMG-40T seismometer), a ground velocity of 2.82 nanometers/second.

There is some interest in the performance of a CMG-40T with a 60 second corner, i.e. twice as long as the 30 second corner on the CMG-40T installed at FARB. The temperature drift of the FARB LHZ signal is ~110 counts/degree and the expected temperature sensitivity of a 60 second CMG-40T is ~440 counts/degree (doubling the period quarters the effective spring constant) and the 60 second CMG-40T will also be 4 times as tilt sensitive as the 30 second version.

Other Installation Considerations

How much effort and how many man-hours are involved in the installation of a broadband seismographic station? That's a simple question that requires a complex answer. Systematically, we evaluate and select sites as a separate process. Knowing where the site will be and the instrument configuration, we are able to plan the construction, pre-fabricate cables to the proper length, and generally bring all the parts with us. (Trips to find the local hardware store are really a big time sink)! We prefabricate all signal cables (two ends, up to 40 conductors each) in the lab, so that we can test the "system" from end-to-end prior to deployment. This almost completely eliminates troubleshooting during the installation. The biggest benefit however is that detailed planning also enables us to do a more hardened installation, which will better withstand long periods of unmanned operation, without hands-on maintenance. We typically go a year or longer without doing maintenance on our sites. Having planned and prefabricated necessary components, it takes 3 or 4 days on site to do the physical installation. At minimum, it takes 500 man-hours to search, plan, travel, prefabricate, and install a site. If the distances are great, or construction is complex, the time requirement can easily go to 2000 man-hours. For example, we spent approximately 1500 man-hours on KCC (sited in an existing tunnel), 2000 man-hours on HOPS (because of vault construction), and we spent 1300 man-hours on FARB (our most inaccessible station).

Is an elaborate installation for a broadband seismometer with a 60 second corner, such as a Guralp CMG-40T, required? The basic answer is YES. Because of the broadband sensor's large dynamic range and wide frequency bandwidth, it is prone to contamination from noise sources that short period stations can not sense. Care taken in the installation process will yield much higher quality broadband data, especially in the long-period band between the microseismic peak at ~7 seconds and the seismometer's corner period. Since it really takes weeks or months for the seismometer to fully settle down, we can only grossly assess how well the station is performing at the time we are doing the installation. Considering that the downstream processing manipulation and interpretion of the data is dependent upon the acquisition, the installation is never "good enough". There are obvious limiting factors, however. Based upon the high background noise levels seen on data acquired by a portable broadband station, set up during a preliminary on-site investigation, we decided that a GURALP CMG-40T with a 30 second corner was an appropriate choice for installation at BDSN station FARB on the Farallon Islands.

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Note that this "installation guidelines" document is still under construction and feedback will be appreciated. Send comments and/or suggestions via email to bob@seismo.berkeley.edu

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