Guidelines for Civil Engineering Works at Remote Seismic Stations

Application Note #42

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Table of Contents

Introduction

Civil engineering work at seismic observatory stations should insure that modern seismic instruments can be used to their fullest potential by sheltering them in an optimal working environment.

Today’s high dynamic range, high linearity seismic equipment is of such quality and sensitivity that seismic noise conditions at the site and the environment of the sensors have become much more important than in the past. Apart from site selection itself, the design of seismic shelters is the determining factor in the quality of seismic data acquisition and transmission.

While required conditions are generally well known, a variety of factors must be considered before the optimal technical solution can be reached:

- Type of equipment installed
- Climate
- Geological conditions
- Variety of available construction materials
- Accessibility of the remote stations

Various solutions can be employed with equal success. Much depends on planned future upgrades of the instrumentation and site, how comfortable the working conditions will be for maintenance and service personnel and on the funds available. Because of these diverse considerations, no firm design and civil engineering drawings are provided in this document.

Instead, the general requirements that must be satisfied are described in detail so that any qualified civil engineer can design the shelter for optimal performance, taking into consideration local conditions in a given country at a specific site. A design example of a seismic vault for a three-component short period (SP) is also shown.

Shelter for seismic data acquisition and transmission equipment should satisfy the following general requirements:

- Provide adequate environmental conditions for the equipment
- Assure the proper mechanical contact of seismic sensors with bedrock
- Prevent seismic interaction between the seismic shelter and the surrounding ground
- Mitigate seismic noise generated by wind, people, animals, and by potential noise sources within the vault

- Assure a suitable electric ground for sensitive equipment
- Provide sufficient space for easy access and maintenance of the instruments

These requirements will be discussed in detail in the following chapters. Some technical hints are given at the end of this document. Drawings and photos of a seismic vault with some technical details are also included.

Controlling Environmental Conditions

Adequate shelter for seismic equipment should:

- Prevent large temperature fluctuations in the equipment due to day/night temperature differences or because of weather changes
- Prevent large temperature fluctuations in the construction elements of the vault, resulting in seismometer tilts
- Assuring adequate lightning protection
- Mitigate electromagnetic interference (EMI)
- Prevent water, dust and dirt from entering the shelter
- Preventing small animals from entering the shelter

At very low seismic frequencies and in VBB seismometers, air pressure changes also influence seismometer output. Special installation measures and processing methods can be used to minimize the effect of air pressure. However this issue will not be treated in this document. See Beauduin, R. et all, 1996 for more information.

Mitigating Temperature Changes

In general, seismic equipment can operate in quite a broad temperature range. Data sheets guarantee that most of the equipment on the market today functions properly between -20^0 to $+50^0$ C. However, this range is merely operational – that is, guaranteeing only that the equipment functions at a given constant temperature within these limits.

Temperature changes in time, particularly diurnal, are far more important than the high or low average temperature itself. Many broadband seismometers even require mass centering if the temperature "slips" more than a few degrees C, although their operating range is much wider. Frequently even small temperature changes cause problems with mechanical and electronic drifts, which may seriously deteriorate the quality of seismic data at very low frequencies. Unfortunately, the practical sensitivity of the equipment to temperature gradients is rarely provided in data sheets. Very broadband (VBB) and some broadband (BB) seismometers require very stable temperature conditions, which are sometime impossible to assure in a vault-type seismic shelter. Short period (SS) seismometers, particularly passive ones, and accelerometers are less sensitive to temperature changes.

Certain elements, for example, some computer disk drives, diskette drives, and certain time-keeping equipment may also require narrower temperature tolerances.

In general, thermal drifts should be kept acceptably small. However, the requirements differ significantly. Maximum +/- 5^0 C short-term temperature changes can be considered a target for passive SP seismometers and accelerometers. To fully exploit the low frequency characteristics of a typical BB seismometer with a 30-sec period, the temperature must be kept constant within less than one degree C. To fully exploit VBB sensors with several-hundred-second period, only a few tens of milidegrees C per month are recommended (Urhammer and Kavas, 1997).

Digitizers can tolerate less stable temperatures – on average, ten times greater changes than BB seismometers for the same output voltage drift. The best of them, for example, change their output voltage less than +/-3 counts in room temperature conditions. If daily temperature changes are less than 1^0 C, their output voltage changes less than +/-1 count (Quanterra, Inc. FAQ letters, June 1994).

The most effective way to assure stable temperature conditions is an underground vault that is very well insulated (Fig. 1 and Fig. 2). Underground installations are also best for a number of other reasons.

Thermal insulation of active seismic sensors is usually made in two places. First, the interior of the vault is insulated from external temperatures, and second, the sensors themselves are insulated from residual temperature changes in the vault. In the most critical installations, the seismic pier itself is also insulated along with the sensors.

Underground vaults are usually insulated with a tight thermal cover made of styrofoam, foam rubber, polyisocyanuratic foam, or other similar, non-hygroscopic insulation material (Fig. 1, 3, and 4). Such materials are usually used in civil engineering for thermal insulation of buildings. They come in various thicknesses, often with aluminum foil on one or both sides. This aluminum layer also prevents heat exchange by blocking heat transfer through radiation. Thinner sheets can be glued together to make thicker ones. Casein-based glues are appropriate for styrofoam and expanding polyurethane resin is used to glue polyisocyanuratic foam sheets.

In continental climates, a 20 cm (8") layer is considered adequate but in extreme desert climates, up to 30 cm (12") of styrofoam is recommended. In equatorial climates a 10 cm (4") layer is considered sufficient.

There are two thermal cover design issues that are particularly important.

Special care must be taken to assure a tight contact between the vault's walls and the thermal cover. If it is not tight, then heat transfer due to convection through the gaps can be easily larger than heat transfer through the thermal cover by conduction. In such cases, the thermal cover becomes inefficient.

One way to achieve a tight thermal cover is shown in Fig 5. A “rope” is pressed into the gap between the vault's walls and the thermal cover. This “rope” is made of insulating fibers and is usually used for industrial hot water pipe insulation. It is available in different sizes and is inexpensive. The rope insulation must be tightly packed into all the gaps between the cover and the walls, otherwise heat convection will undo the insulating effects of the cover itself.

The cover should be placed at or below the level at which the ground heats up during the day – not on the top of the vault. In desert areas, surface ground temperatures can exceed 80^0 C. At 30 cm (12") depth, temperatures of 50^0 C is not unusual. In such conditions the thermal cover must be placed 40 - 50 cm (16" - 20") below ground level. A thermal cover of any thickness at the top of the vault, particularly if the vault's rim stands significantly above the surface, has almost no effect.

If VBB sensor stations are vault types, it is advisable to make a second thermal cover just above the sensors but below the floor where all other equipment is installed (Fig.6). Since the most of maintenance work relates to batteries, data recording and transmitting equipment, the thermal- and mechanical-sensitive VBB sensors are not disturbed at all during service and maintenance and additionally isolated.

A thermal isolation box is usually put around the sensors to additionally insulate them.

Thermal insulation of the seismic pier itself, together with the seismometer, is the best method of insulation (Fig. 7). This method keeps the heat transfer between seismometer and vault interior as low as possible, while at the same time assuring good thermal contact with the thermally stable ground. Thus, the thermal inertia of the system is very large, making seismometers less sensitive to temperature changes.

The seismometer box and the entire exposed seismic pier are typically covered by a 10 - 20 cm (4" - 8") thick piece of insulating material. The seams between the insulation sheets should be well filled with liquid foam. For details see Uhrhammer and Karavas, 1997.

Thermal Tilt Protection

To study extremely low frequency ranges with VBB seismometers, special measures are required to prevent thermal deformations and tilts of the seismic pier. Modern VBB sensors can detect tilts of a few nanoradians. A human hair placed under the corner of a level football field would cause such a tilt (Uhrhammer and Karavas, 1997).

Homogeneity of the seismic pier and surrounding soil, and civil engineering details of vault design become *very* important. Uhrhammer and Karavas (1997) recommend the physical separation of the seismometer pier and the vault walls (Figs. 6 and 7). This separation assures that minute fluctuations in the dimensions of the vault walls due to temperature change do not tilt the seismic pier. However, since these seismic vaults are not constructed as one unit (in one piece), be particularly careful that the contact between the pier and vault walls is watertight.

The seismic pier should be made of homogenous material and neither it nor the walls of the vault should use any steel reinforcement. Steel is unnecessary because structural strength is not an issue, except in the very deepest of vaults. Sand aggregates should be homogenous and of similar sizes rather than different sizes as in the usual concrete mixture. Uhrhammer and Karavas (1997) recommend using well-shifted sand with 50% Portland cement. After the pier is poured, vibrate the concrete to remove any trapped air.

Lightning Protection

Lightning protection is the most important factor in preventing seismic station failures. *Lightning causes most of the damage to seismic equipment around the world*. We have known of several seismic networks that lost half or more of their equipment less than two years after installation because of inadequate lightning protection measures. Of course a direct hit of lightning will cause equipment damage despite the best protection. Fortunately, this rarely happens. However, lightning, even some distance from the station, can cause severe damage. The vast majority of lightning damage is a result of voltage induction surges in cables.

Climactic and topographical conditions at every site vary greatly and determine the degree to which you should protect your system from lightning. Tropical countries and stations on top of mountains are the most vulnerable and therefore require maximum lightning protection measures.

Lightning protection includes the following measures:

- Enclose the equipment in a “Faraday cage,” either by making a metal-shielded seismic vault or a loose mesh of ground metal strips around the vault. This creates as great as possible an equipotential electric field around the equipment, thus decreasing voltage drops on cables during lightning strikes.
- A good grounding system
- Protection of all cables entering the seismic vault from voltage surges
- Proper cabling that minimizes voltage induction during lightning

If any of these measures are not taken, the others become largely ineffective.

The best lightning protection is a metal seismic vault (Fig. 1). The exterior of the vault should not be painted so that good electrical contact can be made with the surrounding soil, thereby lowering impedance. If the main cover or any other part of the vault is metal, it should be connected to the vault's walls by a thick flexible strained wire.

In many cases it is also necessary to protect all cables entering the vault. Many seismic instruments already have internal lightning protection circuitry, however these measures are sometimes not enough for high lightning threat regions. Lightning protection may include gas-discharge elements, transorbs, voltage dependant resistors, and similar protection components.

The lightning protection equipment *must be* installed at the point where the cables enter the vault. It must be grounded *at the same point* with a thick copper wire or strip that is as short as possible. The unprotected part of any cable within the vault *must be kept* to a minimum.

All cables entering the vault must be protected if you wish to protect your equipment from lightning damage. Voltage surges *usually* occur in all cables at a station, *so leaving a single long cable unprotected is virtually the same as leaving all cables unprotected*.

All metal equipment boxes should be grounded with a thick copper grounding wire or strip (> 25 mm^2 cross-section) to the same point where lightning protection equipment is grounded. Follow a tree-shaped scheme of grounding wires. All these wires should be as short as possible and without sharp turns. All cables in a vault should be kept at a minimum length. No superfluous cables or even coiled lengths of excess cables are acceptable. These are true lightning catchers.

Usually telephone line and main power line companies can install lightning protection equipment of their lines. This should be required from them when asking for these utilities. However, Kinemetrics also can provide and install such equipment.

Note that there is no 100% safe lightning protection system. The money invested in it only reduces the probability of damage to an acceptable level. However, for high lightning risk regions and for expensive and delicate seismic equipment, long years of practice show that these investments pay off very well.

Electro-Magnetic Interference (EMI) Protection

The EMI problem is normally not a very important issue because seismic stations are generally situated in very remote locations. However, in such regions the main power lines are frequently of low quality. We recommend using main power voltage stabilizing equipment in these cases. This equipment usually incorporates EMI filters and voltage surge protection, which further protects seismic equipment from failures and EMI-generated noise. In general, metal seismic vaults protect equipment from EMI very effectively.

Passive seismometers with moving magnets radiate EMI during mass motion. Since this may influence surrounding sensors, do not install such seismometers too close to each other. A minimum distance of 0.5 m (1½ feet) between them is recommended. A very simple test can assure you that any cross talk is insignificant. Disconnect and un-damp one component, move the seismometer mass by shaking slightly and measure the output of both other components. The seismometers should not be placed too close to the metal walls of the vault either. A minimum distance of 0.3 m (1 foot) is recommended. This prevents potential changes in the static magnetic field, which may slightly influence the generator constant of some seismometers.

Data recording equipment with main power transformers should not be installed next to sensors on the same pier. The transformer may cause noise in the data either through its magnetic field or due to direct mechanical vibrations at 50/60 Hz. Place such equipment in a metal housing and install it on the wall of the vault.

Water Protection

Water entering seismic vaults is the second most frequent cause of seismic station failures.

The most effective way to prevent water damage is vault drainage (Fig. 8). Use a hard plastic tube of about 4-cm (1½") diameter for water drainage. Such tubes are used for water pipelines. Use 6 AT pressure attested or stronger pipe. The drainage pipe must be continuous and at least a 3% grade, particularly in regions where the ground freezes. In some places drainage is impossible, particularly with deep vaults. In these cases the water tightness of the seismic vault is of the utmost importance.

Water tightness is easy to achieve if the vault's walls are made of metal welded from plain or corrugated iron sheets or from large-diameter metal tubes, providing the welds are good.

If the vault is made of concrete and has no water drainage, the concrete should be of a good, uniform quality. Add water-resistant chemicals to the mix to help keep it watertight. Vibrate the concrete during construction to increase the homogeneity of the walls.

Note that a high ground water level and porous concrete walls more or less guarantee water intrusion.

The bottom of the seismic vault - seismic pier - is always made of concrete. Once again, use good quality, uniform-aggregate concrete with water-resistant additives. The bottom should have a water drainage ditch (Figs. 1 and 8) along the walls and around the flat central pier on which the sensors are installed. For vaults with external water drainage, the ditch should be at least 5 cm (2") deep and 10 cm (4") wide. For the vaults without drainage this ditch should be larger (at least 15-cm by 15-cm or 6”x 6”) so it can collect more water.

Making the vault walls/floor joint watertight requires a special care. Use asphalt to seal any cracks by heating the concrete with a hot-air fan and then pour hot asphalt into them.

The cables entering the vault also require some special care. They are normally installed in a plastic or metal tube that should fit very snugly into the appropriate hole in the vault wall. Use silicon rubber or asphalt to seal any gaps.

In vaults designed for VBB seismometers whose seismic pier is mechanically separated from the walls, water tightness represents a special challenge. Once again use soft asphalt to make the gap between the walls and the pier watertight.

The upper rim of the vault must be at least 30 cm (1 foot) above the ground. At sites where a lot of snow is expected, this dimension should be higher, up to 60 cm (2 feet). Slush is particularly dangerous in regard to keeping vaults watertight. If possible, the surrounding terrain descends radially from the top of the vault.

One good solution is to create a small "overhang" at the top edge of the vault (see Figure 5). Make this ledge about 5 cm (2") out from the vault wall. A thick, watertight fabric cover can be hooked over this metal edging. The cover is pulled tight to the vault by rope and prevents water from entering the vault during windy, rainy periods. It also protects against dust and dirt and provides some additional thermal insulation.

To minimize the danger of flooding, install all equipment except for the sensors on the wall of the vault.

Protection from Small Animals

On first glance this issue may seem amusing. However, animals frequently use seismic vaults as dwellings. We have seen some very strange "seismic" records of ants, grasshoppers, lizards, and mice. Ants, reptiles, mice, rats, etc., can cause not only mysterious seismic records but also severe damage to cables and other plastic parts of the equipment.

Tight metal (particularly effective), fabric or thermal vault covers usually prevent animals from entering the vault from above. Plastic tubes for cables and drainage should be protected by metal mesh. Placing metal, wool or glass shards in the free space in these tubes also helps. Insecticides are used to drive away ants and other insects.

Contact with Bedrock

Good contact between seismic sensors and bedrock is a basic seismological requirement. Surrounding soil and weathered ground layers will modify seismic signals without this vital contact between bedrock and sensor. Today it is well know that the interaction of local soil can significantly modify seismogram waveforms and their spectral properties.

The depth of bedrock (which is effectively equivalent to the depth of the vault) and the degree of weathering of layers beneath the surface can be determined by shallow profiling of the site, drilling, or by actually digging the vault. Except for the sites where the bedrock is evidently outcropped, will a local surface geological survey provide enough information about the required depth of the seismic vault.

If you choose not to do profiles, then expect surprises. It is often a matter of pure chance what you run into. You will need to dig until you reach bedrock and that can sometimes be very deep; vaults have to be repositioned and re-dug if weathered bedrock is extremely deep. These risks make the relatively high cost of profiling a wise investment.

A definition of "good" bedrock is necessary in order to dig vaults without profiles. Unfortunately, the definition is fairly vague, especially because some recent studies show that even an apparently hard rock site may still have significant amplification compared to true bedrock. As a rule of thumb, "good" bedrock is rock hard enough to prevent any manual digging. If profiles are available, P velocities should be better than 2 km/s.

Seismic vaults are on average 2 to 6 m (7 to 20 feet) deep. At sites where the bedrock is outcropped, the required depth is defined solely by the space required for the equipment. One meter (3 feet) or even less may be adequate. On some highly weathered rock sites the required vault depth may exceed 10 m (30 feet). In some places a reasonably deep seismic vault cannot reach bedrock at all.

Sometimes such sites must be used, based on other seismological factors like network geometry, lack of bedrock anywhere in the region, and special interest in certain places. The number of these stations in a network should be kept at a very minimum.

Seismic Soil-Structure Interaction and Wind-Generated Noise

The theories behind design and construction of seismic stations have greatly advanced in the last few decades. The increased sensitivity of seismic stations and the complexity of seismic research, based more and more on waveforms, require very quiet sites and distortion free records. Sixty years ago, seismic stations were usually situated in houses and observatories. Sensors were installed on large, heavy concrete piers, mechanically isolated from structural elements of the buildings, sometimes well above the ground.

Scientists increasingly observed that the interaction between surrounding soil and civil engineering structures in such installations substantially modified seismic signals during seismic events (particularly if the site is on relatively soft ground). Structures swinging in the wind also caused undesired seismic noise.

More and more evidence arose (Bycroft 1978, Luco and al., 1990) proving that every structure at the site modifies seismic waves to some extent. Therefore, today’s seismic stations are mostly ground vaults, using light construction materials and methods, and extending only a few decimeters (about a foot) above ground. All buildings, antenna and other masts are built well away from the vault to minimize interaction.

Ideally, there is no seismic signal modification by the soil-vault structure interaction if vault's average density (taking into account the empty space in the vault as well) equals the density of the surrounding soil. However, in practice, seismic station design is never based on calculated average densities. The most important factors are that:

- The design is not too heavy, particularly if the surrounding soil is soft
- All potential buildings and masts are placed away from the seismic vault
- The vault rises above ground level as little as possible to minimize wind-generated seismic noise

Other Noise Sources

We recommend that seismic stations are fenced, despite the fact that fences usually represent a significant expense. There are a few exceptions, like stations in extremely remote desert or mountain sites. The fence minimizes seismic noise caused by human activities or by animals that graze too close to the vault. It also contributes to the security of the station.

The optimal size of the fence depends on several factors:

- Density of population around the site
- Human activity in close vicinity of the station, particularly agricultural activity
- The probability of animal interference
- Natural and man-made seismic noise amplitudes at the site
- Seismic coupling between ground surface and bedrock. Non-consolidated surface ground and seismometers installed on good bedrock allow a smaller fence. A very deep vault has a similar effect.

The decision about the size is therefore heuristic. The smallest recommended fenced area is 10 x 10 m (30 x 30 feet). In the least favorable case, a fence could be 100 x 100 m (300 x 300 feet). A height of about 2 m (6 - 7 feet) is sufficient. Light construction with little wind resistance is preferable so that wind-generated seismic noise is minimized.

The equipment and the vault itself can also generate seismic noise. Equipment that includes main power transformers or rotating electromechanical elements like disk drives, diskette drives, cooling fans, etc. should be installed on the vault wall rather than on the seismic pier.

If the vault cover is not firmly attached, it can swing and vibrate in strong winds, which can totally ruin seismic records. Be sure that the cover is very firmly fixed to the top of the vault, as its own weight may not be sufficient to prevent vibration in strong wind. When closed and strongly shaken by hand, there should be no play whatsoever between the vault and the cover. If there is, it will cause seismic noise during strong wind conditions.

If a seismic station uses an antenna mast, place it well away from the vault to prevent seismic noise from being generated by the antenna swinging in the wind. The required distance is usually between 5-50 m, depending on a number of factors:

- Maximum expected wind speed and probability of windy weather at the site – the higher the speeds and the more often they appear, the greater the required distance
- The antenna's height – the higher the antenna mast, the greater the required distance
- The vault's depth – the deeper the vault, the smaller the distance
- The type of seismic coupling between sensors and antenna base – strong couplings require larger distances; this is best determined by a seismo-geologist
- Seismic noise at the site – very quiet sites require larger distances

Electrical Grounding

A grounding system is required for the proper functioning of electronic equipment. Grounding keeps the system’s instrument-noise low, allowing proper grounding and shielding of equipment and cables. It is a prerequisite for proper functioning of lightning protection equipment and for interference-free functioning of RF telemetry stations. The grounding system design is usually a part of the RF link design in telemetry seismic systems.

Generally, ground impedance below 1 ohm is desired. The total length of the required grounding metal strips depends a great deal on climate, local soil type, and humidity. Generally, a radial star configured system, of five to six “legs” with 15 to 20 m (45 - 60 feet) length each, is required for a grounding system (Fig. 9). The strips made of zinc plated iron or copper, 3 x 30 mm (1/8" x 1 ¼") in cross-section, should be buried from 25 to 35 cm (~1 foot) deep in the soil. In dry regions they should be deeper. The strips should be laid straight. No sharp turns (around rocks, for example) are allowed, because this decreases lightning protection efficiency as a result of increased inductivity of the grounding system.

In arid regions, high deserts, or completely stony areas, longer and thicker strips are required. In these cases, a different approach to grounding and lightning protection is sometimes taken by trying to obtain an electric equipotential plane all around the station during lightning strikes. Grounding impedance is no longer the most important issue. High lightning threat regions and very dry or rocky ground usually require a specially-designed grounding system.

In seismic vaults without metal walls, bury a loose mesh made of grounding strips around the vault and connect them to the rest of the grounding system. Grid dimension of this mesh should be around 60 to 100 cm square (2 to 3½ feet square).

At seismic stations with RF data transmission and antenna masts, the star-configured grounding system should be centered on the antenna mast, not on seismic vault. The seismic vault is included in one of the legs of the grounding system. One of grounding strips must be laid exactly above the cables connecting the antenna mast and seismic vault (Fig. 9, detail A.). This assures a minimum voltage drop along the cables during lightning strikes and therefore a minimum voltage surge induced in the cables.

The antenna mast itself should be grounded as well and equipped with a lightning protection system. Its highest point should be at least 1 m (3 feet) above the highest antenna or solar panel installed on the mast.

Note that any grounding system requires periodic service checks because contacts between the metal parts may eventually corrode. It is generally recommended that the grounding impedance of the system be checked once every two years. Regular maintenance visits should always include a check of the lightning protection system and equipment and replacement of any burned elements.

Vault Construction

As already mentioned, seismic vault with metal walls can be made of plain iron sheets welded together, of corrugated iron, or of pieces of large-diameter metal pipes. For durability, we recommend zinc-plated metal. It is not necessary to make them very strong and heavy. If made from thinner sheet metal, then pour relatively thin, 15 - 20 cm (6 - 8") concrete walls around the metal to add strength. The quality of this concrete is not necessarily high because water tightness is usually not a problem in this design. Locally available sand aggregates can be used in most cases. If the metal is strong enough, no concrete is necessary.

The walls can also be made of concrete only – in which case it is easiest to make the vault rectangular. Note that the quality of the concrete must be good to make the vault watertight, as explained earlier. Strength is, apart from very deep vaults, not a problem and therefore no steel reinforcement is needed.

At sites where accessibility allows, vaults can be made of the prefabricated concrete pipe sections used in sewerage system construction. They are cheap and can be obtained in different diameters and lengths. In deeper vaults you can simply stack them, as the depth of the vault requires. Care must be taken to make the joints between sections water tight.

The bottom of the seismic vault - seismic pier - is always made of high-quality, watertight concrete. Special requirements must be fulfilled for VBB sensors. More details are given the *Water Protection* section.

The depth of seismic vaults is determined by seismo-geological parameters. But apart from providing adequate space to put all the equipment, the diameter is primarily a matter of the desired ease of installation, maintenance and service.

For three-component stations with single component sensors, from 1 to 1.5 m^2 (10 to 15 square feet) of space on the seismic pier is required. Less space suffices for three-component seismometers, three-component accelerometers, or a single component sensor. If the vault contains (or will contain in future) three-component weak motion and strong motion sensors, about 1.5 - 2 m^2 (15 - 20 square feet) is required.

We have found that a minimum for installation and maintenance is a 1.4 m (4½ feet) diameter vault. If the vault is deeper than 1 m (3 feet), a 1.5 to 1.6 m (5 to 5½ feet) diameter is recommended. Deep vaults (> 4 m (13 feet) require at least a 1.6 to 1.7 m (5½ to 6 feet) diameter. Vaults deeper than 1.2 m (4 feet) require a ladder.

Miscellaneous Hints

Vault Cover Design

A seismic vault cover should:

- Have a minimum of 5% slope so water drains quickly
- Have vertical siding all around that extends at least 15 cm (6”) below the upper rim of the vault to prevent rain from entering in windy conditions
- Have a lock to mitigate vandalism

- Have handles for easy opening and closing
- Be painted a light color, preferably white, that will reflect as much sun as possible, particularly in hot and dry desert regions.

The metal cover and thermal insulation cover of the vault should not be too heavy. They should be designed in such a way that a single person can open and close the vault smoothly. Otherwise, maintenance visits will require two people in the field. For large vaults, the cover can be designed in two parts or a simple pulley system may help.

Alternative Materials

Metal, as material for a vault cover, is less appropriate in very hot and very cold climes as it becomes difficult to handle and work with under extreme conditions. In dry regions, UV light-resistant plastic or water-resistant plywood is a better alternative. Plywood also has less thermal conductivity, which improves thermal insulation, and less weight, making handling the cover easier.

Mitigating Vandalism

Experience shows that, apart from political instability, most vandalism on seismic stations is driven by people's curiosity. Therefore, we believe that a large sign with a short and easy to understand explanation of the purpose of the station posted at the entrance to the fenced area may significantly mitigate vandalism.

Securing Seismometers to the Ground

In regions where earthquakes with more than 1 g peak acceleration can occur, seismometers must be firmly fixed to the seismic pier, exactly as is a common practice with strong motion sensors. Obviously, sensitive seismometer records are clipped during very strong earthquakes. However, they should not shift or move during such events. Numerous aftershocks must still be recorded with the sensors properly oriented.

Literature

Beauduin, R. (1996) et al. The Effect of the Atmospheric Pressure Changes on Seismic Signals or How to Improve the Quality of a Station, BSSA, 86, p 1760.

Bycroft, G.N. (1978) The Effect of Soil-Structure Interaction on Seismometer Reading, BSSA, 68, p 823.

Luco, J.E., Anderson, J.G., and Georgevich, M. (1990) Soil-Structure Interaction Effects on Strong Motion Accelerograms Recorded on Instrument shelters, Earthquake Engineering & Structural Dynamics, 19, p 119.

Uhrhammer, B. and Karavas, B. (1997), Guidelines for Installing Broadband Seismic Instrumentation, The Regents of the University of California, (in preparation), available at bob@seismo.berkely.edu.

Quanterra, INC. FAQ letters, June 1994.

Willmore, P.L. (ed), (1979, reprinted 1982) Manual of Seismological Observatory Practice, World Data Center A for Solid Earth Geophysics, Report SE-20.

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Figure 1. An example of a short-period three-component seismic vault made of a large-diameter metal pipe with thin concrete walls.

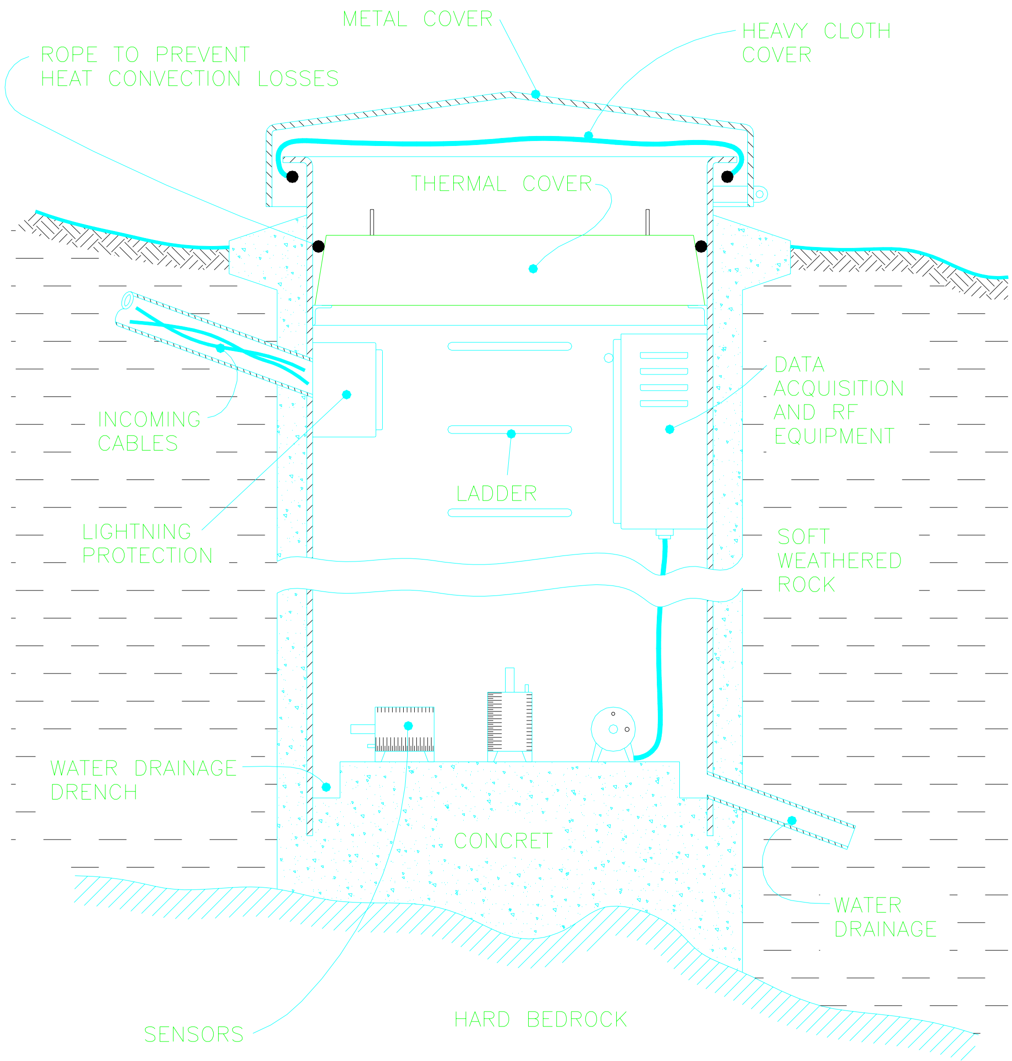

Figure 2. Interior of a seismic vault made of welded metal sheets. The vault is big enough to accept weak and strong motion instrumentation as well as data acquisition and transmission equipment.

Figure 3. The thermal cover of a seismic vault in two pieces made of thick styrofoam. The gaps between the cover and the vault walls and between both pieces must be made tightly sealed.

Figure 4. Installing thermal cover in a seismic vault. In climates with big diurnal temperature changes the cover should be positioned lower in the vault where external ground temperature doesn't change significantly**.**

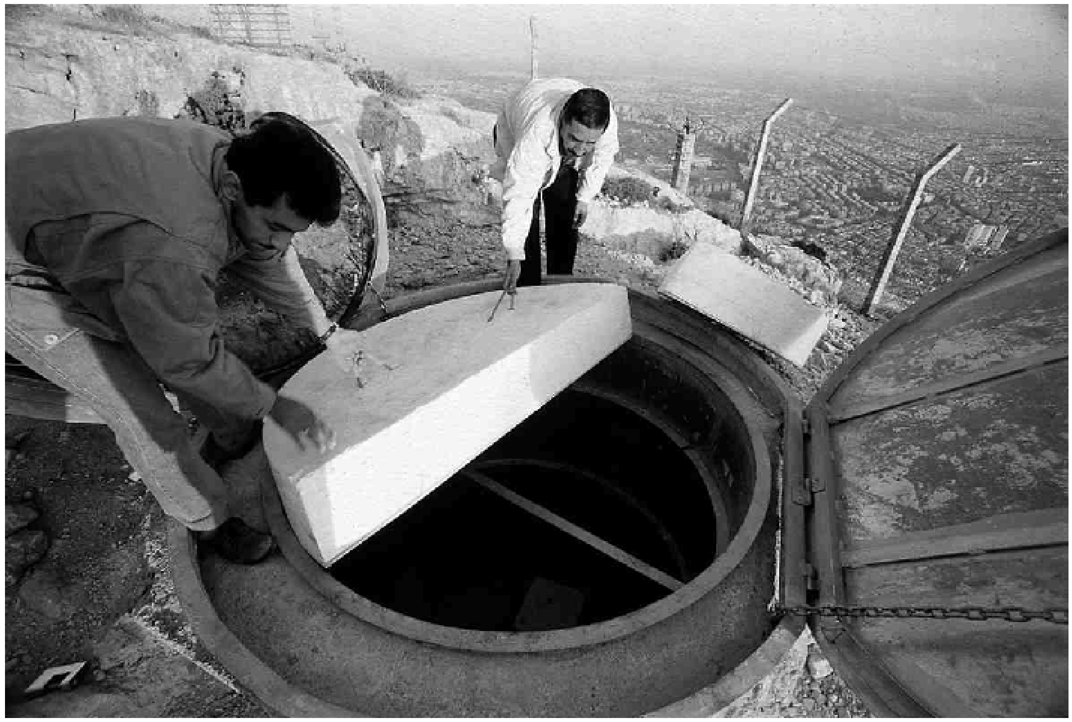

Figure 5. Detail of making thermal cover effective by filling up the gaps between the cover and vault walls with insulation material and making the vault tight against dust, dirt, and rain during windy periods with a fabric cover.

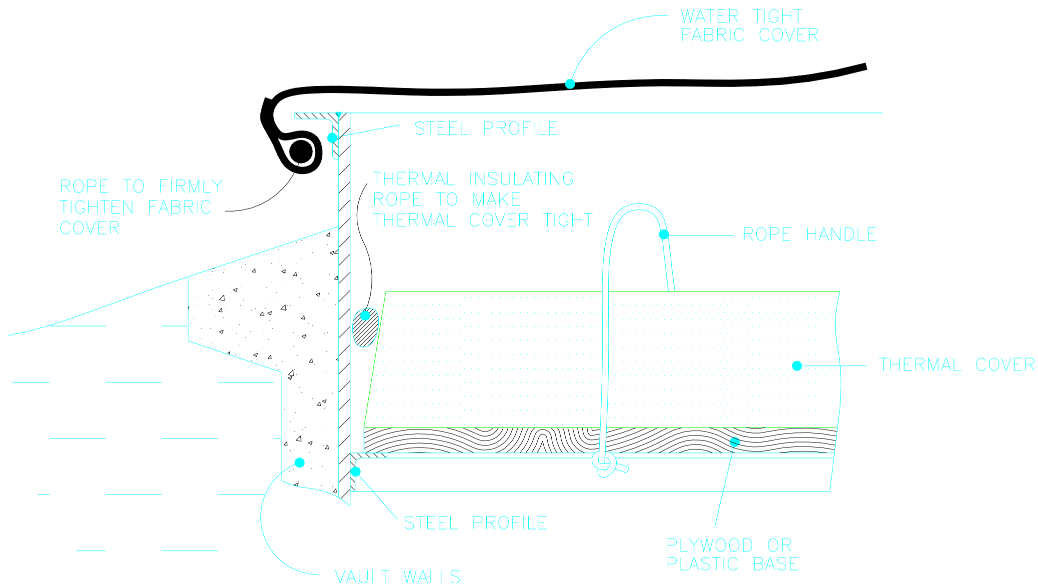

Figure 6. An example of a BB or VBB seismic vault with a separate compartment for sensors and double thermal cover. Usually the sensor itself is additionally isolated.

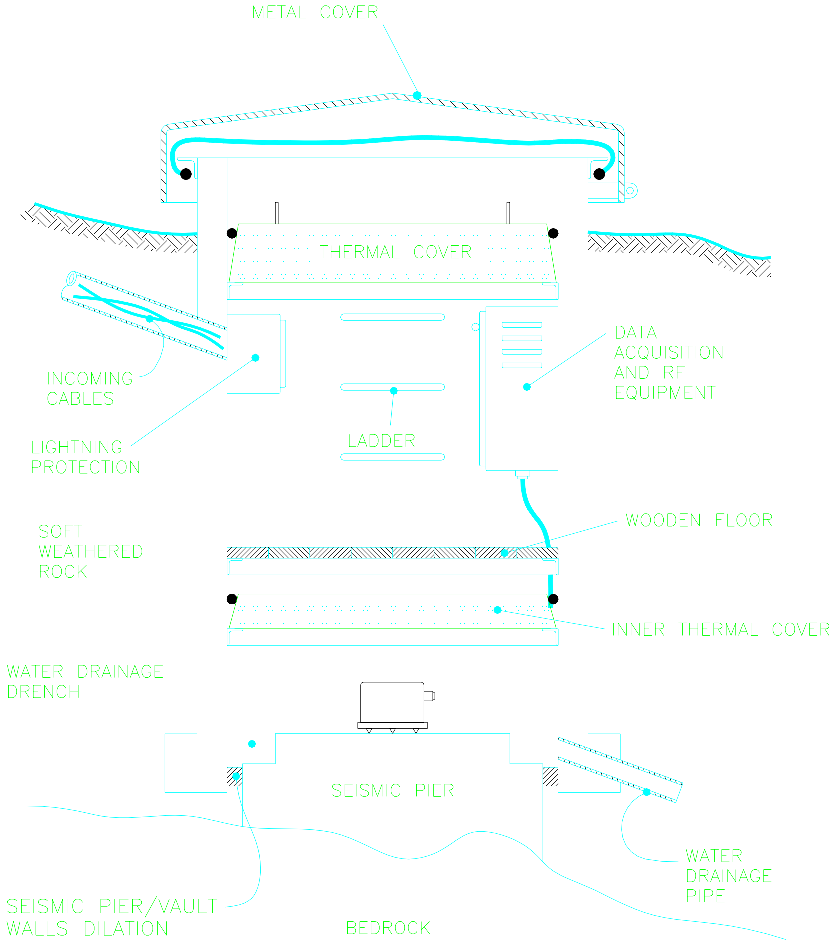

Figure 7. Thermal isolation of a VBB sensor and surrounding seismic pier with mechanical separation of the pier from the vault walls for the most demanding applications.

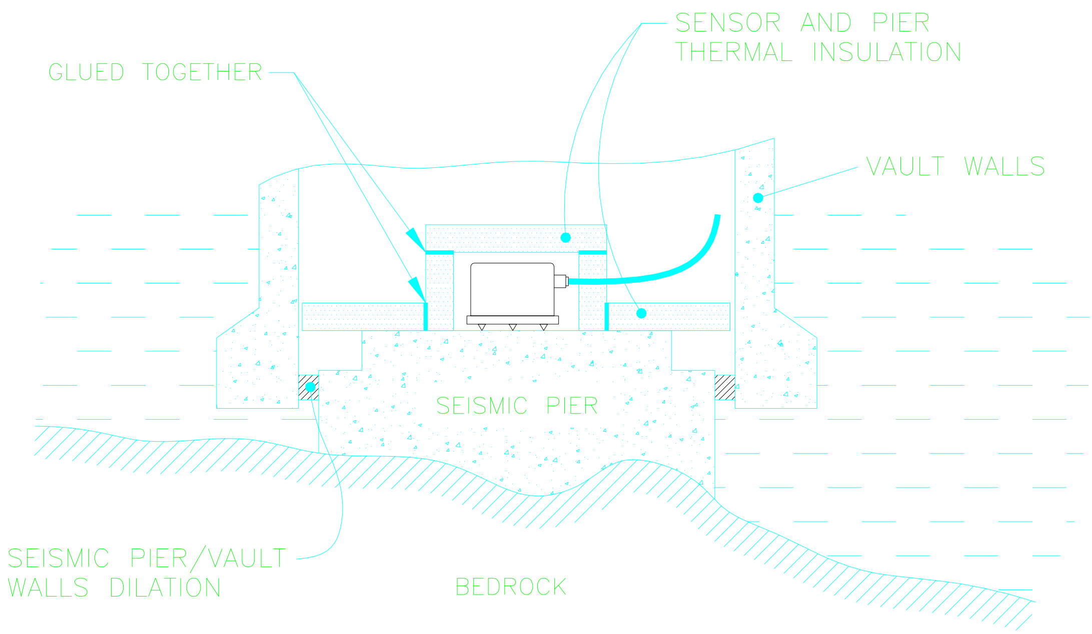

Figure 8. Water drainage pipe and vault trench around the seismic pier.

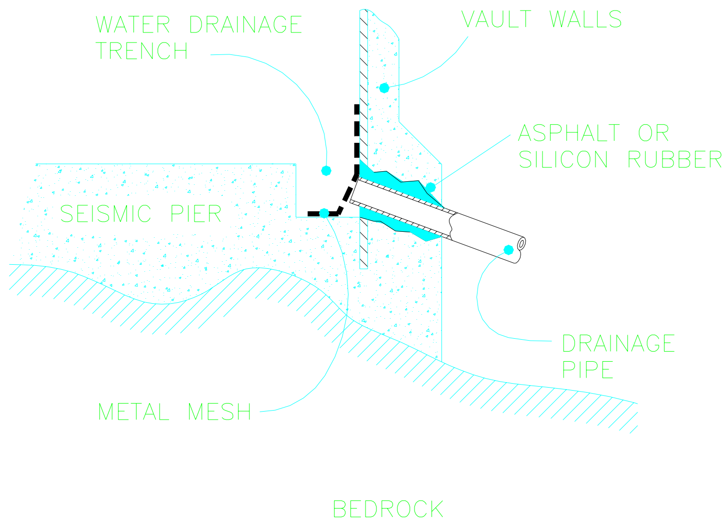

Figure 9. Typical grounding system of a seismic vault. Its dimension depends on local soil humidity conditions.