An Innovation Upon Earth Movement Monitoring Systems:

A Vulcano Funded Project

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Vulcano

1 Introduction

Seismic activities related to plate tectonic activity around the world are monitored by many seismic observer stations. The seismometers in these stations vary from the simplest demonstration unit to complex and expensive professional instruments used for groundbreaking research. Most commercial seismometers cost more than $50,000 per station to purchase, with annual operational costs that can easily exceed the purchase price. For amateur seismologists, teachers, and school systems, this cost can be prohibitively high. With today's technology, we can now make less expensive instruments, if we are able to establish plans that a researcher can use as a basis for construction and maintenance. In general, the necessary instruments require some specific engineering skills and considerable time to maintain and support.

Objectives

1) To develop a seismic monitoring system that will facilitate the monitoring of volcanic activity
2) To implement and test that system
3) To verify and calibrate the system

2 Literature Review

2.1 Introduction to Seismology

Seismology is the scientific study of earthquakes and the propagation of elastic waves through the Earth or through other planet-like bodies. The field also includes studies of earthquake environmental effects, such as tsunamis, as well as diverse seismic sources such as volcanic, tectonic, oceanic, atmospheric, and artificial processes (such as nuclear explosions). A related field, which uses geology to infer information regarding past earthquakes, is paleoseismology. A recording of the Earth's motion as a function of time is called a seismogram.

Seismology involves the study of seismic waves, their propagation through the Earth, their sources, and their effects. Seismic waves result not only from earthquakes but also from other natural and man-made events. Even a person stomping on the ground can generate a seismic wave that can be picked up by a sensitive seismometer.

The size, or magnitude, of earthquakes and other seismic events is measured using the Richter scale. Several thousand earthquakes larger than magnitude 4 on the Richter scale occur each year around the globe. A magnitude 4 earthquake is a fairly light one, which can cause windows and doors to rattle, but does not result in significant damage.

A seismic event generates two types of seismic waves: body waves and surface waves. The faster body waves travel through the interior of the Earth while the slower surface waves – as the name suggests – travel along its surface. Both types of wave are examined during analysis to collect specific information on a particular seismic event.

The instruments employed to measure seismic waves are called seismometers, sensors that convert ground motion into electrical voltages.

2.2 Plate Tectonic Activities

Plate tectonics is a scientific theory describing the large-scale motion of seven large plates and the movements of a larger number of smaller plates that make up the Earth's lithosphere. This model builds on the concept of continental drift, an idea developed during the first decades of the 20th century and accepted as plate-tectonic theory after seafloor spreading was validated. The location where two plates meet is called a plate boundary. Plate boundaries are commonly associated with geological events such as earthquakes and the creation of topographic features such as mountains, volcanoes, mid-ocean ridges, and oceanic trenches.

2.3 Types of Seismic Wave

Seismic waves are elastic waves that propagate in solid or fluid materials. They can be divided into body waves that travel through the interior of the materials, surface waves that travel along surfaces or interfaces between materials, and normal modes, a form of standing wave.

2.3.1 Types of Seismic Waves

There are two types of body waves, Pressure waves or Primary waves (P-waves) and Shear or Secondary waves (S-waves).

P-waves are longitudinal waves that involve compression and expansion in the direction that the wave is moving and are always the first waves to appear on a seismogram, as they are the fastest moving waves through solids.

S-waves are transverse waves that move perpendicular to the direction of propagation. S-waves are slower than P-waves. Therefore, they appear later than P-waves on a seismogram.
Fluids cannot support perpendicular motion, so S-waves only travel through solids.

2.3.2 Surface Waves

The two main surface wave types are Rayleigh waves, which have some compressional motion, and Love waves, which do not.

Rayleigh waves result from the interaction of vertically polarized P- and S-waves that satisfy the boundary conditions on the surface.

Love waves can exist in the presence of a subsurface layer, and are only formed by horizontally polarized S-waves.

Surface waves travel more slowly than P-waves and S-waves; however, because they are guided by the Earth's surface and their energy is thus trapped near the surface, they can be much stronger than body waves, and can be the largest signals on earthquake seismograms. Surface waves are strongly excited when their source is close to the surface, as in a shallow earthquake or a near-surface explosion.

Measuring the azimuths of both P-waves and S-waves makes it possible to identify the direction from which the waves were emitted. Since the waves travel at different speeds, it is also possible to determine the distance to the source by measuring the different arrival times of the waves.

2.3.3 Normal Modes

Both body and surface waves are traveling waves; however, large earthquakes can also make the Earth "ring" like a bell. This ringing is a mixture of normal modes with discrete frequencies and periods of an hour or shorter. Motion caused by a large earthquake can be observed for up to a month

after the event occurs. The first observations of normal modes were made in the 1960s as the advent of higher fidelity instruments coincided with two of the largest earthquakes of the 20th century – the 1960 Valdivia earthquake and the 1964 Alaska earthquake. Since then, the normal modes of the Earth have given us some of the strongest information on the deep structure of the Earth

2.4 How do Seismometers Record Earthquakes

Seismometers record both ground motion and earthquakes. Attached to their base is a free mass, which is usually attached by a spring or string and allowed to move freely in one direction (up/down or side to side). When the earth moves, the base of the seismometer moves as well, but the free swinging mass stays still. Check out the image below to see this principle in action. Originally a pen was attached to the mass and the base had a roll of paper to record the relative movement between the moving base and the stationary pen. Now systems tend to use magnets, which are free to move within a coil of wire – this creates an electrical current which is measured and converted into specific measurements of the amount of ground movement.

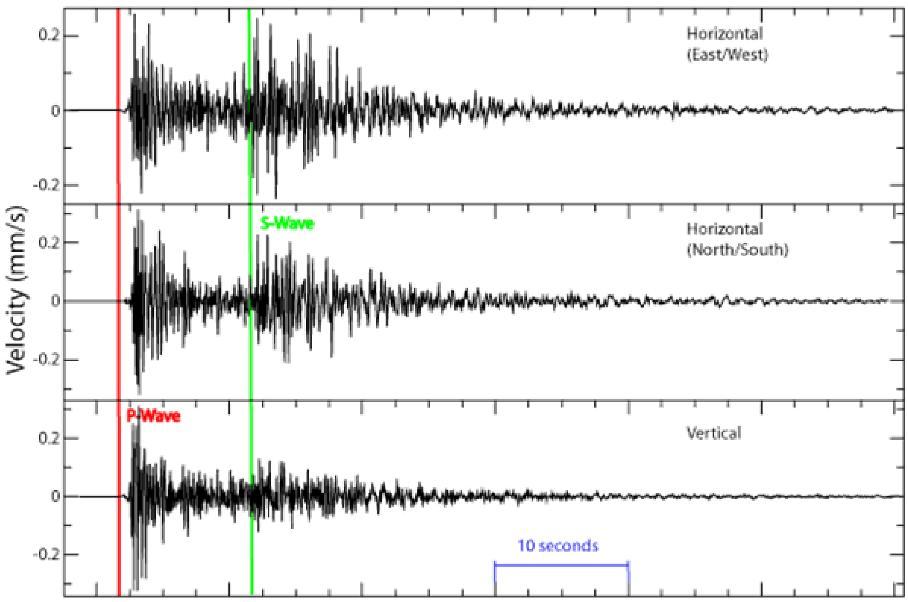

Figure 1 Seismogram

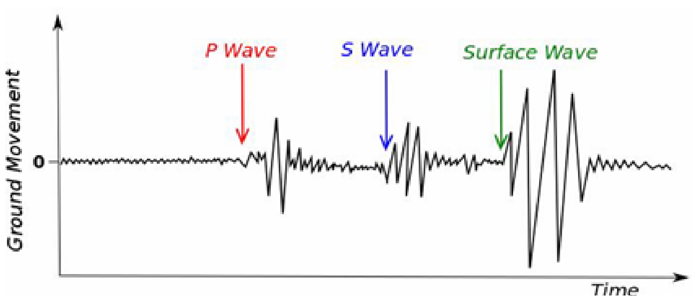

Figure 2 Seismograph Record

2.5 Locating an Earthquake Epicenter

For a shallow earthquake, the epicentral distance is indicated by the interval between the arrival times of the P and S waves. The azimuth and angle of wave emergence at the surface are indicated by a comparison of the sizes and directions of the first movements shown on the seismograms and by the relative sizes of later waves, particularly surface waves. It should be noted, however, that in certain regions the first wave movement at a station arrives from a direction differing from the azimuth toward the epicenter. This anomaly is usually explained by strong variations in geologic structures.

When data from more than one observatory are available, an earthquake's epicenter may be estimated from the travel times of the P and S waves from source to recorder. In many seismically active regions, networks of seismographs with telemetry transmission and centralized timing and recording are common. Whether analog or digital recording is used, such integrated systems greatly simplify the work of observation: multi-channel signal displays make identification and timing of phase onsets easier and more reliable. Moreover, online microprocessors can be programmed to select automatically, with some degree of confidence, the onset of a significant common phase, such as P, by the correlation of waveforms from parallel network channels. With the aid of specially designed computer programs, seismologists can then locate distant earthquakes to within about 10 kilometers (6 miles) and the epicenter of a local earthquake to within a few kilometers.

2.6 Global Seiemographic Network

Figure 3 Component Sensors, Vertical, N-S and E-W Orientations

The Global Seismographic Network is a permanent digital network of state-of-the-art seismological and geophysical sensors connected by a telecommunications network, serving as a multi-use scientific facility and a societal resource for monitoring, research, and educaion. Formed in partnership with USGS, the National Science Foundation (NSF), and the Incorporated Research Institutions for Seismology (IRIS), the GSN provides near-uniform, worldwide monitoring of the Earth, with over 150 modern seismic stations distributed globally. GSN stations are operated by the USGS Albuquerque Seismological Laboratory, the IDA group at UCSan Diego, and other affiliate organizations.

There are two types of seismic monitoring networks: a primary seismic network and an auxiliary network. The stations of the primary seismic network send data continuously in real time to the IDC and will be utilized most extensively. The auxiliary seismic network often takes advantage of existing seismic stations, which are being upgraded to meet the IMS technical standards. These stations do not send data in real time but upon request only.

There are basically two different types of seismic stations: seismic arrays and three-component stations. About 60% of the primary seismic network will consist of seismic array stations, which are essentially sets of nine to 25 seismic sensors geometrically arranged over a wide area. Most of the stations in the auxiliary seismic network are three-component stations.

2.6.1 Seismic Arrays

Groups of individual sensors deployed in a specific geometric pattern across an area ranging from a few to several hundred square kilometers are called "seismic arrays". New seismic arrays built by the IMS usually have a distribution diameter of three to four kilometers. Older array stations, which have been upgraded by the IMS and incorporated into its seismic networks, may cover an area of up to 500 square kilometers.

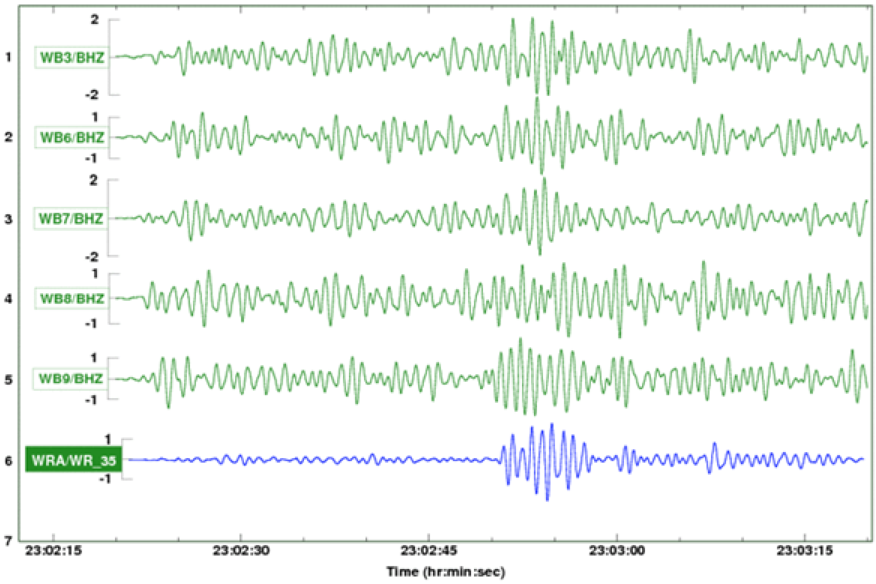

Figure 4 One advantage of seismic arrays is the improvement in signal quality that is achieved when the signals observed at each sensor are added, "summed", or "stacked" - see the lowest trace for the composite.

Seismic arrays enhance monitoring capability for several reasons. First and foremost, they improve the signal to noise ratio. This means that it is easier to distinguish the actual signal from the background noise, since it is filtered out. Array stations allow for a better estimation of the azimuth of incoming signals, i.e. they identify the direction from which the signal arrived. The spatial distribution of the sensors also permits an estimation of the seismic waves' speed. Information on both the direction and speed of the incoming seismic waves is crucial when identifying the source of a particular event.

2.6.2 Three-Component Stations

Three-component stations have one seismic sensor that measures the three spatial components of the waves, i.e. up-down, East-West and North-South. In comparison with seismic array stations, three-component stations often have a broader error margin but are more cost-effective. This type of station also measures body and surface waves, thus providing information on the depth and strength of an event.

2.6.3 Seismic Noise

Modern seismometers can detect ground movements as small as the size of atomic spacing in a crystal. However, continual background vibrations, known as "seismic noise", often distort seismic signals and limit their detection.

While seismic noise is mostly generated by wind and ocean waves, vehicle traffic and industrial activity can also contribute. In order to minimize the influence of seismic noise, seismic stations are usually built in remote areas, preferably on outcroppings of geological hard rock and as far away as possible from human activity.

2.7 World-Wide Standardized Seismograph Network (WWSSN)

When seismometers were individually constructed in the early 1900's, there was little adherence to standards for constructing instruments and recording data. This situation is similar to that faced by amateur seismologists today when they construct their own seismometer or purchase a commercial instrument. Consequently, the sensitivity to ground motion of these early seismometers and the homemade instruments of today may differ widely. Many records of earthquakes exist now for which the instrument response is unknown.

Calibration is essential for accurate measurement of earthquake magnitude, in particular, for measurements used for statistical studies and statistical comparisons of earthquakes in different areas. Even if the seismometer constants are known, the lack of computers in Richter's time would have made corrections to ground motion a difficult computational process. The Richter magnitude scale eliminated the uncertainty in instrument response by limiting magnitude computations to earthquakes observed on one particular instrument, the Wood-Anderson torsion seismometer, and by specifying its gain, free period, and damping. With digital data and today's desktop computers, calibration is not nearly so difficult a task. This objective of this chapter is to explain how a homemade seismometer may be calibrated.

An important component in sharing data from a seismic station involves maintaining a calibrated system. Calibration is essential if data from a seismometer are to be used for research, such as for computing magnitudes and for comparing the signals generated by the earthquake source. If everyone used identical instruments and did not change any of the settings or constants, records could be compared directly, but computation of the ground motion would still require calibration. The World Wide Standard Seismograph Network (WWSSN), which originally consisted of over 159 stations, was installed in the early 1960s. With the WWSSN instruments, calibration and design standards were prime concerns. Standard calibration signals consisting of a known acceleration function and the relevant constants were marked on each record. This calibration pulse and the associated constants contain all the information needed to define a seismometer's response. Coming as it did in the initial phase of the revolutionary ideas of the new global tectonics, the WWSSN facilitated significant advances in the understanding of crustal tectonics and the structure of the Earth's interior. The WWSSN data and much of the seismic data acquired throughout the 1970s were recorded photographically or on analog magnetic tape. Today, digital recording and the advent of low-cost seismometers that can record directly to personal computers has started another revolution in seismology, making possible images of the Earth's structure in much greater detail than ever before. Such instruments can take seismic recording out of the research laboratory and make seismic data widely available through open exchange over the Internet. For home-based systems to contribute to research, they will also need to be calibrated.

The seismometers of today record data in digital format. Instead of using a portion of the digital record for a calibration pulse, as with the WWSSN data, the instrument calibration can be condensed and included in a separate file or as a header to the data file. The format of the header and/or data files is usually transparent to the user. In practice, the format depends on the recording system and the analysis system built for the specific seismometer. Problems can develop when attempting to convert data from one system to another, because the calibration information may be incomplete or expressed in different formats. However, when the calibration facts are complete, techniques borrowed from signal processing theory can be used to generate seismograms that look like those recorded on any system. Only the noise and sampling rate for data recorded on the originating system limit the conversion of the appearance of a seismogram in one recording system to another.

2.8 Example of Seismic Monitoring Station

2.8.1 Seismometer

The seismometers used in NARS Botswana, mid-Africa, are the Nanometrics Trillium 120P and the Streckeisen STS-2 broad band sensors. Both are electronic force-feedback sensors that provide an output signal proportional to ground velocity over a broad frequency range. Three identical obliquely-oriented mechanical sensors are used and standard vertical and horizontal outputs are derived by summing the raw sensor signals within the sensors' electronics. The housing is vacuum-tight and designed to minimize the distortion of the package by barometric pressure changes. The sensors are designed for quick and simple installation, wide temperature range operation, and secure transport, while resolving minimum earth noise levels over the frequency range.

a) Nanometrics Trillium 120P

b) Streckeisen STS-2 broad band sensors

Figure 5 Earth Motion Sensors

2.8.2 Timing

For precise timing we use the Trimble Acutime Gold GPS smart antenna. It generates a pulse- per-second (PPS) output synchronized to UTC within 15 nanoseconds, outputting a timing and position packet for eachpulse.

Figure 6 GPS Receiver

2.8.3 Data Logger

The Seismology group of Utrecht University, together with the Instrumental group of the Physics department, developed the NARS seismic data logger. The data logger consists of mainly two components: (1) a data acquisition module, which does the AD conversion and timing. (2) an off-the- shelf embedded computer, for all further data processing. Data is stored on the datalogger's internal hard disk and (optionally) to an external USB stick. All communication with the outside world is done via mobile cellular network communication.

2.8.4 Portable Computer

For station setup, a portable computer running Linux as data storage and control unit, was employed for data collection and communication. Communication is established by Ethernet using the virtual console program.

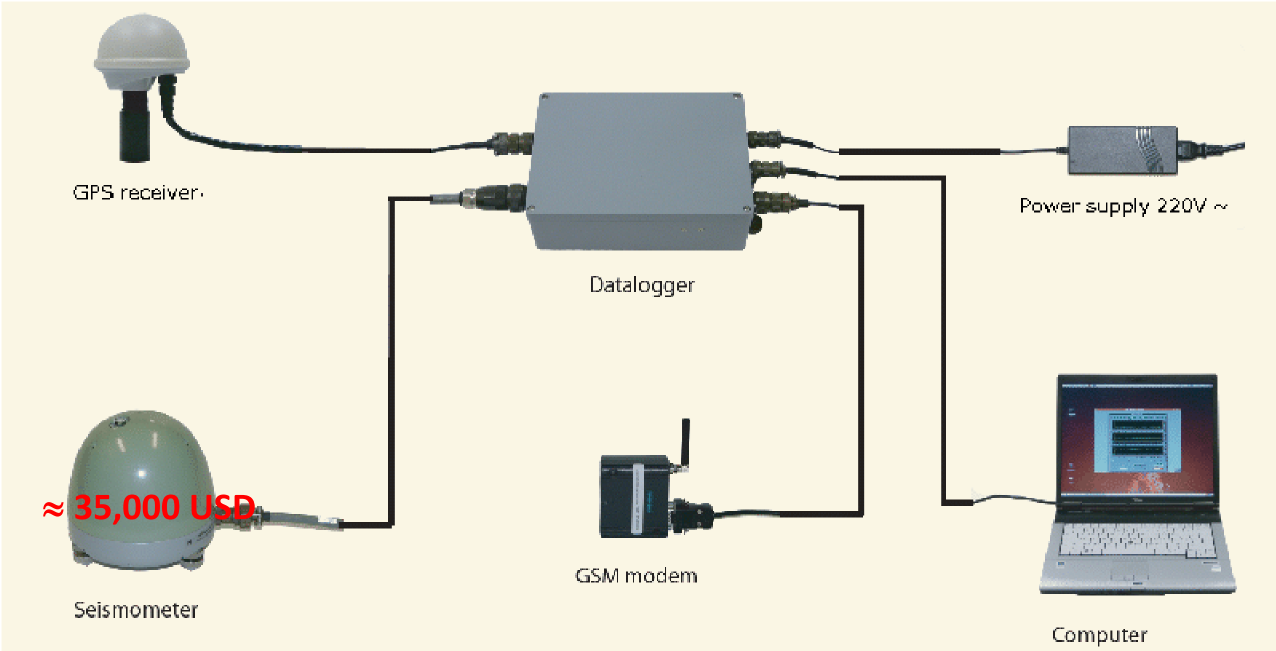

Figure 7 System Diagram

2.9 Seismometer Installation

Site selection: Site selection for a permanent station is always a compromise between two conflicting requirements: infrastructure and low seismic noise. The noise level depends on the geological situation and on the proximity of sources, some of which are usually associated with the infrastructure. A seismograph installed on solid basement rock can be expected to be fairly insensitive to local disturbances while one sitting on a thick layer of soft sediment will be noisy even in the absence of identifiable sources. As a rule, the distance from potential sources such as roads and inhabited houses should be very much larger than the thickness of the sediment layer. Broadband seismographs can be successfully operated in major cities when the geology is favorable; in unfavorable situations such as in sedimentary basins, only deep mines and boreholes may offer acceptable noise levels.

Besides ground noise, environmental conditions must be considered. An aggressive atmosphere may cause corrosion, wind and short-term variations of temperature may induce noise, and seasonal variations of temperature may exceed the drift specifications. Seismometers must be protected against these, some-times by hermetic containers (see next section). As a precaution, cellars and vaults should be checked for signs of occasional flooding.

Seismometer installation: Installation of a seismometer in the open field or inside a building, vault, or cave. The first act is to mark the orientation of the sensor on the floor. This is most effectively accomplished with the use of a geodetic gyroscope, but a magnetic compass will do in most cases. The magnetic declination must be taken into account. Since a compass may be deflected inside a building, the direction should be taken outside and transferred to the site of the installation. A laser pointer may be useful for this purpose. When the magnetic declination is unknown or unpredictable (such as in high latitudes or volcanic areas), the orientation should be determined using a sun compass.

To isolate the seismometer from stray currents, small glass or perspex plates are cemented to the ground beneath its feet. Then the seismometer is installed, tested, and wrapped in a thick layer of thermally insulat-ing material. The type of material seems not to matter very much; alternate layers of fibrous material and heat-reflecting blankets are probably most effective. The edges of the blankets should be taped to the floor around the seismometer.

Electronic seismometers produce heat and may induce convection in any open space inside the insulation; it is therefore important that the insulation has no gap and it fits the seismometer tightly. Another method of insulation is to surround the seismometer with a large box, which is then filled with fine Styrofoam seeds. For a permanent installation under unfavorable environmental conditions, the seismometer should be enclosed in a hermetic container. A problem with such containers (as with all seismometer housings) is that they cause tilt noise when they are deformed by the barometric pressure. Essentially three precautions are possible: either the baseplate is carefully cemented to the floor, or it is made so massive that its deformation is negligible (Figure 8). Some fresh desiccant (silica gel) should be placed inside the container, even into the vacuum bell of STS1 seismometers. Figure 8 illustrates the shielding of the STS2 seismometers in the German Regional Seismic Network (GRSN).

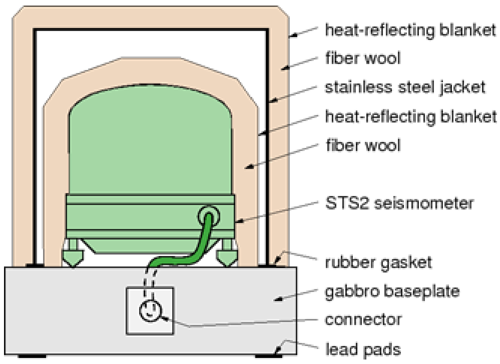

Figure 8 Seismometer of the GRSN Inside its Shields

Magnetic Shielding: seismometers are to some degree sensitive to magnetic fields because all thermally compensated spring materials are slightly magnetic. This may become noticeable when the seismometers are operated in industrial areas or in the vicinity of dc-powered railway lines. Magnetic interference must be suspected when long-period noise follows a regular timetable. Shields can be manufactured from permalloy (μ-metal), but they are expensive and of limited efficiency. An active compensation is often preferable. It may consist of a three-component fluxgate magnetometer that senses the field near the seismometer, an electronic driver circuit in which the signal is integrated with a short time constant (a few milliseconds), and a three-component set of Helmholtz coils that compensate for changes in the magnetic field. The permanent geomagnetic field should not be compensated for; the resulting offsets of the fluxgate outputs can be elec trically compensated for before the integration

3 Methodology

3.1 Building of Seismic Monitoring System

General of seismic monitoring system has 3 main parts following: i) control and recording unit, ii) accelerome ter, and iii) data communication as shown in figure 9.

This project proposes three options for a seismic monitoring system as described below.
1) Buying a well-known system.
2) Develop new control unit based on the Chinese 1Hz geophone and its accelerometer sensor, and a single board computer with local data storage, data communication, solar power supply system, and other necessary components.
3) Development of a mockup prototype system based on a cheap motion and accelerometer sensor (10Hz or higher frequency geophone), a single board computer with local data storage, data communication, solar power supply system, and other necessary components.

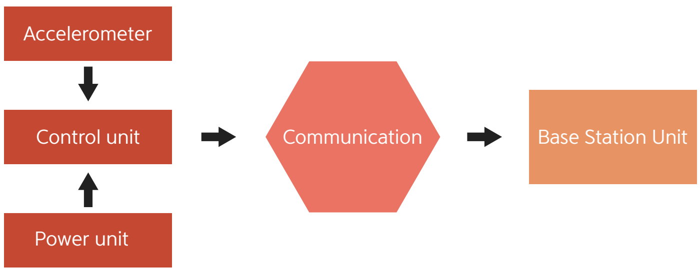

Figure 9 Seismometer Block Diagram

Option 2) and 3) are almost the same but differ in the geophone sensor. Option 2) used a Chinese commercial low frequency geophone sensor and option 3) used a regular seismic sensor available in the seismic surveying sector.

Buying a well-known seismometer system is the best option for a seismic monitoring station. Since the seismic system is certified and used around the world, there are no concerns regarding recorded data. This option is recommended for commercial purposes and long-term use.

Regarding the cost of the system, developing our own system using commercial sensors is also a good choice to minimize the budget. The system can be designed and optimized per the job requirements and the data communication suite can be restricted by location and communication service charges.

3.2 Instrument Calibration

The techniques used to calibrate new digital systems are the same as those used to calibrate simple systems of any age and design. A known force is applied to the seismometer mass and the response is measured. The simplest force is the gravitational attraction of a small test weight that is lifted off the seismometer mass. This is referred to as a weight lift test. The same effect occurs when the test weight is placed on the mass, but this is unreliable because variations in momentum of the test weight when it hits the seismometer mass can cause variations in the signal amplitude. Alternatively, force may be applied via electromagnetic current, that is, by a motor. The motor typically consists of a calibration coil placed near a magnetic portion of the seismometer.

The force applied to the seismometer is proportional to the current sent through the coil. The signal generated when a small test weight is removed, or when a current is sent through the calibration coil, is the calibration pulse. The calibration pulse contains the information needed to compute the frequency response of the seismometer. The rest of the information needed for calibration, the gain, can be obtained either from a careful measurement of the mass and mechanical behavior of the seismometer, or by a comparison of two seismometers sensing the same signal.

3.3 WWSSN Calibration Procedures

Calibration of the WWSSN seismographs was based on several separate but dependent operations. The first step was the factory testing of a standard system to determine the absolute steady- state amplitude and phase response characteristics over the usable frequency band. The second step, also performed at the factory, was to determine the value of a calibration constant that relates the peak amplitude of a step response to the magnification of the seismograph at the seismometer operating period. The third step was the proper adjustment of the seismograph settings at the station during installation. The fourth step involved the application of a calibrating force in the form of a rectangular step function and the use of the calibration constant to properly adjust the sensitivity of the seismograph.

Thereafter, calibration step responses were recorded daily on the seismograms. Finally, during the first years of network operation, there were periodic tests and adjustments, to insure that the variable instrument parameters were kept within acceptable tolerances.

Methods used for calibration are described in Appendix A and Appendix B of the WWSSN Operation and Maintenance Manual, Geotechnical Corp. (1962) and in an unpublished ASL report by Jerry Locke, entitled Calibration of the WWSSN and ESN Seismograph Systems.

3.4 Seismometer Installation and Testing in the Field

This Seismometer will be developed and tested in Rajamagala University of Technology Suvarnabhumi, at the Sam-Chuck Suphanburi campus. The process includes systems design, assembly, data validation, user interface development, system calibration, and data communication.

Wireless data telemetry will be tested to find out the maximum range of the RF module to send data back to base station.

Performance and power consumption will be determined and adjusted for solar power system optimization.