STANDARD 805-01

SIGNATURE MEASUREMENT STANDARDS GROUP
Seismic, Acoustic, and Magnetic Committee

SEISMIC SIGNATURE & METHODOLOGY STANDARD

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SIGNATURE MEASUREMENT STANDARDS GROUP
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PREFACE

The Seismic Signature and Methodology Standard captures the corporate knowledge of personnel who have many years of seismic experience. These individuals are recognized and respected for their contributions to the discipline. It is safe to assume that 38 or more technical personnel contributed to making this document possible. Development of the standard was a team effort that included multiple agencies from the government, military, universities and corporations. These include, but are not limited to, the University of Texas, the National Ground Intelligence Center, the Yuma Proving Ground, White Sands Missile Range, the Chicken Little Program Office, Litton-TASC, Northrop Grumman, MITRE Corporation, Penn State University, the 46TW/TSR Eglin AFB FL, Army Research Laboratory – Picatinny Arsenal, TEXTRON Systems, Arnold Engineering Development Center, US Army Waterways Experimental Station, Aberdeen Training Center, Bishop Multisensors Corporation, and the BAT Program Office.

The Chair of the Range Commanders Council, Seismic, Acoustic, and Magnetic Committee, Signature Measurement Standards Group would like to give special recognition to two individuals, Dr. Henry Bass, University of Mississippi, and Nino Srour from the US Army Research Laboratory, who gave their tireless support to this effort. Special recognition also goes to Dale Bradley, Signature Measurement Standards Group Chair, Arnold Engineering and Development Center, Arnold AFB, for making this possible.

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SECTION 1

INTRODUCTION

1.1 Background

Seismic technology is a branch of the field of geophysics, the study of the earth using physical measurements at the surface. The geophysics field employs many prospecting methods, including the following: seismic refraction; seismic reflection; gravitation; and magnetic, electrical, and radioactive anomalies.

1.1.1 Origin of Seismic Technology. Seismic sensors were initially developed circa 1915 for the purpose of oil exploration, and most recently, some seismic sensors have played an important role in earthquake studies. One type of seismic sensor is a geophone, a motion-sensitive transducer that converts mechanical energy into electrical energy. For the purposes of this report, the terms, seismic sensor and geophone will be used interchangeably.

1.1.2 Military Adoption of Seismic Technology. Seismic sensors, which operate in a passive mode, have been used for military purposes since the Vietnam War. Such sensors are small, inexpensive, and generally consume low power levels during operation. The Department of Defense (DoD) has not designed these devices, but has simply adapted commercially available sensors for military applications. Recent military applications have commonly been in concert with other passive devices such as microphones and magnetometers. The seismic, acoustic, and magnetic signatures from these three types of sensors complement each other very well. These signatures are frequently used for the exploitation, detection, and classification of military vehicles.

1.1.3 Battlefield Applications. Battlefield seismic sensors have the potential for addressing several important military problems because of their passive nature. They have the ability to detect and analyze non-line-of-sight (NLOS) targets. Digital computers within the sensor system can perform Non-cooperative Target Recognition (NCTR), on a wide range of ground vehicles and rotary-wing aircraft. These systems can be utilized in unattended perimeter surveillance, passive artillery and mortar location, and target detection, including classification, localization, and possible identification of smart weapons.

1.2 Military Application Concerns

Military applications require geophones to be very adaptable. A seismic sensor system must be capable of operating in harsh environments. The sensor may be planted at the ground surface or buried in the soil at depths of a meter or more. Other applications require that the device be buried in the soil bottom of a body of water. The geophone may be placed in soft or hard soil, or it may be left to freeze in place when winter arrives.

Seismic waves are generated when some form of dynamic pressure is applied to the soil surface. Several types of seismic waves may be generated, but not all have value for seismic signature applications. Soil and rock are complex media in which seismic waves are generated and through which they must propagate. The variability of soil and rock structure and composition can significantly affect seismic waves. Despite these difficulties, seismic sensors have significant value to the military.

1.3 Importance of Seismic Standards

Seismic signature standards are necessary within the Department of Defense (DoD) to control the constraints of variable site conditions on seismic sensor emplacement and performance. These standards are to be used to establish test compatibility between the sites at all DoD test centers. Regardless of where a test is conducted, the same seismic standards are to be employed.

1.4 Purpose and Scope of this Document

The purpose of this document is to define standard methods for deploying geophones for the collection of quality seismic signatures. The standard is broad enough so that the seismic signature data collected can be analyzed and processed in numerous ways. This standard may be applied in two types of test scenarios: (1) continuous source testing: targets that include wheeled vehicles, tracked vehicles, air-cushioned vehicles, rotary-wing and propeller aircraft; and (2) impulse source testing: explosives and explosive-type sources (i.e., artillery). This standard specifically addresses continuous source testing scenarios, but all methods discussed are equally applicable to impulse source applications.

This report also includes a description of geophone types; identification and definition of sensor parameters; meteorological considerations; instrumentation procedures; calibration techniques; and ground truth documentation procedures.

SECTION 2

PLACEMENT AND UTILIZATION OF SEISMIC SENSORS

2.1 Types of Geophones

As mentioned earlier, a geophone is a type of seismic sensor that employs a motion-sensitive transducer. It is a relatively simple device that uses a magnetic mass in a coil to produce a signal. A geophone that is implanted into the ground vibrates with the ground, and the coil moves with the supporting case while the magnetic mass remains stationary. The motion between the mass and the coil generates an electrical signal, making a geophone a self-generating device. The voltage generated by a geophone is proportional to the rate of cutting of the magnetic field; therefore, the output of the instrument will be proportional to the velocity of the vibrating body. A typical geophone has a natural frequency of 1 to 15 Hz. It is within this frequency band that the maximum signal is produced.

There are two basic types of geophones, those that measure motion on a single axis and those that measure motion on three axes. The single axis geophone is normally planted vertically, while the three axis geophones are positioned with one vertical and two orthogonal horizontal axes. All seismic sensors should be calibrated in accordance with the manufacturer's standard.

2.1.1 The Single Axis Geophone. The simplest type of seismic sensor is the single axis geophone. This device measures vertical motion and is most frequently used for collecting seismic signatures. The single axis geophone is a small device that is mounted in a metal cylinder that has dimensions in the range of 1.25 cm to 2.5 cm diameter and 2.5 cm to 5.0 cm height. The manufacturer calibration certification must be current at the time that the device is used for gathering signatures. Any time single axis geophones are deployed, at least one 3-axis geophone will be part of each seismic array.

2.1.2 The 3-Axis Geophone. The 3-axis geophone provides a broader set of seismic signatures than does the single axis device. Seismic data from the 3-axis geophone provides information that enables the user to analyze the propagation of seismic waves (how the different types of seismic waves compose the measured signal). A 3-axis geophone should be used when seismic signatures are collected. The 3-axis geophone must be a precision device of scientific grade. The seismic sensor must comply with same manufacturer calibration standards as those specified for single axis seismic devices.

2.2 Geophone Emplacements

Geophones may be planted on the surface of the ground or buried at some depth, depending on the application. Regardless of the type of geophone, or the emplacement, there is a need to ensure that the geophone is in good contact with the soil. Therefore, the following procedures for emplacement should be followed when planting the sensors.

2.2.1 Planting the Single Axis Geophone. Single axis geophones often have an attached spike. When used, they should be punched into the ground until the base of the geophone is at rest on the surface, and the geophone is firmly in place. The geophone should be aligned in an upright position, ensuring that true vertical motion is measured. When a single axis geophone is planted at some depth, a hole should be dug into the ground, leaving the bottom of the hole as firm and undisturbed as possible. Then the geophone should be implanted into the bottom of the hole in a similar manner as surface planting. The soil should then be placed back into the hole and compacted in no more than 10 cm lifts (or layers). The geophone cable should be protected during this process to ensure that it is not stressed or damaged.

2.2.2 Planting the Geophone on a Hillside. The geophone will be planted in the same manner as described in (2.2.1). However, the vertical axis must be perpendicular to the center of the earth and not to the hillside. A leveling tool is recommended for this procedure.

2.2.3 Planting the 3-Axis Geophone. The 3-axis geophone is usually larger than one with a single axis, requiring some digging. In most applications involving the collection of seismic signatures, the 3-axis geophone will be planted flush with the ground surface, requiring a small hole in which to place the geophone. The geophone will be placed with one horizontal axis pointed at the anticipated stationary target source and the other placed perpendicular to the line between the sensor and the target. If the target is moving, the longitudinal axis should be aligned parallel to the target path and the transverse axis should be perpendicular to the target path, toward the closest point of approach (CPA).

The sensor is aligned in the hole with the help of a level. Some geophones are designed with a built-in level indicator. The hole should be made only slightly larger than the geophone to enable refilling the hole as tightly as possible. The soil should be compacted (using a small tool such as the handle of a hammer) up to the level of the original surface. A small layer (approximately 0.5 cm) of soil can be placed over the geophone to minimize wind noise. The geophone cable should be protected during this process to ensure that it is not stressed or damaged. All cables (from multiple geophones and other collocated sensors) should be brought out of the soil in a harness.

2.2.3.1 Deep Planting the 3-Axis Geophone. Some test scenarios require that the geophone be planted at depths of half a meter or more. Axes alignment and leveling procedures are the same as discussed section 2.2.3. However, the full depth of the excavated cavity should be filled with soil. For winter scenarios, it is recommended that the device be planted before the ground freezes.

2.2.4 Typical Geophone Placement along a Vehicular Test Track. A vehicular test track (500 meters or more in length) is defined as a pathway for ground vehicle travel. One or more geophones may be placed along the track. The devices are placed at a distance of 50 meters or more from the center of the pathway at the CPA. Seismic placement scenarios for a vehicular test track are shown in Figure 4.1 and in Appendix A.

2.3 Emplacement Environment

Proper coupling between the sensor and the soil/sand is very important. Three techniques are employed to ensure proper coupling with the ground according to conditions:

2.3.1 Warm Weather Scenarios. Soil is used to fill any gaps left between the perimeter of the sensor and the soil surface. Any loose soil should be tightly hand-packed.

2.3.2 Winter Scenarios. Cold weather environments require that dry sand be added to fill in the gaps. Water is poured over the sand and the instrument is left to freeze in place. This enables consistent coupling.

2.3.3 Littoral Sites. Along littoral sites, the emplacement of geophones in locations other than along the surface is not an easy task. This is due to the constant cave-in of sand as one digs. A useful technique employs a piece of pipe with a diameter larger than that of the geophone. The pipe is placed in a hole and a jet of water is applied under the pipe from a water source exterior to the pipe. The jet disperses the sand to the sides, allowing the pipe to sink deeper. Once the pipe is at the desired depth, the geophone is placed in the pipe and the pipe is withdrawn. The sand is then allowed to refill the hole. A waterproof geophone, connectors, and cables are necessary for this application.

2.4 Establishing a Baseline Signature Standard

A calibrated 3-axis geophone is planted close to the target (near CPA for moving targets) during the conduct of tests where seismic signatures are being measured. A 3-axis geophone is required to provide the reference (baseline) signature for the test.

2.5 Collocating a Microphone with the Geophone

It is necessary to have a collocated microphone at each seismic station. The calibrated microphone with windscreen should be placed on the ground surface directly over the geophone. A small, inflated inner tube should be placed under the microphone to prevent seismic coupling. The same procedure applies to both the single axis and the 3-axis geophones.

Coupling of acoustic signals into the soil is a common occurrence that results from vehicle exploitation. Acoustic coupling is enhanced in porous soil, such as sand or clay. Low frequency acoustic signals are sensed by geophones and become part of the spectral product. Thus, it is necessary to compare the data collected by the microphone and geophone at each location. By comparing the seismic and acoustic spectrograms of each of the collocated sensors, an identification of seismic and acoustic signals is possible. This procedure is commonly used to identify acoustic noise that has been introduced into the seismic spectra.

Figure 2-1 is a typical seismic spectrogram. It shows a seismic spectrogram of a large, wheeled vehicle moving at 30 kilometers per hour. The rectangle at the far right shows an increase in signal activity as the vehicle passes the CPA. A distinction between the seismic data from the wheels and the acoustics from the engine harmonics is evident in the data sample

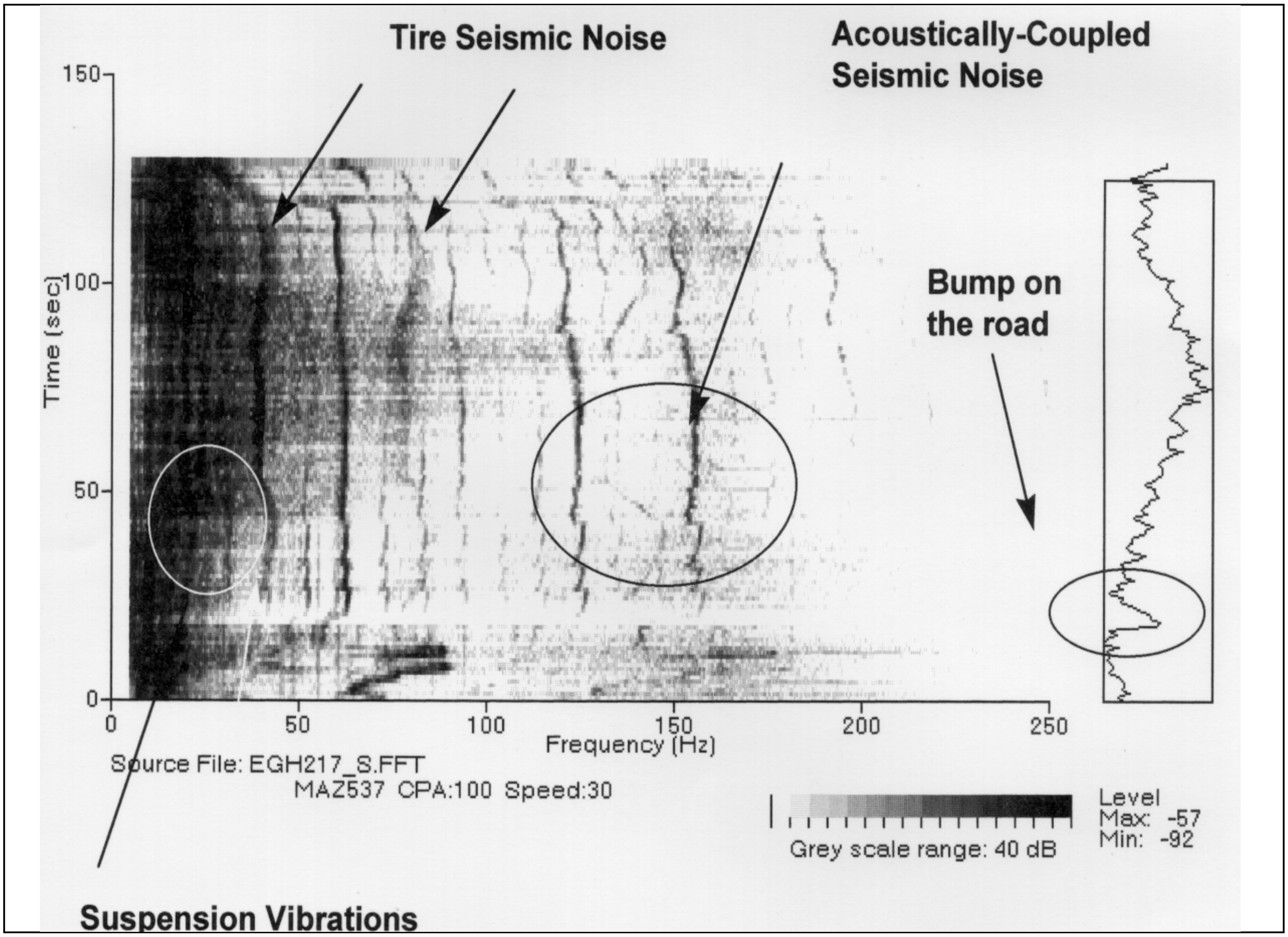

Figure 2-1. Seismic data sample shows acoustic coupling spectral lines. (Note: level is expressed in dB ref 1V/m/sec.)

Figure 2-2 shows the acoustic spectrogram from the collocated microphone. The sample shows acoustics from the engine harmonics. These can be compared to the acoustic spectral lines found in the seismic data sample. In comparing the acoustic and seismic data from the samples, it is evident that acoustic noise does couple into the seismic data.

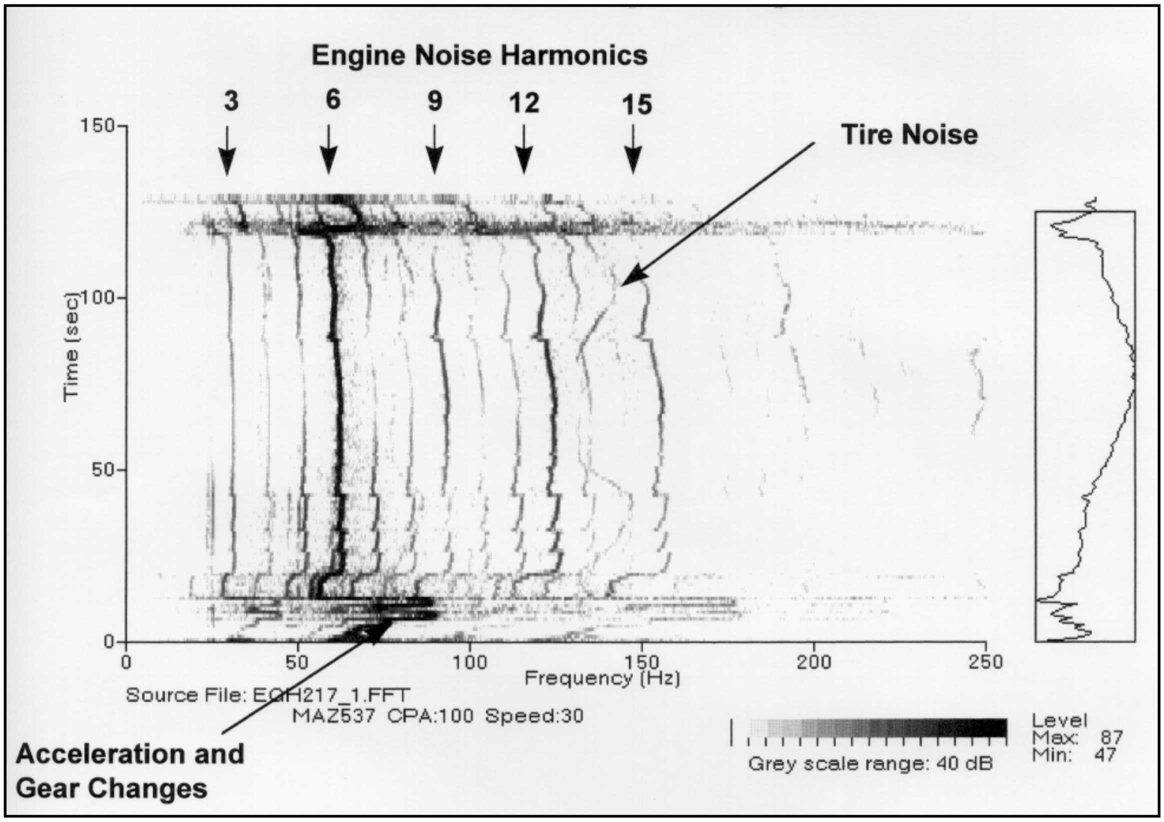

Figure 2-2. Acoustic spectrogram from the collocated microphone. (Note: level is expressed in dB ref 20 uPa.)

2.6 Measuring Environmental and Geophone Temperature

Temperature sensors should be added for monitoring purposes during the geophone soil planting process. One temperature sensor should be placed on the geophone and one in the soil (to the side of the geophone). Both temperature readings should be sampled periodically (at least every 10 minutes). The same temperature gathering technique is employed for underwater and frozen ground test scenarios.

2.7 Establishing Operational Parameters of Geophones

The 3-axis geophone consists of three seismic sensors placed in an orthogonal mount. Two of the sensing units are placed horizontally and the third sensor is arranged vertically. Most seismic sensors are designed to have an operational range of the bandwidth of less than 1 Hz minimum and 1000 Hz maximum. Operational parameters for seismic sensors are fairly common throughout the industry. However, close attention must be paid to the conditions under which the sensors are being used. These sensors must be capable of operating in hot, cold, wet or dry weather environments. The sensor parameters must be known and accounted for because they can be affected by variations in the operating environment, i.e., heavy rain can affect coupling, or large changes in temperature can affect sensor output. Typical seismic sensor parameters and the recommended units are shown in Table 2-1.

TABLE 2-1 GEOPHONE SEISMIC SENSOR PARAMETERS	
Parameter Name	**Recommended Units/Type**
GEOPHONE CALIBRATION COIL	
Calibration Coil Number of Turns	number
Calibration Coil Resistance	ohms @ ^{o}C
Calibration Coil Design	configuration
GEOPHONE SIGNAL DETECTOR	
Signal Coil Detector	axis
Electrodynamic Constant	V/cm/sec.
Coil Resistance	for a range of temperatures
Motor Constant	newton/ampere
Frequency (F_0)	hertz
Open Circuit Damping (B_0)	unitless value
Suspended Mass (m)	grams
GEOPHONE MECHANICAL	
Case Dimensions	centimeters
Total Weight	kilograms
Operating Pressure	pascal
Operating Temperature Range	degrees Celsius

2.8 Geophone Parameter Definitions

Calibration Coil. An internal calibration standard of the geophone, used to determine the transconductance output; expressed in volts/centimeter/second.

Calibration Coil Design. Typically, a series design with a specific number of wire turns.

Calibration Coil Number of Turns. The number of wire turns found in the calibration coil.

Calibration Coil Resistance. The resistance of the coil; expressed in ohms at a specific temperature (ohms @ degrees Celsius).

Coil resistance. The resistance value of signal coil; expressed in ohms.

Electrodynamic Constant. The relationship between electric, magnetic, and mechanical phenomena in a geophone; expressed in volts per meter per second (V/m/sec).

Frequency (F_o). The geophone frequency is the frequency of oscillation; expressed in hertz. This frequency is controlled by the ratio of total mass to spring constant.

Motor Constant. A constant; expressed in newton/ampere.

Open Circuit Damping (B_o). A relationship between the circuit resistance and the voltage applied; expressed as a unitless value of critical damping.

Operating Pressure. The maximum pressure at which the geophone will properly operate; expressed in pascal units.

Operating Temperature. The minimum and maximum temperature limits at which the geophone can properly operate and remain stable; expressed in degrees Celsius.

Signal Coil Detector. The primary coil internal to the geophone; typically, a moving dual coil. It is geometrically placed in either a vertical or horizontal axis to sense pressure and shear seismic wave activity.

Signal Detector. A geophone is a device that converts mechanical energy into electrical energy in some known relationship.

Suspended Mass (m). The weight of a piece of material attached to a spring with a support to earth; expressed in grams. A coil is attached to the mass and becomes a part of the total mass in a geophone. When the earth moves, the magnet and support also move. The mass tends to remain stationary and lags behind the motion of the earth; hence, there is relative motion between the coil and the magnetic field. The resultant voltage is proportional to the velocity of this motion.

Total Weight. The total weight of the geophone; expressed in metric units (kilograms).

2.9 Typical Seismic Sensor Calibration Curves

Seismic sensors are typically low frequency devices (less than 100 Hz) that are used in scientific studies to detect ground activity. Figure 2-3 shows typical curves generated by a geophone as it undergoes calibration.

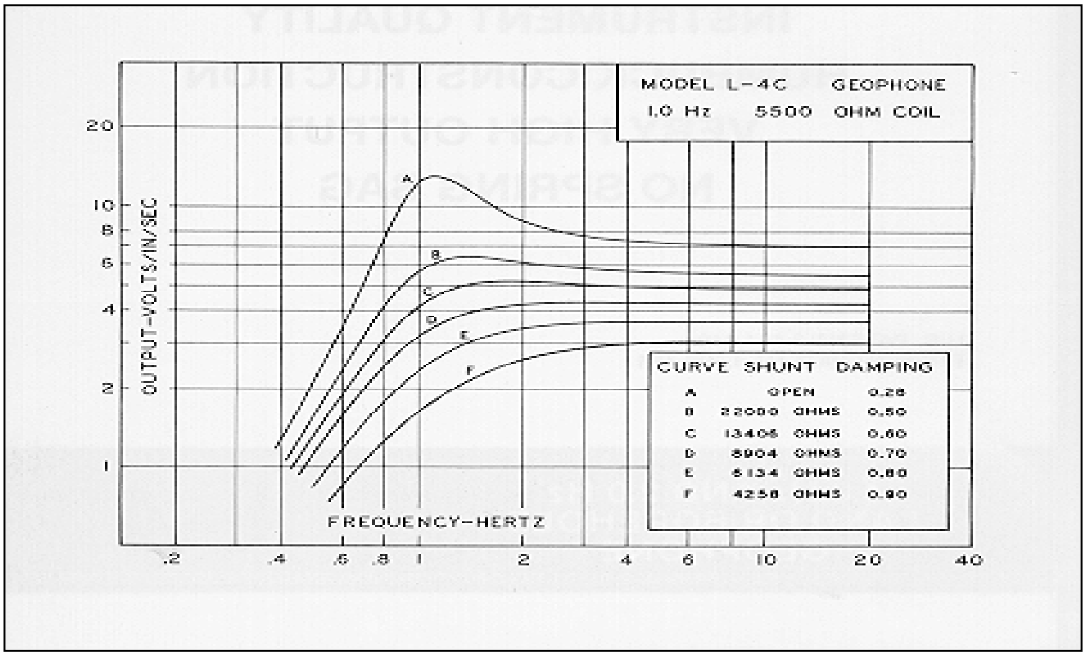

Figure 2-3. Typical seismic sensor calibration curves.

SECTION 3

SEISMIC INSTRUMENTATION

3.1 A Typical Seismic Circuit

A typical seismic circuit (Figure 3-1) consists of a 3-axis (or single axis) geophone, amplifiers for the sensor on each axis, connecting cables, a recording/playback system, and a dc power source.

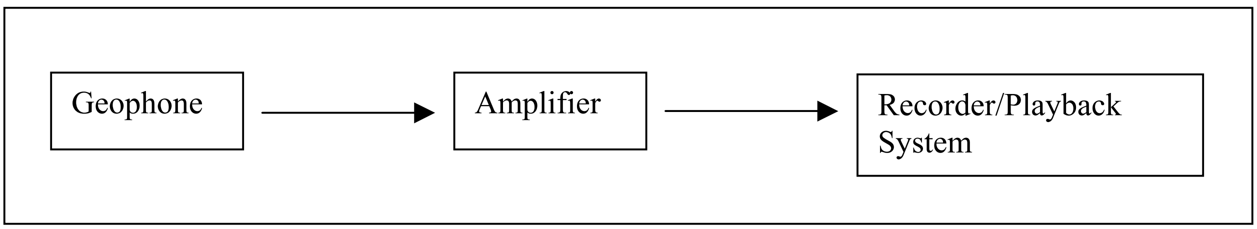

Figure 3-1. Seismic instrumentation circuit diagram.

3.2 Amplifier

The amplifier is attached in the circuit as near to the sensor as possible. It is a low noise device that amplifies signals in the seismic region 0 Hz to less than 1000 Hz. These amplifiers have selective gains of 20 dB, 40 dB, and in some instances 60 dB. The amplifier must be designed to have a relatively flat frequency response across the flat portion of the sensor bandwidth in order for the truest representation of the geophone spectral capabilities. The amplifier must be able to operate flat (frequency and gain) across the temperature range of the sensor. It must match impedance to maximize power transfers. Water-tight packaging for amplifiers is employed in special circumstances, such as when the geophone is used at littoral sites, buried for long periods of time, or submerged in water.

3.3 Cables

Cables used in the seismic data collection circuit must have low noise characteristics. The length of the cable can sometimes influence the quality of the data obtained from hardwired data gathering systems. Therefore, cable lengths should be kept as short as possible, preferably less that 350 meters. Two types of cables are used for collection of seismic signatures depending on the type of test conditions at the site.

3.3.1 Fair Test Conditions. The weather can vary from dry conditions to rain. The use of shielded instrumentation cable, twisted pair, insulated 20 AWG, individual shielded pair cable is employed.

3.3.2 Severe Test Conditions. In this condition, the cable is exposed to winter conditions or submerged in a body of water. Similar cable as described in section 3.3.1 is employed, except that it must be equipped with waterproof and hermetically sealed connectors. This type of cable is very expensive, so its use is recommended only for this type of severe test condition.

3.4 Instrumentation Recorder/Playback System

The instrumentation recorder is a device used to record data that is sensed by the seismic sensor. This instrument is of recognized scientific quality and must be able to undergo a National Institute for Science and Technology (NIST) traceable calibration procedure. These instruments typically have 8, 16, 32, or more channels. The 16-bit instrument must be capable of recording and reproducing seismic signatures on a hard drive, storage device, or similar instrument. Digital recorders are commonly used and are preferable.

3.5 DC Power Source

All devices discussed in this document that require power and are part of the instrumentation circuit should operate from dc power. A dc battery is used to operate the seismic instrumentation amplifiers, and the recorder/playback system. One or several batteries can be used in the circuit. Commercial power, ac generators, and most commercial inverters have been found to generate unwanted mechanical noise and these devices should be avoided.

The use of dc power from storage batteries is necessary when collecting seismic signatures because it is electrically clean, and it reduces self-generated power harmonics or other noise that might be introduced into the data stream. Use of dc battery power also provides the data collector with the autonomy to move to any geographical location to collect seismic data samples.

Some devices draw a significant amount of current over a period of a few hours. In these cases, the battery voltage level must be periodically checked to ensure that the levels are properly maintained. Some instrumentation devices have built-in alarms that warn of low voltage.

3.6 Ancillary Instrumentation

The design of the seismic data acquisition circuit must be kept simple. The addition of unnecessary ancillary 0equipment to the seismic signature collection circuit will only cause problems or introduce unwanted electronic noise into the data product.

SECTION 4

CALIBRATION PROCEDURES FOR EQUIPMENT AND SITES

4.1 General

To successfully capture a valid seismic signature, the test engineer or technician must have a sound understanding of proper calibration procedures. Because the quality of the signature will be directly affected by the calibration techniques employed, it is critical that the procedures be properly conducted. This section outlines various procedures used in evaluating and preparing sites and equipment for testing.

4.1.1. Understanding the Type of Data Collected. The seismic data to be collected must lend itself to various forms of analysis, e.g., spectra, spectrogram, polar or waterfall analysis, etc. The types of analysis used will be affected differently by the calibration procedures used in the evaluation of sites and equipment. Data inputs also vary from minimal vibration levels (vehicles) to extremely high vibration levels (airplanes, explosions). The calibration procedures must be tailored to the type of raw input data expected.

4.2 Calibration of Seismic Devices

It is important that precision devices be used when making seismic measurements. The seismic sensors used must be of scientific quality and have a current calibration traceable to the NIST. Single axis and 3-axis geophones are required to have a built-in calibration coil for field calibration purposes.

4.2.1 Calibration of the Geophone. The lab calibration of the geophone consists of using two calibrated instruments such as an oscilloscope and a signal generator which are used to measure the geophone transconductance value. Geophones are designed with a calibration coil of known characteristics. Newer techniques employ software that is used for the calibration process.

4.2.2 End-To-End Calibration. The entire measurement system, including geophones, amplifiers, cable harness, and the data collection instruments, must be calibrated by the use of shallow refraction. Shallow refraction is conducted before and after a test takes place.

4.3 Site Evaluation and Calibration Procedures

Before any seismic signatures are collected, it is critical obtain a seismic profile of the site. This information provides the user with the necessary wave propagation (p-wave) velocities with which the test engineer can determine if the site is adequate for signature gathering purposes. A refraction study of the site provides baseline data on the speed of seismic waves at specific locations.

4.3.1 Seismic Refraction. A seismic refraction study is conducted by striking the ground surface with a sledgehammer. In areas where the ground is frozen, the strike distance along the track is every 50 meters. For other soils, 100 meter strike points can be used. The seismic wave travels from the strike point to the seismic sensor. Using the distance and time, the propagation of seismic waves can be measured. The refraction profile is conducted in two parts.

4.3.1.1 Part One. The full length of a test track should be characterized.

4.3.1.2 Part Two. Seismic samples are gathered from sufficient locations on the site to characterize the site at each position on the test track relative to the locations where the various seismic arrays are located. Figure 4-1 illustrates a typical configuration of a test track refraction study.

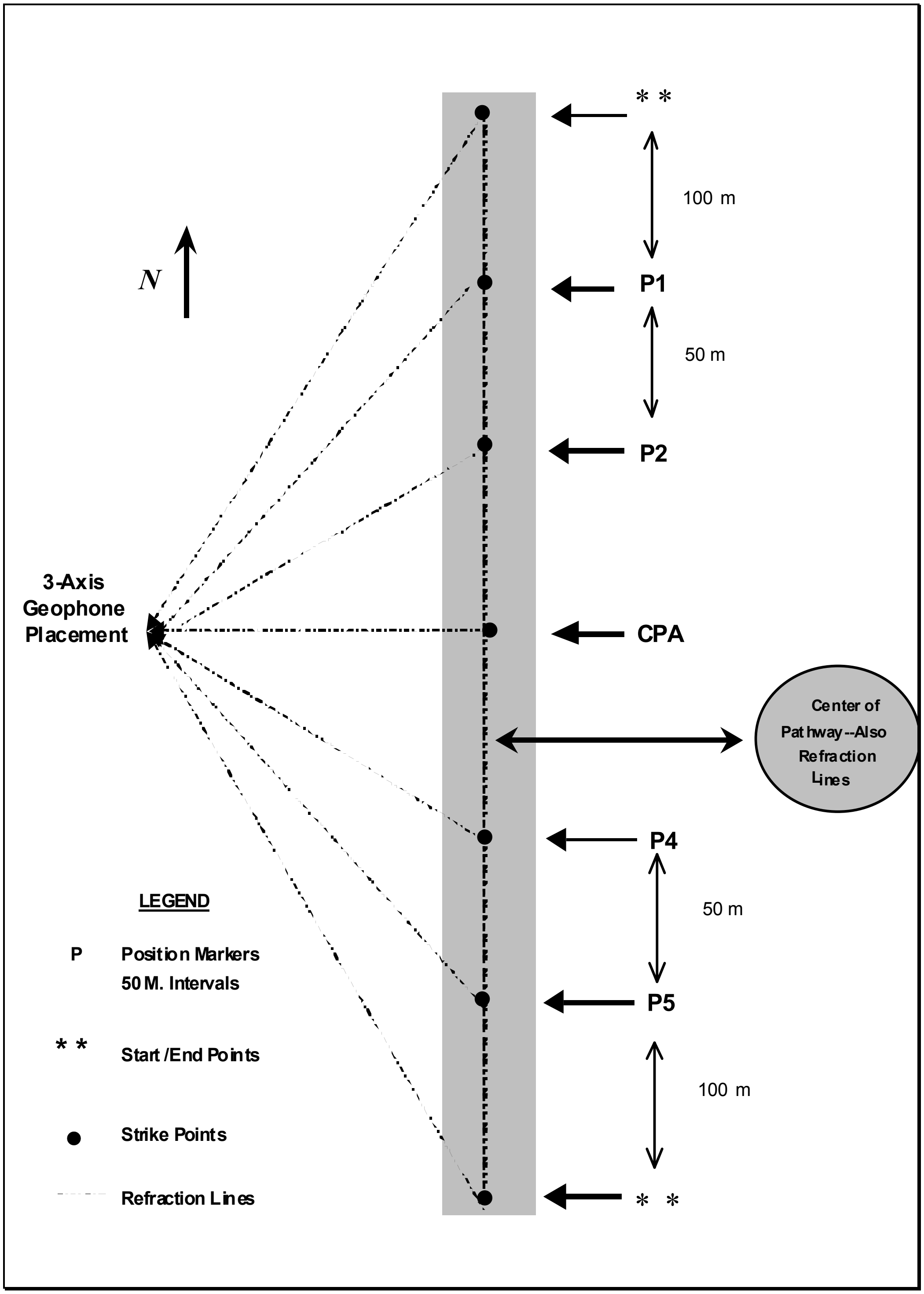

Figure 4-1. Typical refraction points at a test site.

The velocity of the p-wave is the primary seismic velocity obtained in a refraction study. The refraction findings are used to identify the presence of seismic dead zones in the area where the experiments are to take place. Dead zones create a condition where the propagation of a p-wave can exceed 1000 m/sec. However, outside the seismic dead zone area, the p-wave velocity can revert to typical values. The lesser velocity value of the p-wave is a good indication that soil conditions are adequate for testing. Table 4-1 provides guidance on how to set instrumentation gains for various soil conditions. This table applies to a test track that is less than 6 kilometers in length.

TABLE 4-1. SEISMIC AMPLIFIER GAINS FOR SOIL CONDITIONS

P-waveVelocity & Soil Types	Amplifier Gain
Less than 22 m/sec (sand & soft soils	20 – 30 dB
200 to 800 m/sec (packed soils, clay)	30 – 40 dB
800 to 1500 m/sec (frozen soil, rock)	40 – 60 dB

4.3.2 Seismic Ambient Noise. Repeated samples of seismic background noise (generated by equipment and environmental phenomena) must be collected, preferably every hour. The samples should not be less than a minute in duration and can be as long as five minutes. Seismic background noise samples are generally found to have a lower amplitude value than that experienced by acoustic sensors. When measurements are compared in dB, ambient noise should not exceed 20% of the signature undergoing study or a signal to noise ratio greater than or equal to 1.2. Figure 4-2 shows typical seismic ambient noise. This can vary from site to site.

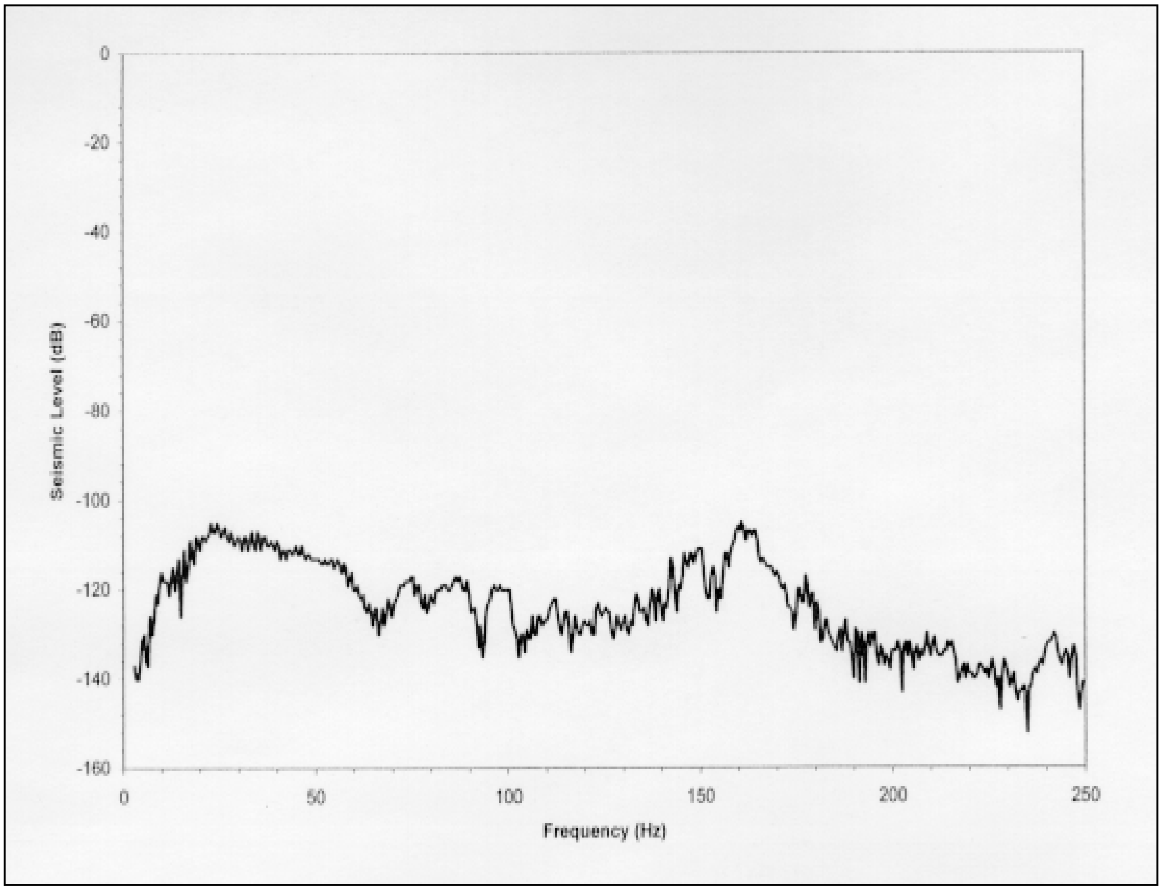

Figure 4-2. Typical seismic ambient noise.

4.3.3 <u>White Noise Injection</u>. A calibrated white noise source is used to inject a signal into the electronic seismic array. This signal is injected at a point before the amplifier. It travels the length of the cable, and into the recording system. The spectral bandwidth of the white noise should extend beyond the entire range of the system. This method should identify any inherent filter characteristics that are part of the system. The white noise source should have a current calibration certification traceable to NIST.

SECTION 5

GROUND TRUTH MEASUREMENTS

5.1 <u>General</u>

Ground truth factors contribute additional technical information necessary for the interpretation of seismic signatures. Documentation of these factors is key to the accurate interpretation of data. Various types of ground truth measurements are described in the following sections.

5.2 <u>Data Logs</u>

The data log is used to document source activity and those changes that take place during a test. The source activity can be any of several types, including vehicles, aircraft, explosion or artillery fire.

5.2.1 <u>Ground Vehicle Test</u>. This type of test involves the use of ground vehicles; wheeled, track, and air cushion types. The data log documentation includes the following information: vehicular runs, type of vehicle, IRIG time, vehicle speed and rpm, transmission range, vehicular gear, direction of travel, changes of amplification, sensor replacements, sensor gains, data channel assignments, other noise sources, observable environmental changes, and unusual events that take place during the test.

5.2.2 <u>Aircraft Test</u>. Vehicles used for these tests include rotary wing aircraft, jet aircraft noise, and large propeller driven cargo aircraft. Data log documentation includes the following information: vehicular run, flight profile, type of aircraft, IRIG time, changes of amplification, sensor replacements, sensor gains, data channel assignments, noise sources, and unusual events that take place during the test.

5.2.3 <u>Explosion/Artillery</u>. Although these types of tests measure discrete impulses, the data log should include type of explosive, the explosive device, manner of deployment and detonation, at minimum.

5.3 <u>Voice Channel</u>

Voice is used to provide a real time narration of all events that take place at the test site during the test. Either an input channel on the data recorder or the memo channel may be used for this purpose. Voice recording data must be transferable to compact disc (CD) format.

5.4 <u>Site Description</u>

A description of the test site should include, length and width of the test track, position of test track markers, composition of the track, size and type of vegetation or ground cover, type of soil, type of snow, position of sensors in relation to the test track, and natural barriers. A map or diagram of the site with the proper USGS topographic references should be included. Documentation of the size and scale should be consistent on all diagrams.

5.4.1 Test Track Markers. These are upright position markers that are placed along one side of the test track. Frequently, track markers are numbered with consecutive numbers. The markers are spaced at 50-meter minimum intervals. The marker positions are included in the overall site survey, and are reference points for shallow refraction calibration.

5.5 Vehicle Position Information

Vehicle position will be determined by using differential GPS techniques. It is necessary to use differential GPS for the archiving of data.

5.6 Instrumentation Equipment Description

Description of the equipment and specifications should include manufacturer, model, type, dynamic range, bandwidth, local modifications to the equipment, calibration certificate, and instrument configuration.

5.7 Sensor Orientation

Documentation of the sensor orientation should include the number of sensors, their placement and location

5.8 Vehicle Specifications

Generally, the more information known about the vehicle, the better the interpretation of the signature data. Vehicle specifications should include description, type of engine, fuel used, propeller description, number of rotors blades, odometer reading, type of exhaust system, number of exhaust outlets, size of wheels, number of wheels, number of road wheels, number of points in the star-chain drive sprocket, distance between the track pins, mechanical drawings, number of forward and reverse gears, the number of engines and the manufacturer's specifications, 4-cycle or 2-cycle, and associated gear ratios. Additionally, the tail number and bumper number should be documented. Maintenance records should also be noted as they typically indicate any modifications made to the vehicle.

5.9 Photos and Drawings

Photos and drawings of the seismic sources, the sensor arrangement, and the range setup contribute significantly to the understanding of the test. Close-up photos of the vehicle undergoing exploitation provide invaluable design detail.

5.10 Operator Interview

Interviews with the vehicle operator prior, during, and after the data collection provide details about the operation of the vehicle undergoing exploitation which may not exist in any other form of documentation.

5.11 Survey and Positioning

All ground seismic sensor positions are precisely surveyed so that the location can be referenced to GPS data from stationary and moving vehicles. To determine the location of the vehicles undergoing exploitation, a GPS time-space position system is installed on ground vehicles regardless of travel scenario. These systems are installed in single vehicles and moving convoys. The location of the GPS antenna on the test vehicles should be noted. In cases where data collection systems are geographically separated, satellite clocks are used to ensure that all data is properly synchronized.

5.12 Meteorological (Met) Data

The environment has an effect on the transmission of seismic waves as they move through the soil. Soil moisture content affects how well a geophone couples with the soil. Therefore, it is necessary to make meteorological measurements at the ground surface level. The Met instruments should be in the immediate vicinity of the test site. Met data to be collected include wind speed and direction, surface and soil temperature, soil humidity, barometric pressure, and dew point. Meteorological data sample averages should be determined at intervals not to exceed every 10 minutes. Meteorological data and units are shown in Table 5-1.

TABLE 5-1. METEOROLOGICAL & ENVIRONMENTAL DATA

Met Parameter	Units
Meteorological Station Date & Time	days, months, years, hours, minutes
Wind speed	meters/second
Wind Direction	degrees
Soil & Surface Temperature	degrees Celsius
Dew Point	degrees Celsius
Barometric Pressure	millibars
Soil Moisture Content	percent
Soil Density	kilograms/meter^3

5.12.1 **Meteorological & Environmental Parameter Definitions.**

Barometric Pressure. The actual pressure of the air in the vicinity of the seismic site (millibars).

Meteorological Station Date & Time. The meteorological station date and time the seismic data was collected. The standard Zulu format applies (dd mm yyyy & HH:MM). The use of seconds is optional.

Soil Density. Bulk density of the soil from the immediate vicinity where the geophone is planted (kilograms/meter^3).

Soil Moisture Content. The relative portion of the weight of a sample of soil that is due to moisture (percent).

Soil Temperature. The soil temperature at the geophone planted depth (degrees Celsius). This is a reading on a calibrated thermometer when the sensing element is dry.

Surface Air Temperature. The temperature of the air measured at 30-centimeters above the ground surface. This is the reading on a calibrated thermometer when the sensing element is dry (degrees Celsius).

Wind Speed. The wind speed at the seismic test site; identified as the average wind speed (meters/second).

Wind Direction. Direction from which the wind is blowing measured clockwise from true north (degrees).

APPENDIX A

DEPLOYMENT OF 3-AXIS GEOPHONES IN THE FIELD

Earlier discussions concerning placement of the 3-axis geophone maintained that the sensor would be used as a standard when single axis geophones are deployed. This appendix shows how the 3-axis geophone is employed in typical stand-alone data collection exercises. Four examples are shown:

Figure A-1. Burial of a single 3-axis geophone near the ground surface.

Figure A-2. Burial of two 3-axis geophones near the ground surface.

Figure A-3. Burial of a single 3-axis geophone one meter below the ground surface.

Figure A-4. Burial of 3-axis geophone on both sides of the pathway.

Note: The [A] designation on the geophone cable is used to identify an amplifier.

The geometric design of geophones varies according to the manufacturer. Some seismic sensors have spikes that penetrate the ground. Others are cylindrical in shape and a handle is provided for easier handling at depths of one meter or more.

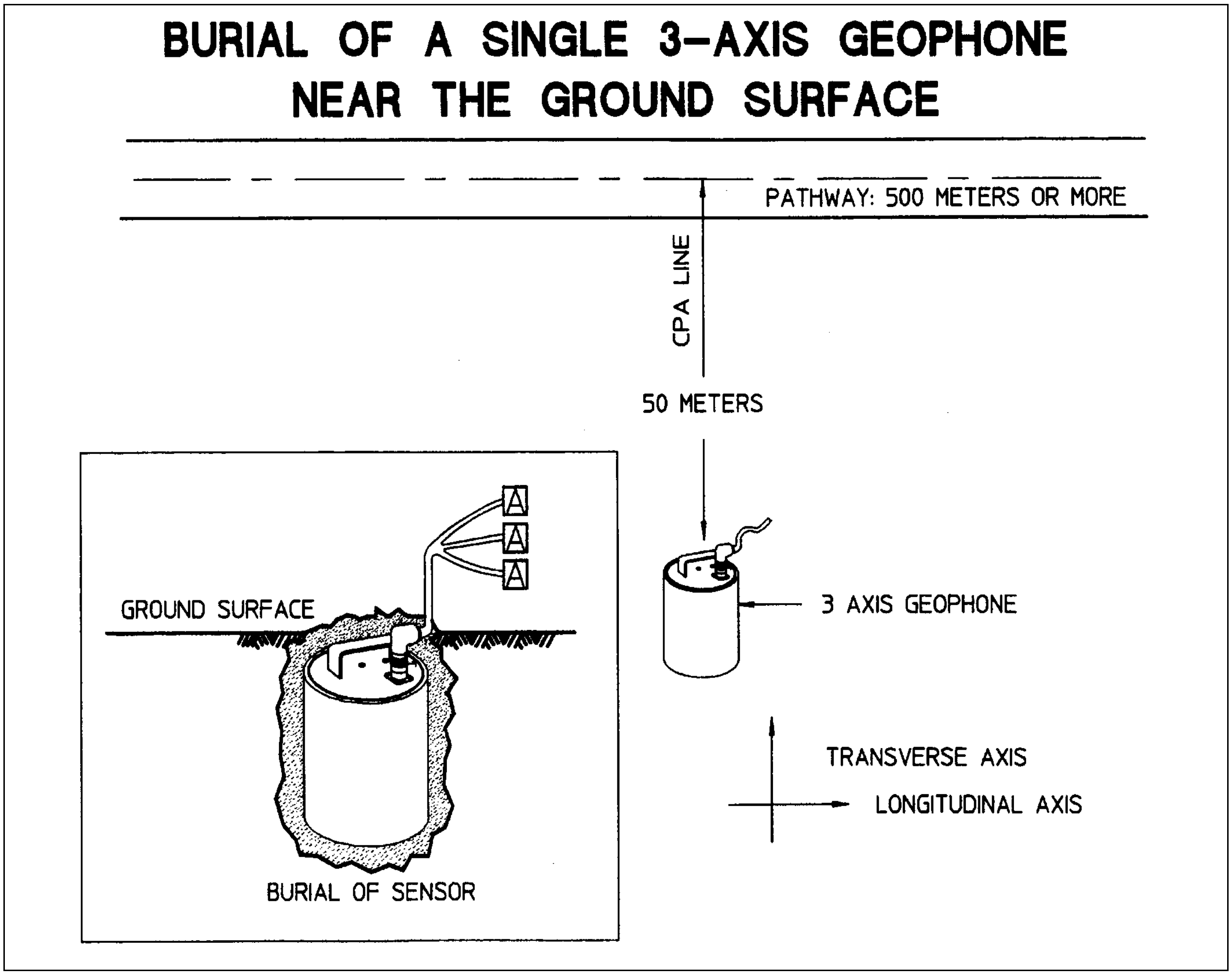

Figure A-1. Burial of a single 3-axis geophone near the ground surface.

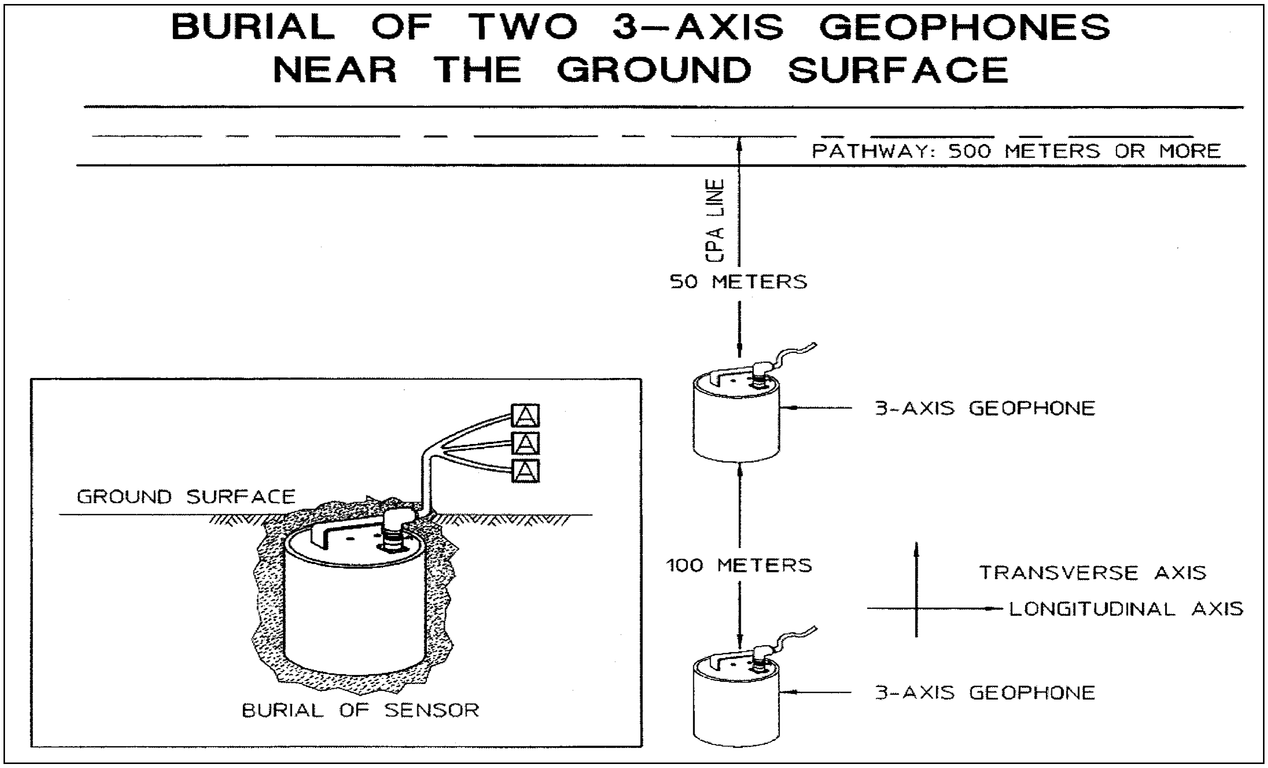

Figure A-2. Burial of two 3-axis geophones near the ground surface.

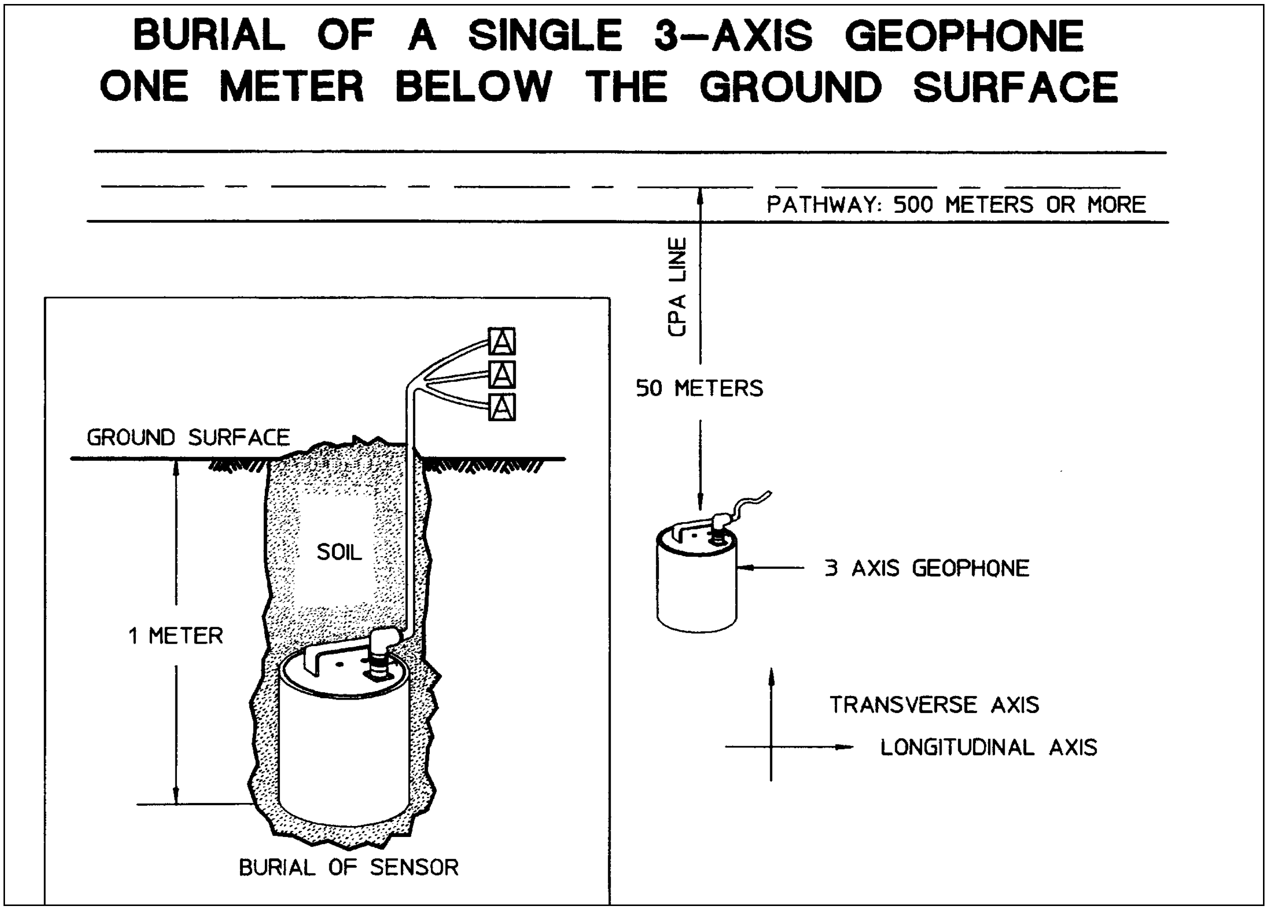

Figure A-3. Burial of a single 3-axis geophone one meter below the ground surface.

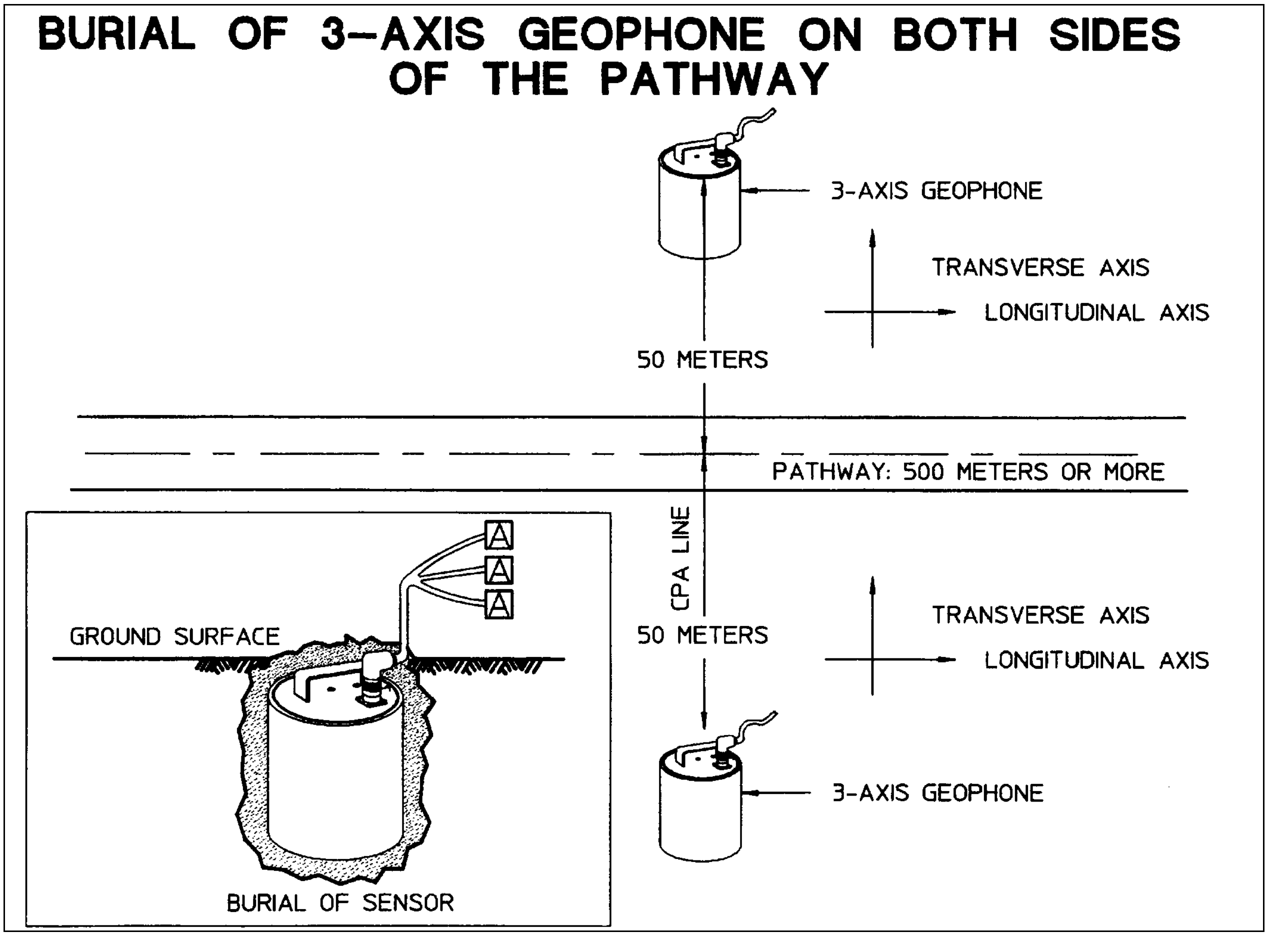

Figure A-4. Burial of 3-axis geophone on both sides of the pathway.