Geophones or Accelerometers?

Introduction

We are regularly asked by potential clients whether they should invest in a system with geophones or accelerometers as seismic sensors for Downhole Seismic Testing (DST) investigations such as the Seismic Cone Penetration Testing (SCPT). In this technical note we want to address this query.

Basic Requirements

The seismic sensor should provide signals which are unaffected by the sensors inherent characteristics and as closely as possible reflect the true soil response to the seismic source wave traveling through it and ambient measurement noise (i.e., input = output). In terms of frequency response of the receiver, its output should be constant for all input frequencies. In addition, the phase of the input frequency should be unaffected so that the wave's shape does not change. In general terms it is desirable to have a seismic sensor with a fast response time and a small settling time.

The response time of the seismic receiver is related to the so-called time constant, which defines how quickly the sensor responds to the input signal. Typically, the sensor's frequency response curves are generated assuming steady state conditions, whereas, in seismic investigations, transient conditions are more commonly encountered. Figure 1 illustrates a typical transient response with the following transient response specifications:

1. Delay time t_d.: the time required for the response to reach half the final value the very first time.
2. Rise time t_r.: the time required for the response to rise from 10 to 90 percent.
3. Peak time t_p. the time required for the response to reach the first peak of the overshoot.
4. Maximum overshoot M_p. the maximum peak value of the response curve measured from unity. If the steady state value of the response differs from unity, then it is common to use the maximum percent overshoot.
5. The amount of the maximum overshoot (percent) directly indicates the relative stability of the system.

Sensor's which are sluggish (i.e., high time constant) cannot keep up with rapidly changing input signals and this characteristic may result in so-called spectral smearing. Spectral smearing occurs when the seismic sensor is unable to record the transient frequency components of the inputted signals resulting in the blending or smearing of ambient noise and seismic wave responses.

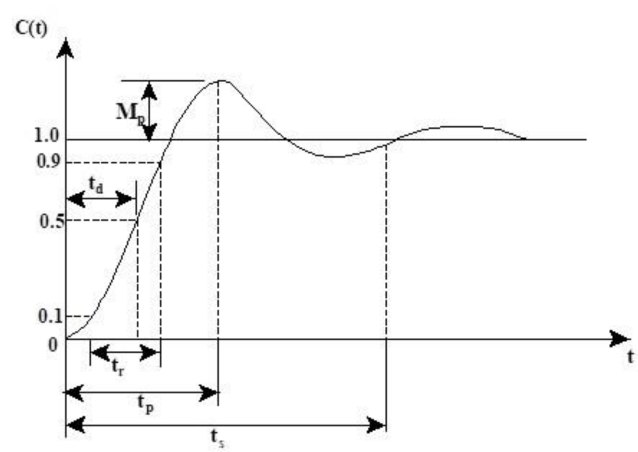

Figure 1: Unit step response curve showing transient response specifications td, tr, tp, ts, and Mp

What is a Geophone

When the geophone case is accelerated, the sensing coil moves with respect to the fixed magnet. The gradient of the magnetic field transforms the relative velocity into an electromagnetic field, which can then be put in series with a load resistor to produce a measurable voltage. The flowing current through the coil generates a linear force, opposite to the direction of motion, that provides a strong mechanical damping effect. The kinematics of a geophone response is described by the classics mass-spring-dashpot 2nd order system.

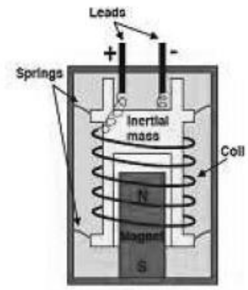

Figure 2: Schematic of a Geophone

What is an Piezoelectric Accelerometer

A piezoelectric accelerometer is an accelerometer that employs the piezoelectric effect, i.e. the characteristic of certain materials to generate voltage when deformed, to measure the acceleration. The high modulus of elasticity of piezoelectric materials cause them to react to compression, but with minimal deflection (resulting in high linearity).

The designs BCE uses consist of sensing crystals that are attached to a seismic mass. A preload ring or stud applies a force to the sensing element assembly to make a rigid structure. Under acceleration, the seismic mass causes stress on the sensing crystals which then results in a proportional electrical output. This design results in highly desirable 5us rise and decay times. In addition, piezoelectric accelerometer have maximally flat frequency response curves with ranges that can exceed 0.5 Hz to 10 KHz.

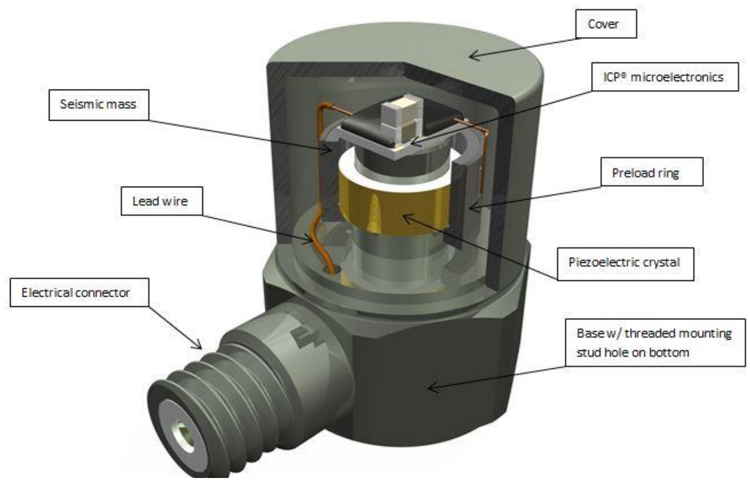

Figure 3: Schematic of a Piezoelectric Accelerometer

What is the difference between Geophones and Accelerometers

Geophones have larger peak times and settling times compared to high precision piezoelectric accelerometers with integrated amplifiers; therefore, they tend to be more susceptible to spectral smearing. Fig. 4 illustrates an example of spectral smearing for recorded SH source waves from a downhole investigation, which makes it very difficult to digitally separate the desired seismic SH-wave from the ambient noise.

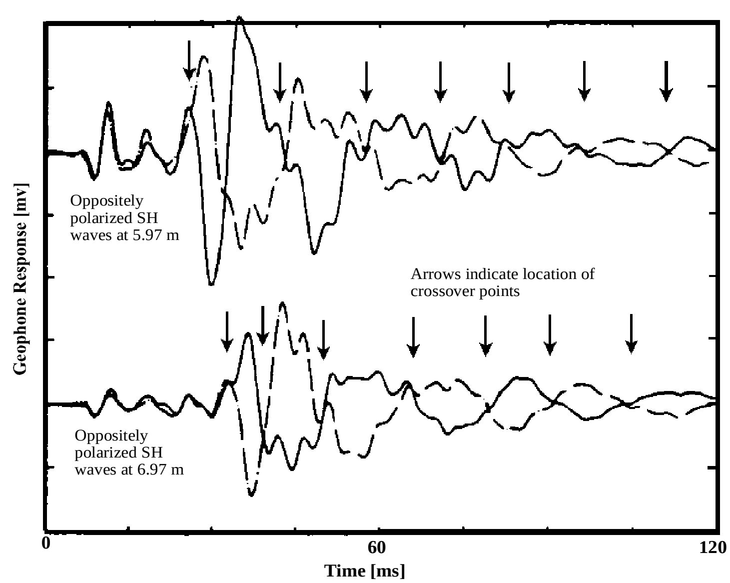

Figure 4: Downhole seismic time series data obtained with a geophone and a 300Hz analog filter applied. This time series illustrates the difficulty in obtaining crossovers due to spectral

So while both geophones and accelerometers are acceptable for downhole seismic investigations, high precision piezoelectric accelerometers (operational amplifier integrated into sensor) are preferable due to their low noise, fast response times, and high bandwidths compared to geophones as is shown in Fig. 5. In general terms, accelerometers typically have highly desirable rise and decay times (in the order of 5 μs), and these characteristics ensure recorded traces with minimal or no sensor distortion (input = output).

However, if geophones are to be utilized it is mandatory that they have sufficient bandwidth (i.e., maximally flat frequency response curves where there is no more than 5% variation over a range of frequencies consisting of the ambient noise and source waves of P, SV, and SH.). This ensures that the geophones capture the desired source waves and background ambient noise without distorting or filtering these signals. In addition, the geophones should not be heavily damped so that spectral smearing does not occur. To increase the sensitivity of the geophone arrays, they can be installed as multiple sensing elements arranged on orthogonal axes.

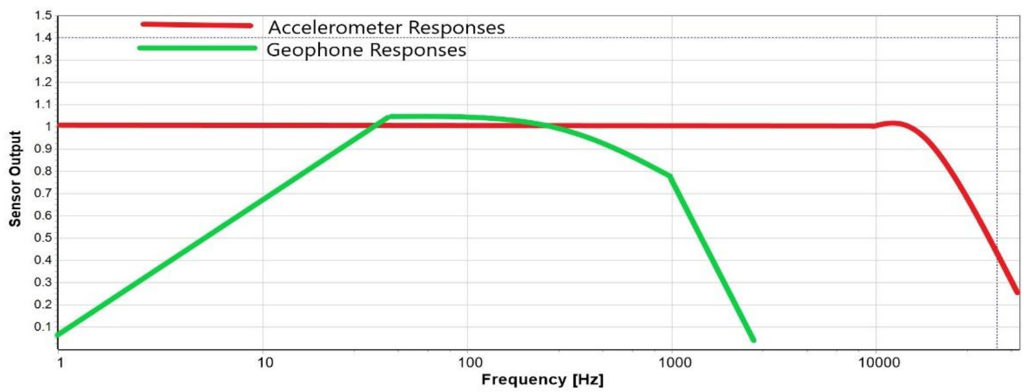

Figure 5: Typical frequency response curves for geophones and accelerometers

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