Evaluation of 3C sensor coupling using ambient noise measurements
Howard Watt, John Gibson, Bruce Mattocks, Mark Cartwright, Roy Burnett, and Shuki Ronen
Veritas Geophysical Corporation

Summary
Good vector fidelity is crucial for various multicomponent applications and can be adversely impacted by poor sensor coupling during data acquisition. We present a method to evaluate the ground coupling quality of three-component (3C) sensors during field deployment using ambient seismic noise data. The method utilizes the directional nature of the noise on the three sensor components for coupling assessment. This is believed to be the first method developed to evaluate in situ sensor coupling from ambient noise measurements.
Introduction

Achieving good vector fidelity is crucial for various three-component (3C) applications including AVO studies, azimuthal anisotropy analysis and polarization filtering. Vector fidelity may be compromised by variations in sensor element sensitivity, deviations from element orthogonality and particularly by poor sensor coupling. 3C MEMS (Micro Electro Mechanical System) sensor manufacturers report vector fidelity exceeding 40 dB as determined from laboratory tests. It is our assertion that the quality of sensor coupling is the primary factor ensuring good vector fidelity.

It is standard practice to acquire passive noise records prior to seismic production recording to establish whether ambient noise is below an acceptable level. In evaluating ambient noise records from a 3C project with poor ground coupling conditions, we observed that ambient noise levels on the two horizontal components were often 6-12 dB higher than noise on the vertical component. Comparative behavior of the RMS amplitudes of various sensor components are shown for an area with typical sensor planting conditions (Figure 1a) and an area with locally poor sensor planting conditions (Figure 1b). Note the large distribution of H1 (inline horizontal) and H2 (crossline horizontal) values in Figure 1b relative to Figure 1a. Such behavior is inconsistent with typical field noise observations. As a result, controlled field tests were conducted to compare 3C ambient noise levels on the three sensor components under various coupling conditions.

Field Test Methodology

Figure 2 shows a schematic using three qualitative descriptions “standard”, “tight but elevated”, and “loose” to describe variations in sensor planting quality that have been observed in practice. “Standard” (Figure 2a) refers to the normal deployment method of drilling a hole with a slightly smaller diameter than the sensor body and placing the sensor body in the hole, up to its base. “Tight but elevated” (Figure 2b) refers to a sensor planted with its base approximately 1.5 inches above the ground surface and “loose” (Figure 2c) refers to a situation where it is easy to rotate or wobble the sensor. Such variations can result from frozen or rocky ground, gravelly or sandy soil conditions and the presence of scree and loose sand.

To test whether sensor coupling quality can be determined from 3C ambient noise records, we conducted experiments in three USA locations, two in Texas and one in Utah. Figure 3
illustrates one such experiment. During each test a significant number of ambient noise measurements were taken using 64 to 100 3C sensors. These measurements were taken over an extended period of time ranging from two hours to two days. Such measurements included the presence of both random and coherent noise. Strong coherent (and directional) noise will unduly influence amplitude measurements on the various elements and will need to be appropriately addressed in the analysis.

Figure 2. Schematic diagram of sensor deployment situations. a) “Standard” deployment, b) “Tight but elevated” deployment. c) “Loose” deployment.

Figure 3. Typical test layout showing the various deployment types. Inset shows an example of a “Tight but elevated” sensor.

Data Analysis

An initial analysis was based on comparing Root-Mean-Square (RMS) levels of ambient noise for the three sensor components hereafter referenced as V (vertical), H1 (inline horizontal) and H2 (crossline horizontal). For isotropic ambient noise and well-coupled sensors, we expected the ambient noise levels on the three components to be comparable. Noise records from well-coupled receivers, however, often show that ambient noise on the horizontal elements tends to be mildly reduced relative to that on the vertical element. Figure 1a) illustrates typical results from this approach.

Early in the initial analysis it became clear that the results were sensitive to the presence of coherent noise and noise bursts and therefore to the choice of data analysis window. Effective field implementation will not allow the seismic observer overseeing production operations to experiment with data windows. As a result, a decision was made to abandon the windowed-RMS approach and look at ambient noise data distributions as a means of mitigating the impact of coherent noise.
Each 3C ambient noise data sample can be viewed as a three-dimensional vector with components (H1, H2 and V) as shown in Figure 4(a). Following vector normalization by the magnitude as depicted in Figure 4(b), each sample unit vector can be described by its polar (\(\phi\)) and azimuthal (\(\theta\)) angles. This normalization has the benefit of reducing the impact of vectors with anomalous amplitudes.

Applying this representation to synthetic data having Gaussian distributions for each of the vector coordinates yields the spherical and angular plots shown in Figure 5. Note the uniform distribution of data points on the unit sphere (Figure 5a) and for the angular display (Figure 5b). This simply shows the two modes of display to be employed.

Figure 6 shows spherical displays for a field data comparison between “standard” and “loose” sensors for two different “loose” deployments. Note the rather uniform distribution of data points on the unit sphere for the “standard” (Figure 6a) case in contrast with the clustering of data points about the equator in the “loose” cases (Figures 6b and 6c). The situation in Figure 6c is quite extreme as the sensor is known to be “very loose”. Though no figure is shown for it, the “tight but elevated” case proves to be very similar to the “standard” case using spherical representations.
Figure 7 shows comparative angular representations for “standard”, “tight but elevated”, “loose” and “very loose” deployments. In this view, the angular representations of “standard” (Figure 7a) and “tight but elevated” (Figure 7b) are more distinguishable than when using spherical representations.

**Conclusions**

Sensor coupling is a critical issue for preserving vector fidelity which is important for a number of multicomponent applications. Ambient noise measurements taken prior to any production recording can be analyzed to evaluate sensor coupling and to effect the necessary remediation. A methodology for field application has been developed.