Geophone orientation, location, and polarity checking for 3-C seismic surveys

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ABSTRACT

A method to compute geophone orientation and location is introduced. This method analyses the horizontal components of 3-C geophones and estimates the azimuth of the source with respect to the geophone. Based on these azimuths for several shots, a solution for the true geophone orientation and location is determined.

INTRODUCTION

A major delay in laying out 3-C seismic programs is the task of correctly orienting the 3-C geophones. This requires considerable time and care in the field, leading to higher costs. Miswiring or misconnection of geophones can also lead to data unknowingly having a reversed polarity. This too leads to data error. A correctly oriented geophone could also be used to check for source-receiver geometry. It would be very useful to have a technique that could allow arbitrarily oriented geophone deployment which would also determine the orientation, polarity and geometry of the geophone. Such a procedure is important in 2-D as well as 3-D multicomponent surveying. This paper proposes a technique to do such an analysis.

THEORY

Orientation error and trace reversal

There are many assumptions that could be made with respect to the geophone orientation problem: That the geophones are level, that the elements have equivalent output, that they are "welded" or totally coupled to the ground surface. In this discussion we shall assume that the geophone is correctly located but incorrectly oriented. Since geophone locations are usually confirmed by survey measurements one finds that poor geophone orientation is more common than incorrect geophone placement. Even experienced 3-C acquisition crews have difficulty orienting geophones with less than 10 degrees error.

Given a single shot and a single 3-C geophone, one would expect that the shot azimuth could be determined by analysing the signal from the two horizontal elements. Assuming this is possible, one can then compare the observed shot/receiver azimuth to the shot/receiver azimuth based on the survey geometry and obtain a value for the angular orientation error (Figure 1.).

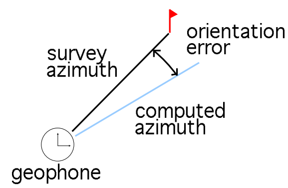

Fig. 1. Orientation error is computed from the shot/receiver azimuth based on the azimuth dictated by the survey geometry and the azimuth computed from H1 and H2 geophone elements.

Using data collected from a number of shots, one can obtain a mean value for the orientation error and the associated standard deviation. These values can be used to infer information about the quality of phone plants and determine polarity reversals (Table 1).

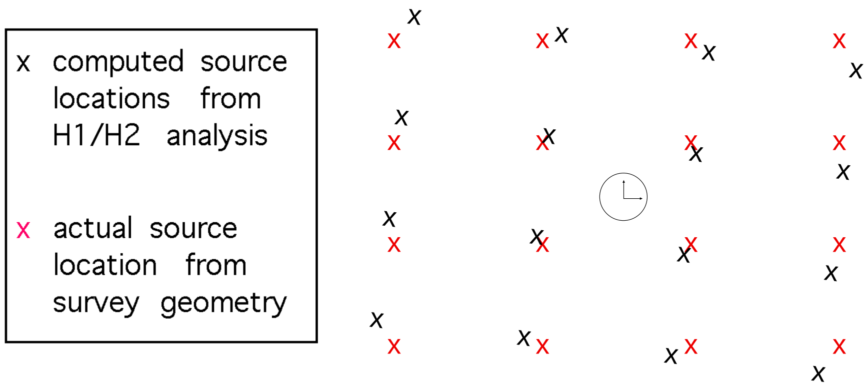

Fig. 2. A poorly oriented geophone causes a statistically consistent rotation in computed shot azimuth.

Approximate orientation error (degrees)	Standard deviation	Diagnostic
0	low	normal phone plant
90 or -90	low	geophone improperly oriented
90 or -90	high	reverse polarity on H1 or H2
180	low	geophone improperly planted
180	high	reverse polarity on both H1 and H2

Table 1. Diagnostic for a single geophone inferred from orientation errors statistics gathered for several shots.

Location error

In the discussion of orientation error the assumption was made that all source/receiver azimuth errors are due to poor geophone orientation. Let us consider the case for geophones that are correctly oriented but improperly located. Assuming that one can obtain a reasonable estimate of the source/receiver azimuth, the geophone location should be obtainable. Using the azimuth from several shots to a single geophone (Figure 3) the location of the geophone can be determined by triangulation. Ideally, only three shots would be required for this triangulatation, however variations in near-surface weathering will affect the accuracy of computed azimuths. To obtain a better estimate, a larger number of shots would be used to reduce the uncertainty of the computed geophone location. Even if the location could not be determined with sufficient accuracy, it should be possible to determine whether a geophone is grossly misplaced, since the horizontal polarity is reversed on either side of a shot point.

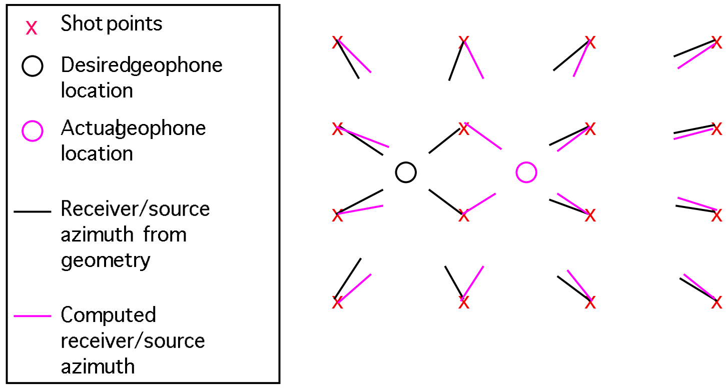

Fig. 3. The computed azimuth from multiple shots to a single receiver is used to determine geophone location.

Automatic geometry

Aided by the additional azimuth information provided by 3-C geophones and multiplicity inherent in 3-D seismic, it may be possible to determine several, or even all of the following parameters:

- geophone location
- geophone orientation
- shot point location

We can relate the geophone and source location using the equation,

$$\mathbf{G} + \mathbf{G}_e + d\begin{bmatrix} \sin(\phi+\phi_e) & -\cos(\phi+\phi_e) \\ \cos(\phi+\phi_e) & \sin(\phi+\phi_e) \end{bmatrix} = \mathbf{S} + \mathbf{S}_e \tag{1}$$

Where:

G is the geophone location vector in Cartesian coordinates
$\mathbf{G}_e$ is the error in geophone location
d is the source/receiver offset
ϕ is the source/receiver azimuth
ϕ_e is the geophone orientation error
S is the shot point location vector
$\mathbf{S}_e$ is the error in shot point location

Although there are several unknowns, a 3-D seismic survey provides enough multiplicity of observations to compute many of these parameters. For instances with few source points or geophones on the perimeter of a receiver patch, it may prove too ambitious to solve for all parameters given no *apriori* geometry.

IMPLEMENTATION

All the techniques that have been described to this point presume that it is possible to obtain a good estimate of the source/receiver azimuth based analysis of the horizontal components only. Using data acquired from the Blackfoot 3C-3D experiment, we have started to examine the validity of this assumption.

A preliminary technique used to obtain an estimate for the source/receiver azimuth is based on the observation that most of the horizontal energy from an explosive source radiates outward from shot point. This is apparent after rotating H1 and H2 signals into radial and transverse components – there is typically much more source energy in the radial component than the transverse component. Plotting unrotated amplitude values from the H1 component versus (north/south) versus the H2 component (east/west) we expect to see sample points fall along a straight line (Figure 4). Rather than use the entire trace, which could be influenced by off-axis reflections, only samples within a short (1-2 cycle) time window are used. Our early tests used a time window starting at the first break time picked from the *P*- wave arrival on the vertical channel. After plotting the samples in the time window, the source/receiver azimuth was then obtained from the angle of the best fit line through the sample points. One unfortunate problem with this technique is that the resulting angle is ambiguous, since the best fit line could be pointing toward, or away from the source.

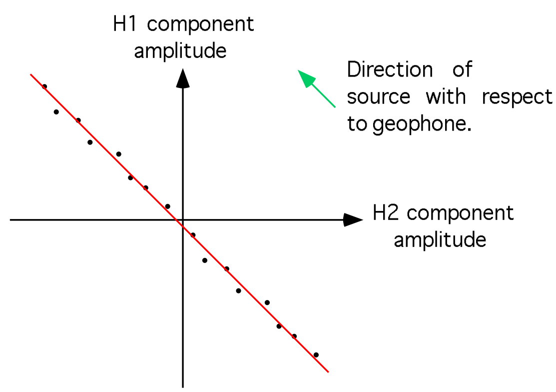

Fig. 4. Expected correlation between H1 (north/south) and H2 (east/west) components of a 3-C geophone when perturbed by the first arrival from a single shot.

Using this simple technique, we found little correlation between the computed source/receiver azimuths based on H1/H2 analysis and the true source/receiver azimuths based on survey geometry. Since work on this problem is still in its early stages, it is difficult to draw conclusions from this single experiment. Possible explanations for this result are:

- Vertical component leakage into the horizontal components, either electrically or from small inclinations in the geophone plant. Due to the steepness of the first arrival, the signal amplitude on the vertical component is almost an order of magnitude greater than of the horizontal components. This may be interfering with the observed response on the horizontal components.

- First arrival *P*- wave energy may not be polarized along the source/receiver plane.

- Although unlikely, an error may exist in geometry or component sequence of the test dataset.

Clearly, more work is required to determine if the problem of computing a source/receiver azimuth is limited to this dataset or this technique. If the first arrival is not polarized in-line with the source/receiver azimuth, we need to examine if the source/receiver azimuth can be extracted from later wavefront arrivals.

CONCLUSIONS

The implications of developing a technique for automatic geometry are great. Correctly planting and orienting 3-C geophones requires a great deal of time. If a rigorous method for determining geophone orientation can be found, it would considerably reduce field expenses. This will be the primary goal for ongoing work. If this goal can be accomplished, we will pursue the greater challenge of fully automatic geometry using the same technique.

REFERENCES

DiSiena, J.D. and Gaiser, J., 1984, in eds. Toksoz, N. and Stewart, R.R., Vertical seismic profiling: Advanced concepts: Geophysical Press.