

The Effect Of Geophone Specifications On Vector Fidelity

C. A. M. Faber, H. A. Laroo

Input/Output, Inc. Sensor Nederland b. v., Rouwkooplaan 8, 2251 AP Voorschoten, the Netherlands



Summary

A theoretical model was developed to quantify the intrinsic vector fidelity of a geophone. Results from the model were compared with actual test data which was acquired on a low distortion shake-table.

A special test fixture was designed containing 30 conventional geophones: 24 geophones positioned horizontally at 30 degree azimuthal increments and 6 geophones oriented vertically. This Multi Azimuth Test Jig (MATJ) was then positioned on a horizontal low distortion shake-table in various rotated and tilted positions. The response of all of the geophones to a swept sine wave input was recorded using a conventional seismic recording system. The table acceleration and the pilot sweep signal were recorded on auxiliary channels as reference signals.

Both time domain and frequency domain analysis were performed on the recorded data. Results show a good comparison between our theoretical model of geophone vector fidelity and the measured data.

Introduction

Three component geophones generally consist of three individual geophones mounted orthogonally inside one protective case. The two horizontal geophones are identical and the vertical geophone is only different in its spring characteristics. Nominal specifications are the same for all three geophones. Tilt specifications may be different. The objective of a three component geophone is to convert a complex three component ground motion into three separate electrical signals.

The vector fidelity of the particle motion (magnitude and direction) is determined by:

- a) the geophone sensitivity (S) in the passband of the sensor
- b) the geophone natural frequency (F_n) and geophone damping constant (D) determine the overall transfer function resulting in a frequency dependent sensitivity
- c) the cross-axis sensitivity of the geophone
- d) the coupling of the geophones to the outer case and also the case to the ground
- e) the orientation of the actual geophone with respect to its intended orientation. This includes the planting orientation in the field as well as the orientation of the individual sensors inside the outer case.

The three component particle motion vector has an amplitude and a direction at any given time. The response on each axis can be transformed into amplitude and phase spectra.

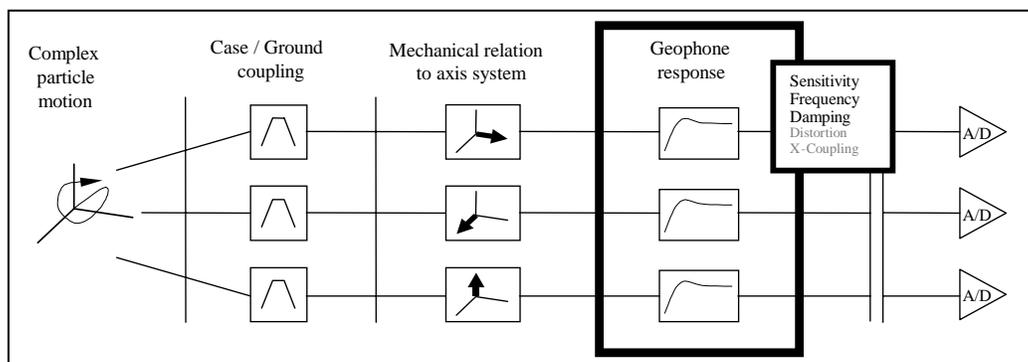


Figure 1

We limit the scope of our investigating to the effects of 1) and 2) therefore focusing on the basic sensor unit however the measured data does include the effects of geophone distortion, cross-axis sensitivity and imperfections of MATJ and shake table.

Sensitivity

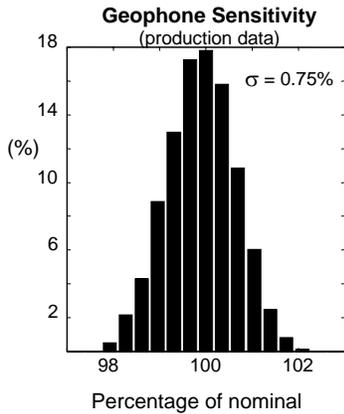


Figure 2

Let's now look at the influence of vector variations caused by the statistical distribution in geophone sensitivity only.

In our model we position two horizontal geophones at exactly 90 degrees to one another. We then apply a rectilinear motion to those geophones within the same horizontal plane.

We can calculate the direction of the applied rectilinear motion from the individual signal amplitudes using:

$$\varphi = \arctan (A_x/A_y)$$

To obtain realistic and meaningful numbers we do not use the extreme geophone specification limits (of +/- 2.5%) but will use normally distributed sensitivity data from our manufacturing (see figure 2)

Amplitude variations due to sensitivity differences of the geophones will have more or less effect depending on the angle of incidence. (i.e. a large sensitivity error in the cross-line geophone will have a small effect on in-line incident and vice versa). By calculating φ for random angles between 0 and 90 degrees we get a good statistical view on the errors that occur.

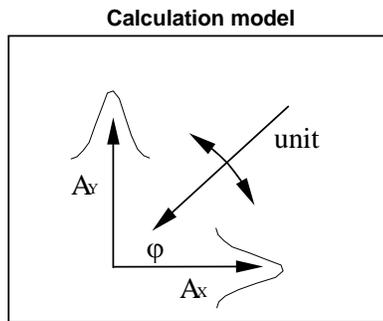


Figure 3

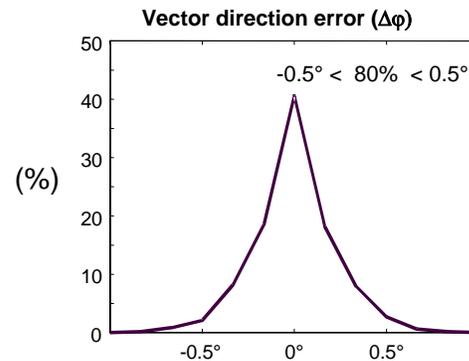


Figure 4

Frequency and Damping

The transfer function of a given geophone is primarily determined by the natural frequency (F_n) and the damping coefficient (D) of the mass-spring system. Variations in the natural frequency and damping coefficient distort the transfer function most near the natural frequency.

If we want to calculate the vector angle using the amplitude of two randomly picked geophones positioned at 90 degrees we will observe a larger error around the nominal natural frequency of the geophone due to the large relative variations.

Vector fidelity around F_n will be worse.

Only three component sensors using geophones with identical F_n and D specifications maintain consistent vector fidelity over the full geophone bandwidth.

Laboratory shaker verification test

The Multi Azimuth Test Jig (MATJ) that was used contains two levels of 12 conventional horizontal geophones at an azimuthal separation of exactly 30 degrees. The center of the jig contains 6 vertical geophones.

A separate reference geophone was mounted in line with the main shake axis.

A large number of records (50 records of 31 traces) was taken using sweeps over the full geophone bandwidth at various drive levels. The MATJ was put in 6 positions during all these tests:

- in-line; flat, 5 degrees and 10 degrees tilt.
- rotated in azimuth by 45 degrees; flat, 5 degrees and 10 degrees tilt. (see figure 5)

The design of the MATJ and the “in-line” and “45 degrees” rotation provides an overall azimuthal coverage/resolution of 15 degrees. Further to this, the 5 and 10 degrees tilted position allowed us to examine the effect of tilt on the geophone performance and consequently the vector fidelity.

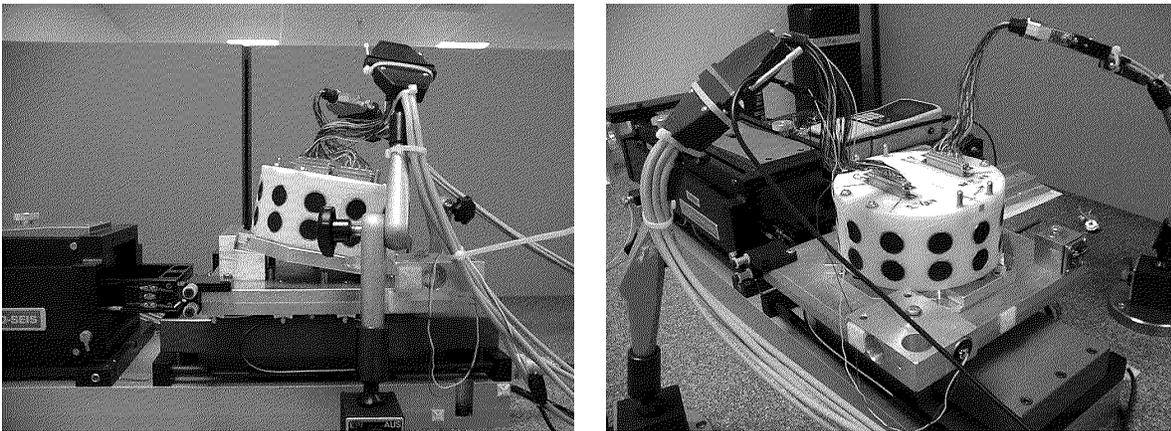


Figure 5

Calculation methods used

1) A time correlation method was applied to cross-correlate all geophone signals over the seismic bandwidth with a reference signal. This reference signal was the independent in-line geophone reference on the shaker.

The auto-correlation maximum of the reference was compared with the cross-correlation maximum of reference signal and individual MATJ geophone under test. The ratio between both maxima was then converted into angle using the *arccos* function.

2) To simulate the response of a rectilinear motion on three component geophones the individual MATJ geophones were grouped in 12 x three component geophone sets. Each orthogonal set of geophones was used to calculate the rectilinear motion vector.

The difference between the expected vector direction and the measured/calculated direction are plotted in figure 6. The results show good similarity with the theoretical values of figure 4.

The differences can be explained by:

- a) Natural frequency (F_n) and damping (D) effects on the sensitivity
- b) Geophone performance degradation due to tilt
- c) Geophone distortion
- d) Geophone x-axis sensitivity
- e) Shake table distortion and cross-axis movements

However it can be observed that approximately 80% of all calculated incident angles are within +/- 1 degree of the actual direction.

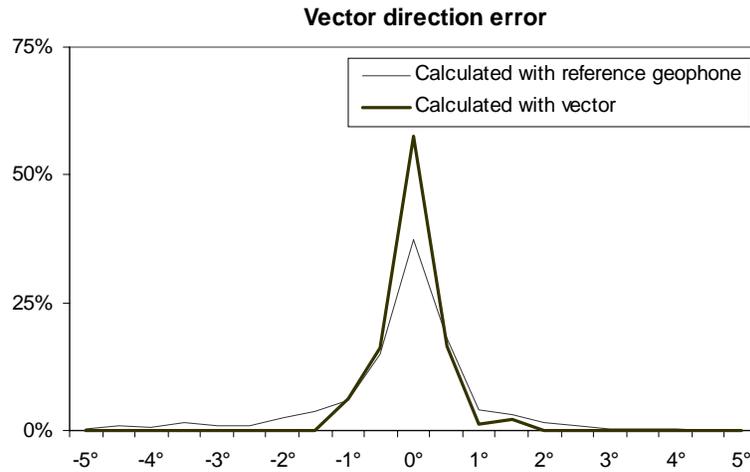


Figure 6

Conclusions

The MATJ contains 12 three component geophones, all in one sensor enclosure.

Data has been collected using various sweeps with MATJ in 6 orientations (tilted & rotated)

We have demonstrated that with conventional geophones we are able, under realistic conditions (up to 10 degrees tilt, full seismic frequency bandwidth and wide azimuthal distribution), to accurately determine the vector direction of a rectilinear motion (-1 degree < 80% < + 1 degree).