The importance of geophone emplacement for onshore seismic surveys

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SUMMARY

One of the inherent requirements for a successful onshore seismic survey is to ensure that ground motion is measured accurately. Our ability to record ground motion is greatly affected by the inherent response of the geophone and its coupling to the ground. Most practitioners are familiar with the natural (resonant) frequency and damping of geophone elements. Less well known, is that coupling also has a resonant frequency. If a geophone is inadequately coupled then this resonant frequency can appear in the bandwidth of interest. Unlike the natural frequency of a geophone, however, this variation of natural frequency with coupling can result in the output of the geophones varying across the survey area if the coupling varies.

Complicating the identification of coupling effects is the influence of ambient noise. Wind noise, for example, predominantly occurs from the wind moving surrounding vegetation which creates noise that is transmitted through the ground. As better coupling improves the ability of the geophone to record ground motion, then it necessarily also results in an apparent increase in transmitted wind noise. Better coupling, however, also improves the strength of the signal component and thus the SNR of the data improves.

Improving the coupling of geophones often involves burying them, which obviously requires additional time and therefore expense. The question, therefore, is if the additional expense taken to improve geophone coupling is worthwhile, and are there alternative approaches to reducing ambient noise? As part of a recent survey we conducted an experiment using a variety of differently coupled geophones. The results, from both shot records and stacks, show that data quality is significantly enhanced from burying the nodes, either partially or completely, rather than placing them on the surface.

Key words: 1 to 5 key words separated by commas. These will assist in cross-indexing of the article.

INTRODUCTION

One of the inherent requirements for a successful onshore seismic survey is to ensure that ground motion is measured accurately. Our ability to record ground motion is greatly affected by the inherent response of the geophone and its coupling to the ground. Most practitioners are familiar with the sensitivity, natural (resonant) frequency, and damping of geophone elements. Less well known, is that coupling also has a resonant frequency (Hoover and O'Brien, 1980; Krohn, 1984). If a geophone is inadequately coupled then, along with a decrease in sensitivity, the resonant frequency can appear in the bandwidth of interest and thus degrade the high frequency response. Unlike the natural frequency of a geophone, however, this variation of natural frequency with coupling can result in the output of the geophones varying across the survey area if the coupling varies due to different surface conditions (Bagaini and Barajs-Olalde, 2007).

Complicating the identification of coupling effects in field data is the influence of ambient noise. Wind noise, for example, predominantly occurs from the wind moving surrounding vegetation which creates noise that is transmitted through the ground (Dean et al., 2015). As better coupling improves the ability of the geophone to record ground motion, then it necessarily also results in an apparent increase in transmitted wind noise. Better coupling, however, also improves the strength of the signal component and thus the SNR of the data improves.

Although relatively minor, wind noise can also be induced directly on Geophones through the movement of the geophone case by the wind. Coney and Krumhansl (2007) suggested using shields over the geophones, either hard shields, or an acoustically absorbing material. Previous studies have found, however that placing buckets over the sensor to shield them from the wind, actually increases the level of noise (Dean et al., 2018).

Improving the coupling of geophones often involves burying them, which obviously requires additional time and therefore expense. The question, therefore, is if the additional expense taken to improve geophone coupling is worthwhile, and are there alternative approaches to reducing ambient noise? As part of a recent survey we conducted an experiment using a variety of differently coupled geophones. We begin by describing our field procedure, then we describe our analysis techniques before showing some results. We finish by discussing the implications of our result, particularly in light of recent developments in node technology.

FIELD PROCEDURE

The field test involved different methods of emplacing nodes with the intent to improve coupling and/or reduce wind noise. The micro-geometry is shown in Figure 1a, the 'production nodes' were buried in the ground to approximately half their height. Between each production node we also placed:

1. Fully buried node.
2. Node on the surface
3. Node on the surface with a foam noise attenuator ('MUTS') placed on top.
4. Node on the surface with a bucket placed on top.

This layout pattern was repeated 10 times at ~100 m spacing perpendicular to a source line (the macro geometry is shown in Figure 1b).

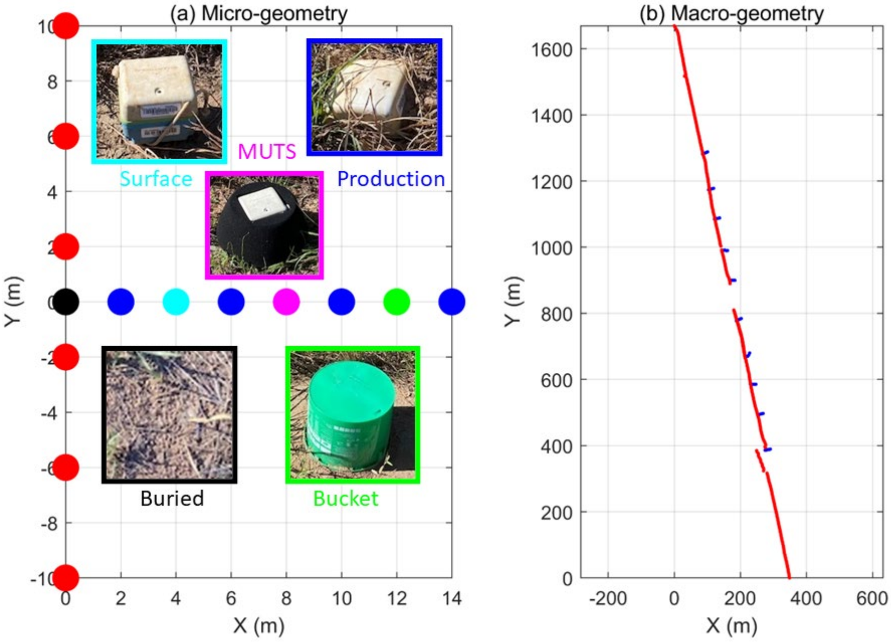

Figure 1. (a) Test micro-geometry, the colour of each photo surround corresponds to the colour of its position marker on the diagram. (b) Macro-geometry with the source points in red and the receivers in blue.

DATA ANALYSIS

Ideally, we would calculate a single metric (ideally SNR) to enable comparison of the various datasets. A simple method to calculate the SNR is to estimate the signal by taking the maximum amplitude in a time window centre on the first-break and the noise as the RMS in a window above the first breaks (e.g. Dean et al., 2010). This process is illustrated using a Ricker wavelet and different noise levels in the left panel of Figure 2. When the signal is weak, the estimated signal value tends to be larger due to the additive affect of the noise (the noise is unaffected as the calculation window is outside that of the first break) but when the signal can be clearly identified, the approximation is adequate. The same process applied to the field data acquired here shows that the process is difficult to apply. For the near offsets, where the signal is strongest, the data is dominated by harmonic noise and thus the SNR cannot be calculated. At farther offsets (>600 m), where random noise becomes dominant, the signal strength is too low to give a meaningful SNR value (we are able to distinguish it as signal only because our eye can follow the linear event).

Bakulin et al. (2022) compared multiple SNR calculation techniques and recommend the use of a semblance-based method for noisy data. The methods they discuss, however, rely on the event to be flattened prior to calculation, something that is not always possible for noisy data. Instead, we calculated the velocity spectrum (Yilmaz, 1987) but with the measure of coherency being the stacked energy rather than the stacked amplitude (SNR is conventionally defined as the ratio between signal energy and noise energy) and using LMO rather than NMO velocities. An example of using this approach is shown in Figure 3, interestingly, even when the signals cannot be easily discerned by eye (SNR = -3 dB), they are identifiable on the velocity spectrum.

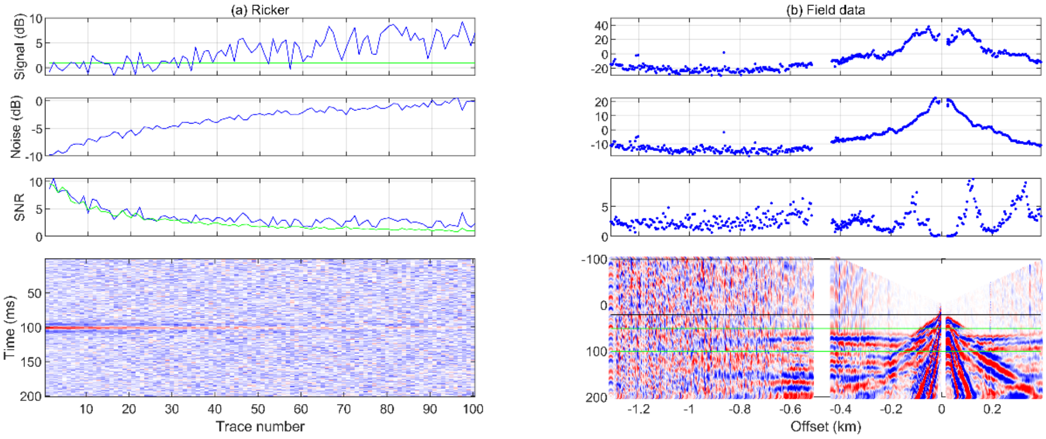

Figure 2. (a) SNR estimation examples using a Ricker wavelet. Where applicable, estimated values are shown in blue and true values in green. Where the signal is identifiable the estimation tends to be valied. (b) SNR estimation using field data. The data has been normalised and a simple LMO correction applied to flatten the first breaks. Green lines indicate the signal window and the black line the bottom of the noise window.

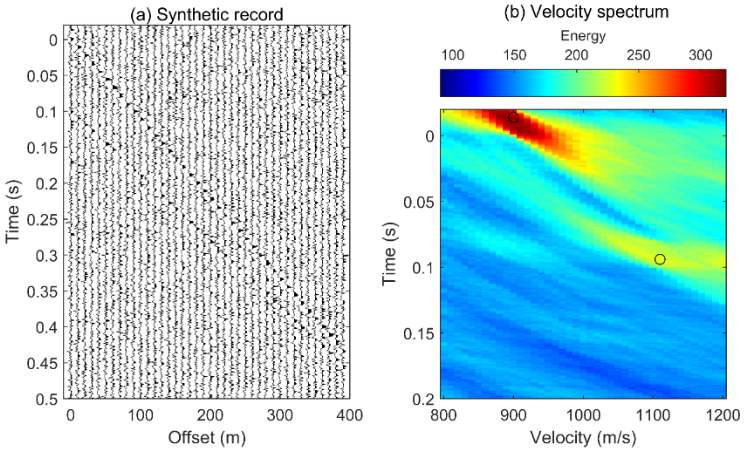

Figure 3. (a) A simple synthetic consisting of two events with SNRs of 0 dB (t_0 = 0 s) and -3 dB (t_0 = 0.1 s). (b) Velocity spectrum of the data. The black circles indicate the positions of the local peaks (which coincide with the actual values).

RESULTS

An example receiver gather from the test is shown in Figure 4. Data quality is good with the first breaks visible to offsets of up to 1 km (the target depth in this case was ~500 m). The sweep employed during the survey had a bandwidth of 1.5 to 220 Hz so the data extends well beyond the likely coupling frequency.

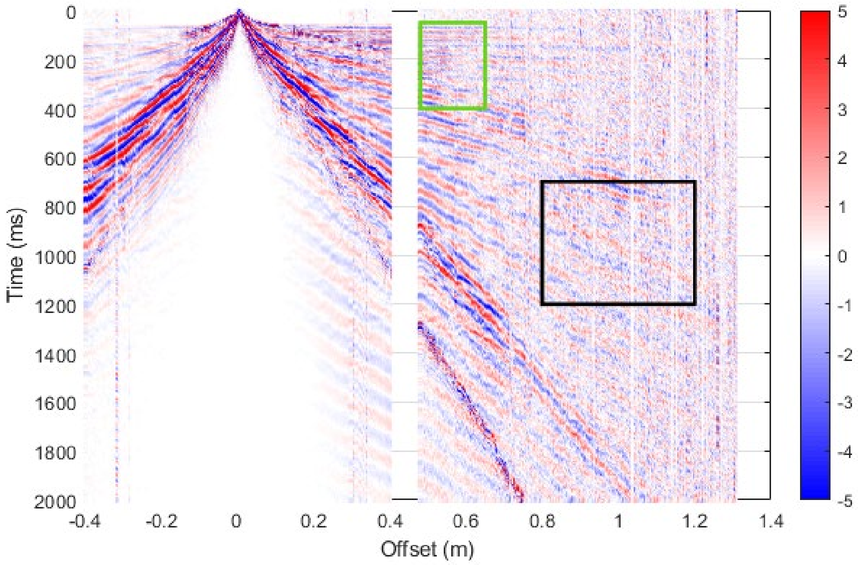

Figure 4. Example of a single receiver gather from the test. The two coloured boxes indicate section of the data that are analysed in a later section.

Figure 5 shows the data (left column) and velocity spectra (right column) of an offset/time window chosen to include several refractors (the green box on Figure 4). The improved quality of the production and buried nodes over the three surface nodes is clearly evident from the data plots. The velocity spectra show two strong events that are clearly enhanced for the buried node data. Comparing the surface nodes, the bucket data appears superior, but the differences are marginal. When the results from the ten different locations are compared, the production/buried node quality are consistently better, with the relative quality of the three surface nodes varying.

The analysis of the deeper section (the black box on Figure 4), shows one clear, strong event which allows straightforward calculation of the SNR by comparing the peak value of the velocity spectrum to the 5th percentile of the velocity spectrum values (noise estimate). The results for the production and buried nodes are 1.4 and 0.7 dB respectively, whilst the surface nodes are -3.8, -3.5 and -1.6 dB (surface, MUTS, and bucket respectively). Again, examination of the data from the other locations shows that the production & buried node data quality was always superior to the surface node data.

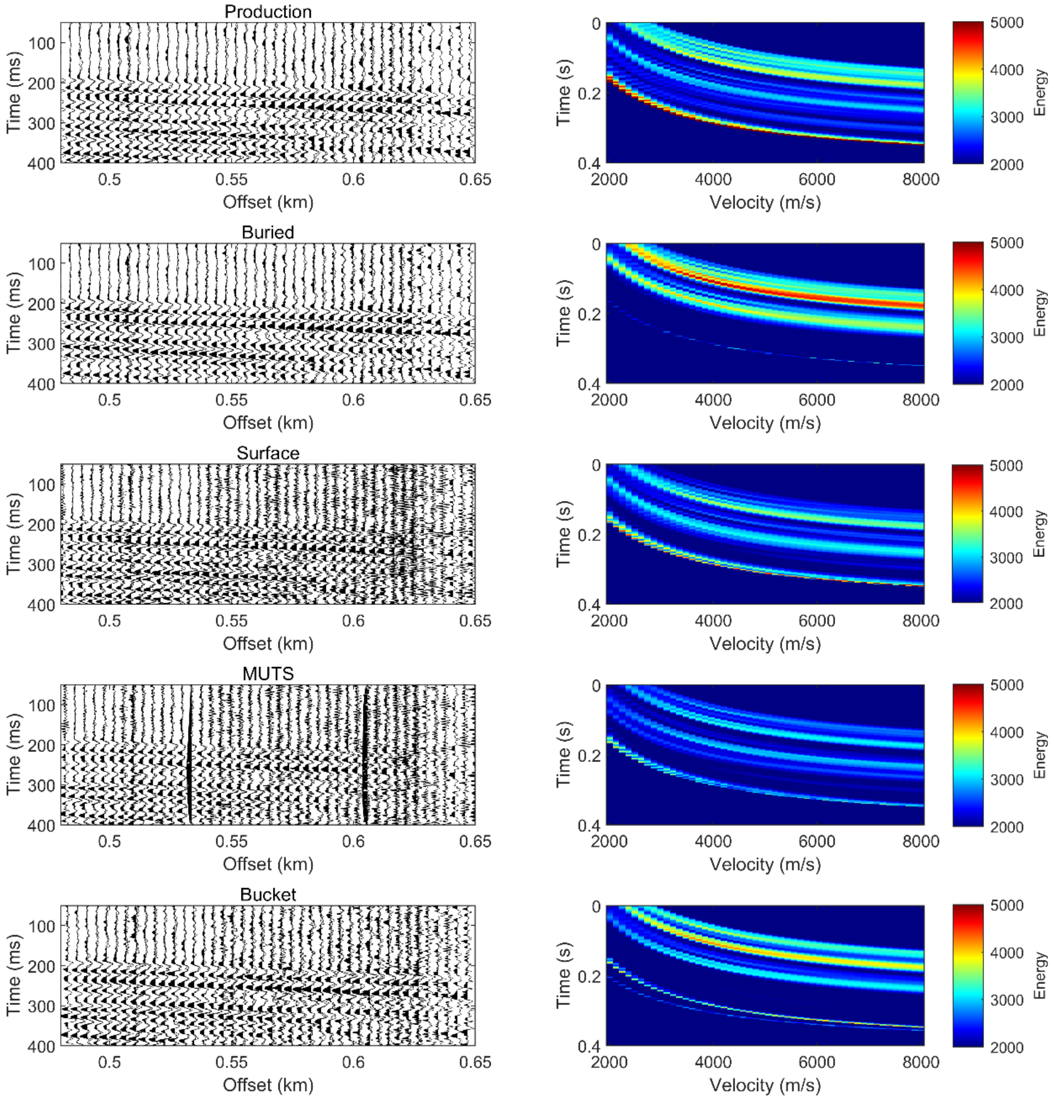

Figure 5. Left column: t-x plots showing the normalised windowed data used for analysis. Right column: velocity spectra corresponding to the data show in the left column. The offset window was 0.45 to 0.65 km and time window 50 to 400 ms.

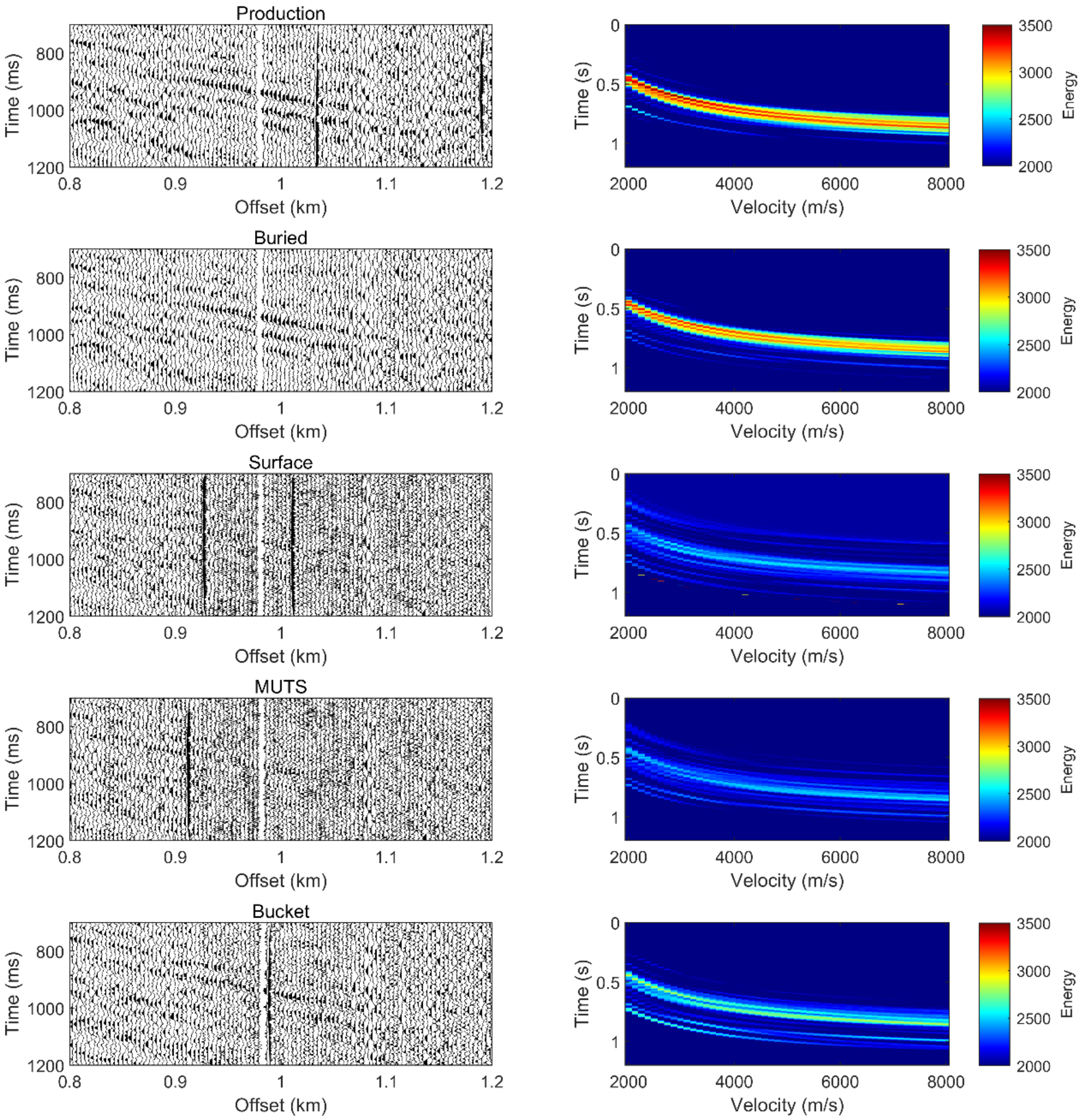

Figure 6. Left column: t-x plots showing the normalised windowed data used for analysis. Right column: velocity spectra corresponding to the data show in the left column. The offset window was 0.8 to 1.2 km and time window 700 to 1,200 ms.

Figure 7a shows the median PSD of the unnormalized trace amplitudes in the window shown in Figure 6, we choose to think of the energy in this window being the sum of the signal and noise. Figure 7b shows the same result but for a window between 1 and 1.3 km and 0 and 0.5 s, we consider this window to be representative of noise. If one were only to consider the data shown in Figure 7a then the mistaken conclusion might be that the surface nodes are superior, but in reality, as evident from Figure 7b, this extra energy is actually just noise.

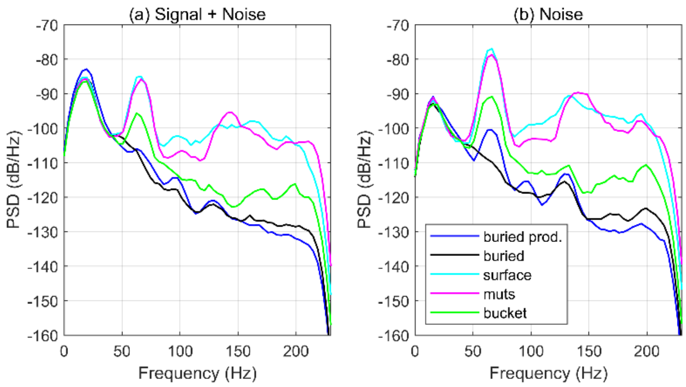

Figure 7. Median PSD of the traces in two windows: (a) signal + noise, 0.8 to 1.2 km/700 to 1200 ms and (b) Noise, 1 to 1.3 km/0 to 0.5 s.

DISCUSSION

Although determining the effectiveness of different methods of emplacing geophones can be difficult, and the results sometimes inconclusive, the results from this study are quite clear. The poorly coupled geophones (those planted on the surface), whether covered or not, had noticeably lower SNR than the better coupled geophones (either fully or half-buried). Although the order in which the data quality of the nodes within the two different groups varied between the stations, the difference between the two coupling classes did not. This binary coupling classification (well/poorly coupled) is consistent with the results of Drijkoningen (2000).

Our study was aided by our ability to directly compare the effects of coupling on SNR as we had definite identifiable events. Studies that are limited to just using recordings of noise are more complicated. Often what is interpreted as noise is in fact signal (of course, for passive surveys most of what is considered noise in active surveys is actually signal), it important to remember that the majority of wind noise is transmitted through the ground rather than being a result of the impact of the wind on the geophone itself. Therefore, what can be interpreted as reductions in the noise levels are actually a result of poorer coupling reducing the amount of energy being recorded by the geophone. This poor coupling would then lead to a proportionally higher decrease in signal and thus a lower SNR.

Although burying geophones is undoubtedly more effective, it does require an increase in deployment effort and therefore cost. Some recently introduced nodes have shapes that are designed specifically to enhance coupling

An effective alternative to burying geophones is placing bags of sand over the top of them (Dean et al., 2018) although this is likely to be even more intensive. There was no evidence in this test that geophone covers, either hard-shell or made from acoustic foam, placed over the geophone made any difference to the SNR. Although Alcudia et al. (2008) and Alcudia (2009) looked at using co-located microphones with geophones to record and then remove acoustic noise, and found that it was promising for attenuating air-blast, lower-energy/high-frequency noise is more problematic. Acoustic foam is most effective at frequencies between 500 Hz and 4 kHz so is unlikely to prove effective within the typical seismic bandwidth. Conceivably, geophone covers could be effective in poor coupling conditions by reducing the rocking of the node by expanding the size of its base, but, if effective, this could be achieved using a simple flat disc to enlarge the base of the node.

Adequate geophone coupling will only become more important in the future as geophone weights continue to decrease (Dean et al., 2018b), heavier geophones, as one would expect, have better ground coupling (Spikes et al., 2001), so it is likely that further decreases in geophone weight will require an improvement in coupling. This has been addressed in some modern nodes, where their shape has been specifically designed to enhance coupling (Figure 8) resulting in improved data quality (e.g., Dean et al., 2019).

Figure 8. Photos of five nodes showing their positions within the ground when emplaced. The two nodes on the left have been specifically designed to have good coupling.

CONCLUSIONS

The results from this study, in agreement with previous studies, showed that good geophone coupling is vital to acquiring good quality seismic data. In our case good coupling was achieved by burying the nodes rather than placing them on the surface. The use of hard or acoustic foam covers placed over surface-mounted geophones resulted in no measurable improvements in SNR.

ACKNOWLEDGMENTS

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