The airwave in hammer reflection seismic data

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Abstract. The seismic wave propagating due to air-coupling between source and geophones is commonly called the “airwave”. Serious problems to the seismic data processing can arise from the presence of airwave arrivals in the data. The low apparent velocity of the airwave, in conjunction with the high frequency content of its pulse, suggests using a very dense geophone geometry in order to be able to record with adequate spatial sampling. When an inadequate spatial sampling is used, F-K filtering has problems in its proper implementation and usually various techniques must be applied to overcome them. In the shallow seismic reflection method, pre-emphasis filtering can lead to spatial aliasing of the airwave over all its frequency bandwidth. In order to maximise the ratio of signal to “removable” noise, analog filters should not be set greater than a limit defined by the receiver interval. Alternatively to elimination of the airwave in the processing stage, the effectiveness of airwave suppression at the generation stage (at the source) is tested, as well as cancellation of reception of the airwave by the geophones. The use of a plastic plate in the “hammer and plate” source instead of a metallic one can limit production of airwave. In common offset sections, the airwave arrivals form a straight horizon parallel to the distance axis. This can be useful as a tool for finding any changes in offset due to an incorrect synchronisation between source and receivers. In the present paper an example of the dependence of the airwave on variations in temperature is also given.

1. Introduction

Over the last decade, a rapid increase in application of the shallow seismic reflection method has occurred, especially for engineering and hydrogeological targets. Developments in electronics, and computer hardware and software technology have helped the transfer of this powerful method to shallow targets, and made the method more competitive in terms of cost and results

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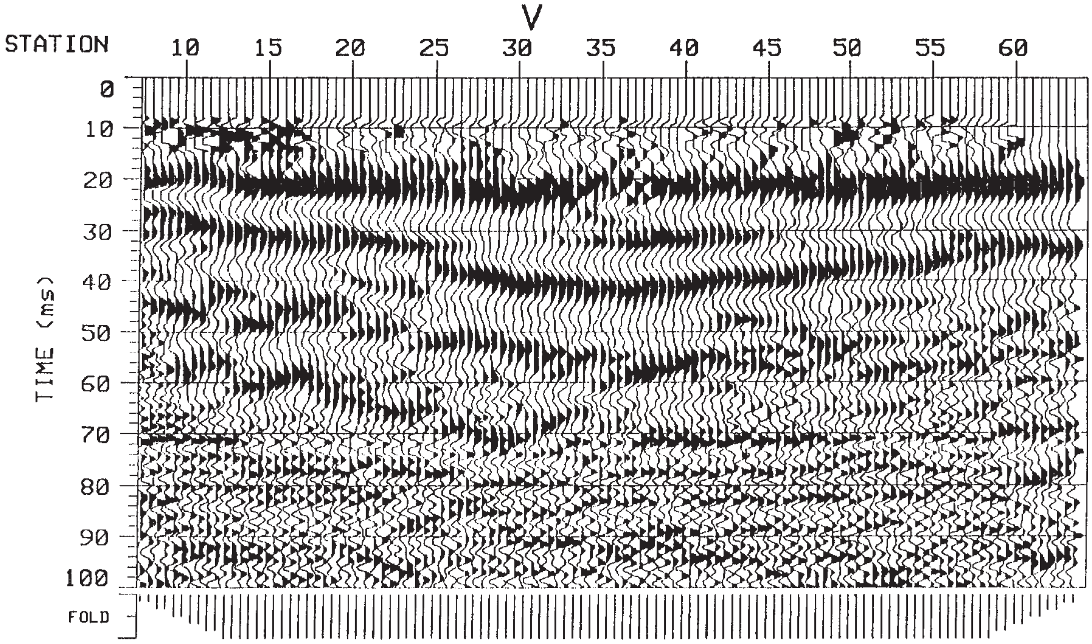


Fig. 1 - Inadequate sampling can lead to the airwave arrivals being stacked in the final seismic section as spurious horizons (indicated with arrows), as can be observed in the seismic section.

than the other, conventional engineering geophysical methods.

Nevertheless, serious difficulties in filtering the coherent noise, the lack of frequencies high enough to provide good resolution, problems in velocity analysis, etc. throw doubt upon the wide applicability of shallow reflection seismics.

Due mainly to its low cost and simplicity in application, the "hammer and plate" is one of the most widely used seismic sources. Although the signal produced by the hammer can be quite rich in high frequencies (Miller et al., 1986, 1992), it cannot usually generate a satisfying ratio of reflected energy to coherent noise. However, the reflection signal can be easily improved by increasing the number of hammer blows.

Although the investigations described here are mainly based on "the hammer and plate" source, the conclusions can be generalised to many other surface impact sources. The problem created by the airwave in the shallow reflection data is examined and some simple solutions proposed.

2. The problem of the airwave in shallow reflection data

When an airwave is spatially aliased, it cannot easily be filtered out by a simple application of F-K filtering. Inadequate spatial sampling can lead to the airwave arrivals being stacked in the final seismic section as spurious horizons, as can be observed in the seismic section of Fig. 1

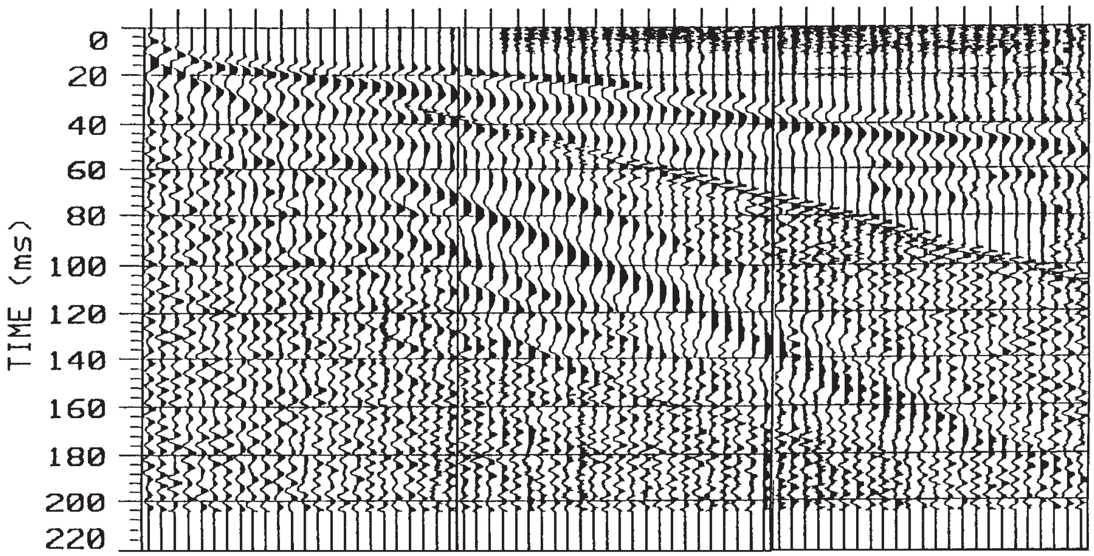


Fig. 2 - A walk-away test acquired with the analog filters at 100 Hz.

(Karastathis, 1991; Karastathis and Louis, 1992), unless there is another option for airwave suppression (e.g., muting).

The problem is critical when the fold is small and the signal-to-noise ratio (SRN) is very low, as the stacking cannot produce a robust pulse, and therefore the amplitudes of airwave arrivals are relatively high compared to those of the signal. This results in very strong spurious horizons, which obscure any other arrivals.

To prevent or reject spatial aliasing of the noise, in order to apply F-K filtering, we can implement various simple techniques. Some of them are referred to by Yilmaz (1987).

- Prior to application of F-K filtering, a time shift of the events can be done in order to make them appear to have smaller dips. After filtering the events are returned to their real positions (nevertheless, this can create spatial aliasing, to events not initially aliased).
- High-cut filtering can be applied at the frequency where the spatial aliasing appears for a given dip (however, this decreases the band-width and so the technique may not be the most preferable).
- Increasing the spatial sampling by the use of a smaller receiver interval can also be a solution to the problem. Alternatively, this can also be produced by interpolation of new traces between the real receiver traces.

For a frequency f=350 Hz and apparent velocity V_{app}=333 m/s, the wavenumber K=f/v=1,05 m^{-1} implies a need for a spacing of less than 0.5 m. It is obvious that any decrease in the geophone interval increases the cost of the investigation and slows it down. Therefore this cannot be the optimum solution.

The aliased energy is concentrated in the negative half of the F-K space. When end-on geom-

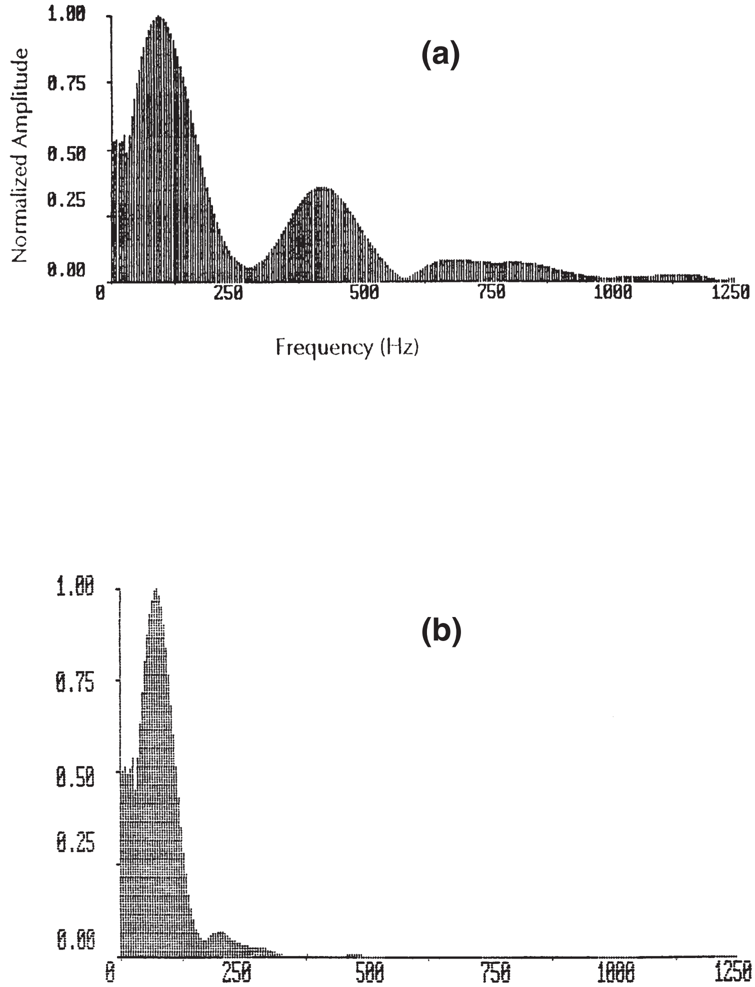


Fig. 3 - A spectral analysis of the normalised amplitude: a) of the airwave; b) of the reflection signal.

etry has been used, this F-K half-space contains only a small part of the signal energy, that related to the backward reflection (events with negative dip). Rejection of the aliased energy can be achieved by zeroing this negative half-space, on condition that it does not contain a significant part of the backward energy. However, this reduction in the wavenumber spectrum can cause ringing in the airwave.

The airwave tends to have dominant frequency equal to the low-pass filter applied before the analog to digital conversion (pre-emphasis filter, Steeples and Miller, 1990). It is possible that if the analog filter is held at a relatively low level (e.g., 100 Hz) the dominant frequency of the airwave will need a more realistic geophone interval (1.5 m).

Let us consider a high dynamic range seismograph. In this case pre-emphasis filtering will not improve the recording spectra substantially. Therefore leaving the analog filters at a relative-

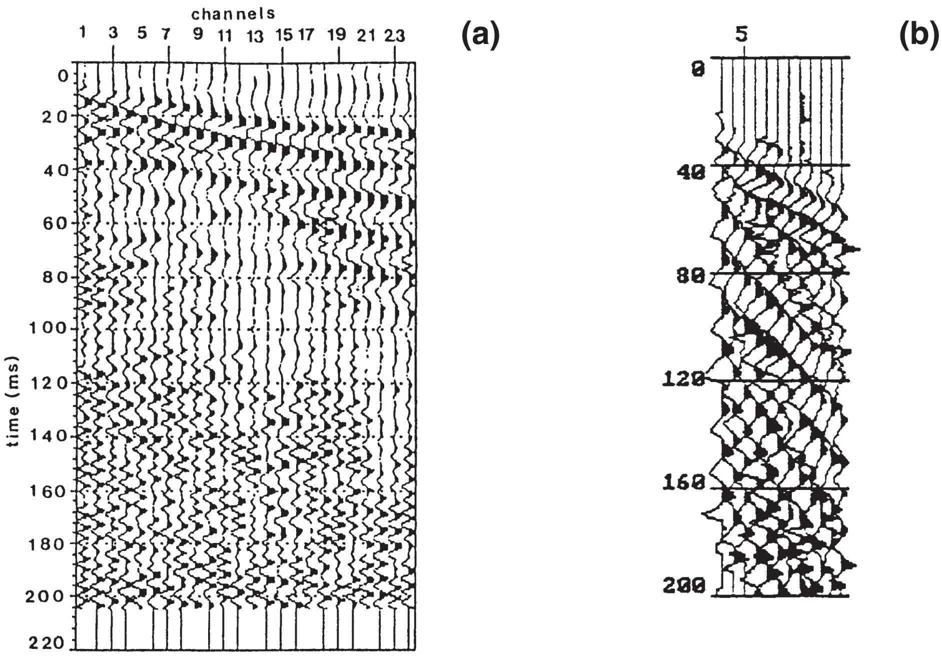


Fig. 4 - Airvawe suppression: a) a F-K filter is successfully applied; b) this record has been acquired with covered geophones in order to prevent reception of the airwave.

ly low level it is possible to strongly filter the airwave out of the data without being obliged to use a denser geophone geometry. As well as lower frequencies in the recording spectra, what is actually gained is that the ratio of signal to "removable" noise is higher.

Elimination of the airwave by F-K filter was tried during attempts to detect of King Xerxes' Canal (Karastathis and Papamarinopoulos, 1994) and provided satisfactory results. Fig. 2 shows a walk-away test from this survey acquired with the analog filters at 100 Hz. In Fig. 3a spectral analysis of the normalised amplitude of the airwave is seen. Fig. 3b shows the same for the reflection signal. The success of the F-K filter is obvious in Fig. 4a.

Nevertheless, in many cases, strong analog filtering is required, especially when a low dynamic range seismograph is used (e.g., with 8-bit A/D converter). In these cases if the use of a smaller geophone spacing is not possible another solution should be sought.

Frequency filtering does not help, as there is almost always overlap between the signal spectrum and that of the airwave, as in the case presented in Figs. 3a and 3b.

Although "muting" the airwave is generally effective, there are many cases where this is not adaptable because of great interference between signal and airwave.

Implementation of multiple geophones (arrays) can be a solution but makes the whole procedure more complicated and slower. It should also be noted that the lengths of suitable arrays are not as large as in the case of ground-roll elimination (where their implementation was judged problematic because of attenuation and frequency degradation of the signal (Knapp and Steeples, 1986). Additional problems are created in the NMO-correction and statics application.

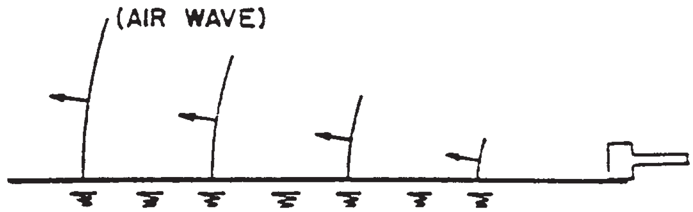


Fig. 5 - Suggested propagation mechanism for ground-coupled airwave after Mooney and Kaasa (1962).

Plastic covers on the geophones can also be tried in order to avoid reception of the airwave. This idea was checked experimentally during the seismic surveys in the Atalanti fault region (Karastathis et al., 1992) but no improvement was observed (Fig. 4b). This idea was also studied in the lab by Mooney and Kaasa (1962), who finally concluded that this approach could not help at all, since the nature of the airwave is different to that of a simple sound wave. More specifically they described it as a soundwave which excites ground vibrations during passage of the wavefront along the ground surface (Fig. 5). The model suggested by Mooney and Kaasa (1962) is different but closely related to the model of Press and Ewing (1951a, 1951b) which considers a kind of resonant coupling between the airwave and the Rayleigh wave in the ground.

Related experiments by Mooney and Kaasa (1962) in which the receiver was covered by foam rubber and heavy blanket showed that the airwave remained unaffected.

In a comparison test of seismic sources appropriate for shallow reflection investigations (Karastathis et al., 1995) a small decrease in amplitude of the airwave was noted with the use of a plastic plate instead of a metallic one in the hammer source. In Fig. 6 an example of this test is given. It should be noted that the plastic plate sometimes suffers problems in coupling with the ground.

The covering of the metal plate by cheap and durable material was also checked experimentally (an old telephone directory seemed to be quite adequate for this). The results were not satisfactory, since absorption of the airwave high frequencies was not sufficient.

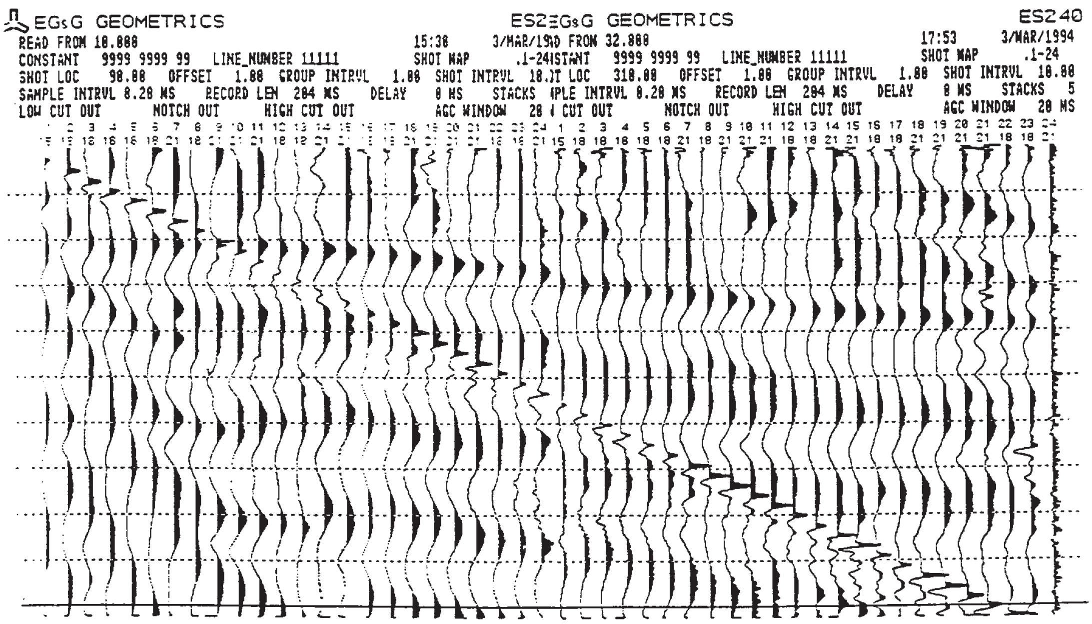
Under the proper conditions the airwave can be kept out of the data by a proper choice of offset.

3. The airwave in the common offset sections

The optimum offset technique (Hunter et al., 1982), based on single channel recording using a constant offset along a line, has been used in numerous cases in the past (Hunter et al., 1982, 1984; etc.).

From the CDP reflection data it is possible to extract a number of common offset sections equal to the number of traces of the multi-channel common source record, after suitable selection of the traces.

Given that the production of such sections does not require any special signal processing



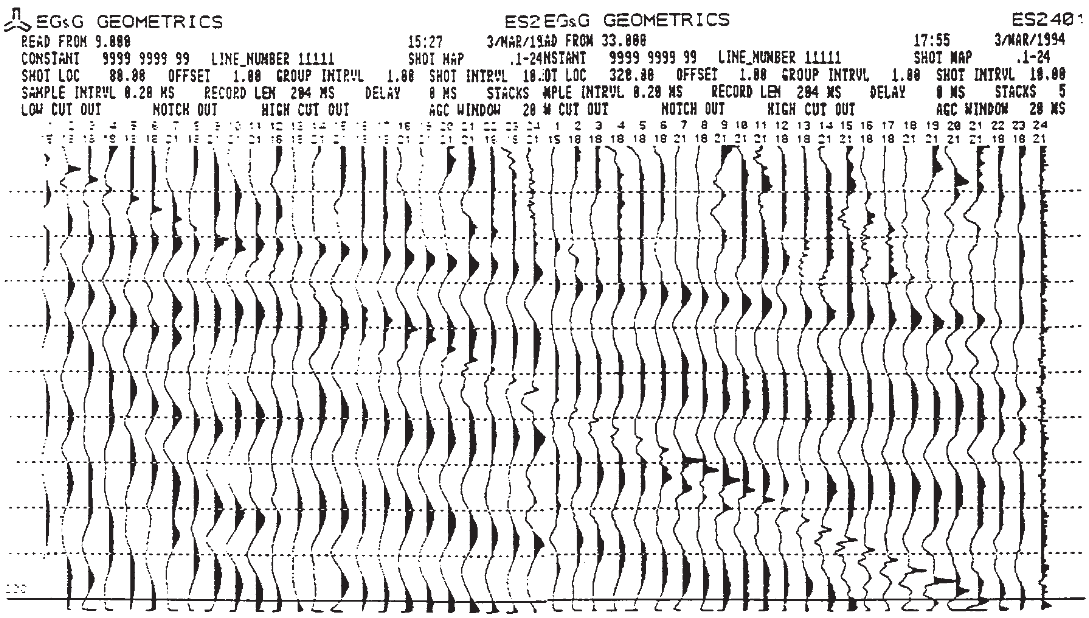


Fig. 6 - An example of the comparison test (low-cut filters out) for the metallic (top) and the plastic plate (bottom).

except for an automatic gain control (AGC), or possibly a band-pass filtering, it gives fast and direct information on the shape of the reflectors, which is very useful at the start of CDP processing. When the structure is simple (e.g. only one reflector) it is easy to choose the optimum offset section in which the noise does not interfer with the signal. Such a section can provide an almost complete answer to a geological problem if it is examined in conjunction with multichannel records, in order to have information on the velocity and depth of the layers.

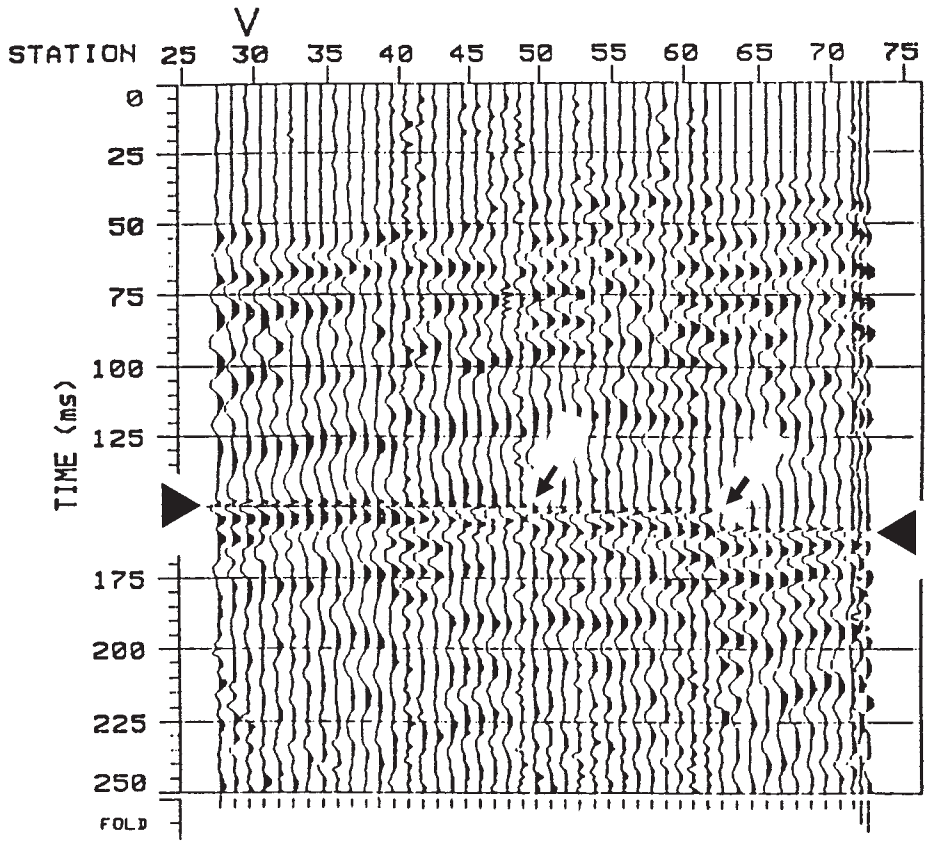


Fig. 7 - In this common offset section, there are two discontinuities (steps) in the airwave horizon indicated with arrows.

The coherent noise (airwave, ground-roll) appears in the common offset sections as straight horizons parallel to the distance axes, due to its linearity in the records. Additionally the airwave is easily distinguished because of its high frequency content.

Although the airwave horizon is undesirable as it can be misleading to an unsuspecting observer, or can hide part of the information, it is useful for checking if the offset was constant during the survey (King, 1992). It is clear that any variation in the offset during acquisition is shown by a delay in the airwave arrivals, and a line interrupted by steps rather than a straight line appears. Although it might not seem very likely, mistakes in synchronisation between the source and the geophones when moving along the line are very frequent.

If the mistake occurs and is not immediately noticed, it will be very difficult to find the exact site in the field of this mistake, later. Having the information from the airwave on the point where the mistake happened, the problem can be solved during processing using a new value for the offset.

But this practical way of correcting such mistakes needs to be used carefully, because changes in the airwave arrivals are not related to changes in the offset in a simple way. This happens because the velocity of the airwave can vary easily with temperature. An example of this dependence is the following.

In the common offset section of Fig. 7 there are two discontinuities (steps) in the airwave horizon. The offset here is 50 m and the survey interval is 2 m. The bigger discontinuity could be the result of a change in offset of about 2 m, while the smaller one about 1 m (!). In the first case it can be claimed that the most plausible reason for this was that the source remained at the same position while the spread advanced 2 m further, increasing thus the offset by 2 m. This mistake was corrected during the data processing.

The same explanation cannot be given for the second, smaller discontinuity however. Observing point 48, where the change has taken place, it was noted that it was here where the survey was interrupted until the next day. Although the explanation was not obvious, it was eventually very simple. The data were acquired properly and the airwave arrivals were also correct. The difference occurred because of the different velocity of sound from one day to the next due to a change in temperature. Differences in temperature can cause changes in the velocity of sound of about 0.607 (m/s)/°C. On one side of the step the airwave arrived at 148 ms, and on the other at 150 ms, giving a difference of 2 ms.

$$V_1 = \frac{50}{148.2} = 0.337\ \frac{\text{m}}{\text{ms}}$$

Thus,

$$V_2 = \frac{50}{150} = 0.333\ \frac{\text{m}}{\text{ms}}$$

where V_1 is the velocity estimated for sound on the first day and V_2 on the next.

A difference of 4 m/s can be produced by a change in temperature equal to 6.5°C.

Given that the relation between velocity (V, in m/s) and temperature (Θ, in °C) is V=331.5 + 0.607 Θ, then the temperature for the first days was

$$\Theta = \frac{337 - 331.5}{0.607} = 9.1°\text{C}.$$

Returning to the first discontinuity (below point 61), this could not be attributed to a change in temperature, since the delay of 6 ms implies a 20°C change, which is virtually impossible in one day (variations in the humidity can affect the velocity of sound only to a negligible degree and in the opposite direction). The velocity of sound on this day was V_2 = 333.3 m/s and thus a change of 6 ms could be produced by a 0.3333 m/ms x 6 ms ≈ 2 m difference in the offset i.e. the spacing of the survey. Consequently, correcting this discontinuity at the data processing stage, by assuming a change in the offset, proved reasonable.

4. Conclusions

Despite the great progress in seismic processing over recent decades it is still not possible to completely eliminate seismic noise from the data. A characteristic case is that of the spatially aliased airwave.

In the shallow seismic reflection technique, where the use of surface seismic sources such as hammer, weight drop, “kangaroo” etc. is frequent due to their low cost, and the duration of the seismic records is short, the percentage of airwave energy is high in comparison with the total seismic energy. Problems in F-K filtering of the airwave can arise from its inadequate spatial sampling. Given that the sampling required for a signal to be recorded without spatial aliasing is strongly dependent on its apparent velocity, as well as its frequency content, pre-emphasis filters, when exaggerated, can lead to spatial aliasing. The geophysicist having understood the above, can design the spread and the filters in such a way as to maximise the ratio of signal to removable noise.

As well as F-K filtering the use of muting is also possible for rejecting the airwave, even when it is spatially aliased. It should also be noted that the first shallow seismic processing programs, which did not include F-K filters, or even if they did, their use was problematic, had only muting for eliminating airwave. However there are situations where such muting does not leave the signal unaffected.

Alternatively, adaption of the source to produce a smaller percentage of airwave energy is also possible. The use of a plastic plate in “the hammer and plate” source gave encouraging results.

Although the airwave imposes problems, it can also be useful. In common offset sections the airwave appears as a constant horizon parallel to the distance axis, and also has the characteristic high frequency of its pulse. This horizon can reveal any changes in offset during data acquisition. A change in offset can cause a step in the horizon, either upwards or downwards, depending on whether the offset is made shorter or longer. Nevertheless, this does not imply that any step in this horizon is due to a variation in offset. A variation in temperature can also create such steps, especially when the survey has been interrupted and later restarted.

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