Optimising slip-sweep for high-productivity Vibroseis coal surveys.

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SUMMARY

The increased scale of 3D seismic surveys in the Australian Coal industry has necessitated the use of high-production slip-sweep surveys.

A method is provided which provides a quantitative visualisation of harmonic noise expected for different slip parameters. This provides a practical tool for planning optimal survey parameters.

Noise conditions must be seriously considered in survey planning. In areas of good data quality, and with specialised data processing, more aggressive slip times may be possible in future coal-scale slip-sweep surveys. However, in noisy situations a more conservative approach is needed.

Key words: coal seismic, Vibroseis, slip-sweep

INTRODUCTION

In the last decade the Australian coal industry has significantly increased the size of 3D seismic surveys (e.g. Battig *et al, 2019*). This has necessitated rapid advancements in acquisition and processing. This includes adoption of nodal systems and high-productivity Vibroseis techniques. Many of these techniques have been well developed in petroleum surveys. However, coal-scale targets generally offer some unique challenges.

In this presentation we investigate slip-sweep Vibroseis in the particular context of broadband coal-scale exploration. This technique employs multiple vibrators configured to allow sweeps from separate source points to overlap to some degree (e.g. Rozemond, 1996). This increases productivity but introduces noise.

One source of noise is generated by imperfect hydraulic control of the vibrator. This causes higher order harmonics of the desired sweep (e.g. *Ras et al*, 1999). For the standard correlation method with an upsweep, harmonics occur earlier in the record for each event. These tend to have much lower energy than the desired reflectors and have little impact. However, for slip-sweep they have the potential to contaminate the later arrivals of earlier sweeps.

In the petroleum industry it has been well documented that this harmonic noise can have a negative impact on the data if the slip times are too short (*Ras et al*, 1999). Coal-scale targets have the advantage that shorter sweeps with wider bandwidth are used. This theoretically reduces the strength of the harmonics, suggesting potentially more aggressive slips. Conversely, coal surveys usually contain more near offsets and stronger groundroll, and require a higher frequency signal for desired resolution. These factors imply that harmonics may have a greater relative impact.

In this paper we present a method to estimate the level of harmonic noise that is generated for given slip and sweep parameters. This method can be used during the planning or testing phases of a survey.

The paper also examines the impact that this noise has on coal-scale data and typical coal-scale processing sequences.

SURVEY PLANNING

During the planning and testing phases of a seismic survey it can be difficult to determine what slip parameters are optimal.

On many coal sites there has generally been prior 2D seismic acquired in the area before a high-productivity 3D survey. This will generally give an idea of the expected data quality and frequency content, but will not usually provide much information on the impact of various slip times.

In Figure 1 we provide a methodology that can assist with visualising this process. The technique requires a sweep containing harmonics. This can be modelled during planning or can be extracted from the ground force recorded by the vibrator during testing.

In this example we have used a 10-180Hz linear sweep of 10s, with a listen time of 2s.

The extracted sweep is convolved with spikes corresponding to a range of slip times (Figure 1a). In this case we have examined slips ranging from 2.5s to 14s.

Figure 1b shows the data generated by correlating each slip trace with the reference sweep. Subtracting the standalone correlated response we get an indication of the harmonic noise for each slip time (Figure 1c). This illustrates that the longer the slip the smaller the impact of the harmonic noise.

By examining each trace we can generate a graph of the noise for each slip time. Figure 2 compares a theoretical sweep generated prior to the survey with a ground-force trace obtained during testing. The theoretical sweep has relative harmonic amplitudes of 0.15, 0.10, 0.07, 0.05, 0.03 for H2 to H6 where the primary (H1) has an amplitude of 1.0.

Figure 2 also compares the average and maximum noise values for each slip. In most cases the maximum is likely to be the most useful.

While the theoretical and ground-force sweeps differ, both suggest a large change in the impact of the noise for slips around 7.3s. This may give an indication of a natural cutoff point.

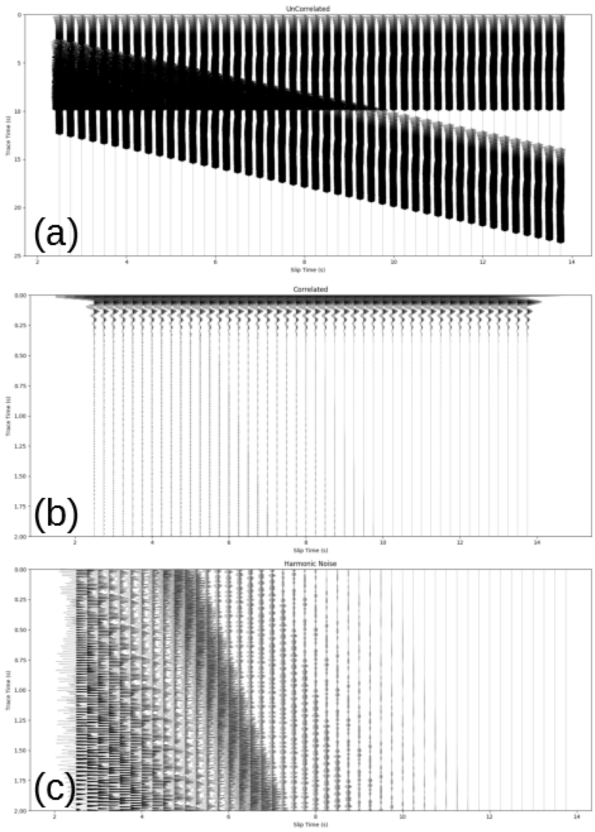

Figure 1. Presurvey estimate of slip-sweep correlation noise. Sweep parameters are linear 10-180Hz, 10s, 2s listen. (a) uncorrelated sweeps with slips ranging from 2.5s to 14s. (b) correlated traces. (c) difference between slip sweep and independent acquisition (harmonic noise).

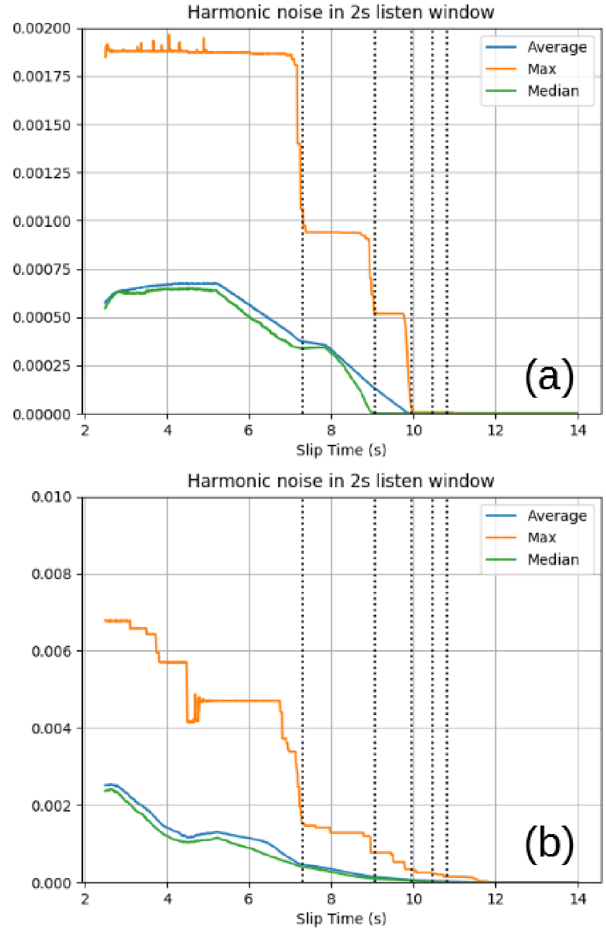

Figure 2. Comparison of the cross-harmonic noise for a theoretical sweep (a) and the ground force (derived during testing) (b). Dotted lines indicate the harmonic limits expected from theory (Pieuchot, 1984).

THE COAL ENVIRONMENT

We have examined a process of estimating the amount of harmonic noise that is generate by a given sweep but it is still uncertain what impact this will have on the final data.

2D Real Simulation and Filtering

To examine the impact further we have used a real 2D dataset. The data were recorded uncorrelated using a traditional acquisition approach (no slip) and combined to simulate a slip sweep sequence. The advantage of this is it allows us to compare various acquisition sequences while ensuring that the signal and noise contents remain consistent in each case.

A number of slip sequences have been tested. A representative case is presented here. This has the same sweep parameters as the above survey-planning example. An extreme case has been selected. This consists of using 4 vibrators and slips being allowed to range from 3s to 6s (half Gaussian with 3s dominance) with realistic move-up times.

Figure 3a compares the uncorrelated records from a representative source point for the traditional and slip-sweep techniques. This indicates that for the given record all four vibrators were sweeping at some point. This is much more than is currently the norm.

The correlated response (Figure 3b) is much simpler. The three interacting vibrators generate noise trains. The largest is produced by the vibrator operating at a later time. This is the harmonic noise and is expected. The other vibrators are early but are still creating some noise. This could be due to more complex harmonics or operation noise.

It would be nice to be able to remove the impact of the harmonic noise. Many methods have been suggested to remove or reduce the impact of the harmonics. These include modelling the harmonics (e.g. Harrison *et al*, 2011) and/or filtering in an alternative domain (e.g. Yu *et al*, 2017).

In Figure 3 we present a method that is based on a time-frequency domain median filter approach. This is a simple technique that is regularly available in coal processing to remove noise bursts. The data are transformed into frequency panels and lateral median analysis is performed. From this noise bursts greater than a threshold can be removed. (We will refer to this process as a TFMED filter.)

Figure 3d indicates that applying this in the source domain give a small improvement. However, if the data are examined in the CDP domain (Figure 3c) the harmonic noise further separates and is more burst like. Applying the filter to CDP gathers removes almost all of the harmonic noise in this case (Figure 3e).

Stack

The primary purpose of coal seismic surveys is to derive a structural interpretation of the target coal seams. Consequently, it is important to examine the noise in the final stacked section.

Figure 4 compares the stacked sections from two separate 2D surveys. The images on the left (Figures 4a, 4c, 4e) are from the data presented above and represent an area with good data quality.

The images on the right (Figures 4b, 4d, 4f) are from a 2D test line within a 3D survey. This line was acquired twice. The first (Figure 4b) using the traditional method and the second (Figure 4d) using a slip-sweep approach (slips of 4-12s). The data from this area were of poor quality, due to the proximity of an operating mine with variable cultural noise.

In areas of good data quality and high fold it can be seen that stacking has a significant ability to reduce the impact of harmonic noise (Figure 4a, traditional versus Figure 4c, slip-sweep). In some environments general processing including standard stacking may be enough. However, an examination of the faulting (mid section ~0.2s) suggests that the slip-sweep image has lost some resolution. Also, the deeper reflectors are less coherent. Much of this can be improved by using one of the harmonic-noise filtering methods such as the TFMED filter in Figure 4e.

A very different story is observed on the poor data survey. At the right hand side of the traditional section (Figure 4b) there are some strong events. These are almost entirely missing from the slip-sweep data (Figure 4d). While some of this may be due to changing cultural noise condition, we have found that the slip sweep technique is further degrading the data. Our TFMED filter has contributed very little (Figure 4f).

CONCLUSIONS

We have provided a simple visual method for quantifying the degree of potential harmonic noise for various slips. This has the potential to be quite useful for planning the optimal parameters for high-productivity Vibroseis surveys in coal-scale environments.

We have demonstrated that readily available processing techniques may allow us to acquire these surveys with shorter slips than are typically used. However, this is highly dependent on the signal-to-noise conditions present.

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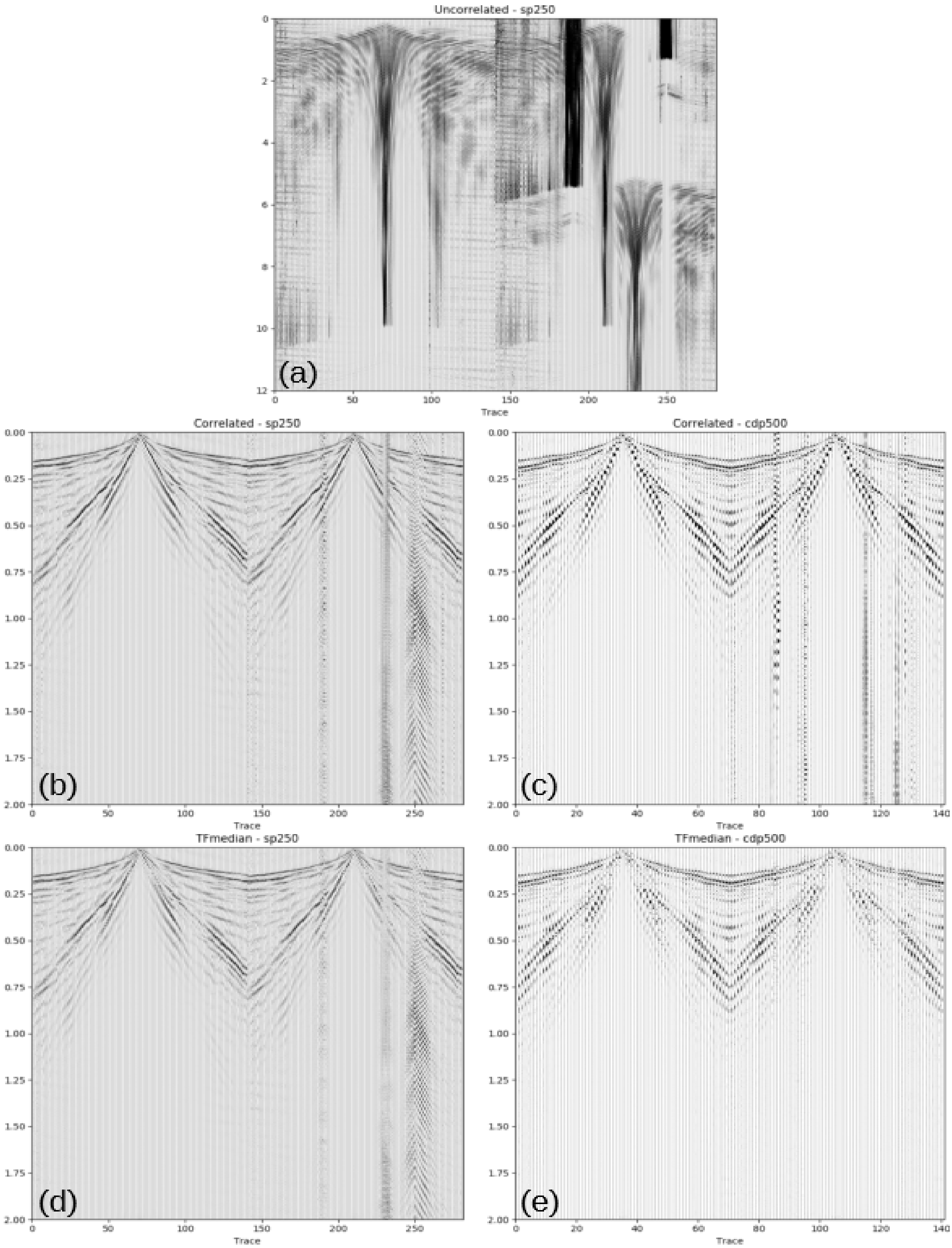

Figure 3. Comparison of traditional (left in each image) and slip-sweep records (right in each image). (a) source point 250 (sp250) uncorrelated. (b) SP250 correlated. (c) CDP500 correlated. (d) SP250 TF median filtered. (e) CDP500 TF median filtered.

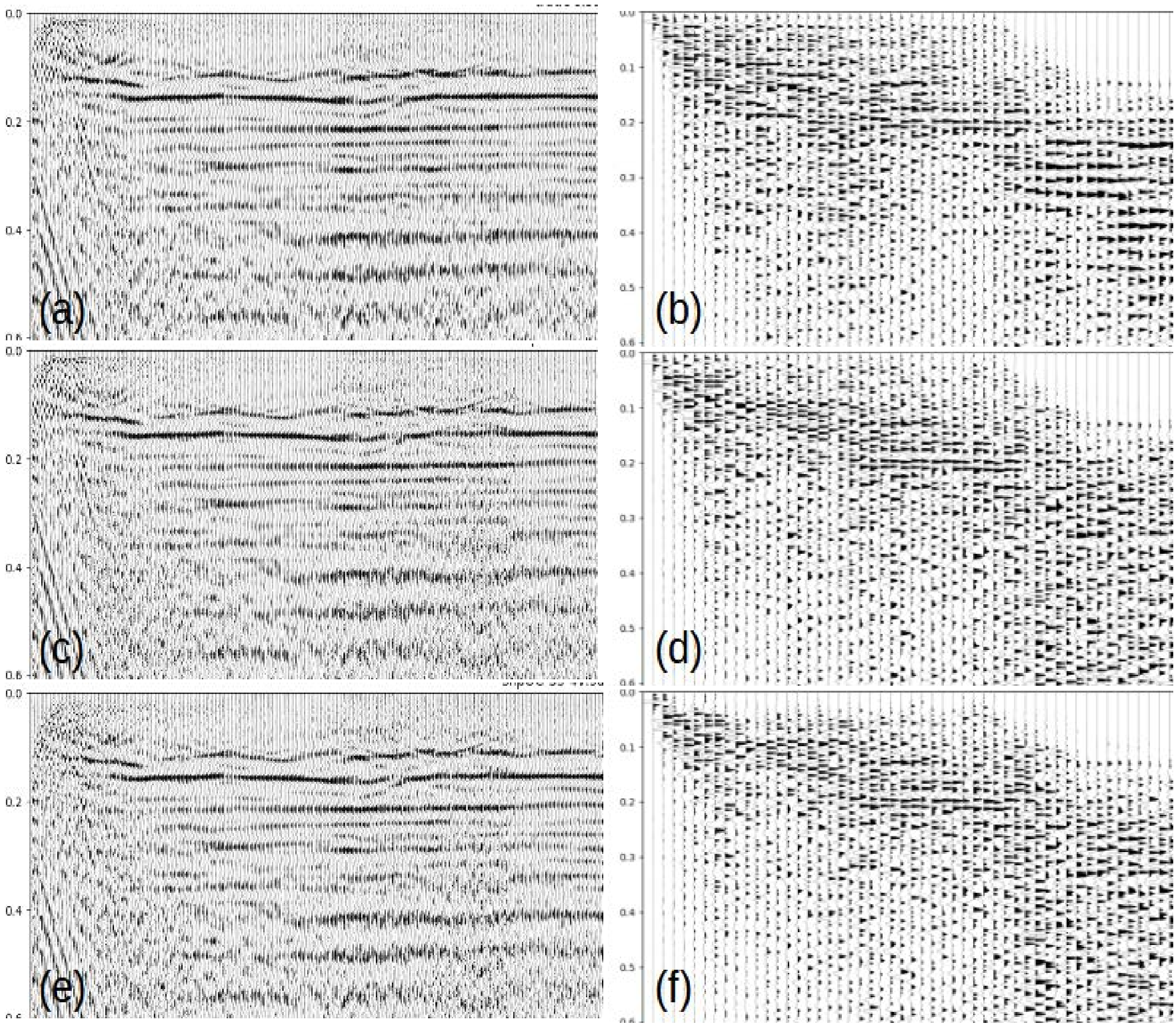

Figure 4. Comparison of the impacts of harmonic noise from slip-sweeps in good (left) and poor quality data (right). (a) & (b) traditional acquisition. (c) & (d) slip-sweep acquisition. (e) & (f) slip-sweep including CDP domain, TF median-filter burst-noise rejection.