Internal Combustion Impulse Source vs. Mini-vibrator vs. Nomad 65 vibrator shot tests

Cliff Delaporte
Anglo Coal
Private bag X7275, Emalahleni(Witbank) 1035, ZA
cliff.delaporte@angloamerican.com

Louis Polome
Spectrem Air
PO Box 2857, Marshalltown, Johannesburg, 2107, ZA
louis@spectrem.co.za

Charles Pretorius
Geophysical Consultant
PO Box 1357, Magaliessig, Sandton, 2067, ZA
cpretorius@mweb.co.za

Anna Leslie
CGG
27, avenue Carnot
91341 Massy, France
anna.leslie@cgg.com

Frédéric Moinet
CGG
15 East road
Johannesburg, ZA
frederic.moinet@cgg.com

Jason Jurok
CGG
2700 61 Ave SE
Calgary, T2C4V2, Canada
jason.jurok@cgg.com

Eric Bathellier
CGG
27, avenue Carnot
91341 Massy, France
eric.bathellier@cgg.com

Michel Denis*
CGG
27, avenue Carnot
91341 Massy, France
michel.denis@cgg.com

SUMMARY

Over the last two decades 3D reflection seismic has been applied for mine planning in South Africa. For coal exploration, the mining targets are at shallower depths of less than 400m. The challenge set by the mining companies is to obtain high-resolution seismic data with maximum vertical resolution at this depth of investigation. The cost of geophysics must also be more attractive than that of the 'total drilling' alternative. Seismic source trials were therefore conducted at one mine site. The ICIS (Internal Combustion Impulse Source) has been developed by CGG to provide a solution for shallow target surveys and for in-fills where access for conventional sources is restricted. The ICIS and Mini-vibrator performance were tested in shallow coal prospects, where existing 2D data have been acquired by Nomad 65 heavy vibrator. The tests demonstrated that ICIS is well suited to image target depths less than 500m with frequencies up to 100Hz. The comparison with the vibroseis sources showed that ICIS I) Delivered very good near offset data (> 50m) and for up-hole/low velocity layer survey ii) Required more shots per shot point in the medium offset range (1000m) due to its low energy iii) Not designed for far offset data (3000m). ICIS was found to be a viable geophysical and logistic solution for certain high-resolution mineral surveys.

Key words: impulse source, vibroseis source, shallow coal exploration.

INTRODUCTION

Over the past two decades 3D reflection seismic has been applied for platinum mining in South Africa. 3D seismic surveys have almost exclusively been conducted in the Western Bushveld where ore extraction depths range between 500 and 2000 m (Gillot et al., 2005; Pretorius, 2009; Pretorius et al., 2009; Trickett et al., 2009; Campbell, 2011). The ore is mined mainly via vertical shafts and also some decline shafts. In the Eastern Bushveld, the mining targets are at shallower depths of less than 400 m. The challenge set by the mining companies is to obtain high-resolution seismic cubes with maximum vertical resolution at this depth of investigation. The cost of geophysics must also be more attractive than that of the 'total drilling' alternative. Trials were therefore conducted at one mine site in the Vaal Basin.

The ICIS (Internal Combustion Impulse Source) has been developed by CGG to provide a solution for shallow target surveys and for in-fills where access for conventional explosive or vibroseis sources is restricted. The source is self-contained, powered by readily available propane gas and oxygen, capable of 3,000 impacts per 16 oz. standard propane canister. A GPS-driven high-accuracy clock and a specially developed impact sensor provide accurate time-stamping and recording of time-break information to better than 1 µs. The shooting system integrates seamlessly with Sercel SN408 or SN428 recording systems, using an additional system process that allows the observer to switch rapidly from explosive or vibroseis mode to ICIS on a shot-by shot basis.

The ICIS and Mini-vibrator performance were tested in shallow coal prospects, where existing 2D data have been acquired by Nomad 65 heavy vibrator. The test plan was to record two 1 km 2D lines with mini-vibrator and ICIS to compare with existing Nomad 65 2D line. Simulations were also performed to skip the shot points along a line acquired with a Mini-vibrator and replacing it with ICIS shot points to assess the quality of the impulse source.

The comparison of the results showed that ICIS I) delivered very good near offset data (> 50m) and for uphole/low velocity layer survey ii) required more shots per shot point in the medium offset range (1000 m) iii) not designed for far offset data (3000 m). ICIS was found to be a viable geophysical and logistic solution for certain high-resolution mineral surveys.

METHOD AND RESULTS

Survey and source parameters

Figure 1 below displays the location of the shot points which were used for the comparison between the ICIS, the mini-vibrator and the heavy vibrator. The acquisition and source parameters are given in Table 1.

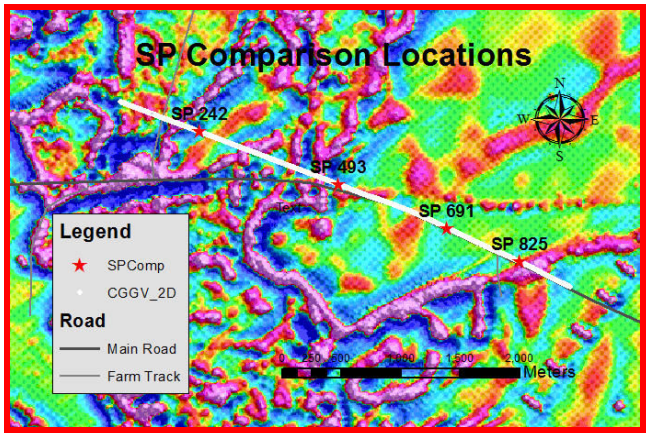

Figure 1. Shot point location of the comparison between the ICIS, mini-vibrator and heavy vibrator.

Shot point interval	5 m
Receiver point interval	5 m
Live spread	60-X-60
Sampling interval	ICIS: 1 ms; Vibrators: 0.5 ms
Record length	ICIS: 2 s; Vibrators: 1 s
Vibroseis sweep	30-200 Hz, 3 dB/octave
ICIS	8 shots/shot point (stacked)

Table 1. Acquisition and source parameters used for the comparison test between the ICIS, mini-vibrator and heavy vibrator.

On Figure 2 are displayed the ICIS raw shot gather (left), the same shot gather after application of amplitude recovery (right) and, after application of a basic processing (middle) at shot point 493. The continuity of the reflected events and the resolution is good in the shallow part of the processed gather but degrades in the deeper part. This is due to the energy of the source. The comparison of the amplitude spectrum of the three types of sources after basic processing shows an improvement of both the very low and high frequency part of the bandwidth, the latest making it adequate for shallow target and uphole/low velocity layer survey.

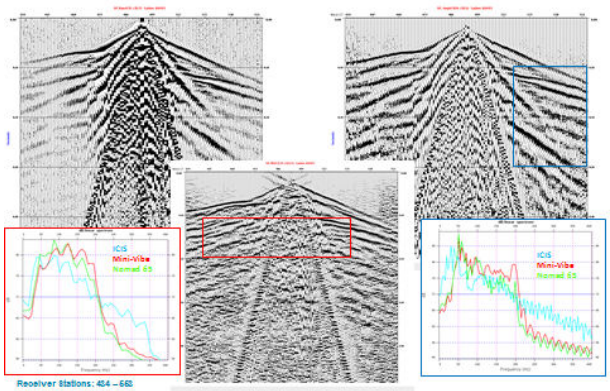

Figure 2. ICIS shot gather display. Raw record (left), basic processing (middle), and amplitude recovery (right). Amplitude spectra are computed in the selected windows.

Figure 3 represents the mini-vibrator shot gather, the same shot gather after application of amplitude recovery and, after application of basic processing at shot point 493. The continuity of the reflections and the resolution of the processed gather are better for shallow and deeper horizons than the ones recorded with the ICIS, the energy emitted by the mini-vibrator being greater than the one produced by the impulse source. The amplitude spectrum recorded for the mini-vibrator in the selected window has more energy in the medium frequency range with respect to the impulse source spectrum but less in the low and high frequency ends.

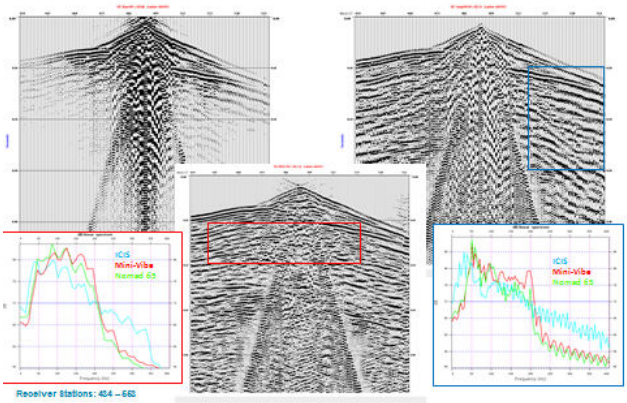

Figure 3. Mini-vibrator shot gather display. Raw record (left), basic processing (middle), and amplitude recovery (right). Amplitude spectra are computed in the selected windows.

On Figure 4 are displayed the heavy vibrator raw shot gather, the same shot gather after amplitude recovery, and after application of basic processing. The continuity of the reflected events and the resolution of the processed gather are even better compared to the mini-vibrator and the ICIS, the energy of the heavy vibrator being greater. The amplitude spectrum is quite similar to the spectrum of the mini-vibrator.

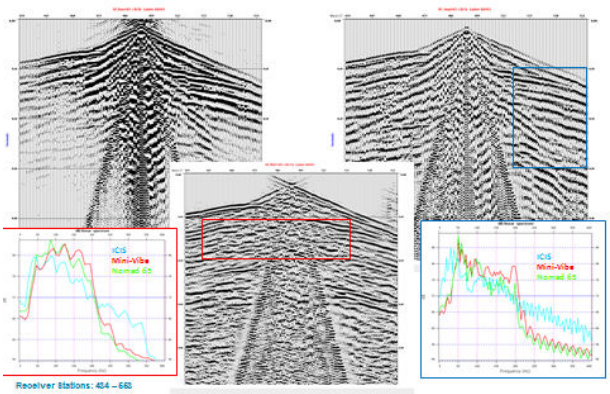

Figure 4. Heavy-vibrator shot gather display. Raw record (left), basic processing (middle), and amplitude recovery (right). Amplitude spectra are computed in the selected windows.

In addition of the amplitude spectra to evaluate the content of the recorded frequencies of the ICIS in comparison with the vibroseis sources, filtered panels were produced. The filtered panels bring detailed information on the frequency distribution of the three types of sources compared to the amplitude spectra (Figure 5, 6 and 7).

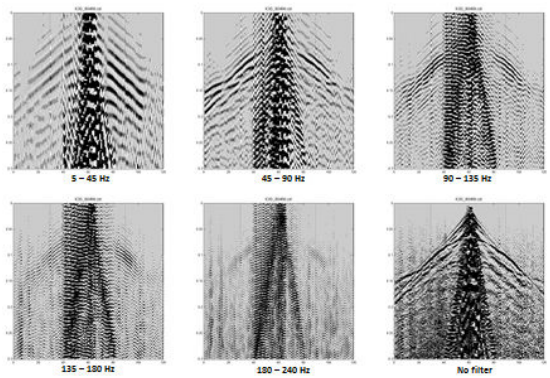

Figure 5. ICIS shot gather filtered by panels. See below each panel for frequency range. Last image corresponds to the raw shot record.

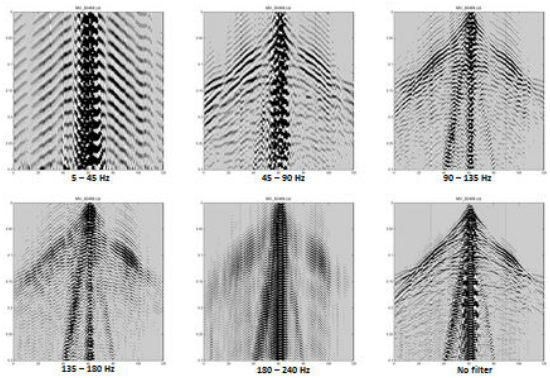

Figure 6. Mini-vibrator shot gather filtered by panels. See below each panel for frequency range. Last image corresponds to the raw shot record.

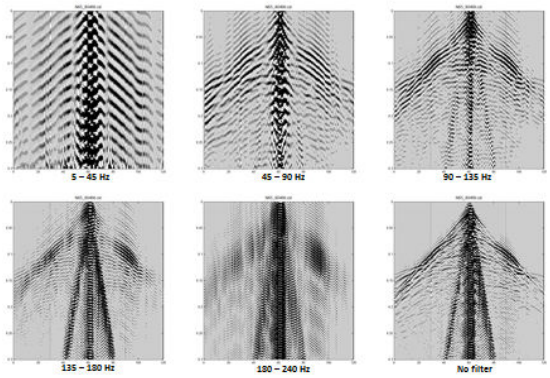

Figure 7. Mini-vibrator shot gather filtered by panels. See below each panel for frequency range. Last image corresponds to the raw shot record.

Figure 8 shows the comparison of Kirchhoff pre-stack migrated images of the 2D line (see Figure 1) recorded with the three sources. The main geological structures are identified on each seismic section. The use of source of greater power improves the temporal and spatial resolution of these images, with a stronger impact on the deeper horizons.

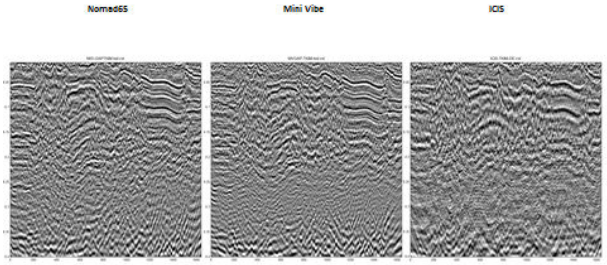

Figure 8. Kirchhoff pre-stack migrated images of the 2D line acquired with heavy vibrator (left), mini-vibrator (middle) and ICIS (right).

To assess the potential of using the ICIS where access for vibrators is restricted, simulations were run by skipping shot points along the 2D line recorded with Mini-vibrator and replacing it with ICIS shot points. Figure 9, 10 and 11 represent successively the mini-vibrator seismic migrated cross-section, the mini-vibrator section with missing shot points for comparison, and the mini-vibrator section with in-filled shot points from ICIS. The "flip-flop" between Figure 9 and Figure 11 demonstrates that the ICIS successfully fill in the gaps and recover the continuity of the reflectors.

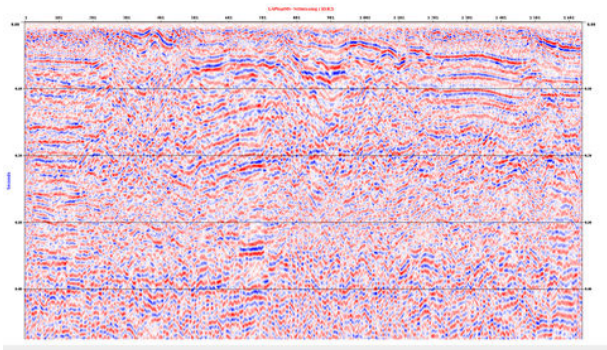

Figure 9. Mini-vibrator seismic migrated cross-section.

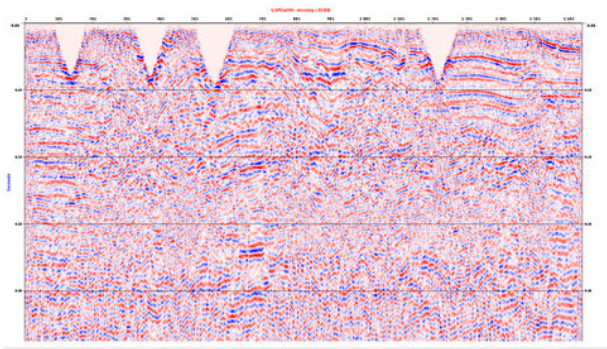

Figure 10. Mini-vibrator with missing shot points.

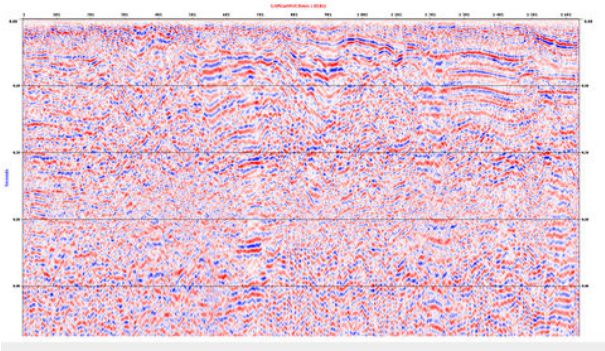

Figure 11. Mini-vibrator with in-filled shot points from ICIS.

CONCLUSIONS

As far as field logistics is concerned, the ICIS requires minimum extra shot line clearing compared to heavy and mini-vibrator. The size of opening required for the impulse source is 1 m as it is minimum 3 m and 5 m for the mini- and heavy vibrator, respectively. The ability to access difficult locations (hills, beside stream, near crops) is very good for ICIS. Mini-vibrator can handle slope less than 20° and heavy-vibrator slope less than 20° minimum but is noisy if the terrain is not dry. The ability to access environmentally sensitive locations (farms, buildings) is very good for ICIS when referenced to mini-vibrator. For heavy vibrator, minimum 50 m offset from sensitive locations and different sweeps are required.

ICIS is suitable to illuminate targets at depth lower than 500 m. 3000 m can be reached with mini-vibrator and heavy vibrator can exceed this depth. Amplitude spectra of the different sources show that for this test, the usable frequency range is lower than 100 Hz for the ICIS but starting from very low frequency. For the mini-vibrator, it ranges from 7 Hz to frequency greater than 200 Hz and from 7 Hz to 180 Hz for the heavy vibrator. ICIS being a low-power source, it requires more shots per shot point compared to vibrators to radiate energy at the depth of interest. This impulse source is very good to acquire near offset data (> 50 m) but needs more shots to build the energy in the mid-offset range (1000 m) and is not designed for far offset data acquisition. The impulse source is very good to record uphole/low velocity layer surveys where using vibrators to perform first break analysis is difficult and requires pre-processing conditioning of data. Using ICIS, the quality of imaging can be improved by recording more shots at the same location where vibrators will need to generate more and longer sweeps.

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