Seismic source comparison in Surat Basin, Queensland

Nabeel Yassi
Chief Geophysicist
Geokinetics (Australasia) Pty Ltd
Nabeel.Yassi@geokinetics.com

Afsha Kaba
Geophysicist
Real Energy Corporation ltd
afsha.kaba@realenergy.com.au

SUMMARY

A 2D land seismic reflection line was acquired 14-17 June 2011 in the Surat Basin, Queensland. Two source types were utilised; a heavy Vibroseis (AHV-IV 60,000 lb), and an impulsive surface source (Geokinetics proprietary Dual Synchronised Electrical Impulsive Source "onSEIS"). The recording system was OYO Geospace Seismic Recorder "GSR" cable-free nodes. The main objectives of the study were to (1) evaluate the response of the different seismic sources on the local geological framework; (2) to establish the optimal source effort for a planned 2D survey within the area. Vintage dynamite data acquired along the same line in 1984 was also used in the source effort analyses.

Qualitative analyses included visual inspection of raw shot gathers and processed brute stack sections; reflectors coherency, signal-to-noise ratio, spatial distribution, and signal penetration, were determined on raw displays. Quantitative analyse included amplitude spectra on Brute stack sections. Frequency content and signal bandwidth were critically evaluated to define which source performs better in terms of seismic resolution.

The dynamite single records showed good S/N ratio with clear reflectors at the target depths down to 1800 ms. However, the processed stack showed less bandwidth and lower imaging resolution due to the coarse source and receiver sampling during data acquisition. The onSEIS and Vibroseis signatures were comparable to the dynamite shots at the deep targets. However, the higher trace fold, longer offsets, and tighter spatial sampling for the onSEIS and Vibroseis, provided higher imaging resolutions that illuminated the entire section.

Key words: Seismic source optimisation, onSEIS, Vibroseis

INTRODUCTION

Explosive sources have been widely used for land seismic surveys for many decades, providing a high-energy high-bandwidth source. However, use of explosive sources is becoming more and more restricted, limiting its applicability in many areas. In addition, the necessity of drilling shot holes often results in compromising on optimum fold and the speed of operation is likely to make it the most expensive source choice. As an alternative to explosives, Vibroseis have been used for traditional reflection profiling in petroleum exploration. In the last decade, exploration activities are increasingly moving toward environmentally sensitive and urbanised areas. A number of land seismic sources have been developed and successfully applied to accommodate these additional challenges; without compromising data quality (e.g. Meunier and Daures, 2008, Suarez and Stewart, 2009 and Kumar *et al*., 2011). The onSEIS "Geokinetics proprietary seismic electrical impulsive source" is one of the latest developments. This seismic source has the benefits of traditional impulsive surface sources, in addition to the synchronization ability where many units can be deployed together as a single source array, therefore increasing the imaging depth. Other benefits are: fast recycle time improving efficiency, lightweight, easy to maneuver in difficult terrain and its minimum impact on the environment including almost no visible footprint left behind.

Seismic source characteristic is one of the key acquisition considerations in seismic surveys. Some of the important criteria in the source selection are its energy content, bandwidth, and ultimate wavelet shape. Other selection criteria are related to its convenience, safety, and repeatability. Finally, all of the previous criteria are judged with respect to the cost of the source. Obviously, there is no single best criterion for choosing a source since the choice depends also on the target and the required depth penetration and resolution. A number of comprehensive source tests have been undertaken in the past (e.g. Yordkayhun, *et al*., 2008, Suarez, *et al*. 2009, and Kumar *et al.*, 2011). Technological advances have improved the performance of the different source types; however, the results of the previous studies showed clear differences between various seismic sources at different locations. Sources which worked well in areas with consolidated surface material are often less effective in areas with loose sand and shallow water table. Moreover, in shallow earth material, even in consolidated sediments and crystalline rocks, the high frequency components of seismic signals are strongly attenuated (Buhnemann and Holliger, 1998), limiting the penetration depth of high frequency signals.

Feroci *et al.*, 2000, compared different sources in a particular area. They found that even if there are no substantial differences in frequency content, significant S/N ratio differences are observed, suggesting that the source can dramatically influence the S/N ratio. Air blasts, ground roll, and source generated noise can be so large in amplitude that they contaminate all the reflections on near offset traces. Wardell, 1970 classified land sources into three groups based on the basis of pulse shape. These are wide frequency band pulses (explosive sources), low frequency pulses (surface impulsive source) with good low frequency energy due to the coupling effect between the impact pad and the surface, and

Vibroseis sources where the shape of the spectrum can be controlled.

Since seismic resolution is directly related to the dominant frequency of the signal, and the quality of the acquired seismic data is influenced by the surface and near surface settings; therefore, it is essential to find a seismic source capable of generating adequate frequency and energy within the survey area.

FIELD DATA ACQUISITION

Prior to a 2D land reflection seismic program in Surat Basin, Queensland, a source effort test was conducted to evaluate the performance of the proposed source types within the survey surface conditions. The target formation to be resolved was Permian aged sandstone at depths of 2,000 meter-plus. A 2D test line totalling 4.88 line kilometres was selected with a 20 metre group interval and a 20 metre shot interval. Two source types were deployed; a heavy Vibroseis (AHV-IV 60,000 lb), and Geokinetics proprietary Dual onSEIS (Synchronised Electrical Impulsive Sources). The recording system was OYO Geospace Seismic Recorder "GSR" cable-free nodes. Table 1 lists the recording geometry for the Vibroseis and onSEIS source effort test. Vintage dynamite data acquired along the same line in 1984 was also used in the source analyses. The available seismic dynamite data along the line is sparser than the newly acquired data. Recording spread was 96 channels symmetrical split spread with 40 metre group interval, and 160 metre shot interval. Nominal CMP fold for the dynamite dataset was 12. Explosive source was a single 36 metre deep hole loaded with 5 kg charge of Anzite Blue and tamped with drill cuttings.

Source type	*Vibroseis*	*onSEIS*
Model / Size	AHV-IV 60,000 lb	Dual IHI IC-70
Group interval	20 m	20 m
Total Rec. St.	245	245
SP/VP interval	20 m	20 m
Units / SP-VP	One	Two - inline
Total # of shots	244 x 2 sweeps	244 x 4 pops
Sweep Freq.	6 – 110 Hz	
Sweeps /VP	Two sweeps	
Sweep length	8 s	
Listening time	4 s	
Pops / SP		4
Records length		4 s
Spread	fixed 245 Ch.	fixed 245 Ch.
Nominal Fold	130	130

Table 1. Test line recording geometry

DATA PROCESSING AND ANALYSIS

The seismic data from the three different source types were passed through the same processing sequence with identical processing parameters to validate a direct comparison of the generated seismic signals. Minimum filtering and simple processing flows were applied to focus on the source generated signals rather than enhancing the acquired data. Similarly, CDP stacking was limited to a simple Brute stack with a wide Bandpass filter to include all acquired frequencies. Datasets were processed and analysed according to three categories: (1) raw shot gather displays, (2) brute stack sections, and (3) amplitude spectral analysis on entire stack sections and selected TWT windows. Vertical stacking was applied on the onSEIS data to sum the 4 pops on the source point and the Vibroseis 2 sweeps on the Vibroseis point.

1 RAW SHOT GATHERS

The dynamite raw shot display (Figure 1a) indicates an improved bandwidth and S/N throughout the record. Reflectors can be traced at 700, 1400 and 1800 ms on the middle and long offset range traces.

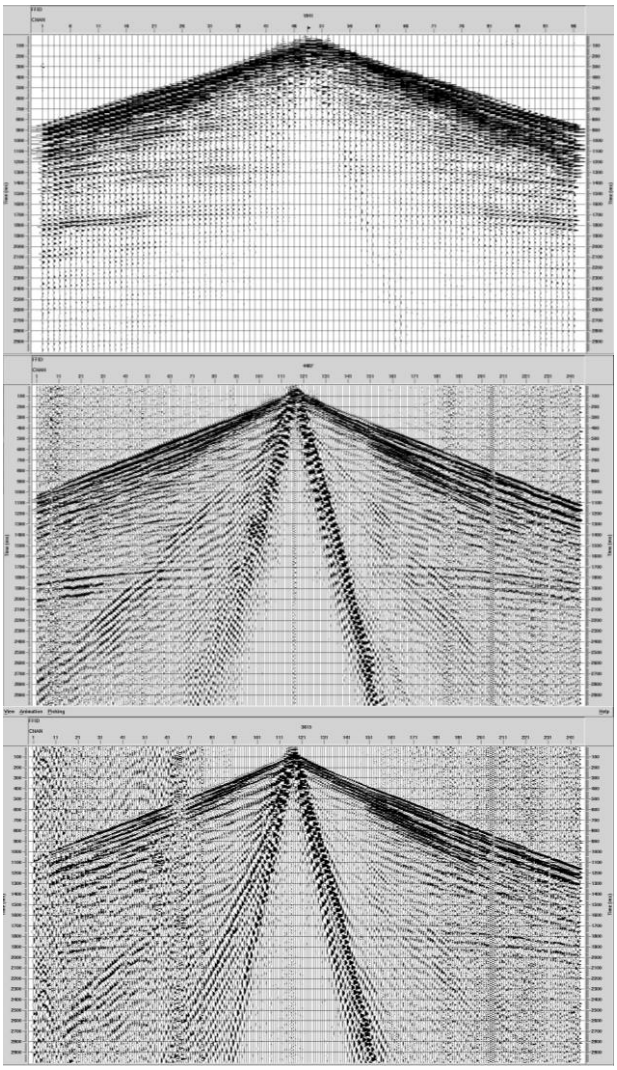

Figure 1. Raw record display dynamite (a - top), Vibroseis (b -middle), and onSEIS (c - bottom)

The Vibroseis and onSEIS raw record displays (Figure 1b and 1c) show good and continuous deep reflectors at 1400-1800 ms TWT. Relatively high amplitude ground roll, air blast, and low frequency seismic noise is also evident on the spread that is typical of surface seismic source at a high impedance surface. The shallow reflectors were concealed by the surface noise; additional filtering and signal enhancement is required to reveal these reflectors on the shot gathers. However, such attempts are out of context with this direct comparison of raw shot gathers.

2 BRUTE STACKED SECTIONS

The dynamite brute stack (Figure 2a) shows smooth and continuous reflectors at 700-1300 ms and 1600-1800 ms TWT. However, at shallower TWT time (0-600 ms) the seismic image drops in resolution and reflectors definition due to the coarse source (160m) and receiver (40m) spatial sampling of the dynamite dataset.

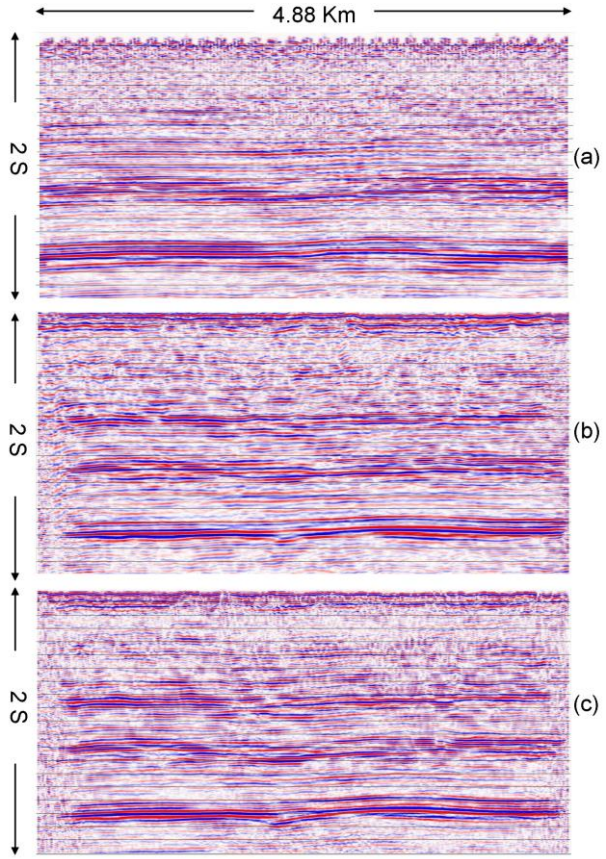

Figure 2. Brute stacks (a) dynamite (b) Vibroseis (c) onSEIS

The onSEIS and Vibroseis stacks show higher reflectors definition across the entire section including the near surface and shallow 400-600 ms TWT window. The stack improvement is mainly related to an adequate signal generated by these surface source types coupled with the high CDP fold of the onSEIS and Vibroseis data. The crisp high resolution / high definition seismic reflectors can readily be traced on the stacked sections, with enhanced spatial and vertical resolution at the target levels. It is also evident that the high trace fold of the onSEIS (4 pops per SP) and Vibroseis (2 sweeps per VP) successfully managed to suppress the random surface noise that was apparent on the single raw shot gathers.

Detailed comparison between the onSEIS and Vibroseis stacks on selected zones of interest indicated that the onSEIS imaging resolution is slightly higher than the Vibroseis. More structural and stratigraphic features can be delineated on the stacked sections.

3 STACKS AMPLITUDE SPECTRA

Amplitude spectral analysis on Brute stacks is an effective quantitative method for evaluating the quality of seismic signals generated by a source. Figure 3 shows all three source types have dominant signal frequencies of around 7-75 Hz; hence, providing enough bandwidth to resolve the geological targets in the surveyed area. The dynamite stack amplitude spectra (Figure 3a) indicates a relatively high amplitude at 20-30 Hz range; however, the Vibroseis and to a higher degree the onSEIS contains a higher amplitude at 30-45 Hz, that is well within the targeted frequency for the area. The onSEIS spectrum (Figure 3c) shows good frequency contents on the lower frequency side at 5-8 Hz. On the high frequency range (about 65 Hz) the dynamite and onSEIS stacks maintained higher amplitudes than the Vibroseis stack. The onSEIS amplitude spectra also indicates less noise fluctuations, represented by the relatively smooth surface of the spectrum compared to the other two source types.

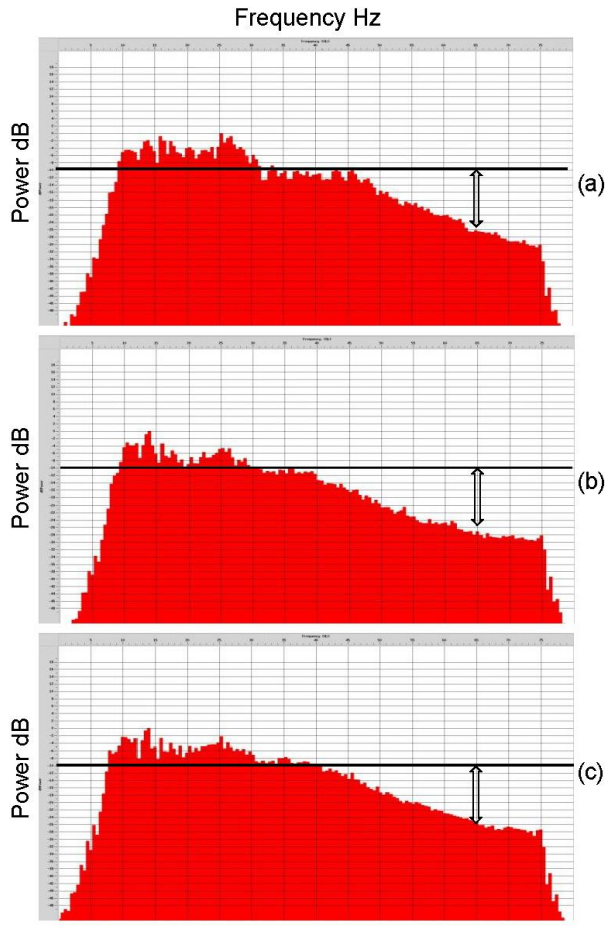

Figure 3. Fourier amplitude spectrum of Brute stacks (a) dynamite (b) Vibroseis (c) onSEIS. Horizontal line at -10 dB power, vertical arrow at 65 Hz frequency

Amplitude spectral analysis was also applied on selected TWT windows of the Brute stacks. The selected windows were at 0-400 ms and 700-1500 ms TWT, and corresponding to shallow depths and the main deep targeted reflectors. In the shallow 0-400 ms window (Figure 4a); the onSEIS spectrum shows slightly higher power at 7-50 Hz compared to the dynamite and Vibroseis. Higher than 50 Hz, the dynamite shows more, amplitude than the onSEIS followed by the Vibroseis.

At the 700-1500 ms TWT window (Figure 4b), the dynamite and Vibroseis signatures indicate higher amplitude at low frequencies (5-20 Hz) than the onSEIS. However, the onSEIS signal indicated higher amplitude between 20 to 45 Hz. After

45 Hz the onSEIS maintained a gentle dropping dip toward the high frequency limit.

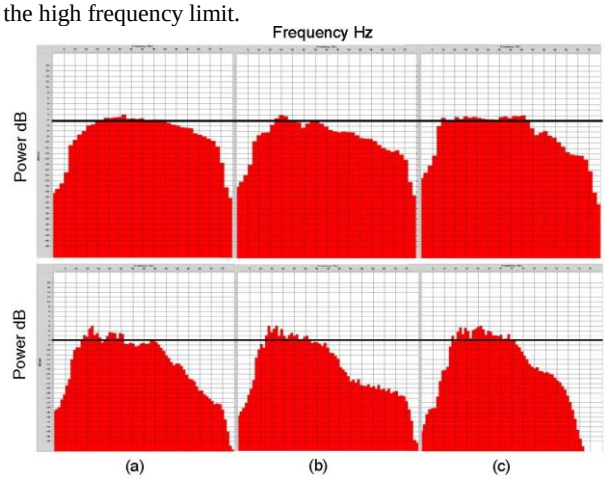

Figure 4. Amplitude spectrum of Brute stacks at 0-400 ms TWT window (top) and 700-1500 ms (bottom). (a) dynamite (b) Vibroseis (c) onSEIS. Horizontal reference line at -2 (top) and -6 (bottom) dB powers

CONCLUSIONS

The three tested seismic source types (dynamite, Vibroseis and onSEIS) were characterised with respect to their signal-to-noise ratios, imaging resolution capability and frequency content through qualitative and quantitate analysis of single shot gathers, Brute stacked sections and amplitude spectrum analysis.

Data analysis indicates the signal-to-noise ratio for raw single shot gathers appear to be better for dynamite compared to Vibroseis, and then onSEIS. Such characteristics are expected as the dynamite is confined at depth; the Vibroseis records endure noise attenuation through the autocorrelation process at data acquisition stage. It is also evident that increasing the traces fold through vertical stacking of many pops per shot point improves the signal-to-noise ratio for the onSEIS dataset.

Brute stacks and amplitude spectra of the tested sources indicate that the onSEIS and Vibroseis signatures were comparable to the dynamite shots at the deep targets. However, the higher trace fold, longer offsets and tighter spatial sampling that is readily available for the onSEIS and Vibroseis, provided higher imaging resolutions that illuminated the entire section; shallow targets in addition to better reflectors definition at the deeper targets.

The amplitude spectra of the Brute stacks show that the retainable frequency content of the three sources is generally comparable. The dynamite and onSEIS contained higher amplitude at 20-30 Hz than the Vibroseis. The Vibroseis and to a higher extent the onSEIS contained higher amplitudes for frequency range 30-45 Hz, that is well within the dominant frequency at the target. The onSEIS shows higher amplitude at the high frequency ranges 45 to 75 Hz. The onSEIS spectra also indicates less noise fluctuation that is related to the noise cancellation effects of the higher trace density and stacking 4 pops per shot point.

Amplitude spectra of the three seismic sources at the selected target TWT windows indicates: at 0-400 ms TWT window the onSEIS then the dynamite shows better amplitude at 7-50 Hz frequency range compared to the Vibroseis. Higher than 50 Hz the dynamite maintained better amplitudes. At 700-1500 ms TWT window, the dynamite and Vibroseis signatures indicate higher amplitude at 5-20 Hz than the onSEIS. However, the onSEIS signal was higher at 20 to 45 Hz.

From the three seismic source types tested and analysed; seismic signature generated by a single explosive, confined at a certain depth is an ample source for exploration. However, onSEIS and Vibroseis are competent alternative sources to explosive when other factors, such as safety, cost, accessibility, permits and environmental sensitivity need to be taken into consideration when choosing a seismic source for a survey.

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