X038

The Feasibility of Permanent Land Seismic Monitoring with Buried Geophones and Hydrophones

A.V. Bakulin* (Saudi Aramco), R.M. Burnstad (Saudi Aramco), M.A. Jervis (Saudi Aramco) & P.G. Kelamis (Saudi Aramco)

SUMMARY

A comprehensive onshore seismic experiment was conducted in Saudi Arabia to evaluate various configurations for seismic monitoring in a desert environment. A line of 80 receiver stations was deployed comprised of both geophones and hydrophones permanently cemented in the boreholes at four different depth levels from 0 to 30 m. This study focuses on the analysis of data acquired using a surface vibrator source. Due to the challenging near-surface conditions and poor signal-to-noise ratio observed on the pre-stack data, a dense source grid was acquired with the surface vibrator. Designing a processing sequence that was optimized for imaging and repeatability was essential. The best stack image and repeatability was obtained using data from the receivers located at 30 m. Post-stack repeatability of around 20-25 % NRMS was obtained over a large portion of the line. We observed additional improvements in imaging when using dual-sensor summation by combining the geophone and hydrophone data. In addition, virtual source redatuming was performed, which produced images with an increased continuity of some of the targeted events. Further work to fully understand the limits and opportunities of land seismic monitoring is in progress.

Introduction

Seismic monitoring in a desert environment is quite challenging. In particular, Saudi Arabia has areas of complex surface and near-surface geology that can compromise the seismic data quality and repeatability (Robinson and Al-Husseini, 1982). For seismic monitoring to be successful on land, we need to deal with issues of data quality as well as ensure that sufficient repeatability can be achieved. This study describes the first attempt to comprehensively evaluate the feasibility of land seismic monitoring using various configurations of sources and receivers in a desert environment typical of Saudi Arabia and the Middle East.

Field experiment

A comprehensive feasibility study for seismic monitoring was conducted in one of the fields in Saudi Arabia to evaluate various source and receiver acquisition configurations (Table 1). The target horizon was located at an approximate depth of around 2 km. A 2D line of 80 receiver stations was instrumented with both geophone and hydrophone receivers at various depths (Figure 1d). Each receiver location was comprised of a bunched set of geophones at the surface covered with sand and three additional sensor levels, each level had a colocated vertical geophone and a conventional hydrophone cemented inside a vertical borehole. Six repeat surveys were acquired over four months, using a surface vibrator, to evaluate the seismic repeatability and 4D noise characteristics of the area. Dense areal shot sampling was acquired for efficient noise removal as well as for use in testing virtual source redatuming technology (Bakulin and Calvert, 2006). In addition, we acquired hourly and daily vibrator tests using multiple sweeps to evaluate short term pre-stack data stability and repeatability.

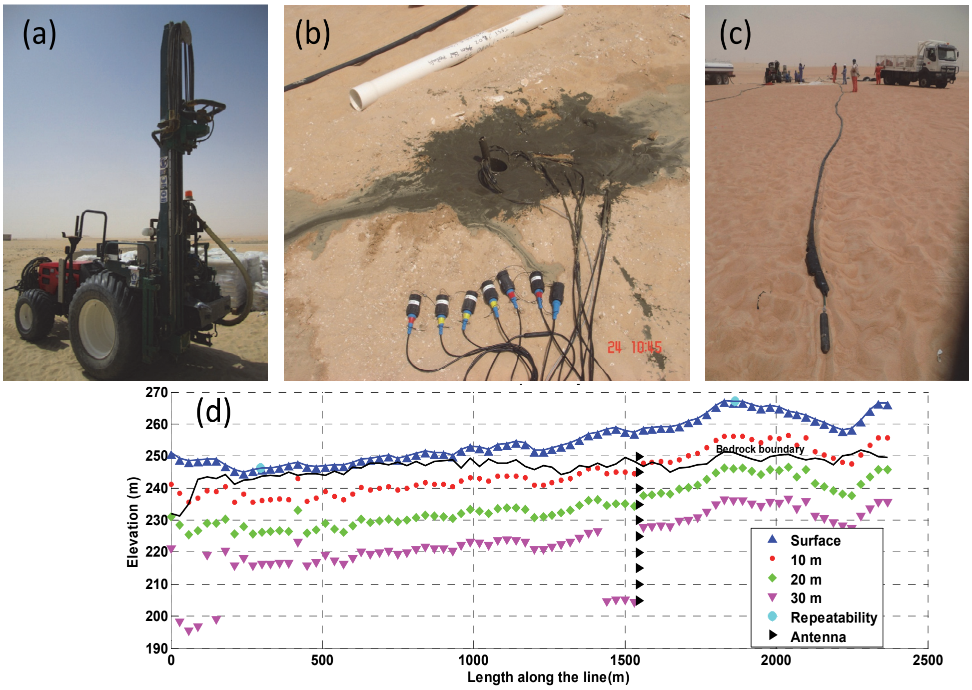

Figure 1 *Equipment and layout for the field experiment: (a) drilling machine, (b) sensors going into the shallow hole, (c) packaged receiver assembly before cementation, (d) cross-section showing the sensor layout (photos courtesy of CGGVeritas/ARGAS).*

Method	Redundancy	Image	Repeatability	4D cost
Surface source – surface receiver	Medium	Good	Poor	Low
Surface source – buried receiver	Medium	Good	Fair	Medium
Virtual Source – buried receiver	Medium	Good	In progress	Medium
Buried source- buried receiver	Single fold	N/A	Excellent	High

Table 1. *A qualitative evaluation of the various acquisition configurations employed using the experimental 2D line.*

As part of the experiment, several permanent surface and buried piezoelectric vibrators (Schissele et al., 2009) were installed to evaluate the source signal penetration in this desert environment for the moderately deep target using this type of relatively weak permanent source. In this paper we discuss results from the first two repeat surveys using only the surface vibrators**.** Stacked sections from the data acquired in these two surveys were benchmarked against images from the high-fold legacy 3D seismic data that has high redundancy and relatively good image quality.

Imaging

Data acquired using point-source and point-receivers in a karsted near-surface desert environment is extremely complex (Robinson and Al-Husseini, 1982). In the presence of challenging near-surface geology, most reflections cannot be seen on the pre-stack seismic data. The use of source and receiver arrays can help reduce the surface noise and scattered energy. High fold and large receiver spreads are also often used to produce a better seismic image. Due to the high redundancy achieved in modern full-azimuth seismic surveys, legacy 3D data can deliver an excellent image despite near-surface complexity. Using a 2D swath acquisition configuration, we acquired data with a dense surface vibrator shooting pattern and 7.5 m sampling in both in-line and cross-line directions. The high source density was critical for efficient pre-stack noise attenuation and increasing the data redundancy, as well as providing data necessary for virtual source redatuming tests. Time processing was performed using a production workflow that included cross-line diversity summing, gain application, noise removal, dual sensor summing (as applicable), NMO correction, application of field statics, time-variant scaling, and CDP stacking. Figure 2 shows a comparison of the images obtained using different combinations of source and receiver acquisition.

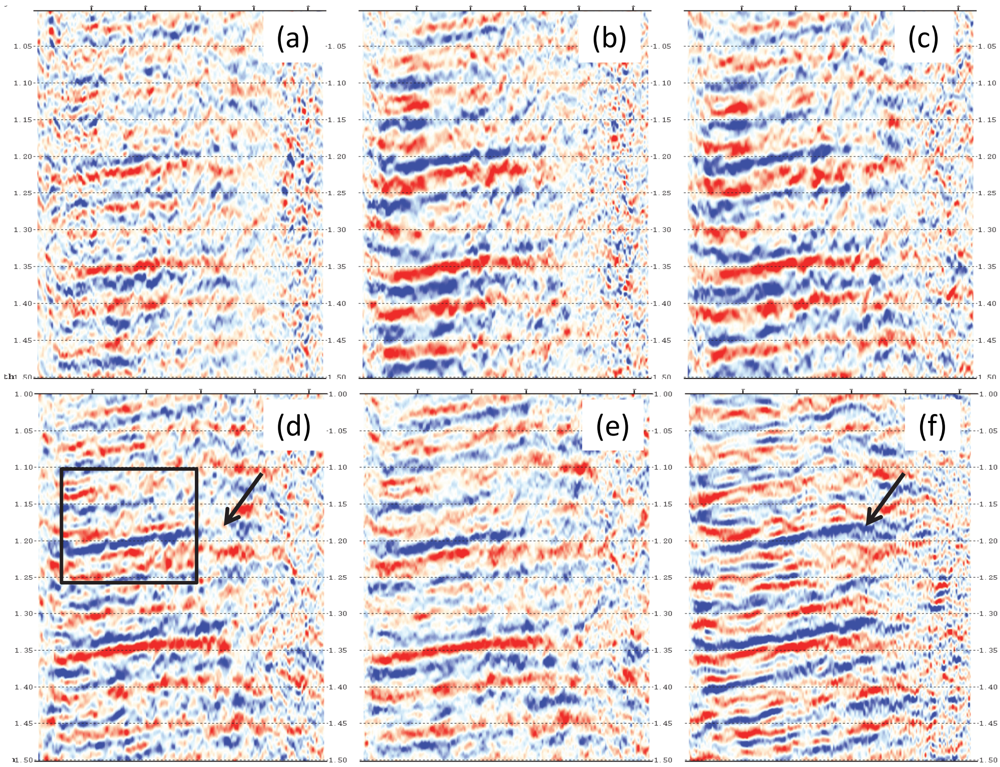

Figure 2 *Images from the first survey optimized for repeatability. These were obtained with various source and receiver configurations including (a) surface source and surface receiver, (b) surface source and buried geophone at 10 m, (c) surface source and buried geophone at 20 m, (d) surface source and buried geophone at 30 m, (e) surface source and buried dual sensor at 30 m (summed hydrophone and geophone), (f) virtual source and buried geophone (all at 30 m, preliminary image). The black rectangle in (d) outlines the window used for deriving the NRMS values shown in Table 2. The black arrows shown in (d) and (f) highlight the increased continuity of events in the virtual source image.*

Clearly, surface receivers produced the noisiest stacked section, while the buried receiver stacks produced higher-quality images with improved reflector continuity and higher bandwidth, particularly for stacks generated from receivers at 30 m. Note that during drilling for deployment of the buried receivers, more than 25% of the receiver holes encountered voids and lost circulation. One reason for the improved imaging with depth is that receivers may be below some of these karsted zones. Additional improvements in data quality were achieved after applying receiver-side deghosting of the buried receiver data by applying dual-sensor summation using a combination of colocated geophones and hydrophones (Figure 2e). Preliminary results from the virtual source redatuming obtained using the geophone data only (Figure 2f), show improved event continuity compared with the conventional single-sensor processing. Data acquired using the buried piezoelectric sources lacked the fold and signal-to-noise ratio to produce an equivalent image. It may be that the permanent piezoelectric sources have insufficient signal strength to illuminate the deep target zone within the acquisition time allowed in the study area

Land dual sensor results

In this experiment, the conventional hydrophones and geophones were cemented above the water table. While the geophones showed consistent signal strength, coupling variations among the hydrophones were significant. In contrast, we observed relatively good coupling for hydrophones which were deployed in 4C sensors, suggesting that packaging type may be critical for proper deployment of effective hydrophones in onshore monitoring applications. Images from buried hydrophone data were generally slightly poorer than those obtained from the regular buried geophones due in part to the coupling variations. Dual-sensor data, however, provided superior images when compared to the geophones only data in terms of bandwidth (Figure 3a) and it had somewhat lower signal-to-noise ratio. The spectra in Figure 3b shows that dual sensor data has higher resolution with less notching in the spectrum. This is due to addressing the near-surface ghosting on the receiver side.

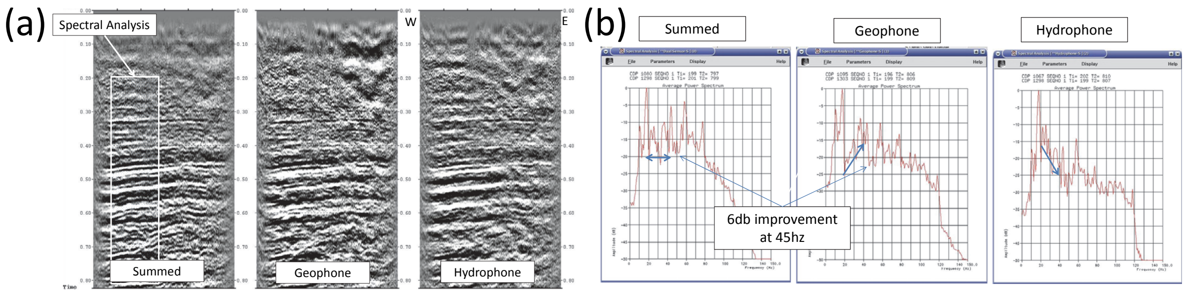

Figure 3 *Images obtained with (a) buried land hydrophone, geophone, and dual sensor data and (b) their corresponding amplitude spectra. Note the complementary behaviour of the geophone and hydrophone spectra and that summation can fill the spectral notch between 20-40 Hz caused by the surface-related multiples (receiver-side ghosting).*

Repeatability

Repeatability of the surface vibrator data is affected by a multitude of factors such as acquisition geometry repeatability, daily/seasonal variation of the near-surface and changes in source and receiver coupling. An analysis of the pre-stack repeatability of the surface vibrator data and its controlling factors are the subject of a separate study. In this paper we concentrate on quantifying post-stack repeatability between the first and second surveys and simply note that the mean deviation between shotpoint locations was less than 0.8 m for two surveys. Table 2 summarizes preliminary repeatability estimates for various acquisition configurations for the two surveys. We observed that receiver burial below sand cover – see Figure 1d far left locations – has the most dramatic impact on data quality and repeatability. NRMS is reduced by 6% by going to 20 m, but little additional improvement in NRMS is seen using data recorded by the 30 m sensors. While dual-sensor summation provided superior images compared to geophone data alone, the repeatability of the results was slightly worse. This is caused by the inconsistent hydrophone coupling and hence, worse signal-to-noise ratio as noted above. These results show similar trends to those observed in non-desert environments (Schissele et al., 2009).

Method	Post-stack NRMS (%)
Surface source – surface geophone	69
Surface source – buried geophone at 10 m	29
Surface source – buried geophone at 20 m	23
Surface source – buried geophone at 30 m	23
Surface source – buried dual sensor at 30 m	25

Table 2 *Repeatability achieved with different configurations for the first two surveys acquired with a surface vibrator. NRMS is estimated from a window of good data seen in Figure 2.*

Discussion and conclusions

A comprehensive onshore seismic experiment conducted in Saudi Arabia was aimed at evaluating various source/sensor configurations for land seismic monitoring. In the presence of a challenging karsted near-surface with a variable thickness sand cover, this study focused on evaluating shallow buried receivers from 0 to 30 m deep using a surface vibrator. Increasing receiver depth provided significant improvement in both image quality and repeatability. The best imaging was obtained with the deepest level of receivers at 30 m, probably because at this depth the receivers were below the near-surface sand layer and also below areas of karsting observed during drilling and deployment. Images obtained with virtual source redatuming using 30 m geophone data showed improved reflector continuity, particularly on the right portion of the section where data quality is poor. The best repeatability resulted from the 30 m sensor data with the most dramatic improvements occurring in sensors buried below the sand layer (10 m deep), whereas repeatability at 20 and 30 m, as measured by NRMS, was almost identical.

Dual sensor data provided some of the best images even though all sensors were deployed above the water table. To gain improvement in repeatability, better more consistent coupling is needed, possibly by using different hydrophone sensors, packaging or deployment methods.

Piezoelectric sources buried at shallow depths did not achieve the desired penetration and suffered from low signal-to-noise ratio. This was most likely caused by near-surface scattering. Deploying a stronger source and/or using a deeper placement may be attempted in the future to mitigate these problems.

Further developments in shallow drilling, sensors, sources, and recording systems, are required to enable cost-effective seismic monitoring on land.

Acknowledgements

We would like to thank Saudi Aramco for allowing us to publish this work and CGGVeritas and ARGAS (Arabian Geophysical and Surveying Company) for dedication in executing the field work.

References

Bakulin, A., and Calvert, R. [2006] The Virtual Source method: theory and case study: Geophysics, **71**, SI139-SI150.
Robinson, D., and Al-Husseini, M. [1982] Technique for reflection prospecting in the Rub' Al-Khali: Geophysics, **47**, 1135-1152.
Schissele, E., Forgues, E., Echappé, J., Meunier, J., de Pellegars, O., and Hubans, C [2009] Seismic Repeatability – Is There a Limit?: 71st EAGE Conference & Exhibition, Extended Abstracts, V021.