Single-sensor 3D land seismic acquisition in Kuwait

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Summary

In seismic data acquisition, the industry is facing a challenge to extend the implementation of temporal sampling principles to the spatial domain as the initial sampling interval in space impacts operational efficiency and is constrained by the availability of a sufficient number of sensors and the capacity and dynamic range of the recording instruments in addition to cost considerations. The use of single-sensor seismic acquisition has the potential to solve the aliasing problems associated with inadequate special sampling. This paper presents the reasoning behind conducting single-sensor 3D seismic surveys in onshore Kuwait and the quality of the results obtained.

Introduction

The seismic wavefield arriving to the surface is the net result of all distortions affecting the wavefield during its travel in the subsurface. This wavefield, ideally, should be properly sampled temporally and spatially in the receiver, source, offset and CDP domains. In 3D conventional land data acquisition, the wavefield arriving to the surface is only sampled at its intersections with receivers configured in an array.

Marschall (1999) defined nominal 3D full fold acquisition in 3D land acquisition as the case in which the surface acquisition template consists of square grids. An active receiver is located at each grid point within a square with side-length equal to a single receiver line and the source at the center. Roll-along in x- and y-directions is with increment of one grid point. This scheme is intended to be the theoretical reference against which other schemes are to be evaluated. Ongkiehong et al. (1988) defined universal land acquisition as a scheme in which we are not forced to commit to a final processing and/or interpretation sampling grid during the acquisition process, but have the ability to change the processing/interpretation bin dimensions at various later times and called this "uncommitted acquisition", i.e., in the field no irreversible step should be carried out such as group forming by conventional arrays. Several other authors have also discussed issues relating to acquisition to better sample the seismic wavefield and improve data resolution.

Conventional land 3D seismic using arrays acquired in Kuwait had shot and receiver arrays having a length of 50m. Consequently, the surface spatial sampling interval is equal to this length. Such array forming in the field by straight analog summation provides suboptimal performance in signal preservation and in antialias filtering. Their responses are distorted by the presence of intra-array perturbations and seismic data quality is adversely affected. Residual ground-roll will alias and consequently will not be effectively removed in processing. Intra-array perturbations are differences in amplitude, phase and timing between the different elements of an array. Intra-group statics, coupling, amplitude and phase variations, near-surface inhomogeneities, geophone sensitivity, dead sensors, polarity reversals, irregular spatial sampling, position errors, etc. cause these differences. Uncorrected intra-array perturbations could introduce pseudo-random noise, cause loss of signal and increased leakage of coherent noise.

Theory

Single-sensor seismic data acquisition has the potential to achieve 3D full fold uncommitted land seismic, which can reduce the above-mentioned perturbations and solve the aliasing problems associated with inadequate special sampling and consequently improve the quality of seismic data. Appropriate pre-processing of cross-spread gathers can remove intra array statics, which is mandatory, reduce amplitude and phase perturbations and suppress both directly arriving and scattered source-generated coherent noise. Initial ground roll attenuation, anti-alias spatial filtering and subsequent summation in a digital group forming (DGF) process of these processed gathers produce output shot records with better anti-alias protection, improved random noise attenuation and a more accurate correction for amplitude and static perturbations within the resulting arrays. However, the initial sampling interval in space is constrained by the availability of a sufficient number of sensors and the capacity and dynamic range of the recording instruments. These factors have cost and operational efficiency considerations. However, it remains mandatory that the spatial sampling of the coherent noise wavefield must be appropriate to ensure un-aliased recording of the noise energy. Baeten et al. (2000) introduced the concept of spatial adequate sampling, which depends on the noise and signal characteristics and suggested that, considering the temporal position and the maximum frequency limitation of the noise, it is possible to adequately spatially sample with sensor spacing a little more than half of the ground roll wavelength.

Acquiring a perfect uncommitted full fold 3D land P-wave survey, as per the concepts discussed above, to meet all requirements in Kuwait, even after relaxing the sampling requirement to adequate sampling, would require a large number of active channels that is still unrealizable in spite of all the recent technological advances in high channel count recording systems and digital sensors. Consequently, compromises have still to be made.

Data acquisition and processing

Noise tests conducted in Kuwait showed that there are very low velocity noise trains with high amplitudes that mask the reflections of shallow events with wavelengths in the order of 8m. Theoretically, to properly sample noises with these wavelengths, spacing between receivers of 4m or less would be required. In Kuwait, shallow horizons need to be imaged for statics determination and there are deep targets for which offsets longer than 6000m would be desirable. In addition, there is a need to achieve higher vertical resolution in the main producing reservoirs to enable better reservoir characterization and management. There are also reservoirs whose production is mainly controlled by fracture density and connectivity and hence there is a need to identify fracture density, connectivity and orientation by analyzing seismic attributes. This in turn requires wide azimuth acquisition geometry and minimization of geometry imprints.

The first test in Kuwait to investigate the value of single-sensor seismic recording was conducted in October 1998. Since then, Kuwait Oil Company took an interest in investigating the benefits of such an approach and in following its developments. This interest culminated in mobilizing in October 2003, under a Joint Technology Agreement with WesternGeco, a single-sensor 3D Q-land seismic crew, which is still operational since then. This system consists of acquisition, and processing imaging techniques that approach the generation of uncommitted seismic data in well-sampled wavefield segments. These data are suitable for data processing manipulation including the removal of time and amplitude perturbations and the use of proprietary algorithms to suppress noise and design and apply appropriate spatial resample filters. The acquisition system architecture records directly on disk to enable the handling of the increased data volume prior to DGF. Various noise and comparative tests were performed. In March 2004, the first single-sensor 3D onshore pilot study in the Middle East was completed. This was followed by two additional pilots whose main objective is resolution of a sand/shale sequence and an exploration/appraisal project targeting Jurassic reservoirs. The crew is currently acquiring 3D single-sensor surveys over two major fields.

Unique equipment being utilized follows:

- A single-sensor acquisition and processing system capable of recording 20,000 live channels at 2ms sample rate or 30,000 live channels at 4 ms sample
- Vibrators capable of exerting 80,000lbs peak force with frequencies starting at 3.5 Hz.

Key acquisition parameters currently used are as follows:

Geometry:	Orthogonal
Number of receiver lines:	7, spacing of 200m.
Sources:	Outside both sides of the template
Cross-line roll	1
Source line interval:	200m
Source interval:	20m, 2 Vibrators, 10 m apart
Sensors' inline spacing:	10m (3,840single sensors in 4 sub-lines with 5m stagger and separation)
Sweep Range:	3.5-84Hz
Sweep Length:	12 secs
Sample Interval:	4ms

The acquired data offered the opportunity to apply, prior to summation in the DGF process, a proper spatial anti-alias filter, corrections for intra array perturbations and schemes that effectively attenuated coherent noise while leaving the underlying signal intact (Figures 1 and 2).

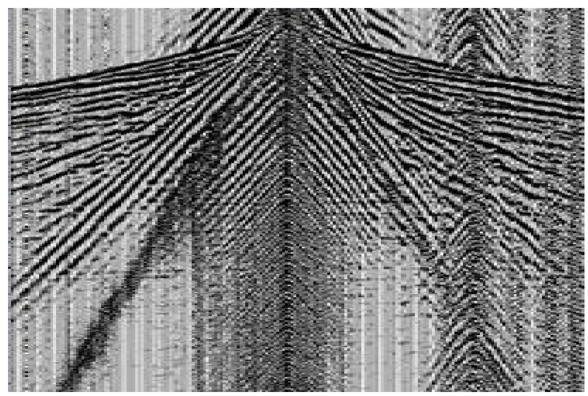

Figure 1: Raw single-sensor cross-spread record.

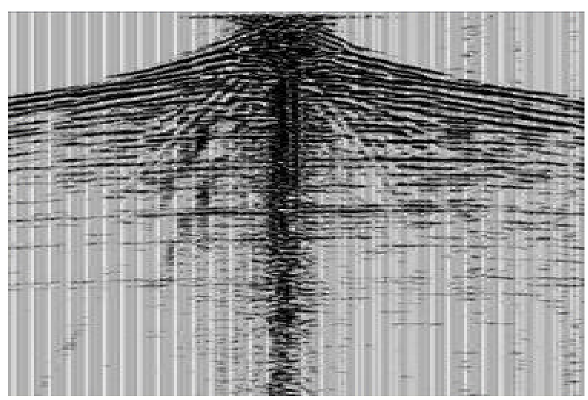

Figure 2: The record of Figure 1 above with noise attenuation applied within the DGF process.

Conclusions

The final processed data in all performed works exhibited increased bandwidth, signal-to-noise ratio and spatial resolution, which achieved most of the desired objectives. Figures 3 to 6 illustrate the improvement in data quality that has been achieved.

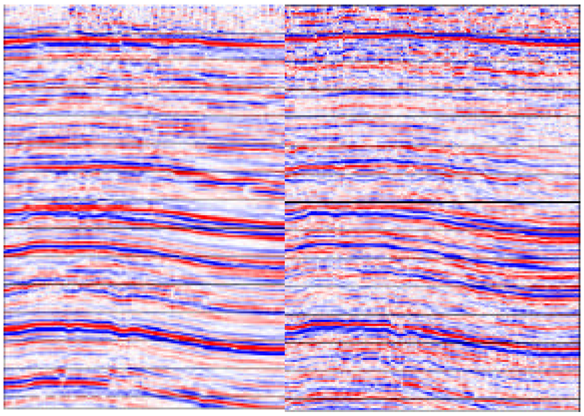

Figure 3: Left: conventional data, Right: single-sensor data.

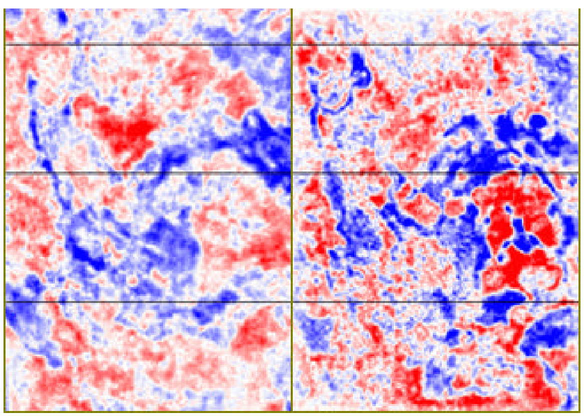

Figure 4: Left: time-slice-conventional data, Right: time-single-sensor data.

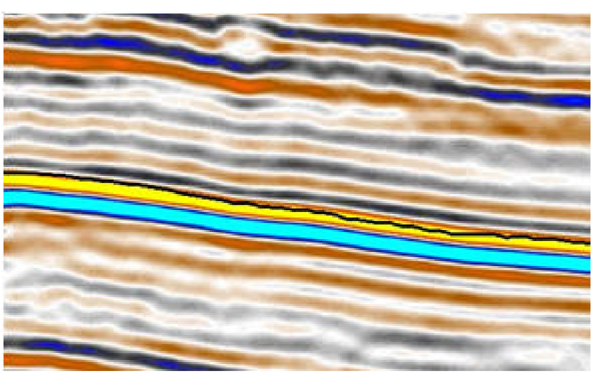

Figure 5: Conventional seismic data

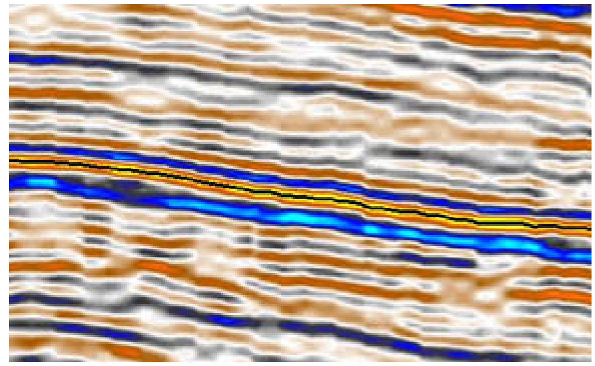

Figure 6: single-sensor seismic data-same location as in Figure 5.

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