

B001

Channel-Count Requirements for 3D Land Seismic Acquisition in Kuwait

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SUMMARY

Recent advances in land seismic recording equipment have increased the options available for acquisition geophysicists. There are now four main competing types of sensors. The selection of sensor type is today a major decision in seismic survey design as it will greatly affect the channel-count requirements for 3D land seismic acquisition and the resulting data quality. Channel-count requirements for 3D land acquisition in Kuwait and the concepts involved, which are not limited to Kuwait environment, are herein presented and their impact examined. The analysis shows that in 3D land seismic data acquisition, in spite of the recent advancements, the industry is still facing a challenge to properly sample data in the spatial domain due to channel-count limitations of today's recording systems.

Introduction

Land seismic data acquisition in Kuwait has to address: multiples, scattered source generated coherent noise, flare noise, high amplitude noise trains (ground roll) with noise wavelengths in the order of 8 meters, image a shallow horizon for statics determination and a shallower heavy oil target, image deep reservoirs, for which offsets in the order of 6,000 meters are desirable, achieve high vertical resolution for reservoir characterization and minimize geometry footprints to enable successful attribute analysis, AVOA, inversion, etc.

Because of the relatively small land area of Kuwait (17,820 sq kms), the large number of structurally similar fields and prospects (Figure 1), it makes sense to consider one land 3D acquisition template that addresses the challenges listed above and enables future seamless merging of all individual surveys to produce a single 3D volume covering the whole of Kuwait.

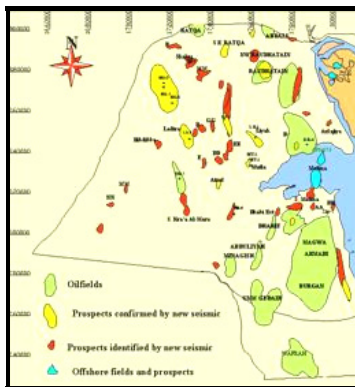


Figure 1: Fields and prospects-Onshore Kuwait.

Theory and Application

Marschall (1999) defined nominal 3D full fold acquisition in 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 (or rectangle) with side-length equal to a single receiver line and the source at the center. The roll-along in x- and y-directions is with increments of one grid point. This scheme is intended to be the theoretical reference against which all other schemes are to be evaluated.

Let us start from the above defined reference scheme by selecting a surface acquisition template consisting of two square grids with equal bin sizes: source-grid (red) and receiver-grid (black), and locating an active single-sensor at each receiver-grid point and a source at the center (Figure 2). The dimensions of the square are determined by the desired maximum offset of 6,000m.

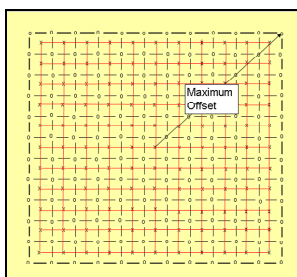


Figure 2: Nominal template.

Marschall (1997) introduced the concept of the number of different bin configurations, which are repeated periodically over the area of a survey and called it "BSC". For a full fold scheme, as defined above, the total number of different bin configurations is 2. This represents the

minimum number possible unless azimuthal variations are ignored, then we have $BSC_{min}=1$. Whereas fold remains constant for each bin throughout a seismic survey, BSC will usually be found not to be the optimum minimum value of 2. This results from design changes caused by cost constraints and equipment availability considerations. Seismic amplitudes vary with offset, if we have changes in the offset distribution from one bin to the next, we will end up with a bias pattern in the amplitudes of the stacked traces, which is called acquisition footprint (geometry imprint).

As seismic data interpretation is no more only focused on structural interpretation and many interpretation tools are based on amplitude analysis, this bias pattern in the amplitudes should be minimized at the acquisition stage and not left to be handled in processing with techniques that generally distort relative amplitudes. The BSC in conjunction with bin size determines the area of different bin configurations which is periodically repeated. We should attempt to minimize the area of the repeated pattern in our survey design to minimize bias pattern in amplitudes. One of the major techniques to minimize bias pattern in amplitudes and maintain areal resolution is to reduce the ratio of source and receiver line intervals relative to the bin size in the source and receiver directions and avoid multi-line roll schemes.

Vermeer (2002) defines proper 5-D prestack wavefield sampling as alias free sampling of the temporal and all four spatial coordinates. Such sampling allows the faithful reconstruction of the underlying continuous wavefield.

Noise tests conducted in Kuwait have shown that the shortest wavelengths of ground roll are in the order of 8m (Figure 3), which would require receiver and shot spacing in the order of 4m or less. However, Baeten et al. (2000) introduced the concept of spatial adequate sampling which is the use of a sampling distance that prevents the noise wavefield from aliasing into the signal passband. Thus, it is possible to adequately spatially sample with sensor spacing a little more than half of the ground roll wavelength (the Nyquist sampling criterion). This concept of adequate sampling would allow relaxing this anti-alias requirement to let us say 5m.

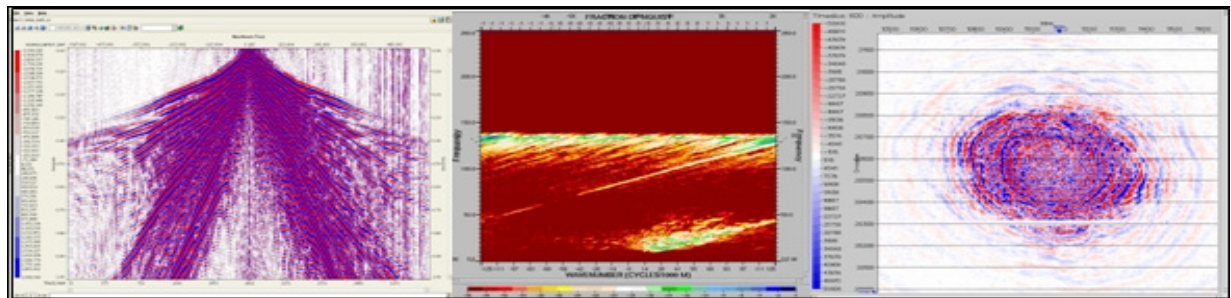


Figure 3: Noise Test: Raw single sensor, FK spectrum, Time-slice from cross spread showing anisotropy in the ground roll velocities.

Using the above concepts, let us choose a template consisting of 1720 lines spaced 5m apart and 1720 single-sensors per line spaced 5m. This template will provide a maximum offset of 6078m, which is adequate for the deep targets in Kuwait. To ensure constant inline and crossline fold, the number of lines should be even and the number of sensors per line should be even and a multiple of 5. This template would result in a fold of 739,600 and would require 2,958,400 single-sensors. Being single-sensors, the same number of recording channels would be required. This is neither practical nor achievable.

Vermeer (2002) meticulously explained that the sampling requirement can be reduced to the proper sampling of the wavefield of the characteristic single-fold minimal data set of the chosen acquisition geometry and demonstrated that proper 3-D symmetric sampling, defined as the proper sampling of the single-fold subsets of the chosen geometry, would be sufficient

to fully construct the underlying continuous wavefield (not the whole wavefield). Thus 3-D symmetric sampling, as a compromise, settles for the more affordable and practical aims of correct sampling of overlapping single-fold 3-D subsets of the 5-D wavefield. For orthogonal geometry, the basic subset is the cross-spread formed by all traces that have a shot line and a receiver line in common. As it is assumed that the cross-spread is a continuous function of its variables, proper sampling of the continuous wavefield allows full reconstruction of that wavefield. The assumption of continuity means that small shifts in source or receiver position would lead to only small change in the wavefield.

The shallowest horizon to be imaged has to be identified and considered in relaxing the requirement of the template discussed above. The imaging of the Rus shallow horizon is needed for static determination and as a reference for depth conversion. The Rus lies at depths ranging between 200m and 600m. Ideally, a fold of 4 would be desirable at this level. There is also a shallower heavy oil target. Obviously, it would be more appropriate to handle the shallower heavy oil target separately.

Based on the above, let us now settle for acquisition line spacing of 200m for shot lines and receiver lines and a template of 44 receiver lines spaced 200m consisting of 1760 single-sensors per line spaced 5m, that is 77,440 single-sensors are required and, being single-sensors, the same number of recording channels would be required. This design results in a maximum offset of 6,150m, cross-line fold of $44/2=22$ and in-line fold of $(1760/2)*(5/200)=22$, that is a maximum nominal fold of 484. On face value, this scheme appears to be reasonable, however, 1000 shots/per sq km would be required to meet the requirements of symmetric sampling – equal shot and receiver sampling interval in this single-sensor scheme (there are no arrays in this scheme). As both the shots and receivers are inline, it is doubtful that ground roll suppression would be optimum. Acquisition schemes that require 1000 shots/per sq km are expensive. The cost of land data acquisition depends more upon the source effort than upon the number of receivers used. In addition, the WesternGeco's Q-Land single-sensor (1C) acquisition and processing system, the only high channel-count currently commercially available, is currently only capable of recording 20,000 live channels at 2ms sample rate or 30,000 live channels at 4ms sample rate.

In five single-sensor surveys and numerous tests conducted in Kuwait, we have established that the use of single-sensor recording in an orthogonal geometry enables the exploitation of the three-dimensional nature of the data representation within the cross-spread gather to suppress noise before group forming. This resulted in that the effective attenuation of noise in the cross-spread gather decouples the source array from the receiver array.

The receiver array adopted in the last survey consisted of single-sensors with 10m inline separation in 4 sub-lines, 5m stagger and 5m cross line separation. Shot array adopted was two vibrators with inline spacing of 12.5m, which is ideal under the circumstance where surface contamination with unexploded ordnance is an issue. This combination allowed optimum ground-roll suppression in processing.

Using the above assumptions, let us now compute the number of receiver stations required in orthogonal acquisition geometry, with one line roll, in a less ambitious 3D land seismic acquisition scheme. We select a template of 16 lines spaced 200m; each line has 4 sub-lines consisting of 1,160 single-sensors spaced 10m apart resulting in receiver lines with effective length of 11,600m and maximum offset of 5,986m. Total number of single-sensors would therefore be $16 \times 4 \times 1,160 = 74,240$. Again, this humble scheme, with aspect ratio of only 0.28, is currently unachievable with the commercially available single-sensor recording instruments.

Considering the 3C MEMS-type sensors, such as Sercel's DSU1 and Input/Output's VectorSeis with three sensors each and depending on using adaptive filtering for noise attenuation, we can modify the sensor requirements in the above template to 590 (3C) units in linear arrangement with 20m spacing resulting in 9,280 units and requirement for 27,840 recording channels. However, even if achievable, this approach might not be good enough to attenuate the various types of noise encountered in Kuwait.

Replacing each 3C unit with an array of 12 conventional analog velocity geophones would result in a requirement for 9,280 recording channels. This is achievable. However, such array forming in the field by straight analog summation provides suboptimal performance in signal preservation and in antialias filtering. The response of the analog array is distorted by the presence of intra-array perturbations and seismic data quality is adversely affected. Residual ground-roll will alias. Consequently, this ground-roll will not be effectively removed in processing. Uncorrected intra-array perturbations could introduce pseudo-random noise, cause loss of signal and increased leakage of coherent noise, Rached and Al-Fares (2006).

A recent 3D land seismic acquisition survey in Kuwait adopted the channel-count limit of WesternGeco's Q-Land system in orthogonal geometry using 7 lines with sources outside both sides of the template to simulate a template of 14 acquisition lines. This compromise has an aspect ratio of only 0.29 and a maximum offset of only 4,990m, while at least an offset of 6,000m is desirable to image potential deeper reservoirs.

Conclusion

In 3D land seismic data acquisition, in spite of the recent advancements, the industry is still facing a challenge to properly sample data in the spatial domain. This is because the sampling interval in space affects operational efficiency and is constrained by the availability of recording systems that have the capacity and dynamic range to handle high channel-count in addition to cost considerations. In any compromises in seismic acquisition design resulting from these constraints, we should attempt to minimize the number of different bin configurations in our survey design to minimize bias pattern in amplitudes. One of the major techniques to minimize the number of different bin configurations is to avoid multi-line roll schemes.

Acknowledgments

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