

Wide-geometry 3D land seismic acquisition in limited channel-count environment

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Summary

Recent advances in land seismic recording equipment have increased the options for acquisition geophysicists. There are now several recording systems that claim high channel-count capabilities and four main competing types of sensors. Today, the selection of a recording system and sensor type is a major decision in 3D land seismic survey design as it will greatly impact the channel-count requirements, operational efficiency, cost and the resulting data quality. Sensor type and the related channel-count requirements for wide-geometry 3D land acquisition are herein presented and their impact examined. Techniques to implement wide geometry in limited channel-count environment are also reviewed. This review concludes that such techniques in 3D land seismic data acquisition have technical limitations. Consequently, the seismic industry is still facing a challenge to properly sample data in the spatial domain due to channel-count limitations of today's recording systems. Although the analysis is based on experience in Kuwait, the concepts involved are applicable in all similar environments.

Introduction

Land seismic data acquisition in Kuwait has to address: multiples, flare noise, high amplitude noise trains (ground roll) with noise wavelengths in the order of 8 meters, scattered noise, image a shallow horizon for determination of statics, image deep reservoirs for which offsets of more than 6,000 meters are desirable, achieve high vertical resolution for reservoir characterization and minimize geometry footprints to enable successful attribute analysis, AVOA, inversion, etc. In addition, due to the relatively small land area of Kuwait (17,820 sq. kms.) and its large number of structurally similar fields and prospects, 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.

Theory and applications

Marschall (1999) defined 3D full fold and Nominal 3D full fold in land acquisition. The schemes are intended as the theoretical references against which all other schemes are to be evaluated. His definition of 3D full fold is here modified to the case in which the surface acquisition template consists of square grids with an active single sensor (receiver) or an array of sensors located at each grid point within a circle whose radius is the maximum tolerable

offset. The roll-along in x- and y-directions is with increments of one grid point. Nominal 3D full fold is the case in which the circle is replaced by a square or rectangle. The dimensions of the square (or rectangle) are determined by the desired maximum offset and the dimensions of the grids are determined by the anti-alias criterion, and the type and geometry of the sensors used. In all cases $\Delta G = \Delta S = \Delta g = \Delta s$, Figure 1.

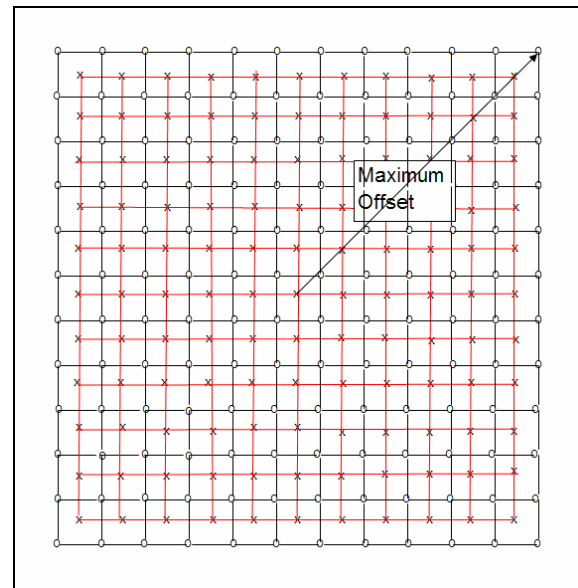


Figure 1: Nominal 3D full fold template.

Marschall (1999) also defined the concept of the number of different bin configurations that are repeated periodically over the area of a survey, called "BSC". For a full fold scheme, as defined above, the total number of different bin configurations is 2. This represents the minimum number possible. Whereas fold usually remains constant for each bin throughout a seismic survey, BSC will usually be found not to be the optimum minimum value of two. 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. This bias pattern is called acquisition footprint (or geometry imprint). Although a number of processing programs are available to address this issue, it is not certain that relative amplitude can be preserved.

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Seismic data interpretation is no more focused only on structural interpretation. Many interpretation tools are based on amplitude analysis. Consequently, 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 that 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 improve areal resolution is to reduce the ratio of source and receiver line intervals relative to the bin size and avoid multi-line roll schemes. Even multi-line roll schemes that can be regularized before stacking to a homogeneous scheme equivalent to symmetric central shooting by discarding redundant traces in processing will not eliminate bias pattern in amplitude but will only reduce it.

Vermeer (2002) defined 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. Vermeer also 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 aim 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 a continuous wavefield allows full reconstruction of that wavefield. The assumption of continuity here means that small shifts in source or receiver position would lead to only small change in the wavefield.

Noise tests conducted in Kuwait (Figures 2 and 3) have shown that the shortest wavelengths of ground roll are in the order of 8m, 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. This concept of adequate sampling allows the relaxing of the anti-alias requirement.

The shallowest horizon to be imaged has to be identified and considered in relaxing the requirement of the template discussed above. In Kuwait, the imaging of the Rus shallow horizon is needed for static determination, for multiple attenuation as it is one of the generators of multiples, and as

a reference for depth conversion. The Rus lies at depths starting from 200m. Ideally, a fold of 4 is desirable at this level.

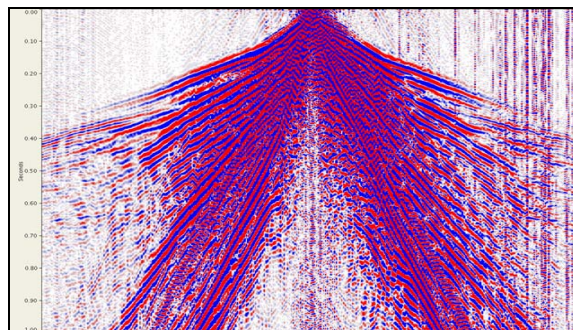


Figure 2: Noise test, raw single sensor record.

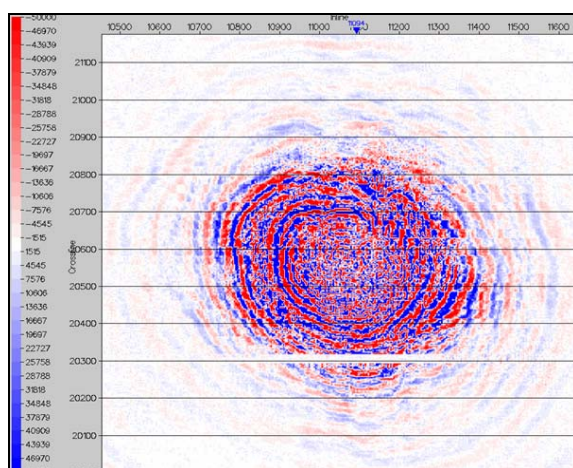


Figure 3: Time slice from a noise test cross spread at 600ms showing anisotropy in the ground roll velocities.

Although the combination of linear shot and receiver arrays in an orthogonal geometry could be adequate for ground roll attenuation, it is not optimum for scattered energy. 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. However, linear arrays alone were not found to be optimum. A combination of an uncommitted receiver array formed from an arrangement of single-sensors (Figure 4) and a shot array of four vibrators enabled optimum noise suppression in processing that included digital group forming.

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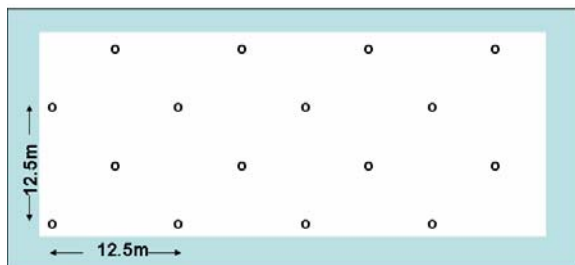


Figure 4: Single sensors in 4 staggered sub-lines for optimum noise suppression.

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 60 lines spaced 200m; each line has 4 sub-lines consisting of 960 single-sensors spaced 12.5m apart resulting in receiver lines with effective length of 12,000m and maximum offset of 6,000m, (Figure 5). Total number of single-sensors would therefore be $60 \times 4 \times 960 = 230,400$. This scheme with shots only between the central two receiver lines, referred to in literature as a homogeneous scheme, is currently unachievable with the commercially available single-sensor 1C recording instruments.

Considering the 3C MEMS-type sensors, such as Sercel's DSU1 and Input/Output's VectorSeis with three sensors each and depending only on using adaptive filtering for noise attenuation, we can modify the sensor requirements in the above template to 480 (3C) units in linear arrangement with 25m spacing resulting in 28,800 units and a requirement for 86,400 recording channels. Even if achievable, this approach might not be good enough to attenuate the various types of noise encountered in Kuwait by depending on adaptive filtering of widely spaced single 3C sensors. In addition, sampling at 25m interval cannot be considered full-wave sampling. Using 3C sensors in arrays will require an unachievable large number of channels

Replacing each 3C unit with an array of 12 conventional analog velocity geophones would result in a requirement for 28,800 recording channels. Even if achievable, array forming in the field by straight analog summation provides suboptimal performance in signal preservation and in anti-alias 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).

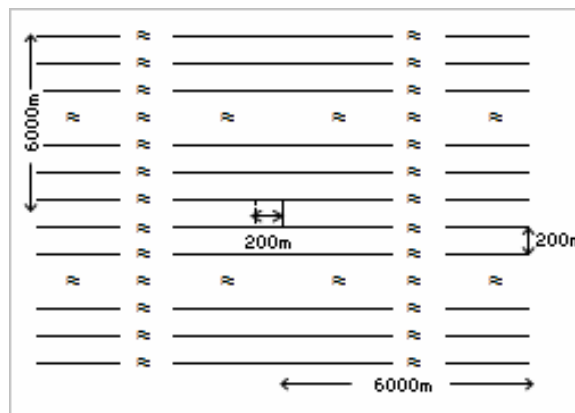


Figure 5: Homogeneous scheme, one line roll.

All the above scenarios are based on one line roll approach with no shot repeat. There are however, techniques to simulate wide acquisition geometry. Saudi Aramco has developed a 3-D wide-azimuth-swath (WAS) geometry as an alternative to conventional 3-D swath acquisition designs. The flexibility of WAS geometry generally offers significant design opportunities for obtaining improved data attributes and increased operational efficiency when faced with crew-recording channel limitations: (Hasting-James et al. 2000, p. 1003). Figure 6, illustrates this approach in which two sets of shots are located on either side of the acquisition template.

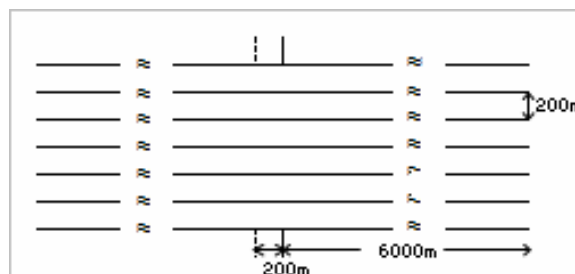


Figure 6: Homogeneous scheme, one line roll, two sets of shots on either side of the acquisition template.

Another technique is illustrated in Figure 7. This full-swath roll technique is promoted by Gijs Vermeer in his book, Vermeer (2002), and in a number of his publications. In such a full-swath roll technique, Vermeer emphasizes that the salvo of shots has to extend on both sides of the template to allow recording of the required maximum crossline offset (ideally this should be equal to the required inline offset). Both techniques require repeated shooting of the same shot point into different templates (swaths) resulting in that the nominal 3D full fold is simulated by more than one data set from one shot position.

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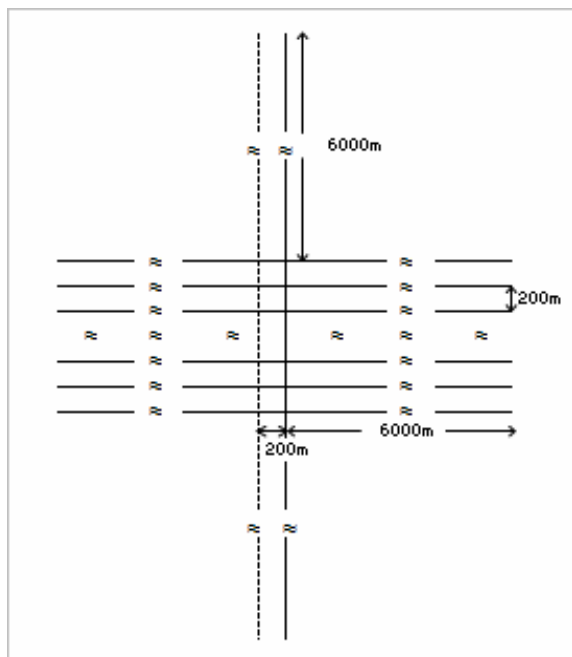


Figure 7: Symmetric sampling cross spread, full swath roll, and the salvos extend far outside both sides of the acquisition template to allow recording of the required maximum crossline offset.

In the above designs of figures 6 and 7, with repeated shots, statics coupling and shot repeatability are issue that should be taken into consideration,

In the full-swath roll (Figure 7), the number of receiver lines should be maximized as a function of channel-count availability rather than as a function of operational efficiency. Also, as it is more convenient to record all the data from all the receivers in the acquisition template from all the shots in the salvo, it is necessary to restore symmetry in processing before stacking the data to reduce bias pattern in amplitude.

In the above designs of figures 6 and 7, with repeated shots, statics coupling and shot repeatability are issue that should be taken into consideration,

The following table summarizes the channel-count requirements for the various designs discussed above:

Figure	Survey Design	lines	Sensors /line pre-grouping	sub-line s	Channels/line post-grouping	sensor spacing	Channel/source spacing	line spacing	Roll	Live channels
1	Single sensors 1C, array of 8	60	960	4	480	12.5	25	200	1	230,400
1	Single sensors 3C	60	480	1	480	25	25	200	1	86,400
1	Conventional, array of 12	60	2,880	2	480	4.17	25	200	1	28,800
6	Single sensors 1C, array of 8	30	960	4	480	12.5	25	200	1	115,200
6	Single sensors 3C	30	480	1	480	25	25	200	1	43,200
6	Conventional, array of 12	30	2,880	2	480	4.17	25	200	1	14,400
7	Single sensors 1C, array of 8	30	960	4	480	12.5	25	200	30	115,200
7	Single sensors 3C	30	480	1	480	25	25	200	30	43,200
7	Conventional, array of 12	30	2,880	2	480	4.17	25	200	30	14,400

Table 1: channel-count requirements

Conclusions

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, there are cost considerations. 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 without repeating shots. Repeating shots results in repeatability and static decoupling implications which increase as the shot repeat factor increases. In any compromises in seismic acquisition design we should attempt to minimize the number of different bin configurations 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 and avoid multi-line roll schemes. This would require higher channel count and improved methods to handle the resulting increase in the data volume. Survey design decisions should continue to consider cost and operational issues. These decisions should also bear in mind that seismic techniques are not only tools for structural imaging, but now they play an important role in reservoir characterization, and in tracking fluid movement and bypassed hydrocarbons. This role results in much higher value added to the exploration and production companies as well as to the future generations. We should face the challenge and be prepared to spend more money.

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EDITED REFERENCES

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