Design of Acquisition Geometry for 3D Seismic Survey having Multiple Objectives

Lavendra Kumar, USD Pandey, ONGC, Mumbai
lavendra@gmail.com

Keywords: 3D Survey Design

Summary:
Optimization of acquisition parameters is very critical step of 3D survey design as it affects quality of subsurface image, productivity and cost of seismic data thereby fulfillment of assigned objective. Exploration requirement, at times, have multiple targets lying at different levels ranging in depth from very shallow to deep. Since the parameters are objective oriented, such areas of multiple (multi level) objectives pose great challenge to the survey designer. The situation could be multiple targets with higher resolution at shallower and deeper levels, or recognition of weak events at deeper level as well as higher resolution at shallow level or high / low velocity layers or anisotropic media in a confined.
In the present study, the parameter has been designed to meets the exploration targets varying from 750 m to 3500 m with anticipated fractures at shallower level and improve imaging at deeper level. Geometry has been designed for primary objective at shallow level (750 m to 2000 m) as well as deeper secondary objective at (2500m to 3500 m).
The paper describes the analysis of various attributes for optimization of geometry based on comparative analysis of near-optimal options.

Introduction:
The land 3D survey started in late 1970s had simple swath geometry essentially multiple parallel lines having modest number of active channels. Recording systems available at that time was capable of recording only 48 channels and therefore two such systems have to be used in master/slave in order to record 96 receiver groups. The geometry used to be constrained by the capability of recording systems and processing techniques. 3D survey design related issues like offset and azimuth sampling etc. were not well understood at that time and these surveys were essentially multiple parallel lines. In these early 3D seismic surveys, the geometries used to be designed simply by drawing/sketching on paper with pen or pencil based on the lessons learned from 2D surveys keeping inline with smaller bin size along dip direction and wider receiver line interval along cross line placed in strike direction resulting longer bin size.
With advancement in acquisition, processing as well as visualization technology modeling methods / pre-survey illumination techniques / studies have become integral part of 3D seismic survey design. AVO studies have further guided to acquire data with sufficient incident angles at target levels. Growth of recording channel counts and capability of recording system with time (Lansley, M 2013) is shown in Fig.1. Improved capabilities of the recording systems enabled acquisition of surveys with high trace density in areas with open surface access. In other areas having problems of surface access, the number of active channels is controlled not by the capability of recording system but it is restricted, to some extent, by logistics or other optimization factors.

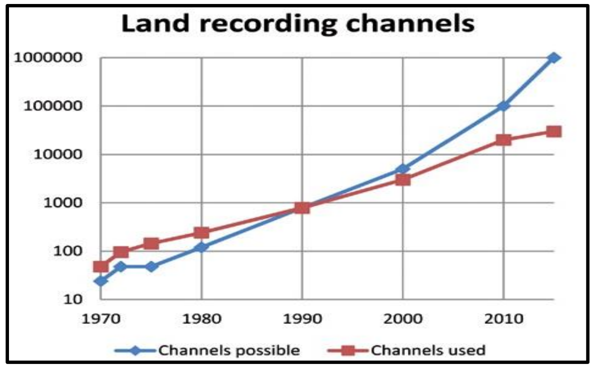

Fig.1: Plot showing a history of recording system channel count (Lansley M, 2013)

In India, 3D technology was introduced by ONGC in 1986 by conducting 1st onland 3D survey in Balol field of Cambay Basin (Unpublished ONGC report, 1986). Four lines swath geometry with total 192 active channels was used with a bin size of 15x60 m. Early offshore 3D survey, in India, was conducted by ONGC's M/V Sagar Sandhani in 1987-88 in west coast (Kumar, L. 2006a). The vessel was equipped with single streamer and single source at that time which was later upgraded to dual source and dual streamer. Since then, 3D seismic technologies have traveled a long way both in onshore as well as offshore areas. From 192 active channels recording in 1986 to more than 4000 channels now in onland 3D seismic crews, channel counts have increased many fold (Fig.2). Majority of onland crews adopt wide-azimuth 3D geometries based on bin attributes analysis and illumination & pre survey modeling studies. Each crew utilizes DGPS system to get online coordinates of actual shots/ receivers position on the ground.

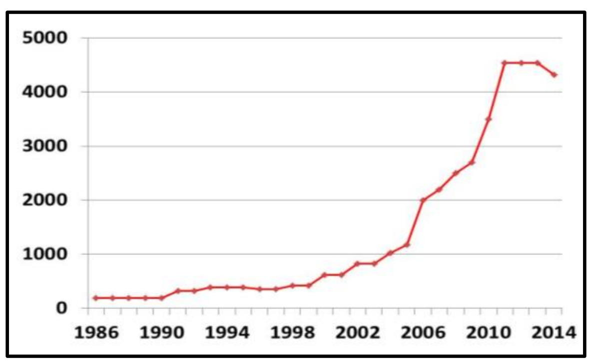

Fig. 2: Plot showing typical channel counts recorded for 3D surveys in ONGC.

With emphasis on pre-stack processing of 3D data it has become essential to focus on spatial sampling of 3D surveys for improved imaging at various target levels. The ideal 3D survey should be able to sample the 5D wave field w (t, x_s, y_s, x_r, y_r) dependent namely upon travel time t, source and receivers locations (Vermeer GJO, 2002). Carefully designed wide-azimuth 3D surveys improve the spatial continuity and therefore tend to have small acquisition footprints. Uniform fold, offset and azimuth distribution for all the bins would reduce the footprints to a great extent but this is practically non-achievable in field. Minimizing variation of these attributes across the bins is aim of the geometry designer so that acquisition footprints are bare minimum. Therefore, the split spread, orthogonal and swath roll by single line has become most common geometry for the land survey but with its impact on input, cost and productivity.

Thus optimization of acquisition parameters is very critical step while 3D surveys design as they affects quality of subsurface image, productivity and cost of survey for fulfillment of assigned objective. Exploration requirement, at times, have multiple targets lying at different levels ranging in depth from shallow to deep. Since the parameters are objective oriented, survey design in such areas of multiple (multi level) objectives pose great challenge to the survey designer. Though acquisition systems are now available with very high channels capacity, dynamic range and flexibility of ground setup of receivers but each channels has its cost implication. To get sufficient fold suitable for shallower target requires closer receiver lines and shot lines while the deeper objective demands long spread with higher channels/offsets. To overcome this problem, a solution is provided for getting sufficient fold at shallower as well as for deeper objective. This is achieved by having variable number of channels in receiver lines as explained in subsequent section. This idea is further extended by optimizing number of channels in extreme lines of the spread to restrict the traces having offsets beyond requirement. From comparison of analysis of the attributes of various options, it has been shown that provided solution is better option for such areas of multiple objectives.

Table 1: Geometrical Parameters and Bin attributes

Parameter	Opt-1	Opt-2	Opt-3	Opt-4
GI	40	40	40	40
SI	80	80	80	80
RLI	320	320	160	160
SLI	400	400	400	400
Bin Size	20X40	20X40	20X40	20X40
Shots/Salvo	4	4	4	4
No of Lines	12	16	24	24
Receivers/line	200	200	12X200 12X80	8X200 2X180 2X160 12X80
Total Channels	2400	3200	3360	3240
Foldage	60	80	84	81
Xmin	45-472	45-472	45-472	45-472
Xmax	3974-4402	4278-4711	3974-4402	3974-4402
Fold(0-750m)	2-4	2-4	4-8	4-8
Fold(0-1000m)	5-7	5-7	11-14	11-14
Fold(0-1500m)	12-16	12-16	24-30	24-30
Fold(0-2500m)	31-35	36-40	56-79	56-59
Fold(0-4000m)	55-60	71-76	79-84	78-81

Probable Options:

The study has been undertaken to optimize acquisition parameters to acquire 3D data in an area having exploration interest ranging in depth from 750 m to 3500m. The depth range of primary objective is from 750 m to 2000m while secondary objective has depth range of 2500 m to 3500 m. Based on seismo-geological inputs, geometry with the binsize of 20x40 m and 60 foldage may provide required trace density for the survey area. Four probable options of split spread orthogonal geometries with single line swath roll were arrived. The geometrical parameter and attributes from these options are compared in table 1. Option-1 has the 12 receiver lines at 320 m apart having 200 channels in each line resulting in total active channels of 2400 (Fig.3). The shot line spacing of 400 m provides 60 fold coverage. Option-2 (Fig.4) has similar geometrical parameters but 16 receiver lines thus resulting in 3200 total active channels. The same shot line spacing of 400 m provides nominal fold of 80 in this option. The option-3 has additional 12 receivers line in between the receiver lines of option-1 but having only 80 channels as shown in template (Fig. 5). The option-4 is discussed in next section.

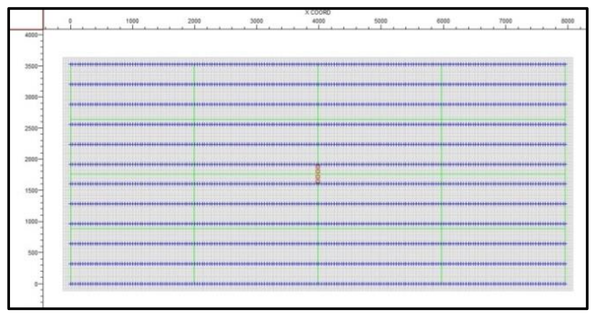

Fig. 3: Unit template of option-1

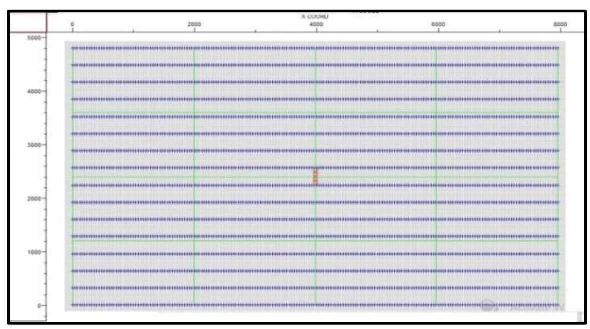

Fig. 4: Unit template of option-2

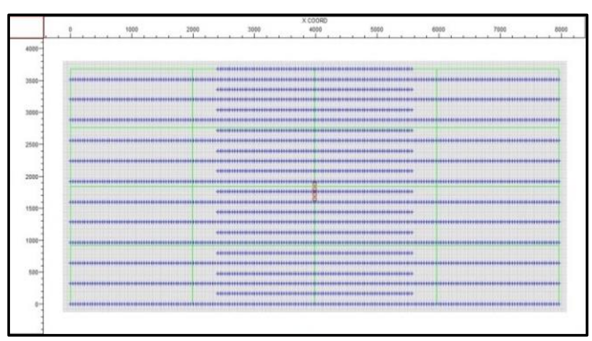

Fig. 5: Unit template of option 3

Comparison of Attributes:

The rose diagram showing bin attributes of offset and azimuth distribution for three options 1, 2 &3 shown in fig. 6, 7 and 8. It can be seen that all the three options provide almost full azimuth coverage for the primary target. The maximum far offset is of the order of deepest target. However, option-1 and option-2 provide only 5-7 traces having offset range of 0-1000 m offset while option-3 provides 11-14 traces for the same offset range (fig. 9,10,& 11) . Similarly, number of traces having offset range of 0-2500 m is more in option-3 than option-1 or 2 as shown in table-1. Number of traces in various offset ranges for these options is also shown in the table. Even if, these traces are normalized with total nominal fold of the respective options, the option-3 is found as better option for primary objective of the survey. A geometry may be designed which provide these many traces at primary objective by decreasing shot line but it will have cost implication. Hence this option is not included in the analysis.

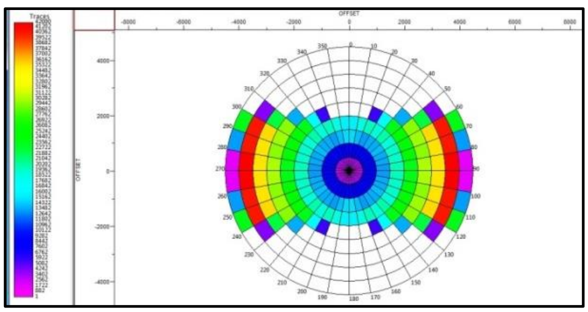

Fig. 6: Rose diagram for option-1

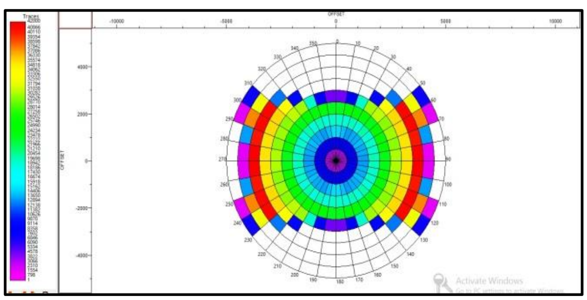

Fig. 7: Rose diagram for option-2

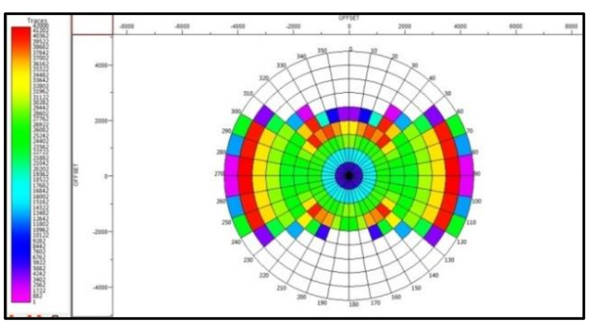

Fig.8: Rose diagram for option 3

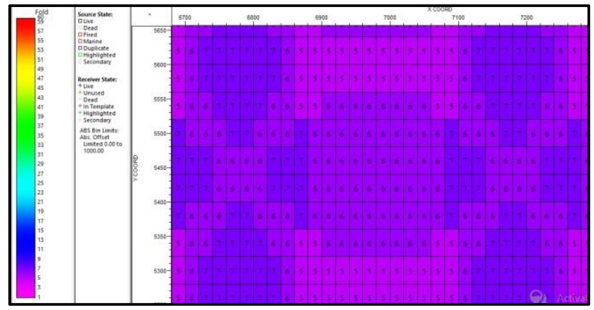

Fig.9: Number of traces is 5-7 for offset range of 0-1000 m in option-1

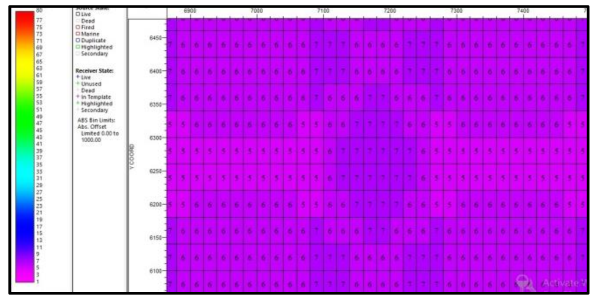

Fig.10: Number of traces is 5-7 for offset range of 0-1000 m in option-2

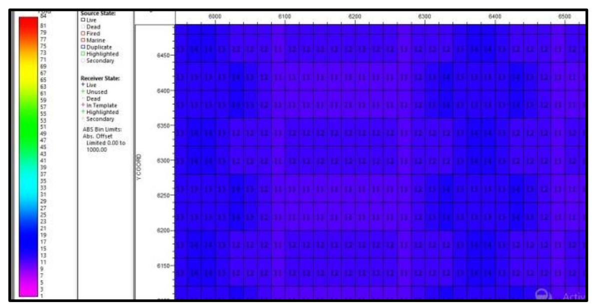

Fig.11: Number of traces is 11-14 for offset range of 0-1000 m in option-3

Further optimization of Active Channels:

Except in node base land acquisition systems, more active channels increases the cost in addition to burden on deployment in field by crews. The receivers at extreme end of the extreme lines contribute for offsets ranges which may be beyond interest. Non-deployment of these channels may further reduce active channels count without affecting the far offset. The number of channels to be omitted from these extreme lines may be optimized. One such option is shown as opt-4 in table-1 and its unit template is depicted in fig.12. Rose diagram and number traces in offset range of 0-1000 m are shown in fig.13 and fig.14. It is clear from comparison of rose diagrams in fig 8 & 13, contribution of traces pertaining to primary objectives are not affected while traces beyond maximum far offset have been reduced considerably. The same inference is explicitly depicted in histogram of offsets as shown in fig. 14 & 15.

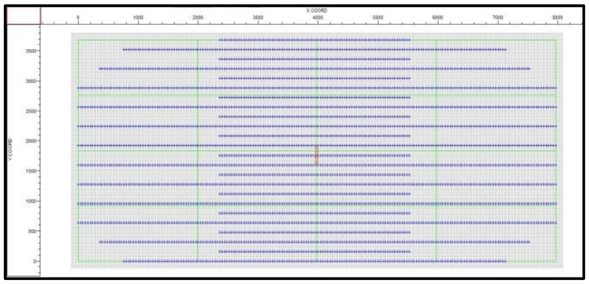

Fig. 12: Unit Template of option-4

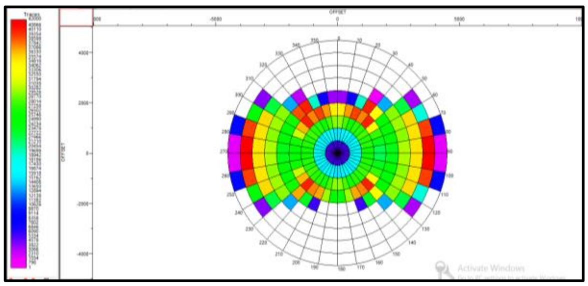

Fig. 13: Rose diagram of option-4

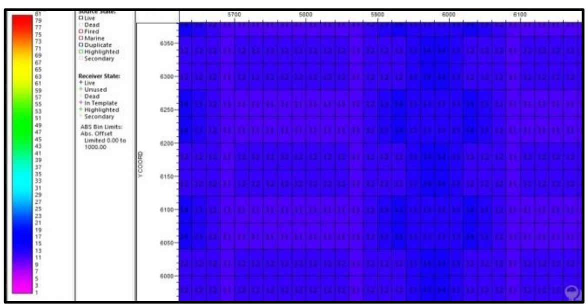

Fig.14: Number of traces is 11-14 for offset range of 0-1000 m in option-4

Discussion:

This analysis can be extended for similar multi-objective 3D seismic data acquisition and trace densities. In case of long offset requirement due to high velocity layers above target zone, the bin attributes can be generated using pre survey modeling / illumination studies using suitable software by including such layers in model and analysis of rose diagram, offset and azimuth distribution charts.

Optimization of final geometry has to be done very carefully and logically. Geometry designing is more challenging jobs for the area having multiple objectives. It needs special attention considering the operational factors like logistics, environmental factors, difficulty in deployment active channels and sources like shothole drilling or vibrators, seismic friendliness, random/noise pattern of the area, productivity, investment and available time to complete seismic API cycle etc.

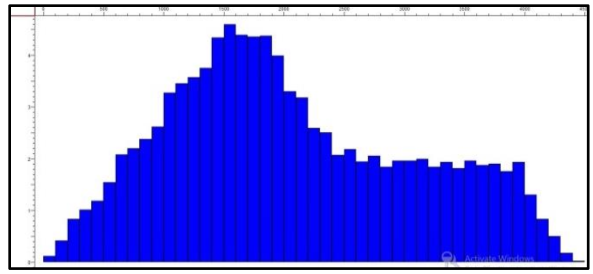

Fig.14: Histogram for option-3 shows considerable traces are available beyond offset of 4000m.

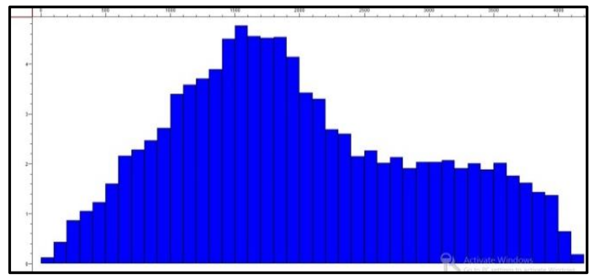

Fig.15: Histogram for option-4 shows number of traces beyond 4000 m offset is reduced considerably

Conclusion:

The split spread orthogonal geometry with variable number of receivers in receiver lines as discussed above is better choice for area with multiple objectives. The analysis provided a method to workout cost effective option of geometry design for such objectives. This analysis can be extended for similar multi-objective 3D seismic data acquisition and trace densities.

Acknowledgement:

The authors are thankful to Director (Exploration) ONGC for permission to publish this paper.

The cooperation from all the colleagues directly or indirectly associated with this work is thankfully acknowledged.

NB: The views expressed in this paper are of the author only and do not necessarily of the organization in which he is working.

Reference:

Kumar L. et.al., 2006a: Growth of 3D seismic technology in India, The Leading Edge, July, 2006, SEG.

Kumar L., CB Yadav, A Saha, 2006b: Designing of 3D survey geometry for reducing acquisition footprints. 6th SPG Conference, Kolkata, 2006

Lansely M, 2013: Shifting paradigms in land data acquisition, First Break, Volume 31, January, 2013, EAGE.

Operational report on 3D sesmic survey in Balol area, Cambay basin- unpublished report of ONGC 1986.

Vermeer GJO, 2002: 3D Seismic Survey Design, SEG.