P-093

An implementable alternate survey geometry design for ideal Land 3D Seismic Acquisition

Hanuman Sastry Maduri*, Agarwal D.N., *ONGC*

Summary

Different 3D Acquisition Geometries are used on land for acquiring 3D Seismic Data worldwide. An acquisition geometry having common applicability for different survey objectives is always preferred for obvious reasons. Many a time, designers have to make compromises in ideal technical parameters, due to various reasons.

3D surveys are generally conducted over smaller areas at different times with different acquisition geometries and a need emerges for merging the different surveys data at a later time. If the acquisition parameters of the areas to be merged are different, then merging of data will not give the desired results. The different aspects to be considered in evolving suitable land 3D acquisition geometry having common applicability are discussed in this paper and a methodology of designing such geometry for land 3D surveys is suggested. It is also suggested that by changing the geometry structure, practically implementable 3D acquisition geometry can be designed, without any compromise on the technical parameters.

Introduction

3D Seismic Surveys are conducted for focussing different types of shallow to deeper exploration targets. Designing the 3D acquisition geometry is essentially an optimizing exercise to achieve proper subsurface sampling of the wave field by suitable sampling / placement of sources and receivers on the surface. Different methods of acquisition geometries evolved over the years viz., parallel line, orthogonal, slant, zig-zag, brick etc.,. These methods are being used in different cases world-wide by the survey designers. Each of these methods offer different advantages and disadvantages both technically as well as in practical aspects of implementation. The orthogonal geometry method is generally being preferred in many situations, due to its ease of implementation. Orthogonal geometry will be used in further discussion in this work.

Out of all the parameters of the acquisition geometry, the most crucial and independent parameters that require to be decided for evolving a common geometry are Bin size and Nominal Fold. Other parameters viz., shot / receiver spacing in both in-line and cross line, offset and azimuth composition of the bins, orientation of the in-line / x-line direction, in-line / x-line fold, minimum and maximum offsets etc. are dependent on the decided Bin size and nominal fold, and also are bound by certain thumb rules based on proper focussing of the targets. Even the Bin size and fold are governed by certain criterion, viz., avoid spatial aliasing and proper velocity estimation etc. It is enough to decide Bin size and the range of fold for making the common acquisition geometry structure. These two parameters can be decided once for all, at least for a given Basin, where the seismo-geological requirements are fairly uniform, if not in global sense.

Decision of Bin size : Land 3D surveys are conducted using either Vibrator or Dynamite source. With these types of sources, it is difficult to obtain practically a recordable signal frequency more than 70 hz. at the acquisition stage, in the general sense, especially from targets of deeper depth. Optimum Bin size is decided using spatial aliasing criterion and should be less than $Vint/(4*Fmax*Sin\theta)$. Table-1(Taken from Ref.-1), gives the maximum un-aliased frequency (hz.) for different bin sizes for a Vint. of 3000 m/s and for varying dips.

It can be observed from the table that, by using a bin size of up to 20 m., un-aliased signal frequencies up to 70 hz., can be recorded without spatial aliasing for dips up to 30 deg. A bin size of less than 10 m. may be required only for the very shallow objectives and for very high target frequency. For a bin size greater than 20 m. spatial aliasing occurs within the recordable frequency range required for many objectives. As the velocity and dip of the target reflection are fairly

Oil and Natural Gas Corporation Limited, Jorhat
shastry_m_h@yahoo.co

uniform in a given Basin, suitable Bin size for maximum target frequency and minimum target velocity can be computed, using the formula given above. It is required to minimize the bin size depending on the availability of the inputs. A survey design with a Bin size of 10 m. and 20 fold or Bin size of 20 m. with 80 fold, require same inputs and can be designed to achieve same geometry attributes. As the fold requirement for imaging in 3D surveys is smaller compared to 2D surveys, the first option is preferable.

Dip	Sub-surface Trace Spacing in Meters (Bin size)					
	10	15	20	25	30	50
5	861	574	430	344	287	**86**
10	432	288	216	173	144	43
15	290	193	145	116	97	29
20	219	146	110	88	**73**	22
25	177	118	89	**71**	59	18
30	150	100	**75**	60	50	15
35	131	87	65	52	44	13
40	117	78	58	47	39	12
45	106	**71**	53	42	35	11

Table-1: Alias freq. (in hz.) for different dips and Bin sizes

A maximum target frequency of 70 hz. and a maximum dip of 30 deg. is considered for the targets of the example case study in this paper.

Decision of Nominal Fold : Technically equal in-line and x-line fold is preferred. A compromise can be made for n*(n+1) in place of n*n, n being the directional fold. Due to the presence of minor / major obstacles, some of the surface locations will be inaccessible for shots and/or receivers and loss of fold occurs. Also, some of the traces within the bins will have redundant offsets. Such traces may be useful only for pre-processing and are dropped during migration, as one trace per offset is used for imaging purpose in many migration algorithms. Though, a smaller fold is sufficient for 3D imaging, a higher range of fold may be required for velocity estimation and noise cancellation in pre-processing. The deepest possible target in a Basin, say the basement, generally has depth varying from shallow to deeper. In places where the deepest target depth is shallow, a smaller fold may be sufficient. Therefore, for a given Basin, considering the above facts, one needs to decide on the range of fold, instead of a fixed value.

Theory

Ideally, 3D acquisition geometry should be able to address the following requirements:

1. Proper focussing of shallow and deeper targets with sufficient fold
2. Generate ideal geometry attributes
3. Convenient for practical implementation
4. Optimally cost effective
5. Flexibility to adopt when the depth of the deepest target varies across the basin, without change in the geometry structure.

Technical requirement of acquisition geometry attributes are discussed by Vermeer (2003) and other design experts over the years, and are summarised below:

- Full Azimuth Coverage with good offset distribution within each Azimuth range
- Single Line Roll-Over for Subsequent Swaths to avoid possibility of acquisition footprints
- Equal surface sampling of sources and receivers in X and Y directions
- All aspect ratio(s) to be equal to One
  - Square Bins
  - Equal Max. Offset on All sides of Shot
  - Equal RLI & SLI
- Equal In-Line & Cross Line Fold is preferred
- The range of variation in Near and Far offset must be minimum across Bins
- Uniform distribution of fold in near / mid / far offset ranges
- 3-D sampled Shot gathers

Compromises are made in geometry parameters, especially, when the channel availability with the crew is limited.

The New Geometry Design Methodology

Let us consider an example case study, where the depth of the survey target is about 4 km. and assume that a bin size of 20 m. and a nominal fold of 10 in each direction is suitable for this case. Also, let us assume that 4000 is the active channel capacity for the crew.

Technically ideal acquisition geometry for the above example case is designed in orthogonal geometry method and with the conventional geometry structure, presently popular in the industry. The template of one such possible geometry is given at fig. 1(a) (Geometry-I).

The thumb rule says that the maximum offset on all sides of shot should be nearly equal to the depth of deepest target. Therefore, to get equal maximum offset on all sides of shot, for an ideal offset aspect ratio of 1, it is required to spread the receivers over an area of square of twice the deepest target depth. That is, if the depth of target is say, 4 km., then the receivers are to be spread over 64 sq. km. and for a target of 5 km deep the receiver spread area becomes 100 sq. km., by using conventional geometry structure. During field operations, most of the effort is directed to get the receiver line connectivity and maintain it for the complete operational period. It would be tedious to achieve this, if the receivers are spread over such a larger area. Therefore, compromises are generally made in the offset aspect ratio.

To get the decided bin size, it is required to place either the shots or receivers at an interval of twice the Bin size in in-line and cross line direction. The popular conventional geometries use receiver station interval in the in-line and shot station interval in the cross line directions for achieving the decided Bin size in these directions. Also the number of receiver lines per swath and the cross line roll distance are used to get the cross line fold, whereas, the number of receivers per line and the in-line roll distance are used to get the in-line fold. This method of achieving cross line fold imposes a restriction on the number of receiver lines or conversely on cross-line fold. For example, if the channel capacity of the crew is limited to say six receiver lines, it would be impossible to get cross line fold more than six, with regular rolls for subsequent swaths.

A different way of acquisition geometry design is suggested, wherein, the decided Bin size is achieved both in in-line and cross line directions by choosing the receiver station / line interval at double the Bin size in respective directions. By doing so, the receiver patch area is reduced to a large extent and maintaining the line connectivity becomes easier. The maximum cross line offset is achieved by using the shot line length of double the maximum offset, keeping the shot line at the centre of the receiver template. The number of shots per shot line, cross line shot interval and the cross-line roll distance are adjusted to get the desired cross line fold. The geometry template is given at fig.1(b).(Geometry–II). Another variant of such geometry structure can be designed just by interchanging shot and receiver locations of Geometry-I, in the cross line direction. In this case the active channels become half and shot requirement is doubled.(Geometry-III) Template is given at fig.1(c).

The main parameters of these geometries are given in Table-2 for comparison. In Geometry-II and III, the total receiver spread area of the template is 6.4 / 3.2 sq. km. compared to 64 sq. km. in Geometry-I. All the Bin attributes for these geometry variants are compared. The comparison of unique fold and rose diagram statistics of the geometries is given in Fig. 2 and 3. It can be observed that the all the Bin attribute patterns for these three geometries are similar. Trace density of these geometries are also similar. So, these geometries are interchangeable without loss in technical detail and any of these geometries can be used to get the same result. Selection of either of the geometries can be made, depending on the area specific factor.

Parameter	Geom-I	Geom-II	Geom-III
No. of Receiver lines	20	20	10
No. of receivers per line	200	200	200
No. of total channels	4000	4000	2000
Receiver Line interval (m.)	400	40	40
Shot Line Interval (m.)	400	400	400
In-line roll (m.)	400	400	400
Cross-line Roll (m.)	400	400	400
Total no. of shots	12600	12600	25200
Shot interval	40	800	400
Receiver Interval (m.)	40	40	40
Full fold area (sq. km.)	97.92	97.92	97.92
Shots / salvo	10	10	20

Table-2 Geometry parameters comparison

Processing issues : Geometry-I has cross-line overlap of only receiver locations and Geometry-III has cross-line overlap of only shot locations, whereas in Geometry-II, both the shot and receiver locations overlap. This will help in better solutions for surface consistent processing algorithms. In geometry-II and III, for any central shot location, a full 3-D sampled shot gathers covering 64 sq. km. with receiver spacing of 40 m. in all the directions of the shot, can be formed, whereas in Geometry-I shot gathers are possible with 400 m. cross line receiver spacing. As we have receivers at 40 m. interval in all directions of the shot location, using this fully sampled shot gather of Geometry II or III, all types of shot generated coherent noises from any direction of the shot can be effectively suppressed in processing. Shot spacing in X

& Y directions and receiver spacing in X & Y directions is same in Geometry-III.

Flexibility: The depth of the same target may vary in different parts of the Basin. By adopting the new methodology of geometry design as in Geometry-II or III, it is possible to design geometry for different target depths with minimal change in geometry structure. Keeping the channel capacity of the crew as 2000, it is possible to design geometries for the deepest target of 3.0 km. and 5.0 km., using Geometry-III type structure, with 14 or 8 receiver lines per template. It is interesting to observe that we can achieve same cross line fold of 10 with a design using 8 or 14 receiver lines. This has become possible because in the new methodology of geometry design, the cross line fold is dependent on the number of shots in the shot line, cross line receiver span and roll distances and gets de-linked from the number of receiver lines. So, any required cross line fold can be obtained by choosing these parameters.

A new common formula for X or Y Fold: For all the geometries, Fold (X or Y) can be computed using a common formula viz., (N/2)*(S/R), where N is number of receivers or shots, S is span of shots or receivers, and R is the Roll distances in the respective X or Y directions. Span S is the product of number of shots/receivers and the station interval in X or Y, i.e., double the Bin size in these directions. N is to be considered for shots or receivers, whose patch width is larger and S is to be considered whose patch width is smaller. To get uniform integer fold, N, S and R to be so chosen to get an integer result from the formula. Thus the new methodology of geometry design offers wide flexibility to adopt for different requirements, with least change in geometry structure / parameters.

Geometry Optimization : Given a full fold survey area of A sq. km., the number of seismic traces NB, required to be generated are (F*A*106)/(Bx*By) , where F is the Fold and Bx / By is the Bin size in X and Y. Apart from these, some traces are also required for the build-up of Fold on all the four directions of the given area. To generate all these total traces we require NS number of shots, each with NR number of active receivers per shot. So, optimizing the cost of survey is dependent on the costs of the shot or receiver only, apart from the logistic factors pertinent to the given area. As the cost of the shot is generally more than that of receiver, it is required to maximize the number of receivers per shot, thereby reducing the shot requirement. No other geometry parameter directly affects the survey cost.

Conclusions

Achieving ideal technical geometry parameters, using conventional geometry structures will be tedious and compromises need to be made. An alternate method of survey design is suggested, which provides the required flexibility and ease for implementation; thereby an attempt can be made to devise uniformity in 3D survey design for different parts of the same Basin, even in cases of limited channel availability.

Acknowledgements

The authors express sincere gratitude to Dir.(E), ONGC, India for permission to publish this work. Thanks are due to Shri S.K.Das, ED-HOI, GEOPIC, ONGC for his keen interest in this work. The views expressed in this paper are exclusively those of the authors and need not necessarily match with official views of ONGC.

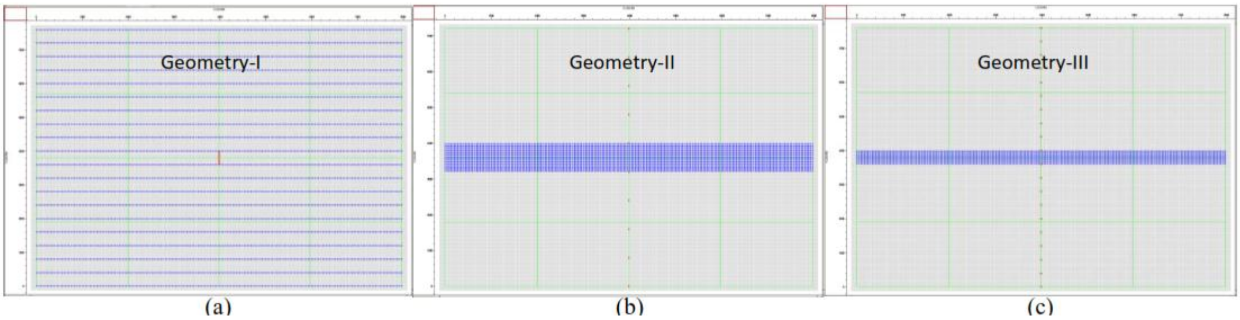

Fig. 1 : Templates of Geometries under comparison

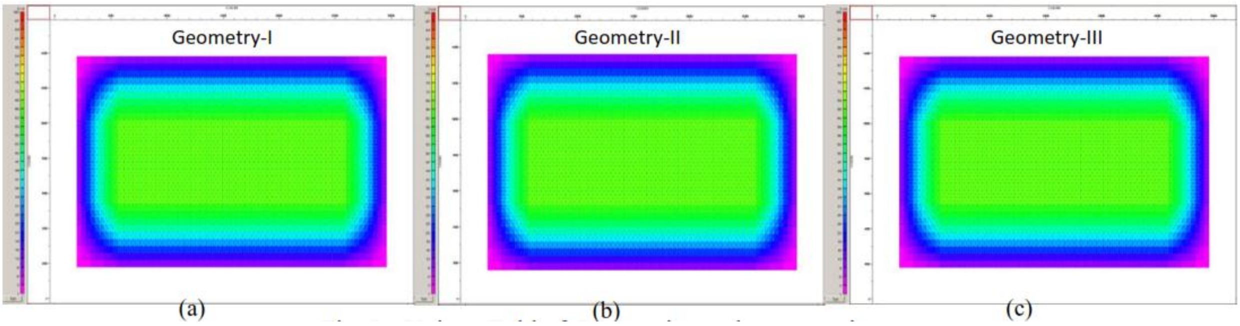

Fig. 2 : Unique Fold of Geometries under comparison

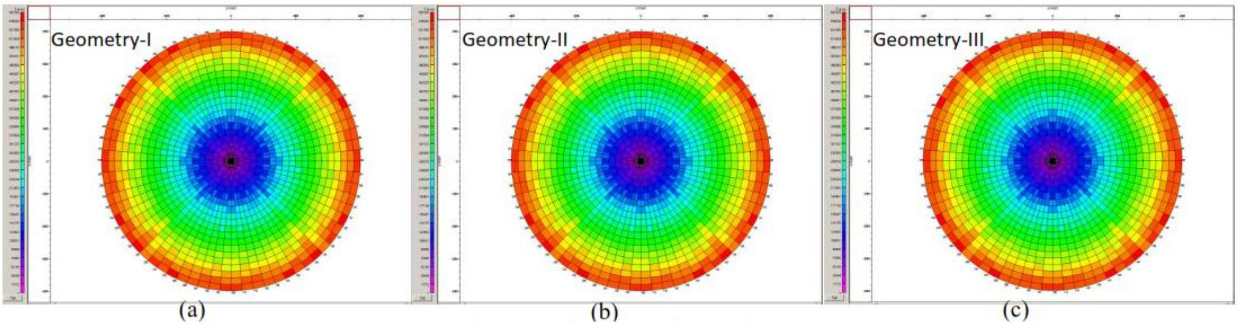

Fig. 3 : Rose Diagram of Geometries under comparison