



# Impact of Irregularities of 3D Seismic Geometry on Subsurface Imaging

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## Summary

3D seismic data acquisition brought a sea change in subsurface imaging. The bridge between geology and seismic is P/S wave velocity of different subsurfaces/lithology. The technique has acquired prime importance due to its inherent strength of determining seismic velocity/amplitudes of the different medium. Lithological variations estimations is possible due to proper  $V_p/V_s$  ratio or either velocity alone. Success of advance seismic studies solely depends on accurate subsurface mapping.

3D seismic subsurface image is biased to a great extent by the acquisition geometry, as it affects lateral & vertical velocities. Thus a proper evaluation of the influence of the acquisition geometry on image quality, in areas with complex geology, needs to be carried out. The acquisition geometry footprint is the cumulative effect of azimuthal fold variations across the near offsets, source-receiver directivity, and subsurface illumination irregularities. The ideal 3D acquisition geometry called "full 3D" is the one in which the whole sub-surface area should be covered with regular source positions, and recorded in receiver positions covering the whole acquisition area. Each receiver position is to be covered by source position as well.

In 3D seismic survey the choices of acquisition geometry is governed by geological objectives. The optimization of acquisition geometry arises out of resource constraints / cost. The impact of offsets, azimuths, inherent acquisition footprint needs to be understood while optimizing these acquisition parameters/geometry. Obstructions, environmental objectives, economic constraints and many other factors cause irregularity and sparse data sampling. This needs to be studied before geometry optimization as demography is altering at a rapid pace with urbanization. The irregularities are observed in the form of variations in the fold coverage, irregular offset which can manifest itself as an acquisition footprint on pre-stack data or even the stacked image.

This study deals with the various irregularities introduced by the choice of geometry. Thus assessing the environmental / logistic /economic resource constraints, design of geometry should not sacrifice the basic objective of the 3D survey.

## Introduction

The CDP technique and rapid advances in seismic has brought the seismic exploration, at forefront out of all the exploration methods. This prominence can be attributed to its inherent strength in extracting seismic velocities which immensely facilitates in understanding the heterogeneity of the subsurface. Subsequent advances in data acquisition utilized seismic velocities to a large extent for imaging the subsurface. Better lithological predictions have also become possible by proper estimation of  $V_p/V_s$ . Thus the success of advance seismic studies solely depends on accuracy of seismic velocity estimations which in turn are dependent on offsets and foldage of seismic data recorded in 2D or 3D methods.

For any given subsurface mapping, the design of 3D acquisition geometry is characterized by a particular distribution of fold, offset and azimuth. Over the last decade the 3D acquisition geometries used are the outcome of the optimization process of geophysical operation and cost estimates.

Irregular spatial distribution is very common with 3D seismic surveys. Ideally a 3D survey is acquired on a regular 4-D grid  $x, y, h, \theta$ . The spatial distribution of traces in this subset is highly irregular in general. Even if it is ensured that midpoints are regularly distributed, there is always an irregularity in the offset and azimuths. Added to this the prevailing logistics further reduces the above subset of the 4-D space. Traces with different offset are oriented in various directions within a bin. Distribution of these traces varies from bin to bin. All this leads to improper sampling of the full wave field.

Thus in 3D it is very difficult to maintain recording of all the offsets in the survey area uniformly. Hence any 3-D seismic survey can have an acquisition footprint. Our problem is to determine whether we have one and if so, whether we can recognize it, how severe it is and, most importantly, what we can do about it.

This paper starts with a description of the conventional 3D geometry design and its associated rationale. Then a review is made regarding the various irregularities

introduced in the different optimized geometries. Finally an effort is made to discuss the optimization of various irregularities introduced without sacrificing the final goal of illuminating the target reflector and its associated faults.

### Conventional 3-D seismic survey design

The conventional approach to 3-D survey design started by extending the 2-D stack-array approach put forward by N. Anstey to 3-D. In the stack array approach, the combination of geophone array and stack (together called the stack array) forms a very good means of suppressing the ground roll. In land data acquisition the pre-requisite for the stack-array approach was equal sampling of shots and receivers for centre spread. This approach results in common midpoints with a regular distribution of offsets. The application of this approach to the design of 3-D geometry, results in emphasis on a regular offset distribution in each bin with minimum scattering of midpoints in a bin. This was achieved in 3-D by use of parallel geometries. Most of these geometries comprise of an ensemble of parallel line of receivers at fixed distances and parallel lines of sources also at regular intervals. The source lines are usually arranged parallel, perpendicular or at an angle with respect to the receiver lines. Regular sampled source lines parallel to receiver lines produces a regularly sampled midpoints with a regular (absolute) offset distribution. The best outcome of this approach was the slant geometry (double zigzag). At this point of time orthogonal geometries were discarded as they produced highly irregular offset distribution, primarily because the receiver lines were placed close to each other. Later on it was realized that in land, orthogonal geometry has considerable advantages in efficiency over parallel geometry. Aspect ratio started playing a major role in the choice of the geometry. However, with limited no. of channels available earlier the aspect ratio will be small (max. X - line offset was much smaller than max. in - line offset).

### Statics Coupling

Static Coupling requirement at processing stage is due to derivation of converging residual statics solutions based on the redundancy of source and receiver positions. One simple way to solve this is to use techniques like flexi bin (Cordson). Processing tricks, such as smoothening the CMP average during Gauss-Seidel iteration, still leaves the long wavelength component unsolved. The only alternative left is to resort to 3-D refraction statics programs. Most refraction statics algorithms involve matrix solutions where shot and receiver delays and velocity (slowness) at CMPs

are related to observed first break times for each refracting layer. Lack of coupling caused by regular geometries once again leads to smoothening requirement and the possibility of bulk shifts from one group of CMPs to another. Thus for each refractor, it is essential to have coupling in the in-line and cross-line directions. This implies that the cross-line offsets should be comparable to that of the in-line offsets so that the deepest refractors are sampled equally in all the directions.

### Irregularity in offset distribution

Offset distribution is an important attribute in data acquisition. A regular distribution of offsets provides a good estimate of velocity and residual statics. The quality of stack and migration in seismic section is highly sensitive to the velocity estimates. Thus a good offset distribution is key to better imaging of the subsurface. However, in practice, it is extremely difficult to acquire a 3D data with the regular offset distributions. All swath geometry has its associated inherent offset distribution pattern. The data acquisition percentage with regular geometries varies from area to area. The demographic setup of the area plays an important role in irregularities of trace offsets. This irregularity in offset, azimuth and non redundancy space is causative for deviation from planned survey. Irregularity in offset domain has two components namely the redundancy and the offset gap in the offset spectrum.

The deviation from the regular distribution of offset can be defined in the form of a coefficient Cd measuring the regularity of bin offsets (as defined in Geoland software documentation) as follows:

### Coefficient of regularity of offset

$$Cd = 100 \times (1 - \frac{\sigma}{e \sqrt{kn}})$$

where

Cd = Coefficient of regularity of offset

n = reference fold

e = interval between trace in cdp domain

Where if the sequence of offsets is Di

Ii is increment of offsets = Di - Di-1

σ is the standard deviation of Ii

k = (Dmax - Dmin) / ne for Dmax - Dmin < ne  
= 1 for Dmax - Dmin > ne

Dmax. & Dmin. are the boundary limits of analysis in offset space.

This factor is independent of the width of the range of selected offsets and of the definition of acquisition spread.



It is evident that the regularity in offset distribution is dependent on reference fold and the offset class. It is also equally important to note that the selection of reference fold and offset class may change the value of regularity.

### Irregularity in Azimuth distribution

Azimuth distribution plays a vital role while carrying out azimuthal velocity and is an important attribute in subsurface imaging. The coefficient  $C_a$  measuring regularity of the azimuths in a bin can be defined similar to irregularity in offset (as defined in Geoland software documentation) as

$$C_a = 100 * (1 - \sqrt{\frac{\sum \Delta \theta^2}{n}}) / 360$$

Where

$C_a$  = Coefficient of regularity of Azimuth

$C_a = 100$  for a regular distribution

$C_a = 0$  for an irregular distribution (all azimuths identical except one)

### Irregularity Factor:

The major reasons for irregularity are

- i) Choice of Geometry,
- ii) Non availability of source / receiver positions due to obstacles
- iii) Overlapping of two surveys
- iv) Improper recovery planning, as it affects the distribution of foldage, offset and azimuth

#### i) Choice of Geometry

All the geometries carry an irregularity factor associated with the design of it. This irregularity factor varies from geometry to geometry. Thus the choice of the geometry has to be the one which fulfills the survey objective with least irregularity (Fig. 1).

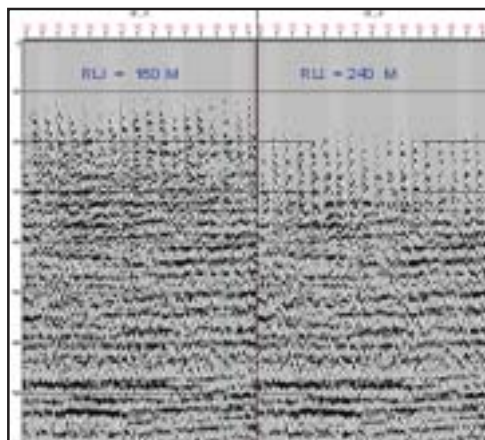


Fig. 1 : Variation in shallow data due to change in receiver line interval

#### ii) Non availability of source / receiver positions due to obstacles:

The common practice is to displace shots and receivers to alternative positions chosen to maintain, as much as possible, the uniformity of fold and the regularity of offsets and azimuth distribution. All sources and receivers are considered equally important to the subsurface image, which is probably not a good idea in general. The presence of large obstacles can be incorporated into the design procedure and alternative source and receiver locations chosen to optimize the regularity of the illumination as opposed to the regularity of fold, offset or azimuth distributions as is standard practice. It may very well happen that some shots in the excluded area (Fig 2) turn out not contributing significantly to the critical parts of the image and so can be simply ignored if they are difficult to replace. On the other hand, it may turn out that those shots are critical and then we have compelling reasons to make a stronger effort to acquire them. This irregularity can be seen in the minimum offset map (Fig 3) or in the shallow time slices.

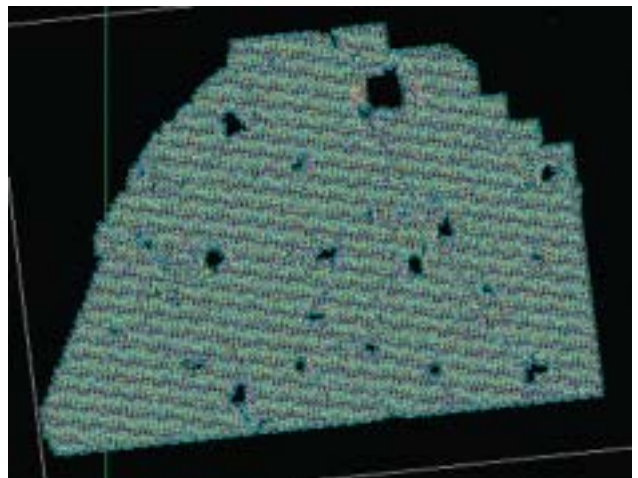


Fig. 2 : Map showing obstacles

The logistics of an area can be mathematically defined as follows:

**SI (Source Irregularity index)** = No. of source points inaccessible or not covered within a skid of  $\frac{1}{2}$  of a group interval / Total No. of theoretical Shot points in the area

**RI (Receiver irregularity index)** = No. of receiver points inaccessible / Total No. of theoretical receiver points in the area

**RCI (Recoveries Index)** = Total no. of shot points recovered / Total no. of points to be recovered

**Skid index** = Mean value of the total skid in the area

Accordingly total logistics irregularity of an area can be defined as



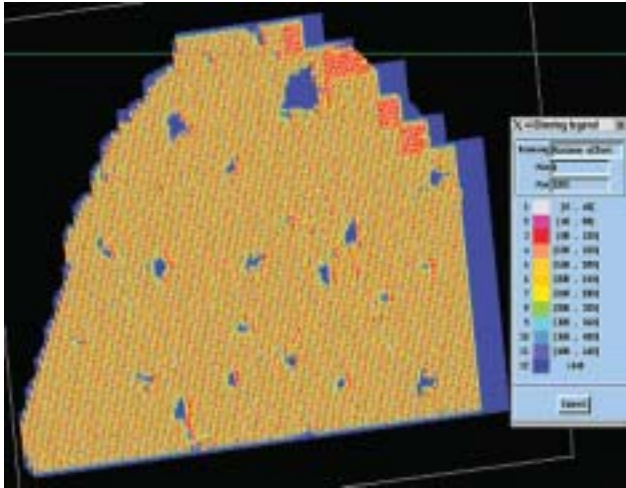


Fig. 3 : Min offset map

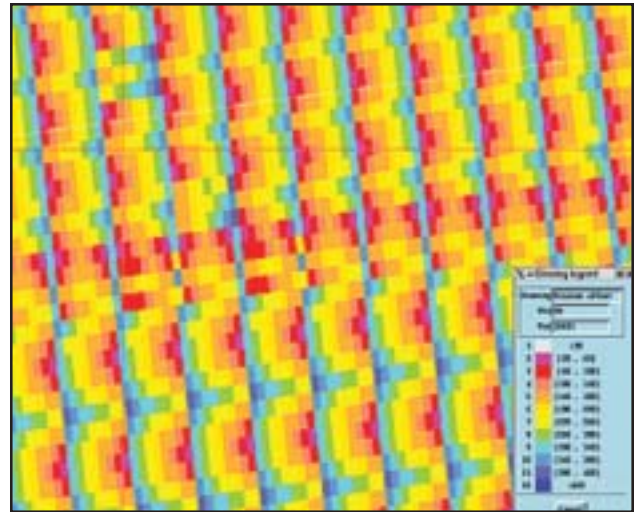


Fig. 4 : Minimum offset distribution

$$LI = SI * RI * RCI$$

Skid index needs to be suitably incorporated in the above irregularity index. The tolerable value of LI will be area dependent and needs to be benchmarked.

### iii) Overlapping of surveys

When different surveys overlap then we need to address the issue of irregularity there as well. Since the irregularities are associated with a particular survey but is random in nature for different surveys. Hence the overlap gives an added advantage to the processor of 3D seismic data to use the irregularity as a random variable and reduce the overall irregularity in the overlapped portion of surveys by considering the total survey data together as one and carving out a subset of data which is more regular irregular as compared to irregularity of the present survey irregularity.

### Overlapped survey examples

#### iv) Improper recovery planning

Recovery for areas where either receiver or shot cannot be placed during the regular shooting needs to be carried out else it will create an irregularity in fold, azimuth and offset. Now whenever a recovery is planned it will always have near offset limited to the smaller dimension of the obstacles. Thus an irregularity created due to obstacles needs to be planned on modeling software like MESA, GEOLAND etc. to reduce / minimize the irregularity in an optimum manner. This needs the proper input of prior surveying of the accessible points in an around the obstacle.

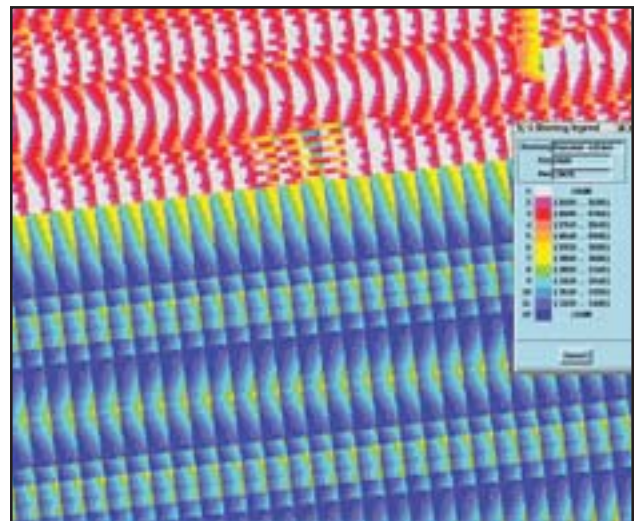


Fig. 5: Maximum offset distribution

### Acquisition footprints

Once the geometry has been optimized we need to address the problem of acquisition footprint. Acquisition footprint is defined as the linear spatial grid patterns seen on 3-D seismic time slices which tend to be mirror image of the acquisition geometry used for acquiring the 3-D seismic survey. They are usually seen on shallow time slices or horizon amplitude maps as striation masking the actual amplitude.

These can be divided into two categories namely due to geometry and non-geometry. Geometry footprints are mainly due to line spacings, fold variations, wide vs. narrow patch geometry & source generated noise. Non geometry effects are due to topography, culture, near surface conditions, processing artifacts.

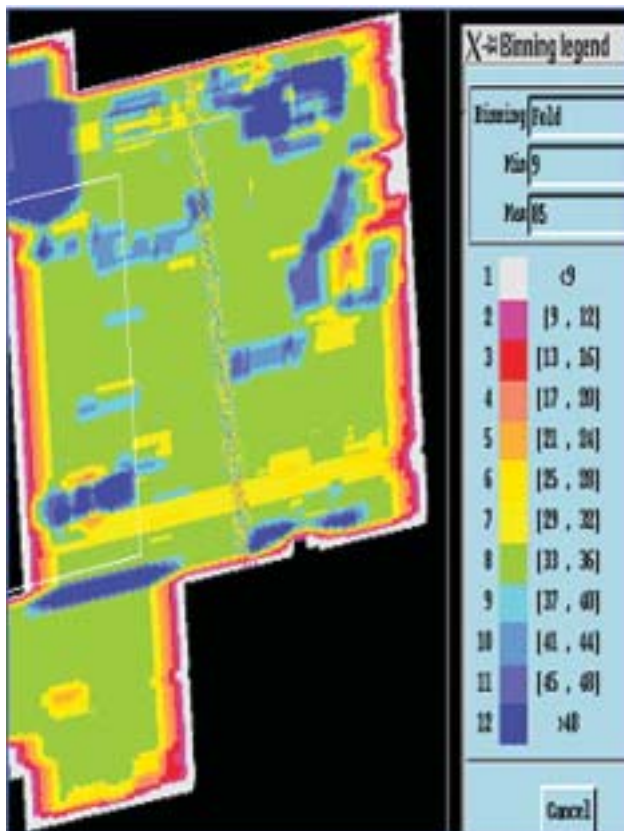


Fig. 6: Acquisition footprint due to road

## Foldage distribution

For analysis of foldage distribution we calculate both total and non-redundant foldage distribution. But for the analysis of foldage distribution we should consider the irregularity of offset (which comprises of non redundancy and the offset gaps) and irregularity of azimuths. After the implementation of the geometry in the field we should again calculate the irregularity in offset and azimuth as it contains component of the topography, culture, near surface conditions which has to be addressed during processing.

## Possible solutions

The possible solutions to tackle irregularities are

1. Choice of swath geometry having wider acquisition patches
2. Proper pre-planning & recovery planning to take care of obstacles
3. Increase in the foldage of data acquisition will reduce the footprints.

Normally the choice is made from the few available

standard geometries, namely parallel, orthogonal, slant, zigzag on the basis of uniformity of offset and azimuth in the subsurface bins. A 3-D surface model is normally obtained from existing 2-D or 3-D data, well logs or geological plausibility. Then modeling software is used to compute illumination maps of interest via forward modeling for various candidate geometries. The geometry that provides the least distortion in illumination at objective level is chosen as the best design.

## Conclusions

A simple fact is that irregularity will exist in any 3D data acquisition. However, it is mandatory to live with irregularities, inherent to the chosen geometries. We need to minimize the irregularity during acquisition with the proper planning of recoveries. We can further reduce the irregularities by advance planning and its implementation during data acquisition and recoveries. We can reduce the irregularities by

- i) Choosing sparse grid of shot and receiver that is the area of unit cell on the surface (as in the case of orthogonal geometry) so that less points are skidded and thus reducing SI and RI,
- ii) Increasing the foldage which gives leverage in processing for harmonization algorithms.

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