



Offset VSP Surveys Going Beyond Traditional Boundaries: A Case Study

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Summary

Traditionally, for low dip stratigraphic setup, extent of subsurface coverage obtained from Offset VSP surveys, so far conducted world wide are governed by the drilled depth (DD) of borehole. In an offset VSP survey, normally to avoid generation and recording of refracted (or mode converted) seismic waves, the energy source is deployed upto $\frac{2}{3}$ of DD, accordingly subsurface coverage available from offset VSP survey is limited to the order of $\frac{1}{3}$ of DD. A new and innovative technique christened as '**Extended Offset VSP Survey**' was implemented in a well in Cambay Basin, India, wherein the deployment of energy source is stretched much beyond the traditional limit. Consequently a much larger subsurface coverage at the zone of interest (ZOI) was acquired despite logistic constraints. The technique, in turn saves a lot of seismic data acquisition, processing and interpretation costs and time normally required for development of oil fields, and provides very accurate and high resolution subsurface image for fast decision making with added confidence.

Introduction

VSP survey, though considered to be specialized seismic technique, is essentially an extension of surface seismic reflection method with unusual configuration of source and receivers, where source is kept on (or near) the surface and receivers are deployed along the borehole.

The orientation of source and receivers in the VSP survey setup has considerable advantage over surface seismic methods. In case of VSP configuration, seismic response of geological boundaries from surface to target depth of borehole (and beyond) can be recorded as function of time & depth. At variance from surface seismic, (which records two way time of reflections), VSP survey records one way travel time and in the process, propagation of seismic energy can be regularly monitored and important information pertaining to origin of primary and multiple reflections, nature of signal attenuation and presence of discontinuities can be obtained. It is also possible to use VSP data to predict lithological boundaries ahead of drill bit, thereby saving precious rig time and forewarning about precautions/consequences of drilling in high pressure zones and to avoid blow outs. From down ward propagating wave form, attenuation of seismic waves may be estimated, which aids in designing of deconvolution parameters.

Offset VSP surveys are carried out for mapping extension of structural and stratigraphic features around well bore. Pre survey ray trace modeling is required to be done specially to account for reflection pattern and

consequential subsurface coverage, due to presence of high dipping stratigraphic layers. Offset VSP survey configuration normally requires:

- (I) The energy source to be deployed in the direction of required subsurface imaging.
- (II) Considering different layers having gentle dips, energy source is normally deployed approximately at an offset of $\frac{2}{3}$ of DD so that obtainable subsurface coverage at ZOI is approx. $\frac{1}{3}$ of DD.
- (III) The receivers are deployed at regular depth intervals along borehole and, the receiver interval is some time reduced as per the requirement of recording close sample VSP data in ZOI.

Walk away VSP survey allows deployment of energy source at a distance comparable with DD, but obtainable subsurface coverage is restricted by the depth of ZOI. Following are the few main factors and considerations associated with walk away VSP, which prohibits explorationists to opt for walk away VSP surveys very frequently:

- (I) Walk away VSP requires deployment of energy source at a regular intervals (normally 30 to 60 m) from wellbore to farthest offset position in the direction of required subsurface coverage, hence in logistically difficult areas such as forest, coastal/tidal belts, highly undulated areas and inhabited areas having buildings and railways, the approach and deployment of energy source at regular interval on a long walk away profile is a big task.

- (II) Stacking of required number of energy source deployment positions and their elevation data is required before the start of walk away VSP survey.
- (III) As number of shots associated with Walk away VSP is enormously high so required rig time is very high.
- (IV) Walk away VSP is being highly focused survey, in situations where ZOI is thick and consists of multiple layers, it will require much more inputs, time and efforts to record VSP data to map full ZOI.
- (V) The processing of Walk away VSP data takes considerably long time (compared to processing of Offset VSP data)

In an effort to find alternative method to over come the above mentioned factors/ considerations and also to map full ZOI with optimum resolution, a very innovative technique, christened as '**Extended Offset VSP Survey**' is used in a well in Cambay Basin, India for the first time.

Well details:

- Drilled Depth (DD) : 1700 m
- Depth of ZOI : 1600 m
- Thickness of ZOI : 80 m
- Dip angle : < 4° (nearly horizontal)
- Required subsurface Coverage : 675 m

In order to account for reflection pattern pre-survey ray trace modeling was carried out considering following 3 situations i.e.

- (I) Short Energy source offset (800 m)
- (II) Normal Energy source offset (1200 m)
- (III) Long Energy source offset (1600 m)

The results of these ray trace models are displayed as fig 1 to 3. It is evident from these figures that:

- For short (800 m) and normal (1200 m) source offsets, obtainable subsurface coverage is 375m & 575 m respectively and only reflected waves are generated and recorded in the borehole. (Fig. 1 & 2)
- In case of long source offset (1600 m) model:
 - (a) The obtainable subsurface coverage (at ZOI) is available only between 375 m and 975 m from well bore.
 - (b) There is no subsurface coverage up to 375m from borehole (at the depth of ZOI)

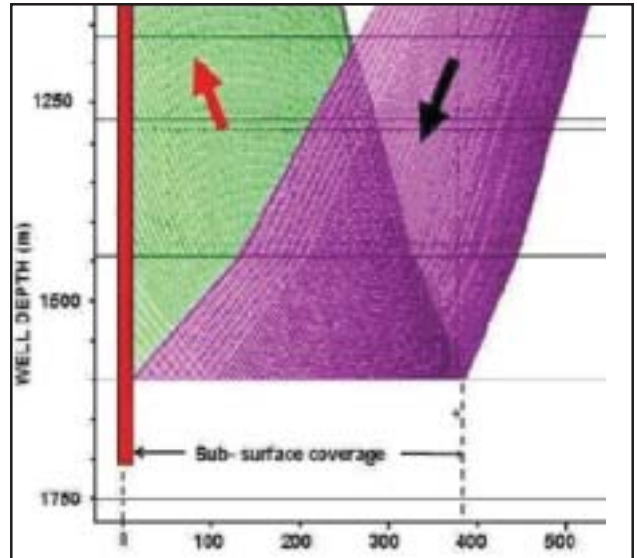


Fig. 1: Ray trace model for 800 m offset

- (c) Refraction /mode conversion of waves has set in and for higher tool depth (~ 1600 m), not only direct & reflected (P-waves) but refracted/ mode converted waves are also reaching the borehole and thus interfering with P waves.

A critical analysis of above observations leads to following inferences:

1. Going beyond conventional source offset range (~ 1200 m) leads to generation and recording of refracted/ mode converted waves and there may be a gap (no subsurface coverage) close to borehole and the extent of gap is proportional to the source offset distance.
2. In order to go beyond conventional barrier of offset distances and to fulfill the requirement of recording continuous and substantial subsurface coverage, the following method was adopted.

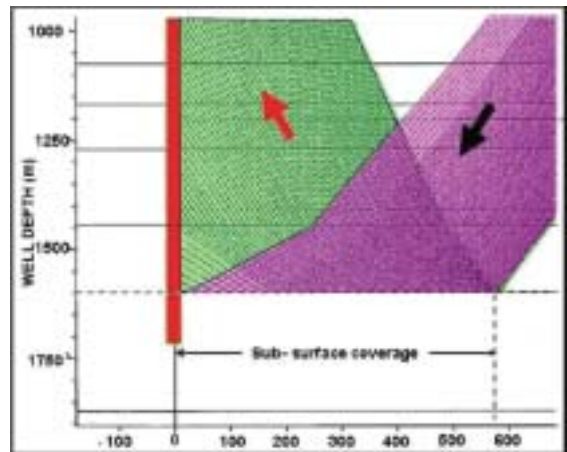


Fig.2: Ray trace model for 1200 m offset



Field data recording

Three sets of Field data were recorded in the following order:

- (I) Zero offset VSP data was recorded for full length of borehole.
- (II) Short offset source position (800 m), in required direction was stacked and Vibrators were deployed. Full set of offset VSP data was recorded.
- (III) Long offset source position (1470 m)*, in the same direction was stacked and full set of VSP data was recorded.

* Though it was planned to deploy vibrators at a distance (~1800m) i.e. more than DD (1700 m), but because of heavy and incessant rains the fields were flooded, as full set of VSP data was already recorded for short offset (800 m), so direction could not be altered to go beyond 1470 m offset.

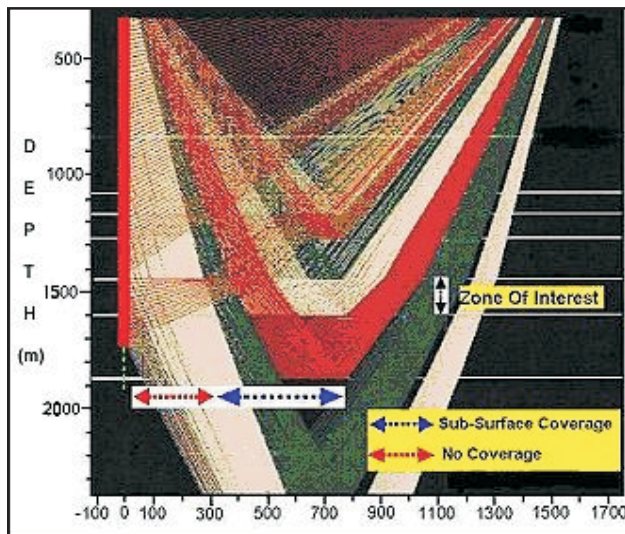


Fig. 3: Ray trace model for 1600 m offset

VSP data recording parameters:

VSP data was recorded with following parameters;

Data recording instrument parameters:

1. Data Recording Instrument : DFS – V
2. Number of Channels : 24
3. VSP Data Recording format : SEG – B
4. Record Length : 4 Sec.
5. Sampling Interval : 2 ms
6. Low cut filter : Out

7. Notch Filter : Out
8. K-Gain (Instrument) : 24 db.
9. Geophone used : Geolock – H
10. Preamplifier gain of Tool Geophones : 45 db.
11. Cable Winch used : SODE SEP

Vibrator parameters

1. Start Frequency : 12 Hz
2. Sweep rate : 8 Hz / Sec.
3. Sweep Length : 12 Sec.
4. Taper Length : 250ms
5. End Frequency : 108 Hz
6. Sweep Type : Linear
7. No. of Stacks : 4 X 2
8. Drive Force : 60 - 65 %
9. Number of vibrators used : 2
10. Name of Vibrators : MERTZ

All the VSP data sets (3) recorded above were processed. Corridor Stack of Zero offset VSP survey is inserted in seismic section of the line as shown in Fig. 4.

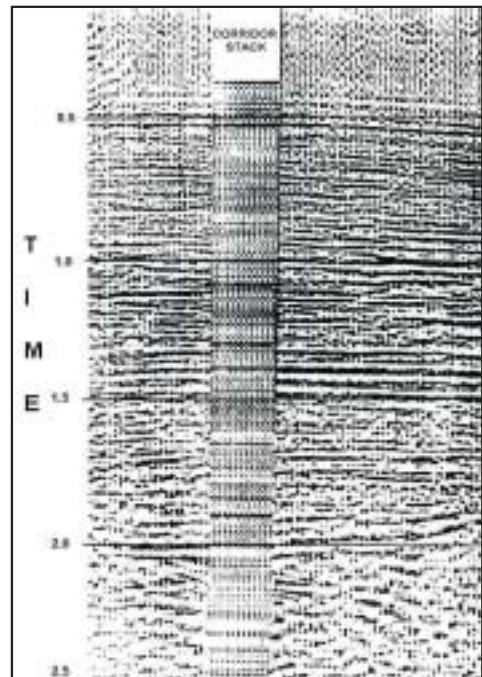


Fig. 4 : Corridor stack inserted in Seismic Section

VSP CDP stacks obtained for short offset and long offset are shown as Fig. 5(a) & 5(b).

Finally both VSP CDP stacks obtained from 800m

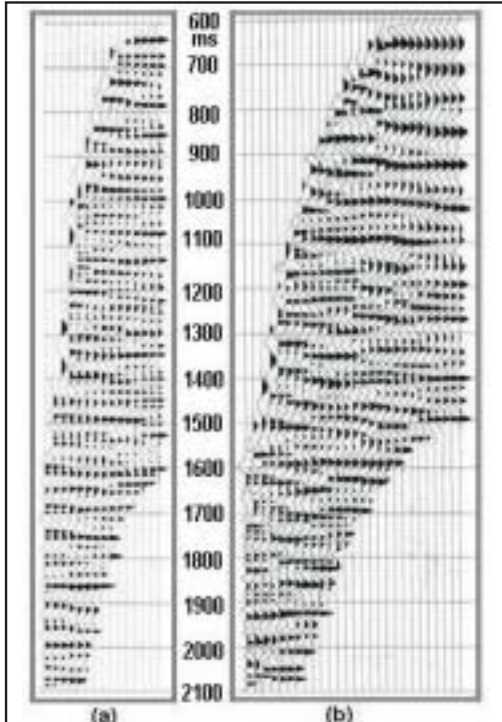


Fig. 5 : VSP CDP Stack for 800m & 1470 m Offset

& 1470 m offset surveys were merged and shown along with seismic section of the line as Fig. 6

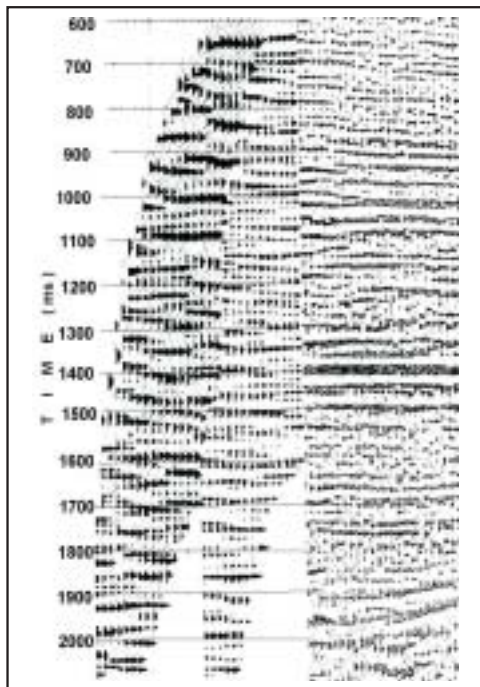


Fig. 6 : Merged VSP CDP Stack along with Seismic Line

Frequency Analysis

To see the available frequency range, frequency analysis was carried for both short and long offset VSP data and results are shown as Fig. 7 & Fig. 8 respectively

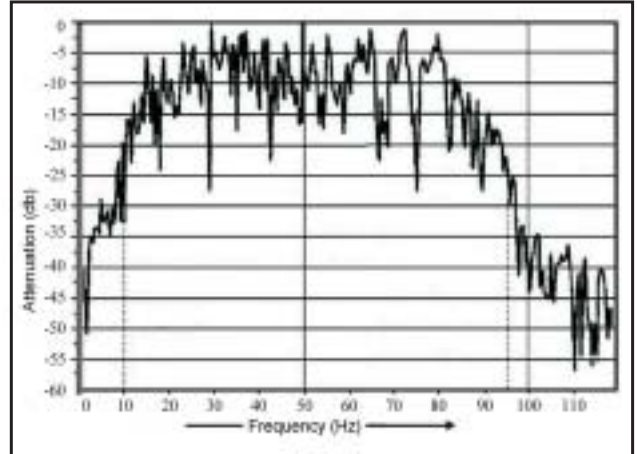


Fig. 7 : Frequency Spectrum for 800 m offset

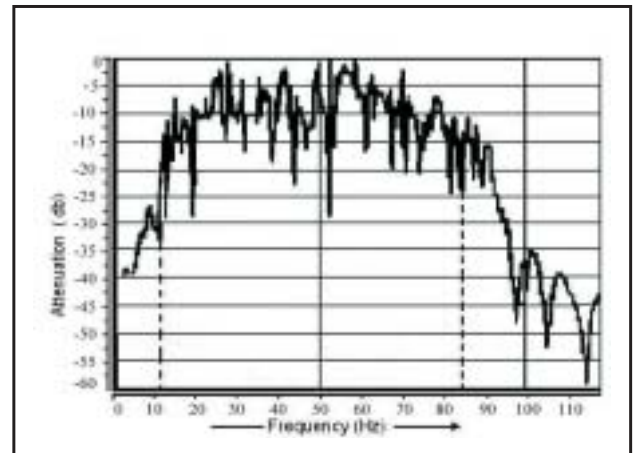


Fig. 8 : Frequency Spectrum for 1470 m offset

Similarly, Fig. 8 pertains to 1470 m offset and indicates the available frequency range from 12 Hz to 85 Hz. (at 25 db)

Fig. 7 pertains to 800 m offset and indicates the available frequency range from 10 Hz to 95 Hz. (at 25 db)

Conclusions

A careful analysis of the merged VSP section, Fig. 6 leads to following conclusions;

1. The conventional barrier of deploying energy source at



$\frac{2}{3}$ of DD (i.e. $\frac{2}{3}$ of 1700 m = 1133 m) is not a problem any more with the new technique, as in the present case energy source was deployed at offset of 1470 m (which can be further stretched to 1800 m or more, had there been no logistic problem)

2. The range of subsurface coverage with traditional offset VSP survey is limited to $\frac{1}{3}$ of DD (i.e. $\frac{1}{3}$ of 1700 = 566 m). The available subsurface coverage with the new technique is 675 m, which can be further increased to 900 m or more with freedom of deployment of energy source.
3. It is evident from VSP CDP stacks (and frequency spectrum curves) that it has optimum resolution and high frequencies for identification of different units with in the ZOI and for more details, seismic attribute analysis can be carried out for VSP CDP stacks and accordingly,

suitable decision for drilling more wells for development of oil field can be taken with added confidence.

4. In order to establish the extent of reservoir and to avoid drilling of dry well, more and more offset and Extended Offset VSP surveys should be carried out.

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Views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.