Planning and Execution of Walkaway VSP in Deep Water of East Coast-India

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Summary
Walkaway VSP data plays a major role in reservoir delineation and characterization. High-resolution VSP data can be integrated with surface seismic data to provide detailed descriptions of formation properties and identification of reservoir compartments, which is not possible with surface seismic data alone. Present study is from a prospect in the deep water of Krishna-Godavari basin. Planning and execution of deep water WVSP survey has been done, to delineate the small scale faults close to well, which were not clearly visible on seismic data and to understand compartmentalization and fluid continuity within the zone of interest.

From the WVSP pre survey modeling, 28 geophone levels at 10 meter receiver spacing and 2 profiles of 8 km. length were designed. According to availability of tool, four settings (seven shuttles in each setting) at consecutive depth intervals were necessary. Expected rig time for 4 acquisition traverses was 36 hours 20 minutes. It has taken 66 hours 20 minutes to finish the whole survey. Reasons for this large time difference were pre survey testing for borehole coupling, tool failure; source gun frame failure, navigation failure, bad weather conditions and movement on rig have been discussed in this paper. With the high day rates for drilling rigs in deepwater, the operation needs to be very efficient to keep costs reasonable. The study discusses planning, execution and optimization of efficiency of the process.

Introduction
Zero-offset Vertical Seismic Profiling (ZVSP) is a key tool for obtaining time-depth information in wells. Over the past couple of decades VSP has also been used to image areas where surface seismic imaging is poor. In this paper, planning and execution of walk-away VSP on a prospect in the deep water of Krishna-Godavari basin is presented. The basin is underlain by a series of NE-SW trending en-echelon horsts and grabens. As such well path was not predicted to intersect any major fault plane, but there were some possibilities of intersecting small scale unknown fault planes at reservoir level, which were not clear on the seismic due to its poor resolution.

Although different vintages of conventional seismic data are available in this area, which were processed using the high end processing techniques and various volumes were generated which includes two sets of PSDM volumes using different algorithms. Each suffers from imaging problems associated with reservoir depth and structural complexity due to the complex nature of the basement in this area. Location of basement faults near the well location was not clear from the seismic section (fig 1). To see the lateral extent of the reservoir, it was necessary to have a good image nearby the well trajectory and also to have a well defined seismic signature at reservoir level. WVSP has been taken as a possible supplementary solution for this problem.

The well is located in a water depth of approximately 500 m. The well was a vertical well to be drilled to approximately 3800m total depth. Walkaway VSP data comprise 28 geophone levels and about 400 shot points within +/- 4000 meter offset from the well location.
Objectives for the WVSP: Major objectives to acquire the WVSP are given below:

1. Delineation of fault/sub-seismic-fault close to well which is not clearly visible on seismic to understand compartmentalization and fluid continuity within the zone of interest.
2. Increased Resolution of reservoir zone.
3. Delineation of reservoir extent with improved S/N ratio compared to Seismic.
4. Anisotropy Estimation – addressing the depth mismatch which is to the tune of 150 meters at reservoir level estimated by ZVSP.
5. Porosity Estimation by Inversion of WVSP – Porosity modeling around the wellbore/structure
6. Estimation of AVO effect
7. Correlation of zero offset VSP, seismic and WVSP for reservoir attribute estimation
8. Appropriate Wavelet Estimation
9. Shear data estimation from multi-component WVSP for reservoir characterization

PRE SURVEY MODELING

Ray Tracing Study

It is important to perform both 3-D and 2-D pre-survey modelling prior to any data acquisition in order to optimize the source and receiver locations. Borehole seismic surveys need to be optimized if they are to meet survey objectives and remain within budget. 3D ray tracing has been conducted for positioning of the VSP receivers at the proper depth inside the wellbore and the sources at the correct offset and suitable azimuth for the proper illumination of the reservoir.

Major inputs for this study were:

1. Structure Map of reservoir top
2. Inline and Xline interpreted depth sections
3. Average interval velocities
4. Depth profile at well location
5. 3D layer grid for main horizons, in ASCII format for full 3D model

Recommendations from Pre-Survey Modelling:

1. Acquire a Rig Source VSP survey from total depth to surface for optimum time to depth correlation.
2. Acquire two walkaway lines:
   (i) Line-1, with azimuth 115 deg and +/- 4000m from the wellhead.
   (ii) Line-2 with azimuth 025 deg and +/- 4000m from the wellhead.
3. Source spacing at 40m intervals. Take approximately 200 shots per line.
4. Geophone deployed at 2600m depth (bottom level). Acquire at least 28 levels at 10m receiver spacing.

Expected Output:

1. Potentially up to +/- 1000m subsurface coverage at Reservoir depth, in Inline and Xline direction. Fig.2a
2. High foldage at reservoir level (reflection density). Fig.2b
3. Frequency Bandwidth will be increased
4. Better signal to noise ratio
5. Improved wavefield separation (more number of spatial samples)
6. Improved imaging
7. Improved resolution of final image

ACQUISITION PLANNING

With the high day rates for drilling rigs in deepwater, VSP tool should have the maximum number of receivers (shuttles) to optimize the survey cost. For obtaining effective coverage as determined by ray tracing study, four settings of the VSP tool (seven shuttles in each setting) at consecutive depth intervals were necessary.
Figure 3: Planned position of shuttles inside the wellbore (not to scale)

While keeping an eye on primary objective of delivering an image with much higher resolution at the reservoir levels along the plane of the walkaway lines, this survey configuration was planned in this way:

<table>
<thead>
<tr>
<th>Pass 1</th>
<th>2480-2600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass 2</td>
<td>2470-2590</td>
</tr>
<tr>
<td>Pass 3</td>
<td>2340-2460</td>
</tr>
<tr>
<td>Pass 4</td>
<td>2330-2450</td>
</tr>
</tbody>
</table>

Figure 3: Planned position of shuttles inside the wellbore (not to scale)

BOREHOLE CONDITION

Borehole condition plays a major role in the signal to noise ratio of the seismic data. These are four preferences of hole condition for good tool coupling:
1. There should be a single casing string with good cementation
2. It should be a competent open hole.
3. There may be a single casing string with poor cementation but it should be old enough for annular debris to solidify.
4. Last preference is, single or double casing string poorly cemented and recently cased.

In the present case study, due to the delay in WVSP instrument availability and other logistics wellbore was cased. CBM log has been studied for assessment of cementation quality in the borehole. Results of CBM log depends on the pressure used which depends on the strength of the cement in the wellbore. At 2000psi, it was not showing appropriate cementation But, at 300psi results were quite good. Fig. 4. Still, we planned to go for zero-offset VSP as a test run for the testing of geophone-borehole coupling, before the acquisition of WVSP.

Test Run For Testing of Tool Coupling

Due to the possibility that poor cement might affect the data quality, it had been decided in the pre-survey meeting to conduct data quality checks at each of the four array depths prior to starting the main acquisition. After completing gamma correlation for depth and tool functionality checks it was locked at the first survey depth 2480m (upper level). The data quality was good at both near and far offsets. Fig. 5. At tool level 2340 meter (upper level), shots were taken much closer to the rig, and there was an evidence of tube wave in the horizontal channels. As such, data quality was good, and the pre-survey fears that poor cement would compromise the survey turned out to be incorrect. Good S/N ratio has been seen on the data, which was analyzed using Promax Software. Fig 5.
ACQUISITION PARAMETERS OF WVSP:

According to the earlier plan we planned to acquire two lines, name as line1 and line2. Survey configuration has been given in fig.6:

<table>
<thead>
<tr>
<th>Receivers &amp; Navigation</th>
<th>7 level Geochain geophone array &amp; GPS System (handled by Fugro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Seismic Source</td>
<td>3x 250 Cubic inch G gun source array @ 2000psi (4 guns on Sled, 3 used and the fourth acting as a pre-deployed backup)</td>
</tr>
<tr>
<td>Surface Seismic Source Controller</td>
<td>A Hot Shot was used to control the guns, this was activated via an RSS (since the Hot Links did not arrive in time) The RSS was also utilised to transmit the hydrophone signature</td>
</tr>
</tbody>
</table>

Figure 6: Acquisition parameters of WVSP

PROBLEMS DURING DATA ACQUISITION OF WVSP AND TIME MANAGEMENT

Problem in Tool: During the testing of final planned survey depth of 2330 meter (uppermost level), it was observed that tool 5 is not locked. The arms were cycled, and another record taken that shows clean data on all tools except tool 5. Fig. 7 Decision was made to pull out of hole and remove the tool from the string. Lost time due to this problem was approx. 5hrs 27mins which includes the 1hr required to bring the vessel alongside

Figure 7: Problem in tool 5 during the pre survey testing

ACQUISITION TRAVERSES

Acquisition of First Pass (Depth 2480-2600 meter):

The Line-1 was shot from the SE to the NW. Acquisition of this pass could be completed, according to our pre-survey plan. Data quality was very good. Fig.8

Figure 8: Data quality in Pass1.

Acquisition of Second Pass (Depth 2470-2590 meter):

During this pass, for Line-1 quite a lot of Navigation fixes were missed at the start of the line. So, it was decided to continue the transit and the second pass of line 2, with the decision to re-acquire the missing data for line 1 before moving the geophone array for pass-3.
It was reported that guns were leaking but this would get rectified during the transit of vessel from line-1 to line-2. But still it took approx. **2 hours and 20 minutes**.

With the exception of the above issues, the data quality was very good, although due to worsening weather, some noise was contaminating the data, which could be removed by using bandpass filter.

**Problem in GUN Frame:** During the repetition of some shots of line-1 pass-2, it was reported again that guns were leaking and the leak was worst at this time. Hence further shooting was not possible before rectification of guns problem. The lost time recorded for these repairs was **approx. 4 hours**.

**Acquisition of Third Pass (Depth 2340-2460 meter) on the north side of Rig only:**

After the acquisition of first few shots on Line 2, we started getting Navigation Fix errors, and the data quality due to the high frequency noise had also increased to an unacceptable level. The weather had continued to deteriorate. Decision was made to increase the length of slack cable above the array, which reduced the noise. The vessel was then instructed to loop back and reacquire the data that had been most badly affected by the noise (Fig. 9).

![Figure 9: Difference in data quality after increasing the slack cable above the array](image1)

**Problem in Gun Frame:** Again problem occurred in third gun due to gun frame. Decision has been made to complete the acquisition program, before the total failure of the guns. Survey design was altered, to maximize the chances of acquiring all the data to the north of the rig, as this was of greater importance than the data to the south side of the rig. Lost time recorded **3 hours 40 minutes**.

**Acquisition of Fourth Pass (Depth 2330-2450 meter):**

According to earlier decision, the tool array was moved to its final depth at 2330 m. The noise was still getting worse; this was partially due to the rig loading heavy casing sections from a supply boat, which was causing the whole rig to vibrate. Approximately half way along the pass from the rig along line 1 to the NW, again source array started leaking, so line was completed with only 2 guns. Because of this, data quality got affected. Fig. 10

![Figure 10: Bad data quality due to change in gun pressure.](image2)

**Problem in GUN Frame:** By the time fourth pass was completed the array gun sled was damaged beyond any hope of temporary repair. Final decision was made to complete the survey by using only one gun but increasing its firing pressure to 3000 psi from the 2000 psi. Reason was, that since the relationship between gun output energy and gun pressure is almost linear, sufficiently high signal to noise ratio data might be acquired, which can be utilized at this point of the survey.

**Total Lost Time = 18 hours**

<table>
<thead>
<tr>
<th>Incident</th>
<th>Problem Description</th>
<th>Lost Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident 1</td>
<td>Replace Snapped Arm on receiver 5</td>
<td>5 hrs 30 min</td>
</tr>
<tr>
<td>Incident 2</td>
<td>First Airgun Array problem</td>
<td>2 hrs 20 min</td>
</tr>
<tr>
<td>Incident 3</td>
<td>Second Airgun Array problem</td>
<td>4 hrs 00 min</td>
</tr>
<tr>
<td>Incident 4</td>
<td>Third Airgun Array problem</td>
<td>3 hrs 40 min</td>
</tr>
<tr>
<td>Incident 5</td>
<td>Fourth &amp; Final Airgun Array problem</td>
<td>2 hrs 30 min</td>
</tr>
</tbody>
</table>
It was decided to acquire line 2 from the rig to the SW. Depending on SNR (Signal to noise ratio) being acceptable or not, accordingly continue acquisition of rest part of the survey or abandon the survey. Further, 2 hours 30 minutes of lost time were recorded. Fig. 11. Data quality was acceptable. Same way southern part of the Pass 4 could be completed using single gun.

Figure 11: a) Data quality using single gun, 3000 psi pressure b) data after application of bandpass filter

Acquisition of Third Pass (Depth 2340-2460 meter) on the remaining south side of Rig:

In this part of the survey we acquired data for the southern part of the survey, which was left earlier.

Figure 12: Actual plan executed in field

Conclusion

We were expecting to finish this survey in approx. 36 hours but due to initial unexpected problem in tool, severe problem in gun frame, lack of proper navigation and bad weather conditions, survey has taken more than 66 hours. Bad weather conditions can not be controlled by somebody but if we could have acquired this data with proper number of shuttles in the tool, we could have minimized all these unforeseen circumstances. To optimize the survey cost in future, planning should be done much before execution of survey. All the instruments should be checked properly before going to field for the final execution of the survey. Inspite of having a complex acquisition geometry and field execution troubles during the acquisition of this survey, data quality was good at all depth levels in terms of amplitude, frequency and seismic imaging.

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