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VSP Tool Orientation Using Magnetometer and Inclinometer Sensors.

C. Naville* (IFP Energies Nouvelles), C. Naville (IFPEN), S. Serbutoviez (IFPEN), S. Nicoletis (Total E&P Bolivie)

Summary

Onshore wireline borehole seismic in rough, mountainous foothill terrains is very often restricted to rig source VSP and Offset-VSP using a single fix surface source, one run per source position, for economic reasons. This technique also applies to common offshore rig-source VSP surveys.

Complex subsurface tectonic complicates surface seismic imaging and borehole seismic imaging is equally difficult. Solving structural feature in the borehole vicinity can benefit from three component (3C) VSP processing techniques, but it requires orientating the 3C data at pre-processing stage.

The orientation of the three-component VSP signals recorded in a near-vertical well section, mostly cased, was successfully obtained by combining in the field a magnetometer–inclinometer orientation tool, namely the common GPIT* general purpose inclination tool, to a single-level VSP tool with fixed setting of three-component seismic sensors, available at the time.

Future field acquisition of rig-source and fix offset source VSP surveys can benefit from combining a magnetometer & inclinometer sensors to at least one of the recording tool of the multilevel VSP tools routinely used nowadays.

* Mark of Schlumberger
Introduction

Onshore wireline borehole seismic in rough, mountainous foothill terrains is very often restricted to rig-source vertical seismic profiling (VSP) and offset VSP using a single fixed surface source, one run per source position, for economic reasons. This technique also applies to common offshore rig-source VSP surveys. Complex subsurface tectonics complicate surface seismic imaging, and borehole seismic imaging is equally difficult. Solving structural features in the borehole vicinity can benefit from three-component (3C) VSP processing techniques, but such processing requires orientating the 3C data at the pre-processing stage. The orientation of the three-component VSP signals recorded in a near-vertical well section, mostly cased, was successfully obtained by combining in the field a magnetometer–inclinometer orientation tool, the GPIT* general purpose inclination tool, to a single-level VSP tool with fixed setting of three-component seismic sensors, available at the time.

The present paper illustrates how the current VSP tools and the common logging orientation hardware, namely the GPIT tool, associated with the borehole geometry, can be used successfully, without need for a third-party gyroscope to be combined with a single or multilevel VSP tool-string. The geologist end-user needs additional accuracy in the VSP processing results that cannot be reliably obtained from the non-oriented rig-source VSP datasets currently recorded in the industry to complement the structural information from the short radius, open hole, borehole wall imaging techniques. Future field acquisition of rig-source and fixed-offset-source VSP surveys can benefit from combining a magnetometer and inclinometer sensors to at least one of the recording tools of the multilevel VSP tools routinely used nowadays.

Method

Rig-source VSPs are usually shot at the end of the wireline logging program, partly in the open hole (OH) deep part of the well, partly in cased hole, deviated or not. VSP recording in borehole depth sections with double or triple casings is generally avoided. The 3C VSPs orientation is achieved by:

1) **Orientation in OH** is obtained using the three angles measured by the GPIT tool.
2) **Orientation in deviated cased hole** is obtained using the relative bearing (RB) and the hole inclination angle (DEV or SDEV) measured by the GPIT-inclinometer connected to the VSP tool. RB angle is meaningless in a cased hole if SDEV<1.5°. The borehole azimuth (HAZI) angles in the cased interval are provided by the borehole survey. (The GPIT tool runs in the open hole prior to casing installation, or gyroscope.) Figures 1 and 2 illustrate the process.
3) **Orientation of the few VSP stations in near-vertical cased hole**, where the GPIT tool cannot yield reliable RB angles, is achieved during preprocessing. The process uses the stable particle motion property of the seismic body waves versus depth to solve the remaining RB rotation jitter of the off-borehole axis components into the same system as the adjacent VSP levels reliably orientated using the angles measured independently by hardware orientation devices, as outlined in Kazemi (2009, chapter 6). Then, processing 3C VSP data can start.

![Diagram](image)

**Figure 1** RB angle definition. RB variations indicate that the VSP tool rotates randomly level to level, although the tool arm remains open while moving between VSP stations.

* Mark of Schlumberger
Figure 2 Three successive rotations illustrate the orientation process from field measurements

Figure 3 Left: Reason for orienting the 3C VSP tools and data (Naville et al., 2015). Right: Geometry of the VSP depth interval. The HAZI changes by nearly 180° right above the casing shoe.

Example of challenging orientation of a VSP dataset recorded in near-vertical cased hole

The vibroseis raw 3C VSP data (isotropic display, Figure 4) is of excellent quality, exempt of undesired tube waves; random noise attenuation was applied during the vertical stack of repeated records before correlation. Continuous noise remains on a few levels in the open hole near total depth (TD), which would compromise orientating the horizontal components without GPIT measurements. The borehole geometry of the VSP depth interval (Figure 3) at scale 1:1 shows near-vertical intervals where the GPIT inclinometer tool cannot expectedly yield a correct RB angle, at the top and right above casing shoe, as observed on 3C data after rotations (Figures 5 and 6). Rush conditions and retyping the rotation angles led to a few errors in the input rotation angles. The final orientation shown in Figure 7 was obtained by correcting the RB values of VSP levels located in the near-vertical cased section, down to 20 m below casing shoe, using the coherency criterion of seismic body waves within a few wavelength of propagation (Kazemi, 2009). The excellent quality of the oriented 3C data (Figure 7) illustrates the high vector fidelity of the 3C seismic data delivered by VSP tools available since the early 1980s (de Montmollin, 1988). Thus, orientation of 3C VSP data is an added value.
Figure 4: Raw 3C data. The VSP tool can rotate randomly level to level, mainly in the open hole.

Figure 5: Raw 3C data after roll-RB angle rotation: no results where the hole inclination DEV <1.5°.

Conclusions
The method for orienting the rig source VSP data illustrated by the present example is robust and reliable. The few VSP levels located in the near-vertical cased hole can be properly oriented without the need for a third-party gyroscope, and with a reasonable extra effort at the pre-processing stage. The next step will be to test orienting the current multilevel VSI versatile seismic imager VSP data with a combined GPIT tool on one of the shuttles, without using cumbersome stiff bridles.

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Figure 6: 3C VSP data after all three successive rotations. RB/azimuth jitter in near-vertical borehole sections remains to be corrected.

Figure 7: 3C VSP data fully oriented in geographic system after jitter corrections based on coherency of seismic data versus depth. 3C seismic data processing can start from this point.

References