Observations and Potential Significance of Tube Waves in DAS VSP Surveys

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Introduction

In conventional 3C geophone VSP surveys it is common to observe tube waves traveling up and down the cased borehole. These waves travel at approximately the velocity of the fluid in the borehole and have been mostly viewed as noise and removed in processing to reveal the underlying reflections. But recent experiments recording similar waves with permanently deployed Distributed Acoustic Sensor (DAS) fiber arrays demonstrate some unusual behaviors. We will present several examples of these recordings and suggest some possible explanations for their unique properties.

Generating and Recording Tube Waves with DAS

A tube wave is an interface wave that occurs in cased wellbores when a Rayleigh wave encounters a wellbore and perturbs the fluid within the wellbore. The tube wave travels down the wellbore along the interface between the fluid and the wall of the wellbore. Tube waves have routinely been observed in near-offset source VSP surveys using 3-component geophone sensors inside casing. In these experiments, however, the recording of this wave occurs on a DAS fiber array that is placed between the casing and the formation and is typically cemented in place. How this wave propagates and is recorded will be discussed in this presentation.

Field Data Examples

In this study we will present several examples from VSP surveys recorded over the last few years from various basins. All surveys were recorded by DAS fiber permanently installed behind casing in onshore oil fields. The fiber in all these examples extends some distance into the horizontal section of the well. Typical receiver sampling was 2m with a gauge length of 10m. All were acquired using Vibroseis surface sources. Some were acquired as repeated VSP surveys for time-lapse analysis.

Observations and Potential Significance

One common observation on nearly all the examples is the abrupt attenuation of the tube wave at some depth. This can be seen in Figure 1. On some surveys this depth can be correlated to the top of cement. This is consistent with the hypothesis that this wave is traveling in the fluid between the casing and the formation.

Another common observation is the appearance of two different waves traveling at slightly different velocities. This can also be seen on Figure 1 when comparing the strong wavefield at the top of the wellbore and the secondary wavefield that continues down the array at a slightly faster velocity. This may be an indication of two tube waves – one travelling inside casing and another outside.

In another survey, we see a reflected tube wave arrival coming in much later in the record indicating it is reflecting off some interface deeper in the well – possibly the top of cement. Interestingly, this reflected wave does not show up consistently along the DAS array but disappears at some depth on the way down and then reappears at roughly the same depth on the way up.

Finally, our time-lapse examples show a change in the tube wave before and after hydraulic fracture stimulation (Figure 1). These changes will be described, and their potential significance discussed.

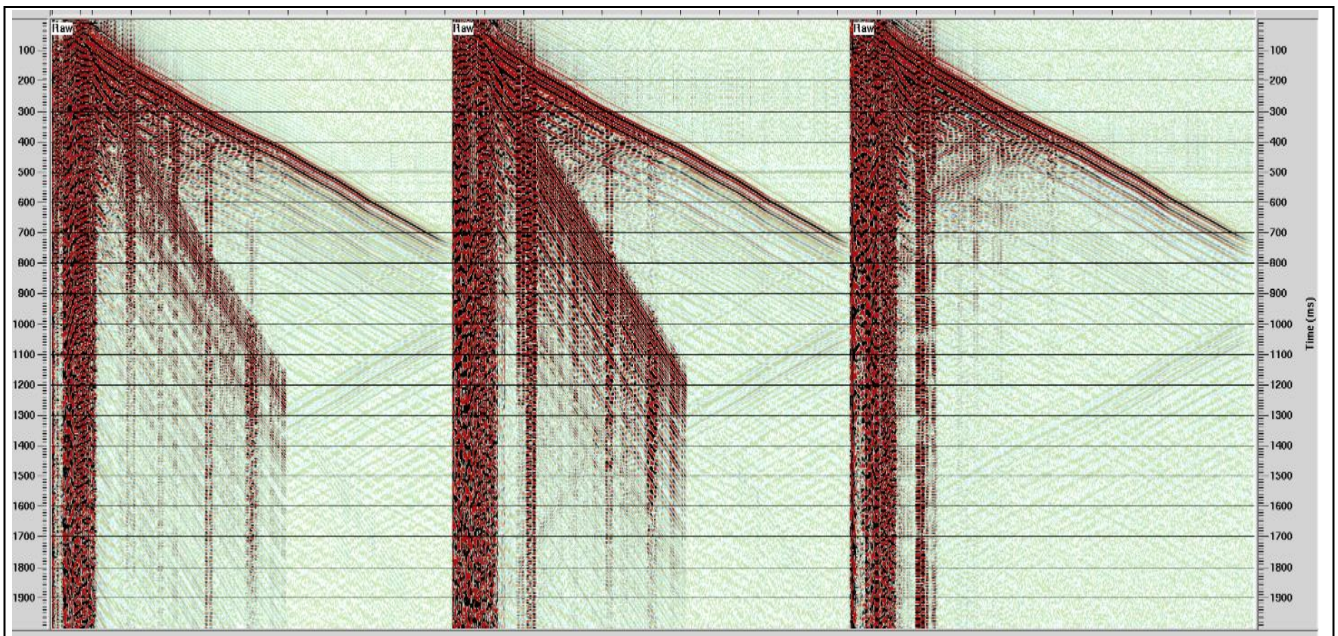

Figure 1: Three near-offset DAS VSP records showing variations in the tube waves over time. Source type and location were the same for all three episodes. The first panel was recorded before hydraulic stimulation, the second immediately after stimulation and the third after several months of production. Note the abrupt attenuation of the tube wave at a specific depth on the first two episodes and its complete absence on the last.