Time lapse seismic monitoring of individual hydraulic frac stages using a downhole DAS array: initial field observations

Diana Tamayo, Gary Binder, Aleksei Titov, James Simmons, Ali Tura, Colorado School of Mines; Grant Byerley, David Monk, Apache Corporation; Rich Van Dok, SigmaCubed

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In 2017, Apache Corporation acquired a unique time-lapse Vertical Seismic Profiling (VSP) survey using fiber optics technology in a horizontal well located in the Permian Basin, Texas. The fiber optics cable was deployed downhole by cementing it to the outside of the casing of the well that was being hydraulically fractured. Two seismic vibrators were placed one mile north of the well, and two more were placed one mile south of the well. This survey utilized Distributed Acoustic Sensing (DAS) to acquire VSP records pre-frac (baseline) and after each of the 78 stages of hydraulic fracturing. This unique survey design can be used to analyze velocity changes and scattering effects caused by each of the 78 stages hydraulic fracturing, characterize hydraulic fractures using the time-lapse response, and analyze fracture dynamics, such as the opening and closing of fractures, using the length of the time-lapse response.

To analyze how DAS records change in the reservoir during stimulation, a trace by trace cross-correlation method was used to calculate the time-shifts between each stage and the pre-frac record. This method was used on the direct P-wave arrivals for both the north and south geometry. The results show negative time-shifts, or a slowdown in velocity, that is related to the location of the stage being hydraulically fractured.

Initial observations were made based on this time-lapse analysis. These initial observations were that the time-delays of the P-wave arrival are related to hydraulic fractures, the time-delays are on the order of 4-5 ms, and the time delay effect lasts 1-2 days.

While this initial analysis showed promising results, it was determined that additional processing would be beneficial. A processing flow was developed to increase the signal to noise ratio, which is especially important in DAS data. Noise attenuation focused on removal of flowback noise, noise that occurs at the location of hydraulic fracturing for a certain stage, and interrogator noise, a type of time-variant noise that is constant across all channels for a certain time. Reprocessing is a critical step for more accurate time-shift calculations, which will allow for more in-depth analysis of this dataset.

Time-lapse DAS VSP is sensitive to stage-by-stage changes in the reservoir during stimulation. Time delays in the data are related to hydraulic fractures, and thus, can provide information about the effectiveness of hydraulic fracturing. With this unique acquisition geometry, the time delays could be used to invert for hydraulic fracture height. Overall, time-lapse DAS VSP has the potential of offering a new, permanent and cost-effective method to monitor hydraulic fracturing.