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Comparison of VSP Data with Geophones and DAS Behind Casing in a Shallow Land Well

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Summary

We compare multiple DAS datasets with different acquisition parameters, acquired in a land test well. The objective is to evaluate achieved acoustic coupling and recommend the "best-mode" recipe to acquire DAS datasets inside boreholes.

Introduction

Seismic acquisition technologies are continuously evolving to find economical and time-efficient solutions to acquire quality seismic data. A recent approach has been to acquire seismic data using cost-effective distributed acoustic sensing (DAS) cables (Daley et al., 2013). DAS cables are basically fiber-optic cables that can be buried in the shallow subsurface or installed in boreholes to record seismic wavefields (Mestayer et al., 2011; Parker et al., 2014; Dean et al., 2017). These cables can also be utilized to monitor fluid flow and temperature in boreholes with high temperature and pressure conditions (Becker et al., 2017). Recently, so-called smart DAS upholes were introduced to better characterize near-surface complexities by acquiring densely sampled wavefields by a fiber-optic cable inserted in multiple upholes and connected by horizontally trenched cables below the earth surface (Bakulin et al. 2017). Utilizing the borehole DAS technology has been an active area of research. For VSP surveys deploying DAS fiber inside wireline cable is the most economic option; however, it often yields datasets with low signal-to-noise ratio (SNR).

In this abstract, we present our latest results of various DAS datasets acquired by installing the cables inside a shallow wellbore. Multiple DAS cables and conventional geophones are permanently installed and cemented behind the casing string. We compare and contrast the different datasets with different acquisition parameters to evaluate achieved acoustic coupling and recommend the “best-mode” recipe to acquire DAS datasets inside boreholes. The datasets are also processed to extract upgoing reflection information and benchmarked against synthetic data extracted from measured sonic logs.

Method

The sonic logs were acquired to estimate the P-wave formation velocities in the open hole of the test wellbore. The borehole extends from the Earth surface to about 500 meters in depth. 40-level geophone tools were permanently installed and cemented behind casing to acquire VSP data in the borehole. Similarly, several DAS cables were permanently installed and cemented behind the casing string to ensure coupling with the formation and accurate measurements of the recorded seismic wavefields.

Initially, we constructed a long-wavelength 1D velocity model by filtering the sonic log profile. We then used a finite-difference acoustic simulation to model a zero-offset VSP (ZVSP) shot gather to benchmark our conventional geophone and DAS gathers, and identify key reflection events (i.e., markers). The bandwidth of both the conventional geophones and DAS datasets are compared to ensure that the seismic signals span a similar frequency range. Also, the amplitude spectra of noise and direct arrivals for each dataset is computed to estimate the signal-to-noise ratio. The DAS data are obtained using different gauge lengths (GLs), which corresponds to different SNRs.

The P-wave first-break (FB) traveltimes are picked on the 40-level ZVSP geophone data to construct a time-depth checkshot. A 1D P-wave velocity model is constructed based on this checkshot profile. A synthetic shot gather was computed using the finite-difference solution to the acoustic wave equation. This gather is compared with the previous simulated gather obtained using the sonic logs. Also, the targeted reflection events are marked in both datasets and compared with the field conventional geophone and DAS datasets.

Results

The acquired sonic log for the test well is shown in Figure 1a. The red arrow marks a significant contrast in the P-wave slowness, which could potentially produce a significant reflection event. Figure 1b shows a smoothed version of the 1D velocity profile, which is subsequently used for the finite-difference simulation. One can also note the large velocity contrast marked with the red arrow. We simulated a synthetic zero-offset VSP (ZVSP) shot gather using the finite-difference solution to the acoustic wave-equation. The shot is placed at 36 ft away from the wellhead and we utilized a 40-level recording borehole geophone array with a spacing of 12 meters. The synthetic ZVSP gather is presented in Figure 1c. Note that the marker associated with the sharp velocity contrast is picked and highlighted by the blue picks.

The initial field datasets is shown in Figure 2a and it is a ZVSP shot gather with the same acquisition geometry as the synthetic shot gather. Note the strong shear arrivals marked with the blue arrow in the recorded gather using the 40-level geophone array. The source in this experiment is an elastic weight drop (EWD) and the source is repeated 15 times. The gathers are then stacked together to enhance the signal-to-noise ratio (SNR) of the final gather. The first arrival agrees well with P-wave first arrivals of the synthetic shot gather. The FB picks on the field cemented geophone data are used to generate a 1D velocity profile shown in Figure 2b. We solved the acoustic wave-equation using the new velocity profile from the ZVSP data and present the new gather in Figure 2c.

The DAS dataset acquired by a single-mode fiber-optic cable is presented in Figure 3a and 3b using a gauge length of 1.8 m and 11.7 m, respectively. The optimal gauge length is found to be dependent on the dominant wavelength in the data, which in turn depends on the subsurface velocity field. While the ZVSP DAS gather in Figure 3a has a low SNR of about 7 dB, the ZVSP DAS gather with the longer gauge length in Figure 3b shows a significant improvement in the SNR, which is found to be 25 dB. Both datasets are acquired with the same vibroseis source by stacking 8 sweeps. The gather in Figure 3b has a comparable SNR ratio to the conventional geophone ZVSP gather acquired by stacking 15 gathers from elastic weight drop source. The wavefield recorded by the DAS data is densely sampled at 0.6 m (i.e., total of 738 stations) compared with that recorded by the 40-level conventional geophones, spaced at 12 m.

We then tested the ability to separate the wavefields to extract upgoing reflections. Applying wavefield separation to the conventional geophone data with coarse spacing intervals was not optimal due to the heavily aliased shear-wave arrivals as demonstrated in Figure 4a. The target reflector at 220 m, marked by the red arrow, is hardly identified after separation as it is masked by severe artifacts. In contrast, the densely sampled DAS wavefield can be easily separated and its FK spectrum does not suffer from aliasing. The target reflector at 220 m is marked by the blue arrow in Figure 4b.

Conclusions

We presented the results of recorded seismic data using fiber-optic DAS cable and conventional geophones cemented behind the casing in a 500 m deep test well. We confirm that behind casing installation provides excellent coupling between fiber and formation and enables recording VSP data all the way to the ground level thus accurately characterizing near surface velocities. We demonstrated that longer GL provides an improved signal-to-noise ratio, which is comparable to conventional geophone data. The low-velocity arrivals are heavily aliased when recorded by coarsely spaced conventional geophones, which yields to sub-optimal wavefield separation results. Lastly, we showed that the densely sampled DAS data provides superior results with wavefield separation revealing a nonaliased targeted upgoing reflection arrival. In deep wells with multiple casing strings, coupling may strongly depend on cementation quality. For accurate estimation of near-surface velocity, installation of fiber behind the shallowest casing string may be recommended.

References

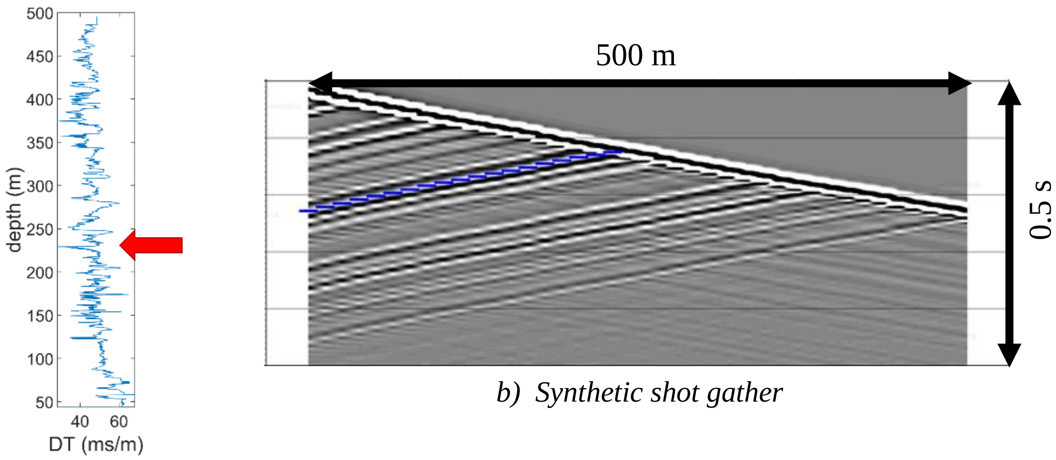
Bakulin, A., Golikov, P., Smith, R., Erickson, E., Silvestrov, I., and M. Al-Ali, 2017, Smart DAS upholes for simultaneous land near-surface characterization and subsurface imaging: The Leading Edge, 1001–1008.

Daley, T. M., Freifeld, B. M., Ajo-Franklin, J., Dou, S., Pevzner, R., Shulakova, V., Kashikar, S., Miller, D. E., Goetz, J., Henninges, J., and Lueth, S. [2013] Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring. The Leading Edge, 32(6), 699-706.

Dean, T., Cuny, T, and A. Hartog, 2017, The effect of gauge length on axially incident P-waves measured using fibre optic distributed vibration sensing: *Geophysical Prospecting*, **65**, 184–193.

Parker, T., Shatalin, S. & Farhadiroushan, M. 2014, Distributed acoustic sensing – a new tool for seismic applications: *First Break* **32**, 61–69.

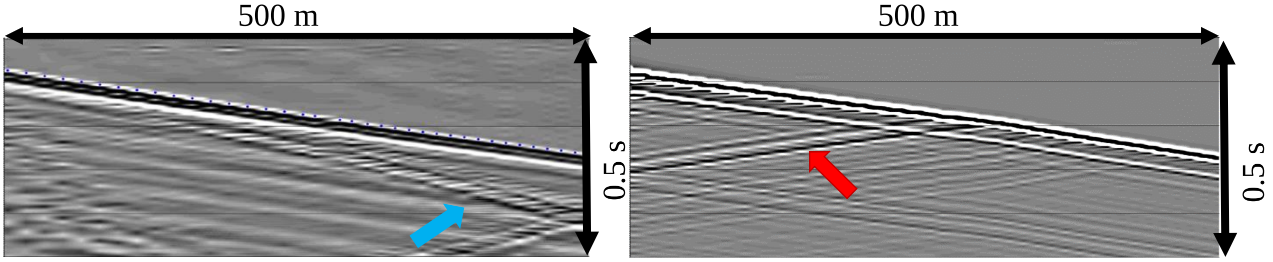
Mestayer, J., Cox, B., Wills, P., Kiyashchenko, D., Lopez, J., Costello, M., Bourne, S., Ugueto, G., Lupton, R., Solano, G., Hill, D., and A. Lewis, 2011, Field trials of distributed acoustic sensing for geophysical monitoring: 81st Annual International Meeting, SEG Technical Program Expanded Abstracts, 4253–4257.



b) Synthetic shot gather

a) Sonic log

Figure 1*: Simulation of the expected response: a) input sonic logs extends to about 500 m depth. The red arrow marks a significant contrast in the P-wave slowness at about 220 m depth; b) A synthetic shot gather obtained by the fnintie-difference solution to the acoustic wave-equation. The marker at about 220 m depth is highlited by the blue picks.*



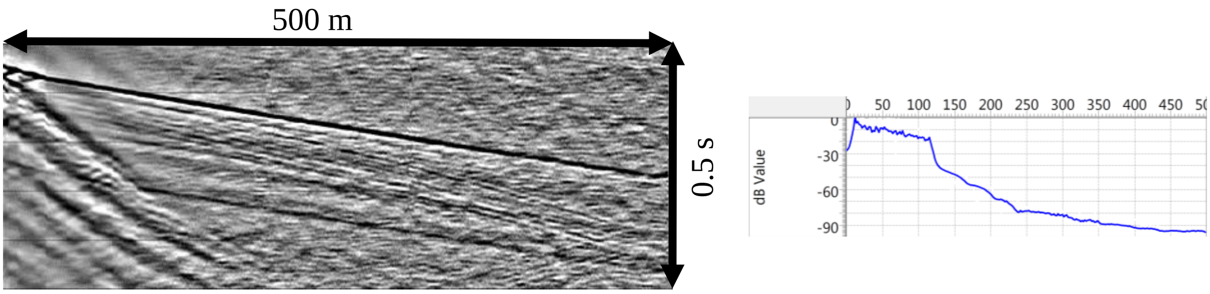
a) 40-level cemented geophone ZVSP data

c) 40-level cemented geophone ZVSP data

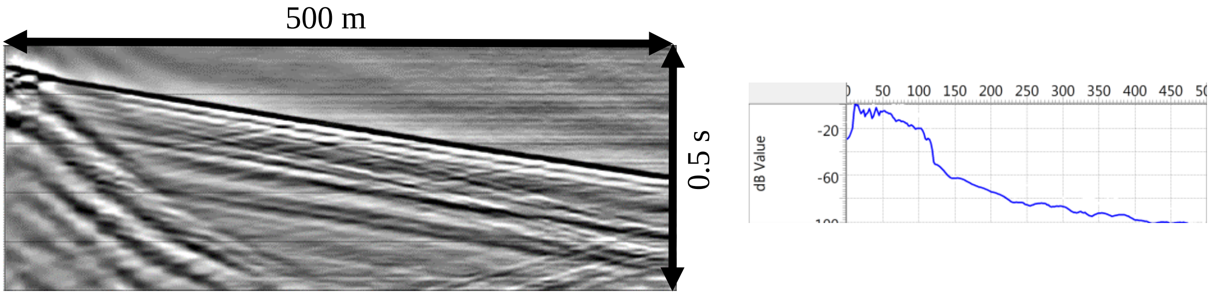
b) Smoothed velocity model

Figure 2*: ZVSP field data: a) ZVSP shot gather using an elastic weight drop source. Note the strong shear-wave arrivals marked with the red arrow. b) a 1D velocity model constructed using the FB picks.*

Note the strong marker at about 220 m depth. c) A finite-difference solution to the acoustic wave-equation reveals the reflection arrival generated by the marker at around 220 m.

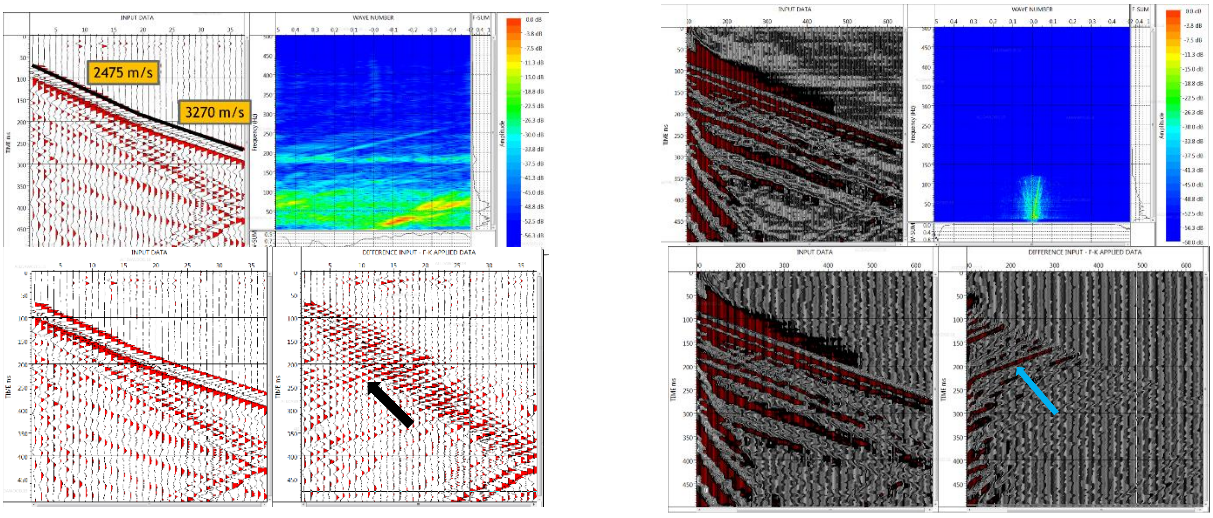


a) *ZVSP DAS data with GL of 1.79 m*



b) *ZVSP DAS data with GL of 11.66 m*

***Figure 3**: ZVSP DAS datasets: DAS ZVSP obtained with a GL of a) 1.79 m and b) 11.66 m. The longer gauge length yields an enhanced SNR. Note the amplitude spectra for both gathers showing the reduction of the high-frequency noise caused by better array filtering with larger GL.*



a) *Wavefield separation of geophone data.*

a) *Wavefield separation of DAS data.*

***Figure 4**: Wavefield separation of ZVSP gathers. The result of upgoing wavefield separation of a) 40-level geophone data and b) DAS data. ZVSP shot gather using an elastic weight drop source. Note the strong shear-wave arrivals marked with the red arrow. b) a 1D velocity model constructed using the FB picks. Note the strong marker at about 220 m depth. c) A finite-difference solution to the acoustic wave-equation reveals the reflection arrival generated by the marker at around 220 m.*