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Introducing a New DAS Test Facility for Evaluating Emerging DAS Technologies

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Summary

The interest in utilizing fiber-optic cables in surface seismic and borehole acquisition designs has led us to establish a test facility in Houston to explore DAS latest developments and technologies. We show the latest results of acquiring zero-offset and offset vertical seismic profiling datasets in the shallow land well in Houston. The datasets are recorded to assess multiple interrogation boxes provided by different vendors. The datasets are also collected using different cable configurations such as cemented DAS cable behind casing, pumped cable inside control line, and a fiber on a spool. We also demonstrate the advantages and disadvantages of utilizing either multi-mode or single-mode fiber-optic cables for recording VSP seismic data. Our objective is to provide the best mode procedure to acquire quality DAS data for different purposes such as checkshot retrieval, velocity analysis, and subsurface imaging.

Introduction

Recording seismic data using fiber-optic or distributed acoustic sensing (DAS) cables has been a major advancement in the field of seismic acquisition. Borehole geophysics is a key stakeholder in the seismic community that has the potential to fully utilize the DAS-based acquisition systems. Miller et al. (2012) showed how DAS cables can be installed in boreholes to acquire vertical seismic profiling (VSP) datasets using these fiber-optic cables as sensors. Daley et al., (2013) demonstrated with a field test the capability fiber-optic cables to acquire seismic data for subsurface monitoring. Mateeva et al. (2014) showed how 3D VSP acquired using DAS cables can be applied for the purpose of a real reservoir monitoring.

Recently, a smart DAS uphole acquisition system has been deployed in desert environment for a high-resolution near-surface characterization and more accurate subsurface depth imaging (Bakulin et al., 2018). Another onshore experiment was also conducted to acquire borehole VSP seismic data using a DAS cable deployed within a carbon rod in a cased well to estimate subsurface interval velocities and image a deeper target (Aldawood et al, 2018). Also, multiple DAS-based VSP experiments were conducted in different boreholes in central Arabia to assess the viability of the DAS cables to work as a seismic recording sensor.

The growth and interest in utilizing fiber-optic cables in surface seismic and borehole acquisition designs has led us to establish a test facility in Houston to assess the latest DAS technologies. In this paper, we present the latest results of acquiring zero-offset and offset vertical seismic profiling datasets. These results were obtained by testing different interrogation boxes provided by different vendors, and different cable configurations such as DAS cemented behind casing, pumped inside control line, and fiber on a spool. Seismic data were also acquired using both multi-mode and single-mode fiber-optic cables. Our objective is to show how acquiring DAS data can provide quality VSP data, which is comparable or even superior to cemented geophone data.

Method and Results

A dedicated shallow test well was drilled and instrumented with geophones and fiber permanently cemented behind casing as a reference to achieve best possible coupling and data quality, and benchmark against all other types of sensor deployments. This Instrumented well was placed in Houston research center to facilitate rapid testing of quickly evolving DAS technologies before deployment in the field. The Effect of coupling on data quality and understanding the DAS response compared to the geophone one represent the focus of initial studies. A sonic delta time (DT) log was initially acquired in the shallow test well to identify major acoustic impedance contrasts to facilitate the comparison synthetic data as well other DAS and geophone datasets. Figure 1 shows compressional velocity log and the largest contrast in P-wave slowness is at about 220 m depth. This marker is set to be our targeted reflector and it is denoted with the red arrow. A smoothed version of the DT log is shown in Figure 1 along with the same target reflector. A finite-difference modeling of wave propagation is used to simulate a zero-offset VSP shot gather shown in Figure 1. The target reflector with the strongest amplitude is marked by the blue picks.

The first dataset, shown in Figure 2, is acquired using a mid-range vibroseis truck and recorded by permanent 40-level geophone array cemented behind casing. The data was processed to try to reveal the target reflector via wavefield separation, deconvolution and tube-wave suppression as demonstrated in Figure 2. The VSP shot gather is heavily aliased due to the large 15 m spacing between geophones replicating normal spacing used in conventional VSP acquisition geometries. This typical acquisition design has caused the imperfect suppression of the slow tube waves obscuring the target reflector marked by the red arrow.

The DAS datasets were acquired using the same source to assess the effect of the gauge length (GL) on the data quality and compare with geophones. The ZVSP DAS shot gathers acquired with a GL of 2 m and 4 m are shown in Figure 3a. The data after the suppression of the first arrival reveals clearly the target reflector at around 220 m depth for both gauge lengths denoted by the red arrows in Figure 3b. This shows clearly that processing densely sampled DAS data could yield results that are superior to conventional geophones data with a large geophone interval.

A notable source of noise in DAS datasets is the common-mode noise (CMN) that appears as horizontal stripes in the shot gather as shown in Figure 4b. These events have a zero dip (k = 0) in the FK spectrum that ease the removal of such type of noise. In the figure, we show how the CMN can be removed from a typical DAS VSP common-shot gather.

The signal-to-noise ratio (SNR) is also a metric that we consider to compare the DAS and geophone datasets. We acquired both datasets with different number of stacked sweeps and compared the SNR for the different data. Figure 4 shows the comparison of both the geophone and DAS data with different number of stacked shots. It is clear that the SNR of the cemented geophone data is higher than that of the DAS data cemented behind casing. Also, a typical improvement of $\sqrt{n}$, where n is the number of stacked shots is noticed on both the DAS and geophone datasets.

Conclusions

We presented initial results from our dedicated shallow test well in Houston validating good performance of permanently instrumented various DAS cables. Analysis of two first datasets acquired using a mid-range vibroseis truck was used to contrast geophone and DAS data recorded with permanently cemented sensors behind casing. Finite-difference modeling using sonic log data confirmed presence of target reflector with a strong impedance contrast at about 220 m clearly seen on all field datasets.

Initial tests show that wavefield separation is possible with both sparse geophone and dense DAS data, but finer sampling offered by DAS provides superior results. We also concluded that the SNR of the geophone data is superior to that of the DAS datasets acquired using the same source. However, the DAS data can be improved by increasing the number of shots at the same shot position. Also, we showed how the DAS common-mode noise can be attenuated by simple processing to remove the horizontal stripes footprint from the data.

Multiple other tests are being conducted at the test facility to compare VSP data quality with fiber behind casing with others inside the casing deployments such as fiber in wireline, fiber on the spool, fiber pumped in the control line, on the tubing, etc. It is believed that fiber coupling is a major factor controlling DAS VSP data quality. Fiber behind casing was proven to deliver high data quality suitable for all possible applications. Ongoing tests are designed to evaluate and contrast coupling achieved with various fiber deployment.

References

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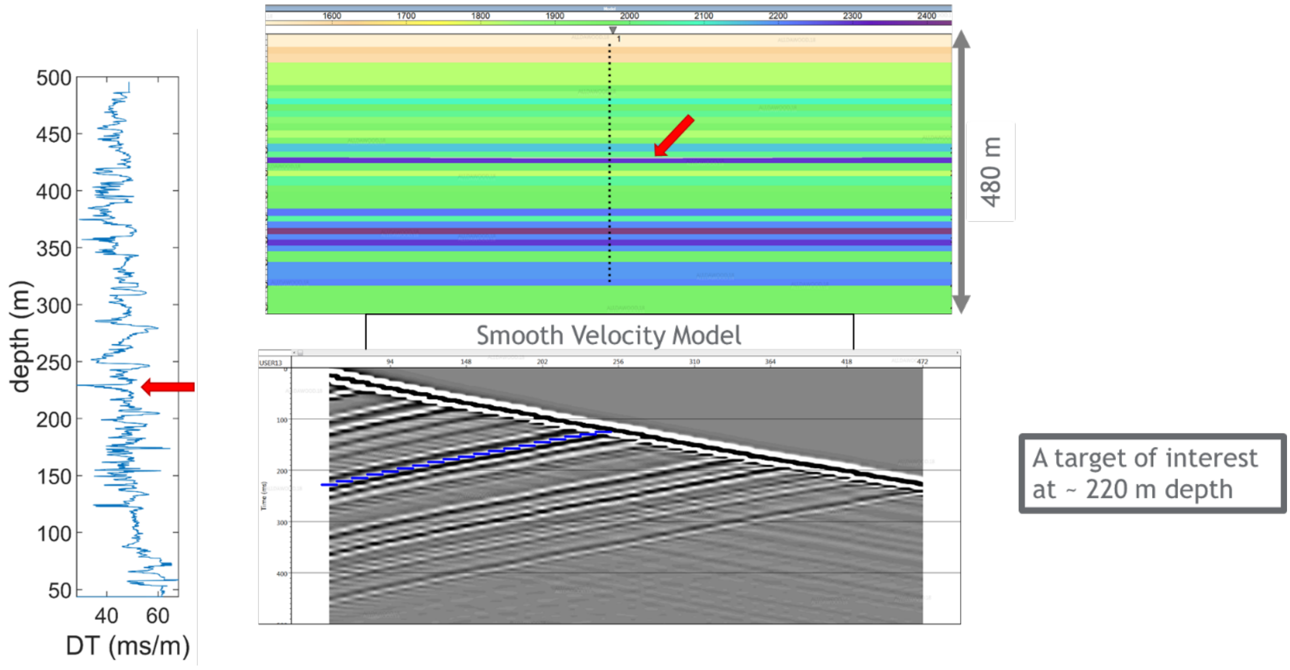


Figure 1 *Synthetic modeling: The sonic log on the left is shown and the arrow mark the highest P-wave slowness contrast. A smoothed version of the log is plotted as a horizontally-invariant velocity model with the arrow marking the largest contrast at around 220 m depth. A zero-offset synthetic shot gather is shown and the strong reflector caused by the largest impedance contrast is picked as shown by the blue marks.*

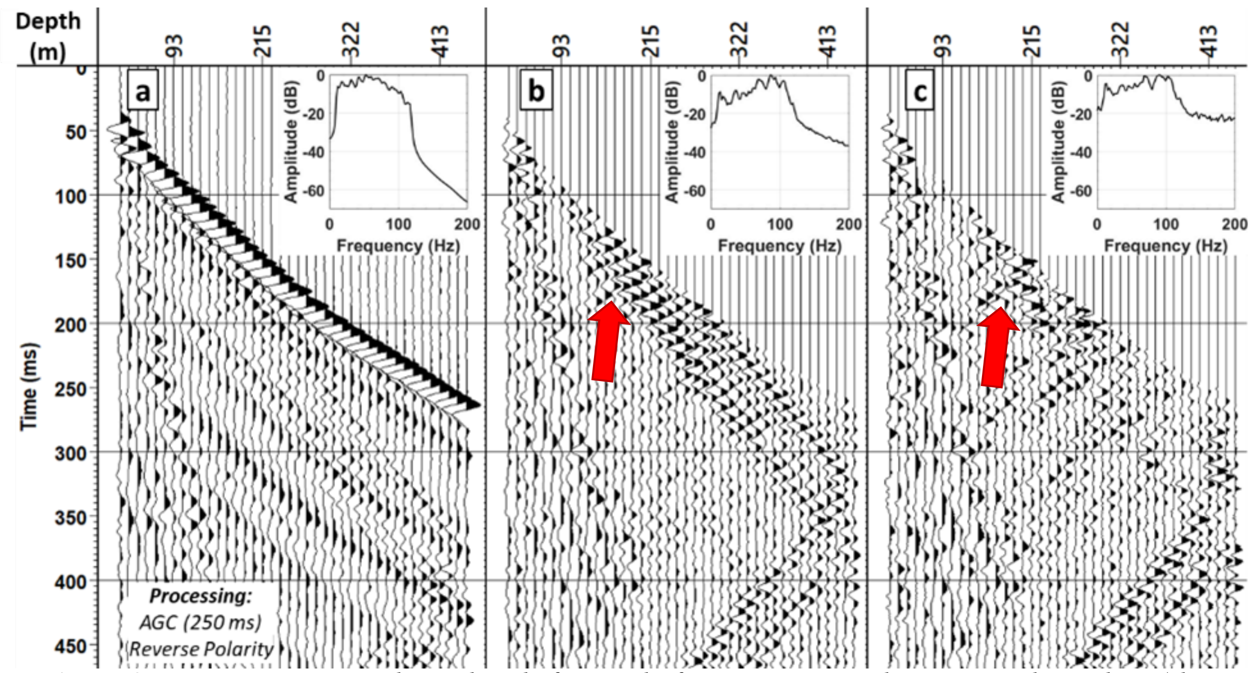
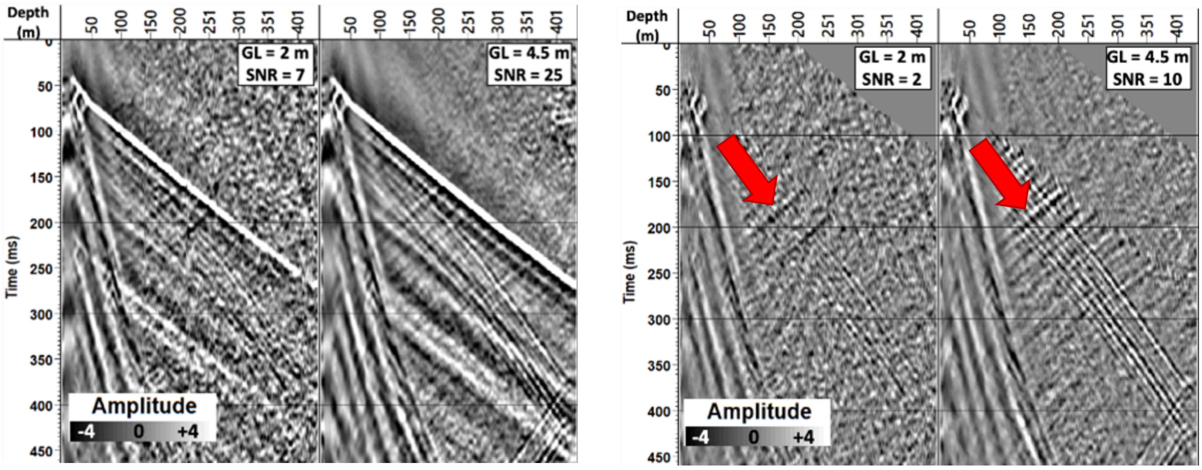
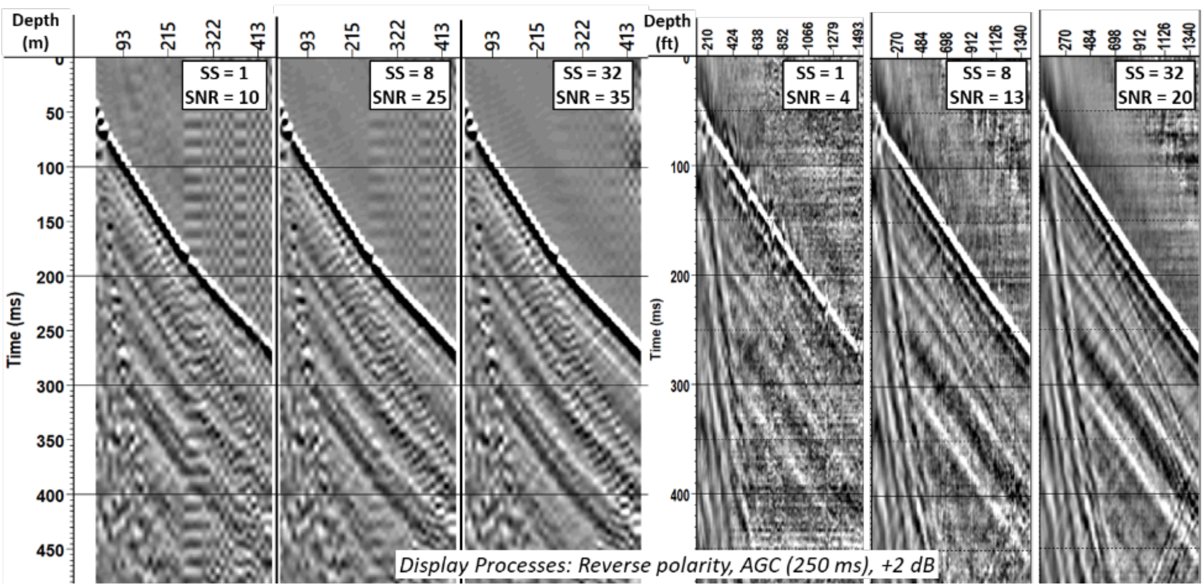


Figure 2 *Representative geophone data before and after processing. The raw geophone data (shown on the left). The geophone data after wavefield separation and deconvolution (middle) shows heavily aliased tube wave and it hardly delineates the reflector at about 220 m marked with the red arrow as it is obscured by the aliasing artifacts. Suppressing the tube wave brings slight improvement in the target reflector (right).*



a) The raw DAS gathers with different GLs *b) The DAS gathers after wavefield separation*

Figure 3 *The effect of different gauge lengths on DAS data quality: a) the raw shot gather acquired with 2 m and 4.5 m gauge lengths. It clearly show the significant increase in SNR by about 3.5 times; b) the wavefield separation on the DAS data is performed more easily as the data is not aliased (sampling of 0.6 m). The tube wave is well sampled and clearly observed after the separation and the P-wave upgoing reflections including the marked targeted reflectors are better reconstructed.*



a) Geophone data *b) DAS data*

Figure 4 *The effect of increasing the number of vibroseis sweeps on data quality. The SNR is significantly enhanced for the geophone data by increasing the number of shots from 1 to 32 (left). Firing the vibroseis for 32 times can increase the DAS signal-to-noise ratio significantly to be comparable to that of the geophone at 25 vibs (right).*