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Vertical Seismic Profiling with Distributed Acoustic Sensing

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Summary

We explain the methods behind distributed acoustic sensing (DAS) using fibre optic cables. We consider the application of DAS in the acquistion of vertical seismic profile (VSP) data. After conversion from optical backscatter to a strain measurement in terms of time and space, we apply common processing techniques to the VSP data.

Introduction

Over the last several years, there has been an increased interest in acquiring geophysical data using fibre-optic cables. Several methods are available for data acquisition using fibre-optic cables; however, in this paper, we discuss the use of distributed acoustic sensing. Furthermore, we apply this process to acquiring vertical seismic profiles in boreholes.

DAS and Fibre Optics

In distributed acoustic sensing (DAS), a laser pulse is sent along a fibre-optic cable and the intensity of the backscattered light is measured as a function of time. This intensity of the backscattered light is related to the elastic strain that the fibre experiences through interference patterns in the Rayleigh portion of the backscatter, and so can be interpreted as an acoustic measurement under certain assumptions.

Interferometry is a measurement technique based upon the superposition of waves that uses the combination of the waves to infer something about their state. To create optical interference within the fibre, a pulse of light is launched into the fibre, is reflected back, and interferes with itself. Figure 1 shows a simple case of the geometry required for interference to occur.

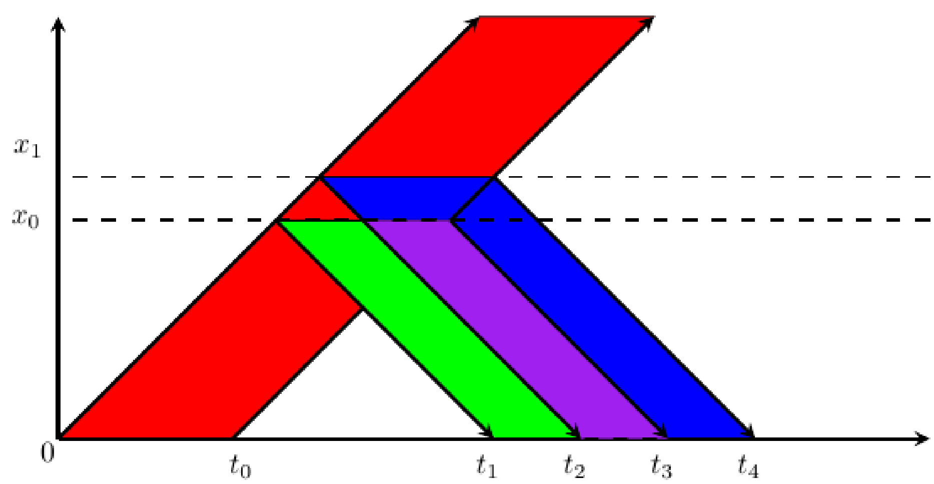

Figure 1: Interference from multiple scattering points.

Between times 0 and t_0, light is introduced and propagates down the fibre, represented as the red parallelogram. When the forward propagating light reaches the first scatter point x_0, light is reflected back, represented by the green parallelogram. When the forward propagating light reaches the second scatter point x_1, it again reflects back, represented here by the blue parallelogram. When the backscattered light from x_0 overlaps with the backscattered light from x_1, interference occurs. The purple parallelogram represents to overlap of the backscattered light from x_0 and x_1. Two-way travel time in the fibre is then used to relate to space and produce a measurement to estimate strain on the fibre with typical sample spacing of approximately two-thirds of a meter.

Examples

We used DAS to acquire a vertical seismic profile of a borehole located at a site in the southern United States. For acquisition, the fibre-optic cable was cemented outside of the casing between the borehole and the formation. In Figure 2, twenty sweeps from the zero-offset are correlated with the 10-100Hz pilot sweep and stacked.

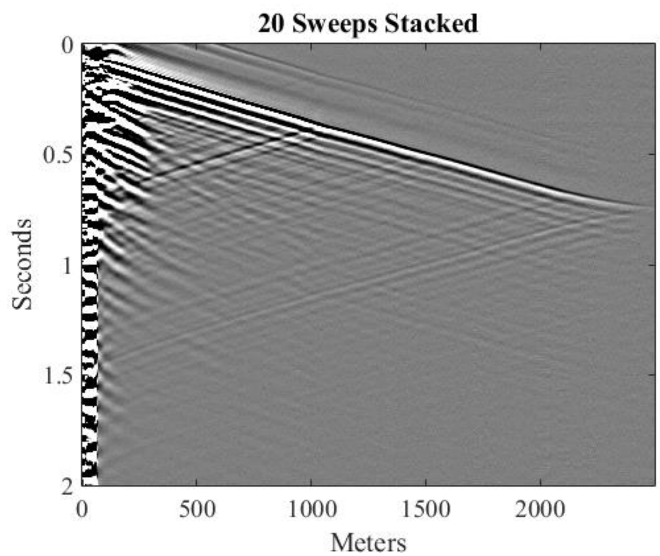

Figure 2: The stacked zero-offset VSP data set.

The stacked data is then *f-k* filtered to separate the wavefield into upgoing and downgoing velocities shown in Figure 3.

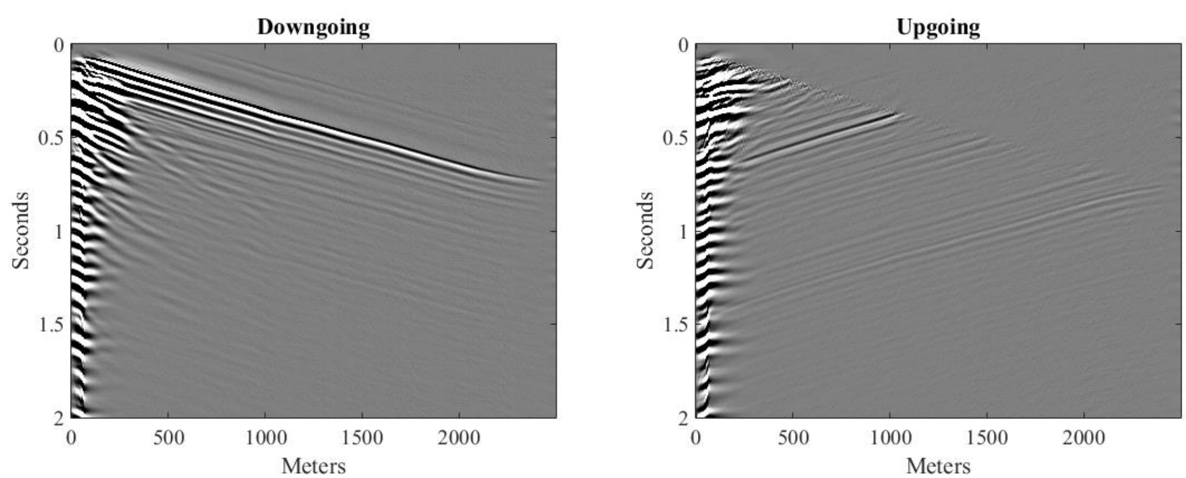

Figure 3: The downgoing (left) and upgoing (right) wavefields for the zero-offset VSP seen in Figure 2.

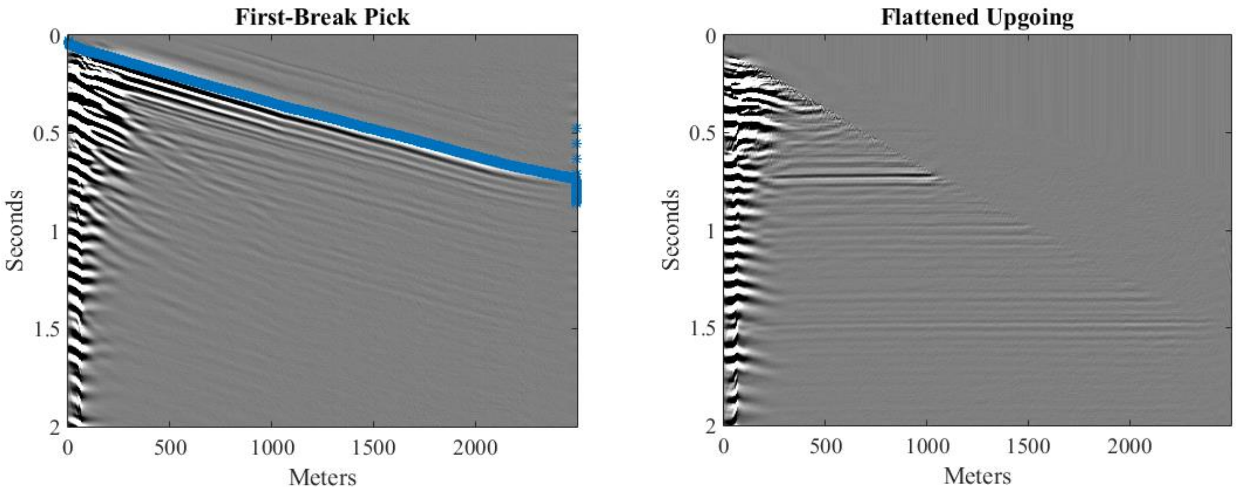

Figure 4: The first-break is highlighted in blue.

We then employ the CREWES public toolbox to find the first break from the downgoing wavefield and flatten the upgoing wavefield, as is plotted in Figure 4. Next, we deconvolve the downgoing wavefield out of upgoing wavefield and chose an outside corrider that avoids multiples, which can be seen outlined in Figure 6 (left). Figure 6 (right) shows the outside corridor.

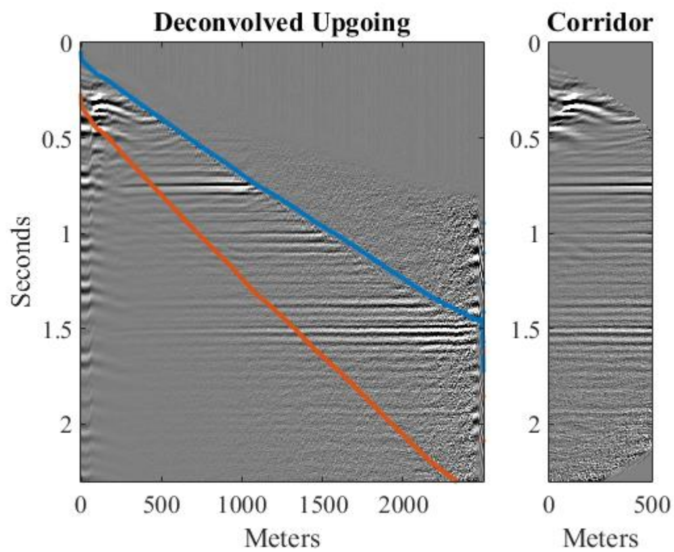

Figure 6: The deconvolved upgoing wavefield (left) and the outside corridor (right). The top (blue) line denotes the first break times and the red line depicts the end-times of the corridor. This outlines the outside corridor on the deconvolved upgoing wavefield.

Finally, we estimate the Q factor from the downgoing wavefield by considering the spectral ratio,

$$S_k(f) = \frac{A_k(f)}{A_{k-1}(f)} = G\exp\left(-\frac{\pi f \Delta t_k}{Q_k}\right)$$

where $A_k(f)$ is the power spectrum of the data at z_k, Δt_k is the travel time between the first-breaks at z_k, and z_{k-1}, and G can be thought of as containing all the frequency-independent energy loss (AVO, AVA, etc) (Cheng, 2013).

Figure 7 compares the results of the frequency independent energy loss G, the attenuation Q factor, and the spectral ratio. The interval chosen between depths is 100*m*. Blank spots in the Q estimate are where the value estimated was considered unreliable.

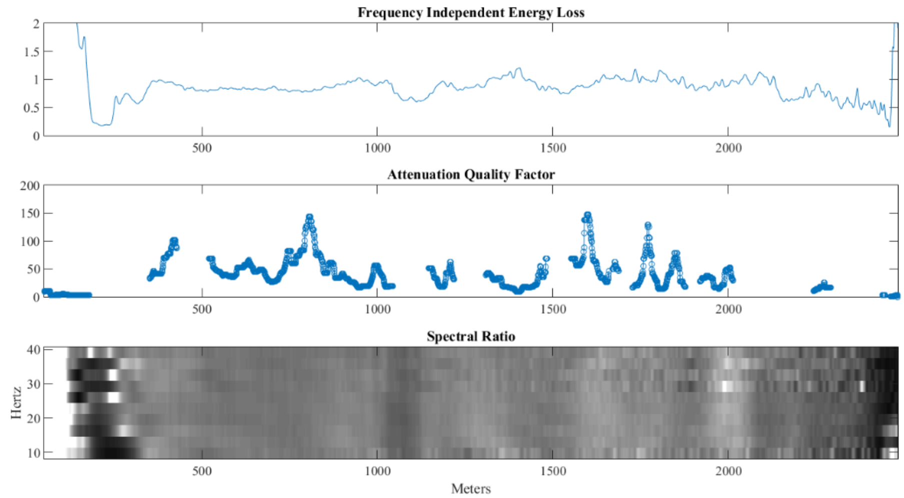

Figure 7: (Top) The frequency independent energy loss. (Middle) The attenuation quality factor for the zero-offset VSP. (Bottom) The spectral ratio.

Conclusions

We explained the process of acquiring DAS data in fibre-optics. We showed that it can be used to acquire vertical seismic profiling data. Once converting the DAS data to a form suitable for seismic interpretation, we processed the DAS-acquired zero-offset VSP data using common geophysical methods. This processing included *f-k* filtering to produce the upgoing and downgoing wavefields, finding the first time-break, flattening and deconvolving the upgoing wavefield, and extracting the outside corridor. We concluded by estimating the quality factor from the downgoing wavefield.

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