A COMPARISON OF A CONVENTIONAL BOREHOLE TOOL AND DISTRIBUTED ACOUSTIC SENSING AT A DEDICATED FIELD LABORATORY

Julia Correa*
Curtin University
Perth, Australia
julia.correa@postgrad.curtin.edu.au

Tim Dean
Curtin University
Perth, Australia
tim.dean@curtin.edu.au

Layne Van Zaanen
Curtin University
Perth, Australia
layne.vanzaanen@graduate.curtin.edu.au

Konstantin Tertyshnikov
Curtin University
Perth, Australia
konstantin.tertyshnikov@curtin.edu.au

Roman Pevzner
Curtin University
Perth, Australia
r.pevzner@curtin.edu.au

Andrej Bona
Curtin University
Perth, Australia
a.bona@curtin.edu.au

**presenting author asterisked*

SUMMARY

Distributed Acoustic Sensing (DAS) uses standard telecommunication fibre optic cables to detect acoustic and seismic signals. The technique utilises optical time-domain reflectometry; a "light-box" measures the light backscattered from a series of laser pulses emitted into the fibre. As seismic waves impinge on the cable, the fibre is strained, causing variations in the time taken for the backscattered light to travel back up the fibre. The acoustic signal can then be reconstructed by analysing phase differences in the backscattered light. DAS is especially suited for VSP applications, as it offers significant efficiency advantages when compared to conventional borehole acoustic sensors. Conventional VSP surveys usually take an extended period to acquire as the tools need to be placed in multiple positions in the well to record data. With DAS, the complete fibre is a sensor, and thus all levels are acquired simultaneously, reducing the cost considerably.

In this work, we compare the results of acquiring a VSP survey using a conventional 3-component geophone tool, a cemented fibre-optic cable, and a suspended fibre-optic cable deployed loosely in the well. The VSP data was acquired at both near and far offset points. Results show that the cemented DAS approached the quality of a conventional geophone VSP survey. The suspended DAS data had smaller SNR, while still clearly acquiring up-going and down-going PP-wave reflections.

Key words: Distributed Acoustic Sensing; Vertical Seismic Profiling; Fibre-optics sensing.

INTRODUCTION

Distributed Acoustic Sensing (DAS) is an emerging technology for acquiering seismic data. DAS sesnses the seismic waves along the entire length of a fibre-optic cable. The method involves the use of an interrogator unit that sends a series of light pulses along the fibre length. By Raileigh scattering, changes in phase of the backscattered light are interpreted as impinging waves.

Some of the limitations associated with DAS technology are the lack of sensitivity and its change with direction of the impinging waves. Performance of DAS is directly dependant on the deployment of the fibre cables. Cables cemented behind the well casing usually yeild better coupling, thus, higher signal-to-noise ratio. However, cementing the cable is an unviable option in many wells. In such cases, DAS can be acquired using a fibre cable suspended inside the well, potentially compromising the quality of the data.

Recent publications show DAS preformance for surface seismic and 3D VSP surveys (Daley et al. 2014; Mateeva et al. 2015). Due to the direcional sensitivity of DAS, its applications are commonly associated with Vertical Seismic Profile (VSP) acquisitions. In order to better understand the performance of DAS in field applications, it is important to compare DAS datasets with convetional and well known tools. For this study, we acquired a VSP survey using a convertional 3-component geophone tool as well as DAS, using both near and far offset shot points. DAS was acquired with both cemented cable and loose cable suspended in the well. We aim to compare datasets, outlining their main differences and relativeadvantages.

FIELD DATA ACQUISITION

A VSP survey was conducted in the National Geosequestration Laboratory (NGL) well facility. The NGL well is a dedicated testing facility located inside Curtin University campus, in Perth. The NGL well is a vertical borehole, approximately 900 m deep, cased with fibre glass. Behind the well casing, a single-mode straight fibre-optic cable is cemented along the whole length of the well.
The VSP survey was acquired with a conventional 3-component geophone tool, and with a DAS interrogator unit. The DAS VSP was acquired with two separate fibre cables: the cemented cable, and a loose cable suspended inside the well. To deploy the suspended

cable, a weight was attached to its end and the cable was lowered in the well until it reached its neutral buoyancy. The fibre in the suspended cable is single-mode, with 11 degrees wounding around the cable axis.

Two offset shots positions were acquired with the geophones, cemented DAS, and suspended DAS. The near offset shot point is located at a distance of approximately 165 m from the well head, and the far offset shot point at approximately 600 m distance. The cemented DAS VSP was acquired for the entire 900 m well depth. DAS with the suspended cable was acquired until depth 660 m. Both DAS acquisitions were measured using 10 m gauge length and 0.25 m sampling interval. The geophone VSP was acquired every 10 m, until the depth of 640 m for the near offset, and 610 m for the far offset positions.

A 26,000 lb vibroseis source was used as the seismic source, with sweeps from 6 Hz to 150 Hz. To increase the signal to noise ratio in the DAS data, cemented and suspended datasets were stacked with 19 repeated sweeps.

WAVEFORM COMPARISON AND SIGNAL TO NOISE RATIO

At near offset, similar quality datasets were recorded with both geophones and cemented DAS (Figure 1a, b, and c). Down-going and up-going PP reflections can be well identified in both recorded. Suspended DAS data show a significant level of tube-wave noise. Due to the weak coupling, the recorded signal appears weaker on suspended DAS. However, p-wave reflections can still be clearly observed in the data.

Signal to noise ratios were estimated by dividing the RMS amplitude of a 20 ms signal window on the direct arrivals with a 100 ms noise window from the beginning of the recorded. A large noise window was chosen in order to minimize the effects of correction side lobes and tube waves. SNR of cemented DAS and geophones are comparable at near offsets, with both records presenting approximately 35 dB of SNR (Figure 1d). Due to the directionality, the recorded direct arrival is weak at shallow depths as the waves arrive closer to 90 degrees angle relative to the cable. Suspended DAS data has slightly inferior SNR. At approximately 500 m depth, SNR decreases considerably as a result of destructive interference of tube waves.

When the VSP is recorded at the farther offset, quality of datasets decays significantly as noise increases and signal becomes weaker (Figure 1e, f, and g). Due to the sparse spatial sampling, reflections on geophones appear aliased. The geophone tool presents a noisy channel at the top level, possibly caused by wind noise on the cable. Yet, geophones have superior SNR than the DAS datasets. Cemented DAS has high level of random noise. Random noise is commonly seen on DAS data as a result of lack of backscatter in the fibre. Cemented DAS has lower signal to noise ratio, with sections of high presence of random noise, between depths from 150 to 250, and 400 to 500 m. Suspended DAS also shows decay in SNR, however it is still able to record p-wave reflections.

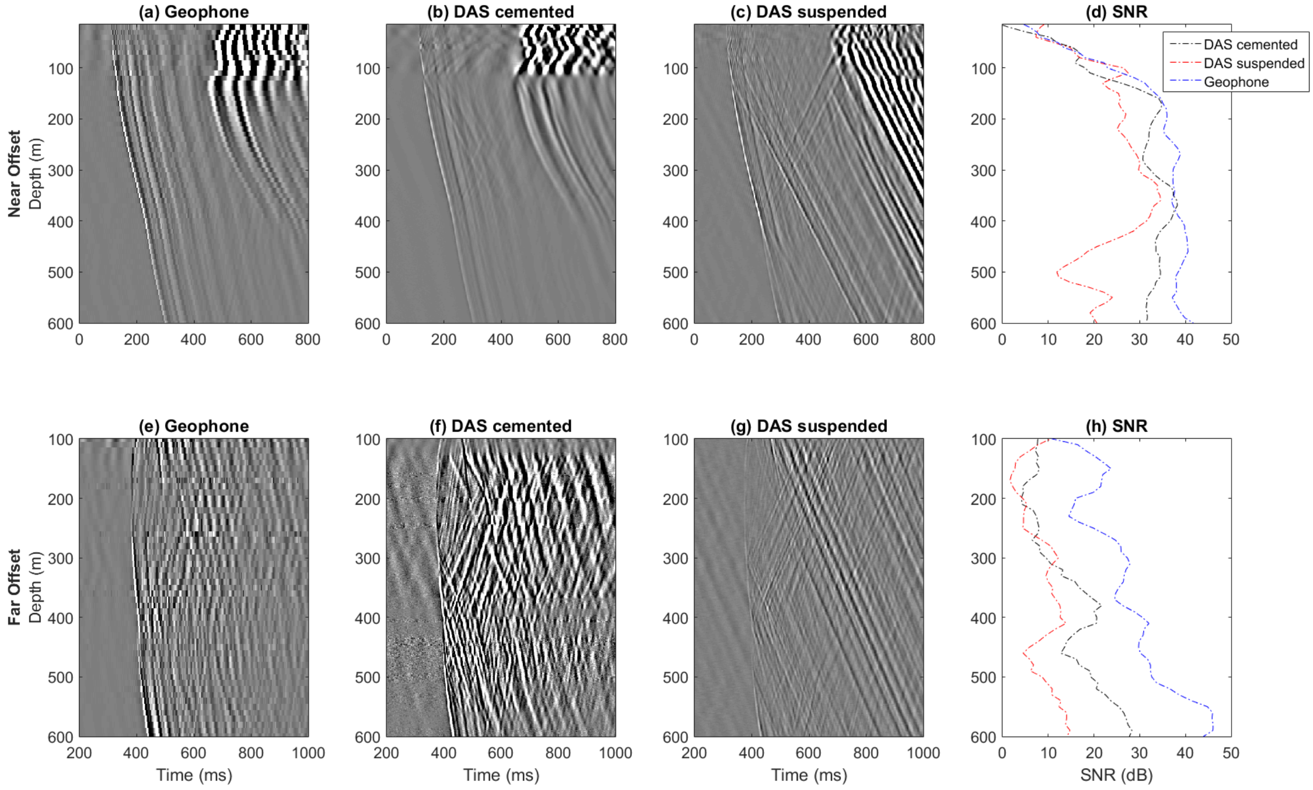

Figure 1: Near offset VSP (165 m) with geophones (a), cemented DAS (b), suspended DAS (c), and respective SNR (d). Far offset VSP (600 m) with geophones (e), cemented DAS (f), suspended DAS (g), and respective SNR (h).

PERFORMANCE IN FREQUENCY DOMAIN

The recorded signal on DAS varies as a function of the gauge length and pulse length of the light traveling along the fibre. The gauge length acts as an averaging filter, as it smooths and attenuates high frequencies on DAS (Dean et al. 2016).

Figure 2 shows the power spectrum of geophones, DAS cemented, and DAS suspended. At the near offset, geophone data has a broader spectrum when compared with both DAS cemented and DAS suspended, showing a strong high frequency content. Cemented DAS and suspended present loss in high frequencies, possibly as a result of "averaging" caused by the gauge length. Suspended DAS, however, has a greater loss of high frequencies. At the far offset, geophone and cemented DAS have a similar frequency response.

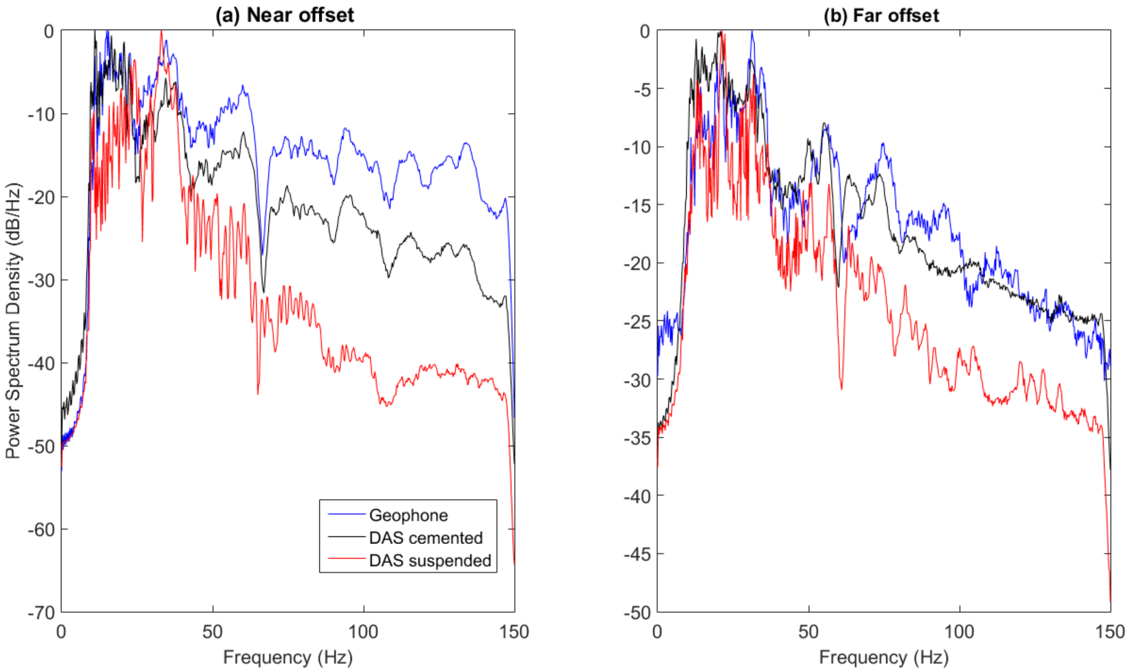

Figure 2: Frequency spectrum of geophone, DAS cemented, and DAS suspended, at near offset (a) and far offset (b).

CONCLUSIONS

A VSP survey was conducted at the NGL test well facility using fibre-optic DAS and a conventional 3-component geophone tool. DAS VSP was acquired using both a fibre cable cemented behind the well casing and a suspended cable deployed loosely in the well. Two offset shot positions were used, at 165 m distance from the well head, and at 600 m.

All acquisition methods successfully recorded the up-going and down-going PP-wave reflections. At the near offset, both DAS datasets present a similar performance to the geophone, with suspended DAS presenting a slight loss in signal-to-noise ratio. At far offset, DAS datasets show increased noise levels, yet, both cemented and suspended DAS are successful in acquiring P reflections. The geophone dataset has a slightly higher SNR than cemented DAS, however, due to the sparse spatial sampling, reflections appear aliased. As the gauge length acts similar to an averaging filter, DAS datasets have lower high frequency content than geophone data.

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