Laboratory study of temperature variation effects on Distributed Acoustic Sensing measurements.

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SUMMARY

Fibre-Optic sensing is being actively used nowadays in various exploration and monitoring applications. Distributed Temperature Sensing (DTS) is used for measurements and monitoring of the temperature. Distributed Acoustic Sensing (DAS) is used to register seismic vibrations along a fibre optic cable. The low-frequency DAS signal can be affected by temperature variations. Studying the effects of temperature change on DAS measurements is crucial for the time-lapse seismic and passive monitoring with DAS because it helps to eliminate or even avoid temperature-related noise.

To estimate temperature effects on DAS measurements we conducted a series of experiments in the Curtin/NGL research facility and Curtin University Rock-Physics Laboratory. Two different fibres were tested in the laboratory and one cable (installed in the Curtin/NGL well) was examined at the site. Obtained results show that DAS is sensitive to temperature changes and its response is proportional to a time derivative of temperature. Our study demonstrates that by using DAS and DTS (temperature logs) together, it is possible to estimate strain – temperature change dependency (thermal coefficients – microstrain/°C) for a particular fibre-optical cable. Estimated coefficients indicate that cable type/design can affect low-frequency DAS response to temperature changes.

Key words: DAS, DTS, Low-frequency measurements, passive seismic monitoring, calibration, fibre-optics.

INTRODUCTION

Distributed fibre-optic sensing is being actively used in various exploration and monitoring applications. Distributed temperature sensing (DTS) allows monitoring of temperature variation while distributed acoustic sensing (DAS) is primarily being used to register seismic signals and mechanical vibrations.

DAS measurements are sensitive to low-frequency seismic signals. Several studies show that it can record signals with a frequency below 1 mHz (Becker et al., 2017b; Lindsey et al., 2019). Other studies show that DAS records signals caused by temperature changes (Becker et al., 2017a; Miller and Coleman, 2018; Karrenbach et al., 2019). As DAS naturally measures strain rate, its response to the temperature change is proportional to the temperature-time derivative.

The temperature change can be considered as a low-frequency change (frequencies are much smaller than typical seismic signal frequencies from an active source). Thus, it is highly likely to get crosstalk between a low-frequency seismic signal and a temperature response on DAS.

Understanding how exactly DAS measurements are affected by the temperature conditions is paramount to avoid or/and eliminate noise related to the temperature variations. This can be particularly critical for the DAS time-lapse seismic and DAS passive monitoring when specifically utilising low-frequency signals.

In this study, we conducted borehole and laboratory experiments to simulate real temperature change effects on DAS measurements. Simultaneous DAS and DTS (temperature) measurements allowed us to estimate thermal coefficients (strain-temperature dependencies) for three different DAS cables.

EXPERIMENTS

Tests were conducted using three different fibre-optic cables. Two different fibres were tested in the Curtin University Rock-Physics laboratory. The third cable, which is installed behind the casing in the Curtin/NGL well, was examined at the bore site.

Borehole experiment

In this experiment, we utilised the fibreglass cased 900 m deep Curtin/NGL well located on the Bentley campus of Curtin University. The well is equipped with a non-metallic armoured loose tube cable that has single and multimode fibres. Each fibre-core housed in a gel-filled plastic buffer tube.

During this experiment, we recorded data continuously over several days using DAS and DTS interrogators located at the Curtin GeoLab research facility. A scheme of the Curtin/NGL well experiment is shown in Figure 1.

To change the temperature inside the borehole environment, we put 50 kg of ice into the well. Both DTS and DAS responses showed the anomaly at 25-30 m depth, which corresponds to the water level in the well at the time of the experiment.

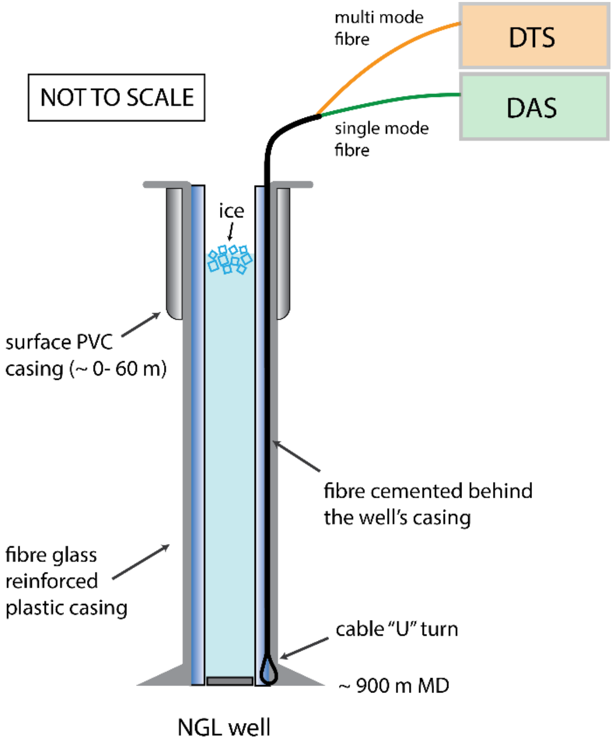

Figure 1. Scheme of NGL well experiment setup.

Figure 2 shows DTS and DAS data recorded at the ice level (26 m depth) during the experiment in the Curtin/NGL well. The upper plot shows the filtered DAS strain rate response as a black line and the DTS time derivative as a blue graph. The black curve on the bottom plot corresponds to the strain calculated from the DAS strain rate and the blue curve corresponds to the DTS response (absolute temperature in degree °C). DTS data show that temperature at 26 m depth dropped from 19 to almost 10 °C. The response on DAS matches with the temperature-time derivative as DAS measures the strain rate. Overall, Figure 2 demonstrates a good correlation between strain and temperature (or between strain rate and temperature time derivative), which indicates that there should be a linear dependency between strain and temperature variations.

It is possible to estimate thermal effect (coefficients) on DAS for a particular fibre-optic cable using strain and temperature data together. The average coefficient estimated during the Curtin/NGL experiment is $3*10^{-6}$ m/(m * °C).

Curtin rock-physics laboratory experiment

To carry out a controlled laboratory experiment on the estimation of the temperature effect on DAS measurements, we designed and prepared a heating/cooling setup in the Curtin Rock-Physics laboratory. The photo of the setup is shown in Figure 3.

In this experiment, we utilised the same DAS interrogator (as for the borehole experiment), a water bath connected to a heating/cooling device, two temperature loggers and two different fibres - bare single-mode and tight-buffered single-mode fibre. Bare and tight-buffered fibres were tested separately. Both experiments were conducted with several heating/cooling cycles.

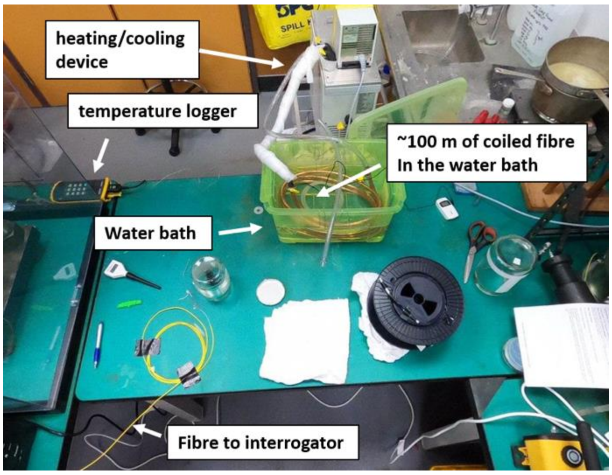

Figure 3. Laboratory experiment setup.

Figure 4 and Figure 5 shows results of the laboratory experiment on bare and tight-buffered fibres respectively. Black curves correspond to the DAS strain rate signal (upper plots) and strain (bottom plots). Orange curves show water's temperature recorded with the temperature logger (bottom plots) and the temperature-time derivative (upper plots).

Results of the bare fibre test show that the time derivative of temperature is very similar to the DAS strain rate and that the DAS strain is similar to the temperature log (similarly to the Curtin/NGL well experiment). Thus, there should be a good linear relationship between strain and temperature variations for a bare fibre.

For a tight-buffered fibre, there is a quite noticeable difference between the strain and temperature (or between the strain rate and temperature derivative). Small black arrows in Figure 5 point to the most noticeable differences. This indicates a non-linearity in the strain-temperature relation for this type of fibre. This non-linearity could be caused by fast heating/cooling processes, which may lead to a complicated mechanical interaction between a tight-buffered plastic jacket and the fibre itself.

The estimated thermal coefficient for the bare fibre is equal to 8.4-9.3 $*10^{-6}$ m/(m * °C). Thermal coefficient estimated for the tight-buffered fibre is not so consistent throughout the experiment and changes between 9 and 14.5 $*10^{-6}$ m/(m * °C). Plastic has a much higher thermal expansion coefficient than silica (four orders higher). Thus, higher obtained values for a tight-buffered fibre indicate that a plastic jacket glued to fibre can cause an additional strain of the fibre during a fast temperature's change.

CONCLUSIONS

Our experimental study showed how temperature variations affect phase-based DAS measurements. The response on DAS is proportional to the time derivative of temperature. Joint analysis of DAS and temperature recordings (DTS) allowed us to make a quantitative estimation of the thermal effect for three different fibre-optic cables. Estimated coefficients are of the same order. However, at this stage it is hard to explain a lower value for the borehole experiment. Nevertheless, obtained coefficients indicate that different cable designs can differently affect the DAS response to temperature variations. Fast heating and cooling processes can cause a non-linearity between the DAS low-frequency response and temperature change. This non-linearity can be explained by the interaction between the cable jacket and fibre core.

Overall, the rapid temperature change can have a significant effect on DAS measurements and should be taken into account in time-lapse DAS seismic monitoring applications and especially in passive monitoring utilising low frequencies.

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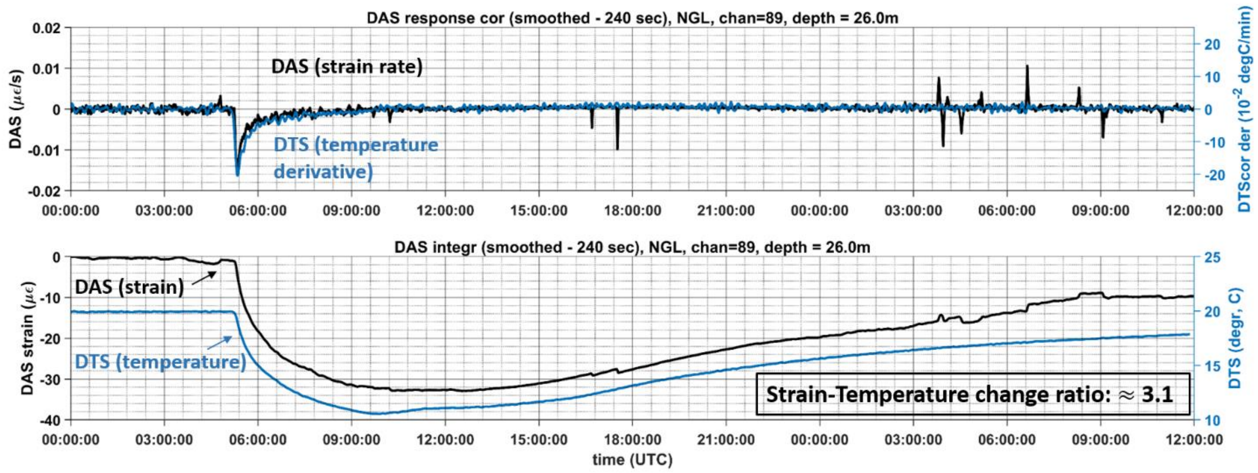

Figure 2. DAS and DTS response at the Curtin/NGL well site. Upper plot: DAS strain rate filtered response (black) and DTS time derivative (blue). Bottom plot: Strain calculated from DAS strain rate (black), DTS response (blue).

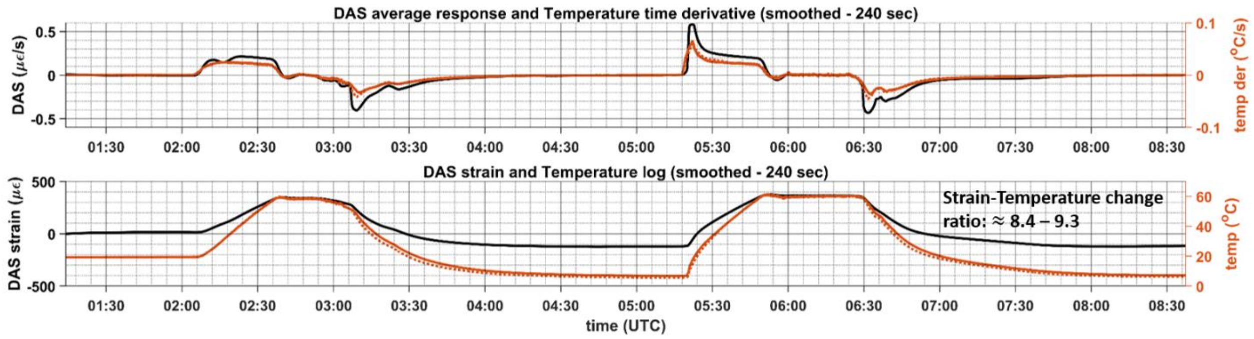

Figure 4. Laboratory response of a bare fibre to temperature variations. Upper plot: DAS strain rate response (black) and temperature log time derivative (orange). Bottom plot: Strain calculated from DAS strain rate (black) and temperature log (orange).

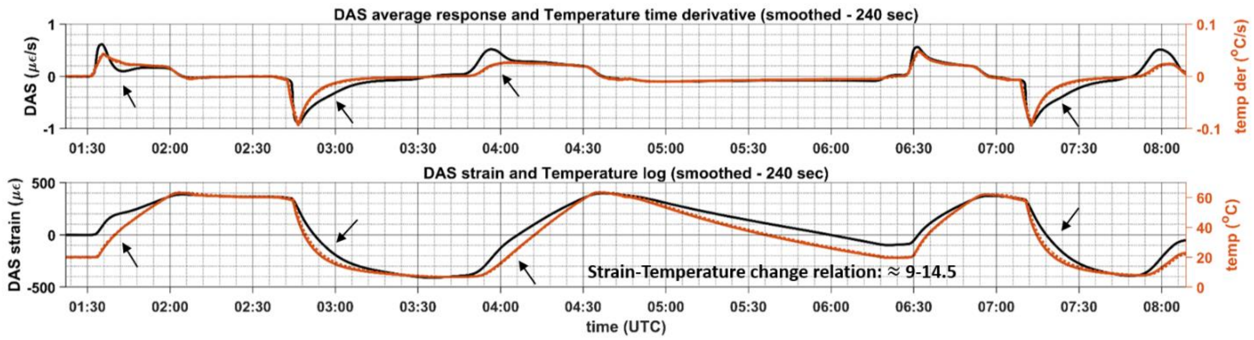

Figure 5. Laboratory response of a bare fibre to temperature variations. Upper plot: DAS strain rate response (black) and temperature log time derivative (orange). Bottom plot: Strain calculated from DAS strain rate (black) and temperature log (orange).