Monitoring mining induced seismicity using optical fibre sensors during mine exploitation

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ABSTRACT

Fibre-optic based sensing technologies are becoming popular in the field of geophysics since enable long range and high spatial resolution acoustic measurements. In this work, we present preliminary results obtained using quasi-distributed Fibre-Bragg grating sensing and Distributed Acoustic Sensing (DAS) to monitor seismic activities in an operational underground mine. 12 FBGs and 800 metres of fiber optic cable was installed in the tunnel lining an operational mine and recorded mine seismicity such as production blasts and a small seismic activity of magnitude 1.41 in September 2022.

Keywords: Fibre-optic sensing, Distributed acoustic sensing, geophone, mine, seismicity.

1. INTRODUCTION

Underground activities such as tunneling and mining need to go through preliminary and essential stages of investigation before the operation design and construction phases. In a mine, the development of the underground cavities takes place over a long time period, and the excavations continue as long as they are economically feasible, typically over decades or more. A careful characterization of the underground is necessary for planning, designing and implementing the excavation. Rock conditions might be investigated before the operative stage through drilling, geotechnical and geophysical surveys. Moreover, geophysical surveys and monitoring operations, such as passive seismic, can be applied during the active excavation to refine and update the geological conceptual model, and thus lower risks connected to the excavation works.

Compared to traditional seismic sensors, quasi- and fully distributed fibre-optic acoustic sensing technologies offer denser sensor arrays with higher spatial resolution (corresponding to 1 geophone every 1-10 metre over kilometre range) and the capability to provide several measurement points in a single and passive optical fiber that works simultaneously as sensing probe and data transmission cable. In addition, the interrogator (electronic readout system and the data processing unit) can be safely placed away from the designated sensing area, increasing the safety of the sensor operators and guaranteeing long-term monitoring since the sensing probe can be permanently installed in the area of interest. Such features enable less complex installation of acoustic monitoring in complex environments, such as in boreholes or along tunnels, and will most likely improve the ability of 3D characterization of the rock volume.

In particular, Distributed Acoustic Sensing (DAS) has gained popularity over the past years and has shown to be a good alternative to standard seismic receivers in seismic and seismological applications by being operated as a continuous geophone for mapping of acoustic events around the area of interest. Although data provided by the optical fibre sensing approach enabled multipoint measurement of surface waves through ambient-noise interferometry and gave results of similar quality with respect to standard seismometers [1,2], only few examples of DAS-enabled seismic monitoring in mining applications can be found in the literature [3,4].

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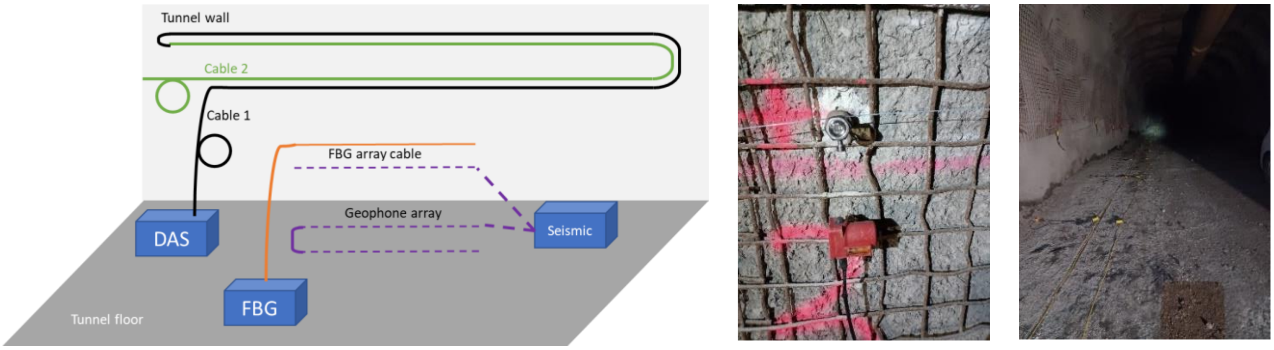
This proposed work aimed at evaluating the feasibility of using fibre-optic sensing techniques for measuring vibration data as a complement to traditional seismic acquisitions from mining induced seismic events and during underground blasting.

2. SENSOR LAYOUT IN THE TUNNEL WALL AND FLOOR



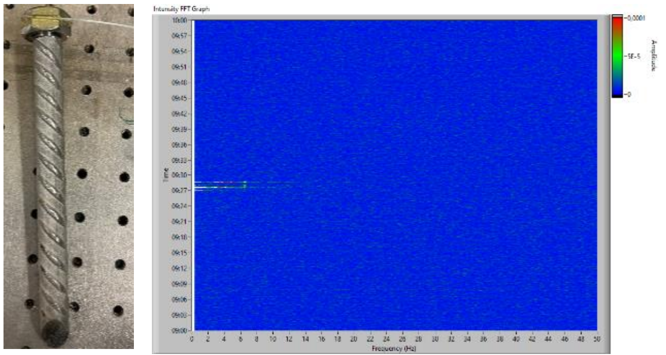
(a) (b) (c)

Figure 1. (a) Sketch of the sensor layout in the underground tunnel wall and floor. (b) Example of a collocated FBG spike and horizontal in-line geophone installed in the tunnel wall at a specific location. (c) Deployment of the geophones on the tunnel floor for further monitoring.

Fig. 1(a) shows the sensor layout deployed on the tunnel wall and floor for this test campaign:

1. Fibre Bragg Grating array cable for quasi-distributed acoustic sensing over 30 metres

A quasi-distributed fibre-optic sensor was also deployed in a tunnel in a mining site in Malmberget over 30 metres (12 FBGs separated by 2.5 metres) to evaluate its performance as fibre-optic acoustic sensors for measuring vibration data as a complement to traditional seismic acquisitions from mining induced seismic events and during underground blasting. They are labelled Sensor 1 to 12, sensor 1 being the closest to the FBG interrogator. The sensor network consisted of 12 metallic spikes, referred to as FBG spikes (Fig. 2(a)) in this work, with grooves to host a 1-mm thick GRFP Fibre Bragg Grating (FBG) array cable at the positions where the FBGs were inscribed along the fibre cable. This custom-made fibre-optic based horizontal inline geophone was designed for easy installation and insertion in pre-drilled holes inside the tunnel wall for the field test. The performance of the FBG spikes were benchmarked to a horizontal in-line geophone in a sandbox in laboratory conditions prior to deployment in the mine and exhibited comparable performance within the acoustic bandwidth 1-200 Hz, which validated the design chosen for the field test in the mine.



(a) (b)

Figure 2. (a) FBG spike used in the experiment. (b) Example of a 2D-map of the acoustic signal v/s time for Sensor 2 between 9-10 am on the 19th.

A commercial FBG interrogator was used to probe the FBG sensor network at 100 Hz for the field test and the corresponding FFT signals for the 12 FBG sensors were calculated and generated on an hourly basis in real-time for analysis from the raw data. An example of this 2D mapping between the frequency measured v/s time is shown in Fig 2(b).

2. DAS measurement with two types of fibre-optic cables in the tunnel

The feasibility of using DAS technology, which allows for continuous monitoring of large areas (-tens of kilometers in range, with a dense spatial sampling (5-10 m) along the fibre) was evaluated in this test campaign. Two fibre cables of 400 metres were evaluated: (i) an armoured fibre-optic cable (Cable 1) and (ii) a standard telecom fibre-optic cable (Cable 2). 300 metres (looped back after 92 metres) of each fibre cable were shotcreted to the tunnel support mesh to ensure good coupling with the tunnel wall, instead of simply suspending the cable on it and the two cables were connected to each other for probing using Chirped-Pulse Phase-Sensitive OTDR Technology [5] with a gauge length of 5 m and an acoustic bandwidth of DC – 250 Hz. The fibre cable configuration was the following: 100 metres of loose reference Cable 1, followed by around 200 metres of shocreted Cable 1, 100 metres of loose Cable 1 connectorised to 100 metres of loose cable 2, 200 m of Cable 2 shotcreted to the wall and 100 metres of loose Cable 2 for referencing.

3. A geophone network on the tunnel wall and tunnel floor for direct comparison

A series of horizontal in-line geophones of 4.5 Hz, collocated with FBG spikes (Fig. 1(b)), were also installed in holes in the tunnel wall for direct comparison. In addition, a set of vertical and horizontal in-line geophones, spaced by 1.25 m on the tunnel floor with variable distance from the wall (~0.2-1 m) was deployed for further measurement (Fig. 1(c)). Induced events such as hitting the ground with a sledgehammer (09:27) and hitting the tunnel walls (09:29) were used as a control to compare the acoustic response measured by the FBG spikes and the geophones (Fig. 2(b)).

3. INDUCED SEISMIC DETECTION USING FIBRE-OPTIC SENSING DURING OPERATION IN THE MINE

The test campaign ran for 1 month starting from the 16th of September, with continuous DAS data for most of that time. Quasi-distributed measurements were performed over the first 6 days. Since the main objective of this campaign was to investigate and test installation procedures and techniques for the fibre-optic and FBG array cables for future deployment, the cables were not specifically positioned in an optimal way to detect events from the active mining area. Nevertheless, production blasts were picked up by several FBG sensors at around 00:00 five out of the six days during which the quasi-distributed sensor was deployed.

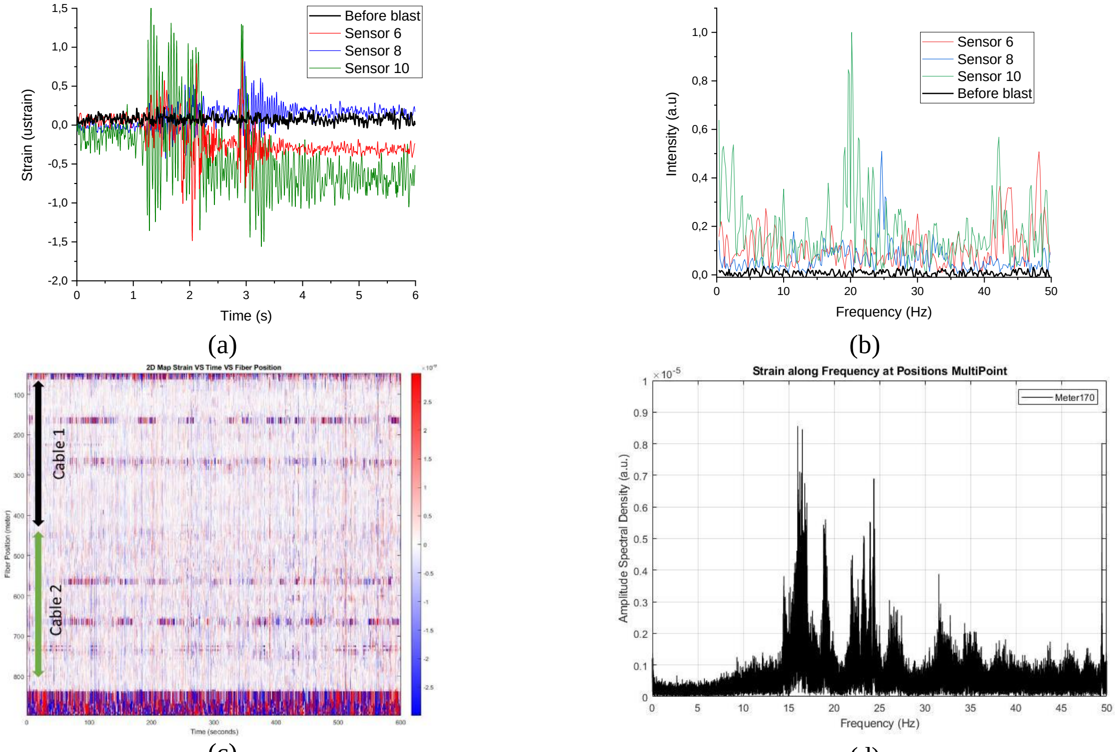


Figure 3. (a) Strain variation with time and (b) measured acoustic signal by 3 FBG spikes (Sensor 6, 8 and 10, evenly spaced by 5 metres each) in response to the production blast at 00:01 on the 17th. (c) 2D map of the strain along the 800 metres of fibre cable and (d) acoustic signal measured at position 170 m along the fibre cable obtained by DAS measurement on the 17th between 00:00 and 00:10.

The DAS and the quasi-distributed sensing data measured on the 17th between 00:00 and 01:00, so during the production blast, were analysed and compared. Fig 3 (a) and (b) show the quasi-distributed FBG recordings related to the production blast on the 17th of September. A huge acoustic signal could be detected at 00:01 on the 17th, with peak acoustic frequencies around 20 Hz being picked up by most FBG sensors. The sensors showed different strain level and acoustic responses, which can be attributed to different coupling efficiencies between the spikes and the tunnel wall.

Due to the large number of generated data over the duration of the test campaign, only a section of the generated data was manually extracted for processing that correspond to recording of the production blasts of the 17th in the mine. Preliminary DAS data from the 17th between 00:00 and 00:10 are displayed on Fig. 3(c). The DAS signal amplitudes at different time and fibre positions are represented as colours and the corresponding frequency signature at position 170m along the fibre cable is shown on Fig. 3(d) during blasting. The latter is in good agreement with those measured by the FBG spikes.

Similar strain mapping were obtained for the armoured fibre cable, Cable 1 (100 – 400 metres) and a standard telecom fibre cable, Cable 2 (400 - 800 metres) during and between the blasting activities, which validated the fact that cheap, standard telecom fibres can be used for these applications.

Frequencies corresponding to the production blast as measured by the FBG were measured at only four positions, with energy at frequencies around 20 Hz, along the fibre cable (~160m, 260m, 570m, 670m) but strain propagation was not detected, which might be explained by poor strain transfer to the fibre cable due to the shotcreting. Indeed, these four points correspond to the positions where the two fibre cables were looped, thus not shotcreted. The few results obtained so far from this test campaign are only preliminary and further tests and more data need to be processed for a fairer comparison between these two sensing techniques and to get more concrete results on the strain trasnfer benefits brought by using an armoured fibre cable and the shotcreting process, if any.

During the monitoring period, two small seismic activities of magnitude 1.4 and 1.89 were reported on the 20th of September at 13:02 and on the 12th of October at 5:27 am respectively. The first event was picked up by FBG Sensor 10 but the second one could not be measured by the DAS system, which was the only monitoring system running at that time.

4. CONCLUSION AND FUTURE WORK

In this communication, event detection such as production blasts and small seismic activities was demonstrated in a tunnel in a mine using fibre-optic based acoustic sensing technologies during mine exploitation. Future work will be oriented towards investigating the use of the quasi-distributed FBG sand the DAS system to measure seismic passive surface waves that provide useful information about the elastic properties of the rock and the relative local response to man-induced seismic events.

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