Determining the Mechanistic Behaviour of Support Systems used in Underground Excavations

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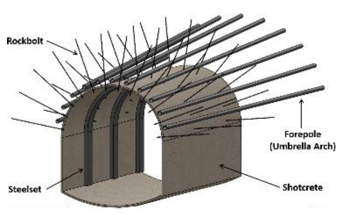
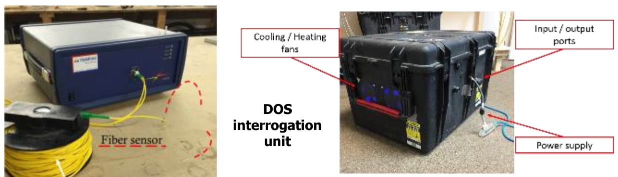
Objective: Investigate the loading mechanisms involved with various support element types in isolation and also as part of a complete support system. The development of a distributed optical strain sensing technique (DOS) is considered a crucial component to the research in order to capture support complexities at both the laboratory scale as well as *in situ*. Such an optical technique shows promise for future monitoring of underground infrastructure.

Development of a distributed optical strain sensing technique

Distributed optical strain sensing (DOS) provides a unique opportunity to capture a continuous strain profile along the length of support element using a standard, low-cost optical fiber. The high spatial resolution monitoring capabilities of the DOS system makes it an attractive solution for monitoring support system used in underground excavation



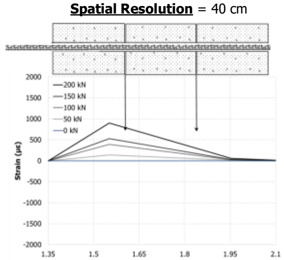


In-situ protection

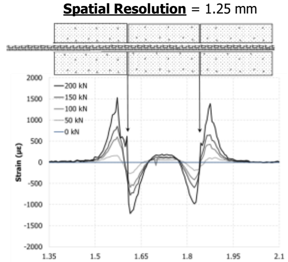
Discrete versus continuous monitoring

Discrete instrumentation technologies (e.g. foil-resistive strain gauges) will ultimately be prone to misinterpretation and possibly omission of support behaviour due to a lack of spatial resolution in measurements. The sub-centimeter spatial resolution monitoring provided by the optical technique has been proven to overcome such limitations and to be capable of capturing fine complexities of support behaviour (e.g. double shear loading of rebar - a comparison between a 40 cm and 1.25mm resolution monitoring is shown below).

Spatial Resolution = 40 cm



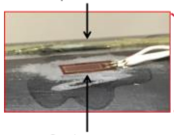
Spatial Resolution = 1.25 mm



Mechanistic behaviour of individual support elements

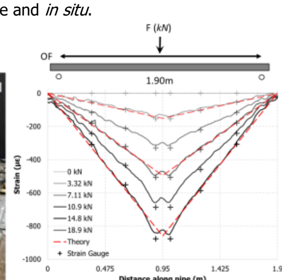
Strain profiling: The DOS transducer was coupled with numerous support element types via surface mounting, suspending above the profile of the element, and embedding and encapsulating within machined out grooves with various adhesives. This allowed for mechanistic behaviour and complexities of support to be captured at unprecedented level at both the laboratory scale and *in situ*.

Surface mounted optical fiber



Strain gauge (verification of DOS)

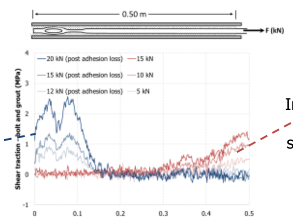
Symmetric bending of forepole support



(Right): Strain profiles along forepole in comparison to theory and strain gauges

At 15 kN of applied load adhesion was lost between the smooth section and grout, resulting in load shifting to the anchors

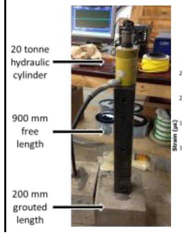
Post adhesion loss the anchors are observed to take on all axial load

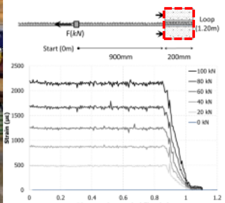


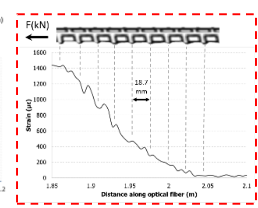
Axial loading of embedded D-bolt specimen

Initial loading localized along the smooth section of the element (i.e. adhesion)

Axial loading of Grouted Rebar → Strain profiles along the length of rebar → Detailed view of the grouted section of rebar – strain in comparison to rib locations







Capturing three-dimensional ground deformations and loading of support

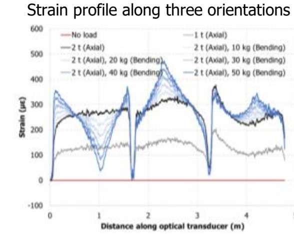
Lateral applied load

Donut face plate

Axial and Bending loading

Support elements will routinely be subjected to a combination of axial loads, bending, and shearing *in situ.* It is therefore critical that a monitoring solution is capable of capturing the three-dimensional loading of a given support element. Without such a solution it is highly probable that bending and shearing loads will be underestimated, especially without a prior knowledge of ground deformation orientation. Experiments have therefore been conducted with the DOS transducer orientated at three directions (i.e. 120 degrees from each other) in order to capture a complete three-dimensional strain distribution. This technique has allowed for multiple loading mechanisms to be separated and analyzed along support elements and can be realized as a potential ground deformation sensor and as a "forecasting" tool during the excavation process.

Strain profile along three orientations



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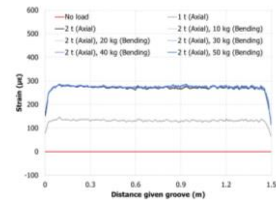

Axial strain component

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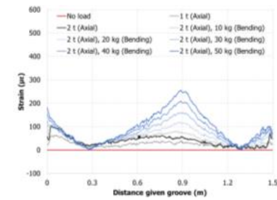

Bending strain component

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