Experimental design for shotcrete tunnel lining with distributed optical fibre monitoring

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ABSTRACT

As the demand for expanding the transport infrastructure increases, sustainable solutions for ensuring the service life and safety of new and existing structures are crucial. By introducing state-of-the art-monitoring solutions and advanced AI-algorithms, continuous verification and prediction of the structural integrity becomes possible. In this paper, the SensIT 2.0 project at Chalmers University of Technology is described and initial experimental design for applying Distributed Optical Fibers Sensing (DOFS) systems to a Fibre Reinforced Shotcrete (FRS) tunnel lining is presented.

Key words: Structural Health Monitoring, Fibre Reinforced Shotcrete, Optical Fibres, Modelling

1. INTRODUCTION

Tunnels are a common solution for expanding infrastructure in densely populated areas, as existing buildings and infrastructure does not need demolishing and noise pollution from traffic can be limited. In hard rock tunnels, a common support system consists of a fibre reinforced shotcrete (FRS) lining systematically anchored with rock bolts. In principle, the support system prevents loose rocks from displacing and causing a progressive failure [1]. In tunnels with high groundwater pressure, an additional lining is often built to prevent water leakage.

Inspection methods in tunnels used today include manual hammer probing for loss of bond between rock and FRS, and visual inspections for leakage, leaching, loose concrete and cracks. Results from inspections depends on the workmanship of the inspector and the reliability of the results can vary. Furthermore, if an additional lining is built, the main structural system is inaccessible and therefore cannot be inspected.

Current monitoring practices in tunnels include several techniques such as the use of total stations, LVDTs and other discrete measuring methods [2]. New modern technologies like LiDAR scanning and photogrammetry have raised as promising solutions in the recent years, although they are not suitable for continuous and automated monitoring. In this regards, Distributed Optical Fibre Sensing (DOFS) based on Rayleigh Backscattering, has the capacity to continuously measure strains for ranges of up to 100 m and have been shown to enable real-time crack detection of concrete elements [3]. The technology uses the natural backscattering of light in an optical fibre to determine changes of strain and temperature. However, its implementation in tunnels is still largely unexplored, being its potential in detecting damage huge.

2. PROJECT DESCRIPTION

The project is part of the SensIT research initiative at Chalmers University of Technology which aims to develop Structural Health Monitoring (SHM) systems using remote monitoring techniques, advanced numerical models and data driven algorithms. For this project, the goal is to identify and define performance indicators in shotcrete tunnel linings that can be followed and monitored by DOFS and to demonstrate how an AI-tool can be used as a means for the verification of performance indicators and predictions of how these are met during long service technical lives. Thus, the project will be divided into three main parts:

- Experimental campaign, aiming the identification and measurement of performance indicators
- FE-modelling/Data acquisition, to reproduce the phenomena and generate a synthetic database
- Development of sensor data-driven AI-algorithm, that allows for verifications and predictions of structural condition.

In a first step, a set of experiments will be devised and conducted, simulating local loading conditions in a tunnel lining. Secondly, an FE-model will be developed and calibrated with the experiments. The purpose of the FE-model is to allow the generation of a synthetic database which in turn will be used for training and developing the AI-algorithm. In the next section, the experimental design and key performance indicators are presented.

3. EXPERIMENTAL DESIGN

As hard rock tunnels are excavated, the surrounding rock mass converges as stress is naturally redistributed along the tunnel perimeter. Then, the main purpose of the FRS and rock bolt support system is to lock loose blocks in place, preventing fallouts of rock and enabling the rock mass to reach a new equilibrium.

The experiments will be designed to simulate common failures in tunnels, i.e., loose blocks pushing through the FRS lining. This will be achieved by either using a hydraulic jack pushing a circular section of concrete, which simulates a loose rock of a specific size pushing above the lining, or by using an inflatable bag, which simulates a broken-up mass of rock pushing the lining due to self-weight, see Fig. 1.

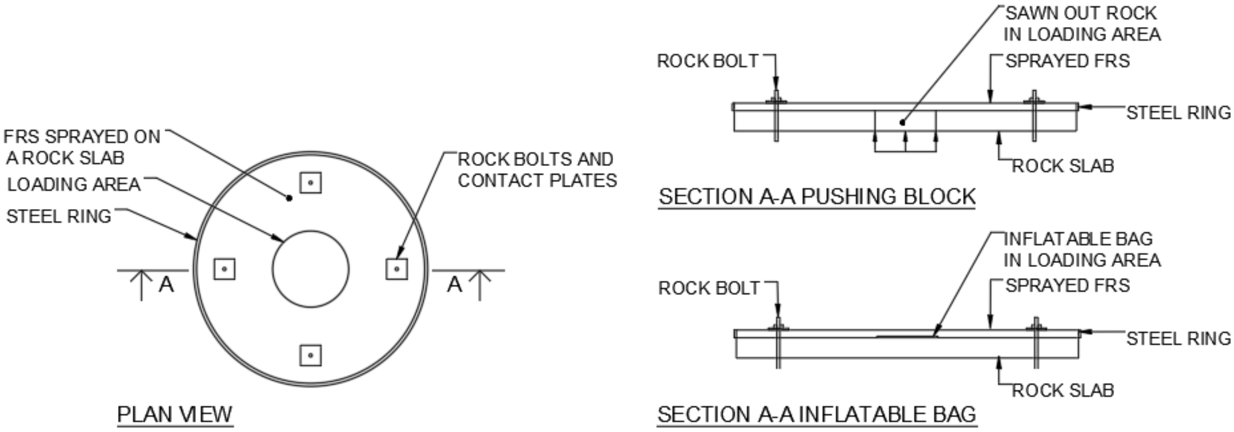

Figure 1 – Geometry of test specimens. Left: Plan view. Right: Alternative sections for load cases.

FE models of the experiments were carried out in order to estimate the different test parameters, such as loads and load conditions, different geometry specifications and material properties. A preliminary geometry for the proposed tests is given in Fig 1, and only the case with displacement-controlled pushing block is studied in this paper. The constitutive material model for the FRS and the bond between rock and FRS is given in [4]. In the model, 4 parameters where varied as shown in Table 1. The models aim to evaluate the maximum force that can be applied to the test specimen and the corresponding displacement needed to reach failure. These estimations will contribute to devise an adequate test set-up with the corresponding experimental equipment, e.g. hydraulic jacks and optimize the size of the specimens.

Table 1 – Variable parameters for each model

Model	Thickness of FRS t_{FRS} [mm]	Loading Diameter $Ø_L$ [mm]	Bolt spacing L_{bolt} [mm]	Total Diameter $Ø_T$ [mm]
Base case	80	200	800	2000
Model 1	60	=	=	=
Model 2	=	400	=	=
Model 3	=	=	600	=
Model 4	=	=	=	2400

4. RESULTS AND DISCUSSION

When comparing the models, a base case was chosen and one factor at a time was varied. Any interaction between the parameters has not been studied. However, key basic understanding of the expected behaviour is achieved for designing the experiments. The results from the FE-models are shown in Fig. 2.

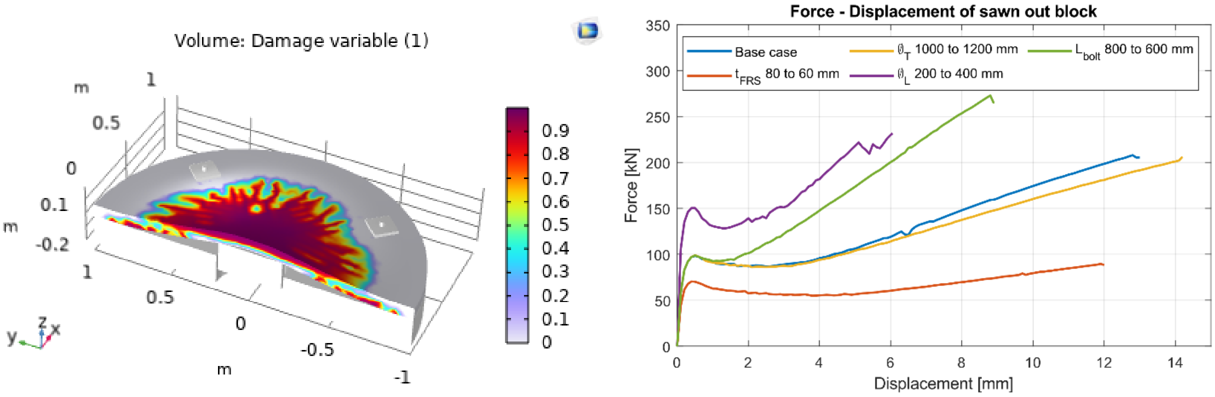

Figure 2 – Left: Model of the base case at 3 mm displacement of central block, magnified by 20. Right: Total applied force and displacement of sawn out block for each model

All models have an initial peak in force at around 0.5 mm of displacement, followed by a slight softening behaviour until the force steadily increases to tensile failure of the FRS. The peak load for the models with a smaller bolt spacing and larger total diameter is equal to the peak load for the base case. The initial peak differs for the models with a thinner FRS layer and a larger loading area. The final load differs for all models except for the base case and the model with increased total diameter. Largest final loads are reached in the models where the bolts are placed closer to the loading block.

5. CONCLUDING REMARKS

As the objective of the experimental study is to identify performance indicators to strains and later use the data for predictions on the structural capacity of the tunnel, the experimental design will mainly focus on the initial response. Consequently, for the experiments, thickness and loading area are more influential parameters. In addition, as the change of total radius has a limited effect on the response, further investigations can optimize the required size of the experiments.

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