My Engineering Challenge: Efficient and Safe SCL Openings

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Summary: Exploiting the residual flexural strength of the steel fibre reinforced (SFR) sprayed concrete is the key to designing thinner, efficient, easier to build and safe tunnel linings, without any further reinforcement requirements. The design approach presented herein delivers considerable health and safety, resource and environmental benefits. Using advanced design tools and appropriate constitutive models we designed a large number of openings which were succesfully built without introducing any steel mesh, and/or bar reinforcement or additional thickenings.

Introduction

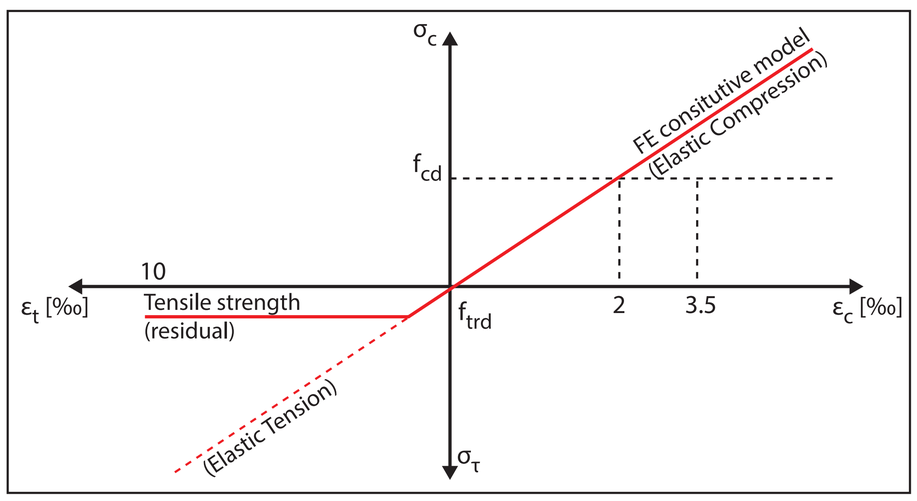
Most metro stations include a large number of junctions. The traditional design approaches for openings in sprayed concrete lining (SCL) may include analytical/empirical solutions or two-dimensional numerical analyses. The purpose of the design in each case is to calculate the redistribution of stresses around the opening in order to assess whether additional support is required. These design approaches however have limitations as they ignore the out-of-plane bending moments and assume a linear elastic model for the SCL. The result is increased required support measures around the tunnel opening, such as additional SCL thickening and reinforcement.

Philosophy

3D Finite Element Analyses (3D FEA) with non-linear plasticity constitutive models for the simulation of the SCL, provide the necessary means for a realistic calculation of the stress redistribution around openings.

Additionally, the use of steel fibres in sprayed concrete, enhances the flexural capacity and can be accounted for when designing openings.

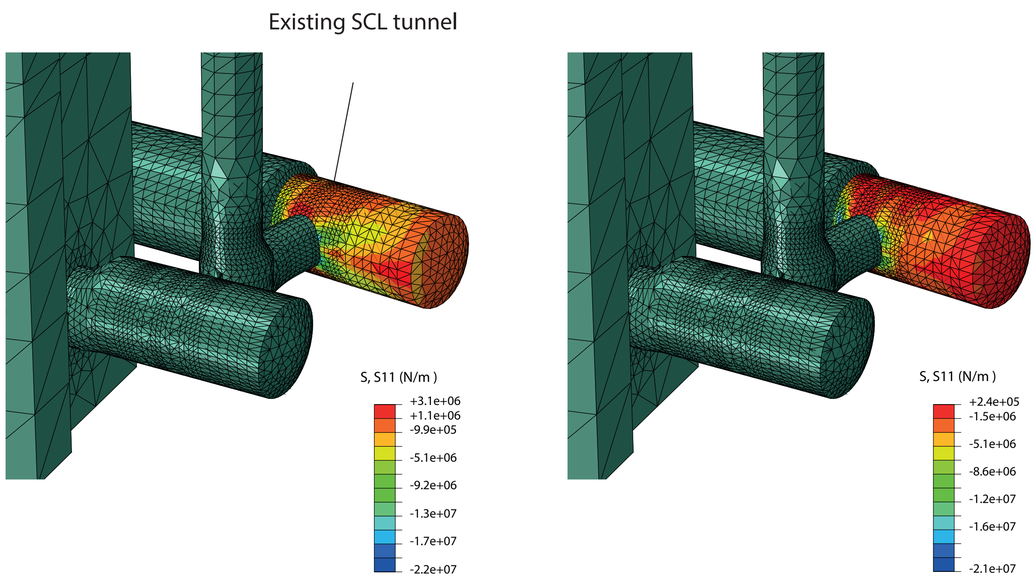
The stress-strain diagram below has been successfully implemented in 3D FEA. It allows an elastic behaviour on the compressive side and introduces a tension cut-off.



Stress-Strain diagram considered for the steel-fibre reinforced SCL in the 3D FEA

As an example, the design of the opening in an existing SCL tunnel is presented below:

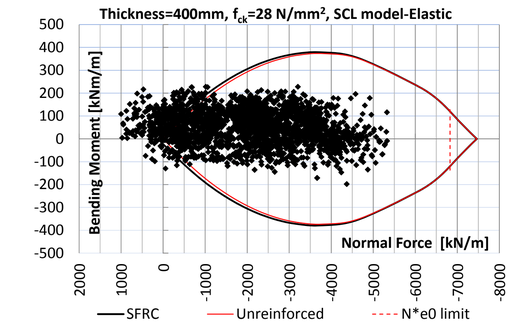
- The elastic analysis yields higher tensile hoop forces resulting in a conservative design approach.
- The comparison of the capacity limit curves, highlights the difference between a linear elastic and a plastic concrete analysis.
- The data points in the plastic analysis fall inside the limit curve whereas in the elastic analysis, the tensile strength is exceeded.
- Based on the elastic analysis, steel bar reinforcement is required to accommodate the "elastic" stress changes induced by the opening.



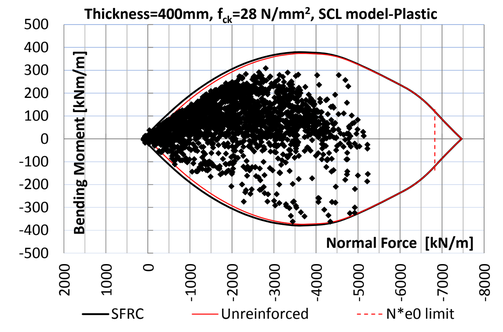
3D FEA - Elastic SCL model

3D FEA - Plastic SCL model

FEA results of an opening in an existing SCL tunnel



Capacity Limit Curve: Elastic Analysis



Capacity Limit Curve: Plastic Analysis

Benefits

The main benefits arising from the design of SCL openings without additional thickening and reinforcement can be in health and safety, time/cost/quality and environmental impact.

	Health & Safety	Construction Benefits (time/cost/quality)	Environmental Benefits
Eliminating manual handling	■		
Faster execution	■	■	
Improved spraying quality		■	
Maximum mechanisation	■		
No spraying through reinforcement	■		
No steel fixing	■	■	■
No works at height	■		
Smaller excavation volume		■	■
Smaller SCL volume		■	■

Benefits from the use of the proposed design philosophy

SCL to SCL connection: Start of Breakout

SCL to SCL connection: Completed Breakout

Conclusions

Constructing tunnel openings without additional thickening and steel bar/mesh reinforcement is possible in a large number of cases using SFR SCL. Predominately this can be achieved by:

- Exploiting the tensile (residual) strength of SFR SCL.
- Performing advanced 3D FEA using non-linear (plastic) concrete models.

In-tunnel monitoring during and after the construction has been used to validate the design, exhibiting an excellent correlation with the predicted tunnel deformations.

This alternative design strategy has been applied successfully by Dr. Sauer & Partners in numerous cases, resulting in programme and cost savings as well as H&S benefits.

SCL to TBM connection: Exposed segments

SCL to TBM connection: Completed Opening

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