This is Chapter 12 “Conclusion” from my PhD thesis

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The full thesis can be downloaded from the TU Graz repository: LINK

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Enjoy reading.

Best regards,
Alexander Kluckner

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Tunnelling at greater depths: Study on the ground and system behaviour when passing a stiff rock block in a weak zone

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Abstract

Title: **Tunnelling at greater depths: Study on the ground and system behaviour when passing a stiff rock block in a weak zone**

Keywords: deep tunnelling, conventional, brittle fault zone, block-in-matrix, stiff block, shear bands

A stiff block in brittle, weak fault zones can lead to unfavourable ground behaviour when being approached by a tunnel drive. It attracts stresses and may fail when it is close to the tunnel face endangering the tunnel stability. The thesis investigates the ground behaviour with a quasi-two-dimensional parametric study. The tunnel diameter is 10 m, the block height is 2 m, 5 m, or 10 m, and the distance between the block and the tunnel is 1 m, 5 m, or 10 m. One critical case is analysed in three dimensions. Another study simulates a real tunnel drive that crosses a block with a height of over 25 m. Strain data from a lining segment measured at the construction site with a distributed fibre optic sensing system is used to set up the Burgers-Mohr model simulating the shotcrete material behaviour. All simulations consider an interface between the block and the matrix material. From the block, shear bands form towards the tunnel. In the parametric study, even if the block-matrix stiffness contrast is high or the block is close to the tunnel, differences in the tunnel displacements between cases with block and related cases without block are little. Of the cases analysed, those with a hydrostatic primary stress state are least favourable. If the primary stresses are anisotropic, the effect of the block on the ground behaviour strongly depends on the block distance. The case study suggests that the block must be not too high to be hazardous if it fails. Otherwise, stresses redistributed because of the tunnel drive cannot concentrate at the block's top and bottom. In case the stresses are high enough at the moment of block failure, large-scale shear failure of the rock mass close to the tunnel may occur. If the location of blocks is unknown, state-of-the-art approaches to evaluate tunnel displacements must be applied to increase the probability of identifying blocks in time during tunnelling. Making the system stiffer of less stiff (e.g., by adapting the moment of ring closure) may not lead to a less hazardous situation. It is advised to minimise the unreinforced rock mass volume close to the tunnel face to prevent shear bands from reaching the tunnel.

Contents

Chapter 12

Conclusion

The thesis studied many cases where a stiff block is next to the side wall or in front of the tunnel face. Because of the stiffness contrast between the matrix and block material, stresses concentrate at the block surface and introduce interface slip. Not in all cases the resulting interface slip is large. Sometimes, the secondary stresses are favourable and prevent significant slip. However, if interface slip is rather large, shear bands develop from the block towards the tunnel. Typical geometric relations between the orientation of the stresses and the shear bands exist. The extensive analysis of the parametric study results and related descriptions in this thesis allow researchers and engineers who investigate block-in-matrix material and tunnel construction in such material to better understand many phenomena happening close to blocks and the block behaviour.

A brittle fault zone is typically heterogeneous. Next to stiffer blocks and zones, joints, faults, and slickensides usually exist. They all affect the characteristics of the tunnel displacements. The site team must have a very good idea about how the characteristics change depending on the predicted geological conditions ahead. The thesis suggests that a block with a maximum dimension of less than 1D will hardly be detectable by interpreting monitored displacement data. Anyway, the possibility of identifying the block also depends on the setting of the monitoring programme. Preferably, the distance of monitoring cross sections is small, the reading frequency is high, and the initial reading is taken immediately after shotcrete application. If the existence of the block is unknown, it can be everywhere, e.g., next to the side wall, above the crown, or in front of the tunnel face. Because then one does not know which displacement component will give first signs for the block (if at all), it is inevitable to apply several evaluation methods. From this study, analysis of the displacement vector orientation and a comparison of the displacements of tunnel parts (e.g., the left tunnel half vs. the right tunnel half if the block is next to one of the side walls) seem most promising.

An increase or a decrease in the system stiffness can lead to early or late block failure. If the location and the characteristics of the block are unknown, changing the system stiffness (e.g., moment of ring closure) to control the moment of block failure may be pointless. But it is advisable to minimise the unreinforced rock mass volume close to the tunnel face to prevent shear bands from reaching the tunnel and, thus, reducing the probability of a collapse.

Applying the Burgers-Mohr model to simulate the behaviour of the shotcrete material of the tunnel lining worked well. The differences between the tunnel displacements observed at the site and the simulated displacements are acceptable considering that the knowledge about primary stress states and rock mass conditions is limited. The interpretation of the site observations (tunnel displacements and lining strains) in the case studies give the reader valuable information on typical system behaviours at conventional deep tunnel drives. Observation and interpretation during tunnelling but also afterwards becomes more important when projects aim for minimisation of using resources (e.g., minimisation of unfavourable events such as the requirement to reshape and repair, as well as the reduction of collapses and associated remedial works) and the extension of the construction's operating time. And even if data analysis is done more and more automatic in the future, its success still will depend on the qualification of the geotechnical engineer.

Future works may

- perform numerical studies considering a block height of over 1D;
- perform numerical studies varying the tunnel shape or the block shape; the tunnel shape determines the orientation of the secondary stresses around the tunnel; the block shape determines the initial orientation of shear bands developing from the block towards the tunnel; the orientation of the stresses relative to the block surface determines the shear strength mobilisation and the interface slip;
- perform numerical studies including weak geological features next to the block like faults or slickensides; this will show how much the stresses in the block will further increase;
- perform numerical studies varying, e.g., the block distance or the block height whereas matrix and block material properties remain unchanged; a database of numerical results could be established being a future reference for comparisons with situations in actual cases; the database may also serve for Artificial Intelligence-driven analyses;
- perform numerical studies including two or more blocks next to each other; this will show the rate at which the stress increase in the blocks decreases; relevant literature are, e.g., the works by [227, 306];
- perform analytical analyses determining the minimum force required to push the mass between the tunnel and the block along the shear bands towards the tunnel; the ratio of the force to the accumulated compressive stresses in the block approximates the possibility of the block triggering large-scale mass movement if it fails;
- investigate the possibility of identifying a stiff block by analysing drilling data; it may be also possible to determine the block size in the direction of the drilling;
- investigate the possibility of identifying a stiff block and its dimension with geophysical investigations in the tunnel; according to [96][1], this mainly depends on the contrast in the density and the wave velocity between the matrix material and the block, on the block size and the wave length, and on the block distance.

[1] He currently is the Business Unit Manager of the Geophysics department at Amberg Technologies AG.