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Interaction of Tunneling and Rock Slope Stability, Case Study St. Michael Rail Ways Tunnel (Wachau Railway/Lower Austria)

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Abstract. This research focuses on the analysis of rock stability in the St. Michael Tunnel, part of the Wachau railway in Lower Austria. The study area includes the entire tunnel and the surrounding rock slopes with Para gneiss alternations and Schists. Initial surveys were conducted to assess the original ground and to identify areas of potential danger due to open fissures and sagging ridge vaults. The tunnel and rock slops was divided into three sections for analysis, using rock mass classification methods such as RQD, GSI, and Q-System. Stability analysis of the rock slope was then performed using a combination of was program such as RS2 and Dips.

The research aims to provide valuable insights into the behavior of rock slopes and tunnels by utilizing analytical approaches and numerical simulation techniques to assess the interactions between a rock slope and a tunnel. The study utilizes the slip line theory to determine the range of influences caused by tunnel excavation and the minimum safe distance between the tunnel arch and the slip belt. The analysis considers various influencing factors such as tunnel radius, rock friction angle, sliding belt slope angle, and rock friction coefficient. The case study of the St. Michael Tunnel in Lower Austria serves to demonstrate the applicability of this research and aid in the design and construction of underground infrastructure projects.

Keywords: Rock stability · Tunnel excavation · 2D Numerical simulation

1 Introduction

Tunneling engineering involves the design and construction of underground infrastructure systems like roads, railways, and subways. A significant aspect of tunneling projects can be the understanding of the interaction between tunnel excavation and rock slopes in terms of slope stability. The stability and safety of both tunnels and rock slopes are crucial, and it is often unavoidable for tunnels to traverse rocky slopes.

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The excavation of a tunnel leads to changes in the stress and displacement fields around the tunnel. This affects adjacent structures but also vice cersa: the resulting displacement and stress fields around the tunnel are influenced by adjacent structures.

In this study, a stability analysis of the St. Michael tunnel - Wachau-Railway in Lower Austria was conducted. The study area was divided into three cross-sections. Joint studies were performed, and the dip and dip direction of the joints documented. The rock compressive strength was in the field determined, and rock mass properties were approximated using GSI and Q-System.

The numerical modeling of the tunnel was performed using finite element programs RS2 [1]. With these programs simulated the behavior of the rock masses and the displacement and stress fields around the tunnel. Rock slope stability analysis was performed using kinematic analysis of slope stability with software's such as Dips, and RS2. These programs analyzed the stability of the rock slope and identified potential failure areas.

The aim of the stability analysis was to comprehend the interaction between the tunnel excavation and the surrounding rock slope and identify potential failure areas. The study results provide additional information for the design and construction of underground infrastructure projects in mountainous terrain and advance knowledge in the field of tunneling and rock slope stability [2].

2 Regional Geology of the Study Area

The regional geology of the study area can be classified as belonging to the Gföhl unit, a unit within the southern Bohemian Massif that primarily consists of gneisses, granites, and The regional geology of the study area can be classified as belonging to the Gföhl unit, a unit within the southern Bohemian Massif that primarily consists of gneisses, granites, and granulites. The Gföhl unit extends from the Dunkel Steiner Forest in the south to partially beyond the Austrian-Czech border in the north, as documented by H. Egger [3]. In the western section of the tunnel portal, the geologic formation is characterized by a relatively uniform Paragneiss-garnet-biotite-plagioclase-Paragneiss sequence, which transitions to the east. This formation is an intermediate stratum of amphibolite, approximately 25 m in thickness that is associated with the Buschandlwand Amphibolite Formation. In the lower part of the eastern tunnel portal and embankment, a 50 cm thick mica schist in two layers (totaling 1 m in thickness) is observed, alternating with gneiss (Fig. 1).

3 Statistical Analyses

In the study of rock masses, rock mass classification is a simple and not expensive way to access the information needed for the design of a structure. Discontinuities play an important role in determining the mechanical properties and classification of rock. Mapping the characteristics of discontinuities together with the rock characteristics of the studied area with high accuracy play an important role.

The scan line method in rock outcrops is considered due to the use of a relatively wide surface of the rock, and on the other hand, the geological relationship and correlation between different fractures. For statistical analysis within the scope of this research, 395

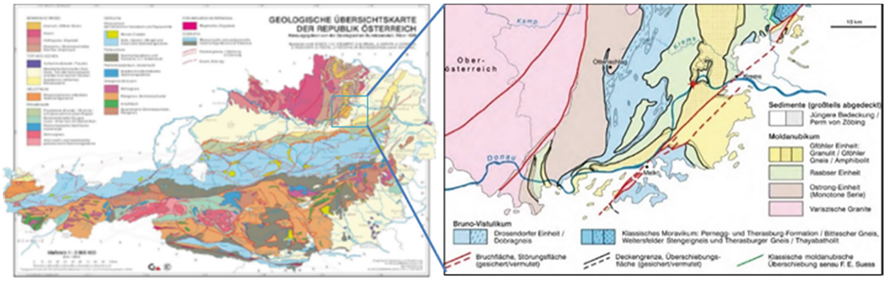


Fig. 1. Geological overview map of Austria (left) and Location of the Gföhler Unit, southern Bohemian Massif (right), (Finger and Schubert [4])

Table 1. Results of the statistical analysis on Software Dips 8.0 in the study area

Section A-A′			Section B-B′			Section C-C′			Section D-D′		
JS	D	DD	JS	D	DD	JS	D	DD	JS	D	DD
JS1	80	220	JS1	80	230	JS1	80	225	JS1	83	92
JS2	85	330	JS2	85	315	JS2	80	130	JS2	82	131
JS3	84	90	JS3	85	90	JS3	45	110	JS3	80	225
JS4	80	60	JS4	80	130	B	10	120	JS4	45	105
B	10	220	B	10	220				JS5	83	62
									B	10	220
JS = Joint Set			D = Dip			DD = Dip Direction			B = Bedding		

discontinuities were measured based on the coating in different outcrops in the range of the tunnels and the rock slops. The results of their statistical analysis using DIPS 8.0 software are as follows (Fig. 2 & Table 1):

4 Compressive Strength Impact of Interface Orientation

The orientation of interfaces within a material significantly affects its compressive strength, as shown e.g. by Wittke [5]. This relationship is visualized by Fig. 3, which plots the rock compressive strength as a function of discontinuity orientation. Analysis of the strength parameters characteristic cohesion c_k and friction angle φ_k in Fig. 3 reveals that the lowest compressive strength occurs at an interface orientation of ß = 60°. Ideal compressive strength would be obtained when the compressive load is either parallel or perpendicular to the interface orientation. However, practical considerations dictate that uniaxial stress states, particularly those aligned parallel to the interface, should be avoided, as shown by experiments conducted by Müller and Pacher [6].

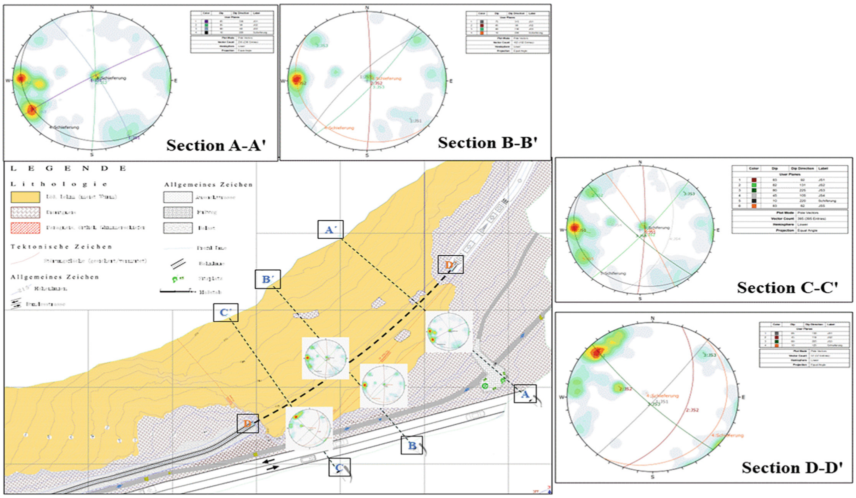
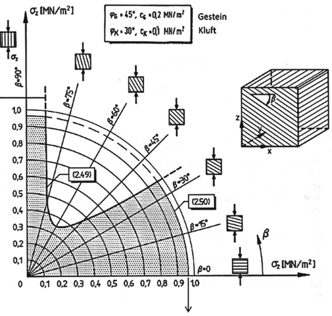


Fig. 2. Contour diagrams generated from statistical analysis of seam data in the Dips Version 8.021 from various sections overlaid on engineering geology map



$$\sigma_{dK} = \frac{c_K}{\sin\beta\cos\beta - \cos^2\beta\ tg\varphi_K}$$

$$\sigma_{dG} = \frac{2\,c_G\,\cos\varphi_G}{1-\sin\varphi_G} = \frac{2\,c_G}{\tan(45^\circ - \varphi_G/2)} = 0{,}97\ MN/m^2$$

Fig. 3. Relation between rock compressive strength and discontinuity orientation [4]

5 Rock Mass Classification

The use of rock mass classification systems can be a crucial tool in situations where limited information is available about the rock mass properties. The classification scheme can act as a checklist to ensure all relevant information has been considered, or it can be used to provide initial estimates of support requirements, strength, and deformation properties based on the rock mass composition and properties. It is important to acknowledge the limitations of mountain range classifications and that they cannot replace detailed design methods that require information on in situ stresses, rock mass properties, and excavation sequences. The use of rock mass classification systems should be updated and combined with site-specific analyses.

Table 2. The results of the stability analysis of St. Michael Tunnel (railway tunnel)

Section	Total Displacement (cm) After the Excavation			Total Displacement (cm) Before the Excavation		
	A-A	B-B	C-C	A-A	B-B	C-C
RS2	3,2	4,1	5,3	2,8	4,0	3,4

Over the past 140 years, various classification systems for rock mass have been developed, such as Ritter [7], Terzaghi [8], Deere, Hendron, and Patton [9], Wickham et al. [10], Bieniawski [11], and Barton, et al. [12]. These systems propose different components of geological engineering specifications and rock mechanics. The latest development in the field is the Geological Strength Index (GSI) method developed by Hoek [13] and and updated by Hoek and Brown [14]. In this research, the GSI method was used to perform the analyses and obtain the necessary input parameters for the software.

6 Numerical Modeling

The stability analysis of a tunnel and its rock slopes can be performed using various finite element analysis (FEA) methods, including 2-dimensional (2D) analysis. The selection of the appropriate analysis method is dependent on the complexity of the geology and the level of detail required in the analysis. 2D Finite Element Analysis (FEA), here as plane-strain analysis, is utilized when the effects of the surrounding rock mass can be caught in a section, and no out of plane deformation is expected. This approach is computationally efficient and is often employed in preliminary design and analysis stages. On the other hand, 3D FEA is employed when the rock mass is more complex, and the deformation is not confined to a single plane. This approach is computationally intensive and requires more detailed information about the rock mass in three dimensions, but it provides a more accurate representation of the behavior of the rock mass. The commonly used software for the stability analysis in 2D is RS2 (Fig. 4 & Table 2).

7 Slope Stability Analysis

Two-dimensional analyzes using RS2 software show that the rock slopes near the tunnel are subject to instability due to their near-vertical orientation. However, the level of instability in the default sections of the tunnel is different due to the difference in the transverse distance between the tunnel and the rock slope. In particular, the instability is more obvious from the east portal side to the west portal side of the tunnel with the highest amount of confusion in the third section.

These findings show that appropriate measures should be taken to ensure the stability of the rock slopes and the safety of the tunnel.

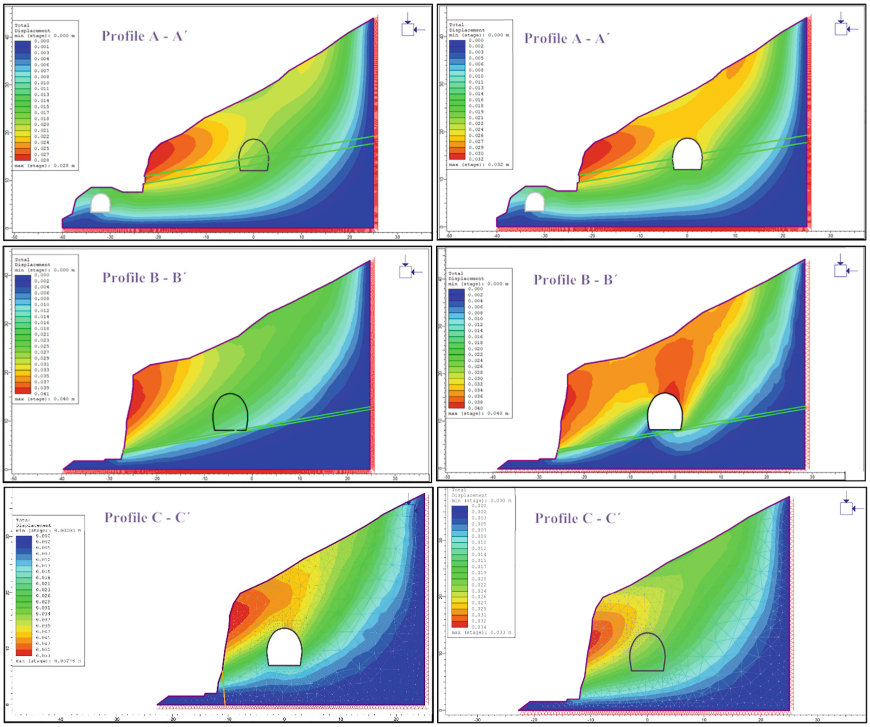


Fig. 4. Representation of the total displacement in the 3 different Sections in two different phases before tunneling (right side) and after excavation of the Tunnel (left side)

8 Conclusion

In this research, the structural behaviour of a tunnel in relation to slope instability was analysed through numerical simulations. The results showed that the biggest disruption to the rock and surrounding slope occurred during and after excavation. This highlights the importance of proper reinforcement and monitoring of the slope and support of the tunnel. It is suggested to stabilize the slope before tunnel construction to ensure overall stability. The study found that the horizontal distance between the tunnel and the trench greatly impacts the level of disturbance. The stress increases as one moves from the eastern to the western portal, leading to visible tensile cracks in the western portal area. It is important to note that these results are based on a 2D analysis, and the excavation process is affected by 3D problems. Thus, monitoring systems such as extensometers and convergence meters should be utilized to quickly detect any changes during the excavation process. In conclusion, the results of this research provide valuable insight into the structural behaviour of tunnels and slopes in mountain tunnel construction. The findings can serve as a reference for ensuring the stability of tunnels and slopes in similar settings.

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