Stability analyses of the partial face advance at the cavern from the access tunnel Wolf, BBT

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Abstract: Nonlinear analysis of the excavation process of the Brenner Base Tunnel is presented. The analysis includes the Drucker-Prager material model for rock and a fracture-plastic material for concrete. The contact between tunnel lining and the rock is modeled with interface elements. The analysis takes into account the construction process and the associated relaxation of the lining pressure. The calculated settlements show a very good agreement with the measured values.

1 GENERAL

The Brenner Base Tunnel is the heart of the Scandinavia-Mediterranean TEN Corridor from Helsinki to La Valletta, Malta. The BBT is meant primarily for freight transport, allowing a modal shift of traffic from road to rail, but passenger trains can also travel through the tunnel from Innsbruck to Franzensfeste. For the freight transport one tunnel access joins up also with the existing Innsbruck bypass creating a 64 km long underground tunnel link. The train traffic will no longer have to contend with the steep up- and downhill slopes on the 20km longer Brenner railway line thanks to the almost horizontal tunnel. Hence this low-gradient railway crossing the Alps is important for an efficient and ecologically friendly freight transport between the economic centers in Europe.

The standard track cross section consists of two single track rail tunnels with an exploratory tunnel in between. For building, ventilation and maintenance purpose a descending access tunnel to the main tunnel level was driven at the construction site Wolf near Steinach Austria. At the end of this access tunnel at 440 m below surface, a cavern of 340 m length and 18 m height was constructed. There the access tunnel Wolf branches into three connection tunnels to the main tunnel system.

The BBT crosses the Tauern Window, which provides an insight into the deeper crust zone of the eastern Alps. During the excavation of the access tunnel and the connection cavern in the construction lot Wolf mostly calcareous Bündner schists, secondarily, limestone Bündner schists and lower Bündner black phyllite schists were encountered [1].

a) Calcareous Schists
The limestone mica schists show a clearly layered structure, with coarsely grained layers of calcite, quartz, muscovite-sericite and smaller amounts of chlorite and graphite. They show uniaxial compression resistances of 50-100 MPa

b) Limestone phyllites
Mostly dark grey, foliated or thinly laminated rock with uniaxial compression resistances of 25-50 MPa. The rock consists mostly of sericite and secondary of chlorite, quartz and calcite.

c) Black phyllites
Dark grey to black finely laminated phyllites with height graphite and pyrite content. They show uniaxial compression resistances of 25 <50 MPa and therefore lower compression resistances than limestone phyllite.

In the cavern the black phyllites (75%) and limestone phyllites (25%) are predominant and can be described by the parameter set in Table 1.

Table 1: Material parameters for excavated rock

	Uniaxial compressive strength (Hoek&Brown)	Ground strength	E-Modul	Friction angle	Cohesion (MC)
	MN/m²	MN/m²	MN/m²	°	MN/m²
black phyllites	0.44	3.13	1400	30	0.8-0.85
limestone phyllites	2.91	11.54	6000	40	1.48-1.61

The cavern with a height of 18 m was constructed with shotcrete SpC 30/37 and SN bolts (6 and 8 m long every 1.5 m) in five excavation sequences according to the numbering in Figure 1.

1 NONLINEAR FINITE ELEMENT ANALYSIS

The numerical model is created in ATENA finite element software [2], [3] (see Figure 2). The used software allows for extensive treatment of material nonlinearities in the rock as well as concrete. The rock was modeled using a Drucker-Prager material model [4]. The Drucker-Prager parameters are determined from the measured friction and cohesion parameters of the encountered rock types as described in Table 1. The Drucker-Prager parameters are obtained such that the Drucker-Prager surface, is represented as an outer cone of the Mohr-Coulomb failure criterion based on Eq. (1).

The concrete is modeled using a fracture-plastic material model [5]. This material model was extensively validated in the past [5], [6], [7] for various failure modes involving concrete cracking, crushing or reinforcement yielding. The used material parameters are listed in Table 2.

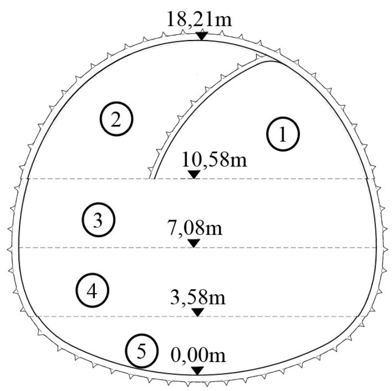

Figure 1: Cross section and excavation concept of the cavern construction lot Wolf according to [1]

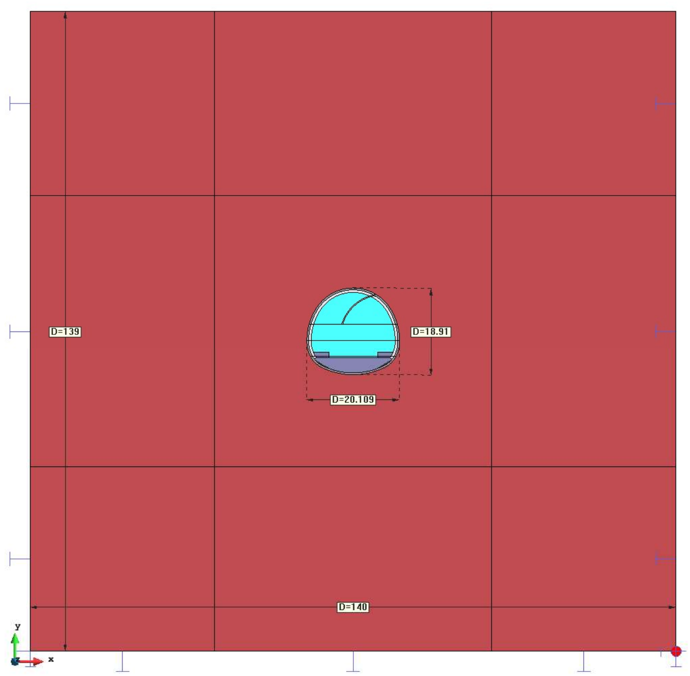

Figure 2: Numerical model of the tunnel cross-section including the 140x139 m block of surrounding rock

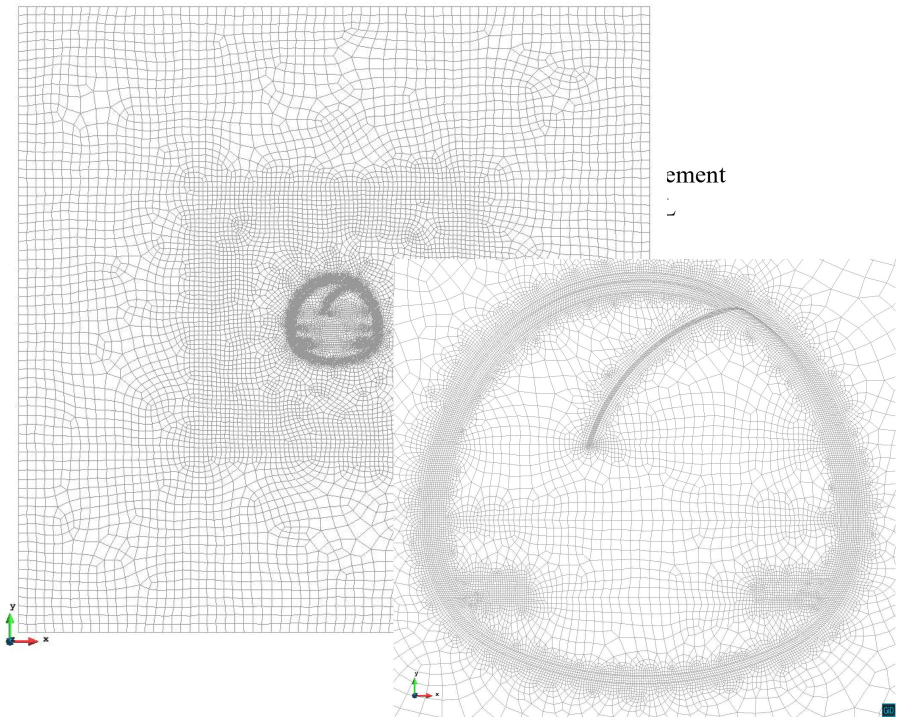

Figure 3: Finite element mesh of the tunnel lining as well as the surrounding rock

Table 2: Material parameters for nonlinear analysis

Rock			
E-Modulus	2 550 MPa	α_{DP}	0.25
Poisson's ratio	0.3	k_{DP}	1.20 MPa
Concrete lining			
E-Modulus	16 000 MPa	Compressive strength f_c	38 MPa
Poisson's ratio	0.2	Tensile strength f_t	2.9 MPa
Fracture energy G_F	72.5 N/m	Plastic strain at f_c, ε_{cp}	0.00097
Critical compressive displacement w_d	0.5 mm	Aggregate size	20 mm
Concrete-rock interface			
Cohesion	0.3 MPa	Friction coeff.	0.3

$$\alpha_{DP} = \frac{2\sin\phi}{\sqrt{3}\left(3-\sin\phi\right)}, \quad k_{DP} = \frac{6c\cos\phi}{\sqrt{3}\left(3-\sin\phi\right)} \tag{1}$$

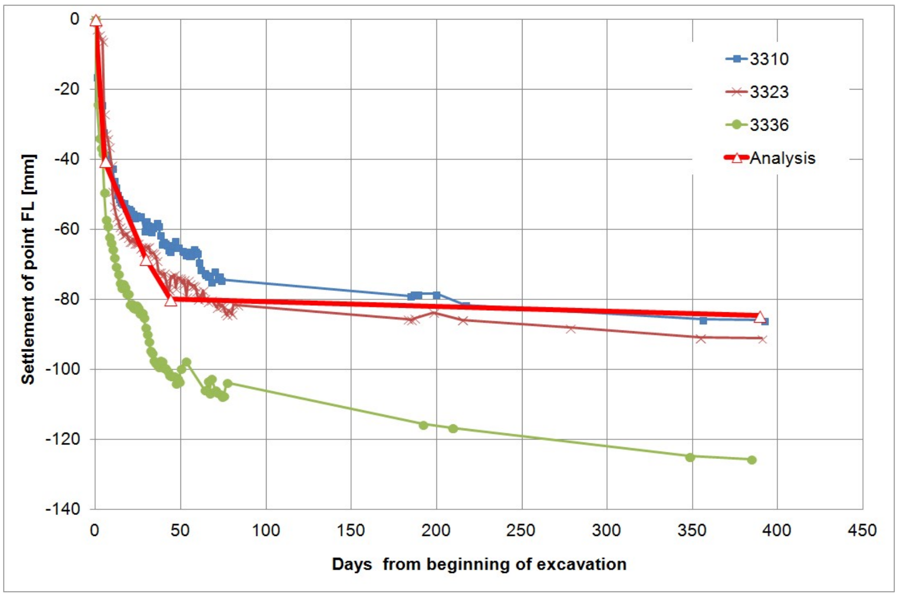

Figure 4: Comparison of settlements at measurement point FL (Figure 3) at three tunnel sections. The section number indicates the distance from the tunnel north entrance in meters

The excavation process (Figure 1) is considered in the model. This involves removal and addition of material groups with appropriate material models. Before each removal the existing rock pressure is stored and before the addition of the liner finite elements it is partially released in order to consider the rock relaxation associated with the used excavation process. The release coefficient was assumed to be 0.9 for the first phase and 0.8 for the subsequent phases. Figure 4 shows the comparison of the settlements at point FL obtained in the numerical analysis with the measurement data from three tunnel stations. The nonlinear analysis showed that significant plastic strains are developing in the rock on the sides of the first excavation profile as well as in the bottom parts of the tunnel primary lining after phases I and II (see Figure 5). This partial concrete crushing develops mainly on the external surfaces of the lining and could not be therefore confirmed by on site observations.

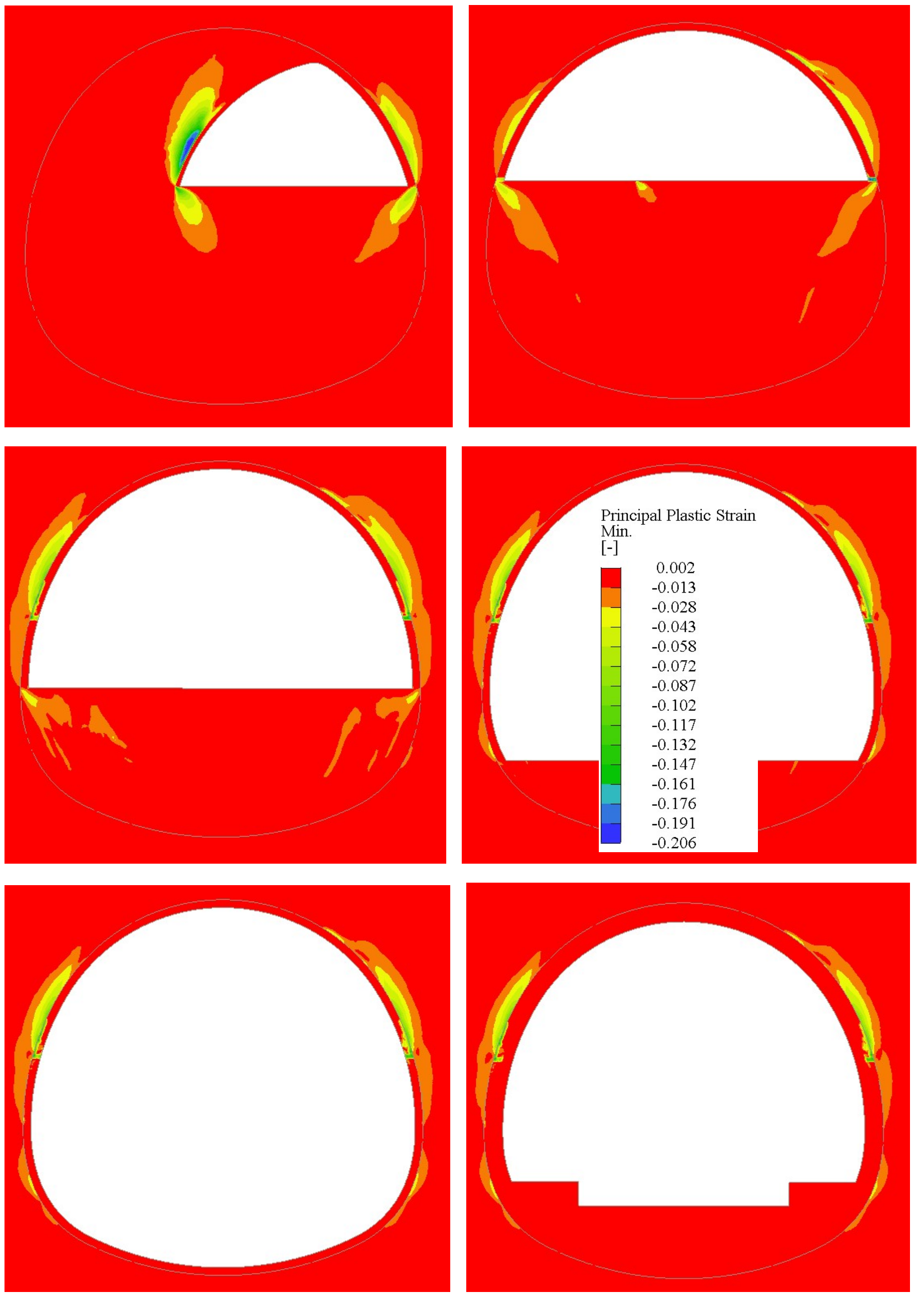

Figure 5: Minimal principal plastic strains in concrete and rock during the five excavation phases

2 CONCLUSIONS

Nonlinear analysis of the Brenner Base Tunnel is presented. The nonlinear analysis is performed with the finite element simulation software ATEBA [3], which enables advanced modeling of brittle materials such as concrete or rock. The rock is modeled using the Drucker-Prager material and concrete by the advanced fracture-plastic material. The interface between concrete and rock is modeled using interface elements with Mohr-Coulomb material. The tunnel excavation and construction follows the new Austrian tunneling method, which allows for significant relaxation of rock mass stresses thus significantly relieving the pressure on the tunnel lining. The excavation process including the pressure relaxation is considered in the modeling approach and the measured convergences are compared with the numerical results and a very good agreement was observed.

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