PU grouting and sealing measures on the Kramer Tunnel

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ABSTRACT: The Kramer Tunnel in the north of Garmisch-Partenkirchen is designed as a single-tube road tunnel with two-way traffic. The tunnel was excavated using NATM. The 3,600 m long tunnel is divided into a pressure-relieved (drained) section and a waterproof (sealed) section, which can withstand pressures of up to 5 bar. Four shotcrete bulkheads were installed to separate the sealed section (rock-slide area) from the drained section. Additionally, PU grouting was employed around the bulkheads to reduce the longitudinal water flow along the main and exploratory tunnels. This article reveals how the radial grout curtains were executed within limestone-marl alternations. Taking the geological conditions into consideration, the success and quality of the grouting work was monitored by water pressure tests and by quantitatively evaluating the grouting records. Construction details concerning the chemical injection material, the grouting equipment and the break-off criteria are discussed.

Keywords: chemical grouting, grout curtain, bulkhead, break-off criteria.

1 PROJECT DESCRIPTION

The Kramer Tunnel in the north of Garmisch-Partenkirchen in Bavaria has been designed as a single-tube road tunnel with two-way traffic. As part of the Western Garmisch-Partenkirchen bypass, the Kramer Tunnel is the primary traffic connection between Bavaria (Germany) and Tirol (Austria). The 3,600 m long tunnel is intended to reduce traffic congestion on the B23 federal road in Garmisch-Partenkirchen. Figure 1 shows a site plan of Garmisch-Partenkirchen, including the project area and the main roads used by traffic.

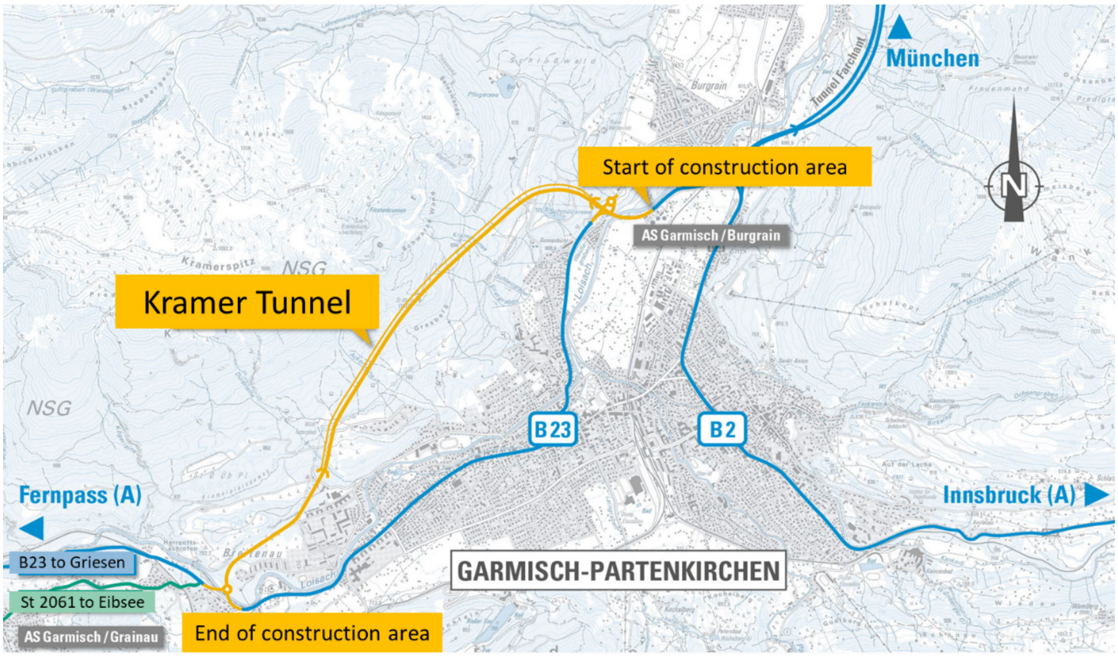

Figure 1. Site plan of the Kramer Tunnel.

The Kramer Tunnel was designed by the Staatliches Bauamt Weilheim and ILF Beratende Ingenieure ZT GmbH, while the Technical University of Munich's Zentrum Geotechnik (TUM-ZG) acted as geotechnical and tunnelling consultant during the construction phase. At an axial distance of 45 m parallel to the main tunnel tube, a reconnaissance tunnel was excavated in advance for use as a rescue tunnel. The construction of a reconnaissance tunnel was required in advance since major tunnel sections could not be explored using drillings due to the topographic conditions. The tunnel was excavated using the New Austrian Tunnelling Method (NATM).

2 GEOLOGICAL CONDITIONS AND SEALING MEASURES

The tunnelling route mainly included a bedrock section and a rock-slide failure zone. The water-filled rock-slide material consists of a mixture of loose rock with low cohesion and a block-in-matrix structure. The water pressure above the tunnel level was measured at around 450 kPa in the rock-slide area. Figure 2 shows a cross-section of the hydrogeological conditions of the rock-slide area. During the construction phase, the groundwater level was temporarily lowered using water wells drilled from the ground surface and underground drainage holes from the tunnels. Sealing measures were designed to separate the sealed section (rock-slide area) from the drained section to avoid lowering the groundwater level in this area for nature conservation reasons following the construction phase. To this end, four shotcrete bulkheads and PU grout curtains were installed to reduce the longitudinal water flow along the main and reconnaissance tunnels.

The bulkheads are in the facies of the Kössen strata, which consists of limestone/marl alternations with thin sublayers of shale or shale-clay. Apart from the shale-clay interlayers, the geology is characterised by rock that is not compactly to moderately loosened, un-weathered to slightly weathered, and not water-sensitive, which has a moderate or high rock strength and shows a stable rock behaviour. The rock mass was disturbed in some areas and intersected with fissures and layers of sediment. Dry or stained rock conditions with local mountain water inflows were also observed.

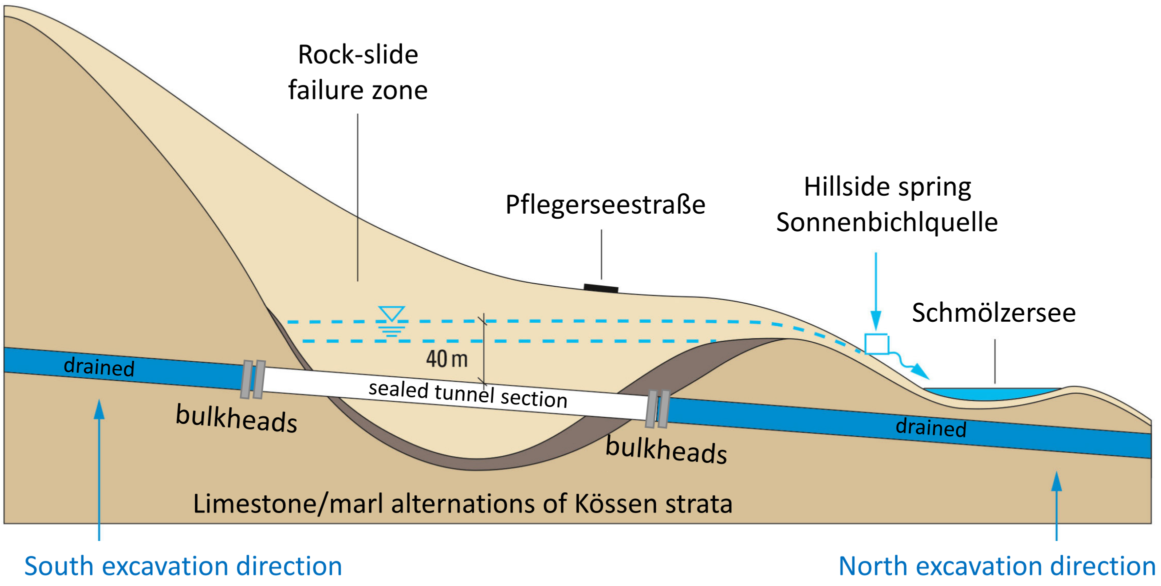

Figure 2. Side view of the rock-slide area.

3 SHOTCRETE BULKHEADS

The four sealing bulkheads were each constructed in the shape of double shotcrete ribs with a depth of 0.75 m; they are shown in Figure 3.

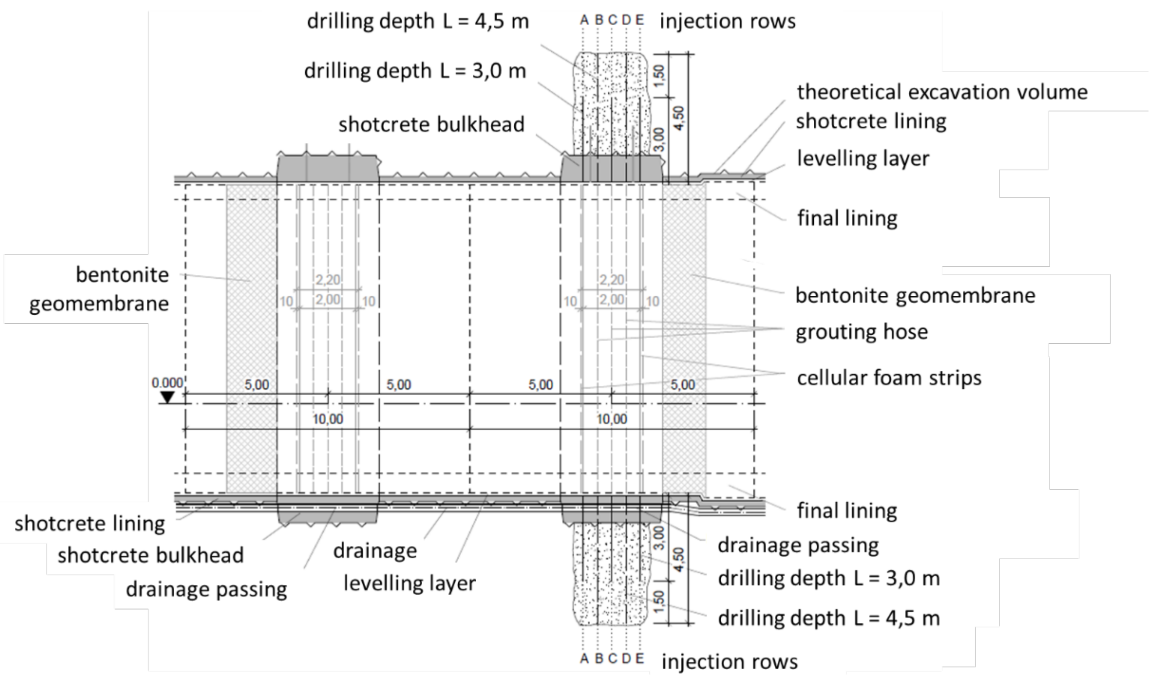

Figure 3. Detailed view of one of the double shotcrete bulkheads (Bemo Tunnelling, 2022a).

The construction of the bulkheads using the shotcreting method has the following advantages over the monolithic cast-in-situ concrete construction:

- Cast-in-situ concrete is difficult to compact overhead.
- No offset of the annular gap between the outer shell of the shotcrete and the cast-in-situ concrete.

- Less hydration heat and less cracking risk than the monolithic cast-in-situ construction.

The depth of the bulkheads was chosen to be higher than the blasting disturbance zone around the tunnel. While excavating the tunnel, it was found that the blast zone did not exceed a thickness of 0.75 m. The depth of the blasting disturbance zone was derived from the boreholes for the injection testing fields and from Lugeon tests. Lugeon (Lu) is defined as 1 litre per minute (L/min) of water flow into a water test stage with a length of 1 metre (m) at an excess pressure of 1,000 kPa, as defined by for example, Kutzner (1996) in Equation (1).

$$1\,Lu = \frac{1\,L/min}{m}\,at\,1{,}000\,kPa \qquad (1)$$

The excavation of the rock around the shotcrete bulkheads was carried out carefully with a cutting machine so that the surrounding rock was only affected minimally. Figure 4 shows photographs of the excavation of the shotcrete bulkheads in the limestone/marl alternations. For operational reasons, excavation was conducted in two steps: the crown and the sides were excavated first, then the bench and invert. The shotcrete for the bulkheads was applied in layers, and the reinforcement mats were pressed into the shotcrete that had already been applied so that shooting shadows were avoided behind the reinforcement.

Figure 4. Photographs of the excavation of the shotcrete bulkheads.

4 PU GROUT CURTAINS

Grout curtains surrounding the bulkheads were planned to further extend the flow path and reduce the directional water permeability. Water pressure tests were performed at different borehole depths to quantify the permeability and injectivity of the rock mass before injection work began. Many of the Lugeon values (> 75 %) were below 10 Lu, indicating that chemical grouting was the only appropriate method to reduce the permeability of the rock (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., 2018; Fell, 2015; Saurer E. et al., 2012).

A two-component PU grout was chosen as the injection material for the following reasons: it has a low viscosity (ca. 120 mPas), a short and adaptable reaction time (5 to 30 min) and long-term chemical durability (Karol, 2003). A five-row grout curtain with drilling holes arranged radially to the tunnel axis was designed for each bulkhead, as shown in Figure 3 and Figure 5. Three short injection rows (A-C-E) with a length of 3.0 m each and two long injection rows (B-D) with a length of 4.5 m each were implemented in a close-mesh grid with a 0.5-m distance between the injection boreholes. The borehole diameter was 51 mm.

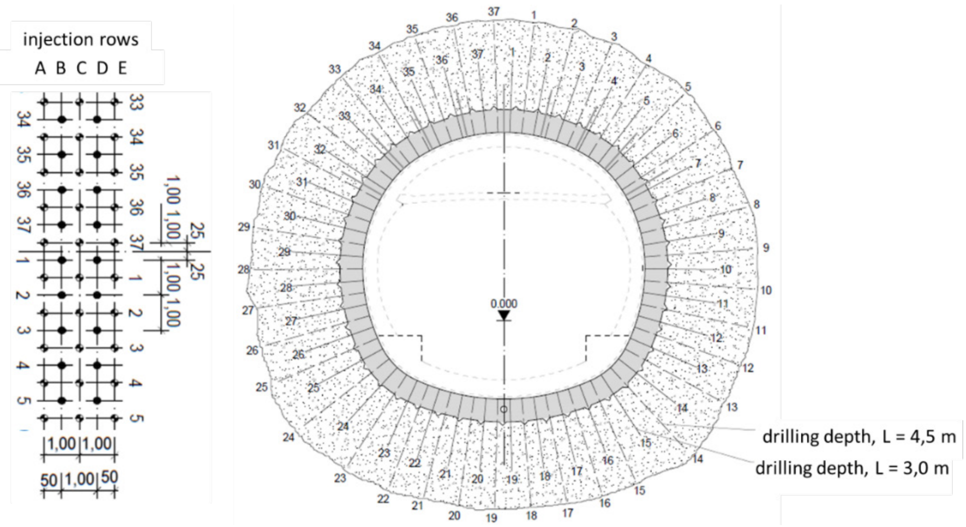

Figure 5. Grout curtain surrounding the bulkheads for the tunnel in cross-section and borehole grid (Bemo Tunnelling, 2022b).

Each of the 37 stable boreholes in an injection row was grouted with mechanical packers in three positions using the ascending procedure, as demonstrated in Figure 6:

- Packer position 1: in the rock mass for joint grouting
- Packer position 2: grouting the interface between shotcrete and rock mass
- Packer position 3: borehole closure

First, the three short injection rows A, C and E, were drilled, and packer positions 1 and 2 were injected using the pilgrim-step method to avoid material circulation between the boreholes. Then, after the curing of the injection material, the drilling and injection of the long injection rows B and D were also carried out using the pilgrim-step method. Finally, the borehole was closed (packer position 3) in all the injection rows.

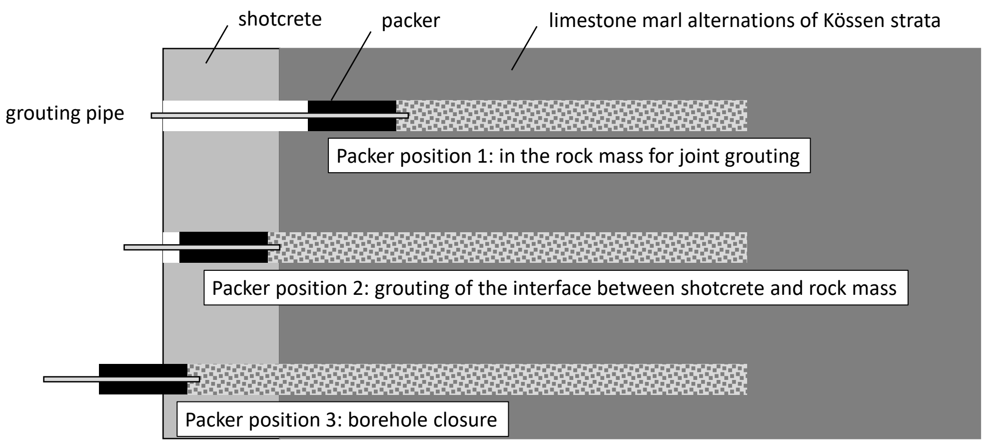

Figure 6. Different packer positions for the five-row grout curtain (Bemo Tunnelling, 2022b).

The break-off criteria defined for the different packer positions are listed in Table 1. The maximum grouting pressure was chosen to be as high as possible to allow an economical flow rate without cracking the rock mass or the shotcrete. The average grouting rate ranged between 0.5 and 1.0 l/min. When the maximum pressure was reached, the flow rate was reduced to keep the pressure constant until the pressure-hold time was reached. The maximum grouting volume was chosen to be high enough to ensure that the permeable joints in the surrounding area of the sealing bulkheads were filled.

Table 1. Break-off criteria for the different packer positions.

Packer	Max. grouting pressure [kN/m²]	Max. grouting volume [l]	Pressure-hold time [min]
Position 1 rock mass	900	22.5 for L = 3.0 m 45.0 for L = 4.5 m	3
Position 2 interface rock mass and shotcrete	900	35	3
Position 3 borehole closure	300	4	1

The volume criterion for abandoning the grouting work was only relevant in very few cases when grouting in the rock (packer positions 1 and 2). Accordingly, the rock mass showed no additional material absorption at a pressure of 900 kPa. As a result, joints that had taken up grouting material were only encountered sporadically.

5 CONCLUSION

The grouting measures could be carried out in a technically efficient way, so that the hydraulic routing in the joints of the surrounding rock could be significantly reduced, as the comparison of the Lugeon tests before and after grouting in Figure 7 showed. It can be concluded that the injection measure around the bulkheads reduced the longitudinal water flow in the already low-permeability rock.

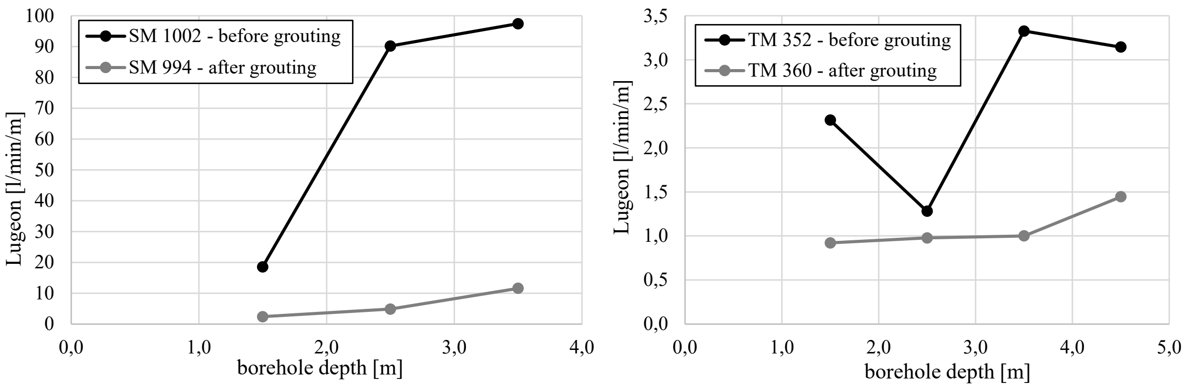

Figure 7. Lugeon test results before and after grouting.

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