Risks and hazards caused by groundwater during tunnelling - geotechnical solutions used as demonstrated by recent examples from Tyrol, Austria

Ludwig Schwarz, Ignaz Reichl, Hubert Kirschner & Klaus Robl

ILF Consulting Engineers, Framsweg 16, A-6020 Innsbruck, Austria;
E-mail: ludwig.schwarz@ibk.ilf.com

Abstract: As demonstrated from recently excavated reconnaissance tunnels, uncontrolled water ingresses frequently pose a risk despite ever improving tunnelling methods. This is regardless of the type of rock encountered and can result in significantly increased construction costs.

Key words: tunnelling, groundwater, water and material ingress, geotechnical solutions, Austria

Introduction

Despite constantly improving tunnelling methods, groundwater remains a decisive influencing factor in tunnels constructed using the NATM (New Austrian Tunnelling Method). During the exploration phase of the Munich-Verona High-Speed Railway Project five reconnaissance tunnels were recently excavated in the Lower Inn ValleyTyrol, Austria to obtain detailed information on the geotechnical and hydrogeological conditions and to be able to compile the main tendering documents. Three of these are used as examples of the risks and hazards, which arise from groundwater during excavation and for the tunnel as a structure. The reconnaissance tunnels were excavated through technically demanding route sections of the app. 42 km long section.

Figure 1. Sketch of the project area

Vomp East Reconnaissance Tunnel – Excavation under high water pressures in unconsolidated sediments

Rock mass structure and hydrogeology

The western section of Vomp East Reconnaissance Tunnel traverses Pleistocene deltaic deposits. Within this sequence the distal delta, where coarse-grained sediments of the fore-sets alternate with fine-grained sediments of the bottom-sets, constitutes the most geotechnically demanding tunnel section. The rock mass is characterised by sequences of gravels of varying grain size intertwined with fan-shaped sequences of sandy silt dipping moderately against the direction of advancement. The litho-structure, alternating water-bearing and impermeable sequences results in a system of confined water bodies where the water pressure is between 3 and 5 bar (see Fig. 2).

Relevance to tunnelling methods – tunnelling hazards

When the fine-grained sequences were advanced onto, hydraulic ground break occurred. Due to the pressure (3 to 5 bar), water ingress occurred which had large erosive forces, leading to the formation of cavities of up to several 100 mł next to the tunnel structure. Sudden failure of the tunnel structure due to redistribution of rock mass loads would have been a possible scenario during further advancement.

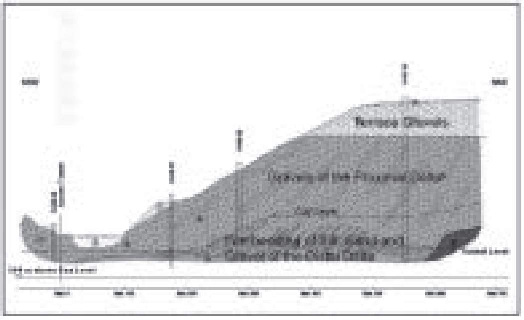

Figure 2. Longitudinal cross-section through the delta facies - Vomp East Reconnaissance Tunnel

Tunnel construction measures

From the available ground investigation data (tunnel and core drillings) it soon became clear that the conditions ahead of the face were not going to change rapidly. Injection measures turned out to be unsuitable due to a high percentage of fine-grained material. In the end it became apparent that tunnel excavation using mining methods in such ground conditions could only be carried out by lowering the groundwater table and reducing the pressure. The section was finally traversed by a combination of drainage drilling ahead of face and pipe arches as support. The continuous adjustment of the geological model and using this consequently for the precision drainage drillings proved to be very important.

BRIXLEGG WEST RECONNAISSANCE TUNNEL – HETEROGENEOUS GROUND CONDITIONS AND GROUNDWATER BODIES

Geological model and tunnelling concept

Over a length of 170 m the Brixlegg West Reconnaissance Tunnel traverses the Matzenpark Syncline, which is filled with Quaternary ice marginal sediments, a heterogeneous sequence of sandy gravel and fine-grained sediments[1]. The syncline is in fact a hanging valley, which joins the over, deepened Inn Valley below the current valley bottom (Fig. 3). The varying litho-structure results in a complex hydrogeological system of slope-water bodies, which intercommunicate with the Inn Valley Aquifer reaching pressures at tunnel level of up to 1.5 bar.

Tunnelling concept

As the "Matzen Park" is a protected natural area, the public authorities initially required that no above ground auxiliary construction measures should be used. The initial excavation concept, for crossing the Matzenpark Syncline, foresaw the construction of a continuous cone of columns around the tunnel with the face shielded by a cork-like system using jet-grouting techniques (Fig. 4). As an additional support measure, an injection umbrella was constructed prior to the jet grouting columns, which was abandoned after a few tunnel metres.

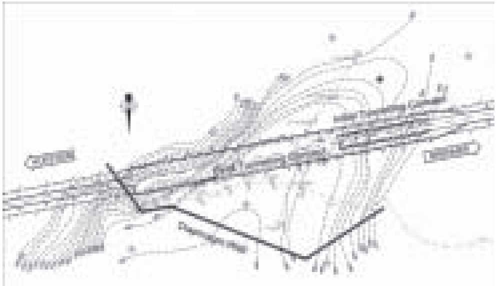

Figure 3. Map of the Matzenpark section

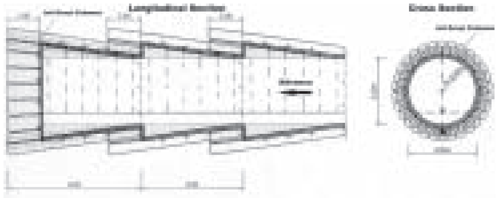

Figure 4. Brixlegg West initial tunnelling concept

Risk scenario

Difficulties became apparent when the columns could not be constructed in the desired dimension and defective areas led to the danger of water and material ingresses. At the sixth cone of columns this scenario became a reality which culminated in development of a 30 m^3 cavity penetrating to ground level. After additionally strengthening the ground around the 4 m diameter tunnel by means of grouting the tunnel excavation was continued. Further problems in the construction of the jet-grouting columns finally made the client abandon this excavation concept due to safety problems and high costs.

New tunnel construction concept and measures

Due to the encountered problems, the public authorities were convinced of the necessity of above ground auxiliary measures. Sealing off the Matzenpark Syncline from the Inn Valley Aquifer allowed this difficult section to be finally and successfully advanced.

Brixlegg East Reconnaissance Tunnel – Excavation in hard rock containing water-bearing fault zones filled with unconsolidated material

Geologic model

Shortly before the planned end of the Brixlegg East Reconnaissance Tunnel, the drilling of an anchor hole was accompanied by an ingress of water (25 l/s) and a flushing out of a few cubic meters of material. At this point the tunnel was situated in a sequence of carbonates with an increasing degree of fracturing within the rock mass. The ensuing reconnaissance programme revealed a fault zone of up to several tens of meters thickness filled in part with unconsolidated material. This fault zone was prognosed to cross the excavation line, at a low angle, a few meters ahead of the tunnel face. Furthermore, the investigations revealed that the fault zone was highly permeable containing water at pressures of up to 5.0 bar. The findings pointed to the following scenarios: 1) Impacts on the stability of tunnel structure due to large-scale flushing out of material and the resulting change in load distribution within the rock mass, 2) Impact on groundwater aquifers and especially on the adjacent spa-water aquifer, and 3) Danger to tunnelling crew due to water ingresses in combination with large-scale flushing out of material.

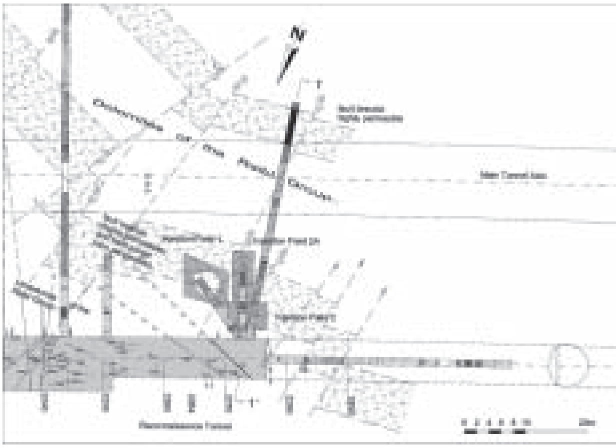

Figure 5. Map of the Brixlegg East fault zone

Tunnelling solution

In order to master this fault zone, the client explored alternative excavation concepts. During an injection test aimed at improving the geotechnical properties of the fault an app. 500 mł zone was grouted using 330 t of cement. This test did not lead to the desired result, namely the successful resumption of tunnelling[3]. In addition, two draw-down tests were carried out in order to investigate the possibilities of lowering the groundwater table and exploring the effects. An extensivehydrological/geotechnical monitoring and testing programme was pursued to investigate the groundwater properties and to evaluate the impacts on the groundwater system and the above mentioned spa-water aquifer. On the one hand, the results showed that artificial draw-down could be used to master the fault zone, on the other hand they also provided clear proof of a quantitative and qualitative but reversible impact on the spa-water aquifer, which is why tunnelling has not been resumed for the time being[2].

CONCLUSIONS

As demonstrated by recently excavated reconnaissance tunnels, water ingresses pose a major risk to the excavation and tunnel structure despite modern tunnelling techniques. A flexible adjustment of the excavation concept, using the NATM in general, allows such situations to be handled successfully.

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