

# The new Bözberg Tunnel (Switzerland) – risk management and auxiliary measures for the TBM break-through

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**ABSTRACT:** The new Bözberg Tunnel is a double-track railway tunnel. It is roughly 2.7 km long and thus the longest of the tunnels, which are being excavated or enlarged for the realization of the so-called "4-metre corridor" on the Gotthard artery through Switzerland. The excavation methods have been chosen according to the expected geology: conventional excavation in soil and by means of a single shielded TBM in (swelling) rock. After a short general overview of the project, the paper focuses on the tunnel section which runs in rock. Particular emphasis is put on the TBM break-through, which – in spite of the very low overburden of 1–2 m of sound rock – occurred successfully in November 2017 close to the existing railway line without interference of the railway operation. For this purpose, the implementation of auxiliary measures (e.g. triple pipe umbrella), a continuous monitoring and exhaustive risk management were necessary.

## 1 INTRODUCTION

At the time being, the Swiss Federal Railways are upgrading the Gotthard route – which can be seen as a centerpiece of the European rail-freight corridor between Rotterdam and Genoa – to further increase the volume of transalpine freight carried by rail. The realization of the so-called "4-metre corridor" (Fig. 1) between Basel (at the German border) and Chiasso (at the Italian border), which will allow as of 2020 semitrailers with a headroom of 4 m and a width of up to 2.6 m to be carried, requires the enlargement of about 20 tunnels and more than 80 adaptations to platforms, traction current systems, signaling installations and overpasses (Swiss Federal Railways 2018). The investment costs are estimated to be CHF 710 millions (Zieger et al. 2018a).

One of the tunnels, which does not satisfy the requirements with respect to the clearance profile, is the 2.5 km long Bözberg Tunnel, which was opened in August 1875. Based on various studies, for this tunnel the Swiss Federal Railways decided to not refurbish the existing tunnel but to excavate a new double-track tunnel running parallel to the existing one. After opening to commercial railway operation of the new tunnel in 2020, the existing tunnel will be converted to a service and escape tunnel, which will be connected to the new tunnel by means of five cross-passages at a spacing of maximum 500 m. With this solution, tunnel safety is increased and a time-expensive enlargement of the existing tunnel under continued railway operation can be avoided. In this respect, it is worth mentioning that such a refurbishment would have led to a considerable loss of capacity on the Bözberg line and to a delayed opening of the 4-metre corridor. The 2.7 km long new Bözberg Tunnel (hereafter referred to as "the tunnel") is the biggest single project of the 4-metre corridor. The investment costs are estimated at CHF 350 millions (Zieger et al. 2018b).

The Swiss Federal Railways tendered the construction works of the tunnel in September 2014 as an overall performance model according to the model "General Contractor Plus (GU+)". According to the tender documents, the GU+ provides the tunnelling works (tunnel and cross-passages), the construction of both portals including two short sections of cut-and-cover tunnel,

the implementation of the dewatering system, the installation of the electrical equipment as well as of the rail system and the conversion of the existing tunnel into a service and rescue tunnel. Furthermore, the GU+ undertakes all the design works for the construction project and provides the building structure documentation. During construction, the Swiss Federal Railways (client) are supported and represented by an Owner's Engineer. The Swiss Federal Railways awarded the contract (with a volume of CHF 145 millions) to Implenia Switzerland in November 2015. On behalf of the contractor, the design works are carried out by the following joint-venture of Swiss engineers: Amberg Engineering AG (lead designer), Basler & Hofmann AG (responsible for the tunnel section in rock), F Preisig AG and Heierli AG.

After a short general overview of the project (Section 2), the paper focuses firstly on the tunnel section in rock (Section 3), which has been excavated by means of a single shielded TBM. Subsequently (Section 4), the paper pays particular attention to the TBM break-through, for which the implementation of auxiliary measures, a continuous monitoring and exhaustive risk management were necessary.

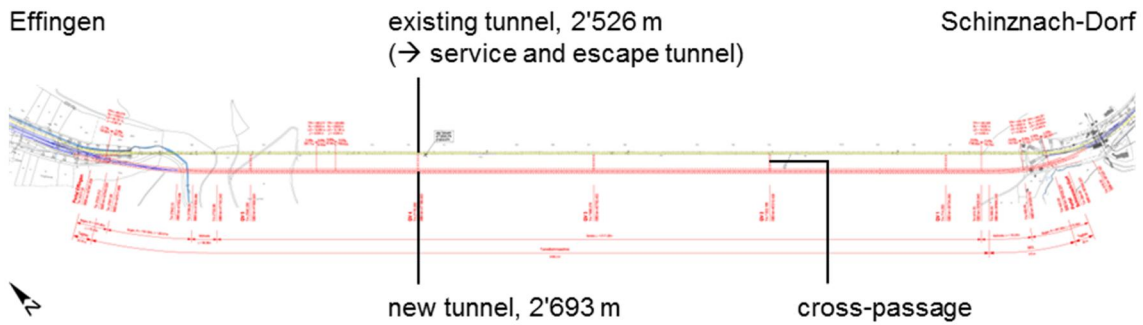


Figure 1. The 4-metre corridor across Switzerland along the Gotthard route (red line; picture: courtesy of Swiss Federal Railways).

## 2 THE NEW BÖZBERG TUNNEL

The new Bözberg Tunnel is 2'693 m long and runs between Schinznach-Dorf and Effingen almost parallel to the existing one (Fig. 2). From Schinznach-Dorf to Effingen, the tunnel can be subdivided in following sections: cut-and-cover tunnel (36 m), tunnel section in soil (quaternary deposits) and heavily weathered rock (175 m, excavated conventionally), tunnel section in rock (2'438 m, excavated by means of a Herrenknecht single shielded TBM, Ø 12.36 m) and cut-and-cover-tunnel (44 m).

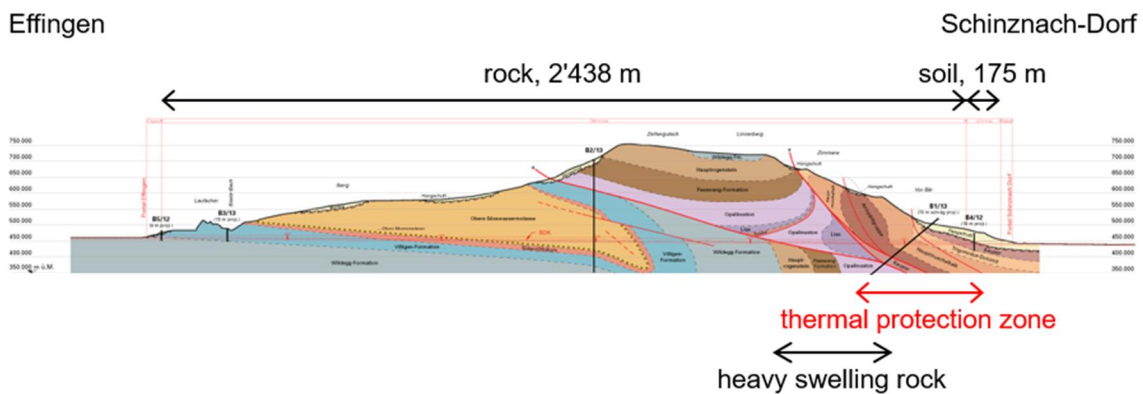
The construction works started in March 2016. The conventional excavation took 7 months (from September 2016 to April 2017). The TBM drive started in Mai 2017 and ended in November of the same year. Advance rates of up to 40 m/day have been achieved working with two excavation shifts (2 x 8 h/day) and one maintenance shift (1 x 8 h/day). Commercial railway operation in the new tunnel will start in October 2020. The conversion of the existing tunnel to a service and escape tunnel is expected to be completed in April 2022.



Figur 2: Plan view of the Bözberg Tunnel.

### 3 TUNNEL SECTION IN ROCK

The 2'438 m long tunnel section in rock runs through the challenging geology of the so-called "Swiss Jura" (Fig. 3). Worth to mentioning is the crossing of the "Hauptmuschenkalk" (a shell limestone), which belongs to the catchment area of the thermal spa Bad Schinznach. Likewise important and particularly challenging is the crossing of zones with heavy swelling rock: the Keuper (clay and sulphate swelling), the Anhydrite Group (clay and sulphate swelling) and the Opalinus Clay (clay swelling).



Figur 3. Geological longitudinal profile (picture: courtesy of Dr. Von Moos AG, modified).

In order to not influence the ground water regime in the catchment area of the thermal spa Bad Schinznach, a so-called "thermal protection zone" with a length of 390 m was defined (Fig. 3), where specific ground water protection measures have to be implemented: (a) in order to avoid a "damage" of the rock mass around the tunnel as much as possible, the excavation has to be carried out by means of a single shielded TBM (Fig. 4); (b) a double-shell lining with full waterproofing (testable and injectable) has to be installed in order to avoid long-term drainage of the rock mass; (c) longitudinal circulation of ground water along the tunnel has to be prevented (the corresponding countermeasures are filling of the annular gap with mortar and ring-shaped bulkhead grouting between inner lining and segmental lining as well as in the rock mass around the tunnel at selected locations).

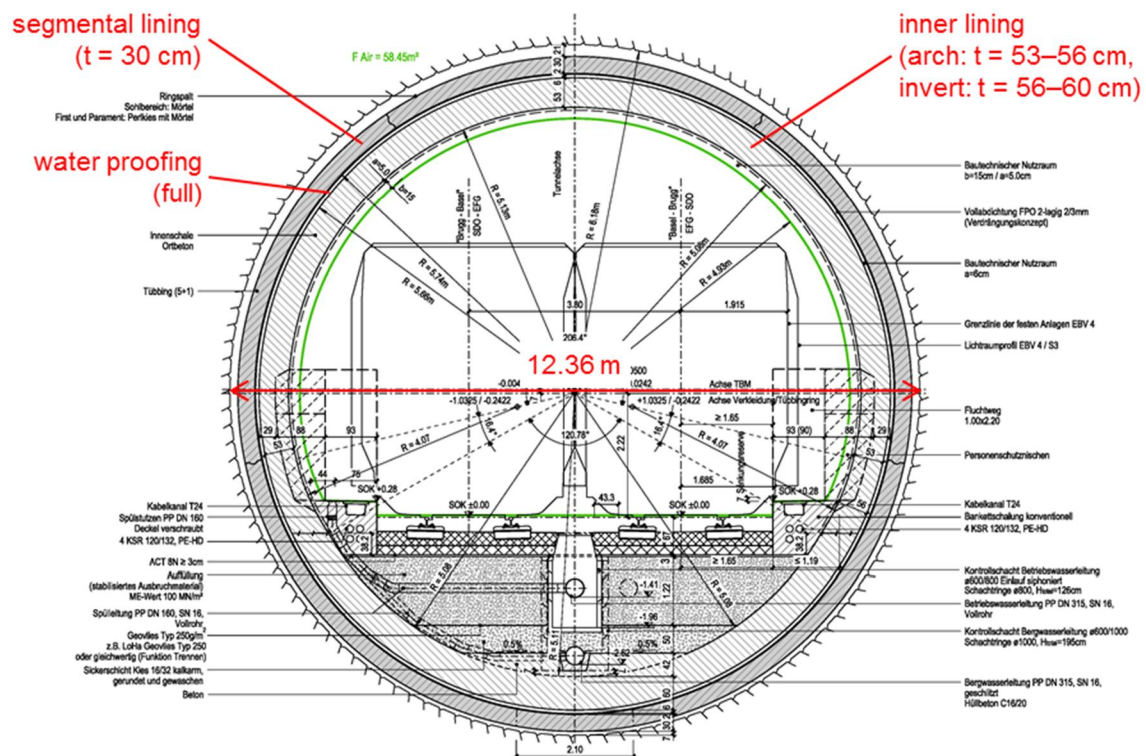
The different boundary conditions concerning waterproofing and swelling potential of the rock led to the application of different lining concepts along the tunnel. In the thermal protection zone, where full waterproofing is required, a full double-shell lining (segmental lining + cast-in-situ inner lining in the arch and in the invert, Fig. 5) is applied. In this case, the inner lining has to accommodate a water pressure of up to 10 bars. In the rest of the tunnel, where a partial waterproofing is allowed, the lining is double-shell in the arch (segmental lining + cast-in-situ inner lining, Fig. 6) and single-shell in the invert (segmental lining, Fig. 6). The swelling potential of the rock is taken into account adjusting accordingly the thickness of the lining and the amount of reinforcement. It is worth mentioning that in the case of "clay and sulphate swelling"

the lining system has to resist a maximum swelling pressure of 2.4 MPa (this in combination with the water pressure mentioned above). This results in a heavy reinforcement of the inner lining over a length of 150 m.

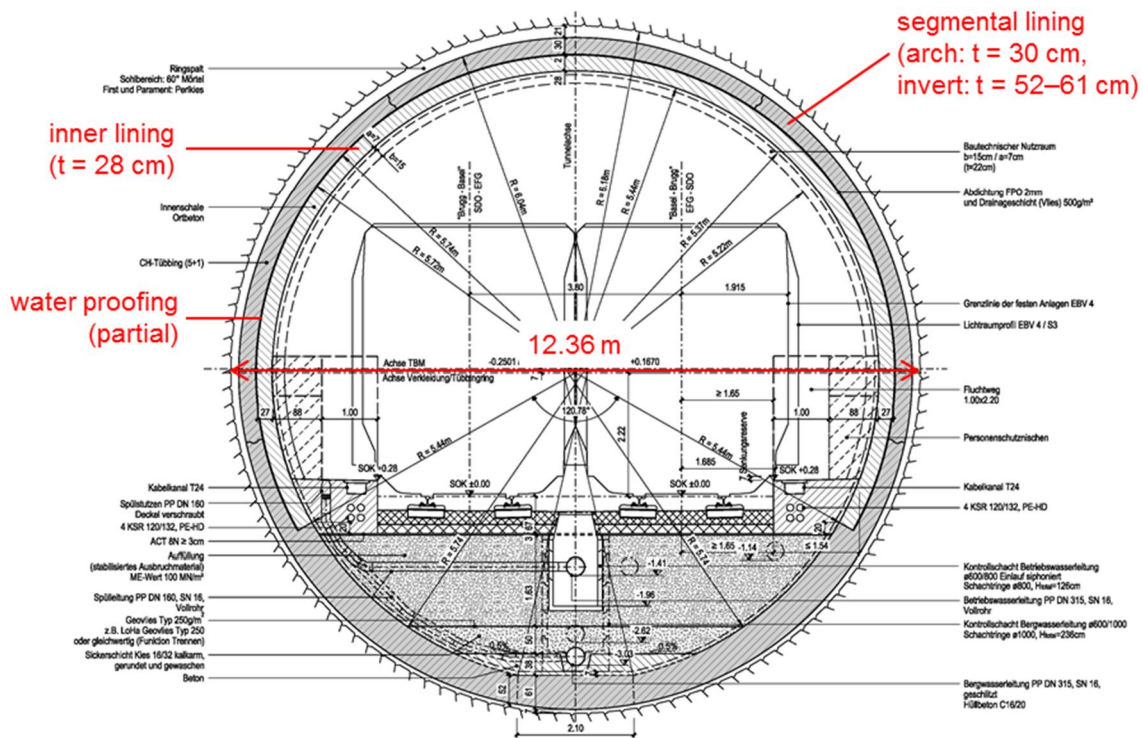
Along the entire tunnel the segmental lining consists of five segments and one keystone (placed always in the invert). The segments are 2 m width and are not waterproofed. The segments are part of the load-bearing structural system also in the long-term and, therefore, are made of sulphate-resistant concrete.



Figur 4: Herrenknecht single shielded TBM, Ø 12.36 m (picture: courtesy of Swiss Federal Railways).



Figur 5. Standard cross-section (tunnel section in rock) with double-shell lining and full water proofing.



Figur 6. Standard cross-section (tunnel section in rock) with double-shell lining in the arch, single-shell lining in the invert and partial waterproofing.

## 4 TBM BREAK-THROUGH

### 4.1 General

The TBM break-through in Effingen happened on 29 November 2017 and was very challenging. First of all, it occurred very close to the existing tunnel and railway line without stops of the railway operation. Furthermore, along the last 60 m the tunnel runs nearly parallel to a very steep slope with low overburden (Fig. 7 and Fig. 8). This required the detailed design and the implementation of auxiliary measures, a continuous monitoring and a very comprehensive risk management.

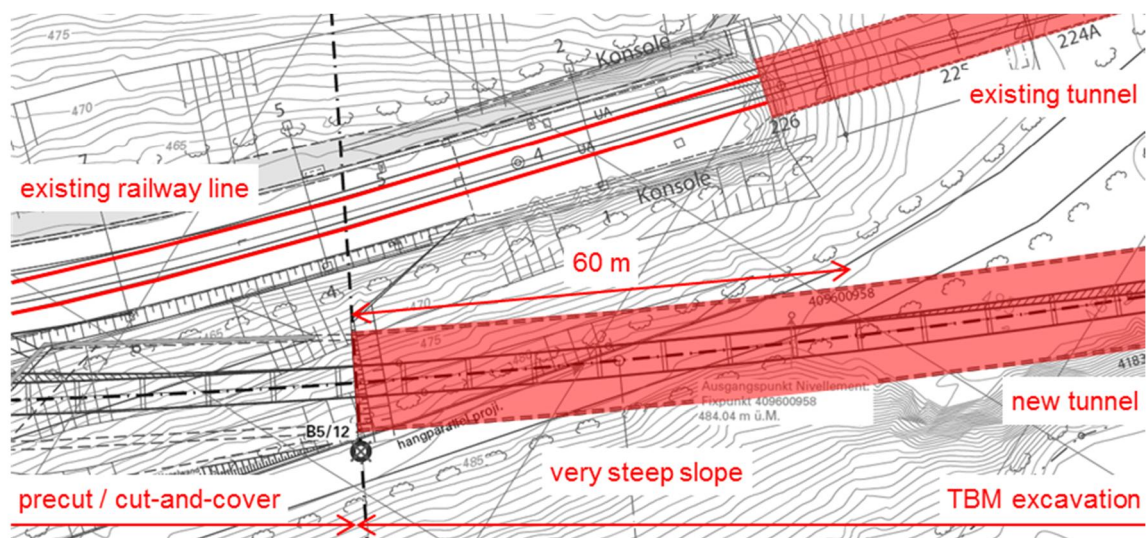


Figure 7. Plan view of the portal zone in Effingen.



Figure 8. TBM break-through.

#### 4.2 Geology / main hazard scenarios

Figure 9a shows a geological cross-section of the tunnel 4 m ahead the portal wall (TBM break-through-point) in Effingen. In this portal zone the ground consists of (from top to bottom): scree, weathered limestone, limestone and marlstone. The layer of scree and the layer of weathered limestone runs both parallel to the slope and have both a thickness of 1–2 m. The weathered limestone is intensively jointed (joint distance  $\leq 10$  cm) and fragmented. In the portal zone, only 1–2 m of sound rock overburdens the tunnel on account of the weathered limestone layer. The overburden of sound rock increases with increasing distance to the portal wall. Beyond the weathered zone, the limestone is less jointed and, in general, of good quality. The same applies for the marlstone. Within the joints, a water circulation is possible.

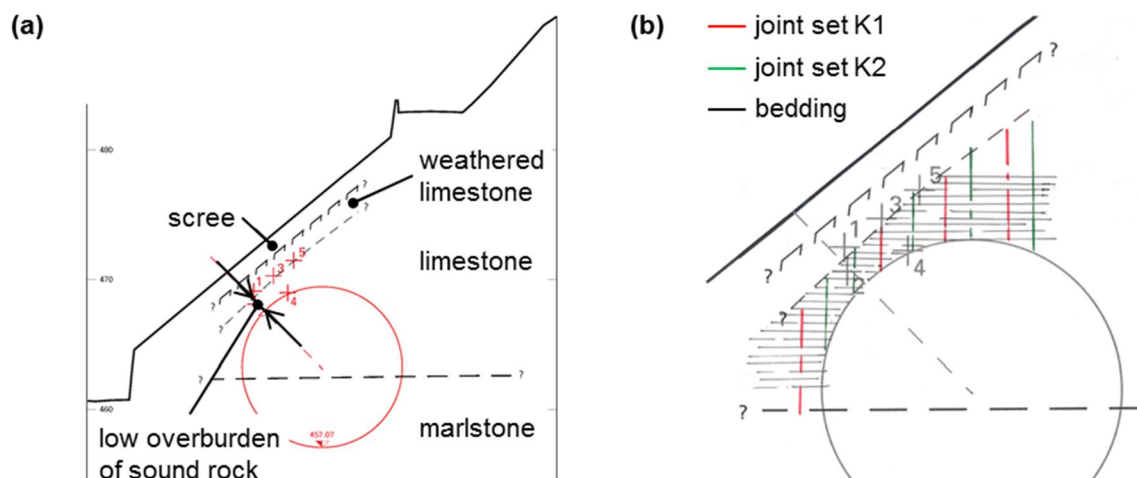


Figure 9. (a) Geological cross-section 4 m ahead the portal wall; (b) Sketch of the discontinuities (pictures: courtesy of Dr. Von Moos AG, modified).

The stability of the rock mass near to the tunnel profile – in particular, the sector with low overburden of sound rock – depends primarily on the characteristics of the joints in the limestone and on their intensity. As shown schematically in Figure 9b, in the limestone there are two pronounced subvertical joint sets (K1 and K2) with a joint spacing of 0.6–2 m and a persistency of 5–10 m, which together with the bedding planes (with a spacing of 0.2–0.3 m) may lead to the formation of instable rock blocks.

The main hazard scenarios to be considered are related to the potential instability of rock blocks. On the one hand, an instable rock block may lead (depending on its dimensions) to a block of the cutter head or to a jam of the shield (Fig. 10a). This is relevant, as – due to the low distance between TBM and slope surface as well as portal wall – the applicable torque and thrust force are limited. On the other hand, such a block may lead to a cave-in up to the surface (Fig. 10b), which itself may cause slope instability, thus endangering the existing railway line. Finally, the TBM might push a rock block towards the surface (Fig. 10c) also causing instability of the block itself or of the slope.

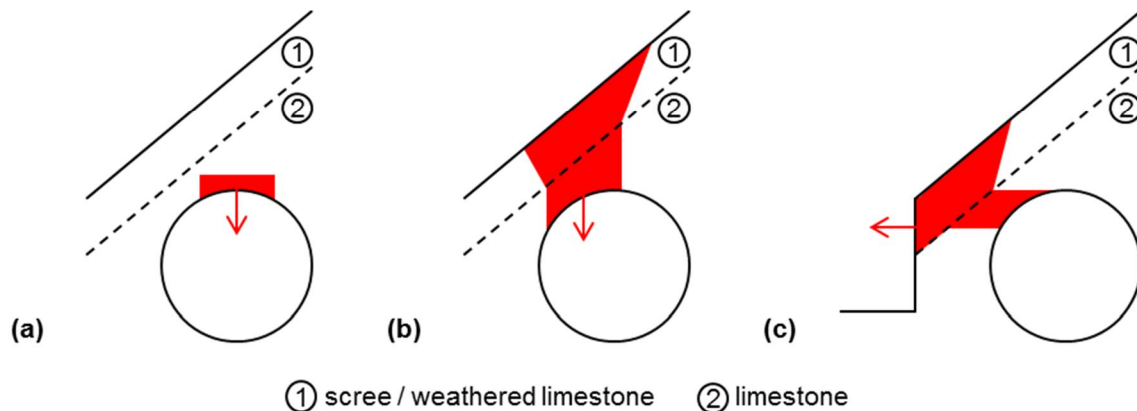


Figure 10. Main hazard scenarios: (a) instable rock block; (b) cave-in up to the surface; (c) "push-out" of a rock block.

#### 4.3 Auxiliary measures

The main auxiliary measure which has been implemented is a triple pipe umbrella (Fig. 11). Further auxiliary measures were the protection of the existing railway line by means of a temporary rolled-out protection wall (along the last 60 m of the TBM drive) and supplementary anchors in the portal wall.



Figure 11. Installation of the triple pipe umbrella (picture: courtesy of Implenia Switzerland).

The triple pipe umbrella is 16 m long and is composed of steel pipes with a diameter of 159 mm, a thickness of 10 mm and a steel quality S355 (Fig. 12). The length of the pipe umbrella has been chosen accordingly to the results of block stability analyses and numerical investigations showing that a stabilization of the rock mass is necessary at least along the last 12 m of the TBM drive. The steel pipes have been installed with a spacing of 0.45 m and an inclination of 5°. The accepted boring tolerance was of 2%. After the installation of the steel pipes, the pipes and the boreholes were filled with mortar.



Figure 12. Steel tubes of the triple pipe umbrella (picture: courtesy of Implenia Switzerland).

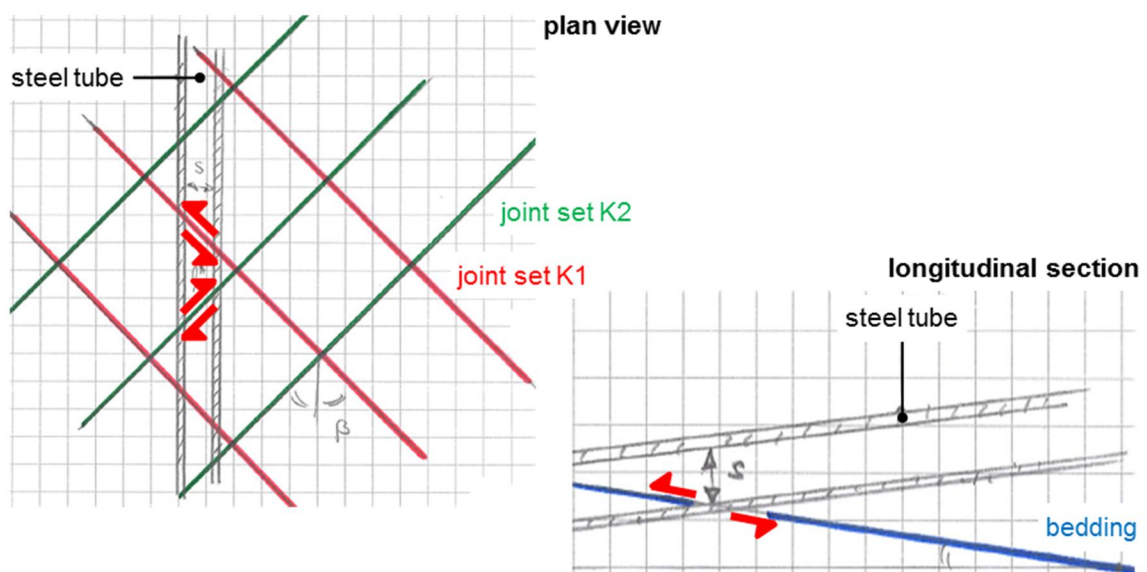


Figure 13. Sketch of the doweling effect of the steel tubes of the triple pipe umbrella.



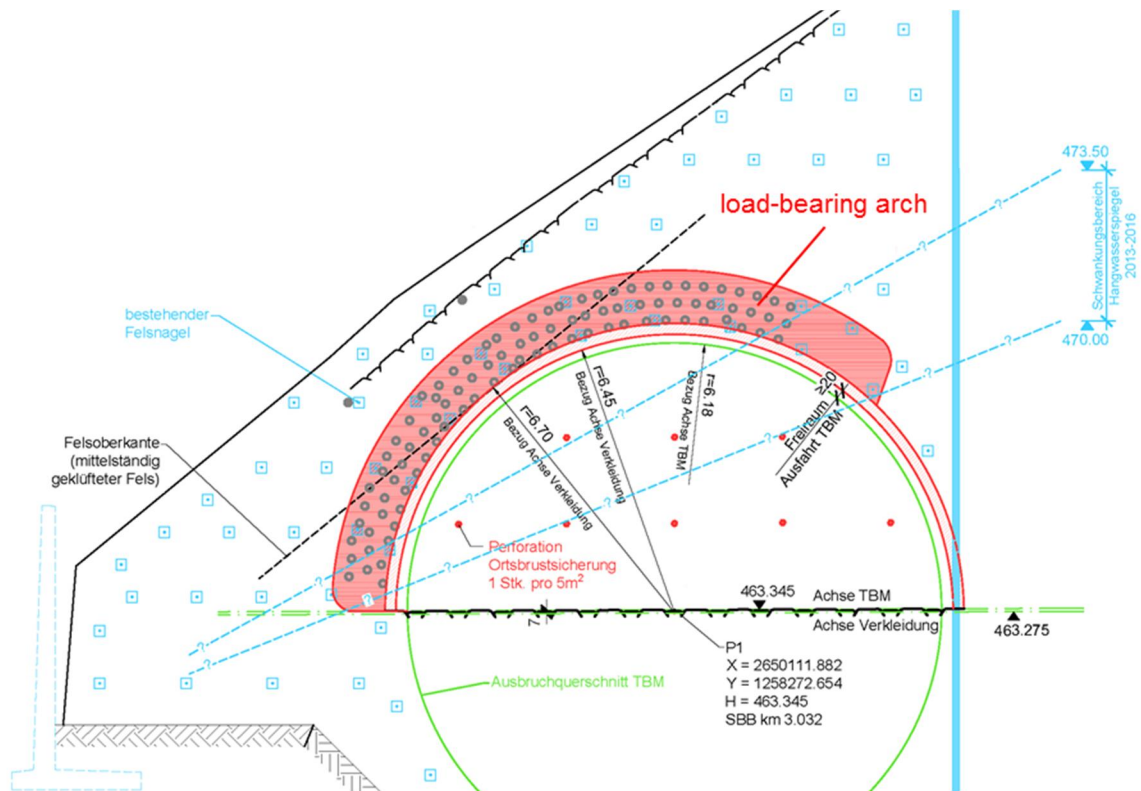


Figure 14. Sketch of the load-bearing arch (idealization).

The main function of the steel pipes is to dowel the joints in the rock mass (Fig. 13). In this way, the shear strength and the stiffness of the joints and, therefore, of the rock mass around the tunnel profile are increased, thus allowing for the formation of a load-bearing arch (Fig. 14) with sufficient bearing capacity to stabilize the opening. The steel pipes avoid not only the instability of rock blocks (Fig. 10a) and cave-ins up to the surface (Fig. 10b), but also that the TBM might push a rock block towards the surface (Fig. 10c).

A load-bearing action of the pipe umbrella in longitudinal direction has not been taken in account. Such a load-bearing action presupposes that the steel pipes are adequately supported in order to limit their span (i.e. the length of the pipes where a load is acting). However, in this case this cannot be assured with sufficient certainty. On the one hand, it cannot be excluded a priori that the rock between pipe umbrella and tunnel profile is removed from the TBM during excavation (in particular considering the presence of weathered rock and joints). On the other hand, the strength of the rock mass is not sufficient to bear the required reaction force.

#### 4.4 Continuous monitoring

During the installation of the triple pipe umbrella and the TBM excavation of the last 60 m of the tunnel continuous monitoring was on-going. The slope and the portal wall were surveyed by means of several 3D geodetic points and two 20 m long inclinometers. The triple pipe umbrella was monitored by means of further two 16 m long inclinometers. The measurements have been carried out and evaluated automatically. The results were available real-time on a web-platform. For each measurement a set of limit values (attention value, intervention value and immediate intervention value) was defined. The continuous monitoring has been stopped only after the installation and complete backfilling of the last segment ring.

In addition to the monitoring mentioned above, visual checks of the slope, the temporary rolled-out protection wall, the portal wall and the existing railway line have been carried out. During the installation of the triple pipe umbrella these visual checks were on regular basis; during the last 60 m of TBM excavation security guards inspected the existing railway line continuously.

#### 4.5 Risk management

In order to guarantee the maximum possible operational safety of the existing railway line, an exhaustive risk management has been implemented, which comprised the continuous monitoring described in Section 4.4, a specific developed alerting scheme and further auxiliary measures to be executed if required. The risk management involved – with clearly defined tasks and responsibilities – the contractor, the designer, the Owner's engineer and the Swiss Federal Railways (client).

With respect to risk management, it is worth mentioning that an emergency system was also set up in order to be able to close immediately the existing railway line in case of danger or incident. Furthermore, a direct contact with the TBM operator was established in order to stop immediately the TBM drive if necessary. This was because, in spite of the implemented auxiliary measures (Section 4.3), it was not possible to exclude totally the occurrence of undesired events with high damage potential for the existing railway line.

### 5 CLOSING REMARKS

The new Bözberg Tunnel is a very interesting Swiss tunnelling project – not only because of the challenging geotechnical conditions encountered but also from the project organization point of view, as for this project the overall performance model GU+ is applied. It is particular worth mentioning that – in compliance with one of the goals of the application of the model GU+ – the contractor and his designer implemented numerous project changes increasing quality, robustness and economics of the project.

As expected, the TBM drive was successful. The TBM break-through close to the existing railway line occurred safely without any interference of the railway operation thanks to the careful planned auxiliary measures (Fig. 15) and risk management.

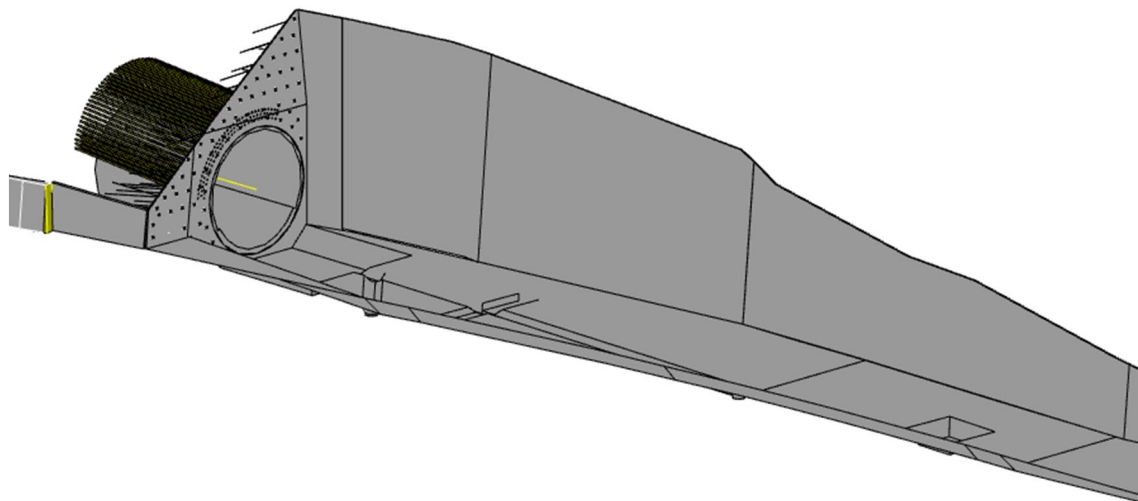


Figure 15. 3D model of the portal zone in Effingen for the detection of conflicts between anchoring of the portal wall and triple pipe umbrella.

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