DESIGN OF A MODIFIED DRAINAGE SYSTEM FOR THE BRENNER BASE TUNNEL

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ABSTRACT: The Brenner Base Tunnel (BBT) is one of the largest and most important infrastructure projects in Europe. It is a new railway tunnel between Innsbruck in Austria and Franzensfeste in Italy, which will form an important part of the European Scandinavian-Mediterranean corridor. By connecting to the existing underground bypass of Innsbruck, it will become the longest tunnel in the world with the length of 64 km. The initial work began in 2007, and commissioning is planned for 2032. In addition to a general discussion of the design and implementation of the Austrian part of the project, this article focuses primarily on the development and design aspects of the drainage system of this underground structure.

1. INTRODUCTION

The Brenner Base Tunnel (BBT) is currently one of the most important infrastructure projects in Europe. It forms the centrepiece of the north-south trans-European rail link – the so-called Scandinavian-Mediterranean Corridor (SCAN-MED) Helsinki-Valetta. It is a new railway tunnel located on the Austrian-Italian border between the cities of Innsbruck and Franzensfeste/Fortezza. In the north, the tunnel connects to the Innsbruck railway station and the existing railway in the Inn Valley; at its southern portal, it will connect to a new railway line towards Verona. Design work on this major project, jointly financed by the European Union (approximately 40-50%), Austria and Italy (approximately 25-30% each), has been underway since 1999. The investor for the entire project is the company *BBT SE*. The first construction work began in 2007. Currently, about 90% of the total 230 km of galleries and tunnels have been excavated. Commissioning is scheduled for 2032. This article focuses on the Austrian side of the project, particularly on the currently ongoing construction phases H41 *Sillschlucht-Pfons* and H53 *Pfons-Brenner*. Work has already been completed on the third section on the Austrian side, H21 *Sillschlucht*.

2. BASIC DATA ABOUT THE TUNNEL SYSTEM

The Brenner Base Tunnel is a twin-tube railway tunnel approximately 55 km long. After connecting to the *Inntal* Tunnel (Innsbruck freight bypass, see Figure 1**Error! Reference source not found.Error! Reference source not found.**) opened in 1994, the tunnel system of approximately 64 km will become the longest tunnel in the world. The tunnel consists of two single-track main tunnel tubes, 70 m apart, which are connected to each other every 333 m by cross passages. About 10 to 18 m below the level of the main tunnel tubes, in the centre between them, there is an exploratory and service tunnel, which will serve for drainage and maintenance during operation. It will also house a large portion of railway's technical equipment. An important part of the system are the three emergency stops (*Innsbruck, St. Jodok and Trens*), which are designed at distances of 20 km. The access to the emergency stops is provided through the *Ahrental*, *Wolf* and *Mauls* access tunnels. South of the *St. Jodok* station there are overpass tunnels for the passage of trains between the east and west tunnel tubes.

Longitudinally, the tunnel is designed with a roof-like gradient, with the northern Austrian side rising at a gradient of 6.7 ‰ up to the top arch at the state border and then descending towards the southern portal in Italy at a gradient of 4.0 ‰. The tunnel line is designed for a maximum speed of 250 km/h, with the exception of the portal areas. The maximum tunnel overburden is approximately 1700 m.

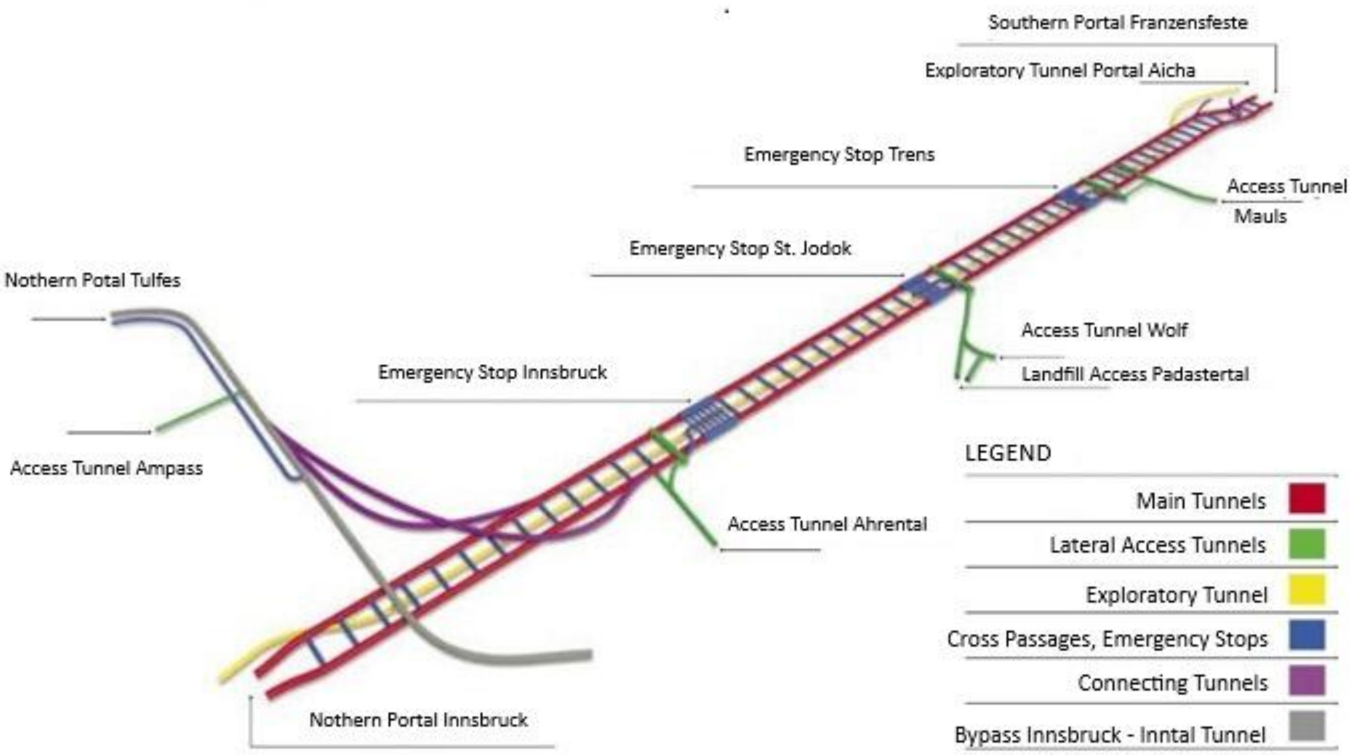

Figure 1: Diagram of the BBT tunnel system

3. GEOLOGY AND HYDROGEOLOGY

The Brenner Base Tunnel passes through the transition zone between the Northern and Southern Alps. It traverses three major tectonic units of the Alps: Eastern Alpine (*Ostalpinikum*), *Penninikum* and Southern Alpine (*Südalpinikum*).

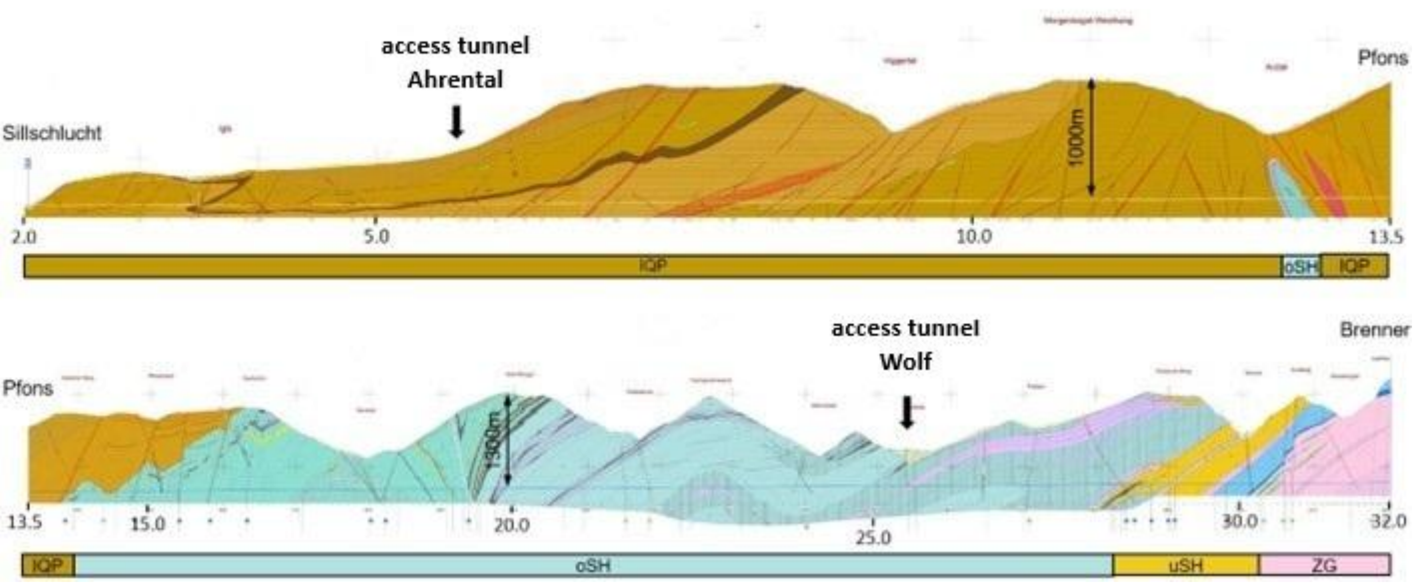

Figure 2: Geological longitudinal section on the Austrian side of the tunnel

The simplified sequence of the most important geological formations, starting from the north portal, consists of:

- quartz phyllites (*Ostalpiner Innsbrucker Quarzphyllit*) – approximately km 0-14

The Tauern window elevation with Penninic schists and the central gneiss massif:

- Penninic schists (*penninische Bündnerschiefer*) upper schist shells (*Obere Schieferhülle*) - limestone schists and limestone phyllites with intercalations of "exotic" blocks of carbonate and sulphate rocks in the northern part; lower schist shell (*Untere Schieferhülle*) with the *Hochstegen* fault zone and partially karstified marble (*Hochstegenmarmor*) at the border with the central gneiss massif – approximately km 14-30.3
- sub-Penninic central gneiss massif (*subpenninischer Zentralgneis*) formed by orthogneisses and metagranites, bordered by amphibolites and gneisses (*Hornblendegneise*) – approximately km 30.3-36
- zone mainly of Penninic schists (*penninische Bündnerschiefer*) – approximately km 36-45.4
- eastern alpine gneisses and schists – approximately km 45.4-47.5
- Periadriatic fault – approximately km 47.5-48.2
- southern alpine Brixen granites – approximately km 48.2-55

The line includes several fault zones, such as the *Inntal* Valley Fault System, the *Wipptal* Valley Fault System, and particularly the Periadriatic Fault, which is one of the largest fault systems in the entire Alpine arc.

The location, characterization and subsequent classification of fault zones was given special attention during exploratory pre-drilling and during the excavation of the exploratory tunnel. Together with data on the individual “homogeneous” areas, information on the fault zones was the starting point for all considerations on the choice of tunnelling method.

Penninic shists and quartz phyllites are generally characterized by low permeability, so that long sections of the excavation were practically dry. Large inflows of pressurized groundwater were encountered in the *Hochstegen* fault zone during the exploratory pre-drilling.

4. OVERVIEW AND CURRENT STATUS OF INDIVIDUAL CONSTRUCTION SECTIONS

4.1 DIVISION INTO CONSTRUCTION SECTIONS

Due to its complexity, the BBT tunnel system is divided into several exploration and construction sections on both the Austrian and Italian sides, with their respective designs being specifically developed for each country. In contrast, all components of the tunnel railway equipment are designed uniformly.

An overview of the exploration as well as main construction sections is provided in Table 1 and **Error! Reference source not found.**.

Table 1: Overview of BBT exploration sections

Designation	Name of exploration section	State	Implementation date
E41	Ahrental	Austria	2010-2014
V41	Ahrental ventilation cavern and Patsch shaft	Austria	2013-2014
E51	Wolf 1	Austria	2011-2013
E52	Wolf 2 - Padastertal	Austria	2013-2017
E53	Geological survey of Hochstegen zone	Austria	2017-2018
E62	Crossing of Periadriatic Fault	Italy	2013-2016
E91	Aicha Mauls	Italy	2007-2012

Table 2: Overview of BBT main construction sections

Designation	Name of construction section	State	Implementation date
H11	Innsbruck Train Station	Austria	2016-2021
H21	Sillschlucht	Austria	2020-2024
H33	Tulfes Pfons	Austria	2014-2021
H41	**Sillschlucht-Pfons**	**Austria**	**2021-2029**
H51	Pfons-Brenner	Austria	2018-2020
H52	Hochstegen	Austria	2022-2023
H53	**Pfons-Brenner**	**Austria**	**2024-2029**
H61	**Mauls 2-3**	**Italy**	**2016-2027**
H71	Eisack Underpass	**Italy**	2015-2024
H81	**Franzensfeste Train Station**	**Italy**	**continuously**

4.2 CURRENT STATUS OF CONSTRUCTION WORKS

As already mentioned in the introduction, the first construction works started in 2007. Currently, approximately 90% of the total of 230 km of galleries and tunnels have been excavated (see Figure 3), of which approximately 50% were excavated conventionally using the New Austrian Tunnelling Method (NATM) and 50% using tunnel boring machines (TBM). On the Austrian side, all access and connecting tunnels, both emergency stops, the exploratory tunnel and most of the length of the main tunnel tubes and tunnel cross passages have already been excavated. The excavation of the remaining parts of the main tunnel tubes and tunnel cross passages in the H53 *Pfons-Brenner* section is currently underway and secondary lining is being built on several construction sections. The Italian part of the project is already completely excavated, except for some parts of the *Trens* emergency stop and tunnel cross passages. An important milestone of the entire project was the breakthrough of the exploratory tunnel at the Austrian-Italian border, which took place in September 2025. The breakthrough of both main tunnel tubes should take place in 2026. The entire tunnel is expected to be put into operation in 2032.

This article will also deal with the Austrian part of the project, which has been processed since 2015 by the design association of companies *Projektgemeinschaft Brenner Basistunnel Nord* (*PG BBTN*), whose leader is *Amberg Engineering AG*. The association was asked by the investor to prepare the tender and implementing documentation of the construction and to deploy geotechnical supervision at the construction site. Specifically, this article will focus on the currently constructed sections H41 *Sillschlucht-Pfons* and H53 *Pfons-Brenner*.

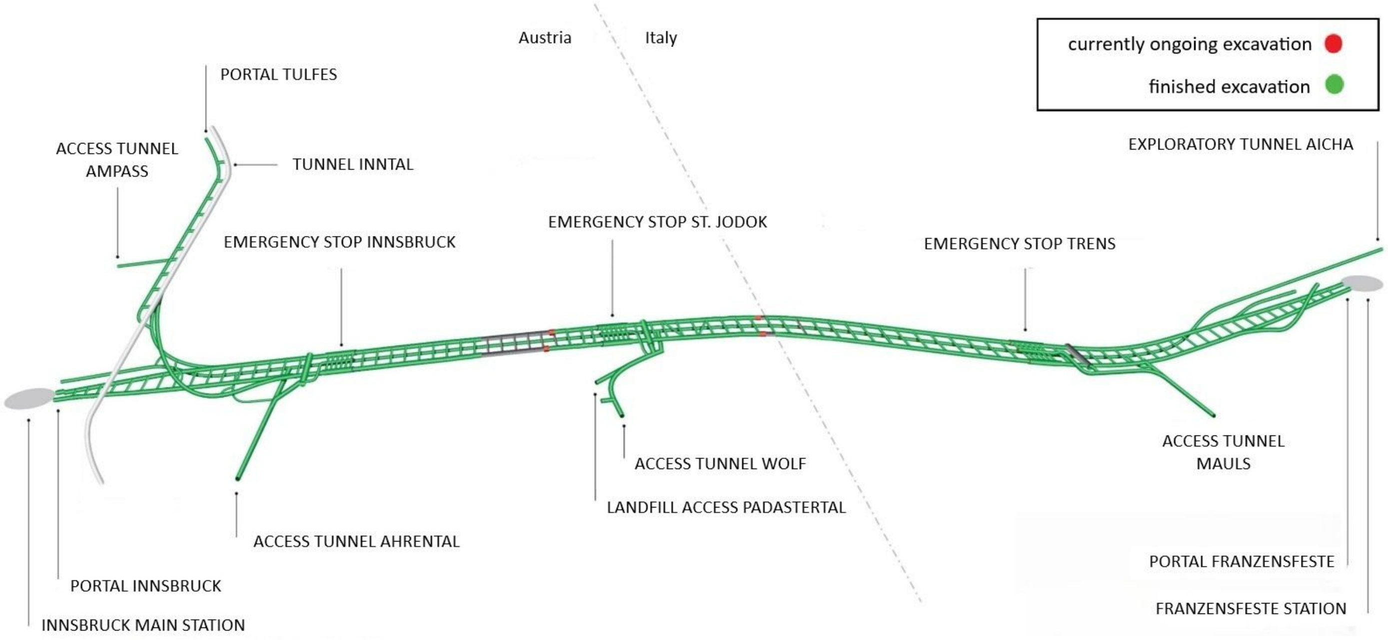

Figure 3: Current status of excavations

4.3 CONSTRUCTION SECTION H41 *SILLSCHLUCHT-PFONS*

The construction section H41 *Sillschlucht–Pfons* includes the excavation of the remaining parts of the main tunnels (approximately 22 km long) and 38 tunnel cross passages in the area between the north portal and the chainage of approximately 16.5 km, which were not excavated during the construction of the previous sections H21 and H33. In addition, the construction section includes the secondary lining of the main tunnels, the exploratory tunnels and 38 tunnel cross passages as well as the secondary lining of the *Innsbruck* emergency stop, the *Ahrental* cross cavern and access tunnel, the *Patsch* tunnel, the *Sillschlucht* access tunnel and the access tunnel to the *Innsbruck* emergency stop. The construction section also includes a large area of site facilities with a factory for the production of tubbings and a bridge over the A13 Brenner motorway.

Construction work on the H41 section has been ongoing since 2022. The excavation of the main tunnels, which was carried out using two tunnel boring machines in the section south of the *Innsbruck* emergency stop and conventionally using the NATM in the section north of the station, was fully completed in the autumn of 2025. Conventional excavation of the remaining tunnel cross passages is currently underway. Secondary lining is being built in several places. All work is expected to be completed in 2028.

4.4 CONSTRUCTION SECTION H53 *PFONS-BRENNER*

The construction section H41 is connected with the construction section H53 *Pfons–Brenner*, which includes the excavation of the main tunnels (approximately 25 km long) and 37 tunnel cross passages between the chainage of approximately 16.5 km and the state border (approximately 32.0 km) and the excavation of the remaining part of the exploratory tunnel to the Italian border. Section H53 also follows on from the construction work previously carried out within section H52. It also includes the secondary lining of the main tunnels, the exploratory tunnels and 45 tunnel cross passages between the chainage of approximately 16.5 km and the state border, the secondary lining of the *St. Jodok* emergency stop including the adjacent transverse cavern and the overpass tunnels and the secondary lining of *Wolf*, the access tunnel, and the tunnels and galleries in the *Iris* and *Hochstegen* fault areas.

Construction work on section H53 started in 2023. The excavation of the exploratory tunnel was completed with a ceremonial breakthrough at the Austrian-Italian border in September 2025. The excavation of the main tunnels is currently underway, consisting of simultaneous mechanical excavation using a pair of tunnel boring machines in the direction north of the multifunctional *St. Jodok* station and conventional excavation in the direction south of the station towards the Italian border. Simultaneously with the excavation of the main tunnels, conventional excavation of the associated tunnel cross passages is underway. Secondary lining is being built in several places. All work is expected to be completed by early 2029.

5. DRAINAGE DESIGN FOR THE AUSTRIAN PART OF THE TUNNEL SYSTEM

Groundwater and water from the traffic area are drained by a separate system. Thanks to the designed longitudinal gradient of 6.7 ‰, all water inflows on the Austrian side are drained towards the north portal of the tunnel.

With respect to such a large structure, the drainage system, as well as all technical equipment requiring future maintenance, have a significant impact on future operational and technical costs. The investor's goal was to design a drainage system with the lowest possible maintenance requirements in the main tunnels so that future traffic closures would be minimized. The BBT tunnel system with a proposed continuous exploratory tunnel below the level of both main tunnels (see Figure 4) enables the effective use of the exploratory tunnel in the future both for groundwater drainage and for maintenance of technical equipment during operation.

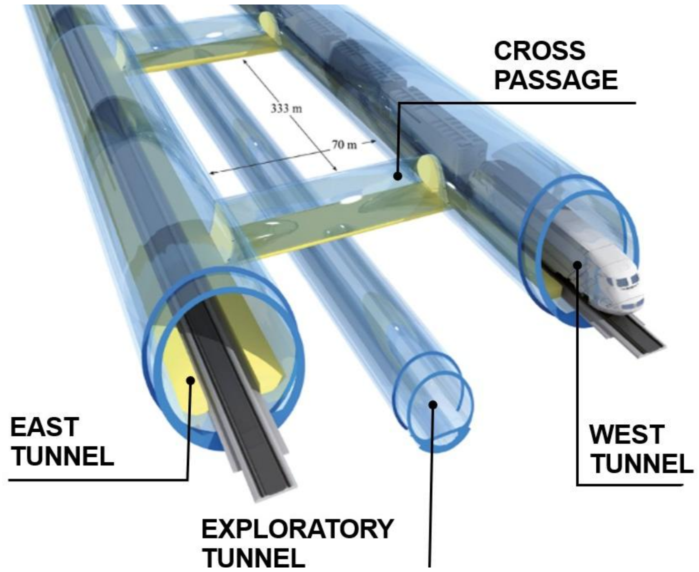

Figure 4: Diagram of the transverse arrangement of the main tunnel tubes and the exploratory tunnel

5.1 ORIGINAL DESIGN OF THE DRAINAGE SYSTEM

Within the scope of the tender documentation for the construction sections H41 and H53, two groundwater drainage systems were defined – A and B.

In system A, in the conventionally excavated sections of the main tunnels, an umbrella waterproofing with back footing drainages was designed. The transverse tunnel cross passages and connecting corridors in the emergency stops have a roof-like longitudinal gradient and are drained using back footing drainages towards the main tunnel tubes. At regular intervals of approximately 125 m, cleaning and/or inspection shafts were designed in the main tunnel tubes.

In system B, which is used in all sections of the main tunnels excavated by the tunnel boring machine, the water is diverted every 333 m into the cross passage, which, unlike system A, always has a falling longitudinal gradient towards the exploratory tunnel, into which the water is diverted via a vertical drainage pipe either in the form of a vertical borehole (see Figure 5) or via a vertical connecting shaft (every 2000 m). The water is then run through the exploratory tunnel to the north portal, where it is directed into the watercourse, the *Sill* River. System B has two sub-variants according to the type of filling behind the back of the segment lining:

- System B1 was designed in a compressive environment, where the space behind the back of the lining is injected with mortar. This material is characterized by low to almost no permeability and therefore cannot fulfil the drainage function. Therefore, to capture and drain groundwater, it is necessary to lay continuous longitudinal footing drains inside the segment lining, from which the water is subsequently drained into the tunnel cross passage.
- System B2 is designed in sections where the space behind the back of the lining can be filled with pea gravel that fulfils the drainage function. Here, it is therefore not necessary to install longitudinal footing drains continuously, but only in limited areas just before and after the mouth of each tunnel cross passage, where the space behind the back of the lining is injected with mortar. In these short sections, water from the space behind the lining is run through drilled holes through tubbings.

The determination of the drainage system (B1 or B2) should always take place in cooperation between the investor and the designer in the implementation phase, depending on the actually detected inflows and the type of filling installed.

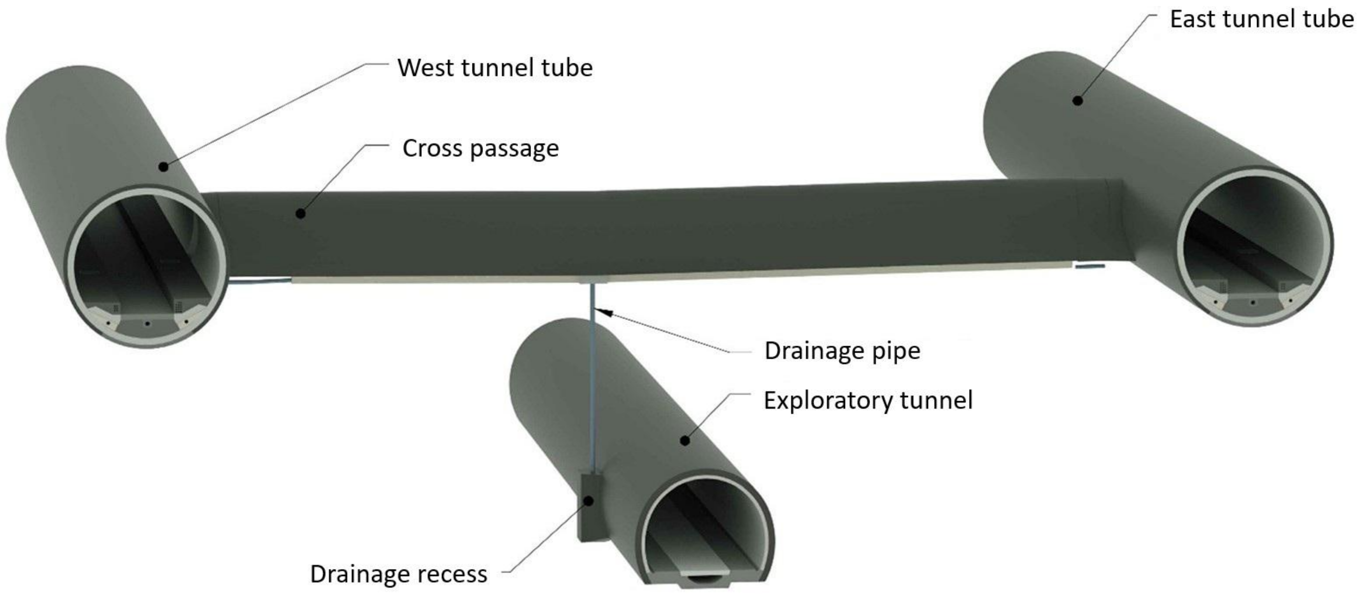

Figure 5: 3D model of the original drainage design in the section excavated by TBM (system B)

5.2 DESIGN OF A MODIFIED DRAINAGE SYSTEM

During the design phase of the detailed design documentation for construction sections H41 and H53, the investor requested, based on the development of long-distance cleaning systems, to modify the original drainage concept designed according to the tender documentation. The aim of this optimization was to reduce future costs for cleaning and maintenance of the entire drainage system and to enable this work to be carried out, if possible, without interrupting operation in the main tunnel tubes.

The basic idea of the modified drainage system is to clean all pipes for groundwater drainage in the main tunnel tubes as "remotely" as possible, i.e. without the need to enter the operated main tunnel tubes. The system assumes the use of a special cleaning device, which will be transported during tunnel operation through one of the access tunnels to the exploratory tunnel (which will serve for drainage and inspection purposes during operation), from where it will be able to clean all the tunnel drainage pipes in a section of approximately 1000 m (= cleaning section, see Figure 6).

The modified drainage concept still works with two drainage systems (A, B), but their division - unlike the original concept - no longer depends on the method of excavation of the main tunnels, but only on the direction and method of groundwater drainage.

System A is used in tunnel cross passages, or rather connecting corridors in emergency stops, which have a roof-like longitudinal gradient and drain water towards the main tunnel tubes using a central drainage, which replaces the originally designed pair of back footing drainages. This system drains all groundwater from the cross passages into the main tunnel tubes in a section of approximately 1000 m (see Figure 6).

The water is then diverted from the main tunnel tubes into the central drainage of the B system cross passage approximately every 1000 m (see Figure 6 and Figure 7)**Error! Reference source not found.**. These cross passages always have a downward gradient towards the vertical connecting shaft, through which the water is discharged into the exploratory tunnel and subsequently to the north portal. All groundwater of the tunnel system therefore ends up in the exploratory tunnel.

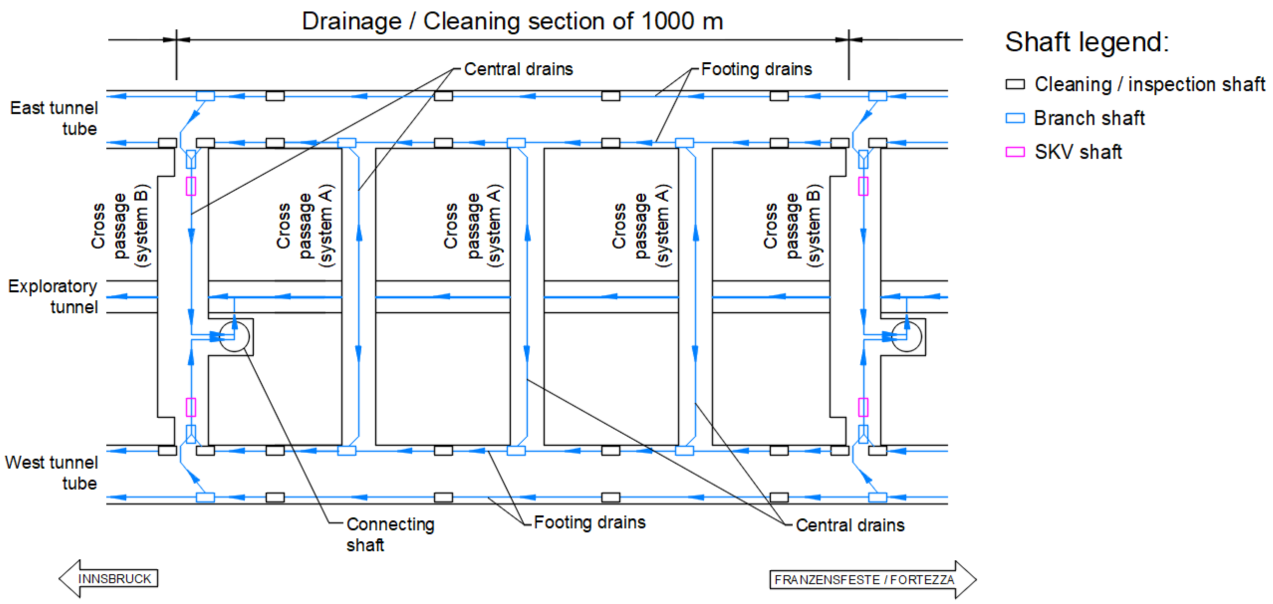

Figure 6: Design of the principle of the modified drainage system

In the main tunnel tubes, the originally designed cleaning and/or inspection shafts are left in the sections between the individual tunnel cross passages, but they will only function as a reserve cleaning system. In the area of the tunnel cross passages, special types of prefabricated inspection shafts (branch and so-called SKV shafts) have been newly designed specifically for the optimized cleaning method. This also requires the use of special fittings for the elbows of the drainage pipes with regard to their minimum radius and maximum angle. Cleaning will be carried out using a special cleaning truck from the recess of the exploratory tunnel at the location of each vertical connecting shaft (see Figure 7), from where all the drainage pipes in the main tunnels and tunnel cross passages of the approximately 1000 m long section will be cleaned using high-pressure pumps. A condition for the system to function is that all pipes must be accessible for cleaning with a flushing nozzle through the branch and SKV shafts. In addition, sufficient space must be provided for the placement of the cleaning equipment including the necessary infrastructure (electricity connection, water supply, data network connection).

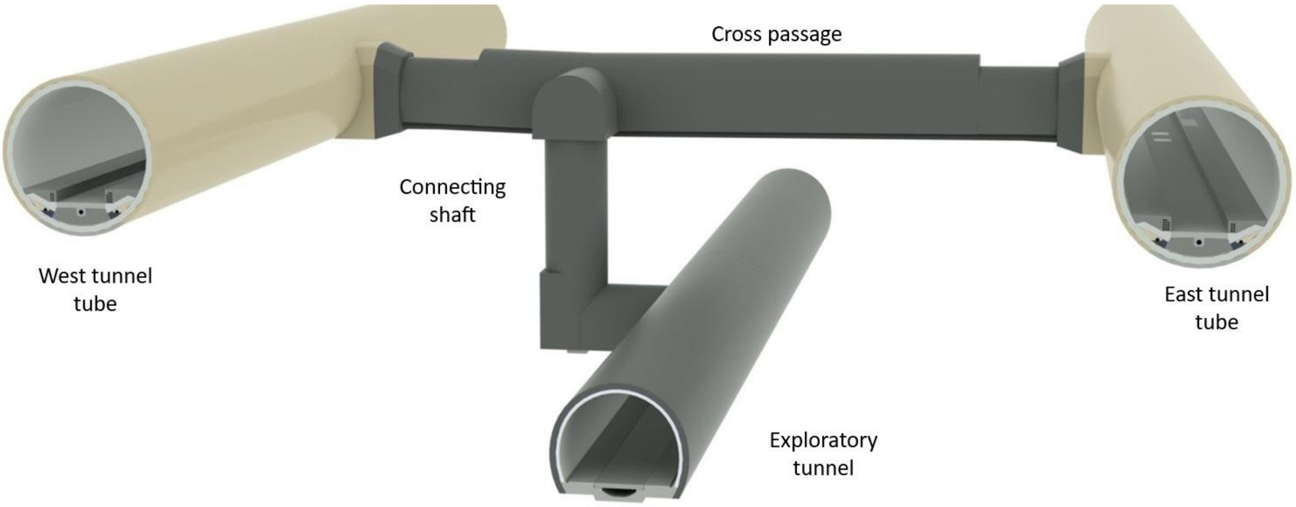

Figure 7: 3D model of the modified drainage system (system B)

6. CONCLUSION

The Brenner Base Tunnel is a completely unique project in terms of its size and significance. Compared to other long tunnel structures in Europe, it has the advantage that, in addition to the standard main tunnel tubes intended for traffic, it also contains a third tunnel tube, which is accessible not only from both portals, but also from three other access structures from the surface. This allows its future use not only for maintenance of technical equipment during the tunnel operation phase, but also - thanks to the new concept of the drainage system - for cleaning all drainage elements without the need to interrupt operation, which will significantly save future operating costs.

The trend in using cleaning systems that do not require restrictions on operation in the tunnel during cleaning is currently also being promoted in other large tunnel projects in Austria. A similar cleaning method was designed, for example, in the *Semmering* or *Koralm* base tunnels.

The change in the concept of the BBT drainage system represented a major challenge for all stakeholders involved in the project (investor, designer, supervisor and contractor). From the designer's point of view, it was a significant modification of the already considerably advanced project documentation, which was developed in parallel with the construction. Thanks to the effective and reliable cooperation between the stakeholders involved, all the challenges and problems associated with the optimization of drainage were successfully managed. At present, elements of the modified drainage system have already been built at several locations in construction sections H41 and H53; the system has already been successfully tested from the point of view of deploying the cleaning equipment directly at the construction site. Nothing now prevents its future operation.

7. ACKNOWLEDGEMENTS

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