

## **Semmering Base Tunnel – Large Caverns for Permanent and Temporary Use**

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### **Abstract**

The paper covers the construction and use of large caverns for temporary and permanent purposes on the example of the 27km long Semmering Base Tunnel in Austria. Semmering Base Tunnel is a twin tube, single-track railway tunnel with numerous cross passages and an underground emergency station with ventilation located approximately at the center of the tunnel system. The construction started in 2014 and is ongoing until 2026.

The emergency station, which is located at the toe of two 400 m deep shafts, requires the construction of large permanent caverns with dimensions in the range of 20 by 18 m. The available space in these caverns will also be used during construction for the placement of site installations underground in order to optimize the logistic procedures and avoid disruptions in supply and discharge via the shafts.

Intermediate access points are provided by 120 to 200 m deep shafts, which also require the construction of temporary caverns at the shaft bottom for site installations, material storage and transport purposes. In one case even shaft head caverns are carried out as the shafts start underground at the end of a 1.2 km long access tunnel.

For the construction in difficult geological conditions complex headings and special support measures using the SEM are applied. Advanced numerical 2D- and 3D-calculations were carried out to verify the adequacy of the designed solutions. The final configuration of the permanent and temporary caverns includes the installation of a drained, secondary lining or a complete backfill in case of the temporary structures.

**Keywords:** Caverns, Shafts, Site Installation, Construction Logistics

### **1. Introduction**

The content of the paper covers the construction of temporary and permanent caverns at the example of an actual project currently carried out in Austria.

The boundary conditions requesting the construction of the caverns such as safety regulations, logistic purposes or overall schedule requirements are addressed.

The chosen solutions for the construction of the caverns as well as its configuration for the temporary and the final stage are presented.

### **2. Project overview**

Semmering Base Tunnel is located app. 80 km south of Vienna in Austria and is part of the Baltic-Adriatic Railway Corridor, which runs between the Baltic Sea from Gdansk in Poland to the Adriatic Coast near Bologna in Italy (see Figure 1).

Currently the mountain crossing consists of a railway line including numerous tunnels and viaducts with a steep gradient and small radii. As such conditions are not matching with modern rail transport requirements the construction of the tunnel is required.

The existing railway line, which is also designated as a world heritage site, will remain in place and act as a fallback in case of necessity and also for touristic purposes.

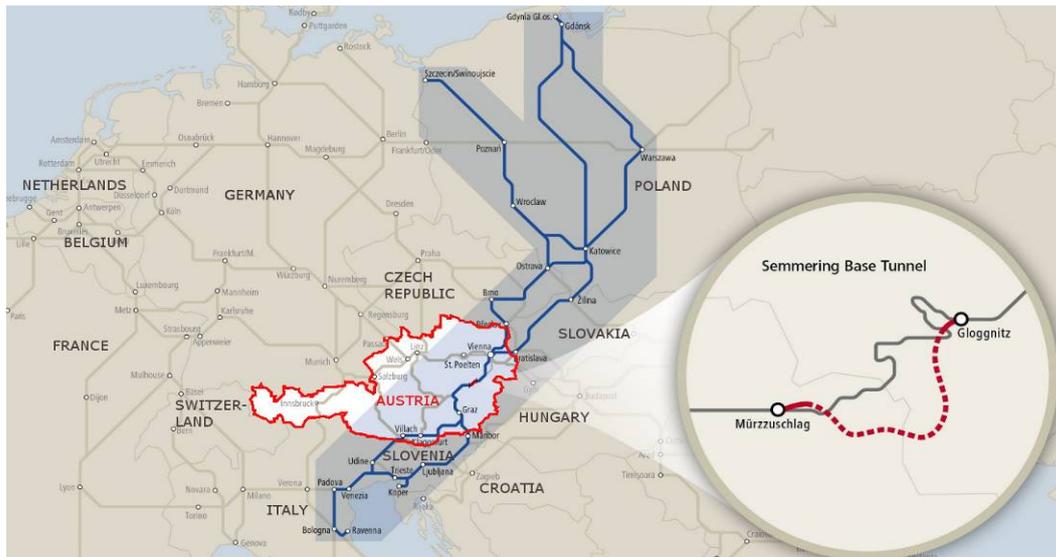


Fig. 1. General location (source: OEGB)

The final tunnel system includes two more than 27 km long parallel single track tubes connected by 56 emergency cross passages and centrally located emergency station with various caverns and two, more than 400 m deep, ventilation shafts.

Additional caverns are required at intermediate access points consisting of two 100 m deep shafts and two additional 200 m deep shafts. The caverns are located at the toe of the shafts and in the case of the deeper shafts also at the shaft heads. These shafts are excavated underground starting at the end of a 1.2 km long access tunnel.

The tunnel and access layout is provided in Figure 2.



Fig. 2. Tunnel layout (source: OEGB)

Due to schedule requirements the entire project is divided into three underground construction lots with individual points of access, mainly via shafts. An additional construction lot includes a cut&cover section as well as the related tunnel ramps and the modernization of the railway station Muerzzuschlag at the southern portal.

The total investment costs for the project are around 3.3 bi. Euros, whereas 1.5 bi. Euros are related to the civil construction works. The underground construction works carried out by NATM and TBM method started in 2014 and will be finished by 2022. The installation of the secondary lining, track works, electrical installations and signaling will take until 2026.

### 3. General geological conditions

Overall the geological conditions of the tunnel system can be described as an area of intense tectonic imbrication. Metasediments such as phyllite, schist, quartzite, locally sulphate rocks and metasediments of various tectonic units as well as carbonate rocks and highly fractured metamorphic crystalline schist and gneiss will be encountered.

Distinct fault zones with extensive folding and nappe stacking divide the individual geological units. Fault zones consisting of cataclastic fault material with high overburden are especially challenging to the construction procedure. Water inflow of up to 300 l/s can be expected within the carbonate rock formations.

For the design and implementation, the tunnel was divided into 33 ground sections, of which more than 50 ground types were evaluated by the geotechnical design team. Ground sections can be characterized as tunnel sections, which show similar conditions in terms of geological structure or units, proportions of ground types and hydrogeological conditions. A ground type consists of a rock mass with similar in-situ properties, which refers to a volume of geotechnical relevance for the project.

Individual designated ground sections are evaluated for the cavern sections including their respective ground types under consideration of the enlarged cross sections and mostly differing heading directions. The geological conditions in the permanent caverns of the emergency station can be characterized as a mixture of fractured gneiss and schists of the Wechsel unit with intersecting cataclastic shear zones. The groundwater conditions are quite favorable with no major water inflow.

Figure 3 shows a typical section of the geological longitudinal profile of a part of the tunnel alignment indicating the frequently changing geological conditions along the alignment.

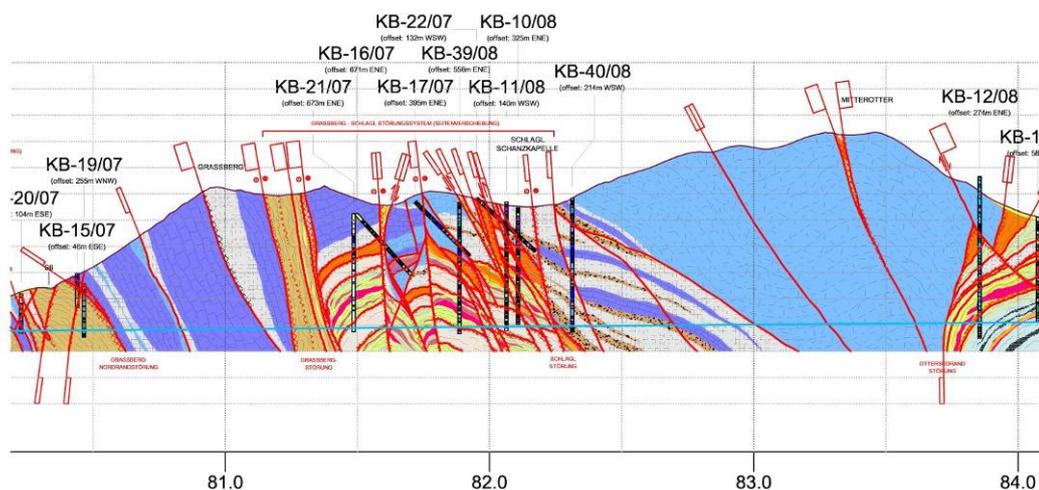


Fig. 3. Geological prognosis of typical tunnel section (source: 3G)

#### 4. Design and construction

Excavation of the caverns and related structures was only possible via the 100 m to 400 m deep shafts, which required already during the design and tender phase the evaluation of detailed heading concepts and support measures by the design team.

Apart from the design for the heading concept and support sophisticated 2D and 3D analyses were carried out as to verify the adequacy of the chosen approach. Figure 4 shows examples of 3D models used in the calculations for caverns at the head and the toe of various shafts.

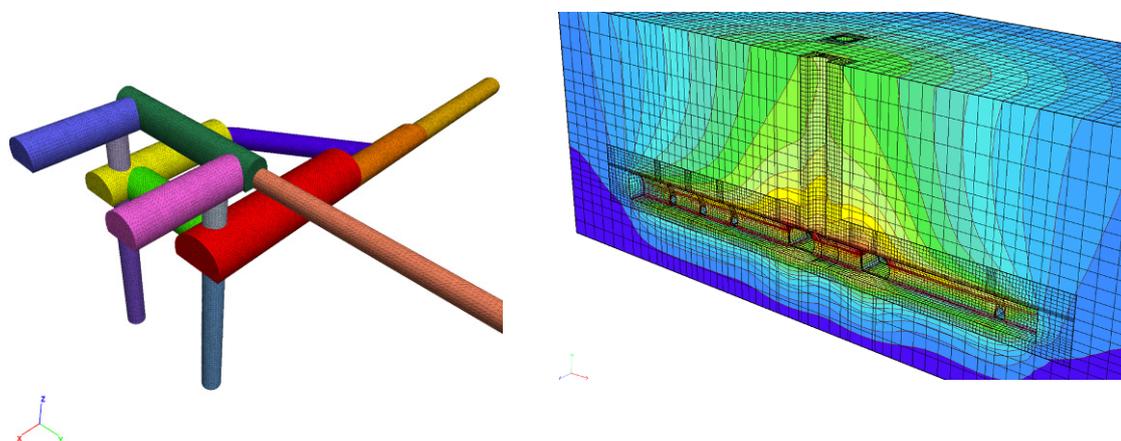


Fig. 4. 3D models of caverns for FE analyses (source: PGST)

Due to the sizes of the caverns a subdivision into a top heading, two or three benches (depending on the size) and an invert was required. In case of necessity the application of a sidewall gallery in the top heading was foreseen. The maximum excavation area for the caverns resulted in approximately 350 m<sup>2</sup>.

The applied support measures included reinforced shotcrete with a thickness ranging between 30 cm and 40 cm, lattice girders and forepoling pipes with a length of 4 m. Self-drilling injection bolts were installed along the excavation contours in the top heading and benches in a regular pattern as well as for face support measures. The face support was combined with a reinforced layer of shotcrete in case of requirement. The round length in the top heading and bench varied between 0.8 m and 1.3 m, with a doubled round length in the invert. In order to compensate enlarged deformations of up to 35 cm for certain caverns lining stress controllers were installed (see Figure 5.).

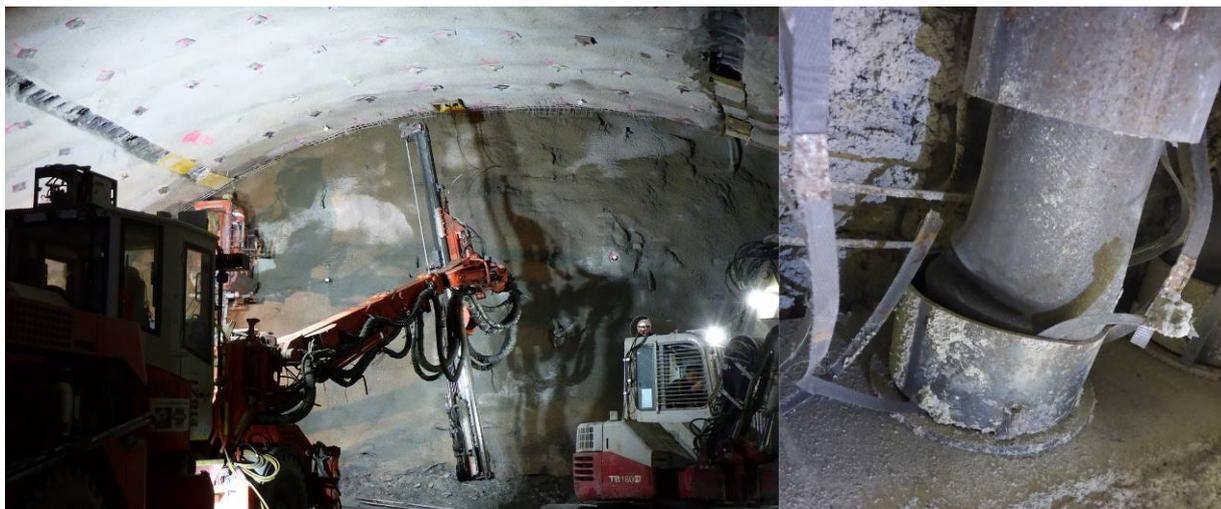


Fig. 5. Lining stress controllers in cavern (source: PGST)

## 5. Permanent Caverns

### 5.1 Layout

At the center of the tunnel alignment an emergency station is positioned, which is in accordance to the required safety regulations. In case of an accident trains will stop in the station and passengers will be transferred to rescue trains approaching via the non-affected tunnel tube.

The main structures within the emergency station are two large caverns for ventilation and logistic purposes, which are oriented perpendicular to the main tunnel tubes. In addition the rescue cavern is situated in between and running parallel to the running tunnels. The maximum size of the caverns is about 20 m by 18 m. The rescue cavern is connected to the main tunnel tubes via short escape passages and ventilation tunnels (see Figure 6.). For a possible material transport by conveyor belts four temporary logistic passages are foreseen, which are aligned accordingly.

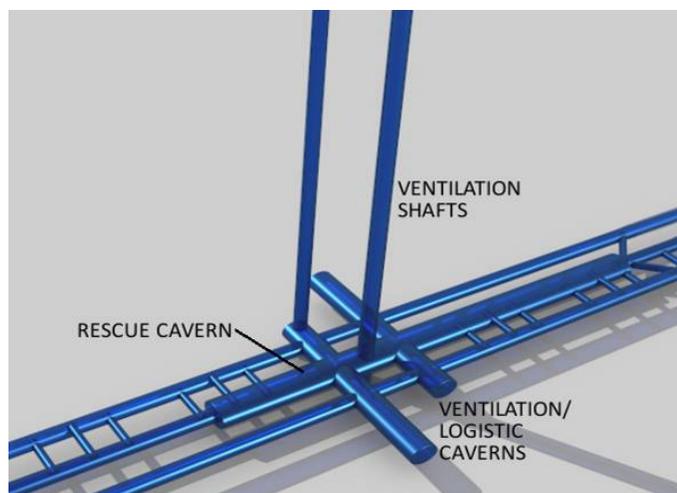


Fig. 6. Scheme of caverns in emergency station (source: OEBB/PGST)

### 5.2 Temporary use of caverns

All supply and discharge of material for the construction of the tunnels is required via the 400 m deep shafts, thus creating a potential logistics bottleneck, which can have a major impact onto the envisaged construction time. Therefore, the majority of the required site installations has to be placed underground.

Offices, staff rooms, sanitary installations, warehouses, workshops, a filling station, a concrete laboratory, an explosives magazine as well as rescue facilities for all staff underground have to be foreseen. In addition for avoidance of shortage of construction materials, depots for cement and concrete aggregates, pea gravel for the annular gap filling or storage areas for various support materials are required to be placed underground. The installations for the mucking of the excavated material include the conveyor belt system, crushers and bunkers. The two TBM's for the northern drives of the main tunnels are also assembled in the caverns.

Pumping and settling tanks are arranged to pump any water to the surface for further treatment prior to the discharge in the receiving waters.

Figure 7 shows the arrangement of some of the installations in the ventilation cavern as well as the permanent ventilation gallery and temporary mucking gallery, connecting the caverns with the main tunnel tubes, during the construction phase.

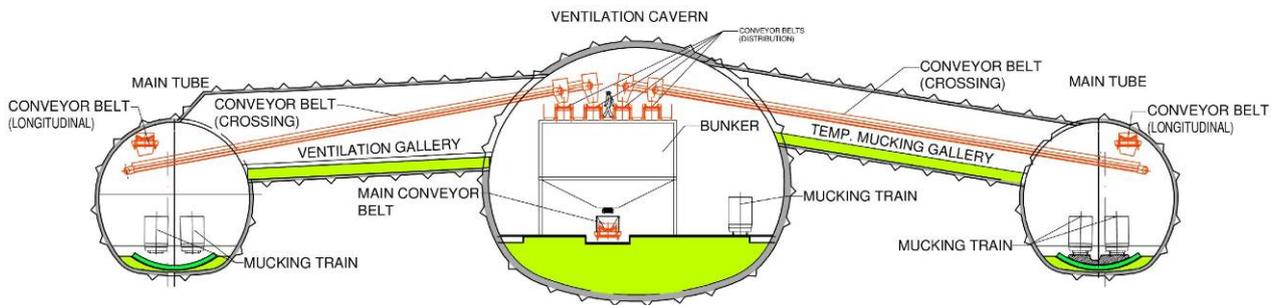


Fig. 7. Cavern and passage installations (source: OEGB/PGST)

Figure 8 shows the TBM assembly in the ventilation caverns.



Fig. 8: TBM assembly in cavern (source: PGST)

### 5.3 Final configuration of caverns

The final configuration of the permanent caverns is governed by its use during the operational phase of the tunnels. The ventilation caverns will be equipped with walls and ceilings as to provide

airflow channels and rooms for technical facilities for electrical and maintenance purposes. The final outfit of the rescue caverns will provide escape areas in case of an emergency. Figure 9 includes typical cross sections of the final cavern configuration.

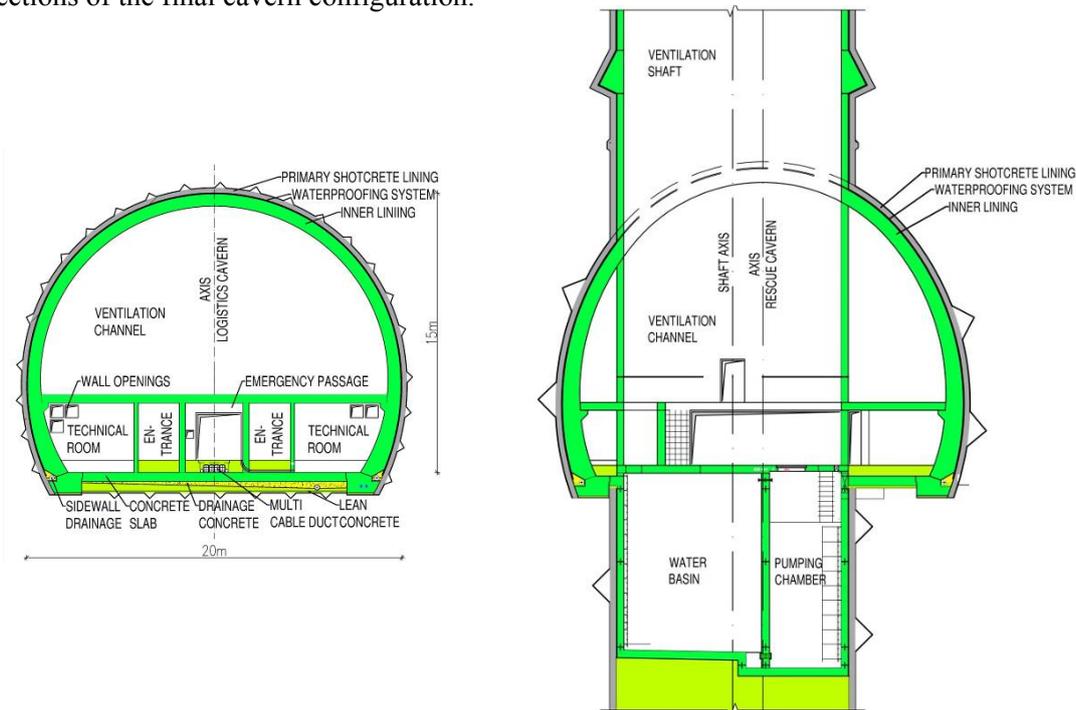


Fig. 9. Final configuration in permanent caverns (source: OEBB/PGST).

The lining system consists of a cast in-situ secondary lining separated from the shotcrete lining by a waterproofing membrane and a protection fleece. Sidewall drainages are arranged on both sides of the caverns at the invert slab level.

## 6. Temporary caverns

### 6.1 Layout

Intermediate access to the tunnel alignment is provided by temporary shafts, which depths are ranging between 100 m and 200 m. At the toe and the head of the shafts temporary caverns are required in order to provide sufficient space for logistic and site installation purposes. Figure 10 shows the cavern configuration at the top and toe of the shafts schematically.

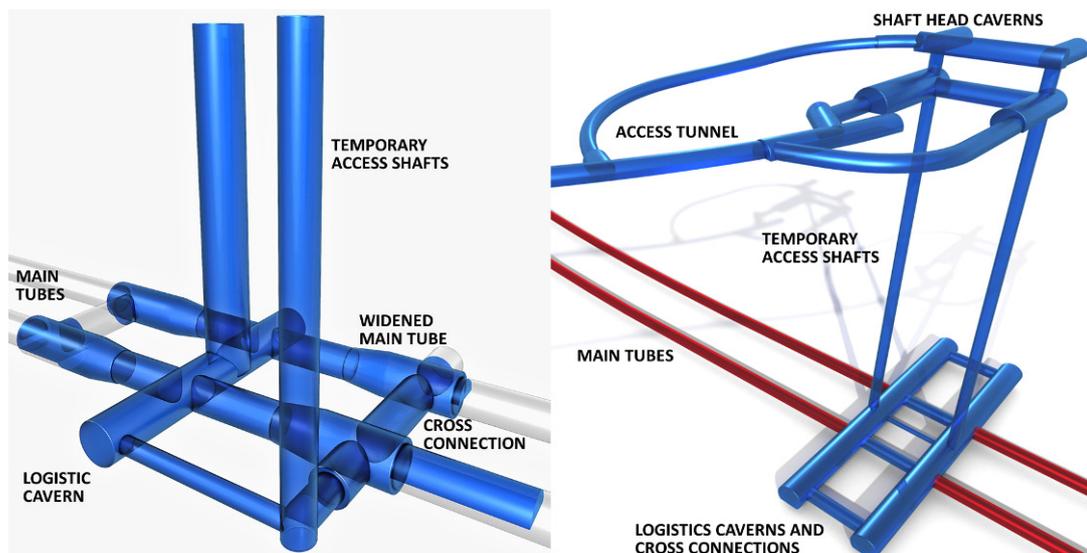


Fig. 10. Scheme - Cavern configuration subsurface shafts (source: OEBB/PGST).

The layout of the cavern systems is designed as to provide optimum conditions in terms of logistics for supply and discharge. The main caverns at the toe of the shafts are oriented perpendicular to the main tunnel tubes accessible via short cross connections. The length of the various caverns is governed by the space requirements for site installation purposes.

The cavern system at the shaft head has to accommodate the hoisting installations for transports via the 200 m dep shafts and therefore stretches over two levels.

### 6.2 Temporary use of caverns

The main purpose of the temporary caverns is the provision of sufficient space for site installations during construction. Figure 11 shows the designed arrangement of the required site installations underground as well as the track system for material transport and mucking purposes in the two caverns at the base of the subsurface shafts in the northern construction lot.

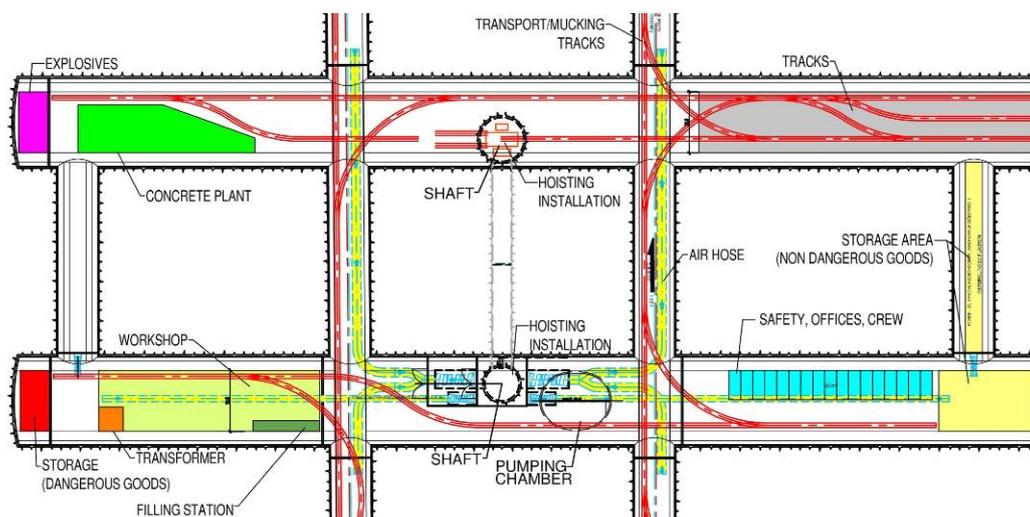


Fig. 11. Scheme of site installations in temporary caverns (source: OEBB/PGST).

At the shaft head caverns the installation of the hoisting system and the transition of the mucking process from the vertical to the horizontal direction had to be arranged. In addition storage areas for material supply and mucking had to be foreseen as to avoid longer waiting periods and interruptions in the logistics process. Figure 12 shows the schematic arrangement of the hoisting installation in the shaft head caverns.

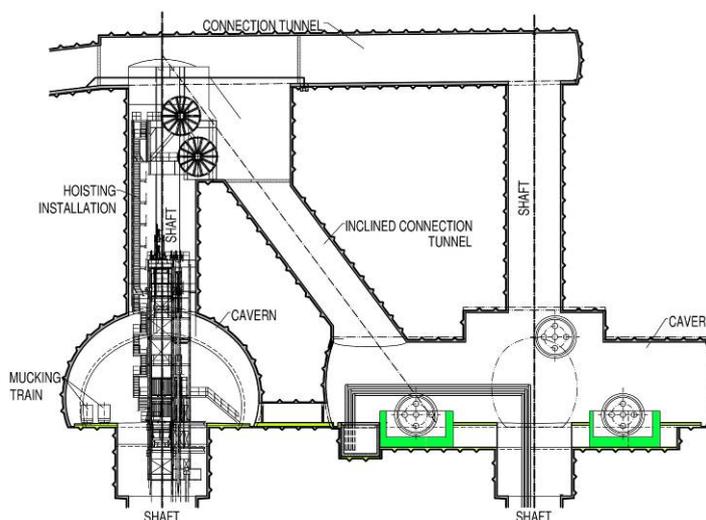


Fig. 12. Shaft head caverns – Hoisting installations (source: OEBB/PGST).

The maximum dimensions of the various caverns are in the range of 25 m by 16 m.

### 6.3 Final configuration of caverns

In the final configuration the temporary caverns will be backfilled for the major part of its extension. Only for temporary purposes a connection between the main tunnel tubes will be kept open in order to provide logistic options for the subsequent contract of track and signal installations.

The size of the openings for this temporary cross passages are based on the turning radii for transport trucks used during the final installations. Only after finalization of these installations, prior to the start of operation of the tunnels, these temporary passages will be closed by reinforced concrete walls. No further use of the areas is foreseen as this would lead to additional maintenance requirements during operation.

Prior to the backfilling of the remaining cavern sections concrete abutments and ceilings will be installed at the intersections with the main tunnel tubes. The temporary shafts will also be backfilled, whereat a concrete plug will be carried out at the shaft cavern intersections. The backfilling of the lower parts above the invert concrete of the caverns will be done by specified rock material. The remaining part up to the ceiling of the caverns will be backfilled by pea gravel, which will be blown in. With such approach a complete filling of the voids shall be ensured.

The backfilling together with the construction of the abutments and ceilings has to take place in a staggered procedure as to enable access into the caverns for filling purposes as long as possible. The following figures show the backfilling arrangement of the temporary caverns.

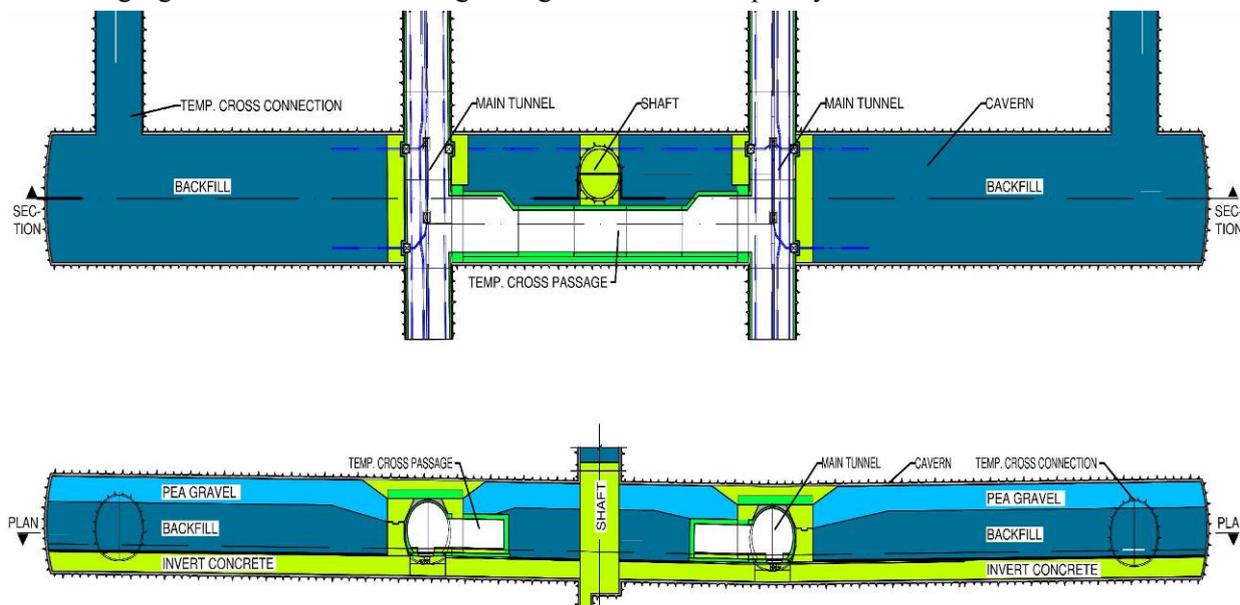


Fig. 13. Section and plan - cavern backfilling (source: OEGB/PGST).

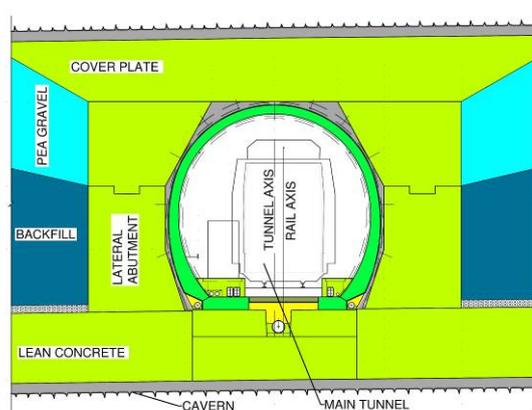


Fig. 14. Intersection cavern – main tunnel (source: OEGB/PGST).

## 7. Current status

At the time of preparation of this paper all three underground construction lots are under construction and the final construction lot at the southern portal is due to be tendered shortly.

Excavation of the main tunnel tubes from the northern portal reached a length of app. 2.5 km. The intermediate access tunnel of 1,2 km length and the shaft head caverns are finished, In addition app. 100 m of the subsurface shafts are excavated.

In the central construction lot the 400 m deep permanent shafts including the caverns at the emergency station are finished and the TBM assembly is currently under progress. The TBM drives are due to start the excavation of the main tunnel tubes towards the northern portal in mid-2018.

The shafts and caverns at the southern construction lot are also finished and the length of excavation of the main tunnel tubes is in the range of 200 m in each direction.

At the peak time of the underground construction in total 14 headings including two TBM drives will be carried out at the same time.



Fig. 15. Cavern construction

## 8. Conclusions

The construction of caverns for permanent and temporary use for the Semmering Base Tunnel project is required to enable a feasible solution in order to meet targeted schedules. Access only via shafts as the main points of attack provides possible bottlenecks in terms of material supply and discharge. Therefore, already during the design phase a detailed evaluation of the required site installation and logistics areas underground under consideration of the foreseen transport solutions was required.

During the execution of the excavation works certain adaptations based on the contractors input or geological reasons were implemented. A common approach with a permanent exchange of opinions and frequent fruitful discussions led to jointly agreed, improved solutions.

In the final configuration the temporary caverns will be completely backfilled or closed as additional permanent space underground is also connected to additional maintenance effort.

The construction works are under way and the provided space underground has passed its initial practical test to the satisfaction of all parties involved.

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