

Semmering Base Tunnel: 17 Miles of SEM and TBM Tunneling Under Challenging Conditions in Austria

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ABSTRACT

The Semmering Base Tunnel is a major infrastructure project in Austria, Europe. This consists of two 17 miles of single-track railway tunnels, numerous cross passages and a complex underground emergency station including caverns, passages, tunnels and two 1,315 ft. deep ventilation shafts. Intermediate access for construction is provided by a 1.1 mile long, temporary tunnel with two 820 ft. deep sub-surface shafts at its end and two additional temporary shafts from the surface with large underground caverns at the shaft bases. The maximum overburden is around 2,850 ft. in difficult, frequently changing geological conditions with large fault zones and extensive water inflow of up to 300 l/s requiring special grouting and support measures. The underground construction works using SEM as well as TBM methods commenced in 2014 and will be completed in 2026.

PROJECT OUTLINE

General

After finalization the 17 miles Semmering Base Tunnel will form part of the Austrian section of the Baltic-Adriatic Railway Corridor stretching across Europe and connecting the Baltic Sea (Gdansk in Poland) and the Adriatic Sea (Bologna in Italy). The tunnels are located approximately 50 miles south of the Austrian capital Vienna connecting the towns of Gloggnitz in Lower Austria and Muerzzuschlag in Styria (see Figure 1).

The new tunnel system will replace the existing world heritage site Semmering-Railway, which includes numerous tunnels and viaducts built in the mid-19th century. The alignment of the existing railway with steep gradients and small radii does not fulfill the requirements for the operation of efficient and modern rail traffic. Heavy cargo trains require the use of an additional locomotive for the route. The newly built tunnels will improve the travel quality and time for passenger and freight trains crossing the mountainous landscape. The existing Semmering-Railway line will remain in place for maintenance purposes of the new tunnel, for local traffic and as a tourist attraction due to its breathtaking scenery.

The total investment costs for the project are around 3.3 bi. Euros (3.5 bi. USD), whereas 1.5 bi. Euros (1.6 bi. USD) are related to the civil construction works. Pre-construction works started in 2011 and underground excavation in 2014. The final opening for operation is scheduled for 2026.

Tunnel System

The final tunnel system includes two single track tubes connected by 56 cross passages with a maximum spacing of 1,640 ft. and a central underground emergency station with two 1,315 ft. deep ventilation shafts. For construction purposes four



Source: ÖBB

Figure 1. General location overview

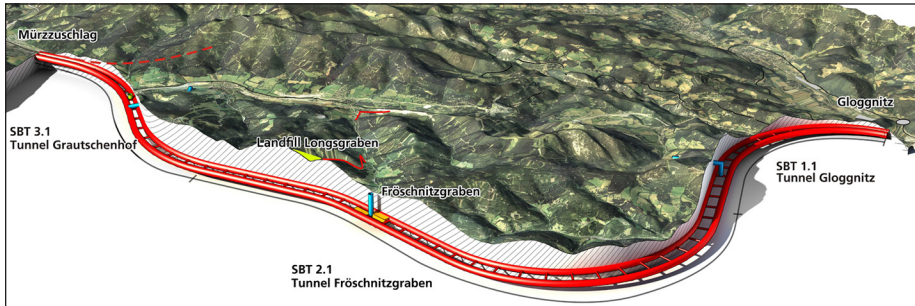
additional, temporary shafts are required. Two of the shafts will be excavated starting underground via a 1.1 miles long temporary access tunnel located around 660 ft. above the main tunnel alignment.

The spacing of the mostly parallel running tunnel tubes is around 130 ft., which is enlarged at the underground emergency station as well as in massive fault zones and reduced in the portal areas. The alignment of the tunnel is based on a maximum train velocity of 140 mph with a maximum inclination of 8.4%.

Due to the envisaged completion date and for logistic reasons, the main underground works for the tunnels, shafts and caverns are divided into three separate construction lots designated SBT 1.1, SBT 2.1 and SBT 3.1 (see Figure 2). An additional construction lot is foreseen at the southern portal including the cut and cover and open cut tunnel section with a total length of 0.4 miles as well as the modernization of the adjacent railway station in Muerzzuschlag.

The excavation works for the underground structures are carried out by means of SEM for a total length of 12 miles in the northern and southern parts of the tunnels. At the peak of the excavation works a total of up to 12 SEM headings at various locations in the main tunnel tubes will be running in parallel. Due to the geological conditions for about 5 miles in the central section of the main tunnel tubes, TBM method is applied.

In the final tunnels a drained secondary lining will be installed. Due to legal reasons in the northern section of the tunnels, mountain water has to be collected below the drainage level and led of separately as to be available for the further use as drinking water.



Source: OEBB

Figure 2. Tunnel scheme including construction lots

Geology, Hydrogeology, and Geotechnics

Overall the geological conditions of the tunnel system can be described as an area of intense tectonic imbrication. The main units are the so called Greywacke zone, the Semmering unit and the Wechsel unit.

Within frequently changing conditions rocks consisting of metasediments such as phyllite, schist, quartzite, locally sulphate rocks and metasandstone of various tectonic units as well as carbonate rocks and highly fractured metamorphic crystalline schist and gneiss will be encountered. The geological units are separated by distinct fault zones which formed during the orogenesis with extensive folding and nappe stacking, leading to an imbricate structure. Out of the numerous fault zones especially the ones consisting of cataclastic fault material with high overburden are challenging the construction procedure. Within the carbonate rock formations a considerable water inflow of up to 300 l/s is expected.

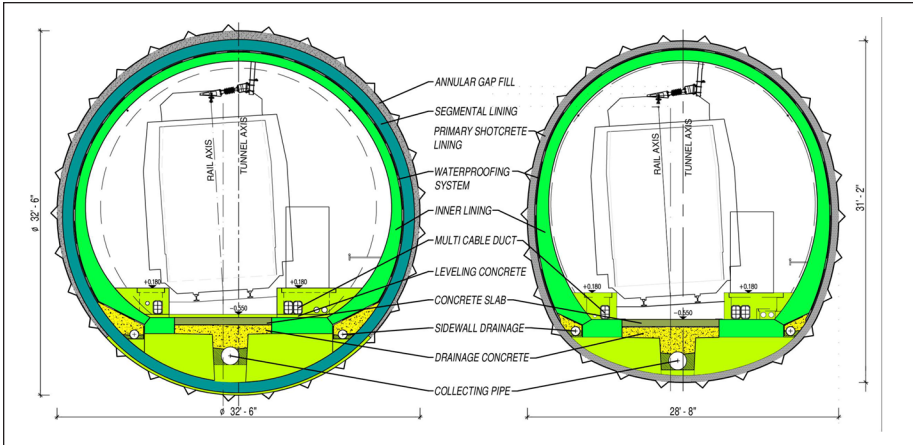
For the design and implementation, the tunnel was divided into 33 rock mass zones, of which more than 40 ground types were evaluated by the geotechnical design team. Rock mass zones can be characterized as tunnel sections, which show similar conditions in terms of geological structure or units, proportions 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.

MAIN STRUCTURES

Running Tunnels and Cross Passages

The main tunnels are single track tubes based on the clearance requirements of the Austrian Federal Railways for high capacity railway lines. The excavation area of the regular cross sections is around 810 ft² for both excavation methods. The inner contours of the tunnels include space for electrical and signaling installations and an emergency walkway. Certain sections of the tunnels are widened due to geotechnical or logistics reasons increasing the excavation area to a maximum of approximately 1950 ft².

The foreseen 56 cross passages between the main tunnels will act as emergency connections in case of an accident. In addition, the cross passages are equipped with technical rooms for electrical and communication purposes as well as maintenance installations. The excavation area of the cross passages is around 380 ft².



Source: PGST

Figure 3. Regular cross sections for TBM and SEM

The cross sections of the single track tubes, the cross passages and the caverns are designed with an outer and inner lining system (see Figure 3). Where the SEM method is applied, the outer lining system consists of reinforced shotcrete with additional support measures such as rockbolts and forpoling pipes. A mandatory 6+0 segmental lining system with a minimum thickness of 12 in. forms the primary lining system for the TBM method.

The inner lining for both methods is made of cast in-situ concrete, which is normally unreinforced. Exceptions with a reinforced inner lining are in areas of fault zone crossings or intersections with cross passages only. A fiber reinforced inner lining is applied in sections underneath residential areas or the main infrastructure where an improvement of the fire resistance properties is required.

The inner and the outer linings are separated by a waterproofing system consisting of a smoothing shotcrete layer, a waterproofing membrane and a geotextile. Groundwater will be drained off by lateral drainage pipes placed at abutment level in between the inner and outer linings.

In order to keep vibration and noise emissions below acceptable limits underneath residential areas the installation of a mass-spring track bed system is required for certain sections of the tunnel. For the main length of the tunnel a slab track system will be installed.

Underground Emergency Station and Ventilation Shafts

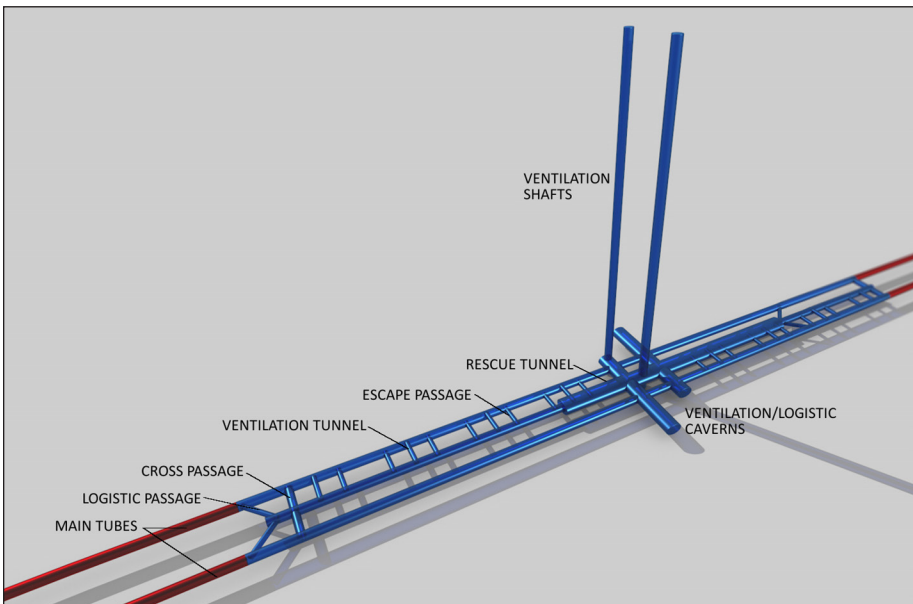
In accordance with Austrian and European laws, the overall rescue concept is based on self-rescue into a safe area, followed by the rescue by others (emergency team). In case of a fire on the train the main target is to reach the portals and leave the tunnel before stoppage. Due to the given length of the new tunnels and the expected available time before breakdown of the train, an underground emergency station is required within the tunnel.

The emergency station is located at the toe of the two permanent ventilation shafts in the central section of the tunnel and has a total length of about 0.6 miles. It comprises tunnels, caverns and passages of various sizes to accommodate all installations and areas required by the safety concept including a ventilation system.

In case of an accident trains shall stop in the emergency station and passengers shall be transferred via a safe and smoke free area to a rescue train approaching in the non-affected tunnel tube.

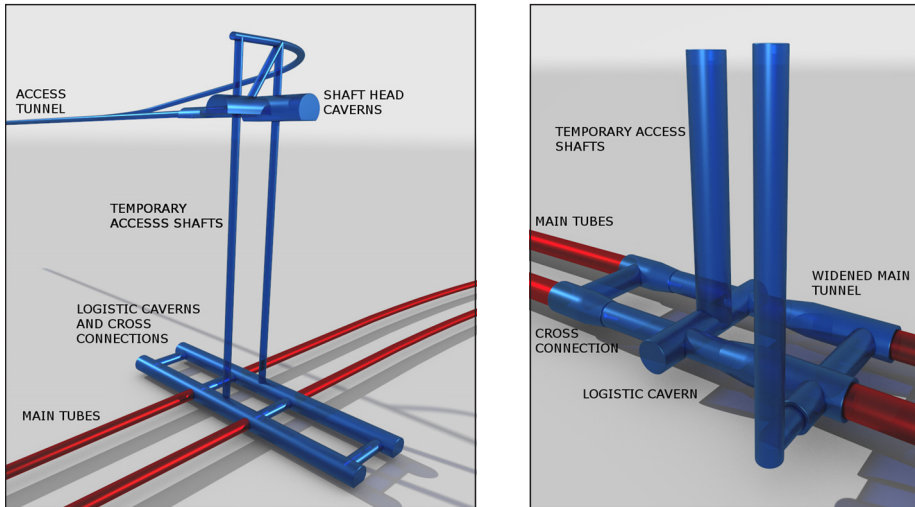
The central structure in the emergency station is the rescue tunnel, which is located in between the two running tunnels. Connections to the running tubes are provided by short escape passages with a maximum spacing of 165 ft., the central caverns and two regular cross passages. Ventilation tunnels are placed in between the rescue tunnel and the main tubes to provide a smoke free environment in connection with the ventilation shafts. Furthermore, four temporary logistic passages are located in the emergency station which are aligned for the use of conveyor belts for material transport during construction (see Figure 4).

The depth of the ventilation shafts is about 1,375 ft. with diameters of 40 ft. and 32 ft. The shafts will be lined with fiber reinforced concrete, which is separated from the primary shotcrete lining by a waterproofing membrane and geotextile. Reinforced concrete abutments in connection with deformation joints in the lining are foreseen at regular spacings of 200 ft. In the final configuration the shafts will be equipped with ventilation and inspection equipment. The top of the shafts will be crowned by a complex ventilation building housing the ventilators, electrical equipment and the control and telecommunication units.



Source: OEGB

Figure 4. Scheme of underground emergency station



Source: OEBB

Figure 5. Scheme of cavern systems at temporary shafts

SELECTED DETAILS

Construction Logistics

One of the major challenges for the construction of the tunnel is to meet the tight time schedule for completion. Therefore, parallel excavation works are required in the three construction lots. Access to the tunnels is given at the north portal or via the permanent or temporary access shafts and tunnels.

Out of the total six shafts only two will remain as permanent structures for ventilation purposes (see Underground Emergency Station and Ventilation Shafts). The remaining four temporary shafts will be completely backfilled after the end of the construction period. Two shafts will be excavated from the surface and the others will be excavated underground via the access tunnel of 1.1 miles in length. The maximum depth of the shafts ranges between 330 ft. and 820 ft., with diameters between 23 ft. and 46 ft. At the top of the underground shafts a complex system of tunnels and caverns is foreseen to accommodate the installations for the hoisting operations during construction. In addition, at the shaft bases of the temporary shafts large underground caverns are located to provide sufficient site installation area for machinery assembly and material handling underground (see Figure 5). Apart from two caverns, which will house permanent cross passages, all other caverns will be backfilled after the end of the construction phase.

For logistic reasons the rescue tunnel in the emergency station is built as a large cavern over a certain length to accommodate site installations and supply including TBM assembly during construction. For the same reason two caverns are carried out perpendicular to the running tubes, which are also required for the construction process. The maximum dimensions of the large caverns are approximately 65 by 60 ft.

The deposit of the excavated material is foreseen in a newly planned landfill site approximately 1.4 miles from the site installation area of the central construction lot (see Figure 6). In order to provide a continuous discharge of the excavated material and for limitation of the intermediate deposit area in the central construction lot

a conveyor belt runs between the shafts and the landfill site. The neighboring construction lots in the northern and southern parts of the tunnel have to transport the excavated material to this landfill site as well, which will be carried out by trucks using newly built construction roads as to avoid additional traffic in residential areas. The total volume of the landfill site is approximately 5.6 million yd³.

Crossing of Major Fault Zones

There are numerous fault zones crossing the tunnel alignment along the entire stretch of the tunnel system. One of the most significant fault zones is the so called Grassberg-Schlagl fault system located approximately 3 miles from the northern portal. The length of the fault zone is about 0.5 miles with an average overburden of 1,640 ft.

The material can be characterized as tectonically heavily stressed, sheared and partially softened rock material consisting of sericite phyllites, quartzites, sulphate rocks and limestones. The fault material is sensitive to water, can be leached partially and contains large quantities of clay material prone to swelling phenomena. The occurrence of gases can be expected.

In order to provide an adequate design solution extensive investigation, testing and analyses procedures were carried out, which resulted in a specially designed cross section, heading sequence and support measures. A cross section with a rounded shotcrete invert was developed as to optimize the load transition between underground and lining.

The initial support consists of an initial shotcrete layer with a total thickness of 16 in., reinforced with two to three layers of wire mesh. Around 40 forpoling pipes consisting of self-drilling injection bolts with a length of 13 ft. will be installed as to provide sufficient overhead protection when opening the rounds. The expected radial deformations



Source: OEBB

Figure 6. Conveyor belts leading to landfill site



Source: PGST

Figure 7. SEM method—LSC elements

are in the range of 20 in. Therefore, up to six deformation gaps equipped with lining stress controllers (LSC elements) are foreseen (see Figure 7). The deformation slots are arranged equally distributed in the top heading. The LSC elements provide a certain support resistance when closing due to the deformations. In case of necessity an additional layer of 8 in. of reinforced shotcrete will be placed after the deformations are ceased.

Up to 20 self-drilling injection bolts with lengths between 20 and 30 ft. will be installed per round of heading. In order to increase the deformation capacity the bolts are installed in plastic hoses along a certain length at the bolt heads. The anchor plates are designed to be deformable accordingly.

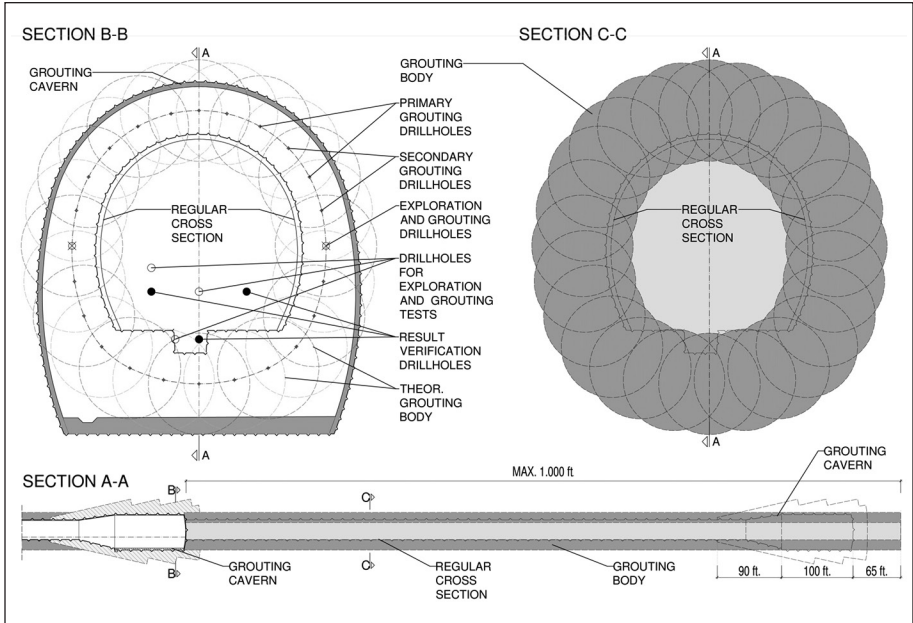
The excavation cross section is divided into a top heading and bench/invert sequence, with a face opening in up to eight steps. The maximum round length is 3.3 ft. and the maximum invert ring closure distance is between 30 and 100 ft.

Grouting Measures

The hydrogeological conditions predict a water inflow in the range of 300 l/s for certain sections along the tunnel alignment in the carbonate rock formation. Furthermore, at the toe of the two temporary access shafts in the southern construction lot, crystalline gneiss with the potential to a complete loss of material strength and subsequent inflow of the water material mix will be encountered. Therefore, extensive grouting measures for sealing purposes and improvement of the ground conditions are foreseen. The target is to create a grouted ring surrounding the excavation boundaries with a minimum thickness of 9 ft.

Prior to the start of the actual grouting procedures extensive testing in differing underground conditions was carried out as to evaluate the most favorable method for optimum grouting results. Varying parameters for testing include admixture, pumping pressure and rate for cement and polymer based grout in differing depths and geological conditions. In case of necessity the grouting process will be carried out in a staggered pattern, starting with cement based grout followed by chemical grouting.

The grouting works in the tunnel are either carried out from logistic caverns at the shaft toes, definite grouting caverns or enlarged cross sections in the running tunnels.



Source: PGST

Figure 8. Grouting measures in main tubes

These enlarged sections are required in order to provide sufficient space for the machinery and equipment handling for the grouting works.

For the testing and grouting procedures directional drillholes with lengths of up to 1000 ft. for a straight direction and 400 ft. for a curved line are to be carried out. In addition short drillholes with a length of 165 ft. are required in the caverns connecting the running tunnels. The drilling pattern around the excavation profiles is defined in detail in order to create the envisaged grouting body and volume (see Figure 8). Due to the existing ground water level all drillings are to be carried out under the protection of blowout preventers.

CURRENT STATUS AND OUTLOOK

At the moment all three underground construction lots of the Semmering Base Tunnel are in progress and the tender design for the western portal area is under preparation. The diversion of main roads in the portal areas, the construction of temporary construction roads and the preparation of the landfill site were tendered and finished ahead of the start of the excavation works.

The tunnel excavation at the northern construction lot which started at the end of 2015 has reached a length of about 1,0 miles for both tubes, with the cross passages following accordingly. The intermediate access tunnel is finished and the shaft head cavern excavation has already started. The subsequent shaft sinking shall be finished by the beginning of 2018 followed by the construction of the caverns at the toe of the shafts. The start of the SEM excavation works of the main tunnels is scheduled for 2019. The excavation works at this construction lot are to be completed by 2022.



Source: OEGB

Figure 9. Cavern excavation

The deep ventilation shafts in the central construction lot are finished and the excavation of the underground emergency station acting as logistic and TBM assembly area during the construction is under progress (see Figure 9). The two single shield TBM's are about to start the excavation of the running tunnels at the beginning of 2018, for about two years. The SEM works for the main tunnels in the opposite direction are planned between the years 2017 and 2021.

In the southern construction lot the two temporary shafts reached their final depths and the cavern excavation including the grouting measures started in spring of 2017 and shall be finished by 2018. The following excavation works for the main tunnel tubes are foreseen until 2022.

The excavation works in all three construction lots will be followed by the lining installation, which will be carried out separately in all three construction lots. The finishing works of tracks and electrical installations as well as signaling will be carried out in a combined lot for the entire tunnel system.

The overall schedule of the project with a partially overlapping construction and final installation phase with a planned final opening for operations at the end of 2026 is on target.

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