HUNTING THE RECORD

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THE IDEA OF BUILDING A tunnel under the Brenner summit first occurred to the Italian engineer Giovanni Qualizza as far back as 1847, but it was another 160 years before the idea became reality.

In 1971, the plan of a tunnel at Brenner came up again. The International Union of Railways (UIC), commissioned a study for a new Brenner railway incorporating a base tunnel. By 1989, three feasibility studies had been drawn up that formed the basis for further planning of this Brenner Base Tunnel.

This was the start of the planning activities. In 1994, the European Union included the Berlin-Naples corridor in the list of priority projects. Ten years later, Austria and Italy signed a state treaty to build the Brenner Base Tunnel (BBT). In that same year, what is today BBT SE was established.

Today, the experts of the engineering joint venture work on the tender design, the final design as well as the geotechnical site supervision for the three remaining lots H21, H41 and H51 at the Austrian side.

THE COMPLEXITY OF THE TUNNEL SYSTEM

The BBT with a length of 64km (including the existing Inn Valley Tunnel) is the centrepiece of the Helsinki-Valletta Trans-European Traffic Corridor from Finland to Southern Italy. The BBT tunnel system connects in the north with the Innsbruck station (Austria) as well as the feeder routes in the Lower Inn Valley towards Germany and Northern Europe and opens to the south with the projected new line in the direction of Verona in Italy. The concrete planning has been underway since 1999; the start of construction on the first section was in the year 2007.

From 2028 onwards the Brenner section, including existing lines, will carry a daily average of 330 trains. Approximately 80 per cent of them will be carrying goods, the other 20 per cent passengers.

The Brenner Base Tunnel is a system that consists of two single-track main tunnel tubes 70m apart that are connected by cross-passages every 333m, as well as a service and drainage gallery lying about 10-12m deeper than, and between the main tunnel tubes that can be used as an exploratory tunnel during the construction phase. Four connection tunnels in the north and south for linkage to existing lines also belong to the tunnel system with a total length of approximately 230km.

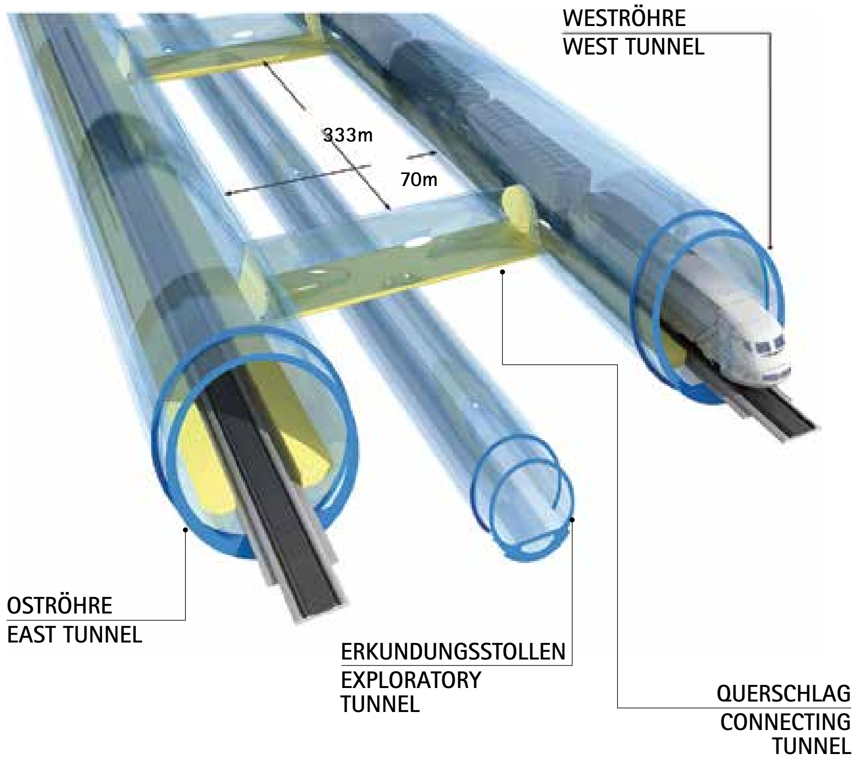
Three emergency stops, each about 20km apart, are planned in Ahrental, St. Jodok and Trens. The emergency stops will serve for the rescue of passengers from disabled trains. In addition, the emergency stops are each accessible through driveable approach tunnels in Ahrental (2.4km in length), Wolf (4km) and Trens (3.6km) and via Mauls (1.8km).

The two-track Inn Valley Tunnel that was completed in 1994 will be integrated into the tunnel system. This will reduce the travel time from Germany towards Italy significantly. The 8km-long section of the Inn Valley Tunnel between the Tulfes portal and the integration of the connection tunnel is part of the BBT system and will, for reasons of safety, therefore be retrofitted with a rescue tunnel. For the tunnel project between the north portal of the Inn Valley Tunnel and the south portal of the Brenner Base Tunnel results a total length of 64km.

The three access tunnels in Ahrental, Wolf and Mauls serve in the construction phase as intermediate logistical access points and have a regular gradient of 10 per cent. Directly adjacent to these are the dumping areas for excavated material. In addition, the access tunnels and the construction areas are directly connected to the upper road network. The largest dumping area is found in the Padaster Valley and can hold up to 7.5Mm^3 of material. A portion of the excavated material can also be recycled for aggregates.

The project is financed by the Italian and Austrian governments with each contributing 30 per cent, as well as by the European Union, which is paying 40 per cent.

Below: ***Brenner Base Tunnel system with two main tunnels and the exploratory tunnel***



THE GEOLOGY OF THE PROJECT

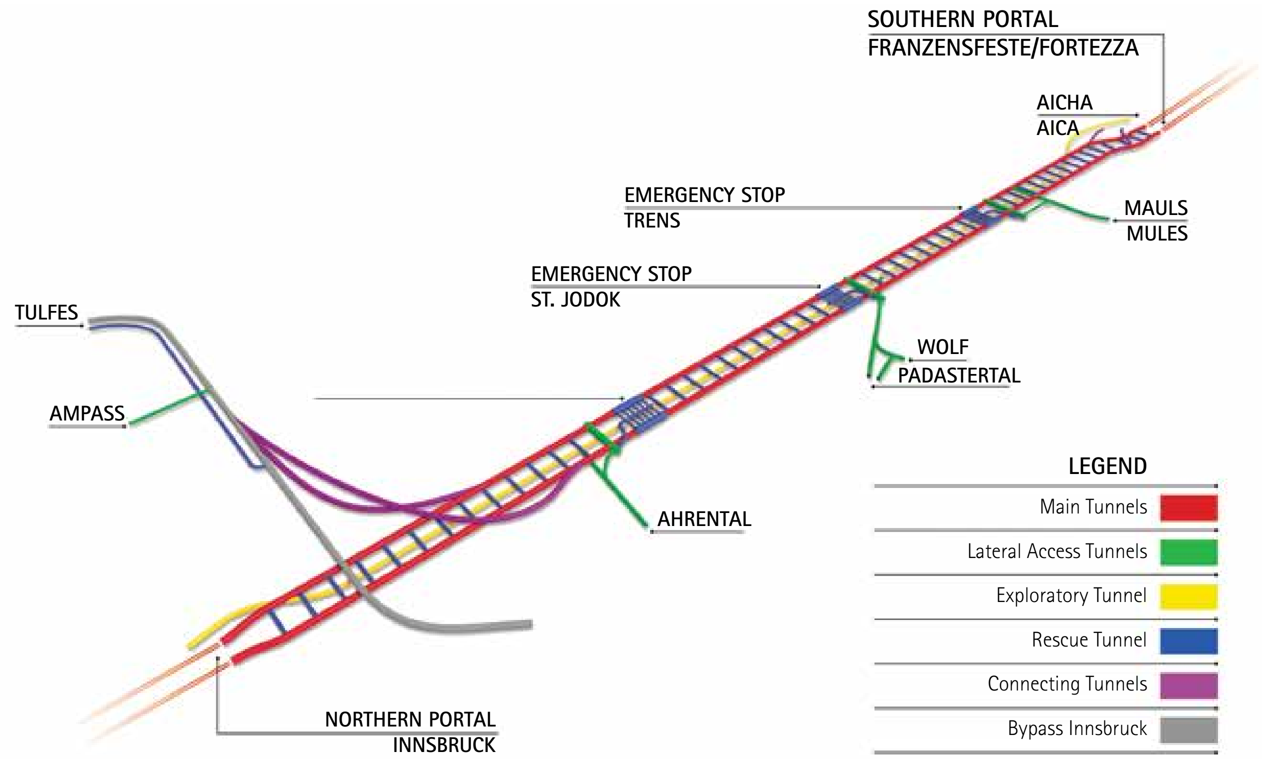
The BBT is geographically positioned in the central eastern alps. Geologically, the tunnel is crossing the collision area of the European and the Adriatic (African) plate.

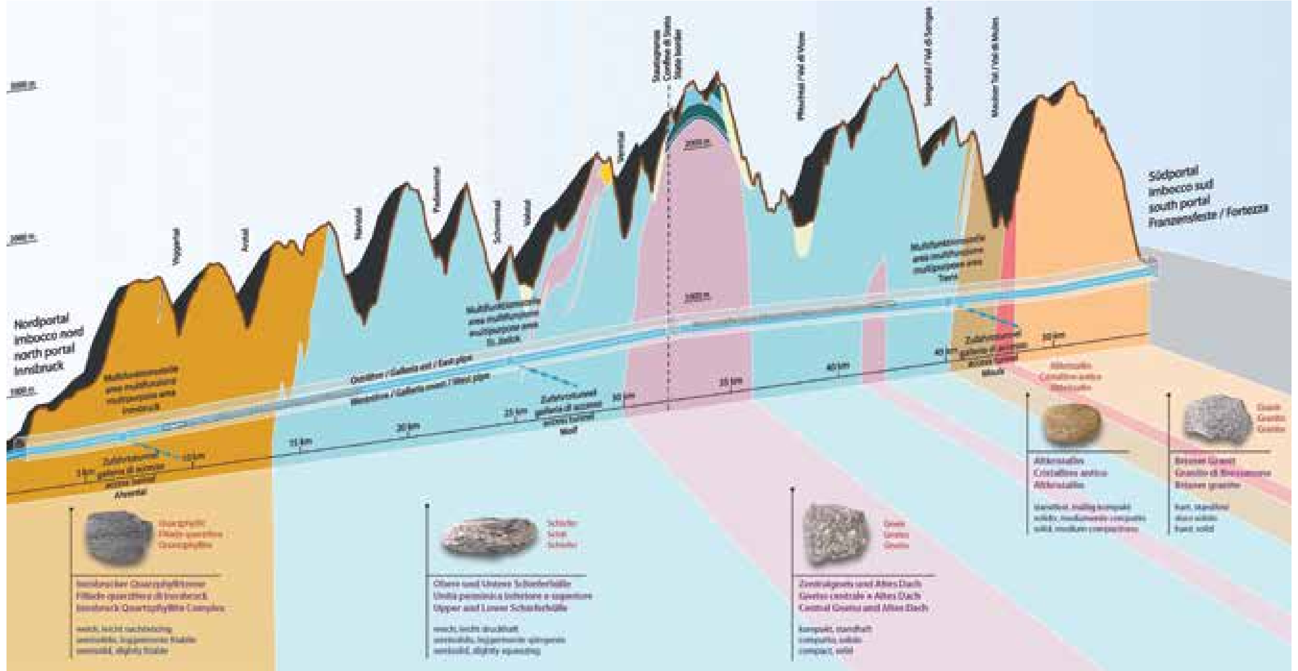
The main lithological units are the Innsbrucker Quarzphyllites, the Bündnershists, the central gneisses and the Brixener Granites. From the North at Innsbruck (km 0) to the South at Franzensfeste (km 54) the tunnel crosses the following:

- Km 0 to 14: Innsbrucker Quarzphyllites (homogenous Phyllites)
- Km 14 to 28.5: Upper and central Bündnerschiefer (changing geological conditions with phyllites, shists and dolomites)
- Km 28.5 to 30.3: Lower Bündnerschiefer (changing conditions, dolomites, shists, rauhwacke)
- Km 30.3 to 36: Central gneisses (very competent gneiss)
- Km 36 to 37.2: Pfitscher Synform of the lower Bündnerschiefer (changing conditions, dolomites, shists, rauhwacke)
- Km 37,2 to 41.2: Bündnerschiefer of the Pfitscher Synform (changing geological conditions with phyllites, shists and dolomites)
- Km 41.2 to 42.3: Central gneisses (very competent gneiss)
- Km 42.3 to 45.4: Bündnerschiefer of the Pfitscher Synform (changing geological conditions with phyllites, shists and dolomites)
- Km 45.4 to 47.5: Cristalline of the eastern alps
- Km 47.5 to 48.2: Periadriatic Fault Zone
- Km 48.2 to 55: Brixner granites (competent granites)

From a hydrogeological point of view the water ingress will be very limited in the homogenous sections of the phyllites, shists, gneisses and granites. Only during the advance through fault zones is the amount of water is expected to increase. Critical sections will be the Hochstegen Area (approximately 500m long) and the shists in the south of the central gneisses (approximately 1km in length). In both areas, high water ingress is predicted. A lowering of the water table at the surface is prohibited there because of environmental aspects. In order to meet these requirements, the rock mass permeability will be reduced by extensive grouting programmes.

Below: ***Brenner Base Tunnel System including the connection to the Inn Valley Tunnel***





Extensive investigation drilling and geophysical investigations from the headings are foreseen to predict the exact positions of water bearing zones and to take the right decisions regarding further measures.

The overburden varies between 1,000 to 1,500m over most of the tunnel. The Maximum of 1,700m will be reached in the central gneiss.

Above: ***Longitudinal profile of geology with main lithological units***

CURRENT STATUS OF WORKS AND PRIMARY CHALLENGES

The initial works at the Brenner Base Tunnel began in 2007, located at the exploratory tunnel from the South portal in Aicha, Italy. In 2009 the construction works at the Austrian side started with the exploratory tunnel in Innsbruck and the access tunnel in Ahrental.

Two years later the excavation of the access tunnel in Wolf (Austria) and Mules (Italy) started. Since then at all three intermediate points of attack the construction is ongoing.

Above: ***A logistics chamber excavated for the Brenner project***

Above: ***Open gripper TBM for the exploratory tunnel in Ahrental***

At the time of writing – in November 2019 – a little more than 114km (or nearly 50 per cent) of the 230km of the entire system is excavated. Some 70 per cent of the exploratory tunnel is excavated and is reducing the risk of unforeseen geological conditions. About 90 per cent of the contracts for the construction works have been tendered. Only the last big tunnel lot at the Austrian side (lot H41) is to be tendered in early Summer 2020.

Current status of the works in Italy

At the Italian side one of the most critical sections – the periadriatic fault zone – has been successfully passed through (with both, the exploration tunnel and the traffic tunnels) in summer 2015 following the completion of the exploration tunnel Aicha-Mauls and the access tunnel Mauls.

The technically challenging underpass below the river Eisack (Isarco), in the north of the Franzensfeste, with systematic ground improvement by conducting ground freezing and grouting, accompanied with the associated construction measures, is under way.

In summer 2016 the works for the biggest lot at the Italian side, lot H61 "Mauls 2-3" have been awarded with a contract sum of nearly EUR 1bn (USD 1.1bn). Works started in late summer 2016.

This lot reaches from the construction lot "Isarco river underpass" up to the border with Austria. In the course of a seven-year construction period, 39.8km of the main tubes and 14.8km of the exploratory tunnel will be excavated, including the emergency stop in Trens and its access tunnel as well as the bypasses which connect the main tubes every 333m. A total of approximately 65km of tunnels will be excavated. In November 2019 in the main tunnels 13.5km of the 40km are excavated and in the exploration tunnel 7km of 14.5km are excavated. In total three TBMs are in operation.

Current status of works in Austria

The entire construction schedule of the Brenner Base Tunnel is based on the idea that the exploratory tunnel is built ahead of the main tunnels to use the geologic and geotechnical interpretation of the results gained from its advance to minimise risks for the main tunnels.

This because a major part of the exploration tunnel works in Austria is integrated in lot H33 that started in 2014. Currently the open gripper TBM with an excavation diameter of 7.9m for the exploratory tunnel from Ahrental to the south has reached the border of the lot at km 22 after heading 15km.

In addition, the emergency station at Innsbruck, the rescue adit at Tulfes (aligned parallel to the existing transit tunnel at Innsbruck) and the additional access adits and cross adits are part of this lot and the excavation works are finished. The final concrete works will last until 2020.

The biggest lot at the Austrian side, lot H51 "Pfons-Brenner" was awarded in 2018 with a contract sum of again nearly EUR 1bn. Currently the drill and blast works of the exploration tunnels and the emergency station and the tunnel crossovers are under construction. In late 2020, the TBM drives to the North will start and in 2022 the TBM drives to the south towards the Italian border.

In summer 2020 the Lot H41 "Sillschlucht-Pfons" will be tendered. This Lot will consist of about 6km alignment towards the south and 5km to the North towards Innsbruck and the connecting Lot H21 "Sillschucht".

Main challenges

The administrative and organisational challenges are related to the situation of the tunnel being built in two countries. Although both Italy and Austria are members of the European Union, this still leads to:

- Different types of contracts for engineering and construction
- Different standards and regulations for the design and the construction works
- Different modes of operation of the two federal railway companies in Austria and Italy

It was necessary to sit together and to create a level of common understanding regarding all levels, regulations, standards and the later operation of the tunnel. Based on that, the design for the main tunnel lots and the tender documents started in 2013.

The next set of challenges are those related to the geological conditions. Compared to the other long alpine crossing tunnel projects in Europe like the Gotthard Base Tunnel and Lötschberg Base Tunnels in Switzerland or the Koralm Tunnel in Austria the geotechnical behavior of the rocks at the Brenner Base Tunnel is considerably worse. On the one hand the average UCS is much lower and the overburden is still very high and on the other hand there are plenty of fault zones that are crossing the tunnel axis in an oblique angle.

Finally, there are also typical challenges present when constructing long tunnels under high overburden:

- Long headings with all logistic, ventilation and cooling problems
- Huge amounts of materials to be handled, especially when constructing the inner lining with high concrete volumes and high construction performance
- Limited space for muck deposits. In case of Brenner Base Tunnel, this leads to long underground transport distances via the exploratory tunnel in order to reach the only available deposit space at the surface

Among these circumstances and under the requirement of high advance rates due to the length of the tunnel the technical possibility of using TBMs was one of the first things to be investigated.

FINDING THE OPTIMAL SOLUTION FOR THE WATER DRAINAGE

Drainage system as potential for optimisation

In the course of the project optimisation for the Brenner Base Tunnel various approaches to a solution for an optimisation of the drainage were discussed. Among these, alongside

Above: TBM Flavia working on the Brenner Base Tunnel

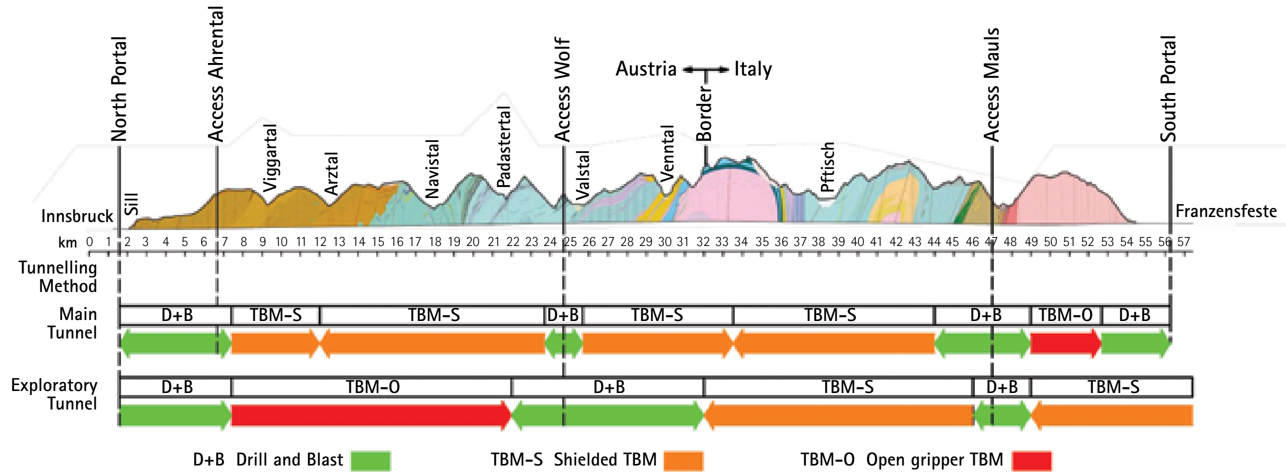
the optimisations for construction and the maintenance procedures for the drainage system, were also the application of construction materials with a low sintering potential, such as for example, shotcrete, injections, drainage bodies, backfilling annular gaps.

The driving of the Brenner Base Tunnel will take place with conventional as well as with mechanical construction methods. In several sections of the main tunnel tubes it can be anticipated that sintering in the drainage system can occur due to the characteristics of mountain water such as the chemistry and quantity of the water, as well as due to the leaching of cement-bonded building materials. The removal of sinters is very labour intensive and can lead to high subsequent costs up to restrictions in operation.

The drainage pipes require maintenance already in the construction phase. The rinsing and cleaning work is to be documented as well in order to ascertain the build-up of sinters in the various sections, and thereby to draw conclusions on

	Drained Construction	Pressure-proof construction
Construction costs	+	-
Maintenance costs	- - -	+ + +
Life cycle costs	- -	+ +
Availability	- -	+ +

Above: Advantages and disadvantages of the drained and pressure-proof construction of the main tunnel tubes with regard to construction costs, maintenance costs, life cycle costs and availability



Above: Longitudinal section and foreseen heading methods

the sintering tendencies in dependence on the local conditions (construction development, materials used, volumes and chemistry of the mountain water, temperatures, etc.) and thus possibly to be able to determine early measures (e.g., application of a hardness stabiliser) with regard to future efficient maintenance.

Single shell lining with dewatering into the exploratory tunnel

As an alternative solution to the construction with drains, in certain sections the execution of a single shell lining of the main tunnel tubes is desired. This idea consists of a dewatering in the annular gap between segment lining and rock surface towards the next cross passage and via a vertical connection towards the exploratory tunnel.

A comparison of the construction costs between the drained (double shell lined tunnel) and single shell lined pressure proofed solutions was carried out for the TBM driven main tunnel tubes. The results showed costs in a comparable range according to the status of the project in 2013.

With the pressure-proof development solution the very expensive to maintain branch drains, cleaning shafts, and cross drains are eliminated. Thereby the maintenance costs can be reduced and the availability of the tunnel system during operation increased.

Intensive studies were carried out to work out how the standard profile has to be defined and which measures have to be taken to allow long term water flow along the main tunnel, to the cross passages and finally into the exploratory tunnel. Finally, it was decided to use pea gravel filling of the annular gap for the water drainage in the longitudinal direction. At the same time, the backfilling of annular gaps must fulfil certain qualities of durability, permeability, frictional bonding between the lining and the mountain, as well as the characteristic of low sintering tendency. The technical specifications and parameters to be defined in the tender were determined by laboratory tests and a large-scale trial, among other things.

In sections with highly fractured rock with higher water ingress additional drainage borings from the exploratory tunnel are foreseen.

As a fall-back solution, the standard profile is carried out as “modular – flexible” with consideration of an intervention space for the possible incorporation of an extra shell of cast-in-place concrete with a planned thickness of 320mm. The standard cross-section can thereby be developed with or without drainage conduits in the course of the execution, depending on the geological and hydrogeological conditions actually found.

The present construction solution envisions a single-shell lining design for the TBM-driven main tunnel tubes. The elimination of the extra shell of cast-in-place concrete in long sections leads to logistic relief and a meaningful reduction in the amounts of concrete.

The authors would like to thank the owner BBT SE, and the design JV of PG BBTN (Amberg Engineering AG, Lombardi SA, Müller+Hereth, Obermeyer Planen und Beraten and hbpm) for the good and successful cooperation and we are looking forward to further collaboration for the next years in this challenging project and its goal to bring Europe closer together and, of course, become the longest underground railway connection in the world.

References

Eckbauer, W., Insam, R. and Zierl, D. 2014. Planning optimisation for the Brenner Base Tunnel considering both maintenance and sustainability. Geomechanics and Tunnelling 7 (2014)

Bergmeister, K. 2015. Life cycle design and innovative construction technology. Swiss Tunnel Congress 2015

Bergmeister, K. 2019. The Brenner Base Tunnel – geological, construction and logistic challenges and innovations at half time, Geomechanics and Tunnelling 5 (2019)

Rehbock-Sander, M., Insam, R., Reinhold, C., Mair am Tinkhof, K. 2018. The Brenner Base Tunnel Overview and TBM specifications for the 2 tunnel lots at the Austrian side. 2018 World Tunnel Conference