BRENNER BASE TUNNEL
PRESENTATION OF THE PROJECT AND STATE OF THE ART

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Abstract

The Brenner Pass is the most important north-south axis of the European Union, due to its central location in the heart of the Alps. More than two million trucks and more than twelve million cars - carrying almost 50 million tons of freights - cross the Alpine pass every year. Consequently, it has become necessary to adopt habitat preservation measures, favouring the shift of freight traffic from road to rail; these include the expansion of integrated logistics systems and, above all, the availability of an efficient and modern railway infrastructure has to be guaranteed.

The design of the entire project is briefly described as follows and the progress of the ongoing work in Austria and in Italy is illustrated, focusing on certain design-related and operational aspects concerning the crossing of the crucial Periadriatic seam, one of the most complex tectonic fault zones of the entire Alpine system.
1 Introduction

The Brenner Pass has been used by man since prehistoric times. The Romans built the first paved road here and its remains are still visible today; in the Middle Ages, the Brenner became the most widely used Alpine pass. Under Austrian rule, the railway lines from Kufstein to Innsbruck and from Verona to Bolzano were built; in later years the railway engineer Karl von Etzel (1812-1865) developed the project for the railway line from Bolzano to Innsbruck, which was inaugurated in August 12th, 1867; the first train travelled the route from Innsbruck to Bolzano in nine hours and ten minutes. Within a few years, the Brenner line became one of the most important rail links in Europe, also thanks to the electrification of the line in 1927/28. However, despite the commissioning of the double track Innsbruck bypass and the 13 km long Sciliar tunnel as well as the new Cardano and Fleres tunnels in 1994, in 1998 the northern and southern access routes still remained to be built.

The Brenner Base Tunnel, the 55 km long link between Innsbruck and Fortezza, will allow the passage of at least 400 trains per day, more than 300 of which will be freight trains, over both the new and the existing lines. The tunnel will also reduce the total rail distance between Fortezza and Innsbruck by about 20 km. Travel time on the current line is at present about 80 minutes; with the new tunnel it will be only 20 minutes for a high-speed train.

This project is part of the Priority Project TEN no. 1 Berlin-Palermo, with a total length of 2,200 km (Figure 1). The centrepiece of the corridor from Munich to Verona, the very heart of the project, and the northern and southern access routes are essential to connect the national rail networks north and south of the Alps, ensuring the connection between some of the most productive and economically advanced areas of Europe. The company charged with carrying out the project is BBT SE, set up as a "European Company" according to EU Regulation 2157/2001, with a dualistic system of governance.
The Brenner base tunnel project involves the construction of two single track tunnels, with a maximum gradient of 7 ‰ and connecting side tunnels every 333m. The distance between the main tubes ranges from 40 m to 70 m, depending on the geomechanical conditions of the rock mass being excavated, and thereby limiting the tube-to-tube effect of the deformations caused by the excavation of each tube (Figure 2/3).
Figure 2 - Three-dimensional project schematic

Figure 3 - Cross-section of the main tubes and of the exploratory tunnel with approximate dimensions
Between the two main tunnels and approximately 12 meters below them, the "exploratory tunnel" is to be built mainly for rock mass prospection so as to allow later planning and construction phases to be carried out on the base of the knowledge gained about the actual geologic conditions; this will drastically reduce construction risks in terms of both timing and costs. The exploratory tunnel will be built prior to the two railway tunnels. Its chosen location is a particular feature of the BBT and will allow the use of the exploratory tunnel for logistical purposes such as transportation of spoil and the supply of construction materials during the construction phase of the main galleries and as a drainage channel for tunnel waters during the operational phase. In Italy, in fact, the section of the exploratory tunnel already completed (excavated with a TBM) deviates from the route of the main tunnels mainly to allow drainage of all the water on the Italian side of the project.

Three multipurpose areas (PMF), about 20 km apart (Figure 2), are planned inside the tunnel; they are named Ahrental, St. Jodok (in Austria) and Trens (in Italy). The multipurpose areas are provided with emergency stops needed to rescue passengers of damaged trains and are equipped with systems for operational management and maintenance; furthermore, they can be reached from the outside by a paved tunnel through which vehicles can be driven. Passenger self-rescue is supported by the ventilation in the waiting areas and the escape routes which are protected from smoke. Should a passenger train on fire halt at a PMF emergency stop, the (connecting) cross passages are kept smoke-free by overpressure generated by the introduction of fresh air.

The distance between the PMF emergency stops is set forth in the Technical Specifications for Interoperability-SRT TSI (Technical Specification for Interoperability - "Safety in Railway Tunnels") regarding the ability of a train on fire to continue its forward motion for a 15-minute period, at a speed of 80 km/h, and then to travel in the tunnel for a further 20-km stretch before reaching a safe area (Figure 4).

![Figure 4 - Schematic of communication systems and multipurpose areas](image)

### Geology and Geomechanics of the areas crossed

The project route crosses a particularly complex area of the Eastern Alps, in terms of lithology and structural geology, as it runs along the western border of the Tauern window, right in the middle of the continent-to-continent collision point between Africa and Europe which caused the Alpine orogeny. In the tectonic window continental units of European origin and oceanic units can be found which were pushed upwards and to the surface due to the tectonic denudation of the overlying strata of the Austroalpine System, of African (Adriatic) origin (Figure 5).
A peculiarity of the Italian part of the project is the section crossing the large fault zone known as the Periadriatic seam, a major tectonic discontinuity in the Alps. This mountain chain is the result of the collision between the African plate and the European plate; it was the event when the only ocean on Earth over 200 million years ago was closed off: the Tethys Sea. During the Oligocene (23-33 million years ago) and the Miocene epochs (23-5 million years ago) enormous tectonic forces compressed the marine sediments of the Tethys Sea, pushing them against the Eurasian plate. The pressure thus created huge folds, faults, aquifers and overthrusts, thus forming the present-day Alps. It is therefore possible to find portions of the old crystalline basement in the mountain chain; it makes up the substrate of the marine deposits, outcropping on the surface.

The Periadriatic seam follows the Alpine chain longitudinally for 1,000 km, separating the Austroalpine domain from the Southern Alps. It was formed in the Neogene era, when, with the development of the groundwater aquifer system of the Southern Alps, after metamorphic changes, a collision-rich, eruptive cycle took place - mainly along the Periadriatic seam - characterized by numerous plutons, lodgings and limited volcanics.

The following sequence of images shows the orogeny of the Alpine chain and in particular the formation of the Periadriatic fault line.
1) Opening of the Tethys sea (Fig. 6) - the image shows the expansion of the oceanic crust and the opening of the Tethys sea

2) Opening of a second ocean - the Pennidic ocean (Fig. 7) - the image shows the start of the Pangea continent's breakup and the concurrent closing of the Tethys Sea (to the west) with the progressive expansion of the earth's crust where the Pennidic ocean is emerging; at the same time, the subduction of the Tethys Sea begins, as the African and European plates move closer to one another.
3) Closing of the oceans (Fig. 8) - As the plates move towards one another, the subduction of the Tethys Sea is complete and the subduction of the Pennidic ocean begins. Start of the Alpine elevation and thus Alpine orogeny.

4) Collision of the continents; (Fig. 9) the European continent is thrust under the oceanic units and undergoes continuous metamorphism, while the thickness of the crust increases below the Alps; along the main tectonic line (Periadriatic seam), magma travels upwards and cools creating granite plutons or tonalites.
4 Excavation methods

The Brenner Base Tunnel will be driven using both conventional blasting and mechanized excavation methods, based on the conditions of the rock mass and the length of the stretches to be excavated.

In Italy
The part of the exploratory tunnel running from Aica to Mules has already been built using a tunnel boring machine and the stretches of the exploratory tunnel and the main tunnels to be driven through the Periadriatic seam are being excavated using blasting. The next important lot concerns the construction of the Isarco river underpass (Fig. 10) using reinforced concrete diaphragm walls for about 1000 m of cut-and-cover tunnels, in a sequence of construction phases that include the repositioning of the riverbed. The contract includes the secondary structures (modifications to the state road, the railway and a highway underpass) and tunnels to be excavated by blasting moving toward Fortezza (2000m) and towards Brenner (800m). First of all all the cut-and-cover tunnels will be built at the north and south ends; from here, the consolidation measures will be carried out that are required for the blasting excavation of the first stretches of tunnel up to the rock face in granite.

![Figure 10 - Schematic of the Isarco river underpass](image)

Concurrently to the shifting of the Isarco river, a single large macro-lot of works is to be activated, including:

- continuing the work on the main tunnels to the north, excavating by blasting (about 145 m/month) to completely cross the area of the Periadriatic line; the chambers for the assembly of the tunnel boring machines that will travel further north will be built at the northern end of these tunnels;
- excavation of the main tunnels will proceed from these chambers (380 m/month) and the TBM will meet the other boring machines coming from the Austrian Wolf construction lot near the border;
- construction by blasting of the Trens multipurpose area;
- the excavation of the main tunnels southwards using a TBM (about 380 m/month) will start from the chambers to be built as part of the current construction lot, up to the stretches excavated as part of the Isarco construction lot;
- excavation of the exploratory tunnel northwards using a TBM (320 m/month) starting from the chamber that is to be built as part of the current construction lot;
- once excavation works are complete, the final lining for the main tunnels, exploratory tunnel and the various niches and connecting tunnels will be put in.

In Austria
Construction has been completed on the stretch of the exploratory tunnel between Innsbruck and the Ahrental lateral access tunnel and the access and service tunnels in St. Jodok (Wolf 1 construction lot), all of which were excavated using blasting.

The lateral access tunnel to the main tunnels will be excavated in the next lot, Wolf 2, also by blasting.

The connecting tunnels for the main tunnels with the Innsbruck bypass, the Ahrental multipurpose area, the assembly chambers for the TBM moving southwards and the exploratory tunnel with a TBM moving south towards the Wolf construction lot will be part of a single tender.

Starting from the Wolf access tunnel, a single tender will include:

- the multipurpose area in St. Jodok;
- the TBM assembly chambers for excavations moving both north and south;
- the excavation of the exploratory tunnel to the north by TBM (280 m/month) to join the stretch of exploratory tunnel excavated from Ahrental;
- the excavation of the exploratory tunnel to the south by TBM (430 m/month) to join the stretch of exploratory tunnel excavated from Italy;
- TBM assembly chambers for the excavation of the main tunnels;
- the excavation of the main tunnels to the north by TBM (300 m/month);
- the excavation of the main tunnels to the south by TBM (360 m/month);
- the application of the final linings for the main tunnels, the stretches of exploratory tunnel and the various niches and cross passages.

Another tender will include the excavation, using blasting, of the main tunnels from the Ahrental access window (northwards) toward Innsbruck (180 - 200 m/month) and, using a TBM, of the main tunnels moving southwards (300 m/month) to join the TBMs coming from Wolf.

Figure 1 shows the excavation sequence for the various construction lots.

![Fig. 11 – Schematic of the excavation methods](image)

5 **Status of the works**

5.1 **Italy**
In May 2007 the activities for the preparation of the construction sites and in particular the Mules site (roughly 14,800 m²), from which the access tunnel of the same name was excavated by blasting; it has a cross-section of 92 m², a slope of 8.67% and is 1,755 m long.

At the date of this writing, the ongoing works in Italy are those known as "Exploratory tunnel crossing the Periadriatic Seam and Preparatory Works in Mules" which were started in December of 2011. These works consist mostly of the excavation of the stretch of exploratory tunnel crossing the Periadriatic tectonic line (Length = about 1,325 m) northwards, starting from the junction of the Mules lateral access tunnel, and of the so-called "Preparatory Works in Mules", a series of tunnels, chambers and passages that extend for about 180 m southwards and about 1,200 m northwards from the above-mentioned junction point (Figure 13).
The graph in Figure 14 shows the numerous faults along the Periadriatic line which create a highly complex fault zone concentrated in the area where work is ongoing at present. Further difficulties in excavation are caused by the water inflows, which based on the boreholes drilled so far can display pressures of over 70 bar and flows of several l/sec.
At present, all the works included in the tender are ongoing, except for certain auxiliary works, and the status is as follows: TBM assembly chambers (finished, cross-section 350 m²) southwards (excavation of the crown is complete and the bench is almost complete); construction of the connecting tunnel (419 m) for removal of spoil from the main tunnels using a conveyor belt (completed); main tunnels northwards (400 m of both tunnels have already been excavated); exploratory tunnels (830 have already been excavated) and logistics chamber (completed).

### 5.2 Austria

Wolf 1 construction lot

The first construction north of the border is the Wolf construction site (Figure 15), a preparatory site for the main construction sites and consisting mainly of the Saxen (1 km) and Padaster tunnels (0.7 km), built to exclusively serve construction site roadways and of the first stretch of the Wolf lateral access tunnel (0.2 km). The Saxen tunnel, which was completed in February of 2012 and paved in concrete allows direct access from the A13 highway to the construction site, avoiding the use of the road network for construction site supply. The Padastertal tunnel, which was completed in October of 2011 allows transport of spoil to the disposal site of the same name.
To deposit excavated spoil in the Padaster valley (Figure 16) through which the brook of the same name flows it was necessary to move a small hydroelectric plant further down the valley, as it interfered with the location of the future disposal site; the water supply for the plant is guaranteed by a 2.5 km long pressurized pipe set along the side of the valley which takes the water from the Padaster brook upstream of the disposal site.
Fig. 16 - Disposal site for spoil in the Padaster valley

Before construction of the disposal site, which will hold about 7.7 million cubic meters, a tunnel will be built to channel the brook waters while the disposal site is being prepared; once the site is finished, the water will be directed into the surface channel along the top of the disposal site.

Downstream of the disposal site a retaining wall was built for separate treatment of the waters coming from the channel during construction, from the gravel drainage layer to be placed on the bottom of the site and finally from the sides of the disposal site. In this way, the amount of water in the site can be evaluated, thereby preventing any rise in groundwater levels which might cause slippage of the disposal site.

The retaining wall (Figure 17) was tested in the recent flood that occurred in Summer of 2012, when it protected the town below from the debris that had flowed downstream.
Innsbruck exploratory tunnel stretch and Ahrental lateral access tunnel

Work on the Innsbruck exploratory tunnel (L = 4660 m) with a portal located in the Sill gorge began in December 2009 using full-bore blasting (4-5 volleys for 8-10 m per day). At present the excavation will continue about 1 km beyond the Ahrental lateral access tunnel; the drainage channel in the slab is being built.
Excavation work on the Ahrental lateral access tunnel (2.4 km - 90 m²), with the highway underpass in its first stretch, was begun in July of 2019 and is complete. The tunnel excavation work encountered the Wipptal fault that separates the rock mass of the Ötztal and Stubai Alps from the quartz phyllite formation; the rock was severely fragmented and the glacial gravel deposits in the upper part of the tunnel cross-section required the use of a pipe umbrella (2 x 18m) which was needed also to prevent settling of the highway above. The volleys were therefore reduced to no more than 1.3 m. The excavated spoil was moved to the disposal site of the same name next to the highway.
Fig. 18 – excavation of the Ahrental tunnel

Construction lot for the Ahrental lateral access tunnel

The current railway line continues from Innsbruck to Kufstein with a 9-km two-track tunnel (the Innsbruck bypass) which will be connected to the actual Brenner Base Tunnel with two junctions that will allow trains to bypass the city; the trains will be able to enter from the north and remain in the tunnel until the Fortezza exit.

To increase the safety standards of this tunnel so that they are aligned with the standards applied to the base tunnel, an emergency or rescue tunnel must be built next to the existing two-track tunnel and connected to it with cross-passages every 330 m (Figure 19).

The tunnel will be excavated starting from multiple points, including the Ampass lateral access tunnel which is under construction.
6  **Monitoring of the environmental impacts of the tunnel construction activities**

This monitoring extends to all the environmental aspects on which the construction of the Brenner Base Tunnel could possibly have a negative impact; it aims to verify and evaluate the effects on the area caused by the construction of the structure at all the construction sites involved. Environmental monitoring consists therefore in the entirety of the tests to be carried out either at certain intervals or continuously to evaluate and show the effects on environmental factors during and after construction and operation of the infrastructure. Monitoring activities are carried out on the basis of a specific project (Environmental Monitoring Project PMA) in which the sensitive areas for environmental components are laid out according to criteria connected to the direct cause of interference in the area or a possible significant link that might cause a variation in the parameters connected to a certain environmental component.

Environmental monitoring activities are divided into 3 stages:

a) prior to the start of the works (this phase has already been completed)

b) during the works, meaning the entire construction phase until the pertinent sites are restored to their original condition

c) once the works are completed, including the pre-operational and operational phases

The environmental aspects that will be monitored are as follows:

- social habitat
- landscape
- flora and fauna
- ecosystems
- hunting and fishing
- air
- groundwater - water resources
- groundwater in construction site areas
- surface waters - hydro-morphology and water quality
- soil
- subsoil
- electromagnetic compatibility
- light pollution
- noise
- vibrations
- cultural assets
- leisure time
- recreation
- tourism
- waste
- excavated material and spoil (Fig. 20)
The aim of environmental monitoring is the assessment of the project impacts expected both during the construction and in the operational phase and the monitoring of environmental conditions during the construction phase; any unexpected situations and/or environmental issues must be promptly noted and the necessary corrective measures must be taken in a timely manner. It is also extremely important to verify the efficiency of the mitigation measures and whether the content and any provisions or recommendations formulated in the environmental compatibility decree have been complied with exactly.

The structure set up to manage the flow of information coming from the environmental monitoring activities launched by BBT SE sets forth specific roles which are assigned to specific people.

First of all, monitoring of environmental impacts is carried out by a third party, known as a "monitor", who, availing himself of all required professionals, carries out all monitoring activities, validates and reports the data in compliance with all applicable norms and regulations.

Environmental management on construction sites and monitoring data analysis on the other hand are the responsibility of an "Environmental Manager" tasked with finding optimal solutions for anomalies. This person coordinates the interdepartmental activities for environmental monitoring, guaranteeing both homogeneity and compliance with the project; he or she carries out the tasks and bears the responsibilities set forth in the Guidelines for the environmental monitoring project for the work included in the Legge Obiettivo (Law No.443 of 21.12.2001);

BBT SE, as contracting authority, provides general supervision and liaises with local bodies and the competent authorities.

An Observatory for the Environment and Safety in the Workplace was set up that acts as an interface between the contracting authority, the competent authorities, local bodies and the population both as a supervisor and a guarantor for the monitoring data and the solution for any anomalies found. The Observatory for the Environment and Safety in the Workplace, with the participation of the involved and interested bodies at a local level, monitors the ongoing process, as it is the body charged with managing and reporting the environmental status of the area touched by the construction of the exploratory tunnel and it is further tasked with verifying and monitoring the impacts produced by the work; it also monitors compliance with the norms on worker and workplace safety and hygiene.
The information on the project and the Observatory's activities are communicated to the public through an organized information centre, known as an Infopoint which opened on November 9th 2008 at the railway station in Fortezza.

7 **Deformation monitoring stations**

The relatively small size of the current lot in Italy, compared to the size of the entire Brenner base tunnel project, is due to the fact that the Periadriatic line is located in this stretch and the data on this fault line (both concerning the mechanical characteristics of the rock mass and the reactions of the rock mass to excavation) can substantially influence the choice of consolidation and support methods to be planned for the tunnel. Therefore, further knowledge on the materials to be used comes mainly from the construction of the exploratory tunnel, starting from which proper measuring instruments allow the gathering of data needed to cross this tectonic line under the best conditions possible when excavating the main tunnels.

To identify the behaviour of the rock mass and thereby estimate with greater precision the cost of the main works, and to further reduce the risk of unforeseen geological conditions, a challenging monitoring process has been implemented during the construction work itself, consisting in a program of prospection drilling beyond the rock face and including geotechnical monitoring to verify the response to excavation of the rock mass being crossed.

To summarize, the system includes, besides the prospection drilling beyond the rock face that we have already mentioned, systematic geological and geo-mechanical surveys, the monitoring of gas and radioactivity, and the installation in several sections (Figure 21) of the following instruments:

- radial (contact between the ring beam and the rock mass) and tangential (contact with the steel inside the ring beams) pressure cells
- extensometers on the inside and outside of the ring beams - steel deformation
- multi-base bolts to measure the shift of the various bases around the excavation so as to indentify the area in which deformation is occurring
- extensometers to measure deformation of the rock face
Fig. 21 - Section equipped with measuring instruments at km 11 + 743

Besides this, special niches have been planned for plate load tests, further extensometers to measure the reactions of the more de-structured and loosened parts of the rock mass, etc. So far all the instruments installed have shown stabilization of the shifts and loads. The most significant is certainly the area in Pusteria at tunnel km 11+123 (Figure 22) where the convergence trend during the stabilization phase seen in Figure 23 was reported:
The tangential pressure cells installed in the same 11+123 section (Figure 24) show that the loads are stabilized on pressure values which are compatible with the characteristics of the lining (Figure 25):
Figura 24 – Location of the radial and tangential pressure cells

Fig 25 – Stress on the tangential and radial pressure cells km 11 +123
Geodetic monitoring

During final planning for the Brenner Base Tunnel, as in projects concerning other Alpine passes, an analysis of possible settling phenomena caused by tunnel drainage of water circulating in the rock mass was carried out. Such events can be caused not only by a loss of hydraulic load in the aquifers but also by natural ground deformations (even in the absence of draining tunnels) due, for example, to temperature, groundwater levels, reservoir levels and so on.

A map of settlement risks (Figure 26) was drawn up based on a digital model of the terrain, on hydro-geological prospection, on the location of sensitive structures (deformed slopes and alluvial deposits) and on the acceptability of the relative level of settlement phenomena. Fault zones and areas with hydraulically interconnected fracture systems - in this specific case the Mules Gneiss-Tonalite and the Brixner Granite lithotypes were also included in the analysis.

![Figure 26 - Map of settlement risks](image)

The results of this analysis, especially for the area around Mules, which is about 2 km from the tunnel route, have been considered valid for the excavation of the exploratory tunnel as well, with overburdens in this area around 600 m.

In this case, however, due to the surrounding conditions, the occurrence of pronounced levels of settling was not considered a probable event, especially near the alluvial cone at the valley floor where most of the buildings in the village of Mules are located.

To be on the safe side, geodetic precision monitoring was put in place, divided into two linked activities:

- Permanent multilevel satellite monitoring (GNSS);
- Ground monitoring with a completely automatic station with prism measuring installed on several buildings in the village of Mules.

Permanent multilevel satellite monitoring (GNSS)

To achieve the highest possible level of precision using satellite measuring technology, in an area of about two square kilometres, a regional GNSS network was set up in the village of Mules consisting of five benchmarks that are also part of a higher-level network. A reference point was installed in a central location to calculate baselines for the other four stations; all stations are further monitored using the data from three locations belonging to the GPS STPOS reference service of the Geodetic Office of the Inspectorate for the Land Register of
the Autonomous Province of Bolzano: the total GNSS network therefore consists of 5 + 3 stations.

**Land monitoring using a fully automatic station**

In addition to GNSS monitoring, a fully automatic system was set up for continuous measuring with prisms located on 38 buildings in the village of Mules and 12 cadastral markers in the immediate vicinity, needed to acquire reliable direct information concerning any ground movement at the surface even in the densely inhabited centre of Mules.

A year prior to the start of tunnelling in the critical Periadriatic line area, the GNSS monitoring system was calibrated with a reference measurement (point zero) and a first verification measurement.

The transfer of the data to an operations centre takes place in real time by GPRS/UMTS with constant verification of data quality; these data are evaluated, again in real time, and any deviation from the prescribed threshold values is reported by automatic message texts or e-mail communications for appropriate action to the people responsible for the works.

Before the construction sites in Unterplattner e Mules were set up and the exploratory tunnel between Aica and Mules was driven, the conditions of the buildings and structures located in the possible area of influence of the structure being built were surveyed.

So far no significant level of settlement has been observed.

9 **Topography**

The Brenner Base Tunnel project has required a series of cross-border geodetic topographic mapping activities in order to represent the Italian and Austrian reference systems in a single geodetic system and a shared geographic foundation: these data, managed with the most modern IT products available today, are the basis for planning and design and construction site set-up activities.

To this end, an extremely high precision geodetic network was created with surveys, measurements and evaluations over the entire cross-border area and benchmarks in the global geodetic system (WGS84-Word Geodetic System 1984) using European definitions (UTM-ITRF94).

As far as elevation is concerned, the precision levelling of the valley floor was re-surveyed and the precision geoid referring to the project area was assessed in the European height system known as UELN (United European Levelling Network).

In this manner, the difficulties in interfacing the two national geodetic mapping systems concerning the area were overcome, by using a univocal system that is recognized in international technical fields and guarantees that data can be transferred between the various systems and thereby provides an appropriate geodetic framework for the benchmarks needed to build the tunnel and the secondary structures. (Figure 27).
Fig 27 – High Precision Geodetic Network

The precision geodetic network, in which the number of benchmarks was subsequently increased, was used to create a digital aerial photo and the corresponding digital terrain model (DTM).

Subsequently, a numerical vector cartography converted to a topographic database was created and used as a geographic base to create a Geographic Information System or GIS specific to the BBT SE project with a specific layering structure (Autocad-ESRI_ArcInfo). This GIS is the present reference system for every planning phase. Recently, detailed surveys have been carried out at the construction sites for the excavation portals and the various pertinent spoil disposal sites.
The geodetic and topographic activities which support both planning and construction are as follows:

- high precision geodetic network
- aerial films
- aerial photography - vector data
- new cross-border high-precision levelling lines
- geoid of the project area
- detailed survey of the construction and disposal sites
- transfer of the project data into a system better suited to tunnel axis tracing operations.

During the construction phase it became necessary to transfer the project data into a system better suited to tunnel axis tracing operations so that the difference between project and tracing data would be minimal and if possible negligible.

So as to interface the data from the study phase with the current state of progress of the works, the project was drawn up using UTM-WGS84 coordinates, using the international convention that projects geographic ellipsoid coordinates on a transverse cylinder according to Gauss with a contraction coefficient at 32 arc; a conventional value of 9° longitude with easting of 500 km was assumed for the central meridian, whereas north coordinates originate at the Equator. The elevation reference point is the ellipsoid, the ellipsoid altitude is therefore zero.

The project is developed in a part of the cartographic plane for which the linear deformation module is slightly above 1, with values reaching 1.00009 which vary as a function of easting and northing.

The differences here concern distances in the project plane and the corresponding distance along the tunnel axis, amounting to about 10 cm for every kilometre of tunnel: 1000,00 m on the project plan are 999,90 m when tracing the tunnel axis.

Every distance planned at zero altitude is actually longer, due to the altitude at which the work is effectively carried out. A project plan distance of 1000,000 m corresponds to 1000,121 m (assuming 770 m of ellipsoid altitude) when tracing the tunnel axis.

The combination of the two effects, due to the linear deformation module and the reduction of the reference surface varies from point to point as a function of the values of the easting and northing coordinates and of elevation.

The project area, in its easternmost point, lies at 2°40’ from the central meridian of the arc; the angle of convergence of the meridians, meaning the difference between geographic and cartographic north is, therefore, high and the reduction values at the chords, meaning the difference between a direction on the cartographic plane and that same direction in reality, are also significant.

It was therefore deemed appropriate to use a new cartographic plane, also generated by a transverse Mercator projection (TM), that is by a Gaussian projection, but using an ellipsoid with no contraction coefficient and in fact slightly expanded to pass through the average project elevation (720 m of UELN elevation, which are about 770 m of ellipsoid elevation).

The "new" cylinder was made tangent to the ellipsoid on the Italian-Austrian border for the easternmost tube.

A shift, or a false origin, was introduced so that the formerly used barycentric point would be conventionally assumed to have coordinates 20 km East and 100 km North, so that no point would have negative coordinates and so as to generate pairs of coordinates that would not have values similar to those typical of other official cartographic reference systems.

The project therefore extends for about 10 km east and west of the central meridian of the "new" arc.

The linear deformation in that case is reduced to about 2-3 millimetres per km.
The advantage of this was the ability to work from the beginning with a single plan for the entire structure without the obstacles caused by the use of different systems for each stretch of tunnel in correspondence with the various construction lots. (Figure 28).

The new map, which was generated by a particular Transverse Mercator (TM) projection, is called BBT_TM-WGS84 (Figure 29).

Fig 28 – A single reference map instead of maps for each construction lot
Conclusions

The work currently underway, which will give way to far larger construction lots, can be considered some of the most difficult work to be faced during the project, not only due to the geological complexity of the rock mass to be excavated, but also because it involves a test run of the logistics and supply systems which serves the entire project.

This phase is therefore extremely sensitive and requires especial care to keep any glitch or malfunction from jeopardizing the entirety of the work.

The management of the imposing process described above involves the setting up of a complex technical and administrative system to manage and prevent any problem that might occur during the construction of a structure of remarkable international importance that will, with its access routes, guarantee mobility among some of the most productive and economically advanced European regions.
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