Brenner Base Tunnel & Isarco River Underpass Section: several technical and operational solutions

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The Brenner Base Tunnel is part of the TEN-T SCAN-MED corridor and allows for overcoming the natural barrier of the Alpine ranges. The Isarco River Underpass represents the southernmost construction lot of the Brenner Base Tunnel, links the Brenner Base Tunnel with the existing Brenner line and the railway station in Fortezza. The work is scheduled to be completed in 2023. The paper summarizes design choices made for the specific construction lot which are mainly related to critical logistic issues. Moreover, as loose fluvioglacial materials and groundwater layer will be crossed, it will be necessary to adopt specific ground consolidation procedures including ground freezing and the jet grouting. The high speed railway of the Brenner Basis Tunnel underpasses the Isarco River, near Fortezza, with four 10 m diameter tunnels, two of them as an interchanging to the existing line, with very shallow cover, ranging between 5 and 8 m under the river bed. To minimise environmental impact of the works it was proposed to build these tunnels by conventional method. The excavation will start then from shafts on the riverbanks, after ground improvement and soil freezing made all along tunnels profiles.

1. Introduction

The Trans-European Transport Network (TEN-T) aims to develop an integrated multimodal transport network allowing people and goods to move quickly and easily across the EU. This is intended to support the development of the internal market and reinforce economic and social cohesion.
The Scandinavian-Mediterrean Corridor (5) is the longest of the TEN-T Core Network Corridors and is based in part on a series of former Priority Projects. It links the major urban centres in Germany and Italy to Scandinavia and the Mediterranean whilst crossing 7 different Member States: Finland, Sweden, Denmark, Germany, Austria, Italy and Malta. The Brenner Base Tunnel is part of the TEN-T SCAN-MED corridor and allows for overcoming the natural barrier of the Alpine ranges. For this reason, the EU is prioritising this tunnel among its infrastructural projects.
Under the Brenner Pass, the longest railway link in the world is being built: the Brenner Base Tunnel (BBT). The Brenner Base Tunnel stretches for about 55 km between Innsbruck train station and Fortezza train station. Together with the existing Innsbruck bypass, the tunnel will reach 64 km and reduce travel time for freight and passenger traffic significantly.
The "Isarco River Underpass" Section is the southern segment of the Brenner Base Tunnel, before entering the railway station at Fortezza. It is situated approximately one kilometer North of Fortezza, Prà di Sopra, Bolzano (Italy). The section will include civil works for the two main tunnels for a total length of roughly 4.3 km, as well as two interconnecting tunnels for a total length of 2.3 km that connect with the existing railway line. Construction will be extremely complex from a technical point of view: both the main tunnels and the interconnecting tunnels will pass under the Isarco River, the A22 motorway, the SS12 motorway and the Verona-Brenner railway line with a minimal leeway (Fig. 1).
Before the start of construction, several preliminary activities have been carried out on the surface, including the re-routing of the national road SS12, the construction of two bridges over the Isarco River and the Rio Bianco and the realization of the interconnecting area on the A22, which has been be required to facilitate the transport and supply of construction materials for the Project (FUOCO *et al*., 2016). The construction works are performing by the "Isarco" Consortium composed by Salini-Impregilo, Strabag Consorzio Integra.

2. Geographical and geological overview

The project area is located in Val d'Isarco in the municipality of Fortezza, at an altitudes varying between 750 and 850 m above sea level. The geological sector is the southernmost sector of the BBT and extends from the Rio Bianco (at the north side) to Fortezza (at the south side). The corridor of the route is divided into two

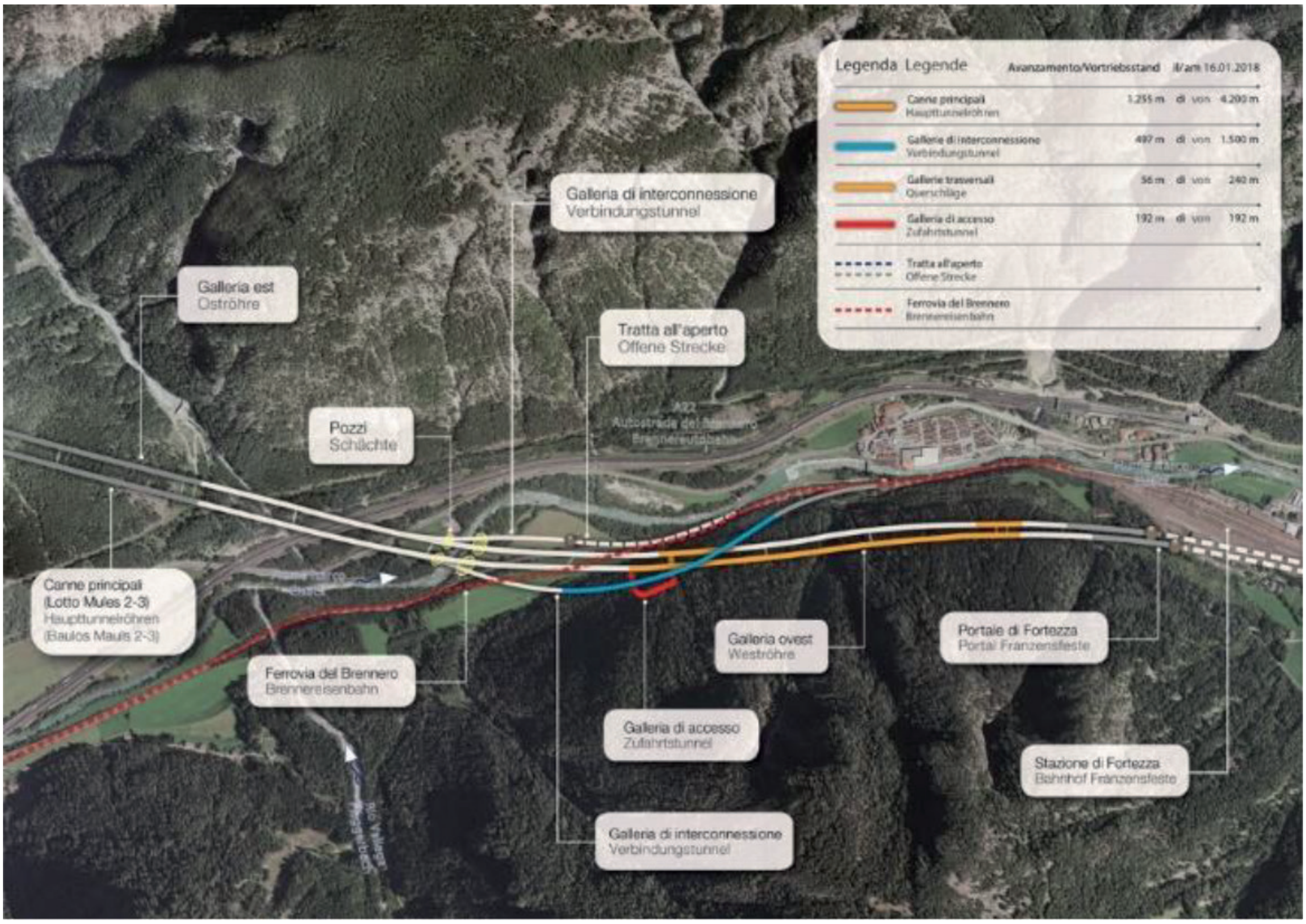

Fig. 1 – Isarco River Underpass overview map (www.bbt-se.com).

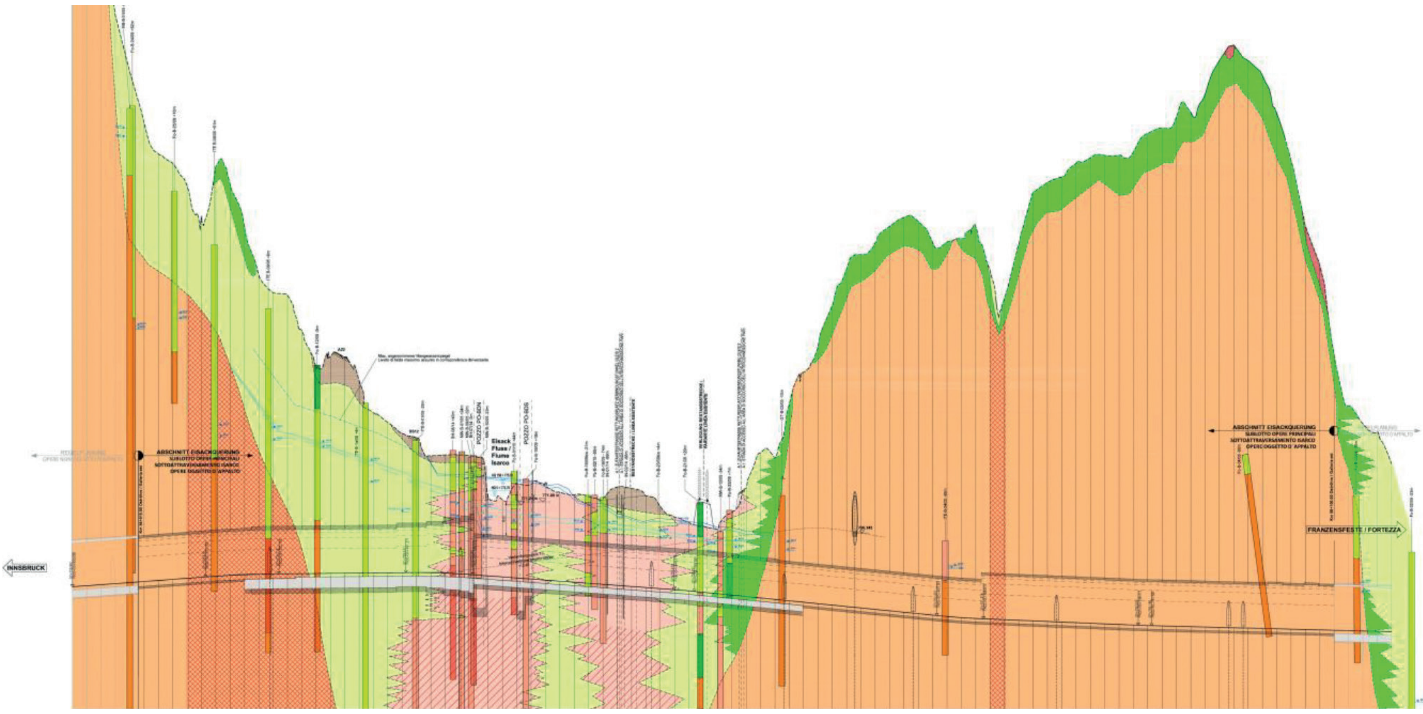

Fig. 2 – Isarco River Underpass Geological Profil.

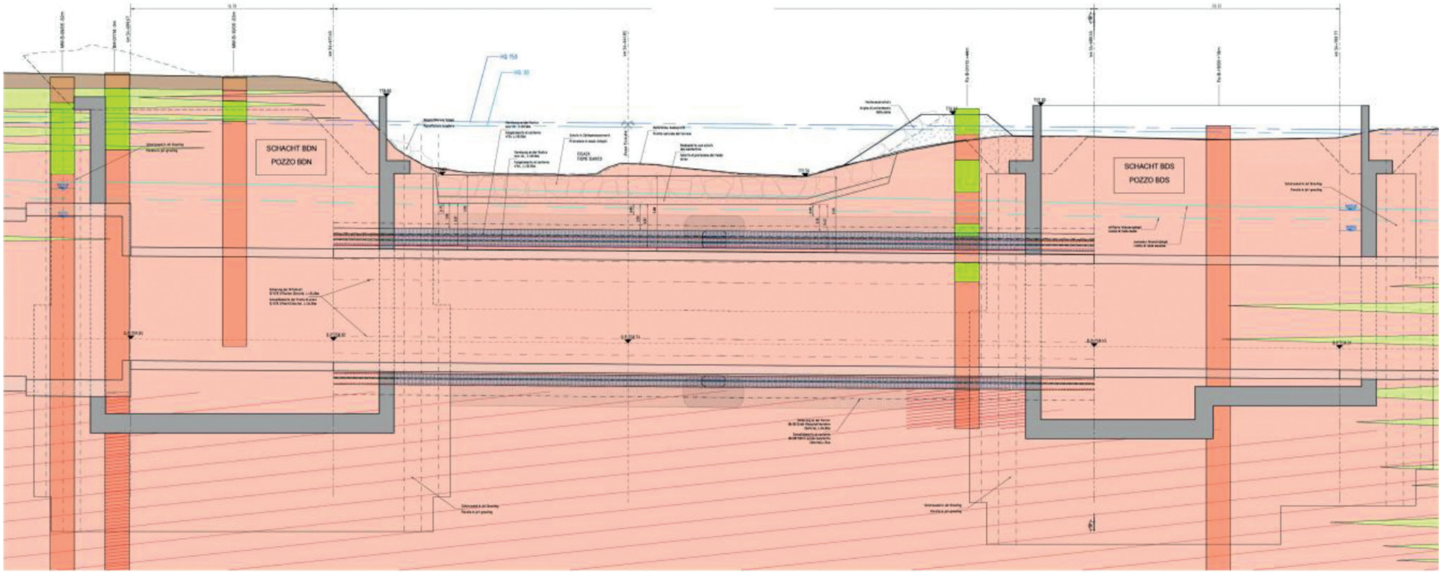

Fig. 3 – Geological Profile: detail of Isarco River Underpass.

Tab. 1 – Rock Mass geotechnical parameter.

	Rock Type [MN/m²]	σ_{cm} [kN/m³]	γ [°]	φ [kN/m²]	c' [MN/m]	E_S
GA-BG-01	Granite: Granodiorite large - medium fracturing	54 (39-69)	26,5	62	1900	15000
GA-BG-02	Granodiorite large - medium fracturing	22 (12-22)	26,5	58	1000	5000
GA-BG-03	Brixen Granite	1,4 (0,8-2,2)	26,7	30	2600	500
GB-G-GA 6	Brixen Granite	44	26,7	64	1800	19000
GB-G-GA 7	Brixen Granite Rio Bianco fault	7,4	26,7	52	300	1700

Tab. 2 – Soil Mass geotechnical parameter.

	Soil Type [kN/m³]	γ [°]	φ [kN/m²]	c' [MN/m]	E_S
A -	Debris Flow	21,0	30	10	60
B -	Slope Debris	21,0	35	0	60
C -	Alluvional Sediments	20,5	36	2	60
D -	Weathered Material	21,0	30	0	30

sectors by the River Isarco with NW-SE direction. The valleys of Rio Bianco, Rio Vallaga and Rio Riol depart transversally from the direction of the main valley. The most prominent relief within the project area is Mount Riol (1547 m), with its steep side south and SE oriented known as "Hohe Wand".

The main residential areas in the Isarco Valley between Fortezza and Rio Bianco are the villages of Pra di Sopra and Fortezza itself. In addition to these villages some farms and buildings are distributed in the project area too.

From the geological point of view, this construction lot is ascribing to the Southern Alps sector. The railway alignment enters into the South-Alpine crystalline basement, on the southern side of the Periadriatico Line (ZURLO *et al.*, 2013), consisting of the Granite-Granodioritic Pluton of Bressanone, Gabbro del "Monte del Bersaglio" and the metamorphosis of encasing (Filladi, micascisti granitiferi) of the Fillade Quarzifera di Bressanone. The Bressanone Granite is the most widespread rock in the project area.

The Isarco River Underpass passes through the alluvial deposit of the valley bottom and through the dejection conoids of the tributary rivers. These loose deposits, heterogeneous both in composition and in granulometry, consist of gravels and rounded sand, with frequent boulders and thick layers of sandy silt (Figure 2 & Figure 3). The flanks of the valley are covered by coarse particle size material, composed by slope debris, alluvial sediments and weather material. The most voluminous rock fragments, up to 1 m, are made of granite. Except for the silty levels, which in any case constitute a minority, the loose deposits are characterized by friction angle value varying between 30° and 40°. Table 1 and Table 2 summarize respectively rock mass and ground mass geotechnical parameters.

A large survey campaign has been carried out during each design stage. Final design required additional in situ and laboratory tests to check stratigraphy, ground's strength and deformability parameters.

The water table flows along the same direction of the Isarco River while remaining independent from it. The water table is bounded at the sides and at the base of the rock surface by the Bressanone granite. Hydrogeological studies were carried

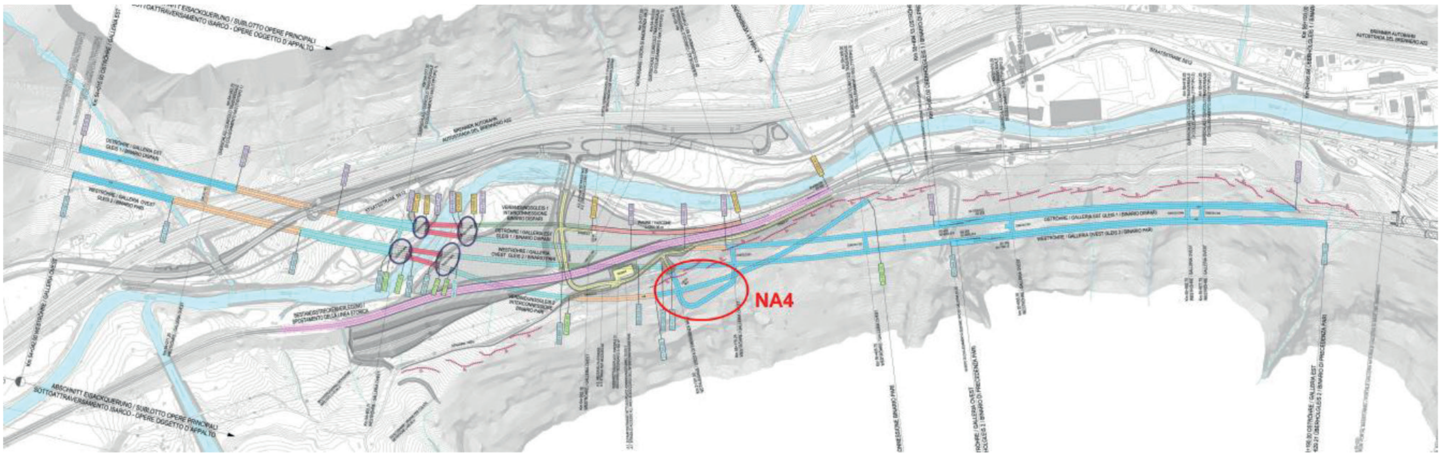

Fig. 4 – Isarco River Underpass Lot.

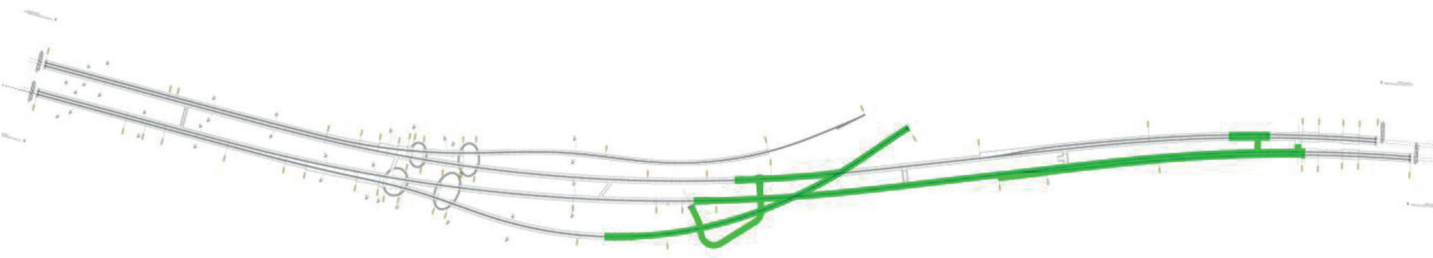

Fig. 5 – today faces' positions.

out in the valley bottom sector, near future tunnels, with the aim of assessing the characteristics of the aquifer and in particular determining the maximum permeability and speed values of the water table, which are of considerable importance for the success of the consolidation intervention preparatory for the tunnel excavation. Alluvial deposits have a maximum hydraulic conductivity equal to 1.9 x 10^{-3} m / s, with a maximum speed, estimated by tracer tests, equal to approximately 14-16 m / g.

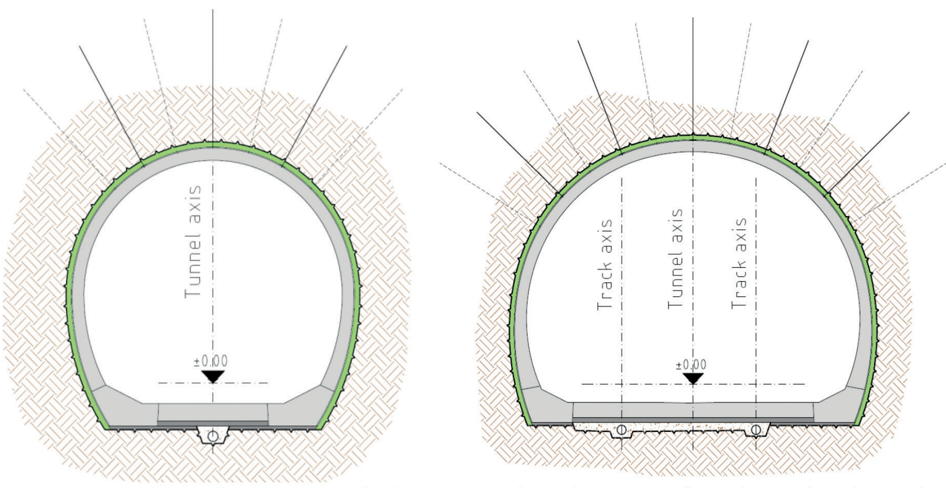

Fig. 5a – Conventional excavation method section type for rock mass - Single track & dual track tunnels.

3. Project description and design choices

With reference to Figure 4, the Isarco River Lot could be subdivided in three main sectors: 1) the tunnels north of the Isarco river, mainly interested by Granite of Bressanone (GB-G-GA6 and 7) with the special passage through the Rio Bianco fault; 2) the tunnels south of the Isarco River, interested by the Brixen Granite and granodiorite (BG-01, 02) and 03) the Isarco river valley, where soft soil, mainly alluvial deposit of the valley bottom and the dejection conoids of the tributary rivers, are present.

The tunnels in rock will be excavated full-face, according to ADECO-RS Approach (Lunardi P., 2015) and by conventional excavation with D&B, with several confinement actions, such as steel bolts and ribs, shotcrete and, locally in fault zones, forepolings (Fig. 5a). The northern tunnels are double track tunnels and will be excavated starting from the shafts located near the Isarco's banks as the last sector of the Lot. The southern tunnels in rock are single and double track tunnels (double track tunnels from chainage 55+485 towards south) and they are being excavated by a mid-access, named NA4, which gives the possibility to work from four face, two toward south portal and two toward the Isarco river; in Fig. 6 the today faces' positions are represented.

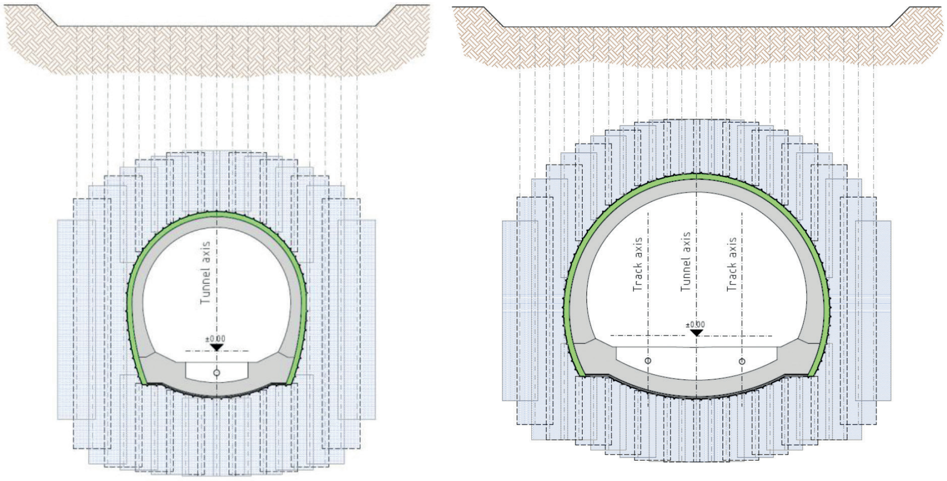

Fig. 5b – Conventional excavation method section type for debris mass. Ground improvement by vertical jet grouting - Single track & dual track tunnels.

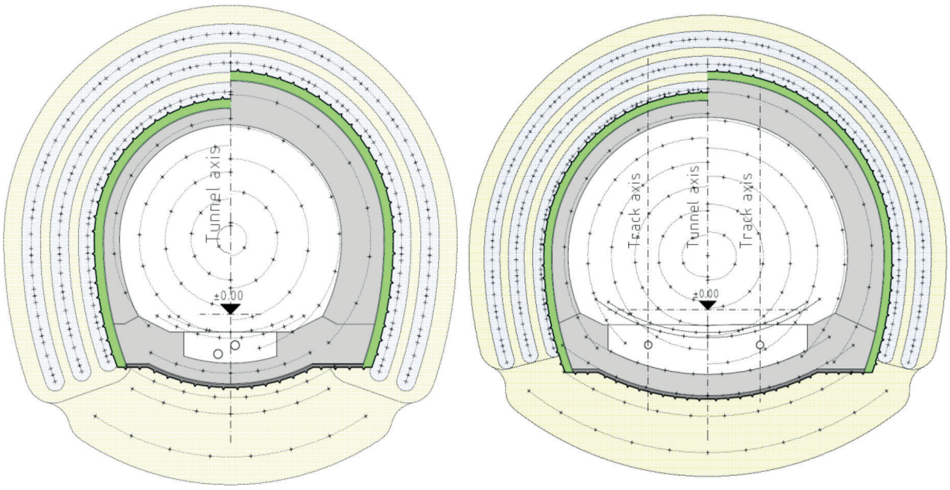

Fig. 5c – Conventional excavation method section type for debris mass. Ground improvement by vertical jet grouting - Single track & dual track tunnels.

For soft soil tunnels, located into the Isarco River, several technical solutions will be applied depending on ground -level interferences, overburdens and local geotechnical context. Where ground-level is clear, grouting from surface by jet-grouting technology has been used, by this way tunnels' construction process switches between excavation and final lining casting, without stops because of grouting treatments (Fig. 5b). This solution speeds up tunnels' excavation. Where it was not possible to operate grouting from surface, it was planned to carry out the consolidation activities from the tunnel to guarantee the stability of the core-face (Fig. 5c), alternating excavation and consolidation to the final lining casting. This construction process will be applied in particular in the northern section for the underpass of the A22 motorway and for the underpass of S.S.22 state road. For these soft tunnels the ADECO-RS Approach has been adopted too.

This delicate river underpass consists of 4 tunnels to be excavated, under the riverbed and the banks, without depressing the water table and without proceeding with any deviation of the watercourse. The underpass is safely performed starting from the 4 shafts previously excavated, thanks to the use of an eco-compatible technology that consists in freezing a crown of soil around the entire perimeter of excavation, after pre-treatment of the ground made by injection of cement mixtures and ecocompatible chemical supplements (Fig. 5d).

The project choices foresee to totally avoid

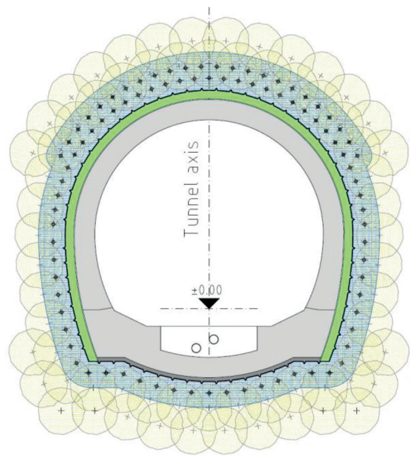

Fig. 5d – Conventional excavation method section type for river underpass ground improvement and ground freezening on the excavation face - single track.

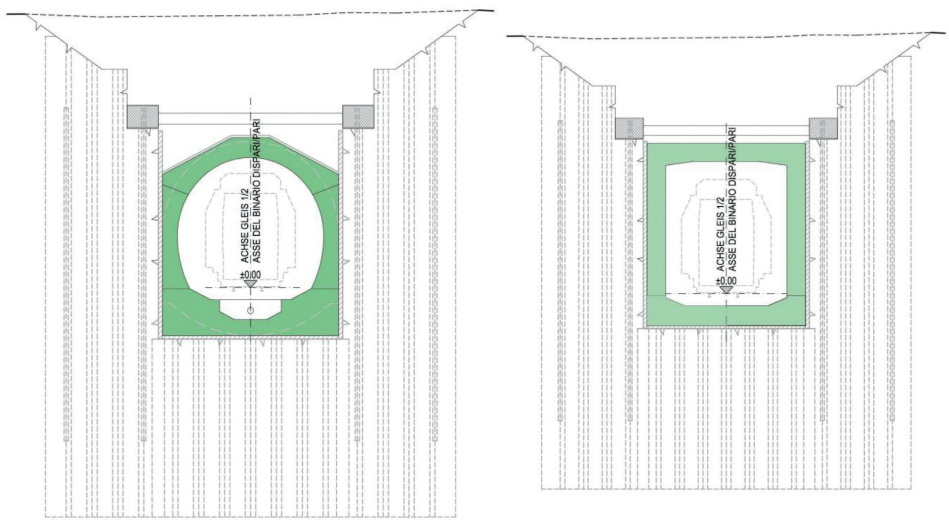

Fig. 5e – cut & cover ground improvement by vertical jet grouting columns.

Fig. 6 – Excavation face interested by granite in very good conditions, with GSI values ranging between 60 and 75.

the lowering of the water table and to eliminate any interference with the flow of the Isarco River, thus reducing enviromental impact. In addition the adopted technical solutions, on respect to a cut&cover solution with temporary deviation of the river, allows to:

- reduce the connection sections between different excavation technologies, thus reducing potential discontinuities and infiltrations;
- reduce the extension of construction areas;
- simplify the constructive process and to achieve faster and controlled progress, reducing the likelihood of unforeseen events and the risk to workers;
- considerably reduce the volume of excavated ground.

The project guarantees the continuity of water flow both underground and at the surface level, both during construction and during operation. The project also drastically reduced the amount of material coming out from excavations and its movement outside the construction sites, reducing a lot the transit of construction vehicles to depot and towards recycling centres or other areas for final conferment.

Finally, some sections, preliminary to the relocation of the historical line, will be constructed by cut&cover (Fig. 5e and Fig. 5f).

4. Underground project sections - details

The project has a total length of 5'628.65 m, 4'841.58 m in conventional tunnel and 787.07 m in Cut&Cover. Tunnels will be excavated full-face; the variable geological context required different section for excavation. For good quality rock mass "A" sections have been designed, "B" sections for fractured rock mass, "C" sections in case of debris flow and soft soils according to ADECO-RS Approach. The water table drawdown has been avoiding by grouting which provides waterproofing effect. Stability of the core-face is regulated by the intensity of the measures applied (Lunardi, 2015). Special guidelines allow to fine tuning the pre-confinements and confinements actions in order to control the face and cavity deformations and, consequently, the surface settlements. In the following, detailed description for the main project sections is reported.

4.1. Rock tunnels

The excavation, through the good quality rock mass, will be performed by drill & blast, with rounds ranging between 3.0 m to 5.0 m, applying the "A" sections: A0, A1 and A2, with GSI values ranging between 50 and 70. The subsequent phases consider the installation of radial steel bolts, Swellex L=3.0-4.0 m capacity 200 KN with mesh approximately 1.20-1.5 m × 2.20-2.50 m, fibre reinforced shotcrete (thickness 5.0-10.0cm with wiremesh 610HD), the reinforced concrete invert (thickness 50.0 cm) and the concrete lining (thickness 36.5 cm for plain concrete and 41.5 cm for reinforced concrete). Very small diametric convergence, 1.0-3.0 cm, are expected considering an elastic behaviour of the core-face.

Fig. 7a – First meters of excavation with "super wedge" to reduce vibrations - 7b. Concrete portal.

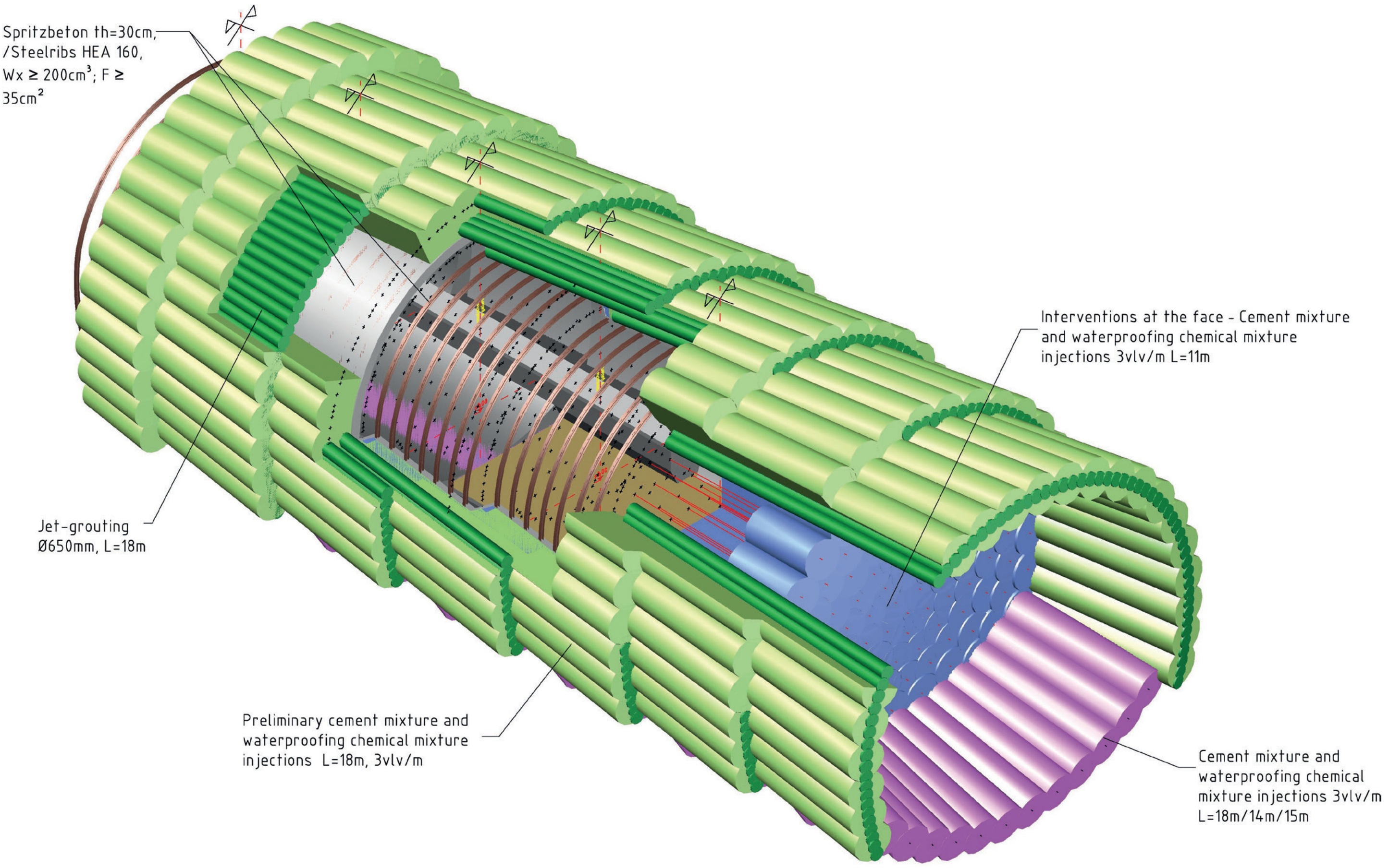

Fig. 8 – Excavation section type C1.

The excavation, through the fractured rock mass or in case of fault zones, will be performed by hydraulic hammer, applying the "B" sections: B0 for GSI in the range 35-50, B0V for GSI in the range 25-35 and B2V for GSI less than 25. The subsequent phase considers the installation of steel pipe umbrella (for the sections B0V and B2V), diameter 88.9/10 mm, with interaxis 40 cm and overlapping 5 m, steel arch (2IPN160 installation step 1.50m, 2IPN180 installation step 1.00m for sections B0V and B2V), fibre reinforced shotcrete (thickness 25.0-30.0 cm), reinforced concrete invert (thickness 65.0-80.0 cm) and reinforced concrete lining (41.5-116.0 cm thickness). For the section type B2V the reinforcement of the core-face, by means of fiberglass elements, is also provided, to stabilize the face; a shotcrete layer, thickness 10-25 cm, is placed too. The expected deformations, in term of diametric convergence, are in the range 3.0-8.0 cm; basing on the deformation response is possible, according to defined Guidelines, calibrate the steel ribs step and the distance, from the face, to cast the final lining, invert and crown. With this purpose a monitoring system was set up, to collect the geotechnical conditions of the face, by means of a continuous face-mapping, and the topographic mea-

Tab. 3 – Jet grouting parameters.

column diameter	cm	200	200
		H > 20.00 m	H < 20.00m
column theoretical volume	mc/m	3,14	3,14
cement per cubic meter of treated soil	kg	430	389
jet grouting mix	C/A	1	1
cement	kg	100	100
water	l	100	100
grout density γ	kg/l	1,51	1,51
grout per meter of column	l/m	1786	1483
jet pressure	bar	400	400
number of nozzles	n°	1	1
nozzles diameter	mm	7	7
air capacity	l/min	10.000	10.000
air pressure	bar	10	10
jet pump capacity	l/min	540	540
step	cm	5	5
stand-by per step	sec	10	9
speed rotation	n/min	6,00	6,00
Specific energy	MJ/m	72,00	63,12

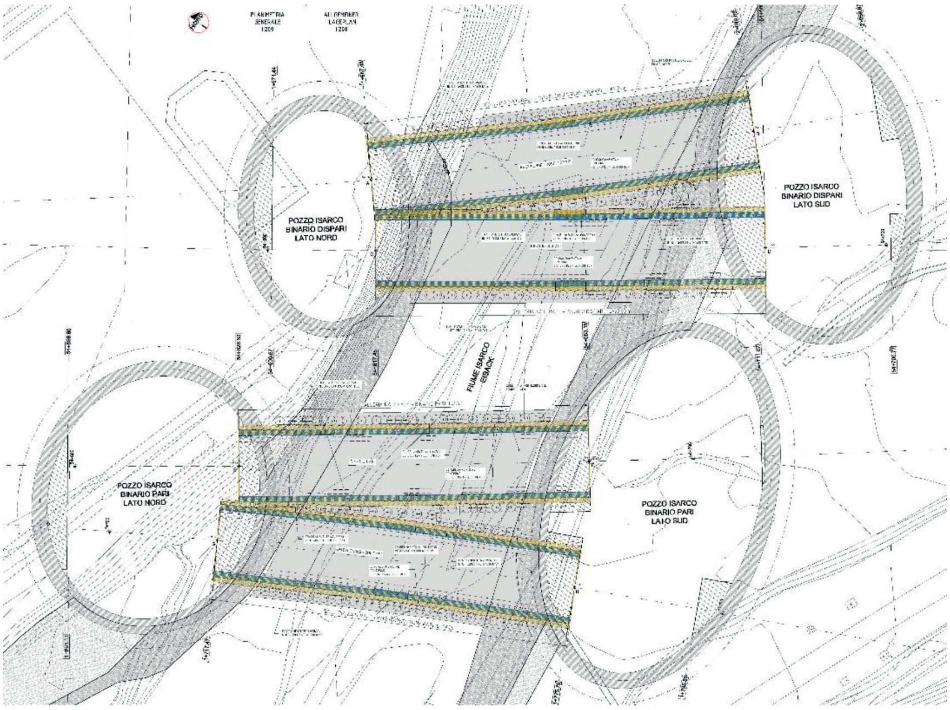

Fig. 9 – Tunnels &Shafts of the river underpass.

surements. Figure 6 shows a typical face condition: the excavation interests mainly granite in very good conditions, with GSI values ranging between 60 and 75. The good quality of the rock is confirmed by the measurement of the convergences that, up to now, have recorded maximum values around of 1.00cm.

The mid-adit to excavate rock tunnels, named NA4, is placed in a hard rock slope. To prepare the starting face for the tunnels, hydraulic flat-jack have been used in order to avoid the vibrational disturbance linked to the drill&blast solutions; a concrete portal has been casted in situ to protect the excavation face (see Figure 7).

4.2. Tunnels in soils – Grouting executed in advance

Excavation section C1 is applied in case of loose soils of quaternary origin. Particularly in the Northern sector, in correspondence of the Debris Flow with unstable behaviour, to underpass the motorway A22 and the SS12; the overburden is ranging between 25 to 30 m. It is applied in the Southern sector too, in correspondence of the detritus conoids where unstable core-face behaviour is expected. This section type considers pre-consolidation intervention around the cavity and at the core-face, aimed creating the conditions of stability and waterproofing of the natural soil. The design requires that excavation is performed without reducing the groundwater level, in hydrostatic conditions. For this reason it is necessary to create a grouted arch around the cavity and a plug at the face, so that the advance core is waterproofed. The interventions at the face are characterized by injections of cement mixture and waterproofing chemical mixture through PVC pipes with valves ("tube-a-manchette"), in the measure of 3 valves/meter. Half of these PVC pipes will also be reinforced by glass fibre structural elements, to increase the stability and the rigidity of the advance core, as well as providing an easier grip for the concrete sprayed on the excavation face. The stability of the tunnel's crow will be ensured by horizontal "monofluid" jet grouting interventions, $\varnothing$=650mm L=18.0 m, which will be performed after a preliminary intervention by cement mixtures injections through PVC pipes, to reduce the permeability of the soil and facilitate the realization of the Jet Grouting interventions (avoiding seepage effects). In correspondence of the invert, only cementitious and waterproofing chemical mixture injections will be used. In presence of boulders local steel pipes will be placed in advance. The excavation sector will have a truncated cone shape with a length of 7.00 m, thus guaranteeing a double overlapping of the boundary interventions; the excavation will be performed for single step of 1.0 m, followed by the installation of steel ribs (HEA160/1.00 m) incorporated into shotcrete, 30 cm thickness (see Figure 8). To check the grouting benefits before starting the excavation, permeability tests will be performed in the pre-treated area by cement injections, looking for a reduced permeability: from 1×10^{-4} m/s up to 1×10^{-6} m/s. Additional interventions, or new injections, will be executed if the waterproofing effect is not achieved. Considering the heterogeneity of the soil, especially the presence of limes strata, the grouting activities should be calibrated during the construction process: injections up to 200 lt/valve are expected. The final lining will be casted in situ: the invert, 85 cm thickness, will be casted within 10-15 m from the face; the crown, with truncated cone shape, 66-150 cm, will be casted within 30-40 m from the face; these distances could be regulated during the construction according to the deformation response (predicted convergence value in the range 5.0-7.0 cm).

4.3. Tunnels in soil – Grouting performed from surface

An extension part of the tunnels in soils will be realised using jet-grouting treatments executed from the surface. It's a very interesting technical solution because it allows to separate the grouting phase from the excavation one. The "double-fluid" system will be adopted to reach nominal diameter of 2000 mm; it should be really considered that very important grouted area will be executed so it possible to consider a "massive" behaviour of the grouted soil. Very important it is the grouting sequence: the drilling mesh will be realised in three step in order to gradually close the unconsolidated area and to obtain a treatment as widely as possible. The grouted soil must guarantee an increase of the mechanical strength of soil (> 5.0 MPa) and a reduced permeability (< 1×10^{-7}-1×10^{-8} m/s), so to proceed with the excavation in stable conditions and without water leakage.

Referring to the area located at the north

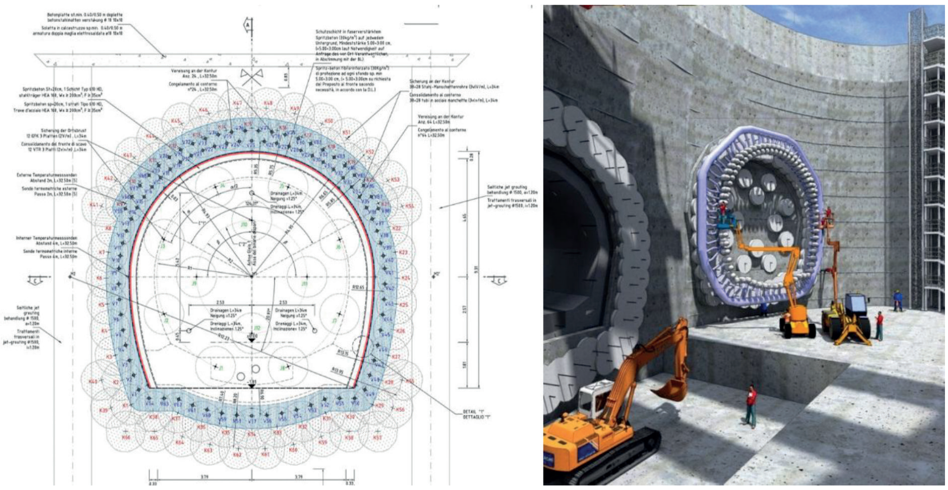

Fig. 10 – Tunnel section type designed for river underpass tunnels.

side of the river, this technical solution will be applied in the odd track from km 54+465,00 to km 54+607,00 and in even track from km 54+440,00 to km 54+608,25; south between 54+700 and 54+968 for the even track, and between 54+711 and 54+889 for the odd track .

The northern section required the application of complex excavation geometries related to the transition between the 4 single-track tunnels under the crossing of the Isarco river and the existing double-track tunnels at the mileage point km 54+608 approximately. The excavation sections, quite large in correspondence of the shaft, characterized by a diameter around 22.0 m, progressively reduce their dimensions to an excavation diameter of 13.50 m. In this sector of the alignment, the overburden ranging from about 10.0 m up to 16.0-17.0 m, suitable for consolidation intervention from the ground level. The tunnel has been subdivided into sectors through the execution of treated soil partitions, executed also by the jet-grouting technology. The excavation is then performed by full section under conditions of hydrostatism, without depressing the water table; in transitional phase, the piezometric head acts on the extrados of the treated soil partition, while in the long term it is expected that the final lining is able to fully support the piezometric head considered at the design stage, substantially coinciding with the ground level (-1 m from g.l.).

The jet-grouting technology is used to realize grouted soil of significant dimensions (massive thicknesses between 3.0 m and 4.5 m and develop of several hundred meters); a square mesh (1.65m x 1.43m) has been adopted also taking into account possible deviations of the perforation. Given the massive characteristics of the treatment, it is however logical to expect a "group effect", in which the treatment of a portion of soil can take place from several injection points, with the effect of voids sealing. It's indeed necessary to consider that the jet-grouting geometry is not necessarily circular shaped, the geometry is a consequence of the previous treatments that are gradually performed. It has been possible to observe this phenomenon during the execution of the shaft trial test: during the execution of the "closure" treatments, an outflow of higher and constant wastewater has been observed compared to the ones related to the primary treatments, testifying the success of the secondary closing jet treatments. The operational parameters for

Fig. 11 – Job Site field tests.

Fig. 12a – Job Site tests: a) ground freezing; b) permeability test showed reduced soil permeability about two orders of magnitude after the injection.

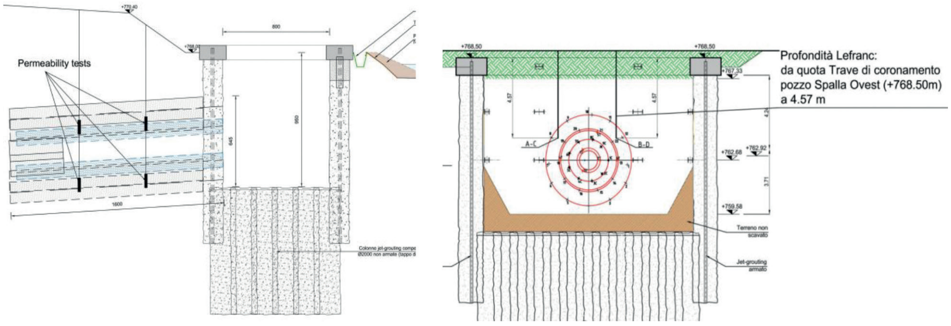

Fig. 12b – Permeability test showed reduced soil permeabilities about two orders of magnitude after injection.

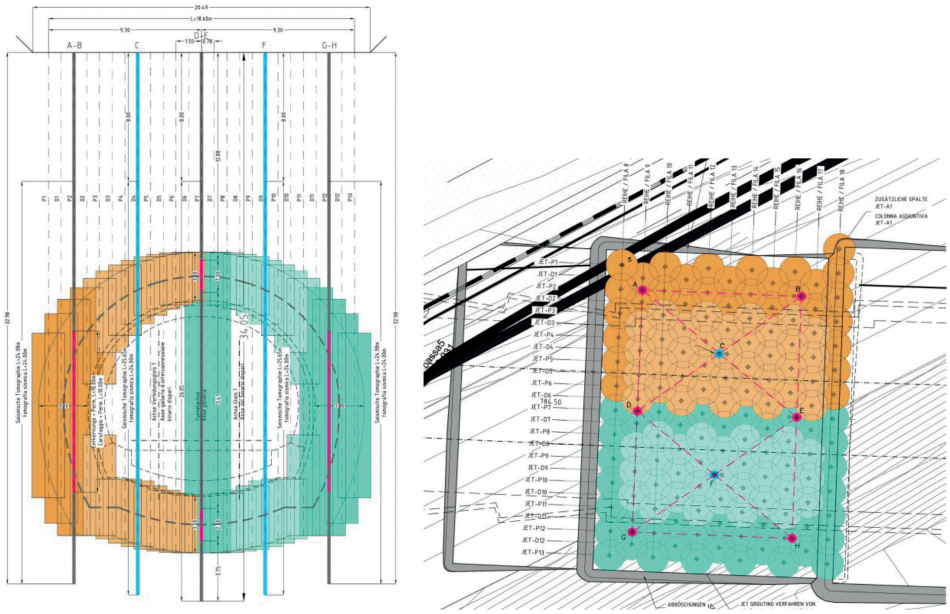

Fig. 13 – Trial test of jet-grouting from surface.

the execution of jet treatments are shown in Table 3 and they have been defined after several tests, as discussed in chapter 4.5.. To check the efficiency of the grouted performed, pumping tests will be executed for each excavation sector (between two treated soil partitions) to verify the absence of defects in the treatments by estimating the residual leakage.

4.4. River underpass by ground freezing

The river underpass has to be performed with low overburden (5.00-8.00m) within a complex geotechnical and hydrogeological context (cfr. par. 2), for this reason the underground excavation could take place only after ground improvement. Different ground improvement techniques have been designed for the execution of the shafts, at the river bank, and of the underpass tunnels.

For the excavation of the shaft, elliptical in shape, depth up to 30 meters, "double-fluid" jet grouting is adopted with the same criteria of the chapter 4.3; three rows of jet-grouting columns will be placed all around the shaft in addition to the bottom plug. The excavation of the shafts will be executed by single step of 2.5 m, followed by the casting of an annular r.c. structure. For the tunnels excavation, ground improvement by means of cement injections and ground freezing will be adopted. The 4 tunnels (Fig. 9) have a length variable between 56 m and 63m and they will be excavated starting from the shafts. The adopted ground improvement techniques have been defined on the basis of a job site test results (see chapter 4.5) and will be executed from the 4 shafts too with a central overlapping of 4-5 m.

Fig. 13 – Excavation data (16.01.2018 www.bbt-se.com).

	Excavation [m]	Total Length [m]	Cross Section [m^2]
Main tunnels	1'255	4'200	60 - 150
Connecting tunnels	497	1'500	60 - 80
Connecting side tunnels	56	240	35 - 45
Access tunnel (completed)	192	192	65

Preliminary soil improvement by cement mixture injections is required with a double scope: strengthening the soil mechanical properties and reduce the soil's permeability, to successfully freeze the soil. It's important to take into account that freezing will be performed very close to the river, so that it will be affected by the water flow. The pre-grouting intervention allows to minimize the water flow. The typical section of advancing is represented in Figure 10: it considers 66 drill holes for the execution of the cement grout and 88 drill holes for the installation of freezing probes with length up to 35 meters. Drillings will be executed by "simmetrix"

Fig. 14 – beginning of construction of the four shafts.

system (140 mm) to place PVC pipes for injections and using steel pipes (114 mm) for freezer probe. The preventer will be installed to avoid water drainage; topographic control will be performed for drillings to consider deviation (generally in the 1.0-1.5% range).
The cement grout sheath has a W/C ratio equal to 1.0, while cement mixture for waterproofing (silicate based) has a W/C ratio variable between 1.2 and 1.4 with a 48 hours compression resistance not lower than 3MPa; this cement mixture will be injected by PVC pipes equipped by valves (3 vlv/meter); the injection will be executed with pressure equal to 15-25 bar and residual pressure of 5 MPa, with flow about 5-8 lt/min and the goal to inject 180-200 lt/valve. Once soil improvement is reached, reducing the permeability value to 1×10^{-5} m/s, the freezing stage can start. The primary purpose of artificial ground freezing is to draw heat from the ground until its temperature falls below the freezing point of the groundwater (freezing stage) and then to maintain the temperature level reached by appropriately regulating the flow of heat extracted until excavation and construction operations have been completed (maintenance stage). Freezing will be obtained thanks to circulation of "liquid nitrogen" inside the freezing probes (at temperature between -100°C and -60°C) equipped with two concentric pipes: an external AISI Inox piping, 76 mm, and an internal copper piping, 25 mm, till the temperature of -10°C will be reached in the soil at 0.50 m at a distance from the freezing probe, so to obtain a minimum freezing diameter of 1.0 m; the frozen soil exhibits a compressive strength of 5 MPa. Freezing maintenance will be got by "brine". Thermometric probes will be placed all around the tunnel cavity to verify the continuity of the freezing, moreover a drainage will be placed in the tunnel axis so to check the absence of water leakage in the core-face to be excavated. The excavation will be made for single step of 1.00 m, followed by the steel rib and shotcrete placing and finally by the final lining casting.

4.5. Testing activities

To develop in detail soil treatment technologies, several trial tests have been performed, starting from the spring 2015 up to now. The first field test was executed in the jobsite at the foundation shaft of the "Isarco Bridge", as showed in Figure 11, south on respect to the Isarco River Underpass. To define the best parameters for jet-grouting, test columns were executed with different combinations of extraction and rotation speed, pressure and nozzles' number and dimension. The diameter columns, investigated by excavation, were ranging from 0.80-1.0 m for "mono-fluid" system to 1.80-2.20 m for "double-fluid" system. Other jet-grouting tests were executed in the north part of the jobsite, where fine sand and silt are present to make more difficult the jet-grouting execution at depth (more than 25-30 m). The best parameters, chosen for the execution of the works, are reported in Table 3.
In spring 2015 too, inside the shaft for the "Isarco bridge" foundation, a real test for freezing was performed, as showed in Figure 12a. Starting from the shaft wall, drillings, equipped by PVC pipes, were executed to improve soil by cement injections. This allowed to define the technical specifications for injections; permeability test showed reduced soil permeabilities after injection, able to control the water flow on respect to freezing (see Figure 12b). After soil treatment, freezing procedures by liquid nitrogen were tested, experiencing the designed temperature in the frozen soil. A new interesting trial test was executed in autumn 2016, performing a tunnel section by jet-grouting from surface, as illustrated in Figure 13. The scope of the test was to check the efficiency of the "massive" jet-grouting treatment: a mini tunnel was confined by jet-grouting columns, so to perform a pumping test inside and to check the hydraulic seal of the grouted mini-tunnel. The experimental program provided also coring of the grouted soil, to control the RQD value and the compressive strength, and seismic analyses, able to investigate the continuity of the treatment.

5. State of work

The current phase (main construction phase I) provides for the construction of four shafts, 25-30 meters deep, to access the faces of excavation of the Isarco River Underpass (Figure 14). Furthermore, it includes the excavation - already completed - of the access tunnel on the right side of the valley using drill and blast, and of part of the main tubes and the connecting tunnels in rock, to be built with the drill and blast method.
As a preparatory measure for the relocation of the existing line which will be carried out during the following construction phase, slope stabilization and earthmoving measures will be implemented.
Table 4 summarizes the excavation data up to 2018 middle of January.

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Riassunto di:

Galleria di Base del Brennero: alcune soluzioni tecniche e operative per il sottoattraversamento del fiume Isarco

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La Galleria di Base del Brennero è parte del corridoio TEN5, Scandinavia-Mediterraneo, e rappresenta l'opera che consente il superamento della catena montuosa delle Alpi. La Galleria di Base del Brennero è l'elemento centrale della nuova linea ferroviaria del Brennero, che collega l'asse da Monaco a Verona. Una volta completata, con i suoi 64 km di sviluppo, rappresenterà il collegamento ferroviario sotterraneo più lungo del mondo.

Il lotto di costruzione denominato "Sottoattraversamento Isarco", costituisce la parte estrema meridionale della Galleria di Base del Brennero prima dell'accesso nella stazione di Fortezza, ed è ubicato ca. 1 Km a nord dell'abitato di Fortezza, in località Prà di Sopra in provincia di Bolzano. Il lotto comprende la realizzazione delle opere civili delle due canne principali per un totale di circa 4,3 Km e delle due gallerie di interconnessione che si allacciano alla linea storica, per un totale di circa 2,3 Km (Fig. 1).

La realizzazione dei lavori è tecnicamente molto complessa: le gallerie delle canne principali e delle interconnessioni passeranno al di sotto, con un franco minimo, del fiume Isarco, dell'autostrada A22, della strada statale SS12 e della linea ferrovia storica Verona-Brennero.

Prima dell'avvio dei lavori di costruzione delle gallerie sono state svolte una serie di attività propedeutiche in superficie, ivi compresi lo spostamento della strada statale SS12, la costruzione di due ponti sul fiume Isarco e sul Rio Bianco e la realizzazione dell'area di carico/scarico sull'A22, necessaria per il trasporto e la fornitura dei materiali di costruzione. Nell'ambito delle fasi realizzative dell'intervento è inoltre prevista la deviazione definitiva della linea ferroviaria storica Verona – Brennero per un tratto di circa 1 Km.

L'articolo presenta le scelte progettuali condotte per la costruzione delle opere, tenendo conto del delicato contesto di inserimento della nuova infrastruttura, sia per la presenza di diverse interferenze in superficie, quali l'Autostrada A22, la SS12, il corso fluviale dell'Isarco, sia per le caratteristiche dei terreni di fondovalle, alluvionali e fluvioglaciali (Figg. 2-3), che hanno reso necessario introdurre diverse tecnologie di consolidamento dei terreni per la realizzazione delle opere, quali il jet-grouting, la tecnologie di iniezione di miscele cementizie e la tecnica del congelamento (Figg. 4-8). Le opere di sottoattraversamento del fiume Isarco rappresentano senza dubbio una sfida ingegneristica molto importante, avendo previsto la loro realizzazione con scavi in sotterraneo con coperture assai ridotte, 5÷8 m, senza modifiche al corso del fiume, facendo affidamento ad estesi interventi di pretrattamento dei terreni interessati dagli scavi (Fig. 9). Le modalità di esecuzione degli interventi di consolidamento rivestono una notevole importanza nel successo di scavi in sotterraneo come quelli in esame; per questo motivo le specifiche di esecuzione dei trattamenti, sono state verificate e tarate sul posto, mediante specifico campo prove (Figg. 10 – 13), al fine di tenere conto delle caratteristiche peculiari dei terreni da trattare e del contesto idrogeologico locale. Attualmente sono in fase realizzativa i quattro pozzi, profondi 25÷30 metri per l'accesso ai fronti di scavo del Sottopassaggio del fiume Isarco (Figura 14). La tabella 4 riepiloga i dati di scavo fino a metà gennaio 2018, a tale data risultava completato lo scavo in roccia della galleria di accesso sul lato destro della valle, di parte delle gallerie principali e della galleria di collegamento, il cui contesto geologico ha permesso lo scavo mediante drill&blast.