# The ring road system of Merano – South Tyrol, Italy

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ABSTRACT: The choices and solutions adopted for the construction of the Merano's ring road system, are presented. It consists of an urban tunnel approximately 3,400 m long, of which 1,200 m carried out with cut & cover method in loose soil, and 2,200 m with conventional mining methods. This latter stretch is about half in loose soil and half in rock. The portion of the tunnel in loose soil (up to > 20 m-span) runs through the town center with shallow overburdens, less than 10 m, alongside or directly under numerous buildings. In the rocky part, an underground roundabout with a total diameter of 42 m, consisting of a toroidal cavity with a central rock pillar with a diameter of 8 m, is present. The roundabout connects the ring road to an underground 7-storey car parking, consisting of a cavern, 170 m long, 20 m high and 25 m deep, with shallow vertical and lateral covers.

## 1. INTRODUCTION

The Merano's ring road is a project of the Autonomous Province of Bolzano, being the access and exit fast-moving road to and from the city center and connecting the existing western Bolzano-Merano motorway to the eastern Passiria Valley. Lot 1 is already in operation, while Lot 2 is currently under construction, through a contract for an amount of approximately 130 million €.

Lot 2 is a complex and challenging underground work, characterized by interferences with existing structures in urban environment. It comprehends an underground roundabout, connecting the road to an underground 7-storey car parking cavern (Public-Private Partnership, amount 35 million €), directly accessible on foot from the city center. When completed, the ring road and car parking system will allow a 50%-reduction of the city crossing time and a doubling of the city center parking capacity.

This paper is a follow up paper to that presented to WTC 2023 (Barovero et al. 2023b).

## 2. PROJECT OVERVIEW

The Lot 1 consists of a 1,300 m cut & cover (C&C) tunnel (up to a 30 m-span and > 20 m-depth) in loose soils (in blue in Figure 1); Lot 2 runs eastwards below the city and Monte San Benedetto, and then connects to the existing surface road network in Passiria Valley (in orange in Figure 1).

It mainly consists of a tunnel with a total length of approx. 2,200 m, which can be divided into two parts. The first part is a C&C tunnel (L = 136 m - in green in Figure 1), connecting to Lot 1 and the surface road system via an underground exchange node. The second part is a mining method (MM) tunnel (L = 2,064 m). The latter, for approximately the first km, passes under the city of Merano in loose soils with shallow overburdens (in pale blue in Figure 1); moving eastwards, the tunnel crosses the metamorphic rock of Monte San Benedetto, with overburdens up to approximately 100 m (in red in Figure 1). Near the transition between the rocky section and the loose soil, an underground roundabout is planned, with a maximum rock cover of approximately 45 m and a total diameter of 42 m, consisting of a toroidal cavity with a central rock pillar with a diameter of 8 m. The roundabout connects the ring road to an underground 7-storey car parking, consisting of a cavern excavated in rock with mining method, 170 m long, 20 m high and 25 m deep, with shallow vertical and lateral covers, represented in Figure 2, with its connections to the roundabout.

The standard section of the tunnel has a total internal width of 11.8 m (left in
Figure 3). The road platform widens at the lay-bys (center in
Figure 3) and in two stretches containing the entrance and exit lanes (right in
Figure 3). Consequently, the tunnel excavation area increases from approximately 150 $m^2$ up to approximately 240 $m^2$.

The longitudinal ventilation system in the tunnel is provided by jet-fans, which are located above the road and anchored to an intermediate concrete slab. In the event of fire, by means of specific hatches, smoke is sucked into the upper ventilation duct (

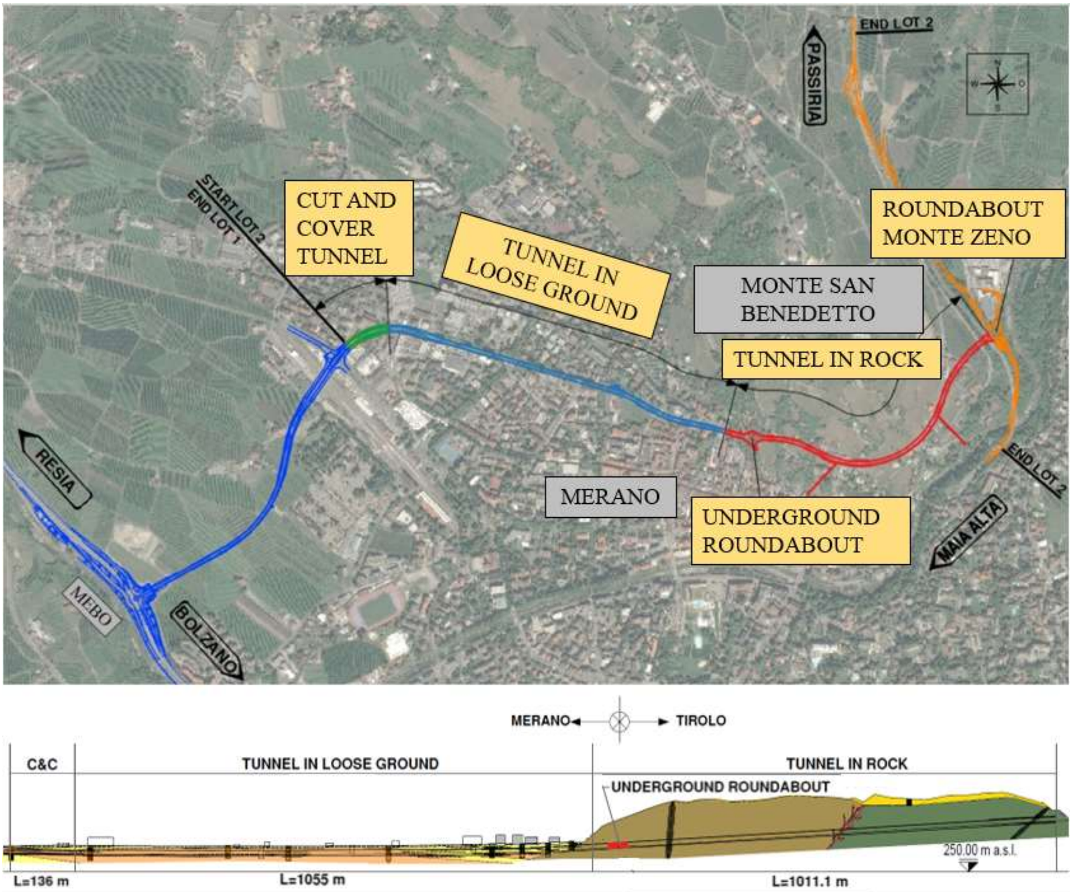



Figure 3).

Figure 1. Merano Ring Road general plan and Lot 2 geological profile (Donelli et al. 2022, modified by the authors).

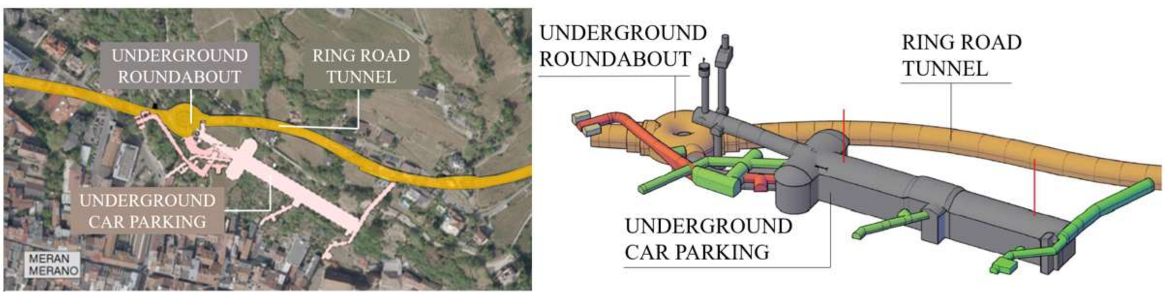


Figure 2. Underground car parking and ring road with roundabout: plan view (left), 3D model (right) (property of the authors).

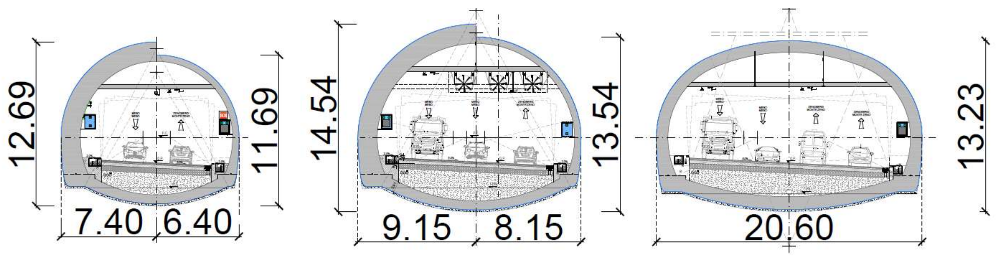



Figure 3. Standard section (left), lay-by section (center) and enlarged section (right) (Barovero et al. 2023b, modified by the authors).

## 3. GEOLOGY, GEOTECNICS AND GEOMECHANICS

The loose soil (Lot 1 and western part of Lot 2) mostly consists of silty sands with moderate cohesion in the shallowest portion (approx. 2-4 m) and underlying gravels, sandy gravels and gravelly sands (alluvial deposits), with pebbles and frequent boulders, generally less than 1 $m^3$. The following average geotechnical parameters are the following: $\gamma' = 22$ kN/$m^3$, $\varphi' = 35°-38°$, $c' = 0$ kPa and $E = 120$ MPa. An aquifer with strong level fluctuations (up to 7 m) is present, at an average depth of approximately 20 m, possibly interfering with the tunnels.

The main geological peculiarity of the rocky part (eastern part of Lot 2, roundabout and car parking) is the crossing of the Periadriatic Lineament, separating the Southalpine Unit, consisting of phyllites, from the Austroalpine, with a prevalence of gneisses and micaschists, often cataclastic. Where the tunnel excavation crossed the Periadriatic Lineament, recrystallised milonites were found. For the metamorphic rock formations, the average geomechanical parameters, according to Hoek and Brown's criterion (Carranza Torres et al. 2002), are: $\gamma = 29$ kN/$m^3$, $\sigma_{ci} = 50$ MPa, $m_i = 15$, $E_i = 5.8$ GPa and GSI = 25-45, with geomechanical class varying between classes III and IV of the Bieniawski rock mass classification (Bieniawski 1989).

## 4. DESIGN ASPECTS

### *4.1 Lot 2 Cut&Cover tunnel*

The C&C tunnel (Figure 4) has a two-lane, two-way carriageway on the main axis and two ramps on either side, housing the entrance and exit lanes respectively (Figure 5, Donelli et al. 2022).

The width reaches approximately 30 m, while the depth of the excavation reaches, at its lowest point, approximately 22 m from ground level. The construction was carried out after a shallow excavation supported by soil nailing. It consisted of the execution of: i. two lateral retaining walls of large-diameter $\phi$1200/1.5 m piles; ii. the construction of a reinforced concrete cover slab; iii the subsequent lowering of the excavation under the slab (top-down method), with a level of temporary active tie rods; iv. the casting of the inner shell and finishing works (Figure 6). To optimize the large span roof slab (approximately 30 m), temporary intermediate piles with 6 m spacing were built, re placed in the final phase by the internal walls. Only before the connection to the MM tunnel, the roof slab has only two lateral supports. To cope with the demanding loading conditions, a double-T RC slab, 3.65 m height heavily reinforced was designed, compared to the 1.5 m thick reinforced concrete slab used along the rest of the tunnel.

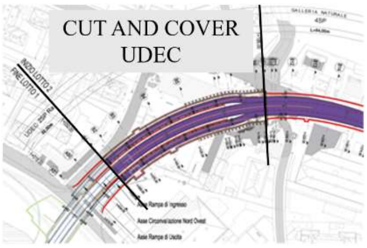



Figure 4. C&C tunnel plan view (Donelli et al. 2022, modified by the authors).

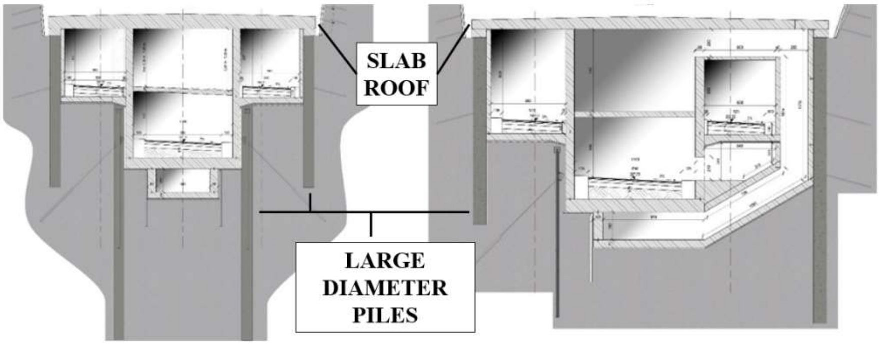
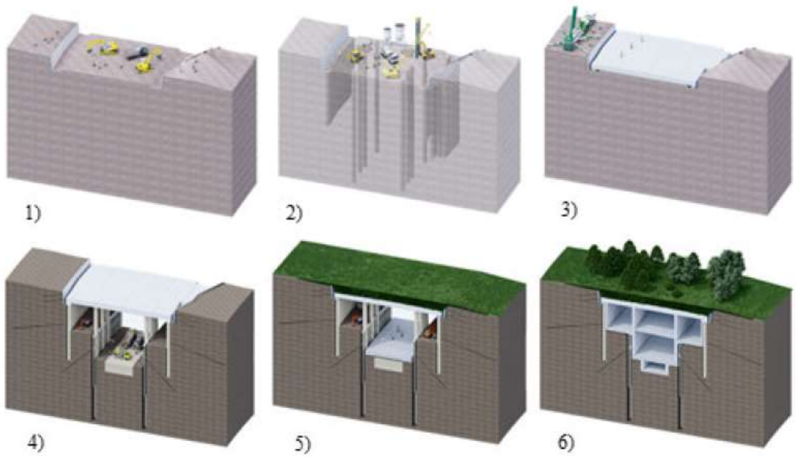



Figure 5. C&C tunnel typical section and section across the ventilation duct (Barovero et al. 2023a, modified by the authors).




**1) Initial excavation reinforced by soil nailing**
**2) Installation of large-diameter piles**
**3) Construction of the slab roof**
**4) Excavation to the level of the main foundation axis**
**5) Construction of the main slab and tunnel covering**
**6) Finalizing the structure and removal of intermediate piles**

Figure 6. C&C tunnel, top-down method, construction phases (Barovero et al. 2023a, modified by the authors).

### *4.2 Lot 2 MM tunnel*

The western MM tunnel half in loose soil (Barovero et al 2023b) is characterized by shallow overburdens (approximately 7-8 m) and by a series of buildings very close to the tunnel or directly above it. A sawtooth excavation (Figure 7) has been designed, with $\phi$ 600 mm 18 m long jet-grouting injections on both the face and the boundary, 15 m long umbrella steel pipes, and a primary lining consisting of fiber-reinforced shotcrete reinforced with steel ribs. The final reinforced concrete lining has a full-round waterproofing.

To safely excavate and reduce subsidence near and under the existing buildings, the intensity of the jet-grouting injections was modulated by foreseeing 2 different excavation lengths (12 m and 9 m) and, consequently, different overlaps of the jet-grouting columns (single and double). Under the buildings the excavation was further strengthened with more intense jet-grouting face injections and boundary jet-grouting columns reinforced by steel pipes. In particular, the buildings to be underpassed, without interrupting their normal use with minimal distance between foundations and excavation (< 5 m), are four different school factory bodies.

For the excavation of the largest section (

Figure 8 - width > 21 m, height = 13.5 m), considering the approximately 6 m cover, the design foresaw: i. the excavation of a pilot tunnel similar to the standard section; ii. the execution of radial injections of cement-bentonite mix with a thickness of 4.5 m by means of PVC sleeved pipes; iii. the subsequent widening with the installation of the first-phase lining (Barovero et al. 2023c).

For a deep insight to the excavation analysis and modelling (FLAC 2016, FLAC 3D 2017) refer to Barovero et al. 2023a. Based on the results of these analyses, Attention and Alarm threshold values were defined for settlements and distortions in the free field and underneath the existing buildings, to limit their damage level within acceptable values. In the rocky part, waterproofing was planned only for the upper part of the final lining. The excavation (class III of the Bieniawski rock mass classification) was carried out with Drill&Bast (D&B), fiber-reinforced shotcrete and nailing. Only for limited stretches (class IV of the Bieniawski rock mass classification), it was necessary to reinforce the first-phase lining with lattice or profile steel ribs.

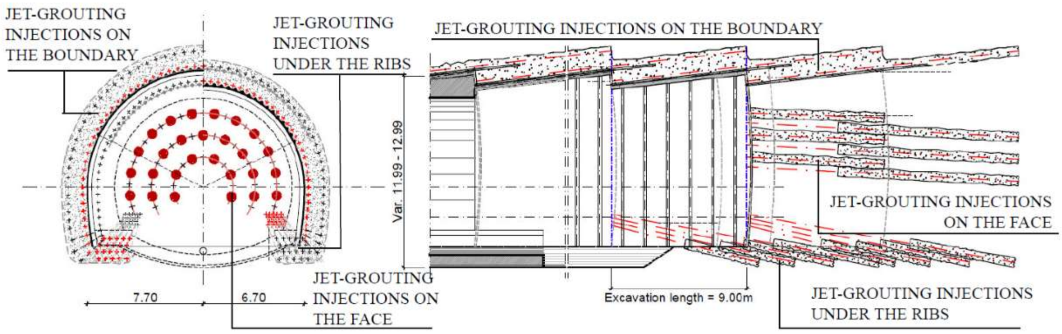



Figure 7. Excavation section (double Jet-grouting overlap) (Barovero et al. 2023a, modified by the authors).

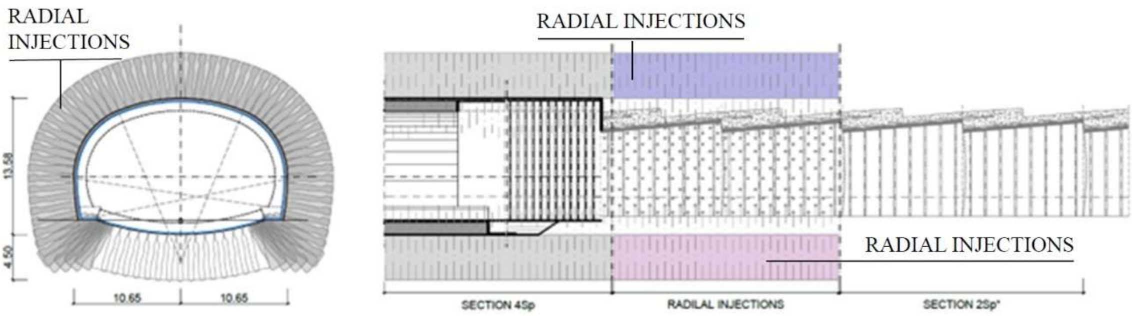



Figure 8. Enlarged section injections (Barovero et al. 2023a, modified by the authors).

### *4.3 Lot 2 Underground roundabout and underground car parking*

The underground roundabout (Figure 9) has a maximum rock cover of approximately 45 m (Barovero et al. 2023a). The cross section in the radial direction has a width of 17 m and a height of 12 m; the overall diameter is 42 m and the central rock pillar has a diameter of 8 m. At the entrance and exit of the roundabout, the adjacent sections of the main tunnel reach an excavation width of approximately 21.5 m (transition zones).

The following phases of excavation of the roundabout have been planned and modelled with 3D analyses (performed with the software FLAC 3D 2017). (Figure 9, Figure 10):

1. Excavation of the entire section of the main tunnel and the transition zone up to the intersection with the roundabout (from East to West).

2. Excavation of two side tunnels, 8 m wide, tangent to the central pillar up to the opposite transition zone (on the West side), to allow the continuation of the excavation in the main tunnel towards West.
3. Excavation of two by-passes, 7 m wide, between the two side tunnels around the central pillar.
4. Circling of the central rock pillar with a reinforced concrete collar.
5. Excavation of the remaining rock septa between the two side tunnels.
6. Widening from the side tunnels to the final section of the roundabout, by successive cloves.
7. Excavation of the connection with the future underground car park.
8. Casting of the final lining.

The main objective of the design of the roundabout was to maintain the integrity of the central rock pillar and to acquire direct information about the quality of the rock mass during the excavation of the two side tunnels (phase 2), carried out by applying a first-phase lining of shotcrete and radial nailing.

For a deep insight to the excavation analysis and modelling (2D and 3D, performed with FLAC 2016 and FLAC 3D 2017, respectively) refer to (Barovero et al. 2023a).
After the excavation of the side tunnels (phase 2), through the observation of the rock characteristics and behavior, a set of geomechanical parameters was defined for the rock (Austroalpine, micaschists) in the area of the roundabout and the car parking cavern (class IV following Bieniawski 1989, Figure 11).

The final lining consists of two different parts: on the crown it is composed of 30 cm fiber-reinforced concrete and lattice girders, forming with the first-phase lining and an interposed waterproof PVC membrane a composite lining structure. Circling the central rock pillar and on the sides of the roundabout, up to the level of the intermediate slab, it consists of 50 cm reinforced concrete. For the underground car parking design (Figure 12) also the software FLAC 3D was used.

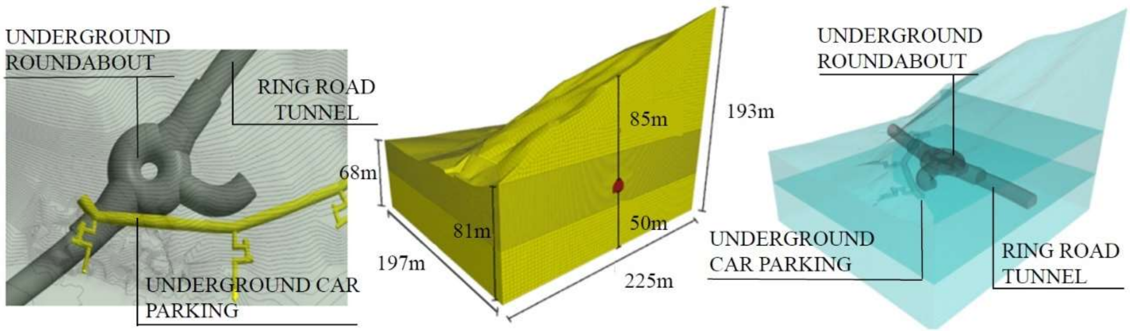



Figure 9. Roundabout and existing World War II anti-aircraft tunnel (yellow) layouts (left); 3D model (center) and transparent view (right) of roundabout and existing anti-aircraft tunnel (Barovero et al. 2023a, modified by the authors).

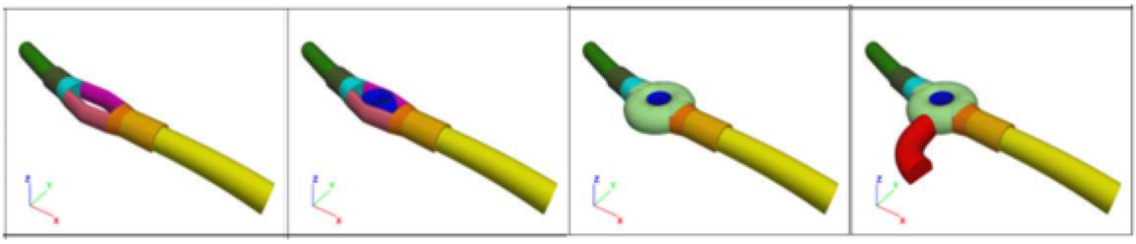


Figure 10. FLAC 3D numerical model for the roundabout analysis, excavation phases: first - phases 1 and 2; second - phases 3 e 4; third - phases 5 e 6; fourth - phase 7 (Barovero et al. 2023a, modified by the authors).


Figure 11. Geomechanical conditions in the roundabout area (property of the authors).

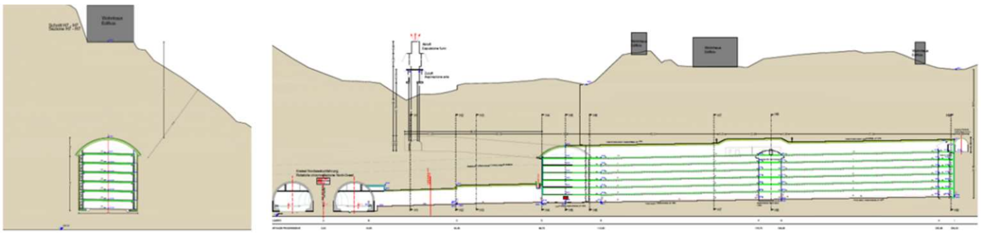


Figure 12. Typical section and longitudinal profile of the car parking cavern with underground roundabout (property of the authors).

## 5. CURRENT WORKS PROGRESS (SEPTEMBER 2024)

The Lot 2 works begun in April 2021. The excavation of the C&C tunnel has been completed in April 2022 and the internal structures completion is ongoing. In April 2022 the excavation of the MM tunnel in loose soil began from the C&C tunnel. From the East side, the advancement in loose soil followed the completion of the rocky section. The completion of the two opposite excavation drives is foreseen in April 2025 (with a rate of advancement of about 1 m/d from West and 0,5 m/d from East, due to the passing near and below the existing buildings and the excavation of two lay-bys). The cement mix injections from the pilot tunnel in the enlarged western stretch are ongoing, following an in-depth testing phase. The excavation of the tunnel rocky section has already been completed, together with the underground roundabout, and the casting of the final lining is in progress. In

Figure 13, with reference also to Figure 10 and to the previous numbered list, the construction phases of the underground roundabout are shown. The underground car parking construction reached 80% completion (Figure 14).

Figure 13. Underground roundabout construction phases: upper left- phase 2; upper center - phase 3; upper right, bottom left and bottom center - phase 4; bottom right - phases 5-7 (property of the authors).

Figure 14. Car parking cavern ongoing excavation phases (property of the authors).

## 6. CONCLUDING REMARKS ON OBSERVED BEHAVIOUR

For MM tunnel in loose soil, to verify the correctness of the design hypotheses, a continuous monitoring of the surface was planned, based essentially on the control of subsidence, using total stations capable of detecting subsidence hour by hour on specific cross sections, spaced about 10 m apart. Each section consists of 5-6 optical sights and topographic prisms. Moreover, level gauge chains and tiltmeters have been applied on the underpassed or bordered buildings. The measured settlements are below or, in the worst case, close to the value predicted at the design stage. The maximum surface settlement is about of 3.5 cm, while the maximum settlement below the buildings has been about of 2.5 cm.

During the MM tunnel in rock, the excavation did not present criticalities in terms of deformation and stability, except for the need to carefully fine-tuning the explosions. It was necessary, indeed, to reduce vibrations and the risk of damage induced by blasting on the surrounding buildings, valuable and very delicate, given their short lateral and vertical distance (50-70 m) from the tunnel. Vibration control under the most conservative conditions and a careful study of the explosive charges' patterns have been carried out. It led to limit the depth of each footage and to use the maximum number of delays to reduce the unit charge. A monitoring system was adopted, providing immediate and continuous feedback and used to allow the sizing of each subsequent blast. It was avibrometric control, consisting of triaxial measuring instruments, 60 fixed measuring points, with remote data transmission every 20 minutes and a software capable of showing on the boundary curves of iso-velocity peaks.

At the end of the excavation of the underground roundabout, no anomalous stresses and strains have been recorded by the monitoring system installed. This system was composed of: i. optical targets on the first phase lining; ii. radial (side tunnels and transition zones) and horizontal (central pillar) extensometers; iii. load cells in the central pillar; iv. a horizontal inclinometer carried out from the existing World War II anti-aircraft tunnel up to beyond the central pillar. Also, during the excavation of the car parking cavern no anomalous stresses and strains have been recorded by the monitoring system installed, like that of the underground roundabout.

## CREDITS

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Lot 2 For Construction Design: Pro Iter S.r.l., Milan
Lot 2 Work Management: Ingenieurteam Bergmeister S.r.l., EUT Engineering Sl, Valdemarin S.r.l., Plan Team S.r.l., Kauer Seehauser Engineering, Pfeifer Planung Srl, Ingenieurgemeinschaft Eng. Aribo Gretzer & Partner GMK, Sint Ingegneria S.r.l., Eng. Manfred Ebner and Ferro Studio Ingegneria S.r.l.
Lot 2 and underground car parking Contractor: San Benedetto Consortium (Carron Bau S.r.l., Mair Josef & Co S.a.s. and PAC S.p.A.)
Underground car parking Design and Work Management: GMK, IME
Monitoring instrumentation and systems and data management: GdTest, Turin.

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