The Widening of the "Montedomini" A14 Motorway Tunnel in the Presence of Traffic

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ABSTRACT

At a distance of 10 years from the first application of the Nazzano Method, the widening under traffic of a tube of an existing motorway tunnel was realized near Ancona, along the A14 Motorway in Italy.
This paper describes the works for the enlargement with conventional method of the second tube, very close to that already widened under traffic.
This enlargement was realized very fast, taking into account the advantages of some interesting technological improvements of the Final Design proved in the first tube.

INTRODUCTION TO THE WIDENING OF EXISTING MOTORWAY TUNNELS

The widening of a twin-bore motorway tunnel usually considers the double option of creating a third bore as an alternative or closure to traffic of one of the two bores with the resulting reduction in the level of service for users.

On the contrary, the extension in situ of a road, motorway, railway or underground tunnel in the presence of traffic, made possible by an inspired idea of Prof. Pietro Lunardi, enables the level of service of the infrastructure to be maintained without the need to resort to alternative routes to create new permanent or temporary bores, not always feasible because of the lack of the necessary space.

This construction technique, known as the 'Nazzano Method', is part of the technologies refined and offered by the ADECO-RS approach to tunnel design and construction (Lunardi P., 2008) which is increasingly used in the world, leading to the industrialisation of tunnelling (meaning respect for the times and costs set out during detailed design) both in conventional and mechanised (through TBM) excavations.

The first true experimentation of the 'Nazzano Method' was carried out between 2004 and 2007 to enlarge the two-bore 'Nazzano' tunnel (Italy, Milan-Rome A1 motorway) in the presence of traffic, widening it to house from two to four lanes in each direction (Lunardi P. et al., 2007). Following the success achieved in this first application, the Nazzano Method was strengthened considering all the possible suggestions arising from the previous experience and then taken up to enlarge the north bore of the 'Montedomini' two-bore tunnel (Italy, Bologna-Taranto A14 motorway), in situ and the presence of traffic.

Once the north bore had been enlarged in the presence of traffic, with very good production, given the hydraulic conditions found, better than expected (absence of water within the core-enlargement face) and

Figure 1. Location of the "Montedomini" tunnel

after considering that the level of service of the motorway would have been acceptable due to the opening of the north bore of the tunnel with two lanes in both directions, the Client, Designer and the Contractor decided in full agreement to examine the possibility of achieving a significant reduction in costs by enlarging the south bore in a conventional manner, subject to its closure to traffic. The study, carried out from this perspective by the designers of Rocksoil S.p.A., Milan, took advantage of the availability on site of the machinery and equipment already used to widen the north bore of the tunnel in the presence of traffic and achieved the purpose, aiming at the complete industrialisation of advance, carried out with conventional full-face advance according to ADECO-RS principles. In particular, the plan was made to complete the active arch final linings in prefabricated segments, already used for the north bore, with a definitive invert, also in prefabricated segments, positioned close to the excavation face.

In effect, two work faces were created, the first for the advance excavation and the positioning of the side walls and the invert; the second, at short distance from the first but fully compatible with the necessary space, for the assembly and commissioning of the active arch through the erector already used in the north bore.

GENERAL OVERVIEW OF THE WIDENING OF THE 'MONTEDOMINI' TUNNEL AND GEOLOGICAL-GEOTECHNICAL CONTEXT

The 'Montedomini' tunnel, about 217+217 m long (north and south bores), is on the Bologna-Taranto A14 motorway, in the section between Ancona Nord (northern Ancona) and Ancona Sud (southern Ancona) (Fig. 1). The widening of the tunnel is part of the work planned for the modernisation of the said motorway through the passage from a two-lane roadway of 3.50 m in each direction to a three-lane roadway of 3.75 m plus hard shoulder of 3.00 m. This is why a significant increase in the size of the existing tunnel was necessary, taking the diameter at the intrados of the lining from the original 10 m to 18 m.

From the geological point of view, the enlargement involved an area consisting of mainly clayey-silty deposits of the Late Pliocene-Pleistocene, with medium-fine sandy interbeds (always in an abundant silty-clay matrix) and deposits of alluvial cover, consisting of silts and silty-sand and eluvium-colluvium. From the geotechnical point of view, the following geotechnical parameters were considered for the clay deposits under the thicker cover (14-22 m) (Table 1):

Table 1. Geotechnical characteristics of grounds

Formation	z	γ	c'	φ'	E'	υ'	K_0
[-]	[m]	kN/m^3	kN/m^2	[°]	[MPa]	[-]	[-]
Alluvial deposits	0-3	20	20	25	50	0.3	1.140
Clayey-silty deposits	3-15	20	30	25	100	0.3	1.140
Clayey-silty deposits	>15	20	40	25	150	0.3	0.850

All the enlargement of the tunnel was carried out with the following order:

- firstly, the north bore was enlarged in situ, applying a planning solution arising from the 'Nazzano Method', which enabled the flow of motorway traffic to be maintained more or less unchanged on two lanes 3.25 m wide throughout the work, subject to the installation of a prefabricated reinforced concrete box shield to protect passing vehicles and an automatic system managing the interferences between the site and traffic to prevent access to the

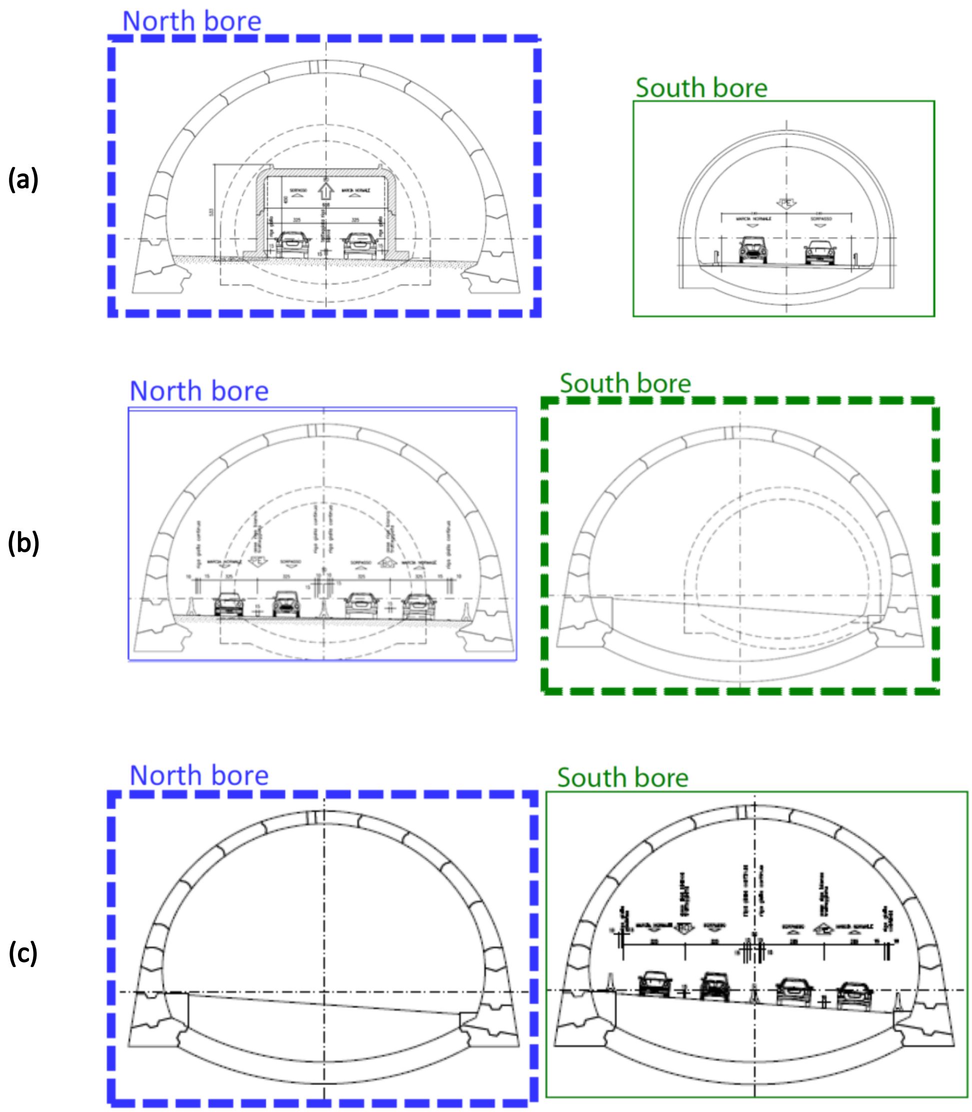

Figure 2. Stages of the enlargement of "Montedomini" tunnel north bore under traffic

shield, and thus the tunnel, of any vehicles not falling within the clearance gauge (max. height 4.5 m) (Fig. 2a);

- once the enlargement of the north bore was completed, the south bore was enlarged in situ, without traffic. The traffic was temporarily channelled into two of the four lanes which became available through the north bore (Fig. 2b);
- once enlargement of the south bore was completed, including the cast of the inverted arch and completion of the roadway (pavements, hydraulics, and road section), the traffic in two directions will be channelled through the four lanes available in the south bore while the inverted arch will be created in the north bore and the works for the roadway completed (pavements, hydraulics, and road section) (Fig. 2c).

WIDENING OF THE NORTH BORE (UNDER TRAFFIC)

The plan adopted for widening the north bore of the 'Montedomini' tunnel in situ, in the presence of traffic, followed the 'Nazzano' method, as we have said. Nevertheless, compared to the first application of the method, the engineering effort fielded at Montedomini to widen the 'Nazzano' tunnel had to take account of the larger size of the section to be widened (until almost 300 m^2 against 270 m^2 at the Nazzano tunnel) and the different geotechnical conditions (clay soil instead of sandy soil).

The larger size of the excavation (see the section type in Fig. 3) and the different geotechnical conditions made adoption of a stronger pre-cut shell necessary: 50 cm thick instead of 30 and 6 m long instead of 5.5. As a consequence, the overlap between the pre-cut shells also increased taking it from 1.5 m to 2 m. The size of the segments of the final active arch linings also increased (from 2.2 to 2.8 m thick at the base and from 60 to 70 cm thick at the crown). As a result of the larger size, the maximum weight also increased, reaching 80 kN. Vice versa, the maximum distance of the lining from the workface and the width of the advance cycle remained unchanged with respect to the Nazzano tunnel at 6.5 m

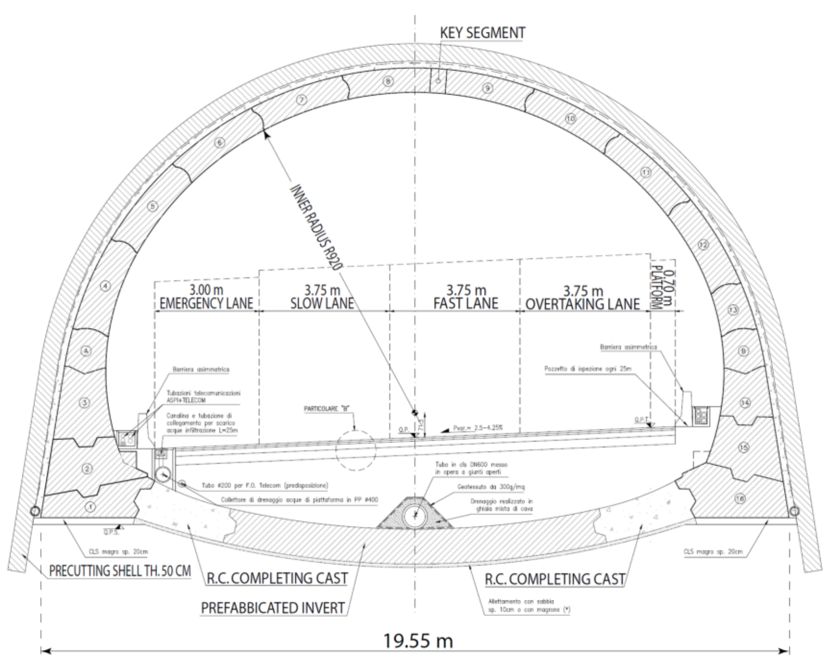

Figure 3. Section type of the "Montedomini" tunnel (north bore)

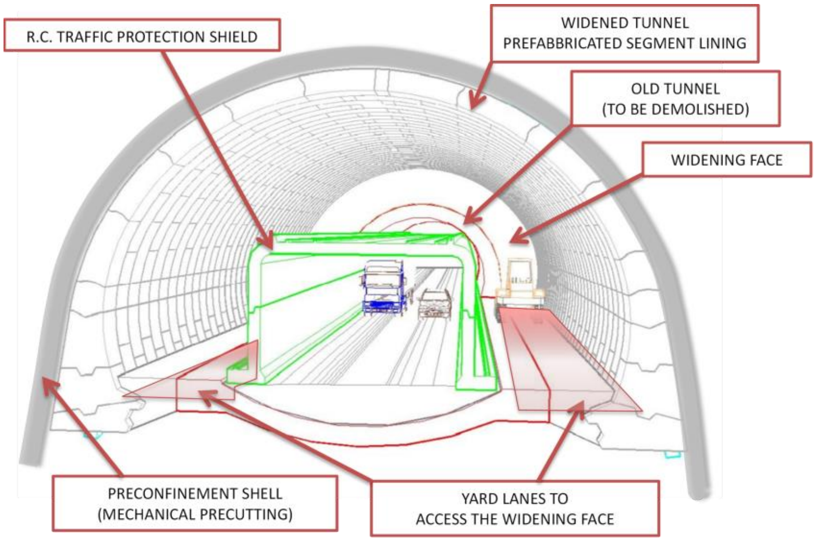

Figure 4. Lay-out of the "Montedomini" tunnel (north bore)

and 4.0 m respectively.

Considering the precarious short-term stability condition of the core-face foreseen during diagnosis, the workface was created in accordance with an elementary advance cycle 4 m long, subject to preconfinement work around the cavity through mechanical precutting (with which truncated conical shells of flint concrete 6 m long and 0.5 m thick, systematically overlapped by 2 m, were created ahead of the excavation face) and the installation of a final 'active arch' lining consisting of prefabricated reinforced concrete (concrete Rck ≥ 40MPa, FeB44k steel) segments (Fig. 4), close to the face made

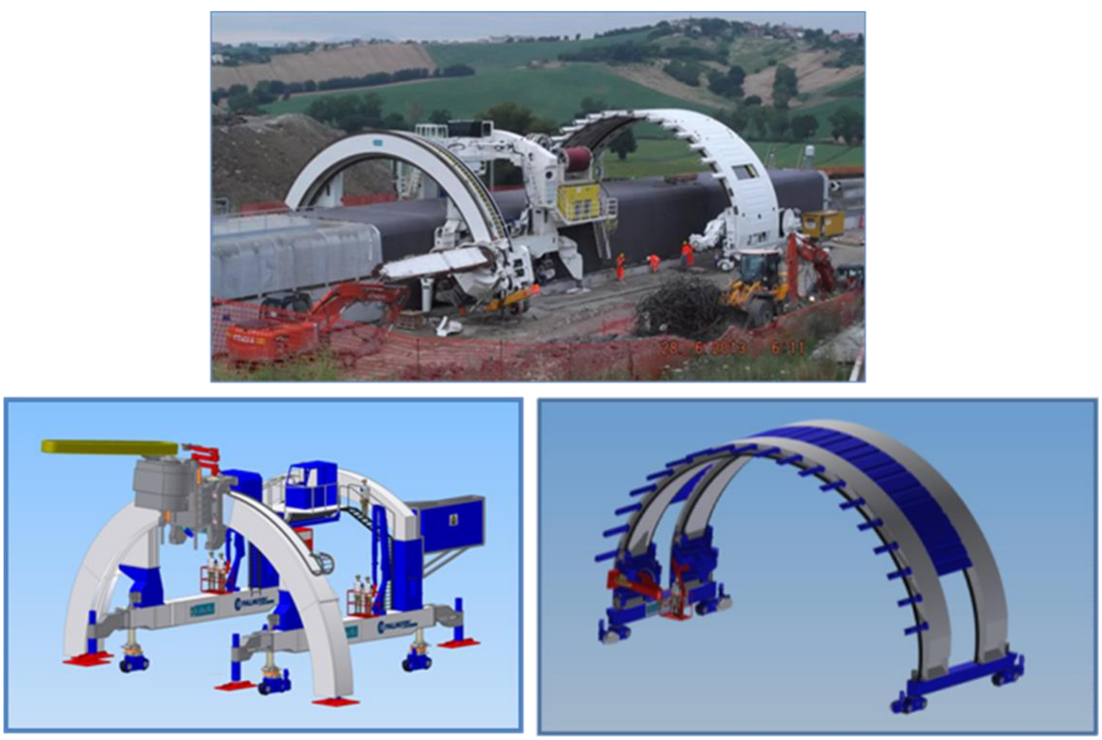

Figure 5. View of the two independent equipments for the execution of mechanical pre-cutting and for placing of the prefabricated segments of "active arch" lining

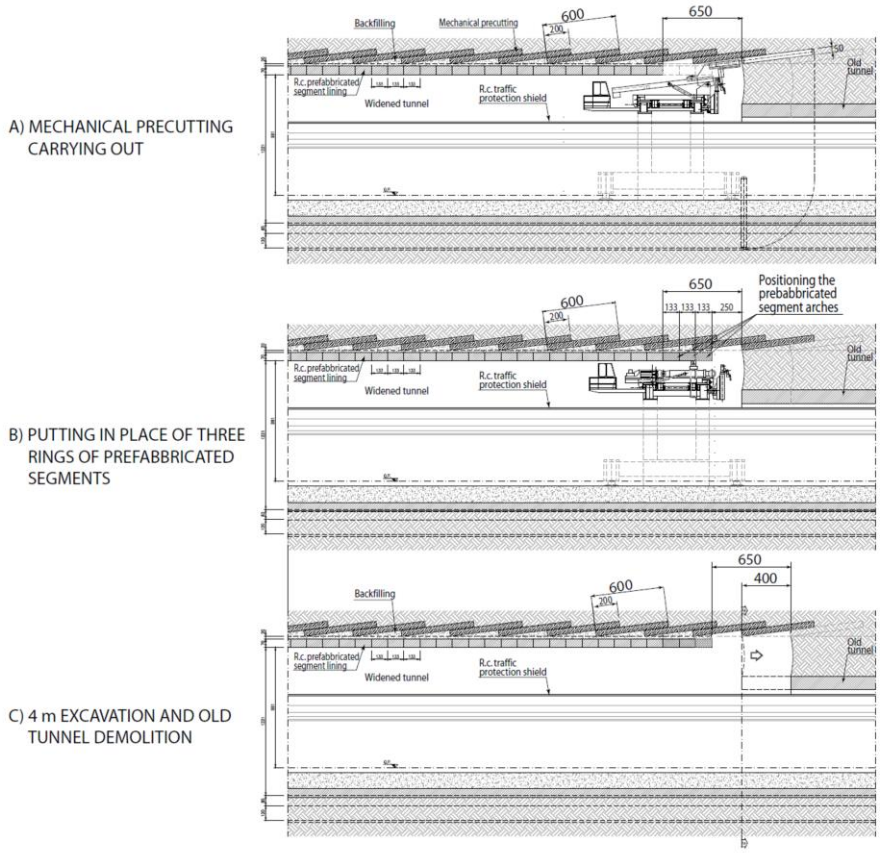

Figure 6. Advance cycle (north bore)

active (self-supporting) by special pre-stressing applied through a flat jack in the key segment of each ring.

This work was carried out in a highly industrialised manner through the adoption of two, separate pieces of equipment (Fig. 5) specially designed and built. One was for precutting and filling the precut while the other, an erector, was for the fitting of the prefabricated lining segments and the backfilling of the extrados. The two pieces of equipment were structured so that the precutting machine can move below the erector, both in the direction of the excavation and back, in the direction of the rest position, at about 30-40 m from the workface.

The advance cycle set out the uninterrupted performance of the following three macro-stages (Fig. 6):

1. Making the precut (distance between the face and lining of 6.5 m);
2. Fitting the 3 prefabricated segment arches for a total of 4 m (distance between the face and lining of 2.5 m);
3. Excavation 4 m ahead (distance between the face and lining of 6.5 m).

After the necessary fine-tuning of all the work, the enlargement in the presence of traffic of the north bore of the ‘Montedomini’ tunnel moved forward with this system with an average production of about 1.10 m of finished tunnel per day.

WIDENING OF THE SOUTH BORE (WITHOUT TRAFFIC)

Once the north bore of the tunnel had been enlarged and all the motorway traffic, as described above, moved into it, the south bore was also enlarged. Considering that the service level of the motorway was, in any case, acceptable, due to the opening of the north bore to traffic in two lanes in both directions, the Client, Designer and Contractor decided in full agreement to examine the possibility of achieving a significant reduction in construction costs and times by carrying out the enlargement without traffic using a highly industrialised process providing for the positioning of an 'active arch' lining of prefabricated segments of reinforced concrete completed with an invert, also formed of prefabricated reinforced concrete segments.

The study enabled an optimal solution to be found through the separation of the necessary work, achieved by the opportune activation of two distinct workfaces - the first for the advance excavation, the casting of a pre-lining of shotcrete 35 cm thick reinforced with pairs of IPE 270 steel ribs and the positioning, close to the enlargement face, of side walls and the invert of prefabricated segments. The second, at about 24 m from the first, intended for the completion of the final lining through the implementation of crown segments with the aid of the erector.

The activation of two separate workfaces allowed significant time advantages to be achieved compared to the traditional procedures.

PLANNING AND CONSTRUCTION ASPECTS OF THE WIDENING OF THE SOUTH BORE

The innovative solution found was subjected to a careful analysis focused on the forecast of the deformation response of the soil to the widening excavation both ahead of and behind the advance face, as prescribed by the approach in accordance with the Analysis of Controlled Deformations in Rock and Soil (ADECO-RS). In detail, the study was conducted through 3D numerical FEM modelling (Plaxis 3D), making use of the base data available but also the monitoring data and all the knowledge acquired during the enlargement of the north bore of the tunnel. Special attention was paid to the stability study of the earth separation diaphragm between the two bores which, at the end of the widening work, would be a lot thinner.

In a first 3D model, the stages of widening of both bores were simulated. This enabled the widening stages of the south bore to be optimised so that the interference, in stress-strain terms, with the existing north bore, already enlarged and open to motorway traffic, was limited. The model assured that, apart from localised areas, where peculiarities were highlighted, the plastic deformations in the soil of the separation diaphragm would be extremely reduced and completely acceptable. A conventional excavation solution was studied in the second three-dimensional modelling which could guarantee deformation behaviour of the core-enlargement face (extrusion) comparable to that of the north bore, excavated prior to mechanical pre-cutting (Fig. 7). The deformation check obtained by taking the invert and crown lining very close to the enlargement face (minimisation of the extrusion surfaces) was sufficient to ensure the stability of the excavation of the bore for most of the natural tunnel.

Similar analyses were made for the entry areas with low covers where work was necessary to keep the separation diaphragm with the north bore in elastic conditions (plastic poles from the top) and to strengthen the core-enlargement face with fibre-glass structural elements. Figure 8 shows the standard sections designed to create the enlargement of the south bore of the 'Montedomini' tunnel as the result of this modelling, and then adopted, both for the entry sections under a low cover and the sections with cover greater than the excavation diameter.

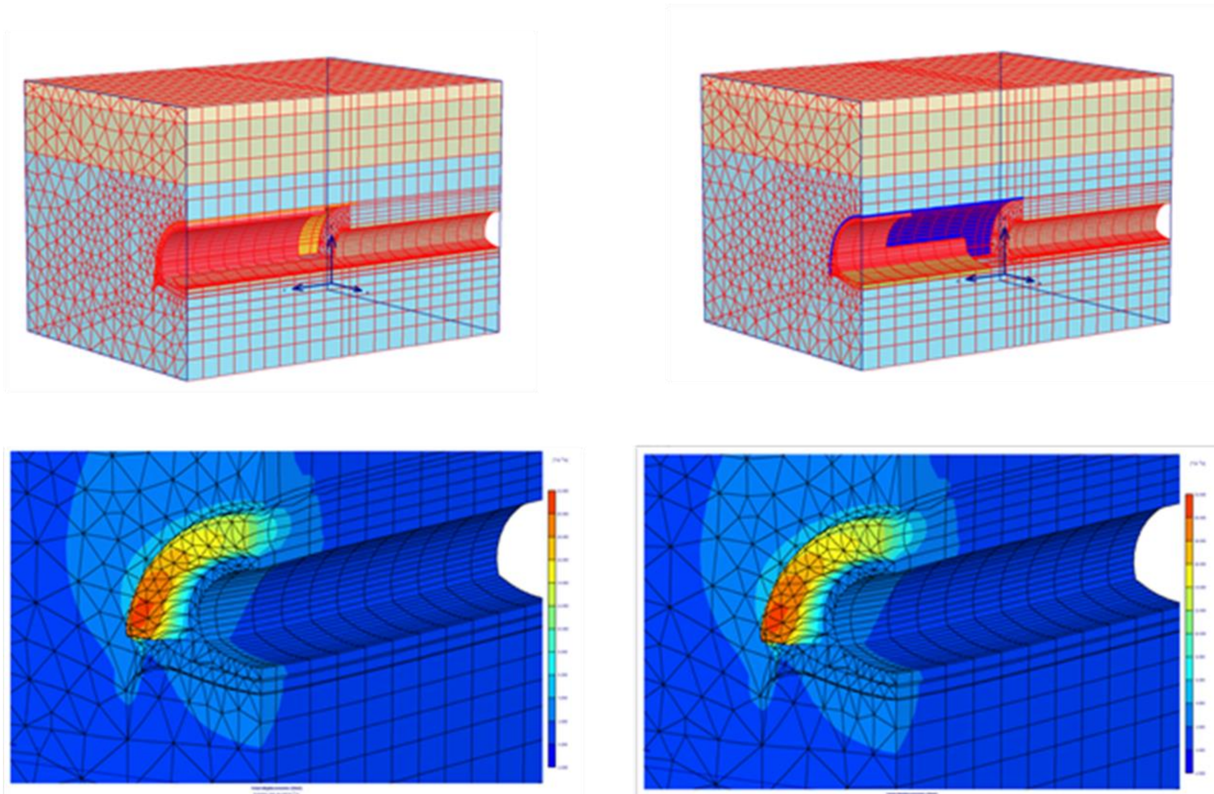

Figure 7. 3D model: deformations of the enlargement face for an advance by using mechanical precutting (left) and for a conventional advance (right)

During the work, the regularity of the enlargement excavations was continuously checked according to the data collected by the specially prepared systematic monitoring system, both during the excavation of the south bore, using extrusion and convergence measurements, and the north bore, already transitionally opened to traffic, through an automated system (installation of 2 total convergence stations positioned at the entries and 21 monitoring sections, each consisting of 5 mini checking plates and readings made ‘continuously’ and sent to an FTP site that can be consulted remotely). The stress-strain state measured during the work was in line with the theoretic forecasts made during planning.

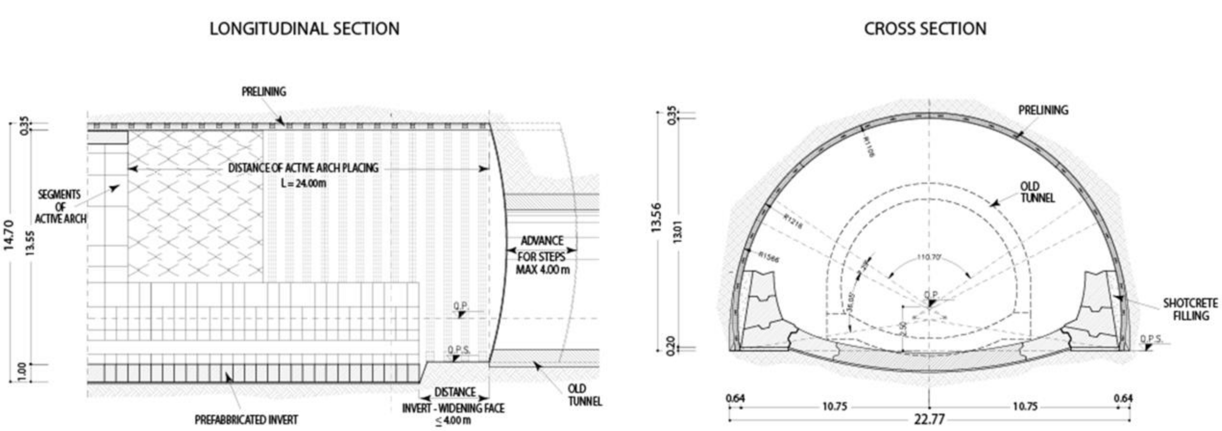

Figure 8. Section type for the south bore advance

Figure 9. Placing of the prefabricated segment of the invert, reinforcing and placing of side completion casts

MAIN NEW TECHNOLOGICAL ITEMS - THE PREFABRICATED INVERT

The main new technological item introduced during the excavation of the south bore of the 'Montedomini' tunnel was certainly the creation of the prefabricated invert. The introduction of this new item was suggested by the evidence acquired while working during the excavation to widen the north bore, which enabled the development of new static considerations on the geometry, steel structural work and reinforcement of the invert which, for completeness, then concerned the whole final lining of prefabricated segments in both the crown ("active arch") and the invert.

To summarise, the construction of the invert in prefabricated segments set out:

- the positioning of a central prefabricated element in reinforced concrete (Rck = 40 MPa) 66.5 cm long, positioned according to the as-built drawings already used (odd/even rings) for the lining of the tunnel in segments, with an extent at the intrados of 10.665 m and a thickness of 1.00 m; this prefabricated element (Fig. 9) with steel structural work at the ends with dovetail slot, is connected longitudinally by a couple of bolts similar to those used for the final crown lining and has special hooks for lifting, handling and positioning it;
- performance of side completion casts in reinforced concrete (Rck 40 MPa), between 100 cm and 120 cm thick at the attachment to the side wall, through the preparation of reinforcement aimed at taking up the sleeves of the side walls of the active arch.

Compared to a traditional approach, this solution enabled important advantages to be achieved including:

- the reduction of the performance times in relation to the reinforcement, formwork, casting and curing stages;
- better product quality and, as a result, a higher performance level of the work;
- the reduction, with the same strength, of the thickness of the steel structural work of the invert (due to both an increase in the rigidity of the prefabricated element created with a higher class concrete and lesser curving), with the resulting savings in excavation volumes and the relative reinforcement.

Figure 10. General view of the south bore of “Montedomini” tunnel during the widening works

PERFORMANCE TIME FOR THE WIDENING OF THE SOUTH BORE

Production of around 1.3 m of finished tunnel per day (already fitted with invert), in line with the planning forecast, could be obtained with the innovative widening method adopted for the south bore of the ‘Montedomini’ tunnel, which enabled the widening of the bore to be completed in just 7 months (Fig. 10).

CONCLUSIONS

The experience gained in the ‘Nazzano’ tunnel, an absolute world première, and the ‘Montedomini’ tunnel, shown in this article, demonstrates that the widening of a tunnel in situ in the presence of traffic is now really a possibility to consider every time that the adaptation of existing tunnels to new and more difficult traffic conditions has to be assessed. The ‘Nazzano Method’, with the subsequent innovations and optimisations (north bore, Montedomini), can have a natural development where there are no alternatives, as in the case of urban tunnels or road or railway tunnels which come out on viaducts or other works of art.

The industrialisation driven by excavation in conventional tunnelling through the creation of a final lining in prefabricated segments both in the crown and the invert, tried out for the enlargement of the south bore of the ‘Montedomini’ tunnel, has enabled interesting performance results and significant benefits from the time and construction costs points of view to be obtained.

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