L'élargissement du tunnel «Montedomini» en présence de traffic : l'évolution de la méthode «Nazzano» et les nouvelles modalités opératives.

Widening the "Montedomini" tunnel in the presence of traffic: the evolution of the "Nazzano" method.

G. Lunardi, *Rocksoil S.p.A., Milano, Italia*

A. Selleri, *Autostrade per l'Italia S.p.A., Roma, Italy*

A. Belfiore, *Spea Ingegneria Europea S.p.A, Milano, Italia*

R. Trapasso, *Ghella S.p.A., Roma, Italy*

Résumé

L'élargissement in situ d'un tunnel autoroutier en présence de trafic, sans l'emploi de variation du tracé ou a réductions du niveau de service de l'oeuvre a été employé pour la première fois au monde dans le premières années 2000, près le tunnel Nazzano (Autoroute A1 Milan-Rome-Naples), dans les alentours de Rome. Ce résultat a constitué une pierre miliaire et a montré la faisabilité et l'efficience de la méthode qui, avec une réduction de consommation de terroir, permet le renforcement d'infrastructures routières, autoroutières o ferroviaires, sans réduction de service pendant l'exécution des travaux. Evidemment, les techniques et les modalités opératives utilisées à Nazzano réfléchissent le niveau de l'époque (années 1999-2000) ; donc l'emploi d'une seule machine fonction-multiple, en gré d'exécuter travaux de confinement du front de taille et disposer les revêtements, choix déduit de l'expérience pendant la construction de la station Baldo degli Ubaldi (Metro Rome). A 10 ans de distance, pour un nouveau élargissement infrastructurel sous trafic (Tunnel Montedomini, Autoroute A14, près d'Ancone), la disponibilité de nouvelles possibilités technologiques a permis choix différents et plus productifs, en maintenant, en général, les idées et les techniques constructives du tunnel Nazzano. L'article, après un résumé des principaux concepts et des possibilités d'élargissement in situ de tunnels en présence de trafic selon l'application Nazzano, illustre l'évolution actuelle près du chantier Montedomini, où l'introduction de solutions et d'instruments modernes, permettra de franchir un significatif progrès dans la méthode.

Abstract

Widening a motorway tunnel in the presence of traffic without resorting to alternative routes or reductions in the level of service was attempted for the first time in the world in the early 2000's to widen the Nazzano Tunnel (A1 Motorway, near Rome). Completion of that project constituted without doubt a true milestone for tunnelling. It demonstrated the feasibility and efficiency of the method, which by reducing land consumption to a minimum, made it possible to expand the capacity of strategic road, motorway or rail infrastructures without reducing the level of service during construction operations. Naturally the technologies adopted to widen the Nazzano tunnel reflected the knowledge available at the time of construction. Hence the adoption of a single multifunction machine able to carry out both ground improvement work and operations to line the tunnel. This was the result of prior experience acquired during the construction of a Station on the Rome Metro. At a distance of 10 years, the availability of new technology for a new project to widen a motorway in the presence of traffic (Montedomini Tunnel, A14 motorway, near Ancona) has made it possible to make higher performing choices, while maintaining the general approaches and construction technologies adopted for the Nazzano Tunnel. After first reviewing the main concepts and potentials of widening a tunnel in the presence of traffic using the Nazzano Method, this article illustrates how the method has evolved today on the "Montedomini" site, where the introduction of innovative solutions and machinery will allow significant progress to be achieved in tunnel widening technology.

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G. Lunardi, *Rocksoil S.p.A.,Milan,Italy*

A. Selleri, *Autostrade per l'Italia S.p.A., Rome, Italy*

A. Belfiore, *SPEA Ingegnaria Europea S.p.A., Rome, Italy*

R. Trapasso, *Ghella S.p.A., Rome, Italy*

1 Introduction

Until just a few years ago, when a road tunnel consisting of two bores side-by-side needed to be enlarged while maintaining the tunnel in service, either a new bore was driven beforehand through which traffic was deviated or one of the two bores of the tunnel was closed, thereby reducing the level of service to users as a consequence.

A technique conceived of by the author was developed in Italy at the beginning of the 2000's on the Nazzano motorway tunnel. It enables a road, motorway, rail or metro tunnel to be widened without halting traffic and therefore without substantially affecting the level of service provided by the infrastructure and without the need for resort to expensive alternative routes through new bores, whether final or temporary, which moreover are not always feasible due to the lack of the necessary space.

After a brief description of the procedures employed in the first experimentation in the world of the method used to widen the Nazzano Tunnel without halting traffic, an analysis is given below of the data acquired during the first experimentation. An illustration is then given of the improvements, modifications and developments which were implemented in the second experimentation to widen a tunnel in the presence of traffic, which is currently in progress on the Montedomini tunnel (A14 motorway).

2 The main aspects of the “Nazzano method”

The first step to be taken when widening a tunnel while it is in service is to identify a system designed to guarantee total safety for the users, who to all intents and purposes pass through a complex construction site for an underground project. At the same time a construction system must be devised which will allow the necessary work to be carried out in very small spaces, because the space in the centre of the tunnel is used for traffic flow.

The safety of users can be achieved by in-stalling a special shield designed to physically separate construction areas in the tunnel from those used for traffic flow.

The solution devised at Nazzano to perform this function was a “tunnel widening traffic protection shield” or “counter tunnel” made of steel, which separates the construction site area from the motorway.

The protection in question must satisfy the following requirements:

- resistance to shocks from excavated material or from ill-fated collapses, which might fall on the protection itself;
- its dimensions must be compatible with the transit of vehicles inside it and with the dimensions of the tunnel to be enlarged. In consideration of the dimensions and the characteristics of the Nazzano tunnel, the shield employed al-lowed traffic to transit on two lanes, a 3.50 m lane for heavy traffic and a 3.00 m overtaking lane for lighter vehicles;
- resistance to potential impacts from vehicles in transit.

Generally, a shield of this type must be either in steel, shorter in length than the tunnel, self-propelled and positioned continuously astride the face, as it was at Nazzano, or in reinforced concrete, longer than the tunnel and immobile.

The presence of a traffic protection shield has an appreciable effect on the working areas used to widen the tunnel and it also affects the choice of the type of construction significantly, because the central part of the tunnel face is reserved for motorway traffic. Two types of technology were therefore chosen for the preliminary and the final linings that could be adapted to the construction site layout as constrained by the presence of a traffic protection shield.

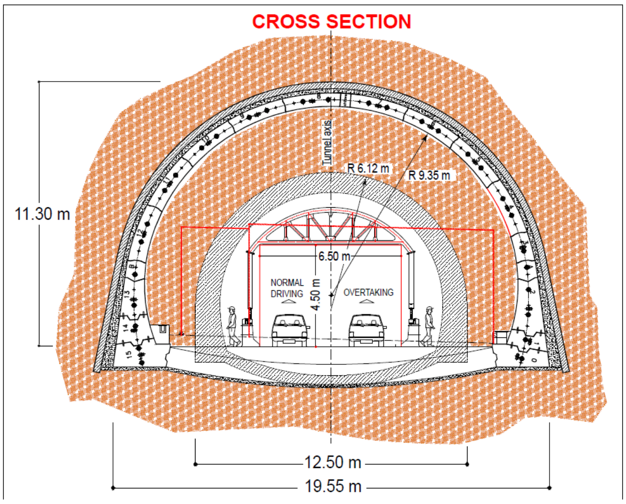

Figure 1. Nazzano Tunnel: tunnel section type for widening in the presence of traffic

The technology chosen for the construction of the final lining, on the other hand, was that known as the "Active Arch" technique, which consists of erecting an arch of prefabricated concrete segments below the intrados of the precut shell. This arch is then immediately rendered self-supporting by the action of a flat jack fitted in the key segment.

This system enables a final lining to be installed at a very short distance from the face (3-6 m) extremely rapidly that is already self supporting.

The precut is executed and the prefabricated concrete segments are erected with the use of one or more pieces of equipment, which nevertheless operate on an arch shaped steel frame which is compatible with the presence of the traffic protection shield and therefore with the particular layout typical of a construction site for widening a tunnel in the presence of traffic.

Work on the precut and the active arch, together with that on the tunnel advance and demolition of the existing tunnel is organised in the form of a production cycle which involves the repetition of the different types of operation.

Finally, the construction of the tunnel invert completes the tunnel widening operations. In cases of a twin bore tunnel, the tunnel invert can be constructed after widening both bores by channelling all the traffic through one bore while the tunnel invert is constructed in the other, which is closed to traffic.

3 Widening in the presence of traffic on the Nazzano tunnel

3.1 General details of the project

The Nazzano Tunnel is twin bore, each approximately 337 m in length, and it is located on the A1 Milan-Naples motorway, approximately 40 km from Rome. The tunnel was widened from two to three lanes plus an emergency lane in each direction between 2004 and 2007. The area to be excavated inclusive of the tunnel invert but not including the existing tunnel was 158 m^2.

Figure 2 shows a photograph taken during operations to widen the old tunnel. The self-propelled traffic protection shield can be seen in the foreground mounted on prefabricated rein-forced concrete components, fitted on the traffic side with a special profile similar to that of a "New-Jersey" safety barrier.

The shield, which met the requirements of size and strength specified in the preceding section was systematically moved forwards by special pistons as the tunnel face advanced in order to ensure that the reinforced part of the shield was maintained at the face.

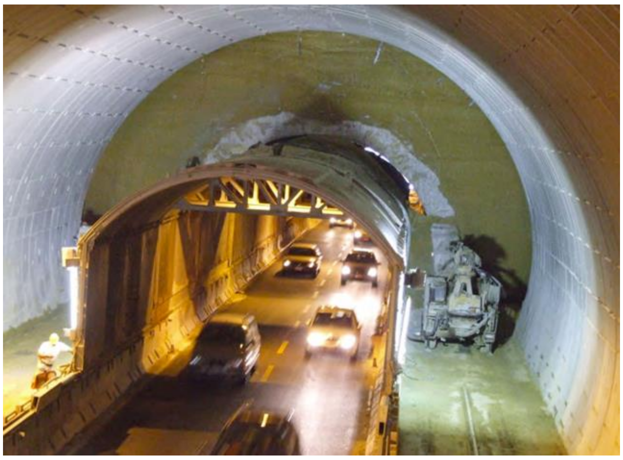

Figure 2. Nazzano Tunnel: traffic protected by the steel protection shield while the old tunnel is being widened

Finally, the client for the widening project was ASPI - Autostrade per l'Italia Spa, Rocksoil Spa was engaged for the design and for construction supervision, while the general contractor was Impresa COSSI Costruzioni Spa.

3.2 The advance production cycle in the tunnel

The tunnel advance cycle, as carried out to widen the Nazzano tunnel, is summarised in Figure 3. As can be seen, each cycle consists of the execution of the precutting stage and four subsequent alternating stages of excavation and erecting the final lining of pre-fabricated concrete segments.

An advance cycle is 4 m in length and the distance between the face and the last arch of the lining erected varies between a maximum of 6.5 m and a minimum of 4.5 m.

As already mentioned, operations for precutting and the erection of the active arch final lining are carried out using a single machine, named a Multifunction Machine (M.M.), consisting of a robust dual arch steel structure (Figure 3).

A carriage is fitted on the first arch, which carries the cutter that makes the precut and the equipment used to fill it. The cutter is fitted with a toothed chain specially designed to break up the ground and remove it from the incision at the same time

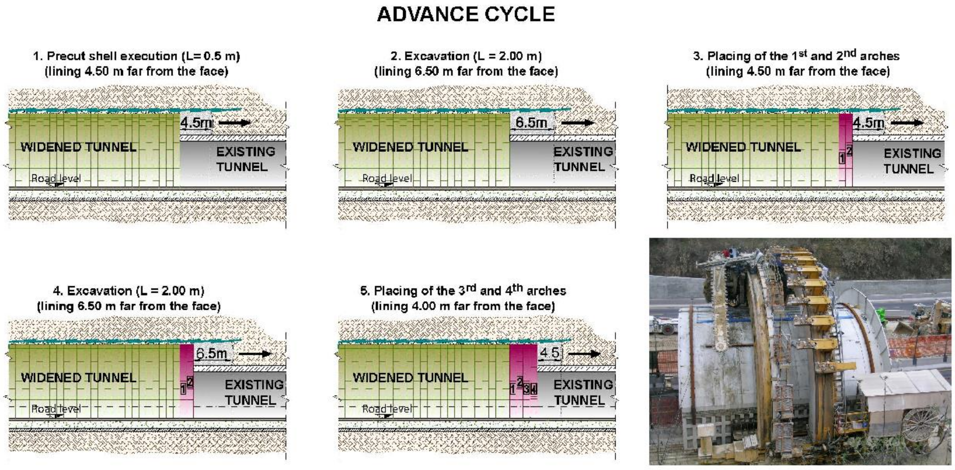

Figura 3. Nazzano tunnel: advance cycle and Multifunction Machine

A carriage fitted with an "erector" runs on the rear arch, specially designed and dimensioned for placing the concrete segments of the lining. It "clips onto" the segments and positions them correctly in place. Special telescopic structures (retractable arms), anchored to the arch itself and fitted with sensors which enable all the essential manoeuvres to be carried out in safety, support the segments in the correct position for the whole of the time needed for the lining to become self-supporting.

The machine moves from the face to its resting position on top of a special transport shield which separates it from the traffic below while it is moving.

4 Analysis of production data acquired during the widening of the Nazzano tunnel in the presence of traffic

As already mentioned, widening a tunnel in the presence of traffic necessarily involves a construction site layout in which working spaces are very small and this puts substantial limits on the size of the equipment that can be used, which must nevertheless operate at considerable heights (10 m approx.).

The limits just mentioned obviously have strong repercussions on the maximum production rates that can be achieved during widening work.

The advance speeds achieved during widening of the two bores of the Nazzano Tunnel varied between 0.75 metres per day and 0.90 metres per day, with peaks very close to 1 metre per day (Figure 4).

An analysis of the time taken for each stage of the advance cycle and its relative impact on production, together with an objective examination of the operating procedures adopted at Nazzano, generated some extremely useful ideas for improving and optimising the method.

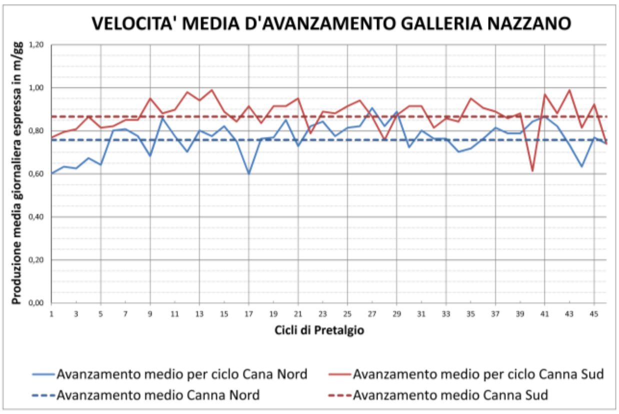

Figure 4. Nazzano tunnel: advance speeds for the widening face (showing the progress of the widened tunnel with the final lining already in place)

More specifically, production data was analysed, divided into macro-work stages, for a significant number of advance production cycles. By measuring the duration of each operating activity, its length as an average percentage of the advance cycle was calculated.

Each stage was therefore calculated as a percentage of the entire advance cycle and its im-pact on production was seen as a consequence.

It was found from the analyses conducted that 22% of the time taken for the cycle was spent on the execution of the precut, 24.1% on excavation for tunnel advance, 46.1% on the erection of the final lining and 7.8% on ancillary operations. As a consequence the macro-work stage which had most impact on the length of the cycle was that for the erection of the “Active Arch” final lining, accounting for close to 50% of production.

5 Application of the tunnel widening method in the presence of traffic on the Montedomini tunnel.

In view of the good results achieved with this first experiment, the client, Autostrade per l’Italia S.p.A., which had commissioned the widening of the Nazzano Tunnel in the presence of traffic, decided to use the same method to also widen the Montedomini Tunnel, as part of the project to modernise the A14 Bologna-Taranto motorway and provide a third lane plus an emergency lane in the section between Ancona North and Ancona South, currently in progress.

For this new work, the contract for design and construction supervision was awarded to SPEA INGEGNERIA EUROPEA Spa and to ROCKSOIL Spa, while the construction work was awarded to GHELLA Spa.

5.1 The Montedomini tunnel

The twin bore Montedomini Tunnel is approximately 280 m long and currently houses two 3.75 m lanes on each carriageway. The project in progress consists of widening it to three 3.75 m lanes plus one 3.00 m emergency lane for each carriageway. Section of tunnel which will be widened using the Nazzano method is 217 m in length. The remaining sections at the portals will in fact be transformed from ordinary underground tunnels into artificial tunnels. As opposed to the Nazzano tunnel, which passes through sandy ground, the Montedomini Tunnel lies in clayey ground. The risk of encountering gas during excavation is very low. The overburden varies from just a few metres to a maximum of 25 m. The area to be excavated inclusive of the tunnel invert but not including the existing tunnel is 211 m².

5.2 Evolution of the method and differences from the Nazzano Tunnel

Some modifications were made to the procedures for widening operations on the basis of the Nazzano experience. These modifications were made for two main reasons. The first regards the larger dimensions of the excavation area and the different geotechnical conditions of the context, with the presence of clayey rather than sandy ground. The second regards the improvements and optimizations to the construction system made on the basis of the studies and analyses described in the previous section with regard to improvements to the construction site layout at the various construction stages.

The larger dimensions of the excavation and the different geotechnical conditions made it necessary to employ a larger precut: 50 cm thick instead of 30 cm and 6 m in length instead of 5.5 m. The overlap between precut shells in-creased as a consequence from 1.5 m to 2 m.

The dimensions of the prefabricated concrete segments of the active arch, final lining also in-creased (from 2.2 m to 2.8 m thick at the base and from 60 cm to 70 cm thick in the crown) and as a consequence of the larger dimensions their maximum weight also increased to 80 kN.

On the other hand, the maximum distance from the face and the length of the advance cycle remained unchanged with respect to the Nazzano Tunnel at 6.5 m and 4.0 m respectively.

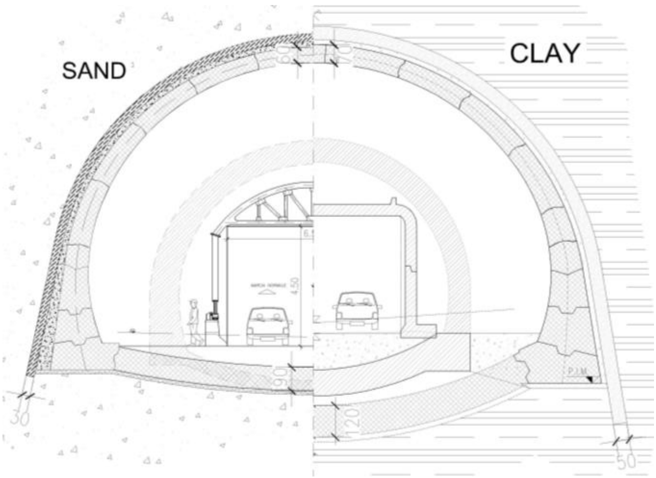

Figura 5. Comparison between the Nazzano tunnel section type (left) and that for Montedomini (right)

As can be seen in Figure 6, the first change made to improve the situation was to the traffic protection shield. The movable steel shield solution with a curved extrados in the crown, already described, was abandoned and a fixed shield approximately 400 m in length was constructed entirely in reinforced concrete with a square profile to the extrados. With this solution the protection shield can house a true and genuine construction site area on top of it, along which materials needed at the face can be transported (prefabricated concrete segments for the crown of the final linings, concrete to fill the precut and the concrete segments just mentioned, by using a system of tubes and pumps housed inside it).

This change resulted firstly in a safer working environment, by reducing the transit of vehicles to and from the face, with a substantial reduction in the risk of accidents for site personnel who can access the face by moving on the upper surface of the shield without interfering in any way with vehicles moving along the sides of the roadway and the tunnel to be widened.

Figura 6. Montedomini tunnel: construction site area above the shield

Furthermore, a shield that is longer than the tunnel makes it possible to also commence work to prepare the portals on the side opposite to that of tunnel advance and it also makes it possible to organise another production unit if the tunnel to be widened is longer than 500 m, in order to be able to advance on two faces.

On the basis of the results of the production analyses described previously, changes were made at the design stage to reduce the number of prefabricated lining arches to be erected for each 4 m advance cycle from four (1 m in length each) to three (1.33 m in length each). This reduces erection operations by 25% with clear benefits also in the consequent reduction in the number of ancillary operations (parking the M.M. etc.). On the other hand, the greater size of the segments means that their weight is consequently also greater, which does not impact on installation as long as the relative assembly equipment is designed to the correct size. In order to carry out this modification and gain further benefits in terms of the management of maintenance stages, an important change was also made to the equipment used to perform the precutting and active arch operations.

In fact widening the Montedomini Tunnel without halting traffic will not be performed by using a single M.M. consisting of two portals joined together as at Nazzano, but by two separate machines, one dedicated exclusively to mechanical precutting and one dedicated exclusively to erecting the active arch (Figura 7).

Figura 7. Montedomini Tunnel: the two machines used to widen the tunnel in the presence of traffic

The main advantage of separating the functions of the two machines is that it is possible to make more powerful and better performing equipment capable of making larger precut incisions than on the Nazzano Tunnel and of erecting heavier concrete segments. The two machines are structured so that the segment erection machine can travel above the precutting machine both when moving towards the face and when returning to its parked position at approximately 30-40 m from the face.

Finally advantages also exist for maintenance management, because the downtime for the individual machines is longer than the downtime possible for a multifunction machine, which basically only occurs during the excavation stages. The decision to separate the precutting and active arch machines also implicitly confirmed the validity of some decisions made at Nazzano concerning the need to carry out the excavation stage and the spoil removal stage using conventional excavators and diggers, rather than by using tools fitted on the portals of the two precutting and active arch machines. At the same time this change made it possible to reduce the overall size of the machines operating at the face and to increase the space available for the manoeuvre of vehicles in those areas. More specifically, the separation of the multifunction machine into two specialist pieces of equipment made it possible to reduce the distance between the tunnel face and the final lining to that minimum necessary for erecting the active arch segments, because it reduced the spaced occupied by the cutter unit. This solution resulted in the adoption of the following cycle: 1. execution of the precut (tunnel face-lining distance of 6.5 m); 2. erection of three arches of prefabricated concrete segments for a total distance of 4 m (tunnel face-lining distance of 2.5m); 3. tunnel advance of 4 m (tunnel face-lining distance of 6.5 m), with the excavation of the macro-work stages without interruption compared to previously at Nazzano with considerably shorter non-productive times in the cycle (parking the machine, protection of the face was shotcrete, etc.). The change in the thickness of the rings (from 1 m to 1.33 m), together with the erection of the final lining in a single stage instead of two has so far resulted in production times that are shorter by more than 35% for this specific operation compared to previously on the Nazzano Tunnel.

Finally, additional innovations regarded precutting spoil removal, which was carried out using automatic suction devices. These convey the spoil to an appropriate truck by means of a neoprene tube which easily reaches the areas concerned.

5.3 Construction work

Work to widen the Montedomini Tunnel without halting traffic began in September 2013. The first excavation cycles were used to fine tune the system as well as to allow site personnel to acquire the necessary experience. At the end of that period, during which tunnel widening advanced by approximately 50 m, a further 30 m were required to achieve average daily production of greater than one metre. Average production to date is 1.10 m per day, equivalent to 87 hours for a 4 m excavation cycle with peaks in production of 1.20 m per day, equivalent to an excavation cycle of 80 hours. The resulting construction site layout generated the significant advantage of making all areas of the tunnel independent and easy to reach.

This circumstance made it possible the overlap site operations and render them continuous. For example, while the last precut is being executed on one side with the removal of the spoil, the next work cycle can be started at the same time on the other side.

This operational possibility constituted an extremely important ingredient in the achievement of production rates that were fully comparable with those for conventional tunnel advance without a shield for an excavation cross-section of the same size.

5.4 Financial aspects of the Nazzano Method employed on the Montedomini Tunnel

The cost of widening in the presence of traffic, net of safety costs, was approximately 57,000 €/lm, while the cost for widening with a third bore is approximately 55,000 €/lm, again net of safety costs. An examination of this data shows that on a like-for-like basis the costs for the two solutions are very similar, with a difference of 3.65% of the cost for widening the existing tunnel. The extra safety costs for widening an existing tunnel (a traffic protection shield) can reach 8.90% of the cost of the works and therefore do not substantially alter the financial feasibility of the project itself. As a percentage these costs will tend to reduce as the length of the tunnel to be widened increases and therefore the overall costs of the project increase.

6 Conclusion

The “Nazzano Method” for widening a road or rail tunnel without halting traffic is evolving through an important phase with the second use in the world of this construction system on the Montedomini Tunnel.

The main problems with the method were already solved for the Montedomini Tunnel not only at the design stage, but also during the organisation of the production cycle. This was also possible because of the experience acquired in the first application of the method in the world on the Nazzano Tunnel where some of the main problems connected with the reduced space available for machine operators in the tunnel had nevertheless already been solved, although not without difficulty.

The traffic reduction shield has been transformed from an obstacle and constraint into an operational opportunity and now constitutes the main and safest route to supply the face.

In any event, the experience acquired to date with the Nazzano Tunnel and the Montedomini Tunnel demonstrates that today widening a tunnel without halting traffic is a real possibility to be considered every time the upgrade of an existing infrastructure with sections that run underground in order to satisfy new and more difficult traffic conditions must be assessed. The Nazzano Method, with its subsequent innovations and improvements, may find its natural ground for development where no alternatives are possible as in the case of urban or road or rail tunnels with exits onto viaducts or other works of art.

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