Widening the Nazzano motorway tunnel from two to three lanes + an emergency lane without interrupting traffic

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When modernising road, motorway and railway transport routes, improvements to tunnels constitute without doubt the issue which presents the greatest difficulty. Until today there were only two ways of increasing the capacity of major transport routes with sections running underground:

1. *close the route to traffic for the whole of the time necessary to widen the tunnels;*
2. *construct costly new routes to add new bores to the tunnels already in existence.*

Clearly both solutions are difficult and sometimes impossible to implement. And this is also without taking account of the huge costs that would be incurred to implement them (halting traffic, environmental problems, etc.).

A new technology is now available which solves the problem simply and economically because it allows tunnels to be widened without interrupting traffic during construction work. It is being tried out for the first time in the world to modernise the Nazzano tunnel located between the Orte exit and the North Rome branch of the Autostrada of the Sole (motorway of the sun). The work to widen it will finish in April 2007.

The report illustrates the basic concepts of the technology and discusses the results of this first experimentation in detail.

Dans le cadre de la modernisation des voies de communication routiers, autoroutiers et ferroviaires, l'adaptation des tunnels constitue sans doute le problème qui présente les majeures difficultés. Jusqu'aujourd'hui, pour augmenter la capacité d'un importante voie de communication avec traites de trace en souterrain on avaient seulement deux possibilité :

1. fermer la route au trafic pour tout le temps indispensable à réaliser l'élargissement des tunnels ;
2. construire des onéreuses modifications de tracé pour ajouter des nouvelles arcades à celles déjà existantes.

Il est évident que toutes les deux solutions sont de difficiles réalisation et pas toujours de possible actuation. Ceci aussi sans tenir en compte des considérables coûts qui serait nécessaire soutenir pour les réaliser (interdiction de la circulation, problématiques liées è l'environnement).

Depuis aujourd'hui une nouvelle technologie est disponible, qui règle le problème d'une façon simple et économique, étant donné que permet d'élargir les tunnels sans arrêter le trafic pendant les travaux. On est en train de la expérimenter pour la première foie dans le monde entier pour rénover le tunnel Nazzano, situé entre la sortie Orte et la bifurcation Rome nord de l'autoroute A1. Les travaux d'excavation termineront pour le mois de avril 2007.

Le mémoire montrera les renseignements de la technologie et relatera amplement sur les résultats obtenus dans le cours de cette première expérimentation.

1. INTRODUCTION

The economic and demographic development of the society in which we live is leading to increasing demand for mobility and road transport. This need runs into the problem of the inadequacy and often the insufficiency of modern transport networks which are unable to absorb ever increasing volumes of traffic. This situation, which is generally encountered in all developed countries, is particularly acute in Italy where 80% of goods traffic moves by road and where the morphology of the geography makes the construction of new transport routes particularly difficult and costly. The current tendency with regard to these considerations is to increase the capacity of existing infrastructures as much as possible, especially where the creation of new transport networks is not possible. For example the most logical method of proceeding to increase the capacity of road networks is that of increasing the number of lanes available in each direction; this method of operating is easy to follow for 'simple' sections of road, where this term is intended as meaning those sections for which particular constructions such as viaducts and tunnels are not required. The innovative construction technology discussed in this report was developed with the intention of overcoming the problem of widening sections of road which pass underground where the two standard solutions used so far employed are not feasible and that is:

1. The adoption of a new route by driving a new bore of sufficient size for the number of lanes required or a temporary bore used to take traffic while existing tunnels are being widened.
2. Widening an existing tunnel in the absence of traffic.

The technology in question takes a third route which consists of widening tunnels while traffic is flowing.

This technology has been developed by Rocksoil spa and is currently being applied for the first time in the world on the twin bores of the Nazzano tunnel which are each 337 m long. The Nazzano tunnel is located on the A1 motorway at the entrance to the North Rome motorway tollgate (chainage km 522+450) (figure 1).

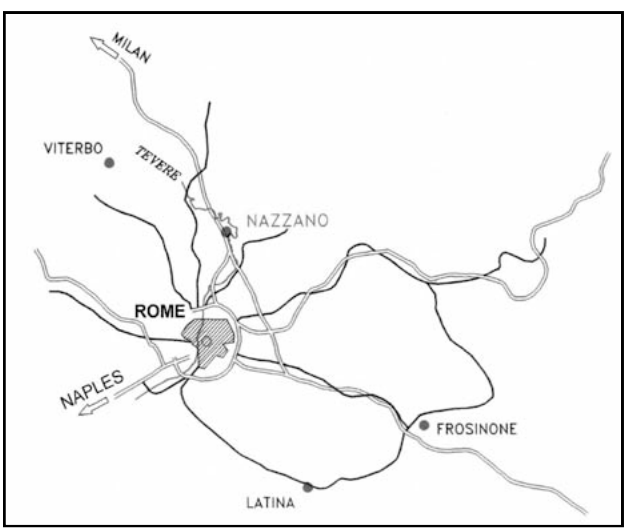

Figure 1. **Location of the work.**

This construction technique for widening a tunnel was proposed and applied because it was not possible for this particular section of road to construct a new route because the municipality of Nazzano is located inside a nature reserve (the Tiber-Farfa Reserve), where it is not possible to drive a third permanent or temporary tunnel for environmental and landscape reasons. The second option for action, which would have closed the tunnel to widen it was not taken for traffic motives. It would have allowed the use of only one bore of the tunnel for the full duration of the works with only one lane open in each direction. On the basis of traffic studies, which considered daily average traffic data and rush hour traffic data it was calculated that vehicles would have been queuing along that section of the route between 6.00 a.m. and 10.00 p.m. with serious economic consequences. Given these conditions and this context it was decided to try out for the first time in the world the technique for widening tunnels with traffic running designed using the ADECO-RS approach.

2. GEOLOGIC SITUATION OF THE NAZZANO TUNNEL

The ground through which the Nazzano tunnel passes belongs to the marine Plio-Pleistocene series. This succession is characterised by prevalently fine sediments and granulometry with a tendency to coarsen towards the upper part of the series (figure 2). The sand lithozone is composed as follows: yellow-nut coloured medium to fine sands from weakly to averagely silty alternating with silts from weakly sandy to clayey, grey in colour in irregular layers; rare interbedding with grey blue coloured silty clays. Lenses of gravels of varying size at times in a fine sandy matrix. The gravels are generally well classed (Ø medium 2.5-3 cm) and of polygenic composition.

The arenaceous layers were found mainly at the top of the positive sequences, coarsening upwards and giving way to medium to coarse sands or gravels to be followed by a new series characterised by fine deposits at the base. There were also silty clayey layers ranging from very compact to lithoid and peat in layers some decimetres thick.

3. GENERAL CHARACTERISTICS OF WIDENING A TUNNEL

If it is to be genuinely practical a technique for widening a tunnel without interrupting traffic must satisfactorily solve two types of problems:

– problems of performing the work of excavating and lining the widened tunnel and demolishing the existing tunnel while ensuring the necessary safety and minimising inconvenience as much as possible;

– the problem of adapting the method to fit any type of ground and stress-strain situation that might arise, minimising effects on nearby pre-existing buildings and ensuring constant operational safety.

Clearly a special construction approach must be developed to solve these problems, which will allow all types of advance ground improvement and reinforcement in the face and around the future excavation that may be required to be performed without danger to traffic. This work will include the placing and activation of the final lining very close to the face. It is only by operating in this fashion that the following can be achieved:

– control the effects of the probable presence around the existing cavity of a band of ground that has already been subjected to plasticisation and must not be disturbed any further;
– widen the cross section of the tunnel without causing damaging deformation of the ground, which would translate into substantial thrusts on the lining of the widened tunnel and the development of differential surface settlement which would be dangerous for pre-existing buildings and structures;
– guarantee at least the same standard of service for users as that provided prior to widening for the whole duration of the works and to provide a real increase in traffic capacity as soon as the first bore is widened.

All these requirements translate into a construction site scenario which is much more complicated and delicate than that found on a normal tunnel construction site. In fact in order to be able to work under these conditions all the specified operations must be studied and the best solution and techniques found for each of them which will guarantee the necessary safety.

This process of risk screening performed on the Nazzano construction site was carried out very carefully because it was the first construction site of its type in the world and its success would lead to systematic use of the new method in all similar cases of which a large number exist both in Italy and abroad.

Safety must in fact be guaranteed both for vehicles transiting under the construction site and for site vehicles and personnel working under much more complex conditions than usual.

4. THE CONSTRUCTION SITE

Widening the two bores of the Nazzano tunnel was performed in three main stages:

1. the first stage of the work consisted of widening the North bore of the tunnel while the South bore was left in normal service. Widening operations are performed by inserting a traffic protection shield inside the perimeter of the existing tunnel above which special multifunction equipment performs the work required to widen the existing tunnel. During this stage traffic continues to run on the two narrow 3.25 m lane motorway protected by the steel shield passing literally underneath the construction site (figure 3);
2. during the second stage, currently in progress, it is planned to use the north carriageway which has already been widened where all four 3.5 m lanes may be used with three running north and one South, or for directions chosen by the company that runs the motorway, and the South carriageway with the widening work in progress with two narrow 3.25 m lanes. At this stage 6 lanes will therefore be available as there will be on completion of the work, while all that is lacking are the emergency lanes (figure 4);
3. the third and last stage is that for the tunnel invert, the finishings and pavement of the two tunnels to be performed once widening in the crown is complete, by alternating first on one tunnel and then on the other, leaving three lanes open in each direction (figure 5).

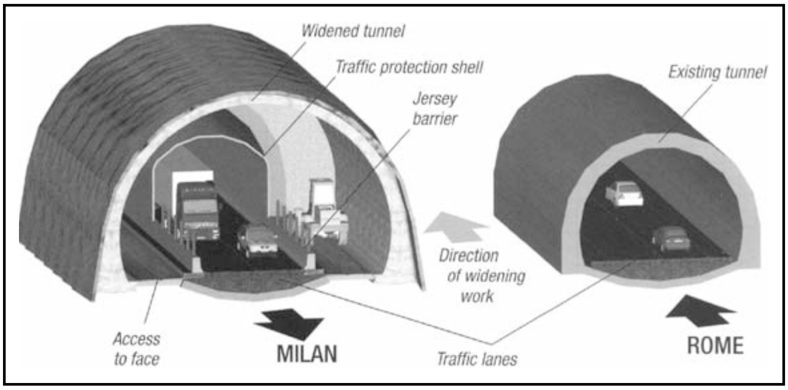

Figure 3. **The first stage of the work.**

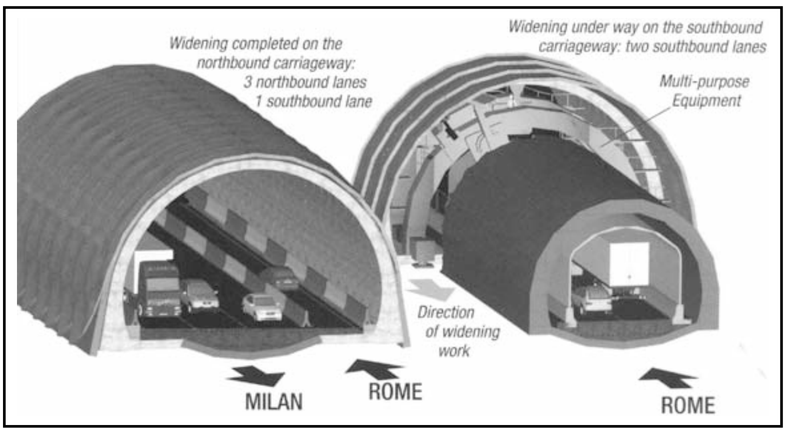

Figure 4. **The second stage of the work.**

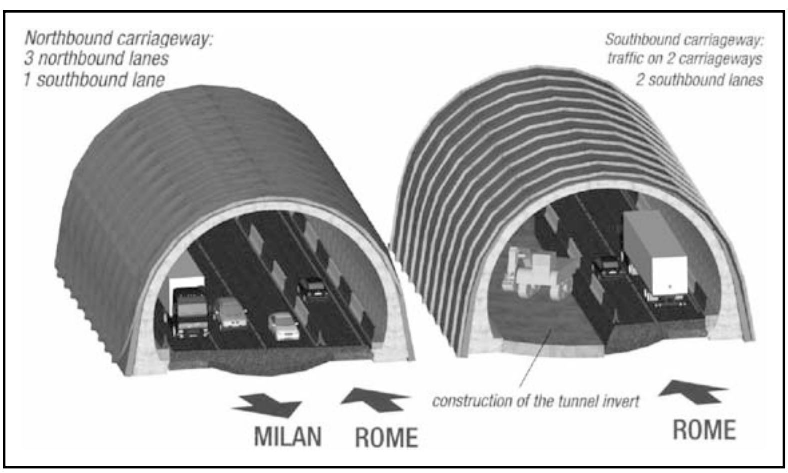

Figure 5. **The third stage of the work.**

5. THE TECHNIQUE OF WIDENING UNDER TRAFFIC FLOW

The project to widen the Nazzano tunnel involves the use of an extremely innovative system compared to standard operations for underground works. The innovation lies not so much in the single technologies employed as in how they are merged into a single process which allows work to be performed with both tunnels maintained constantly in service. This system is characterised by:

– the adoption of preconfinement of the cavity as a means of reducing deformation ahead of the face. Precut technology can be used depending on the type of ground encountered and integrated, if necessary, with ground improvement using low or high pressure cement or chemical grout injections in circumstances where the cohesion of the ground is insufficient to guarantee the integrity of the precut incision;

– the adoption of a final lining (active arch) placed at an extremely short distance from the face to immediately reduce deformation occurring after the passage of the face. The active arch consists of concrete segments, prefabricated in the factory, of variable transverse dimensions with a longitudinal length of 1 m, which are joined to form one solid piece by means of a special resin glue placed on the contact surfaces. They are made self supporting by applying a precompression force using special flat jacks fitted in the key segment;

– the presence of a traffic protection shield, 60 m long, which allows traffic to pass along the old two lane motorway during the work and which moves forward as the work advances;

– the use of a technologically advanced, single combined piece of equipment which performs all the advance ground reinforcement and making a precut and placing of the segments for the final lining in repeatable 4 m modular steps.

– the stages for the excavation and demolition of the existing tunnel were performed using standard means such as diggers and bucket loaders. In some particular situations, such as in portal sections for example, where the geotechnical conditions required it, systems had to be designed specially for the particular circumstances involved in widening a tunnel to reinforce the ground ahead of the face with fibre glass structural elements and to improve the ground around the cavity using low or high pressure cement or chemical grout injections.

6. THE MULTIFUNCTION EQUIPMENT

The multifunction equipment in operation in the Nazzano tunnel consists of a sturdy double arched steel frame connected at the base by means of independent telescopic beams which allow rapid and precise longitudinal and transverse movement. Transverse centring and accurate vertical positioning are performed by means of hydraulic controls (figures 6a and 6b).

A particularly sophisticated carriage is fitted on the arch nearest to the face which holds the cutter for making the precut. The circular movement of the carriage around the arch, obtained by means of gear motors and a rack and pinion mechanism, together with the individual and complex movements of the various items of equipment fitted on it, allow the various operations specified in the design to be performed. A system is located on the arch, specially positioned next to the cutter, to control the tubes and the nozzle used to fill the precut and the cavity between the extrados of the segments and the precut with grout.

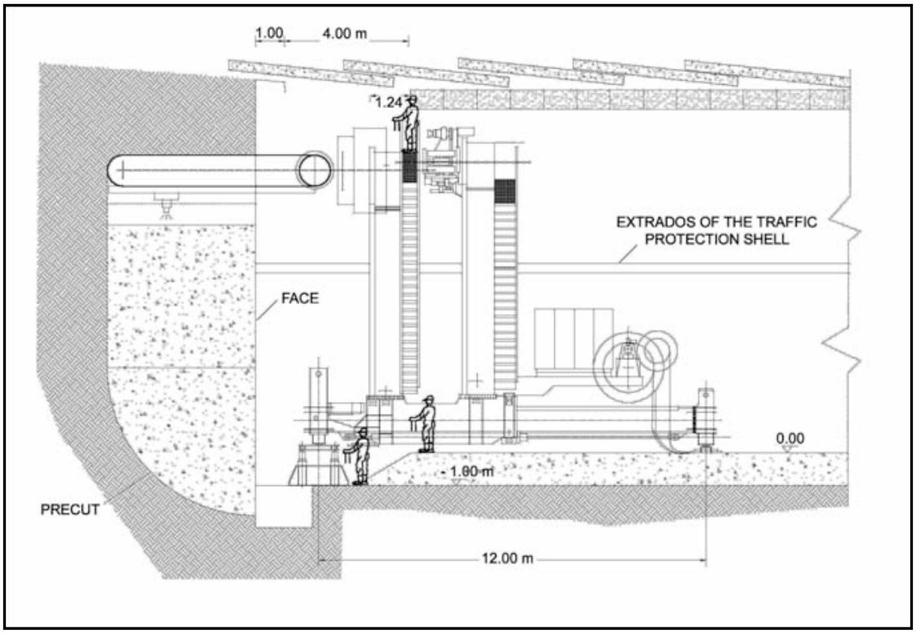

Figure 6a. **Scheme of the multifunction equipment.**

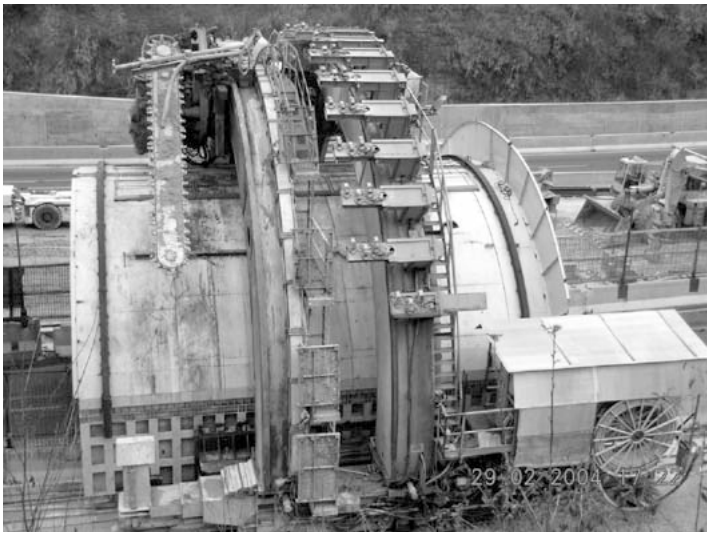

Figure 6b. **A view of the multifunction equipment.**

The rear arch, on the other hand, was designed for placing the concrete segments. A carriage runs on it fitted with an 'erector' capable of joining the segments together and setting them in position. The erector is completely electrically and hydraulically powered and is controlled from a mobile control panel fitted with a display, which provides information on the manoeuvres to be performed.

Before the key segment is placed and backfill grouting is performed to make the arch self-supporting, the segments rest on a telescopic framework anchored to the arch and fitted with sensors which allow the various manoeuvres to be performed in safety.

The structure is fitted with service gangways in different positions to allow personnel to operate with good visibility and in maximum safety.

The various functions of the equipment are managed by a PLC (Programmable Logic Controller), which is able to recognise the commands it receives, activate safety locks and send information to the monitors on the various control panels needed for proper and safe control of the movements of the equipment.

7. THE SECTION TYPE

The Nazzano tunnel was widened by using mechanical precutting to preconfine the cavity. The precut had a thickness of 30 cm and a length of 5.5 m with an overlap between consecutive shells of 1.5 m. A final lining was placed consisting of 19 prefabricated concrete segments (active arch) with a thickness in the key of 0.6 m.

The cavity preconfinement controlled the state of deformation of the cavity itself, prevented the ground from loosening, and as a consequence reduced the stresses on the final lining. Furthermore, excavation and positioning of the prefabricated segments in small steps of 100 cm placed at around 5-6 m from the face and ‘activated’ immediately put a direct halt to the onset on any possible deformation phenomena with the construction of the final lining. The factory manufacture of the segments used for the active arch also helped guarantee the excellent quality of the concrete lining.

In addition, the ability to exert precompression action with two movements of the key segment interacting actively with the surrounding ground gives the following benefits:

1. when the arch of prefabricated segments is first placed it gives perfect adherence between the arch, the backfill, the precut and the ground;
2. the second compression centres the loads again perfectly with the elimination of any tensile stresses that may be acting on the final lining.

The following is achieved by operating in this fashion:

– it ensures that construction occurs on schedule, independently of the type of ground and the stress-strain conditions, with construction times and costs contained and planned in order to reduce traffic deviations and inconvenience to users to a minimum;

– it controls the effects of the probable presence around the existing tunnel of a band of ground that has already been subjected to plasticisation and must not be disturbed any further;

– it widens the cross section of the tunnel without causing damaging deformation of the ground, which would translate into huge thrusts on the lining of the final widened tunnel and into the development of differential surface settlement which would be dangerous for pre-existing buildings and structures.

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Figure 7. **The steel shield to protect traffic.**

8. OPERATIONAL STAGES FOR WIDENING THE TUNNEL

The individual construction stages (making the precut, placing the segments, excavation and demolition) involved building the widened tunnel in 4 m steps organised in repeated modules, which enabled optimisation of the work.

Stage 1: Creation of the precut shell filled with a high strength, rapid setting, fibre reinforced cement mix

Mechanical precutting technology consists of making an incision in the face of a predetermined thickness and length around the line of the extrados of the future tunnel. The incision is made with a cutter 5.5 m long and 30 cm thick and is filled with a fibre reinforced cement mix (Rck = 35 MPa, fibre 30 kg/m^3) with appropriate additives and rapid high strength properties.

The grout mix is cast using a 'casting robot' grouting system which pumps the fibre reinforced mix into the incision created by the precut cutter. A preliminary lining in advance is thereby created of cement material that prevents the ground ahead of the face from loosening. At this stage the face is located at around 4.5 m from the last arch of segments placed.

Stage 2: Tunnel advance of 1m

Excavation, spoil removal from the face (zone between the existing tunnel and the intrados of the precut shell) and demolition of the 2 m lining of the existing tunnel is performed in this stage. Excavation and demolition of the existing tunnel is then performed using two road header excavators performed using two road header excavators, one working on the right and the other on the left of the traffic protection shield (figure 8). After the excavation the excavators are removed from the face and two bucket loaders (one on each side), not on tracks, perform the function of loading and transporting the spoil outside and loading it onto dumper trucks for delivery to the dump. When tunnel advance is complete, a 10 cm layer of fibre reinforced shotcrete is sprayed on the face to guarantee complete safety and to prevent possible spalling of the ground. On completion of this stage the face is at a distance of 6,5 m from the final lining.

Figure 8. **The demolition of the widening face performed using two road header excavators.**

Stage 3: placing of an 'active arch' of concrete segments, precompression with the jacks in the key segment and backfill of the cavity between the extrados of the segments and the precut; to be performed in two consecutive steps

The active arch technology consists of placing a final lining consisting of prefabricated reinforced concrete segments with a thickness in the crown of 0,6 m, of varying thickness in the walls and with a longitudinal thickness of 1 m. Once the two arches have been erected the face lies at a distance of 4,5 m from the last arch placed.

The gap between the final lining and the precut is filled with shotcrete (Rck = 25 MPa) which avoids the need for formwork behind the lining.

The arch of segments positioned during the erection stage using a special framework (figure 9), is made self-supporting by applying precompression force using special jacks fitted in the key segment.

The arch is activated after backfilling has been performed and the backfill must have setting characteristics that enable it to absorb the movements of the arch during the precompression phase without cracking.

Stages two and three are repeated twice for each precut shell that is created. Once these stages of the cycle have been completed to give a 4 m section of finished tunnel, the operations that have just been described are repeated until the end of the tunnel is reached. When, following face advance, the distance between the face and the front end of the shell is considered to be at the minimum required for safety (30 m approx.), the protection shield is moved forwards by around 10 m and the various stages are then repeated in cycles until widening of the entire tunnel is complete. The main characteristic of the technique was the adoption of excavation in steps with immediate placement of the final lining of prefabricated concrete segments using the 'active arch', which made it possible to eliminate the onset of all deformation even at a short distance from the face enabling all problems connected with the deformation response of the ground to be solved. The machinery employed operates completely above the 'traffic protection shield' and consists of a modular steel framework, mounted on prefabricated New Jersey profile elements designed to absorb possible bumps from vehicles in transit. The shield is also fitted with a runner system, anchors, motors and sound proofed panels designed to absorb shocks from the fall of blocks of material during the demolition of the existing tunnel and of the surrounding ground, including potential rockfalls.

Figure 9. **Erection of the prefabricated lining segments in pretressed r.c.**

The magnitude and critical nature of the works and the need to contain the development of deformation in the ground made it essential to work continuously at the face until the completion of the tunnel invert, round the clock 24 hours a day, 7 days a week. A temporary layer of lean concrete is cast for confinement during widening operations to level the working surface of the new structure with that of the existing tunnel invert in order to house the rails on which the multifunction equipment runs.

Figura 10. **View of the widened tunnel.**