TUNNEL WIDENING

New technologies for widening road, motorway and rail tunnels without taking them out of service

The first application in the world at Nazzano (Rome)

1 - INTRODUCTION

It is well known that as volumes of traffic progressively increase, the need to widen roads, motorways or railways to augment their capacity becomes increasingly urgent. While meeting these needs does not present any huge problems as long as the routes run completely on the surface, it is very complicated when they run through stretches of tunnel, because it is indispensable in these cases to resort to costly alternative routes to construct the new tunnels in addition to those that already exist.

And then a tunnel can only be widened while it is in service if it is possible to:

- guarantee the necessary safety of users and limit inconvenience within an acceptable threshold;
- solve the technical and operational problems connected with driving the widening face in ground that has already been disturbed by the previous excavation;
- construct the new load bearing structure at the same time as the old one is demolished and deal adequately with any stress-strain conditions without any danger to tunnel users and to any human activity there may be on the surface.

Experimentation of a construction method is at an advanced state of progress in Italy which is actually able to satisfy all the above requirements and make it possible to widen existing road, motorway and rail tunnels without interrupting traffic flow during construction work.

2 - ILLUSTRATION OF THE TECHNIQUE

The technique consists of three main stages (Fig. 1 and 2)

- a first stage of ground improvement and excavation in steps during which the work, if necessary, to reinforce the face and/or to preconfine the excavation is performed, depending on the geological and geotechnical condition and then the ground between the theoretical profile of the future widened tunnel and that of the old existing tunnel is excavated;

Figure 1 - Excavation of ground of the widening face and demolition of old tunnel

Figure 2 - The stage of placing of an arch of prefabricated segments is alternated to the stage of excavation of the widening face
2.2 - The second construction stage (lining)

The second construction stage entails placing the final lining of the widened tunnel consisting of prefabricated concrete segments.

Excavation in steps with the final lining consisting of prefabricated concrete segments placed immediately according to the active arch principle constitutes the key factor. It halts any possible deformation phenomena before it starts at a short distance from the face and overcomes all the problems of the deformation response of the rock mass. This is the most characteristic feature of the technique presented here.

The operations involved in this stage are as follows (Fig. 2):

A) transport of the concrete segments to the face using conveyor belts and/or fork lift trucks positioned on the two sides of the widened tunnel;

B) the application of slow setting epoxy resins on the two sides of the segment to be placed and on the front end that will be in contact with the arch of the lining already placed;

C) raising and positioning of the segments using a special erector machine which places the lower segments first on both sides of the tunnel and then the upper segments until the arch is completed with the key segment in the roof;

D) mortar is introduced between the extrados of the prefabricated segments and the wall of the excavation behind it;

E) the pressure jack in the key segment is then activated to bring the segments into firm contact with each other and immediately produce the confinement pressure required on the ground around the tunnel according to the active arch principle.

2.3 - The third construction stage (foundation)

If a foundation structure is needed, it can be placed according to the situation either by simply joining the lining of the widened tunnel to the tunnel invert of the old tunnel or a genuine new tunnel invert is cast. To do this, traffic must be deviated as illustrating in the paragraphs below.

3 - RESOLUTION OF PARTICULAR PROBLEMS TO MAINTAIN TRAFFIC FLOW DURING THE THIRD OPERATIONAL STAGE

A distinction must be made between road and rail tunnels as far as maintaining traffic flow during the third operational stage is concerned.

3.1 - Rail tunnels

Once the tunnel has been widened rail traffic will have to be interrupted to change the layout of the tracks in the new situation. The structure to join the final lining of the widened tunnel with the existing tunnel invert or, alternatively (if the static conditions require it), the casting of a new tunnel invert can be performed in this interval of time.
3.2 - Road (single tunnel) or motorway (twin tunnel) with 2 lanes in each direction

Traffic in road tunnels can always be kept flowing on at least one lane in each direction by appropriate organisation of the works to construct the foundations and to widen the road itself. Similarly, two lanes in each direction can always be kept open with twin motorway tunnels by switching the works between the two tunnels and deviating traffic flow accordingly onto lanes as they become free (as illustrated in the example in Fig. 3).

4 - USE OF THE SYSTEM FOR THE WIDENING OF THE NAZZANO TUNNEL

As has been said, the new technology is being applied experimentally for the first time in the world to widen the Nazzano tunnel located on the A1 Milan-Rome-Naples motorway between Orte and Fiano Romano, between chainage km. 522+00 and km 523+200 (Fig. 4). The route of this tunnel is completely rectilinear and lies at an altitude of 166 m. a.s.l. It is 337 m long and runs under an overburden of 45 m. From a geological viewpoint, the tunnel runs through sandy and silty-clayey ground of the Plio-Pleistocene series on which the town of Nazzano is located (Fig. 5).
Given the type of ground to be tackled, the design first specifies the creation of a shell of fibre reinforced shotcrete around the tunnel using mechanical precutting before starting excavation to widen the tunnel. Tunnel widening therefore takes place in the following four main stages (Fig. 6):

1) creation of a mechanically precut shell (5.5 m. in length, thickness 35 cm.) around the future tunnel (19.74 m. span) and ground improvement ahead of the widening face if necessary (Fig. 7);

2) demolition of the old lining in steps under the protection of the previously improved ground and excavation of the ground until the design profile of the widened tunnel is reached (Fig. 8);

3) immediate erection of the final lining behind the face (4 - 5 m. max.) by placing an arch of prefabricated concrete segments, using the active arch principle (Fig. 9);

4) construction of the foundation structure (new tunnel invert).

All the operations for the first three stages are performed protecting the road with a self propelled steel traffic protection shell under which vehicles may continued to pass in safety (Figures 10 and 11). The shield used has a length of 60 m. and extends for a length of approximately 40 m. ahead of the widening face. It consists of a modular steel structure and is equipped with runner guides, anchors, motors, sound proof and anti shock panels to absorb the shock of falling blocks of material during excavation and demolition of the existing tunnel including any ground that falls accidentally. All the machinery for performing the various operations moves and operates above the shield. When tunnel widening advances to the point
where the distance between the face and the front end of the shield reaches what is considered the minimum safety limit for vehicle traffic, it is moved forward and the various stages repeated in cycles until the whole tunnel has been widened.

5 - THE MACHINE AND ITS EQUIPMENT

The design of the machine prototype and its equipment required particular effort because a series of operating functions had to be optimised to work in a very limited space between the finished tunnel and the shield: precutting at the face, excavation, placing of the segments, various mortar operations, demolition of the existing tunnel.

The problems were solved by using innovative technology and the result was a versatile and compact design, highly computerised capable of performing all the functions required with movements and therefore also operating times reduced to a minimum.

Basically it consisted of a robust double arch steel structure (Fig. 12) connected at the bottom by telescopic beams which gave rapid and precise longitudinal movement forwards and backwards. Centring in the cross sec-

Figure 8 - Nazzano tunnel: demolition of the old lining and excavation of the ground of the widening face

Figure 9 - Nazzano tunnel: final lining of prefabricated segments

Figure 10 - Nazzano tunnel: all the operations are performed protecting the road with a “steel traffic protection shell”
tion and correct positioning of the height are achieved by hydraulic control systems.

A particularly sophisticated carriage is fitted on the arch at the face which carries the precutting blade. The circular movement of the carriage around the arch is obtained by a gear reduction motor and a rack and pinion and the single and complex movements of the different equipment allow the different operations specified in the design to be performed.

A dual system is also appropriately positioned on the same arch to manage the tubing used for filling the cut made with the precutting blade with mortar and the space between the segments and the walls of the excavation.

The rear arch was designed for placing the concrete segments. A carriage runs on it, equipped with an erector capable of grabbing the segments and placing them. The movement of the erector is totally powered by electricity and hydraulics and it is controlled from a panel equipped with a display which gives information on manoeuvres and errors that may have been committed.

Before the key segment of the arch is placed and it consequently becomes self-supporting, the segments rest on special telescopic structures anchored to the arch. They are equipped with sensors which allow the different manoeuvres to be made in safety.

The structure is equipped with various service gangways to allow personnel to work with a clear view of operations.

The various functions of the equipment are controlled by a PLC (Programmable Logic Controller), which recognises commands it receives and sends information to the display for correct and safe control of the equipment.

The table below contains the main technical specifications of the machine used.

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<thead>
<tr>
<th>TECHNICAL SPECIFICATIONS OF THE MACHINE</th>
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<td>Power</td>
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Table 1
6 - STATE OF PROGRESS OF THE WORKS

Regular advance rates for tunnel widening were achieved after first overcoming problems of an exclusively contractual and financial nature, which delayed the actual start of widening operations several times and secondly after solving a series of problems connected with advance through the portal zone with shallow overburdens and the subsequent calibration of the system.

Approximately 210 m. of widened tunnel had been completed in May 2005 with advance rates of between 0.7 and 0.8 m. per day.

Optimisations applied to the system and the advance cycle mainly regarded the adoption of a longer cutting tool to perform a pre-cut of 5.5 m and a thickness of 35 cm.

The pre-cut is then followed by two stages of demolition of the existing tunnel and placement of shotcrete at the face, each two metres in length with the erection of two consecutive active arches each with a length of 1 metre.

7 - CONCLUSIONS

The first results of the experimentation indicate that the technology illustrated effectively solves the typical problems of widening tunnels while keeping them open to traffic during construction work.

The main features of this technology are:

- the adoption of a final lining consisting of prefabricated concrete segments to stabilise the widened tunnel placed in short steps according to the active arch principle, which therefore comes into operation at a very short distance from the widening face (4.5 to 6.5 m. max). As a consequence passive stabilisation operations such as shotcrete and steel ribs are avoided;
- the final lining can be put under pressure by using jacks in the key segment designed to recentre unsymmetrical loads should there be bending moments sufficient to make partial the resisting section of the arch of prefabricated segments;
- the ability to perform ground improvement ahead of the face, if required, to contain or even completely eliminate deformation of the face and of the cavity and therefore avoid the uncontrolled loosening of the rock mass and thereby ensure operational safety;
- intense mechanisation of the various construction stages, including the operations for ground improvement ahead of the face if required, with consequent regular advance rates and shorter construction times, all factors that have advantageous side effects for site economics and the production rates that can be achieved;
- the extremely linear production rates obtainable (industrialised tunnelling), which it is predicted will be around 0.6 - 1.2 m./day of finished tunnel;
- the ability to perform all construction operations while protecting the road with a "steel shell" under which traffic can continue to flow in safety;
- the extreme versatility of the machine used, which is able to operate under extremely varied ground and stress-strain conditions.

After a lengthy phase during which the system was calibrated and fine tuned, because the technology employed to widen a tunnel with traffic flowing was completely new, the experimentation, currently underway, has already demonstrated that this technology is capable of:

- controlling the effects of the probable presence of a band of ground around the existing tunnel which has already been subjected to plasticization phenomenon and which must not be disturbed further;
- widening the cross section of a tunnel without triggering harmful deformation of the ground and therefore preventing the development of very strong thrusts on final lining of the widened tunnel and of differential subsidence on the surface which would be dangerous to any structure existing there;
- ensuring compliance with time schedules set at the design stage regardless of the type of ground and the stress-strain conditions, containing and planning costs construction times with certainty, thereby reducing deviations of traffic lanes and therefore hardship for tunnel users to a minimum.

BIBLIOGRAPHY