Rehabilitation of a Tunnel under Traffic

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1. Location of the infrastructure

The Monts tunnel is located on French National Route 201 and forms part of the Fast Urban Highway (VRU) which bypasses Chambéry. This VRU, which is 14km long, provides continuity of the motorway network consisting of the A43 between Lyon and Turin/Italy via the Fréjus tunnel and the A41 between Grenoble and Geneva/Switzerland. It was commissioned in late 1981 with two lanes in each direction and widened to 3 lanes in each direction in July 1985. The Monts tunnel consists of two parallel one-way tubes dug 20 metres apart (the minimum distance between side walls; the distance between the centrelines is 30m), linked by three communication galleries. The tunnel allows the limestone mass which constitutes the ‘colline des Monts’ overlooking the Chambéry urban district to the east to be crossed, in an urban environment, at a maximum depth of 70m. The Northern tube (Italy – Lyon traffic) is 889m long while the Southern tube (Lyon – Italy traffic) is 870m long.
2. Situation

After over 25 years in service, the installations in the Monts tunnel presented a number of anomalies, most of which were due to accelerated ageing of the equipment required to operate the infrastructure, particularly that part located within the infrastructure itself, where the environment proved to be particularly aggressive. The absence of waterproofing led to ingress of water from the mass through cracks in the crown concrete. This water ingress - which could be significant during periods of rainfall - ran over lighting, ventilation and safety installations amongst others, leading to major corrosion of their metal parts and rapidly ensuing damage to electromechanical components. In cold weather, black ice formed on the roadway, as well as icicles on the crown and ice columns on the side walls. This led to major operational concerns. The local subdivision of the Highways Agency (a body run by the French state) based in Chambéry had to work virtually every night when temperatures fell below zero to break up icicles which penetrated cableways and lighting installations and sometimes even made opening the emergency stations impossible.

3. Renovation contract

Works costing a total of €33m at 2004 values related to the following:

- Complete waterproofing of the infrastructure by installing a geo-membrane applied over the existing lining and protected by a fresh, thin coating consisting of a formwork concrete lining. In order to preserve the existing usable height and width in the infrastructure, the works also included lowering the roadway.
- Compliance with the French circular 2000-63 (dated August 25, 2000 and covering safety considerations in national road network tunnels) for all installations (ventilation, lighting, pollution sensors, signage, security of electrical networks, implementation of AID (Automatic Incident Detection) and the installation of a drainage network connected to a new retention basin with a volume of 200m³ as well as new installation control and command equipment).

4. Principal parties involved

- Contracting authority: French Government
- Engineer: Direction Départementale de l’Equipement (Savoie) assisted by the Tunnels Study Centre (CETU – French Government)
- Prime contractor: joint consortium of companies comprised of BEC (Structural Work and consortium representative), SATELEC (Equipment) and SCREG (earthworks, highway, networks and roadways)
- Principal suppliers and subcontractors: CMC (formwork), PRATI (waterproofing), BF and BRA (concrete), MECSIDER (reinforcements) and SECO-RAIL (cutting and planing).

5. Principal quantities for structural work (Northern tube and Southern tube)

- HA steel for slab on D1500, \(2 \times 200t\)
- HA steel for side walls, 2 x 190t
- HA steel for crown, 2 x 35t
- Waterproofing (geo-membrane) 2 x 25,000m²
- Concrete for highway, networks and drainage 2 x 4100m³
- Crown concrete 2 x 6550m³

6. Completion schedule

The works were performed over a period of two years and three months, comprising two different phases of work with distinct schedules. The structural work in each tube was limited to eight and a half months and was carried out solely at night.

- Notification of tender: 29/09/2004
- Instruction to Proceed with works: 25/10/2004
- Instruction to Proceed with works in Northern tube 04/2005 within a period of 8.5 months
- Instruction to Proceed with works in Southern tube 04/2006 within a period of 8.5 months

7. Distinctive characteristics of the worksite

7.1. Traffic issues

Traffic on the Chambery fast urban highway grew from annual average daily traffic of 18,000 vehicles on commissioning in 1982 to 83,000 vehicles in 2004. This sustained growth is due to the fact that this route, with three lanes in each direction, represents the sole artery in the urban area which, thanks to short distances between junctions, enables effective travel between residential and business sectors. This is borne out by the type of traffic: three out of four journeys are for local travel.

Traffic volumes on working weekdays in one direction are virtually identical to those in the opposite direction. There is very little night-time traffic, with less than 1000 vehicles per hour between 9.30pm and 6.30am. From 6.30am onwards, there is a sharp increase in traffic levels, with peak levels between 7.45am and 8am and up to 1500 vehicles per quarter hour. Between 9.30am and 4.30pm, the traffic fluctuates between 2700 and 3300 vehicles per hour (v/h) with a late afternoon/early evening peak of 3500-4500 v/h between 4.30pm and 7.30pm.

The traffic structure varies considerably depending on the time of day, the season and between working days and weekends. Analysis of the urban road network very quickly led to the conclusion that it was impossible to envisage partial diversion of the traffic from the fast urban highway onto the rest of the network, which was already congested during morning and evening rush hours. Given this state of affairs, the sole option was for work to take place in one tube at a time, at night, during which the traffic used two lanes (one in each direction) in the unaffected tube.

7.2. Maintenance of safety levels

Performance of the works under consideration also involved particular measures relating to an exceptional operating environment (highways in use on the outside and control station in service close to the infrastructure ready to deal with any incidents).
Given the works to be performed and the traffic flow considerations, the principle of night works with lane restrictions or closures with warning lights was systematically adopted.
The tube not being worked on benefited from all its installations and their respective management systems, irrespective of the phase of renovation works in the other tube.

7.3. Traffic flows during works

The nature of demolition work and the installation of site equipment meant that a maximum of two lanes could be left open to traffic in the tube being worked on. Moreover, during particular phases of works, specifically the lowering of the existing surface by some 80cm, only one lane was reopened to traffic in the tube being worked on. In order to have an indispensable second lane open in the direction in question to accommodate fast urban highway (VRU) traffic as adequately as possible, one lane in the other tube was used in contraflow. This lane was also used at night when the tube being worked on was completely closed.

As a result, at the start of works a reinforced concrete barrier was installed in the tunnel's Southern tube. Use of this contraflow lane in the Southern tube during the day was planned to last...
approximately three months at the start of works. In terms of safety, this was the most critical phase of the worksite. In the tube being worked on, one lane was reopened to traffic during the day, located to one side of the tube (either the slow lane or the fast lane side, depending on the stage work had reached).

During the day, two lanes to traffic in the tube being worked on were reopened. In particular, this layout was used throughout the stage during which the crown was concreted, since the formwork structure left sufficient clearance for both these lanes.

Every night, a period of at least eight consecutive hours during which the tube was closed to traffic was required. Throughout the duration of the worksite, the daily task of changing the flow of traffic every evening and morning was entrusted to a specialist contractor. This contractor's responsibilities also included monitoring and maintenance of the signage installed (signs, cones, beacons, etc). They worked closely with the tunnel control station which operated the dynamic installations at the approaches to the infrastructure during traffic changeovers as well as providing monitoring of the structure and the VRU approaches 24 hours a day, 7 days a week.

7.4. Technical options

For the structural work, one of the key considerations of the project related to the extent to which the roadway could be lowered, with two absolute limiting factors:

- the existence of a collector drain beneath the roadway with a diameter of 1500mm in the Northern tube: this had to be kept intact to allow the stream to pass through,
- the lengthwise profile of the lowered roadway had to be linked smoothly to the more general lengthwise profile of the VRU so as not to create surface drainage problems and in order to preserve a satisfactory level of driving comfort.

Since reducing the minimum height clearance was not an option, the maximum thickness of the waterproofing concrete layer could not exceed 25cm. This is much thinner than the normal thickness of formwork concrete lining. At the preliminary design phase of the renovation project, the contracting authority was able to choose from a comparative study of seven renovation options which were compatible with the large number of constraints for the project. The chosen option used a thin lining of self-compacting concrete, protecting a layer of traditional waterproofing identical to that used in new tunnels. Work was planned in phases so that the works could be suspended, allowing the tunnel to be properly operational on the date by which it had to be fully re-opened to traffic (December 15 of each year of works).

8. Means used

8.1. Side wall formwork

After lowering the roadway and rearranging the networks on both the slow and fast lane sides (works performed on half the roadway at a time as indicated in the work phases described in the next chapter), repair of the tunnel began with the construction of new side walls of a height of 2 metres.
It was firstly necessary to remove the existing concave side wall lining in order to have sufficient thickness for the waterproofing complex plus the new 25cm lining. The new side walls were reinforced along the whole tunnel length and on both sides. They were constructed in 25m segments by means of formwork. For the tender, the rate of construction was set at 50m per night.

The self-compacting concrete was installed using a mobile pump via an injection pipe located one metre above ground level, in the middle of the formwork. The end caps were steel and sealed by means of neoprene joints.

8.2. Crown formwork

In order to comply with the deadlines for the works, the contractor had two tunnel formwork structures made specifically for the worksite, designed and built by CMC in collaboration with BEC's Methods department. Weighing 120 tonnes each, one distinctive characteristic of this plant was its ability to retract in order to enter the tunnel, as shown on the diagram, so as to pass beneath the existing ventilator fans and the lighting. Work was carried out at night (9pm-5am); the tunnel was reopened to traffic during the day (5.30am-8.30pm); all the tunnel installations had to be operational irrespective of the tunnel zone in question: this applied to lighting, ventilation and signage and both to existing equipment to be removed and to new items to be installed.

The two structures ran along “Burbac” steel rails behind the waterproofing application gantries. The retracted forms were introduced into centre of the tunnel from the Western end, with one set carrying out the lining in an eastward direction and the other returning westwards.

Two crown hydration systems followed behind the lining forms. These were designed so as to be exactly the same size as the formwork structure. This meant that as soon as the formwork structure moved on, the lining could be hydrated, with a wet geotextile applied to the hardened concrete.

Specifications for lining required progress in 12.40m segments from the middle of the tunnel to the two ends. Consequently, in two locations, there was a "works train" extending for about 100 metres consisting of a form of "tunnel within a
tunnel” comprising the following: one segment of existing lining with the former tunnel lighting being removed (10m), a waterproofing gantry installing one segment of geomembrane lining (10m), two waterproofed segments (20m), one segment being concreted (10m), one segment being cured by hydration (10m), one segment with provisional lighting being installed (10m) and 1 or 2 more segments fitted with permanent lighting (20m).

For the segments ready for lining, the self-compacting concrete was distributed from an injection unit at a fixed location on the structure via five feeder pipes using a mobile engine-driven pump.

The works cycle allowed for a drying/hardening time of 16 hours (from the end of concreting at 5am to the start of removal of forms at 9pm). Based on the strength requirements specified for this concrete and the high quantity of heat it produces, curing the concrete by hydration formed a necessary part of preparation.

8.3. Self-compacting concrete

Self-compacting concrete is a very liquid type of concrete deployed by gravity with no vibration. Its high degree of fluidity is due to the use of additives (a superplasticizer and in some cases a water retaining agent) - never due to an increase in the quantity of water used. This means it has good properties both when fresh (with no segregation or bleeding) and when hardened (mechanical strength and durability).

The requirements for concrete on this worksite were numerous and sometimes difficult to reconcile. Some derived from the Special Technical Specifications (CCTP), others from the speed of progress adopted by the contractor.

They related to the following aspects:

− Flow characteristics when fresh complying with the recommendations of the AFGC (French Association of Civil Engineers) applying to SCC.
− short and long-term strength (respectively, 10mPa after 16hrs and C45/55 in an XF2 category environment).
− durability as regards:
  - alkali silica reaction (prevention level between categories B and C of the LCPC (French Central Civil Engineering Laboratory) recommendations)
  - the effects of frost and de-icing salts (category G+S, moderate resistance to frost with frequent salting as per “Specific Recommendations for the manufacture of concrete for parts of structures which are not protected from adverse weather conditions and subject to frost” drawn up by the Rhône-Alpes working party)

There were many arguments in favour of the use of self-compacting concrete:

− The ease of implementation of SCC made the concreting process faster and made the worksite easier to organise in terms of daily reopening to traffic.
− The highly fluid nature of the substance (slump value of 600mm in an Abrams cone) ensured the formwork was properly filled despite the thinness of the lining and despite the presence of reinforcement bars in the segments with accelerators in the crown.
− No vibration is required, with a resultant decrease in noise pollution which considerably improved conditions both on the worksite itself and in the immediate environment.
− SCC also comes into its own in a confined space. Acoustic measurements taken during the vibration of concrete in tunnels had previously revealed unacceptable noise levels (105dB).
− Formulation considerations relating to the need for a high level of fluidity whilst avoiding segregation have led to the design of types of concrete with very good durability.
– The good quality of the lining (with few blow-holes) should make it possible to allow the side walls to be painted in excellent conditions without any prior screeding. However, all these advantages should not obscure a certain number of considerations which had to be taken into account in order for the expected gains not to be compromised:

– The formwork was dimensioned to sustain the high pressure of the self-compacting concrete. Safety considerations led to the total hydrostatic pressure being taken as a guide.
– Special attention was paid to sealing the tool (edges and ends).
– The surface quality of the formwork was very good, since any blemish would be replicated on removal of the forms. This was especially important for the side walls across a height of approximately 3m.
– To benefit fully from the effects of the additives and ensure a good strengthening speed (with 10mPa required after 16hrs), specific measures were required during cold weather.
– Staff received a high level of skills training (precautions to be taken during the handling of forms, applying form removal products, using a maturity meter, formwork removal and curing.

This was the first time a crown had been made using self-compacting concrete. Its formula was developed by Sigma Béton's laboratory and it was manufactured in ready-mixed concrete plants belonging to Béton de France and Béton Rhône Alpes based in the suburbs of Chambéry (Savoie - France).

External control of the concrete used was performed by the Regional Civil Engineering Laboratory (LRPC), part of the Lyon Technical Highways Design Centre (CETE), in collaboration with research work by the Tunnels Study Centre (CETU) in this field.

9. Phases of work

<table>
<thead>
<tr>
<th>Daytime (5.30am – 8.30pm)</th>
<th>Night-time (9pm - 5am)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grenoble – Aix les Bains</strong></td>
<td><strong>Southern Tube</strong></td>
</tr>
<tr>
<td>• 1 lane open in Northern Tube</td>
<td>• 1 lane open for Grenoble - Aix les Bains traffic</td>
</tr>
<tr>
<td>• 1 contraflow lane in Southern Tube</td>
<td>• 1 lane open for Aix les Bains – Grenoble traffic</td>
</tr>
<tr>
<td><strong>Aix les Bains - Grenoble</strong></td>
<td><strong>Northern Tube undergoing work</strong></td>
</tr>
<tr>
<td>• 2 lanes open in Southern Tube</td>
<td>• Lowering work on fast lane side using planing machine</td>
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<td></td>
<td>• Demolition of drain conduits</td>
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<td></td>
<td>• UGM and porous concrete</td>
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<td></td>
<td>• 20cm of GB4, 2 layers</td>
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| **Grenoble – Aix les Bains**                                  | **Southern Tube**                                           |
| • 1 lane open in Northern Tube                               | • 1 lane open for Grenoble - Aix les Bains traffic          |
| • 1 contraflow lane in Southern Tube                         | • 1 lane open for Aix les Bains – Grenoble traffic          |
| **Aix les Bains - Grenoble**                                 | **Northern Tube undergoing work**                           |
| • 2 lanes open in Southern Tube                               | • Lowering of roadway on slow lane side                     |
|                                                           | • Demolition of drain conduits                              |
|                                                           | • UGM and porous concrete                                   |

Fig. 18 – Day traffic

Fig. 19 – Night traffic
<table>
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**Southern Tube**
- 1 lane open for Grenoble - Aix les Bains traffic
- 1 lane open for Aix les Bains – Grenoble traffic

**Northern Tube undergoing work**
- Reinforced concrete slab on D1500 (existing stream)
- 20cm of GB4 on porous concrete
- Demolition of foundations by cutting and planing followed by foundation earthworks
- Drainage, highway/networks work, slot drainage, multitube ducting

**Fig. 20 – Phases of work**

10. Conclusion

A meticulous planning and detailed execution methods allowed us to minimize the traffic disruption. In addition, a continuous dialogue between all the parties to the site was favoured by a jointly liable joint-venture managing directly all the coordination between the multiple interfaces. As a result, we managed to control and hold all the specifications.

Due to this innovating method of pouring the self-compacting concrete, specifically created for this project (quick pouring and removal of the vibrating sound), and to two outside standards formworks, supplemented by a gantry crane keeping the water saturation of the concrete (this suppressed the short term contraction), we obtained a perfectly dry and sound coating.

All the electrical and ventilating equipments, and road signs were replaced: Thus, after two years of works, the Tunnel des Monts found a new revival.