AFTES
Recommendations

Rail tracks and track beds in tunnels

GT40R2A1
Rail tracks and track beds in tunnels

Text submitted by Jean-Marc POTIER (SNBPE), coordinator, and Serge HORVATH (CIMBETON) co-coordinator, Working Group GT40

This recommendation has been approved by the AFTES Technical Committee following a critical review of the text by:

Michel DEFFAYET (CETU) - Alain BOCHON (SYSTRA) - Christian PLINE (GEODATA) - Daniel MERAKEB (ex RATP) - Michel PRÉ (SETEC)

AFTES welcomes all suggestions relating to this text.

1 - Foreword 228

2 - Expectations on the part of project owners, project managers and users 228
  2.1 - General considerations 228
  2.2 - Projects 228
  2.3 - Nuisance for local residents (diversions, costs) and user expectations 229
  2.4 - Decision-making criteria 229

3 - Design and civil engineering for rail tunnels 230
  3.1 - Structural design of the track bed 230
  3.2 - Influence of tunnel construction type and geometry on design of the track bed 230
    3.2.1 - Traditional excavation: track bed resting on natural soil or arch + backfill 231
    3.2.2 - TBM excavation: track bed resting on concrete slab 231
    3.2.3 - Shafts and covered trenches: track bed resting on a concrete slab 232
  3.3 - Drainage 233

4 - Track beds and track in rail tunnels 233
  4.1 - Background 233
  4.2 - Ballasted Track 233
  4.3 - Ballastless track (cement concrete or asphalt) 234
    4.3.1 - Concrete sleepers embedded in the concrete slab 236
    4.3.2 - Tracks on “railsseats” 236
    4.3.3 - Embedded Rail System (ERS®) 237
    4.3.4 - Other possible techniques: prefabricated slabs 237
  4.4 - Transition zones 237
  4.5 - Particularities of installation of track beds in rail tunnels 238

4.5.1 - Construction of ballasted track 239
  4.5.2 - Track built on cement concrete 239
  4.5.3 - Track laying 241
  4.5.4 - Asphalt track beds 242
  4.5.5 - Tunnel drainage construction 243

4.6 - Major maintenance and renovation 243

4.7 - Comparative analysis 243
  4.7.1 - Comparison between ballastless and ballasted track 244
  4.7.2 - Technical comparison of ballastless/ballasted track in urban tunnels 244
  4.7.3 - Economic aspects 245

5 - Fire, Environmental and Health-related considerations 245
  5.1 - General considerations 245
  5.2 - Rail tunnels 246
    5.2.1 - Risks of accident 246
    5.2.2 - Intervention of rescue services 246

6 - GT 40 Recommendations 247

7 - Examples and construction of tunnels and rail tracks 248

8 - Bibliography 253
  8.1 - Main reference documents 253
  8.2 - Principal standards for cement concrete roadways 253
  8.3 - Main standards relating to asphalt pavements 253
  8.4 - Photo credits 254

9 - Glossary 254
Following the GT40R1 recommendation specifically treating road pavements in tunnels, published in 2011 (TES 226) [17], this one (GT40R2) will examine the case of rail platforms in tunnels.

Rail tunnels are unavoidable, and as a result of growing transport needs, they are having to deal with increasingly large volumes of traffic. Located in sensitive sites and difficult to bypass, whether in built-up areas or in natural surroundings such as mountain barriers, these structures – limited in number – are being subjected to increasing pressure from large numbers of users seeking mobility.

This traffic and the resulting constraints are supported by rail platforms that are all too often considered as a minor point in the construction of tunnels, to be treated like the rest of the linear in the section outside the tunnel.

It is therefore well worth highlighting the main differences:

- the design of rail track beds in tunnels and in the open air,
- construction methods in new tunnels, maintenance and renovation,
- requirements in terms of safety and passenger evacuation.

### 2 - Expectations on the part of project owners, project managers and users

#### 2.1 - General considerations

For tracks in tunnels, project owners have to take a large number of criteria into consideration before adopting a given technical solution. These include:

- Maintenance costs compared to investment costs
- User safety (one TGV trainset carries approximately 500 people, or 600 in double-decker trains, i.e. as many as 1,000 people or more for trains consisting of two trainsets)
- Protection of individuals, particularly in stations and also in standard sections (with the creation of an "anti-suicide pit")
- Sustainability of operation
- Protecting the support

- Frequency of maintenance for track upkeep and cleaning of ballasted track in tunnel stations

Compared to road tunnels (see Recommendation GT 40-1), vehicle speed (in this instance, that of trains) is much higher, for both local and inter-city transport.

- RER Line A tunnel between Charles de Gaulle and La Défense: 90 km/h
- Channel Tunnel: 160 km/h
- TGV tunnel in Marseille: 230 km/h

#### 2.2 - Projects

Track bed design for tunnels must be incorporated right from the outset of the project. This is not simply a matter of secondary options, since a number of key considerations and ancillary works (discussed below) must be taken into account.
Indeed, it is extremely difficult to change design considerations subsequently, since once the structure has been built, there is very little room for manoeuvre in terms of clearance. Therefore, the right decision must be made at the outset, without ‘over-excavating’ as a precautionary measure, since this will also have a financial impact.

Clearance can also be improved during upgrading (e.g. by replacing ballast with a concrete track bed).

In many cases the tunnel section is considered as a standard part of the route, which makes it difficult to make a specific decision for the tunnel. This is most probably due to the habit of drawing up an overall “track bed” tender for the route: using a different technique solely for the tunnel leads to complications in such cases.

Selecting the right technical solution must take into account the location of the network and its purpose, including details such as whether the site is in a built-up area, whether there is a gradient, the tunnel profile, and the number of people to be transported.

Some current considerations:
- **SNCF**: rail track beds in tunnels are an extension of the outdoor track bed
- **RATP**: the urban nature of the network means that most track beds are in tunnels, with related constraints and purposes:
  - Accessibility
  - Maintenance
  - Lifespan
  - Cannot shift traffic to another track
  - Cannot set up diversions, etc.
  - Very short maintenance time (approx. 3 hours)
  - Tracks can be used in the wrong direction for maintenance, or there can be temporary wrong way traffic (TWWT) in the event of disruptions.

### 2.3 Nuisance for local residents (diversions, costs) and user expectations

Tunnels provide a means of access between two points, generally to replace a longer route over a pass or along a valley.

Except in emergencies, the performance of maintenance works in a tunnel requires prior information and scheduling in order to minimise disruption for tunnel users (passenger train customers and goods trains), local residents and industrial stakeholders at both ends of the tunnel.

Indeed, closing a tunnel involves setting up a diversion (usually the previous route) that can safely cater for the amount and volume of traffic.

This means that track bed construction techniques designed to have a long lifespan and minimal maintenance are used.

For road tunnels, noise reduction for local residents is one of the main concerns, as opposed to rail tunnels where the issue is one of keeping vibrations to a minimum.

### 2.4 Decision-making criteria

Nowadays, taking into account sustainable development in tunnels is leading to an overall approach to the life cycle of the infrastructure as a whole, in much the same way as for other civil engineering works and indeed any other construction.

Tunnel track beds are no exception to this new approach, which involves taking due account of considerations relating not only to construction materials, their manufacture and their implementation, but also to their maintenance and renovation.

a) **Durability of the structure**: In principle, this consideration should result in a design of the tunnel track bed that keeps maintenance and renovation work to a minimum, and may also have a bearing on the choice of construction materials. This leads to the further question of the potential impact on the environment of such decisions, bearing in mind issues relating to the constraints arising during the operational phase of the structure.

These considerations, which project owners are already particularly aware of, illustrate the benefits of adopting a global, Life Cycle Analysis (LCA) type approach, in order to identify the best choices in terms of Sustainable Development and more particularly, in terms of the potential impacts on the environment.

Lastly, a new AFTES working group was set up in 2010, GT41. This working group is looking at the issue of underground works and Sustainable Development.

The underground works profession also needs to have a methodology that includes the following aspects:
- assessment and comparison of possible modes of construction of an underground structure from the point of view of Sustainable Development
- estimation of the impact of the materials used, particularly as regards their energy content
- guidance for design and construction aimed at keeping the environmental impacts relating to the operation and lifespan of the structure to a minimum.

The objective of this group is therefore to draft a Recommendation which can serve as a reference for assessing the impact of underground works in terms of Sustainable Development; a common framework is vital in that this type of assessment will be used to compare different solutions. In particular, the group will have to deal with the following types of issue:
- Identification and analysis of the aspects which have the greatest impact in this respect
- Establishing the basis for comparison, in terms of Sustainable Development, of different materials and methods which may be used
- A review of available environmental data and identification of any related needs.
b) Lighting

Rail tunnels for transit are fitted with normal lighting to aid passenger evacuation and the movement of rescue services [19]. This lighting does not relate to train driver assistance. However, tunnel stations (such as in Monaco or on the RATP network) are lit.

In the event of a failure of the electricity supply, specifications call for type B safety lighting with minimum autonomy of one hour and minimum brightness of 2 lux at all points on the ground along walkways and for emergency access facilities.

Safety lighting installations are powered in such a way as to prevent a fire cutting the power to a section longer than 100 m. They must be spaced no more than 50 m apart on the same walkway.

In two-way tunnels, they are offset on either side.

3 - Design and civil engineering for rail tunnels

For assistance with technical terms, readers are referred to the [French] glossary drafted by SETVF [17] www.setvf.com

3.1 - Structural design of the track bed

The design of track bed structures in rail tunnels depends on a number of factors.
- The type of tunnel (or shaft): immersed, pre-fabricated or excavated, in which the load-bearing capacity of the ground needs to be taken into consideration.
- the type of track [16]
- the lifespan of the track bed
- traffic (axle load or typical train, maximum authorised operating speed)
- geometry
- available materials
- temperature in the tunnel.

For the specific case of dedicated-corridor public transport systems with rolling stock on tyres guided by a central rail, see the GT40 report on road pavements in tunnels, published in 2011, for all aspects of design.

The major product families used in France are as follows:
- Track beds with ballast (§ 4.2) [17]
- Track beds without ballast, in cement concrete or asphalt.

3.2 - Influence of tunnel construction type and geometry on design of the track bed

The thickness available for the track bed depends very directly on:
- the construction mode used for the tunnel
  a) Traditional excavation: Track bed resting on natural soil, construction road can be used as a foundation (HSL, Tartaglia/Valence)
  b) TBM excavation: Track bed resting on a concrete slab (Channel Tunnel)
  c) Shafts and covered trenches: Track bed resting on a concrete slab (Rouen Metrobus)
  d) Immersed tunnels: Track bed resting on a concrete slab (RATP line 14)
  e) the tunnel diameter.
  f) compliance with the final dimensions.

This thickness must be taken into account from the project design stage.
3.2.1 - Traditional excavation: track bed resting on natural soil or arch + backfill

For this type of worksite and excavation works, a construction road is built, usually using RCC (Roller Compacted Concrete). Provided stricter specifications are used for the geometric tolerances for this road, it may be well worth taking it into account in the final design. The additional cost of this road will be more than outweighed by the savings made on pavement layers.

The excavation (and finished) diameter is very close to that of the design and does not involve any particular constraints for construction of the track bed.

3.2.2 - TBM excavation: track bed resting on concrete slab

For this type of worksite and excavation works, a construction road is built, usually using RCC (Roller Compacted Concrete). Provided stricter specifications are used for the geometric tolerances for this road, it may be well worth taking it into account in the final design. The additional cost of this road will be more than outweighed by the savings made on pavement layers.
For RATP, tunnel boring (with an average diameter of 8 m) forms part of the civil engineering contract. Overlaying the tunnel base to a height of some 1.80 m takes place using roller compacted cement concrete (RCR) plus a 10 cm layer of cement concrete. The track is then laid on top.

TBM excavation involves constraints in terms of height and thickness for the track bed relating to the machine’s diameter.

### 3.2.3 - Shafts and covered trenches: track bed resting on a concrete slab

No particular constraints on track bed construction.
3.3 - Drainage

Drainage systems are installed in tunnels over 5 km long which are to be used for the transport of hazardous materials [19]. Characteristics of these drainage systems:
- can absorb a flow of at least 100 l/s
- have a capacity of at least 80 m$^3$

Each drain (one per track) empties at least every 50 m into a buried collector. There is a siphon at every connection in order to halt flames before the liquid is directed into the retention tank.

If the system is also used to collect runoff water, in any event the tank must still be able to store 80 m$^3$ of hazardous materials.

**Note:** Experience in the installation of tracks on mixed track beds in urban areas indicates that the structural design required for rail traffic is strong enough to cater for road traffic at crossovers with no alterations. However, special care must be taken with the surfacing at interfaces, as these are the most liable to be damaged.

4 - Track beds and track in rail tunnels

**4.1 - Background**

At present, 60% of RATP track beds are ballasted. However, new and upgraded lines (line 14 and the line 13, 12 and 4 extensions), which may be viewed as light, low-speed transport lines, use cement concrete.

On the other hand, almost all the national rail network, consisting essentially of heavy, high-speed transport lines, uses ballasted track.

**4.2 - Ballasted Track**

Traditionally, a railway track consists of a track base (rails and supported sleepers) resting on the track bed via a layer of ballast, consisting of 25/40 mm granular material with the following main purposes [23]:
- transmission and distribution of the loads exerted by the rolling stock on the track bed
- deadening vibrations due to its rheological properties (vibration energy is
dissipated through attrition of the ballast)

• anchoring sleepers both lengthwise and crosswise
• quick drainage of water from above.

It also allows track geometry to be rectified by mechanical packing and raising: this calls for quality and minimal thickness.

It also restricts cross-wise and lengthwise displacement, which is particularly important for long sections of rail welded together.

Beneath the ballast lies a capping layer and an underlayer in materials selected to provide stability under traffic and durability, particularly resistance to water and frost. In addition, in new tunnels, in almost all cases there is a concrete foundation beneath the ballast; in older tunnels, there are foundations in some structures or certain sections thereof for reasons of geology and/or difficulties encountered during excavation. Consequently, ballasted track often rests directly on natural ground (soil or rock; a geotextile may be inserted beneath the underlayer and the track bed). If the tunnel is located near housing, an anti-vibration mat may be laid between the foundation and the ballast.

This type of track is known as **ballasted track**.

In Chapter 11 of its procedure [21], SNCF specifies that in underground structures (tunnels and covered trenches with no openings) standard track laying should use Long Welded Rails (Longs Rail Soudés, LRS), irrespective of the route in question. [21] This is also stated in chapter 7.1 of the document [22].

Holding sleepers in place with ballast is very competitive in terms of construction and the maintenance techniques are perfectly understood. However, this technique does require:

• considerable overall track height
• monitoring of track geometry
• maintenance in line with the actual traffic density

4.3 - Ballastless track (cement concrete or asphalt)

The alternative to the ballasted track is the ballastless track for which the ballast is replaced by foundation layers made of cement concrete or asphalt. Currently the asphalt solution is not applied on the French National Rail network. This type of track must provide the same functions as traditional tracks by superimposing several layers of decreasing stiffness.

**Figure 6 - Schematic cross-section of ballasted track [23].**

**Photo 3 - Ballasted track (RATP).**

**Figure 7 - Schematic cross-section of ballastless track.**

Note: Details of these structures can be found in the appendix.
The development of ballastless track can be explained firstly by the search for longer track bed lifespans, thereby decreasing the frequency of maintenance.

At the present time, there are two main practices in the design of ballastless rail track beds:
- Reinforced concrete track structures based on Eurocode 2. For this case, care should be taken with the possible presence of stray voltage. In damp conditions this can lead to a battery phenomenon, which may damage the reinforced concrete rebar.

- Plain concrete track structures on concrete or asphalt foundations: mechanical stress is assessed using three-dimensional finite-element models (FE-3D) that take into account:
  - the rails
  - slab geometry
  - bonded and sliding interfaces
  - and calculation of the permissible loads using the rational approach applied to traditional roads and motorways

These permissible values are then adapted using specific adjustment factors to take into account:
1. total traffic throughput
2. effects of discontinuities + thermal gradients that differ from the traditional road/motorway environment.

In France, this approach has now been adopted by almost all design firms, project managers, contractors, rolling stock manufacturers, inspection bodies, etc.

As far as we know, there is no guide or “official” recommendation in favour of this approach, although it has been very widely adopted in France and on export markets.

The ballastless techniques that are currently available are summarised in the following table:

<table>
<thead>
<tr>
<th>Type</th>
<th>Direct support</th>
<th>Foundation layer</th>
<th>Construction type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-piece concrete slab</td>
<td>Concrete</td>
<td>Rails fixed on sleepers on an elastic level, embedded in concrete slab laid on site</td>
<td>RHEDA 2000 * Stedef RHEDALBERLIN Sonneville RHEDA Classic Züblin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rails fixed on sleepers on two elastic level embedded in concrete poured on site</td>
<td>Shinkansen slab track (J-slab) Edilon ATD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rails fixed on concrete slab poured on site</td>
<td>Embedded rails Bögl Embedded Rail Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rails fixed on prefabricated concrete slab</td>
<td>IPA Balfour Beatty</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OB-Porr</td>
</tr>
</tbody>
</table>

All reproduction, translation and adaptation of articles (partly or totally) are subject to copyright.
4.3.1 - Concrete sleepers embedded in the concrete slab

This technique involves embedding the sleeper in anchoring concrete (the French solution is known as “VSB”). Installation is easy in principle but requires considerable expertise since the track geometry must be extremely accurate, especially for high operating speeds.

It requires little maintenance. Sleepers are generally fitted with inserts that allow the track height to be adjusted (specification for concrete tramway tracks) prior to the concrete being poured. However, in tunnels, STEDEF sleepers are normally used, fitted with boots or rigid cases, in which case inserts cannot be used and adjustment is carried out using gauges fixed to the rail. This concept gives the track two elastic layers: rail deflection is thus exactly the same as with ballast.

While this type of track can be used in rail tunnels, access for maintenance resources, particularly road vehicles, is limited. As for ballasted track, the upper part of the sleepers and the rails are above the slab surface, which impedes road vehicle access for maintenance operations.

Note:
1 – For booted bi-block STEDEF® sleepers, the spacers are also above the level of the concrete, preventing both vehicular and pedestrian access (since there is a risk of tripping on the spacer and falling). Consequently, this type of track is not good in terms of movement of personnel or evacuation of users in the event of an incident or accident.

2 – Rhéda® solutions or similar, with steel ties embedded in the concrete, do not have this drawback.

3 – RATP has noted maintenance difficulties with sleepers embedded in concrete (photo 5) and favours the installation of encased sleepers.

4.3.2 - Tracks on “railseats”

Track rests on independent supports known as “railseats” that are bonded or anchored onto a concrete slab. In all cases, a topographic team carries out a geometric inspection of railseat positioning in order to determine the adjustments required so that the rail can be installed within the required tolerances.

Alstom has developed an automated installation method known as Appitrack® for “Automatic Plate and Pin Inserter for Trackwork”. A slip-form machine (cf. § 4.5.3.2) guided by a total topographic unit lays a support slab for the concrete track in plain extruded concrete. A specific machine then inserts the railseats and fixings by vibration.

This procedure brings down track laying time, with an average rate of progress of some 80 m/day/track. Its limits relate to singular points such as crossovers and city centre areas where successive phasing is required.
4.3.3 - Embedded Rail System (ERS®)

This is a continuous fixing system developed by Edilon. Rails are held in a notch that can be moulded in a concrete slab. The principal characteristic of the ERS system is the complete absence of traditional fixing components such as plates, bolts, railseats, springs and so on.

After adjustment and positioning, the rail is embedded and bonded using a two-component resin, with mechanical characteristics appropriate to the project (noise/vibration damping). This resin must not change over time and withstand radiation and chemical, thermal and mechanical attack. It must also be easy to use in standard worksite conditions:

• suitable packaging of components
• consistency and polymerisation time appropriate for the work to be done
• perfect adhesion to all surfaces
• unaffected by damp.

Note: The elastic performance of the resin varies depending on the load exerted on the rail.

Figure 10 - Embedded Rail System (ERS) – cross-sectional view.

Photos 7 - Embedded Rail System (ERS).
Left: installation
Below: Channel Tunnel

4.3.4 - Other possible techniques: prefabricated slabs

This technology is used in Germany, Japan and China (Shanghai-Beijing line). It is very little used in France and, to the best of our knowledge, not yet used in any tunnel.

Factory production of baseplates and prefabricated slabs for rail tracks offers an alternative to slabs poured on site. The first applications were in the Netherlands over 30 years ago.

Factory prefabrication of large-scale elements (3-8 m long, 2.40 m wide and 40 cm thick) allows for manufacturing tolerances of approximately one millimetre.

Components are generally made of reinforced concrete with a compressive strength rating of C55/65, pursuant to standard NF EN 206-1. The rebar distributes stress and loads. The slabs built can accommodate all systems, both ERS and traditional: rail fixings are pre-installed.

Transport of slabs and installation must be carried out using equipment appropriate for specific tunnel considerations such as clearance, accessibility and so on. To be positioned, each slab (weighing some 15 tonnes) is first numbered and identified on a layout plan in line with the track geometry.

Components are installed on a cement-based load-bearing layer some 20-30 cm thick. The slabs are adjusted on site using positioning elements. They are then joined together using sealing mortar.

4.4 - Transition zones

One of the more delicate points that requires particular attention during construction of a cement concrete track bed in tunnels (as well as level crossings, viaducts and stations) is the risk of creating a “hard point” compared to the previous and subsequent ballasted track.

Some procedures (ERS® Embedded Rail System) provide the benefits of a concrete foundation as well as all the flexibility of ballast. However, too sudden a change in the flexibility of the foundation will always lead to additional stress on the track. To avoid these effects, transition zones must be built. These zones must be stable and provide a gradual increase in flexibility towards the ballasted track.
The issue of transition zones has not yet been fully resolved. Research is underway on this topic; some types of slab-mounted track are more flexible than ballasted track.

A number of commonly-used methods are presented below.

On ballast: Ballast bonded with resin. On the French National Rail Network (RFN), ballast is bonded to avoid scattering due to operating speed (rather than to add rigidity to this shock-absorbing layer).

On subgrade: gradual compacting (“ramping”) with successive installation of layers of treated base material. Stabilisation with geotextile.

On rigid track: resilient strips. Care must be taken re: deflection.

Alternative solution:
Rail duplication: this involves installing 2 rails between the track rails (stiffeners). These are laid in the transition zone across the track bed change. The advantage of this system is that rail deflection is better distributed.

Additional difficulty: Packing against the rigid track slab is virtually impossible (unless the ballast is over 15 cm thick). A transition slab with adjustable fixings may be installed.

4.5 - Particularities of installation of track beds in rail tunnels

There are relatively few particularities relating to rail tunnels.

- Ballast generally creates dust when unloaded, so spraying the ballast prior to unloading is recommended.
- The need for fire services to have access to the tunnel as quickly as possible means that technical solutions enabling them to enter using their emergency vehicles and drive on the track should be preferred (fig. 13).

In all cases, installation calls for the following:

- very good ventilation. Consequently, this additional installation must be designed to allow for work to be carried out in acceptable health conditions, bearing
in mind the fumes from transport and installation plant (for concrete and asphalt) and the fumes given off during application of asphalt. The significant condensation that occurs at that time, often linked to a major thermal gradient, should also be alleviated. For ventilation, reference should be made to AFTES recommendations [4].

- Appropriate lighting should be installed in order to ensure the safest possible working conditions.

4.5.1 - Construction of ballasted track

Two scenarios must be envisaged: twin-track and single-track tunnels.

In twin-track tunnels, tracks are laid one after the other. This enables the contractor to have one track open for supply.

To lay the first track, plant travels on the tunnel foundation, or on an initial concrete layer consisting of concrete infill to raise the surface to at least some extent.

A first layer of ballast is installed, carried using a tyre-mounted loader or by side-unloading tipper trucks. This layer is not compacted. The rails and sleepers are then supplied and the track is laid on this initial layer. Initial heightening is then carried out to reinforce the track. Traffic can then use it at reduced speed.

To install the second track, rolling stock is used to supply the necessary materials from the first; installation phasing is much as before.

Lastly, final heightening and stabilisation of the tracks is carried out.

In a single-track tunnel, there is no supply route. The first layer of ballast must be installed from a loader; rails and sleepers must then be installed using a caterpillar excavator travelling along the ballast, in reverse. The first heightening takes place manually, with ballast installed using ballast forks. Rolling stock can then work in the conventional manner.

As explained previously, ballast should be sprayed prior to unloading.

Traffic can pass through these tunnels using rail/road plant (“railing” zones must be provided at the tunnel ends) or by specific rescue service rolling stock.

In the event of an accident, only the pedestrian walkways along the tunnel sides can be used.

4.5.2 - Track built on cement concrete

4.5.2.1 - General principles

The composition and manufacturing procedures for cement concrete used in tunnels are exactly the same as for outdoor concrete except if “concrete trains” are used, in which case the concrete is manufactured on site in the tunnel.

a) Supply

Concrete may be supplied by mixer trucks if they can access the worksite, or by pumping using access shafts built for this purpose (photos 9).

---

1 - Access zone where tyre-mounted plant can access the rail track.
b) Installation

Installation methods are adapted to the tunnel configuration:

- twin-track single tube or twin tube
- bored using a TBM (circular profile) or excavated using the conventional method
- short or long

For short tunnels and twin-track single tube tunnels, traditional means may be used to lay the first track from the outside or the adjacent track. For all other cases, specific equipment has been developed: gantries travelling either side of the track on ledges or a temporary track.

For urban tunnels such as those of RATP, Metro and RER stations are spaced approximately 600 m and 1,500 m apart respectively. The maximum distance for supplying a worksite from a station is thus 300-750 m. This calls for specific procedures and systems during concrete formulation (setting retardant) and delivery (reworked concreting, manufacture of "premix").

4.5.2.2 - Installation

Installation of cement concrete pavements calls for the use of specific machines that are altered and adapted by manufacturers and contractors depending on worksite conditions: “one solution for each site-specific problem”.

The considerations for single-track tunnel installation are the same as for the installation of ballasted track installation discussed above.

a) Types of plant

Two types of plant are used to install concrete, depending on the size of the worksite and the configuration of works: slip-form machines and vibrating tamps or roller finishers.

There are a large number of slip-form machines, with widths between 2 and 15 lm, for which standard modifications are possible as required by construction conditions. The use of vibrating tamps or roller finishers is generally confined to smaller or more complex structures.

b) Guiding slip-form finishers

Two techniques are used for slip-form finisher guiding: guiding by means of height/direction sensors (which is the commonest) and the more complex and accurate 3D system.
**d) Laying concrete at the tunnel walls**
The so-called "zero clearance" principle involves laying the concrete using 3 trackers flush with the tunnel wall (fig. 14).

**e) Using concrete in tunnels excavated with a TBM**
In this case, the required adjustment involves introducing an angle beneath the trackers (fig. 15) in order to stabilise the footplates against the tunnel walls. This technique was developed to build the foundation for the Channel Tunnel.

**g) Supply to machinery**
To ensure the best possible productivity, tipper trucks are used for supply. 8x4 trucks or semi-articulated vehicles may be used depending on worksite considerations. Generally speaking, 8x4 trucks are preferred in tunnels for reasons of height clearance for the tipper. Specific supply from a feeder unit is used if keeping traffic congestion in the tunnel to a minimum is an issue.

Note: For RATP tunnels, supply must reach worksite plant located 15 metres below ground.

**4.5.3 - Track laying**
Principal types of concrete laying are as follows:
- Laying on sleepers
- Laying on railseats (anchored and/or bonded)
- Embedded rails (pre-asphalt or anchoring resin).

**4.5.3.1 - Laying concrete track bed**
Generally, an initial layer of infill concrete is laid to achieve a flat surface on which to travel and to reduce the thickness of the track concrete.

The start of works is as usual for the laying of concrete track bed. Rails are supplied and stored in such a way as to enable plant movement. Sleepers are then distributed according to set spacing (the number of sleepers per km).

Using a hydraulic excavator fitted with a lifting beam or substitute gantry, the rails are installed and fixed to the sleepers. Once the rails are welded, the track is adjusted to its proper position, suspended on gauges (photo 17) so that concreting can take place.
In this instance, a specific method is used for tunnels. Depending on the length of the tunnel, one of two methods is generally used:

- either a concrete pump is installed as close as possible to the tunnel entrance (in an area that is accessible for mixer trucks) and connected to interlocking tubes through which the concrete is pumped directly to the tunnel, for distances of up to 800/1000 m (special concrete composition is used)

- or for longer tunnels, specific equipment is used to supply the concrete as close as possible to the face whilst mixing it, then a secondary pump is used to direct the concrete to the working area.

At this point the rails are above the top of the concrete, protruding by some twenty centimetres. In order to provide a flat surface that allows for use by road vehicles, a concrete or asphalt surface may be laid on this layer of concrete.

4.5.3.2 - Installation on railseats

The same principle as for installation on sleepers applies. Railseats may be installed on a concrete slab or on beams (fig. 18).

4.5.3.3 - Laying embedded rails + concrete surfacing

The infill concrete must be laid in such a way as to leave a space in which the rail is installed and then secured in place prior to the resin being poured. If the tunnel is not too long, mixer trucks can reverse in and supply a slip-form machine, with spaces left directly as the forms are removed. Rails are then installed using the conventional embedded rail laying method.

Once the concrete has finished setting, any kind of road vehicle can travel over the infill concrete.

4.5.3.4 - Guide rails for tyre-mounted dedicated-corridor public transport

The central guide rail for tyre-mounted dedicated-corridor public transport is installed once the concrete or asphalt track bed has been built, with a laterally cut notch that is then milled to the appropriate depth. The rail is then located and sealed in resin (figure 16).

4.5.4 - Asphalt track beds

4.5.4.1 - General principles

The composition of asphalt materials for application in tunnels is similar to that of asphalt used outdoors and in the open country. However, certain adjustments need to be borne in mind for manufacture and use.

4.5.4.2 - Manufacture

To manufacture asphalt materials to be applied as pavement layers (wearing course, base course and base layers), the aggregates need to be heated to a temperature equal to that at which the asphalt can be piped to the asphalting unit. The manufacturing temperature for asphalt [11] generally lies between 150°C and 170°C depending on the nature and hardness of the asphalt (pure bitumen, bitumen modified by polymers or synthetic binder) In this context, asphalt is applied at temperatures in excess of 125°C. Use of warm mix asphalt [17] enables the temperature to be lowered by at least 30°C. Prior to application of asphalt, a tack coat must be spread on the surface in order to encourage the asphalt to bond. This tack layer consists of bitumen emulsion.

4.5.4.3 - Installation

Installation is by means of a finisher, with transport of the asphalt from the manufacturing unit to the finisher by means of trucks which pour the asphalt into the finisher bin feeder. The difficulty of supply relating to the confined space (in terms of both width and height) and the required precautions with regard to existing installations all mean that the worksite takes longer than in the open air; for instance, the tunnel is not always high enough to allow truck tippers to be fully raised. Alternatives should be considered, such as the use of trucks with tippers fitted with thrust jacks to push out the asphalt.
The mechanical characteristics of the asphalt are obtained by means of compacting. In tunnels, the asphalt mix for tunnels is chosen to reconcile ease of handling and resistance to rutting, in order to reduce the intensity of compacting, which causes vibrations.

4.5.5 - Tunnel drainage construction

In most cases, tunnel drainage consists of little more than a central collector or a slotted drain with an integrated kerb. This is designed to avoid any combustion in the event of flammable liquid runoff, with siphon type inspection traps (fig. 20).

There are two modes of construction:
- prefabrication (generally in 3 m sections)
- continuous pouring and extrusion on site.

Care and expertise are required for drainage. The low construction tolerances required by legislation have a direct impact on the longitudinal profile. Tunnel geometry must be taken into account in the choice of construction technique. The continuous poured gutter solution is to be preferred, since it is more accurate and closer to the longitudinal profile and evenness of the pavement. Prefabricated construction necessarily involves broken lines which are more difficult to align, often resulting in a need to reprofile the pavement.

It is highly preferable for drainage to be carried out either by the contractor responsible for the track bed or as a minimum, a contractor working in full coordination with the former.

4.6 - Major maintenance and renovation

Irrespective of the lifetime of the track bed, sooner or later complete renovation work will be required, involving deconstruction. Similarly, in extreme circumstances, such as sagging of the track bed, a change in the longitudinal profile, or when the rail has come to the end of its life, it may need to be replaced. This involves deconstruction. Consequently, deconstruction methods should be taken into account right from the design stage (fig. 21).

The significance and duration of works mean that the disruption discussed in § 2.3 is particularly relevant here. If the tunnel is single-track, the same operational considerations apply as for new builds.

For embedded rail installations, the rail is cut beforehand and then gradually removed (using an excavator and a lifting grip) in 2-3 metre lengths working from the cut. It is then left on battens as works progress.

Embedded rails can be removed and replaced during major maintenance works. However, care must be taken with regard to the clearances required for lifting plant to ensure it has room to operate inside the tunnel.

4.7 - Comparative analysis

As for road tunnels, the Working Group has attempted to present, in summary form, the specific aspects of the techniques available for the construction of rail tunnels. Rather than attempting to be exhaustive, these tables seek to highlight factors which are important in the decision-making process and provide a general overview of the solutions available.
### 4.7.1 - Comparison between ballastless and ballasted track

<table>
<thead>
<tr>
<th></th>
<th>Ballasted track</th>
<th>Ballastless track</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spécificités</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Project</strong></td>
<td>Track bed structure must be taken into account right from the project stage</td>
<td>Track bed structure must be taken into account right from the project stage</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Rheological properties of ballast vary</td>
<td>Rheological properties of cement concrete are uniform</td>
</tr>
<tr>
<td></td>
<td>Limited resistance to sideways displacement</td>
<td>Highly resistant to sideways and lengthwise displacement</td>
</tr>
<tr>
<td></td>
<td>Quiet</td>
<td>Louder but easy to dampen</td>
</tr>
<tr>
<td></td>
<td>Track geometry maintained in line with use</td>
<td>Lower tunnel clearance</td>
</tr>
<tr>
<td></td>
<td>Ballast scatter at high speeds</td>
<td>Concrete/ballasted track transition calling for specific construction must be factored in</td>
</tr>
<tr>
<td></td>
<td>Vibration transfer may be minimised by adding anti-vibration baseplates, either beneath railseats or beneath sleepers (e.g. Stedef).</td>
<td>Vibrations can be damped using anti-vibration baseplates</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>Well-understood, highly productive installation</td>
<td>Quick rate of progress (depends on concrete supply and laying techniques)</td>
</tr>
<tr>
<td></td>
<td>Highly mechanised</td>
<td>Overall control of speed and costs</td>
</tr>
<tr>
<td></td>
<td>Relatively insensitive to manufacturing flaws</td>
<td>Current French experience on high-speed lines</td>
</tr>
<tr>
<td></td>
<td>Controlled cost</td>
<td>Many generally favourable experiences in other countries</td>
</tr>
<tr>
<td></td>
<td>Uses large quantities of high-quality aggregates</td>
<td>No offsetting of any settlement of the track bed or supporting soil (rarely applies in tunnels)</td>
</tr>
<tr>
<td></td>
<td>Offsetting of any settlement of the track bed or supporting soil (rarely applies in tunnels)</td>
<td>Vibrations can be damped using anti-vibration baseplates</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>Perfectly understood maintenance techniques</td>
<td>Relatively little experience in France in rail maintenance</td>
</tr>
<tr>
<td></td>
<td>Regular replacement of ballast and adaptation of articles (partly or totally)</td>
<td>Major works to renew the structure if necessary.</td>
</tr>
<tr>
<td></td>
<td>Track geometry can be adjusted in the long term</td>
<td>Long overall durability of the track bed without renovation or levelling works</td>
</tr>
<tr>
<td></td>
<td>Monitoring and inspection is mandatory</td>
<td></td>
</tr>
</tbody>
</table>

Tableau 3 - Technical comparison of ballasted/ballastless track.

### 4.7.2 - Technical comparison of ballastless/ballasted track in urban tunnels

RATP has made the following comments on the types of installation and fields of application.

<table>
<thead>
<tr>
<th></th>
<th>Ballasted Track</th>
<th>Ballastless track</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particularités</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>Bi-block concrete sleepers on ballasted track bed</td>
<td>Bi-block concrete sleepers on concrete track bed</td>
</tr>
<tr>
<td></td>
<td>Quick, easy and cheap to build</td>
<td>Complex, long and expensive to build</td>
</tr>
<tr>
<td></td>
<td>Quick, easy and cheap to alter the route or profile or add track apparatus</td>
<td>Highly complex, long and expensive to alter (e.g. adding track apparatus)</td>
</tr>
<tr>
<td><strong>Operation and maintenance</strong></td>
<td>Poor anti-vibration performance</td>
<td>Good anti-vibration performance</td>
</tr>
<tr>
<td></td>
<td>Risk of deteriorating track geometry (ballast movement)</td>
<td>Low maintenance</td>
</tr>
<tr>
<td></td>
<td>Requires regular inspection and maintenance (ballast packing)</td>
<td>Easy to clean</td>
</tr>
<tr>
<td></td>
<td>Filter drainage through ballast leads to the latter becoming clogged</td>
<td>Efficient drainage</td>
</tr>
<tr>
<td></td>
<td>Renewal is complex and expensive (sleepers and ballast)</td>
<td>Easy and cheap to renew (sleepers only)</td>
</tr>
</tbody>
</table>
4.7.3 - Economic aspects

It has been estimated that track bed accounts for 10% of the overall cost of the investment including civil engineering works (tunnel), the track bed, the track itself, and so on. The cost of this phase may appear marginal in comparison to the civil engineering costs. However, the related knowhow calls for highly specific skills.

Moreover, RFF and RATP sources suggest that the track accounts for 90% of maintenance and management costs.

Estimated construction costs for ballastless track are usually higher than for conventional track, but maintenance costs for ballastless track are lower. An overall analysis is recommended.

Economic considerations play a major role in any decision to lay ballastless track. This aspect must be examined considering both construction costs (including those relating to reducing clearance) and operating costs (fig. 17).

Further development of this technique has been hindered by its high total cost. Taking overall costs into account sets this claim in a new light, since the direct installation of track is particularly attractive for tunnels and bridges.

The network with the most critical distance in this respect is the Japanese network (cf. Appendix 10.2.2.1) with its various Shinkansen lines.

Construction costs for slab-based track in Germany are 20-40% higher than for conventional track [24]. Document [25] confirms the extent of this additional cost for both the Japanese network (+30-40%) and the US network (+30%).

RATP considers an additional cost of cement concrete track bed of some 30% to be acceptable in view of the lower maintenance costs (to be confirmed with RATP).

Slab-based solutions allow track to be maintained in proper condition for longer than traditional track, since there is no ballast defragmentation. This aspect should be included in maintenance costs: these favour slab-based track by a factor of four to one.

Japanese experience indicates that the surplus investment in slab-based track is offset after between two and six years' worth of operation.

Deutsche Bahn (DB) experience (cf. Appendix 10.2.2.2) in this field leads to similar conclusions.

5 - Fire, Environmental and Health-related considerations

5.1 - General considerations

Fire performance in tunnels will be treated at a later date in the GT 37 recommendation. The issues here are the safety problems affecting the construction of the platform, essentially those concerning emergency exits and access for the emergency services.

In particular, fires in tunnels are never a trivial matter given the confined space in question. Regrettably, they may lead to loss of life, both in road and rail tunnels.

For rail tunnels, a noteworthy case is that of the Vierzy tunnel in Aisne (1972) in which two passenger trains collided following a rock fall. More recently, in 1996 a freight train derailed and caught fire in the Channel Tunnel.

It may be noted that in road tunnels, “high fire risk” vehicles are interspersed with others (HGVs among cars), which is not generally the case with rail traffic.

Smoke extraction systems are mandatory in tunnels longer than 5,000 m and with predominantly goods (freight) traffic.

Fire has the following effects:

a) A loss of visibility due to the tunnel being filled with smoke
b) A gradual increase in toxicity leading to increased breathing difficulties
c) Increase in temperature, possibly rapidly
d) Varying degrees of damage to materials making up infrastructure and installations
This point has already been examined through the works of the GT37R2 that more specifically examine the fire performance of tunnels [2].

This may result in the following:
e) Users having difficulty in becoming aware of the danger
f) Difficulties in evacuating users that have not reached a shelter quickly, due to worsening visibility
g) Difficulties in the fire service reaching the incident.

In the presence of smoke or flames, users may behave differently depending on their physical condition (children, the elderly, persons with reduced mobility, and so on).

As a result, construction measures and installations should be implemented to facilitate evacuation and provide guidance as to how to behave, as well as providing signage for emergency exits. It is also important to facilitate easier, faster access for emergency services.

Consequently, each tunnel element – including the pavement – must be designed with this in mind, and form part of a coherent overall safety system.

5.2 - Rail tunnels

The European Commission Decision of December 20, 2007 [20] sets out requirements for the fire protection of tunnels. This specification applies to all tunnels on the trans-European network, irrespective of their length.

In the event of fire, structural integrity must be preserved for long enough to enable self-rescue and evacuation of passenger and train personnel, as well as the intervention of rescue services, without them being exposed to the risk of structural collapse.

Fire resistance of the finished tunnel surface – whether rock or a concrete lining – must also be assessed. This surface must be able to withstand the heat generated by the fire for a set period of time. The specified “time-temperature” curve (known as the EUREKA curve) is shown in the figure 18 below. It is used solely for the design of concrete structures.

The same document [20] also details the fire safety requirements applicable to construction materials. The specification applies to all tunnels, irrespective of their length, construction materials and the equipment used inside the tunnels, and does not apply to any structures covered by the previous paragraph.

Depending on design requirements, construction materials must have a low degree of flammability or be fireproof. The base structure must be made out of a material that satisfies the requirements of standard EN 13501-1:2002 Category A2. Panels that do not form part of the structure and other equipment must comply with the requirements of standard EN 13501-1:2002 Category B.

5.2.1 - Risks of accident

Accidents in tunnels have the same effects as those in the open air.

• Train derailments: may involve several hundred passengers
• Head-on collisions or collisions of passing trains
• Fire is the most serious risk for rail tunnels and metros [12].

5.2.2 - Intervention of rescue services

The easier it is to use routes and access points
• the easier self-evacuation and rescue of users will be (evacuation of 1000 people, the number of passengers carried by a train or RER train)
• the faster the deployment of extinguishing resources.

The need for fire services to have access to the tunnel as quickly as possible means that technical solutions enabling them to enter using their emergency vehicles and drive on the track should be preferred.

One of the possible alternative solutions is to dispense with ballast and fix the rails directly to a reinforced concrete slab (fig. 22a-b).
The issue of access is of primary importance in tunnels. Indeed, all types of intervention are more complicated in tunnels than in the open air. Tracks without ballast present the dual advantage of reducing the number of these works (lower maintenance level) and simplifies their execution by, in certain configurations allowing the access of vehicles using tires in addition to dedicated rail-road vehicles. This last point is particularly important in the event of rail accidents involving passengers.

This is why ballastless track has been increasingly used in tunnels even though it is relatively little used in the open air in Europe. Indeed, for some years now, ballastless track has been regularly used to build tracks in rail tunnels and metros, including for high-speed lines such as in the Channel Tunnel.

6 - GT 40 Recommendations

Tunnel track beds should not be considered simply as an extension of standard open-air sections. Decision-makers should be encouraged to undertake specific studies. Indeed, a number of factors have greater influence than the track foundation itself:

a) Influence of the tunnel construction type and geometry on design of the track bed
b) Future track bed maintenance
c) Ease of access of emergency services and evacuation of users

Consequently, these factors should be taken into account right from the project phase.

1) The total track bed thickness must be optimised: significant savings are often possible if the track bed is defined at the design stage. The thickness of ballastless track is considerably less than ballasted track. In some cases, this may allow for a smaller excavation diameter (for new works and renovation)

Recommendation 1
"Study the platform at the same time as the rest of the tunnel"

2) Future maintenance of the structure must be taken into account when comparing the cost of different solutions. Maintenance is often more complex in tunnels than for standard sections. Techniques that require relatively little maintenance should thus be preferred in most cases.

Recommendation 2
"Take maintenance into consideration (including any operational losses) when comparing platforms"

3) Prefer technical solutions that allow:
- the fire service to access the inside of the tunnel as quickly as possible, and to be able either to enter directly with their emergency vehicles and drive along the track, or with appropriate rail/road vehicles.
- easy evacuation of users

Recommendation 3
"Take into consideration the access conditions for the emergency services and the evacuation of users"
### 7 - Examples and construction of tunnels and rail tracks

- TGV Marseille
- Perthus
- Antwerp
- Experimental track for HSL Est
- Inntal tunnel (Autriche)

---

**Marseille Tunnel**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel construction date</td>
<td>1997-1999</td>
</tr>
<tr>
<td>Location</td>
<td>Outskirts of Marseille, France</td>
</tr>
<tr>
<td>Client</td>
<td>RFF</td>
</tr>
<tr>
<td>Type de construction</td>
<td>Rail tunnel</td>
</tr>
<tr>
<td>Operation</td>
<td>Paris-Marseille HSL</td>
</tr>
<tr>
<td>Type of excavation</td>
<td>Explosives</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>1</td>
</tr>
<tr>
<td>Traffic</td>
<td>Rail</td>
</tr>
<tr>
<td>Tunnel diameter</td>
<td>Usable cross-section = 63 m²</td>
</tr>
<tr>
<td>Tunnel length</td>
<td>Total length = 7834 m</td>
</tr>
<tr>
<td>Track subbase</td>
<td>934 m in covered trench</td>
</tr>
<tr>
<td>Drainage</td>
<td>Concrete foundation</td>
</tr>
<tr>
<td>Track bed construction date</td>
<td>Drain in concrete foundation</td>
</tr>
<tr>
<td>Track type</td>
<td>Concrete track with bi-block sleepers in rigid cases</td>
</tr>
<tr>
<td>Track structure installation</td>
<td>Concreting on site</td>
</tr>
<tr>
<td>Particularity</td>
<td>Welded wire mesh in areas with camber &gt; 90 mm</td>
</tr>
<tr>
<td>Track adjustment</td>
<td>Theodolite based on tunnel traverse line</td>
</tr>
<tr>
<td>Supply</td>
<td>Concreting train</td>
</tr>
<tr>
<td>Site platforms</td>
<td>Yes</td>
</tr>
</tbody>
</table>
GT40R2A1

Perthus tunnel

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel construction date</td>
<td>2005-2007</td>
</tr>
<tr>
<td>Location</td>
<td>Pyrénées Orientales, France</td>
</tr>
<tr>
<td>Client</td>
<td>TP FERRO</td>
</tr>
<tr>
<td>Type de construction</td>
<td>Rail tunnel</td>
</tr>
<tr>
<td>Operation</td>
<td>Link between Perpignan-Figueras (Spain)</td>
</tr>
<tr>
<td>Type of excavation</td>
<td>TBM</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>2</td>
</tr>
<tr>
<td>Traffic</td>
<td>Rail</td>
</tr>
<tr>
<td>Tunnel diameter</td>
<td>9.20 m</td>
</tr>
<tr>
<td>Tunnel length</td>
<td>2 x 8,400 m</td>
</tr>
<tr>
<td>Drainage</td>
<td>Slotted drain</td>
</tr>
<tr>
<td>Track bed construction date</td>
<td>2007 - 2009</td>
</tr>
<tr>
<td>Track type</td>
<td>Cement concrete</td>
</tr>
<tr>
<td>Foundation beneath track</td>
<td>60 cm of concrete</td>
</tr>
<tr>
<td>Track bed construction Foundation</td>
<td>Full-width slip-form</td>
</tr>
</tbody>
</table>

Particularities

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guiding</td>
<td>All-in unit</td>
</tr>
<tr>
<td>Transport</td>
<td>Crossover bridges</td>
</tr>
<tr>
<td>Supply</td>
<td>yes</td>
</tr>
<tr>
<td>Side platforms</td>
<td></td>
</tr>
</tbody>
</table>

All reproduction, translation and adaptation of articles (partly or totally) are subject to copyright.
Antwerp tunnel - Liefkenshoek link

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel construction date</td>
<td>Scheduled for 2014</td>
</tr>
<tr>
<td>Location</td>
<td>Antwerp (Belgium)</td>
</tr>
<tr>
<td>Client</td>
<td>Concession contract with Locarail</td>
</tr>
<tr>
<td>Type of construction</td>
<td>Rail tunnel</td>
</tr>
<tr>
<td>Operation</td>
<td>Liefkenshoek link</td>
</tr>
<tr>
<td>Type of excavation</td>
<td>TBM</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>2 (northern and southern tubes)</td>
</tr>
<tr>
<td>TBM diameter</td>
<td>8.40 m</td>
</tr>
<tr>
<td>Tunnel diameter</td>
<td>7.30 m (finished internal diameter)</td>
</tr>
<tr>
<td>Tunnel length</td>
<td>5,972 m (southern tunnel)</td>
</tr>
<tr>
<td></td>
<td>5,979 m (northern tunnel)</td>
</tr>
<tr>
<td>Track bed construction date</td>
<td>2011 - 2012</td>
</tr>
<tr>
<td>Type of track bed</td>
<td>Concrete</td>
</tr>
<tr>
<td>Type of sleeper</td>
<td></td>
</tr>
<tr>
<td>Installation of track bed</td>
<td></td>
</tr>
<tr>
<td>Particularity</td>
<td></td>
</tr>
<tr>
<td>Track adjustment</td>
<td>Concrete supplied by pumping plus small wagons</td>
</tr>
<tr>
<td>Supply</td>
<td></td>
</tr>
</tbody>
</table>
### Experimental East European HSL track

<table>
<thead>
<tr>
<th>Localisation</th>
<th>Chauconin (Seine et Marne), France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>RFF</td>
</tr>
<tr>
<td>Type of construction</td>
<td>Dowelled cement concrete slabs</td>
</tr>
<tr>
<td>Operation</td>
<td>East HSL</td>
</tr>
<tr>
<td>Traffic</td>
<td>Rail</td>
</tr>
<tr>
<td>Length</td>
<td>2 x 1,800 m</td>
</tr>
<tr>
<td>Width</td>
<td>3.68 m</td>
</tr>
<tr>
<td>Track bed construction date</td>
<td>January-September 2006</td>
</tr>
<tr>
<td>Track type</td>
<td>15 cm 0/20 reinforced cement concrete slabs (150 kg/m³)</td>
</tr>
<tr>
<td>Lower layer</td>
<td>28-37cm Cement Gravel</td>
</tr>
<tr>
<td>First track bed construction</td>
<td>in half-widths</td>
</tr>
<tr>
<td>Cement concrete layer</td>
<td>Guided slip-form machine</td>
</tr>
<tr>
<td>Base layer</td>
<td>Leveller</td>
</tr>
<tr>
<td>Particularities</td>
<td>5-10 mm cut in slabs every 5 metres</td>
</tr>
<tr>
<td>Guiding</td>
<td>Temporary rails caused obstruction</td>
</tr>
<tr>
<td>Supply</td>
<td>1 curved section (with 10% camber)</td>
</tr>
<tr>
<td></td>
<td>Height tolerance of 5 mm</td>
</tr>
<tr>
<td></td>
<td>All-in unit</td>
</tr>
<tr>
<td></td>
<td>Train adjacent to machine</td>
</tr>
</tbody>
</table>
Unterinntalbahn tunnel (Austria)

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel construction date</td>
<td>December 2012</td>
</tr>
<tr>
<td>Location</td>
<td>Austria</td>
</tr>
<tr>
<td>Client</td>
<td>Railway</td>
</tr>
<tr>
<td>Type of construction</td>
<td>TBM</td>
</tr>
<tr>
<td>Operation</td>
<td></td>
</tr>
<tr>
<td>Number of tubes</td>
<td>2</td>
</tr>
<tr>
<td>Tunnel length</td>
<td>9.5 km</td>
</tr>
<tr>
<td>Tunnel diameter</td>
<td>13 m</td>
</tr>
<tr>
<td>Lining</td>
<td>45,000 segments</td>
</tr>
<tr>
<td>Start of works</td>
<td>2003</td>
</tr>
<tr>
<td>Type of track bed</td>
<td>RC slabs</td>
</tr>
<tr>
<td>Track type</td>
<td>Ballastless with direct fixing on railseats</td>
</tr>
<tr>
<td>Particularity</td>
<td>Free slabs punctual supports</td>
</tr>
<tr>
<td>Anti-vibration system</td>
<td></td>
</tr>
<tr>
<td>Fire</td>
<td>4 fire trucks</td>
</tr>
<tr>
<td>Max speed</td>
<td>220 km/h</td>
</tr>
</tbody>
</table>

All reproduction, translation and adaptation of articles (partly or totally) are subject to copyright.
8.1 - Main reference documents

Ref. 1 - “Dossier pilote des tunnels génie civil – section 8 – chaussées”, (Pilot dossier for civil engineering works for tunnels, section 8: pavements) CETU, MEDAD, December 1997

Ref. 2 - “Tunnels routiers: résistance au feu.” (Fire resistance of road tunnels) AFTES recommendation no. 205 – January/February 2008

Ref. 11 - “Les enrobés bitumineux” (Asphalt concrete), volumes 1 & 2, RGRA/USIRF, 2001 & 2003

Ref. 3 - CETU Appendix 2 “Instruction technique relative aux dispositions de sécurité dans les nouveaux tunnels routiers (conception et exploitation)” (Technical memo on safety measures in new road tunnels: design and operation) to circular 2000-63 of August 25, 2000 on safety in national road network tunnels

Ref. 4 - “Ventilation des ouvrages souterrains en cours de construction” (Ventilation of underground structures during construction) – GT 27 R1F1 no. 176 – 2003.

Ref. 5 - Chaussées en béton: guide technique (Technical guide to concrete roads), Sétra-Lcpc – March 97 – revised edition, 2000

Ref. 6 - “Comportement au feu des tunnels routiers” (Fire behaviour of road tunnels), CETU Tunnels Study Unit Guide methodological guide – March 2005

Ref. 7 - “Comportement au feu des enrobés bitumineux” (Fire behaviour of asphalt concrete) (CSTB, June 2006)

Ref. 8 - “Accidents ferroviaires en milieu ouvert et fermé” (Rail accidents in enclosed and open spaces) – Le Sapeur pompier magazine, Sept. 2004.


Ref. 14 - Presentation of the design and construction of Phase 2, Section H, Lot 47 (Execution and inspection of cement concrete roadways) [CETU Tunnels Study Unit Guide methodological guide – March 2005]


Ref. 22 - “Armentage des voieries principales – Matériel de voie à mettre en œuvre” (Reinforcement of principal track: track equipment to be used), SNCF, Application Document IN 3012 version 2, 2008.


Appendices

Ref. 9 - “Asistencia técnica para el diseño e implantación de la vía sin balastro en RENFE” TIFSA, September 1998


8.2 - Principal standards for cement concrete roadways


NF EN 13877-1 (January 2005) Concrete pavements, part 1: materials

NF EN 13877-2 (April 2005) Concrete roadways, part 2: functional requirements

NF EN 13877-3 (April 2005) Concrete roadways, part 3: specifications for dowels to be used in concrete roadways

NF EN 13863-1 (May 2004) Concrete pavements, part 1: non-destructive test method to determine the thickness of a concrete slab

NF EN 13863-2 (June 2004) Concrete pavements, part 2: test methods to determine adherence between two layers

NF EN 13863-3 (May 2005) Concrete pavements, part 3: test methods to determine thickness of a concrete roadway using core samples

NF EN 13863-4 (June 2005) Concrete pavements – Part 4: test methods for the determination of wear resistance of concrete roadways to studied tyres.

8.3 - Main standards relating to asphalt pavements


8.4 - Photo credits

Agilis, AFTES, CETU, Cetex Lyon, Colas Rail, Comatelec, Eiffage Travaux Publics, Egis, Eurovia, FNSPF, Métalliance, NGE, SNCF, SNBPE, SPECBEA, Wirtgen, Usirf, Xelis.

9 - Glossary

AFSSET - French Agency for Environmental and Occupational Health and Safety (Agence Française de Sécurité Sanitaire de l'Environnement et du Travail)
AFTES - French Association for Tunnels and Underground Spaces (Association Française des Tunnels et de l'Espace Souterrain)
LCA - Life Cycle Analysis
CRC - Continuous Reinforced Concrete
AC - Asphalt concrete
CC - Cement Concrete with undowelled slabs
CCI - Class I Cement Concrete
HDAC - High-modulus DAC
DAC - Dense asphalt concrete
VTAC - Very Thin Asphalt Concrete
TBCO - Thin Bonded Cement Overlay
CETU - Tunnels Study Centre

CE - International Lighting Commission, Commission Internationale de l’Eclairage
HMA - Class I High-Modulus Asphalt (HMA)
ERS - Embedded Rail System
FEHRL - Forum of European National Highway Research Laboratories
RBA - Road Base Asphalt
RBAi - Class I Road Base Asphalt
UG - Untreated Gravel
TWWT - Temporary Wrong Way Traffic (Itinéraire Provisoire à Contre-Sens, IPCS)
LRS - Long Rail Soudé (Long Welded Rail)
LCPC - Central Laboratory of Ponts et Chaussées (Laboratoire Central des Ponts et Chaussées)
RATP - Paris Transport Authority (Régie Autonome des Transports Parisiens)
RFF - French Rail Network (Réseau Ferré de France)
RFN - French National Rail Network (Réseau Ferré National)
SETRA - French Transport, Road and Development Study Office (Service d’Études sur les Transports, les Routes et leurs Aménagements)
SETVF - French Rail Track Contractors’ Union (Syndicat des Entrepreneurs de Voies Ferroviaires de France)
SMA - Stone Mastic Asphalt
SNCF - French National Railways (Société Nationale des Chemins de Fer Français)
SNBPE - French Ready-Mixed Concrete Association (Syndicat Nationale du Béton Prêt à l’Emploi)
SPECBEA - French Concrete Pavement and Related Equipment Contractors’ Association (Syndicat Professionnel des Entrepreneurs de Chaussées en Béton et d’Equipements Annexes)
TCSP - Transports en Commun en Site Propre (Dedicated-corridor public transport)
USIRF - French Road Industry Associations Union (Union des Syndicats de l’Industrie Routière de France)

10 - Appendices

10.1 - Situation in France and internationally

10.1.1 - Synthesis of the Spanish experience

This is a French translation. The Spanish text (Ref 9) can be consulted on the AFTES site.

10.1.1.1 - Construction of test zones:

Aim: To compare different systems for ballastless track laying along the “Mediterranean Corridor” route.

The systems tested:
Each system over a length of approximately 400 m

10.1.1.2 - Comparison between ballasted track / ballastless track solutions

Generally speaking, the comparison is difficult as there are many criteria.
Ballastless tracks: lower construction tolerances.
Problems of transitions with hard points (bridges or tunnels) due to the different rigidity of the support.
10.1.2 - Synthesis of the German experience

10.1.2.1 - Various techniques:

- **Top/down**: starting from the finished track (rails and ties/blocks are hung from a gantry) and lowered towards an approximately adjusted subgrade. The altimetric difference is picked up using very liquid concrete around the ties.

- **Bottom/up**: starting from the bottom with successive layers of foundation that become increasingly precise, with the final adjustment of the rails being carried out using standard fixings with enough play to pick up tolerances.

10.1.2.2 - A few experiments with the systems used:

- **Getrack**: The ties are surrounded by a layer of hot mix asphalt. However, the use of asphalt as a final layer requires a highly skilled laying contractor (tolerances).
  - Good value for money and possibility of using smoke emission ties during installation, non-accessible for vehicles with tires, visible ties, use of “Y” ties is not possible.
  - Like the inside of tunnels, temperature differences are not applicable: no bitumen creep – but pay attention to zones where there is transition to the open air.

- **Rheda Berlin**: The concrete is directly cast around the ties – obligatory cracking between the prefabricated and in situ components – especially in the case of prestressed ties: concrete creeping with prestressing (32 t), the in-situ concrete does not move. Filling and compacting under the ties is always risky, the concrete must be very liquid – only an average quality can be obtained.
  - Disadvantages: sensitive to impacts during transport and unloading, height of construction, no possibility of using vehicles with tires, vibrations and noise.

10.1.1.3 - Comparison between tracks on concrete / tracks on asphalt

- **Tracks on asphalt**:
  - **Advantages**
    - No joints
    - Possibility of levelling to ± 2 mm
    - Traffic flow possible shortly after laying
    - Reduced construction time for the platform
    - Recyclable
    - Low noise emission
    - Standard road-building machinery
    - No interruption to site works due to weather conditions
  - **Disadvantages**
    - Low track laying speed
    - Risk of plastic behaviour at high temperatures or under the effect of high traffic flows
    - High cost

- **Tracks on concrete**:
  - **Advantages**
    - Better resistance to forces caused by train movements
    - Better load distribution on the platform
    - In tunnels, does not generate harmful smoke emissions in case of fire
    - Reduced thickness of structure
    - Greater stability to vertical movements
  - **Disadvantages**
    - Need for a shock absorption system
    - Time required for traffic to resume
    - Repairs are more difficult
    - Noise level is higher (except Edilon)

10.1.1.4 - Choice of technique in function of the type of structure

**NOTE**: In addition to the six systems described above, two other systems whose use is limited to speed zones of less than 160 km/h are proposed. These are systems using prefabricated blocks sunk into a concrete foundation: the TRANOSA and VIESA systems.

- Stations and sections at less than 160 km/h: EDILON
  - TRANOSA
  - VIESA

- **Standard section**: EDILON
  - RHEDA DYVIDAG
  - RHEDA 2000
  - STEDEF
  - GETRAC
  - ATD

- **Bridges**: EDILON

- **Tunnels**: RHEDA DYVIDAG
  - RHEDA 2000
  - STEDEF

- **Suburban lines**: EDILON
  - TRANOSA
  - VIESA

**Points of comparison studied**:

- Site management: favourable for tracks on ballast (construction period)
- Operability: favourable for ballastless tracks (less maintenance)
- Noise and vibrations: more favourable for ballastless tracks
- Works experience: generally favourable for ballasted tracks, with the exception of tunnels where there is good experience without ballast
- Cost: Ballastless tracks are more expensive over standard sections, but less expensive for tunnels (less height) and bridges

**10.1.2 - Synthesis of the German experience**

**10.1.2.1 - Various techniques**:

- **Top/down**: starting from the finished track (rails and ties/blocks are hung from a gantry) and lowered towards an approximately adjusted subgrade. The altimetric difference is picked up using very liquid concrete around the ties.

- **Bottom/up**: starting from the bottom with successive layers of foundation that become increasingly precise, with the final adjustment of the rails being carried out using standard fixings with enough play to pick up tolerances.

**10.1.2.2 - A few experiments with the systems used**:

- **Getrack**: The ties are surrounded by a layer of hot mix asphalt. However, the use of asphalt as a final layer requires a highly skilled laying contractor (tolerances).
  - Good value for money and possibility of using smoke emission ties during installation, non-accessible for vehicles with tires, visible ties, use of “Y” ties is not possible.
  - Like the inside of tunnels, temperature differences are not applicable: no bitumen creep – but pay attention to zones where there is transition to the open air.

- **Rheda Berlin**: The concrete is directly cast around the ties – obligatory cracking between the prefabricated and in situ components – especially in the case of prestressed ties: concrete creeping with prestressing (32 t), the in-situ concrete does not move. Filling and compacting under the ties is always risky, the concrete must be very liquid – only an average quality can be obtained.

- **Rheda 2000**: The blocks are fixed into the concrete using non-prestressed standby reinforcements: cracking and filling to be monitored, but good value for money, good transmission of loads and positive for the installer (considerable work).

**Disadvantages**: sensitive to impacts during transport and unloading, height of construction, no possibility of using vehicles with tires, vibrations and noise.

While installation is difficult, it is not as difficult as using a slipform machine – minimum 16 h for hardening, also possibility of dimensioning errors. Sensitive
to temperature differences (cracking); must be installed by night.
Repairs: Using pinning – it works once but is subsequently difficult; however,
the system is very flexible in terms of adjustment: +56 mm in height and +/-5
mm of lateral play.
Fixing of plates by rods: as the concrete is of mediocre quality, the pins loosen
over time – need for resins.

Sonneville, Sateba: block ties with shoes – the track is graded and hung from
gantries, with the filling concrete poured around.
Experience has shown that the shoes deteriorate in the presence of water and
dust.

Bögl: The concrete slabs are factory manufactured; standard slabs are machi-
ned by milling.
Very few tolerances, the concrete quality is very good and production is rapid.
Possibility of in-situ repairs.
But: considerable construction height, high price, very complex drawings and
logistics (each slab has a specific position); installation contractors do not like
this solution: no added value.
The first test line is now in operation and we are awaiting experience
feedback.

10.1.2.3 - Transition zones
The main argument against application of non-flexible track in level crossings,
tunnels, viaducts and stations is the creation of a “hard point” against the
upstream and downstream ballasted track.
The ERS system can provide comparable flexibilities on a concrete foundation.
However, it is true that too rapid a change in the flexibility of the foundation
always results in additional loads on the track. To avoid these effects, it is
necessary to create transition zones which must be stable and guarantee a
gradual increase in flexibility towards the ballasted track.

Methods applied to rails and ties: stiffen the track by using “Beischienen” (heavy
rails fixed in the middle of the ties on the ballast), or by doubling the ties.
Methods applied to the ballast; bonding the ballast using resin.
Methods applied to the subgrade: progressive compacting (“rammed”),
successive laying of layers of cement-bound graded aggregate, stabilisation
using a geotextile.
Methods applied to non-flexible track: resilient strips (but be careful of deflec-
tion).
Additional difficulty: the tamping of the ballast against the non-flexible
track slab is virtually impossible – possibility of installing a transition slab with
adjustable fixings.

10.2 - Ballastless track laying
(Bibliographic study – initial version dated 4 May 2007 by Yves CHAMEROIS
(SNCF Ingénierie))

10.2.1 - Ballastless track construction principles
When laying standard tracks, the ties bear on the platform through the
intermediary of a ballast whose role is to:
- Distribute the transmitted loads,
- Provide the track with sufficient elasticity to be able to accept the static and
dynamic loads,
- Limit transversal movements.
Ballastless track is a superstructure where the ballast, which is susceptible to
tamping, is replaced by bearing layers formed from concrete slabs or even
bitumen.
This type of track must provide the same functions as standard tracks by the
superimposition of various stages of decreasing stiffness.

<table>
<thead>
<tr>
<th>Superstructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail UIC60</td>
</tr>
<tr>
<td>Rail fixing Tie</td>
</tr>
<tr>
<td>Concrete (or macadam)</td>
</tr>
<tr>
<td>bearing layer</td>
</tr>
<tr>
<td>Hydraulic binder layer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frost protection layer</td>
</tr>
<tr>
<td>Soil</td>
</tr>
</tbody>
</table>

Figure A2 - Schematic section of the ballastless track.

The necessary elasticity and shock absorption – absent from the highly
resistant bearing layer – are provided by fixing the rail or an elastic material
under the ties. The advantage over the ballast is that in this case the elasticity
is fully controlled and deteriorates much more slowly under the effect of dynamic
loadings.
Various technical solutions exist on the basis of these principles and can be
classified as follows:
- Point fixings: with or without tie
- Continuous laying: inserted or embedded rail

10.2.2 - Main types of ballastless track
The first direct laying of tracks began in the early 20th century and, up until
the 1960s, direct laying systems were simply used for underground transport.
The end of the 1960s and beginning of the 1970s saw the proposal of solutions
for main line links in Japan. Ballastless laying is now almost always used for
new lines in Japan.
Experiments began in Germany in 1972 with a 740 m section in the RHEDA
station. It was also in Germany that this technique was more recently used
with greater interest in 1997 with 145 km of track over 60 sections concerning
20 different types (62%: embankments – 29%: tunnels – 9%: bridges).
The most widespread applications of ballastless tracks are as follows:
- Ballastless tracks in Shinkansen (Japan, South Korea),
- RHEDA and variants (Germany),
- EDILON embedded rail (Holland),
- STEDEF (France) and SONNEVILLE.

10.2.2.1 - The Shinkansen ballastless track
Studies examining tracks on slabs began in 1965. This laying system has been
systematically chosen ever since. There are now over 2,200 km of ballastless
track, with over 150 km on bridges.
The Seikan tunnel (54 km) between Honshu and Hokkaido islands, using a standard line (other than Shinkansen) is equipped with ballastless tracks.

For this type of laying, the ties are fixed to the bedding course by a filler concrete. To improve the pick up of horizontal loads, the bedding course for the RHEDA/Sengeberg laying system takes the form of a trough.

**ZÜBLIN construction**

In this case, the ties are "vibrated" in the fresh concrete. Since 1994, duo block ties have been used, a variant with direct fixings onto the existing slab. Using special equipment, the ties are precisely positioned by groups of ten with a spacing between the ties of 65 cm. The assembly of the rails and positioning corrections on the level of the attachment points are carried out after the concrete has hardened.

**ATD construction**

The asphalt based bedding course is laid with a straightness to within ± 2 mm and has a central base to pick up the lateral forces. This is followed by the laying of the ties and tracks. The track adjustment is carried out by inserting an elastic material between the base and the ties.

**Construction RHEDA**

For this type of laying, the ties are fixed to the bedding course by a filler concrete. To improve the pick up of horizontal loads, the bedding course for the RHEDA/Sengeberg laying system takes the form of a trough.
SATO-FFYS construction

Y-shaped concrete ties are laid on an asphalt bedding course whose height is adjusted by milling. A new version of this laying system (FFYS) assures the jointing of the track and the asphalt bedding course by using two transversal bars under the ties that are positioned in grooves.

Photo A1 - Ballastless track in Germany - SATO-FFYS.

10.2.2.3 - EDILON embedded rail

This type of track laying is an application of continuous laying. A mixture of cork and polyurethane called Corklast provides the support for the rail. The rail is positioned in a groove and then the Corklast is poured. This is advantageous as the tolerances on the loadbearing structure do not have any influence on the track geometry. This laying system has been successfully used in Holland over the last 15 years, especially for civil engineering structures.

Figure A7 - Ballastless track in Germany - Edilon.

10.2.2.4 - 10.2.2.4 STEDEF and SONNEVILLE laying system

The French STEDEF system is generally used in tunnels to protect the environment from vibrations. The rail is fixed in a standard manner to a duo block tie. The latter is inserted into an elastomer shoe at the bottom of which is placed a cellular neoprene footing. This system provides considerable elasticity and results in rail sinkages of over 2.5 mm for a load of 200 kN. The Swiss Walo and American Sonneville systems are based on the same principle.

Figure A8 - Ballastless track in Germany - Steff and Sonneville.

10.3 - Improved safety from the point of view of the emergency services

10.3.1 - Risks of accident

Accidents in tunnels are translated by the same effects as those taking place outside. Without going into excessive detail, it is worth citing [Réf 10].

• Train derailments: several hundred passengers might be involved. For the emergency services, the task is to evacuate a large number of passengers, with the number depending on the type of train (metro, suburban, regional and high speed trains). There is always a risk of fire. When the cause is the merchandise carried, the emergency response solution will depend on the dangerousness of the transported merchandise.

• Frontal collisions or collisions due to train meets: operations to free passengers and the potential treatment of fires need to be carried out. In these operations, and given the configuration of the location, the emergency services may have to intervene in unfavourable conditions (reduced lighting, narrow and confined spaces, toxic gases, vapours, etc.).

• Fires represent the most serious risks for railway tunnels and metros. Depending on the situation (passenger train fire, transport of hazardous materials or merchandise, etc.) the parameters may concern smoke development, temperatures, destruction of equipment, victims and their evacuation, duration of the operation, the means to be used, and the difficulty of the operation.
10.3.2 - Operational aspects

The difficulties in treating these accidents are linked to the constraints governing the approach of the emergency services. It is necessary to reduce intervention and evacuation times to allow passengers to be able to escape the dangers of smoke inhalation and allow the emergency services to get as close to the incident as possible. Speed without load transfer is vital.

10.3.3 - Tunnel accesses

The emergency services must be able to intervene within a very brief time at one or other of the tunnel portals. It is necessary to construct access roads reserved for special fire brigade and emergency services vehicles and machinery. As most tunnels are located in mountainous regions with very steep slopes, the routes must be usable in all weather conditions. Treatment of the access roads by cement stabilisation is often a good solution.

The construction of a stabilised road (a concrete road is a sustainable solution) accompanied by an area where the emergency services can assemble, the creation of a command post and, if required, a helicopter landing area, is necessary.

10.3.4 - Proceeding through the tunnel

Rescue materials such as stretchers, pipes, pumps, etc. supplied by the fire brigade or stored at the tunnel portals must be transportable inside the tunnel to be as close as possible to the scene of the accident. Transport solutions using lorries result in having to make return trips to collect the materials and this leads to additional time losses and very low transported volume capacities. The rail/road vehicles that could equip the fire brigade only provide a one-off capacity and do not permit the rapid, large-scale evacuation of the injured and the passengers. This is particularly applicable to very long tunnels.

The Swiss and German solutions using rescue trains are not used in France.