SLAB TRACK CONSTRUCTION IN THE TUNNELS OF GUADARRAMA

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SUMMARY

Spain, through its rail infrastructures entity ADIF, has been investing in new rail lines that are gradually forming the second longest high speed rail network in the world. A key part of this network is the new Madrid – Valladolid line, which will connect later on in the north to France, and therefore, Europe’s high speed rail network. Construction of this line included the Tunnels of Guadarrama, which represented at the time one of the most challenging railway projects worldwide (it is currently the fifth longest railway tunnel in the world).

To construct the Tunnels of Guadarrama’s 28.4 km length with no intermediate access points, extremely accurate logistics planning was undertaken in order to achieve the high efficiency required to finish the project in time. Slab track structure was chosen for the tunnel section since it enables improved operating conditions, easier emergency evacuation and reduced maintenance, thus reducing cost and track occupancy. Nevertheless, as slab track needs precise construction the latest track technologies were used.

This paper concerns the construction of the tunnels, from the design of the track configuration to each activity undertaken during the construction stage.

INTRODUCTION

In 1992, Spain inaugurated its first high speed line connecting the capital, Madrid, with its most important southern city, Sevilla. The opening of the new line was a complete success with passenger traffic increasing significantly and snatching 80% of the Madrid - Sevilla air traffic. These excellent results were a huge step towards revitalisation of the Spanish railway system.

Since then, the Spanish high speed network has grown with four new links (Madrid – Barcelona, Zaragoza – Huesca, Cordoba – Malaga and Madrid – Valladolid) as shown in Figure 1, and will continue expanding until the whole network is completed in 2020 (Figure 2).
When the new lines were opened to commercial services rail patronage started to increase and become progressively a serious competitor to air transport. One clear example is the Madrid – Barcelona connection, which in its first year of operation enticed 40% of the passengers of the busiest air link in Europe to rail.

1. MADRID – VALLADOLID HIGH SPEED LINE

The high speed line between Madrid and Valladolid forms part of the European Atlantic Railway Corridor and hence is considered by the Transport Department of the European Union as one of the 14 priority projects of European Rail Transport Plan.

The new connection reduced travelling time by 60%, from 2 ½ hours to just 1 hour. It also permitted a decrease in travelling time to other northern cities of Spain as new trains equipped with a dual-gauge system are able to run independently on the conventional lines (1,667 mm) and high speed lines (1,435 mm).

The new line was designed according to the strict parameters of geometry, materials, etc. that are required to enable high speed trains to reach speeds up to 350 km/h. As a result of such strict geometry requirements, 18 viaducts and four tunnels had to be constructed. One pair of these tunnels, the Tunnels of Guadarrama, stand out as the most significant and iconic work of the line.

1.1. Tunnels of Guadarrama

Many aspects made the Tunnels of Guadarrama a challenging project, such as the complexity of its works and logistics, but overall its main feature is its length. At 28.4 km they are the fourth longest tunnels in Europe (only after the Gotthard tunnel, the Eurotunnel and the Lötschberg tunnel).

This monumental work required an investment of 1,219 million €, took three years to complete and involved more than 4,000 people working around the clock.

1.1.1 Characteristics of the tunnels

The Tunnels of Guadarrama are composed of two parallel tubes, separated 30 m between axis and connected every 250 m through emergency galleries. The smallest radius of the line layout is 8,400 m and the maximum inclination 1.5 %.
The track is in standard gauge (1,435 mm) and it runs on an overhead wiring system of 2 x 25 kV in alternating current.

2. CONSTRUCTION OF THE TUNNELS OF GUADARRMA

2.1 Excavation of the Tunnels

During the construction of the tunnels, four TBMs were utilised, with an excavated face diameter of 9.5 m and an advance speed up to 1 km per month. The length of one TBM was 250 m and each contained 60 cutting heads.

The excavated material amounted to 4,000,000 m$^3$, which was enough to build 1.5 Cheops pyramids.

2.2. Type of Track Structure

Despite the type of track chosen outside the tunnels being a “classical ballasted track” (composed of rail UIC 60 and sleepers Monobloc Al-99), it was decided to install slab track in the tunnels, in order to optimize the tunnel’s diameter (the use of slab track allows a reduction in the tunnel’s diameter), to improve conditions of operation and emergency evacuation and to reduce cost and track occupancy requirements for ongoing maintenance.

On the other hand, the construction of slab track presents some disadvantages in comparison to ballasted track, such as higher initial capital outlay and the need for greater precision during installation.

Although the use of precast slabs, based on the Japanese design, was considered, the type of track adopted was the Rheda 2000 slab track because of their successful use in the high speed network in Germany and the very positive results achieved by this technology in different trials conducted in Spain with several types of slab track systems.

2.2.1. Improvement of the design criteria

The Rheda 2000 system consists of modified bi-block sleepers which are embedded in a monolithic concrete slab. A lattice truss reinforcement connects the two blocks of the bi-block sleeper in order to guarantee an effective embedding. In addition, a longitudinal reinforcement is also placed under the blocks and through the lattice truss reinforcement.

The fastening type used was the Vossloh 300.

The conventional design of Rheda 2000 was improved with the incorporation of polypropylene fibres, with a dosage of 900g/m$^3$, instead of the traditional steel reinforcement. The addition of these fibres made possible not only an increased flexural resistance of the concrete slabs, but also permitted an easier track installation methodology.

![Figure 6. Transition section.](image)

The installation of ballastless track systems demands special attention for the transitions between ballasted and ballastless track systems. In this particular project such transitions were conceived as a concrete section of 20 m length made up of two different segments of 10 m each. The first is a ballasted track confined in a U-type concrete section which prevents its liquefaction and displacement. The track stiffness is also increased by the installation of two additional longitudinal rails fastened to the sleeper, as shown in Figure 6. The second transition section is made up of a slab track built on compacted soil.

Such transition configuration, along with soil stabilization treatment through the whole transition, prevents the appearance of differential track settlements.
2.3 Delivery of Materials

The fact that the project runs through an environmentally protected area made it impossible to use intermediate construction access points, adding to the logistics challenges inherent in such long tunnels.

For the transport of material to the work fronts, two auxiliary tracks were installed, one at the centre of the future slab, to distribute the rails, and the other at the side of the tunnel, for the distribution of the sleepers.

![Diagram showing rail off-loading process](image)

**Figure 7.** Auxiliary tracks for material delivery.

Therefore, special rolling stock for the materials distribution was required. Rail trains, trains with flat wagons to carry sleepers and small equipment and trains fitted with concrete mixer wagons for the casting of the concrete slab were utilised in the construction process.

**2.3.1. Off-loading rail**

The rail off-loading was carried out using a rail train that ran on the central auxiliary track conveying the rails from the outside stock yard to the working area inside the tunnel.

Once the train reached the unloading section, the rails were off-loaded and strung out alongside the auxiliary track, working from inside the tunnel out. This process required the use of fish-plates to connect each rail to the previous one in order to drag the rails off the rail train as the train moved forward. Once these new rails had been laid out the central auxiliary track was dismantled in panels.

**Figure 8.** Diagram showing rail off-loading process.

The productivity rate achieved in this process was eight rails each 90 m long per day, that is to say, 360 m of track daily.

**2.3.2. Off-loading sleepers**

For off-loading the sleepers, a sleeper train and a Hi-rail excavator fitted with a sleeper distribution frame were utilised. The sleeper train ran on the lateral auxiliary track and two pairs of sleepers were attached to the excavator’s distribution frame and positioned alternately, in a two-step process, so as to maintain the right spacing between sleepers, as represented in Figure 9.
2.4. Rail Installation

The rail was threaded into position using a rail threader at a rate of 200-300 m of track per day (400-600 m of rail).

2.5. Lining and Levelling

Since slab track demands very accurate initial alignment of the rails prior to pouring the concrete slab, the latest technologies, such as topographic vehicle Leica GRP 1000 and positioning trolleys, were utilised.

The final alignment was achieved through the use of spindle brackets, which suspended the track panel and allowed the final horizontal and vertical adjustments to be made.

2.6 Casting Concrete Slab

The concrete slab was cast by using a special concreting train (train fitted with concrete mixer), that ran on the auxiliary track, and a working platform, that travelled on the new track that was being constructed. The strength of the concrete used was 35 Mpa, with a dosage of 900 g/m³ of polypropylene fibres.

The average daily output for concrete slab track cast was 170 m/day, with the project achieving a maximum of 324 m/day and 1651 m/week.
CONCLUSIONS

The assembly of railway lines within tunnels generally presents difficult logistic problems, since the access to the work front is very limited, but when the tunnel is 28.4 km long, these problems are greatly magnified.

In order to overcome construction problems, a detailed study of logistic operations was undertaken and the special rolling stock and machinery was required.

The high output rates achieved in this project validate the quality of the chosen methodology, proved the effectiveness of the organisation and the execution of the works.

The construction of the Tunnels of Guadarrama is considered an outstanding success for civil engineering and Spanish passenger transport.