Rossio Railroad Tunnel – Surveillance and Analysis of the Rehabilitation Works

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ABSTRACT

The current *study* focuses on the main construction methods used in tunnel *reconstruction,* and specifically at the *Rossio Railroad Tunnel*, as well as on the role and contributions of *Inspections* in public works' contracts.
The main methods of renovation of the Rossio Railroad Tunnel are described in this work, namely the methodology of making soil nails, forepoling, steelarches and the respective use of shotcrete with steel fibres, micropiles, inverts and concrete pouring of the poles and vaults with pre-fabricated metallic formwork.
Special attention is paid to the role of Inspections and how they may contribute to an increase in quality and productivity.

1 INTRODUCTION

A tunnel is an underground passageway built to facilitate crossings. Tunnelling is quite useful nowadays, because it decreases the construction of surface infrastructures in an urban environment. It helps to minimize the visual impact on the landscape and the impacts that these constructions have in everyday life while the work is being carried out. Hence, the construction of tunnels in large towns is extremely helpful, because they allow a better space management in order to provide the services and equipments required by high demographic levels.

The major impact in the media and the restrictions and difficulties caused to the population, can be justified by the Rossio Railroad Tunnel's single characteristics. In fact, it is the first Portuguese tunnel to have such a deep rehabilitation process, which justifies a detailed study of its construction methods.

Nevertheless, it is important to clarify that the purpose of this work is to give a contribution, even though it may be considered a small one, in order to clarify the construction methods and to lead to a reflection about the role of inspections in a work of public interest and even more with such a huge dimension as this one.

This contract work consisted of:

- A structural intervention by building a closed section in the interior of the tunnel, in an extent of about 1.226 meters, in four fronts, keeping the present circulation loading gauge;
- Building, in the whole extension (2.613 meters), of a direct track platform in concrete, with a covered track, allowing, if necessary, the access of the road traffic and being moreover an important stiffness element for the structural stability of the Tunnel.

- Installing a new measured monitoring system with remote data transmission, allowing the permanent control of measured strains and checking the appearance of cracks in the tunnel;
- Installing new equipments of passive safety: dry standpipe in the whole extent of the tunnel, ventilation and fume collector vertical and longitudinal systems and a vertical emergency exit located at the middle of the tunnel.

2 TUNNELS - STATE OF ART

Construction methods

The choice of a tunnel's construction method is based essentially, in geological and geotechnical studies so that it is possible to adjust the definition of the alignment, the choice of construction processes and the scaling calculations to the characteristics of the soil.

Some of the key aspects that may affect the choice of method in the design and construction phase: reduced thickness of the coating of soil and rock; water table level; natural tensions existing in the mass; masses of heterogeneous materials, with variable mechanical properties; masses consisting of easily perishable and expansive rocks; and geological structures.

These are the main construction methods useds:

NATM - New Austrian Tunneling Method: It is a method that is based on soil excavation, which in turn leads to a deliberate stabilization / deformation, in order to outline the mass to the excavated shape, redistributing and reducing the maximum induced tensions, thus avoiding their breakdown. This relief of tension is controlled through the monitoring of deformations and convergences of the land.

TBM - Tunnel Boring Machines: Construction in TBM is a technique that consists in carrying out the excavation with a shield punch (mechanical equipment in a metal cylinder with sharp edges – Tunnel machine), bearing an open or closed front, to prevent the collapse of the mass until the final support is placed, ensuring the protection of men and machines. Immediately back, the segmented coating is assembled in concrete pre-fabricated barrel stave, embedded in each other. The progress of the tunnelling machine is done by the reaction of hydraulic motor against the coating rings already implemented. Shield construction can be divided into: open shields, compressed air confinement shields, mechanical confinement shields, liquid containment shields, containment shields by counter-pressure of land (*Figure 1*).

Figure 1 - Containment shields by counter-pressure of land

Building by fire: When the subterranean areas to dig are essentially rocks, a widely used method is to dig by fire. This process depends on drilling speed and the power of the explosive. The excavation by fire consists in opening a certain number of holes in the front of excavation, loading them with explosives concerning only a specific area of detonation. The holes are scaled down by location, direction, quantity and sequence of detonation.

Cut-and-cover construction: This method is applied when there is no interference with the road system, or when it is possible to divert traffic without causing major inconveniences. The technique of building on the surface is to open ditches of large, creating sidewalls of containment, buttress brace or sloping. Following that is the lowering of water table, if necessary, and then proceeding to the implementation of the final support. This process ends with an embankment on the final support.

Mechanical pre-cut: The mechanical pre-cut consists in cutting the ground only in the vault of the tunnel, with robust equipment and shaped like the section of the tunnel. After the cut, projected concrete is applied to consolidate the vault and subsequent excavation of the interior section of the tunnel. After the excavation of the interior section, a concentric ring is executed with the previous application of shotcrete. With the stabilization of the vault, the work is continued by excavation of shafts and the sill, ending up with the implementation of the final coating.

Benchmarking

The increase in urban population has contributed to a significant increase in the construction of tunnels, primarily on road and railway works. However, the high cost associated with its construction together with environmental and maintenance costs has been an obstruction for them to become more widespread.

The construction methods depend on the soil where the tunnel is opened. When the solid rock, the decision is between the excavation by fire or TBM. For soils (prevalent in urban areas), the decision is between the NATM and TBM.

Comparing the applicability of the described construction processes, it appears that the TBM method, although not being the most common, is the one that has a greater progression margin. It also has the advantage of being a fast method either in bulk or in rocky soil, with great results from excavation and support placement. However, the lack of flexibility in terms of geometry variation, converges to other methods being still the most used currently (NATM and excavation by fire).

Rehabilitation techniques

Tunnel rehabilitation can be performed both at structural and at non-structural level.

Non-structural rehabilitation includes repair works for anomalies associated with moisture, without relevant importance for contributing to the instability of the support. They are designed to eliminate what is harmful to the masonry, or concrete, minimizing the potential for deterioration. Possible cleaning and protection techniques are the following: cleaning of masonry (mechanical cleaning, cleaning with high-pressure water, sandblasting by wet screening, pressurized steam and chemical agents) and protection and repair techniques (moisture-proofing, maintenance and treatment of joints).

Structural rehabilitation consists in improving the mechanical characteristics and cohesion of the existing elements (supports) as well as the surrounding land, preventing and / or controlling instability events or excessive deformations. Examples are: reclosing of joints, drainage, consolidation injections, shotcrete, soil nails, forepoling, application of pre-stressing, artificial freezing of land, micropiles and jet grouting.

3 PROBLEM DESCRIPTION

The Rossio Tunnel is a centenarian construction, which has been preserved until now without large scale interventions. However, some problems could be identified, showing the fragilities on the structure's [1] behaviour, such as:

- Subsidence, of 25 cm, of the vault at Pk 2+020 (primordial factor, which determined the closing of the tunnel, due to the coating eminent rupture and raising up the need of its reconstruction);
- Subsidence of the invert ground in the space between the tracks, giving rise to a rupture in the masonry aqueduct (in 1916);
- Problems of instability of the platform in consequence of the ballast contamination with clayed sludge and water infiltration (since circa 1926);
- Drawdown of 50 cm of the track bed and restuffing of the gable walls with an identical value;
- Execution of an invert in simple concrete between Pk [0+194; 0+780], due to the convergence of the gable walls;
- Settlement of the gable wall alongside the up line between Pk [1+920; 1+960] (right side in the direction of Rossio-Campolide) accompanying its restuffing;

The aforementioned problems are the causes of some pathologies, such as [2]:

- Water infiltration through the coating;
- Huge strains of the existing coating;
- Instability of the platform, owing to the existence of soft soils set by the surface waters;
- Deterioration of the surface of the brick and stone masonry of the gable walls and of the respective mortar;
- Reduction of the loading gauge, owing either to constructive effects or in consequence of the strains suffered by the coating;
- Voids and deterioration of the surrounding grounds (*Figure 2 and 3*).

Figure 2 – Displacement and erosion of the masonry of the vault surface [2]

Figure 3 – Vault deformation [2]

4 DESCRIPTION OF THE REHABILITATION SOLUTIONS

According to the analysis to the existing conditions, two main types of solutions were adopted. In the most affected areas, the solution consisted of executing a closed section in reinforced concrete (New Section Area). In the other areas (Keeping Masonry Area), the solution consisted of cleaning the masonry and restuffing the gable walls with the execution of an invert in concrete.

The execution of a closed section in reinforced concrete was divided into three main phases. Firstly, a temporary shoring (assembly of temporary HEB metallic profiles, in *Figure 4*) was erected, which follows the demolition of the existing masonry, in order to execute the primary support, allowing this the execution of the final coating in reinforced concrete (*Figure 5*).

The type of primary support adopted was defined regarding the conditions presented by the soil, using some different techniques and materials, such as, steel arches, micropiles, forepoling, metallic soil nails and injected fibre glass soil nails.

Figure 4 – Section with temporary shoring (steel arches) between Pk [0+194;0+221]

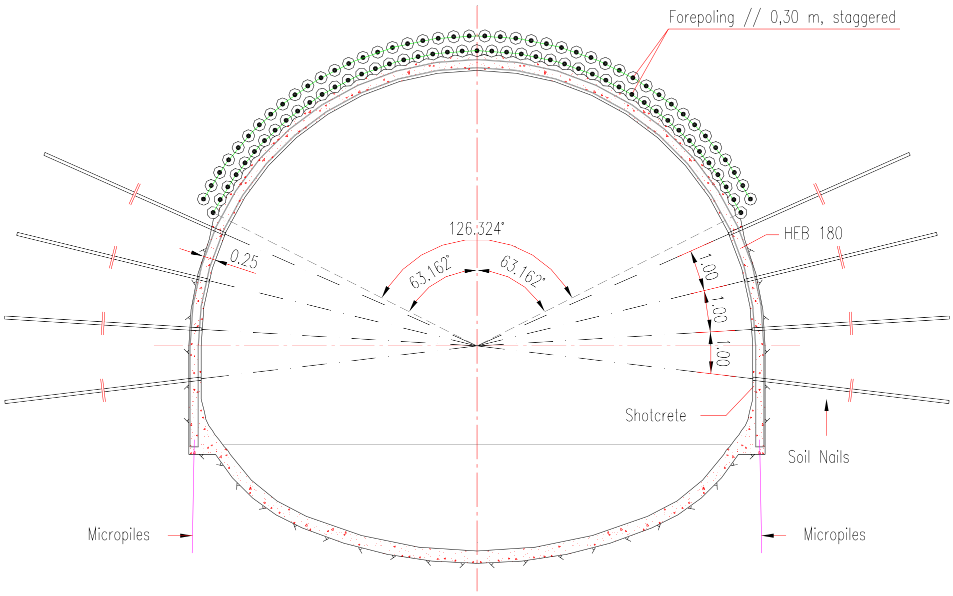

Figure 5 – Example of a Primary Suport [3] – between Pk [0+360;0+610]

5 DESCRIPTION OF THE CONSTRUTION METHODS

The description of the construction methods of the intervention on the tunnel emerged after a careful analysis of the characteristics of the work and the soil, of the kind of equipment to use and the execution deadlines.
The construction methods are briefly described next:

Temporary Support: This support, which has the objective of limiting at the minimum the soil deformation and the damages in the buildings existent at the surface, consists of assembling metallic profiles HEB 180 or HEB 200, distanced at 80 to 100 cm according to the affected area, and clamped with Ø32 mm bars, both in the gable walls and in the vault;

Soil Nails: They are structural elements used in order to improve the structures binding and for the reinforcement of the masonry. In this construction soil nails Swellex FLP20 and FLY35 were used, and their execution is described as follows: a) The Drilling is made using drag bits, through the rotative action of the head of the drilling equipment. The drilling progress is done as far as the disintegrated material is expelled through the introduction of water; b) Preparation and placement of the steel reinforcement inside the hole. The steel reinforcement is assembled in the injection system, consisting of a PVC tube with O-ring rubber valves, or by two other polyethylene tubes for selective and repetitive injections; c) The Injection, which begins with the mixture of the cement grout, that is finally injected by one of the polyethylene tubes serving the other one as scour tube. The cement grouting is finished when it reaches a constant pressure of 2 bar during 30 seconds (*Figure 6*).

Figure 6 – Soil nails execution

Forepoling: These are elements that function as a primary support of the tunnel in areas of low covering or in areas of bad quality of the solid. The forepoling are executed in fan, in a way that allows that the execution is an arch, providing safety conditions in the work front, assuring the solid stability, with the absence of subsidence's and prominent deformations. The forepoling execution consists of two phases: a) The drilling is made by rotation using drag bits, or by rotopercurssion without coating. In the generality of the cases the metallic tube of the forepoling was used (steel reinforcement) as a drilling bar (auto-drilling system). In one extremity of the forepoling tubes a drag bit is assembled, which becomes lost with the application of the steel reinforcement; b) The other phase, injection, is executed into the interior of the steel reinforcement, through a valve placed on the other extremity of the forepoling tube which remains outside the solid (*Figure 7*).

Figure 7 – Forepoling execution

Disassembly of the Primary Support: Consists of disassembling the steel arches one by one, allowing the excavation advancement up to the theoretical exterior outline of the new section. The steel arch is released by taking the wedges and the iron bars, prop it up, and if necessary, turn off its binding screws before transferring it, disassembled, in order to protect the next excavation advancement;

Excavation, demolition, definitive steel arches and shotcrete: This activity consists of executing by successive advancements the solid excavation according to the theoretical outline or until the forepoling umbrella, assembling of definitive steel arches and its clamping with Ø32 mm bars, followed up by the wet-mix shotcrete application of C 25/30 concrete with steel fibres against the excavation outline, covering the previously assembled steel arch (*Figure 8*).

Figure 8 – Excavation with cutter-loader

Micropiles and Reaction Girders: Elements of high slender which are part of the structure and transmit to the soil, mainly skin friction, but also by point load, the transmitted loads. This activity can be divided into three phases: a) The Drilling, which consists of drilling with the rotation of a continuous special auger; b) Subsequently there is the execution of the hole, which follows the placement of the steel reinforcement and the assembly of the reaction girder; c) The Injection consists of using the cement grout, after connecting the pipe that comes from the injection pump in the extremity of the steel reinforcement. The injection is finished when the cement grout appears at the surface.

Inverts: The execution of inverts starts with the soil Excavation using a dragshovel, sometimes with a pneumatic drill. Afterwards, the soil is removed to an authorized deposit, and it follows the application of shotcrete, C25/30-S4, until reaching the thickness defined in the project (*Figure 9*). Next, the application of the waterproof system, which consists of 3 layers: a geotechnical blanket; a PVC waterproof geomembrane; and finally the lining of the geomembrane with a polypropylene blanket. It follows the execution of the panels side form in Nervometal, in order to start the steel reinforcement assembly. After the installation of the reinforced cage, the placing of concrete follows, with a concrete C25/30-S2 by direct dumping. In last place is the assembly of the collector tube and of the panels' side form, finishing this activity with the placing of mass concrete, application of C12/15-S2.

Figure 9 – Shotcrete

Vault definitive coating: The final coating system is implemented in order to allow the safe and functional use of the tunnel, regarding the requirements of strength, durability and functionality along its serviced life. This activity can be divided into 4 phases: a) Waterproofing – the waterproof system which consists of 3 layers: a geotechnical blanket to protect the waterproof membrane from punching and tear-off; a PVC waterproof geomembrane; and finally the lining of the geomembrane with a polypropylene blanket; b) Steel Reinforcement – bounding of the steel reinforcement of the gable walls to the invert one, trough the splicing. Afterwards the steel reinforcements of the gable walls and vault is carried out. The bars are properly positioned with 'tie wire' to avoid its displacement while the concrete is placed; c) Start up of the Gable walls – this sub activity starts with the cleaning of the surface where the concrete is going to be cast, followed by the assembly of the panels side form. Afterwards, the concrete C25/30 is placed into the side form; d) Placing concrete into panels side form of the gable walls and vault – placing and positioning of the metallic formwork with topographic help, followed by the concrete placement using C25/30-S4 (*Figure 10*);

Masonry cleaning: the treatment of the brick or stone masonry is done in an exhaustive way, by wet shooting a mix. The distance and the wide spread of the shooting depends on how dirty the section is (*Figure 11*);

Figure 10 – Metallic Formwork

Figure 11 – Masonry cleaning by wet shooting a mix

6 INSPECTION SERVICES FOR THE CONTRACT WORKS

One can define Inspection as a set of services. Its main target is to assure the management and supervision of the activities related to the execution of a contract work, according to the design architecture's, engineering and other related building areas and the Contract Documentation, until the provisional reception, assuring the Quality and Safety, and making the Administrative Closure of the contract works.

Therefore, for this contract work the Inspection Services consisted of the following services provision contracted by the Contracting Entity:

- Start, Planning and Control of the Contract Works;
- Information Management of the Contract Works;
- Control of quantities and costs;
- Control of Planning and Progress of work;
- Quality Management on the site;
- Safety Management on the site;
- Environmental Management on the site.

The Inspection Services carried while the construction was developed had a very important contribution, allowing its improvement, and optimizing production with high levels of quality. The quality control parameters were based in studies and analysis about the construction methods, exhaustive evaluation of the materials and equipments, planning analysis and control, as well as to interconnection bridge among the Contractor, the Contracting Entity and the Design Engineer.

As an example of the positive intervention of the Inspection Services, the behavioural structure study carried out and the monitorization of the gable walls and the vault, detect solved the convergence problems verified (ex: between Pk 0+320 and Pk 0+360), mainly the subsidences, using consolidation grouting in the solid (*Figure 12*).

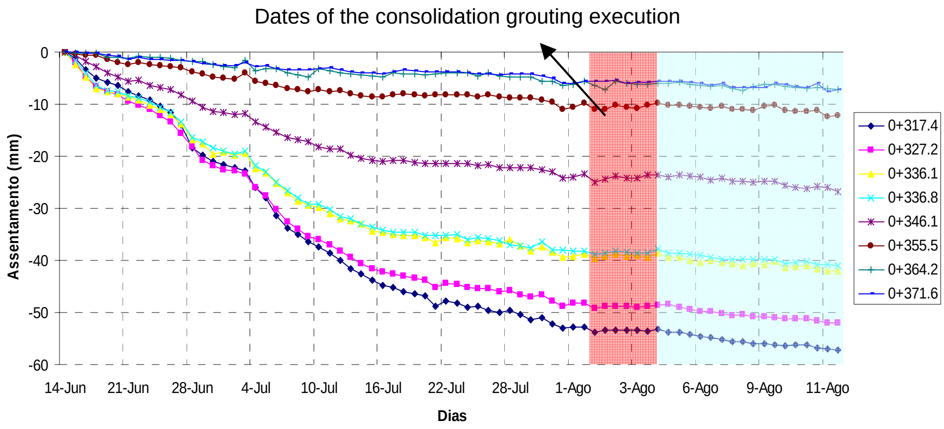

Figure 12 – Vertical subsidences of the topographic rules between the Pk [0+320;0+360]

The control of the convergences of the tunnel interior walls, allowed following the evolution of the displacements of the gable walls and vault. The solution that was pointed out to invert the tendency of increase of the distance between the gable walls was the soil nails execution, becoming more solid through the welding to UNP double profiles, and concrete placement at the invert level (*Figures 13 and 14*).

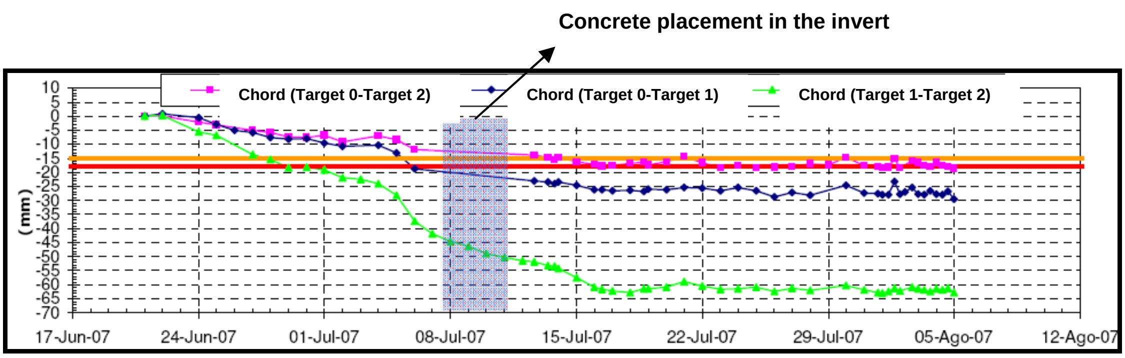

Figure 13 – Target Convergence at Pk 0+325

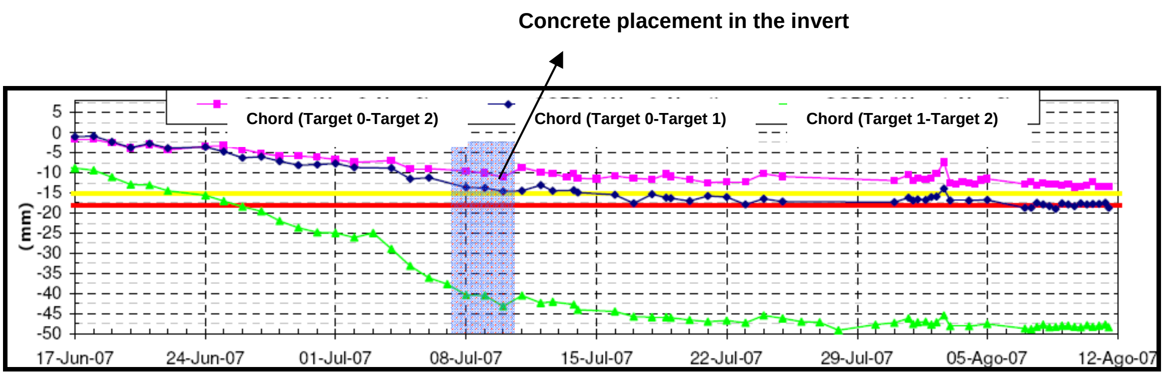

Figure 14 – Target Convergence at Pk 0+345

Analysing the construction processes and after the daily perception in accompanying of the works, the Inspection made possible to change some construction methods, the return of equipment and the performance of work teams. Highlighting those changes, one can refer the replacement of the injections in the forepoling from one O-ring valve to another O-ring valve, in advantage of direct injection; the addition of fibre glass to the shotcrete mix to be made at the centre; and the assembly of the steel reinforcement of the inverts to be made using trestles instead of pre shaped steel.

7 CONCLUDING REMARKS

The present study intends to be a contribution to an improved awareness of the construction processes used in tunnelling, mainly the methodologies applied to the rehabilitation of the Rossio Railroad Tunnel. It also aims to approach the services, which the Inspection has provided, and the role it performed on the contract development.

The following construction methods, were analysed: the application of the primary support, in order to achieve better safety conditions; the execution of soilnails and forepoling to improve the solid; drilled micropiles, to assure the upper structure stresses were distributed by soil; and, finally, the implementation of the waterproof system, in order to obtain a more efficient drainage.

The area of construction is, in Portugal, a sector of activity with a significant value to the national economy, in which massive investments are made to modernize the country. Therefore, the existence of entities able to provide inspection services in order to assure the construction quality is extremely necessary and, by the other hand, to control investments with the purpose of eliminating budget slippages. Assuming that the contract work for the Consolidation, Reinforcement and Rehabilitation of the Rossio Railroad Tunnel was only possible with a substantial investment, there was an implicit justification for the recruitment of an Inspection Services team. This team was of major importance to the development of the construction, assuring the quality of the intrinsic activities of this contract work.

The Inspection team found and/or discussed solutions together with the Contractor, to solve unexpected situations, which has been a decisive factor to the progression of the work. The analysis of the work teams performance in the several work fronts, was a valuable contribution too, as well as the collected and analysed data, produced by the instrumentation and monitorization program, which allowed foreseeing and solving unexpected problems. Another major contribution was the prevention of occupational accidents and diseases.

Based on the above considerations, the existence of an Inspection team in the coordination and follow-up of projects elaborated by a several number of specialists is more often requested and justified, mainly in full-time contract works with tight deadlines and when, most of the problem solving is delayed to the execution phase. Minimizing problems, in this stage, is of extreme importance, by means of previous and efficient project coordination. The possibility of those factors coinciding and the occurrence of unpredictable circumstances is greater when dealing with rehabilitation and/or geotechnical contract works, since the work is made with “soil” material, which is not manufactured by us, heterogeneous and whose characterization is not simple.

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