Tunnelling under the city centre of Antwerp: a new underground railway link for the HSL Paris-Brussels-Amsterdam

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ABSTRACT: The most important structure of the Antwerp north-south railway link, situated on the high speed line Paris-Brussels-Amsterdam, is definitely the twin-tube tunnel of 1,225 m length and 8.00 m diameter which was bored in dense – slightly silty – sands, under the old city centre, between the "Koningin Astrid" and the "Dam" squares. During the design phase, as well as during the construction phase of the tunnel, constant care was taken to limit subsidence in this sensitive urban area. This required the combination of traditional underground construction techniques, such as galleries, "sheeted trenches", grout injections, pipe-jacked roof, jacked tubes ... with the boring process itself using a slurry type Tunnel Boring Machine (TBM).

1 SCOPE OF THE WORKS

1.1 *Introduction*

The Antwerp north-south railway link, situated on the line Paris-Brussels-Amsterdam, is the major project of the northern part of the Belgian high speed network. From 2006, this project will allow trains to travel below the city continuously and make the Antwerp Central Station an integral part of the new high speed railway network, instead of the dead end facility as it has been before.

1.2 *Bored tunnel section between the "Koningin Astrid" and the "Dam" squares*

North of the historic Antwerp Central Station, the underground railway link between the "Koningin Astrid" square and the "Dam" square consists of the boring of two single-track tunnel tubes under a densely populated part of the city centre. The tunnel tubes have an outer diameter of 8.00 m and an inner diameter of 7.30 m. The tunnel boring machine (slurry shield) had an outer diameter of 8.27 m. The tunnel pipes had to cross below existing underground structures (premetro station and premetro tunnel), but also under a 15 storeys building (Astrid Park Plaza Hotel). In addition to the start and arrival shafts, the following constructions had to be carried out along the bored tunnel section: an emergency shaft in the middle of it, and two cross-passages at intermediate distances.

The contract for the bored tunnel was awarded to the Joint Venture "ASDAM" in March 2001. The works started in May 2001 under the supervision of the company Tuc Rail (assisted by De Lijn), and are expected to be delivered early 2005.

1.3 *Geotechnical aspects of the project*

The tunnel tubes were bored mainly in Tertiary Miocene sands ("Sands of Berchem"), consisting of fine, dense – slightly silty – sands ($\phi = 25°$ to $30°$), with inclusions of shells, of clay, and presence of glauconite. Glauconite is a clay mineral which results from an organic decomposition process caused by bacteria within salty sea water, but which looks more like sand regarding the size of its grains.

Nevertheless, due to a sticky and clogging behaviour in specific circumstances, it can have a lot of negative consequences on the boring activities.

Above the Tertiary sands, Quaternary alluvia and relatively recent backfilled grounds ($\phi = 15°$ to $25°$) were encountered. The clay layer ("Boom clay") situated under the Tertiary sands has never been reached during the works.

The water table, which is normally situated 3 to 5 m under street level, was locally lowered down to

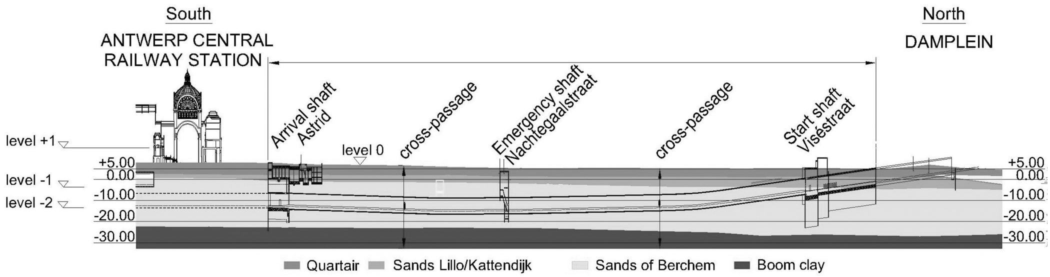

Figure 1. Longitudinal profile of the tunnel.

20 m, without any significant incidence in terms of settlements.

2 TUNNELLING IN A CITY CENTRE ENVIRONMENT

During the design phase as well as during the performance of the works, constant care was taken to limit subsidence. This required combining traditional underground construction techniques with the boring process itself.

In addition to the measures taken before, during, as well as after the passage of the TBM (such as permanent monitoring the front pressures, tail injections synchronised with the boring process, daily check of settlements at ground level, checking of displacements in the tunnel...), several underground construction techniques including innovative methods were used at critical places along the tunnel route, for the execution of the ancillary works (arrival shaft, emergency shaft, cross-passages...).

Above-mentioned construction techniques will be further explained in the paper.

3 SPECIFIC AND INNOVATIVE METHOD STATEMENTS

3.1 *Pipe-jacked roof under the houses situated between the Viséstraat and the Sint-Jobstraat*

In the immediate vicinity of the start shaft, a block of houses (whereof the expropriation was not wanted) had to be under crossed with a very small soil cover between their foundations and the tunnel tubes (i.e. about 3.00 m or less than half the tube diameter). Consequently, the decision was made to carry out a pipe-jacked roof, with the following functions:

- preliminary survey of the ground, in order e.g. to localise old water wells which could possibly disrupt the boring process by causing "blow-out" phenomena (sudden loss of slurry pressure from the excavation front to the surface).
- safeguarding of the houses from any risk due to the collapse of the boring front or other calamities during the crossing of the TBM.

A major advantage consisted in the possibility to bore with a higher pressure. In addition, the jacked pipes were equipped with openings in order to enable injection works before and during the passage of the TBM's. These matters are detailed below.

The characteristics of the protective pipe roof can be summarised as follows:

- 21 parallel jacked pipes with an average intermediary distance of 30 cm (precast concrete pipes, diameter 1,000 × 1,216 mm, tube length 3 m)
- use of a micro shield with a closed excavation face, and evacuation of the spoil hydraulically
- average length of a jacking was 70 m
- sequence of execution was that no pipe had to be jacked before the adjacent one was injected and concreted : 1-5-9-13-17-21, followed by 3-7-11-15-19, at last 2-4-6-8-10-12-14-16-18-20
- injection holes were foreseen in the pipes to allow three types of injection works:
  - > primary and secondary grout injections around the pipes.
  - > grout injections between the pipes.
  - > vertical injections from the pipes situated just above the tunnels, during the crossing of the TBM's.

This protective pipe roof with a surface of about 2,100 sqm was successfully carried out, in soils with mixed characteristics (backfilled grounds). Jacking performances were 2 tubes of 70 m a week. Absolute settlements of the roof and of the tunnel tubes were limited to 15 mm. (Fig. 2).

The method showed a lot of possibilities to execute tunnel borings with very low soil cover, without damaging the neighbouring buildings.

3.2 *Galleries, "sheeted trenches" and jacking under the Astrid premetro station*

In order to receive the TBM's (Fig. 3), a box structure had to be built under the existing Astrid premetro

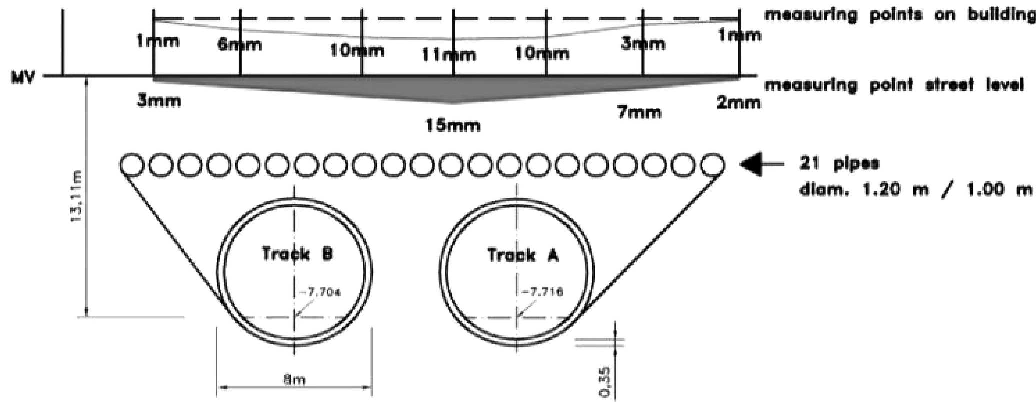

Figure 2. Cross section of the tunnel tubes at the pipe-jacked roof Absolute subsidence data: roof + tunnels A and B borings at the Viséstraat.

Figure 3. Arrival of the TBM (2nd drive) under the Astrid station.

station, to meet the following functions: location of the shunting to allow the passage between circular to rectangular section tunnel sections, escape way for the passengers and access way for the intervention teams of the fire brigade and of railway personnel, ventilation and smoke evacuation.

Considering their location in the centre of the city, the works had to be carried out in different phases, after a preliminary lowering of the water surface down to the clay layer.

Galleries (1) were excavated under the raft of the station (built in 1978), which had already been designed to allow for a later tunnel.

From these galleries, the "sheeted trenches" walls (2) for the railway tunnel were started. After placing flat jacks and concreting ring beams (3), began the jacking works (4). This sequence of works was followed by excavation works and by the concreting of the intermediate slab (5).

The walls for the staircases were carried out in the same way: galleries (6), sheeted trenches (7), placing of jacks and concreting of ring beams (8), jacking works (9), excavation and concreting of intermediate slabs (10) (11) (12). After a last sequence of excavation over a reduced length, the basement slabs were poured (13).

After arrival of the TBM's, it was proceeded to the construction of the middle wall (14), the laying of a drain and the pouring of the track base concrete (15).

Finally, the upper staircase (16), (17) and (18) was built together with the escape corridor and the technical rooms for the electrical and mechanical equipment (19).

In this manner, the existing premetro station was jacked to keep its initial level.

NB: The "sheeted trench" method is a typical excavation method for vertical walls, consisting in the succession of manual excavation phases and the placing of precast concrete shuttering plates, as frequently used in Belgium in confined areas, where a preliminary dewatering of soil is possible.

3.3 *Grout injections during the under crossing of existing premetro infrastructures and of the Astrid Park Plaza Hotel*

At the end of the boring section, premetro infrastructures as well as a hotel building had to be tunnelled with low soil cover between their foundations and the tunnel tubes, i.e. about 0.15 m under the Astrid-Elisabeth premetro tunnel, 3.50 m under the basement plate of the underground car park of the Astrid Park Plaza Hotel and 4.00 m under the basement plate of Astrid premetro station.

Grout injections were carried out from the basement of above mentioned structures, to block any further displacements apart from those directly related to the boring process. For this purpose, injection openings were bored in the basement slabs, and were

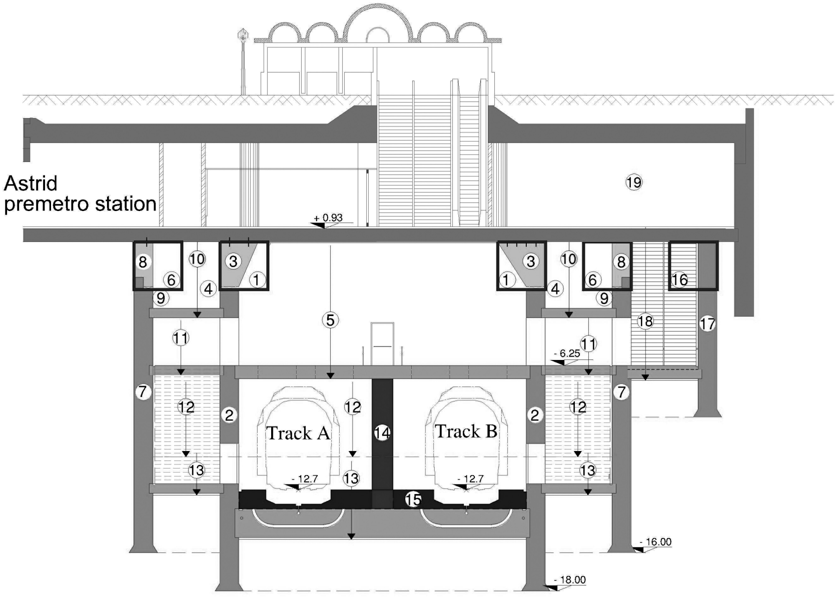

Figure 4. Cross section at the Astrid premetro station.

equipped with removable injection devices. Later on, the injection openings were filled up with grout.

The product used for the injection works was a "dämmer" (micro cement) with a strength of 1 N/mm^2 at 28 days. The injection pressures (2 to 3.5 bar) were adjusted to the actual circumstances (distance from existing constructions, ground water pressure …).

The hotel building was equipped with a very sophisticated monitoring system in order to enable "on line" measurements of any possible displacements.

The excellent performance of the boring works together with the performance of grout injections made it possible to keep the settlements under abovementioned constructions within the contractual limits of 10 mm (3 mm actually measured after the first drive and 8 mm after the second).

3.4 *Sheeted trenches for the execution of the emergency shaft of the Nachtegaalstraat, within a very limited work area*

The emergency shaft situated about in the middle of the 1,225 m bored tunnel section had to be executed in the vicinity of existing buildings and under a narrow street where the traffic of the tramways could not be interrupted. The "sheeted trench" method was adopted for these works, with a preliminary dewatering of the soil.

Special attention was given to integrate structurally the shaft walls and the bored tunnel lining. This connection had been carried out fully under the ground, with continuous care for the stability of the already bored tunnel tubes.

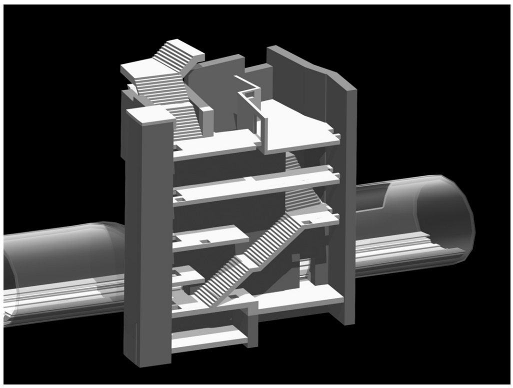

Figure 5. "3 D" view of the emergency shaft of the Nachtegaalstraat.

3.5 *Jacking of tubes for the cross-passages*

At two intermediate locations, the tunnel tubes had to be connected by cross-passages with a length of respectively about 6.00 m and 10.00 m. The soil cover at these places reached about 22.00 m.

The method consisted in the jacking of precast reinforced concrete pipes, from one tube to the other (Fig. 6), after a preliminary lowering of the water surface in the work area. The tubes with an inner diameter of 3.20 m have a reinforced steel core. Tube length is 2.5 m.

In this area, steel segments were used instead of concrete segments. By cutting these steel segments, an

Figure 6. Jacking installation used for the cross passages.

opening for pipe-jacking was created. After the jacking operation, a perfect water tightness could be reached by welding the steel core of the pipes with the steel segments of the tunnel tubes. In a later stage, the steel segments were embedded with concrete.

The works were successfully performed, keeping at any time the possible movements of the soil under control.

4 CONCLUSIONS

The modern TBM technology has fully benefited from more traditional underground techniques (such as "sheeted trenches", pipe-jacked roof and grout injections) for the crossing of particular structures along the tunnel route.

The works situated in a sensitive urban environment resulted in minimal subsidence, in full accordance with the contractual requirements.

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