1. Introduction

Zaventem Airport in Brussels, Belgium can be reached by both road and rail. However, most journeys towards the airport are not that easy. The road traffic on the Brussels’ motorway ring is practically during the whole day very dense, leading to severe delays. As there is no fast solution to solve this traffic problem, the only alternative is to go by rail.

Therefore, the accessibility of the Brussels Airport by rail needed to be improved urgently. At this moment, Brussels Airport still has a dead end station with 3 platforms of about 180 m long. Until 2005, the station was only serviced by shuttle trains coming from and going towards the 3 major stations in the city (the south, central and north station) [1]. Until then, the Brussels Airport station only disposed of an access track in the direction of Brussels, connecting to the railway line 36 between Brussels and Leuven.

Since 2005, the curve of Nossegem is in service, enabling regional and intercity trains on the line Brussels – Leuven – Liège to pass by the airport. Only conditions are that these trains are shorter than 180 m (because of the platforms) and that they have a steering unit in each direction (because of the dead end station). The high speed trains circulating on the axis Brussels – Cologne (the Thalys with a length of 204 m, and the German ICE with a length of 200 m) are too long and loose too much time while they have to turn back.
To resolve all these problems, the Brussels Airport station had to be transformed into a line station with an access to the north, connecting to the new high speed railway line from Brussels to Mechelen now under construction in the central reservation of the motorway E19. At the same time, the platforms have to be lengthened and modernised. A larger travel centre with ticketing hall has to make the station more attractive for passengers.

To pass underneath the airport and its most frequently used runway, two bored tunnels had to be constructed [2]. This construction method was chosen because it doesn’t interrupt the air traffic and because of security reasons (working in a sensitive area).

On both sides of the bored tunnels, switching areas are foreseen. Towards the station, trains coming from each of the two tunnels must be able to reach all three platforms. Towards the E19, the trains from the bored tunnels must reach the four tracks (two towards Brussels and two towards Mechelen). Because of the switches, no intermediate supports are possible in these areas.

Due to a possible future extension of the station to five platforms, we find on the south side an underground construction under the taxiways an airport stands with a maximum span of 30 m.
As the construction of the northern link has a huge impact on the road traffic, it was decided to extend the road interchanger at the same time [3]. Vehicles circulating between the cargo airport Brucargo and the E19 will then have a direct connection by a fly over, without loosing time at traffic lights. At the same time, all the vulnerable road users are separated from the motorised traffic. They will have separate cycling paths and crossings by means of a cyclists’ tunnel and a cyclists’ bridge over the E19.

3. Contract

The contract is the result of four separate tenders. For the rail project, the responsible net operator Infrabel organised a tender for the financing (F) and a tender for the design and building (DB). For the road project, the Flemish road administration AWV organised a tender for the financing (F) and a tender for the design, building and maintenance (DBM).

The result is the first and double public-private partnership in Belgium.

On the clients’ side, two special purpose companies were founded: Northern Diabolo nv for the rail project and Via-Zaventem nv for the road project. Northern Diabolo is representing Via-Zaventem towards the contractor, so that he has only one company to address.

On the contractor’s side, the design, building and maintenance of the roads will be done by the joint venture THV Dialink. THV Dialink is a consortium of CEI-De Meyer, Wayss & Freytag Ingenieurbau AG (both subsidiaries of the Dutch Royal BAM Group), MBG, Vinci Construction Grands Projets (both subsidiaries of the French Vinci Group) and Smet-Tunnelling (an independent Belgian company).

The contracts were closed on the 29th of September 2007. The works started on the 29th of October 2007 and have to be ended before the 25th of February 2012. The maintenance of the roads is foreseen for a contractual period of 30 years after construction.

The contract value of the design and construction is € 322 million.
4. Bored tunnels

4.1 Geology

The tunnels are build in the so called “Brussels sands” [4]. These mixed-grained fine sands contain sandstone layers (sedimentary rock type sandstone) that occur very irregularly in thicknesses of 10 to 30 cm. They are the result of chemical reactions in combination with over consolidation and were formed during the last ice age. The sandstones have unilateral strength that varies between 70 and 120 MPa.

The groundwater level is about 6 m below the surface.

4.2 Tunnel boring machine – cutter head

For the tunnelling process, the choice was made for a hydro shield tunnel boring machine [5]. This technique is commonly used in the soft soils in Belgium and the Netherlands. Due to the presence of the sandstone layers, special attention was given to the cutter head. It had to be able to cut through the sands and stones in the safest possible way, given the presence of the airport on the surface.

THV Dialink chose for a relatively closed cutter head. The maximum inlet is 550 mm. The cutter head has 49 disc cutters, not only to bore through the sandstones but also through the concrete of the slurry walls of the starting and arrival shaft. To deal with the sands, 104 grippers were installed symmetrically. On the outside, 8 curved spacers have to lead the excavated material through the openings.

4.3 Tunnel lining

The tunnel lining has following dimensions [6]:
- inner diameter: 7,30 m
- outer diameter: 8,00 m
- ring length: 1,50 m
- ring division: 7 + key stone
- conicity: 50 mm
- connection: cam & pocket
- concrete: C50/60
- reinforcement: 90 kg/m³
- PP-fibres: 3 kg/m³
The tunnel segments were fabricated at the Max Bögl prefab plant in Hamminkeln, Germany. They were transported with flatbed trucks to the jobsite (260 km).

**4.4 Bored tunnel alignment**

The two bored tunnels are each 1.080 m long [7]. There is an evacuation towards the surface possible in the starting shaft (EV04), the arrival shaft (EV06) and approximately in the middle (EV05). In between two evacuation shafts, there is a cross passage from one tube to the other.

As the evacuation shaft EV05 is situated near the runway, it is linked to a horizontal escape tunnel of about 200 m long. This tunnel connects to a service tunnel of Brussels Airport. This solution avoids that passengers would arrive in the sensitive area of the airport during evacuation.

The horizontal escape tunnel and the slurry walls for the evacuation shaft were built in August 2008, in a period where the runway was taken out of service for maintenance works [8].
The cross passages and the connections between the bored tunnels and the evacuation shaft EV05, are made by soil freezing. Freezing tubes were bored from one tunnel towards the other in a circular shape. In this way, a frozen ring was formed. Under the protection of this ring, the soil was excavated. The small tunnel was immediately stabilised with reinforcement nets and shotcrete. After installing a watertight layer, the actual connection was built in concrete.

4.5 Tunnel drives

The first tunnel drive started on the 10th of April 2009. The breakthrough was on the 25th of June 2009. The second drive started on the 4th of September 2009. The breakthrough was on the 26th of October 2009.

5. Monitoring

To measure possible settlements on airside, an on-line monitoring system was developed. 5 control rows were installed transversal to the tunnel alignment. Each row consists of 25 reflectors and 1 total station. The total station first calculates its own position by measuring reflectors out of the influence area of the tunnel boring machine. Then it measures the 25 reflectors of the row, one after the other. In this way, every 2 minutes a new surface measurement was available.

As the runway has a massive foundation, settlements would not occur immediately at the surface. Therefore, 8 extensometers were installed in the runway. The upper part was fixed in the concrete of the runway, the lower end was fixed in the soil at about 3 meters depth. In this way, every change in the ground level underneath the runway could be tracked instantly.

As there is practically never immediate access to the airside possible, THV Dialink also installed a superzoom camera on one of the hangars near the tunnel track. This camera was operated with a remote control in the tunnel boring machine. In that way, the TBM operator could check the surface above the tunnel in case extraordinary circumstances would occur.

The maximum settlements allowed were 8 mm after the first drive and 15 mm after the second one. In practice, negative settlements occurred. The surface was between 3 and 5 mm higher than before. This phenomenon can be explained by the presence of sand stone layers. Due to the mortar injection during the boring process, the same conditions as for compensation grouting are present.
For compensation grouting, you need two hard layers. Normally in soft soils, they are created by preliminary grout injections. To compensate settlements, grout is injected in between these two consolidated volumes. A small volume of grout with a slightly higher pressure than the ground and water pressure is sufficient to heave the ground above.

Boring a segmental lined tunnel in the Brussels’ Sands creates similar conditions as for compensation grouting. The tunnel lining forms the lower consolidated volume. The first sand stone layer above forms the upper volume. The mortar injection necessary to fill the annulus (larger diameter of the TBM compared to the lining) is similar to the grout injection. The mortar is injected at a higher pressure than the ground and water pressure and enables to heave the soil above.

6. Experiences

Boring tunnels under an airport needs special preparations while the working area is not free accessible. Every intervention near the runways has to be demanded officially and discussed with the airport authorities. All personnel working on airside has to be screened by the federal police, in order to receive an access badge. Car and truck drivers need an additional drivers’ license and a special access permit for the vehicle.

Working with metal obstacles (e.g. cranes) in the sensitive area needs preparations that take months. For high cranes, simulations on the effects on the ILS (instrument landing system) have to be made. When such a crane is built up, a calibration flight with a special aeroplane has to be made.

In some working areas near runways and taxiways, all installations must be removable within 2 hours (in case of upcoming heavy rainfalls or fog).

It was also difficult to find insurers for this project. A tunnel collapse under a runway in operation could provoke a major disaster with extreme financial consequences. Therefore, the airport demanded a coverage of € 900 millions during the period of the tunnel boring process.