Recent and future railway tunnels in Belgium

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RECENT AND FUTURE RAILWAY TUNNELS IN BELGIUM

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INTRODUCTION

In the past decade, two major railway projects have been dominating the building activity in Belgium. A 300 km long high-speed railway network has been constructed, including 2 major tunnels. This infrastructure has now been completed, the last parts waiting to be commissioned for commercial use. Since a few years, additional railway projects, including tunnel construction are started. Among them is the construction of a regional express network around Brussels, an easier connection to the Brussels airport from the North of the country and a new freight connection between the left and right bank of the river Scheldt in Antwerp. The following describes 4 tunnelling projects for new railway connections. The geological conditions and requirements due by stakeholders, such as surrounding property or construction limitations, of these tunnels are different for each case and have influenced the design and building.

ANTWERP NORTH-SOUTH LINK TUNNEL

For more than 30 years plans have been made for a North-South railway link below the city of Antwerp. This is due to the numerous inconveniences of the old configuration of railways in and around the city. All trains coming from the south and passing through the Berchem suburban station had either to continue to the North by the circular track and not travel to the Central Station, or enter the latter and change front side to continue to the Netherlands. This operation causes trains to run late and burdens the circular track, as well as the Berchem to Central Station section, which has 4 tracks and is a bottleneck.

The construction of the high-speed lines in Belgium has been the opportunity to improve this situation, by establishing a direct link between the Central Station and the north end of the circular track at Antwerp-Dam. This crossing is called the North-South link. The most important structure of this link is the twin-tube bored tunnel section of 1228 m length. This bored tunnel section consists of two single-track tunnel tubes, having an outside diameter of 8 m and inner diameter of 7.3 m. The type of tunnel bore machine (TBM), a mixshield, has been chosen according to the soil properties. Most of the tunnels were bored in fine tertiairy sand, containing glauconite substance. When the substance is subjected to mechanical deformation, the fine fraction increases and the glauconite behaves as clay soil.

The tunnel pipes were bored from the North towards the South. Since the southern side of the tunnels is located at the heart of the city, boring from this point would have required the evacuation of about 180 000 m³ of extracted soil, to be transported across the city centre. The Northern starting point is located on abandoned marshalling yards, owned by Belgian Railways Company. From this point, transportation of extracted soil could easily be done either by train or by truck. Subsidence from the boring process occurred from two separate causes. In order to spread the settlements in the whole area of the boring a safety ground water lowering was applied to the whole section. After this, the ground water level reached a constant level corresponding to the tunnel crown. This lowering had some advantages during the process. At the starting and arrival points, the water level needed to be lowered anyway, since this is necessary for beginning and ending the boring process. In addition, the cross-passages and the emergency exit also required ground water level lowering.

Since the boring length is 1228 m only, the entire section would be influenced by these particular points anyway. In addition, the reduction of water pressures also enabled to reduce the bore front pressure and to increase the boring speed. Settlements have been measured during the entire boring process. They have been reported in detail in (Van Bogaert and Vereerstraeten, 2005). The maximum value of settlements after the first boring reached 11 mm, whereas after construction of both tunnels a maximum value of 18 mm was found. An interesting result concerns the ground loss due to the tunnel boring. Again, the first boring caused an average value of 0.41 %, whereas the final value for both tunnels was 0.725%. These data are larger than what is generally predicted or claimed at present. Fig. 1 shows the location of the tunnels within the existing infrastructure network around the city of Antwerp. Fig. 2 displays the inside of one of the tunnels after completion and before installing the railway track.

Fig. 1 : location of Antwerp tunnels

Fig. 2 : Tunnel pipe completed

SOUMAGNE TUNNEL

The 5940 m long tunnel from Vaux-sous-Chevremont to Ayeneux is located on the high-speed section from Liège to Aachen. The Western tunnel exit is located at Vaux in the River Vesdre valley at 90 m altitude, whereas the Eastern end at Ayeneux is located at 210 m altitude, the average slope of the tunnel being 1.7%. The maximum ground cover of the tunnel reaches 130 m. This can be seen in fig. 3. Construction became easier by using an intermediate shaft at Bay-Bonnet, at 2 km distance from the Eastern tunnel end, the ground cover reaching a minimum value of 24 m at this location. As the maximum train speed is limited to 200 km/h on this section, a single tunnel with free cross-section of 69 m² has been designed, which required a total section of 110 m² to be excavated. (Couchard, 2005).

The longitudinal section of the tunnel can be seen in fig. 3, whereas fig. 4 shows a typical cross-section. Concerning the site geology, the tunnel was driven through Westphalia slate for about 3.3 km to the West and Namurian slate for 1.9 km to the East. Near the centre, 650 m of tunnel length had to be bored through limestone. The initial plan was to drill the tunnel, using adequate equipment for the slate sections, whereas explosives were to be used through the limestone. Work could start from 3 locations, namely the West end and in both directions from the Bay-Bonnet shaft.

Lack of the necessary workspace at the East tunnel end, to mount the necessary equipment, initially prevented a fourth starting point. However, as 400 000 m³ had to be evacuated, a fourth drilling point became necessary and the necessary workspace was purchased.

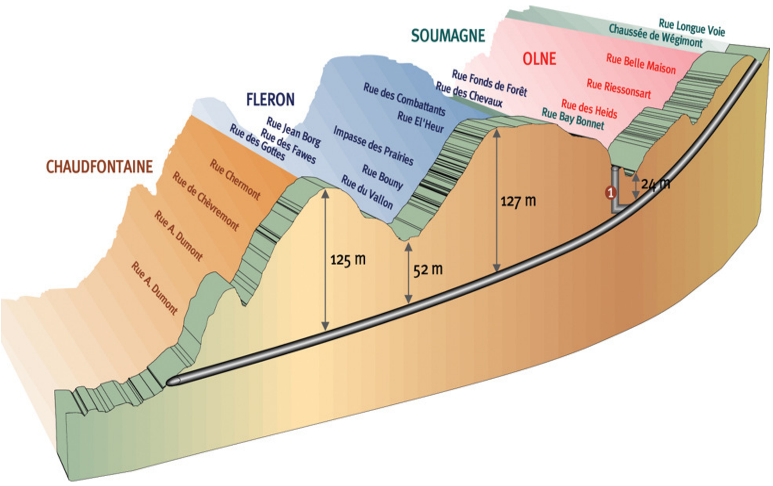

Fig. 3 : Longitudinal section of Soumagne tunnel

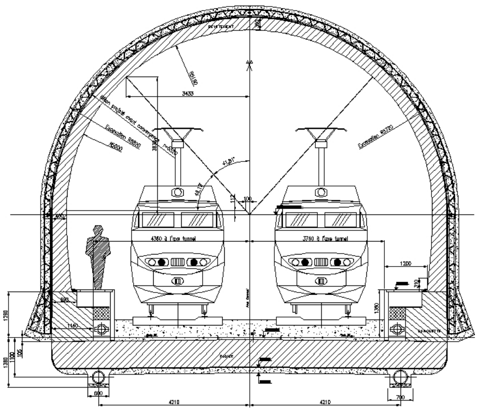

Fig. 4 : Cross-section Soumagne tunnel

During boring of the tunnel, it became clear that the slate soil contains sandstone horizons, having a thickness up to 1 m. Obviously, this reduces the effectiveness of the boring process and it was decided that the use of excavation by explosives should be extended to the whole tunnel length. This required close monitoring of the effect of explosions on the surrounding buildings and estate. Explosions were limited to a daily period between 7AM and 8PM and 12 measuring stations have recorded vibrations due to the explosions and compared them to the comfort requirements of DIN 4150. The detonation of explosives occurred in a sequential manner, allowing 1 daily explosion and boring speed up to maximum 22.5 m. Obviously drilling by explosives requires larger excavation.
The tunnel boring ended in October 2004 and commissioning of the high-speed line from Liège to Cologne is now scheduled by the end of 2009.

DIABOLO TUNNEL

Brussels airport is located at less than 8 km from the city centre, thus offering easy connections to all passengers, travelling to the various activities at the heart of Europe. However, the short distance to the city causes noise disturbance by aircraft and many problems for reaching the airport from the North side, by road congestion. As for public transportation, the airport is easily reached by train, but not from the North of the country, since the airport connections necessarily go via one of the Brussels stations. This situation has inspired authorities to improve the railway and road connection to the airport. The link between the circular motorway and the airport entrance will be improved mainly by building a viaduct above local crossing roads. The largest part of the project is concerned with establishing a direct link between the existing underground station and a new line between Brussels and Mechelen, located at the central reservation of the motorway between these cities (Van Bogaert and De Pauw, 2008). Because of the general plan view of these connections, resembling to the toy called likewise, the project has been given the name Diabolo. The part below the airport itself, crossing 2 of the 3 aircraft runways and several piers and maintenance buildings, has now been fully developed and the work has started at the beginning of November 2007. The bored tunnel section has a length of 1084 m and crosses below the air side. It consists of two bored circular sections of 7.3 m inner diameter, the thickness of the ring segments being 0.35 m. The tunnel boring machine (TBM) is of the mixshield type and has a diameter of 8.2 m and allows boring of curved tunnels. The ground water level is about 2 m higher than the tube crown and slightly rises towards the station. Fig. 5 shows a simulation of the bored tunnel section, seen from the underground station towards the motorway. Initially, the tunnel boring would start from the North side and arrive at the forefront of fig. 5. The TBM would then have been turned and the second tunnel would have been bored from this location towards the North side. This procedure was adopted, since no high-rise cranes or equipment can be allowed in the air side, and turning of the TBM does not require that type of equipment. However, the contractor has negotiated special terms to allow extraction of the TBM at the air side and subsequent transportation to the North side. Hence, the second boring will be in an identical direction as the first one, and the soil and materials installations can be kept operational at the same location.

Fig. 5 : Simulation of future tunnel below Brussels Airport runways

An important obstacle near to the departure location of the bored tunnels is the hangar number 117, used by Brussels Airlines for maintenance of smaller aircraft. As this building is just 60 m away from the starting point of the tunnel boring, and the first section generally is used for fine tuning the boring parameters, the crossing may become critical. Already during the preliminary design and discussions with the client and his consultants for fund raising, the passage below hangar 117 was considered to be a critical phase. The building consists of a steel truss roof, as can be seen in the cross section of fig. 6. The truss structure is simply supported and thus some moderate settlement should be acceptable. However, the aircraft enter through large doors, which can be seen in the rear of fig. 5. These doors are partly suspended tot the roof structure and are partly supported by beams. The building has a foundation of precast concrete piles. The odd situation is that the building Nr 117bis, next to this one, also seen in fig. 5 and occupied by Lufthansa, has no piles and is supported by simple footings. As shown in fig. 6, at some locations, the tunnel crown is at 2 m distance from the pile base. There is a risk that, while boring the tunnels, and subsequent destabilization of the surrounding soil mass, the piles would suddenly collapse. The initial idea was to provide a reinforcement of the pile bases by fraction grouting. Obviously, the vertical pressure can not be active during the passing of the TBM. As an alternative, the contractor proposed to reinforce the piles by passive jet grouting, which can be sufficiently effective for the doors below the beams. However, this requires considering an accidental situation of patch loading on the tunnel lining by the pile forces.

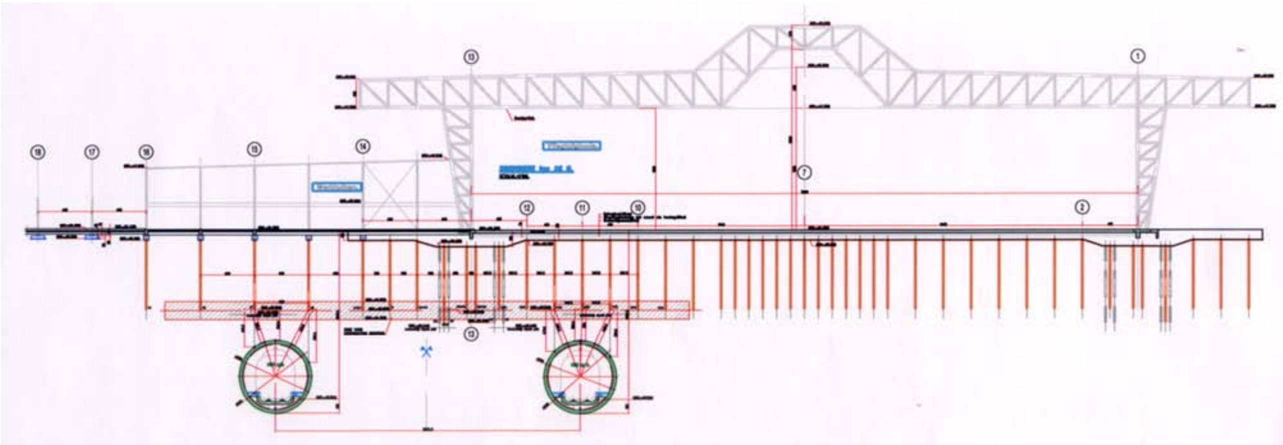

Fig. 6 : Tunnel boring below hangar 117 for aircraft maintenance

Safety of passengers in railway tunnels is an important issue, especially in sensitive locations such as near airports. Hence, cross-passages between both tunnels have been foreseen, as well as a central escape route. The latter connects both tubes to a vertical shaft and staircase and a smaller tunnel, which ends on the existing airport service road. Both the cross-passages and escape shaft must be built without ground water lowering, to prevent large settlement of the facilities. Consequently, the cross-passages are to be built by freezing of the soil and subsequent excavation by the New-Austrian method with sprayed concrete, as for the Liefkenshoektunnel. The freezing unit will be installed outside the tunnels and needs about 30 days before complete frost has become effective.

LIEFKENSHOEK FREIGHT TRAIN TUNNEL

The development of the sea-port of Antwerp on the left bank of the Scheldt, especially following the commissioning of the wet dock, called `Deurganckdok' having a future annual capacity of 7,5 million containers, causes considerable growth of the railway transport in this area. When the exploitation of the new wet dock is fully developed, more than 100 freight trains will have to run between the two river banks, the share of the rail becoming 15% of the total rail transport. Figure 7 shows a scheme of the harbour installations, as well as the location of the principal terminals, inland waterways and of the only rail link in particular, the JF Kennedy tunnel, below the river. The new connection is also indicated, numerous alternatives having been considered (Van Bogaert, 2008). It will connect the parts to the west of the port area directly to the marshalling yards on the right bank. The connection will allow the circulation of freight trains without having to leave the port area. Moreover the distance by rail between the two poles is shortened by 22 km. The operational costs will be reduced considerably. The design had to take account of the presence of a road tunnel established close to the new location. This tunnel, built by immersion in 1980, allows the crossing below the Scheldt, its slopes being too steep to allow railway traffic. During its establishment, the possibility of incorporating railways in a separate opening has been considered. Since railway tracks require more shallow gradients, the formerly built tunnel required the prolongation below the channel harbour called B1-B2, indicated to the centre of figure 7 and parallel with the river. However, at the time of the construction of the first tunnel, this additional investment did not appear to be justified. The geotechnical data have been derived from CPT-tests, drillings, pressiometer tests, as well as from laboratory testing of undisturbed samples. The results of these tests revealed a rather variable composition along the tunnel axis. The stratification of soil layers shows a general downward slope of the West towards the East. On the left bank of the Scheldt top soil layers are men-made during industrial developments. Layers of sand appear on the surface until a depth varying from 4 to 6 m. Below these, quaternary soil is found as soft clay, containing vases and peats. This layer does not occur on Right Bank of the river, since it was constituted in the past by the flood of the estuary of the Scheldt. The compressible layer is followed by a maximum of 6 m fine sand of the tertiary era. It contains silt and a mixture of fine sand and clay. A third subjacent layer having maximum thickness of 6 m consists of fine tertiary sand. The fine sand contains silts and lenses of clay. The subjacent soil horizon from 9 to 14 m of depth also consists of tertiary fine sand. However this sand contains fractions of clay as well as glauconite. On left bank of the river, these sandy layers are definitely less thick. The grounds at large depth consist of Boom clay, a rigid, overconsolidated and fractured tertiary clay. The thickness of this layer exceeds 60m. This clay is saturated with water and behaves as impermeable soil. The connection to be established is mainly in tertiary sands, although, as shown in fig. 8, in its low part below the river, the tunnel passes through the tertiary clay, indicated by the dotted green line. The figure also shows the situation of the starting and arrival shafts of the TBM’s, as well as the part of tunnel, below the Channel of Waesland, currently including space for the future rail link. This existing tunnel is on the left fig.7.

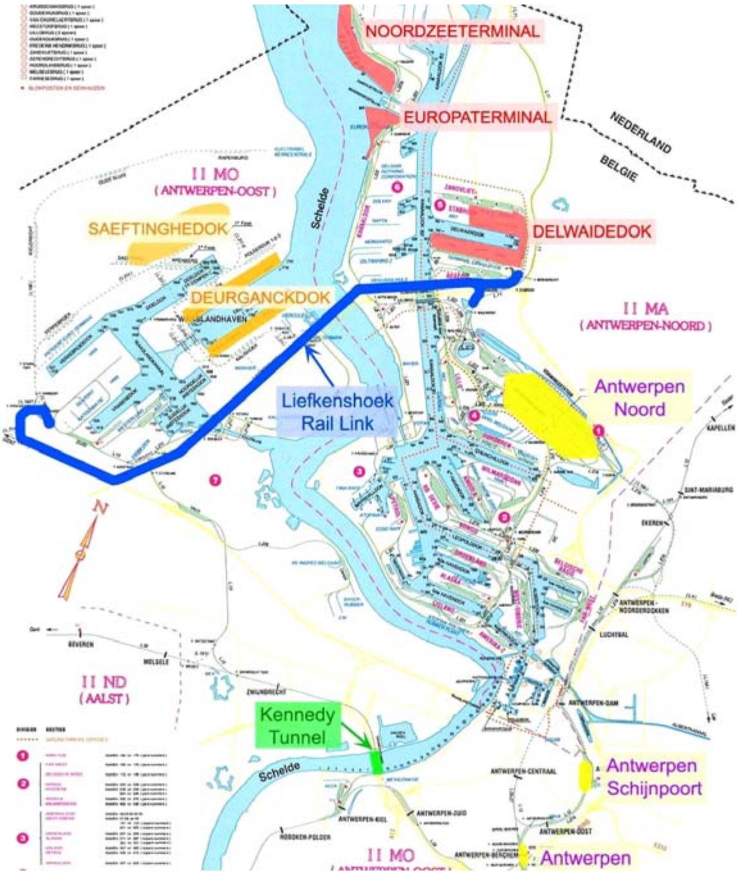

Fig. 7 : Location of Liefkenshoektunnel and connections around Antwerp

The geotechnical tests in the inland waterways, the Scheldt river in Channel B1/B2 giving access to the wet docks of the port, were carried out by means of the floating crane shown. This machine was equipped with the necessary tools for geotechnical data sampling. This had to be carried out without blocking the river traffic, the pontoon having to move when needed urgently. Thus, a close coordination with the manager of the port and the maritime police services was imperative.

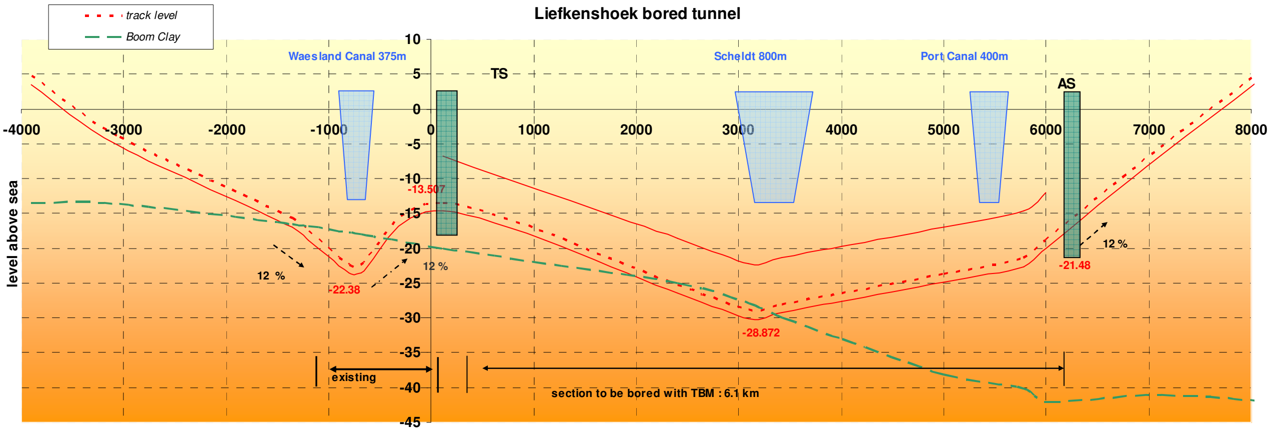

Fig. 8 : Longitudinal profile of Liefkenshoektunnel.

The twin bored tunnel being the major part of the connection, will be passing below the two inland waterways and the industrial areas. Two parallel tunnels are to be bored, having an internal diameter of 7,30 m and rings made up of 7,5 segments, of 0.4 m concrete thickness. These characteristics were determined by the railway gauge, the necessary rail equipment and the water pressure. For safety reasons, cross-passages must be built between both tubes, to allow resuing people in case of calamity in one of the tubes. Some of these passages are located under the inland waterways and must thus be built under important water pressure, after freezing of the surrounding areas. The principle of the construction of the passages is based on Austrian method, namely by excavation of limited parts and subsequent shotcreting in two layers, the sealing being guaranteed by a flexible membrane. The interior concrete lining will be built by casting in formwork. In total, 13 cross-passages have to be built. These passages are insufficient to provide access for fire brigades, or to permanent power supply and smoke extraction channels. Hence, at an average distance of 600 m 11 access shafts are provided. Six of these shafts contain the fire extinguishing equipment, complying to the hot foam system.
Special attention is given in the passing of the TBM's below the river Scheldt and the harbour channel. Geotechnical recognitions showed that there are vases on the river bottom. At present, the exact depth of these vases is uncertain. It is expected that the minimum boring pressure will be close to the necessary maximum value to avoid boring face destabilization. Obviously, this situation does not make it possible to change from the mode mud pressure to air pressure. Thus, replacement of the boring tools on the cutting wheel, or access to the boring chamber, will be impossible during the crossing below the major part of the Scheldt. The passage of the TBM's below the harbour canal is even more critical. Indeed, the bottom of the channel being on the level -12.58 m, the track alignment is rising as steeply as possible to the depth of -22.14 m at this location. Hence, in the final situation the sand protection above the top of the section of the tunnel would be limited to 3 m. During the passage of the TBM's this would result in the rather unsafe condition where the bore front pressure is amply higher than the soil resisting pressure. Increasing safety conditions to an acceptable value would require filling the canal by 7 m of sand. However, a temporary backfill of 5 m is the maximum acceptable for the port authority. In addition, distinction can be made between the large vessel canal width, which extends only on 120 m and the remainder section. Rising 5 m the canal bottom, requires that 4000 ships must be diverted to other harbours. Should the canal bottom rise with 2 m only, the number of ships to be diverted is only of 4 per annum. In any event, after work, the bottom of the channel must reach on its original level. Hence, the problem will be solved by placing a concrete slab on the canal bottom, which also serves as anchor protection and will form shelter during TBM boring. This slab of 2 m thickness replaces at least 3 m of sand and is

thus still insufficient to guarantee the stability of the face of drilling. Consequently, in phase of passage of the TBM's, the slab is covered with an additional sand bed of 2 m. This overburden can be removed after tunnel boring. A cross-section of the situation is shown in fig. 9.

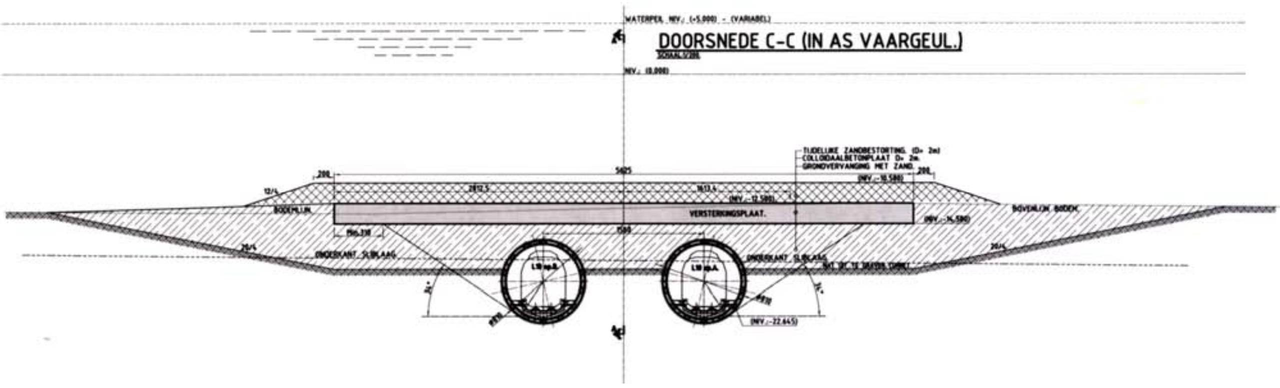

Fig. 9 : Cross-section through harbour canal with stabilising concrete slab

CONCLUSIONS

Four different tunnelling railway projects in Belgium have been presented. The conditions for building these tunnels show large variety. The Antwerp North-South link tunnel has been constructed below a major city, controlling of settlements being the main issue. During the construction of the Soumagne tunnel, driven through various rock and stone formations, using the Austrian method, restrictions on environmental disturbance by the explosions, has been the main concern. The variety of geology and the building time required an additional boring starting point.
The beginning of the boring of Diabolo tunnel below Brussels airport, is difficult, due to immediate vicinity of the runways and the aircraft maintenance hangar. In addition, sandstone formations may influence the boring process and working in the airside of an international airport requires heavy security measures, interfering with normal building activity. The detailed design and construction of the Liefkenshoek tunnel for freight trains have started in November 2008. The two main issues seem to be the crossing of TBM's below the river and the harbour canal. Adequate measures are believed to be taken to allow successful boring of these tunnels.

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