Geotechnical processes for security shafts of the Premetro tunnel under the River Scheldt at Antwerp

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SUMMARY

The real hydroshield tunnelling for the Antwerp Premetro tunnels under the River Scheldt started in October 1986 and finished April 1st, 1988.

The twin tubes are situated between two stations over a length of about 1,000 m of which 375 m is under the River Scheldt. The maximum depth of the tunnels is 32 m below average high water level.

In the quay wall vicinity, two vertical extraction shafts were constructed to a depth of about 31 m. These shafts were separately connected with the tunnels, to ensure adequate smoke evacuation in case of fire.

Several innovative techniques were applied, such as groundwater lowering, shaft construction with prefabricated tunnel segments, injections and very high pressure grouting were carried out in the fill or disturbed quaternary, and the tertiary sand and the fissured tertiary clay (called 'Boom'-clay). The connection of the shafts with the tunnels was achieved by the thrustjacking method.

The article does not only broach the application of these techniques but also the influence on the quay area, comprising an underground gas pipeline and the flood embankment wall. This influence was checked by means of extenso-meters.

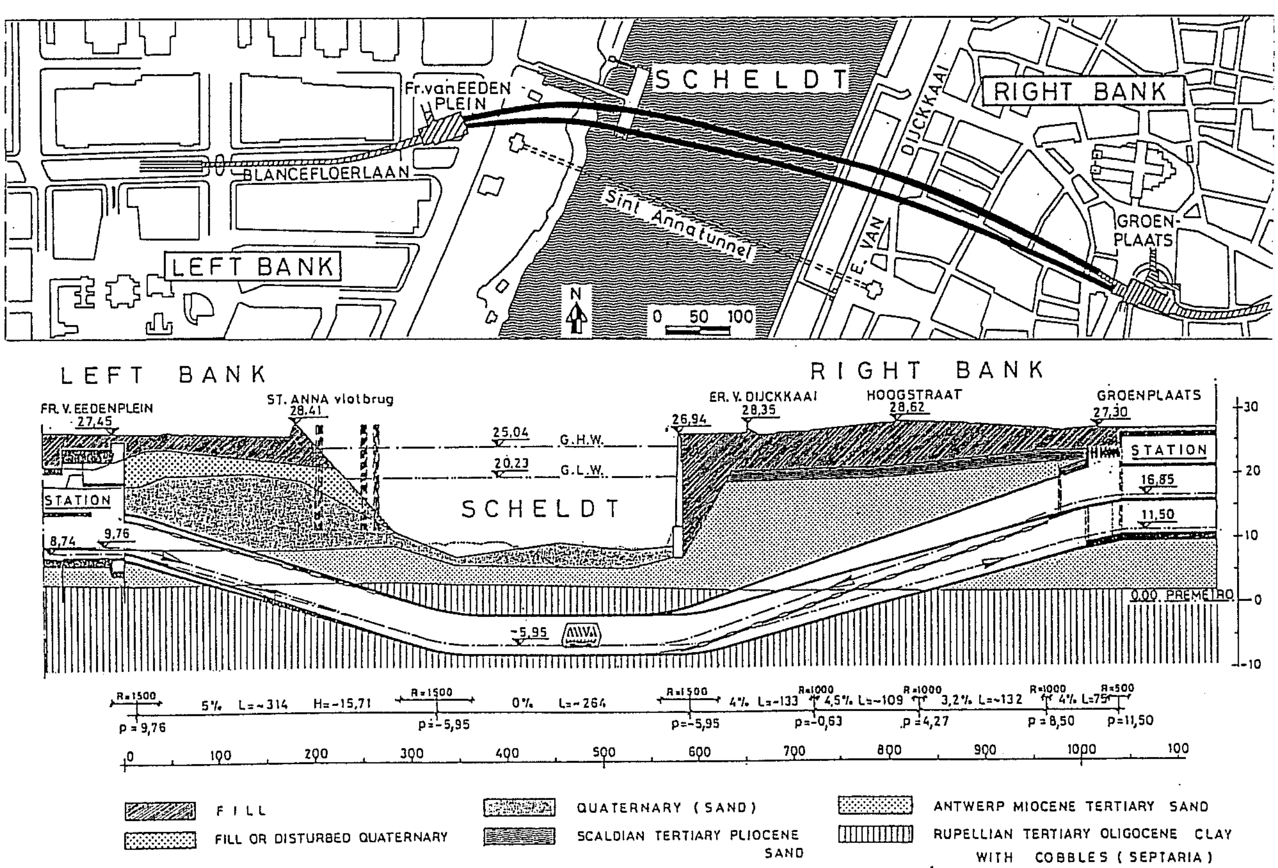


Fig. 1 : Location and vertical alignment of the new PREMETRO tunnel / Longitudinal geological section

1. INTRODUCTION.

At Antwerp a new PREMETRO tunnel has been constructed in order to link the old town center on the Right Bank of the River Scheldt to the residential area on the Left Bank. This in addition to the existing tunnels (2 road tunnels, a railway tunnel and a pedestrian tunnel).

Traffic studies have shown that the creation of a tramway tunnel between Groenplaats and F. van Eedenplein was the most adequate solution to meet the present needs (figure 1). From an economic point of view, the costs involved in building a tramway tunnel were considerably lower than those involved in other similar alternative solutions.

The new Scheldt tunnel consists of two adjacent tubes each having an internal diameter of 5.70 m. Both tubes were constructed using the shield method. The hydroshield has an outer diameter of 6.80 m. The total length of the single track is 2,010 m of which 2 x 375 m is situated under the river bed. The superelevation is a max. 5.5 %. The horizontal tunnel section under the river is about 32 m below mean high water level. The effective protective soil cover above this tunnel section is about 7 m. On the Right Bank the tunnels were situated at about 5 m below the existing quay wall on the Right Bank.

In the quay wall vicinity, two vertical extraction shafts were constructed to a depth of about 31 m. These shafts were separately connected with the tunnels, to ensure adequate smoke evacuation in case of fire.

2. SOIL CONDITIONS.

From an extensive soil investigation with borings and static cone penetration tests it appeared that in the vicinity of the quay wall on the Right Bank the Substrata have the following geological characteristics (fig. 1).

Fill.

Immediately behind the quay wall fill was found down to its foundation level. Further behind the quay wall a top layer of fill and disturbed soil with a thickness of about 7 m was present. The fills were very heterogeneous and consisted of sands, stones and mud.

Quaternary.

In front of the quay wall a mud layer was found on the bottom of the river together with some 3 m of quaternary sands.

Tertiary.

- Scaldian Pliocene Tertiary; under the Right River Bank pliocene glauconitic fossiliferous sand was encountered from a depth of about 7 m below street level down to a depth of about 9 m.
- Antwerp Miocene Tertiary; this dense layer of alluvial sands containing hard shells and shell pieces, was found to a depth of 25 m below street level.
- Rupelian Oligocene Tertiary (Boom type clay); from a depth of about 25 m down to a depth of more than 75 m a stiff fissured overconsolidated clay was found. Directly under the quay wall on the Right Bank the tunnels were completely situated in this clay layer.

3. GENERAL DESCRIPTION OF THE SECURITY SHAFTS.

Considering on the one hand the 1,000 m long Scheldt twin tube tunnel with gradients up to max 5.5 % and on the other hand the use of tramcars and rapid tramcars by which fire-risk is not excluded, the Premetro Study Office has carefully investigated the problem of the safety and passenger evacuation.

Bearing this in mind the tunnel is coated with a fire resisting and acoustical layer based on rockwool fibres. The layer has a minimum thickness of 20 mm and a fire resistance of Rf = 2 h.

On the other hand, some special requirements are stipulated for the cables of the electro-mechanical equipment in order to restrict flame extension. Moreover, two vertical security shafts are constructed at a distance of about 1/3rd of the tunnel length, reckoned from the Groenplaats Station (see figure 2).
These 31 m deep vertical shafts with both an inner diameter of 2 m are connected separately with each Scheldt tunnel and run at street level into a common ventilation room.
An extraction ventilator with an output of 200,000 m^3/h is installed for each tunnel. These extraction ventilators together with the extractor ventilator in the stations vicinity, will admit to force up the existing natural ventilation in the Scheldt tunnels; this will facilitate the passenger evacuation through a smoke proof emergency exit in case of fire. Moreover the security shafts will allow a prompt intervention of the fire brigade.

EXTRACT SHAFTS

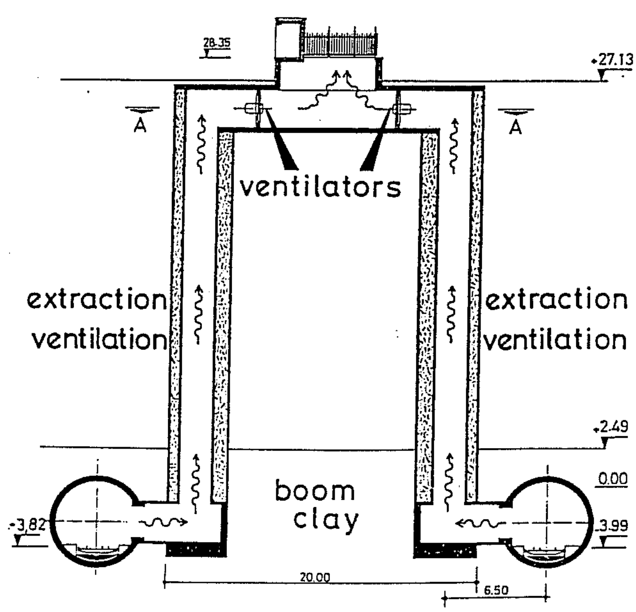


Fig. 2 : Cross section of the extract shafts

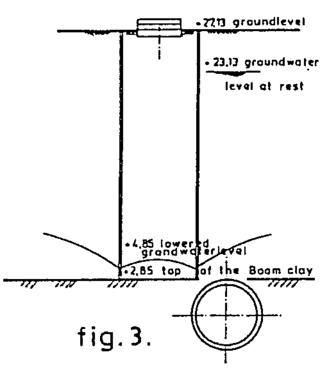
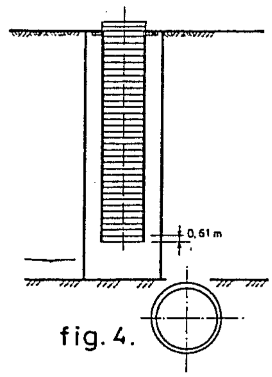


fig.3.



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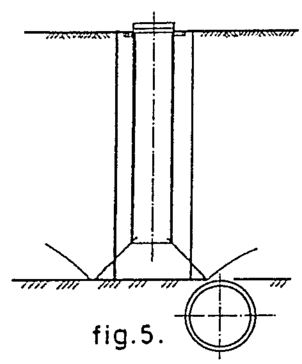

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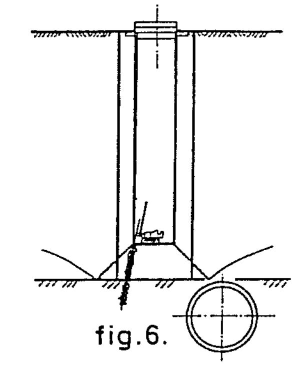

fig.6.

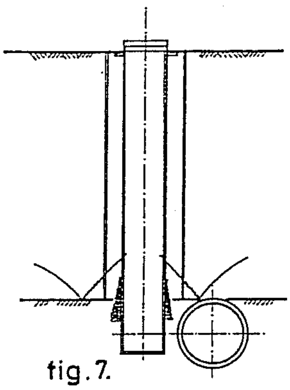

fig.7.

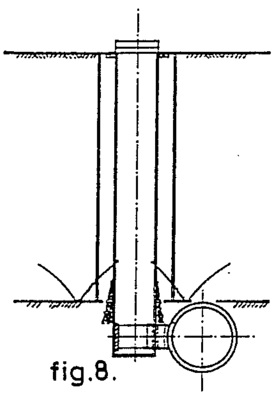

fig.8.

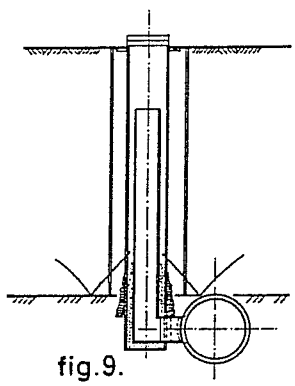

fig.9.

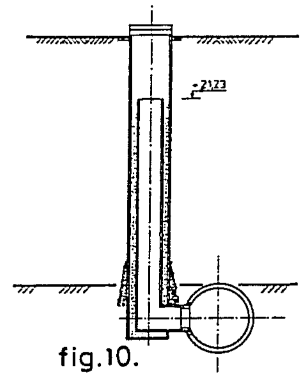

fig.10.

4. EXECUTION METHOD.

An execution method with several innovative techniques has been proposed by the n.v. Smet-Boring for the installation of the extraction shafts.
This method can be summarized as follows :

- General groundwater lowering to about 2 m above the top of the Boom clay layer (fig. 3);
- Mechanical excavation in passes of 0.61 m and installation of a temporary lining with segments of precast concrete, till 1.50 m above the lowered groundwater level (fig. 4);
- Installation of an additional groundwater lowering system (fig. 5) and of vertical groutcolumns sealing the transition zone between the Thertiary sands and the Boom clay (fig. 6);
- Further mechanical excavation in passes of 0.61 m and installation of a temporary lining with segments of precast concrete, till a depth of about 31 m (fig. 7);
- Horizontal boring following the pipe jacking method (fig. 8);
- Installation of a permanent lining of reinforced concrete provided with a continuous steel plate (fig. 9);
- Opening of the tunnel wall and installation of a ring beam of reinforced concrete (fig. 10);
- Excavation with "Berliner Bauweise" of the ventilation room.

5. GROUNDWATER LOWERING.

Before any excavation was started, 6 discharge wells were installed around each shaft. They consisted of a P.V.C.-tube with an inner diameter of 160 mm and a filter length of 1 m situated just above the top of the Boom clay layer. The boreholes with a diameter of 0.40 m were drilled by the direct flush method.

According to the calculations a groundwater lowering to about 2 m above the top of the Boom clay layer was expected. However shortly after starting the groundwater lowering system it seemed that the expected water level could not be obtained and 11 additional discharge wells had to be installed in order to obtain the projected water level.
After the shaft was lowered to 3.5 m above the top of the Boom clay layer, 24 additional filter elements were installed from the bottom of each shaft. They consisted of a P.V.C.-tube with an outer diameter of 50 mm and a filter length of 0.50 m, situated just above the top of the Boom clay layer. The boreholes were installed manually under an inclination of 40° with the vertical. All filter elements were connected to a ring pipe. Within this pipe a negative pressure of about 7 m water height was installed by means of vacuum pumps.

With the help of this additional filter elements, the groundwater level could be lowered to less than 0.50 m above the top of the Boom clay layer.

6. EXCAVATION AND TEMPORARY LINING.

The excavation of the soil was carried out in passes of 0.61 m by means of an hydraulic excavator provided with a vertical telescopic arm. The walls were trimmed manually in order to limit the thickness of the zone between the soil and the temporary lining to a few centimeters.

Each temporary lining ring consists of 6 segments and a key, which were connected to each other by means of bolts (fig. 11). The lining has an inner diameter of 3.60 m and an outer diameter of 3.96 m. These dimensions have been chosen as a function of the horizontal boring which had to be performed from the bottom of the shaft.

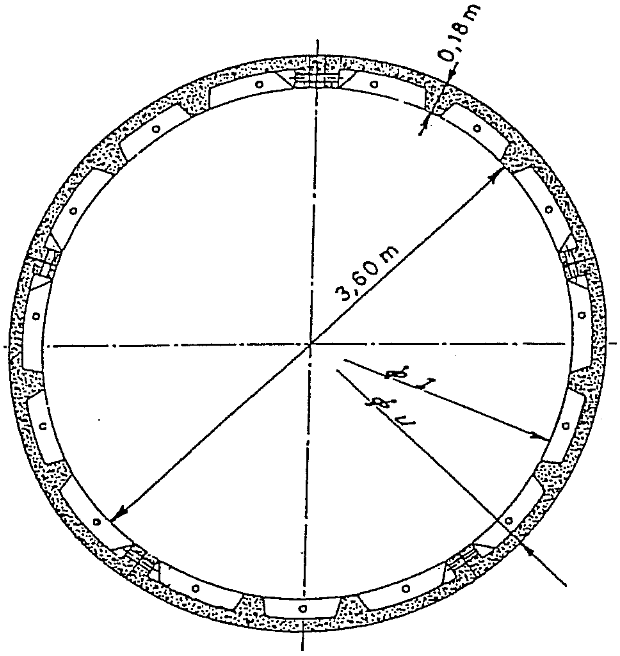

Fig. 11 : Typical section through the temporary lining of the shaft

The elements were hung on the last installed ring by means of vertical bolts. The individual segments were also bolted together in a horizontal direction. Before starting the excavation, a reinforced concrete slab has been installed around each shaft. This slab was necessary to fix the first lining elements during their installation and before any injection could be performed.

The zone between the soil and the temporary lining was injected with cementgrout at regular intervals. This was necessary to transmit the weight of the temporary lining to the soil by means of friction and to avoid that a too large weight had to be transferred by the vertical bolts.

At the location of the second shaft a six metres thick layer of hardcore was encountered. It was necessary to inject this layer with cement-grout before the excavation could be started.

7. VERTICAL GROUT COLUMNS.

In order to create a barrier for the remaining water just above the top of the Boom clay layer, a series of grout columns were installed by means of Very High Pressure grouting (fig. 12).

In the first stage a series of rods were introduced down to the requested depth by means of direct flush. The lower end of the rods were equipped with a drilling head and a special ejector valve carrying two nozzles orthogonal to the rod axis. In the second phase the rods are extracted with simultaneous injection. The grout is injected through the nozzles under a pressure of about 40 MPa. The material in place is intensively mixed with the grout to form a mortar. By varying the rotation velocity and the vertical extraction speed it is possible to obtain volumes of treated material of the desired shape and dimension. After hardening of the grout a solid column is obtained.

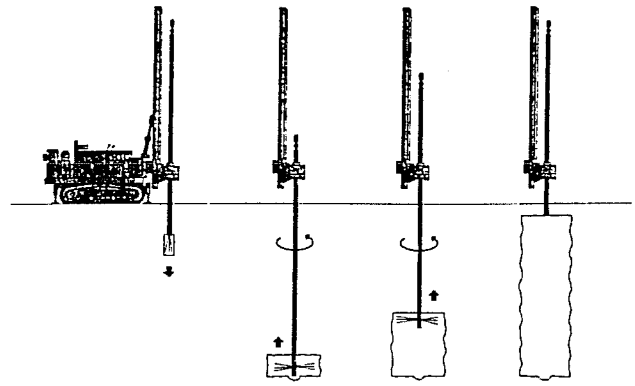

Fig. 12 : Installation method of consolidated soil columns by V.H.P.-grouting

The grout columns were installed from about 2 m above the top of the Boom clay layer to 2.5 m underneath this layer (fig. 8). Around each shaft 28 columns were installed. The columns are secant.

As there was no experience available with Very High Pressure grouting in stiff layers an extensive preliminary test program was performed in an old clay pit where the clay was excavated for the fabrication of brick stones. From the results of these tests it could be concluded that the proposed method was appropriate for the creation of a sealing within the transition zone between the Tertiary sands and the Boom clay.

8. HORIZONTAL BORING.

After reaching the bottom level of the shaft a reinforced concrete slab with a thickness of 0.50 m was installed in order to create a temporary plug and to facilitate the installation of the pipe jacking equipment.

Then the temporary lining of the shaft was strengthened over a height of about 5 m by means of shotcrete. Additional vertical reinforcement bars were also placed within the shotcrete layer. This strengthening was necessary to limit the deformation of the shaft lining when a part of it was broken off, for the start of the horizontal boring.

The horizontal boring was performed with tubes of reinforced concrete having an outer diameter of 2.96 m and an inner diameter of 2.50 m and provided with a steel core and a double sealing in the joints. These tubes were pushed into the soil with simultaneous excavation inside. The first tube was provided with a special cutting shoe in order to obtain a close contact between the horizontal boring and the tunnel.

By providing elastic joints between the two tubes of the horizontal boring, slight differential settlements can be accepted between the shaft and the tunnel.

After reaching the tunnel a temporary plug was placed between the cutting shoe and the tunnel. Some reinforcing bars were drilled in the tunnel elements and fixed to the cutting shoe. Afterwards a shotcrete layer was placed over these bars.

9. PERMANENT LINING AND OPENING OF THE TUNNEL WALL.

After finishing the horizontal boring a prefabricated T-shaped element was lowered into the bottom of the shaft and fixed to the tubes of the horizontal boring. These connected the horizontal boring with the permanent vertical shaft. The permanent vertical shaft has an inner diameter of 2 m and an outer diameter of 2.30 m. All the elements are of reinforced concrete and are provided with a steel core. These are welded to each other on the site in order to obtain perfect watertightness. The area between the temporary and permanent lining was filled with a sand-cement mixture.

When the permanent lining was installed, the tunnel wall was opened and a ring beam of reinforced concrete installed. During this operation the tunnel was strutted with a special construction containing flat jacks in order to resist any movement of the tunnel wall.

10. MEASUREMENTS.

During the entire construction of the extract shaft measurements have been performed by means of vertical extensometers installed at different levels. The maximal observed settlement amounted to 7 mm.

When the first shaft was excavated a few meters into the Boom clay the vertical movements of the bottom shaft were measured during a week-end, in order to check the swelling of the clay. Over a period of almost 3 days a maximum uplift of 3.2 mm was observed.

11. CONCLUSIONS.

In rather difficult soil conditions two extraction shafts have been constructed to a depth of about 31 metres.

By introducing several innovative techniques, such as extreme groundwater lowering, shaft construction with prefabricated tunnel segments, injections and Very High Pressure grouting, a safe and economic solution has been obtained for the construction of these shafts.

Measurements performed throughout the construction period of the shafts indicated that rather small settlements took place.