QUAY WALL ANCHORING AND RESTAURATION ON THE RIGHT BANK OF THE RIVER SCHELDT AT ANTWERP

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SUMMARY

The PREMETRO link to the left bank of the River Scheldt consists of two tubes with an inner diameter of 5,70 m, executed by means of a hydroschield. At the right bank these tunnels are situated about five meters underneath the foundation level of the existing quay wall, installed in 1881 according the compressed air caisson method.

In order to prevent this quay wall from sliding towards the River Scheldt it was decided to install prestressed ground anchors of 510kN at 0,75 m above mean low water level. These anchors with a length of 43 m were executed from a submersible drilling chamber suspended under a self-propelled jack-up platform.

During the drilling of holes through the quay wall for the installation of extensometers, it appeared that the masonry of the quay wall was in very bad condition. So a complete restoration of the quay wall had to be performed. In a first stage the deteriorated concrete within the working chamber of the former caisson was treated by means of Very High Presure grouting. Afterwards the masonry was injected with cement-grout and strenghtened with four rows of Gewi-bars. In a last stage the joints between the quay wall elements were treated by means of V.H.P.-Grouting in order to guarantee the sand-tightness of these joints.

1. INTRODUCTION

At Antwerp a new PREMETRO tunnel is now under construction 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).

Performed 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 in connection with other similar alternative solutions.

The new Scheldt tunnel consists of two adjacent tubes each having an internal diameter of 5,70 m. Both tubes are constructed following the shield method. The hydroshield has an outer diameter of 6,80 m. The total length of the single track is 2010 m of which 2 x 375 m is situated under the river bed. The superelevation is max. 5%. The horizontal tunnel section under the river is about 32 m under mean high water level. The effective protective soil cover above this tunnel section is about 7 m. On the right bank the tunnels are situated at about 5 m below the existing quay wall on the Right Bank.

An extensive stability study showed that for this quay wall the safety factors against the bearing capacity, the overturning and especially the sliding were insufficient. In order to ensure the stability of the quay wall (elements nrs 23 and 24) during the underpass of the shield it was initially decided to install 18 prestressed ground anchors with a capacity of 75 ton.

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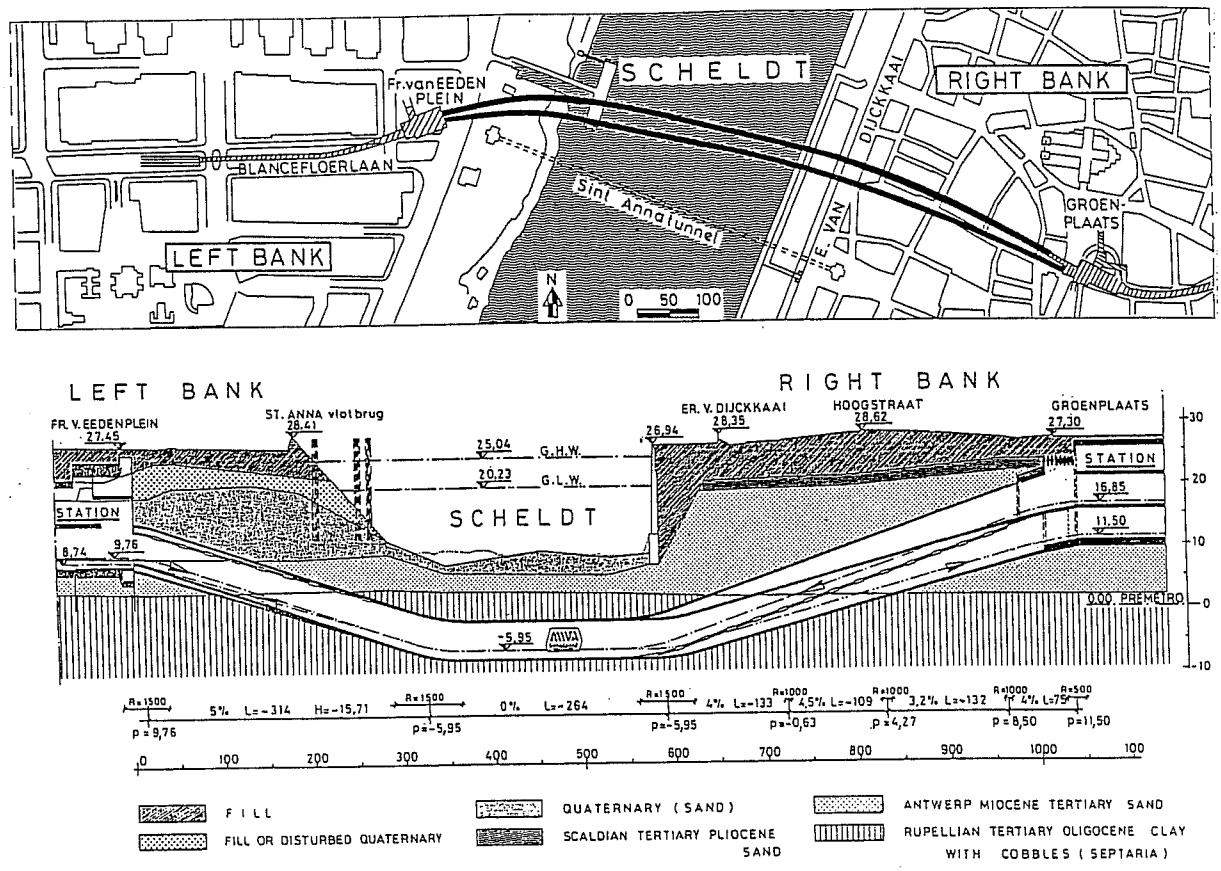

Fig. 1 : Location and vertical alignment of the new PREMETRO tunnel
Longitudinal geological section

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 (figure 1)

FILL

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

QUATERNARY

In front of the quay wall a mud layer is found on the bottom of the river and also some 3 meter of quaternary sands.

TERTIARY

- Scaldian Pliocene Tertiary = under the Right River Bank pliocene glauconitic fossiliferous sand is encountered from a depth of about 7 m b.l.s.down to a depth of about 9 m.
- Antwerp Miocene Tertiary = this dense layer of alluvial sands containing hard shells and shell pieces, is found up to a depth of 25 m b.l.s.
- Rupellian Oligocene Tertiary (Boom type clay) = from a depth of about 25 mdown to a depth of more than 75 m a stiff fissured overconsolidated clay is found. At the spot of the quay wall on the Right Bank the tunnels are completely situated in this clay layer.

3. CONSTRUCTION OF THE EXISTING QUAY WALL

The existing quay wall on the Right Bank has been constructed some 100 years ago in the periode 1877-1887, applying the compressed air caisson method. Steel caissons with a length of 25 m, a width of 9 m and a height of 6 m have been floated into the location of the quay wall. At the base of these caissons a working chamber with a height of 2 meters was foreseen (figure 2).

After positionning, the caissons were lowered onto the bottom of the river and ballasted with masonry and concrete. Then the sinking operation was continued by the compressed air method. As the ciasson descended air pressure was maintained in the working chamber at the value of the hydrostatic pressure in the porewater at the level of the cutting edge. Simultanously soil was removed within the working chamber and the quay wall was build with masonry and concrete. After reaching the foundation level the working chamber and the different air shafts were filled with concrete.

From the construction reports of the caissons nrs 23 and 24, situated above the tunnel axes, it can be deduced that the whole sinking operation tooke 4 to 5 days of continuous work.

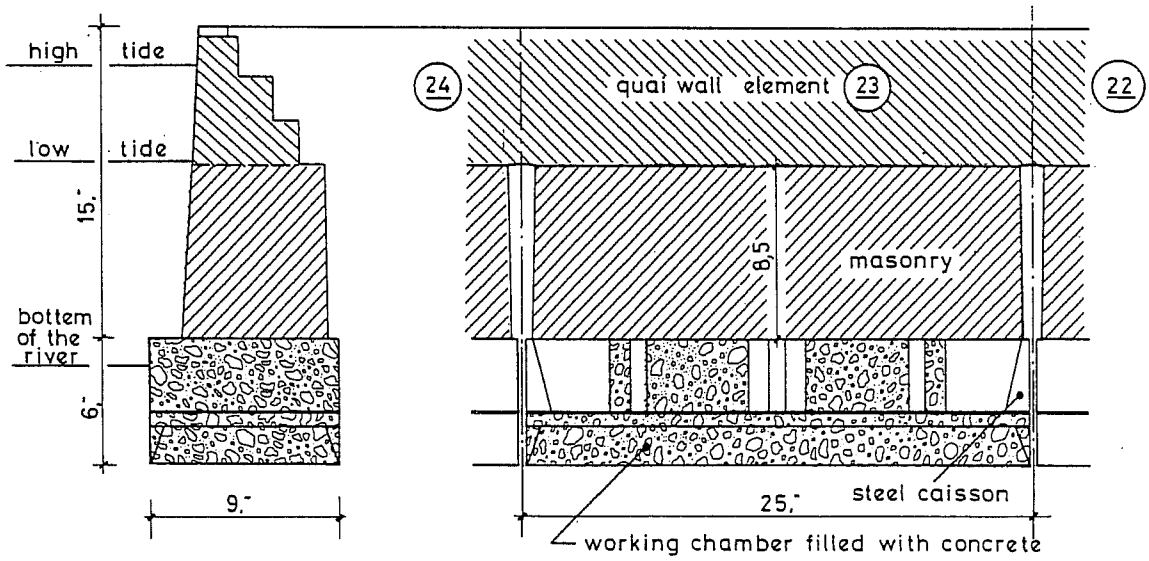

Fig. 2 : Cross-section of the existing quay wall
Situation during construction

4. INVESTIGATION OF THE EXISTING QUAY WALL

When making vertical boreholes for the installation of extensometers underneath the quay wall it was observed that the masonry and concrete were in a very bad condition. The concrete within the working chamber was completely deteriorated and consisted almost only of loose stones. Important cavities were detected immediately underneath the steel plate. Moreover the masonry and concrete above the working chamber had also cavities and contained sludge layers.

In order to check the quality of the masonry a core drilling has been performed in each quay wall element and different destructive borings with registration of the drilling parameters were performed :

- rate of penetration (V)
- pull-down (PD = axial force on the drilling tool)
- flushing fluid flow rate or water level in the reservoir
- flushing fluid pressure (FP)

The results of these borings confirmed the prior observations. The example on figure 3 shows the transition between a zone with masonry in good condition and a zone with highly deteriorated masonry.

As the installation of the tramway tunnels could cause settlements stresses, which could cause on their turn damages to the already deteriorated inner quay wall structure, it has been decided to strenghten the inner structure of the quay wall by means of injections and the placing of vertical reinforcement bars.

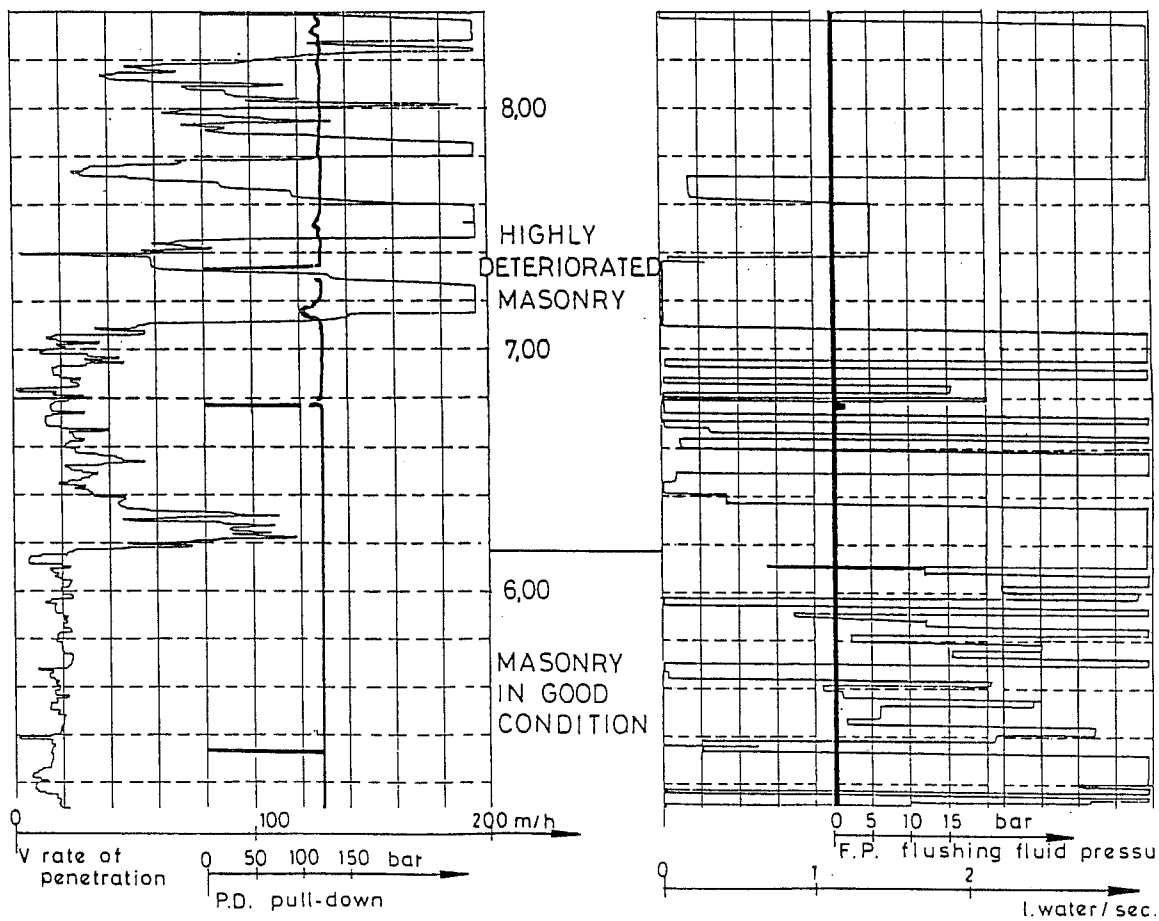

Fig. 3 : Typical results of a destructive boring with registration of the drilling parameters

5. INSTALLATION OF THE GROUND ANCHORS

In order to ensure the stability of the quay wall during the passage of the shield it was decided to install 18 prestressed ground anchors with a capacity of 75 ton.

Due to the bad quality of the masonry preference has been given to limit the localised forces on the masonry. Therefore the number of prestressed ground anchors was increased from 18 to 26. The capacity of the anchors was decreased from 75 ton to 52 ton. The intermediate distance between the anchors was decreased from 2,75 m to 2,00 m.

In order to reduce as much as possible the additional vertical stress on the foundation of the quay wall, the ground anchors had to be installed with a very small inclination.

This was obtained by execute the anchors from a submersible drilling chamber (Bathyscaphe) suspended under a self propelled jack-up platform. (figure 4)

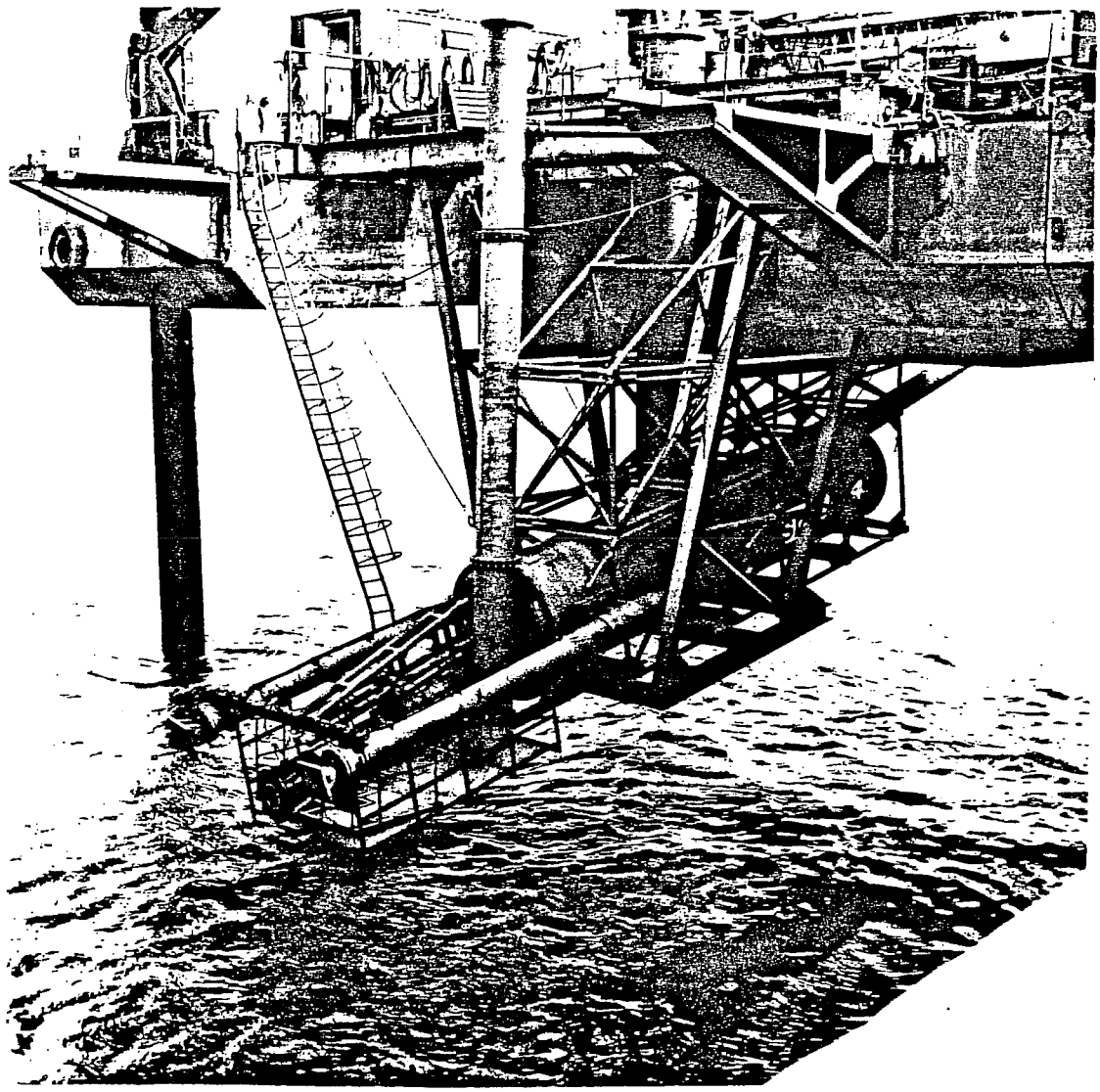

Fig. 4 : Drilling chamber (Bathyscaphe) suspended under a self propelled jack-up platform (Photogr. G. COOLENS N.V.)

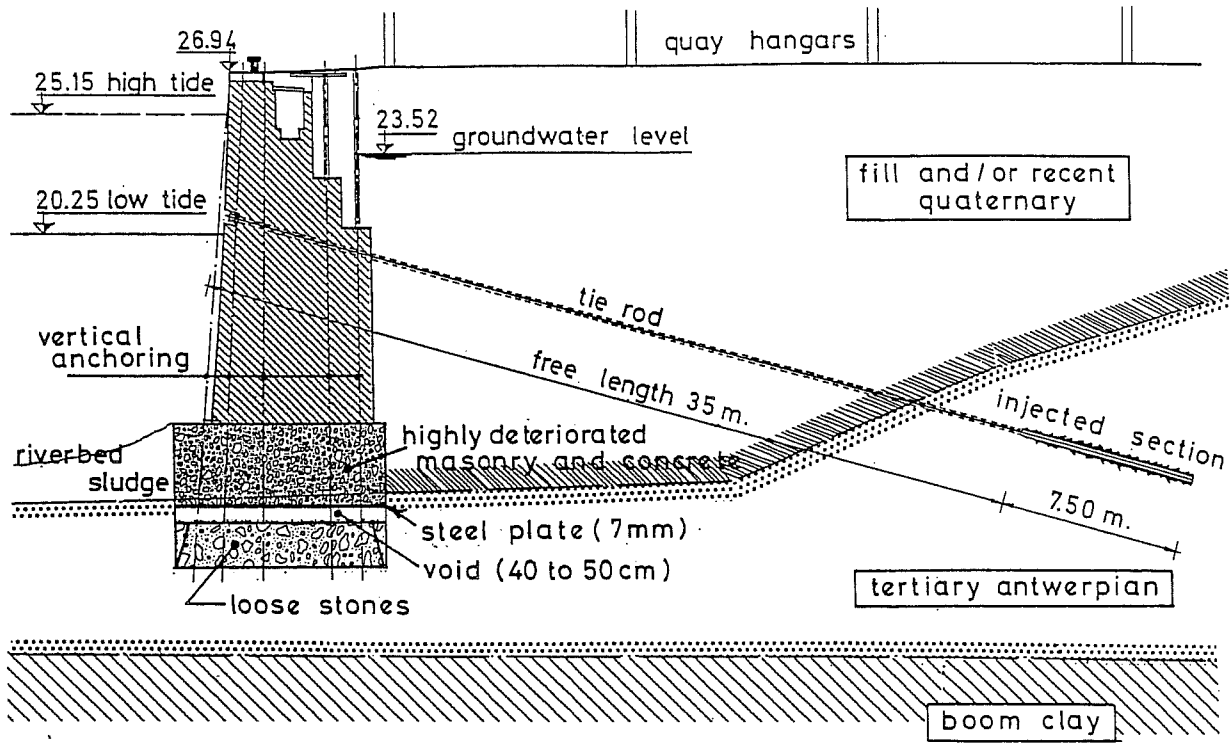

Fig. 5 : Quay wall protection : Ground anchors and strenghtening of the inner structure

The drilling chamber is connected to the jack-up platform by three shafts, one for the evacuation of the drilling mud, onefor the access of the driling crew and one for supply of materials. All driling operations are performed under normal atmospheric pressure. The only constraints are formed by the rather limited space within the drilling chamber.

The installed anchors have an inclination of 15° and the anchoring point is stiuated 0,75 m above mean low water level. The total length of the anchors is 43 meters of which 9 meters are grouted (figure 5).

The installation of the ground anchors proceeds as follows =

- positioning of the jack-up platform
- pushing out of a telescopic guide tube onto the front of the quay wall and installation of a sealing mass
- destructive drilling through the quay wall with a down the hole hammer
- double tube flush boring until the final depth
- extraction of the inner tubes filling of the borehole with cementgrout and installation of the prefabricated ground anchor
- extraction of the outer tubes in passes of 2 meters and injection of the anchor bulb.

The anchor head has been installed within the masonry itself.

Prestressing of the anchors has been performed after the complete restauration of each quay wall element.

6. STRENGHTENING OF THE INNER STRUCTURE OF THE QUAY WALL

The strenghtening of the inner structure of the quay wall preceeded as follows (figure 6).

- Drilling of vertical or slightly inclined boreholes (diameter approx. 150 mm) through the masonry and through the steel plate of the working chamber.

- Washing out of the cavities within the masonry with the help of a high-pressure water-jet, this in order to eliminate as much as possible all sand and clay particles within the cracks and cavities of the masonry.

- Consolidation of the deteriorated concrete within the working chamber by means of Very High Pressure grouting. In a first phase a series of rods is introduced down to the requested depth by means of destructive drilling. The lower end of the rod series is equipped with a drilling head and a special ejector valve carrying one or more 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 pressures between 20 MPa and 80 MPa. The material in place is intensively mixed with the grout to form a mortar. By varying the rotation velocity and the vertical extraction velocity 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 (see fig. 6).

  Special precautions have been taken to avoid uplift of the quay wall during the grouting operation. The extensometers underneath the quay wall have been measured continuously and an alarm system has also been installed.

  Considerable settlements have not been observed during the grouting operations.

- Filling of the voids underneath the steel plate of the working chamber.

- Cleaning up of the boreholes, partially filled with grout after the V.H.P.-grouting and the filling of the voids underneath the steel plate.

- Filling of the boreholes with cement grout and introduction of reinforcing Gewi-bars diam. 50 mm (vertical anchoring).

- Installation of a packer at the top of the boreholes and injection of the masonry.

Core drillings and destructive borings with registration of the drilling parameters have been performed to check the quality of the injections.

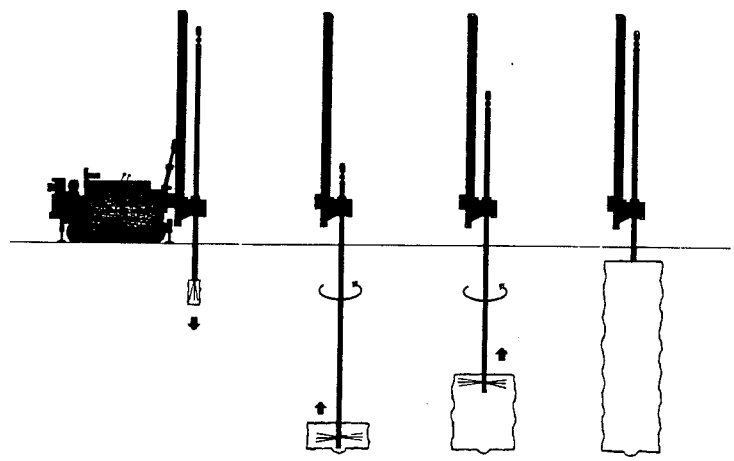

Fig. 6 : Installation method of consolidated soil columns by V.H.P.-grouting

7. TREATMENT OF THE JOINTS BETWEEN THE QUAY WALL ELEMENTS

To avoid differential settlement between adjacent quay wall elements could cause a soil collapse through the joints between these quay wall elements, it has been decided to create a sand tight plug within this joints.

In a first stage the exact contour of the masonry had to be determined by means of CPT tests and drillings. The width of the joints varied between 1,50 m and 2,00 m. Within this joints a mixture of mud, bricks and sand has been found.

Afterwards the sand tight plug has been installed by a combination of a primary injection with polyurethane and the installation of cement grout.

Columns according to the V.H.P.-Grouting method (figure 7).

The preliminary injection with polyurethane was necessary to fill the existing voids within the joints. In this way a provisonal plug was created and the loss of grout during the formation of the grout columns following the V.H.P.-grouting method could be avoided.

Two rows of grout columns have been installed. These columns have a diameter of ca. 50 cm and were installed at intermediate distances of about 40 cm.

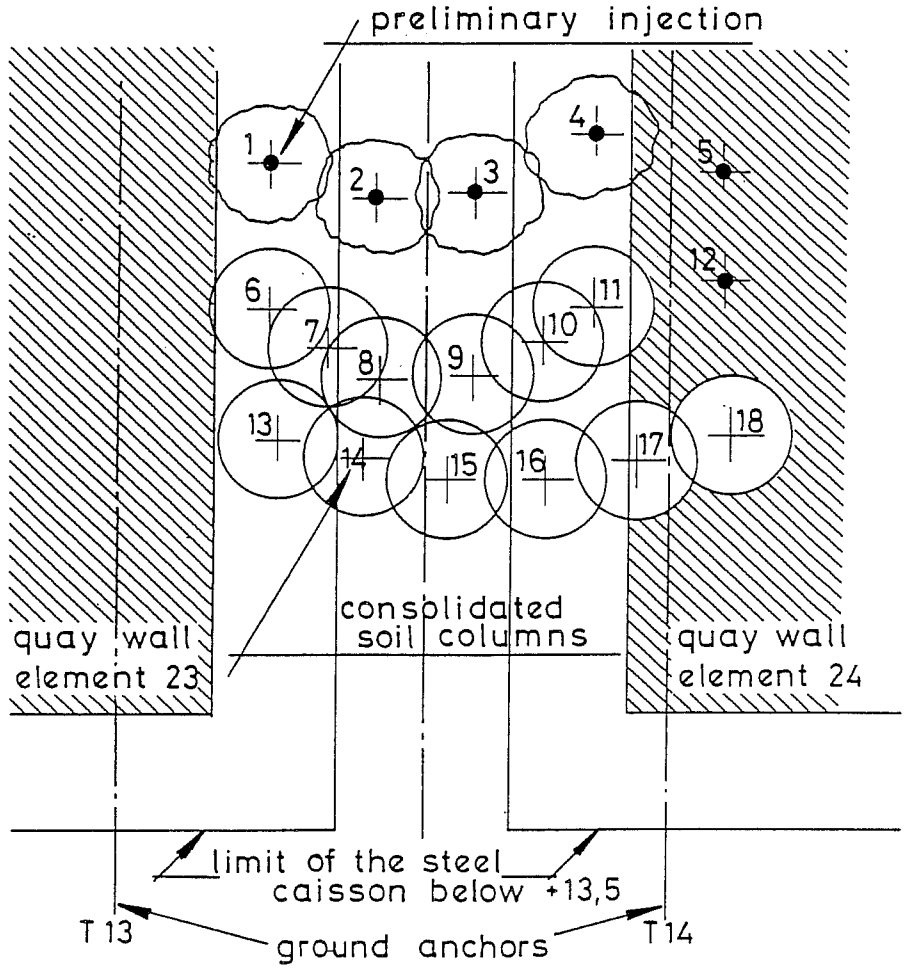

Fig. 7 : Treatment of the joints between the quay wall elements

8. SETTLEMENTS

Four extensometers and 1 inclinometer were installed in the quay wall element nr. 23. The extensometers made it possible to measure the relative displacement of a number of diagnostic points with an accuracy of 0,01 mm during the passage of the shield underneath the quay wall. The measuring points were provided in the side of the quay foundation, the sand and the Boom Clay. A maximum settlement of 4 mm has been observed at approximately 4 m above the tunnel axis. The +/- 5 mm expansion of the clay is also typical (figure 8).

The variation of settlements with time is given on figure 9. At the foundation level of the quay wall (+7,25) settlements were negligable. At the level +5,75 settlements have stabilized at -0,76 mm. In the area beneath the quay wall foundation swellings due to the expansion of the clay have been observed with a later transition to settlements. Local gradient changes in the quay wall have been measured with the inclinometer.

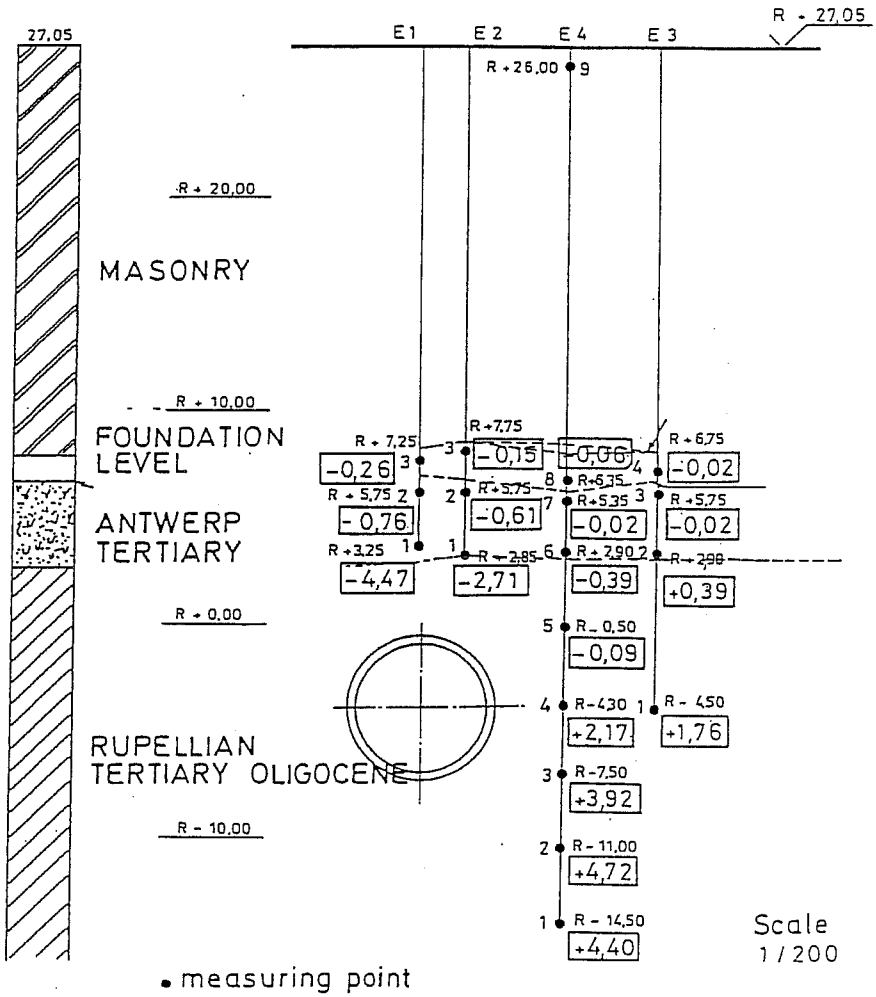

Fig. 8 : Settlements (in mm) observed during the installation of the tunnel underneath the quay wall

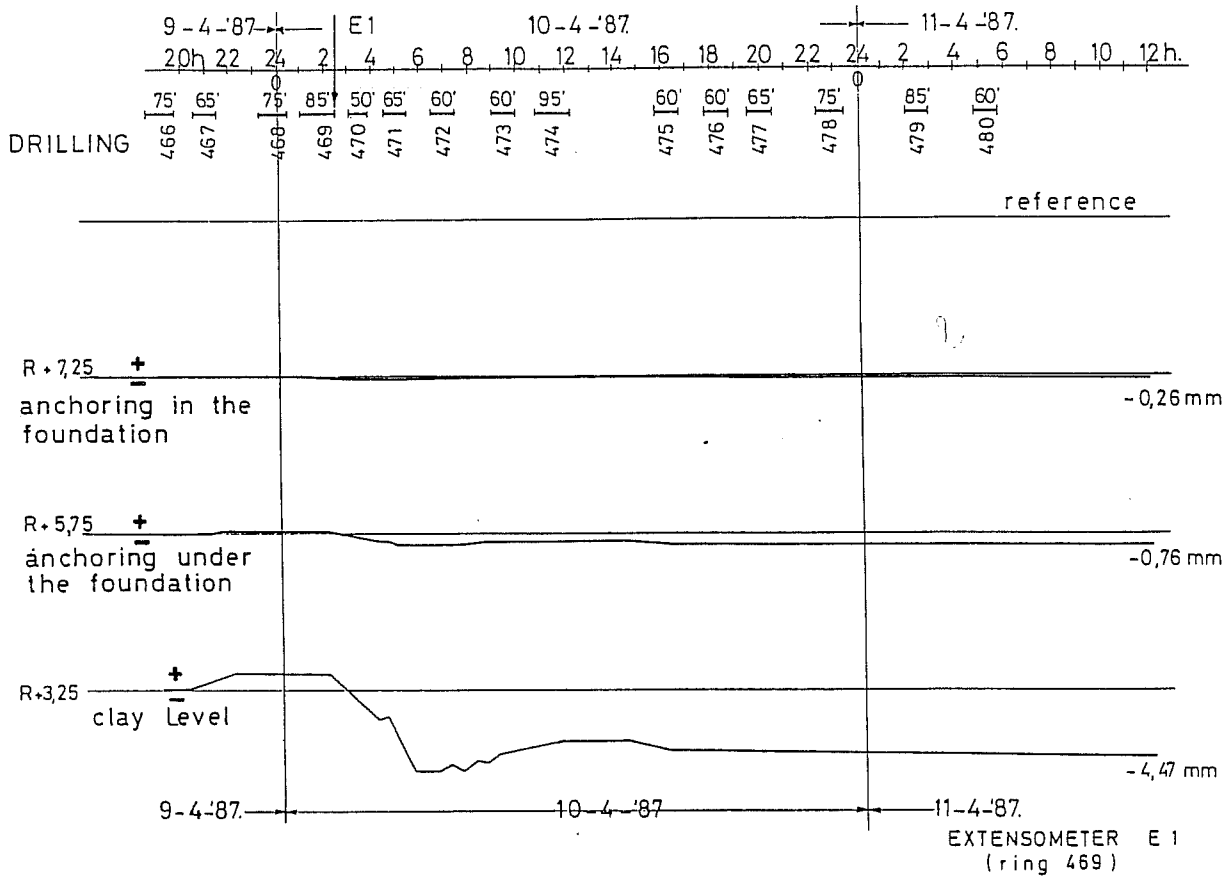

Fig. 9 : Variation with time of the settlements during the installation of the tunnel underneath and near the quay wall

9. CONCLUSIONS

The skillfull combination of new techniques made it possible to strengthen the old quay wall on the Right Bank of the River Scheldt at Antwerp.

The strenghtening of the quay wall consisted of two elements :

- a strenghtening of the inner structure of the quay wall by means of Very High Pressure grouting, low-pressure-injections and the introduction of vertical reinforcement bars.
- an improvement of the stability of the quay wall by placing ground anchors of 52 ton at intermediate distances of 2 m. The anchors were installed at a low level by means of a new developped drilling bathyscaphe.

The very small settlements, measured during the underpass of the tunnelshield indicate that an adequate consolidation has been achieved.