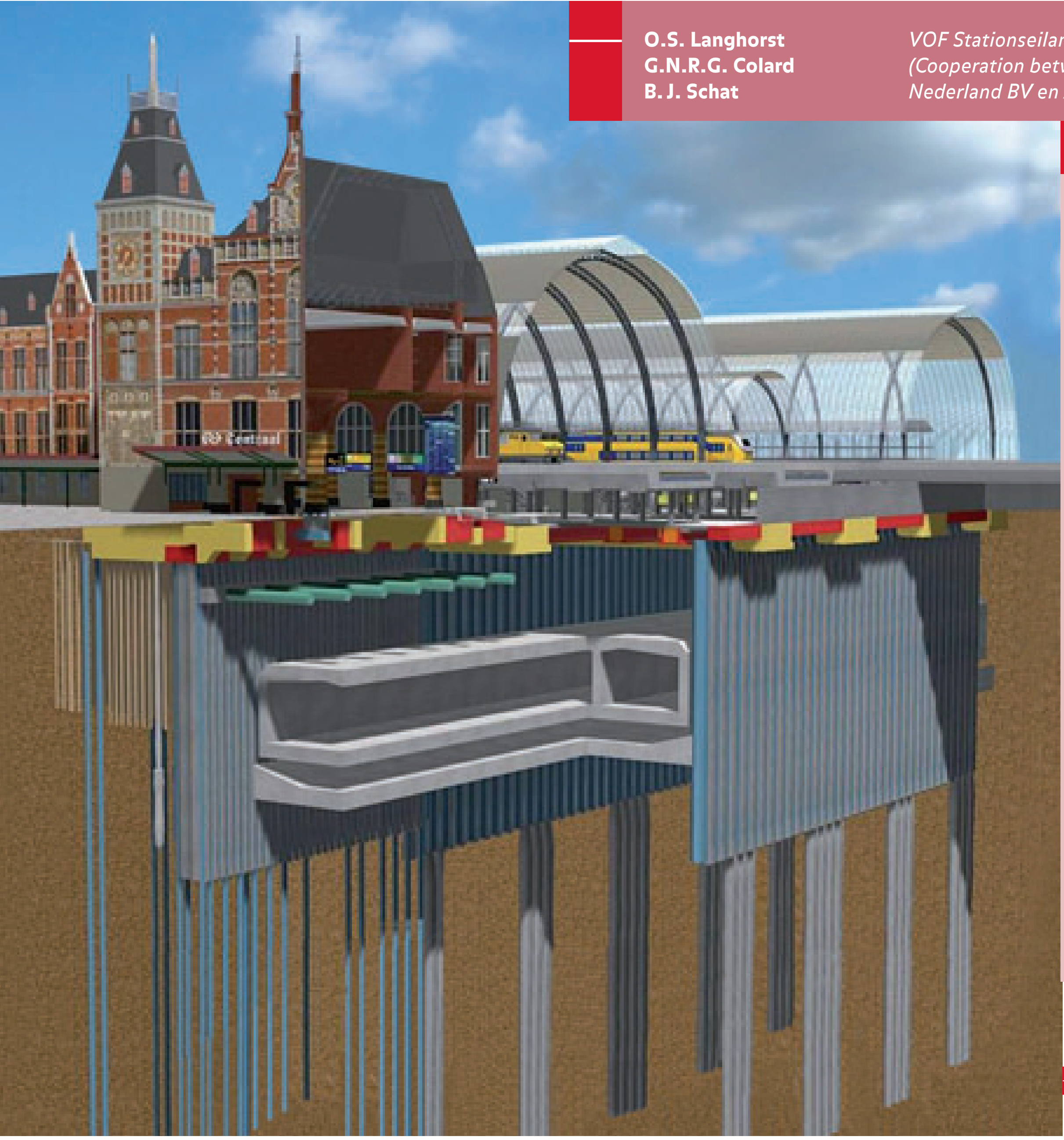
O.S. Langhorst
G.N.R.G. Colard
B. J. Schat

VOF Stationseiland Amsterdam (Cooperation between Movares Nederland BV en Arcadis Infra BV)



Summary

Within the scope of the construction of the 'Noord/Zuidlijn' metro line of Amsterdam, a new metro station is being constructed under the existing central train station. The two walls of the excavation situated under the railway yard consist of steel Microtunneling piles (MT-piles) connected together by an interlocking system. The walls perform the ground and water-retaining functions and provide the load bearing capacity. Due to the lack of working clearance, the MT-piles are made-up of a succession of rings that are bolted together. The MT-pile system is based upon horizontal microtunneling, which technique has been modified and adapted to a vertical operating procedure. The boring and realization processes were fine-tuned mainly during the realization of the first wall (west wall), through implementing modifications to the cutting wheel and the interlocking system and by improving the filling-up of the annular space between ground and MT-pile.

Figure 1 *Impression of the works under the railway station and railway yard.*

Micro Tunneling piles: an innovative foundation system under Amsterdam Central Station

Introduction

The new 'Noord/Zuidlijn' underground metro link will connect the northern and southern suburbs with the city centre of Amsterdam. One of the most challenging sections of this project is the construction of a new metro station under the Amsterdam Central Station. The train station of Amsterdam was built around 1885 on an island dredged beforehand in the IJ waterway. About 9,000 wooden piles support the existing buildings. It is a fundamental requirement that, during construction, the operation of the railways are not to be disturbed and inconveniences to passengers are to be kept to a minimum.
The works are carried out over a relatively small footprint within one of the largest public transport junction in the Netherlands.
The walls of the excavation under the railway yard are made-up of the so-called MT-piles.
The technique used for the MT-piles is adapted from the technique of horizontal microtunnelling. This technique has being especially modified for this project to cope with the constraints of vertical steered boring. The two walls of the construction pit under the railway yard have a length in excess of 100 m and are each made-up of 15 long MT-piles and 30 short MT-piles; every long MT-pile is followed by 2 short MT-piles.
The long piles perform a ground and a water retaining function and provide the vertical bearing capacity; the short MT-piles only have a ground and a water retaining function.

The long MT-piles are composed of 36 rings; the short MT-piles only count 17 rings. The height of the rings is dictated by the available working clearance of 3,1 meters in the central tunnel under the railway yard. Each MT-pile is connected to the next one by an interlocking system.
The boring process of the first MT-pile started on May 24, 2005 but in the early stages of the production process, numerous problems were encountered. By carrying out multiple adjustments to the boring process, work was able to resume in mid December 2005. Improvements

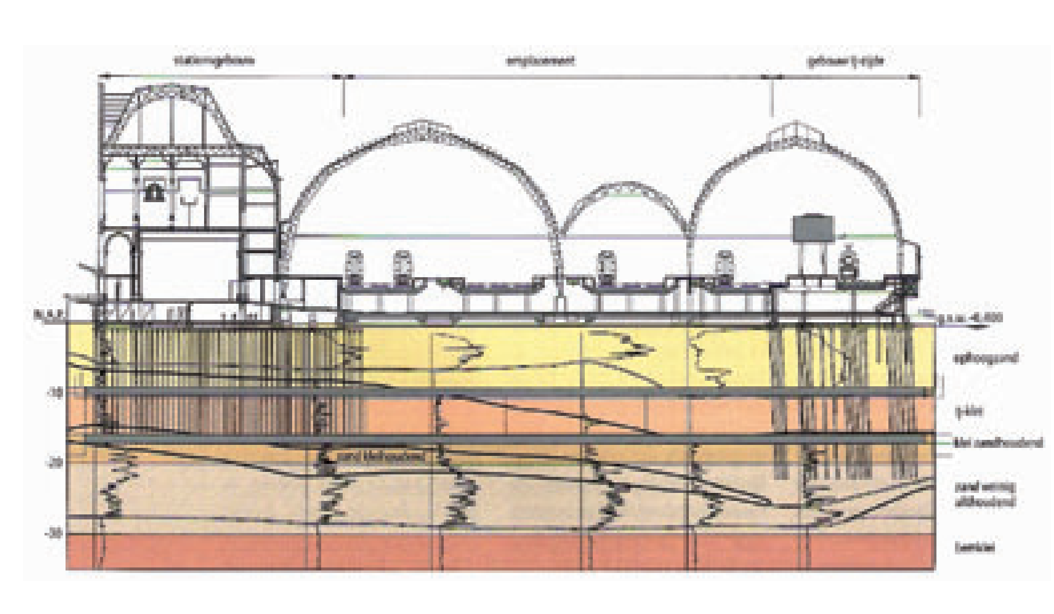


Figure 2 *Geotechnical longitudinal profile.*

The contracting parties involved in this project are:

VOF Stationseiland Amsterdam
A cooperation between Movares Nederland BV - H. van Oosten and Arcadis Infra BV - P. Bout

Adviesbureau Noord / Zuidlijn
A cooperation between Royal Haskoning, Witteveen & Bos en Ingenieursbureau of Amsterdam)

CSO
Principal contractor (Combination Strukton Betonbouw en Ban Oord ACZ) - C. Bosma

CMM
Sub-contractor (Combination Gebroeders Van Leeuwen, Strukton Betonbouw and Van Oord ACZ) - R. v.d. Meer

and optimalisations to the boring process were implemented throughout the production phase of the MT-piles. Finally, on February 05, 2007, the west wall of the future excavation was completed. The boring process of the east wall started on October 22, 2007 and was completed within 6 months (delivered on April 16, 2008).

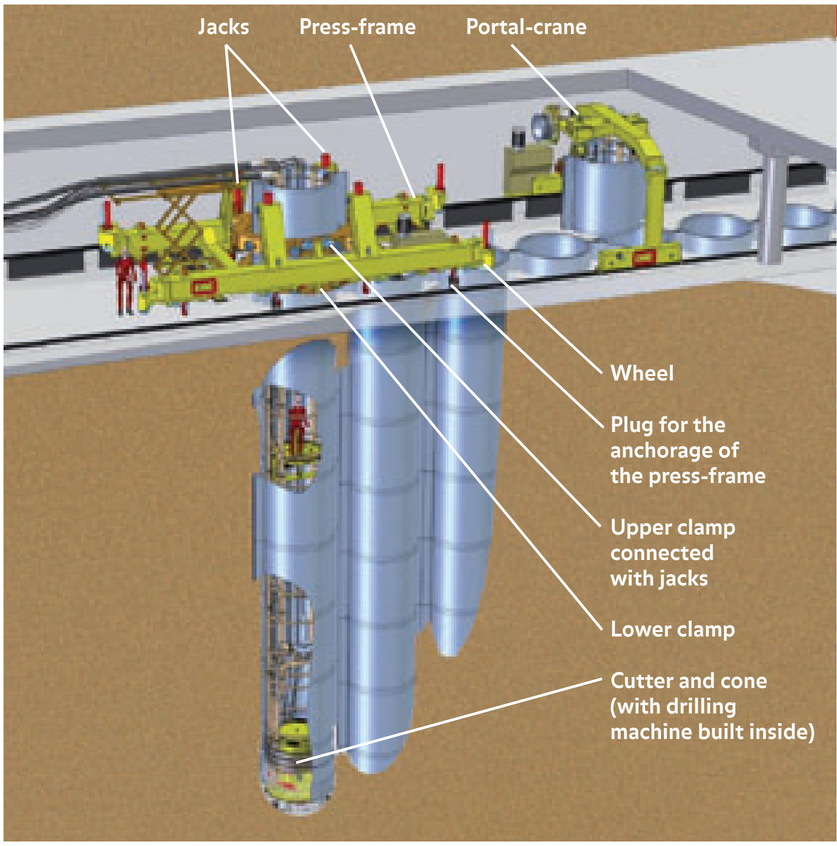


Figure 3 *Detail of the press frame and representation of the production process of the MT-piles.*

Global ground profile

The elevation of the natural ground level railway yard is approximately NAP+1,5 m (NAP: Normal Amsterdam Level). The first encountered ground layer is a 6 m to 10 m thick sand layer. Hereunder, layers of relative weak clay (IJ-Clay) and sand enriched clay layers are found until about NAP-20 m to NAP-30m. A second sand formation follows until a depth of about NAP-30 m. This Second Sand layer disappears in the direction of the IJ, and is replaced by the IJ-clay and the sand/clay layers. The Eem-clay is encountered between roughly NAP-30 m and NAP-45 m and is followed by the 'Glacial-clay' until a depth of about NAP-56 m. The Third Sand layer (load bearing layer) is found from a depth of approximately NAP-56 m. The long MT-piles are installed in this last sand layer.
The phreatic water table varies between NAP-0,25 m and NAP-0,40 m; the height of rise of the groundwater in the Second Sand layer lies around NAP-1.50 m, the height of rise of the groundwater in the Third Sand layer amount to about NAP-3,00 m.

Geotechnical design of the MT-piles

Load bearing capacity function: Based on engineering judgement, it was expected that the MT-piles should have a higher bearing capacity and stiffer load/consolidation behaviour than drilled piles and could be comparable with auger piles. The pile tip level of the long MT-piles was chosen in order to keep the settlements under the pile tip to a maximum design value of 45 mm and so that the difference of settlement between two piles never exceeds 10 mm.
In practice, achieving such a limited pile tip settlement proved to be complex and depended amongst other things on the successful injection of the pile tip. The aim of the injection at the pile tip is to improve the load/consolidation behaviour of the MT-piles.
Ground retaining function: The length of the short piles (NAP-31 m) is chosen in order to have enough fix-end length under the excavation

level. Thereby, the bulging of the wall as well as the settlement of the ground behind the wall have to be kept to a minimum. The design with regard to horizontal deformations relies upon the optimum filling of the annular space between the MT-pile and the surrounding ground over a height of 30 m with grout.
Water retaining function: The water retaining function of the wall depends on the successful installation of the short MT-piles into the Eem-clay and on the performance of the locks. The short MT-piles extend at least 2 m in the Eem-clay. The waterproofing of the wall is completed by filling up the locks between the MT-piles with clay pellets.

Principle and boring process of the MT-piles

The MT-piles are made of a number of steel rings bolted together. The rings have an external diameter of 1820 mm and a height of 1850 mm. The waterproofing between two rings is achieved through fitting a rubber seal in a groove. The drilling machine is installed in the first ring of the MT-pile (cone). The cone has a height of 800 mm a diameter of 1940 mm. The cone diameter is 20 mm wider than the bored diameter. This ensures a good seal between the bore-front and the annular space, which prevents any blow-in or blow-out from occurring. The cutter wheel probes out under the cone and is equipped with three cutters. The space between the drilling machine and the inside of the cone amounts to 15 mm and is sealed off by inflatable rubber bellows. This sealing provides the reaction force to allow the free rotation of the cutter wheel whilst the drilling machine remains secure. The cutter wheel rotates at a speed of 3 to 8 revolutions per minute and burrows with a diameter of 1920 mm.

The boring process begins by the pumping of 'production' water from the IJ. This water is send to the cutter wheel with a debit of 2 to 3 m^3 per minute. The excavated ground is transported to the rinsing-chamber where it is mixed with the production water. This mixture of water and ground is drained away as slurry. The bored diameter is larger than the diameter of the rings (with the exception of the 1ste segment, the cone) in order to create an annular space of about 50 mm between the external surface of the pile and the surrounding ground. This annular space prevents the 'sticking' of the pile to the ground and allows some steering of the cone during the boring process. The annular space is maintained open during the boring process by constantly pumping confining fluid (bentonite). The injection of the bentonite takes place from underneath the cone through four injection tubes. When the MT-pile reaches the design depth, 'Dammer' replaces the betonite. Finally, the pile tip of the long MT-piles is injected in order to achieve a favourable load/consolidation behaviour of the long MT-piles.

Principle of the interlocking system

Each MT pile-wall is made-up of a 45 MT-piles joined by an interlocking system. The interlocking system consists of 'male' and 'female' components by which the male component slides into the female component. The fitting tolerance of the locks is +/- 45 mm. At first the locks were filled with bentonite; later in the production process the bentonite was replaced by grout or clay pellets.

Installation process of the MT-piles

Two hydraulically operated clamps (upper en lower clamps) are mounted onto the press-frame. Four jacks are coupled to the upper clamp, the lower clamp is static. The lower clamp clasps the MT-pile when no boring activity takes place. When boring, the lower clamp is released and the upper clamp is closed to allow the four jacks to press the MT-pile downwards. The force needed for the pressing of the pile is drawn from previously installed Leeuwankers® anchor piles. The press-frame can generate a maximal pressure of around 250 tons. When the boring of a ring is completed, the next ring is conveyed by the portal-crane and positioned above the previous ring. After completion of the coupling of two rings and the installation of the service tubing's, the boring process resumes. When the MT-pile has reached the design depth, the bellows are deflated. This is one of the most critical phases of the boring process. When the air pressure in the seals decreases, a direct connection is created, at pile tip level, between the outside and the inside of the MT-pile. If the differential in pressure is high

Photo 1 *The drilling machine and the cutter wheel hang in the portal-crane.*

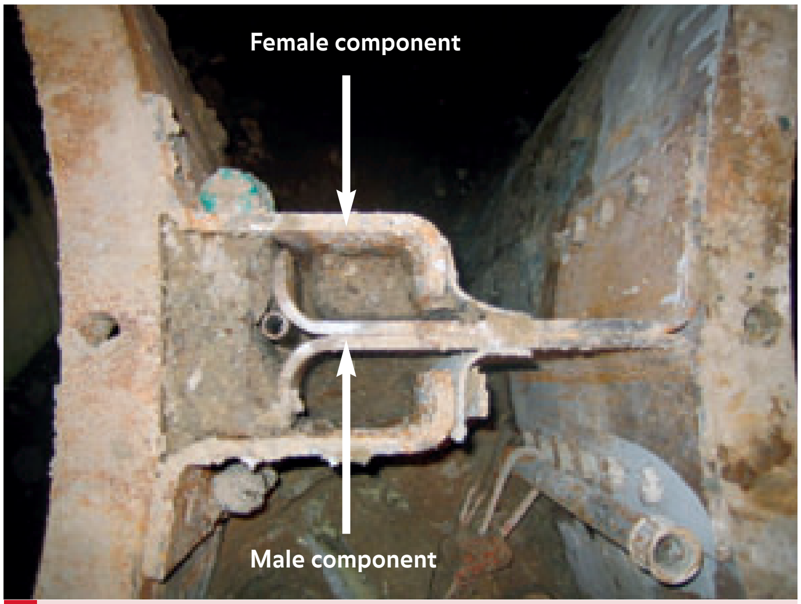


Photo 2 *Above view of the interlocking system.*

enough, a 'blow-in or blow-out' can occur. In order to achieve equilibrium of pressure, the short MT-piles are filled-up with water and the long MT-piles are filled-up with bentonite before deflation of the bellows. The dismantlement of the service-pipes is undertaken only when the situation at pile tip level is stable. The drilling machine is removed directly after the dismantlement of the service-pipes. At first, the drilling machine is lifted by about 500 mm in order to allow the cutters teeth to retract under the cone. The retracting of the cutters teeth's allows a complementary pressing of the pile past the level of the cutters teeth's. With this final adjustment, the MT-piles reach their design depth. After the dismantling of the service pipes and the removal of the drilling machine, the following activities are carried-out:

- The annular space is filled from underneath with 'Dämmer' (replaces bentonite).
- The long MT-piles are filled with concrete (C28/35). The pile tip is injected with grout after setting of the concrete in order to restrain the relaxation of the load bearing sand layer hence preventing excessive settlement underneath the piles.
- The short MT-piles are filled with sand and the locks are injected with a grout mix or clay pellets in order to achieve an optimal seal of the locks.

The installation of the MT-piles had little influence on the environment (railway yard). The measured water (over)pressure, the horizontal en vertical ground displacements behind the MT-piles were very limited and stayed well within the imposed limit values. Regular inspections throughout the production process were necessary in order to be able to steer as optimally as possible the progress of the works and to be able to carryout the geotechnical monitoring safely.

During the production process various adjustments and optimizations were implemented, such as:

- Adjustment to the cutter wheel: Vertical hinged cutters were preferred to horizontal hinged hydraulic operated cutters.
- Adjustments to filling of the annular space after the MT-pile reaches his design depth: The injection mix (cement Portland) caused jams and was replaced by 'Dammer'. For the longest MT-piles, Drillmix has been implemented from a depth of NAP-32 m to the pile tip level of NAP-66 m.
- Adjustments and optimisation of the interlocking system: Clay pellets (Mikolite) replaced bentonite in the locks.

Excavation phase

The dewatering of the building pit to NAP-6,5 m was started on January 22, 2008 followed from April 01, 2009 by the first excavation phase (to a depth of NAP-6,2 m). At the end of May 2009, about 2/3 of the excavation under the railway yard has been completed without uncovering noticeable leaks by the locks or discrepancies with the design. So far, sensible items such as the filling of the locks and the annular space are meeting expectations.
Parameters such as ground water levels, horizontal and vertical deformations and exerted forces in the struts are closely monitored through-out the execution phases; the measured values are in turn tested against critical values. Most of the gathered data can be consulted 24/day through the internet.

Conclusion

The MT-pile is based upon innovative techniques which were for the first time implemented underneath Amsterdam Central Station. Constant improvements to the boring process, ultimately led to the successful delivery of the west and east walls. Thanks to the commitment and collaboration of all the implied parties in this project, the MT-pile wall has grown to be a fully recognized and reliable foundation and ground/water retaining system.

References

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[2] J.C.W.M. de Wit, P.J. Bogaards, O.S. Langhorst, R.D. Essler, J. Maertens, B.K.J. Obladen, C.F. Bosma, J.J. Sleuwaegen and H. Dekker *Design and validation of jet-grouting for the Central Station of Amsterdam.*

Photo 3 *View of the west MT-pile wall (excavation to NAP-6,2 m).*