Amsterdam North-South line – Tunnel immersion underneath a historic monument

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Abstract

For the North-South line in Amsterdam a tunnel element has been immersed underneath the historic station building of Amsterdam Central Station. To make this possible the station building, the railway tracks and platforms had to be given a new foundation and a bridge construction was necessary to create the immersion trench. Especially the lack of space and high risks forced the immersion team to several innovative solutions such as horizontal and vertical guiding structures, optimized immersion pontoons, newly developed positioning systems, an adjusted survey system and an inverted temporary support system.

1. Introduction

In Amsterdam a new metro line is being built from the north to the south side of the city. Part of this project is the tunnel underneath Amsterdam Central Station (Amsterdam CS). Here the metro line crosses 15 railway tracks, 6 railway platforms and the station building, a historic monument built between 1881-1889. During construction of the tunnel under Amsterdam CS the railway traffic should not be disturbed and nearly no displacements were accepted.

Fig. 1 *Transport of tunnel element in immersion trench*

The solution was an immersed tunnel, which avoided the problems that arise in a traditional construction method such as large water level lowering and subsequent movements of the retaining walls.

2. Tunnel element and immersion trench

2.1 Construction of the tunnel element

The tunnel element underneath Amsterdam Central Station has a length of 136m, is 21m wide, 8m high and has a weight of 21000 tonnes. Besides this tunnel element, three more tunnel elements had to be built for the North-South Line project. These tunnel elements will be used to cross the river IJ at the north side of the railway station.

From 2005 to 2007 the four elements were built in two shifts in the coffer-dammed dry dock at the North bank of the river IJ. After completion of the building activities the dock was filled with water and the tunnel elements were floated up. They were transported to a temporary mooring location in the "Suezhaven" in the western harbour area of Amsterdam. Afterwards the dry dock was emptied and the northern approach of the metro tunnel was built inside it.

2.2 Construction of immersion trench

For receiving the tunnel element under the station an immersion trench was made. The existing foundation comprising of thousands of wooden piles was replaced by new foundation walls (fig. 2) with a roof slab on top. The weight of the station building and railway platforms was taken over on this new foundation. The immersion trench was created in between the walls.

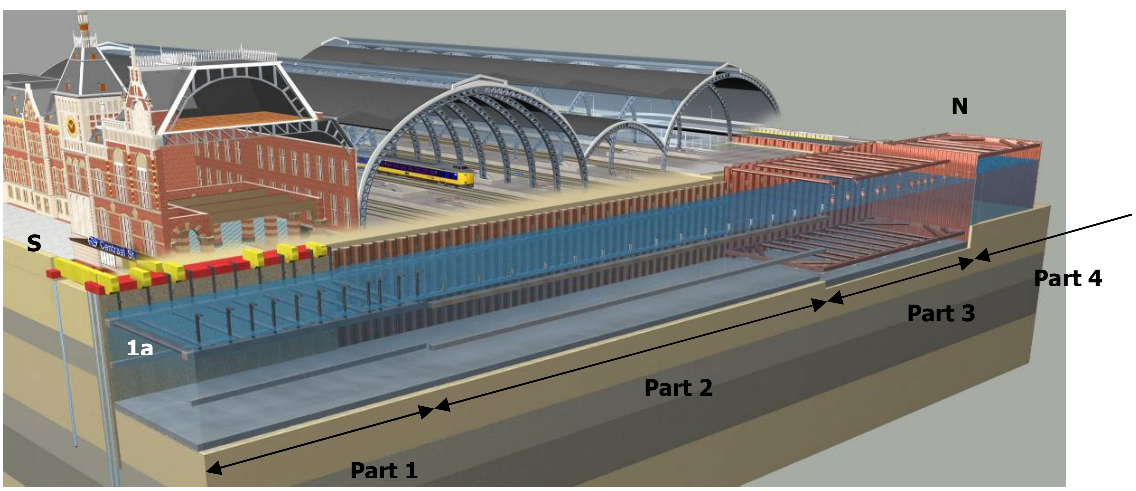

Fig. 2 *Immersion trench – building pit (Illustration: Verdult Kennis in beeld)*

Underneath the station building (part 1) so-called sandwich walls are used. These walls consist of two rows of tubex piles with the space between the rows filled with grout. The sandwich wall is supported by an under water strut layer (1a). For the foundation of the railway tracks and platforms a bridge construction has been built consisting of retaining walls formed by vertically bored piles with a diameter of 2.2m on both sides of the immersion trench and a concrete roof slab (part 2). All of the constructions had to be installed in limited space with ongoing rail traffic at all times. To be able to get the tunnel element underneath the roof slab, the building pit was extended with two more parts. The "Ruijterkade" (part 3), building pit for the Northern entrance of the metro line and an extra sluice/cofferdam in the river IJ (part 4) to be able to lower the water level within the immersion trench. In part 1, 2 and 3 under water concrete was used for supporting the walls at the bottom level.

3. Transport

3.1 Three step Water Level Lowering

To be able to transport the tunnel element under the roof slab of the platforms three phases of water level lowering were required. With a natural water level of the river IJ of -0.4m NAP (Amsterdam Ordinance Datum) in relation to the underside of the roof slab of 0.0m NAP, only 0.4m of space remained. To create working space underneath the roof slab additional cut off walls were installed in the building pit.

Fig. 3 *Water levels in immersion trench*

Getting the tunnel element under the platforms was done in three phases:

1. Transport from mooring location into immersion trench (fig. 2 part 3 and 4)
2. Lower water level and move the tunnel element under roof slab (fig. 2 part 2)
3. Lower water level for immersion and transport underneath the struts (fig. 2 part 1)

On the 31st of May 2011 the tunnel element was transported from the mooring location with four tugs and one push boat. After arriving at the immersion trench the IJ water was blocked for all shipping. A longitudinal winch wire was connected to the front of the tunnel element to winch it in until the front end reached the roof slab of the platforms. Now the first cut off wall was installed at the end of part 4 of the building pit so the water level could be lowered from -0.4m NAP to -1.5m NAP resulting in an increase of space between water level and the bottom side of the roof slab to 1.5m.

Now it was possible to winch the tunnel element underneath the platforms as far as the under water struts below the station building. The second cut off wall was placed between compartment 3 and 4 whereafter the water level could be lowered another 1.5m, sufficient for the immersion equipment to be placed on top for the upcoming immersion operation.

3.2 Winches

For winching in the tunnel element two winches were used. One at the front side of the station building for pulling forward (LP) and one next to the retaining wall of part 3 of the building pit for pulling backward (LS). By decreasing the force on the LS winch and keeping the LP winch under tension the element was transported in a controlled way, reaching speeds up to 0.5m/min.

Winch wire LP was bypassed down to a sheave block connected to the diaphragm wall at the end of the immersion trench. From this point the wire was directed horizontally to the immersion trench and connected to the tunnel element. With this configuration contact of the winch wire with the struts underneath the station building was prevented (fig. 4). Winch LS was installed next to the trench, the wire was directed to the tunnel element by sheave blocks attached to the retaining walls.

3.3 Guiding structures

The width of building pits is, in relation to the width of the tunnel element, limited over most of its length. Underneath the platforms approximately 1m space was left on both sides of the tunnel element and underneath the station building no more than 15cm was available. To prevent the tunnel element from colliding with the retaining walls a combination of guiding structures was used.

In part 2 of the building pit six horizontal guiding frames were placed at -2.5m NAP for winching in the tunnel element at the water level of -1.5m NAP. For guiding the element during the next lowering of the water level and during immersion, four of the guiding frames were equipped with a vertical guiding structure as well. A vertical H-beam connected to the retaining wall at the position of the horizontal guide was used. At the bottom, the beam was placed in a recess in the under water concrete floor.

4. Immersion

The immersion itself was carried out in three phases. First the tunnel element was lowered as much as necessary to pass the under water struts (fig. 4). The tunnel element could not be lowered too much to prevent the element from clashing with the struts temporarily positioned down in part 3 of the building pit.

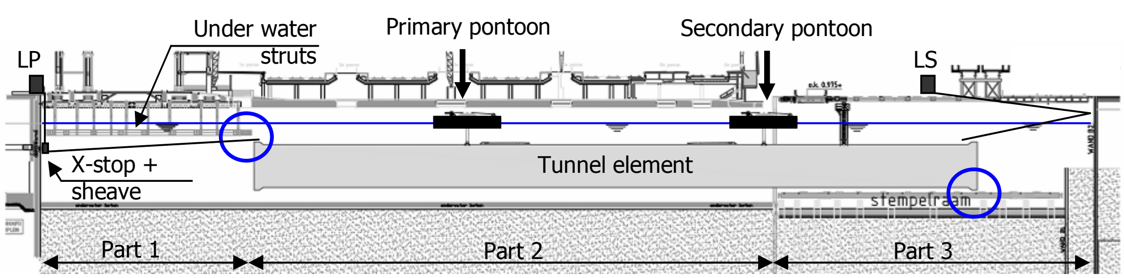

Fig. 4 *Immersion*

In the next phase the tunnel element was moved forward so that the rear of the element was within compartment 2. In this phase the primary immersion pontoon moved over the under water struts. In the third phase the tunnel element was lowered and winched to its final position.

4.1 Pontoons

For the immersion of the tunnel element pontoons were used. Due to the limited space the construction height of the pontoons had to be minimized. For the pontoons nine container pontoons with a height of 1.2m were used. The pontoons were coupled in a way that two moon pools were created for the suspension wires. On top of the pontoons the winch frames and winches were placed with a total height of 1.1m. With a freeboard of the tunnel element of 150mm average and some tolerances, only 0.3m space was left between the immersion winch and the roof slab (fig. 5).

Fig. 5 *TE and pontoons under roof slab*

To gain some time, the pontoons were temporarily positioned at the rear of the deck of the tunnel element while the cut off wall between part 3 and part 4 of the building pit was placed. After the second water lowering the pontoons were lifted off the deck with hydraulic jacks in a steel structure with rollers underneath and moved forward with auxiliary winches on the pontoons.

For the immersion 7 tons hydraulic winches powered by electric hydraulic power packs were used. The winch wire was reeved 12 times to meet the maximum safe working load of 35 tons. The nominal working load for the suspension wires was 25 tons, equivalent to 0.5% overweight. This low working load was justified by the controlled conditions during the immersion in a shielded immersion trench and made it possible to minimize the dimensions of pontoons and winches.

4.2 Positioning system

For this tunnel element no immersion joints were applied. On both ends of the tunnel element the connection with the in situ parts of the tunnel will be made by in situ closure joints. Once the immersion is finished the space in front and rear of the element will be back filled and the soil will be frozen to make it possible to build the remaining parts.

As the immersion joint normally determines the position of the tunnel element in longitudinal direction, for this project an other solution had to be found, the so-called X-stop (fig. 4 & 6). Besides the positioning of the tunnel element the X-stop had the additional function of protecting the diaphragm wall at the front of the building pit against damage. The X-stop was connected to the diaphragm wall with anchor bolts and was positioned so that the roof of the tunnel element would touch it in fully immersed position. Adjustments in the longitudinal position were done with separate steel infill plates which could be placed between the X-stop and tunnel the element. The X-stop was combined with the sheave required for the longitudinal winch wire (LP).

Fig. 6 *X-stop*

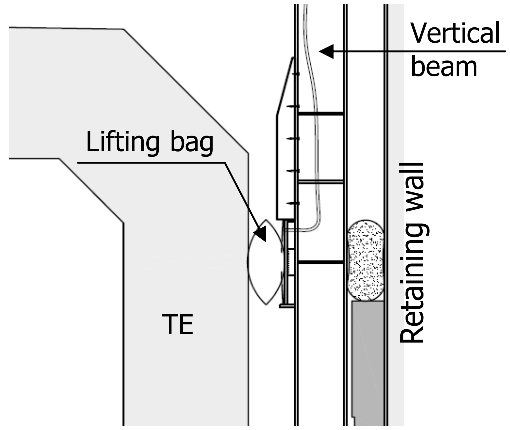

Fig. 7 *Position of lifting bag*

The lack of an immersion joint gave new challenges for transverse positioning as well, Normally this is done with jacks in the immersion joint chamber. For the metro-line project a combination was made with the horizontal and vertical guiding constructions as mentioned in §3.3. Between the outer walls of the tunnel element and the four symmetrically placed vertical guiding beams lifting bags (fig. 7) were installed. After immersion all four lifting bags were pumped up and operated separately to move the tunnel element to the desired transverse position.

Finally the vertical position had to be fixed. In common practice the temporary support system of a tunnel element consists of two jacking pins in the outer walls resting on pre layed concrete foundation pads on the bottom of the immersion trench. For this project it was not possible to use the concrete slabs due to the under water concrete strut and the position of the retaining walls. The solution was found by inverting the system and suspending the tunnel element to the roof slab with steel H-beams. While floating, the suspension beams were placed on the deck and connected to it by means of a hinge construction at the lifting point (fig. 8). After the immersion the suspension beams were lifted and coupled to the jacking frame connected to the roof slab.

Fig. 8 *Suspension beams on tunnel deck*

Fig. 9 *Jack in frame*

With the integrated jack frame (fig. 9) the final position in vertical direction could be established. The jacks were also used to measure the forces in the suspension beams and to monitor the pressure underneath the element during the sandflow process.

4.3 Survey system

An innovating survey system had to be used due to the limited space between the tunnel element and the construction above. Normally two points are used for the immersion survey: The access shaft at the secondary end of the tunnel element combined with an alignment tower at the primary end of the element. For this project, the access shaft was present from the beginning of the immersion operation, the survey tower was placed later on.

In the first phase of immersion the access shaft descended to a level just enough to pass the struts of compartment 3 and to fit underneath the floor slab (fig. 10). After immersion the top of the shaft remained just above water.

Before immersion | After 1st immersion phase | After immersion

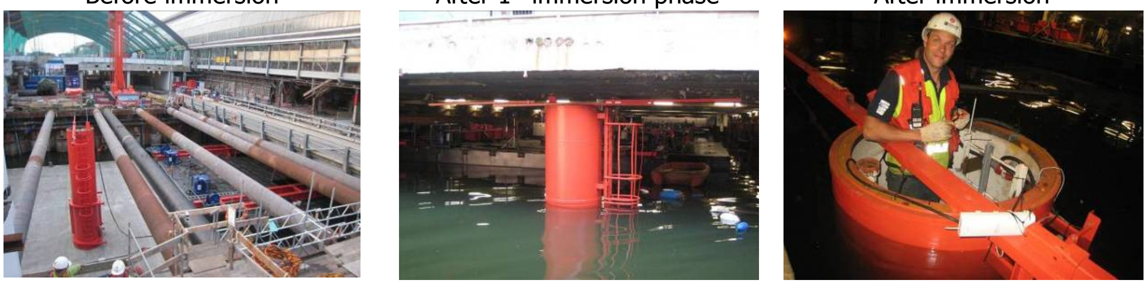

Fig. 10 *Access shaft in immersion phasing*

The alignment tower could not be placed before immersion for the simple reason that the space available was not sufficient. The survey of the first immersion phase was only done with the survey points on the access shaft. The accuracy of measurements was lower but this was acceptable due to the extensive guiding system present. For the next immersion phases a more accurate system was necessary so therefore a folding alignment tower was used. The tower was lying flat on the deck of the tunnel element before immersion and was connected with a hinge. During the first immersion steps the tower floated up automatically. At the end of this phase the alignment tower could be fixed in upright position.

5. Sand flow

A traditional sand flow system was used for the final foundation of the tunnel element consisting of cast in pipes in the walls and floors to which a sand mixing pump was connected. Two rows of so-called pancakes were made filling the space of 0.65m underneath the tunnel element as shown in figure 11.

Primary suspension beam | Secondary suspension beam

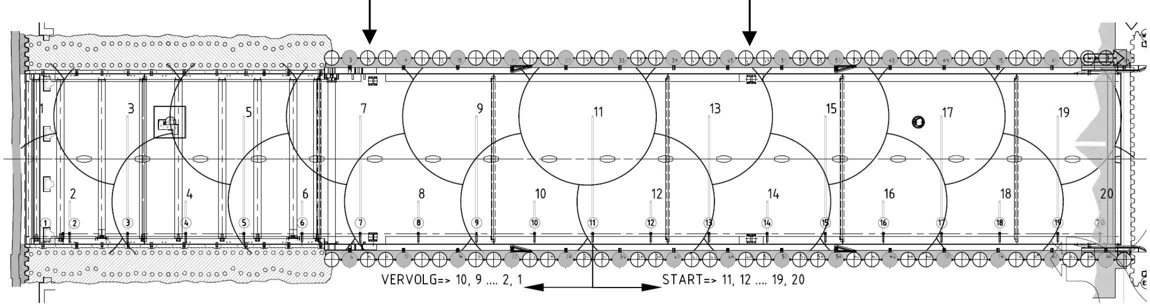

Fig. 11 *Sand flow pattern*

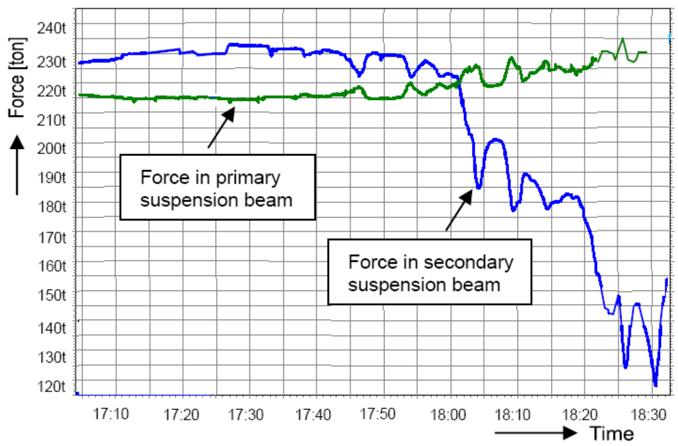

Fig. 12 *Forces in suspension beams for sandflow point 16*

Due to the narrow space between tunnel element and retaining wall up to 15cm at pancake 1 to 6 extra attention was needed during the sand flow process to prevent the tunnel element frome being pushed up. To minimize the risks, the forces in the jacks were monitored in detail during sand flow. In figure 12 the forces in the suspension beams are given for sandflow point 16. While finishing the pancake the forces in the secondary suspension beams decreased and, as result of leverage, the force in the primary suspension beams increased.

6. Process control

Because of the complex project environment with high risks involved an integrated approach of the immersion process was necessary. A risk based approach was used for the engineering and preparation works where preventive measures were implemented in the earliest possible stage so the residual risks decreased to an acceptable level.

During the construction of the tunnel element extensive checklists were used to check the relevant parts of the construction for transport and immersion. The same was done before starting inundation of the dry dock, the transport from Suezhaven to the immersion location, the immersion itself and for the constructions needed in the immersion trench. By checking in an early stage it was still possible to anticipate and to make adjustments.

For the operations themselves detailed method statements and work instructions were made with integrated go-nogo decisions at several moments. In dialogue with all parties involved it was decided if all preparations and circumstances were satisfactory to start the upcoming operation.

7. Conclusion

For the new metro line in Amsterdam the passage with the Central Station was one of the most challenging parts. The special circumstances either technical and social forced the immersion team to be creative and use several innovative solutions. All operations were performed with high safety standards and detailed process control to decrease the risk of failure. The immersion was carried out successfully in July 2011.

Colophon:
Client: Dienst Noord/Zuidlijn (Municipality of Amsterdam)
Designers: North/South Line Consultants (JV Royal Haskoning and Witteveen+Bos)
VOF Stationseiland (JV Arcadis and Movares)
Contractor: CSO (JV Strukton Civiel Projecten and Van Oord)
Mergor Underwater Construction/Strukton Afzinktechnieken (Sub contractor Transport and Immersion)