Existing structures govern building methods near Rotterdam Central Station

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ABSTRACT

Extensive building activities mark the area around the Central Railway Station of Rotterdam, the Netherlands, during the period 2005 - 2012. A number of projects is under construction, others are still in the design stage. The building methods of these projects are governed by the presence of nearby structures. The geotechnical challenges that are encountered during the realisation of the projects are discussed, and the influence of these projects on the densely built environment.

Introduction

The development of six new key projects in and around the high-speed train stations in the Netherlands is in full swing. Work has started at three locations, including Rotterdam Central Station. The investment in the development of the station area will give the economic position of the city a significant boost.
The extensive reconstruction of the area around Rotterdam Central Station requires a great deal of juggling. It means realizing many new constructions in a very confined space, and trams, buses and underground trains must keep to their schedules, passengers and passers-by must be able to go on their way, cars and bicycles must not be held up and taxis must remain visible and accessible.

The project 'Rotterdam Centraal' consists of a number of projects. Some of them are presently under construction, others are still in the design stage (*figure 1*):

- reconstruction of the Central Railway Station of the city of Rotterdam, including a new large Public Transport Terminal to facilitate passenger transfer between (inter)national trains including the high-speed train to Paris and regional and local public transport like trams, buses and underground trains;
- construction of the new RandstadRail underground line, a high-quality public transport system that will provide connections from the centre of Rotterdam to the towns and cities in northern direction. RandstadRail will be linked to the existing Erasmus underground line at the underground metro station CS;
- reconstruction of the underground metro station CS that has to be enlarged to provide sufficient passenger transfer capacity;
- construction of an underground parking facility for about 5.000 bicycles;
- doubling of the existing Weenatunnel for road traffic;
- construction of the new underground parking facility Kruisplein;
- construction of a tunnel between the new underground parking facility Kruisplein and the existing underground parking facility Schouwburgplein.

The construction of the new RandstadRail underground line, two single-track shield tunnels with each a length of 2.4 km and an outer diameter of 6.5 m, started in 2004. The first tunnel has been completed in spring 2007. The second tunnel is presently being bored. The reconstruction of the underground metro station CS started in 2005, and the doubling of the existing Weenatunnel in 2006. The other projects are expected to follow soon. All projects are planned to be completed in 2012.

This paper discusses the geotechnical challenges that are encountered during the realisation of the projects that are currently under construction, and the influence of these projects on the densely built environment of Rotterdam Central Station.

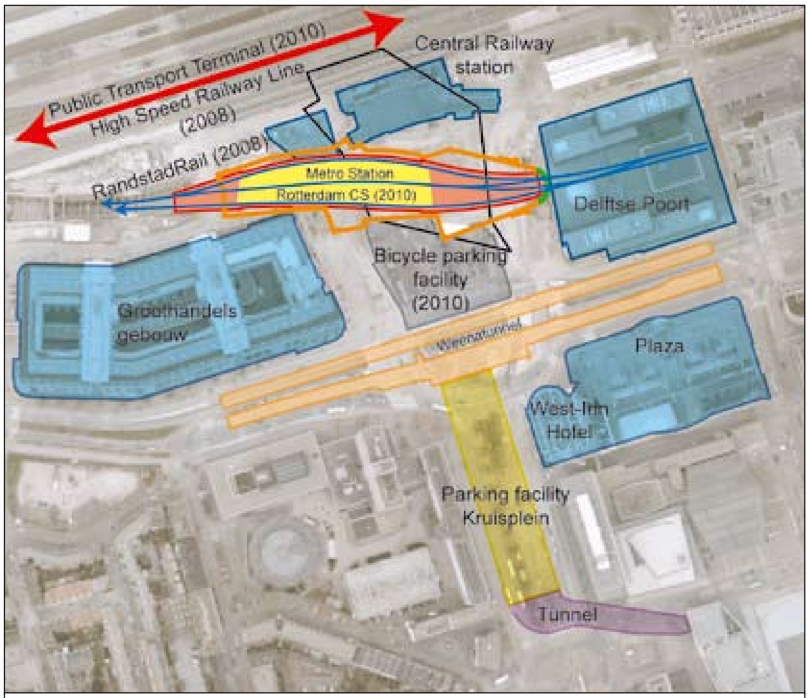
Soil and groundwater conditions

The ground level in the area is situated at about NAP (sea level). The phreatic groundwater level is about NAP –2 m. The geotechnical profile of the Rotterdam city area consists of anthropogenic layers (from NAP to about NAP –5 m), and soft Holocene peat and organic clay layers (from about NAP –5 to NAP –17 m). Below this level Pleistocene coarse sand layers are encountered up to 35 to 40 m below NAP. These sand layers are underlain by overconsolidated clay and sand layers called 'Kedichem'. *Figure 2* shows the soil profile at the underground metro station CS.

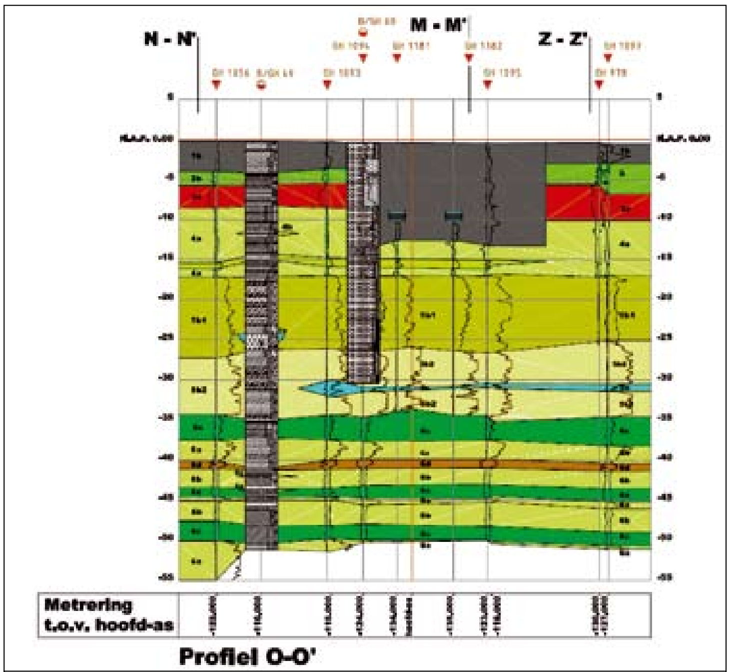
The environment

During the extensive reconstruction of the area the following structures may be influenced (*see figure 1*):

- Groothandelsgebouw, an office building, opened in 1955. The building is a post-war architectural monument and has been founded in the top of the Pleistocene sand layer on concrete piles with an enlarged tip. The foundation is vulnerable;
- Existing Central Railway Station, built in 1957. Although it will be pulled down, it has to maintain its function during the adjacent reconstruction works of the underground metro station CS;
- Existing underground metro station CS, built in the period 1962-1967. This station has to maintain its function during the reconstruction works;
- Office building Delftse Poort. The tallest office building in the Netherlands opened in 1992, and has been founded on concrete piles into the Pleistocene sand layer. Parts of the temporary supporting structures and ele-



↑ **Figure 1** The projects and existing structures in the Rotterdam Central Station area



↑ **Figure 2** Soil profile at the underground metro station CS. The fill around the existing metro tunnel is clearly visible

ments (such as retaining walls and anchors) that were used during the period of construction of this building are still in place and hamper new building activities;
- Underground metro tunnel below the office building Delftse Poort, built in the period 1962-1967. A new foundation has been built during the construction of the office building;
- Existing Weenatunnel, built in the 1950's. This tunnel will be demolished, but has to maintain its function until the first of the two new tunnels can be used by the traffic;
- A water main to the south of the new Weenatunnel;
- West-Inn hotel, built in the 1990's.

Existing Underground Metro Station CS

The existing tunnel of the "Erasmus" underground line was assembled from prefabricated segments, which were built in dry docks.
The tunnel segments were floated to their final destination through a canal. Once arrived on the spot, the segments were immersed onto their permanent foundation which consists of pre-installed concrete 'oppers'-piles. It is typical for this foundation concept that tension loads cannot be transferred through the pile-tunnel connection. After construction of the tunnel, the canal was filled with sandy material.

Existing Weenatunnel

The original two-lane tunnel dates back from about 1950. It has a limited height, and the tunnel part is relatively small. The tunnel has been founded on prefabricated concrete piles.

Typical building methods for new underground constructions

The possible building methods comprise of a number of options. Common practice for the soil conditions in Rotterdam is an excavation up to about 8 m deep that is realised by using sheet piles in combination with a dry or a wet excavation. For excavations up to 8 to 12 m deep a combined wall of steel pipe piles and sheet piles is needed together with a dewatering system for a dry excavation. For deeper excavations a diaphragm wall or a prefabricated wall placed in a slurry trench is required.
Dry excavations may be realized by means of dewatering or by using the deep almost impermeable ground layer 'Kedichem' as a natural water barrier. This latter method creates an 'into the ground' polder. A polder construction ensures that the construction pit can be excavated under dry conditions. The advantage of this method is that the pumping of water out of the construction pit does not affect the groundwater in the vicinity, thus minimising the risk for the structures in the neighbouring areas.

Negative influence on the surroundings may be caused by settlement due to dewatering, and deformations due to the excavation. Another important criterion during the selection of a building method is the expected nuisance for the environment. Especially in inner cities nuisance by vibrations and noise are hardly accepted. Building activities normally make a lot of noise, for example during the driving of foundation piles. These activities also cause vibrations that may be harmful to computers and other hardware in the nearby offices.

The selection of the building method for the projects that are currently under construction will briefly be discussed in this section: the RandstadRail project, the extension of the underground metro station CS and the construction of the new Weenatunnel.

RandstadRail

Because of the limited room and the many building activities that take place near the Central Railway Station, both single-track tunnels are bored from the construction site at the St. Franciscus Gasthuis at the north side of the city. This means that unnecessary building traffic in the city is avoided. The tunnel boring machine (TBM) ultimately arrives in the Conradstraat, west of the Central Railway Station, where the end shaft is constructed. Here the TBM is dismantled (*figure 3*).
The construction of the end shaft is being made with the aid of the "polder construction". This is realised by constructing the diaphragm walls down to the low permeability clay/peat/loam layers of the Kedichem formation below NAP –35 m.

↑ **Figure 3** Dismantling the TBM at the end shaft (photo Aeroview)

↑ **Figure 4** Work in progress. Left: the building pit for the new Weenatunnel. Right in front: the building pit for the underground metro station CS. Right at the back: the building pit for RandstadRail, including the end shaft (photo Aeroview)

Underground Metro Station CS

Governing design condition is that regular underground traffic and passenger transfer at the existing underground station CS is not affected during the construction works, thus no damage (e.g. cracks, water leakage) to the tunnel due to the works is allowed.

The extension of the underground metro station CS is being realised with the aid of diaphragm walls constructed around the current station to a depth of approximately NAP –38 m. The building pit covers about 7.500 m². The dimensions of the required excavation are: length 230 m, width 30 to 50 m, and a maximum excavation depth of 14 m. Diaphragm walls cannot be constructed at the eastside of the excavation, due to presence of the existing underground tunnel and underground obstacles such as abandoned sheet pile elements and anchors from ancient projects. For closing this gap in the cut-off wall the ground freezing technology is applied for retaining the soil and water pressures by means of a collar construction around the underground tunnel (Thumann & Haβ 2007). The ground will be frozen all the way down into the layer of Kedichem. The curved shape of the frozen block of ground will resist the pressure from the surrounding soil strata during the excavation of the construction pit. Together with the layer of Kedichem, the diaphragm wall and the frozen soil ensure that the construction can take place in a dry construction pit. The excavation is done from underneath the roof of the new station, that has been built during the very first stage of the project. This allows more or less normal traffic at the ground surface.

Weenatunnel

The new Weenatunnel will consist of two double lane tunnels. The tunnel part will create space for a large pedestrian area at the ground surface. For the two stages of the construction two building pits are created surrounded by combined walls of steel pipe piles and sheet piles and by only sheet pile walls. The combined wall with the future parking facility Kruisplein consists of a diaphragm wall up to a depth of NAP –42 m. Dry conditions in the building pit are provided by drainage of the Pleistocene sand layer between NAP –17 m and NAP –35 m.

Influence on adjacent structures

The new RandstadRail underground line, the reconstruction of underground station CS and the doubling of the existing Weenatunnel are currently under construction (*figure 4*). The adjacent structures are monitored during the execution of the projects. The extensive monitoring plan was based on the risks involved (Berkelaar et al. 2007). Some of the expected and measured influences of the construction works on the surrounding structures will be discussed briefly.

Groothandelsgebouw

Diaphragm walls for the building pit of metro station CS have been installed at a minimum distance of 2 m from the pile foundation (*figure 5*). An almost uniform settlement of a few mm's was measured at the corner of the building during the execution. No damage was caused to the building.

In the design stage the driving of piles within the building pit for metro station MCS was restricted to a distance of more than 25 m. At a shorter distance a low vibration system was used to prevent damage to the Groothandelsgebouw. During the driving of the piles, the vibrations of the building were monitored.

Since the start of the drainage for the building pit of the Weenatunnel monitoring data showed that the settlement of the building is limited to a maximum of 5 mm in the first half year of 2007.

Existing Underground Metro Station CS

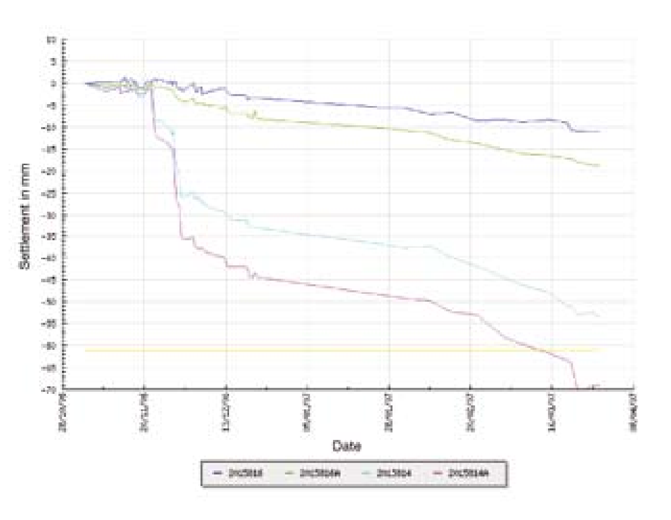
In order to reconstruct the station without disturbing the metro exploitation, a new floor with a thickness of 2 m was designed below the existing station. To construct this floor a dry excavation of 4 m below the existing metro tunnel to NAP –14 m is necessary. Because of loss of buoyancy additional bearing capacity for the existing metro tunnel has to be provided in advance. This was done in two different ways:

- holes with a diameter of 200 mm were drilled

↑ **Figure 5** The installation of diaphragm walls next to the Groothandelsgebouw (photo Aeroview)

through the roof, the intermediate floor and the tunnel floor, and about 20 jet grout columns with a diameter of 1.000 to 1.200 mm were installed from the ground surface to a depth of NAP –20 m;

- holes with a diameter of 252 mm were drilled through the roof, the intermediate floor and the tunnel floor, and about 60 steel pipe piles were driven from the ground surface (NAP) to a depth of NAP –31 m.



↑ **Figure 6** Settlement of the water main at the south of the Weenatunnel

The driving of piles through the station was a challenging activity. The steel piles have an outer diameter of 244.5 mm and a wall thickness of 20 mm. The bottom consists of a massive steel point with a length of about 480 mm. Before driving some dry concrete was brought into the steel pipe. The piles were driven by dropping a weight of steel, length 16 m, on the bottom of the pile. The piles were, without major problems, installed against the water pressure, through 'preventers'. Although the base level of the piles was much deeper than of the existing 'oppers' piles, the existing piles only settled 2 to 3 mm.

Underground metro tunnel below the office building Delftse Poort

One of the reasons that freezing technology was opted for here, was the fact that the foundation of the underground tunnel under the Delftse Poort office building was not designed to cope with a large drop in the groundwater level. Dewatering of the deep Pleistocene sand layer is also causing some side effects. This is due to the Holocene layers that contain local inclusions of sand layers, with a thickness varying up to several meters. These so-called 'donken' are suspected to cause a hydraulic connection between the top sand layers (including the fill around the metro tunnel) and the Pleistocene sand formation. To avoid the risk of loss of buoyancy due to the lowering of the groundwater table, an infiltration system was installed in the perimeter of the tunnel. This system functioned well during the drainage for the construction of the new Weenatunnel.

Water main adjacent to the new Weenatunnel

The sheet pile wall for the building pit of the Weenatunnel was installed by vibration. Settlements of the ground surface and of the water main at the south of the building pit have been predicted, and were considered to be acceptable. A monitoring programme had been set up to check the behaviour of the water main.

Installation of the sheet pile walls started at the end of 2006. In the period of the installation of the sheet piles a maximum settlement of the water main at a distance of 8 m from the building pit of about 45 mm was measured (*figure 6*). Next to the water main the maximum settlement amounted to 35 mm.

Settlements continued after the installation and amounted 50 and 40 mm respectively at the end of January 2007.

Drainage for the building pit started at the end of January 2007. The effect became visible in February 2007 by an increase of the settlement in the time from about 0.125 to 0.25 mm/day at the most settled measuring points. To date more than 70 mm of settlement has been measured. The stresses in the water main have been calculated. So far the stresses are within acceptable limits, because the differential settlements are relatively small.

Conclusion

Building in inner cities is a major challenge, not only from geotechnical point of view. Designs may be well-thought-out, the timetable for the construction of the different project is not as accurate as that of a train. Realizing many new constructions in a very confined space, each with its own timetable leads sometimes to conflicting interests. The construction period until 2012 will therefore pose sufficient challenges.

Building in inner cities needs direction to create added value for the city. A station equipped with new facilities, attractive office locations and additional greenery for the creation of pleasant and safe residential areas is expected to do so.

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