Coping with underground risks during the development of a new underground metro station in Rotterdam

ROBERT BERKELAAR[1]

[1] *Rotterdam Public Works, Engineering Dept. (e-mail: r.berkelaar@gw.rotterdam.nl)*

Abstract: Rotterdam Central Station was opened in 1957 in the period of rebuilding after World War II. The building and public transport infrastructure in its direct surroundings has served its purpose well for many years. However, the increasing pressure on public transportation resulted in the development of several mega projects in and around Rotterdam Central Station in the heart of the city. In the coming years this area will be transformed to a modern public transport hub where connections are made between local, national and international public transport systems.

One of the associated projects is the expansion and upgrading of the existing underground metro station. This project is engineered by Rotterdam Public Works. One of the prior conditions was unobstructed running of metro traffic during all building activities. Because of the high risk profile, risk management was given an important role. The lack of knowledge of subsurface conditions and underground obstacles became very obvious from the risk analyses. The main underground risks can be grouped in 2 themes: 1) unknown underground obstacles and 2) unforeseen ground behaviour. These two risks will be discussed and illustrated in this paper.

An extensive historical research programme has been performed to identify and locate potential underground obstacles. This desk study resulted in a list of obstacles possibly obstructing building activities. Examples are remnants of ground anchors and sheet pile walls used for the construction of a nearby skyscraper and foundation remnants and wooden piles of the former Rotterdam Zoo. The zoo was initiated in 1857 and destroyed during WWII. The design and building methods of the metro station had to be adopted to cope with these underground obstacles.

Unforeseen ground behaviour has been incorporated in the design where possible. However, a 100% fail safe solution is neither possible nor practical when dealing with the soil. Therefore, a lot of effort has been put into monitoring the underground and the surrounding structures during building activities. A system of hazard warning levels has been introduced linked to several levels of remedial action.

Résumé: La Gare Centrale de Rotterdam (Rotterdam CS) a été inaugurée en 1957, durant la période de reconstruction qui a suivi la deuxième guerre mondiale. Le bâtiment et l'infrastructure pour les transports publics dans les environs immédiats ont depuis déjà de nombreuses années rempli leur fonction. La pression croissante qui pèse sur les transports en commun a toutefois abouti au développement de plusieurs méga-projets dans et autour Rotterdam CS dans le centre de la ville. Au cours des prochaines années, cette zone sera transformée en un centre moderne de transports collectifs, où les connexions seront réalisées avec les systèmes de transports publics locaux, nationaux et internationaux.

L'un de ces projets concerne l'agrandissement et la modernisation de l'actuelle station de métro souterraine. Ce projet est réalisé par les Travaux Publics de Rotterdam. L'une des principales conditions était de n'entraver en aucune façon le trafic du métro durant les travaux. Etant donné le profil des risques élevé, la gestion des risques occupait une place importante. L'analyse des risques a clairement montré que l'on connaissait insuffisamment les conditions en sous-sol et les obstacles souterrains. Les principaux risques souterrains peuvent être divisés en 2 catégories : 1) les obstacles souterrains inconnus et 2) le comportement imprévu du sol. Ces deux risques seront examinés et commentés dans cet article.

Un vaste programme de recherches historiques a été réalisé pour déterminer la présence et la position des obstacles souterrains potentiels. Cette étude a permis d'établir une liste des obstacles susceptibles d'entraver les activités de construction. Il s'agissait par exemple des restes des rideaux de palplanches et des tirants qui avaient été utilisés pour la construction d'un gratte-ciel situé à proximité et des restes de fondations et des pieux en bois de l'ancien zoo de Rotterdam, construit en 1857 et détruit durant la seconde guerre mondiale. Il a fallu adapter les plans et les méthodes de construction de la station de métro en tenant compte de ces obstacles souterrains.

Les plans ont le plus possible tenu compte d'un comportement imprévu du terrain. Cependant, lorsqu'il est question de sol, une solution fiable à 100% n'est ni possible, ni pratique. On a donc consacré beaucoup d'attention à la possibilité de pouvoir toujours surveiller de près le sous-sol et les bâtiments situés à proximité durant les travaux. Un système a été mis sur pied avec des niveaux d'alerte, tous reliés aux différentes contre-mesures.

Keywords: risk assessment, monitoring, tunnels, desk study, site investigation.

INTRODUCTION

The present Rotterdam Central Station was opened in 1957 in the period of rebuilding after World War II, Figure 1. The train station was built in the neighbourhood of the former train station which connected Rotterdam to the first railway line in the Netherlands, being Amsterdam - Haarlem. The building and expanding public transport infrastructure in its direct surroundings has served its purpose well for many years. However, the increasing pressure on public transportation resulted in the development of several mega projects in and around Rotterdam CS in the hearth of the city, Figure 2. The high speed railway line between Paris and Amsterdam stops amidst 2006 at Rotterdam CS. The arrival of a new metro line called RandstadRail at the underground metro station Rotterdam CS in 2008 demands the expansion and upgrading of the present underground metro station. Above ground level a new public transport terminal will be realised in 2009 where all streams of passengers come together in a modern public transport hub where connections are made between local, national and international public transport systems.

Figure 1. The Netherlands and area of interest

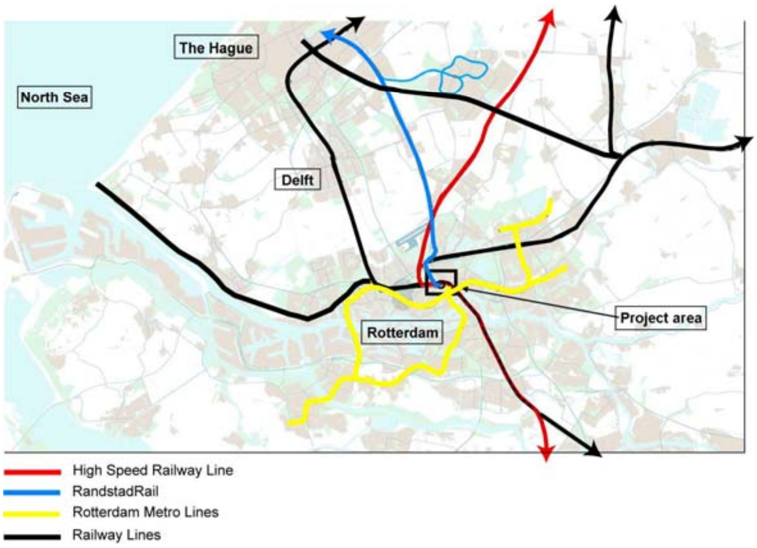

Figure 2. Public transport in and around Rotterdam

ROTTERDAM PUBLIC WORKS

Consultancy, engineering, development and implementation of plans for infrastructure, construction and the environment are the core activities of the engineering department of Rotterdam Public Works. The engineering department is ranked number 9 in the top 50 of 2005 of Dutch engineering consultants based on an annual turnover of 90 million and has 1.047 employees. The engineering department forms part of the administration of the city council of Rotterdam. Within this framework of administrative relations the know-how of Rotterdam Public Works as an engineering consultant is also used in other parts in the Netherlands and in projects around the world, for example in Shanghai, sister city of Rotterdam.

NEW METRO STATION ROTTERDAM CS

The project distinguishes itself by the very complex conditions under which the project has to be realised. The development of the underground metro station is a key project which interfaces with other big projects under construction or to be realised shortly at the same location, Figure 3. Among these are the expansion of the Weena car tunnel, the RandstadRail project which will be connected to the new metro station, a new public transport terminal will be build on top of the metro station, tram traffic will be led over the construction pit and the upgrading of the train station will take place directly next to the construction of the new metro station.

The building pit itself encloses the present metro station. One of the prior conditions during construction is unobstructed running of metro traffic in this station during all mentioned building activities. The continuous flow of pedestrians (approximately 50,000 passengers each day at the metro station) cyclists, trams, busses and taxis in and around the zone of building activities makes the project even more complex. Another important factor is the presence the ING 'Nationale Nederlanden' headquarters in a 151m high skyscraper on the eastern side at approximately 10m from the building pit. On the western side the building pit touches a monumental building from the 1950s, the 'Groothandelsgebouw'.

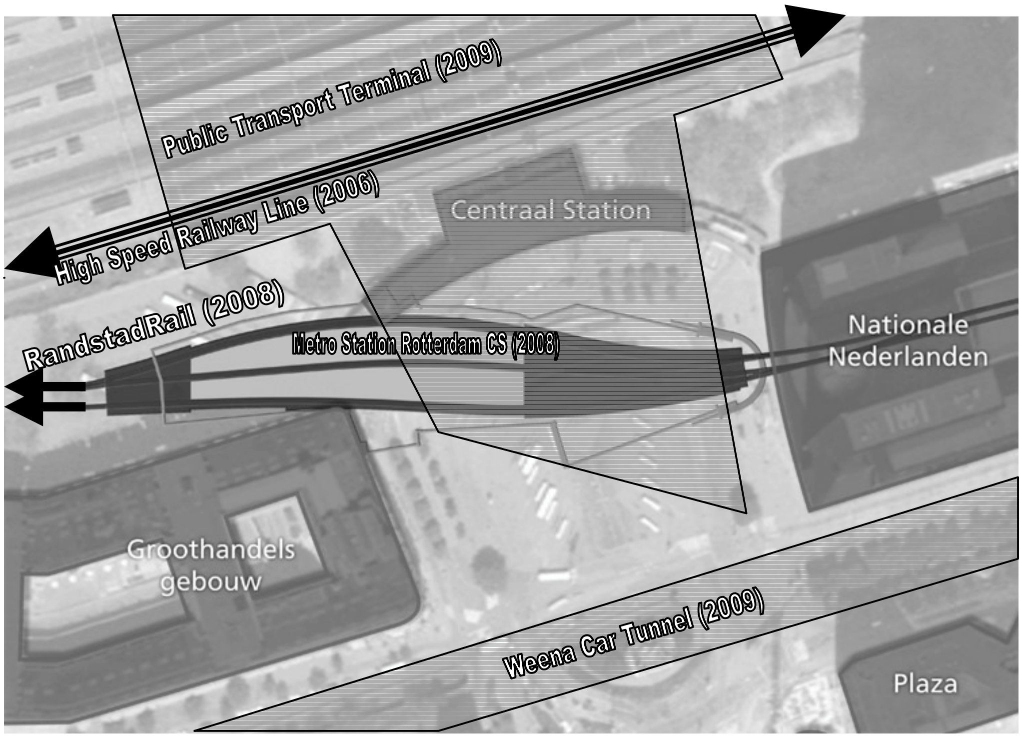

Figure 3. New metro station Rotterdam CS with adjacent projects and structures

Not only has the project to be executed under very complex site conditions, the technical aspects are very challenging and on the cutting edge of technology as well. The development of the new metro station is split in two phases. Phase 1 consist of making the walls for the construction pit needed for phase 2. This is being done by installing 490m of diaphragm walls around the existing metro station to a depth of 38m below reference level NAP. At this level a thick continuous clay-loam layer is present and thus a watertight construction pit is created. NAP is approximately equal to surface level in the project area. Within these contours 650 vibro-combination piles are driven to a maximum depth of 28m below NAP. These piles will serve as the foundation of the new metro station and the public transport terminal on top of it, Figure 4 and 5. In the second phase of the project, which is tendered as a separate contract, the building pit will be closed on the eastern side between the diaphragm walls and around the metro tunnel with a semi-permanent ice-body, Figure 4.

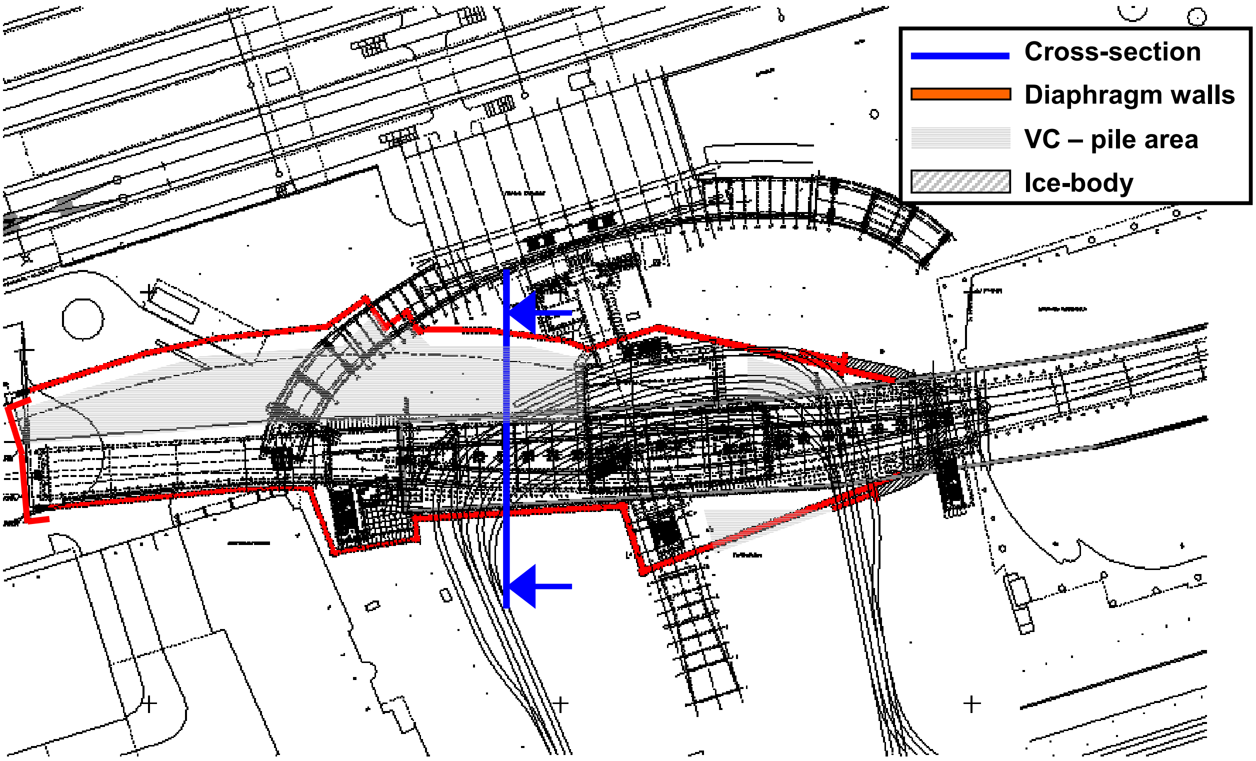

Figure 4. Building pit contours new metro station, situation at the end of Phase 1

After tests of water tightness of the diaphragm walls and the ice-body the pit will be excavated in phases and the existing metro station will be exposed. In this stage the foundation of the metro station will be reinforced by approximately 1,000 Tubex piles. These vibration free piles will be installed under the metro tunnel while metro is continuing, Figure 6. After this the frame work of the new metro station will be transformed from 2 to 3 tracks with longer platforms and ready to carry the load of the new public transport terminal, Figure 7.

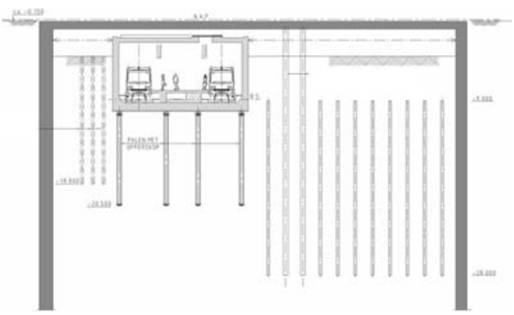

Figure 5. Cross-section, initial situation start phase 2

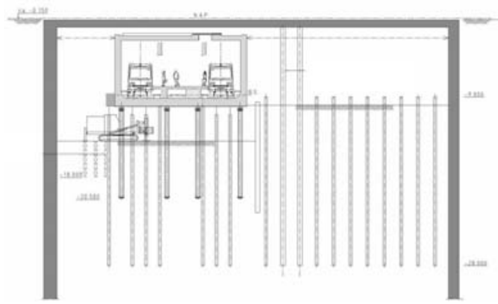

Figure 6. Cross-section, Tubex-pile installation under metro station

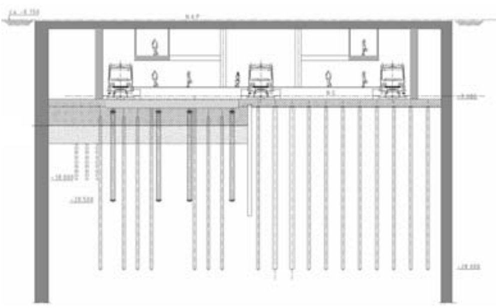

Figure 7. Cross-section, final situation

RISK MANAGEMENT APPROACH

As carried out regularly with big construction projects risk analyses were carried out in the planning and design phase of the project to determine the risk profile. The complex conditions and technical solutions, as illustrated above, contributed to a high risk profile. Because of this high risk profile, risk management was given an important role not only during the design phase but in all project phases.

Risk management is the next step to monitor and control the risks in the construction phase as identified during the risk analyses. During the construction phase of the new metro station Rotterdam CS technical monitoring and risk control techniques are used. With these tools, which complement each other, it is possible to perform pro-active risk management. Together they are used to update the risk profile, control technical- and project risks and support communications and negotiations with large stakeholders, Figure 8.

- Technical monitoring involves monitoring of the technical parameters of the construction process. In order for corrective actions to be made effectively it is essential to compare the measured technical parameters with predefined hazard warning levels. Beforehand fall-back scenarios have to be defined in order to be able to react in time with the appropriate measures.
- Risk control involves the pro-active structural monitoring of risks concerning the technical aspects and the possible consequences for time, cost and quality in the construction process. New risks can arise or risks may change with unforeseen circumstances and changes in the plans or activities.

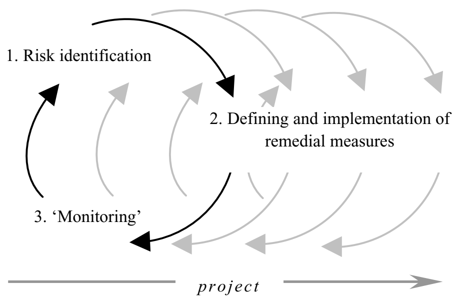

Figure 8. Risk management, pro-active approach

Risk analyses

The risk analyses made the importance of underground related risks very clear. These risks were quantified as huge because of the high probability of occurrence and huge consequences as well as the lack of knowledge of subsurface conditions and underground obstacles. Therefore a lot of effort has been made to control these specific risks.

The main underground related risks can be grouped in 2 themes: 1) underground obstacles and 2) unforeseen ground behaviour. The two have had different approaches in risk control. The risk of underground obstacles is minimised by doing a lot of research during the design phase in archives and site investigation. The unforeseen ground behaviour has been minimised by performing an extensive site investigation and laboratory testing. Furthermore by executing technical monitoring of ground and construction behaviour during the construction phase. These risks and controlling approaches will be discussed and illustrated in more detail.

UNDERGROUND OBSTACLES

An extensive historical- and obstacle research programme has been performed to identify and locate potential underground obstacles in the project area. This programme played an important part during the design process. The research has been carried out following a systematic approach under supervision of a multi-disciplinary team including archaeologists, as well as engineering geologists and civil engineers. The obstacle investigation started off with extensive historical research. The aim of this research was to backtrack all relevant developments in the project area from approximately 1850, when the area still was undeveloped as a polder, to recent years. Focus was on activities or buildings which could have led to obstacles in the ground. With the results of this desk study, a list of obstacles possibly obstructing the planned building activities were identified. This list required in some cases further (field) investigation to obtain answers concerning unresolved issues. Examples of underground obstacles in the project area are remnants of ground anchors and sheet pile walls used for the construction of the nearby ING headquarters and foundation remnants and wooden pile foundations of buildings of the former Rotterdam Zoo.

Ground anchors and sheet pile walls

In 1987 the construction of the ING headquarters was started. The building pit for this skyscraper consisted of sheet pile walls back tied with ground anchors. The ground anchors were only partially removed after construction was finished. These anchors were potential obstacles for the construction of the diaphragm walls and of emergency exits of the new metro station which had to be constructed at that point, Figure 9.

During the design phase the supposed locations of the anchors was indicated by as-built drawings. The reliability of these drawings was very limited however. The design was adopted in such a way that conflicts between the diaphragm walls and the anchors remains were minimised. This was acheived by adjusting the diaphragm wall contours and by limiting the depth of the diaphragm walls locally. These 'shallow' diaphragm walls were installed to a level where the anchor remains were encountered. Below this depth the walls were extended in depth by high pressure jet grout columns. Where conflicts were inevitable, and the jet grout extension option was not sufficient, the design prescribed removal of the anchors by vertical or inclined drilling techniques. During the installation of the diaphragm walls the anchor remains were encountered indeed. The contractor proposed removing those remains with the hydraulic diaphragm wall trench cutter, which was very successful in the end.

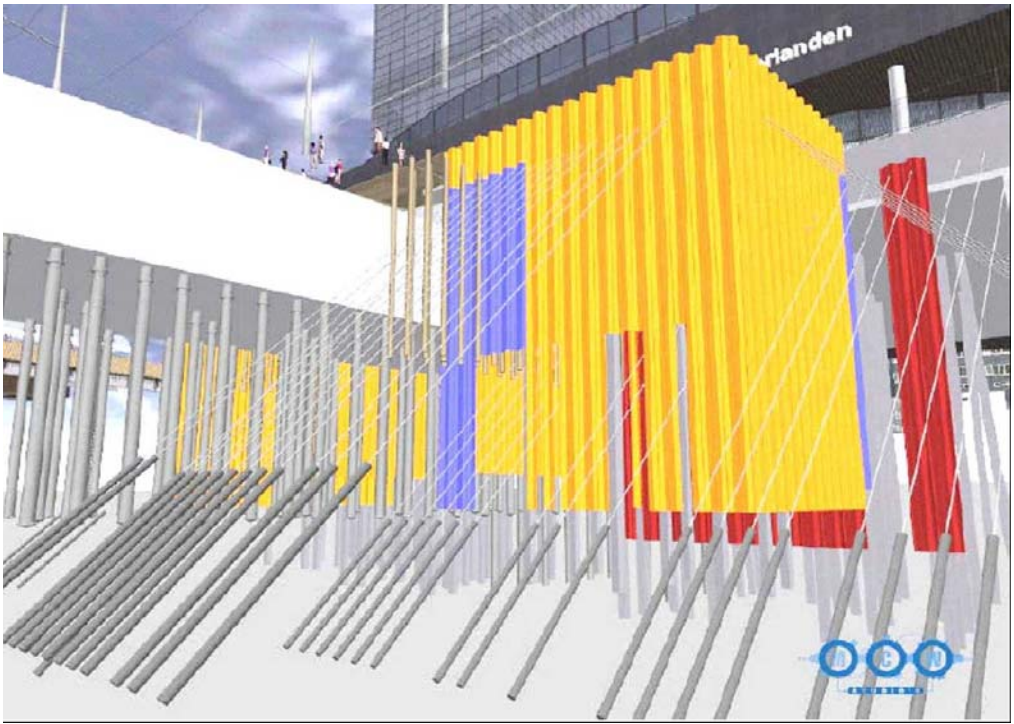

Figure 9. 3D-Visualisation of obstacles near the ING headquarters (MCW Studio's - Rotterdam)

Rotterdam Zoo

The zoo was initiated in 1857 as a small zoological garden. The garden developed to a, at that time, famous zoo and of such a size that it formed an obstacle for the expansion of the city of Rotterdam. It was decided by the city council to move the zoo to the northern side of the railway yard and demolishing of the old buildings was commenced upon. These activities could not be finished as the big fires following the German bombardment in WWII destroyed all remains of the Rotterdam Zoo completely. In the years after that all debris was removed and the area was made barren. The foundations, however, were left in place. The risk analyses identified these foundation remnants as big risks for the construction of the new metro station since the location and type of foundations remnants were unknown and the impact on construction activities could be very big.

The historical- and obstacle investigation was therefore aimed in filling in the gaps of knowledge on the foundation remnants and by doing so reducing its risks. During the design phase of the project desk studies in the private archives of the Rotterdam Zoo, Rotterdam Public Works and various libraries were performed. These studies resulted in a range of maps, drawings, photographs and illustrations of the developments of the Rotterdam Zoo from start to end. By a lot of puzzling and back tracking the locations of almost all buildings were identified with respect to the current topography. Now that the locations of most buildings were known a lot of effort has been put in trying to reveal the exact building plans. This was very important as to determine the type of foundation of the buildings in the project area. One can imagine a shallow footing foundation having much less impact on the construction of diaphragm walls compared with the impact of deep wooden pile foundations. In the end the foundation details of most buildings were recovered with a supposedly acceptable degree of accuracy, Figure 10. With aid of these data the potential conflicts between the diaphragm walls and the wooden piles could be identified.

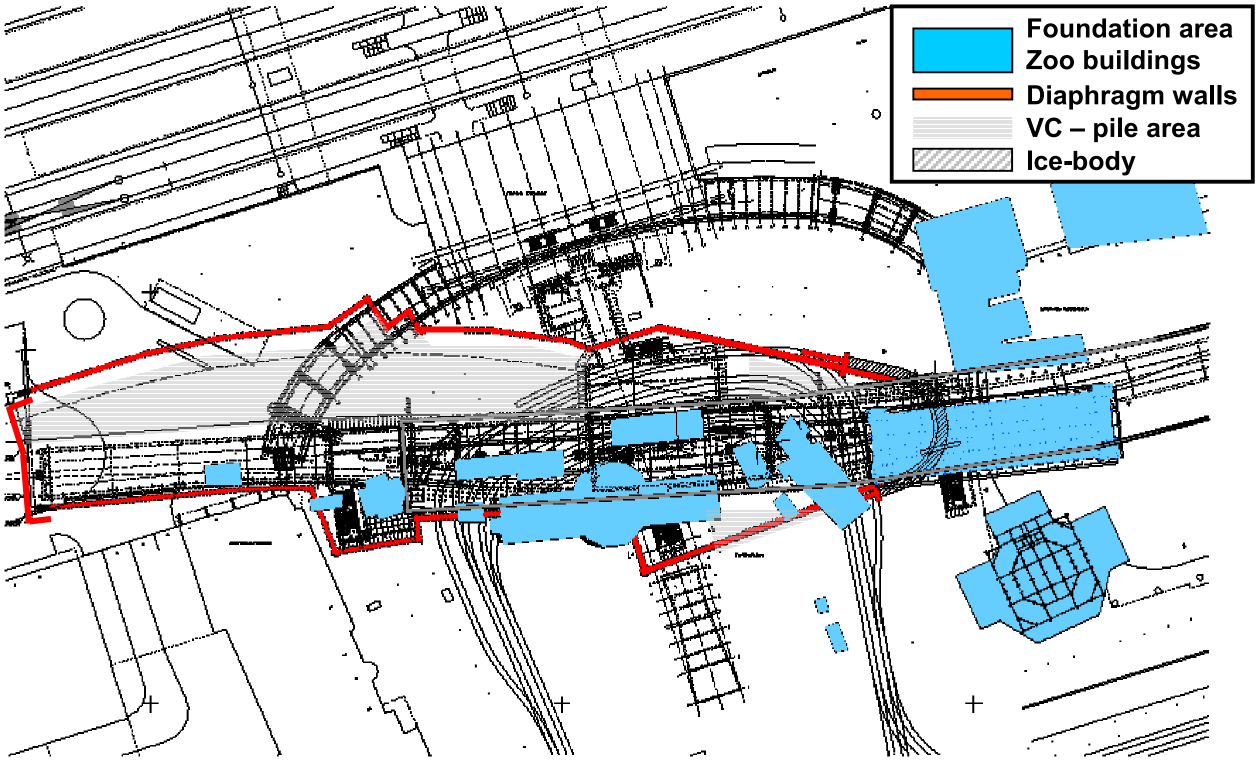

Figure 10. Obstacles: former Rotterdam Zoo buildings

During the design phase, 40 cone penetration tests (CPTs) were made to verify the presence of foundation obstacles within the diaphragm wall contours as indicated by the historical investigation. Of these 40 tests only one reached its target depth. Most tests refused on 2.5 m below surface level. As a result pre-digging to 2.5 m and removing all debris and obstacles following the diaphragm wall contours was prescribed in the contract. After filling back these trenches with clean soil another test run with CPTs had to be made. At this time only one out of 40 did not reach its target depth. During the installation of the diaphragm walls no wooden pile foundations were noticeably encountered. There are several possible explanations for this: 1) the accuracy of the old plans was overestimated and the deep foundation remains were therefore not located within the diaphragm wall contours, or 2) the wooden pile foundations were present but removed and not documented during the construction of the present metro station in the 1960s or 3) the wooden pile remainders were present but easily removed by the hydraulic diaphragm wall trench cutter and not reported by the contractor.

UNFORESEEN GROUND BEHAVIOUR

The risk of unforeseen ground behaviour has been minimised by 1) performing an extensive site and laboratory investigation during the design phase and 2) by technical monitoring during the construction phase. During the construction phase of the project the technical monitoring was given a place within risk management. This approach was new and aimed to achieve a pro-active approach with the monitoring results and thus preventing risks resulting from unforeseen ground behaviour.

Site- and laboratory investigation

Site- and laboratory investigation has been carried out with respect to geotechnical, geological, geohydrological and environmental purposes. All investigations were focussed on minimising the underground risks by gaining as much knowledge as possible. Another goal was to deliver design parameters for construction. A summary of performed investigation is given in Table 1. The entire investigation has been designed, co-ordinated and performed by Rotterdam Public Works.

However, one can never get 100% certainty about the design parameters and subsurface models no matter how much investigation you perform. The remaining risks of unforeseen ground behaviour has been covered by monitoring the behaviour of the underground and surrounding structures during construction activities.

Table 1. Overview site investigation

Type of investigation	Number of tests	Max. depth (m-NAP)
cone penetration tests	117 of which 12 through the metro station floor	60
boreholes	6	52
laboratory classification tests	14	n.a.
laboratory strength and index tests	30	n.a.

Monitoring

During the design phase of the project a very detailed programme of monitoring specifications was prepared. These specifications formed an integral part of the contract. Apart from the detailed monitoring specifications a set of hazard warning levels was introduced. These hazard warning levels had to be used by the contractor to control the construction process. The levels were differentiated into: 1) a warning level and 2) an intervention level. At the warning level the contractor has to take action like increasing frequency of monitoring, informing the client and adjusting the building process. The warning levels also serve as a trigger of awareness for both contractor and client. The intervention level may not by exceeded. If this does happen the contractor has to stop the activities causing the breach immediately and take action to stabilise and if possible reduce the exceeded parameter to a level below the intervention level. Of course all parties like client, insurance and permitting parties have to be informed immediately. In Table 2 an overview is given of some of the most important types of monitoring with related hazard warning levels.

Table 2. Monitoring examples

Object	Type of monitoring	Hazard warning levels	Aim
metro tunnel	tachymetric deformation	based on rail track and tunnel deformation criteria	prevention of tunnel damage and unobstructed exploitation of metro traffic
surrounding buildings	vibration and sound measurements	based on hindrance and damage criteria from building codes	preventing hindrance (where possible) and damage
groundwater	open standpipe piezometers	as dictated by groundwater extraction permits	working within permits

The contractor is contractually responsible for execution all monitoring including performing the checks on the hazard warning levels. The measures to be taken by the contractor when exceeding one of the warning levels have to be defined by the contractor beforehand and documented in building documents. All these responsibilities put a lot of extra pressure on the contractor and forms a risk on its own. This remaining risk is controlled by a strong back office on the side of the client specialising in risk management and technical monitoring. A risk management team has therefore been introduced by RPW. The most important tasks are checking of monitoring and monitoring documents supplied by the contractor and checking monitoring parameters on the hazard warning levels. Furthermore pro-active response on risks by identifying, labelling, analyzing and allocating, finally resulting in proposals to the project manager on how to control these risks.

CONCLUSIONS

- Investing time and money in extensive historical investigations and risk analyses pays off in risk reduction and determining the risk level used in fund raising for a project.
- Defining a set of hazard warning levels is essential when executing technical monitoring.
- A pro-active approach during the construction phase of a project is essential in risk prevention and reduction.

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Corresponding author: Mr Robert Berkelaar, Rotterdam Public Works, Engineering Dept, Postbus 6633, Rotterdam, 3002 AP, Netherlands. Tel: +31 10 4896250. Email: r.berkelaar@gw.rotterdam.nl.

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