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Risk management during the reconstruction of the underground metro station Rotterdam Central Station

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ABSTRACT: At the moment the underground metro station at Rotterdam Central Station (CS) is being reconstructed from a two-track to a three-track station. The project is carried out under very complex circumstances. The most important one is the politically imposed demand that the underground station has to maintain its full functionality at all times. This demand together with the technical complexity of the project, the complicated project phasing and other circumstances lead to a very high risk profile requiring risk management during the design and construction phase of the project.

Different approaches to risk management were taken during the design and construction phase. During the design phase straightforward risk analyses were carried out. For the construction phase it was decided to switch to a fully integrated risk management system with a dedicated risk management team. This team was responsible for managing the so called ‘soft’ and ‘hard’ risks. Examples of soft risk management are account management with important licensing authorities and dealing with the project environment. Hard risk management deals with risks which are primarily controlled by monitoring the ground(water) and construction.

An example of risk defined monitoring deals with the requirement of the uninterrupted metro operation. To control the risk of metro traffic disruption caused by tunnel and track deformation, a set of parameters was defined which were monitored during construction. Furthermore, monitoring parameters were defined regarding legal obligations and standards, insurance and safety requirements and structural conditions imposed by the project environment.

For each monitoring parameter warning levels were defined. When the signal level is exceeded mitigating measures have to be implemented to avoid exceeding the intervention level. Exceeding an intervention level means that the risk of damage has become unacceptably large. The difference between signal- and intervention level is chosen in such a way that sufficient time to implement these measures is available.

Keywords: risk management, monitoring, warning levels, earth works, organisation

1 INTRODUCTION

The present Rotterdam Central Station (CS) was opened in 1957 in the period of rebuilding after World War II. The station and the public transport infrastructure in its vicinity has served its purpose well for many years. However, the increasing pressure on public transport has resulted in the development of several mega projects in and around Rotterdam CS, figure 1. Among these are the high speed railway line between Paris and Rotterdam and the recently opened RandstadRail metro line, van Zanten and Thumann (2008). These projects demanded an expansion and upgrading of the present underground metro station. The engineering department of Rotterdam Public Works provided the architect, performed the complete engineering, contract management and construction supervision.

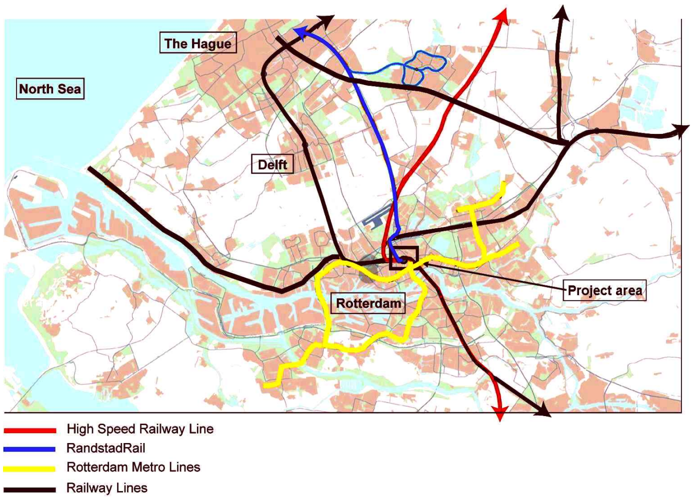

Figure 1. Heavy- and light-rail public transport in and around Rotterdam

The scope of the development of the new underground metro station is to upgrade the existing metro station from a two-track station with one platform into a three-track station with two platforms. The project is carried out under very complex circumstances. The most important one is the politically imposed demand that the underground station has to maintain its full functionality at all times. This means that a vast number of passengers use the metro station daily while construction under, next to and above the station continues. Other complicating circumstances are the deltaic soil conditions (soft soil with a high groundwater level), the fact that the location is right in the centre of Rotterdam, the technical complexity of the project and the complicated project phasing. These circumstances lead to a very high risk profile demanding explicit risk management during all project phases.

The excavation method of the building pit is based on isolating the Pleistocene sand aquifer inside the building pit by means of a diaphragm wall to a depth of NAP -38 m, figure 2. At this depth a continuous low permeable clay/loam layer is present. This method provides a water regime inside the building pit which can easily be maintained as only a very limited amount of water is expected to pass through the clay/loam layers and the diaphragm walls, Thumann and Haß (2007).

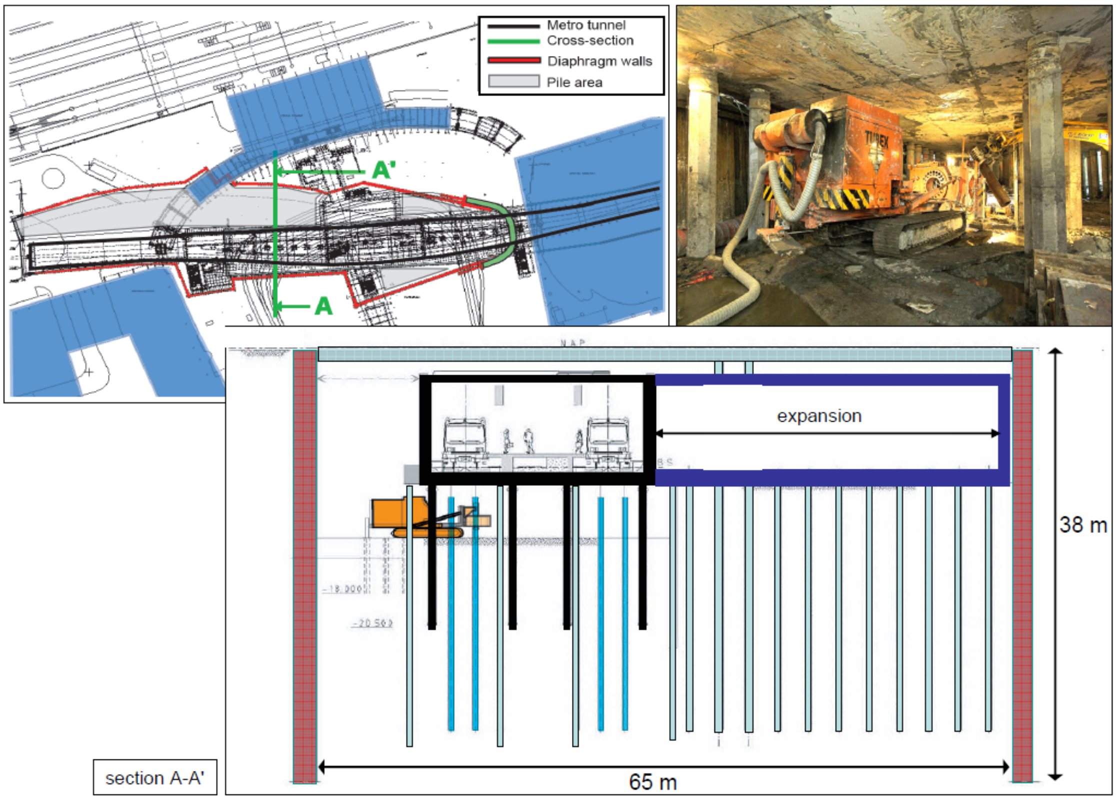

Figure 2. Plan view and cross section of the old metro station Rotterdam CS plus area of expansion and building pit contours, photograph of Tubex-grout injection pile installation under the old metro station

2 RISK MANAGEMENT DURING THE DESIGN PHASE

2.1 *Risk management approach and top risks*

The design phase can be entitled as a relatively 'static' phase concerning risk management. 'Relatively static' as there are no building activities yet and therefore the dynamics with the project surroundings are not as intense as during the construction phase. During the design phase risk management was primarily executed with straightforward risk analyses at set intervals and track was kept of the implementation of the remedial measures in the design and contract specifications. Because of the technical complexity of the project, focus was put on technical risks for: 1) risk remediation and 2) risk quantification. The results showed that the top risks are related with disturbance of metro operation and groundwater inflow in the building pit, table 1.

Table 1. Top risks

risk	cause	chance	consequence [M€]
leakage, water inflow in building pit	no water tight connection between diaphragm walls and metro tunnel	> 50 %	2
interrupting metro operations	deformation of metro tunnel due to multiple (interacting) causes such as: - strut failure - uncontrolled groundwater inflow - unexpected ground behavior	10 %	10

Emphasis was put on remediating the top risks. Therefore, a lot of effort was put in soil and obstacle investigation, implementation of design adjustments and the set up of a monitoring programme. Table 2 indicates the remedial measures belonging with the top risks.

Table 2. Top risks - remedial measures

risk	cause	remedial measure
leakage, water inflow in building pit	no water tight connection between diaphragm walls and metro tunnel	- historical and obstacle investigation - implement alternative design solutions
interrupting metro operations	deformation of metro tunnel due to multiple (interacting) causes such as: - strut failure - uncontrolled groundwater inflow - unexpected ground behavior	- soil investigation - set up of monitoring programme - struts with hydraulic jacks

Most remedial measures have been implemented during the design phase. In section 2.2 an example will be given of how the risk of ground water inflow in the building pit, at the point of entry of the metro tunnel, has been mitigated. Section 4 will illustrate how monitoring has been used as a remedial measure, or risk control tool, to mitigate the risk of interrupting metro traffic.

2.2 *Risk remediation by obstacle investigation and alternative design solutions, an example*

On the east-side of the project the existing metro tunnel enters the building pit, figure 3. The realization of a water tight connection between the diaphragm walls and the metro tunnel led to a very high risk of water inflow in the building pit. Obstacle investigation revealed the presence of a large number of obstacles at the same location: sheet piles walls, wooden piles, tie back anchors and the 'unknown' obstacles, figure 3. Several options on how to overcome these risks were considered. In this evaluation the alternatives were primarily compared on functionality, weighing on costs was secondary. Of the available design solutions ground freezing seemed most promising because of its water tightness, its variable (adaptable) geometry and the fact that obstacles do not interfere with the ground freezing process significantly, Thumann and Haß (2007).

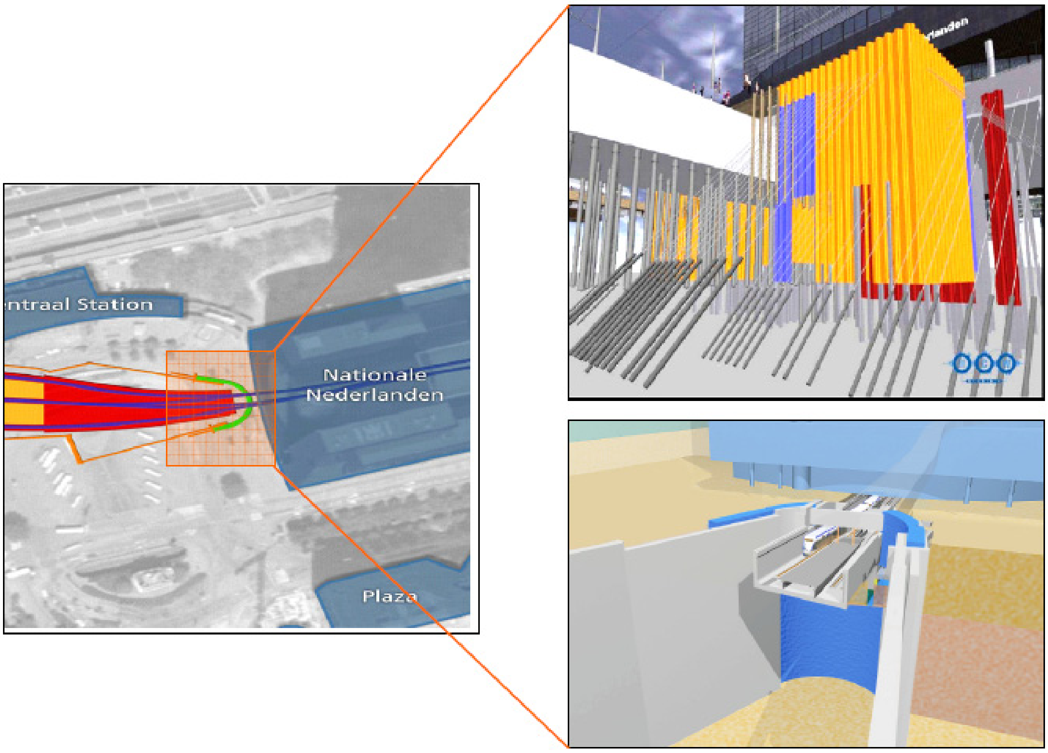

Figure 3. Results obstacle investigation and frozen ground body at the east-side of the building pit

The risk of groundwater inflow in the building pit has been mitigated by changing the design: introducing the frozen ground body. However, ground freezing has never been performed on this scale and context in the Netherlands before and in doing so new risks were introduced, such as unknown freezing pressures, frost heave and working with liquid nitrogen in confined spaces. These new risks were primary mitigated by making design adjustments such as making locally thicker diaphragm walls and reinforcing the existing metro tunnel. Secondary, a back up freezing system was implemented. Further, an extensive monitoring programme was set up to monitor the behavior of the metro tunnel and the frozen ground body.

3 RISK MANAGEMENT DURING THE CONSTRUCTION PHASE

In the construction phase the ‘dynamics’ of the project increase significantly. The interaction of the project with its surroundings becomes tangible and time pressure increases. Therefore, it was decided to make a switch in the risk management approach; from the straightforward risk analyses during the design phase to a fully integrated risk management system with a dedicated risk management team during the construction phase.

The risk management team is positioned as a staff department but has very close relations with (financial) control, engineering and construction supervision, figure 4. By giving the risk management team a clear position in the project organisation and by clearly delineating the responsibilities, it proved possible to act proactively. The team is managed by the risk manager and consist of specialists (geotechnical, hydrological, environment engineers etc.) but also of generalists (account manager to licensing authorities and a monitoring coordinator).

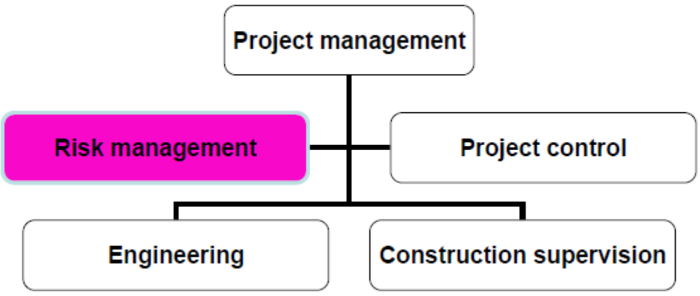

Figure 4. Position of risk management in the project organisation

This team was responsible for managing the so called ‘soft’ and ‘hard’ risks and the interaction of the two. The interaction is based on linking the ‘hard’ risk management, i.e. controlling risks by monitoring geotechnical and structural parameters, with the ‘soft’ risk management, figure 5. Examples of soft risk management are account management with important licensing authorities, dealing with the project environment and act as counter part of the insurance risk controller. Communication with these parties improved when it was demonstrated that risks and legal obligations were met using the monitoring results. In section 4 examples of ‘hard’ risk management will be given.

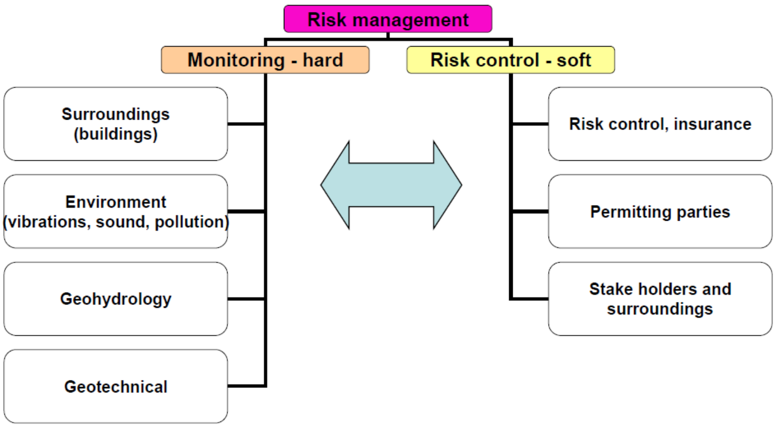

Figure 5. Organisation in risk management team

The main tasks of the risk management team are to ensure that remedial measures are actually implemented, to signal new risks and to make sure that all risks are allocated. This ‘risk monitoring’ is done in several ways. Firstly based on the actual monitoring results; unexpected behaviour of the ground or the structure may give indications of a risk about to occur. Secondly, risk based interviews and site visits, as well as communication with other team members on an almost daily basis, contributes to early risk detection.

4 MONITORING AS RISK CONTROL

4.1 *General*

The risk register at the end of the design phase gave significant input to the monitoring programme. Additional monitoring demands were based on legal obligations, insurance demands, safety requirements, demands from the project surroundings and research purposes. The monitoring programme has been made part of the contract specifications. The specifications gave detailed descriptions of how, what, where and when to monitor. Further the warning levels are defined as well as technical demands and reporting requirements.

Monitoring goes beyond just taking measurements. When using monitoring as a risk control tool the measurements should be compared with warning levels. For each monitoring parameter these levels are defined in advance. The warning levels consist of a signal level and an intervention level. When the signal level is exceeded, mitigating measures have to be implemented to avoid exceeding the intervention level. Exceeding an intervention level means that the risk of damage has become unacceptably high. The difference between signal- and intervention level is chosen in such a way that there is sufficient time to implement these mitigating measures.

A good example of risk defined monitoring deals with the requirement of the uninterrupted metro operation at all times during all construction works, see table 1 and 2. In this case monitoring serves to detect any changes in the deformational behaviour of the existing underground metro station. The main criteria for the warning levels were to assure the structural integrity of the existing metro station and safe operation of metro traffic, Berkelaar et al. (2007).

4.2 *Monitoring as risk control - example 1*

One of the first building activities was pile driving just north of station section A4. Within 4 weeks time a vertical deformation of 22 mm was detected, figure 6. Based on demands on the structural integrity of the station the warning level was set at 35 mm and the intervention level at 50 mm absolute vertical displacement. The measured vertical deformation was directly related to the pile driving. Exceeding of the signal level could be expected shortly considering the development of the deformation. It was therefore decided to change the installation method of the piles by adding a pre-drilling phase. After this no significant additional settlement took place. The risk of disrupting metro traffic was therefore controlled effectively.

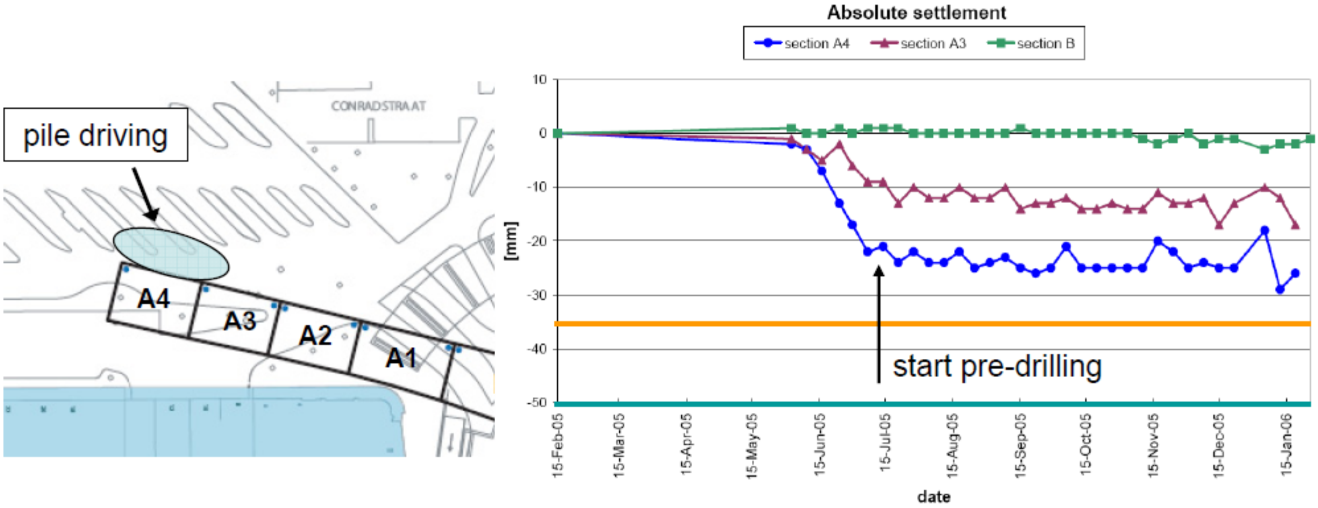

Figure 6. Example 1, Monitoring as risk control

4.3 *Monitoring as risk control - example 2*

An important warning value for safe metro operation was the differential settlement over station section joints. Figure 7 shows the development of the deformation over the joints. The warning levels were set at ±8 and ±10 mm. When the signal value was exceeded the operator of the station was informed. The operator decided to execute track corrections at the moment the intervention value was reached. After the track correction on joint W13-W14 the measurements were reset (not shown in figure 7). This case shows that monitoring proved to be very helpful in controlling the risk of disruption of metro traffic.

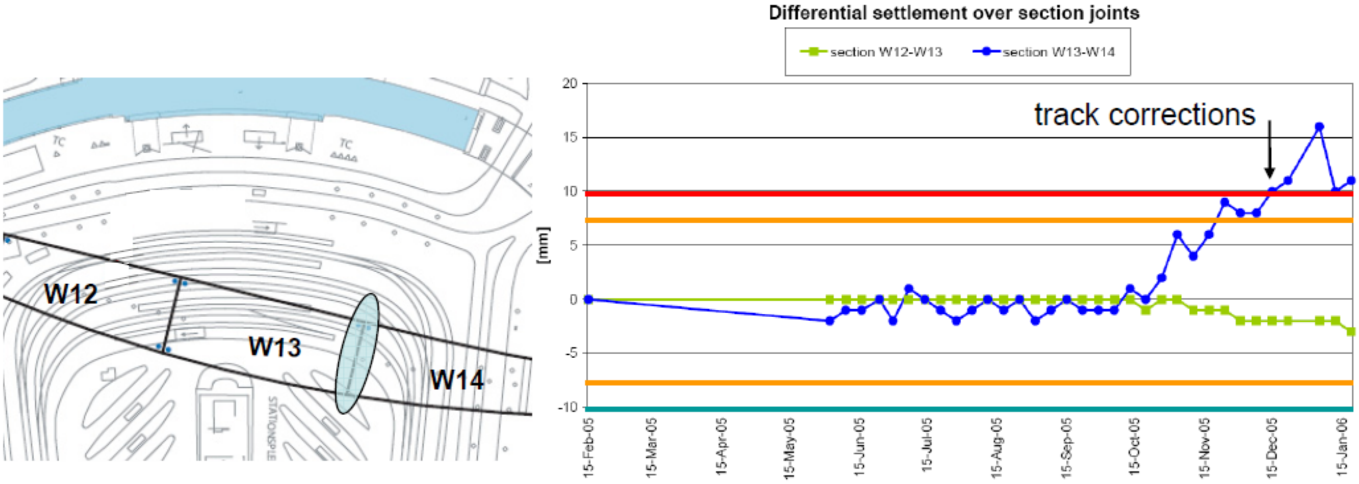

Figure 7. Example 2, Monitoring as risk control

4.4 *Monitoring as risk control - concluding remarks*

Full accessibility of all services in and around the underground metro station was maintained during all building activities so far. Monitoring proved to be very useful in controlling the risk of disruption of metro traffic caused by deformation of the station. However, not all risks can (completely) be controlled with monitoring. There is always the chance of the unexpected.

5 THE UNEXPECTED

Just before Christmas in 2007 a major leak occurred at a joint of the diaphragm wall at the time the maximum excavation depth of 14 m was reached. A huge amount, over 100 m^3/hour, of water and sand entered the building pit. Monitoring did not reveal any warnings before the leakage took place.

Immediately the four rigs for installation of Tubex-grout injection piles under the existing metro station were hoisted out of the building pit. Pumps to remove the water out of the building pit were installed and the public area was closed off because of the rapidly developing ground surface settlements. At the same time monitoring was intensified to check the possible deformations of nearby buildings. A poly urethane (PU) foam was injected to seal of the leakage, but it appeared that this could not solve the problem. The foam was washed away due to the enormous amount of water entering the building pit. After this it was decided to reduce the ground water flow by installing two drainage wells outside the building pit. Due to the reduction of the flow it was now possible to inject the PU-foam effectively. The final solution consisted of a sheet pile wall outside the building pit with jet grout piles, Thumann et al. (2009).

During the leakage an estimated 500 to 600 m^3 of sand entered the building pit. This resulted in an extensive ground surface settlement in an area of about 25 m by 25 m. Close to the leak the settlement was estimated to be over 2 m, figure 8.

Figure 8. Photographs of leakage and ground surface settlement

The above shows that, although monitoring can be very useful in risk control, one should always be prepared for the unexpected. When incidents as described occur, a fast switch from risk control to accident control has to be made. In these situations it is important to have good (alarm) procedures and have a good team (principal and contractor) to cope with the problem, resilience is essential. Risk management is a very useful tool to define the alarm procedures.

6 CONCLUDING REMARKS

From the risk management approach and case histories as described in this paper following concluding remarks can be made:

- It is important to make a difference in the approach in risk management during the design and the construction phase of a project. Straightforward risk analyses do not always meet the required level of risk management.
- Risk management should be given an explicit place in the project organisation. Risk management has to be visible. Depending on the contract type you have assign risk managing responsibilities.
- The most prominent risk, interference of operation of the metro station, did not occur. Full accessibility of all services was maintained during all building activities.
- Determine warning levels for each monitoring parameter and mitigation measures before construction works starts which can be taken when the warning levels are exceeded.
- Technical monitoring can be very useful in controlling risks, but be aware of the unexpected.

REFERENCES

Berkelaar, R., Huisman, L. & Luijten, C.J.L.M., 2007, Monitoring the underground metro station Rotterdam CS, a case study, Proceedings 7th FMGM, Boston, USA, 2007.

Thumann, V.M. & Haβ, H., 2007, Application of ground freezing technology for a retaining wall at a large excavation in the centre of Rotterdam, the Netherlands, Proceedings 14th ECSMGE, Madrid, Spain, 2007.

Thumann, V.M., Hannink, G., & de Doelder, B.R., 2009, Ground freezing and ground water control at underground station CS in Rotterdam, Proceedings 17th ICSMGE, Alexandria, Egypt, 2009.

Van Zanten, D.C. & Thumann, V.M., 2008, Engineering highlights of RandstadRail in Rotterdam, the Netherlands, Geotechniek, April 2008.