Risk Management for the Underground Car Park Kruisplein

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Abstract. In the preparation and construction stages of the underground car park beneath Kruisplein with diaphragm walls, risk management played an important role. After a description of the structure and the construction, the preventive measures that were invented and carried out are summarised. These relate to the organisation of the project (experienced advisors, consequent risk management), the preparation of the construction stage (detailed plan of action, lessons learned from other projects, analysis of the environment and physical conditions), environment management, monitoring and the supervision of the construction process. The monitoring process and a new method to detect anomalies in the joints of diaphragm walls are presented in more detail.

Keywords. underground car park, diaphragm walls, soil related risks, measures, monitoring

1. Introduction

In order to offer parking facilities to 760 cars, the municipality of Rotterdam (contractor: Besix, Brussels) built an underground car park beneath Kruisplein (Cross Square). Since the bottom of the structure is 20 metres below the surface (the excavation was about 20.5 metres below the surface) it was decided to apply diaphragm walls.

However, in several recent projects incidents occurred with diaphragm walls during construction. In that of the new underground station at Rotterdam Central Station a severe leakage arose in the interface of two wall sections, and in Amsterdam historical houses got severely damaged by large displacements caused by leakages in the diaphragm walls of an underground station under construction. For this reason an extensive study on incidents like the two mentioned above was carried out, in order to investigate measures to prevent incidents as well as measures to be taken when leakages do occur, despite all preventive efforts. Naturally, it all started with a risk inventory. With the incidents in mind, experienced advisors were selected for this complex (technical, environmental) project.

In this paper the technical risks (soil – structure interaction) are discussed as well as the measures taken in the project. We conclude with some recommendations for future projects.

2. The Structure of the Underground Car Park

The dimensions of the underground car park are: length: 150 metres, width 33 metres. It consists of 5 floors, which implies that the upper side of the basement floor is 18 metres below the surface (18.5 metres below Amsterdam Ordnance Datum (NAP)). The bottom is 20 metres below the surface (thickness of the floor is 2 metres). Some parts of the floors are sloping to facilitate driving from one floor to the next, Figure 1. The floors act as props in the final situation (cross section, Figure 2). Half way the width of the car park, columns support the floors.

![Figure 1. Longitudinal section of the car park](image-url)
below the surface, about 3 (at least 1.5 m) metres under a 1 metre sand layer in an impermeable clay layer of more than 10 metres. Thus an impermeable box (150 m * 33 m * 41.5 m) was created in which the groundwater level could be varied by means of pumping without influencing the level outside of the structure. Two additional diaphragm walls were built under the basement floor down to 39.5 metres below the surface as extra tension elements for the vertical equilibrium, Figure 2.

The connection of the basement floor with the diaphragm wall was not fixed but designed as a hinge (vertical reaction force on a beam, cross section 1 metre by 1 metre, Figure 3), so that during curing of the concrete of the floor no tension force could occur and thus cracking (and leaking) was prevented (more or less free shrinkage).

3. Construction of the Underground Car Park

After preparing the building site the contractor made the diaphragm walls. The width of the walls surrounding the structure was 1.2 metres, the width of the walls below the basement floor was 0.8 metres. The length of the sections was either 5 or 7 metres. The reinforcement was prefabricated and brought to the building site in 4 or 6 parts (two in height) for each section.

The impermeable box mentioned before consisting of the surrounding diaphragm walls and the impermeable clay layer enabled us to excavate in the dry. Before the excavation we did a pumping test: the groundwater level inside the structure was lowered up to 20.5 metres below the surface to see how much water would seep through the diaphragm walls and the impermeable soil layer. It appeared that there was hardly any leakage.

During excavation, which was done layer by layer, the props were placed on locations that were calculated beforehand (because of the required support of the diaphragm walls, the sloping floors and the columns that were skew as well). The props were steel tubes placed in five layers, Figure 4.

The diaphragm walls at the beginning and the end of the structure were supported by small parts of the floors that were constructed during the excavation stage.

After the excavation the basement floor was built (Figure 5) and successively the combination
of floors and columns (Figure 6) and the roof were made.

Figure 5. Reinforcement basement floor

Figure 6. Props and skew columns

The groundwater level inside the structure was gradually lowered during excavation down to 21 metres below the surface. During the construction stage of the final structure the groundwater pressure under the basement floor was gradually increased, depending on the weight of the part of the structure realised.

4. Preventive Measures (Invented, Carried out)

4.1. Measures Concerning the Project

Defining a project starts with an inventory of the relevant disciplines involved. In this project the most relevant disciplines are:

- soil mechanics
- structural design
- construction expertise
- risk management

For a complex project such as this one the cooperators of all disciplines should be selected upon skill and their experience (paragraph 1).

Because in the initial stage of a project important decisions about size, depth, foundation et cetera, are made, the properties of the soil and the structural conditions should already be known or investigated in this stage. Risk management starts here. In the design stage the main risks in the construction stage should become clear and the measures to prevent those from happening can be invented.

During the project, both in the design and the construction stage the risk inventory as well as the preventive measures should be regularly updated, evaluated and discussed.

4.2. Measures Proposed in the Initial and Design Stages

In the initial stage it was decided that the width of the structure should be relatively small (33 metres) compared to the width of the square. This was because of the requirement that the exploitation of the tram system (several crucial tram lines) on the square should not be interrupted. To compensate for this relatively small width the car park would need to have 5 floors and a depth of 20 metres below the surface, including the basement floor, thus resulting in the deepest car park in the Netherlands up to now. The depth in combination with the requirement to prevent noise and vibrations in the environment as much as possible, led to the selection of diaphragm walls. From the examination of the soil it appeared that use could be made of the aforementioned impermeable clay layer from 38.5 metres underneath the surface (paragraph 2). Constructing the diaphragm walls deep in this layer made it possible to excavate in the dry.

From the examination of the buildings in the environment it appeared that an apartment building that was only 7 metres away from the diaphragm wall was vulnerable for displacements. The same holds for the tram that was less than 1 metre away from the diaphragm wall. Other buildings were further away but these (like offices, a theatre, a congress centre/concert hall, the school of the arts) were sensitive to noise and vibrations.
All of this and the incidents with diaphragm walls near Rotterdam Central Station and in Amsterdam discussed in the introduction (paragraph 1), led to an extensive risk inventory. The main identified technical risks during construction were:

- leaks in either the diaphragm walls or the impermeable layer. In particular soil transporting leaks are dangerous;
- displacements during excavation due to bending of the diaphragm walls (though prevented as much as possible by 5 levels of props).

The following measures were proposed:

- A pumping test before excavation: lowering the groundwater level inside of the structure to 0.5 metre below the excavation level in order to verify the impermeability of the diaphragm walls and the clay soil layer.
- Excavating layer by layer after gradually lowering the groundwater level, and immediate cleaning the diaphragm walls, to enable a visual inspection (possible imperfections).
- After reaching the levels that were calculated in the design stage, the props were placed. The exact locations were not only determined by the support of the diaphragm walls but also by the sloping floors, the skew columns and the construction process.
- Providing the props close to the apartment building with jacks in order to be able to reduce the displacements of the diaphragm wall and the soil behind it.
- Checking the already excavated parts of the diaphragm walls to see if leakages occur (especially during weekends, etcetera).
- Groundwater extraction filters mobilised in order to be able to quickly install pumps to lower the groundwater level outside of the structure in case of leakages or displacements exceeding the limit values.
- Extensive monitoring on displacements, vibrations, groundwater level and noise in order to discover the effects on both the environment and the structure under construction.

Furthermore it was decided to:

- intensively supervise the construction process by the inspection team;
- have an organisation and know the procedures in the case of incidents;
- organise environment management;
- study the incidents quoted before.

4.3. Measures Proposed after the Study of Incidents

The leakage in the diaphragm wall of the new underground station at Rotterdam Central Station took place in the interface of two wall sections. When the construction of the diaphragm walls started in August 2009 no other measures were possible but closely taking care of the joint between the two sections and the profile in it, and inspecting the diaphragm walls during excavation as described above.

However, a research project was started into methods to detect imperfections in or nearby the joint, ahead of the Geo – Impuls project, in which the results were used. Several methods that were in principle promising were applied in four joints. The ‘Crosshole sonic logging’ (CSL), a method based on sending and receiving acoustic waves, appeared applicable in practice (Spruit, Van Tol, Broere, Slob, Niederleithinger, 2013; Spruit, Van Tol, Broere, 2015) and is indeed applied in new projects.

Figure 7. Detection of an anomaly with CSL

Figure 7 shows the principle of the method. The source/receiver equipment is lowered in the four
tubes next to the joint in which an anomaly may be detected.

Figure 8 shows the corresponding results, from which the anomaly was concluded. In this case repair before excavation was not considered necessary because it did not extend through the whole cross section and the soil consisted of stiff clay at this depth. After excavation the anomaly indeed was found.

From the Amsterdam incident, which we closely studied, we learned that the construction of the diaphragm walls should be done carefully and accurately. In particular continuously pouring the concrete of the diaphragm walls is required in order to prevent sand inclusions caused by casting stops at which severe leaks may occur. Although large interruptions of the pouring process could be avoided (in most cases less than 20 minutes), some small leakages already occurred here. Furthermore we learned that monitoring results should be watched 24/7.

5. Carrying Out the Measures

In this paragraph attention is paid to the execution of the monitoring programme and the pumping test.

5.1. Monitoring

The main purpose of the monitoring programme is to check that the construction is under control and that, as a consequence, there is no damage on the building site or in the environment. The monitoring on the building site (like displacements of walls, basement floor, force in the props) was carried out by the contractor. The monitoring in the environment was done by the inspection team, partly as an obligation to the authorities (if groundwater outside of the structure was not affected, flow rates, noise, et cetera), partly to check and to convince the environment that no damage arose (displacement of structures, surface, tram; vibrations; noise). Monitoring the displacements was done in the quarters surrounding the building site.

We now focus on the apartment building mentioned in paragraph 4.2, only 7 metres from the diaphragm wall. Figure 9 shows the locations (of the buildings west of the building site, as well as those of the structure) of where the displacements were measured.

Most measurements were done on a regular basis (e.g. each week), but in the immediate environment of the building site measurements were done continuously, resulting in diagrams like Figure 10.

The actual measurements were carried out by means of a tachymeter (total station) and were automatically stored in the Argus system. All measurements were related to the measurements before the construction started. For each location a signalling and an intervention value were determined from predictions. Exceeding the signalling value led to an automatic warning by SMS at the inspector on duty. Fortunately this only happened because of errors in some measurements.
5.2. Pumping Test

As described in paragraph 3 and 4.2 a pumping test was carried out before excavation which proved that there was hardly any leakage water. The test however, did have a substantial effect on the displacement of, in particular, the apartment building located 7 metres from the diaphragm wall (Figure 11), as shown by Figure 10 (in June 2010: a vertical displacement of 8 mm of the pillars closest to the diaphragm wall, whereas the intervention value was 15 mm). The explanation is, that by lowering the groundwater level inside of the structure the total horizontal outward pressure there diminishes, which will cause horizontal inward displacements of the diaphragm walls (not yet supported by props) and consequently it will cause displacements of the soil outside of the structure. In fact, this is a load case that should have been analysed beforehand.

Figure 10. Results of continuously measuring in time (apartment building, columns 7 metres from the diaphragm wall); all measuring points show the same tendency

Figure 11. The pillars of the apartment building with attached the measuring points

According to the risk inventory we performed the following measures:
- we designed a new foundation of the pillars closest to the diaphragm wall with a possibility to jack those;
- we immediately informed the owner of the apartment building and agreed to report the displacements of the critical parts every 2 months during excavation.

In the end the displacements did not exceed the intervention values and were in fact close to the predictions. During the first part of the excavation the displacement was stable, then increasing gradually. So the sudden displacement of the pumping test would have occurred anyhow, but then gradually.

6. Concluding Remarks, Recommendations

Thanks to the organisation of the project (experienced advisors, consequent risk management), a thorough and accurate preparation of the construction stage (detailed plan of action, lessons learned from other projects, accurate analysis of the environment and physical conditions), environment management, monitoring and an intense supervision of the construction process, we avoided the main identified risks as described above.

In addition we recommend for future projects:
- for detecting anomalies in joints the CSL – method is now available;
- the pumping test should be considered a separate load case;
- any interruption of the pouring of the concrete of the diaphragm walls should be avoided.

References