Evaluation of diaphragm wall as-built data to determine the risk of leakage for the Kruisplein car park excavation in Rotterdam, The Netherlands

Evaluation des données de fabrication des murs diaphragmes pour déterminer le risque de fuite dans le chantier du parking souterrain Kruisplein à Rotterdam, Pays-Bas

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ABSTRACT: In the centre of Rotterdam, the Kruisplein car park is becoming the deepest underground parking facility in the country. It is being constructed since 2009, and will provide around 760 parking places on a total of five floors, of which the deepest is reaching to almost 20 m below ground surface. The retaining wall has been designed as a diaphragm wall reaching from ground surface to approximately 40 m depth. Because of some major leakage incidents in diaphragm wall type excavations in Rotterdam and elsewhere in The Netherlands, additional effort was raised to define and prepare mitigating measures to reduce the risk of leakage for the Kruisplein car park project. An extensive evaluation of as-built data of the diaphragm wall was made, including all available field records of process-parameters. Based on the outcome of the evaluation, it has been concluded that in general the diaphragm walls were of sufficient quality. No major leakage incidents have occurred to date.

RÉSUMÉ : Dans le centre de Rotterdam, le parking de la place Kruisplein est en train de devenir le plus profond garage souterrain du pays. Ce parking est en construction depuis 2009 et pourvoira 760 places de stationnement réparties sur cinq niveaux. Le plus profond d'entre eux atteint plus de 20 m de profondeur sous la surface du sol. Le mur de soutènement a été conçu comme une paroi moulée atteignant approximativement 40 m de profondeur. À cause de divers accidents majeurs de fuites d'eau survenus dans des excavations utilisant des parois moulées à Rotterdam et ailleurs dans les Pays-Bas, des efforts supplémentaires ont été fournis pour définir et préparer des mesures d'atténuation pour réduire le risque de fuite lors du projet du parking Kruisplein. Une évaluation étendue des données des parois moulées, incluant toutes les données de chantiers enregistrées lors de leur fabrication, est présentée. Il n'y a eu jusqu'à ce jour aucun incident majeur de fuite sur le chantier de Kruisplein.

KEYWORDS: diaphragm wall, deep excavation, risk of leakage, field records, as-built data, mitigating measures.

1 INTRODUCTION

In Rotterdam diaphragm walls are regularly applied since the construction of the Willem Railway tunnel in the nineties of the past century. For underground infrastructural projects, it is an appropriate building method, because it facilitates deep excavations under dry conditions. By connecting the diaphragm walls to the rather impermeable soil layers of the Formation of Waalre a dry building pit can easily be created. The geological conditions are favorable for this building method: in the centre of Rotterdam the rather impermeable layers of the Formation of Waalre are everywhere present between 35 and 40 m below sea level (this corresponds to the Dutch reference level NAP).

Diaphragm walls have been applied at several locations of the metropolitan light rail project RandstadRail in the beginning of this century. During the extension of metro station CS a major leak through the diaphragm walls arose when the excavation inside the building pit was at its maximum depth (14 m below sea level). As a result a huge amount of water and sand entered the building pit. With a lot of trouble, the leak was fortunately stopped within two days, and the construction of the metro station could be continued (Thumann et al. 2009).

In the same period the preparation of the underground car park Kruisplein was in full swing. The design consisted of 40 m deep diaphragm walls to make a 20 m deep excavation possible. A logical question at that moment was, how to minimize the possibility of a similar incident during the construction of the car park. This paper describes the mitigating measures taken in advance, the supervision during the construction, and the effectiveness of the precautionary measures in practice.

The construction of the Kruisplein car park is part of the overall project Rotterdam Centraal (Hannink & Thumann 2007). This major project comprises of the building of a large Public Transport Terminal in the vicinity of the Rotterdam Central Railway Station. It is designed to facilitate passenger transfer between (inter)national trains including the high-speed train, and local public transport like trams, buses and underground trains. The excavation as required for the construction works of the Kruisplein car park covers about 5.000 m^2.

Engineering of the car park Kruisplein, and supervision of the execution of the project is performed by the Engineering Consultancy Division of the City of Rotterdam.

Figure 1. Building pit of car park Kruisplein.

2 SOIL CONDITIONS

The ground level in the area is situated at about sea level. The geotechnical profile of the Rotterdam city area consists of anthropogenic layers (from ground level to about 5 m below sea level), and soft Holocene peat and organic clay layers (from about 5 to 17 m below sea level). Below this level Pleistocene coarse sand layers are encountered up to 35 to 40 m below sea level. These sand layers are underlain by the Formation of Waalre, consisting of over consolidated clay and sand layers. Figure 2 shows the result of a CPT. The phreatic groundwater level is about 2 m below sea level.

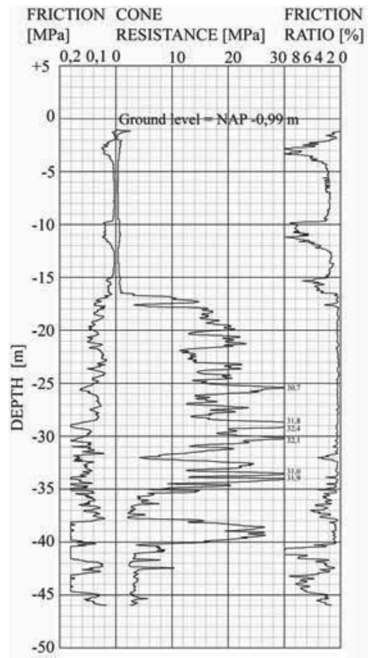

Figure 2: Results of a CPT at car park Kruisplein.

3 RISK ANALYSIS

In this project the principal is responsible for the design, and the contractor is responsible for the construction. The contractor is obliged to present plans about the way the risks connected to the building method are controlled, including relevant solutions and mitigating measures.

The possibility of leakage into a building pit with diaphragm walls is small, but the consequences may be very serious in case groundwater flows into the building pit. Especially in an urban environment a sand carrying leak is seen as a huge risk. Piles are founded in the sand layer with the top at 17 m below sea level. This is the same sand layer that may flow into the building pit. There are several possible causes for leakage out of this sand layer:

- the panels of the diaphragm wall are insufficiently connected;
- the base of the panel is not or insufficiently connected to the impermeable layer, for example as a result of the presence of an obstacle;
- the concrete of the panel contains intrusions of sand, peat or clay, that form weak spots in the diaphragm wall;
- the concrete of the panel contains bentonite, that forms weak spots in the diaphragm wall.

The starting point in the design stage of the car park was that the diaphragm walls would be placed at least 1.5 m into the impermeable layers of the Formation of Waalre. At the deepest point of the excavation the diaphragm wall must be able to retain a groundwater pressure difference of about 20 m.

Measures to minimize the possibility of a leaking diaphragm wall were prescribed in the contract. However, to minimize the possibility of leakage, the most was expected of measures that could facilitate the building process.

The outcome of the risk analysis indicated that to minimize the possibility of a leaking diaphragm wall:

- additional requirements should be prescribed in the contract;
- early observations of imperfections during the building process are of utmost importance;
- the execution of the project has to be monitored adequately;
- the analysis of as-built records is essential as to identify hazardous locations.

4 MEASURES IN THE CONTRACT

The building contract included Dutch standard RAW specifications regarding quality control of the diaphragm wall building process. The following additional contract requirements have been defined:

- the verticality of the panels shall be within 0.5% of the depth in both transverse and longitudinal directions;
- the horizontal deviations of the exposed face of a panel shall be less than 100 mm;
- 150 mm wide water-stops (rubber profiles) shall be put into every steel stop end of the diaphragm wall;
- the concrete surface of adjacent panels shall be cleaned from bentonite cake before the commencement of concreting;
- the maximum rate of concrete rising in the trench shall be 6 m/h in the Holocene clay and peat layers;
- a good connection between the floors and the diaphragm walls shall be secured. It is important not to drill unnecessary additional holes for reinforcement bars into the diaphragm walls. Zones of overlap of the reinforcement of the diaphragm wall were not allowed at the locations of the reinforcing bars;
- the maximum aggregate particle size of the concrete shall not exceed 16 mm.

Concreting records of the diaphragm wall panels had to be made to register the following possible execution imperfections:

- the time during which the trench is left open before concreting;
- the deviations of the steel stop ends;
- the deviations of the reinforcement;
- steel stop ends which are left behind;
- discontinuities in concreting.

After completing the diaphragm wall, and before starting the excavation, a check had to be made on the permeability of the building pit by means of generating a 20 m pressure difference between inside and outside of the diaphragm wall. This pumping test was meant to deliver information about the water tightness of the diaphragm wall in the sand layer with the top at 17 m below sea level, and about the water tightness of the rather impermeable layers at 40 m below sea level. A successful test however, does not exclude leakage in the execution phase, because the diaphragm wall will be excavated at one side, and will deflect. This may result into open joints between the panels.

According to the contract four boreholes for so-called sleeping wells had to be drilled around the building pit, to be able to act quickly in case of a leak. The purpose of these 'sleeping' wells was, in case of a calamity, to decrease the difference in water pressure between the inside and the outside of the building pit as soon as possible. This will make it easier to control the amount of groundwater that penetrates the building pit. The installation of pumps and mains was not required in the contract. The idea was that in case of a calamity the mobilization period would be limited.

5 MEASURES DURING THE EXECUTION

It was considered to be important to specify the most vulnerable processes into a number of documents that made it possible to control the processes:

- the excavation plan describes the sequence of the execution of the panels of the diaphragm wall as to minimize the possibility that a leak will occur during the night;
- the supervision plan for the construction of the diaphragm wall and for the excavation of the building pit is meant to detect imperfections in an early stage during the excavation;
- the calamity plan describes the risks connected to the construction of the diaphragm wall and the available mitigating measures at the moment of signaling a (potential) leak or a threatening calamity;
- results of monitoring activities and records give detailed information on the execution of each panel, and of possible imperfections. It is of utmost importance that the content of the documents and the point in time of handing them in are mutually agreed;

The results of the supervision by both the principal and the contractor are discussed at the building meetings, and a separate regular monitoring meeting with all persons concerned was convened.

6 ASSESSMENT OF DIAPHRAGM WALL QUALITY

All relevant data have been evaluated to determine potential weak-spots in the diaphragm wall along the excavation circumference.

6.1 Pumping test

The pumping test to check the water tightness of the diaphragm walls was executed in June 2010. The measuring results showed that the water tightness of the building pit as a whole met the requirements as formulated in the permit for water extraction. This implicated that the average quality of the diaphragm walls came up to expectations about water tightness in not excavated circumstances.

6.2 Field observations

Field observations by both the contractor and the supervisors of the City of Rotterdam were meant to record regular and any extraordinary circumstances during the building process of each individual panel. In practice, general data on the duration of the consecutive building stages (a.o. excavating, refreshing of bentonite suspension, lowering of steel reinforcement, concreting) and identification of excavated soil type (sand or clay) have been recorded. For some panels, underground obstacles were encountered.

6.3 As-built documents

Information from as-built documents has been thoroughly examined to detect any hazardous sections of the diaphragm panel. These data have been visualized as for example shown in Figures 3 to 5. Figure 3 shows amongst other things the elapsed time between:

- the start of the excavation of the trench and the start of the installation of the steel stop ends;
- the start of the installation of the steel stop ends and the end of the excavation of the trench;
- the end of the excavation of the trench and the start of the cleaning of the concrete surface;
- the start of the cleaning of the concrete surface and the start of the installation of the reinforcement cage;
- the end of the installation of the reinforcement cage and the commencement of concreting.

Long periods of elapsed time for a particular activity may indicate an increased risk of imperfections.

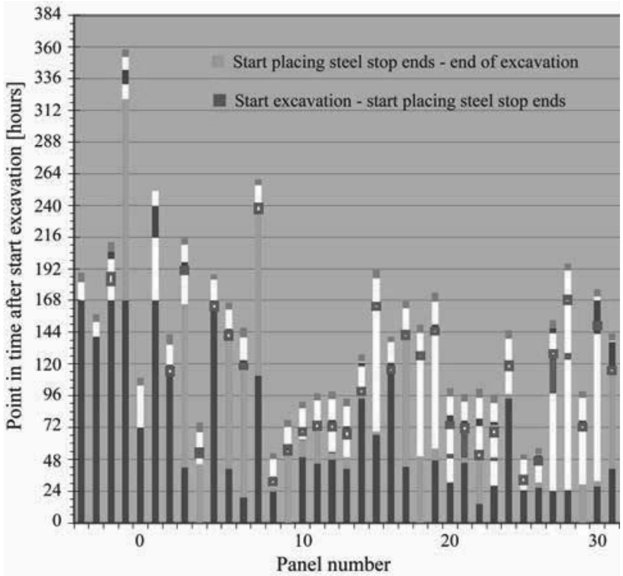

Figure 3. Continuity of the production process.

Figure 4 shows the calculated deviation of wall thickness as can be calculated from the concreting progress reports. From Figure 4 it can be identified where the panels are suspected to have a reduced thickness of more than 0.2 m. However, it is recommended to have more detailed information on the progress of the concreting process for future projects, as to increase the resolution (reliability) of this graph.

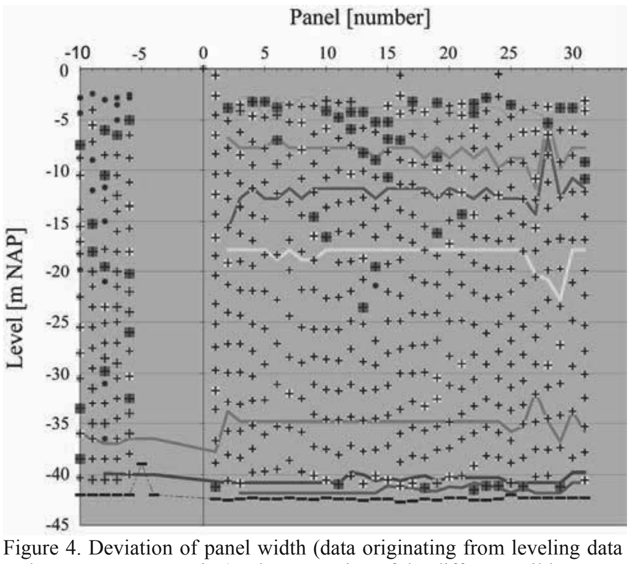

Figure 4. Deviation of panel width (data originating from leveling data and concrete consumption). The separation of the different soil layers as derived of excavation data and of geotechnical investigations is also indicated.

Figure 5 shows the position of all diaphragm wall panels at 40 m depth, as derived from crane operating monitoring equipment. Most of the panels have been excavated in two or three parts, thus giving at least two monitoring records (inclination and deviation vs. excavation depth) per panel. From Figure 5 it can be identified where the panels are suspected to have insufficient overlap. The diaphragm wall thickness as designed was 1.20 m; the allowable position with respect to overlap (zone width of 1.60 m at 40 m depth) follows from the 2% deviation of the verticality.

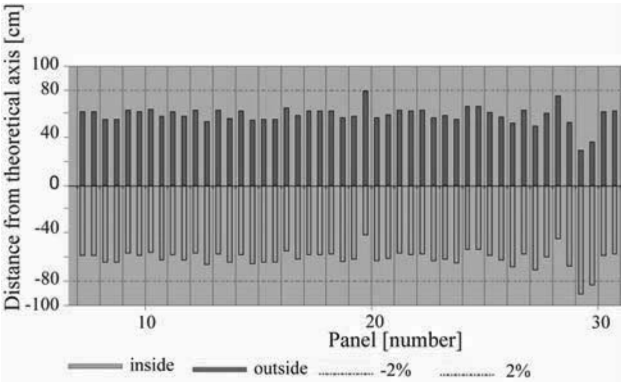

Figure 5. Relative position of the panels at 40 m depth. Dark represents the outside of the diaphragm wall; light the inside. The dotted red lines represent the 2% deviation of the verticality.

6.4 Non-standard measurement techniques

Reference is made to Doornenbal et al. (2011) and Spruit et al. (2011) for more information on the experiments using non-standard measurement techniques to detect imperfections in diaphragm walls, which appeared to be quite successful.

6.5 Increased risk of leakage

Combined interpretation of Figures 3 to 5 reveals areas where an increased risk of leakage has to be anticipated for, as compared to normal conditions. Following aspects have been evaluated using the outcome of the interpretation of the as-built records:

- a missing/damaged water-stop;
- no cleaning of the concrete surface;
- the elapsed time between refreshing of the bentonite and the commencement of concreting greater than 24 hours;
- encountered problems during the stop end removal works;
- concrete characteristics;
- wall thickness reduction > 0.20 m (Figure 4),
- reduced overlap < 0.80 m (Figure 5).

An overview of locations with an increased risk of leakage along the excavation circumference has been generated as shown in Figure 6.

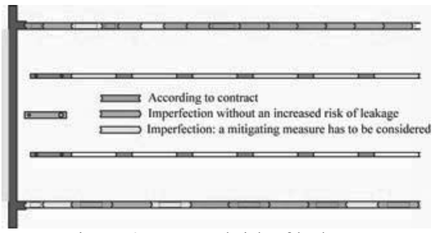

Figure 6. Increased risk of leakage.

Subsequently, a number of mitigating measures has been defined for each individual panel as to compensate the increased risk. It appeared from the overall risk analysis that careful positioning of four ‘sleeping’ wells around the excavation would provide sufficient means for acting in case of leakage at any of the identified weak spots as shown in Figure 7. Additionally, for a number of panels it has been recommended to call for an intensified inspection and repair program (when necessary) during the excavation works.

7 CONCLUSIONS

The realized diaphragm wall panels were in general of sufficient quality. A number of hot spots along the circumference of the building pit with a increased risk of leakage were identified. The risk profile related to leakage was considered to be at an acceptable level if a number of mitigating measures were executed. These measures were supplementary to the required measures in the contract.

A pumping test to check the water tightness of the diaphragm walls is very valuable in case the subsoil conditions are similar to those in Rotterdam.

Supervision of the construction process appeared to be an important mitigating measure, in combination with the registration of the execution data of the diaphragm wall, and the subsequent analysis of these data.

The extensive acquisition of data as such is not new for the construction of diaphragm walls, but the systematic analysis of the data, as performed for this project, has not been noticed so far. It is recommended to do so for all future projects.

The positioning of ‘sleeping’ wells can be considered as a major mitigating measure, and is a lesson learned from the construction of the (leaking) diaphragm wall at metro station CS.

Figure 7. Positioning of the four ‘sleeping’ wells east and west of the building pit. Additional wells may be installed at the north and south side in case of a calamity in the northern or southern wall.

ACKNOWLEDGEMENTS

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