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Large scale monitoring during Amsterdam metro construction; risk control, procedures and experiences

Monitoring pendant la construction de métro d'Amsterdam; le contrôle de risque, les procédures et l'expérience

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ABSTRACT

The new North/South metro line is being constructed in Amsterdam. The construction of three deep station boxes started in 2003 right in the historic inner city of Amsterdam. The sensitive structures surrounding the station boxes are automatically monitored by a system of robotic total stations and prisms. A dedicated geographical information system automatically checks on an hourly basis whether individual measuring points have exceeded limit values. The limit values are based on the results of full scale trials and FEM calculations. The paper deals with the deformation risk control of deep station boxes in a sensitive historic environment. The large amount of monitoring data, daily several thousands of measuring points are checked for exceeding trigger values, requires special analyses. Once limit values are exceeded clear and comprehensive procedures are defined to inform geotechnical engineers to take action. In the paper these procedures and the experience with such an extensive system are presented.

RÉSUMÉ

La nouvelle ligne de métro Nord/sud est construite dans Amsterdam. La construction de trois station profondes a commencé dans 2003 dans la ville historique d'Amsterdam. Les structures sensibles entourant les station sont automatiquement contrôlées par un system de *total stations* et prismes robotisés. Un système informatique géographique dévoué automatiquement contrôles sur une base horaire si l'individu mesure des points ont dépassé les valeurs de limite. Les valeurs de limite sont basées sur les résultats de essai et de calculs de FEM. L'article traite le contrôle de risque de déformation de station profondes dans un environnement historique sensible. La grande quantité de data, par jour plusieurs milliers de points à mesurer sont vérifiées pour dépasser de valeurs de détente, exige que le spécial analyse. Une fois les valeurs de limite sont dépassées des procédures claires et complètes sont définies pour informer les ingénieurs geotechnique pour prendre des mesures. Dans l'article ces procédures et l'expérience avec tel un système vaste sont présentés.

1 INTRODUCTION

Construction of the three deep stations boxes Rokin, Vijzelgracht and Ceintuurbaan of the new Amsterdam North/Southline metro started in 2003. One the most important issues in this project are the displacements of the surrounding structures in relation to the construction process. The monitor this influences and to steer the construction process on displacement readings a substantial monitoring system is installed along the rout of the North/South Line. This system generates daily a vast amount of data that has to be processed efficiently in order to be effective in the construction process. This paper describes the role of monitoring around the deep station boxes of the North/South Line and specifies how monitoring functions within the construction process of the three deep station boxes.

2 MONITORING

In order to determine the displacement of the historic structures along the deep station boxes at least four prisms are attached to the façades in the influence zone of the station box as described by Netzel and Kaalberg (2001). The displacement of the prisms is measured in three directions (x, y and z) by a robotic total station. Each robotic total station monitors about 75 prisms. The monitoring data of each robotic total station is transmitted automatically to the monitoring contractor on an hourly basis. During construction of the deep station boxes the monitoring contractor sends the data every four hours to the client. The client receives the measured value of each prism that is closed to the average value of the four hourly readings. Besides the monitoring of the structures four arrays of underground instrumentation is installed around each deep station. This instrumentation consists of automatic extensometers and inclinometers as well as piezometers. The underground monitoring data is also provided on a four hour basis to the client. On a daily basis the client receives around 7 Mb of monitoring data.

figure 1: impression of the site conditions at Ceintuurbaan station

3 GEOGRAPHICAL INFORMATION SYSTEM

In order to handle the large amount of monitoring data software applications have been developed by the client. The applications use the Geographical Information System (GIS) Arcview as user interface. Using a GIS offers the opportunity to easily visu-

alize the data which provides an immediate graphical status overview of the displacements around the construction sites. Besides visualizing the monitoring data, the GIS acts as a geographical database system from which essential project data can be retrieved. For instance, for every 25 m along the trajectory of the North/South line a geotechnical profile is generated from the 3D geotechnical model of the project, which is immediately accessible from the GIS. The data of the each structure within the influence zone is also included in the database. Information on the state of the structure, the foundation class and the angular distortion of the façade is also included in the GIS.

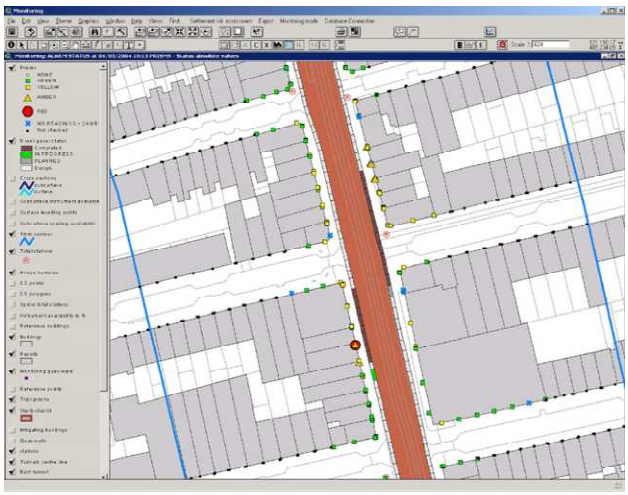

Figure 2: overview of the GIS status screen

4 DEEP STATION BOXES

The deep station boxes Rokin, Vijzelgracht and Ceintuurbaan are excavated to 25 to 31 m depth. Diaphragm walls are constructed to a depth of 38 to 45 m. After construction of the diaphragm walls the roof is constructed followed by excavation and propping underneath the roof (Bormans et al. 2004). With respect to the supervision of the construction process four construction phases are of importance:

1. Removal of underground obstacles
2. Construction of diaphragm walls and roof
3. Excavation
4. Passage of the tunnel boring machine and finish of the station

All the three deep station boxes are at the moment of writing in construction phase 2.

5 LIMIT VALUES

For each construction phase or part of a construction phase limit values are defined. These limit values are based on results of full scale trials, finite element model calculations or a combination of both. In the finite element calculations both most-likely and lower limit approaches are adopted.

For the construction phase “diaphragm wall construction” the limit values are base on the results of a full scale trial at a construction site in Amsterdam described in de Wit et al. (2001). Based on the trial results, the maximum displacement of the structures near the diaphragm walls in this construction phase is expected to be 5 mm.

Besides the maximum expected displacement (limit value) a number of sub limit values are defined that act as a warning code. Five color codes are used. The definition of the applied color codes is given in table 1. The values given in table 1 are valid for a certain construction phase. When the status RED is reached in a construction phase it means that for this certain construction phase the predicted value has been reached. The necessity for adapting the construction process is determined by the absolute value of the total displacement and the option for adapting the construction process in subsequent construction phases.

Table 1: limit value codes for the construction phase “diaphragm wall construction”

code	description	Limit value for the D-wall construction phase
Green	No significant displacement in relation to the trend	< 2 mm
Yellow	First indication of displacement of the monitoring point	> 2 mm
Amber	The displacement for this construction phase approach the maximum value	> 4 mm
Red	The limit value for this construction phase is reached	> 5 mm
Purple	A limit value for sudden extreme displacements	> 25 mm

6 ALARM APPLICATION

Within the Geographical Information System runs an alarm application that automatically checks and visualizes new monitoring data (figure 2). When limit values are exceeded, the alarm application takes a number of actions. An important condition in the procedures definition is that when limit values are exceeded the warnings reach the proper actor and that the number of irrelevant warnings are kept low without an increase in the chance that no actions are taken on actual warnings. Regarding the last type of warnings it is obvious that when the number of irrelevant warnings becomes too large, the risk of a decrease in interest in the warnings becomes to high and actual warnings can be neglected.

For the supervision of the construction phase “diaphragm wall construction”, two important risks can be distinguished that require immediate action: 1. trench instability and 2. sudden instability of surrounding structures. To control these risks measures are taken, both in the preparation of the project as well as in the construction phase. The procedures when limit values are exceeded anticipate an adequate reaction in the unlikely situation that these risks actually occur.

When a limit value is exceeded this has to be reported to the proper actor. The alarm application in GIS is capable of sorting the destination of the report based on location (in or outside the influence zone of the diaphragm wall panel in progress) and time (who is present on the construction site). The proper actor is reported by SMS and email. Consequently the Actor should evaluate and react on the report. The email includes an automatically generated report form that provides all relevant monitoring data and acts as a guidance to deal with the report according to procedures.

7 DISPLACEMENTS

Figure 3 provides monitoring data including the defined limit values for the diaphragm wall construction phase around Ceintuurbaan station. It becomes clear that raising the street level gives 1 to 2 mm of displacement. When the diaphragm wall is constructed in front of the structure it is interesting to see that no instantaneous displacement of the structures is observed, but that the displacement is clearly time dependent. The displacement as a result of diaphragm wall construction is around 3 mm, which is within the limits that are defined based on the full scale trial.

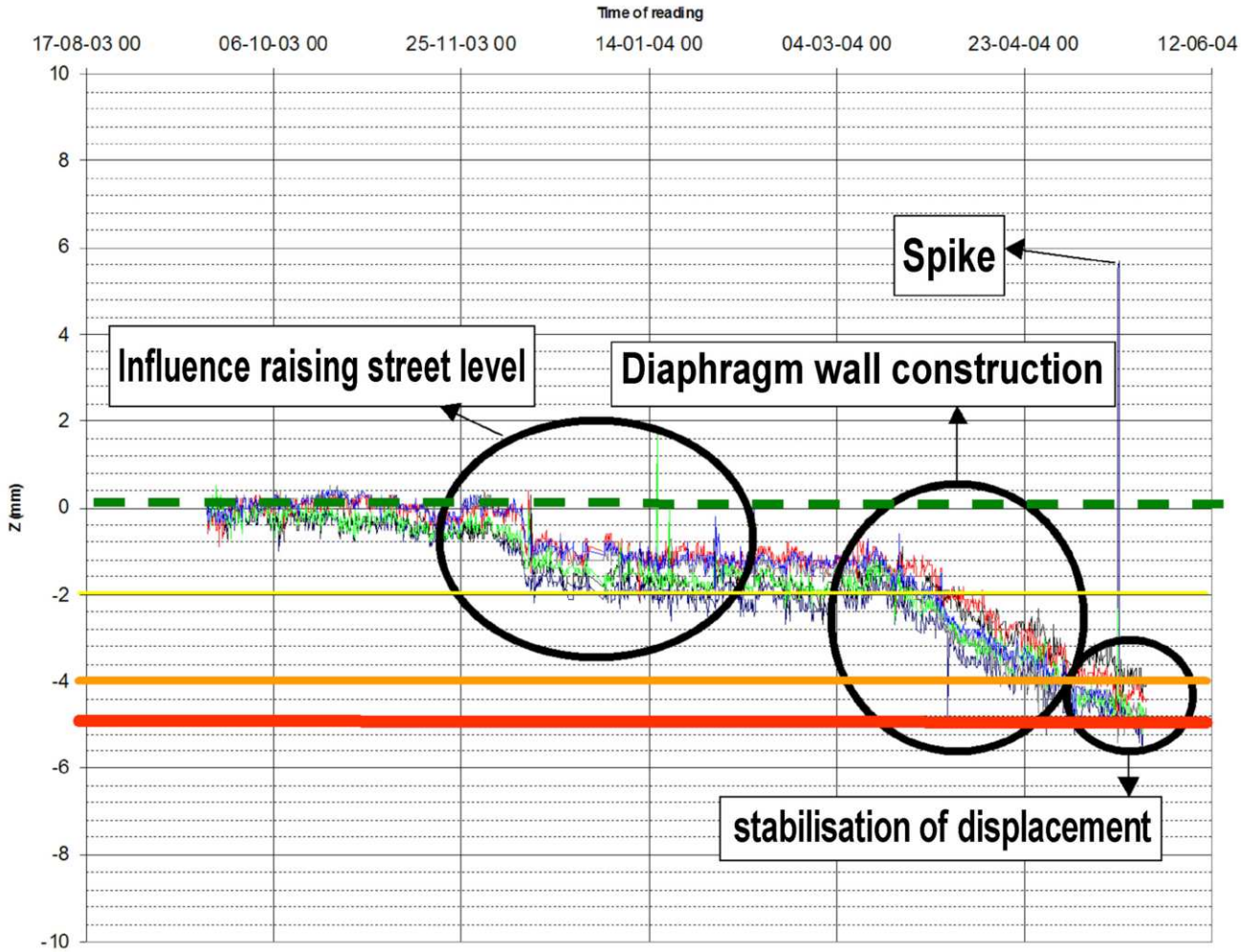

figure 3: Example of displacement lines around Ceintuurbaan station

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