On-line monitoring for underground works in Amsterdam

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ABSTRACT: This paper deals with the on line monitoring system for the adjacent structures and the soil in Amsterdam. The aim of the monitoring system is to control the influence of excavation works (TBM-tunnelling and deep building pits) regarding ground movements on the adjacent surrounding. 1500 buildings are situated in the influence area of the works. They will be monitored on line before, during and after the construction period. On line Monitoring plays a very important role in the observational control of the excavation processes with the aim to minimize the impact on existing buildings. The highly advanced monitoringssytems and the development of a GIS-system for the datamanagement are described in this paper. This monitoring project is the biggest ever installed for the construction of an infrastructure project in urban surrounding.

1 INTRODUCTION

About 3.8 km of the new North/South metroline in Amsterdam will be constructed under the old historic centre of the city. The route under the inner city will be constructed with two bored tunnels of 7 m diameter, varying in depth between 20 and 31 m below ground level. There are three underground stations to be constructed using a strutted excavation with the cut and cover method. The tunnelling and the construction of the deep underground stations could induce soil deformation in the surrounding. The observational method will be applied for both construction methods to combine design and work on site with the aim to achieve the best performance regarding the minimalisation of settlement induced damage.
On line monitoring and control of the effect of soil deformation in the surrounding area such as on buildings, bridges and services has therefore been an essential aspect in the design of the North/South metroline. On line automatic monitoring of the surrounding is an essential part of the strategy of an interactive tunnelling system IBCS (Integrated Boring Control System) to guide the TBM to minimise ground deformations.
Monitoring will be used for various purposes:

- To check the contractor´s performance against the contractual deformation limits;

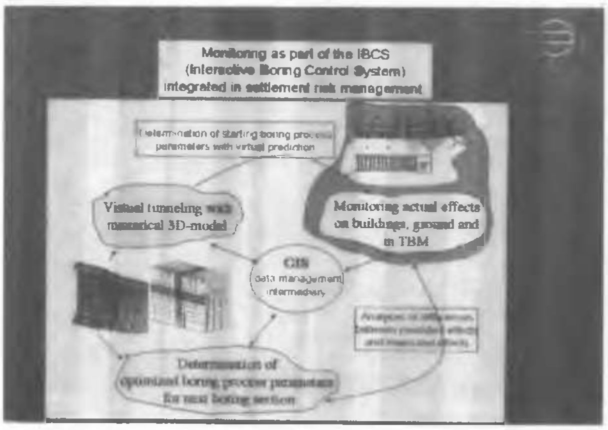

Figure 1: Settlement Risk Management with IBCS

- As part of the IBCS, to use the on line monitoring data from the surroundings to guide the Tunnel Boring Machine (TBM) (Kaalberg and Hentschel, 1999); see Figure 1.
- As legal evidence of deformation with regard to damage in relation to the construction work on the North/South metroline in Amsterdam; in assessing damage claims.

2 MONITORING CONTRACT

In the North/South metroline project, monitoring activities are to be contracted separately from the contracts for the main construction works. The monitoring contract comprises detail design, installation and maintenance of a remote on line monitoring system for buildings and soil, supplemented by traditional manual precise levelling as backup. The performance of the monitoring contractor comprises the provision of monitoring data in digital format at the frequencies and accuracies as stated in the contract. The monitoring contract has been awarded to the French-Dutch consortium SOLDATA/GRONTMIJ JV.

3 ZONE OF INFLUENCE

Settlement predictions with advanced numerical models are used to establish the area along the route that will be affected by the construction process (Netzel and Kaalberg, 2001). This area of influence is defined as the area where settlement greater that 1 mm is predicted (see Figure 2). Structures within the area of influence will be monitored on line by the automatic monitoring system for buildings. Some 1500 buildings in Amsterdam are in the area of influence.
Beyond the influence area a buffer zone has been defined. The buffer zone is 35m wide (beyond the 1mm line) en is monitored only by precise levelling for juridical reasons. Precise levelling in this zone is only carried out if a damage claim of a structure within this zone has been submitted.

4 DEEP DATUMS

To obtain absolute measurements, the deformation measurements within the area of influence are related to stable reference

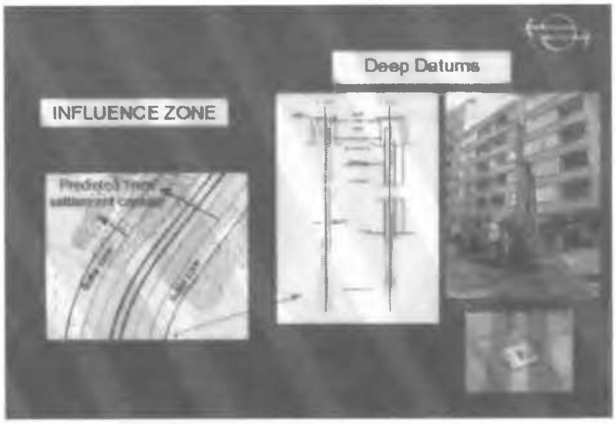

Figure 2: Influence zone and deep datums

points not subject to deformation. For this purpose, 19 deep level datums are installed close to the North/South metroline (see Figure 2). These reference points are outside the area of influence in the soil and have their foundations in a deep soil layer, either the second or third sand layer. The deep datums for the North/South metroline are integrated in the existing surveying network in Amsterdam.

5 ON LINE MONITORING SYSTEM FOR BUILDINGS

The on line monitoring system comprises about 75 fully automated total stations, computer-controlled theodolites, which monitor some 5500 prisms in a continuous operation. The prisms (four per building, see Figure 3) and the total stations are installed on the front and side facade walls of the buildings in the area of influence. The locations have been selected along the entire route so that each prism can be monitored by at least one total station. The prisms are measured within a visible range of 75 m to the required degree of accuracy. For the North/South metroline, between 50 and 100 prisms are monitored by one total station. They are linked to a datalogger that collects the data and transfers it via radio link to the head office of the monitoring contractor.
The *total stations* are split into groups of up to four instruments each to form a geodetic network. The on line monitoring system determines the x,y,z deformations of the prisms. The monitoring frequency depends of the construction activities. For properties within the actual tunnelling zone (app. 50m in front and behind the TBM), monitoring data will be provided every hour.

Three monitoring frequencies are defined for buildings along the route of the TBM:

1) Base monitoring
For information about the natural deformation behaviour of buildings (as a consequence of temperature or moisture), without the effect of the North/South metroline: Low frequency.

2) Process monitoring
Active monitoring during the passage of the TBM: high frequency.

3) Close out-monitoring
Monitoring of long-term settlement effects for approximately a year after construction works: Low frequency.

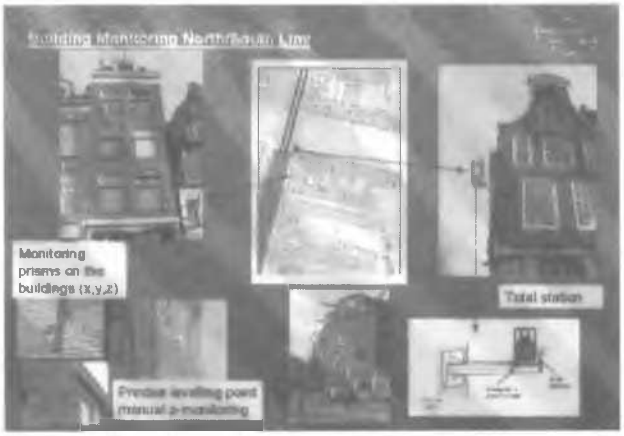

Figure 3: On line building monitoring system

In addition to the on-line monitoring system for buildings - the primary system - a secondary system has been installed for the structures. This system comprises traditional precise levelling bolts at the bottom of the front facade wall of the buildings (see Figure 3). This manual system can be used as a backup in the event of problems with the primary, automated measuring system.

6 ON LINE MONITORING SYSTEM OF THE SOIL

At 18 characteristic locations with representative configurations of the alignement of the tunnels the and soil profile, instrumentated cross sections have been installed in the soil. This has been done to monitor deformation at the surface and on subsurface levels. This information will be used during the boring process to calibrate and validate the numeric model. The numerical predictions of soil deformation in the design stage will be compared with the actual soil deformation. If the measurements in the surroundings, on the buildings and in the soil, indicate that the boring process should be modified, new predictions with the numerical calculation model will be made in the framework of IBCS (see Figure 1). Steering parameters, such as tail void grout pressure, jacking forces and bore-front support pressure, are modelled so that if required, these parameters can be adjusted in the following section of the work.

The subsurface underground monitoring instrumentation comprises combined extensometers/inclinometers, placed in a bore hole of about 150-200 mm diameter. An example of the configu-

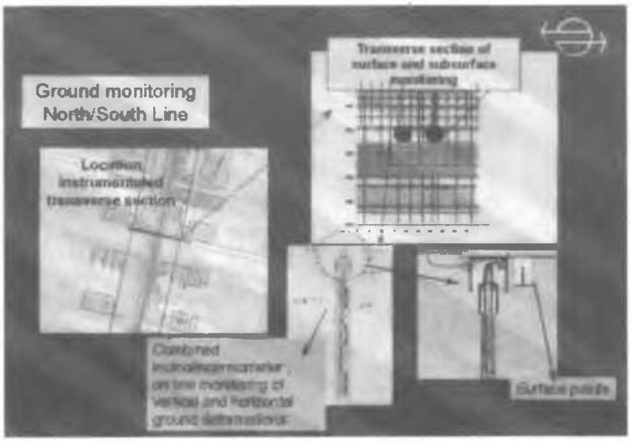

Figure 4: On line ground monitoring system

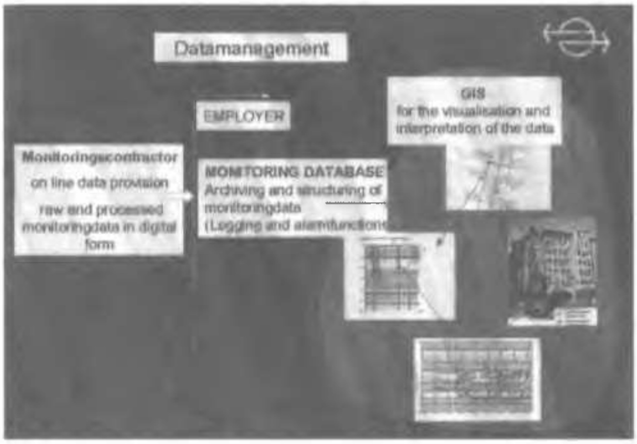

Figure 5: Dataaquisition with GIS

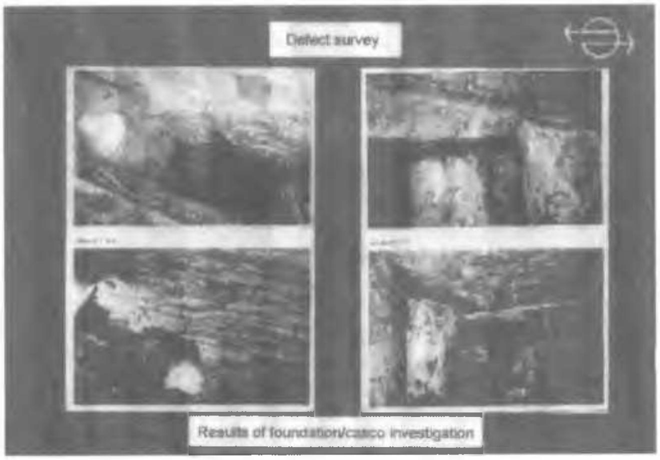

Figure 6: Foundation\casco investigation

The vertical distance between the inclinometer sensors varies with depth from 2 to 4 m and there are 2 to 5 extensometer sensors in each bore hole depending on the depth of the tunnels.
To establish absolute movements in the vertical chains of the sensors, the subsurface measurements have to be related to stable reference points. The boreholes for the inclino/extensometers are therefore continued under the area of influence of the bored tunnel. The lowest sensor of the cross section functions as the stable reference point to which the relative deformation of the measuring sensors above can be related. The instrumentation is completely automated and provides data every hour during the passage of the TBM. For every cross section, there is a datalogger which collects the data which are then transmitted via radio link. The measuring instruments at surface level are covered and are only accessible for maintenance and repair by the contractor, and are protected against vandalism with a closeable cover.

7 DATA MANAGEMENT WITH GIS

For efficient use of the data collected during passage of the TBM and construction works, it is essential to have rapid access to a large quantity of data and that data can be interpreted rapidly. For these reasons, the client has developed a GIS system for the storage, rapid interpretation and visualisation of measurement data before, during and after construction activities (see Figure 5).
An estimation of the amount of data during the 6 years construction work of the North/South Line indicates, that approximately three times as much data as for the JLE Extension will come available.

The GIS system is linked with a database specially designed for the monitoring requirements. The structure of the GIS system and the database use unique codes to identify each monitoring sensor, which is registrated digitally in the GIS system at its location. GIS is the important intermediary for settlement risk management with the IBCS (Netzel and Kaalberg, 1999).

8 DEFECT SURVEYS OF SURROUNDING STRUCTURES

Another part which belongs to the monitoring of the surrounding structures is the defect survey which is carried out before the start of construction activities for the North/South Line. The activities for the defect surveys are however not part of the monitoring contract.

To define the condition of the adjacent structures before tunneling, defect surveys have to be carried out. The information is either used for recording the condition of the buildings before construction work for the North/South Line started and implementing the condition of the structures in the settlement risk assessment studies for the design.

A lot of buildings in the vicinity of the tunneling activities in Amsterdam are originated from the 17th century en founded on wooden piles. For these buildings structural and foundation investigations are carried out by a team of structural specialists experienced in the Amsterdam area (see Figure 6).
Data from these inspections will be integrated in settlement risk assessment, because the condition of the structure and the foundation affect the deformation capacity of the buildings and thus also the risk of damage.
Data are collected on the structural condition of each building (masonry, concrete frame, deformation and cracks, age of the building, historical value), the pile foundation (foundation level, condition of the foundations, pile configuration), landregistry information and use of the building (shop, house, use of vibrating and settling sensitive machines, etc.). Data on each building inspected is stored in the GIS database, including a digital photograph to identify each building, Data can be accessed on screen by clicking on a specific building in the city map.

9 REFERENCES

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