Preservation of Panorama Mesdag, The Hague

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ABSTRACT

This paper deals with the preservation of the Panorama Mesdag, a cylindrical painting, more than 14 meters high and 120 meters in circumference. The vista of the sea, the dunes and Scheveningen village was painted by one of the most famous painters of the Hague School, Hendrik Willem Mesdag. It is the oldest 19th century panorama in the world in its original site and a unique cultural heritage. About three years ago the building, which is a uniquely complex structure, was damaged by a nearby excavation. In the years to follow a series of measures have been taken of which the compensation grouting of the foundation is the most extensive from a geotechnical point of view. This paper outlines the history of the damage, the construction of the building and most importantly the extents of the compensation grouting and the result of the grouting and the extensive monitoring. The effectiveness of the grouting is determined and conclusions have been drawn for the still to be performed excavations and construction activities.

1. INTRODUCTION

For the realization of a two layered underground parking garage at the Mauritskade in The Hague a 6m deep building pit had to be constructed. This parking garage is situated between the Museum Panorama Mesdag, the The Hague Hilton hotel, the gardens of the British Embassy and the Maurits Canal. The museum’s Rotonde building, with the historical Mesdag painting inside, is particularly at short distance of the building pit. To prevent damage to the building and the painting due to possible vibrations caused by installing sheet piles by vibrating, the decision was made to realize this side of the building pit constructing a secant piled wall. In Figure 1 and Figure 6 and 11 an overview is given of the project location and the location of the secant piled wall.

Figure 1 : Overview of location Museum Panorama Mesdag and the building pit (source: Google Earth)

Although the Rotonde building is now a monument by itself, deformation of the building may cause severe tension in the painting, which is attached to its walls.
During the construction of the secant pile wall significant deformations were observed at the Rotonde building. After these observations the work on the building pit was stopped and several investigations
were started to find the possible cause of the deformations and to determine the structural stability of the building. The conclusion of these investigations was that the building had insufficient structural stability and that mitigating measures needed to be executed. These measures consisted on the one part of strengthening the construction of the building and on the other on stabilizing the foundation and partly compensation of the vertical movement of the building by conducting compensation grouting. This paper deals with the geotechnical part of the compensation grouting measures that are taken.

2. **ROTONDE BUILDING**

The Rotonde is build in the eighties of the 19th century and has a regular hexadecagon shape. The construction of the building can be characterized by its simplicity. The columns at each of the 16 corners are made of steel and are connected with concrete footings. Between the columns the spacing is filled with plastered brickwork. The roof of the building consists of cast iron construction which carries its own weight. The building is founded on a shallow foundation. In Figure 2 a cross section of the building is shown.

![Figure 2: Cross section of the Rotonde building](image)

3. **SOIL CONDITIONS**

Before the work started several cone penetration tests (CPTs) were executed at the construction site. Several of these CPTs were located near the secant pile wall. In Figure 3 a typical CPT of the construction site is shown. The greenfield is at a level of about 0.6m above NAP (NAP is the reference level used in the Netherlands).

![Figure 3: Typical CPT construction site The Hague](image)

From the CPT it can be concluded that beneath the sandy top layer, at a depth of about 1.5m below greenfield, a Holocene peat layer is found with a thickness of about 1m. Below this layer sand layers are
found varying from a loose density to dense. From a depth of about 6,5m below the greenfield thin sandy clay layers can be found between the sand deposits.

4. MONITORING

Before the start of the construction work, in 2007 a comprehensive monitoring system was installed inside the Rotonde. The system consists of a automatic leveling system with a sensor placed at each column at foundation level, 16 sensors in total, as well in the roof construction. In Figure 4 an overview is given of the sensors positioned at foundation level. Figure 5 shows the total station used for the measurements and a detail of a deep CPT that was used as an absolute reference level. The deformations of the building were measured in three directions, the vertical direction and the longitudinal and transversal horizontal direction.

Due to the large amount of sensors the time interval between two measurements of an identical sensor was about 60 minutes. This could be speeded up to about every 15 minutes if the sensors in the roof construction and at the back of the building, sensors no. 90 until 160, on foundation level were neglected. This means that only the sensors directly linked to construction works thus of particular interest, the sensors directly next to the building pit no. 10 until 80, were measured.

During all stages of the work, the deformations of the Rotonde in both the horizontal as well as the vertical plane were continuously monitored. To register the vertical displacements during compensation grouting a faster and more accurate measurement system was needed. Therefore, to monitor the grouting process and compare the strict requirements for the distortions with the measured distortions, a hydrostatic leveling system was installed as a secondary system. This system records realtime the vertical displacements at 15 sensors, which were located on the foundation footings and the wall between the footings.
Before the start of the compensation grouting a comprehensive analysis was made of the deformations of the Rotonde that occurred during the installation of the secant pile wall. The analysis was based on the measured displacements in vertical and horizontal direction using the automatic leveling system. Based on the measured deformations the rotation ($\alpha$) and relative angular distortion ($\beta$) in both vertical and horizontal direction were determined. This analysis was executed to determine the maximum rotation ($\alpha$) and relative angular distortion ($\beta$) which has occurred in the past. The analysis was used to compare the deformations during the compensation grouting with the historic deformations.

Based on the measured data in the past the natural movements, for example due to temperature change and groundwater fluctuations, of the Rotonde were also analyzed. From this analysis it could be concluded that the building shows a natural vertical displacement of about $+/-0.3$ mm per day.

The Municipality of The Hague specified a limit value of 2mm of vertical deformation for each sensor during the installation of the compensation grouting. The alarm value was set to be 1mm. If the alarm value was exceeded the involved parties where warned by means of a text message. Also for the rotation ($\alpha$) and relative angular distortion ($\beta$) in both vertical as well as horizontal direction a limit value of $1:1200$ was set by the Municipality.

Considering the natural movements of the building and the accuracy of the measurement system the requirements for the deformation were considered to be very strict.
To be able to determine and evaluate the rotation and relative angular distortion of the building on the fly, a special spreadsheet has been prepared which, based on the direct measurements, directly calculates all the rotations and relative angular distortions.

Prior to the compensation grouting it has been determined that the measured displacements on July 26, 2010 would serve as a reference for comparing the measured displacements during the compensation grouting works.

5. COMPENSATION GROUTING

Compensation grouting offers the possibility to lift the foundation of the Rotonde as well stabilize the ground underneath the building, this method is found to be the most appropriate mitigation measure. The horizontal fixation of the building level is ensured by installing a structural horizontal fixation using a sort of spokes at foundation level to connect the outer wheel of the Rotonde to the core of the structure.

The compensation grouting was carried out according to the Soilfrac® principle as developed by Smet-Keller. With this technique specific grout injections are made to increase the effective stress in the ground. With the increase of the effective stress cracks a created around the injection valve and the grout suspension can flow into the soil. By filling the soil with the grout suspension the soil above the injection valve while finally be lifted, so the occurred settlement during the construction will be (partially) compensated.
The injection work consisted of three phases:
1. Initial injections, to fill the pores in the soil.
2. Contact injections which equals the horizontal effective stress to the vertical effective stress.
3. And finally the injections that will lift the foundation of the building.

In Figure 7 the Soilfrac® principle is shown.

In August 2010 the work was started by installing Tubes-à-Manchette’s (TAMs) into the ground to a depth of approximately NAP -7m. A total of 64 TAMs including 32 vertical and 32 diagonal TAMs were installed in a period of two weeks (see Figure 8). The vertical TAMs were placed at a distance of approximately 0.6m from the Rotonde. The top of the diagonal TAMs was located approximately 1.6 m from the façade. The diagonal TAMs passed the foundation footings of the Rotonde at a depth of about
NAP -2.5 m. To reduce the deformation of the building during the installation process as much as possible, the TAMs where installed using a cased drilling system. During the installation process of the TAMs the borehole was kept stable using a drilling fluid. After pulling the inner tube the TAM was inserted.

During the installation of the TAMs the limit value of the vertical displacement was set to be ± 2mm. An initial alarm value was determined at a measured vertical displacement of ± 1mm. This alarm value was increased to ± 1.5mm at several sensors during the installation process, because it was the expectation that the 2mm boundary would not be reached at these points. This increase was necessary because at several sensors the alarm value was exceeded. During the last two days of the installation of the TAMs the limit value of ± 2mm was exceeded at the final installation points / sensors. A maximum vertical displacement was measured of about -2.5mm at the Rotonde footing which was at the shortest distance of the secant piled wall. In consultation with all the involved parties it was decided to allow this exceedance if the rotation and the relative angular distortion in both vertical as well as horizontal direction did not exceed the limit value 1:1200. These requirements were met at all sensors.

To perform the necessary grout injections, double packers are placed inside the TAMs. The TAMs have injection valves with a centre to centre distance of approximately 500 mm. Through the injection valves the grout is injected under a high pressure (>5bar) into the soil. To compensate pressure losses in the pipes a higher initial pressure is applied. The pressure losses in the pipes are particularly depending on the applied water-cement ratio (liquidity) of the grout and are determined on the basis of proofs.

Before the start of the compensation grouting the decision was made to end the initial and contact injection after a arbitrarily chosen lift of the building of 0.3mm. After the first two days of initial grouting the measured lift at several sensors already exceeded 0.3mm indicating a high efficiency of the injections. The reaction of the ground was so good that at the same time the pores were filled and the vertical- and horizontal stress were leveled. This meant that the first two stages of the injection process were effectively executed at the same stage. This can be explained by the fact that during the drilling process the pores of the sand were already being filled with drilling fluid so less grout was needed to fill the pores than initially assessed.

On the third day of grouting, it was decided to adjust the lift criterion from 0.3mm to 0.5mm and possibly adjust the injection volumes. After one week of initial grouting and contact grouting all sensors reached the lift criterion of 0.5mm. After a 3-day ‘resting’ / consolidation period it could be decided that the
amount reached lift was permanent.

After this the actual to lift the Rotonde injections could be started. By alternately grouting the vertical TAMs a wall was created around the foundation of the Rotonde. By grouting the lower injection valves of the diagonal TAMs a kind of footing was placed below the walls. The remaining non-grouted injection valves were then alternatively used for controlled lifting of the foundation/building.

The required amount of lift can be divided into three components, being:
1. lift to compensate for subsidence as a result of installing the TAMs;
2. lift to reach the desired net lift at each footing;
3. lift to compensate for plastic shrinkage (“bleeding”) of grout (volume reduction by bleeding occurred, the efficiency of the grouting was approximately 90%, which is very high!).

For lifting the foundation footings by compensation grouting the maximum net lift was set to be about 4mm for the footing closest to the secant pile wall (point 50). The lift for the other footings was a linear reduction from the maximum lift to about 0.5mm for the footings which are located at the edges of the building (point 10 and 80).

After reaching the desired lift a consolidation period of two weeks considered of the Rotonde was sufficiently stable / settlement free.

In Figures 8 and 9 an overview is given of the measured vertical displacements during the compensation grouting process.

![Figure 9: Vertical deformations during compensation grouting process](image)

From Figure 9 it can be concluded that a maximum lift of approximately 6.5mm was needed to achieve a net lift of about 4mm. The compensation grouting operations were ended in the morning of September 23.

At the time the grouting stopped, the desired amount of lift was reached at all but one sensor and the sensor that did not reach the desired lift was only 0.1mm short. During the rest period of two weeks, the vertical displacement was monitored and it was concluded that the building was stable. At the first couple of days of the rest period a noticeable relaxation / consolidation was measured which can be explained by the bleeding effect and the natural behavior of the Rotonde.
6. CONCLUSION

During all stages of the work, the monitoring data was analyzed directly on the site and compared with the required limit values. This way, if necessary, the compensation grouting scheme could be adjusted immediately, which was vital due to the particular vulnerable construction and unpredictable behavior of the Rotonde building.

During TAM installation a maximum settlement of 2.5 mm was measured in the vicinity of the secant pile wall which meant a small but acceptable exceedance of the limit value of ±2mm. Because of the very strict and on the fly monitoring of the deformations and the excellent communication between all the involved parties this was allowed and the installation process could be continued.

After installation of the TAMs, the initial injections showed an very good reaction of the ground. At the same time the pores were filled and the vertical and horizontal stress were leveled. This meant that the first to stages of the grouting process were effectively executed simultaneously. Subsequently, the actual charge grouting was performed. The foundation of the Rotonde was lifted for a maximum of approximately 7mm with a 4mm net heave. The grouting works have were completed successfully September 23rd 2010.

After this first grouting stage, grouting has been repeated successfully in July 2011 during the construction process. Finally the building pit has been excavated until the final depth (see Figure 9 en 10) without any further problems for the Panorama Mesdag building.

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Figure 10: View and cross section of flat excavation level -2 with floor, struts, piles wall and bottom part of the Rotonde

Figure 11: Plan view of the building pit and part of the Rotonde