Corrective grouting in sand to restore pile foundations, Vijzelgracht, Amsterdam

Injection corrective dans le sable pour reconstituer la portance des pieux de Vijzelgracht à Amsterdam

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ABSTRACT

Leakage of sand and water through a diaphragm wall for the Vijzelgracht station of the Amsterdam North South line at a depth of 12 m –NAP led to settlements up to 0.15 m of the adjacent buildings. These buildings are founded on end bearing piles that were installed with their tip in the first sand layer (at the same depth as the leakage). The leakage led to a local ground loss and decrease in density of the sand underneath the piled foundations. Corrective grouting was performed initially to restore the capacity of the pile foundation. Although the lifting of the building was successful, it appears that for these conditions (loose sand due to ground loss) the efficiency of the corrective grouting process is rather low. Injections of up to 600 litres/m^2 led to a heave of only 10 mm at maximum. Although the original stiffness of the load bearing sand layer was completely restored, ongoing settlements were found up to at least 5 months after finishing the compensation grouting.

RÉSUMÉ

La fuite de sable et d'eau par une paroi moulée de la station Vijzelgracht de la ligne de métro Nord Sud d'Amsterdam à 12 m au dessous du niveau de référence des eaux a provoqué jusqu'à 0.1 m de tassement des bâtiments adjacents. Ces bâtiments ont été construits sur des pieux dont l'extrémité porte sur la première couche de sable (à la même profondeur que la fuite). La fuite a causé à une diminution de la densité du sable sous la base des pieux. Une injection corrective a été exécutée pour reconstituer la capacité de la base des pieux. On réalisait bien que le tassement ne pourrait être résorbé pas injection corrective. Toutefois, la portance de la base des pieux devait être reconstituée afin de pouvoir résorber le tassement. Il est apparu évident que dans ces conditions (sable lâche), l'efficacité de l'injection corrective est plutôt faible. Injecter jusqu'à 600 litres/m^2 a conduit à un rehaussement maximum de seulement 10 mm. En outre on a observé que les tassements ont continué après avoir fini l'injection corrective.

Keywords : Corrective grouting, field measurements, efficiency, settlements.

1 INTRODUCTION

In June 2008 there was a leakage in a diaphragm wall that was made for the Vijzelgracht station of the Amsterdam North South line. This leakage caused a sand-water mixture to pass through the wall, resulting in significant (up to 0.15 m) settlement of a block of 4 adjacent buildings (Korff et al, 2009). It was acknowledged that the piled foundations under 2 of these buildings had not only settled because of the sand that disappeared, but that also the bearing capacity was significantly reduced because the remaining soil around the pile tips now had a much lower density than it had before the incident. The brickwork walls of the buildings were braced with timber beams immediately after the incident in order to avoid progressive collapse of the buildings. After this bracing , it was therefore decided to use corrective grouting to increase the bearing capacity of the sand and consequently lift the buildings up to an agreed maximum of 10 mm. When lifting of the building would be possible, it would implicitly be proven that the end bearing capacity was restored, and stability of the building was guaranteed again. Moreover it would be proven that it was possible to compensate for future settlements that could possibly occur by ongoing construction of the station.

2 THE CORRECTIVE GROUTING PROJECT

The layout of the site is shown in Figure 1. The diaphragm wall is shown on the right side of the picture. The big grey area is the corrective grouting area, the lines are the TAMs and the thick, grey lines show the positions of the foundations of the settled buildings.

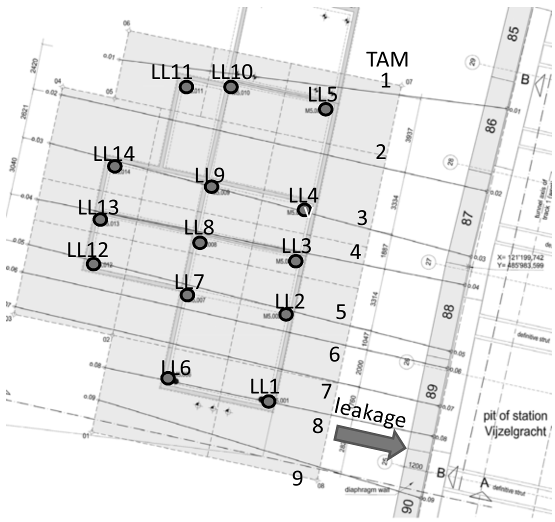

Figure 1. Top view of corrective grouting location, Vijzelgracht.

The foundations of these 17th century buildings consist of a row of 2 wooden piles under the brick walls to a depth of -13 m below surface into the 1st sand layer, see Figure 4 (Netzel and Kaalberg, 2000). The positions of the liquid leveling instruments (LL1 through LL14) attached to basement walls

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that were used for the displacement monitoring, are presented in Figure 1 as well as the position in the diaphragm wall where the leakage occurred (between panels 89 and 90).

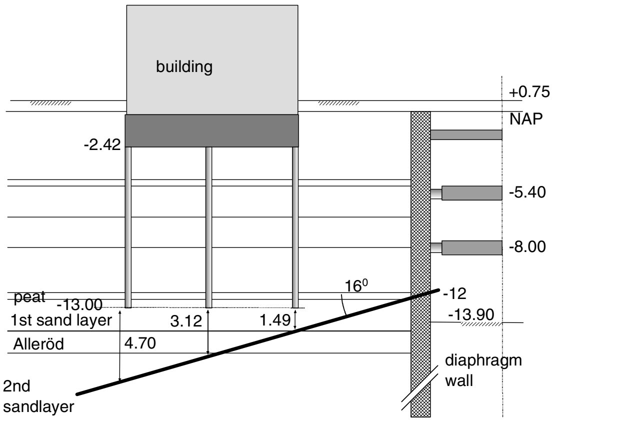

Figure 2. cross-section location. Dimensions in m.

A cross-section is shown in Figure 2. The TAM's were placed at an angle of 16 degrees. Horizontal TAM layout was not possible because it was not allowed to excavate the box further before stabilizing the buildings.

Grouting was performed using a Biltzdämmer a hydraulically-setting premixed dry mortar (Heidelberg, 2009). Three different mixtures were used, see Table 1. The different mixtures were used for all pumps, sleeves and in the beginning and end of the grouting operations. However, MF was used more in the beginning, M8 in the middle and M6 was mostly used at the end,. In this table the average date is the mean date of all injections with this mixture. Grout was injected using different TAMs at the same time in the injection periods.

Table 1: Data on injection grout mixtures used, see also text.

Mixture	kg dämmer/ liter water	Density (kg/m^3)	number of injections	Total Litres	Average Date
M6	0.714	1360	1636	41735	24-09
M8	0.625	1323	1298	29315	09-09
MF	0.5	1269	601	12500	23-08
Total			3535	83550	

3 RESULTS

3.1 *Overview*

Figure 3 shows an overview of the corrective grouting site. The figure shows in plan view the position of the piled foundations (the black lines), the positions of the liquid leveling points (the black dots), the total amounts of grout injected in litres during the project (the grey circles) and the heave created at the end of the corrective grouting project. The heave indicated is the heave of the basement walls and is interpolated from the results of the liquid leveling system. Additionally Figure 3 shows the position of 5 CPTs: An 'old CPT' taken before the start of the works for the station, and 8 CPTs in the basements of the building. (4 taken before and 4 after the corrective grouting). Each pair of CPTs indicated with the same number are performed within a distance of 0.5 to 1 m.

The results of the old CPT and the CPTs after the leakage, before and after the corrective grouting campaign are shown in Figure 4.

The colours on the right side of the plots show the different layers in the Amsterdam subsoil at Vijzelgracht. Layers with a number less than 13 are soft Holocene layers as can be seen from the CPTs. 13 is the first sand layer, in which the pile toes are founded and which consists originally of medium dense, medium fine sand, 14 is Alleröd, a sandy silt layer and 17 is the second sand layer, fine to medium coarse sand. In places where a lot of grout is injected (at the location of CPT 1), there is a very large increase in cone resistance. For CPT 2, where much less grout is injected, the increase in cone resistance is only limited. For CPT 4 the increase in cone resistance was only limited and the increase in cone resistance is mostly located underneath the first sand layer (no.13).

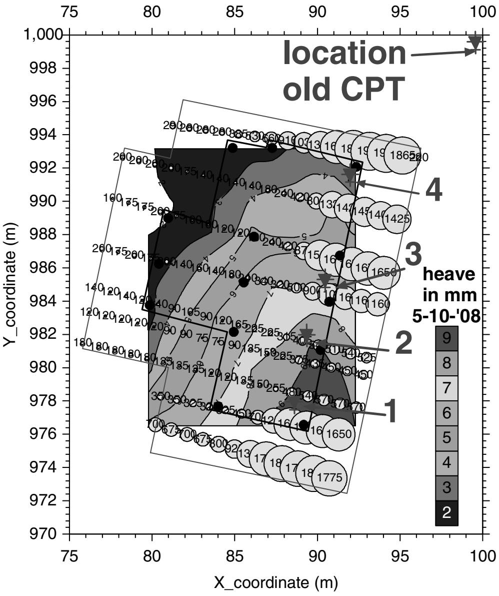

Figure 3. Overview corrective grouting at Vijzelgracht, see also text.

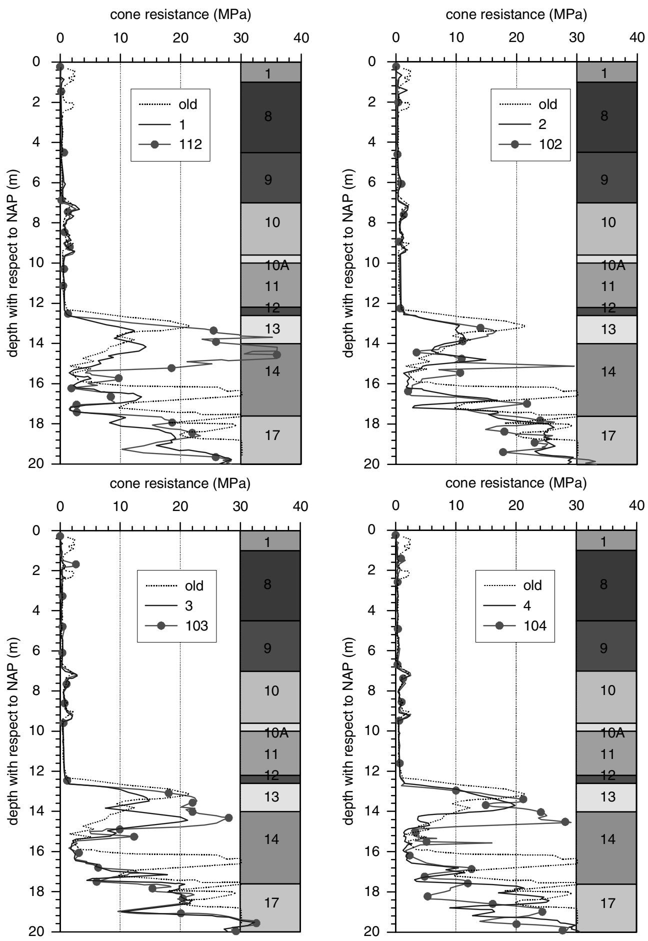

Figure 4: CPTs for location 1, to 4 before (1 - 4) and after (112,102 - 104) the corrective grouting campaign, but both after the leakage compared with the 'old CPT'. Locations see Figure 3.

3.2 *Injection pressures*

3.2.1 *Pressure losses in injection system*

To be able to evaluate the injection pressures, first the pressure losses in the injection system were determined. Using the M8 mixture, with a marsh funnel time of 36 s, an injection with a discharge of 10 l/min was performed in the open air and in a TAM that was in the open air. The last test was performed to measure the additional resistance of the rubber sleeve of the TAM. It was found that at 10 l/min the resistance of the injection system was 5.5 bar, the resistance of the injection system with TAM was 7.5 bar. This means that the flow resistance in the TAM adds another 2 bar to the pressure drop. In the tests the outflow point was at approximately the same height as the pump, so no correction for hydrostatic pressures was needed. The flow through the injection system will be laminar; this means that the pressure drop will depend on the type of grout. The flow through the TAM will be turbulent and therefore the pressure drop through the TAM will hardly depend on the viscosity, but only on the density. The density differences between the mixtures are only small. The pressure losses appeared to be significant when compared to the injection pressures measured.

3.2.2 *Grouting pressures*

The grouting pressures vary significantly during the various injections. Sometimes the grouting pressure was hardly above the free flow pressure of 7.5 bar as determined in the section before. The injections were performed from the partly excavated station box, so the difference in hydrostatic pressure was only a few meters at maximum and can be neglected.

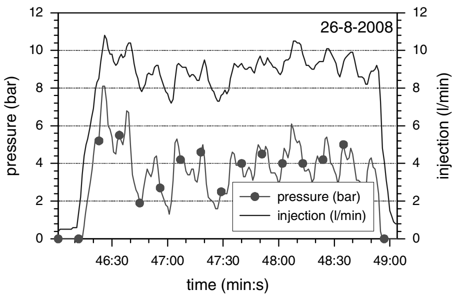

Figure 5. Example of a registration with a low injection pressure.

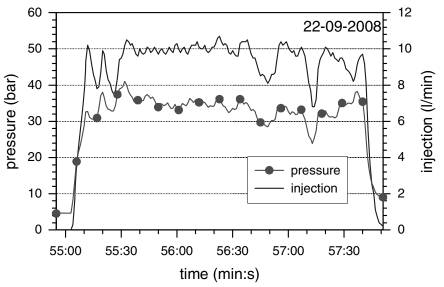

Figure 6. Example of a registration with a high injection pressure.

Figure 5 and Figure 6 show examples of a pressure registration with a low and a relatively high grouting pressure. Taking into account the pressure loss due to the injection system and the TAM, there is hardly any pressure necessary for the injection shown in Figure 5. Both plots show a pressure that fluctuates with the injection rate.

In addition, it was investigated where the injections with the lowest grouting pressures were found. The 100 lowest and 100 highest pressures found (of the total of 3,535 injections) were selected and their locations are plotted in Figure 7 (some injections with low or high pressure were at the same location, therefore there are not 100 markers for each selection). It shows that from TAM 1 (the highest black line in the plot) a lot of injections were performed with low injection pressures and hardly any with high pressures. The TAMs 7, 8 and 9 have a lot of injections with the highest pressures.

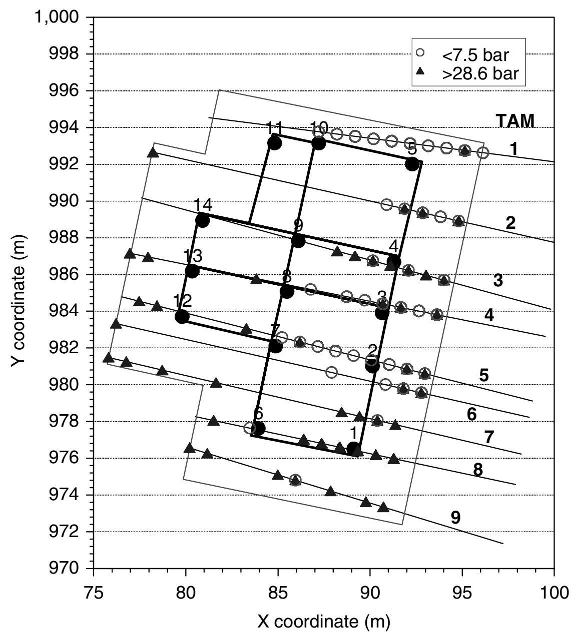

Figure 7. Locations where low and high injection pressures were found.

3.3 *Settlement during and after grouting*

Figure 8 shows the heave and settlement measured just before, during and after the corrective grouting campaign. The vertical lines in the figure indicate the period in which grout was injected.

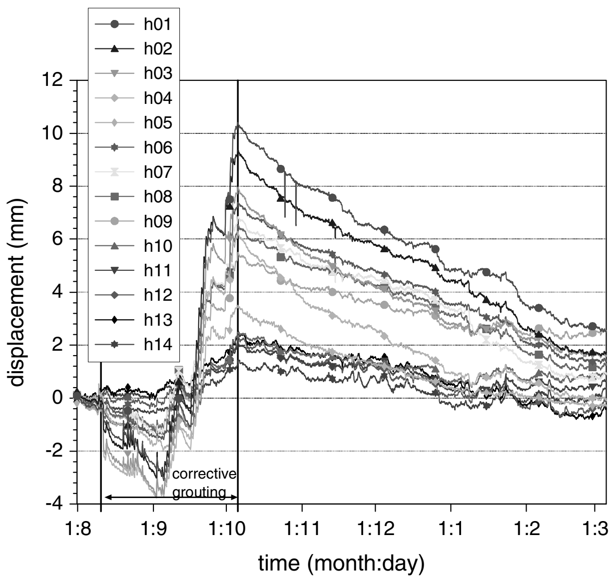

Figure 8. Heave and settlement as a function of time.

The figure shows that although the grout injections that start at 10-08-2008, it first only increased the settlement rate, probably due to disturbance of the 1st sand layer by the TAM installation and first injections. Most settlement was recorded at the instruments LL3 and LL4 at some distance from the leakage, see Figure 1. The injection of the first 21,000 liters of grout did not directly reduce the settlements but were needed to strengthen the soil and to reduce the progress of ongoing settlements. Grouting in September and the beginning of October of 2008, when another 62,000 litres were injected, led to heave of the buildings. In the periods between the grout injections there was still an ongoing settlement. The settlement more or less continues after grouting stops. In the few days before grouting there is a settlement rate that is comparable to what is found directly after the injections (approximately 0.05 mm/day for the instruments that settle most). In between the grouting periods a larger settlement of up to 0.2 mm/day was found.

3.4 *Area of influence of an injection*

It has been investigated whether or not it was possible to indicate an area that is influenced by the injection of grout in one location. However, no correlation could be found.
This can be caused by the very stiff timber beams that strengthened the buildings.

4 DISCUSSION

This corrective grouting project was performed in rather disturbed soil conditions. Due to the ground loss through the diaphragm wall there will locally be areas in the first sand layer (the layer that supports the piles) that have a lower density than other areas. It is clear from the CPTs in Figure 4 that the cone resistance has been significantly reduced close to the location of the leakage (CPT 1 and to a lesser extent CPT 2). Also CPT 3 shows a reduction of the cone resistance in the first sand layer. Only for CPT 4 this is not the case.

The achieved heave pattern (see Figure 2) is almost exactly according to the target values, however the correlation with injected volumes is not directly clear. A lot of grout was injected using the TAMs 8 and 9 (see Figure 1 and Figure 3) before some heave is created in this area. The soil has to be strengthened in areas of former ground loss before heave can be achieved. The achieved heave decreases gradually towards TAM 1. One could expect a decrease of injected volumes from TAM 9 towards TAM 1 as well. This is not the case as can be seen in Figure 3). Above the TAM's 5,6&7 a relatively low grout volume is used. The reason for this is the presence of the strengthening timber stability beams which were installed in the buildings. The process operators observed also heave above the TAM's 5,6,&7 when injections were performed in the TAM's 8&9. The stabilizing cross timber beams appeared to have stiffened the buildings so much that it acts like a girder itself, spanning the support area above TAM's 8&9 and 1 to 4. When this phenomenon was acknowledged the bolts connecting the temporary timber cross beams were loosened and the building settled 1-2 mm in the area above TAM's 5-7. In the remaining part of the grouting operation it appeared not necessary to disproportionally increase the injected volumes in TAM's 5-7 in order to maintain a smooth heave pattern. The explanation for having injected relatively large grout volumes above TAM's 1-4, whereas the anticipated (and achieved) heave was relatively small, is related to the fact that this area is connected to an adjacent building of the block which loads also partly have to be lifted. Close before reaching the target values the stabilizing timber cross beams were "locked" again, however it was decided not to remove them but finish the corrective grouting process at the target values, as was agreed before with the municipal authorities.

The ongoing settlements of the buildings after finishing of the grouting process were more than expected but the settlement rate seem to decrease after 5 months (see Figure 8). A possible explanation is that during the incident the weight of the building is partly taken by the friction between the piles and the soft soil layers above the first sand layer. When the grouting stops, the soft soil layers will consolidate (these layers were disturbed by the leakage and the grouting) and will develop a negative skin friction on the piles. The pile foundation is still loaded on ultimate bearing capacity and therefore the development of negative friction will lead to extra settlement. This settlement will continue until the consolidation of the soft layers is finished and the friction piles become end bearing piles again.

The construction with the stiff timber beams explains that there is hardly a correlation between the location where the grout is injected and the location where the heave is measured.

Apart from the loose sand and the ongoing settlement there is an additional reason for the low efficiency and that is the use of the Blitzdämmer as injection material. The permeability of Blitzdämmer cake is 10 times higher than the permeability of a bentonite cement cake. Research from Bezuijen & Van Tol (2008) and Sanders (2007) has shown that this will prevent the formation of fractures and will lead to compaction grouting with a lower efficiency. Furthermore, all liquid will be pressed out of the Blitzdämmer in the permeable soil before the hardening starts. Only this consolidation of the Blitzdämmer decreases the maximum possible efficiency to 25% depending on the type of mixture used.

Still puzzling are the low injection pressures that were found around TAM 1. Compaction grouting should lead to higher injection pressures. It is possible that inhomogeneous soil conditions lead to an easy path for the injection fluid.

5 CONCLUSIONS

Corrective grouting was studied underneath a piled foundation in layers of sand and silty sand that were partly disturbed due to ground loss through a nearby diaphragm wall. The corrective grouting has led to significant increase of the CPT values of the layers injected. Although the buildings are successfully lifted and stabilized, it was found that the efficiency of the corrective grouting (measured on the foundation) was very low 1.7% or less. Furthermore, ongoing settlements after the corrective grouting campaign, lead to a further decrease of the efficiency. The pressure losses in the injection system were tested separately and appeared to be significant compared to the injection pressures, therefore these have to be taken into account when injection pressures from various sites are compared.
The buildings are relatively stiff due to temporary stabilizing timber cross beams, so the result of one single injection on the deformation could not be found. For these sandy soil conditions it is probably better to use a grout with gives a grout cake with a lower permeability.

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