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Injection/grouting near pile foundations: Full scale test Amsterdam

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ABSTRACT: This paper outlines the injection techniques, geophysical surveys and special soil investigation techniques that will be used in stage 3 of the "Full Scale Injection Test". Objective of this stage is to determine the influence of injecting / grouting near to (Amsterdam) pile foundations. The injection techniques used are permeation grouting, jet grouting and compensation grouting (both fracturing as well as compaction grouting). Outlined are amongst others: the aim of the test, specific site conditions, characterisation of the foundation, monitoring program and the actual test program. The test-results will hopefully be presented at the poster presentation of the congress.

1 INTRODUCTION

1.1 *General Information*

The North/South metroline Amsterdam will use the shield tunnelling method for construction of two ∅ 6,5 m metro tunnels. Therefore, due to settlements, complications with some historical buildings founded on pile foundations may occur. To prevent these complications, mitigating measures by means of stabilising the soil using injection-techniques, are planned at these locations. The lack of experience with injection in the vicinity of pile foundations, in combination with the fact that the non homogeneous, soft, stratified soil in Amsterdam has been injected only limited, has led to the development of the "Full Scale Injection Test".

More information concerning the project can be found in other North/South metroline papers in these proceedings and in the ITA 1997 (Vienna), 1998 (São Paolo) and 1999 (Tokyo) congress proceedings.

1.2 *Scope of the paper*

The test program is divided into three stages:
- stage 1: the testing of several different geophysical surveys;
- stage 2: injection of different Amsterdam soil types by means of permeation grouting;
- stage 3: injection near pile foundations with different injection methods:
  - 3a: permeation grouting;
  - 3b: jet grouting;
  - 3c: compensation grouting.

Stage 1 was completed in February 1998 and stage 2 was completed in February 1999. Stages 3a and 3b will be conducted from March till July 1999, so the first results will probably be available during the Congress. Stage 3c is planned to start June 1999 and will probably end in September. This paper outlines stage 3 of the test.

1.3 *Organisation*

Because of national interest, the Full Scale Injection Test is a co-operation of:
- Design Office North/South metroline (75%);
- Centre for Underground Construction Studies (in Dutch: COB *, 20%);
- Delft University of Technology (TU Delft, 5%).

* The COB is a co-operation of Dutch contractors, engineering consultants, specialist institutions and others involved in underground construction.

2 AIM OF STAGE 3

The aim of stage 3 is to gain (additional) knowledge concerning the various above mentioned injection techniques, with regards to:
- the influence of (the installation of) the injection body with regards to pile bearing capacity;
- displacement and deformation of the foundation piles;
- soil deformations;
- changes in (effective) soil stresses and water pressure;
- mastering and controlling the injection process;
- the feasibility of some design variants.

Roughly, a distinction can be made between the (possible) negative influences and the (possible) positive influences. During installation of a injection body, settlements and a reduction of bearing capacity may occur, whilst when the injection body has hardened the pile may have both a higher bearing capacity as well as more rigid settlement behavior.

3 SPECIFIC CONDITIONS

3.1 *Normative conditions*

To simulate the designed mitigating measures, in the design of the full-scale test ideally three conditions should be satisfied. Firstly, the soil conditions of the test site should be similar to those at the building locations. Secondly the foundation piles should behave correspondingly to those of typical Amsterdam houses. And finally, a TBM should pass the test location to determine the effectiveness of the injection body's. Since non of these three conditions could be satisfied simultaneously, it was chosen to satisfy only the first two, because the aim of the test could be achieved best this way.

3.2 *Soil conditions*

A detailed description of the soil conditions is given in previous papers (ref). Only a brief summary is given here (with NAP = Amsterdam Ordnance Datum, the Dutch reference level for vertical measurements):

- street level at NAP + 2 m; groundwater level at NAP –0,4 m;
- NAP + 2 m to NAP –13 m: *Holocene package* (restively sand, rubble, peat, clay, silty/sandy layers, compressed peat);
- NAP –13 m to NAP –16 m; *1st sand layer*; cone resistance (CPT) 6 - 30 MN/m²;
- NAP –16 m to NAP –19 m; *In-between layer*; cone resistance 2 -12 MN/m²;
- NAP –19 m to NAP –28 m; *2nd sand layer*; dense to very dense; cone resistance 15 - 45 MN/m²;
- NAP –28 m to NAP –45 m; *Eem Clay layer*.

The piezometric surface of the 1st and 2nd sand layer is NAP –2 m.

3.3 *Pile foundations*

In general, buildings constructed before 1945 have a wooden pile foundation, placed on the first sand layer. Most (mayor) buildings constructed afterwards have concrete piles, placed on the second sand layer. More detailed information concerning the buildings and damage criteria are given by Netzel et al (1999). Table 1 shows the characteristics of the Amsterdam wooden and concrete foundation piles.

4 CONSTRUCTION

Based upon the above-mentioned desired conditions, a test site was chosen in the northern part of Amsterdam. Here a construction as illustrated in Figure 1 will be built (note the similarity with the Test Pile Project (TPP; Teunissen, 1998).

Table 1. Pile Characteristics.

Feature	Wooden pile	Concrete pile
Diameter tip (mm)	Ø 230	[] 350
Diameter toe (mm)	Ø 130	[] 350
Pile toe level (m NAP)	–13,5	–20,0
Length (m)	15	22
Material	Soft Wood	Concrete B35
Pile toe resistance (%)	75-85	65-70
Pile shaft resistance (%)	15-25	30-35
Service bearing capacity (SLS)	135 kN	1000 kN
Ultimate bearing capacity (ULS)	205 kN	3410 kN

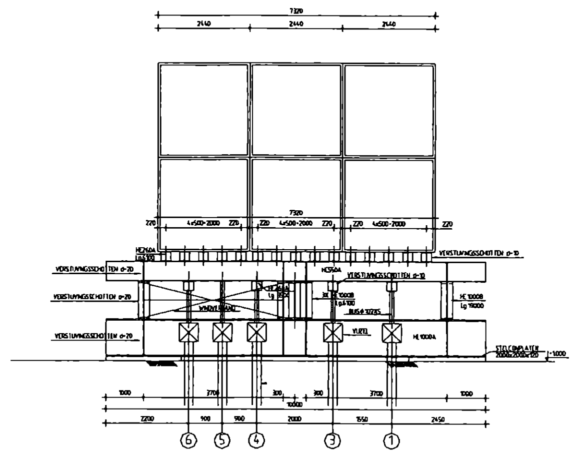

Figure 1. Cross Section of the Ballast Frame.

The construction consists of:

- 9 wooden piles used for stage 3a (and later on for 3c);
- 3 wooden piles and 3 concrete piles exclusively used for stage 3b;
- 6 wooden piles exclusively used for stage 3c;
- hydraulic jacks to adjust the load on the piles;
- various steel profiles to redistribute the load;
- steel containers filled with sand, serving as ballast.

During the tests, the jacks are used to maintain the SLS loads on the piles (no redistribution of loads). This way the displacement as a function of time (injection process) at constant load rate will be obtained.

5 MONITORING PROGRAM

5.1 *Introduction*

Because of the large quantities of data that will occur from the test, very strict regulations regarding these data are given. Some important aspects are mentioned:

- the distinction that is made between continuous measurements and measurements with regular intervals; where continuous is described as the lowest possible interval with the prescribed monitoring equipment.
- time synchronizing of the monitoring equipment (every our);
- required format of the data (time, temperature & reference location registration; units; accuracy);
- presentation (daily digitally (CD-RW) & hardcopy, graphs, concept & final report).

In the next paragraphs, a survey of the measurements / monitoring equipment is given. Generally a distinction is made between the several different stages. This because although some of the monitoring methods are the same for all the stages, the application can differ. Essential for the design of the test is that injection takes place at different distances from the pile (toe).

The pile load test to determine the (ultimate) bearing capacity of the pile and the used monitoring equipment are the same for all stages and are therefore discussed separately.

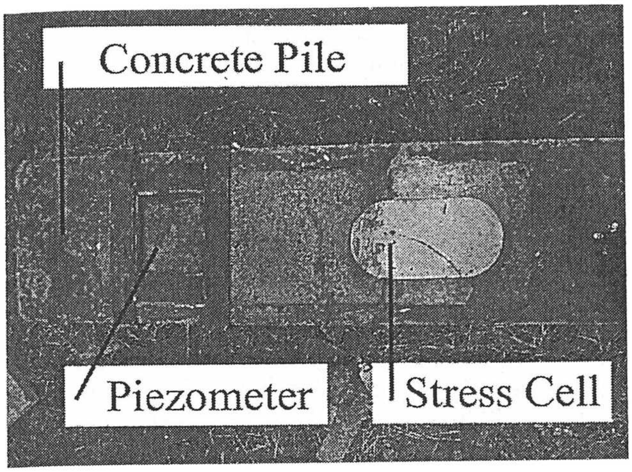

Figure 2. Integrated monitoring equipment: concrete pile.

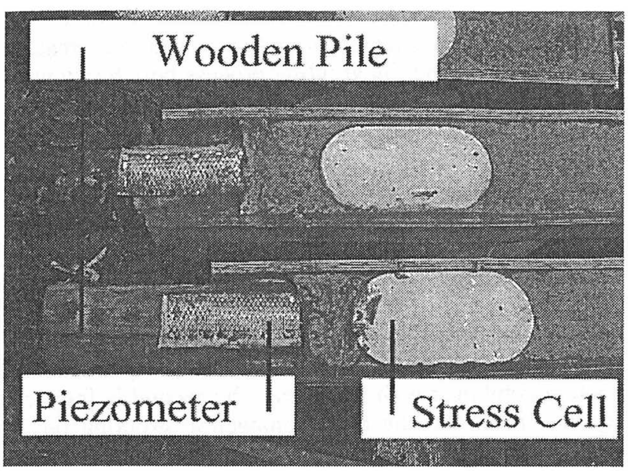

Figure 3. Integrated monitoring equipment: concrete pile.

5.2 *Pile load tests*

The pile load test consists of applying increments of static load to a test pile and measuring the deflection of the pile. The load is jacked onto the pile by using the dead weight of the ballast frame (sand filled containers).

All the piles used in this test are tested at least 3 times. The first two load tests are conducted before injecting the soil, the third afterwards. Results of the TPP show that the first and second load test can consider substantially; the aim of the first test is therefore to be able to compare representative tests before (2nd) and after (3rd) injection to determine the difference in bearing capacity.

Because the pile behavior is not known exactly before the load tests, the first test is used to determine the appropriate load increments and ultimate bearing capacity $F_{u;1}$. The ultimate bearing capacity is defined as the load at which the vertical pile displacement reaches 10% of the pile toe diameter. The load scheme is shown in table 2. When in the first load test the pile hasn't reached $F_{u;1}$ by step 9, an increment of +10 kN / +200 kN is used until $F_{u;1}$ is reached.

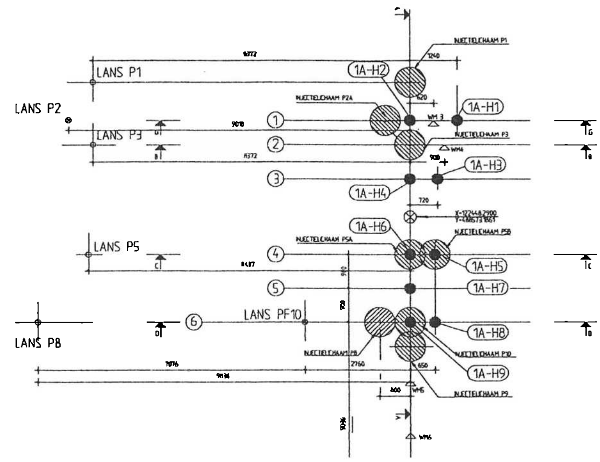

Figure 4. Plan of the permeation-grouting test.

Table 2. Load increments for pile load test.

Step	Wooden piles		Concrete piles	
	Test 1	Test 2 & 3	Test 1	Test 2 & 3
1	50	$0{,}50 * F_{u;1}$	600	$0{,}50 * F_{u;1}$
2	100	$0{,}70 * F_{u;1}$	1000	$0{,}70 * F_{u;1}$
3	120	$0{,}80 * F_{u;1}$	1400	$0{,}80 * F_{u;1}$
4	140	$0{,}85 * F_{u;1}$	1800	$0{,}85 * F_{u;1}$
5	160	$0{,}90 * F_{u;1}$	2200	$0{,}90 * F_{u;1}$
6	180	$0{,}95 * F_{u;1}$	2800	$0{,}95 * F_{u;1}$
7	190	$1{,}00 * F_{u;1}$	3000	$1{,}00 * F_{u;1}$
8	200	$1{,}05 * F_{u;1}$	3200	$1{,}05 * F_{u;1}$
9	210	$1{,}10 * F_{u;1}$	3400#	$1{,}10 * F_{u;1}$
>9	$\Delta F=+10$	$\Delta F=+0{,}05*F_{u;1}$	$\Delta F=+200$	$\Delta F=+0{,}05*F_{u;1}$

Approximate calculated ULS (ref. table 1)

5.3 *Special monitoring equipment*

Among the monitoring equipment used are water pressure meters, soil stress meters, load cells, extensometers, inclinometers, CPT's and horizontal and vertical levelling equipment (total stations). Most of the equipment is used in a regular way, but an exception is made for the piezometers and the soil stress meters. Results of the TPP showed that it was possible to integrate them in the pile, as shown in Figure 2 and Figure 3, with satisfactory results. A big advantage is that when this equipment is installed this way, the soil isn't disturbed like when installing them in a borehole. The piezometers could be installed by pushing them into the soil; therefore boreholes are not used.

5.4 *Monitoring frequency*

The used frequency differs throughout the test period. During installation of the TAM's and during injection, most of the monitoring equipment is read out every minute. When no injection takes place the frequency is reduced at least 5 times. After injection the frequency is reduced each week. Monitoring stops four weeks after injection (unless the results show further monitoring is necessary).

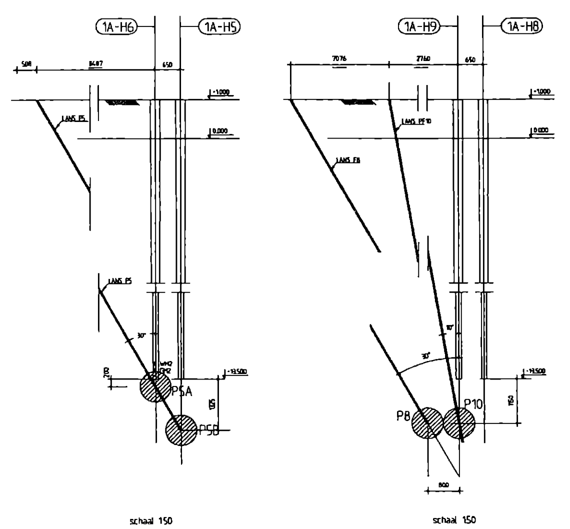

Figure 5. Permeation grouting stage 3a (left) permeation grouting combined with fracturing stage 3c (right).

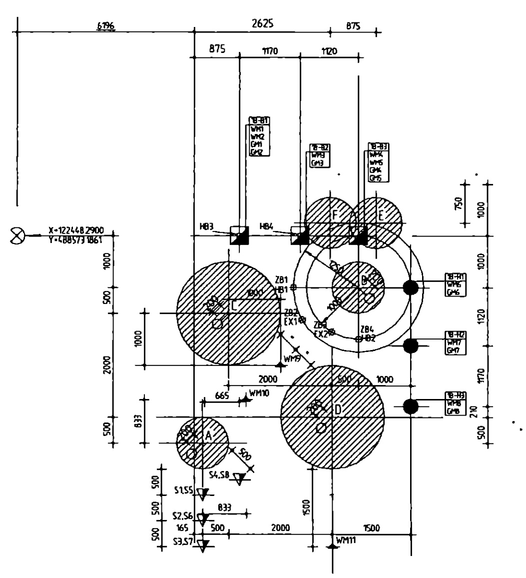

Figure 6. Plan of the jet grouting test (stage 3b).

6 INJECTION TEST STAGE 3

6.1 *Stage 3a: Permeation grouting near wooden piles*

In Figure 4 the plan of the permeation grouting injections for stage 3a are shown. Figure 5 shows some characteristic cross-sections.

Tube à manchettes (TAM's) are used to create a more or less spherical permeation grouting body either just beside / under the pile toe or surrounding the pile toe. Only wooden piles (1st sand layer) are used. During the process of installing the TAM's and during the injection process vertical displacements of the piles are intensively monitored. Also monitored are the horizontal stresses and the water pressure, the first only in the piles, the latter both in the piles as well as in the soil. The piezometers in the soil are placed at increasing distance from the injection points, to monitor the influence of the injection pressures. Note that during the installation of the TAM's, the placing accuracy is of the utmost importance.

6.2 *Stage 3b: Jet grouting near wooden & concrete piles*

Figure 6 presents the plan of the jet grouting for stage 3b. Before jet grouting four CPT's (S1 – S4) are taken at varying distance from the intended edge of jet grouting body A. After jet grouting another four CPT's (S5 – S8) are taken to determine the differences.

For the creation of the jet grouting bodies, a two-phase jet grouting system (double jet) is used. Injection bodies A through D reach from NAP –10 m to NAP –35 m. The deeper part (from NAP –28 m) is used to test the groutability of the Eemclay layer, a/o. because in the station design struts are integrated there (De Wit, 1999). Injection bodies E and F are used to first create a collar on concrete pile 1B-B3 and then grout near its toe.

Two injection bodies with a diameter of 1 meter (A & B) and two with a 2-meter diameter (C & D) are created respectively. During the grouting process both horizontal as well as vertical displacements of the piles are intensively monitored. Also monitored are the displacements at depth (extensometers and inclinometers), horizontal stresses and the water pressure.

6.3 *Stage 3c: Compensation grouting near wooden piles*

Stage 3c consists of three different injections. The first is a supplement of stage 3a and consists of permeation grouting combined with fracturing, the second is fracturing on 3 piles and the third compaction grouting on 3 piles.

6.3.1 *Permeation grouting and fracturing (supplement of stage 3a)*

Some additional permeation grouting bodies are created under the toes of the piles of stage 3a. After one day (the silicate has hardened) fracturing is used to crack the soil under the permeation grouting bodies (and the piles) and lift them.

The permeation grouting bodies are created to spread out the pressures that are induced by the fracturing. This way it is prevented that the soil is pressed between the piles.

6.3.2 *Fracturing*

Figure 7 (left) shows a characteristic cross-section for the fracturing compensation grouting. For the fracturing a plastic grout is used to crack the soil horizontally. The upper and lower manchette are used for preconditioning, the middle is used for the actual lifting of the soil. Lifting will take place in steps of 2-3 mm / injection until a total uplift of approximately 25 mm is reached.

In this stage, no permeation grouting is used. This way the spreading effect of the permeation grouting bodies can be evaluated.

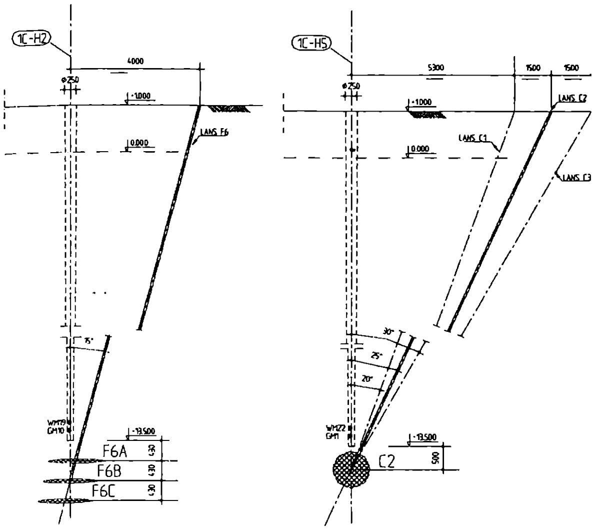

Figure 7. Compensation grouting; compaction grouting (left) and fracturing (right).

6.3.3 *Compaction grouting*

In Figure 7 (right) characteristic cross-section for the compensation grouting injections is shown. For the compaction grouting a very stiff grout is used to tighten the soil. The horizontal effective stresses are increased this way. A series of 4 or 5 manchettes are used one time only for grouting. Multiple injection through one manchette is virtually impossible, because of the high stiffness of the grout.

7 PREDICTIONS

7.1 *Introduction*

Because of the complex nature of injecting in soft soil near pile foundations, predictions have been made with increasing convergence.

First an extensive desk study has been made. This was followed by analytical, empirical and 2D and 3D FEM analysis.

7.2 *Desk Study*

The desk study consisted of a literature study and interviews with contractors and engineering agencies.

The result of the study showed that there was very little experience with any of the injection techniques applied near to deep pile foundations. Most of the experience lies with the contractors, and as a consequence (to protect their investments in technical developments) little has been published. Also, only very limited numerical analysis concerning soil stresses or deformations has taken place.

7.3 *Analytical Predictions*

Determining of the dimensions of the permeation grouting have been made using Raffle & Greenwood (1961). For the jet grouting, Kauschinger (1992) will be applied (in a somewhat altered form). For the compaction grouting, Vesic is used.

No relations were found for the influence of any of the injection bodies on pile foundations.

7.4 *FEM Analysis*

Both 2D (PLAXIS) FEM analysis as well as 3D (ABAQUS, DIANA) is being conducted now. Problems that are being encountered especially relate to the modelling of the (driven) pile.

Most likely, the FEM analysis is ideal for interpreting the test results.

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