Uretek Deep Injection Method

Lifting of settled foundations
Analysis of full scale test results

Roelof van Reenen
Std.no. 9682735

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Uretek Deep Injection Method
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URETEK
resina
TU Delft
Delft University of Technology

Colophon

Organizations

Delft University of Technology
Faculty Civil Engineering and Geosciences
Stevinweg 1
2628 CN Delft
Tel +31 15 278 5440

Resina Chemie BV
Korte Groningerweg 1A
9607 PS Foxhol
Tel +31 598 317 907
www.resina.nl

Uretek Nederland
Zuiveringweg 93
8243 PE Lelystad
Tel +31 320 256218
www.uretek.nl

Student

Roelof van Reenen
Rotterdamseweg 9
2628 AH Delft
Tel +31 6 46340415
Email vanreenen@gmail.com
Std.no. 9682735

Committee

Chairman (TU Delft)
prof. ir. A.F. van Tol
Chair Foundation Engineering

Daily supervisor (TU Delft)
ing. H.J.Everts
Chair Foundation Engineering

External supervisor (Uretek)
ing. A. ter Huurne
Executive Uretek Nederland en Duitsland

External supervisor (Resina Chemie BV)
dr. ir. A. van der Wal
Head Research and Development

Preface

The report that lies before you is the result of a nine months lasting graduation project done at the faculty of Civil Engineering and Geosciences at the Technical University of Delft.

I am greatly indebted to my supervisors; prof. ir. A.F. van Tol, ing. H.J.Everts of the TU Delft, ing. A. ter Huurne of URETEK and dr. ir. A. van der Wal of Resina Chemie BV. At this place I want to thank them for the support and reflection of my work.

I would like to thank Stefan Segers with whom I supervised and executed the construction and research on the test-site in Wolvega.

Without the help of Han de Visser, the people of Punter BV in Wolvega and the injection crews of Uretek the full scale test and measurements could not have been performed. My thanks go out to them.

Delft, July 2006

Roelof van Reenen

Summary

When large or differential settlements of a foundation occur action has to be taken, to raise and level the foundation. A relatively new way to undo the settlement for shallow foundations is the Uretek Deep Injection Method (UDI), performed by Uretek. This method is based on injecting an expansive resin, produced by Resina chemie, under settled buildings to lift the buildings back to a predetermined level.
The two companies wanted to increase their knowledge on the effects of the injected resin on the soil strength, stiffness and to analyze the properties of the resin in the soil. The best way to measure and analyze these points is to perform a full-scale test. Such a test was performed by two students from the faculty of Civil Engineering and Geosciences of Delft University for their master thesis. The master thesis consisted of designing a test program, constructing a test facility and performing and analyzing measurements. The test program included three test-facilities:

1 A facility that has been lifted with the UDI-method and will be used to measure long term settlements (2-3 years) after the resin injections have taken place.
2 A facility that has been lifted with the UDI-method and of which the injected soil has been excavated after performing the injections in order to observe the propagation of the injected resin in the soil.
3 A facility that provides a reference for the other two; this foundation has been built and loaded in the same way as the other two foundations but has not been treated with the UDI-method.

The three identical facilities consist of two concrete foundation strips which are loaded in two steps of about 50 kPa each. The first load is the combination of the weight of the structure itself increased with the weight by placing filled sand bags. The second load, only sand bags, was applied after the two facilities had been lifted by the UDI-method.
Through level measurements the settlements of the test-facilities have been monitored. These settlements were the same for both the injected test-facilities as the reference test-facility. This indicates the stiffness of the soil is not influenced significantly the resin injections. The energy of the expansion of the injected resin is mainly absorbed by lift of soil, including foundation. For a minor part the resin causes an increase of soil stresses. In permeable layers this will lead to some densification; in badly permeable soils it will only result in excess pore pressures; not in densification.
In order to measure if an increase of soil strength was realized, dynamic sounding and cone penetration tests have been performed. After analyzing the results of these two methods from before and after injecting the resin, no increase or decrease of the strength was found.
In theory it is assumed that the expansive resin propagates through the soil by creating fractures. At first vertical fractures increase the horizontal effective soil stress. When the horizontal stress is almost equal to the vertical stress, due to injecting a horizontal fracture is created, which lifts the construction above.
The excavation of the injected soil beneath the short term test facility confirmed this pattern of resin disc perfectly. In detail, the resin chooses the line of the least resistance, along the borders of two different soil layers.
Laboratory tests showed that the unit weight of the injected resin was 200 kg/m^3 on average. Combining the lift, of the test facility with 2 cm, and a volume of injected resin of 45 liters per m length of the foundation strip, a lift efficiency of 27% is reached for lifting foundations. Most of the lift created by the expanding resin consists of lift of the soil surrounding the foundation.
Samples of excavated resin have been subjected to a creep test. The estimated creep after 50 years is less than 1% for stresses of 100 kPa and less than 4% for stresses up to 500 kPa. In case of a total

thickness of injected resin layers of 50 mm, on the long term this will lead to a settlement due to creep of about 0.5 to 2 mm. In normal practice this settlement due to creep is negligible.

Table of Contents

1. Introduction

When a house is build on ground which has weak soil layers, these layers can compress under the load of the house which causes settlement. This settlement of the foundation is hard to predict. A uniform settlement is in most instances no problem, the house as a whole is lowered. Problems arise when differential settlements of the foundation occur, which cause an increase of the stresses in the walls and leads to cracks and fractures. The conventional ways of repairing are expensive and require a major reconstruction of the foundation. The building is not usable for a prolonged period of time while the work is carried out.
A relatively new way to stabilize and undo the settlement for shallow foundations is the Uretek Method, a Deep Injection Intervention performed by the Uretek Company.

Picture 1.1a Wall fracture due to settlement of foundation.

Picture 1.1b Wall fracture closed by lifting the settled part with the Uretek injection method.

The method is based on a resin injected in the soil under the settled parts of a foundation. The resin consists of two chemical components produced by Resina Chemie which react when added together. During the reaction the material expands lifting the settled foundation up. The expansion also reduces or closes the cracks in the walls. The method can be applied with little hinder and down time to the normal usage of a building.

To increase the applicable range of the method a full-scale test has been performed to investigate the soil improvement and lifting qualities of the injected resin.
On a strip of land on the outskirts of Wolvega in the Netherlands three full scale foundations have been constructed. With big sand bags a load equivalent to the weight of a house has been put on the foundations. Beneath two of the foundations resin was injected. The third foundation is used as a reference to be able to measure the settlement difference of the foundations between treated and untreated soil. The reference and one of the injected foundations will be left for a longer period (2-3 years) to be able to see settlements over a longer period of time. The other injected foundation has been excavated in the course of this project to be able to determine how and where the resin has expanded. On the retrieved resin creep and ultimate stress tests have been performed.

The contents of this report will show the results of the measurements done on the test site and the findings from the excavated foundation. From these results conclusions on the soil improvement quality of the resin will be presented.

Chapter 2 defines the objectives and the problem to be investigated. Chapter 3 explains the Uretek method. In chapter 4 the test-setup is summarized. In chapter 5 the level measurements of the lift and settlements of the test facilities are analyzed and how these affect the soil stiffness. In chapter 6 the soil strength changes are tested by dynamic sounding and cone penetration tests. The propagation of the resin in the soil is investigated in chapter 7. The creep and specific weight of excavated resin is determined in chapter 8. In chapter 9 the efficiency of the UDI-method is calculated. Chapter 10 and 11 are respectively the conclusions and recommendations.

2. Problem analysis and objectives

In this chapter the problem of the research will be defined. From these, objectives will be formulated for a test, resulting in the objective for this master thesis.

2.1 Problem definition

The Uretek deep injection intervention (UDI) method is successfully applied for lifting of settled floors and buildings to a desired level. The method of injecting is mostly based on the experience of the injection crew. They have the aid of a laser device which measures the lift of the objected being raised.
Prior to an injection intervention the available knowledge is usually very limited. An estimated of the amount of resin to be injected in the soil can't be made and it is not known what shape the injected material will form. Uretek Netherlands and Resina Chemie want to perform research to increase their knowledge on how to predict this resin behavior as well as the influence on soil properties.
To achieve this, the companies have taken the initiative to perform a test, to get a better insight in their product. To help them perform the test they contacted the geotechnical department of the faculty of Civil Engineering and Geosciences of the TU Delft. It has been decided to carry out a full scale test because of the absence of scaling errors.

The objectives of the full scale test are:

- To study the effects of injected resin on the soil strength and stiffness properties.
- To analyze the properties of the resin in the soil.
- To measure the settlements over a longer period of time. To determine short and long term effects on the stiffness of the treated soil.

To achieve the goals three test-facilities are constructed on which measurements are and have been done.

1. A facility that has been lifted with the UDI-method and will be used to measure long term settlements (2-3 years) after the resin injections have taken place.
2. A facility that has been lifted with the UDI-method and of which the injected soil has been excavated after performing the injections in order to observe the propagation of the injected resin in the soil.
3. A facility that provides a reference for the other two; this foundation has been built and loaded in the same way as the other two foundations but has not been treated with the UDI-method.

2.2 Objective master thesis

The objective of this master thesis is to present the data from the measurement on location and the test performed on the excavated resin and to analyze the results. This will result in a conclusion on the soil improvement qualities of the resin.

3. The Uretek injection method

Uretek is a worldwide brand name for restoration of settled floors and foundations. The franchise companies of Uretek lift settled floors and foundations back to desired levels. The procedure for lifting foundations is explained in more detail in paragraph 3.1. This method was used for the injections under the test-facilities which are described in chapter 4. An indication of the resin properties is given in paragraph 3.2. These two paragraphs are based on the Dutch Uretek website.

3.1 The Uretek method

The lifting method used by Uretek is a deep intervention injection. A resin is injected under a foundation up to 5 meters below ground level. The resin expands and lifts the foundation. The injections can be used in granular soils and cohesive soils with a plasticity index smaller than 25.

The procedure consists of 3 stages:

1. Drilling a hole with a diameter between 12-20mm and inserting an injection pipe. This is done every meter along the foundation.
2. Connecting the injection pistol and injecting the resin.
3. Expansion of the resin and monitoring the lift with a laser reader.

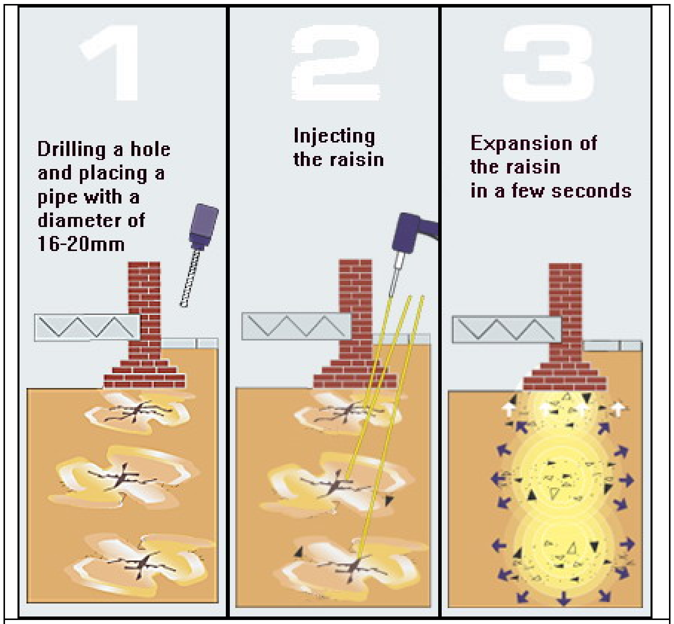


Figure 3.1 Injection stages.

This procedure is repeated with 1 meter intervals between the injection points under the part of the foundation which has to be treated. When one level is injected the procedure is repeated on a lower level in the ground till the desired lift is reached. Starting just below the foundation each successive injection level is 0.5 to 1 m deeper than the previous. This way the last injection pushes against the previous injection, preventing the resin from blowing out to the surface.

By using this method also cracks in the masonry of the walls created by the settlement are reduced. The work is performed with minimal interference, often normal work can continue during the process. Downtime due to the lifting is therefore minimal. The method is also very vast, in most cases a day of injecting is enough to complete the lifting.

3.2 The injection resin

The resin is supplied by Resina Chemie BV and is a polymer consisting of two components. The components start reacting 5-10 seconds after mixing. The components have a specific density of about 1000 kg/m^3. The maximum expansion of the unrestrained (in air) resin is 30 times the initial volume. The reaction is finished in 30-120 seconds. In the ground the reacted resin has a specific weight of 150-300 kg/m^3 an expansion of 3-6 times the initial volume. The reacted material has no influence on the environment; the substance is inert which means it doesn't interact with other substances in the soil.

4. Testing the Uretek Deep injection Method

This chapter will give a summary of the full scale test performed. In paragraph 4.1 the test setup is clarified and the objectives of the research are explained. The results from the research are presented in following chapters. In paragraph 4.2 an overview of the test-facility building and performed measurements will be presented in chronological order. Paragraph 4.3 the general layering of the soil is presented. Paragraph 4.4 explains how stiffness and soil strength will be measured. In Paragraph 4.5 the test is summarized.

4.1 Test setup and measuring methods

The research was conducted in Wolvega the Netherlands, see Appendix A. To be able to investigate the effects of the two components injection resin on strength and stiffness of the soil beneath the foundation level a full scale test has been carried out. The advantage of a full scale test is the absence of possible scaling errors. Quantifying scaling errors is difficult, unexpected side effects can ruin the results.
To do the measurements three identical test-facilities (paragraph 4.2) have been constructed;

1 A facility that has been lifted with the UDI-method and will be used to measure long term settlements (2-3 years) after the resin injections have taken place.
2 A facility that has been lifted with the UDI-method and of which the injected soil has been excavated after performing the injections in order to observe the propagation of the injected resin in the soil.
3 A facility that provides a reference for the other two; this foundation has been built and loaded in the same way as the other two foundations but has not been treated with the UDI-method.

With the three test-facilities the objectives (chapter 2) can be achieved. The objectives are repeated and clarified;

- **Investigation of the effects of injected resin on the soil strength and stiffness properties.**
  The soil strength is measured with:
  - dynamic soundings.
  - cone penetration tests (CPT's).

  Level measurements have been done with a theodolite to measure the rise produced by injections in the soil and the settlements induced by weight on the test-foundation and consolidation of the soil. From the difference in level measurements between the reference and the two injected under facilities, conclusions can be drawn on the influence on soil stiffness.
- **To analysis of the properties of the expanded resin in the soil.**
  After removal short term test-facility cross sections were excavated in the injected soil to visualize the form of the resin in the ground. By analyzing the cross sections the resin forming process can be better understood. The excavated resin has been investigated to determine its properties;
  - the specific weight.
  - the creep over a longer period of time and with different loadings.

- **To measure the settlements over a longer period of time. To determine long term effects on the stiffness of the treated soil.**
  The level measurements of the reference test-facility and the long term test-facility over a period of 2-3 years, will give an indication of the long term effects on the stiffness of the treated soil.

4.2 Test-facilities

4.2.1 A single test construction

For the full scale tests the three test-facilities have to represent a foundation of a house. To achieve this, two concrete foundation beams, so called strip foundations, have been used with a width equal to a foundation of a normal house (0.6 m). These strip foundations are loaded with the weight of big bags filled with sand and the construction needed for the placement and distribution of the weight of these bags. The weight is equal to that of a normal house. The foundation level is 0.6 meters below ground level, a normal level for shallow foundations. See figure 4.1a.

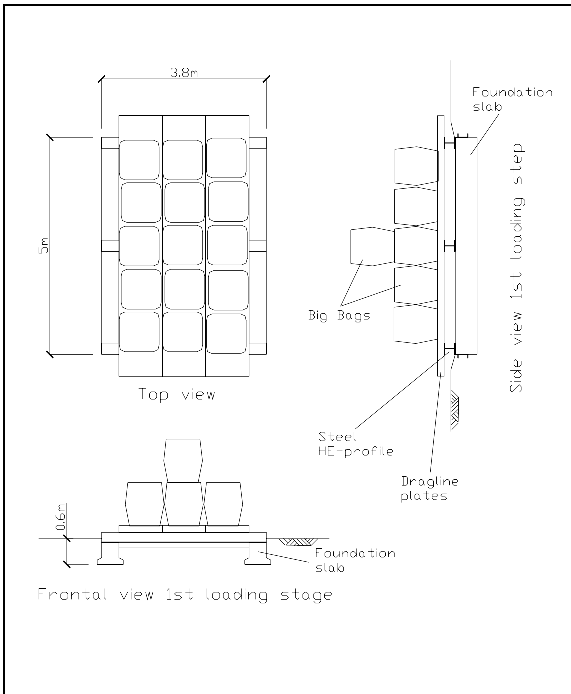


Figure 4.1a Shallow test-facility foundation.

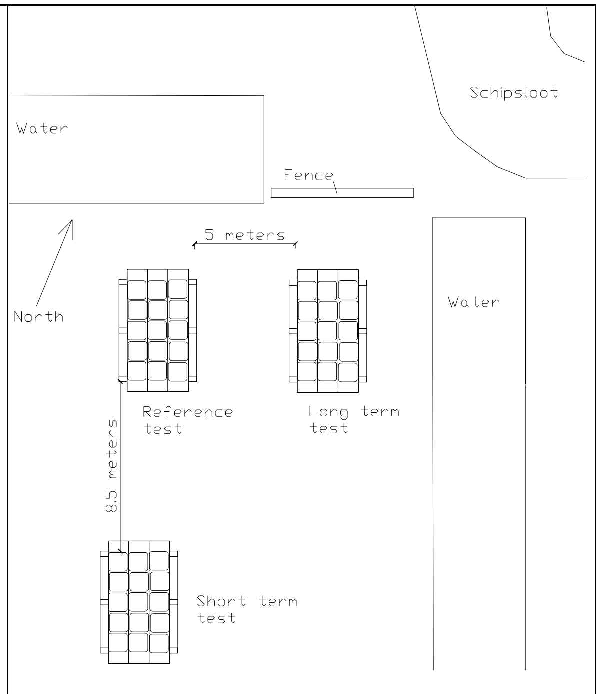


Figure 4.1b Test site layout

4.2.1 Placement of test-facilities at test site

The reference and the long term test-facilities have been placed next to each other. The short term test-facility has been placed more than twice the excavation depth away to reduce the influence of the excavation on the two remaining facilities. See figure 4.1b.

4.2.2. Measurement and injection points and reference lay-out

The strip foundations have 18 pre-made vertical holes (diameter 50 mm) for injection and dynamic sounding. The holes at each end of the strip are also used for precise placing of the level measuring scale every measurement. These holes are numbered according to figure 4.2. The individual test-facilities have been split up in quadrants with the same numbering. When referring to a specific test-facility/quadrant/point in this report the same numbering as in this figure will be used.

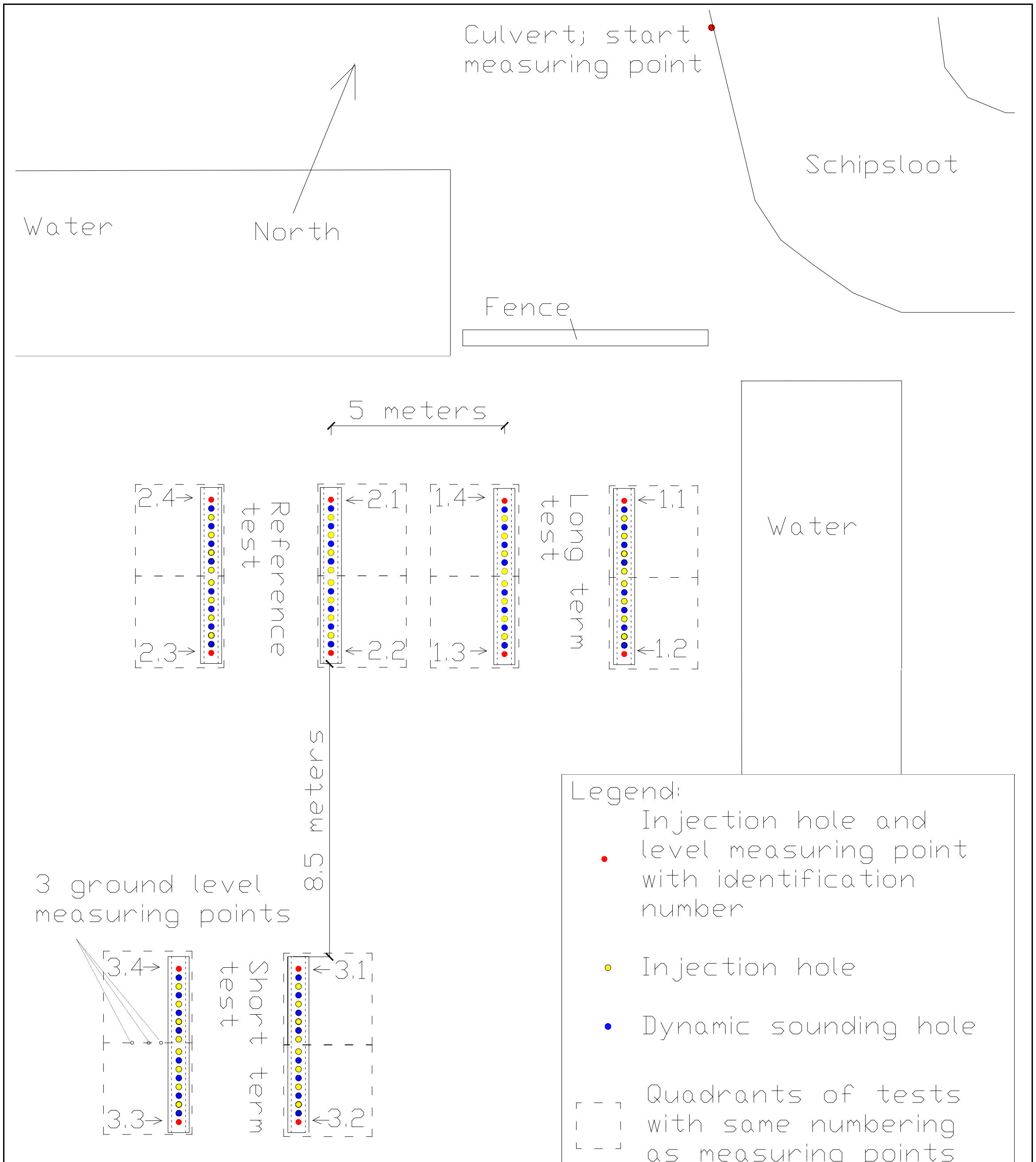


Figure 4.2 Layout and numbering of measuring and injection points.

4.3 The soil layers in the ground at the test site

The general layering of soil layers from grade (approximately NAP) to -25 m is; Brown sand to -1.1m below grade. Followed by a dark brown “oer” layer of 5-10 cm consisting of gravel and sand. From -1.2 m to -2.7 m below grade a silty-sand (loam). In appendix B a geological map and cross section of the area indicate Pleistocene sand from NAP -3 to NAP -25 m.

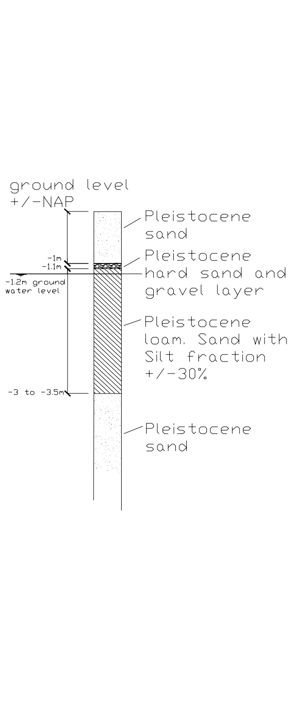


Figure 4.3a Soil layers.

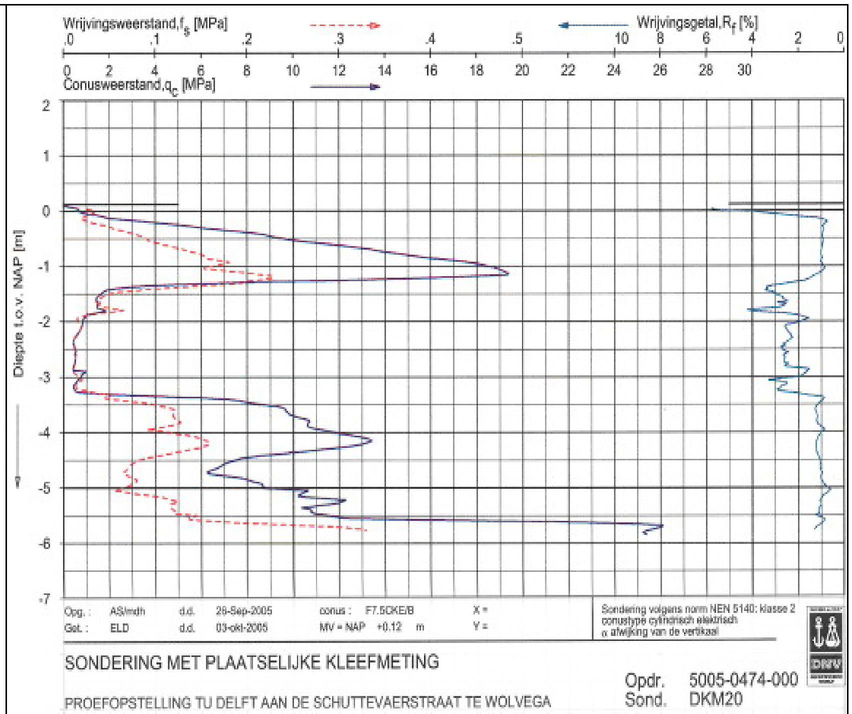


Figure 4.3b Cone penetration test by Fugro.

4.4 Testing stiffness and strength of the soil

After constructing the three test-facilities, they are loaded with a load equivalent to the weight of a one story house (+/- 50 kPa). The settlements are measured with a theodolite to see how the foundation reacts. After injection of the soil under the long term and short term test-facilities a second loading stage is applied of +/-50 kPa. Now the difference in settlement due to the injection can be measured between the first and second loading. Also the difference with the settlement of the reference test-facility due to 2^{nd} loading can be measured. With this difference the increase in stiffness of the soil can be derived.

The strength of the soil is measured before and after injecting by dynamic and continues sounding.

4.5 Day to day summary of test

Days	Date	Work performed	Performers
0	Monday 7 November 2005	Setting out of the 3 test-facility locations.	2 students (Stefan Segers and Roelof van Reenen)
		Preparing the terrain	Contractor (Punter)
		Deliveries of ordered materials	
1	Tuesday 8 November 2005	Level measurements from sewage (NAP +0,80m, measured by Fugro and Wiertsema) to a culvert (NAP -0.109m) and back. The culvert is our fixed point for the rest of the measurements. See figure 4.2.	Students
		Finishing preparations terrain and excavation foundations. See appendix XX.	Contractor (Punter) Students
		Placing foundations and fixating them with steel UNP 240 profiles. See appendix XX.	Contractor (Punter) Students
		Level measurements after placement foundation from culvert. See appendix F.	Students
2	Wednesday 9 November 2005	Placement HE 260 profiles on the foundations.	Contractor (Punter) Students
		Weighing and placing dragline plates on the HE-profiles	Contractor (Punter) Students
		Level measurements after placement dragline plates from culvert.	Students
		Filling Big Bags with sand.	Contractor (Punter) Students
3	Thursday 10 November 2005	Finished filling Big Bags with sand.	Contractor (Punter) Students
		Weighing and placing 10 Big Bags per turn on one foundation. 20 Bags per foundation, for the weights see appendix H.	Contractor (Punter) Students
		Level measurements after placement Big Bags from culvert.	Students
4	Friday 11 November 2005	Level measurements (bad weather).	Students
7	Monday 14 November 2005	Dynamic sounding, with Pagani sounding instrument, through the foundations at every corner.	Students and Uretek Belgium
		Level measurements.	Students
8	Tuesday 15 November 2005	Injections below first foundation strip (points 3.1-3.2) of the short term test-facility. See appendix XX. Heavy rains.	Uretek Netherlands and students

9	Wednesday 16 November 2005	Second foundation strip (points 3.3-3.4) of the short term test-facility and foundation strip (points 1.3-1.4) of the long term test-facility have been injected. See appendixes K. Deepest injection level of last foundation strip of long term test-facility (point 1.1-1.2) injected. Still bad weather.	Uretek Netherlands and students
		Level measurements of short term and reference test-facilities.	Students
10	Thursday 17 November 2005	Level measurements.	Students
		Finished injecting last foundation strip of long term facility (point 1.1-1.2).	Uretek Belgium
		Dynamic sounding, with Pagani sounding instrument, of the short term facility and when finished injecting the long term facility as well.	Students and Uretek Belgium
		Level measurements.	Students
11	Friday 18 November 2005	Filling 72 Big Bags with sand for the second loading stage of the 3 tests-facilities.	Contractor (Punter) Students
		Weighing and placing 24 bags per test-facility. See appendix H.	Contractor (Punter) Students
		Level measurements.	Students
14	Monday 21 November 2005	Level measurements.	Students
15-16	Tuesday 22 and Wednesday 23 November 2005	In the morning and afternoon performed level measurements.	Students
17-18	Thursday 24 and Friday 25 November 2005	Level measurements.	Students
21-24	Monday 28 November till Thursday 1 December 2005	Level measurements.	Students
24	Thursday 1 December 2005	Meeting; decided to do an extra injection under one short term foundation strip (point 3.3-3.4)	Allard van der Wal, Alwin ter Huurne, Bert Everts, Stefan Segers and Roelof van Reenen
37	Wednesday 14 December 2005	Level measurements.	Students
38	Thursday 15 December 2005	Dynamic sounding, with Stitz DPL device, of short term facility.	Students
39	Friday 16 December 2005	Placing and level measuring 3 piquets to measure the ground movement next to the foundation strip of the short term strip (point 3.3-3.4) which is will be injected under a 2nd time.	Students
		Injecting in a dense pattern of injection points part 3.3 of short term facility. Appendix K.	Uretek Netherlands
		Injecting while pulling the injection pipe out of part 3.4 of short term facility. Appendix K.	
		Dynamic sounding, with Stitz sounding instrument, of reference facility.	Students and Allard van der Wal

42-44	Monday 19-21 December 2005	Level measurements.	Students
56	Monday 2 January 2006	Level measurements. Dynamic sounding with Stitz DPL Device, short term test -facility which had been injected twice and the long term facility.	Students
94	Thursday 9 February	Cone penetration tests (CPT's)	Associate of department of geo-engineering (Han de Visser) and student (Roelof van Reenen)
97	Sunday 12 February 2006	Dynamic sounding with Pagani measuring device.	Students
98	Monday 13 February 2006	Placing filters of the dewatering system.	Landman Bronbemaling
99	Tuesday 14 February 2006	Approach excavation of short term facility part 3.4. Two injections rounds with last round pulled injections.	Punter the contractor and students
100	Wednesday 15 February 2006	Excavation of cross section part 3.4. Stopped due to excessive rain.	Contractor (Punter) Students
107	Wednesday 22 February 2006	Excavation of cross section of short term facility part 3.3. Two injections rounds with last round a dense matrix of injections. Excavation of 2 cross sections of short term facility part 3.1 and 3.2. One injection round.	Contractor (Punter) and students
108	Thursday 23 February 2006	Taken soil samples	Contractor (Punter) and student (R. van Reenen)
169	Monday 25 April 2006	Level measurements in the morning and afternoon.	Student
219	Wednesday 14 June 2006	Level measurements in the morning	Student and Bert Everts

5. Effects of a resin injection on the settlements and stiffness of the soil

The level measurements presented in appendix I will be analyzed and clarified in this chapter. In paragraph 5.1 an indication of the error in the measurement is needed to be able to determine accuracy of the data. Paragraph 5.2 analyses the measurements.

5.1 Error in level measurement

The level measurements have been made from a start point on a culvert. The settlement of this culvert has been assumed to be neglectable, read a fixed point. In 3 steps with the leveling instrument all 12 measurement points of the 3 test-facility can be determined. An extra step is added to be able to measure back to the culvert. See Appendix F for the measuring scheme. The marker used has a scale accurate up to millimeters (mm), tenths of a millimeter were estimated. The difference in level found in the measurement of culvert between beginning and end of a measuring cycle is taken as a reference for the total measurement error. The measurement error consists of:

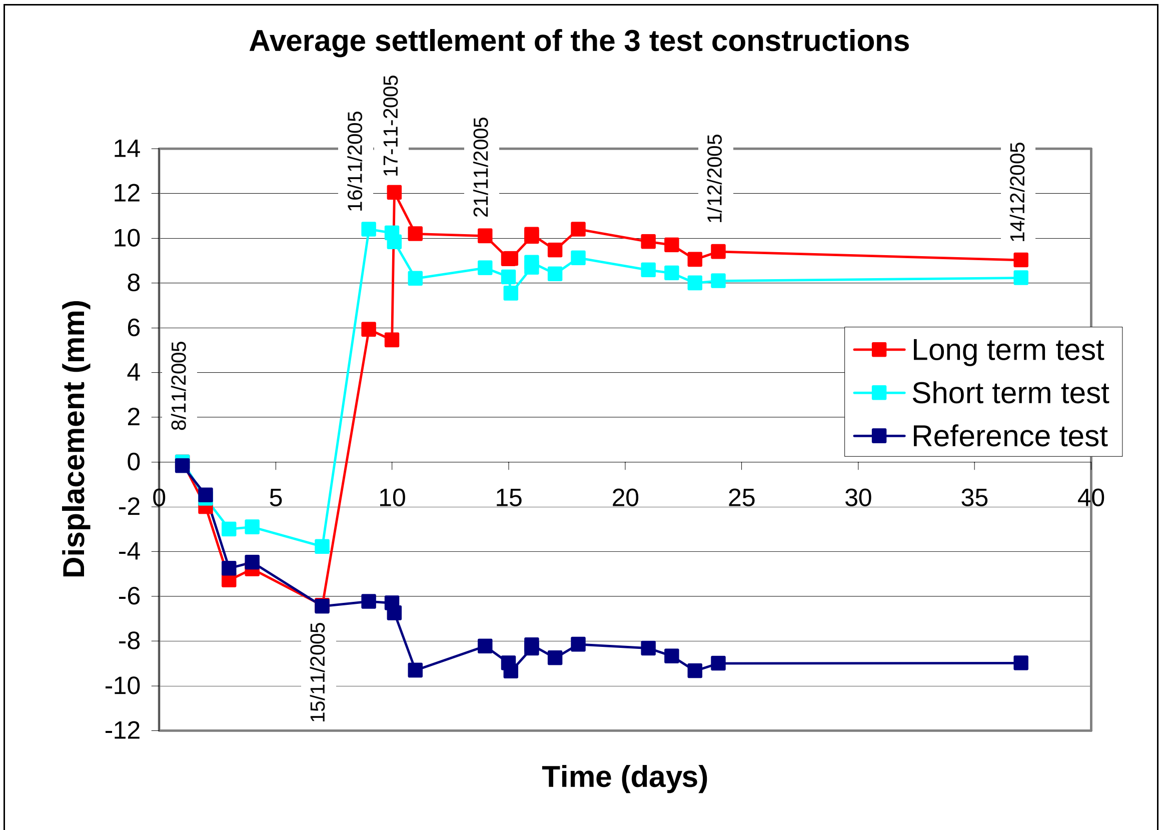
- reading errors on the instrument
- movement of the marker
- dirt between foundation and marker (measurements point locations were kept as clean as possible)

With the differences of 17 measurement cycles an average error and standard deviation of this error is estimated. See appendix G. The derived average error is 0.9 mm and de standard deviation is 0.8mm. The maximum error is the sum of both, +/-2 mm.

5.2 Settlement analysis

Settlement analysis after 1st resin injection

During the test the settlements of the 3 test-facility have been measured. The measurements have been averaged per test-facility to make the comparison easier. See graph 5.1 below.



Graph 5.1. Average settlement of test-facilities first 37 days.

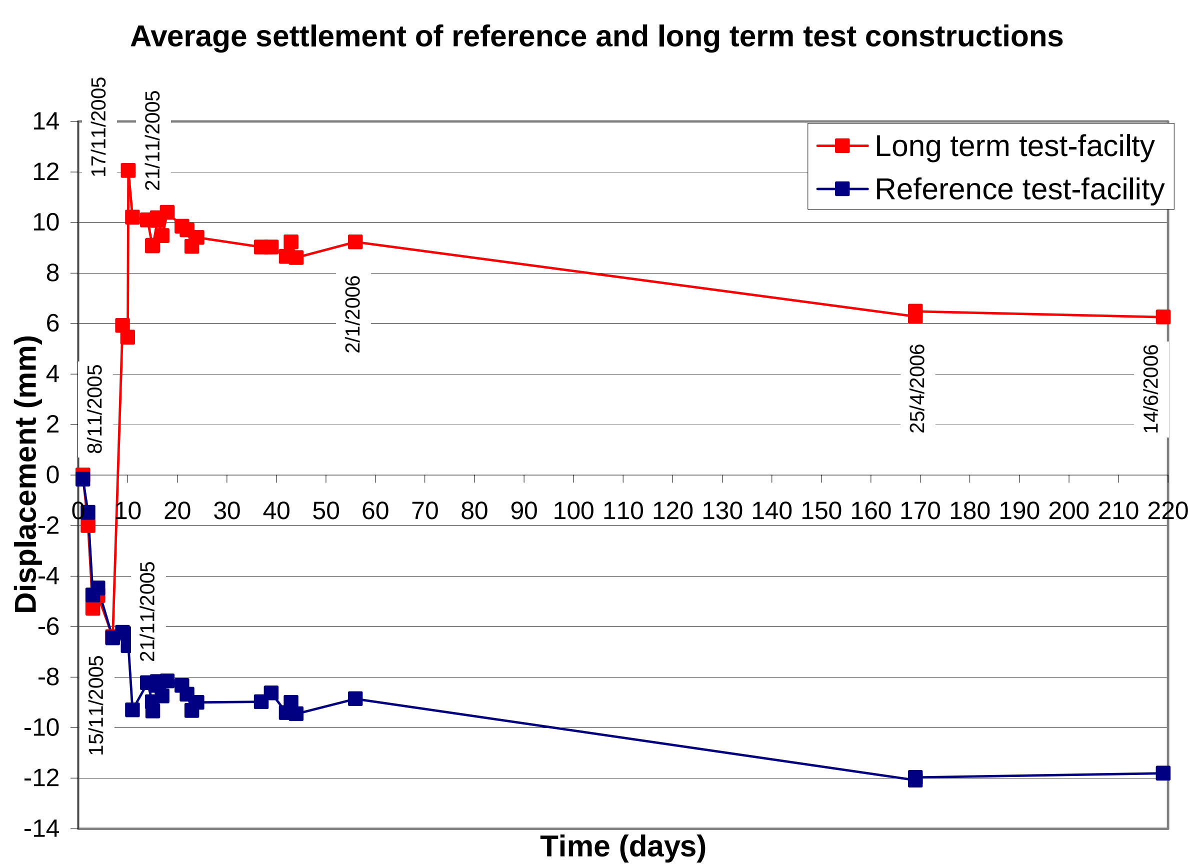
The displacements between stages from the graph 5.1 are presented in following table.

	Reference facility	Long term facility	Short term facility	Date	Measurement time (days)	Time line (days)
Settlement; start test + 1st loading till 1st injection (mm)	-6.5	-6.4	-3.8	8-11-2005 to 15-11-2005	7	1-7
Rise; after first injection (mm)	no injection	18.5	14.2	16-11-2005 and 17-11-2005	1	8-10
Settlement; initial consolidation and 2nd loading (mm)	-1.5	-2	-1.7	17-11-2005 to 21-11-2005	4	10-14
Settlement; after injection and initial consolidation till 2nd injection (mm)	-0.8	-1.1	-0.5	21-11-2005 to 14-12-2006	23	14-37
Total settlement; after 1st injection till 2nd injection (mm)	-2.2	-3	-2.2	17-11-2005 to 14-12-2006	27	10-37

Table 5.1. Settlement per stage of the test.

Before injection of the resin the settlement of the three test-facilities is in the same range, 4-7 mm. This settlement is result of the own weight and 1st loading stage on the foundations, total foundation pressure is about 65 kPa.
After the injections the injected facilities have risen +/- 15 mm. The consolidation of the short and long term facilities due to the 2nd loading stage (+60 kPa) and consolidation caused by the injected resin is about 2 mm, the same as the consolidation of the reference facility due to only the 2nd loading stage. The 2nd loading stage was applied the day after the injections were finished. It would have been better to wait a few days to be able to measure the consolidation initiated by the injection of the resin separately from the 2nd loading. After 23 days this settlement has increased with +/-1 mm, giving a total settlement of about 2-3 mm, 27 days after lifting the foundations.
From the measurements it can be concluded that the settlements after a month are small and that there is no difference between the settlement of the raised foundations and the reference facility.

The long term and reference test-facilities will be measured for a longer period. The data up to 14 June 2006 is presented in graph 5.2.



Graph 5.2. Average settlement of test-facilities first 219 days.

The displacements between stages from the graph 5.2 are presented in following table.

	Reference facility	Long term facility	Date	Measurement time (days)	Time line (days)
Settlement; start test + 1st loading till injection (mm)	-6.5	-6.4	8-11-2005 to 15-11-2005	7	1-7
Rise; after injection (mm)	no injection	18.5	16-11-2005 and 17-11-2005	1	8-10
Settlement; initial consolidation and 2nd loading	-1.5	-2	17-11-2005 to 21-11-2005	4	10-14
Settlement after injection and initial consolidation till 25/4/2006	-3.7	-3.6	21-11-2005 to 25-4-2006	145	14-159
Total settlement after injection till 25/4/2006	-5.2	-5.6	17-11-2005 to 25-4-2006	149	10-159

Table 5.2. Settlement per stage of the test.

From graph 5.2 and table 5.2 the creep from both, reference and long term, test-facilities are in the same range after 149 days. From the measurements can be concluded that the settlement of the foundation is the same with or without the injection. The settlement is not stopped after the lifting of the structure.
The increase of the stiffness of the soil can be calculated with the measured settlement of the foundation. Because the settlement of the reference facility and the treated test-facilities is the same also the stiffness will be the same.

The reason for the stiffness not differing between injected and un-injected soil is explained below.
The energy created by the resin expansion has two effects:

1. Vertical and horizontal fracturing of the soil and filling the fractures with the expanding resin see figure 10.1 below. The vertical fractures displace the soil in a horizontal direction, creating heave and densification of the soil. For soft soils the proportion heave and densification are equal. With vertical fractures with a width of 20 mm, a densification influence of 2 meters on either side of the fractures and a pore volume of 40% the densification can be estimated to be 0.25%. That is densification increase which is neglectable and un-measurable.

   The horizontal fractures create lift and displace the soil and foundation in vertical direction. Lifting does not increase the density of a soil and hence not the stiffness.

   The calculated lift of soil and building together is almost equal to the total calculated volume of expanded resin which was injected. These are calculated values but they lead to the same conclusion stated above.

   An effect induced through the lift of the soil is that a coned shaped cross section of the soil is lifted by the resin. See the surface enclosed by the dashed line of figure 10.1. As can be seen the body of sand influenced by the resin is wider than horizontal propagation of the resin in the soil. The mass of the extra triangles, create extra stress over the width of the resin expansions in the soil, resulting in densification and increase in stiffness. The increase in stress is marginal compared to foundation pressure of 100 kPa which dominates the vertical stress in the profile. The resulting increase in stiffness will therefore be neglectable.

2. Densification of the soil by compaction of the sand particle structure of the soil.

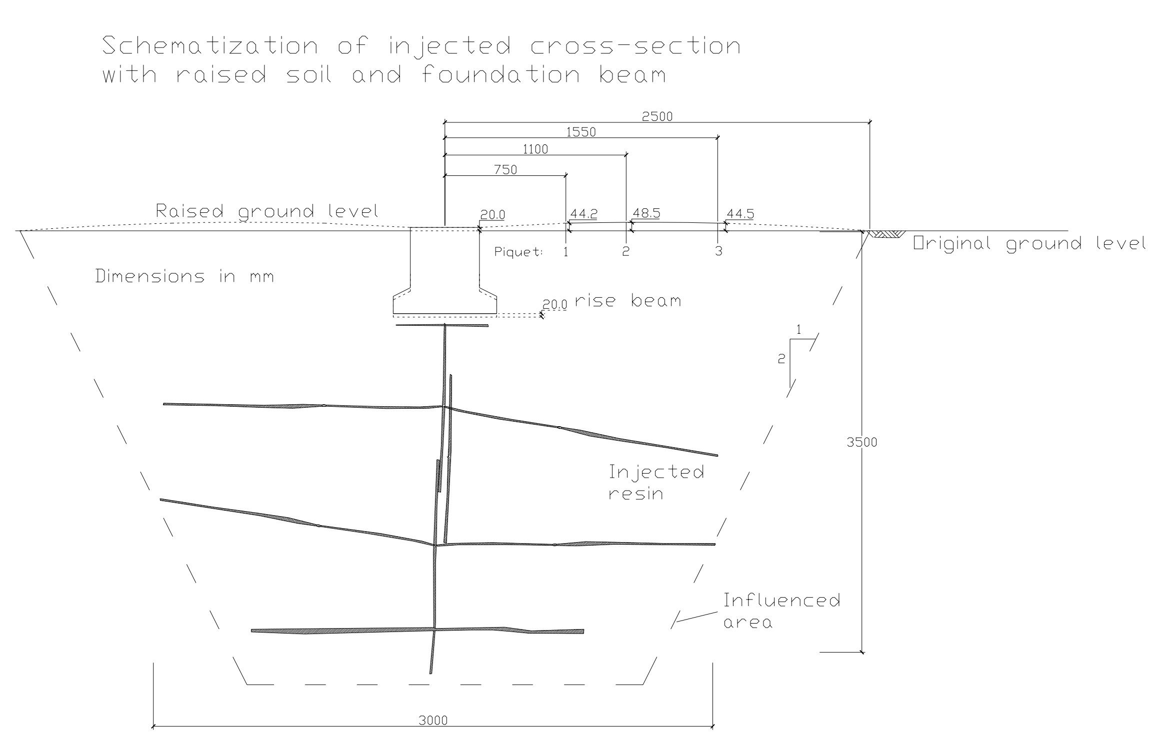


Figure 10.1. Schematization of a resin injected cross-section under a foundation beam.

Creating and filling the fractures consumes most of the expansive capacity of the resin. This fracturing mechanism will be present in both dry soils and in wet soils, meaning respectively above and below freatic level. For further expansion of the resin a distinction may be made between the dry and wet situation.

In dry soils further expansion of the resin produces more lift and maybe some higher effective stresses resulting in densification. Also none of the reaction heat of the resin is dispersed through water leaving more expansive capacity present.

When injecting below groundwater level in soils with a low permeability further expansion of the resin will create more lift and excess pore pressure. Therefore the increase in total stress and water stress will be almost the same, not resulting in an increase of the effective stress and compacting of the soil mass. Water will also absorb reaction heat reducing the left over expansion of the resin.

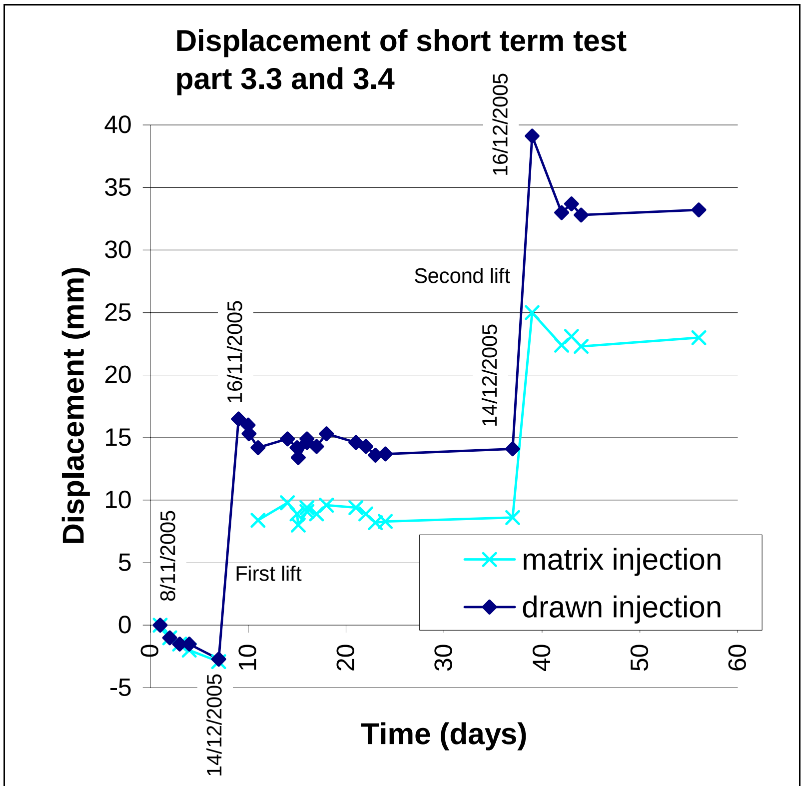
The conclusion that most expansion of the resin is transferred to lift is in accordance with chapter nine on the efficiency of the UDI-method. The calculated lift of soil and building together is almost equal to the total calculated volume of expanded resin which was injected. These are calculated values but they lead to the same conclusion stated above.

Settlement analysis after second resin injection

After 40 days one of the strip foundations parts 3.3 and 3.4 of the short term facility was injected under a second time (see appendix C, Day to day summary test). Two different methods of injecting were used, each under one half of the strip;

- part 3.3 a dense pattern of injection points (see appendix K, figure K.5). The injection points were fixed during injecting
- part 3.4 a drawn injection (see appendix K, figure K.5), pulling the injection tube while injecting.

The measurements are shown in graph 5.3 below. These measurements represent only one measuring point per injection method.



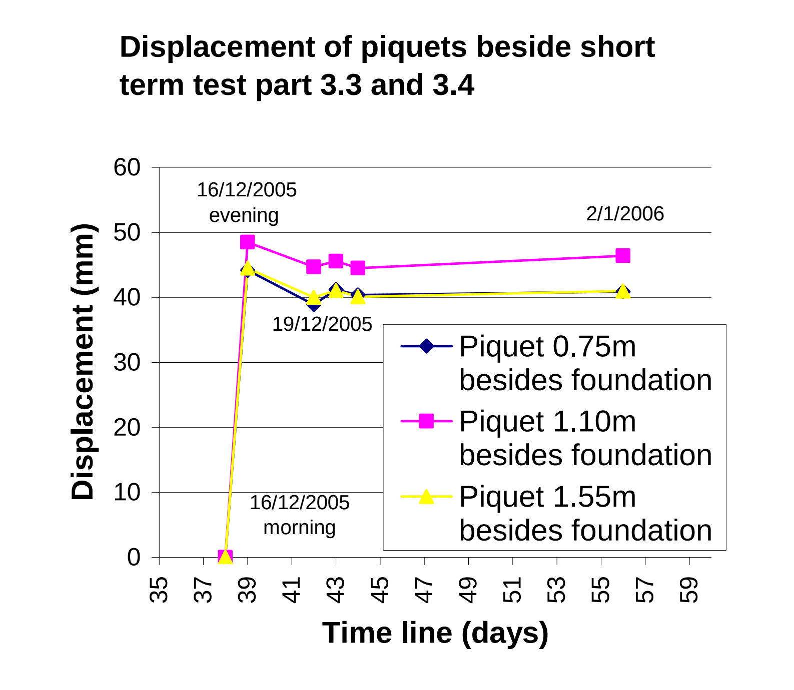
Graph 5.3 Displacements after second injection.

During injecting with both methods, the same amount of resin has been injected (see appendix K, table K.5). The drawn injection gives a rise of about 25 mm and an initial consolidation of +/-5 mm after four days. This results in a strain of 2.5‰ of the soft layer of 2 meters. The dense injection pattern has raised the foundation 15 mm and produced an initial consolidation of +/-2.5 mm after 4 days. It seems the drawn injection produces greater lift but also gives a bigger initial settlement after injection.

The excavation of the soil injected by the different methods showed similar propagation of the resin, resulting in the conclusion: “no distinction between the injection methods is found with respect to the propagation”. To verify this conclusion a test on virgin soil can be performed. The results however are promising for drawn injections, reducing the amount of injection tubes needed and of holes to be drilled, which saves a lot of time in comparison to the other method.

Movement of the ground next to the foundation

For the second injection three piquets, graph 5.4, have been placed beside the middle of the strip foundation to measure the vertical ground displacement caused by the injection. See appendix D for placement of the piquets.



Graph 5.4 Displacement 3 piquets from day 38 to 56.

The piquets have been lifted +/-45 mm after the injection with the resin.

To show the difference in lift after the resin injections between the strip foundation and the soil figure 5.5 is drawn.

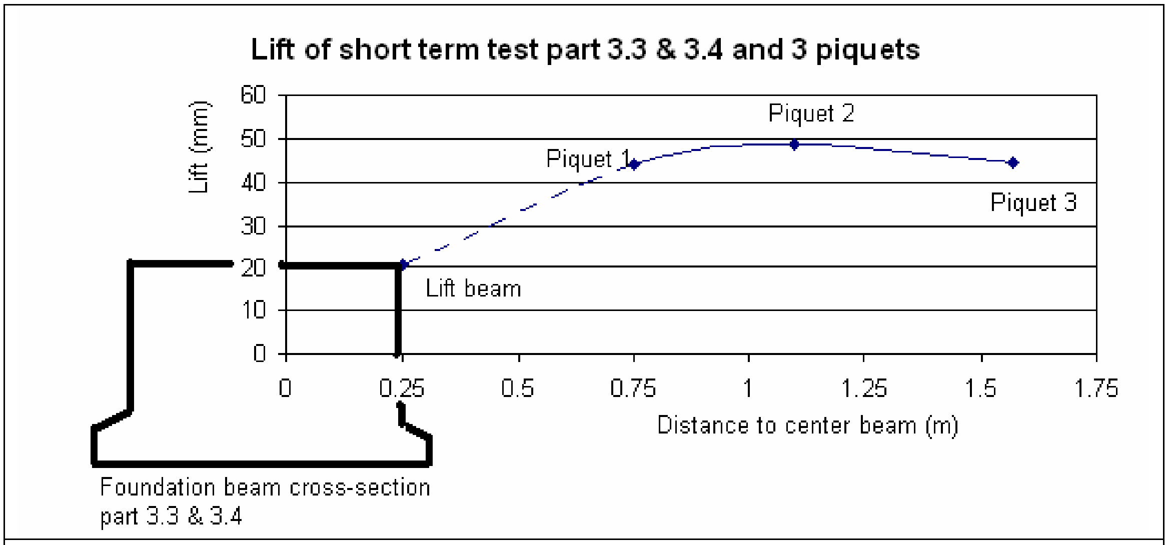


Figure 5.5 Lift of 3 piquets and short term test-facility part 3.3 & 3.4 on 16/12/2005

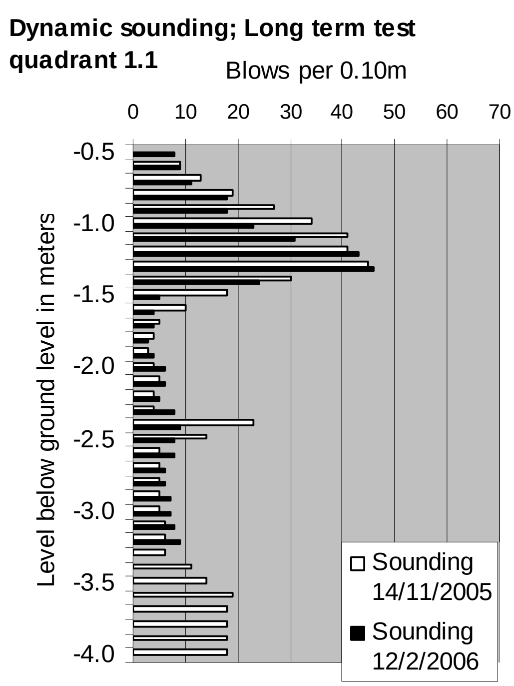
The lift of the soil is about 2 times the lift of the strip foundation. The measurement here is based on 3 piquets in one cross section. This gives a good indication how the soil reacts, more cross sections would have given more accurate measurements.

6. Effects of a resin injection on the soil strength

For measurement of the strength of the soil, dynamic soundings and cone penetration tests (CPT's) have been performed at the test site. In the Netherlands cone penetration tests, which measure the soil resistance, are most often used to investigate the soil strength. This is because of the reliable measuring results in soft soil layers which are common in the Netherlands. Dynamic sounding is a world wide accepted and therefore understood way of measuring soil strength characteristics. This is the reason why this measuring method is also executed. Paragraph 6.1 analyses the dynamic soundings and 6.2 the cone penetration tests (CPT's).

6.1 Dynamic sounding

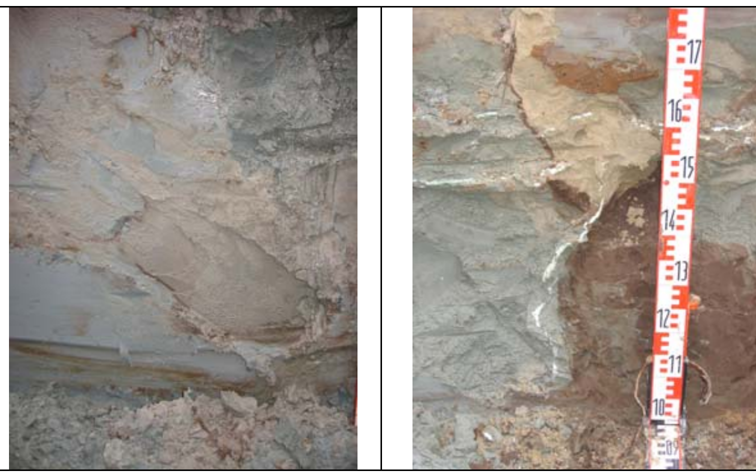
Dynamic sounding means counting the amount of blows needed to penetrate the soil with a cone a further 10 cm into the ground. The so called blow-count is an indication of the local soil strength. This indication has an empirical relation to the real soil strength (kN/m^2) which itself is hard to measure directly. For the comparison of the soil strength only the difference in blow-count is needed between before and after injecting the soil with resin. More or less blows needed for penetrating the ground indicate respectively an increase or a decrease in soil strength. For the resin injections to increase the soil strength, the blow count has to increase.
The dynamic soundings have been executed with a Pagani sounding device with drop weight of 20 kg. The soundings were made through the prefabricated holes in the foundation strips. The numbering of the soundings is according to appendix D. The sounding locations are drawn in the figures of appendix E and K. 14 November 2005 and 12 February 2006 were dates of the dynamic soundings. The soundings can be found in appendix M. The graph of the dynamic soundings at the long term test-facility part 1.1 is repeated below to clarify the analysis of the data.



Graph 6.1 Dynamic soundings; Long term test-facility part 1.1, before and after injection.

When analyzing the graph of the dynamic soundings the results are contradicting. Some soil layers have increased in blow count, others decreased in comparison to the situation before injecting the resin in the soil. Besides the influence on the strength of the soil by the injected resin, which is being investigated, there are three influences which can affect the measurements as well:

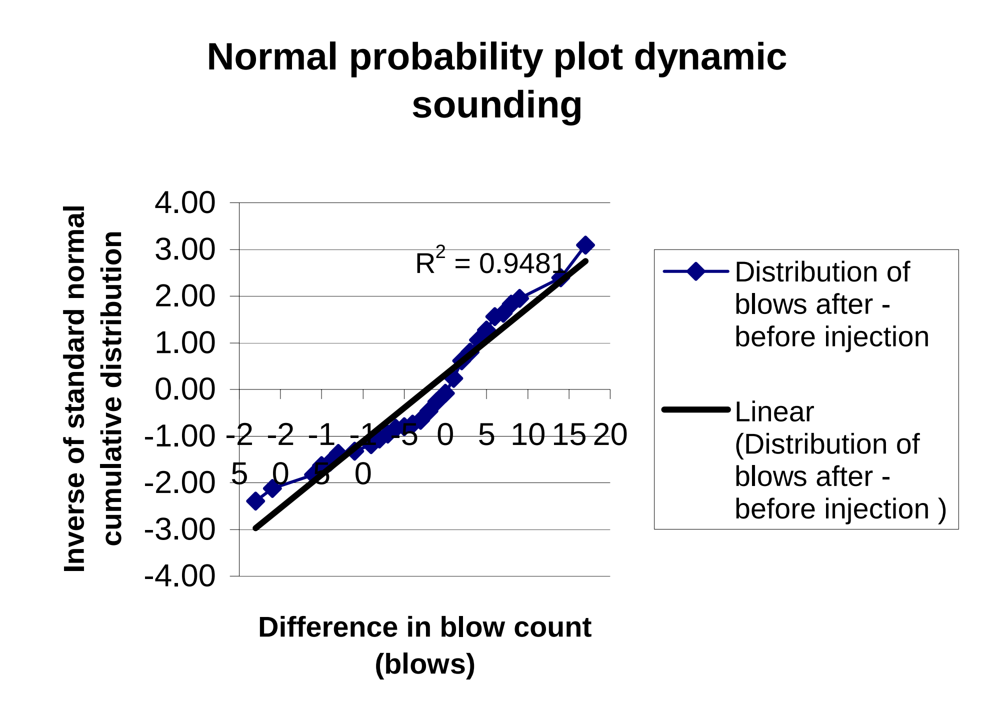
1. The location of the soundings. Soundings cannot be done on the same spot. Sounding influences the soil locally; therefore a second sounding on the same location has to be done at least 0.5 meters distance from the previous. The soft soil or loam layer from -1.5 to -3 m below grade is very heterogeneous (see figure 6.1). Sounding 0.5 meter from the previous sounding can therefore result in higher or lower blow-counts.



Picture 6.1. Heterogeneous soil from - 1.2m to - 3-3.5m below grade.

2. The groundwater level has risen between the two soundings, reducing the effective soil stress see Appendix L groundwater level measurements.
3. The movement of the sounding device during blow sounding will create friction along the shaft connecting to the cone depending on how well the device is centered above the sounding hole. With increasing friction also the blow-count will increase.

Determine whether the blow-count has increased significantly by the resin injections the soundings of the weak soil layer from -1.2 m to –3-3.5 m below grade has been analyzed. For establishing if the increase or decrease is significant a paired t-Test is used. The dataset has to be normal distributed to be able to use this test. This is checked with a normal probability plot, see graph 6.1.



Graph 6.1 Normal probability plot of dynamic sounding dataset.

The linear line indicates the exact normal distribution for the dataset. The fit of the data is relatively good. The assumption that the dataset has a standard normal distribution is justified and the paired t-Test can be used.

Paired t-Test

Given two paired sets X_i (soundings after injecting resin) and Y_i (soundings before injecting) of n measured values, the paired t-Test determines whether they differ from each other in a significant way under the assumptions that the paired differences are independent and identically normally distributed.
A hypothesis h_0 is stated to answer the question "Is the observed difference sufficiently large to indicate that the alternative hypothesis h_1 is true?

Hypothesis;

h_0: there is no significant difference between the mean value of the two sounding dataset from before and after the injection.

Alternative hypothesis;

h_1: there is a significant difference between the mean value of the two sounding dataset from before and after the injection.

For the hypothesis to be true either for h_0 or h_1 with an accuracy of 95% a certain statistical t is introduced.
The outcome of the paired t-Test has to be in the range of $-2.120 < t > 2.120$ for h_0 to be true otherwise h_1 is true.

To apply the test, let

$$\hat{X}_i = (X_i - \bar{Y}_i)$$
$$\hat{Y}_i = (Y_i - \bar{X}_I)$$

Then define t by

$$t = (\bar{X} - \bar{Y}) \sqrt{\frac{n(n-1)}{\sum_{i-1}^{n} (\hat{X}_i - \hat{Y}_i)^2}}$$

This statistic has n-1 degrees of freedom

	part	t from t-Test
Long term test-facility	1.1	-0.80
	1.2	-1.91
	1.3	2.87
	1.4	-1.40
Short term test-facility	3.2	-0.34
	3.3	-0.83
	3.4	1.77

Table 6.1 Outcome of paired t-Test for short and long term test-facilities.

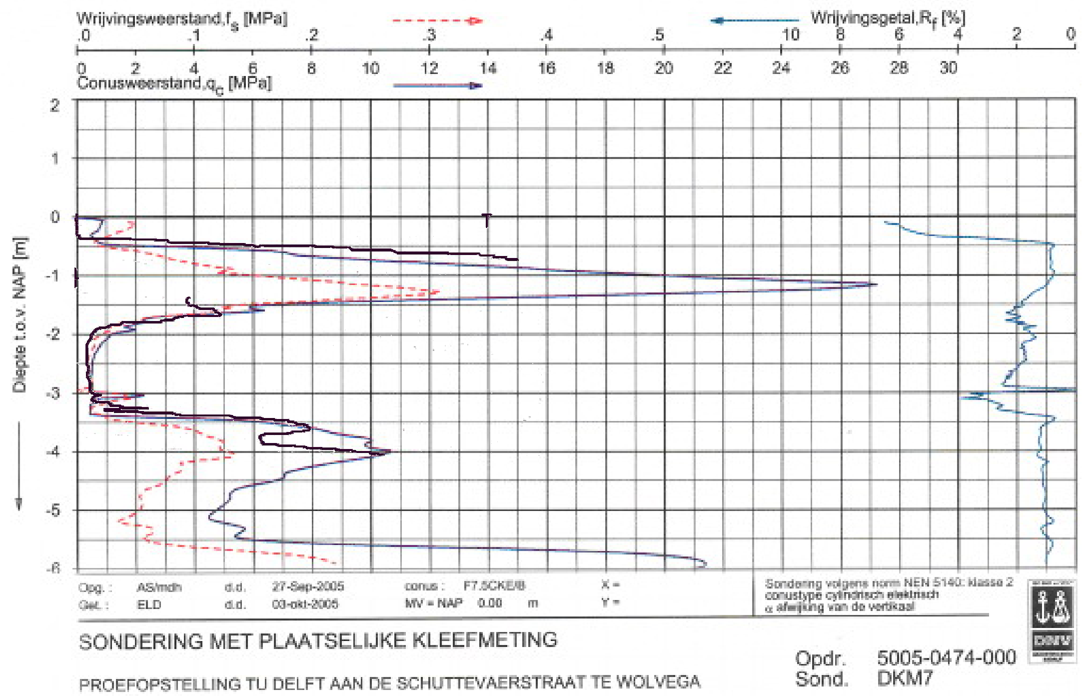
Only one value of t is outside the range, the other t-Tests all have a chance of 95% that the strength of the soil layer hasn't changed significantly. This can be caused by:

1. A large standard deviation of the datasets, indicating heterogeneous soil, inconsistent measurements or injection procedure.
2. When the standard deviation is small indicating that the measurements and injection procedure are correctly applied the inability to improve the blow-count by injection.

The reason for the soil strength to not have changed significantly is probably caused by the large standard deviations, resulting from the heterogeneous soil. The conclusion from the analysis is that the soil strength has not increased or decreased in strength.

6.2 Cone penetration tests

To be able to compare the soil strength before and after the resin injections cone penetration tests have been made in the soil. The cone penetration tests before are executed by Fugro; the tests after by a hand operated sounding device which could be placed close to the test-facilities. Due to the high cone resistance (+14 MPa) of the layer at +/- 1 m below grade the hand sounding device was unable to penetrate this layer. To be able to proceed with a sounding a hole was made by driving a pipe through this soil layer and continuing from there; hence the gap in the graphs. The cone penetration tests graph made with the hand sounding device after the resin injections are plotted into the closest Fugro soundings (appendix E, location soundings) made before the resin injections, see graph 6.2.



Legend:

In the left half of the graph;

- The darkest black line is the cone resistance (q_c) after the resin injections.
- The lightest black line is the cone resistance (q_c) before the resin injections.
- The red line is the friction resistance (f_s) before the resin injections.

In the right half of the graph the blue line is the friction number (R_f) before the resin injections

The y-axis is the depth below NAP (normal Amsterdam level, the Dutch reference level) in meters

Graph 6.2 Cone penetration test before and after injection of Long term test-facility part 1.2

Graph 6.2 is explained in detail all of the compared soundings are in appendix N.

From top to bottom in the graph;

0 to NAP -0.5 m;	loosely packed top layer.
NAP -0.5 m to NAP -1.75 m;	sand layer with very high strength. Peak cone resistance could not be measured with the hand operated sounding device.
NAP -1.75 m to NAP -3.5 m;	loam or silty sand. No increase in soil strength.
NAP -3.5 m to NAP – 6 m;	sand layer.

The cone resistance of the weak soil layers is the same before and after the resin injections. No increase of strength has been found by injecting the resin. This holds for all seven compared cone penetration test, see appendix N, Cone penetration tests.

7. Propagation of the resin in the soil

Paragraph 7.1 analyses the excavated cross-sections. In paragraph 7.2 the found propagation in the soil of the injected resin is discussed.

7.1 Analysis of the excavated short term test-facility

7.1.1 Analysis of five excavated cross sections

To discover the propagation of the expanded resin beneath a foundation the short term test-facility has been excavated. Five cross-sections from grade to -3.5 m below ground level have been made, see figure 7.1 below for the locations.

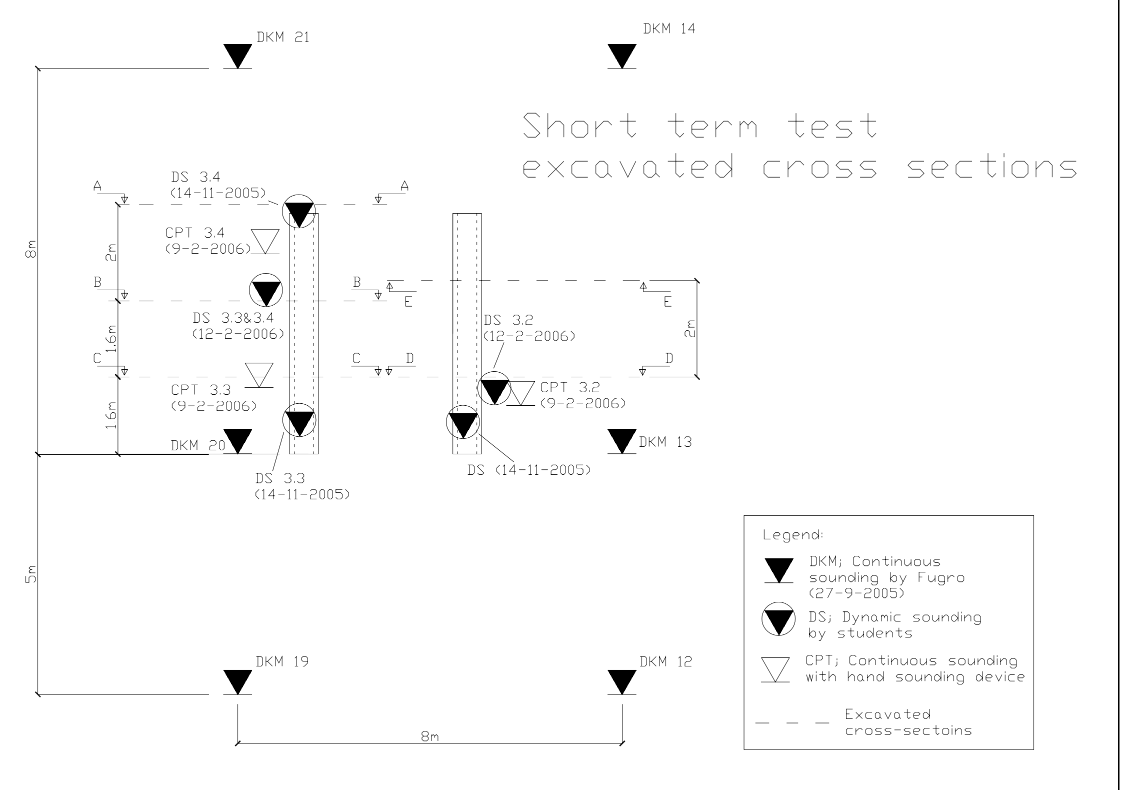


Figure 7.1 Cross-sections excavated of the short term test-facility.

The five excavated cross-sections of the short term test-facility are:

- A-A: Approach of the resin from the front of the concrete strip
- B-B: Excavated cross-section of the two times injected soil (part 3.4). The latter being the pulled injection (see appendix K, figure K.5; Injections short term test-facility part 3.3-3.4, 2nd injection).
- C-C Excavated cross-section of the two times injected soil (part 3.3). The latter being a dense pattern of injections points (See appendix K, figure K.5).
- D-D Excavated cross-section of once injected soil part 3.2.
- E-E Excavated cross-section of once injected soil part 3.1.

	
Figure 7.2a. Part 3.4, cross-section A-A. Excavation approaching the injected resin from one side to a depth of 2.7 m below grade. Soil layering; Brown sand to -1.1m below grade. Followed by a dark brown “oer” layer of 5-10cm consisting of gravel and sand. From -1.2 m to -2.7 m below grade a silty-sand (loam). Three horizontal resin discs at -0.6 m, -1.2 m and –1.7 m below ground level. The horizontal at -1.2 m is located directly under the hard “oer” layer. These horizontal discs are crossed by vertical resin discs which are directly under the location where the strip foundation used to be.	Figure 7.2b. Part 3.4, cross- section A-A Close up of the left part next to the measurer of the resin. (-0.6 m to -1.7 m below grade)

Figure 7.3a. Part 3.4, Cross-section B-B, under strip foundation -0.6 m to -3.4 m below grade; drawn injection.

Figure 7.3b. Close up cross-section B-B, -0.9 m to -2.5 m below ground level. Resin discs generally in horizontal and vertical direction sometimes consisting of stacked discs from the first and second injection, see cut out.

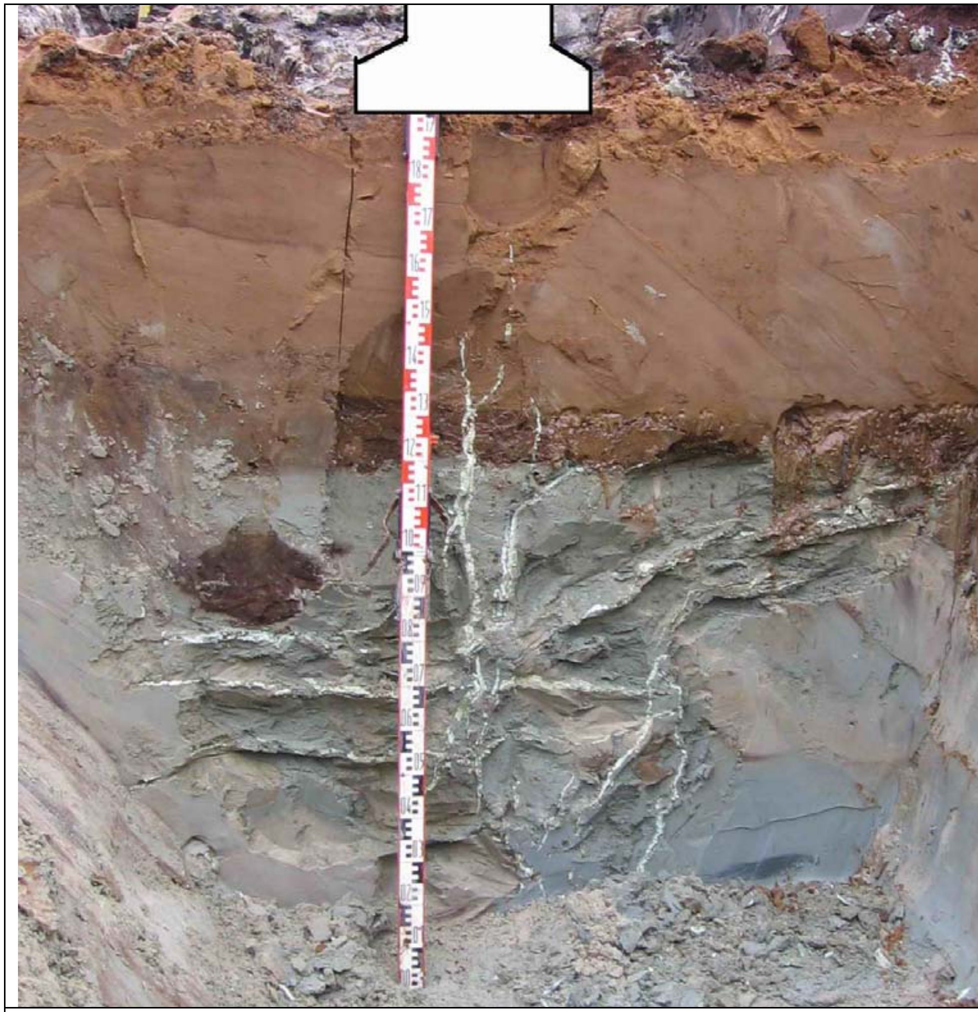


Figure 7.4a. Part 3.3, Cross-section C-C, under strip foundation -0.6 m to -2.5 m below grade; matrix injection. Multiple resin discs next and on top of each other both in vertical and horizontal direction. Note how the resin goes around the sand pocket in the loam on the right side of the picture.

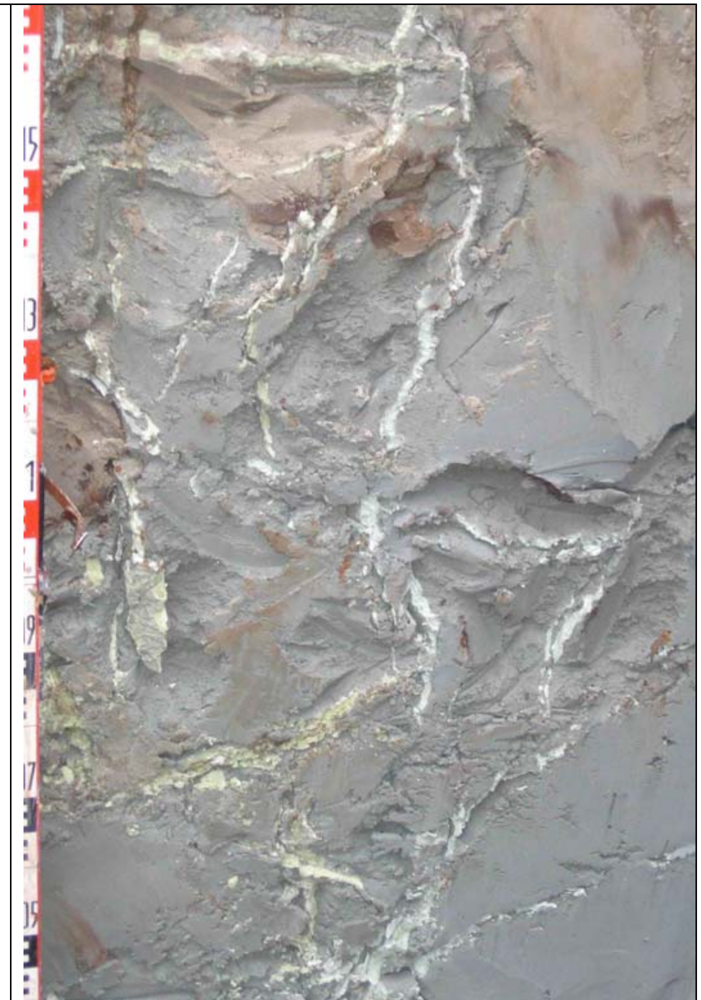


Figure 7.4b. Cross-section C-C, -1.6 m to -3.3 m below grade. Erratic forms of the resin discs.

Figure 7.5. Part 3.2, Cross-section D-D, -0.6 m to -2.8 m below grade. Two horizontal and a vertical resin discs. This strip is injected under once.

Figure 7.6a. Part 3.1 cross-section E-E, -0.7 m to -2 m below grade. Horizontal resin disc at -1.6 m grade

Figure 7.6b Cross-section E-E, -1.5 m to -2.6 m below grade.

7.1.2 Differences between the injection methods

Cross-sections D-D and E-E
These cross-sections are made beneath the short term facility which has been injected under once (see appendix K figure K.3; Injections short term test-facility part 3.1-3.2). The different injection levels with spacing of a meter between the injection points per level produces little interference of the individual injections with each other. The propagation of the resin along already hardened resin is not found, this in comparison with the cross sections were a second injection round has been done.

Cross-section B-B
This is the cross-section of the two times injected soil (part 3.4). The latter being the pulled injection (see appendix K figure K.5; Injections short term test-facility part 3.3-3.4, 2nd injection). The resin of the second injection has created new fractures but also a lot of propagation along the first injections discs and even along discs created during the second injection. Up to five discs next to each other have been found.

Cross-section C-C
Excavated cross-section of the two times injected soil (part 3.3). The latter being a dense pattern of injections points (see appendix K figure K.5; Injections short term test-facility part 3.3-3.4, 2nd injection). The same propagation as in cross-section B-B is seen, new discs of resin and multiple discs on top of each other.
The only difference is in the way the resin has been injected. The pulled injections require only one drilling hole and one injection pipe to treat a complete soil column. This saves time in comparison to the dense injection pattern where for every injection point a new hole has to be drilled. The pulled injection seems to be an efficient way to inject, it has to be noted that the soil has been injected in prior to the pulled injection. The propagation of the injection is therefore influenced; to be sure the propagation is correct a test on an untreated soil could be done.

7.1.3 Propagation of the resin

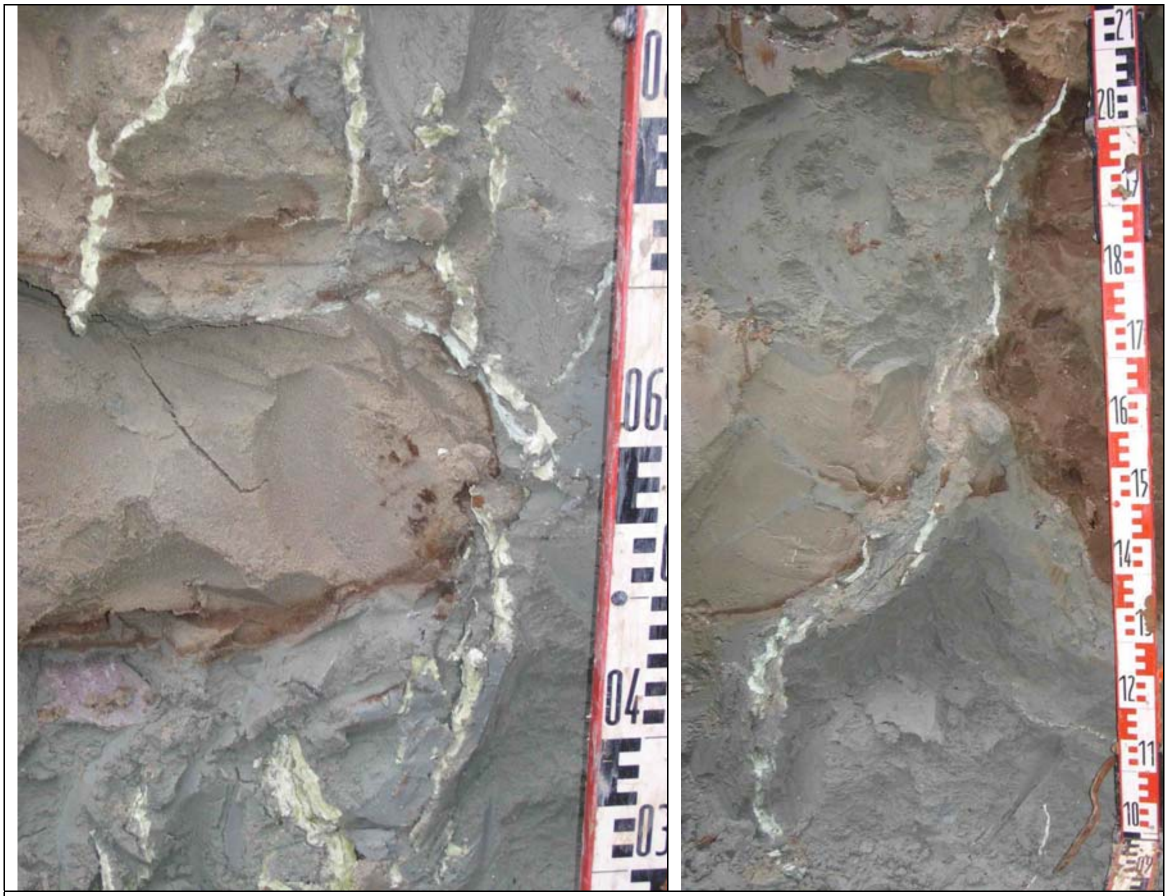


Figure 7.7. The resin takes the way of the least resistance; along the borders of two different soil types in the weakest soil.

7.1.3 Horizontal spread of the injected resin in the soil

Figure 7.8. The horizontal resin discs have a maximum width of about 2.5 to 3 meters. The injection point being near the middle of the disc.

7.1.4 Resin expansion perpendicular to the fractures in the soil

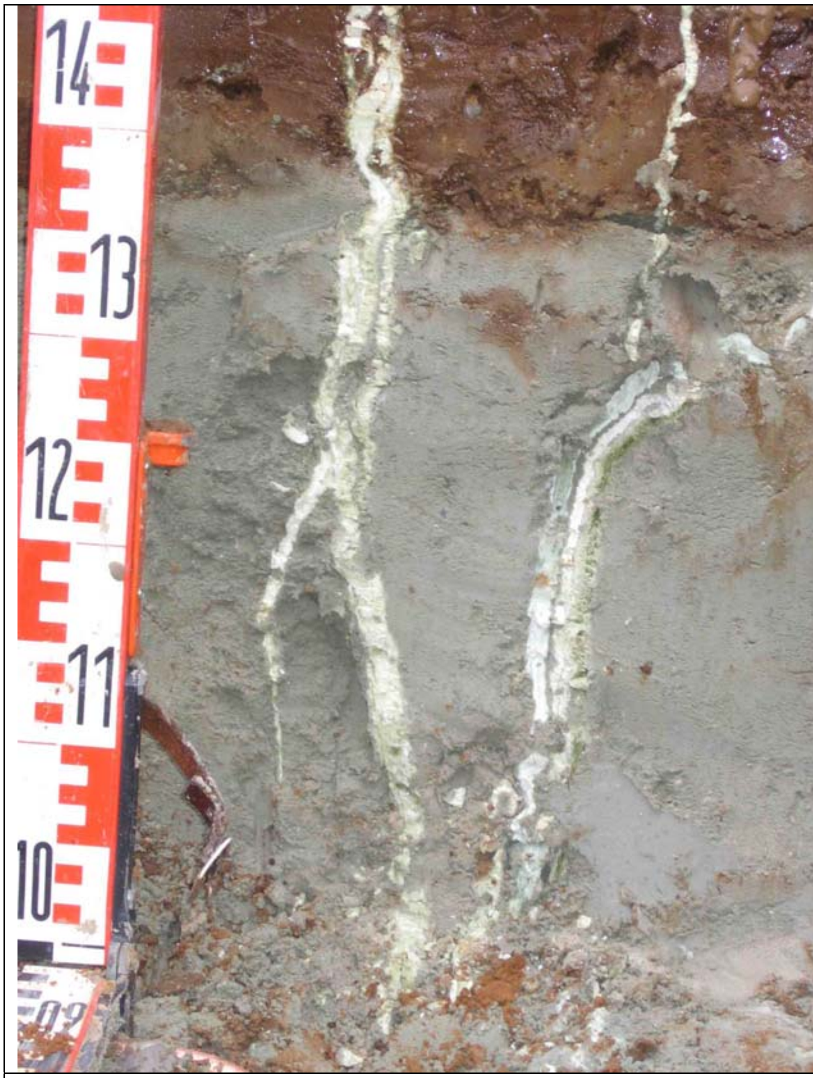


Figure 7.9. The created resin has a thickness of +/- 1 cm. per disc in both horizontal and vertical direction. On the right two discs have formed along the first injection, the most right disc of the three. Identifiable by the light bleu color of the resin.

The reason for the resin discs to be only 1 cm thick is probably the fact that all the injections have been done under groundwater level. The width of the created fractures is small. The resin entering the fracture loses its reaction heat rapidly to the water, because of the relative big surface in comparison to the mass of the resin. The expansion of the resin is hereby reduced. More expansion creates more lift but reduces the specific weight of the expanded resin, maybe inducing more creep of the resin.
A bigger injection cavity gives room for the resin in which the heat can increase but the expansion will probable be directed upward along the drilled hole itself and not so much in creating a horizontal disc which creates lift. Drilling a bigger hole also affects the ground in a negative way. The hole will reduce the effective stresses in the surrounding soil, the bigger the hole the greater the effect. Compensating this stress relief is difficult and takes time.

7.2 Schematization of propagation of the resin in the soil

The resin will take the route of the least resistance. When the injection is started, this will cause the resin initially to expand mostly in horizontal direction. The reason for this is that the horizontal stresses are 0.5-0.8 of the vertical stresses in normally consolidated soils. This can be explained by the distribution of the vertical force on soil grains. See left figure 7.10a below.

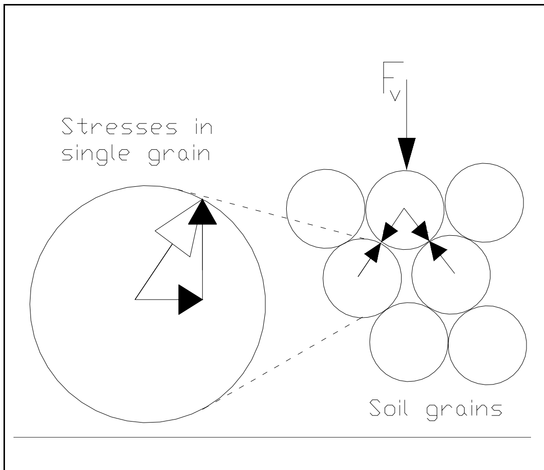


Figure 7.10a Stress distribution in soil

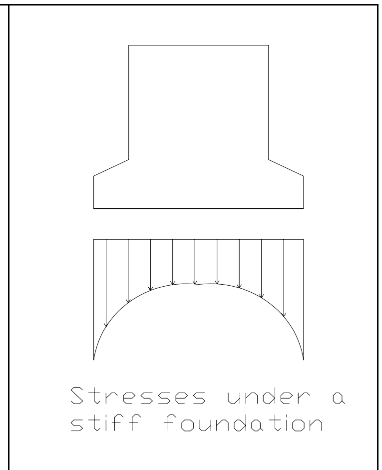


Figure 7.10b

The horizontal expansion of the resin will create a vertical fracture in the soil; the soil is pushed to the side. The fracture is filled by the resin creating a vertical disc. The load distribution beneath a stiff foundation has the form as shown in the picture 7.10b above. The form of the distribution causes the plain to stay beneath the foundation along its length. This means there are no perpendicular vertical discs to the foundation strip.

After the horizontal stresses have become equal or greater to the vertical stresses a horizontal plain is created at the end of the injection pipe. The horizontal plain produces the lift which raises the foundation. See the stages in figure 7.11 below.

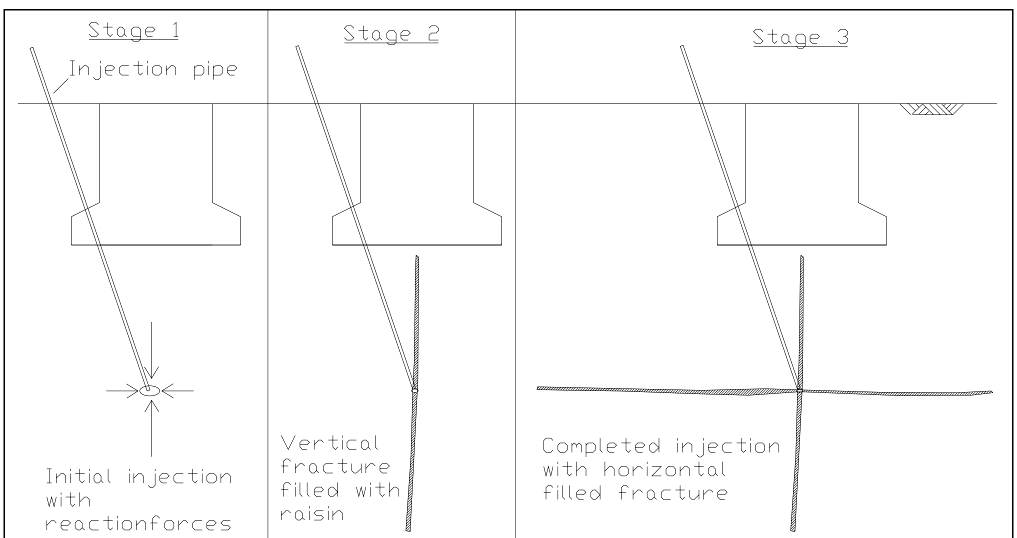


Figure 7.11. Stages in the propagation of the resin in the soil.

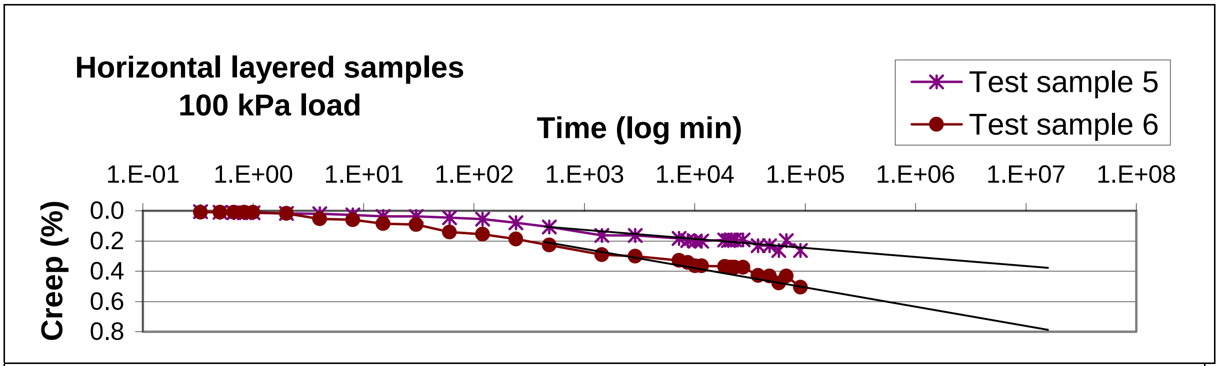
8. Testing of excavated resin

To be able to analyze the expanded resin retrieved from the excavated short term test location three kinds of laboratory tests have been performed. An oedometer or creep test, a shear test and an unconfined compressive strength test.
The height of the test samples needed for the tests had to be higher than the thickness of the resin discs, created during the fracturing of the soil and the expansion of the resin. The thickness of these discs is about 10 mm. To get the desired height, the samples were taken from larger pieces of excavated resin, consisting of multiple resin discs created when successive injections propagated along each other. The consequence of this is that the samples are layered and contain small enclosures of soil. When testing in situ materials this is not a problem, the objective is to analyze the properties of the whole sample.
In paragraph 8.1 the results from a creep test are presented. Paragraph 8.2 the specific weight of the excavated resin is determined.

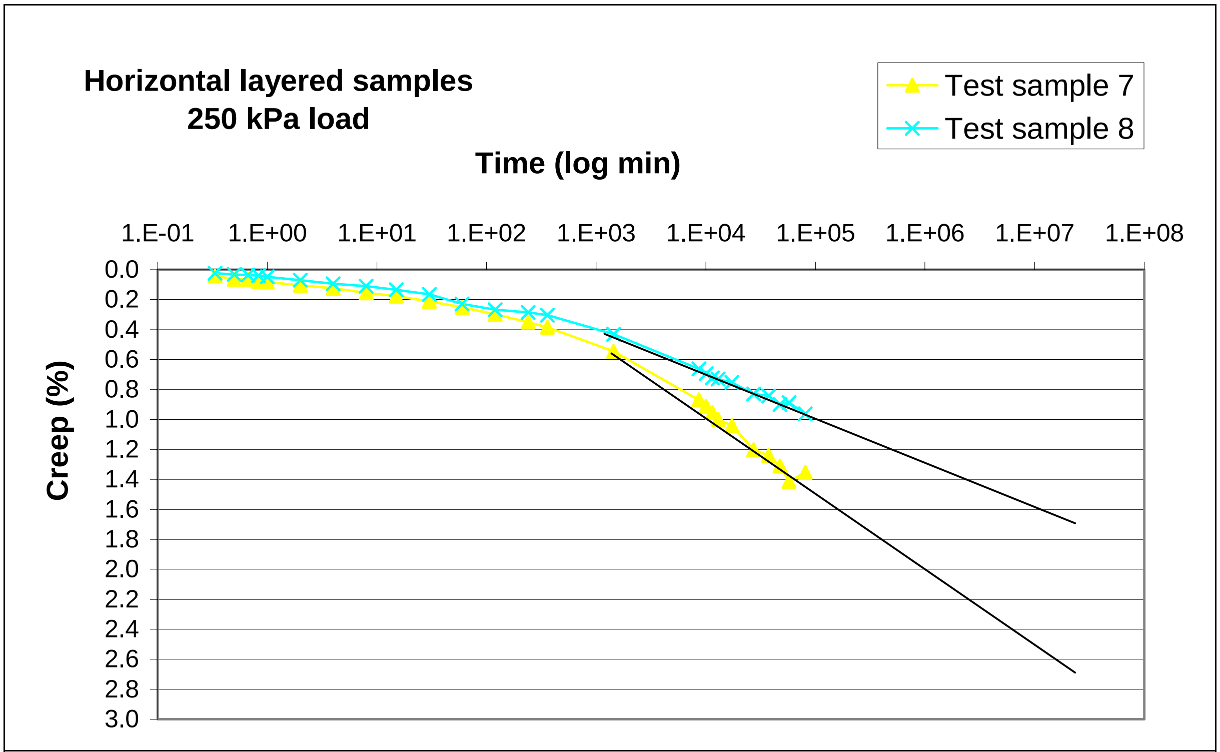
8.1 Creep test on excavated resin

The oedometer test will show the magnitude of the creep of the expanded resin. The creep has to be small otherwise the effect of injecting the resin, lifting a building, will be undone.
Eleven resin samples have been subjected to an oedometer test. The loads are 100, 250 and 500 kPa. The range from 50-100 kPa is about the equivalent to a one story building, a two story building is 150-200 kPa and so on.
The start dimensions and load on each resin sample are given in table 8.1. A distinction has been made between the loading directions on the layers of the samples. Seven samples have layers which are horizontally loaded. Four samples have been placed with the layers (vertical) in the direction of the load. The idea is that the stiffer layers will take the greater part of the load reducing the creep in comparison to the horizontally loaded layers. These layers all have to take the same load, there is no redistribution of the load possible.
No water was added, which is normal for an oedometer test, to the test setup. The reason for this is that the penetration of the water in the samples will be minimal. The resin seemed to be dry when a just excavated disc from the short term test-facility was broken in two pieces. This resin had been in the ground for three months.
The measurements from the first three months, up to July 2006, are presented in graphs 8.1-8.5. The graphs represent the creep in mm divided by the original height of the sample. The surfaces of the samples have been scaled to a surface of 1963 mm^2 (circle with a diameter of 50 mm) to be able to compare them more accurately. For estimating the creep in the lifespan of a building a logarithmic trendline up to 50 years is added.
The first measurements, till 10 seconds after applying the load, have been left out. The measurement after 10 seconds contains errors caused by small imperfections to the samples which can hold the small weight put on before the test starts but are compressed in the first seconds after applying the weight. It is normal practice to remove these first measurements from the test. The graphs including the first measurements are reported in appendix O.

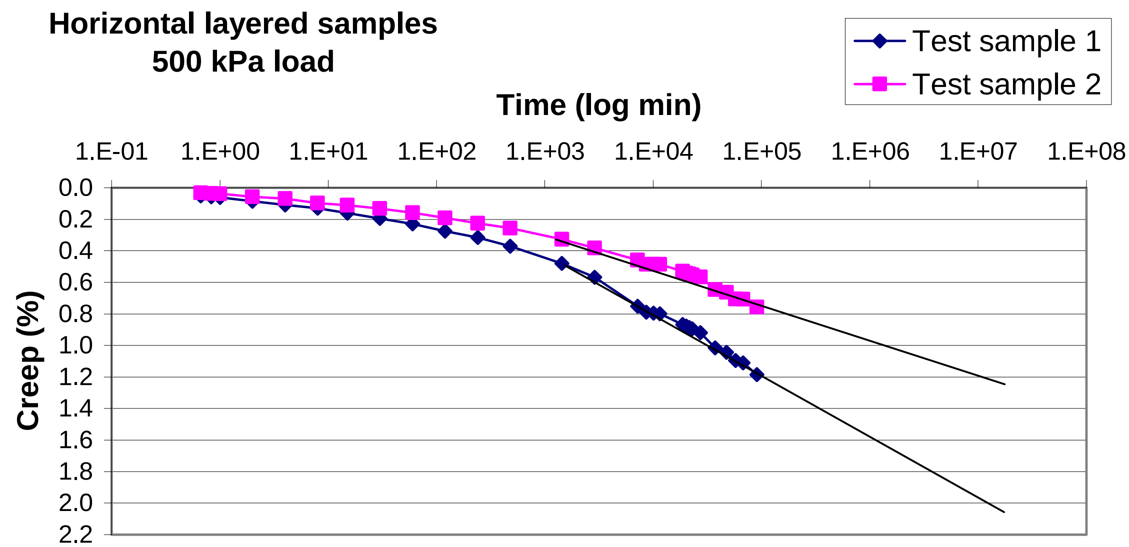
Horizontally layered test samples;



Graph 8.1 Creep horizontal layered samples load 100 kPa and trendline till 50 years.



Graph 8.2 Creep horizontal layered samples load 250 kPa and trendline till 50 years.



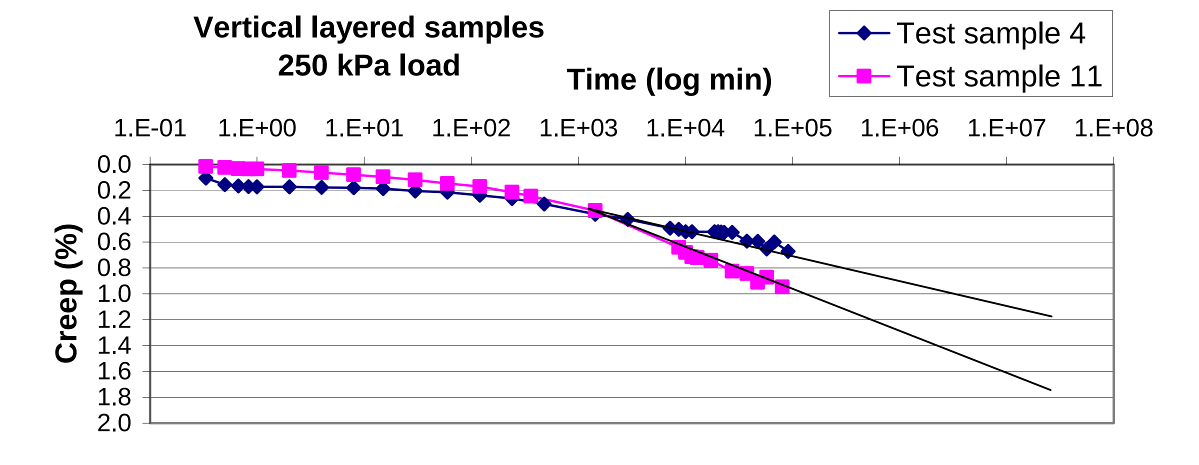
Graph 8.3 Creep horizontal layered samples load 500 kPa and trendline till 50 years.

The higher the load the more creep is expected of the samples. This is true for the tests with a 100 kPa load in comparison to the others. It does however not hold for the higher loaded test samples. As can be seen from the graphs the 250 kPa loaded test samples have the same creep range as the 500 kPa loaded samples. The explanation for this is related to the test samples, the 500 kPa loaded samples probably have less imperfections and/or the resin is stiffer than the 250 kPa loaded samples. Test sample 2 with the least creep has the highest specific weight (241 kg/m^3), see table 8.1. The other samples have all about the same specific weight (+/- 190 kg/m^3). A higher specific weight for these samples taken from excavated resin can mean three things;

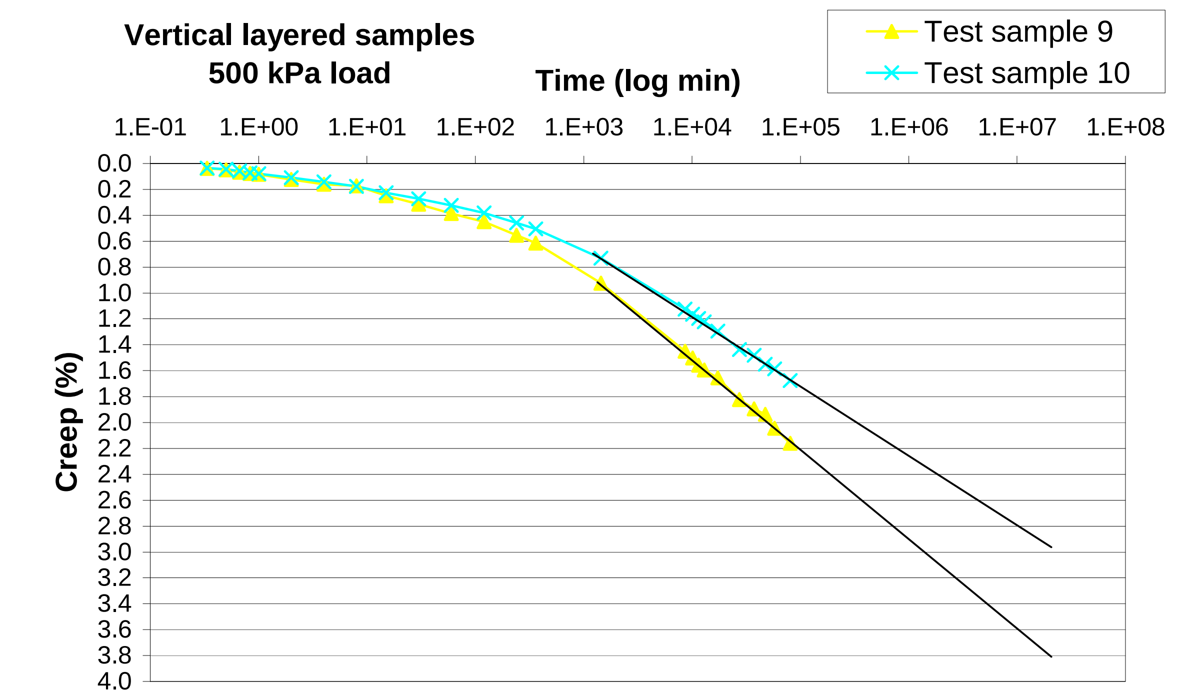
1. Stiffer material; the resin is denser; in other words it has had less expansion.
2. The soil enclosures are bigger increasing the weight, because the specific weight of sand is higher than the resins. This will not increase the stiffness and thereby reduce the creep.
3. A combination of 1 and 2.

Test sample 2 has probably a denser resin, hence the low creep percentage. An explanation why the other 3 samples have the same creep is not so obvious. An estimated creep of less than 1% for a load of 100 kPa and less than 3% with loads of 250 and 500 kPa after 50 years is however still a very low percentage.

Vertically layered test samples;



Graph 8.4 Creep vertical layered samples load 250 kPa and trendline till 50 years.



Graph 8.5 Creep vertical layered samples load 500 kPa and trendline till 50 years.

Looking only at the graphs with the vertical layered samples a higher load gives a higher creep, in accordance with expectations. Doubling the load seems to double the estimated creep from 1.8 to 3.8% after 50 years. The specific weights of the 500 kPa loaded test samples are lower than those of the 250 kPa loaded samples; this will influence the results and should be reckoned with.

Comparing the horizontally and vertically layered test samples it is not possible to conclude the direction of the load makes a difference. The 250 kPa loaded samples confirm the redistribution theory and the 500 kPa samples deny it.

Conclusions

More and longer tests on samples have to be done, if necessary, to be able to analyze the results statistically and obtain more definite creep percentages. What can be concluded is that the creep is very small less than 2.5 % after 3 months and less than 4% after 50 years. In practice this means very little settlement due to creep of the resin. For example; 5 centimeters of resin layers in the height of a cross section will give about 2 mm of creep after 50 years with a 3 story building on top as load.

Test sample	Diameter (mm)	Height (mm)	Surface (mm^2)	Normal load (kPa)	Weight (gram)	specific weight (kg/m^3)	Direction of layers
1	49.70	31.70	1940	506	11.95	194	Horizontal
2	49.55	31.50	1928	509	14.65	241	Horizontal
3	50.06	30.30	1968	249	13.69	230	Vertical
4	50.19	28.70	1978	248	12.39	218	Horizontal
5	50.13	21.85	1974	99	7.27	169	Horizontal
6	49.80	23.32	1948	101	10.69	235	Horizontal
7	49.60	25.75	1932	254	9.34	188	Horizontal
8	49.60	25.65	1932	254	9.40	190	Horizontal
9	49.50	25.40	1924	510	8.83	181	Vertical
10	49.60	25.75	1932	508	8.71	175	Vertical
11	49.70	25.50	1940	253	9.37	189	Vertical

Table 8.1 Dimensions test samples.

8.2 Specific weight of injected resin

The specific weight of the samples is in the range of 170-240 kg/m^3. The samples can have enclosures of sand which will increase the specific weight. The specific weight of sand particles is 2650 kg/m^3 (note this is sand without pores). The measured weight is therefore an indication of the specific weight and not an exact figure. The average specific weight of the 11 samples is 200 kg/m^3.

9. Efficiency of resin injections

In this chapter it will be tried to establish the lift efficiency of the resin in the soil at the test site with the Uretek deep injection method. To determine the lift efficiency the amounts injected resin under a strip foundation and the surrounding soil will be taken into account. The drawing below is a schematization of the lifted strip foundation and ground which will be used as a reference for the estimation.

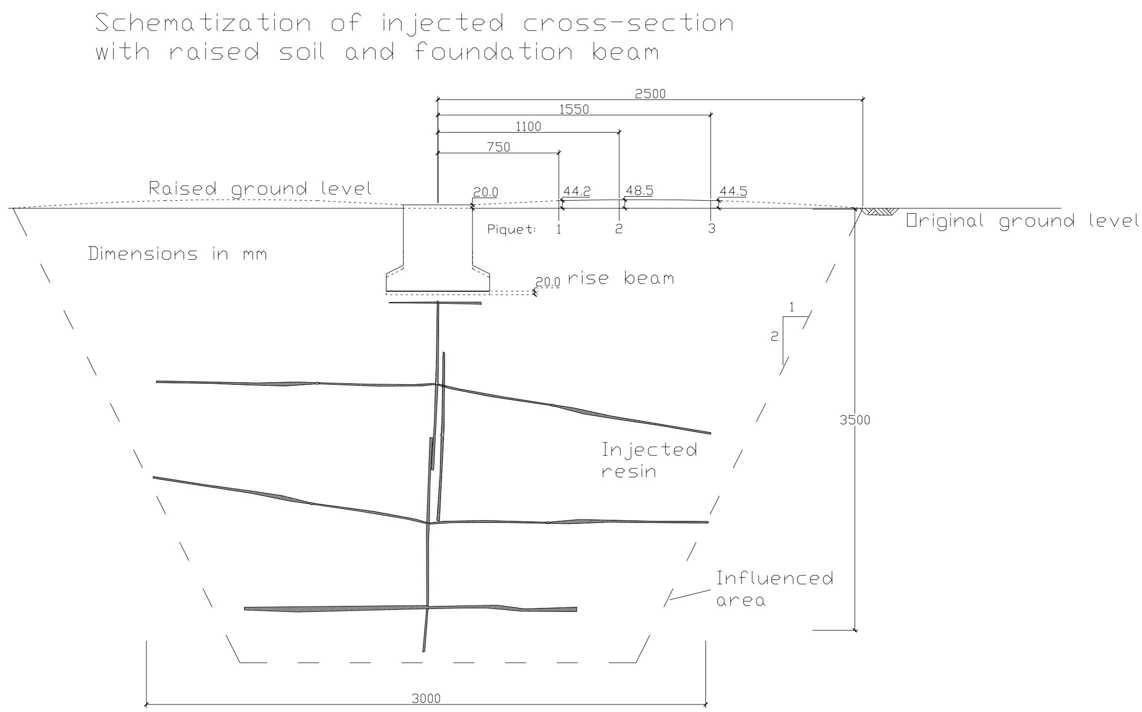


Figure 9.1. Schematization of a resin injected cross-section under a foundation beam.

The average amount of lift of the strip foundation from the second resin injections is 20 mm (graph I.6 appendix I). The lift of the soil is measured with piquets (see appendix J, figure J.2) and is assumed to be the same on both sides of the beam. The injected resin is a representation of the real structure which was excavated. Three to four horizontal layers and a few vertical layers close together under the foundation beam.

Calculation average volume of resin injected per meter length of the beam

The amount of resin injected lifting the beam over a vertical distance of an average of 20 mm is 326 kg (see appendix K, figure and table K.5 Injections short term test-facility part 3.3-3.4, 2nd injection). The length of the beam is 5 meters, assuming a propagation of the resin 1 meter on both sides of the foundation beam; the total length is 7 meter. Resulting in an injected weight of about 45 kg/m length of the beam. To calculate the volume the resin has expanded to in the soil the specific weight of the expanded resin has to be used. The 11 samples used for the creep test made from excavated resin have an average specific weight of 200 kg/m^3, see table 8.1. This gives an expanded volume of about 0.23 m^3/m length of the beam.

Created lift of foundation beam and soil

To calculate the surface lifted in a cross section the lift of the soil has been schematized see figure 9.2.

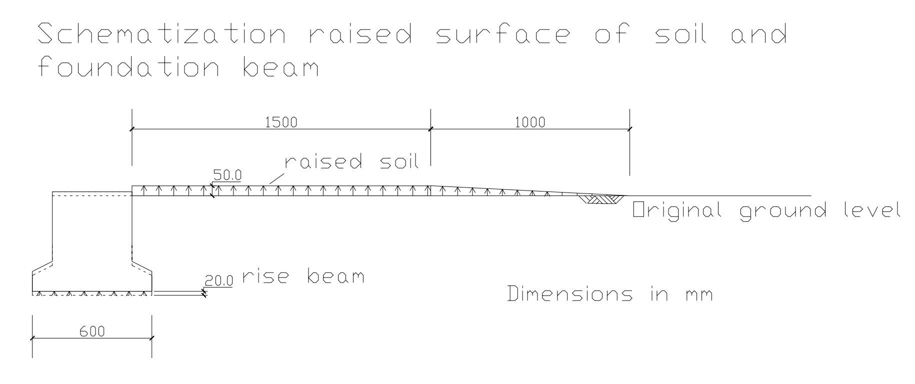


Figure 9.2. Schematization of half a cross-section of lifted soil and the foundation beam

Surface raised under the foundation beam;
Width beam: 0.6 m
Average lift: 0.02 m
Surface lift: 0.012 m^3/m length of the beam

Surface raised soil;
Rectangle: 1*1.5 m*0.05 m = 0.075 m^3/m
Triangle: 1*½*1.0 m*0.05 = 0.025 m^3/m
Total lifted soil surface: 2 sides*0.1 = 0.2 m^3/m length of the beam

Total calculated lift: 0.212 m^3/m length of the beam

With the injected resin volume before and after expansion and the volume of lift of the soil and foundation beam the efficiency of the injection method is estimated.

Efficiency lifting foundation beam	volume lift beam/injected resin volume	$\frac{0.012}{0.045} * 100\% \approx 27\%$
Efficiency lifting foundation beam	Lift volume beam/ expanded resin volume	$\frac{0.012}{0.23} * 100\% \approx 5\%$
Efficiency expansion	volume lift/injected resin volume	$\frac{0.212}{0.045} * 100\% \approx 470\%$
Efficiency total lift	volume lift/expanded resin volume	$\frac{0.212}{0.23} * 100\% \approx 100\%$

Table 9.1 Efficiency of resin

10. Conclusions

10. Conclusions

By order of the companies Uretek Netherlands and Resina Chemie a full scale test has been performed to investigate the effects of the Uretek Deep Injection Method (UDI) on soil characteristics. The UDI-method is based on injecting an expansive resin under settled or tilted buildings to lift the buildings back to desired levels.
The full-scale test consisted of performing measurements on three test-facilities:

1 A facility that has been lifted with the UDI-method and will be used to measure long term settlements (2-3 years) after the resin injections have taken place.
2 A facility that has been lifted with the UDI-method and of which the injected soil has been excavated after performing the injections in order to observe the propagation of the injected resin in the soil.
3 A facility that provides a reference for the other two; this foundation has been built and loaded in the same way as the other two foundations but has not been treated with the UDI-method.

The three identical facilities are made from two concrete foundation strips which are loaded in two steps of about 50 kPa each. The first load is the combination of the weight of the structure itself increased with the weight by placing filled sand bags. The second load, consisting of only sand bags, was applied after the two facilities had been lifted by the UDI-method.

The first objective.
The first objective was to investigate the effects of the injected resin on the stiffness and strength properties of the soil. The following can be concluded with respect to these aspects.

Stiffness of the silty soil

Stiffness itself is not directly measurable. By measuring the settlements after loading the test-facilities a qualitative conclusion with respect to the stiffness of the soil can be derived. After lifting the two facilities with about 15 mm with the UDI-method, the next day the second load step was put on the test-facilities. In retrospect it would have been better to wait half a month till the consolidation had taken place before putting on the second load. Distinction between the consolidation settlement created by both actions (second loading and injecting) would then have been possible.

The settlements of the three test-facilities were measured with a theodolite. After 38 days the settlement due to the loading of the two lifted test facilities and the reference facility was in the same order of about 2-3 mm. This indicates that during the observed period the stiffness of the three test-facilities changed equally. After 38 days the short term test-facility was injected for a second time. From then on only the settlement of the reference-test and the long term test-facility are compared. The settlement after 219 days is about 5 mm and still the same for both remaining facilities. What we can conclude from that is that no extra soil stiffness has been created, nor a reduction.

The reason for the stiffness not differing between injected and un-injected soil is explained below.
The energy created by the resin expansion has two effects:

1. Vertical and horizontal fracturing of the soil and filling the fractures with the expanding resin (see figure 10.1 below). The vertical fractures displace the soil in a horizontal

direction, creating heave and densification of the soil. For soft soils and during undrained loading conditions the proportion heave and densification are estimated to be equal. With realized vertical fractures with a width of 20 mm, an estimated influenced with of 2 meters on either side of the fractures and a pore volume of 40%, the densification (decrease in pore volume) can be estimated to be 1% (pore volume injected soil 39,5 %) That densification is negligible and un-measurable.
The horizontal fractures create lift and displace the soil and foundation in vertical direction. Lifting does not or to a small degree increase the density of a soil mass and hence not the stiffness.
The calculated lift of soil mass, including structure, is almost equal to the total calculated volume of expanded resin which was injected. This leads also to the conclusion that no significant densification occurs.

An effect induced by the lift of the soil is that a coned shaped cross section of the soil is lifted by the resin. See the surface enclosed by the dashed line of figure 10.1. As can be seen the body of sand influenced by the resin is wider than the horizontal propagation of the resin in the soil. During lifting the mass of the extra triangles, create extra vertical stress over the width of the resin expansions in the soil, resulting in some densification and increase in stiffness. The increase in stress however, is marginal compared to foundation pressure of 100 kPa which dominates the vertical stress in the profile. The resulting increase in stiffness will therefore be negligible.

2. Densification of the soil by compaction of the sand particle structure of the soil.

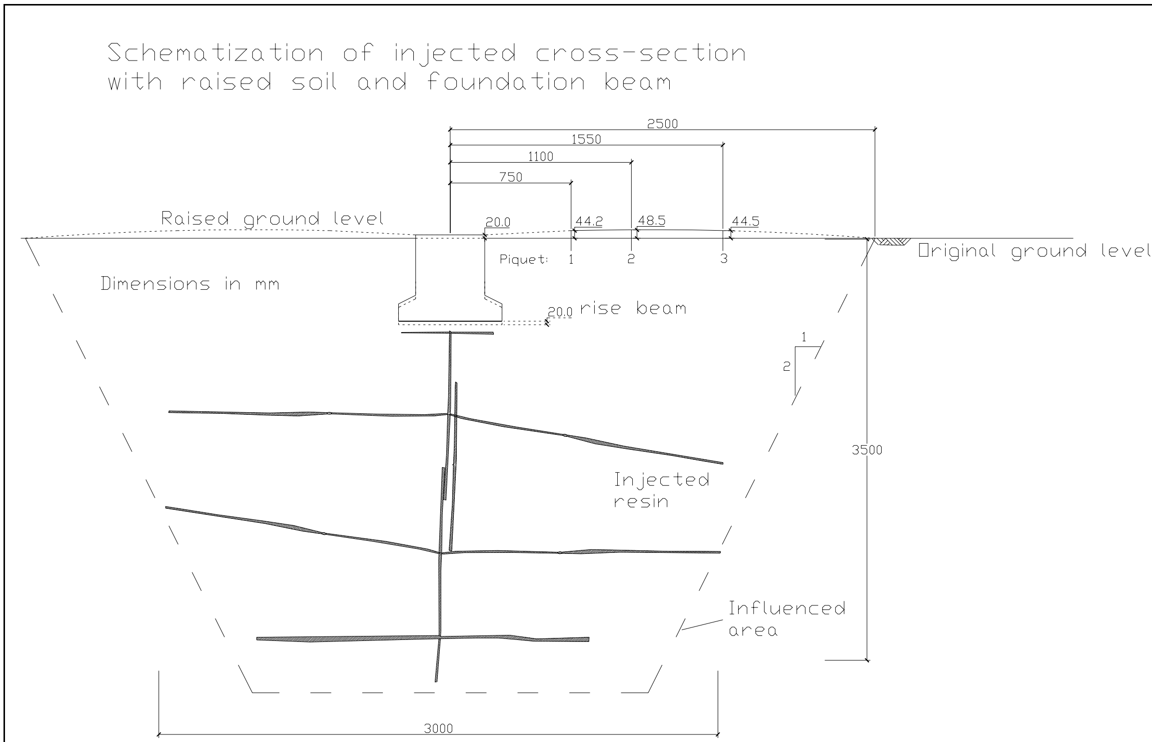


Figure 10.1. Schematization of a resin injected cross-section under a foundation beam.

Creating and filling the fractures consumes most of the expansive capacity of the resin. This fracturing mechanism will be present in both dry soils and in wet soils, meaning respectively above and below freatic level.
In dry soils further expansion of the resin produces more lift and may be some higher effective stresses resulting in some densification. Also none of the reaction heat of the resin is dispersed through water leaving more expansive capacity present.
When injecting below groundwater level in soils with a low permeability further expansion of the resin will create more lift and excess pore pressures. Therefore the increase in total stress and water stress will be almost the same, not resulting in an increase of the effective stress and compacting of the soil mass.
The conclusion that most expansion of the resin is transferred to lift is in accordance with chapter nine on the efficiency of the UDI-method.

Strength of the soil

An indication of the strength of the soil is obtained by dynamic tests and cone penetration tests, performed before and after the injections The focus of the injections was on the loam or silty-sand layer from 1.2 m to 3 m below grade. Therefore the analyses have been done for this relatively soft soil layer. Statistical analyses of the results of the dynamic sounding showed no significant increase or decrease of the blow-count. The continuous soundings showed the same results before and after injecting the resin in the soil under the short and long term test-facilities indicating, no change in the strength of the soft soil.

The second objective.
The second objective was to analyze the properties of the expanded resin in the soil.

From excavated soil cross-sections below the short term test-facility, the propagation of the expanded resin was analyzed. Samples retrieved from excavated resin have been analyzed and tested. The analyses have provided the following results.

Propagation of the resin in the soil
The resin follows the way of the least resistance in the soil, along the borders of two different soil types in the weakest soil. See figure 10.2.

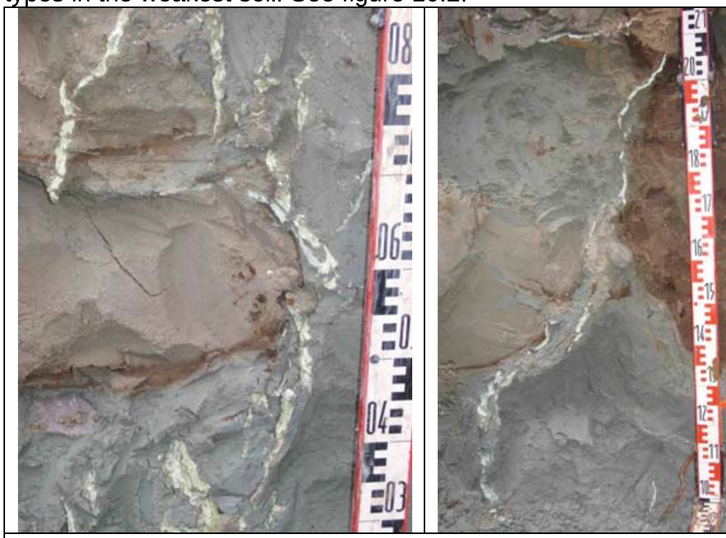


Figure 10.2 The resin takes the way of the least resistance

The soil reacts in three stages on the expansion of the resin (see figure 10.3);

1. Initially horizontal expansion of the resin due to smaller horizontal soil stress in comparison to vertical soil stress.
2. The horizontal expansion creates a vertical fracture which is filled by the expanding resin. The horizontal soil stress increases.
3. When the horizontal soil stress is equal or greater than the vertical soil stress a horizontal fracture is created. This fracture is filled by the expanding resin.

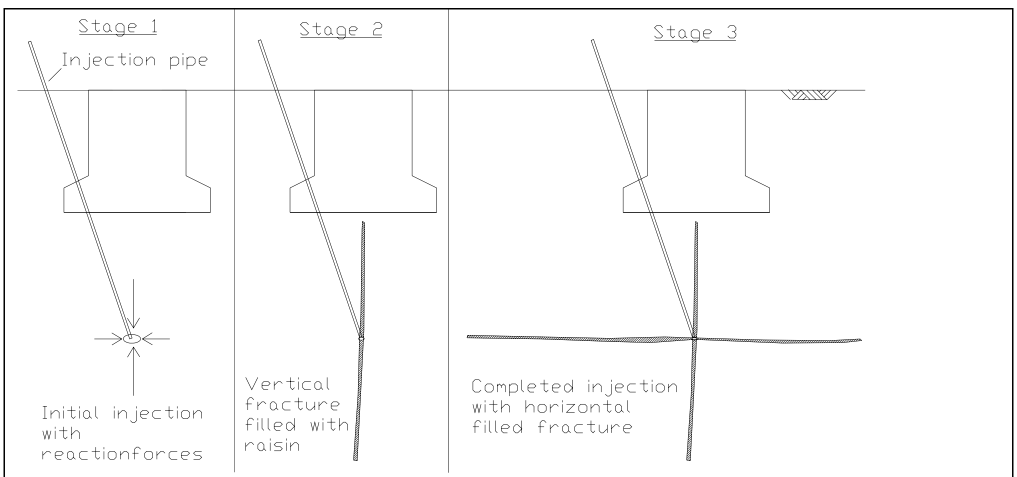


Figure 10.3 Stages in propagation of the resin in the soil.

These fractures or resin discs have a width of about 1 centimeter and a maximum length of 3 meters, with the centre at the location of the injection tube. Groundwater affects the expansion of the resin. Due to the large surface of the discs in comparison to the width of the fractures a lot of reaction heat is dispersed reducing the expansion ability. Increasing the expansion ability will increase the lift and reduces the amount of injection material needed. It will however also reduce the specific weight of the expanded resin and may be increasing creep of the resin, which is unwanted. Whether an optimum can be reached in groundwater could be investigated with a new test.

Specific weight of the expanded resin

The two components of the unmixed resin material have the same weight as water, about 1000 kg/m^3. From excavated resin, eleven samples have been measured and weighed, including enclosures of soil. The average specific weight was 200 kg/m^3 ±30 kg/m^3. From other tests it is known that the volume expansion is about 5 times the original volume.

Creep of excavated resin

The estimated creep of the excavated resin (200 kg/m^3) is less than 1% after 50 years when loaded with the weight of a normal house (100 kPa) and less than 4% when loaded with 500 kPa. The total creep of the resin layers (total thickness +/-5 cm) will be negligible in comparison to the creep of the soft soil layers when these are 1-2 meters.

Lift efficiency of the injected resin

Besides the stiffness and soil strength analysis a calculation of the lifting efficiency of the method was made. An average amount of resin of about 45 kg/m length of the foundation strip or a volume of 45 liters/m length of the foundation strip was injected. The created lift of the strip foundation has an average of 20 mm and a volume of 0.012 m^3/m length of the strip foundation. The efficiency of the lifted foundation volume divided by the injected resin volume is: $\frac{0.012}{0.045} * 100\% = 27\%$

When the injected volume of resin expands, the volume will be 0.23 m^3 with a specific weight of 200 kg/m^3. The efficiency of the lifted foundation volume divided by the expanded resin volume is:

$$\frac{0.012}{0.23} * 100\% = 5\%$$

This is comparable to the efficiency of compensation grouting. Most of the lift created by the expanding resin lifts the soil surrounding the foundation (see figure 10.4).

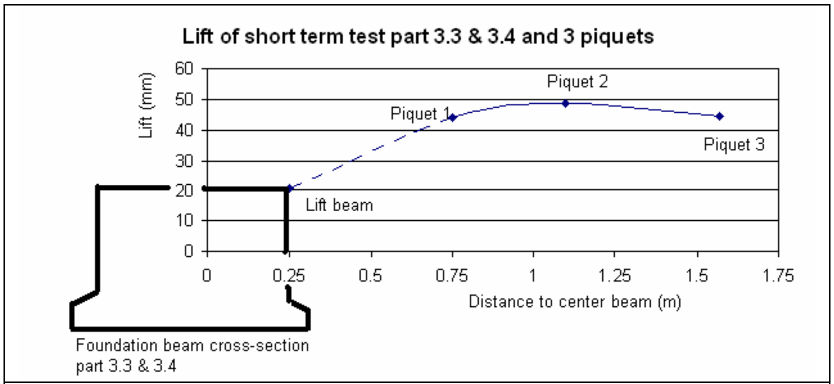


Figure 10.4 Lift of 3 piquets and short term test-facility part 3.3 & 3.4 on 16/12/2005

The foundation strip is lifted 20 mm the soil about 50 mm.

Two injection methods

Two different methods of injecting were used during the second injection of the short term test-facility;

- A dense pattern of injection points (see appendix K, figure K.5). The injection points were fixed during injecting.
- A drawn injection (see appendix K, figure K.5), pulling the injection tube while injecting.

During injecting with both methods, the same amount of resin has been injected. The drawn injection gives a rise of about 25 mm and an initial consolidation of +/-5 mm after four days. This results in a strain of 2.5‰ of the soft layer with a thickness of 2 meters. The dense injection pattern has raised the foundation 15 mm and produced an initial consolidation of +/-2.5 mm after 4 days. It seems the drawn injection produces greater lift but also gives a bigger initial settlement after injection.

The excavation of the soil injected by the different methods showed similar propagation of the resin, resulting in the conclusion: “no distinction between the injection methods is found with respect to the propagation of the resin”. To verify this conclusion a test on virgin soil can be performed. The results however are promising for drawn injections, reducing the amount of injection tubes needed and of holes to be drilled, which saves a lot of time in comparison to the other method.

11. Recommendations

Three recommendations for research are presented and one general one concerning execution of a full-scale test.

Research recommendations

1. When the creep measurements of the long term and reference test-facilities are finished, the test setups can be re-used to perform an investigation on resin injections in a clayey soil on another location. Establishing the lifting capabilities and to confirm the injected material stays near the foundation which is being lifted in such soils can be the objectives. The aim should not be to give a guarantee that no new settlements will occur after injecting. Such a guarantee can not be realized with the current method of injecting.

2. The method of drawn injections has potential. The method is work and time-saving, uses less injection tubes and seems to create more lift with the same amount of resin. The propagation of the resin in the soil seems to be the same as the top-down method used before. The findings concerning lift and propagation are established in already injected soil; to confirm these findings an investigation on virgin soil is recommended.

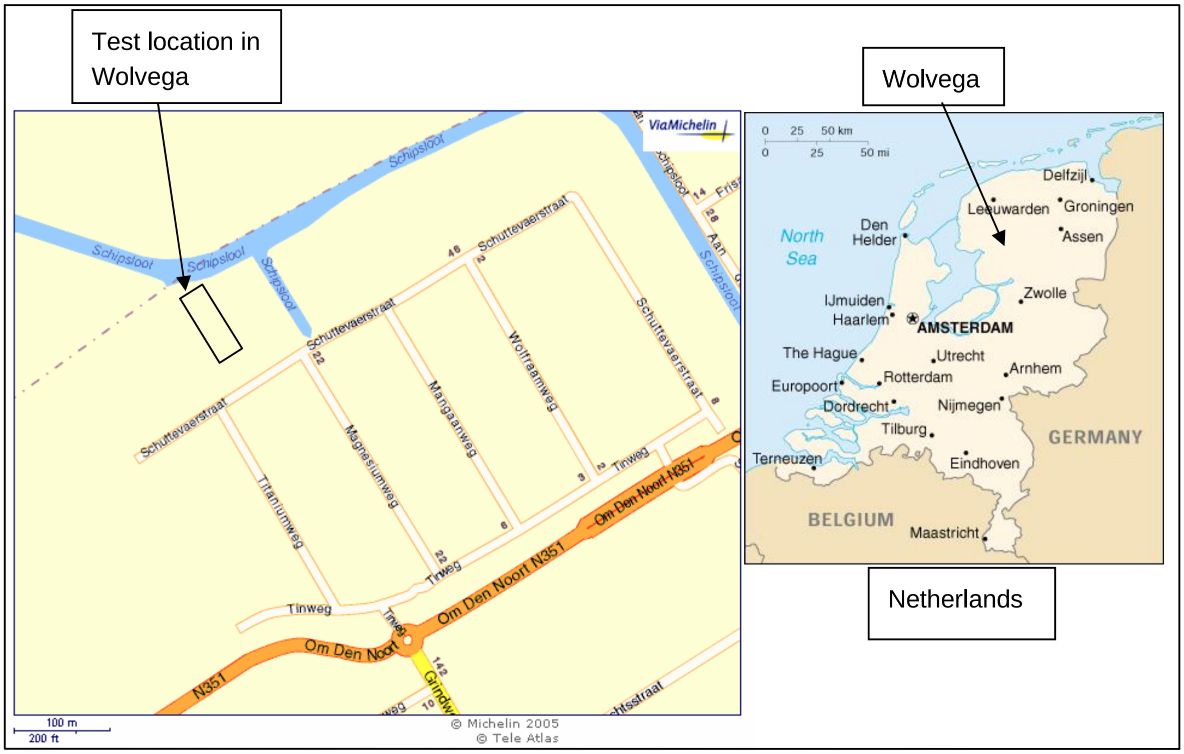
3. The effects of the groundwater on the expanding resin in the soil are unknown. Is the heat dispersion through the water of influence on the expansion of the resin? Will this increase the specific weight? Are these influences negative or positive?
Trying to create more expansion in spite of groundwater will increase the lift and reduce the amount of injection material needed. It will however also reduce the specific weight, 200 kg/m3, of the expanded resin, maybe inducing more creep of the resin which is unwanted. Whether an optimum can be reached in groundwater could be investigated with a test.

General recommendation

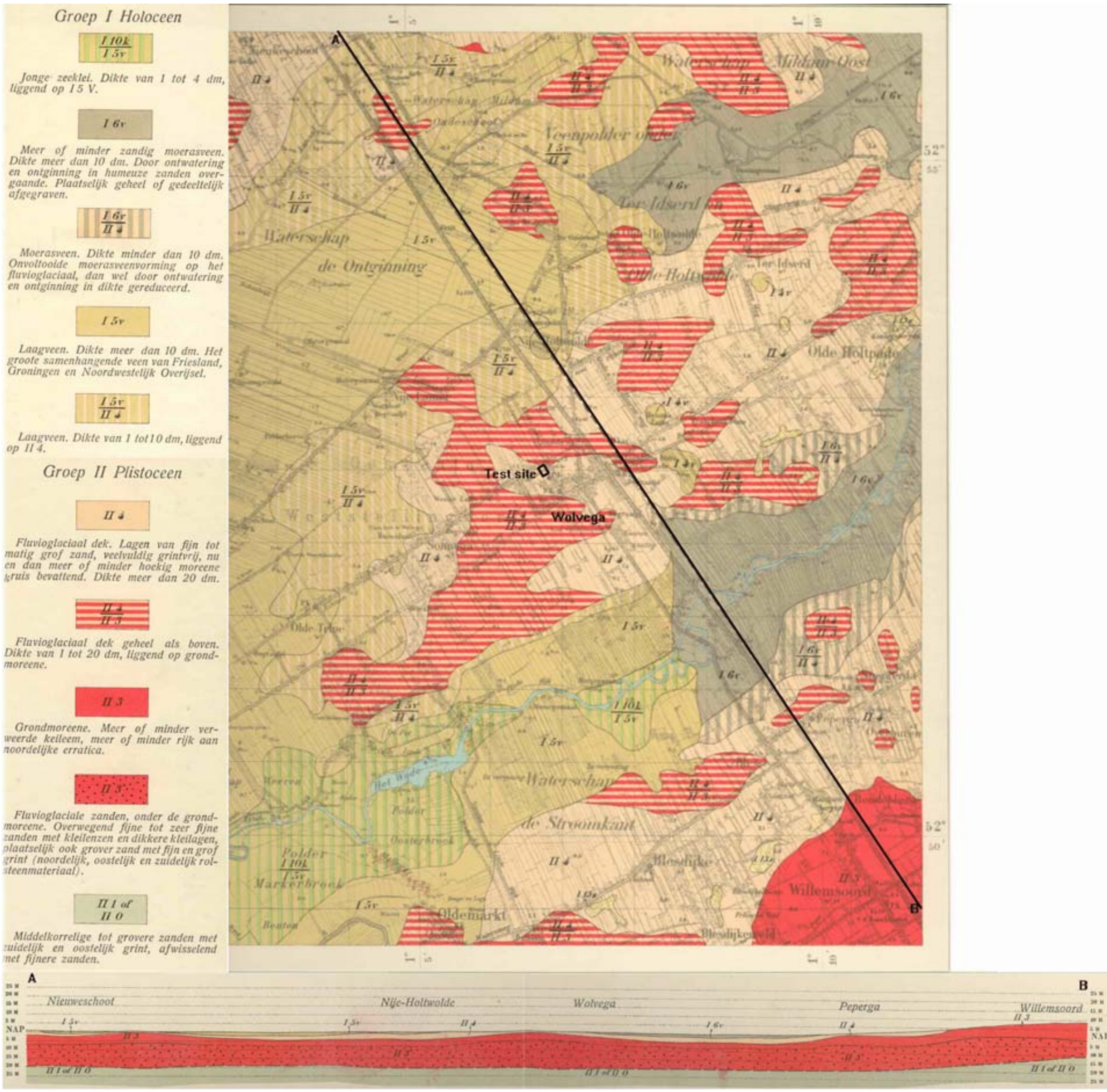
The last recommendation is to perform a full-scale test in the open air during the spring or summer. When cold, wind and rain are less common features of the weather. The end result may be the same but the way to get there much more pleasant.

Appendices

Appendix A: Location test site



Appendix B: Soil layers Wolvega



Dutch geological map.

Rijksgeologische dienst
Topografische dienst, s'Gravenhage 1934

Appendix C: Day to day summary of test

Days	Date	Work performed	Performers
0	Monday 7 November 2005	Setting out of the 3 test-facility locations.	2 students (Stefan Segers and Roelof van Reenen)
		Preparing the terrain	Contractor (Punter)
		Deliveries of ordered materials	
1	Tuesday 8 November 2005	Level measurements from sewage (NAP +0,80m, measured by Fugro and Wiertsema) to a culvert (NAP -0.109m) and back. The culvert is our fixed point for the rest of the measurements. See figure 4.2.	Students
		Finishing preparations terrain and excavation foundations. See appendix XX.	Contractor (Punter) Students
		Placing foundations and fixating them with steel UNP 240 profiles. See appendix XX.	Contractor (Punter) Students
		Level measurements after placement foundation from culvert. See appendix F.	Students
2	Wednesday 9 November 2005	Placement HE 260 profiles on the foundations.	Contractor (Punter) Students
		Weighing and placing dragline plates on the HE-profiles	Contractor (Punter) Students
		Level measurements after placement dragline plates from culvert.	Students
		Filling Big Bags with sand.	Contractor (Punter) Students
3	Thursday 10 November 2005	Finished filling Big Bags with sand.	Contractor (Punter) Students
		Weighing and placing 10 Big Bags per turn on one foundation. 20 Bags per foundation, for the weights see appendix H.	Contractor (Punter) Students
		Level measurements after placement Big Bags from culvert.	Students
4	Friday 11 November 2005	Level measurements (bad weather).	Students
7	Monday 14 November 2005	Dynamic sounding, with Pagani sounding instrument, through the foundations at every corner.	Students and Uretek Belgium
		Level measurements.	Students
8	Tuesday 15 November 2005	Injections below first foundation strip (points 3.1-3.2) of the short term test-facility. See appendix XX. Heavy rains.	Uretek Netherlands and students

9	Wednesday 16 November 2005	Second foundation strip (points 3.3-3.4) of the short term test-facility and foundation strip (points 1.3-1.4) of the long term test-facility have been injected. See appendixes K. Deepest injection level of last foundation strip of long term test-facility (point 1.1-1.2) injected. Still bad weather.	Uretek Netherlands and students
		Level measurements of short term and reference test-facilities.	Students
10	Thursday 17 November 2005	Level measurements.	Students
		Finished injecting last foundation strip of long term facility (point 1.1-1.2).	Uretek Belgium
		Dynamic sounding, with Pagani sounding instrument, of the short term facility and when finished injecting the long term facility as well.	Students and Uretek Belgium
		Level measurements.	Students
11	Friday 18 November 2005	Filling 72 Big Bags with sand for the second loading stage of the 3 tests-facilities.	Contractor (Punter) Students
		Weighing and placing 24 bags per test-facility. See appendix H.	Contractor (Punter) Students
		Level measurements.	Students
14	Monday 21 November 2005	Level measurements.	Students
15-16	Tuesday 22 and Wednesday 23 November 2005	In the morning and afternoon performed level measurements.	Students
17-18	Thursday 24 and Friday 25 November 2005	Level measurements.	Students
21-24	Monday 28 November till Thursday 1 December 2005	Level measurements.	Students
24	Thursday 1 December 2005	Meeting; decided to do an extra injection under one short term foundation strip (point 3.3-3.4)	Allard van der Wal, Alwin ter Huurne, Bert Everts, Stefan Segers and Roelof van Reenen
37	Wednesday 14 December 2005	Level measurements.	Students
38	Thursday 15 December 2005	Dynamic sounding, with Stitz DPL device, of short term facility.	Students
39	Friday 16 December 2005	Placing and level measuring 3 piquets to measure the ground movement next to the foundation strip of the short term strip (point 3.3-3.4) which is will be injected under a 2nd time.	Students
		Injecting in a dense pattern of injection points part 3.3 of short term facility. Appendix K.	Uretek Netherlands
		Injecting while pulling the injection pipe out of part 3.4 of short term facility. Appendix K.	
		Dynamic sounding, with Stitz sounding instrument, of reference facility.	Students and Allard van der Wal

42-44	Monday 19-21 December 2005	Level measurements.	Students
56	Monday 2 January 2006	Level measurements. Dynamic sounding with Stitz DPL Device, short term test -facility which had been injected twice and the long term facility.	Students
94	Thursday 9 February	Cone penetration tests (CPT's)	Associate of department of geo-engineering (Han de Visser) and student (Roelof van Reenen)
97	Sunday 12 February 2006	Dynamic sounding with Pagani measuring device.	Students
98	Monday 13 February 2006	Placing filters of the dewatering system.	Landman Bronbemaling
99	Tuesday 14 February 2006	Approach excavation of short term facility part 3.4. Two injections rounds with last round pulled injections.	Punter the contractor and students
100	Wednesday 15 February 2006	Excavation of cross section part 3.4. Stopped due to excessive rain.	Contractor (Punter) Students
107	Wednesday 22 February 2006	Excavation of cross section of short term facility part 3.3. Two injections rounds with last round a dense matrix of injections. Excavation of 2 cross sections of short term facility part 3.1 and 3.2. One injection round.	Contractor (Punter) and students
108	Thursday 23 February 2006	Taken soil samples	Contractor (Punter) and student (R. van Reenen)
169	Monday 25 April 2006	Level measurements in the morning and afternoon.	Student
219	Wednesday 14 June 2006	Level measurements in the morning	Student and Bert Everts

Appendix D: Layout and numbering of measuring and injection points

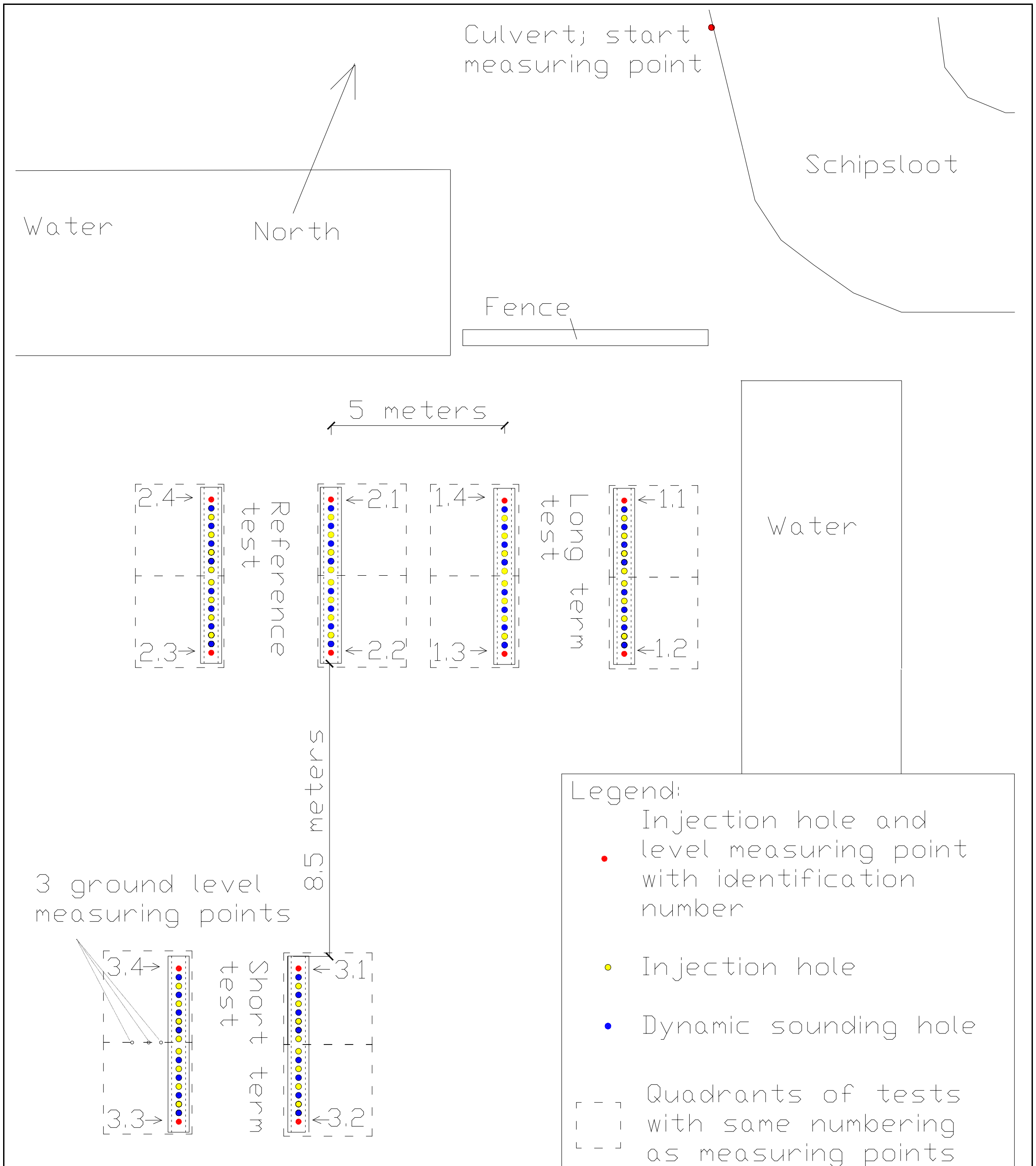


Figure D.1. Layout and numbering of measuring and injection points.

Appendix E: Location dynamic soundings and cone penetration tests on test site

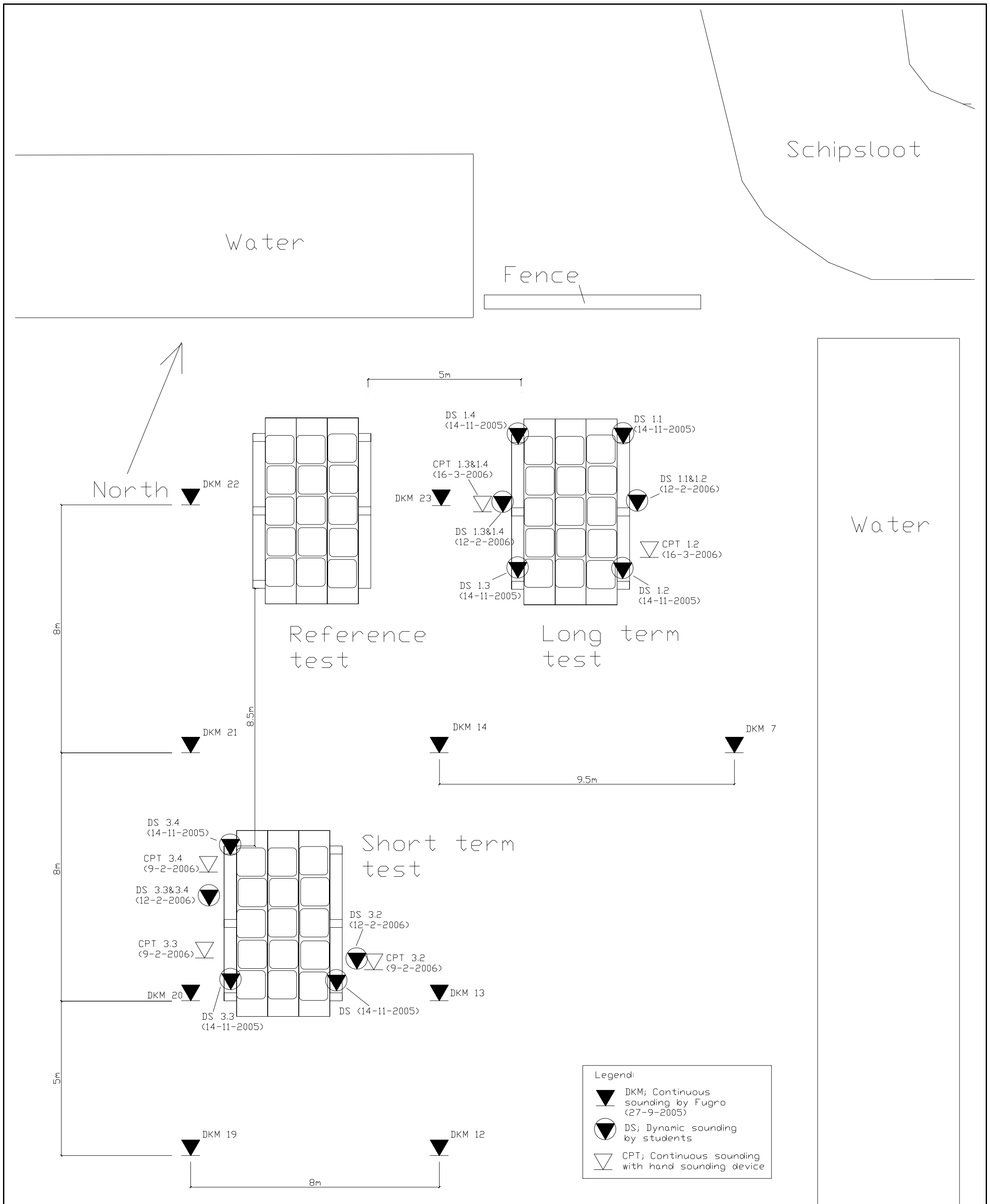


Figure E.1. Locations dynamic soundings and cone penetration tests

Appendix F: Level measurement scheme

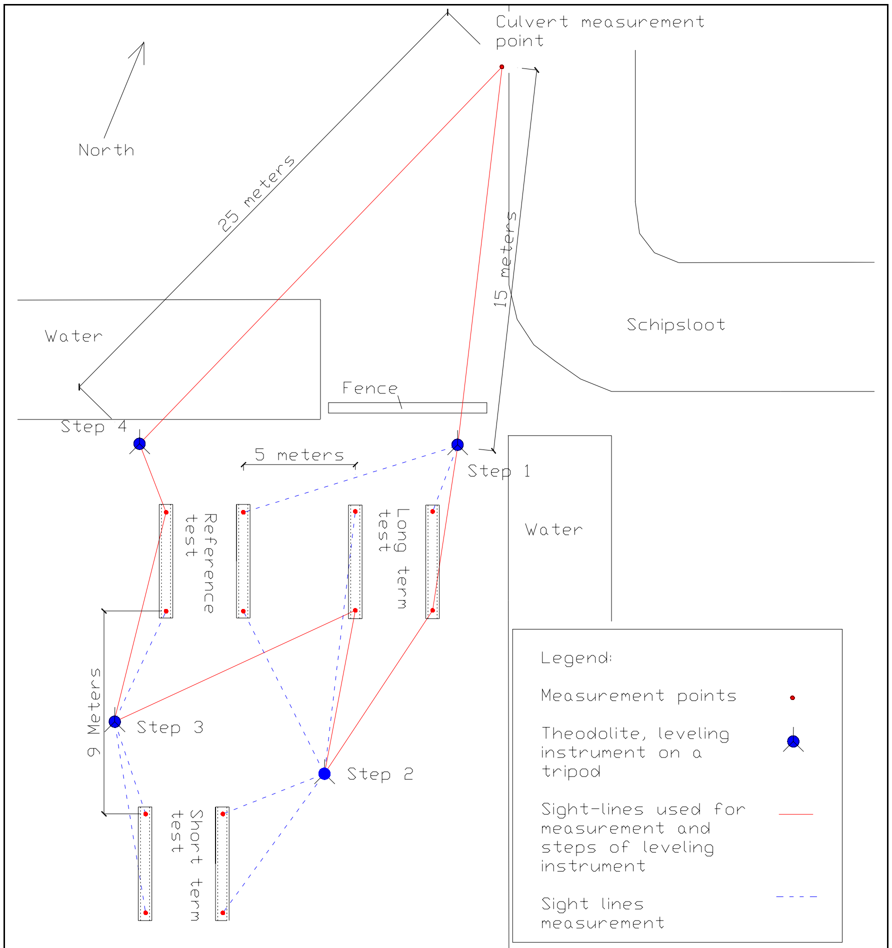


Figure F.1. Level measurement scheme.

Appendix G: Error in level measurement

Measure date	NAP level of reference point (m)	Measured NAP level of reference point (m)	Absolute difference (mm)
22/11/2005	-0.1090	-0.1092	0.2
22/11/2005	-0.1090	-0.1103	1.3
23/11/2005	-0.1090	-0.1091	0.1
23/11/2006	-0.1090	-0.1081	0.9
24/11/2005	-0.1090	-0.1088	0.2
25/11/2005	-0.1090	-0.1078	1.2
28/11/2005	-0.1090	-0.1076	1.4
29/11/2005	-0.1090	-0.1084	0.6
30/11/2005	-0.1090	-0.1095	0.5
1/12/2005	-0.1090	-0.1093	0.3
14/12/2005	-0.1090	-0.1081	0.9
19/12/2005	-0.1090	-0.1096	0.6
20/12/2005	-0.1090	-0.1088	0.2
21/12/2005	-0.1090	-0.1105	1.5
2/1/2006	-0.1090	-0.1092	0.2
25/4/2006	-0.1090	-0.1116	2.6
25/4/2006	-0.1090	-0.1118	2.8
		average	0.9
		standard deviation	0.8

Appendix H: Load on the soil under the foundations of the tests

To calculate the load per m^2 the weight of the load and the surface on which the load is placed is needed.

Foundation beam measurements:

- Length 5m
- Width 0.6m
- Surface $3m^2$

Two beams per foundation

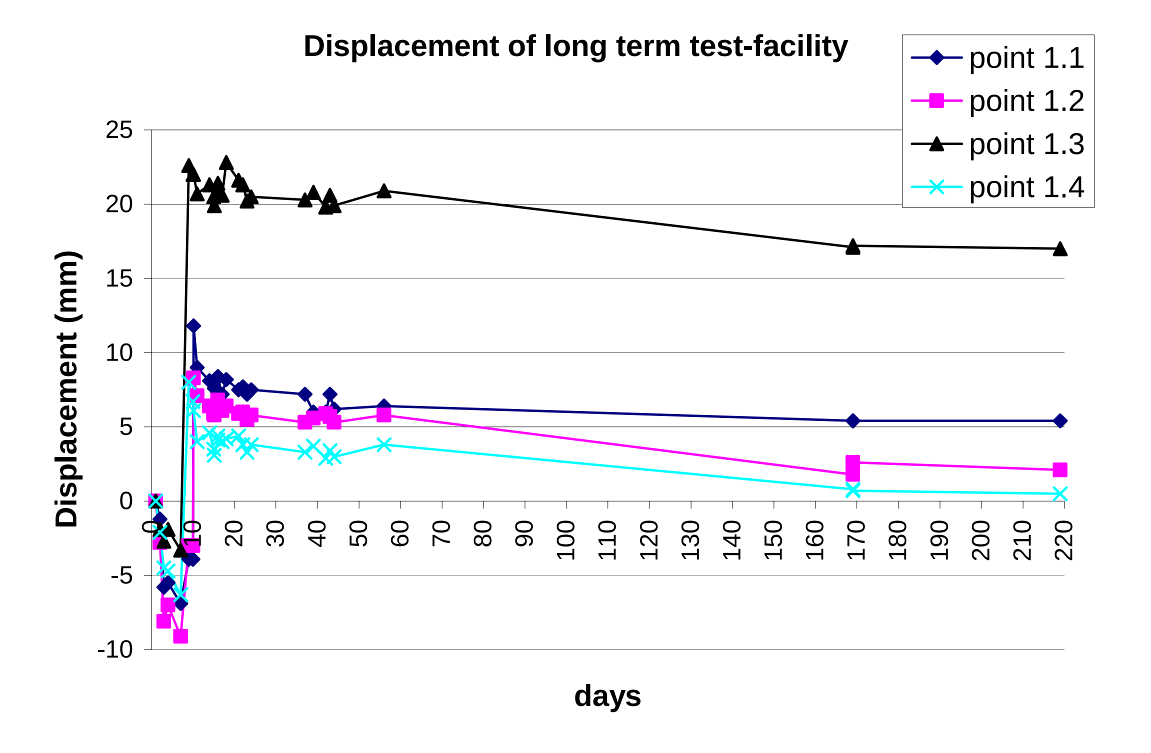
- Surface $6m^2$

	1st loading stage (10/11/2005)		2nd loading stage (18/11/2005)	
	Weight foundation and 20 Big bags (kg)	1st load (kPa)	Weight 24 Big bags (kg)	2nd load (kPa)
Long term test	40006	65.4	37667	61.6
Short term test	40226	66.2	37668	61.6
Reference test	40486	65.8	37669	61.6

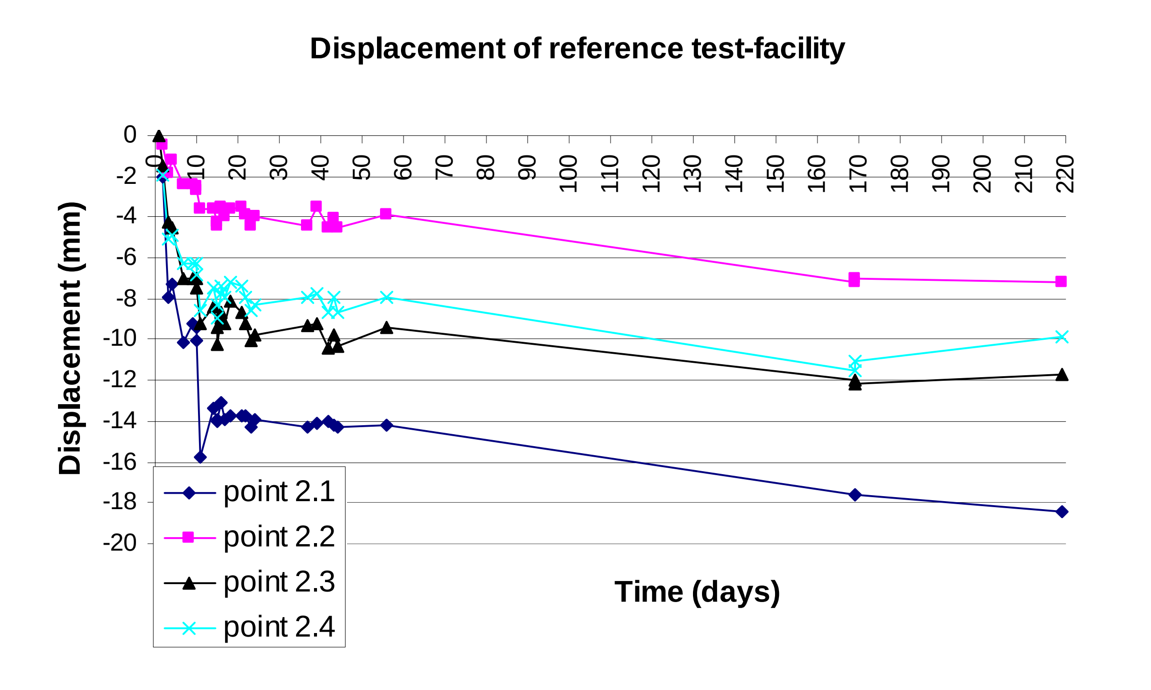
Table H.1 Weights and loadings on the test foundations

Appendix I: Level measurements of test-facilities

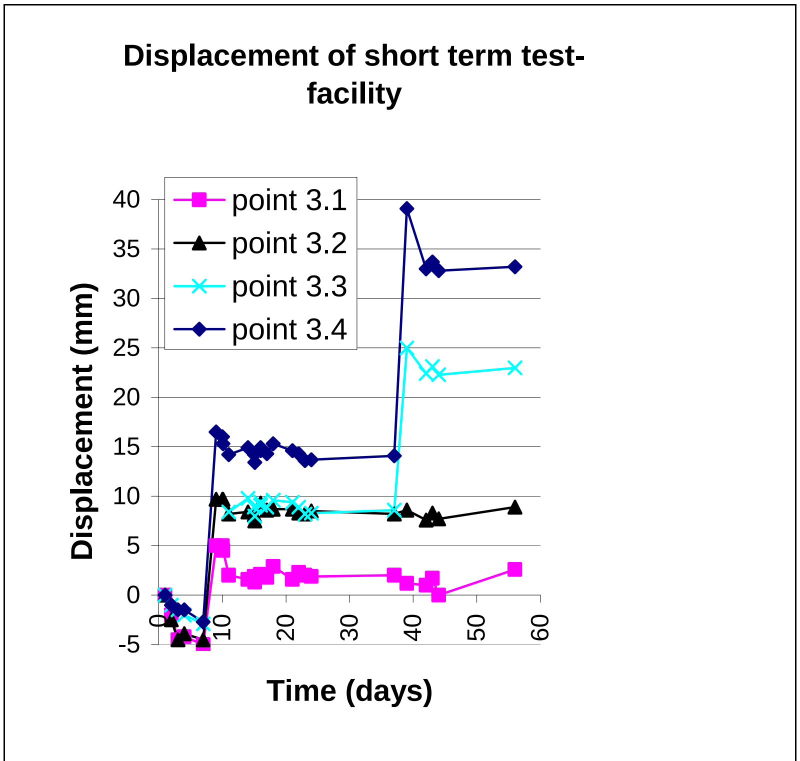
Graphs of level measurements of the four measuring-points per test-facility. See appendix D for location of these points at the test-site.



Graph I.1 Level measurements long term test-facility

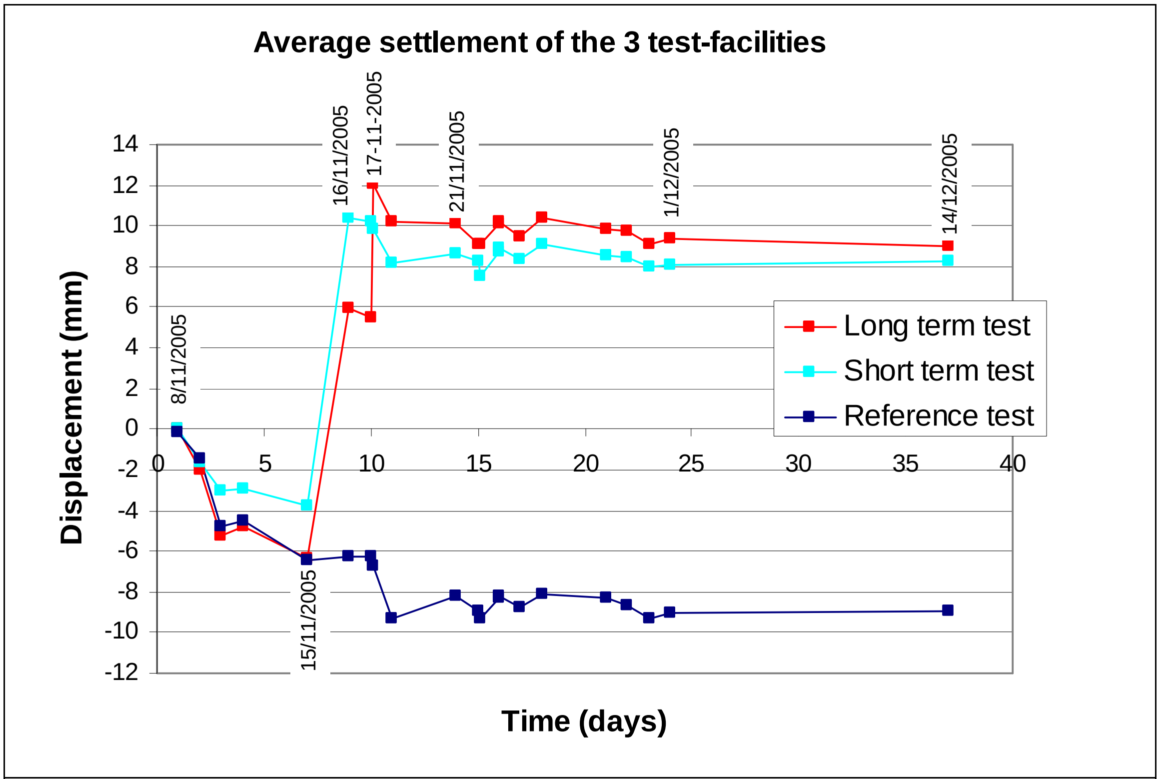


Graph I.2 Level measurements reference test-facility

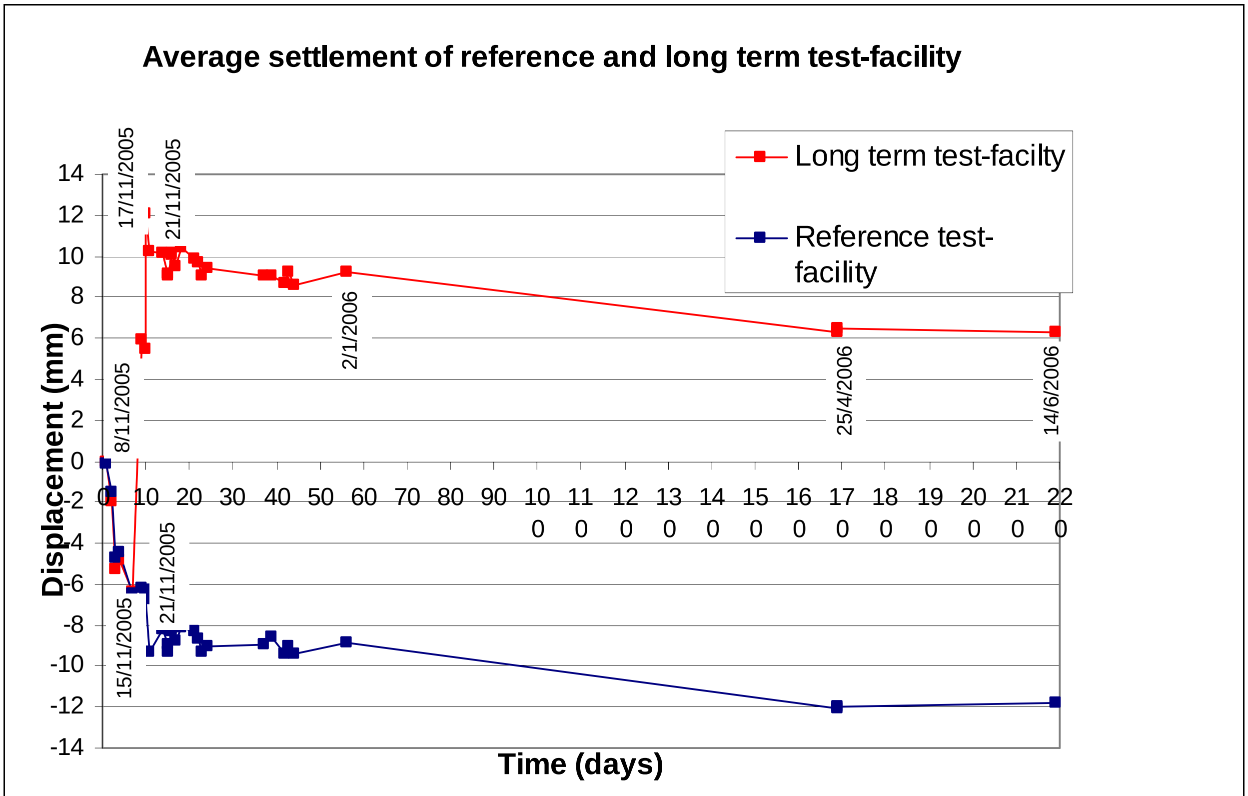


Graph I.3 Level measurements short term test-facility

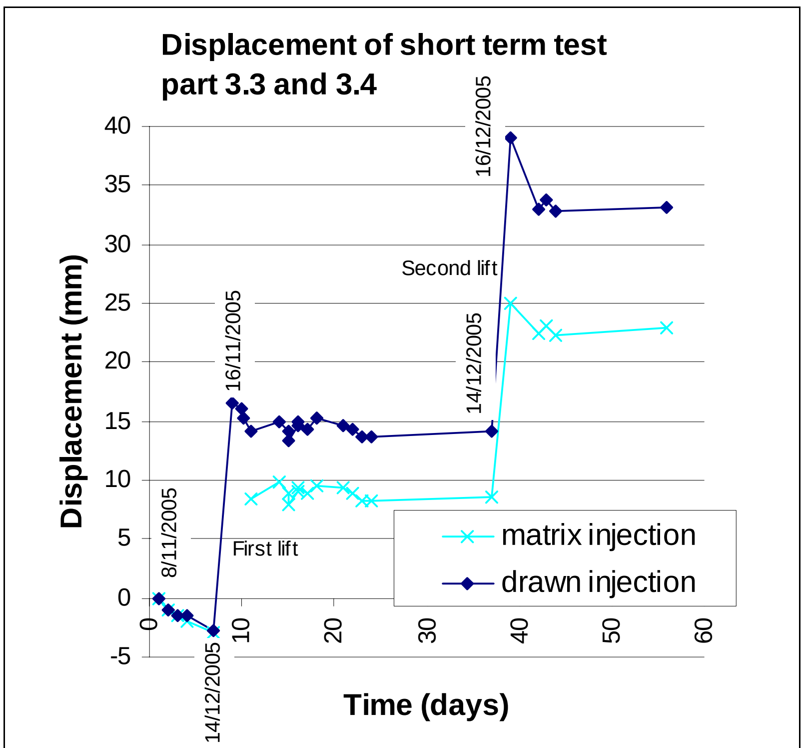
Averaged level measurements.



Graph I.4 Average settlement of test-facilities first 37 days.



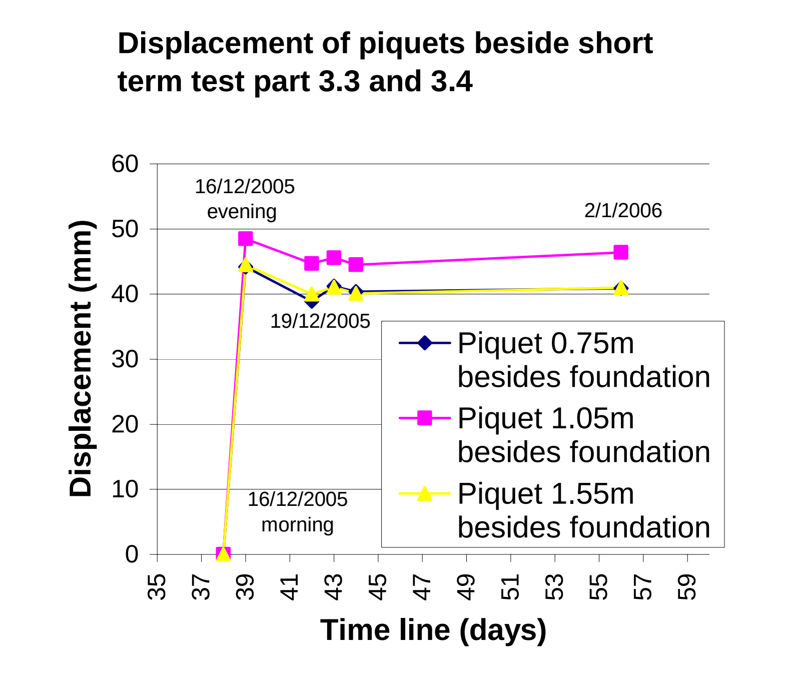
Graph I.5. Average settlement of test-facilities first 219 days.



Graph I.6. Displacements after second injection.

Appendix J: Level measurement piquets

To measure ground level displacement three piquets were installed beside the short term test-facility before the second injection. See appendix D for the location on the test-site.



Graph J.1. Displacement 3 piquets from day 38 to 56.

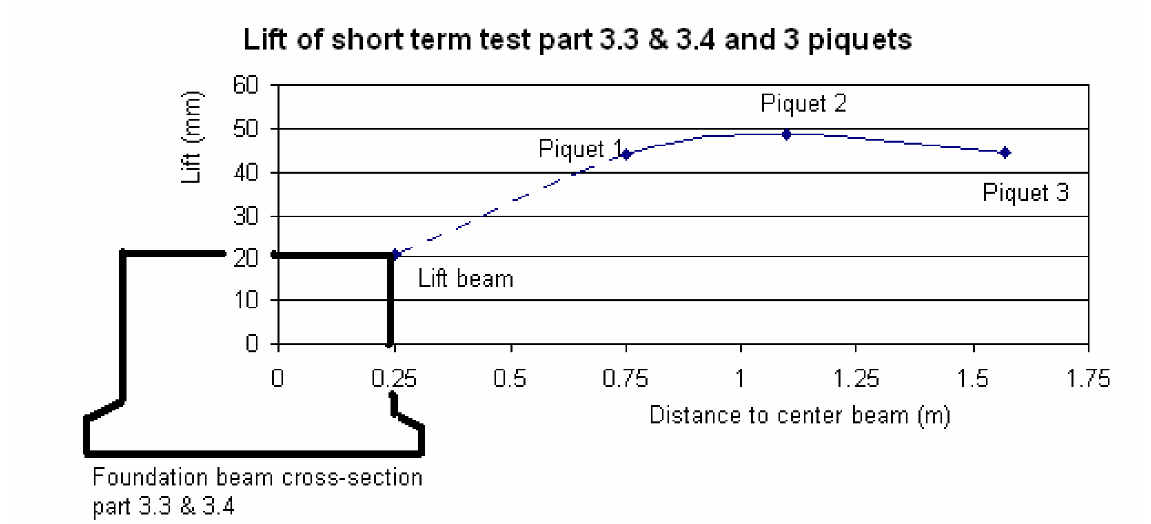
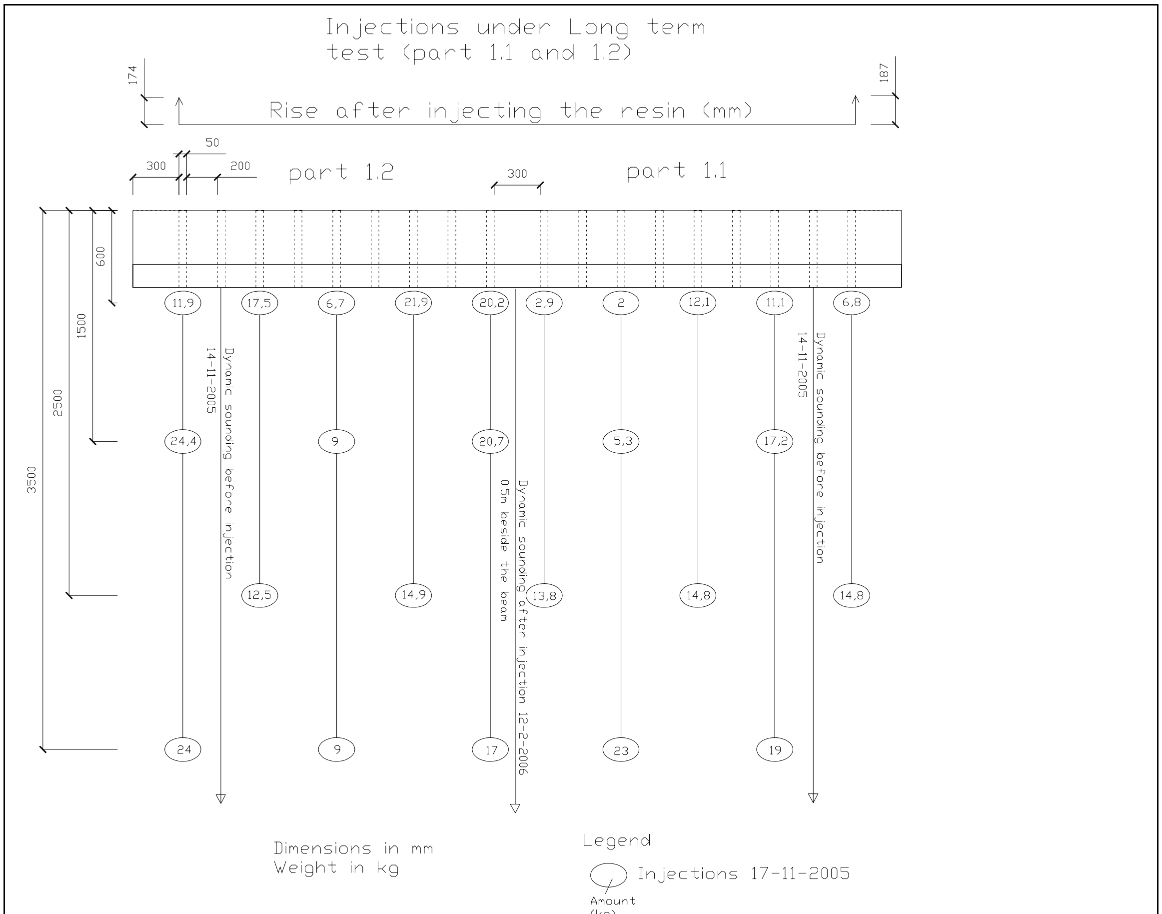


Figure J.2. Lift of 3 piquets and short term test-facility part 3.3 & 3.4 on 16/12/2005

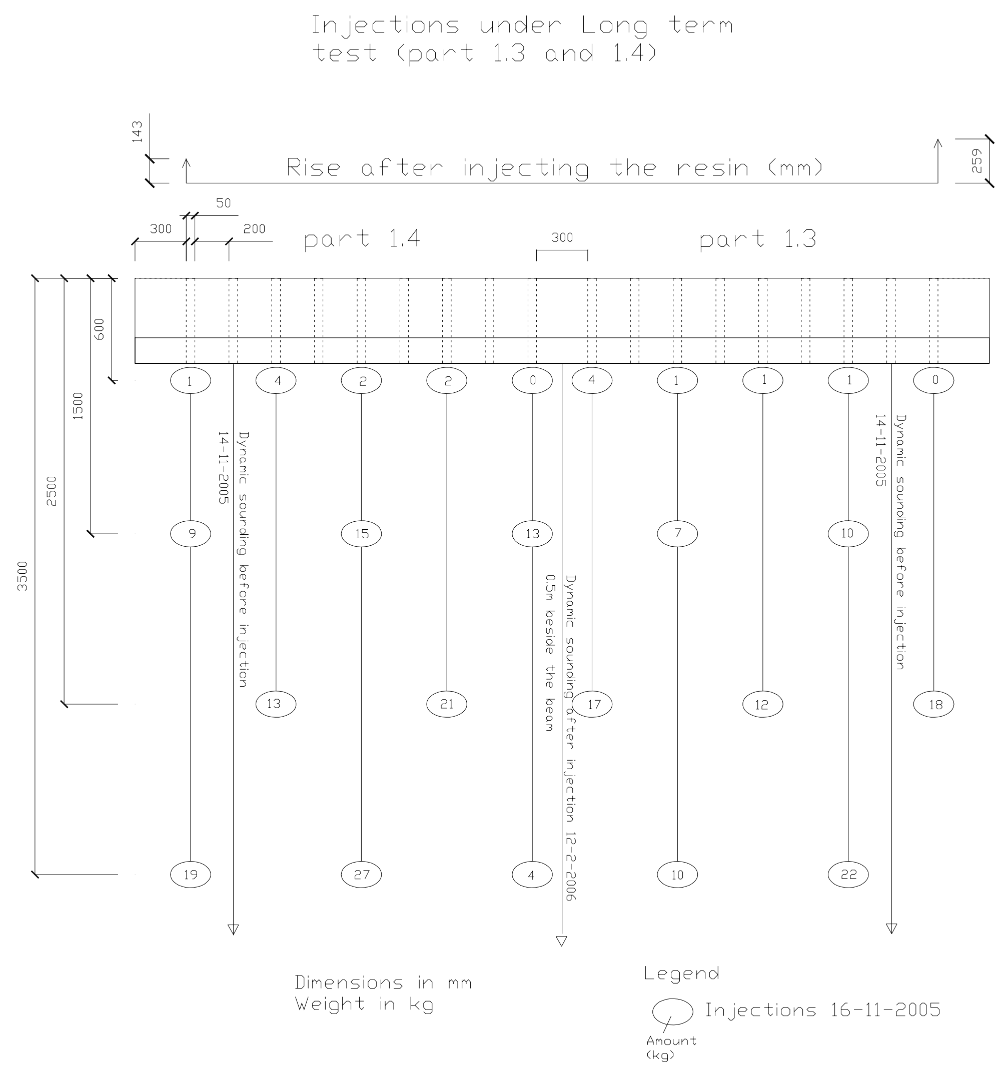
Appendix K: Injected quantities and injection point locations

The amounts of resin injected and depth of the pipe when injecting under the strip foundations are shown in the following pictures. The first injection under the foundation strips of the long and short term test-facility were done from 15-17 November 2005, the second injection only under strip 3.3-3.4 of the short term test-facility was done 16 December 2005. Also the dynamic sounding locations of 14 November 2005, before the injections, and 12 February 2006, after the injections, are drawn in. The injections per level and the total injected amount under one strip foundation are calculated in the attached table. The holes through the foundation are numbered 1-18 from left to right. All injections levels are below groundwater level.



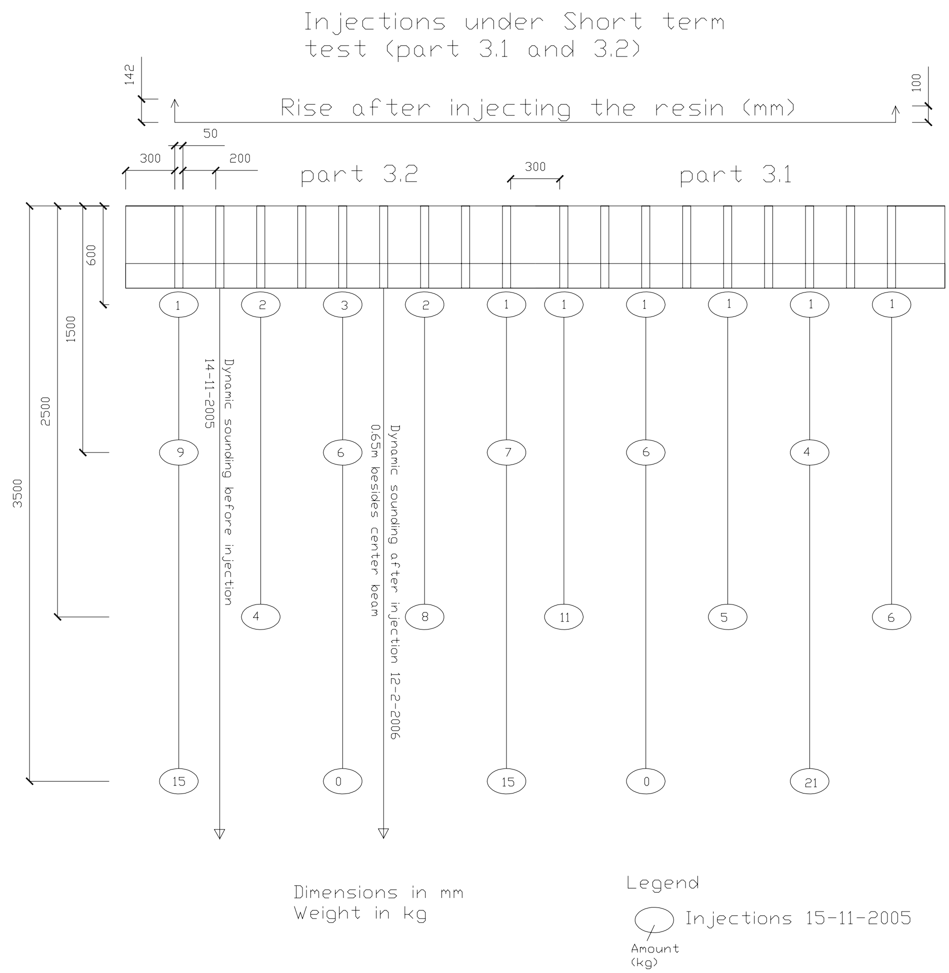
Injected amounts of resin under the strip foundation of long term test-facility part 1.1 - 1.2											
Injection hole number:	**1**	**3**	**5**	**7**	**9**	**10**	**12**	**14**	**16**	**18**	**sum**
Injection depth below ground level (m): **-0.6**	11.9	17.5	6.7	21.9	20.2	2.9	2	12.1	11.1	6.8	113.1
-1.5	24.4		9		20.7		5.3		17.2		76.6
-2.5		12.5		14.9		13.8		14.8		14.8	70.8
-3.5	24		9		17		23		19		92
Injection amounts in kg										**Total**	**352.5**

Figure and table K.1. Injections long term test-facility part 1.1-1.2.



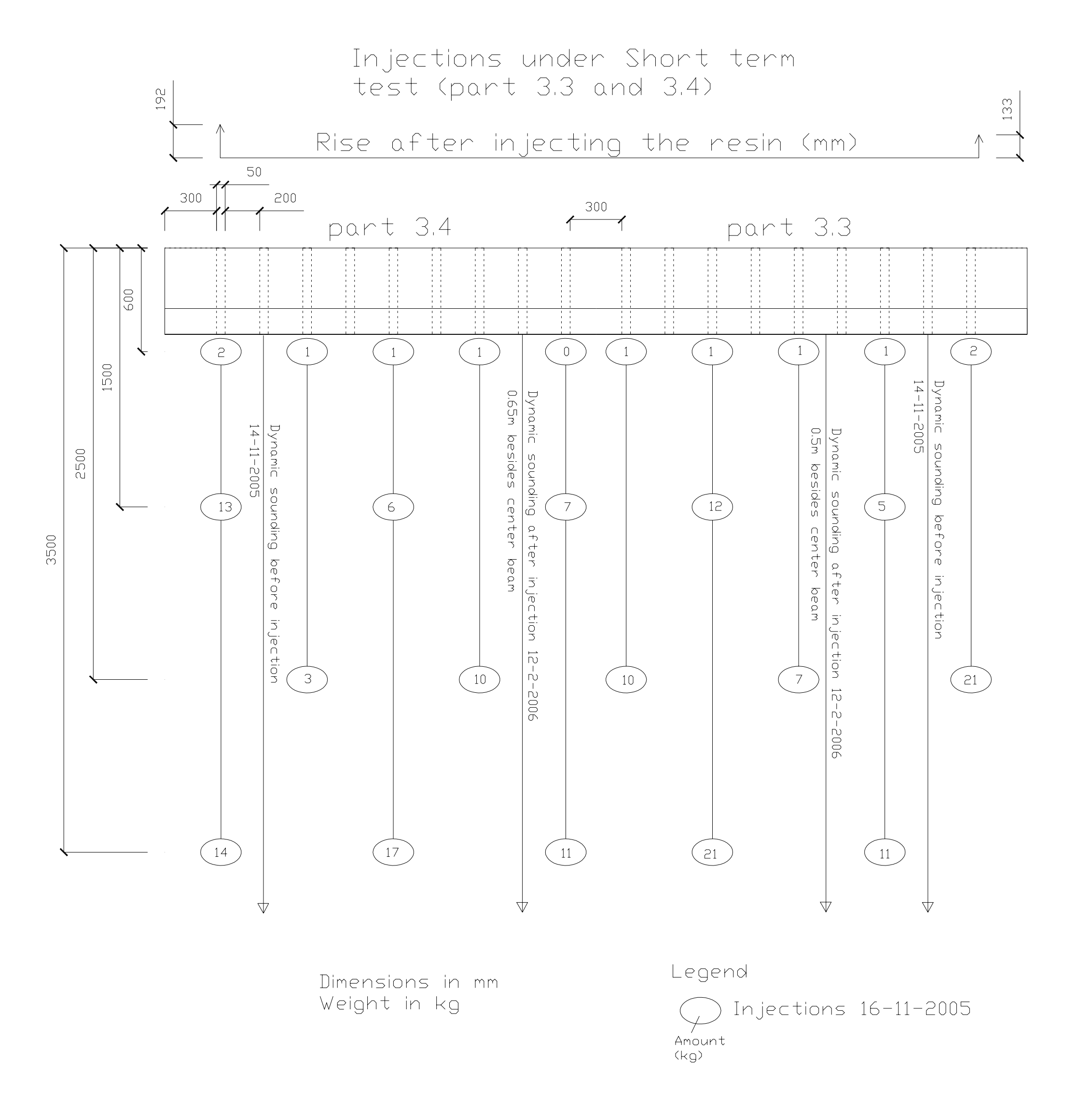
Injected amounts of resin under the strip foundation long term test-facility part 1.3 - 1.4											
Injection hole number:	**1**	**3**	**5**	**7**	**9**	**10**	**12**	**14**	**16**	**18**	**sum**
Injection depth below ground level (m): **-0.6**	1	4	2	2	0	4	1	1	1	0	16
-1.5	9		15		13		7		10		54
-2.5		13		21		17		12		18	81
-3.5	19		27		4		10		22		82
Injection amounts in kg									**Total**		**233**

Figure and table K.2. Injections long term test-facility part 1.3-1.4.



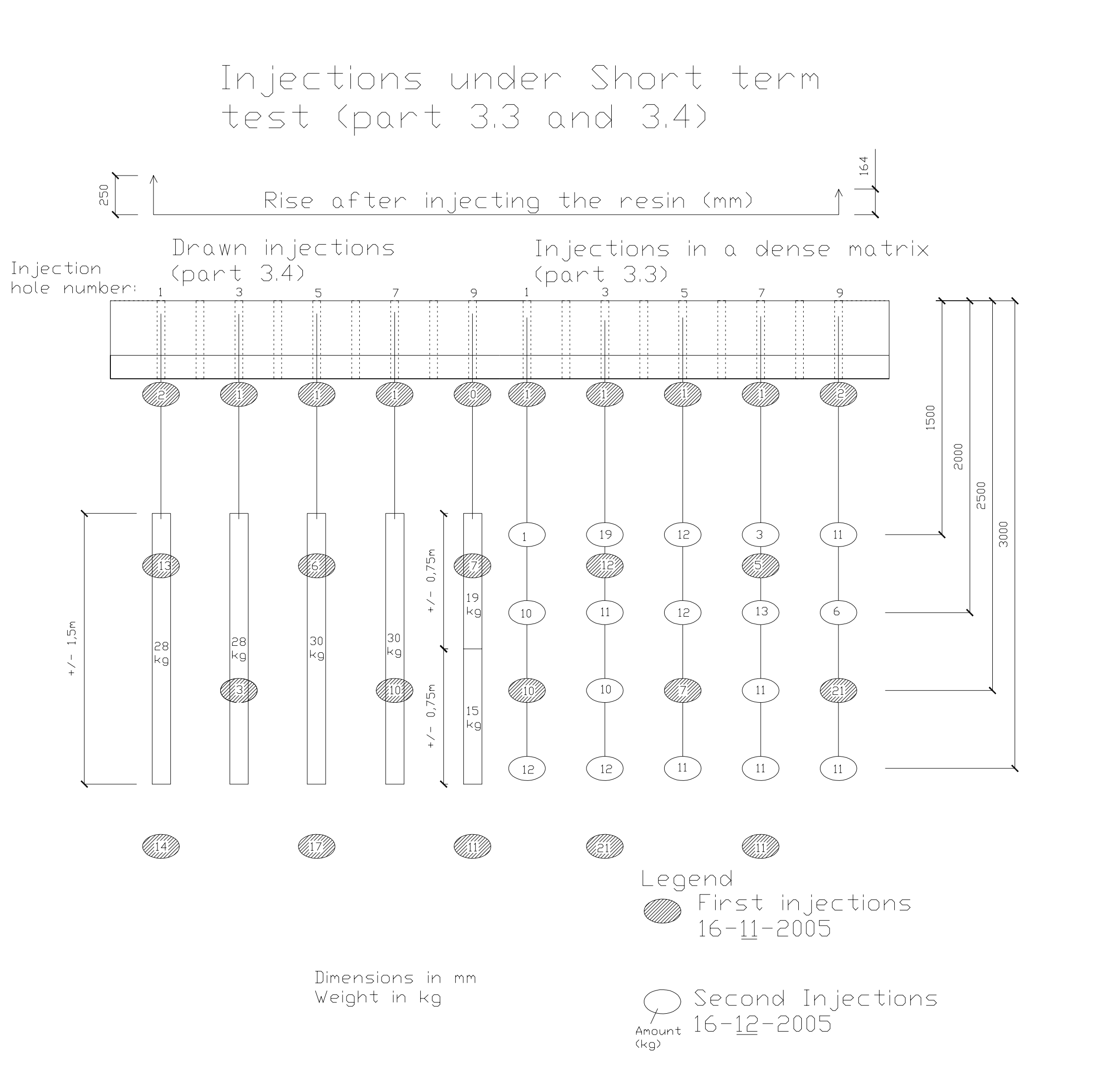
Injected amounts of resin under the strip foundation short term test-facility part 3.1 - 3.2											
Injection hole number:	**1**	**3**	**5**	**7**	**9**	**10**	**12**	**14**	**16**	**18**	**sum**
Injection depth below ground level (m): **-0.6**	1	2	3	2	1	1	1	1	1	1	14
-1.5	9		6		7		6		4		32
-2.5		4		8		11		5		6	34
-3.5	15		0		15		0		21		51
Injection amounts in kg									**Total**		**131**

Figure and table K.3. Injections short term test-facility part 3.1-3.2.



Injected amounts of resin under the strip foundation short term test-facility part 3.3 - 3.4											
Injection hole number:	**1**	**3**	**5**	**7**	**9**	**10**	**12**	**14**	**16**	**18**	**sum**
Injection depth below ground level (m): **-0.6**	2	1	1	1	0	1	1	1	1	2	11
-1.5	13		6		7		12		5		43
-2.5		3		10		10		7		21	51
-3.5	14		17		11		21		11		74
Injection amounts in kg									**Total**		**179**

Figure and table K.4. Injections short term test-facility part 3.3-3.4.

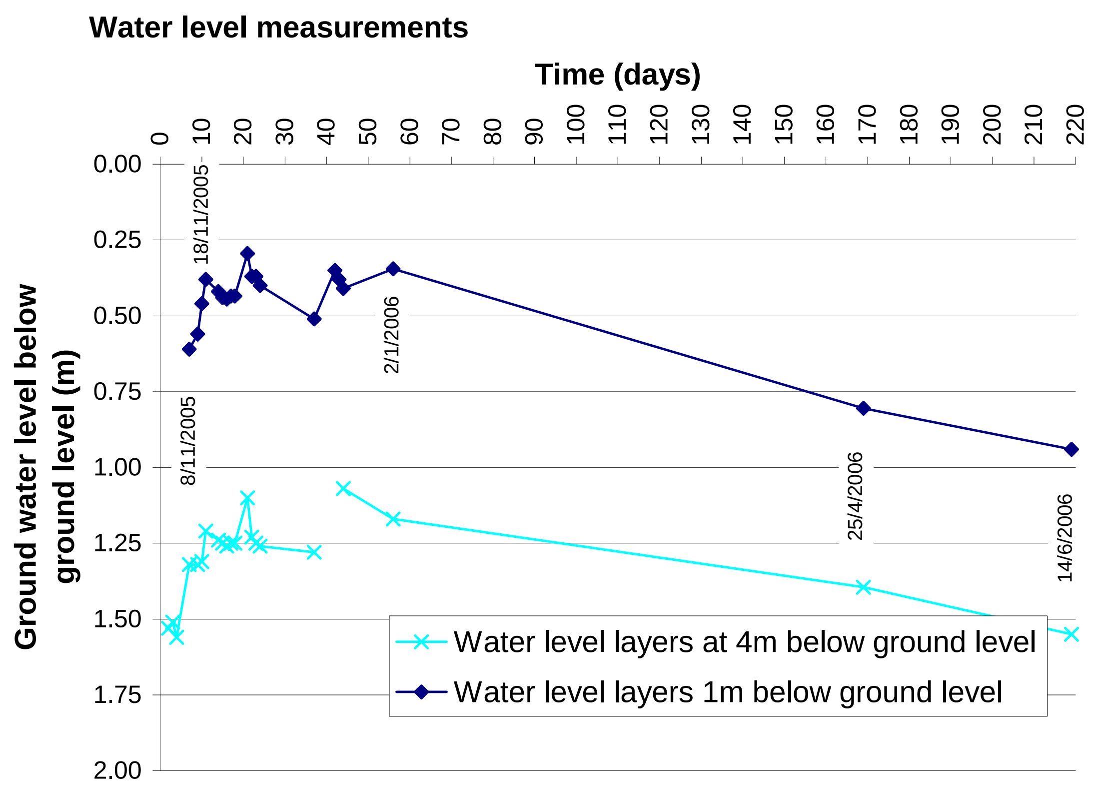


<table>
<tr><td colspan="10">Injected amounts of resin under the strip foundation short term test-facility part 3.3 - 3.4;</td><td>2nd injection</td></tr>
<tr><td>Injection hole number:</td><td>1</td><td>3</td><td>5</td><td>7</td><td>9</td><td>10</td><td>12</td><td>14</td><td>16</td><td>18</td></tr>
<tr><td>Injection depth below ground level (m): -1.5</td><td rowspan="4">28</td><td rowspan="4">28</td><td rowspan="4">30</td><td rowspan="4">30</td><td rowspan="2">19</td><td>1</td><td>19</td><td>12</td><td>3</td><td>11</td></tr>
<tr><td>-2.0</td><td>10</td><td>11</td><td>12</td><td>13</td><td>6</td></tr>
<tr><td>-2.5</td><td rowspan="2">15</td><td></td><td>10</td><td></td><td>11</td><td></td></tr>
<tr><td>-3.0</td><td>12</td><td>12</td><td>11</td><td>11</td><td>11</td></tr>
<tr><td>Injection amounts in kg</td><td></td><td colspan="3">Total part 3.4</td><td>150</td><td colspan="4">Total part 3.3</td><td>176</td></tr>
</table>

Figure and table K.5. Injections short term test-facility part 3.3-3.4, 2nd injection

Appendix I: Groundwater level measurements

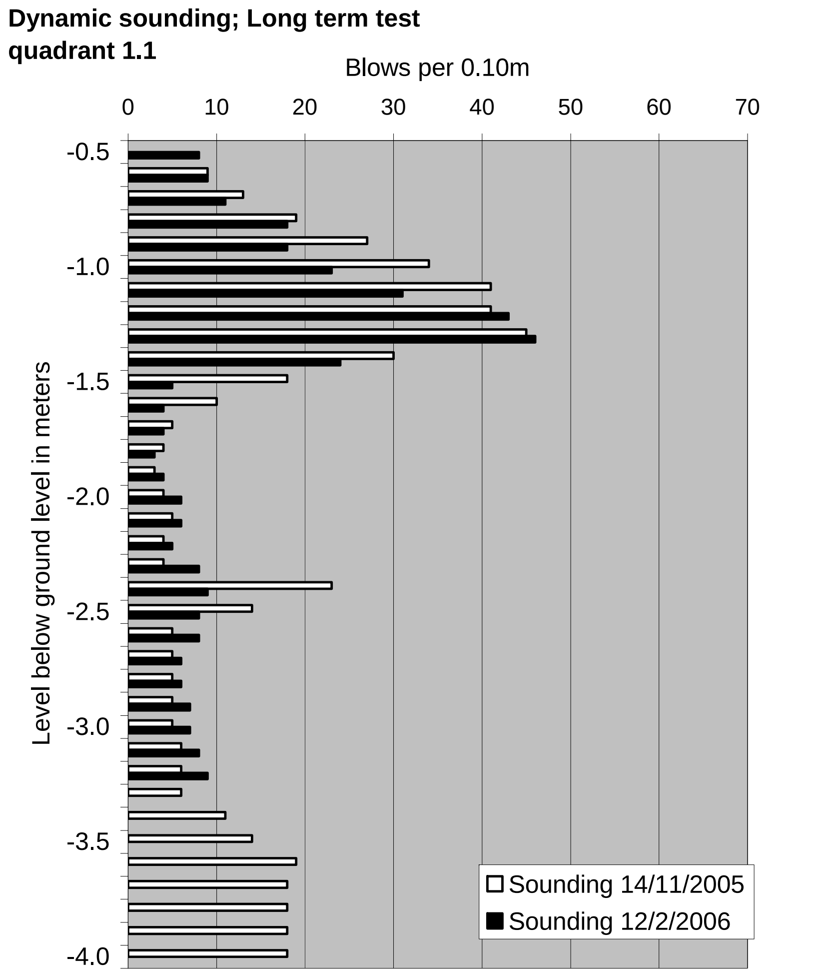
To monitor the changes in groundwater levels two observation wells were installed at 1m and 4m below ground level which is about NAP. The measured depths are presented in graph K.1.

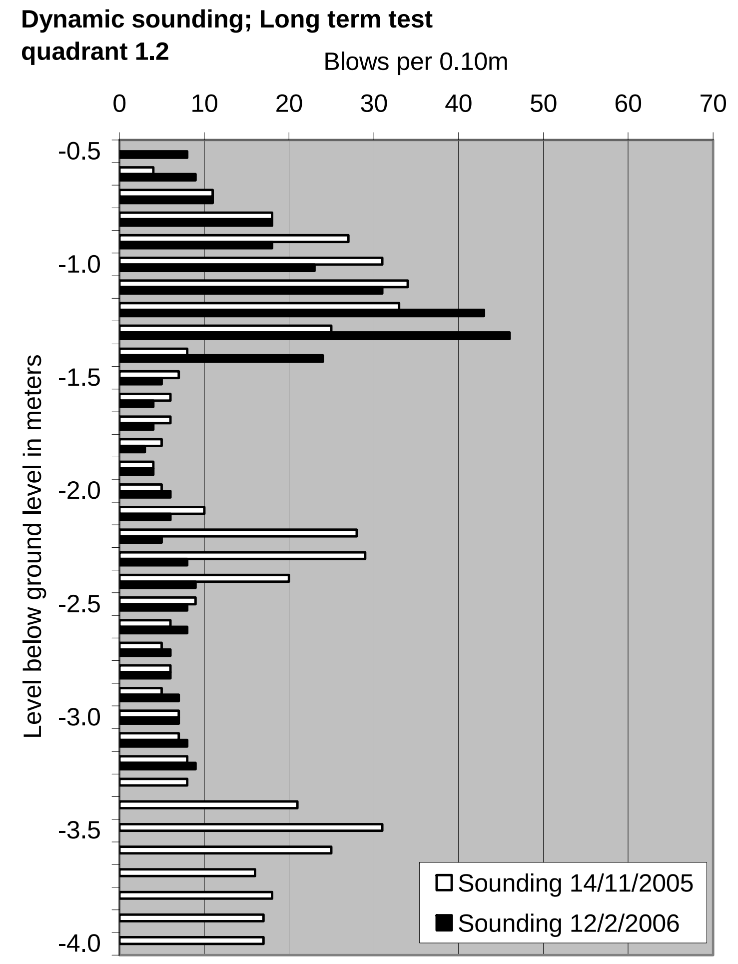


Graph I.1. Groundwater levels at 1 and 4 meter below ground level

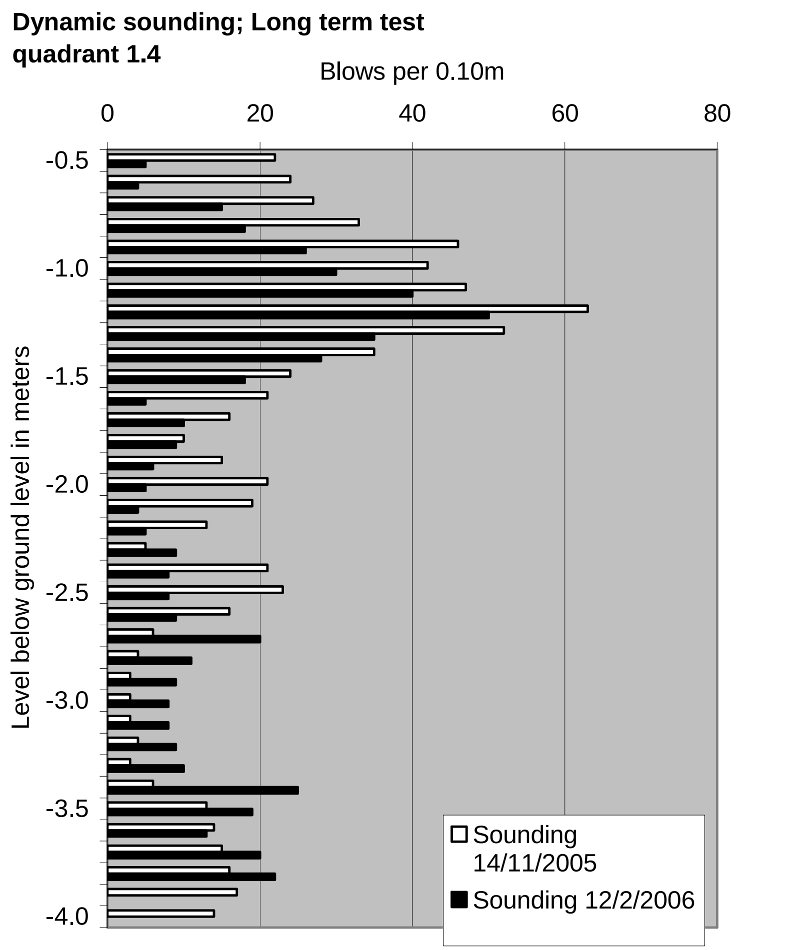
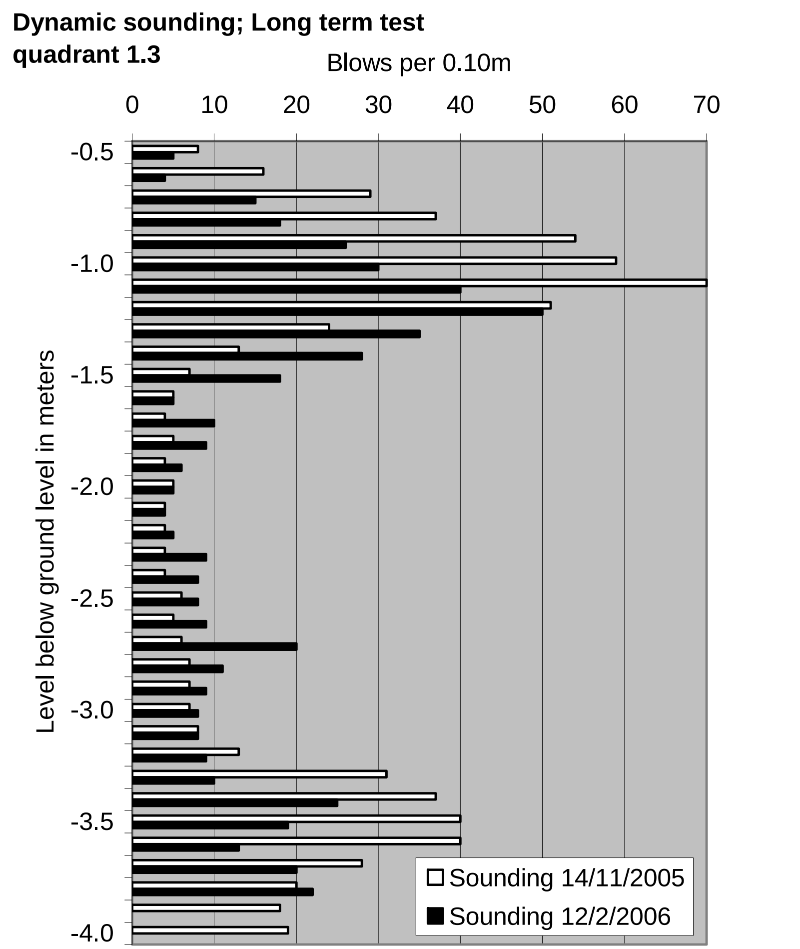
Appendix M: Dynamic soundings

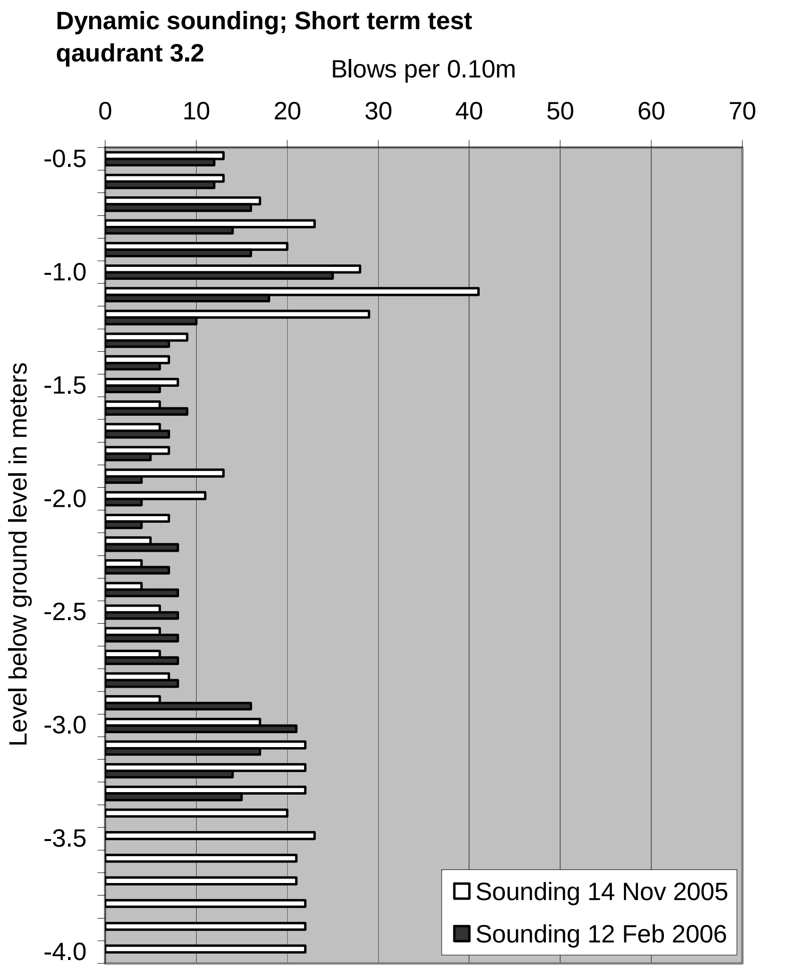
The dynamic soundings have been done with a Pagani sounding device of 30 kg. The soundings were made through the prefabricated holes in the foundation strips. The numbering of the soundings is according to figure D. The sounding locations are drawn in the figures of appendix E and K; Locations dynamic and cone penetration tests. The dates of the soundings are 14 November 2005 before injecting the resin and 12 February 2006 after the injections and consolidation.



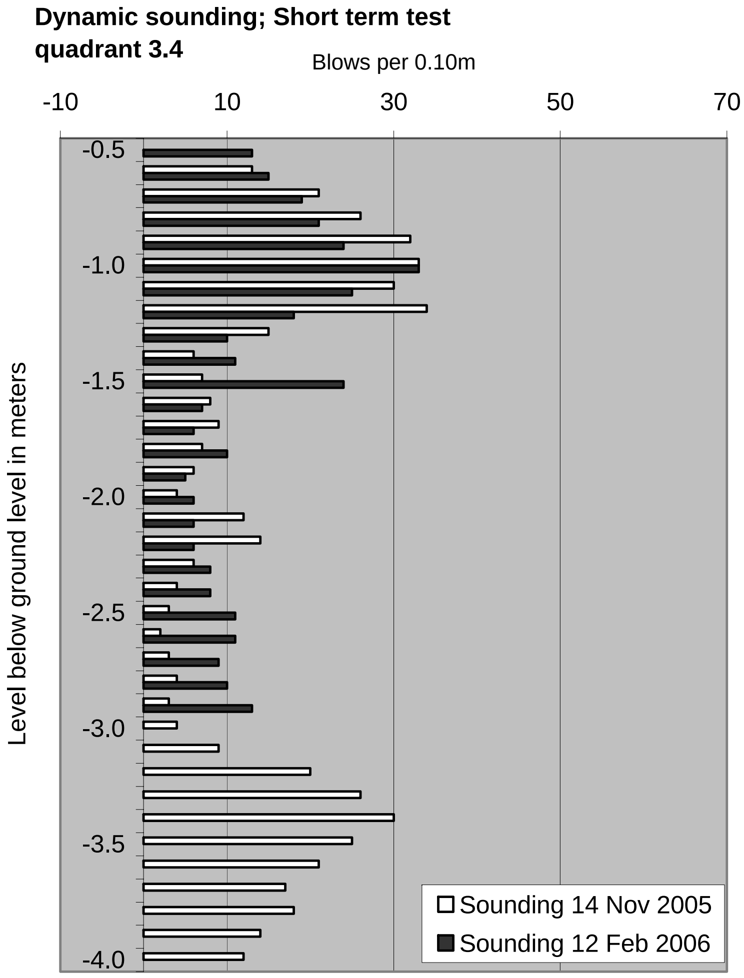


Graph M.1a. Dynamic soundings; Long term test-facility part 1.1, before and after injection.	Graph M.1b. Dynamic soundings; Long term test-facility part 1.2, before and after injection.

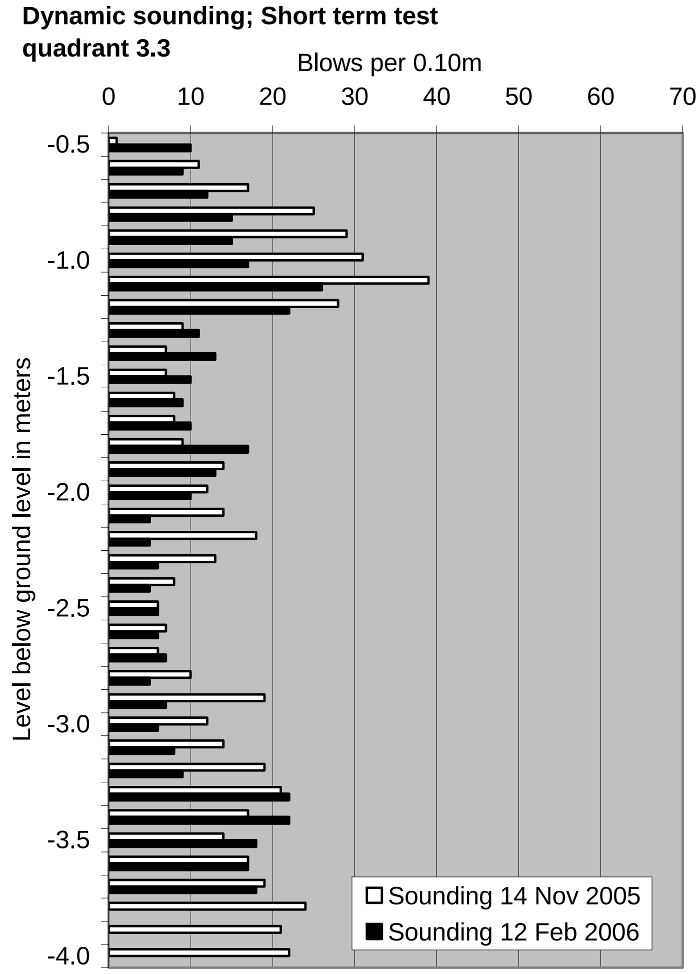
	
Graph M.2a. Dynamic soundings; Long term test-facility part 1.4, before and after injection.	Graph M.2b. Dynamic soundings; Long term test-facility part 1.3, before and after injection.



Graph M.3. Dynamic soundings; Short term test-facility part 3.2, before and after injection.



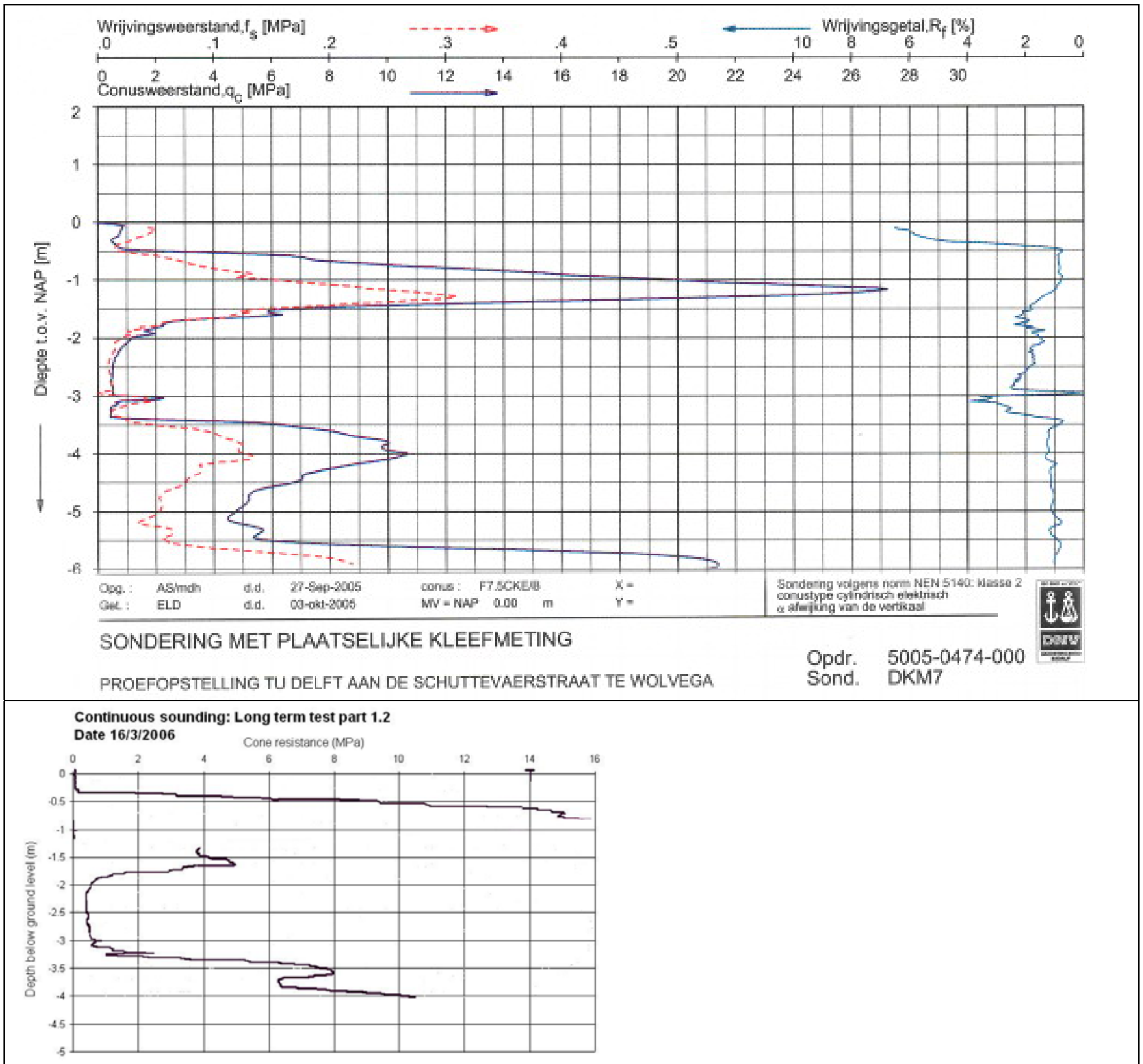
Graph M.31. Dynamic soundings; Short term test-facility part 3.4, before and after injection.



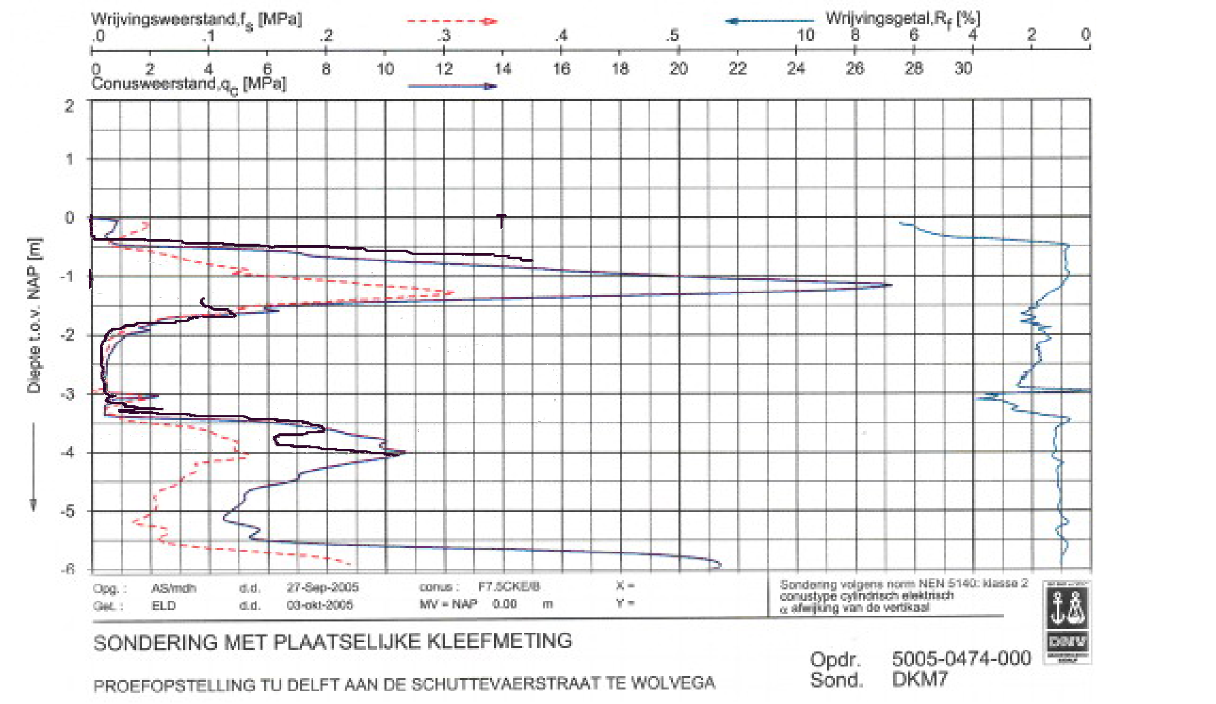
Graph M.3b. Dynamic soundings; Short term test-facility part 3.3, before and after injection.

Appendix N: Cone penetration tests

During the start up of the test soil investigations have been performed by the geotechnical engineers of Fugro. During the research cone penetration tests have been made with a small hand sounding device. The soundings of Fugro before injecting (made 27/9/2005) and the soundings (made 9/2 & 16/3 2006) made with the hand device after injecting are given in this appendix. For location of cone penetration tests see appendix E.



Graph N.1 Cone penetration tests before and after injection of Long term test-facility part 1.2



Legend:

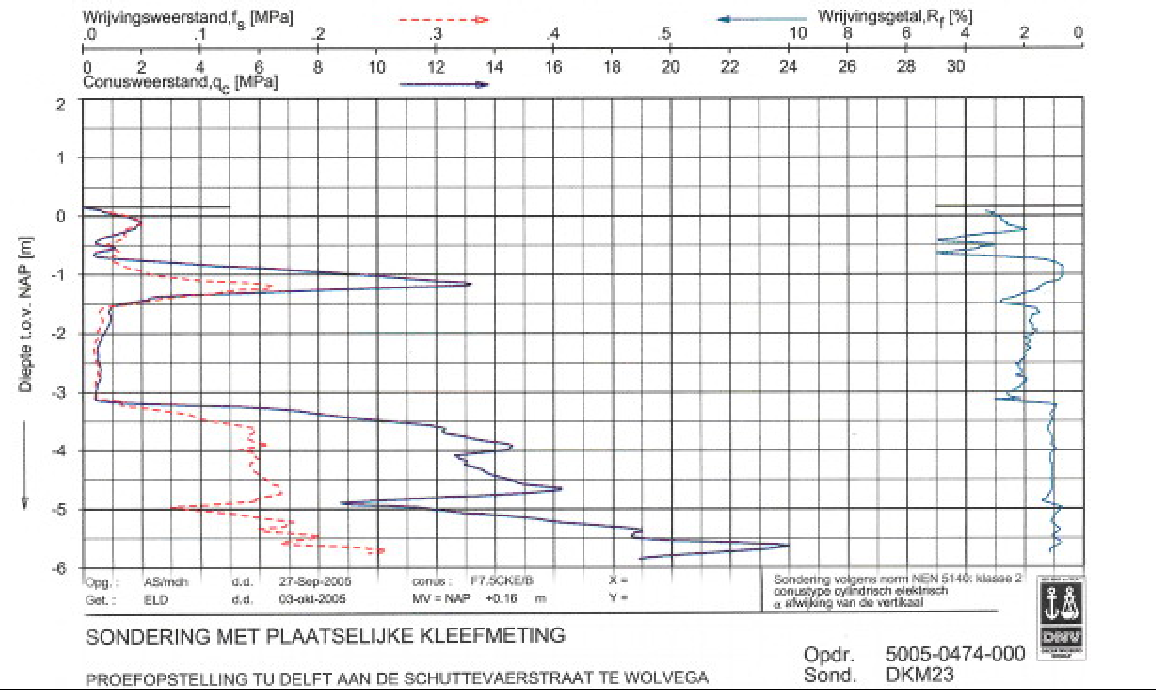
In the left half of the graph;

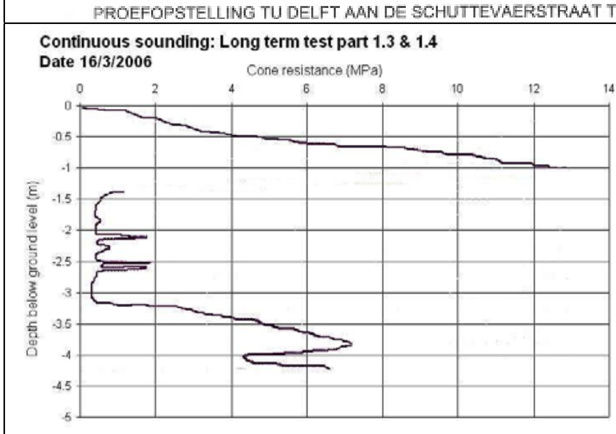
- The darkest black line is the cone resistance (q_c) after the resin injections.
- The lightest black line is the cone resistance (q_c) before the resin injections.
- The red line is the friction resistance (f_s) before the resin injections.

In the right half of the graph the blue line is the friction number (R_f) before the resin injections

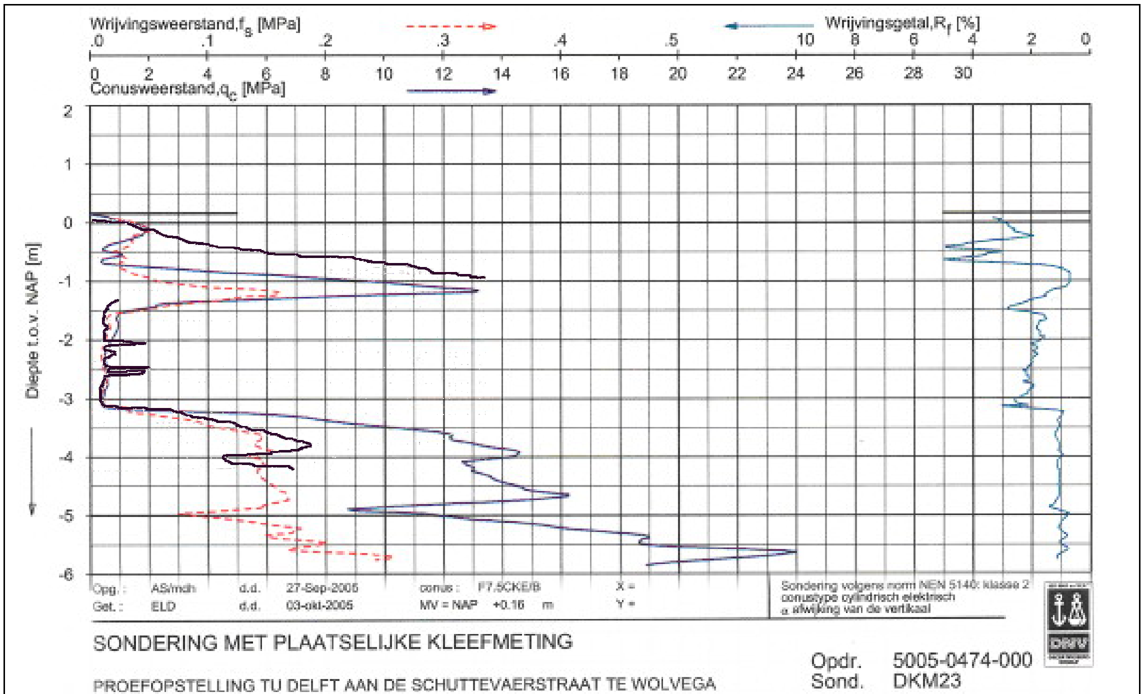
The y-axis is the depth below NAP (normal Amsterdam level, the Dutch reference level) in meters

Graph N.2. Combined cone penetration tests before and after injection of long term test-facility part 1.2

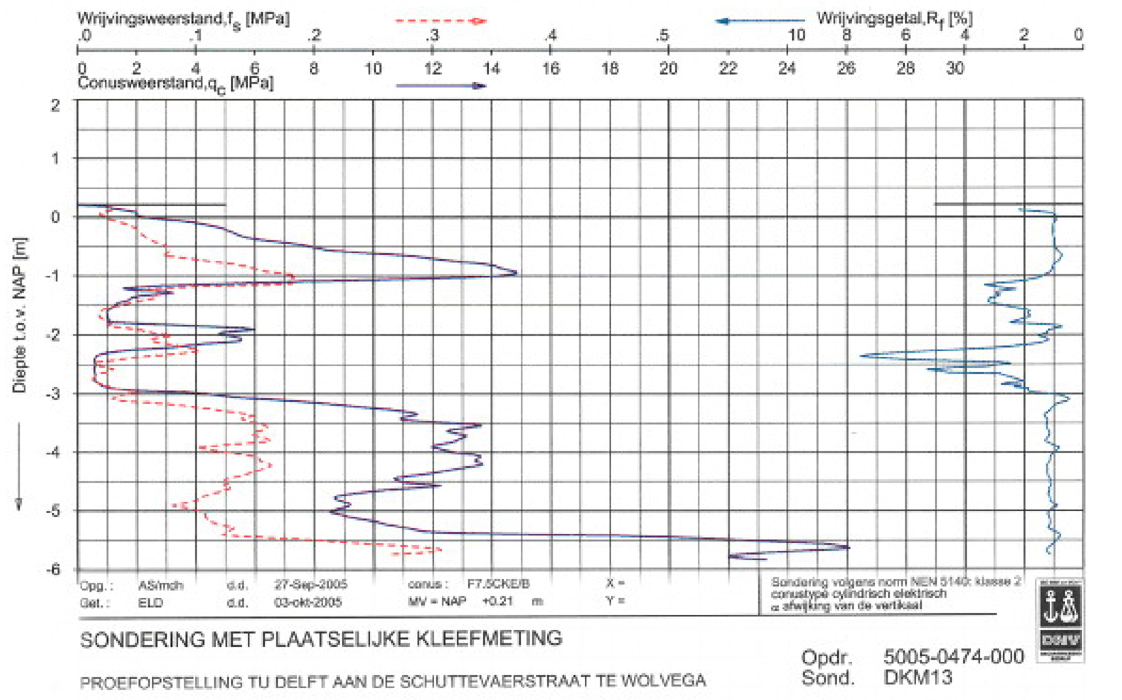


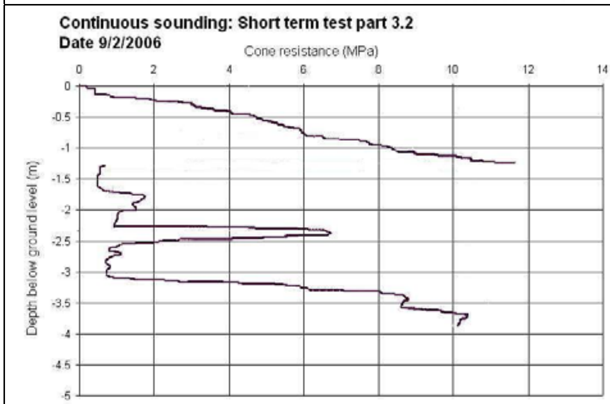


Graph N.3. Cone penetration tests before and after injection of long term test-facility part 1.3 & 1.4

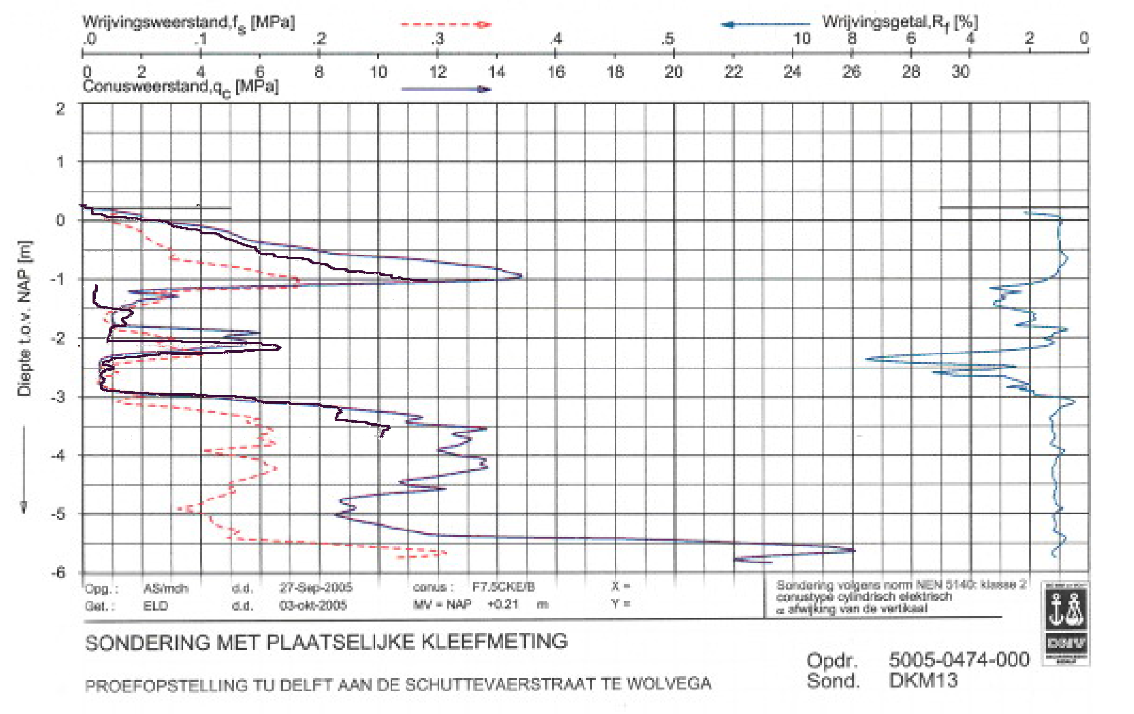


Graph N.4. Combined cone penetration tests before and after injection of long term test-facility part 1.3 & 1.4

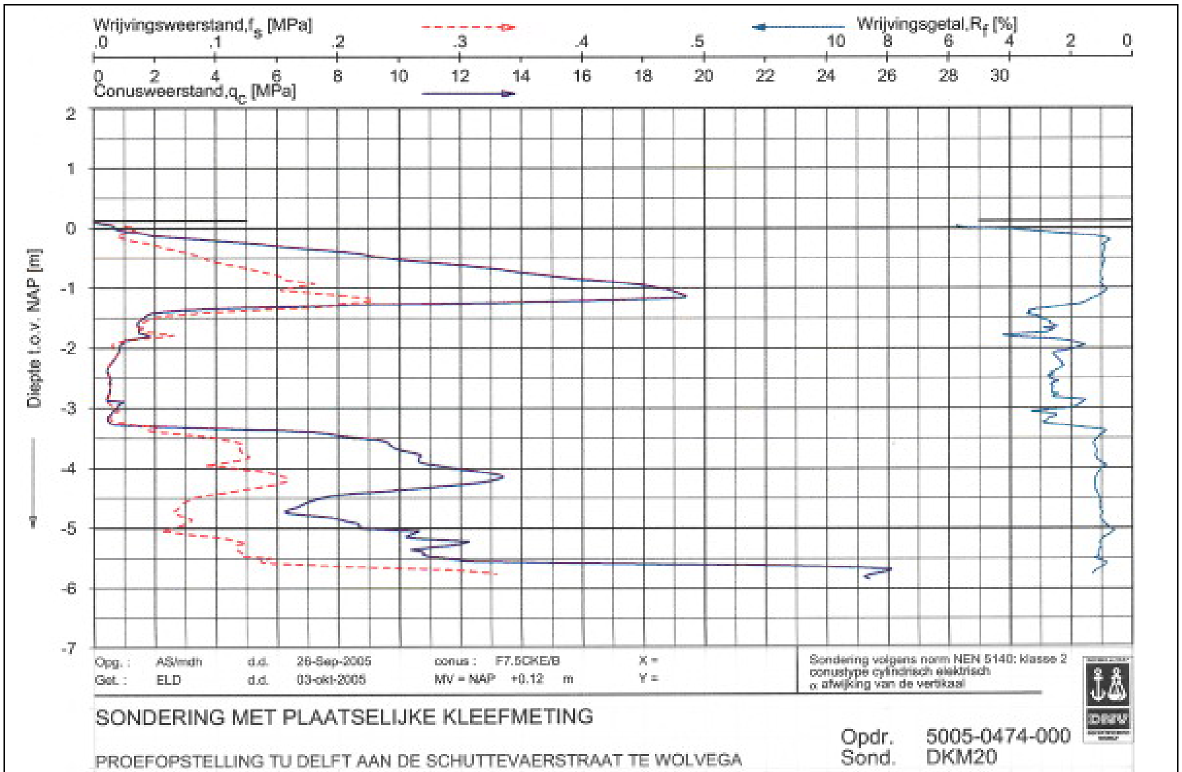


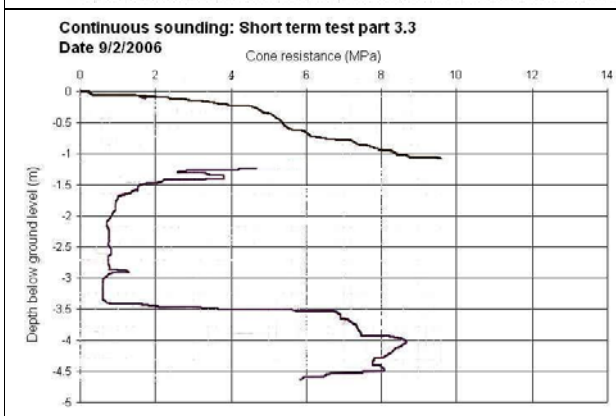


Graph N.5. Cone penetration tests before and after injection of short term test-facility part 3.2

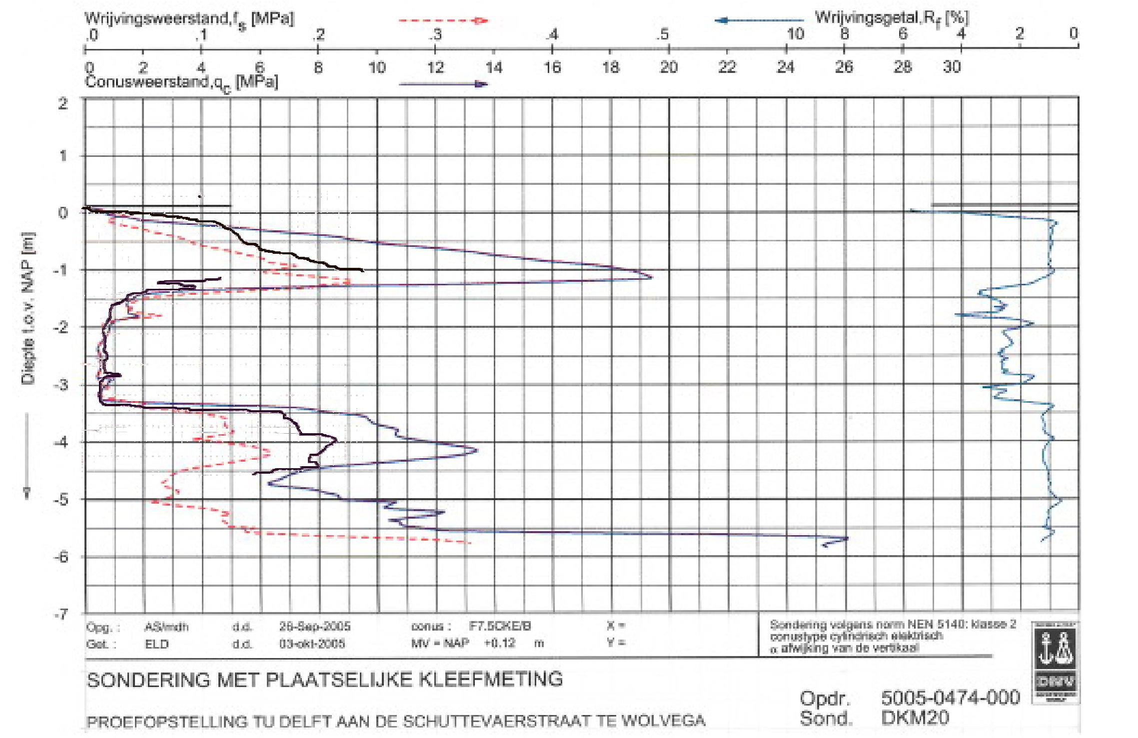


Graph N.6. Combined cone penetration tests before and after injection of short term test-facility part 3.2

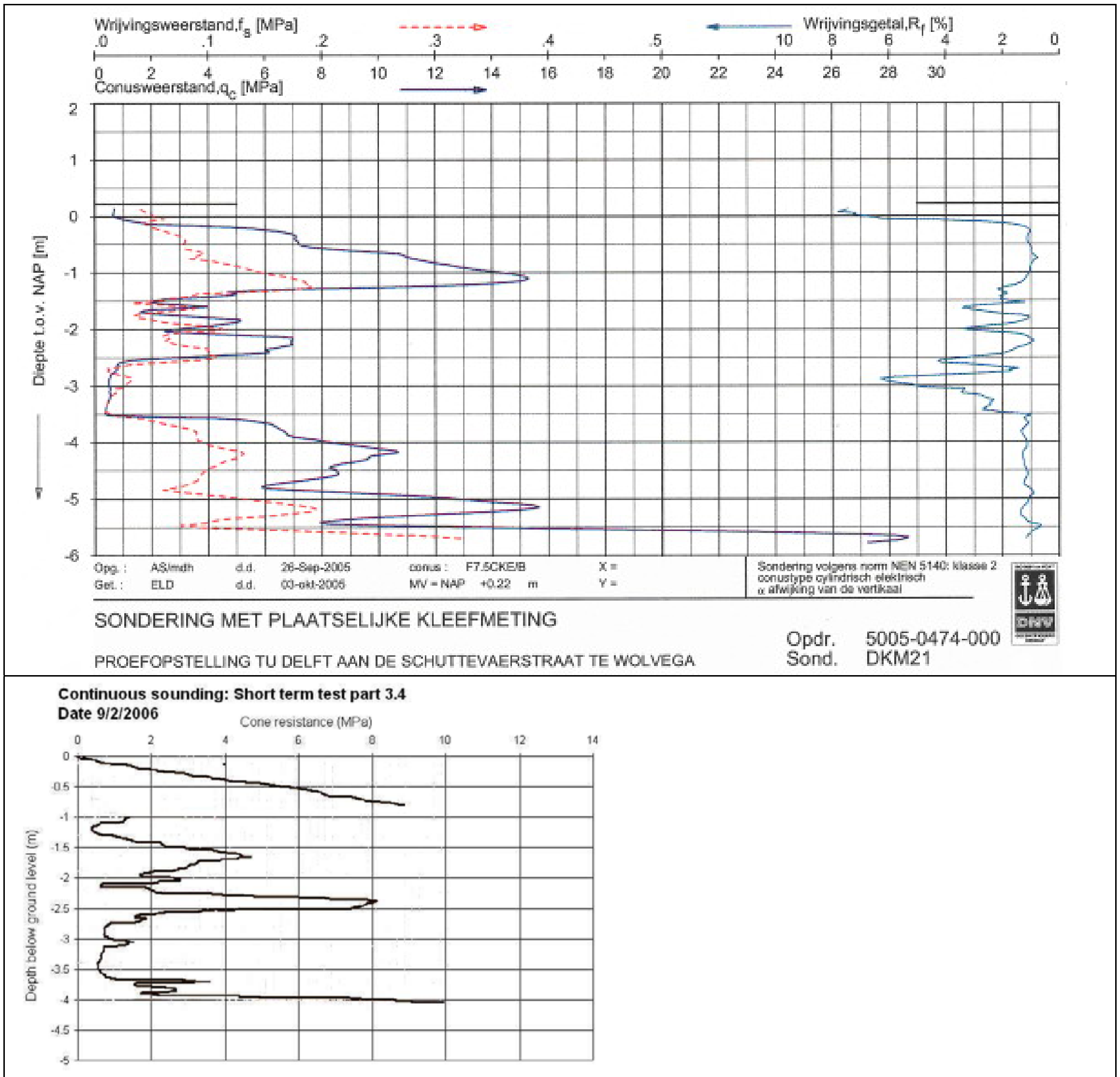




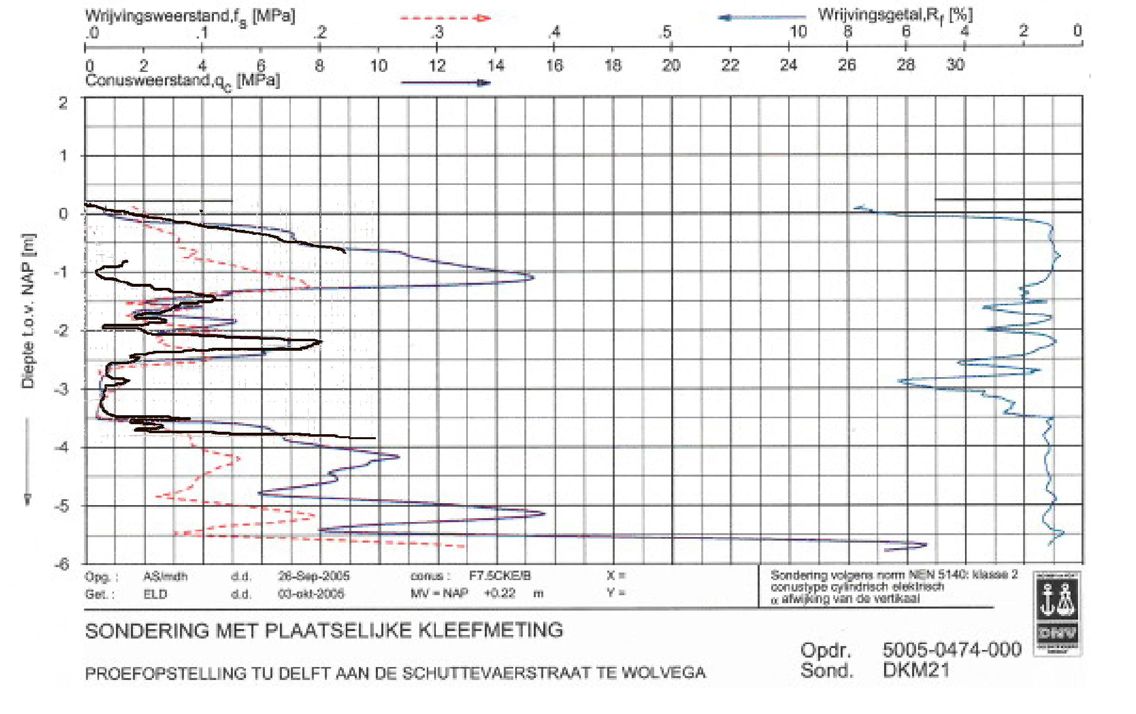
Graph N.7. Cone penetration test before and after injection of short term test-facility part 3.3



Graph N.8. Combined cone penetration tests before and after injection of short term test-facility part 3.3



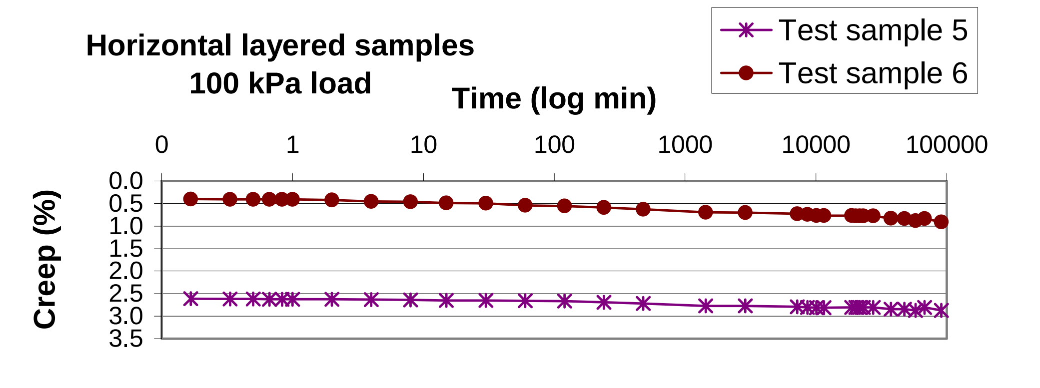
Graph N.9. Cone penetration test before and after injection of short term test-facility part 3.4



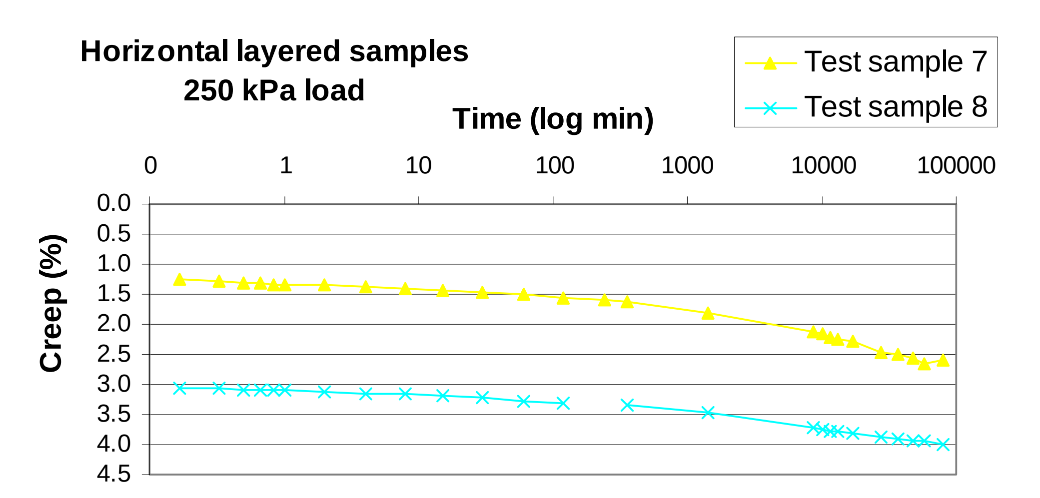
Graph N.10. Combined cone penetration tests before and after injection of short term test-facility part 3.4

Appendix O: Creep test

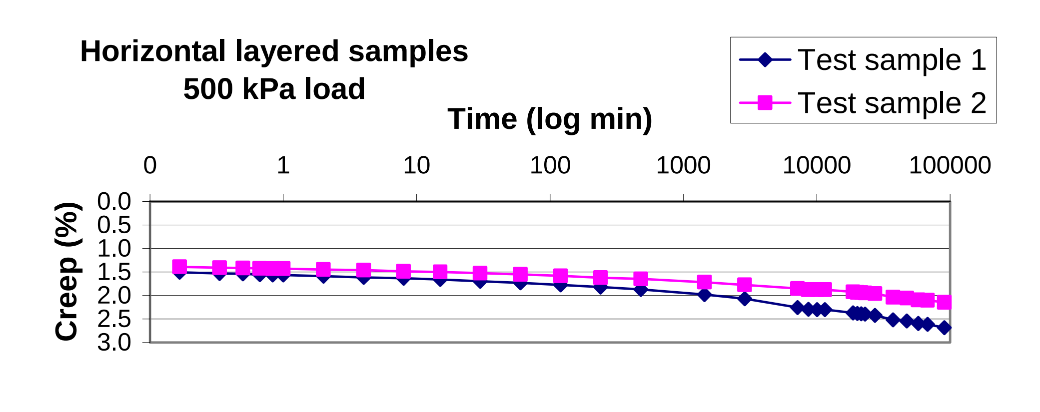
The oedometer tests results without leaving out the first measurement.



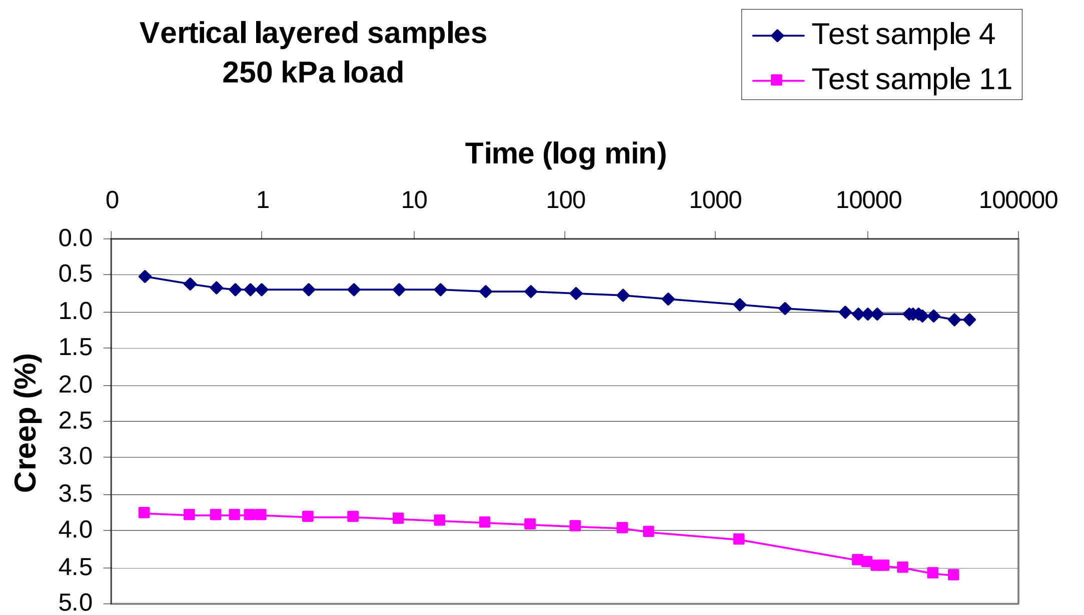
Graph O.1 Creep horizontal layered samples load 100 kPa



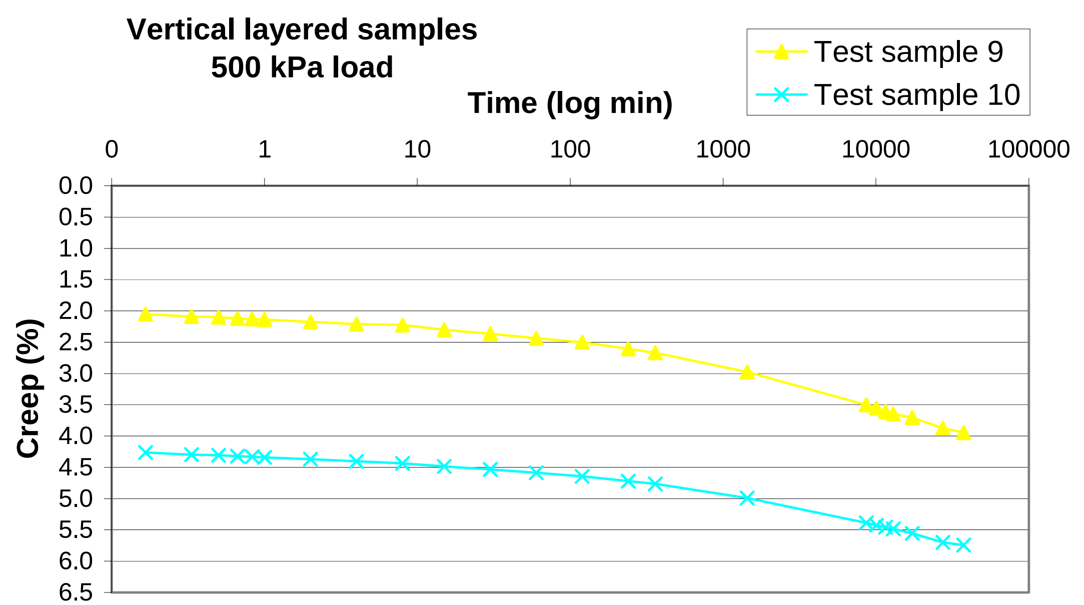
Graph O.2 Creep horizontal layered samples load 250 kPa



Graph O.3 Creep horizontal layered samples load 500 kPa



Graph O.4 Creep vertical layered samples load 250 kPa



Graph O.5 Creep vertical layered samples load 500 kPa

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